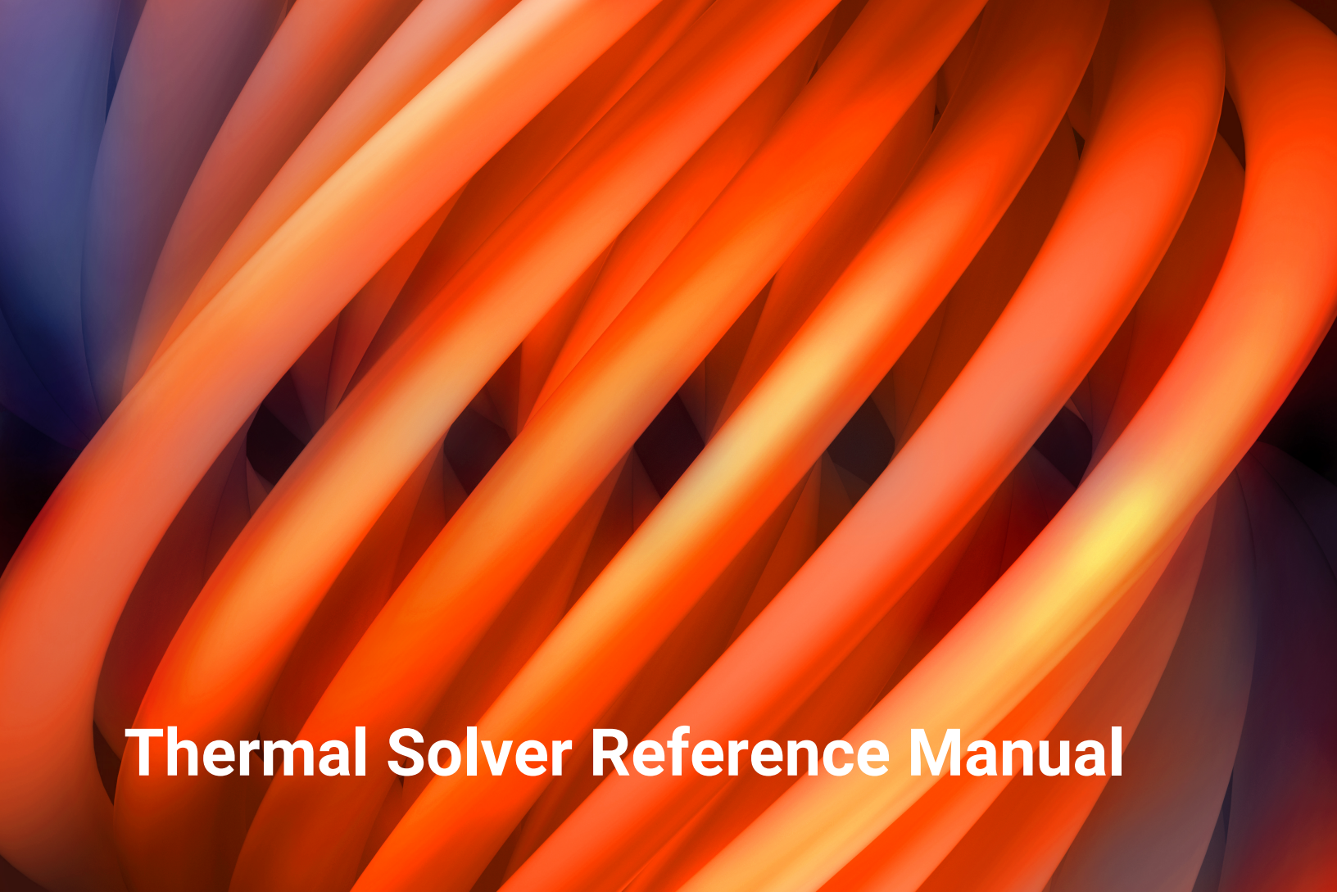

Thermal Solver Reference Manual

June 2024

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Introduction

In most situations, a thermal model can be defined and solved from within your CAE software. The thermal model is built using the software interface. The results can then be displayed and analyzed within the software using the built-in post-processing functionality.

Before solving, all thermal models and their operational data are translated into a TMG input file. This process is transparently integrated into the TMG interface. Under normal circumstances it is unnecessary to know how it works.

However, advanced users may occasionally need access to TMG functions that are unavailable from within the software. To do so, some knowledge of TMG's underlying structure is required, since individual commands and data sets must be inserted directly into the TMG input file.

This document describes the format and contents of the input file and the output files, and gives an overview of how TMG's various modules interact.

The document is divided into three main sections:

- The first section describes the format and content of the TMG input file (or data deck). It describes in detail all TMG input cards.
- The second section gives a list of all files created during a TMG run with a brief summary of their content.
- The third section explains the function of all TMG modules that are executed during a TMG run.
- Finally, the last section provides the theory and methods used by the thermal solver.

Section 1: Input cards

Input File Format Overview

To use TMG features from outside your CAE software, you must place instructions and data directly into TMG's input file (also known as the data deck). This can be done with any text editor.

In most cases, a single input file (always called INPF) is created in the following manner:

1. Build a thermal model using TMG within your CAE software.
2. Set run time options to only build an input file in the TMG thermal analysis task.
3. Select the solve button in the TMG thermal analysis task.

This creates the INPF file in the run directory. When the TMG input file is complete, the model can be solved by entering `tmg` at the operating system's command prompt where the input file resides and selecting TI for interactive thermal solve.

You can also create the TMG data deck from an empty file by using any text editor or user written code that produces the proper TMG input file format. Only very advanced users should attempt this.

TMG's input deck, INPF, consists of 10 different Card types, separated by `-1` Delimiter Cards. Only the first two Card types, and the ten `-1` Delimiter Cards are mandatory.

Data Deck Format

Card 1 Title Card – Mandatory

–1 (Delimiter Card)

Card 2a Program Control Card – Mandatory

Card 2b Analyzer Control Card – Optional

–1 (Delimiter Card)

Card 3 Plot Card – Obsolete

–1 (Delimiter Card)

Card 4 Node Cards – Optional

–1 (Delimiter Card)

Card 5 Element Cards – Optional

–1 (Delimiter Card)

Card 6 View Factor & Thermal Coupling Cards – Optional

–1 (Delimiter Card)

Card 7 Element Merging Cards – Optional

–1 (Delimiter Card)

Card 8 Element Elimination Cards – Optional

–1 (Delimiter Card)

Card 9 Additional Model Parameter Cards – Optional

–1 (Delimiter Card)

Card 10 User–written subroutines for the Analyzer – Optional

–1 (Delimiter Card)

Input Convention

1. Input is in free format. Blanks or commas may separate data fields.
2. Data may be either a mnemonic or a numerical value. A mnemonic may be a code, a symbolic variable, or a group name.

   Group names are mnemonic symbols that represent groups of elements. Group names are defined with Card 9 NAME Cards, and may be used instead of element numbers. The liberal use of group names is encouraged, since it makes both data input and output more legible.

   Symbolic variables are mnemonic symbols that represent numerical values defined with Card 9 VARIABLE Cards. Whenever a symbolic variable is encountered in the data deck, its numerical value is substituted.

3. Delimiter Cards and lines starting with mnemonic codes must start in column 1.
4. No line may exceed 90 characters.

Expressions

1. Expressions enclosed in brackets may be used instead of numerical values on Cards 4 through 9. Several levels of brackets may be used, but the length of the expression must not exceed 29 characters.
2. The operators `+`, `-`, `/`, `*`, and `**` (exponentiation) may be used.
3. There must be no spaces inside the brackets.

Comment Cards and Fields

Comment Cards may appear anywhere in the data stream after the Title Card. Comment Cards must have the letter C or a dollar sign ($) in the first column. Comments may also be entered on the Data Cards themselves, following a dollar sign ($).

Example

```
$ THIS IS A COMMENT CARD


1,10.6,11,12.8

$ INPUT FORMAT EXAMPLE WITH COMMA SEPARATORS


1 10.6 11 12.8             $ SAME WITH BLANK SEPARATORS


401 1.0 2 (3*(5.2/2.8+1))  $ USE OF AN EXPRESSION


GENER 2 2 1 10 1 0 0 0 1 0

$ MNEMONIC CODE


NAME XSISTOR 5

$ CARD 9 NAME CARD


VARIABLE %HEATIN .5
```

```
$ CARD 9 SYMBOLIC VARIABLE CARD

QNODE XSISTOR %HEATIN
$ SYMBOLIC VARIABLE & GROUP NAME

QNODE XSISTR2 (%HEATIN*.5)
$ SYMBOLIC VARIABLE IN AN EXPRESSION
```

Card 1 - Title Card – Required

TITLE

Must not exceed 70 characters, and must be the first Card in the data deck.

Example

```
WHITE ALUMINUM T IN SPACE
```

Card 2a - Program Control Card – Required

`M, N, MESH, RK, IST, KSP, SIGMA, PSUN, IA, TLIN, PIR`

`M` is the program control parameter that defines which modules are to be run. Different values of `M` may be summed to run different modules. For example, if $M = 3 = 1 + 2$, the COND module and the VUFAC module will be run.

`M` = `0` : TMG executes the MAIN, DATACH and ECHOS modules, which performs data checking. This option is always performed.

`M` = `1` : TMG executes the COND module to calculate capacitances, conductive conductances, and hydraulic resistances from geometry.

- Two options exist for calculating conductances from geometry: the older element center method, and the element CG method (recommended). The latter can be specified with a Card 9 PARAM COND NEW option.

`M` = `2` : TMG executes the VUFAC module to calculate view factors, solar view factors, Earth view factors, albedo factors, and thermal couplings.

- For this option, you also need to specify Card 6 Request Cards.

`M` = `4` : TMG executes the GRAYB module to calculate radiative conductances from view factors.

- There is a caveat: If there are no Card 6 view factor requests, and it is not a restart run (i.e. there are no files MODLF or VUFF present), then the GRAYB module is not run.

`M` = `8` : This is an obsolete option, which is not recommended.

- It executes the GRAYB module to calculate the solar spectrum gray body view factor matrix from view factors, which can be used to calculate solar spectrum heat loads in the POWER module. Any existing solar spectrum gray body view factor matrix on file VUFF will be overwritten.

`M` = `16` : This is an obsolete option, which is not recommended.

- It executes the GRAYB module to calculate the IR spectrum gray body view factor matrix from view factors, which can be used to calculate IR spectrum heat loads in the POWER module. Any existing IR spectrum gray body view factor matrix on file VUFF will be overwritten.

`M` = `32` : TMG executes the POWER module to calculate collimated (sun) solar spectrum heat loads.

- Solar view factors, view factors, and the PSUN parameter are necessary for this calculation.
- There is a caveat: If there are no Card 6 solar spectrum view factor (solar view factor, orbital view factor, heat flux view factor) requests, and it is not a restart run (i.e. there are no files MODLF or VUFF present), then the POWER module is only entered but not executed.

`M` = `64` : TMG executes the POWER module to calculate IR spectrum heat loads.

- Earth view factors, view factors, and the PIR parameter are necessary for this calculation.
- There is a caveat: If there are no Card 6 solar spectrum view factor (solar view factor, orbital view factor, heat flux view factor) requests, and it is not a restart run (i.e. there are no files MODLF or VUFF present), then the POWER module is only entered but not executed.

`M` = `128` : TMG executes the POWER module to calculate diffuse solar spectrum (e.g., albedo) heat loads.

- Albedo factors or heat flux view factors, view factors, and the PSUN parameter are necessary for this calculation.
- There is a caveat: If there are no Card 6 solar spectrum view factor (solar view factor, orbital view factor, heat flux view factor) requests, and it is not a restart run (i.e. there are no files MODLF or VUFF present), then the GRAYB module is only entered but not executed.

`N` is the input/output format control parameter.

`N` = `0` : None of the options below is selected.

`N` = `8` : NASTRAN format input, all of Card 4 is a NASTRAN bulk data deck.

`N` = `16` : NASTRAN format output. If the Analyzer is run, NASTRAN element temperatures are written on file FMODLF.

`N` = `512` : The VUFAC module does not write the details of the view factor calculations to [Simulation name]_report.log in order to reduce its size.

`N` = `1024` : Card 4 and 5 data is read from file VUFF.

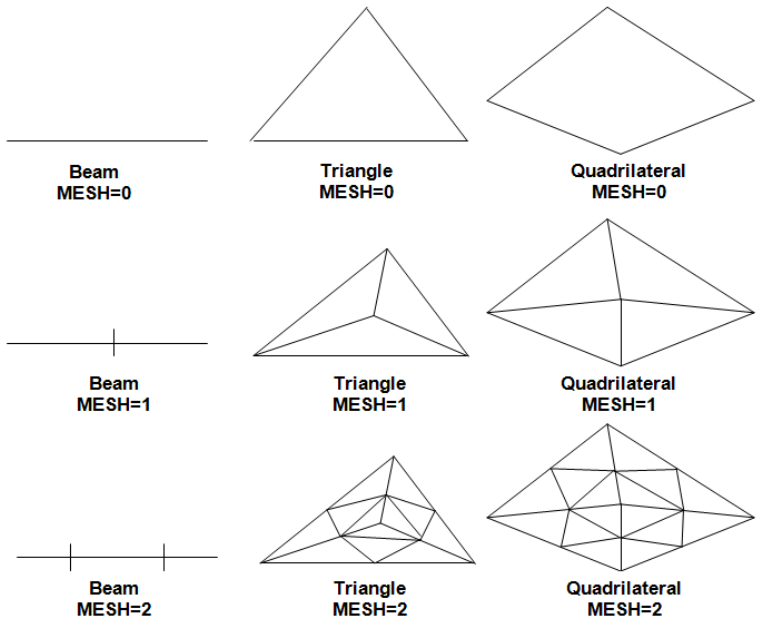
Any combination of these options may be executed by summing their codes.

`MESH` specifies the element subdivision parameter for view factor shadowing, ray tracing, and Card 6e thermal coupling calculations by the VUFAC module.

Unshadowed view factors and solar view factors are calculated exactly and are not affected by the MESH value.

`MESH` may be `0` , `1` , `2` , `3` , `4` , or `5` . For `MESH = 0` no subdivision is performed. For `MESH > 0` each beam is subdivided into MESH line segments, and each planar element into $NV*MESH^2$ triangular sub–elements, where `NV` is the number of nodes (as shown below).

The Card 6f MESH Redefinition Card overrides the MESH parameter value.



`RK` is used by the GRAYB module with Gebhardt's (but not Oppenheim's) Method to eliminate insignificant radiative conductances, or to connect them to element KSP. A radiative conductance is considered insignificant if its gray body view factors to both elements are less than abs(RK) times the largest gray body view factor of either element to a non-space element. RK must be between `-1` and `1`.

- If `RK` > `0`, the conductance is eliminated, except if it is connected to a space element defined on a Card 5 SPACE Card.
- If `RK` < `0`, it is connected to element KSP, unless KSP is a space element.
- `RK` = `0` defaults to `RK` = `1E-4`.

Typically, `RK` = `.05` can thin out the radiative conductances without significantly affecting accuracy.

`IST` is obsolete.

`KSP` is used by the GRAYB module either to create residual view factors = 1 – `VFSUM` for Gebhardt's method when the view factors do not sum to unity. Generally view factors do not sum to unity because of approximations made during the shadowing calculation process.

- `KSP` = `0` creates self–view factors = `1` – `VFSUM,` i.e., the elements are made to see themselves. This option works well when there are a lot of low–emissivity elements present.
- `KSP` = `1000000` has the effect of adjusting the gray body view factors to compensate residual view factors. This is an **obsolete** method, and it does not work with Oppenheim's Method.
- `KSP` = `NSP` creates view factors = `1` – `VFSUM` to element NSP. NSP must be the Card 5d space element number.
    - If multiple enclosures exist, then each enclosure is flagged as being able to see space or not. An enclosure is characterized as being able to see space if at least element of that enclosure sees a space element.
    - If an enclosure does not see space, the `KSP` = 0 option is used for that enclosure. This way, the creation improper space couplings from enclosures that do not see space is avoided, and inside and outside enclosures can be safely mixed.
- `KSP` = 2000000 is similar to `KSP` = `NSP`, except that the space element number is obtained from the Card 5d Space Element Card.
- `KSP` = 3000000 attempts to iteratively adjust the shadowed view factors proportionately to reduce the residual view factors. This is the recommended option.

`SIGMA` is the Stefan-Boltzmann constant value in approximate units, e.g., 0.1714×10^{-8} Btu/hr·ft^2·R^4 , or 5.6696×10^{-8} W/m^2·K^4, or 3.6577×10^{-11}W/in^2·K^4.

`PSUN` is the collimated solar spectrum radiative source's (sun's) power output per unit area arriving at the element. PSUN is used by the POWER module in solar spectrum heat load calculations (`M` = `32 or M` = `128`).

Typical values are 429±7 Btu/hr·ft^{2}or 1353± 21 W/m^2.

`IA` is used if a sinda85 output is requested with Card 9 PARAM SINDA85. If `IA` = `0,` a transient format output is created on file sinda85.dat. If `IA` = `-99990`, then a steady-state format output is created on file sinda85.dat.

`TLIN`

$TLIN = (T_1 + T_2)(T_1^2 + T_2^2)$ is used by the MEREL module to linearize radiative conductances during substructuring and Card 9 PARAM THIN model thinning operations. Only conductances that are connected to both radiative and conductive conductances are linearized.

`T1` is the typical estimated absolute temperatures of the elements to be eliminated, and T2 is the typical absolute temperature of their environments.

`PIR` is the heat load per unit area leaving the surface of the Earth. PIR is used by the POWER module (`M = 64`) to calculate Earth heat loads. A typical value for `PIR` for Earth heat load calculations is 75BTU/hr/ft^2 or 236W/M^2 .

Notes

All parameters of Card 2a must be present. Zeros may be used for the parameters not used.
Restart runs may be performed using previously calculated data.

1. The most common type of restart run is rerunning the Analyzer after all the model parameters (conductances, capacitances, thermal couplings, radiative heat inputs) have been calculated from geometry. For this option, you should use `M = 0` and make sure files MODLF and tmggeom.dat are present.
2. The second most common type of restart is to use re-use previously calculated radiative geometric view factors (e.g. view factors, solar view factors, etc.) For this option, make sure files VUFF and tmggeom.dat are present from the previous run, delete all Card 6 requests for calculating view factors and solar view factors etc. (but not thermal coupling requests), and `M` should be the value used in the previous run.
3. Other types of restart runs are also possible, e.g. when you wish to calculate additional view factors. For this type of run, newly calculated data is appended to the verbose log file, VUFF, report log file, and MODLF. However, on file VUFF the newly calculated data will supersede earlier data whereas on file MODLF (capacitances, conductances, heat loads) newly calculated data will be added to existing data. If necessary, file MODLF may be cleared of unwanted previous results with Card 9 KEEPDEL Cards.

Example

```
7 0 1 0 0 84 1.713E-9 440 0 26463592 80 $ CARD 2A
$ The VUFAC, GRAYB and COND modules will be executed.
```

Card 2b - Analyzer Control Card – Optional

`GRADNT, TABS, DTP, DT, TST, TF, TRDMP`

This Card runs the Analyzer to calculate temperatures. Its parameters are interpreted according to whether the run is steady–state or transient.

Steady–State Runs

`GRADNT` is the convergence criterion.

Convergence is achieved when `GRADNT` > `TDMAX`, where `TDMAX` is the maximum temperature difference between two iterations.

`GRADNT` must be ≥ `0`. `GRADNT` = `0` defaults to `0.001`.

An additional energy balance convergence criterion may be specified on a Card 9 PARAM ENGBAL Card.

If `GRADNT` = `-9,` then the Analyzer is not run.

`TABS` is the temperature of absolute zero. It is used to evaluate radiative conductances and air densities for hydraulic elements. It can be `>` `0` or < `0`, e.g., ± `273` or ± `460`.

`DTP` is the number of iterations between printouts.

`DTP` = `0` defaults to a single printout at the end of the run.

`DT` is the iteration damping parameter. `DT` should be between `0` and `1. DT` = `0` defaults to `1.0`.

At each iteration, for each element, an equilibrium temperature T_{eq} (at which the element is in thermal equilibrium with its neighbors) is calculated. T_{new} is then the mixture of T_{eq} and the temperature T_{old} of the previous iteration:

$$T_{new} = (1 - DT)T_{old} + T_{eq}DT$$

Larger `DT` values speed up convergence for well–behaved models. Smaller `DT` values increase stability.

If hydraulic elements are used in the model, smaller `DT` values, e.g. `0.3`, are recommended.

`TST` is the time value at which the time–dependent heat load and sink temperature boundary conditions are evaluated for the run.

If all boundary conditions are specified as CONSTANT, i.e. there are no time-dependent boundary conditions specified, `TST` = `0` may be used.

If time–dependent parameters are defined in tables on TABDATA Cards, `TST` must not exceed the largest time value of the table.

If `TST` = `-89990`, an integrated average of the time-dependent heat loads with TIME values `≥0` is used for boundary conditions.

`TF` is the maximum number of iterations.

`TRDMP` is ignored for steady-state runs.

Transient Runs

`GRADNT` = `-2`

The explicit exponential forward differencing integration technique is used. The temperature of an element at time `t + dt` is calculated from the temperatures heat loads and conductance values at time t.

At time `t` the equilibrium temperature T_{eq} and the RC value for each element are calculated, where RC is the element's capacitance divided by the sum of its conductances. The new temperature T(t + dt) is calculated by:

$$T(t+dt) = T(t) + (T_{eq}(t) - T(t)P(1 - e^{\frac{-dt}{RC}})$$

The exponential forward differencing technique is unconditionally stable for all values of dt, but does not conserve the energy of the system, which may lead to erroneous results with `dt >>` RC_{MIN}, where RC_{MIN} is then the smallest non–zero RC value in the model.

Performance of the algorithm is degraded if zero capacitance elements are present, because the temperatures of zero-capacitance elements are calculated iteratively at each integration time step.

`GRADNT` = `-3`

The explicit forward differencing integration technique is used:

$$T(t+dt) = T(t) + (T_{eq}(t) - T(t))(\frac{dt}{RC})$$

The forward differencing technique is first-order accurate and conserves the energy of the system, but may become unstable if `dt>RC`$_{\texttt{MIN}}$`.` If this option is used, it is a good idea to set `DT = 0`. However, this can often yield very small integration time steps, which may result in excessively long runs.

Since this method is explicit (no iterations are performed) for models containing only non-zero capacitance elements, it is quite efficient if a reasonable integration time step can be specified.

The temperatures of zero-capacitance elements are calculated iteratively at each integration time step, resulting in slower runs.

`GRADNT` = `-4`

The implicit forward–backward or Crank–Nicolson technique is used:

$$T(t+dt) = T(t) + \left(\frac{T_{eq}(t) - T(t)}{2} + \frac{T_{eq}(t+dt) - T(t+dt)}{2} \right) \frac{dt}{RC}$$

where

- `RC` is the time constant of the element.
- `T(t + dt)` is calculated iteratively, because `T`$_{\texttt{eq}}$`(t + dt)` has to be estimated at each time step.

The default value for the maximum number of iterations is `100`, but this may be changed on a Card 9 PARAM NLOOP Card. The temperature converge criterion for the iterations defaults to `.001`, but this may be overridden with a Card 9 PARAM TDIFS Card. A warning message is issued if the maximum number of iterations is exceeded.

This method is unconditionally stable for all values of `dt`.

Picking a reasonable integration time step `dt` can be tricky. If `DT = 0` is used, the integration time step defaults to `RC`$_{\texttt{MIN}}$`/2`, which is generally too small, yielding very long runs. However, large integration time steps can result in inaccuracies and lack of convergence. dt = DT should be specified explicitly, typically as the largest time interval for which each element's temperature rise can be safely considered to be linear.

`GRADNT` = `-5`

The implicit variable α method is used:

$$T(t+dt) = T(t) + \left(((1-\alpha)(T_{eq}(t) - T(t)) + \alpha(T_{eq}(t+dt) - T(t+dt))\right)\frac{dt}{RC}$$

- where α is the degree of implicitness of the method.
- α defaults to `1` (backward differencing technique), but may be specified at any value with a Card 9 PARAM ALPHA Card.

For α = 0 this defaults to the forward differencing technique, and for $\alpha = .5$ to the forward-backward differencing technique.

For large integration time steps the default backward differencing technique generally yields more accurate results than the Crank-Nicolson technique. Otherwise, the same rules apply to specifying DT.

This is the recommended integration algorithm.

`GRADNT` = `-6`

The fully implicit integration method is used. It is similar to the implicit variable `α` method (`GRADNT = -5`), except that all heat loads, capacitances, and conductances are updated in every iteration of the nonlinear solve loop of the transient run.

`GRADNT` = `-9`

The Analyzer is not run.

`TABS` is the absolute temperature, see above.

`DTP` is the elapsed time between printouts.

`DTP` = `0` results in a single printout at the end of the run.

`DTP` may be interpolated from tables (see Card 9 - INTERP Analyzer Table Interpolation - Optional, Card 9 - TABTYPE Table Variable Type Definition Card - Optional, and Card 9 - TABDATA Analyzer Table Data Cards - Optional Cards) or defined in a user–written subroutine.

If `DTP` is a negative integer, (e.g. `-5`), then a printout will occur every DTP'th time step.

`DT` specifies the integration time step parameter `dt`. `DT` may also be interpolated from tables (see Card 9 - INTERP Analyzer Table Interpolation - Optional, Card 9 - TABTYPE Table Variable Type Definition Card - Optional, and Card 9 - TABDATA Analyzer Table Data Cards - Optional Cards), or defined in a user–written subroutine.

$$\mathrm{DT} = 0$$

defaults the integration time step to $\mathrm{RC}_{\mathrm{MIN}}/2$.

$$\mathrm{DT} > \mathrm{RC}_{\mathrm{MIN}}$$

the solution may become unstable with the forward differencing technique.

$$\mathrm{DT} < 0$$

Sets the integration time step to $|\,\mathrm{DT}\,|\,\mathrm{RC}_{\mathrm{MIN}}/2,\ \mathrm{i.e,\ a\ constant\ multiple\ of}\ \mathrm{RC}_{\mathrm{MIN}}$ i.e., a constant multiple of $\mathrm{RC}_{\mathrm{MIN}}$.

`TST` is the starting time of a transient run.

`TF` is the final time of the run.

`TRDMP` is the transient iteration damping parameter, equivalent to `DT` of steady–state runs. `TRDMP` = blank defaults to `1.0`.

Notes
For more information, see Analyzer Module. For more information on table interpolation and other analyzer options, see Card 9.

1. Temperatures are written on file TEMPF at each DTP printout interval.

   Initial temperatures default to zero, unless specified by Card 9 TINIT Cards or if a file TEMPF is present at the start of a run, in which case the set of temperatures whose time value is closest to the TST parameter are used as the starting temperatures. This is useful for defining the initial temperatures for transient runs, or

for restarting steady–state runs that have not completely converged. TINIT Cards override temperatures specified in a TEMPF file.

2. Temperature printouts are specified with Card 9 PRINT Cards.
3. Temperature boundary conditions are specified with Card 9 SINK Cards. Heat load boundary conditions may be calculated from geometry (orbital heat loads), or specified with Card 9 QNODE Cards. Both temperature and heat load boundary conditions may be specified to be table-dependent with Card 9 INTERP Cards or varied in a user–written subroutine.
4. A number of techniques may be used speed solution convergence for steady–state runs. If you find that your model has not converged, or is converging too slowly, you must first determine the cause of the problem:

- Specify Card 9 PRINT TRACE, PRINT ILUTRACE, and PRINT HYDTRACE Cards. These will at each iteration print a summary both to the screen and to the report log file, from which you will be able to determine whether your model is converging too slowly, or whether the solution is oscillating.
- Specify a Card 9 PRINT HFGROUP Card. This will print the values of each conductance and the elements it connects to the report log file. This is generally an extremely useful tool for model debugging.

If you find your solution is oscillating, try the following:

- If you have a very nonlinear model that is oscillating, try lowering the DT parameter to 0.3 or lower. If you have a hydraulic model that is oscillating, specify a low hydraulic damping parameter with card 9 PARAM HYDDAMP.
- You may have ill–conditioning, which occurs when the sum of the conductances of some elements is much larger than the conductances for the rest of the model. You can get the conductance sums from the PRINT HFGROUP printout to the report log file.
- If your steady-state model is converging slowly, try increasing the DT parameter to 1.

A number of techniques are also available to speed up slow transient runs. The most common cause is a small integration time step. Often this is because the default `DT = 0` is specified, and RC_{MIN} is very small. To get around this, specify a physically realistic `DT` value (e.g. `DT = TF/100 or DT = TF/1000`) and use an implicit technique.

To determine a suitable `DT` for your model, re–run your problem with `DT/2`, and compare the results. If the results are unacceptably different, lower your `DT`. Lower `DT` values should yield more accurate results.

Another possible cause of slow transient runs is that the temperature difference convergence criterion of `0.001` is too tight. You can alter it with a Card 9 PARAM TDIFS Card, but make sure your accuracy is acceptable.

Example

```
0 -273 0 0 0 100  $ STEADY STATE, 100 ITERATIONS, DEFAULT DAMPING
                  $ PARAMETER IS USED
-3 -273 10 0 0 20 $ TRANSIENT RUN, FORWARD DIFFERENCING PRINTOUT
                  $ EVERY 10 UNITS. TOTAL TIME = 20 UNITS,
                  $ INTEGRATION TIME STEP = 20 UNITS.
```

Card 4a - Single NODE Cards – Optional

`N, X1, X2, X3`

`N` is the node number, $1 \leq \mathrm{N} \leq 999999$. A node is a point in space defined by its coordinates.

`X1, X2, X3` are the:

- $(\mathrm{X}, \mathrm{Y}, \mathrm{Z})$ coordinates of the node in the Cartesian (local or global) coordinate system, or
- $\mathrm{R}, \phi, \mathrm{z}$ coordinates of the node in the local cylindrical coordinate system defined by Card 4c, or
- R, θ, ϕ coordinates of the node in the local spherical coordinate system, which is defined by Card 4c. θ is the angle in degrees the radius vector makes with the local `Z` axis, ϕ is the angle in degrees the projection of the radius vector on the local `XY` plane makes with the local `X` axis (CCW is positive).

Notes

Node number duplication is not permitted.
Node dimensions should not exceed `0.5E6.`

Card 4b - Multiple Node Generation Cards – Optional

`KODE, NA, NB, NDA, NDB, DA1, DA2, DA3, DB1, DB2, DB3`

`KODE` = `GEN` (or `-5`)

`NA` is the number of nodes in the `A` direction.

`NB` is the number of nodes in the `B` direction.

`NDA` is the node number increment in the `A` direction, must be ≥ 0.

`NDB` is the NODE number increment in the B direction, must be ≥ 0.

`DA1`, `DA2`, `DA3` are the $(\mathrm{X}, \mathrm{Y}, \mathrm{Z})$ or $(\mathrm{R}, \phi, \mathrm{Z})$ or $(\mathrm{R}, \theta, \phi)$ increments for the generated nodes in the A direction.

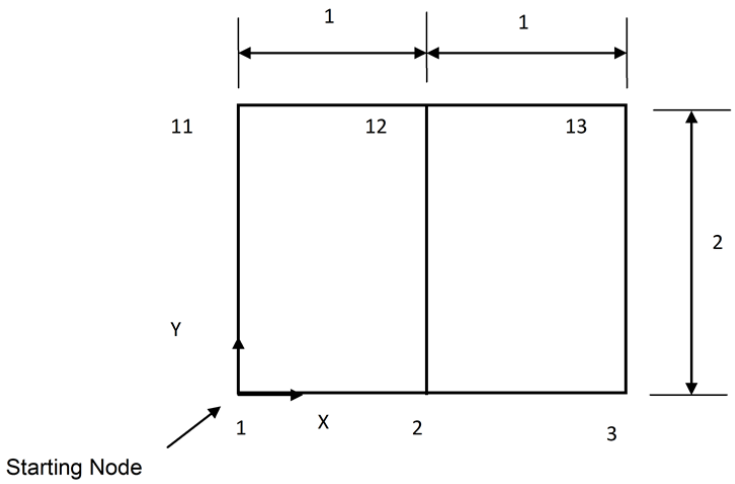
`DB1`, `DB2`, `DB3` are the $(\mathrm{X}, \mathrm{Y}, \mathrm{Z})$ or $(\mathrm{R}, \phi, \mathrm{Z})$ or $(\mathrm{R}, \theta, \phi)$ increments for the generated nodes in the B direction.

Notes

A Card 4b following a Card 4a generates a matrix of $\mathrm{NA} * \mathrm{NB}$ nodes. The nodes start with the coordinates and number of the Card 4a node. It is possible to generate nodes on a rectangular flat plane, a polar flat plane, a cylinder, a cone, a sphere, or other complex shapes.

Example 1

```
1 0 0 0
GEN 3 2 1 10 1 0 0 0 2 0
In a Cartesian coordinate system the above two Cards are equivalent to the following six
Cards.
1 0 0 0
2 1 0 0
3 2 0 0
11 0 2 0
12 1 2 0
13 2 2 0
```



Example 2

```
1 1 0 0
GEN 6 3 1 10 0 60 0 0 0 1
```

In a cylindrical coordinate system the above two Cards will generate $6 * 3$ nodes on the surface of a cylinder of unit radius at increments of `PHI = 60` degrees and `Z = 1`. Node numbers are incremented by `1` in the `PHI` direction and by `10` in the `Z` direction.

Example 3

```
1 1 30 0
GEN 6 5 1 10 0 0 60 0 30 0
```

In a spherical coordinate system the above two Cards will generate 30 nodes on the surface of a sphere of unit radius at increments of $\phi = 60$ and $\theta = 30$. Node numbers are incremented by 1 in the ϕ direction and by 10 in θ direction.

Card 4c - New Local Coordinate System Cards – Optional

`KODE, N1, N2, N3`

`KODE`

`= SCART` (or `-2`) creates a Cartesian coordinate system.

`= SCYL` (or `-3`) creates a cylindrical coordinate system.

`= SSPHER` (or `-4`) creates a spherical coordinate system.

`N1` is a previously defined node, where the origin of the new coordinate system is located.

`N2` is a previously defined node, which lies along the new Z axis.

`N3` is a previously defined node, which lies in the new XZ plane, on its +X side (e.g., along the new +X axis).

Notes

This card creates a new coordinate system, using three previously defined nodes to define the orientation of its axes and the location of its origin. All node Cards following this Card will be in the new coordinate system, until a new Card 4c is encountered. The default is the Cartesian global coordinate system.

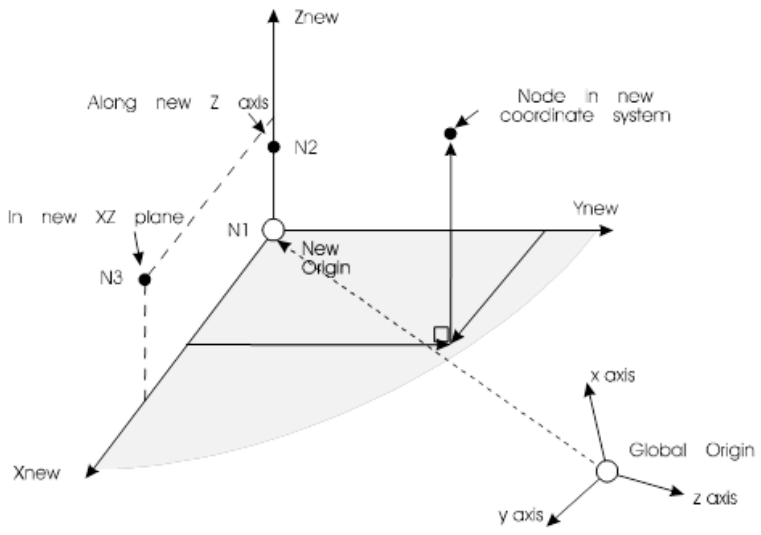
If `N1`, `N2`, and `N3` are all blank, the location of the origin and the orientation of the new local coordinate system are not altered from their current value, only the type of the coordinate system changes, depending on the value of `KODE`.

Example

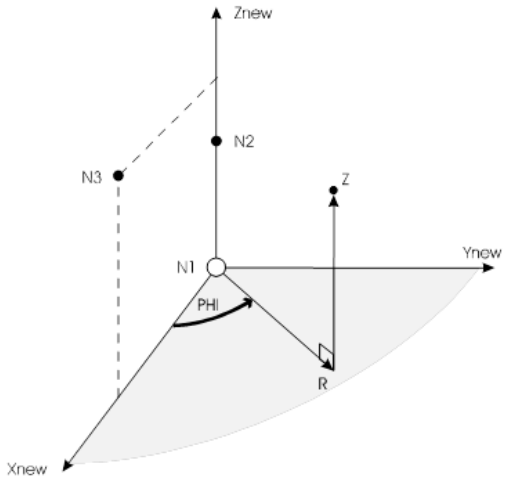
```
-1
$ STARTING CARD 4 DATA
$
1 1.0 0.0 0.0     $ THESE 3 NODES ARE USED TO DEFINE THE NEW LOCAL
2 1.0 0.0 1.0     $ COORDINATE SYSTEM. BY DEFAULT THEY ARE IN THE
3 2.0 0.0 0.0     $ GLOBAL CARTESIAN COORDINATE SYSTEM.
$
$ THE NEXT CARD 4C CREATES A NEW CYLINDRICAL COORDINATE
$ SYSTEM WHOSE ORIGIN LIES AT (1.0 0.0 0.0) OF THE
```

```
$ GLOBAL COORDINATE SYSTEM AND WHOSE AXES ARE PARALLEL
$ TO THE AXES OF THE GLOBAL COORDINATE SYSTEM.
$
SCYL 1 2 3
$
$ THE NEXT CARD IS A NODE IN THE NEW CYLINDRICAL
$ COORDINATE SYSTEM, WITH COORDINATES R = 2, PHI = 45,
$ Z = 1. THE COORDINATES OF THIS NODE IN THE GLOBAL
$ COORDINATE SYSTEM WILL BE(2.414, 1.414, 1.0).
$
4 2.0 45.0 1.0
-1
```

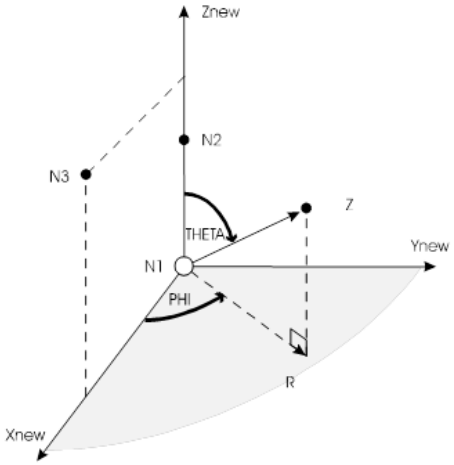
New Local Coordinate System



Cartesian Coordinate System
KODE=SCART



Cylindrical Coordinate System
KODE=SCYL



Spherical Coordinate System
KODE=SSPHER

Card 4d - Third Level Node Generation Card – Optional

`KODE, NC, NDC, DC1, DC2, DC3`

This Card, when it follows a Card 4b, which in turn follows a Card 4a, creates a matrix of $NA * NB * NC$ nodes in the A, B, and C directions. Card 4b generates the nodes on a plane in the A and B directions. Card 4d generates NC of these planes in the C direction.

`KODE` = `GEN3RD` (or `-7`)

`NC` is the number of nodes in the C direction.

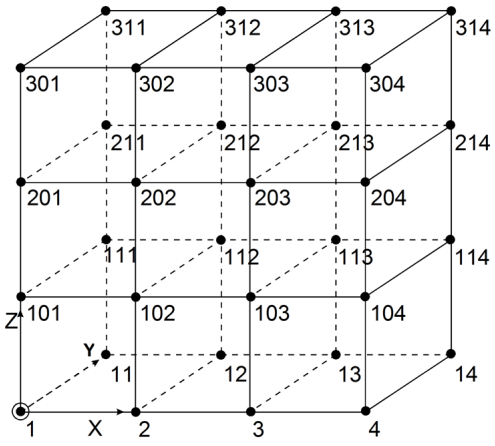
`NDC` is the node number increment.

`DC1` , `DC2` , `DC3` are the (X, Y, Z), or (R, θ, Z), or (R, θ, ϕ) increments of the node coordinates in the C direction, depending on the coordinate system defined on Card 4c.

Example

```
1 0 0 0                        $ IN THE GLOBAL CARTESIAN COORDINATE
GEN 4 2 1 10 1 0 0 0 1 0       $ SYSTEM CREATES 4*4*2 = 32 NODES
GEN3RD 4 100 0 0 1             $ ON TWO PARALLEL PLATES
```

Node Generation



Card 5a - Element Cards – Optional

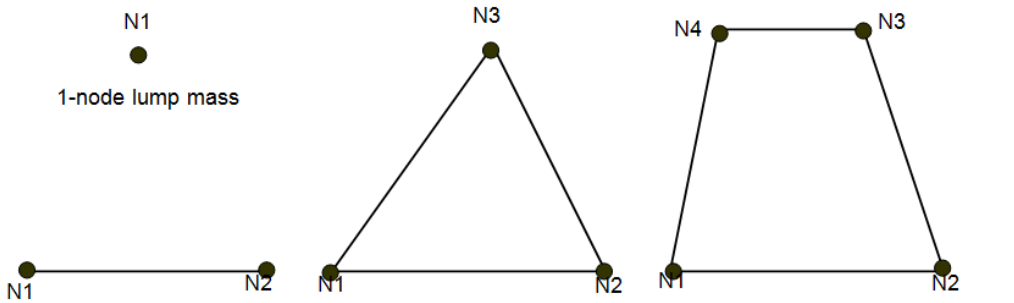
`N` , `TYPE` , `MAT` , `FRONTOPTPROP` , `PROP` , `NODE1` , `NODE2` ,....

Card 5a defines the elements from which TMG calculates conductive, convective, and radiative, conductances and hydraulic resistances. The `TYPE` parameter and the number of its nodes (between 1 and 8) define the shape of an element. Elements may be spherical lump masses, cylindrical beams, triangles, quadrilaterals, tetrahedra, wedges, or hexahedra.

`N` is the element number, `1` ≤ `N` ≤ `9999999`.

`TYPE` defines the element type. `TYPE` may be `SURFACE`, `SOLID`, `MIDSIDE`, `NONTHERM`, `FLOWSEC`, `BLSTART`, `AMBIENT`, `DUCT`, `FLOWRES`, `FANPUMP`, `FLOWCON`, `STREAM` or of the form `On`.

= `SURFACE` specifies that a lump mass, beam, or planar element.



A `SURFACE` element can support capacitance, conductive conductance, radiative conductance, and thermal coupling calculations.

Internal angles must be `< 180` degrees.

The orientation of a `SURFACE` element's surface normal is determined by the ordering of its nodes. If the element is so viewed that its nodes are seen to be in a counter–clockwise order, the element surface normal points towards you.

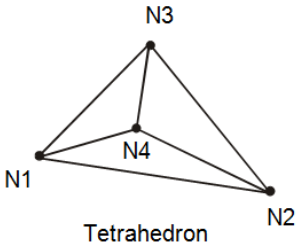
= `On` is a special type of `SURFACE` element, where the reverse side optical properties are defined on Card 9 OPTICAL Card n (e.g. `O10`).

The front side surface properties may be defined with an OPTICAL Card ID in the `FRONTOPTPROP` field.

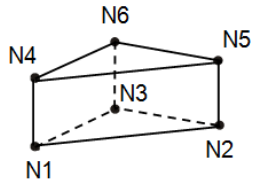
= `SOLID` (or `-9`) specifies that it is a solid tetrahedron, wedge, or hexahedron.

The COND module calculates capacitances and conductances to adjacent solid and planar elements.

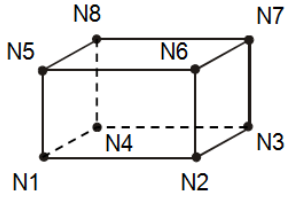
The nodes of a non-tetrahedron solid element must be input in a specific order. For wedges the 4th node must be above the 1st node. For hexahedra the 5th node must be above the 1st node.



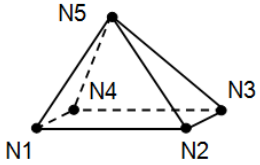
Tetrahedron



Wedge



Hexahedron



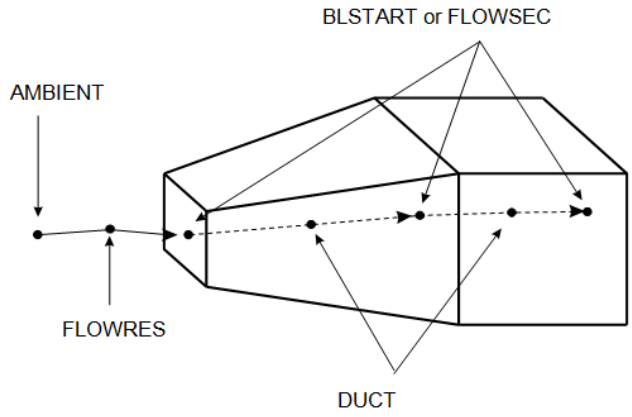
Pyramid

= `MIDSIDE` (or `-11`) specifies that the element is parabolic and lists the midside nodes. The `MAT, FRONTOPTPROP, PROP and MAT` fields are ignored.

- If a parabolic element is specular and if ray tracing is performed, the curvature of the element will be taken into account for the calculation of the reflected ray direction.

= `NONTHERM` (or `-12`) specifies that the element will not take part in the thermal calculations, but can be referenced as a characteristic element for Card 6e free convection options

Hydraulic Elements



Hydraulic elements are used to model heat transfer and pressure drops in 1–D duct flow networks.

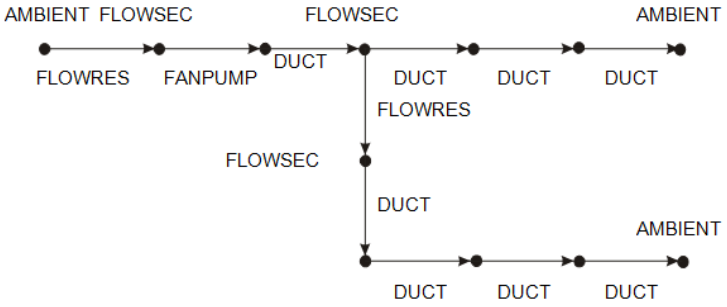
Hydraulic elements may be `1–node` `FLOWSEC` , `BLSTART` , or `AMBIENT` elements, or `2–node` `DUCT` , `FLOWRES` , and `FANPUMP` elements.

1–node hydraulic elements define the fluid and the duct cross–sectional properties.

For 2–node hydraulic elements the COND module connects the element CG to its ends with equal flow resistances to model pressure drops and 1–way conductances to model heat transported by the fluid.

Temperatures and total pressures are computed at both the CG's and ends of hydraulic elements. Gas densities are computed with the Ideal Gas Law.

The nominal and initial flow directions are defined to occur in the direction from `NODE1` to `NODE2` .



The environmental properties (standard temperature & pressure, gravity, `AMBIENT` element pressure & temperature) are specified on a Card 9 HYDENV Card.

Gravity value and direction specified on the HYDENV Card are used to calculate the buoyancy forces and free convection heat transfer coefficients. Buoyancy effects may be turned off with the Card 9 PARAM NOBUOY option.

Total pressure boundary conditions are specified on Card 9 PSINK Cards and on AMBIENT elements. Flow boundary conditions are specified on `FANPUMP` elements.

Convective heat transfer between surface elements and hydraulic elements is modeled with the Card 6e NEARCx options.

During each thermal steady–state iteration or transient time step the complete hydraulic element network is solved in a separate iterative solution loop. The convergence criterion for this iterative loop may be specified with a Card 9 PARAM PDMAX Card.

= `FLOWSEC` (or `-2450`)

A 1-node `FLOWSEC` element defines a duct cross–sectional area, hydraulic diameter, and fluid properties at its location. `FLOWSEC` elements are automatically created at the ends of 2-node hydraulic elements that do not have one specified. At free ends, AMBIENT elements are created.

If `MAT` and `PROP` fields are set to 0, the material properties are set to those of the immediately upstream 1–node hydraulic element. Thus `FLOWSEC` properties are propagated downstream until a new `FLOWSEC` or `BLSTART` element is encountered.

A `FLOWSEC` or `BLSTART` element must be specified wherever 3 or more 2-node hydraulic elements meet.

`FLOWSEC` elements may not be referenced on Card 6e NEARCx convective thermal couplings.

= `BLSTART` (or `-2451`)

A `BLSTART` element is similar to a `FLOWSEC` element, but it also defines the start of the boundary layer for the downstream hydraulic elements. A `BLSTART` element is useful for calculating heat transfer coefficients for a flat plate in free stream (Card 6e NEARC4) or duct flow with boundary layer (Card 6e NEARC12).

= `AMBIENT` (or – `2452`)

A 1-node `AMBIENT` element specifies the properties of the ambient fluid. There must be at least one `AMBIENT` element present in a hydraulic model.

`AMBIENT` elements define temperature and pressure boundary conditions with values are specified on the HYDENV Card. These values may be updated through table interpolation or a user–written subroutine.

`AMBIENT` elements can act as inlets or exhausts to hydraulic networks. The area and hydraulic diameter are very large, hence the computed velocities and dynamic pressures will be near zero.

The `PROP` field is ignored for `AMBIENT` elements.

= `DUCT` (or – `2000`)

For 2-node `DUCT` elements TMG computes length–dependent flow resistances.

A `DUCT` element may be a straight duct, or a diffuser or a nozzle if it has different cross-sectional areas at its ends. A flow resistance multiplier may be specified on the PROP Card to model roughness effects.

The pressure–flow relationship for a `FLOWRES` or a `DUCT` element is defined by:

$$DELTA_{PT} = KLOSS\,\rho\frac{V^2}{2} = RES_{IJ}\,MASSFL$$

where:

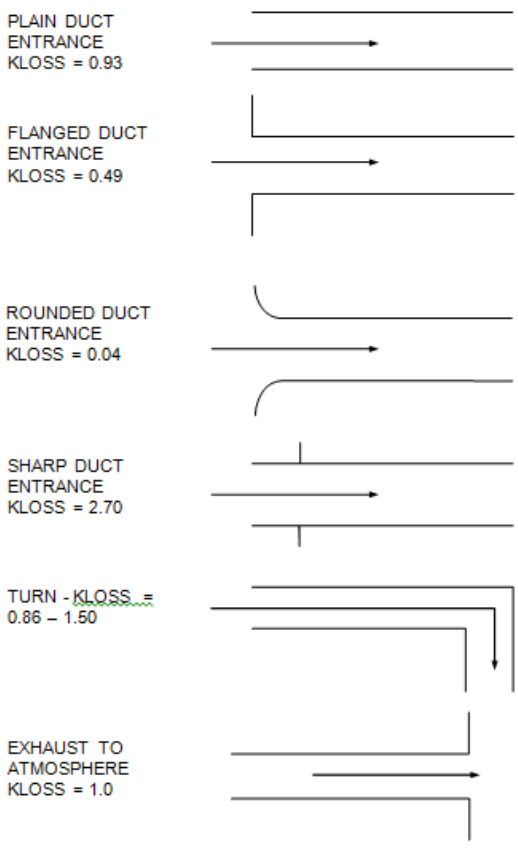
- $DELTA_{PT}$ is the total pressure drop over the 2–node element, > 0 when the total pressure at `NODE1` is > than the total pressure at `NODE2` .
- V is the flow velocity at the narrower end.
- ρ is the fluid density at the narrower end.
- $MASSFL$ is the mass flow through the element.
- RES_{IJ} is the hydraulic flow resistance computed for a smooth duct.
- $KLOSS = R \cdot K \cdot KTABLE$ is the head loss factor.
- $KTABLE$ is the table-dependent hydraulic flow resistance multiplier specified on the PROP Card (default = 1).
- R is the head loss factor computed for fully developed flow in a smooth duct.
- K is a head loss factor multiplier specified on the PROP Card (default = 1).
- The `MAT` field is ignored for `DUCT` elements.

= `FLOWRES` (or `-2002`)

A `FLOWRES` element is similar to a `DUCT` element, except that the computed flow resistance is length–independent. `R = 1` for a `FLOWRES` element in the above equation.

`FLOWRES` elements may be used to model losses over elbows, exits, entrances, and orifices.

Exit and entrance total pressure drops may be modeled with either `FLOWRES` or `DUCT` elements. The difference is that for `FLOWRES` elements the `KLOSS` factor is totally specified on the PROP Card, while for `DUCT` elements it is automatically calculated whenever if an abrupt area change is encountered. Some typical `KLOSS` values are presented below (see images below). The `MAT` field is ignored for `FLOWRES` elements.



Typical FLOWRES Element Head Loss Factors

= `FANPUMP` (or `-2003`)

A `FANPUMP` 2–node hydraulic element is used to specify a flow boundary condition such as total pressure rise, mass flow, volumetric flow, and flow velocity. These values are specified on the PROP Card.

The outlet is at defined at `NODE1`, inlet is at `NODE2`.

The `MAT` field of a `FANPUMP` element is ignored.

The total pressure rise boundary condition $DELTA_{PT}$ over a `FANPUMP` element is modeled with:

$$DELTA_{PT} = K * KTABLE$$

where:

- K is a multiplier defined on the PROP Card
- $KTABLE$ is a value interpolated from the table specified on the PROP Card. For this table, the dependent variable code on the Card 9 TABTYPE Card must be $DELTA_{PT}$.
- $DELTA_{PT}$ is considered > `0` when the total pressure at the inlet is lower than the one at the outlet. Note that this definition is the opposite of the one adopted for the `FLOWRES` and `DUCT` elements.

The mass flow boundary condition through a `FANPUMP` element is modeled with:

$$MASSFL = K * KTABLE$$

- The dependent variable code on the TABTYPE Card must be `MASSFL`. The mass flow is considered positive if it flows from inlet to outlet.

The volumetric flow rate boundary condition VOLUME through the element is modeled with:

$$VOLUME = K * KTABLE$$

- The dependent variable code on the TABTYPE Card must be `VOLUME`. Volumetric flow rate is considered positive if it flows from inlet to outlet.

The velocity boundary condition at the narrower end of the `FANPUMP` element is modeled with:

$$VELOC = K * KTABLE$$

- The dependent variable code on the TABTYPE Card must be `VELOC`. Velocity is positive if it flows from `NODE1` to `NODE2`.

Stream elements

Stream elements are similar to hydraulic elements in that they describe advective heat transfer due to fluid mass flow, but they give a more flexible way to directly control the fluid mass flow distribution with only minimal user input for the element properties and boundary conditions. Unlike the regular hydraulic elements they do not have flow resistance, cross-sectional, or fluid conduction properties and do not model pressure drops. Their pressure is not defined unless it is set explicitly with Card 9 PSINK cards. Stream elements include 2-node STREAM and 1-node FLOWCON elements. FLOWCON elements, which define the fluid material properties, must be assigned to all nodes of the stream network (including free ends). Stream elements may not have fluid flow connections (may not share a node) with regular hydraulic elements.

For stream elements that do not have explicitly defined mass flows, the mass flows are solved for so that to best match all the mass flow boundary conditions in a given stream network while optimizing mass flow continuity (minimizing the mass flow imbalances at the junction points) throughout the network and, for under-constrained problems, also optimizing flow equality between different inflow or outflow branches of each network junction. Mass flow imbalances at network junctions are permitted (over-constrained problems with conflicting boundary conditions), but a warning is issued for junctions where such imbalances are significant (greater than 1 percent). To prevent a mass flow imbalance at a given junction from causing a heat flow imbalance in the thermal solve, a compensating mass flow injection or loss is added internally at that junction, assuming the temperature of the extra mass flow to be the same as the calculated temperature at the junction.

Because of their unset cross sectional properties, stream elements have undefined fluid velocities and Reynolds numbers. They also cannot be used in thermal coupling Card 6e requests with convection NEARCx options. For other thermal coupling request options they can only be referenced in the secondary element selections, unless the coupling request is of CONVSN, CONVLP, XCOND, NEAR, or NEARLP type. The stream fluid material capacitance is used for calculating advection conductances, but not for modeling stream element heat capacitances, which are taken to be zero, in transient runs.

`= FLOWCON` (or `-2450`)

A 1-node FLOWCON element defines a stream fluid properties at its location. FLOWCON elements should be created at all nodes referenced in the STREAM elements, including the free ends. Though a FLOWCON element is defined synonymously to a FLOWSEC element, it is distinguished by that its `PROP` field should always be defined (not set to 0) and should reference a valid FLOWCON PROP card instead of a FLOWSEC one.

If the `MAT` field is set to 0, the material properties are set to those of the immediately upstream 1–node hydraulic element.

`= STREAM`
(or `-2003`)

A 2-node STREAM element is used to either specify a mass flow boundary condition or to simply define the fluid flow path (inter-node connections) in the stream network, depending on the PROP card used. A STREAM element is synonymous to a FANPUMP hydraulic element except that it references a STREAM PROP card, which is similar to a FANPUMP PROP card except that it can only have either a mass flow definition (not total pressure rise, volumetric flow, or flow velocity) or no flow boundary condition at all. The outlet is defined at NODE1 and the inlet is at NODE2. The MAT field of a STREAM element is ignored.

`MAT` may be `0`, or a mnemonic of the form `Mm` (e.g., `M10`), where m is a material property id of a Card 9 MAT Card.

For non–hydraulic elements `MAT` = `0` defaults to the default material properties.

For hydraulic elements `MAT` = `0` defaults to the properties of the immediately upstream 1–node hydraulic element.

`FRONTOPTPROP` may be `0` or a mnemonic of the form On (e.g. `010`), where n is an optical property number referencing a Card 9 OPTICAL Card.

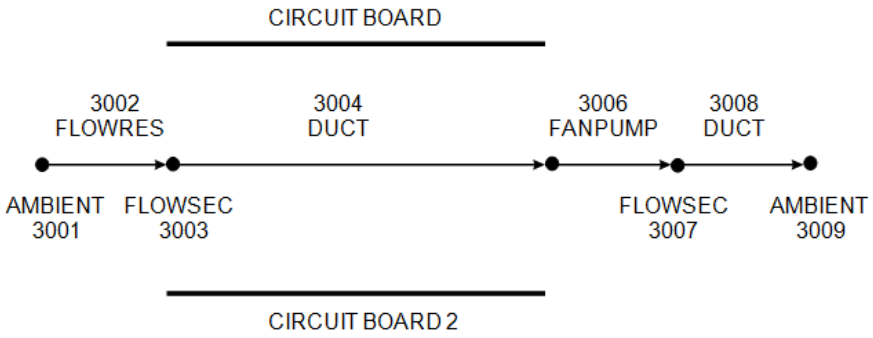
If `FRONTOPTPROP` is `0` and `TYPE` is SURFACE, then the optical surface properties are taken form the Card 9 MAT Card specified in the `MAT` field.

`PROP` may be `0` or a mnemonic of the form `Pp` (e.g., `P12`), where p is a physical property number referencing a Card 9 PROP Card.

A PROP Card is mandatory for `SURFACE`, `FLUID`, `DUCT`, `FANPUMP`, `FLOWRES`, `FLOWCON`, and `STREAM` elements.

A Hydraulic Element Example

Consider the problem of air flow between two circuit boards, driven by a fan located at the outlet. Inlet and exhaust are to the atmosphere. The flow path is defined as follows:



1–node elements are specified at nodes except the one at the end of the circuit board. It is not necessary to define one here because the duct profile is the same as at the 1–node element upstream, and one will automatically be created with the correct upstream duct profile of `FLOWSEC` element `3003`.

Since the air inlet to the circuit boards is the ambient air, the 1–node element before the inlet is `AMBIENT` element `3001`. Since the fan outlet is to the atmosphere, the element at the end of the flow path is `AMBIENT` element `3009`.

A `FLOWRES` element is used to model the length–independent entrance flow resistance.

The outlet resistance is modeled with a `DUCT` element, which undergoes a rapid change in cross section, in effect becoming a diffuser, but it could also have been modeled with a `FLOWRES` element.

The flow between the two circuit boards is modeled with a `DUCT` element. Its flow resistance values are calculated assuming fully developed flow in a smooth duct. A flow resistance multiplier value of `2.0` is entered to account for anticipated surface roughness effects.

The fan is modeled with a `FANPUMP` element, whose characteristics are entered into a table referenced on the PROP Card.

Example

```
RTEST667 CARD 5A EXAMPLE - FLOW IN A SINGLE CHANNEL
-1
3 0 0 0 0 0 0 0 0 0 0   $ CARD 2A M=1+2 - VUFAC +
$                       $ COND MODULES RUN
0 273 0 0 0 200
-1
-1
1 -.0254 0 0            $ AMBIENT NODE
```

```
2 0 0 0
11 1 0 0
12 1 .00254 0
13 1 .00254 .15
14 1 0 .15
3 .254 0 0
4 .30 0 0
5 .33 0 0
31 0 -.01 -.075
GEN 2 2 1 2 .254 0 0 0 0 .15
GEN3RD 2 10 0 .02 0
-1
$ CARD 5A ELEMENT DEFINITIONS
$
1 SURFACE M1 0 P1 31 32 34 33   $ BOARD ELEMENT 1
2 SURFACE M1 0 P1 41 42 44 43   $ BOARD ELEMENT 2
$
$ 1-NODE HYDRAULIC ELEMENT DEFINITIONS
$
3001 AMBIENT M2 0 P8 1     $ AMBIENT ELEMENT IS
$                          $ AT ENTRANCE
3003 FLOWSEC M2 0 P2 2     $ FLOWSEC ELEMENT AT
$                          $ BOARD INLET
9900 FLOWSEC M2 0 P2 3     $ FLOWSEC AT FAN INLET
3007 FLOWSEC M2 0 P3 4     $ FAN OUTLET AREA
3009 AMBIENT M2 0 P8 5     $ AMBIENT ELEMENT AT EXHAUST
$
$ 2-NODE HYDRAULIC ELEMENT DEFINITIONS
$
3002 FLOWRES 0 0 P4 1 2    $ ENTRANCE RESISTANCE
3004 DUCT 0 0 P5 2 3       $ DUCT BETWEEN CIRCUIT BOARDS
3006 FANPUMP 0 0 P6 3 4    $ FANPUMP
3008 FLOWRES 0 0 P7 4 5    $ EXIT RESISTANCE
$                          $ TO ATMOSPHERE
4000 0 M1 0 P1 11 12 13 14 $ QUAD ELEMENT DEFINES
$                          $ DUCT PROFILE
-1
$ CARD 6 CARD
$
$ FORCED CONVECTION CONDUCTANCES
$
AREA BOARDS 0 0 FLUID 0 1 NEARC1
-1
-1
-1
$ CARD 9 CARDS
$
```

```
NAME BOARDS 1 2              $ BOARD ELEMENTS GROUP NAME
NAME FLUID 3001 3009         $ FLUID ELEMENTS GROUP NAME
HYDENV 101351 20 9.81 180 0 $ ENVIRONMENT IN SI UNITS
TABTYPE 1 VOLUME TIME        $ CONSTANT VOLUME FAN
TABDATA 1 .002 0             $ SINGLE TABDATA CARD
QNODE BOARDS 20              $ BOARD DISSIPATION 20 W
PRINT 1 9999 TEMP            $ PRINTOUT CARDS
PRINT 1 9999 HFGROUP
MAT 1 KTHERM 0               $ MAT CARD FOR BOARDS
PROP 1 SHELL 0               $ PROP CARD FOR BOARDS
MAT 2 RHO 1.207              $ MAT CARD FOR FLUID
MAT 2 CPP 1007               $ MAT CARD FOR FLUID
MAT 2 KTHERM .0263           $ MAT CARD FOR FLUID
MAT 2 VISC 1.85E-5           $ MAT CARD FOR FLUID
$
$ MAT CARD FOR AMBIENT ELEMENTS
$
PROP 2 FLOWSEC 0 0 4000      $ PROP CARD FOR BOARD INLET.
$                            $ DUCT PROFILE DEFINED AT
$
$                            $ DUCT PROFILE DEFINED AT
$                            $ ELEMENT 4000
PROP 3 FLOWSEC .001          $ FAN OUTLET AREA = .001
PROP 4 FLOWRES .83           $ ENTRANCE RSISTANCE = .83
PROP 5 DUCT 2                $ DUCT RESISTANCE MULTIPLIER=2
PROP 6 FANPUMP 1 1           $ FANPUMP REFERENCES TABLE 1
PROP 7 FLOWRES 1             $ EXIT RESISTANCE 1.0
PROP 8 AMBIENT               $ AMBIENT PROP CARD
-1
-1
```

Card 5b - Multiple Element Generation Cards – Optional

`KODE, NA, NB, NDA, NDB, (NDVA(I), I = 1, MM), (NDVB(I), I = 1, MM)`

A Card 5b following a Card 5a Starting Element generates a matrix of `NA*NB` elements with the properties of the Starting Element.

`KODE` = `GEN` (or `-5`), or `GENCL` (or `-6`), or `GENCLA` (or `-9`)

= `GEN` (or `-5 )` generates elements on open surfaces and in open volumes (e.g., on flat or unclosed curved planes, rectangular volumes, and half cylinders).

`=` `GENCL` (or `-6`) generates elements on closed surfaces and in closed volumes (e.g. spheres, cylinders).

- The last (NA'th) element's nodes in each row are joined to the nodes of the first element for each row to close the surface.
- Beam elements: the first node of the first element is joined to the second node of the NA'th (last) element of each of the NB rows.
- Triangular elements: the first and third nodes of the first element are joined to the second and third nodes of the NA'th element respectively. To approximate a circle with a series of triangular elements, the third node should fall on the center of the circle.
- Quad elements: the first and fourth nodes of the first element are joined to the second and third nodes of the NA'th element respectively.
- Wedge elements: the first, third, fourth, and sixth nodes of the first element are joined to the second, third, fifth, and sixth nodes of the NA'th element respectively. If a solid cylinder is modeled with wedges, the third and sixth nodes of the wedges should fall on the axis of the cylinder.
- Hexahedra: the first, fourth, fifth, and eighth nodes of the first element are joined to the second, third, sixth, and seventh nodes of the NA'th element respectively.

= `GENCLA` (or `-9`) also generates elements on closed surfaces and volumes, but the nodes of the NA'th element that are joined to the first element of each row differ from those of the `GENCL` option.

- Triangular elements: the second and third nodes of the first element are joined to the first and third nodes of the NA'th element respectively. To approximate a circle with a series of triangular elements, the third node should fall on the center of the circle.
- Wedge elements: the first, second, and third nodes of the first element are joined to the fourth, fifth, and sixth nodes of the NA'th element respectively.
- Hexahedra: the first, second, third, and fourth nodes of the first element are joined to the fifth, sixth, seventh and eighth nodes of the NA'th element respectively.

`NA` is the number of elements in the A direction (in a row).

`NB` is the number of elements in the B direction (number of rows).

`NDA` is the element number increment in the A direction.

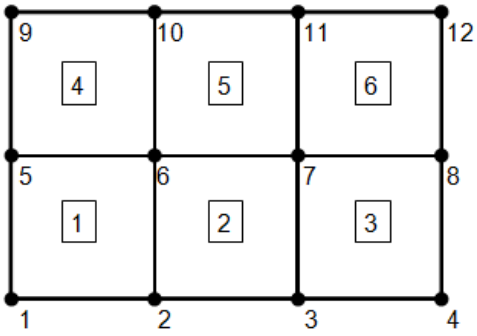
`NDB` is the element number increment in the B direction.

`NDVA(I)` is the I'th node number increment in the A direction.

`NDVB(I)` is the I'th node number increment in the B direction.

`MM` is the number of nodes of each element, which may be from 1 to 8, and must equal the number of nodes of the Starting Element.

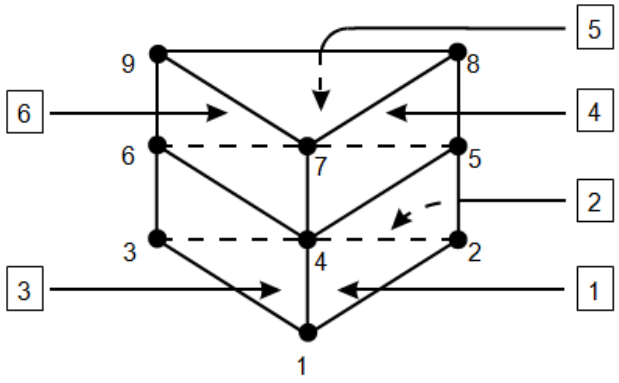
Example 1



Quad elements in two rows of three are generated.

```
1 0 0 0                    $ STARTING NODE
GEN 4 3 1 4 1 0 0 0 1 0    $ 4*3 NODES ARE GENERATED
-1
1 0 M1 0 P1 1 2 6 5
$ ELEMENT 1, STARTING CARD 5A ELEMENT
GEN 3 2 1 3 1 1 1 1 4 4 4 4
$ CARD 5B GENERATES 6 ELEMENTS IN 2 ROWS OF 3
```

Example 2



This example produces six rectangular elements in two rows of three that define a triangular cross–section tube.

Example

```
$ CYLINDRICAL COORDINATE SYSTEM DEFINED
SCYL
1 .577 0 0                    $ STARTING NODE 1
$ 9 NODES GENERATED, 120 DEGREES APART, AT Z = 0, 1, AND 2.
GEN 3 3 1 3 0 120 0 0 0 1
-1
1 0 M1 0 P1 1 2 5 4           $ STARTING ELEMENT
GENCL 3 2 1 3 1 1 1 1 3 3 3 3 $ GENERATES 6 ELEMENTS IN 2 ROWS OF 3.
```

Example 3

12 rectangular elements in 2 rows of 6 are generated, on the surface of a cylinder of radius 1 and height 2.

Example

```
SCYL                  $ CYL. COORDINATE SYSTEM CARD 4C.
1 1 0 0               $ STARTING NODE 1
GEN 6 3 1 10 0 60 0 0 0 1
-1
1  0 M1 0 P1 1 2 12 11          $ STARTING ELEMENT 1
GENCL 6 2 1 10 1 1 1 1 10 10 10 10 $ CARD 4B GENERATES
$                               $ 12 ELEMENTS, 1 THRU 6
$                               $ AND 11 THRU 16.
```

Card 5c - Third Level Element Generation Card – Optional

`KODE, NC, NDC, (NDVC(I), I = 1, MM)`

A Card 5c preceded by a Card 5b and a Card 5a generates a matrix of `NA*NB*NC` elements with the properties of the Card 5a element. Card 5b defines the elements to be generated in the A and B directions, Card 5c defines them for the C direction.

`KODE` = `GEN3RD` (or `-7`)

`NC` is the number of elements in the C direction.

`NDC` is the element number increment in the C direction.

`NDVC(I)` is the I'th node number increment in the C direction.

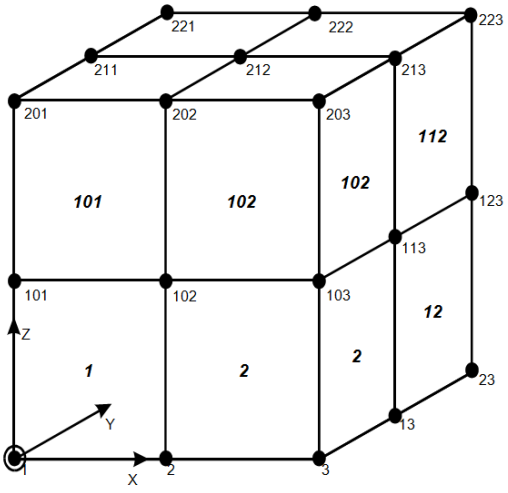
`MM` is the number of nodes in each element, which may be from 1 to 8, and must be equal to the number of nodes of the Starting Element.

The following example generates 8 solid elements 1, 2, 11, 12, 101, 102, 111, 112.

Example

```
$ CARD 4 CARDS – GLOBAL CARTESIAN COORDINATE SYSTEM
$ IS IN EFFECT.
1 0 0 0
$ STARTING NODE
GEN 3 3 1 10 1 0 0 0 1 0
$ CARD 4B GENERATES 3*3 = 9 NODES
GEN3RD 3 100 0 0 1
```

```
$ CARD 4C GENERATES 3*9 = 27 NODES
-1
$ CARD 5 CARDS. 8 SOLID ELEMENTS ARE GENERATED.
1 SOLID M1 0 P1 1 2 12 11 101 102 112 111
$ CARD5A STARTING EL.
GEN 2 2 1 10 1 1 1 1 1 1 1 10 10 10 10 10 10 10 10
$CARD5B 4 EL.
GEN3RD 2 100 100 100 100 100 100 100 100 100
$CARD 5C 8 EL.
```



Card 5d - Space Element Generation Card – Optional

`KODE` , `NSP` , `DIV`

`KODE` = `SPACE` (or `-8`)

`NSP` is an element number or a group name from a single–element group. NSP must not conflict with other elements in the model and must not exceed the maximum allowable element number.

`DIV` is an optional integer subdivision parameter.

Notes

This Card generates a set of large inward-facing black elements forming an enclosure about the origin. If the model is not axisymmetric, these elements form a tetrahedron or a cube.
For axisymmetric models a large cylinder is created about the origin. The number of elements on the circumference of the cylinder is `3*T1`, where `T1` is the number of tangential elements specified on the Card 9 AXISYMM Card.
If `DIV` is blank or zero, then four triangular space elements form a large tetrahedron about the origin. These are assigned the sequential numbers `NSP`, `NSP + 1`, `NSP + 2`, and `NSP + 3`.
If `DIV` is `> 0`, then six large square faces are created which form a cube about the origin. Each face is further subdivided into `DIV**2` square elements, with `DIV` elements along each edge. The elements on the faces are assigned the group names `SPACE+X`, `SPACE-X`, `SPACE+Y`, `SPACE-Y`, `SPACE+Z`, `SPACE-Z`. In addition, all the space elements created are assigned the group name SPACE.
All points on a space element are at a distance `> 1.E6` from the origin.
All the space elements are automatically merged into element NSP by the MEREL module.
A Card 9 SINK Card should be used to define NSP's temperature.
If Card 2a `KSP` = `NSP,` then for each element a residual view factor equal to 1- the sum of the view factors will be created to element NSP.

Example

```
SPACE 2001
```

Card 6a - View Factor Request Cards – Optional

`L, N1, N2, FLAG, REVN1, REVN2, SPACEFLAG`

`L` is the type of view factor calculation request.

`L` may be:

`VFSALL` (or `1`) calculates all the view factors with shadowing, starting with the view factor from `N1` to `N2`, and following the order in which the elements are defined on Card 5a.

- To calculate all the view factors leave all fields except the first one blank.

`VFNALL` (or `2`) is the same as `VFSALL` with no shadowing.

`VFS12` (or `3`)

- If `N1` and `N2` are element numbers, `VFS12` calculates a single view factor from `N1` to `N2` with shadowing.
- If `N1` and `N2` are both group names, all the view factors from the elements of `N1` to the elements of `N2` will be calculated. For this option, the REVN1, REVN2, and SPACEFLAG fields may also be active.

`VFN12` (or `4`) is the same as `VFS12` with no shadowing.

`VFS1ALL` (or `5`)

- If `N1` is an element number, `VFS1ALL` calculates all the view factors for `N1` with shadowing, starting with the view factor from `N1` to `N2` and following the order in which the elements are defined on Card 5a. `N2` = blank calculates all view factors for `N1`.
- If `N1` is a group name, all view factors for the elements of `N1` will be calculated. For this option, the REVN1, REVN2, and SPACEFLAG fields may also be active.

`VFN1ALL` (or `6`) is the same as `VFS1ALL` with no shadowing.

`N1` may be an element number or a group name.

`N2` may be an element number, group name, or blank.

`FLAG` may be:

blank or `0`,

`VFTRACE` (or `-3.4E5`).

- `VFTRACE` uses ray–tracing to calculate view factor if specular and/or transparent surfaces are present. For more information, see VFTRACE Option in the **Notes**.

`REVN1` may be 0, or an element number, or a group name, and it specifies that the reverse sides of the `REVN1` element(s) are to be added to the `N1` elements. It is applicable for `L = VFN12`, `VFS12`, `VFS1ALL` or `VFN1ALL`.

`REVN2` may be `0`, or an element number, or a group name, and it specifies that the reverse sides of the `REVN2` element(s) are to be added to the `N2` elements. It is applicable for `L = VFN12`, `VFS12`, otherwise it must be blank or 0.

`SPACEFLAG` may be the code `SPACE`, or `NOSPACE`, or blank, or 0. `SPACE` is applicable only for `L` = `VFN12`, `VFS12`, `VFS1ALL`, `VFN1ALL`. `NOSPACE` is applicable only for `L` = `VFNALL`, `VFSALL`.

- If `L` = `VFN12` or `VFS12` and `SPACE` is present, then the space elements of Card 5d are added to the `N2` group.
- If `L` = `VFN1ALL` or `VFS1ALL` and `SPACE` is present, then the space elements of Card 5d are added to the `N1` group.
- If `L` = `VFNALL` or `VFSALL` and `NOSPACE` is present, then the space elements of Card 5d are removed from the `N2` group.

Notes

Restart Option:

- If `VFSALL` or `VFNALL` are used, and the `VUFAC` module stops prematurely, e.g. at the view factor of elements `J1` to `J2`, the rest may be calculated in a restart run by using the same `L`, `N1 = J1` and `N2 = J2`. The previously created file VUFF must be present, the new view factors will be automatically appended to it.

Accuracy Check:

- The GRAYB module performs a view factor calculation accuracy check by summing the view factors for each element.
- The view factor sum should be close to 1. Compensation for view factor calculation inaccuracy is provided by the Card 2a KSP parameter. View factor calculation accuracy may be controlled with a Card 6f MESH ERROR Card.
- If the `N = 512` option is not specified on Card 2a, the view factor module will write a detailed view factor calculations to the report log file. You may use this to debug your model.

No Shadowing and No Radiation Flags:

- The Card 9 PARAM NOSHADOW option can be used to specify non-shadowing elements.
- The Card 9 PARAM NORAD option can be used to specify SURFACE elements that take part only in convective conductance calculations and not radiative calculations.
- The Card 9 PARAM NOSOLAR option can be used to specify elements that will not take part in solar spectrum calculations.

`VFTRACE` Option

- If the `VFTRACE` option is specified view factors are calculated with ray–tracing whenever specular and/or transparent surfaces are encountered.
- If specular and/or transparent surfaces are present the effect of `VFTRACE` is increased accuracy in two areas: radiative couplings between elements, and the diffusely reflected component of incident solar radiation or radiation originating from Card 6n heat flux view factors. Ray-tracing is always performed for **directly** incident component of solar radiation and Card 6n heat flux view factor requests.
- If the `VFTRACE` option is **not** specified, view factors are calculated with the assumption that all surfaces reflect incident radiation diffusely. It is important to note the ray-tracing is Cpu-intensive and its benefits in increased accuracy are often negligible.
- If transparency/specularity values are specified only in the solar spectrum of an element referenced from Card 9 - MAT Material Property Definition Card - Optional , they are considered by default to be valid for the IR spectrum as well. If the IR spectrum transparency or specularity is also specified, a separate set of view factors will be calculated for the IR spectrum as well.

The view factors calculated with ray-tracing are written on file VUFF with the mnemonic BVF. They are distinguished from view factors calculated without ray-tracing by the following:

1. For view factors calculated without ray-tracing the flag in the TIME field is `-1.E36` , for view factors calculated with ray-tracing in the solar spectrum the flag is `-1.1E36` , and for view factors calculated with ray-tracing in the IR spectrum the flag is `-1.2E36` .
2. The area specified in the AR field is not the area of the element, but its area multiplied by the factor (1-specularity/transmissivity). The emissivity and absorptivity values in the E and A values divided by (1-specularity/transmissivity).

Calculating view factors in an enclosure.

- For calculating all the view factors in an enclosure with VfxENC Cards, see Card 6r - View Factor Request Cards in an Enclosure – Optional.

Example

```
VFSALL
$ ALL VIEW FACTORS ARE CALCULATED WITH SHADOWING

VFS12 ENC ENC
$ ONLY THE VIEW FACTORS WITHIN THE ENCLOSURE
$ WHOSE ELEMENTS ARE ASSOCIATED WITH THE NAME
$ ENC ARE CALCULATED

MESH 1
$ ALL THE VIEW FACTORS ARE CALCULATED WITH MESH = 1

VFSALL
MESH 2

VFS1ALL SHIELD
$ THEN ALL THE VIEW FACTORS TO THE GROUP OF
$ ELEMENTS CALLED SHIELD ARE RECALCULATED FOR
$ GREATER ACCURACY WITH MESH = 2

VFS12 4 5
$ VIEW FACTOR FROM ELEMENT 4 TO 5 IS CALCULATED
```

Card 6b - Solar View Factor Request Card – Optional

`L` , `N1` , `THETAS` , `PHIS` , `TIME` , `PSUN` , `REVN1`

`L` is the type of solar view factor calculation request.

`L` may be:

`SOLS1` (or `7`) calculates a single solar view factor with shadowing for element or group `N1` .

`SOLN1` (or `8`) is the same as `L` = `SOLS1` with no shadowing.

`SOLSALL` (or `9`) calculates solar view factors with shadowing for all elements starting with element `N1`, in the order the Card 5 elements occur. For solar view factors to all elements, `N1` should be `0`.

`SOLNALL` (or `10`) is the same as `L` = `SOLSALL` with no shadowing.

`THETAS` is the angle in degrees the sun vector makes with the Z axis. The sun vector is defined as a unit vector at the origin pointing towards the sun.

`PHIS` is the angle in degrees the projection of the sun vector on the XY plane makes with the X axis (CCW is positive).

`TIME` defines the time when a solar view factor occurs. `TIME` can be blank, or the flag `CONSTANT` for constant heat loads. `TIME` = blank defaults to CONSTANT.

`PSUN` is optional, it defines the collimated solar spectrum radiative source's (sun's) power output per unit area for the view factor request. `PSUN` overrides the Card 2a default `PSUN` value.

If `PSUN` is `0` or blank, the Card 2a `PSUN` value will be used.

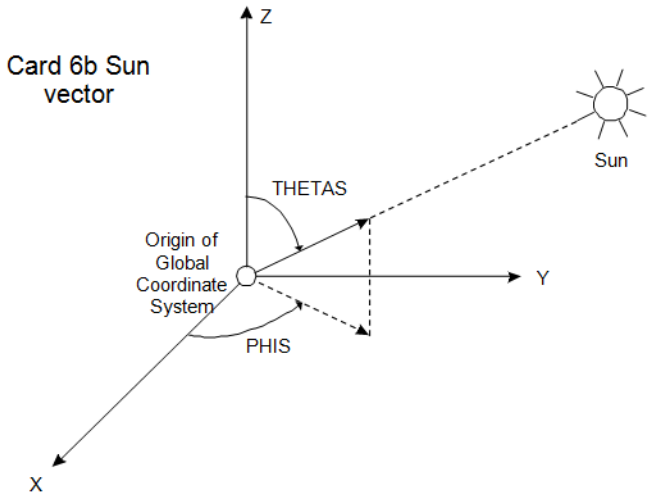
If `PSUN` is `Tn` or `-n`, where `n` is a table number (e.g. `T10` or `-10`), and `n` is a table whose dependent variable is `QNODE`, and `TIME` = `CONSTANT`, then the `PSUN` value will be interpolated from the table n by the Analyzer during run time.

`REVN1` is applicable for `L` = `SOLS1` or `SOLN1`, otherwise it must be blank or 0. `REVN1` may be 0 or an element or a group name, and the reverse sides of the `REVN1` element(s) are added to the `N1` elements.

Notes

The sun is modeled as a collimated point source at a distance of `1.E6` from the origin, and pointing towards it.

Solar view factor calculations to the space elements are not performed, and space elements do not cause shadowing. For elements to be considered non–shadowing space elements, their nodes must be at distances `> 1.E6`, to prevent them from shadowing the sun. See Card 5d - Space Element Generation Card – Optional for more information.
If duplicate solar view factor requests are present to the same element, the first one takes precedence.



Example

```
SOLS1 3 45 38 12     $ SOLAR VF WITH SHADOWING FOR EL. 3 TIME = 12
SOLSALL 0 45 38 12   $ SOLAR VF'S FOR ALL ELEMENTS, TIME = 12
```

Card 6d - Earth Card – Optional

`L`, `HR`, `ALB`, `THETAE`, `PHIE`, `TIME`, `PIR`, `PIRSUBSOLAR`

`L` may be:

= `EARTHN` (or `12`): albedo factor and Earth view factor calculations will be performed with no shadowing.

= `EARTHS` (or `13`): the above will be performed with shadowing.

`HR` is the H/R value, where `H` is the distance from the origin to the Earth's center, and R is the Earth's radius. The Earth's radius is equal to 3441 nautical miles, 3963 miles, or 6378 km.

`ALB` is the albedo value, typically `0.35`. Albedo is the solar reflectivity (1–absorptivity) of the Earth.

If `ALB = 0`, no albedo factors or Earth view factors will be calculated, and the Earth Cards will be used for solar eclipse calculations only.

`THETAE` is the angle in degrees the Earth vector makes with the Z axis. The Earth vector is a unit vector at the origin pointing towards the center of the Earth.

`PHIE` is the angle in degrees the projection of the Earth vector on the XY plane makes with the X axis (positive CCW).

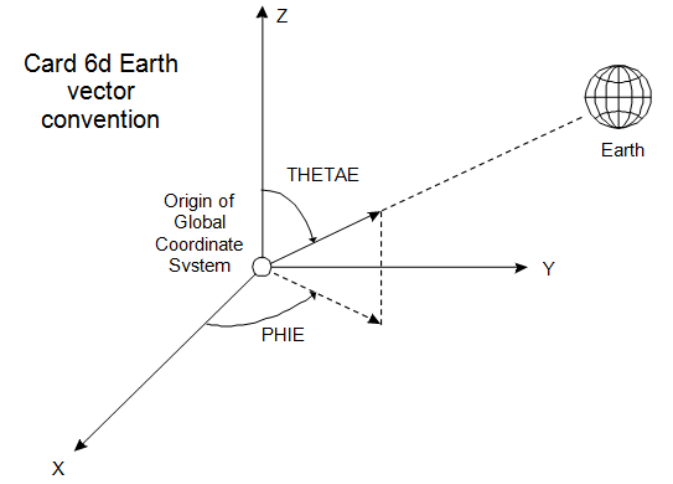
`TIME` is the time at which the Earth's position is defined by the Earth Card. TIME can be blank, or the flag CONSTANT.

`PIR` is optional, it defines the heat load per unit area leaving the planet. `PIR` overrides the Card 2a default `PIR` value. If `PIR` is blank, the Card 2a `PIR` value will be used.

`PIRSUBSOLAR` is optional, it defines the ratio of the IR emissive power of a planet at its subsolar point to its IR emissive power on the side opposite to the subsolar point. Alternatively, the `PIRSUBSOLAR` value can be defined on the Card 9 PARAM PIRSUBSOLAR Card. If neither is present, `PIRSUBSOLAR` = `PIR` will be used.

Notes

The Earth Card defines the position and albedo of the Earth at a particular TIME. It is used for albedo factor, Earth view factor, and solar eclipse calculations. These are performed only for those elements that appear on Solar View Factor Request Cards 6b with the same TIME parameters as on the Earth Card. An Earth Card without a corresponding Solar View Factor Request Card will be ignored.
Earth is modeled with its center at a distance of .8E6 from the origin, with a radius of .8E6/HR.



Example

```
SOLSALL 0 30.0 40.0 8.0
EARTHS 1.1 .35 20.0 30.0 8.0
Solar view factor, albedo factor, and Earth view factor calculations will be performed
for all the elements TIME = 8
```

Card 6e - Thermal Coupling Request Card - Optional

`L` , `N1S` , `N1F` , `N1D` , `N2S` , `N2D` , `HN1` , `KODE` , `EXP` , `P1` , `VX` , `VY` , `VZ`

`L` = `AREA` (or `11`)

Card 6e creates conductances that are fixed or area-proportional between two sets of elements `N1` and `N2` .

Card 6e is active only if the VUFAC module is run (Card 2a `M` = `2`).

- Only the following types of elements are recognized:
- Card 5a SURFACE elements with emissivity `≥ 0` , or flagged as NORAD with the PARAM NORAD Card.

2-node hydraulic or stream elements or 1-node AMBIENT elements.

Solid elements are not recognized.

Two conductance generation options are available. The NEARx (recommended) options connect the `N1` elements to the nearest of the `N2` elements. The non-NEARx options generate conductances according to a specified numbering scheme.

Electrical couplings may also be created. An electrical coupling is similar to a thermal coupling, except that it takes part in the electrical network calculations, and not in the thermal network calculations. An electrical coupling is a linear thermal coupling that references a table or expression (through the `EXP` parameter) whose dependent variable on the TABTYPE Card is ELECRES. The value of the electrical coupling will be the value of the thermal coupling multiplied by the value interpolated from the table.

The Non-NEARx Options

`N1S` defines the `N1` elements.

It may be an element number or a group name.

If `N1S` is an element number, the `N1` elements start with `N1S`, end with `N1F`, and are incremented by `N1D`. `N1D = 0` defaults to `N1D = 1`.

`N2S`: the `N2` elements start with `N2S` and are incremented by `N2D`, corresponding to `N1S` and `N1D`.

If `N2S` is a group name, it is interpreted to be the first element of the group, and it must be a Card 5a element.

For the `CONVASN` and `CONVSN` options `N2S` is a table number specifying a time vs temperature behavior.

`N2D`

If `N1S` and `N2S` are both group names, `N2D` is the ID number of the Card 9 DESCRIP Card associated with this request.

If `N1S` and `N2S` are both element numbers, `N2D` is an increment value described above.

`HN1` is a coefficient associated with element N1.

`KODE` is a mnemonic.

`COND` (or `1`) creates a linear conductance = `A(N1)*HN1/RL.`

- `RL` is the distance between the CG's of `N1` and `N2`.

`CONV` (or `0`) creates a linear conductance = `A(N1)*HN1` between elements `N1` and element `N2`.

- `EXP` (optional) is a conductance multiplier table or expression number. The dependent variable on its TABTYPE Card must be `COND`.

`CONV1W` (or `34`) creates a linear 1-way conductance = `A(N1)*HN1` between elements `N1` and element `N2`. `A(N1)` is the area of `N1`. `N2` is affected by the `N1` elements, while the `N1` elements are not affected by `N2`.

`CONVASN` (or `21`) creates a linear conductance = `A(N1)*HN1` between the `N1` elements and a SINK element whose temperature history is described by table or expression `N2S`. The number of the `SINK` element is assigned during run-time.

- `EXP` is an optional table or expression number for a conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.
- `N2S` is a table number specifying a time vs temperature behavior.

`CONVLP` (or `23`) creates linear conductances for beam elements. The `N1` elements must be beam elements and the resulting conductance is equal to `LENGTH(N1)HN1`.

- `EXP` is an optional table or expression number for a conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

`CONVSN` (or `20`) creates a linear conductance = `HN1` between the `N1` elements and a `SINK` element whose temperature history is described by table or expression `N2S`. The number of the `SINK` element is assigned during run-time.

- `EXP` is an optional table number for a conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.
- `N2S` is a table number specifying a time vs temperature behavior.

`CSERIES` (or `6`) creates a conductance = `A(N1)*HN1` in series with the already existing linear conductance between `N1` and `N2`, thereby reducing it.

- `EXP` is an optional table or expression number for a table-dependent conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

`CYLINDASN` (or `3834`)

Free convection coupling(s) from element(s) `N1` on the surface of a cylinder are created, convecting to a `SINK` element whose temperature history is described by table or expression `N2S`. The fluid is assumed to surround, i.e. be both above and below the element. The `SINK` element ID is assigned during run-time.

- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the diameter of the cylinder. The `EXP=SELF` option is not valid for this correlation.
- `P1` must be the length of the cylinder.
- `VX`, `VY`, `VZ` are the directional components of the unit axis vector of the cylinder.

`FREE` (or `4`) creates a free convection conductance = `A(N1)*HN1`. Heat flow through it is calculated with:

$$Q_{N1N2} = A(N1) * HN1 * (T_{N1} - T_{N2}) * (T_{N1} - T_{N2})^{EXP}$$

- `EXP` = blank defaults to `.25`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate convect. If `P1` is unspecified or 0, the thermal solver determines the coupling side, depending on the sides that "see" each other: either `TOP` or `BOTTOM`.

`FREECONVASN` (or `3835`) creates a free convection conductance = `A(N1)*HN1` between the `N1` elements and a SINK element whose temperature history is described by table or expression `N2S`.

- The `SINK` element ID is assigned during run-time. The fluid is assumed to surround, i.e. be both above and below the element. Heat flow through it is calculated with:

$$Q_{N1N2} = A(N1) * HN1 * (T_{N1} - T_{N2}) * (T_{N1} - T_{N2})^{EXP}$$

- `EXP` = blank defaults to `.25`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate convect. If `P1` is unspecified or 0, the thermal solver determines the coupling side, depending on the sides that "see" each other: either `TOP` or `BOTTOM`.

`FORCEDCASN` (or `3837`)

- Forced convection coupling(s) from element(s) `N1` on the surface of a cylinder in cross flow are created, convecting to a `SINK` element whose temperature history is described by table or expression `N2S`. The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the velocity of the flow.
- `P1` is 0.
- `VX` is the diameter of the cylinder.

`FORCEDPASN` (or `3836`)

- Forced convection coupling(s) from element(s) `N1` on the surface of a flat plate are created, convecting to a `SINK` element whose temperature history is described by table or expression `N2S`. The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the velocity of the flow.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate convect.
- `VX` is the length of the plate in the direction of the flow.

`FORCEDSASN` (or `3838`)

- Forced convection coupling(s) from element(s) `N1` on the surface of a sphere in cross flow are created, convecting to a `SINK` element whose temperature history is described by table or expression N2S. The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the velocity of the flow.
- `P1` is 0.
- `VX` is the diameter of the sphere.

`INCCHNLASN` (or `3840`)

- A free convection coupling from the element(s) `N1` on the inner surface of either wall of an inclined open parallel plate channel is created, convecting to a `SINK` element whose temperature history is described by the table or expression `N2S.` The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `EXP` is the distance between the walls of the channel.
- `P1` is the length of the channel.
- `VX`, `VY`, `VZ` are the directional components of the vector of the surface normal of the walls of the channel.

`INTER` (or `12`) defines the `N1` elements to be interface resistance elements.

- If `N1` is a planar element surface coated onto the surface of a solid element I, and a conductance of value G_{INI} is calculated between them by the `COND` module, G_{INI} is reduced to G_{NInew}

$$G_{IN1new} = \frac{1}{\frac{1}{GIN1} + \frac{1}{A(N1)HN1}}$$

- If `N1` lies at the interface of two solid elements then G_{INI} is reduced to:

$$G_{IN1new} = \frac{1}{\frac{1}{GIN1} + \frac{1}{2A(N1)HN1}}$$

- With this option you can model with zero-thickness planar elements the interface resistance of a thin glue line.
- If the `N1` elements are beams, they must be connected to the edges of planar elements, and their area per unit length should be 1.
- `EXP` is an optional table or expression number for a table-dependent conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

`INTERB` (or `44`) defines the `N1` elements to be interface resistance elements.

- `INTERB` behaves the same way as the `INTER` option, except for beam elements. If the `N1` elements are interface beam elements between two shell elements, the interface conductance between the two shells is proportional to the length of the interface beam element, not its surface area (as with the `INTER` option).
- If a conductance of value G_{IN1} is calculated between the two shell elements by the `COND` module, G_{IN1} is reduced to $G1_{N1new}$:

$$G_{IN1new} = \frac{1}{\frac{1}{GIN1} + \frac{1}{L(N1)HN1}}$$

`INTER2` (or `42`) creates interface conductances between the `N1` and `N2` elements where they are connected conductively. Conductive connection means the adjacent elements share the same nodes. The `PARAM COND NEW` option must be used.

- `HN1` is the interface conductance value per unit length for shells, per unit area for solids, and interface conductance value for beams.
- If `N1A` is a shell element conductively connected to one of the shell elements of `N2`, the effective conductance G_{bN1} between `N1A` and the beam boundary element that is shared by `N1A` and the `N2` element it is connected to is reduced to G_{bN1new}:

$$G_{bN1new} = \frac{1}{\frac{1}{G_{bN1}} + \frac{1}{L(N1A)HN1}}$$

where:

- $L(N1A)$ is the length of the beam boundary element joining `N1A` and the element of the `N2` group.

- If $N1A$ is a solid element conductively connected to one of the solid elements of `N2`, the effective conductance G_{bN1} between `N1A` and the shell boundary element that is shared by `N1A` and the `N2` element it is connected is reduced to G_{bN1new}:

$$G_{bN1new} = \frac{1}{\frac{1}{G_{bN1}} + \frac{1}{A(N1A)HN1}}$$

where:

- $A(N1A)$ is the area of the boundary element joining `N1A` and the `N2` group.

- If $N1A$ is a beam element conductively connected to one of the beam elements of `N2`, the effective conductance of value G_{bN1} between $N1A$ and the lump mass boundary element that is shared by $N1A$ and the N2 element it is connected is reduced to G_{bN1new}:

$$G_{bN1new} = \frac{1}{\frac{1}{G_{bN1}} + \frac{1}{HN1}}$$

- `EXP` is an optional table or expression number for a table-dependent conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

`INTER2TOT` (or `43`) creates interface conductances between the `N1` and `N2` elements where they are connected conductively. Conductive connection means the adjacent elements share the same nodes. The `PARAM COND NEW` option must be used.

- `HN1` is the total interface conductance value created between the `N1` and `N2` elements.
- If $N1A$ is a shell element conductively connected to one of the shell elements of `N2`, the effective conductance G_{bN1} between $N1A$ and the beam boundary element that is shared by $N1A$ and the N2 element it is connected to is reduced to G_{bN1new}:

$$G_{bN1new} = \frac{1}{\frac{1}{G_{bN1}} + \frac{LTOT}{L(N1A)HN1}}$$

where:

- $L(N1A)$ is the length of the beam boundary element joining $N1A$ and the element `N2`.
- $LTOT$ is the total length of the boundary between the `N1` and `N2` groups.

- If $N1A$ is a solid element conductively connected to one of the solid elements of `N2`, the effective conductance G_{bN1} between $N1A$ and the shell boundary element that is shared by $N1A$ and the `N2` element it is connected is reduced to G_{bN1new}:

$$G_{bN1new} = \frac{1}{\frac{1}{G_{bN1}} + \frac{ATOT}{A(N1A)HN1}}$$

where:

- $A(N1A)$ is the area of the boundary element joining `N1A` and the `N2` group.
- $ATOT$ is the total area of the boundary between the `N1` and `N2` groups.

- If $N1A$ is a beam element conductively connected to one of the beam elements of `N2`, the effective conductance of value G_{bN1} between $N1A$ and the lump mass boundary element that is shared by $N1A$ and the `N2` element it is connected is reduced to G_{bN1new}:

$$G_{bN1new} = \frac{1}{\frac{1}{G_{bN1}} + \frac{NTOT}{HN1}}$$

where:

- $NTOT$ is the number of connections where the `N1` group joins the `N2` group.

- `EXP` is an optional table or expression number for a table-dependent conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

`INTERTOT` (or `35`) defines the `N1` elements to be interface resistance elements.

- `HN1` is the total interface conductance for all the interface elements `N1`.
- If `N1` is a planar element surface coated onto the surface of a solid element I, and a conductance of value G_{IN1} is calculated between them by the `COND` module, G_{IN1} is reduced to $G1_{N1new}$:

$$G_{IN1new} = \frac{1}{\frac{1}{GIN1} + \frac{ATOT1}{A(N1)HN1}}$$

- where $ATOT1$ is the total area of all the `N1` elements.
- If `N1` lies at the interface of two solid elements then G_{IN1} is reduced to:

$$GI_{N1new} = \frac{1}{\frac{1}{GIN1} + \frac{ATOT1}{2A(N1)HN1}}$$

- With this option you can model with zero-thickness planar elements the interface resistance of a thin glue line.
- If the `N1` elements are beams, they must be connected to the edges of planar elements, and their area per unit length should be 1.
- `EXP` is an optional table or expression number for a table-dependent conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

`INTERBTOT` (or `45`) defines the `N1` elements to be interface resistance elements.

- `INTERBTOT` is similar to `INTERTOT`, except for beam elements that lie at the interface of shell elements. For these, the interface conductance is proportional to the length of the beam element, not its surface area (as with the `INTERTOT` option). If a conductance $G1N1$ is calculated between the two shells be the `COND` module, $G1N1$ is reduced to $G1_{N1new}$:

$$G_{N1new} = \frac{1}{\frac{1}{G_{N1}} + \frac{LTOT}{L(N1A)HN1}}$$

`MERGE` (or `27`) merges elements `N1` with the first element of `N2`, such that the `N2` elements are left and the `N1` element numbers disappear during Analyzer runs.

- As a rule, `N2` should only contain a single element.

`PLATEASN` (or `3831`)

- Free convection couplings from the top/bottom/both sides of elements `N1` on a plate are created to a SINK element whose temperature history is described by table or expression `N2S`. The fluid is assumed to surround, i.e. be both above and below the element. The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the characteristic length. Typically this should be the distance along the plate connecting its highest and lowest points. Alternatively, EXP may be the code SELF, in which case the vector components `VX`, `VY`, and `VZ`, as well as the characteristic length are calculated from the geometry of the group `N1`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, indicating the side of the plate that convects. If `P1` is `BOTH`, two separate thermal couplings are created, one from each side of the plate.
- `VX`, `VY`, `VZ` are the directional components of the unit vector of the surface normal of the plate.

`PLATEHASN` (or `3832`)

- Free convection coupling(s) from the top/bottom/both sides of elements `N1` on a horizontal plate are created to a SINK element whose temperature history is described by table or expression `N2S`. The fluid is assumed to surround, i.e. be both above and below the element. The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the characteristic `length = area/perimeter` of the plate. Alternatively, `EXP` may be the code `SELF`, in which case the characteristic length is calculated from the geometry of the group `N1`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, indicating the side of the plate that convects. If `P1` is `BOTH`, two separate thermal couplings are created, one from each side of the plate.

`RAD` (or `2`) creates a radiative conductance parameter `R`.

$$R = A(N1)HN1e(N1)$$

- If the emissivities of the `N1` and `N2` elements are table-dependent, the value of `R` is adjusted at run-time.

$$R = \frac{A(N1)HN1e(N1)e(N2)}{efirst(N2)}$$

where:

- $efirst(N2)$ is the first emissivity value in the table for element `N2`.
- $e(N1)$ is the emissivity value for element `N1`.

- $e(N2)$ is the emissivity value for element `N2`.
- $HN1$ is the gray body view factor from `N1` to `N2`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate radiate. `EXP` must be zero.

`RAD2` (or `36`) creates a radiative conductance parameter `R`.

$$R = A(N1)HN1$$

- If the emissivities of the `N1` and `N2` elements are table-dependent, the value of `R` is adjusted at run-time.

$$R = \frac{A(N1)HN1e(N1)e(N2)}{efirst(N1)efirst(N2)}$$

where:

- $efirst(N1)$ is the first emissivity value in the table for element `N1`.
- $efirst(N2)$ is the first emissivity value in the table for element `N2`.
- $e(N1)$ is the emissivity value for element `N1`.
- $e(N2)$ is the emissivity value for element `N2`.
- $HN1$ is the `(effective emissivity of the N1elements)*(gray body view factor from N1 to N2)`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate radiate.

`RAD3` (or `50`) creates a radiative conductance parameter `R`.

$$R = A(N1)HN1EXP$$

- If the emissivities of the `N1` and `N2` elements are table-dependent, the value of R is adjusted at run-time.

$$R = \frac{A(N1)HN1e(N1)e(N2)}{efirst(N1)efirst(N2)}$$

where:

- $efirst(N1)$ is the first emissivity value in the table for element `N1`.
- $efirst(N2)$ is the first emissivity value in the table for element `N2`.
- $e(N1)$ is the emissivity value for element `N1`.
- $e(N2)$ is the emissivity value for element `N2`.

- $HN1$ is the gray body view factor from `N1` to `N2`.
- EXP is the specified emissivity.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate radiate.

`RADASN` (or `24`) creates a radiative conductance parameter `R` between the `N1` elements and a `SINK` element whose temperature history is described by table or expression `N2S`.

$$R = A(N1)HN1$$

- The `SINK` element number is assigned during run-time.
- If the emissivity of element `N1` is table-dependent, the value of R is adjusted at run-time.

$$R = \frac{A(N1)HN1e(N1)}{efirst(N1)}$$

where:

- $efirst(N1)$ is the first emissivity value in the table for element `N1`.
- $e(N1)$ is the emissivity value for element `N1`.
- $HN1$ is the (effective emissivity of `N1`) `*` (gray body view factor from `N1` to `N2`).

`RADASN2` (or `29`) creates a radiative conductance parameter R between the `N1` elements and a `SINK` element whose temperature history is described by table or expression `N2S`.

$$R = A(N1)HN1e(N1)$$

- The `SINK` element number is assigned during run-time.

where:

- $e(N1)$ is the emissivity value for element `N1`, may be table-dependent.
- $HN1$ is the gray body view factor from `N1` to `N2`.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate radiate. `EXP` must be zero.

`RADASN3` (or `3839`) creates a radiative conductance parameter R between the `N1` elements and a `SINK` element whose temperature history is described by table or expression `N2S`.

$$R = A(N1)HN1EXP$$

- The `SINK` element number is assigned during run-time.

- If the emissivity of element `N1` is table-dependent, the value of R is adjusted at run-time.

$$R = \frac{A(N1)HN1EXPe(N1)}{efirst(N1)}$$

where:

- $efirst(N1)$ is the first emissivity value in the table for element `N1`.
- $e(N1)$ is the interpolated emissivity value for element `N1`.
- $HN1$ is the gray body view factor from `N1` to `N2`.
- EXP is the specified emissivity.
- `P1` may be `TOP`, `BOTTOM`, or `BOTH`, depending on whether the top, bottom, or both sides of the plate radiate.

`RADTOT` (or `26`) creates radiative conductances between the elements of `N1` and `N2` such that the elements of `N1` are coupled to the average temperature of `N2` and the elements of `N2` are coupled to the average temperature of `N1`.

- For each element pair `N1` and `N2`, two thermal conductance parameters created, one between `N1` and `N2AVG`, and another between `N2` and `N1AVG`.

$$R_{N1N2AVG} = A(N1)e(N1)HN1$$
$$R_{N2N1AVG} = A(N1)e(N2)GBVF_{N2N1}$$

where:

- $HN1$ is the specified gray body view factor between the `N1` and `N2` elements, i.e. the fraction of the radiation emitted by the `N1` elements and absorbed by the `N2` elements.
- $N2AVG$ is a newly created element whose temperature is the average temperature of the `N2` elements.
- $N1AVG$ is a newly created element whose temperature is the average temperature of the `N1` elements.
- $GBVF_{N2N1}$ is the gray body view factor between the `N2` and `N1` elements, i.e. the fraction of the radiation emitted by `N1` and absorbed by `N2.` $GBVF_{N2N1}$ is computed from the emissivities and areas of the `N1` and `N2` elements and `HN1`. If the emissivities are table-dependent, the first value of the table is used to compute $GBVF_{N2N1}$.
- $e(N1)$ is the emissivity of element `N1`.
- $e(N2)$ is the emissivity of element `N2`.

- If the emissivities are table-dependent, their values are computed at runtime. The value of $GBVF_{N2N1}$ is not recomputed at runtime.

`RADTOT2` (or `39`) creates radiative conductances between the elements of `N1` and `N2` such that the elements of `N1` are coupled to the average temperature of `N2` and the elements of `N2` are coupled to the average temperature of `N1`. `HN1` is ignored.

- For each element pair `N1` and `N2`, two thermal conductance parameters created:

$$R_{N1N2AVG} = A(N1)e(N1)GBVF_{N1N2}$$
$$R_{N2N1AVG} = A(N2)e(N2)GBVF_{N2N1}$$

where:

- $GBVF_{N1N2}$ is the gray body view factor between the `N1` and `N2` elements, i.e. the fraction of the radiation emitted by the `N1` elements and absorbed by the `N2` elements.
- $GBVF_{N1N2}$ is computed assuming the `N1` and `N2` elements are located on two opposing very close parallel plates. If the emissivities are table-dependent, the first values of the tables are used.
- $N2AVG$ is a newly created element whose temperature is the average temperature of the `N2` elements.
- $N1AVG$ is a newly created element whose temperature is the average temperature of the `N1` elements.
- $GBVF_{N2N1}$ is the gray body view factor between the `N2` and `N1` elements, i.e. the fraction of the radiation emitted by the `N1` elements and absorbed by the `N2` elements.
- $GBVF_{N2N1}$ is computed from the emissivities and areas of the `N1` and `N2` elements. If the emissivities are table-dependent, the first values of the tables are used to compute $GBVF_{N2N1}$.
- $e(N1)$ is the emissivity of element `N1`.
- $e(N2)$ is the emissivity of element `N2`.

- If the emissivities are table-dependent, their values are computed at runtime. The values of $GBVF_{N2N1}$ and $GBVF_{N1N2}$ are not recomputed at runtime.

`RADTOT3` (or `41`) creates radiative conductances between the `N1` and `N2` element such that the elements of `N1` are coupled to the average temperature of `N2` and the elements of `N2` are coupled to the average temperature of `N1`.

- For each element pair `N1` and `N2`, two thermal conductance parameters created:

$$R_{N1N2AVG} = A(N1)HN1$$
$$R_{N2N1AVG} = A(N2)e(N2)GBVF_{N2N1}$$

where:

- $HN1$ is the specified $e(N1)^*GBVF_{N1N2}$ value between the `N1` and `N2` elements.

- $GBVF_{N1N2}$ is the gray body view factor between the `N1` and `N2` elements, i.e. the fraction of the radiation emitted by the N1 elements and absorbed by the N2 elements.
- $N2AVG$ is a newly created element whose temperature is the average temperature of the `N2` elements.
- $N1AVG$ is a newly created element whose temperature is the average temperature of the `N1` elements.
- $GBVF_{N2N1}$ is the gray body view factor between the `N2` and `N1` elements, i.e. the fraction of the radiation emitted by `N1` and absorbed by `N2`. $GBVF_{N2N1}$ is computed from the emissivities and areas of the `N1` and `N2` elements and `N1`. If the emissivities are table-dependent, the first value of the table is used.
- $e(N2)$ is the emissivity of element `N2`.

- If the emissivities are table-dependent, their values are computed at runtime. The values of $GBVF_{N2N1}$ and $GBVF_{N1N2}$ are not recomputed at run-time.

$$R_{N1N2AVG} = \frac{A(N1)HN1e(N1)}{efirst(N1)}$$
$$R_{N2N1AVG} = \frac{A(N2)e(N2)^2GBVF_{N2N1}}{efirst(N2)}$$

where:

- $efirst(N1)$ is the first emissivity value in the table for element `N1`.
- $efirst(N2)$ is the first emissivity value in the table for element `N2`.
- $e(N1)$ is the interpolated emissivity value for element `N1`.
- $e(N2)$ is the interpolated emissivity value for element `N2`.

`RESISTANCE` (or `33`) creates a linear conductance = $\mathrm{A(N1)/(HN1 * ATOT1)}$

- `EXP` is an optional table or expression number for a conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.
- `ATOT1` is the sum of the areas of all the elements `N1`.

`RSERIES` (or `7`) creates a radiative conductance = $\mathrm{A(N1) * Emissivity * (N1) * HN1}$ in series with the already existing radiative conductance between `N1` and `N2`, reducing it.

`SOLAR` (or `16`) writes a solar view factor Card on VUFF with area `A(N1)` absorptivity(`N1`), solar view factor `HN1`, and `TIME = EXP`.

`SPHEREASN` (or `3833`)

- Free convection coupling(s) from element(s) `N1` on the surface of a sphere are created, convecting to a SINK element whose temperature history is described by table or expression `N2S`. The fluid is assumed to surround, i.e. be both above and below the element. The `SINK` element ID is assigned during run-time.
- `N1D` is the material ID of the fluid, must be present as a Card 9 MAT Card. If it is zero, the fluid properties are obtained from the HYDENV Card.
- `HN1` is the convection coefficient multiplier.
- `EXP` is the diameter of the sphere.

`VIEWF` (or `3`) writes a view factor with area `A(N1)`, emissivity `(N1)`, and view factor HN1 on file VUFF.

`XCOND` (or `22`) creates a linear conductance = `HN1`.

- `EXP` is an optional table or expression number for a conductance multiplier. The dependent variable on its TABTYPE Card must be `COND`.

The NEARx Options

The NEARx options connect each of the `N1` elements to the nearest of the `N2` elements. The algorithm calculating which element is the nearest assumes the elements are parallel to each other, and partially or wholly overlap.

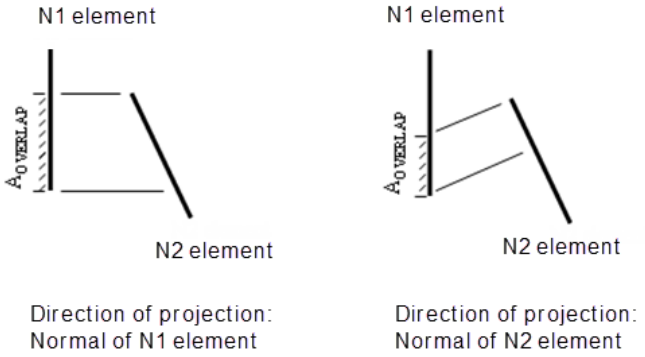
The area for the thermal coupling A_{TC} is always based on the primary selection area. It is calculated with the assistance of the Card 2a/Card 6f MESH parameter. Each element `N1` is subdivided into $MESH^2 * NV$ sub-elements, according to the approach described on Card 2a, where `NV` is the number of nodes of `N1`.

For all the NEARx options described below, A_{TC} is by default based on the areas of the primary sub-elements. If the OVERLAP or OVRFLP options are used, then A_{TC} is the area of overlap between the primary element and the secondary element.

If the thermal coupling request is not preceded by a Card 6f MESH card containing the term OVERLAP or OVERFLP, then each primary element sub-element is coupled to the nearest secondary element. For area dependant conductances, the area, $A_{TC}(N1)$, used for each coupling is based only on the proximity test and it is the area of the sub-element of the `N1` element. The resulting conductances from the sub-elements of the `N1` element to the same `N2` element are summed.

If the Card 6f MESH card preceding a thermal coupling request contains the term OVERLAP, then calculations are performed with the proviso that no thermal couplings are created for elements that do not overlap. An overlap test between each sub-element of each element from the `N1` group and the elements in the `N2` group is performed. The overlap test is done by projecting the primary element onto the secondary element. The normal used for the projection of the primary element is selected according to the rules described in Card 6f Mesh. Each sub-element of the primary

selection is coupled to the nearest secondary overlapping element. For area dependant conductances, the area A_{TC}(N1) used for each coupling is the area of the sub-element of the N1 element that has an overlap with an element from the secondary selection. The coupling is dependant on the normal used for the projection of each primary element onto the secondary group. The resulting conductances from the sub-elements of the N1 element to the same N2 element are summed.



Similar rules apply when the thermal coupling request Card 6e is preceded by a Card 6f MESH card containing the expression OVERFLP, except that the primary N1 and secondary N2 groups are interchanged if the average area of the primary group is greater than the average area of the secondary group. The option to select the primary or the secondary normal for the overlap test is not available in this case. If the primary and secondary selections are flipped, the original primary normal is used for the overlap test and the area A_{TC} is based on the original secondary selection area. The use of OVERFLP is no longer recommended.

The minimum MESH value is 1, resulting in 4 sub-elements for a quadrilateral element. MESH=0 defaults to MESH=1. The maximum is MESH value 5, resulting in 100 sub-elements for a quadrilateral.

If the Card 6f MESH RESET option is used, no subdivision is performed, and only a single conductance is calculated for each element. With this option, false diffusion will not occur. False diffusion is the phenomenon of unintended lateral heat transfer between adjacent N1 elements joined to the same N2 element.

N1S defines the N1 elements.

If N1S is an element number, the N1 elements start with N1S, end with N1F, and are incremented by N1D. N1D = 0 defaults to N1D = 1.

If `N1S` is a group name (the preferred option), `N1F` and `N1D` must be `0`.

`N2S` must be a group name. For each element in the `N1` set the elements to be coupled to it are chosen from this group, based on either the overlap or the proximity algorithm.

`N2D`

If `N1S` and `N2S` are both group names, `N2D` is the ID number of the Card 9 DESCRIP Card associated with this request.

`HN1` is a coefficient associated with element `N1`. `HN1 = 0` defaults to `1`.

`EXP` is a parameter associated with the NEAR, NEARA, NEARF and NEARCx options. Otherwise, it should be blank.

`KODE`

`NEAR` (or `5`) creates a linear conductance = `HN1`.

- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARA` (or `8`) creates a linear conductance = $\mathrm{A_{TC}(N1)} * \mathrm{HN1}.\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.

- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARAFU` (or `38`) does exactly the same as NEARA, except the `N2` elements must be hydraulic elements.

`NEARA1W` (or `32`) creates a linear 1-way conductance = $\mathrm{A_{TC}(N1)} * \mathrm{HN1}$.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.

- The elements `N2` are affected by the `N1` elements, while the `N1` elements are not affected by the `N2` elements.

`NEARA1WTOT` (or `49`) creates a linear 1-way conductance = $\mathrm{HN1} * \mathrm{A_{TC}(N1)/ATOT1}$.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`. `ATOT1` is the sum of the areas of all the elements `N1`.
- The elements `N2` are affected by the `N1` elements, while the `N1` elements are not affected by the `N2` elements.

`NEARA1WTOT2` (or `48`) creates a linear 1-way conductance = $\mathrm{HN1} * \mathrm{A_{TC}(N1)/ATOT2}$.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.
- $\mathrm{ATOT2}$ is the sum of all the overlap areas of `N1` onto `N2.`

- The elements `N2` are affected by the `N1` elements, while the `N1` elements are not affected by the `N2` elements.

`NEARAR` (or `11`) creates a radiative conductance parameter `R`.

$$R = A_{TC}(N1)e(N1)HN1$$

- If the emissivities of `N1` and `N2` elements are table-dependent, R is adjusted at run-time.

$$R = \frac{A_{TC}(N1)HN1e(N1)e(N2)}{efirst(N2)}$$

where:

- $efirst(N2)$ is the first emissivity value in the table for element `N2`.
- $e(N1)$ is the emissivity value for element `N1`.
- $e(N2)$ is the emissivity value for element `N2`.
- $ATC(N1)$ is the area of the overlap of `N1` onto `N2`.
- $HN1$ is the specified gray body view factor from `N1` to `N2`.

`NEARAR2` (or `37`) creates a radiative conductance parameter `R`.

$$R = A_{TC}(N1)HN1$$

where:

- $A_{TC}(N1)$ is the area of the overlap of `N1` onto `N2`.

- $HN1$ is the (effective emissivity of `N1`) `*` (gray body view factor from `N1` to `N2`).

`NEARAR3` (or `40`) creates a radiative conductance parameter R assuming the `N1` and `N2` elements lie on flat parallel plates very close to each other.

$$R = \frac{A_{TC}(N1)}{\left(\frac{1}{e(N1)} + \frac{1}{e(N2)} - 1\right)}$$

- If the emissivities `N1` and `N2` are table-dependent, the value of R is adjusted at run-time.

$$R = \left(\frac{A_{TC}(N1)}{\left(\frac{1}{efirst(N1)} + \frac{1}{efirst(N2)} - 1\right)}\right)\left(\frac{e(N1)e(N2)}{efirst(N1)efirst(N2)}\right)$$

where:

- $ATC(N1)$ is the area of the overlap of `N1` onto `N2`.
- $efirst(N1)$ is the first emissivity value in the table for element `N1`.
- $efirst(N2)$ is the first emissivity value in the table for element `N2`.
- $e(N1)$ is the emissivity value for element `N1`.
- $e(N2)$ is the emissivity value for element `N2`.

`NEARAS (or 9)` creates a conductance = $A_{TC}(N1)*HN1$ in series with the already existing linear conductance between `N1` and `N2`, thereby reducing it.

- $A_{TC}(N1)$ is the area of the overlap of `N1` onto `N2`.

`NEARF` (or `14`) creates a free convection conductance between `N1` and `N2`. Heat flow through it is calculated by:

$$Q_{N1N2} = A_{TC}(N1) * HN1(T_{N1} - T_{N2}) * (T_{N1} - T_{N2})^{EXP}$$

- $A_{TC}(N1)$ is the area of the overlap of `N1` onto `N2`.
- `EXP` = blank defaults to `.25`.

`NEARLP` (or `18`) creates a linear conductance = `LENGTH(N1)*HN1`.

- `N1` must be a beam element.
- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARM` (or `13`) creates a perfect contact coupling between `N1` and `N2` by imposing an equality constraint using the penalty method.

`NEARP` (or `15`) creates a linear conductance = $\mathrm{A_{TC}(N1)} * \mathrm{HN1/RL}$ between `N1` and `N2.`

`RL` is the perpendicular distance between `N1` and `N2`, `N1` and `N2` should lie on parallel planes.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.
- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARRES` (or `31`) creates a linear conductance = $\mathrm{A_{TC}(N1)/(HN1 * ATOT1)}$.

- $(A_{\mathrm{TC}}\mathrm{(N1)}$ is the area of the overlap of `N1` onto `N2`.
- $\mathrm{ATOT1}$ is the sum of the areas of all the elements `N1`.
- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARRES2` (or `47`) creates a linear conductance = $\mathrm{A_{TC}(N1)/(HN1 * ATOT2)}$.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.
- $\mathrm{ATOT2}$ is the sum of all the overlap areas of `N1` onto `N2`.
- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARS` (or `10`) creates a conductance = `HN1` in series with the already existing linear conductance between `N1` and `N2`, thereby reducing it.

`NEARTOT` (or `30`) creates a linear conductance = $\mathrm{HN1} * \mathrm{A_{TC}(N1)/ATOT1}$.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.
- $\mathrm{ATOT1}$ is the sum of the areas of all the elements `N1`.
- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARTOT2` (or `46`) creates a linear conductance = $\mathrm{HN1} * \mathrm{A_{TC}(N1)/ATOT2}$.

- $\mathrm{A_{TC}(N1)}$ is the area of the overlap of `N1` onto `N2`.
- $\mathrm{ATOT2}$ is the sum of all the overlap areas of `N1` onto `N2`.

- `EXP` is an optional table or expression number for a conductance multiplier.
- The dependent variable on its TABTYPE Card must be `COND`.

`NEARVF` (or `28`) writes a black body view factor on file VUFF with a magnitude $A(N1) * HN1/AN1$.

- $A(N1)$ is the area of the overlap when `N1` is projected onto `N2`, and $A(N1)$ is the full area of element `N1.`

The Forced Convection NEARC Options

The following NEARC options model forced convection to hydraulic elements.

The `N2` elements must be 2-node hydraulic elements. The forced convection conductance G is computed with:

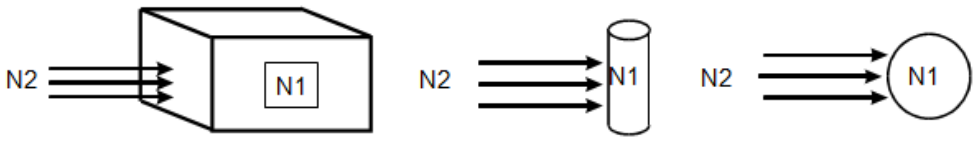
$$G = A_{TC}(N1) * h * KT * HN1$$

where:

- h is the computed forced convection heat transfer coefficient. `KODE` may be `NEARC1`, `NEARC4`, or `NEARC12`.
- $HN1$ is a constant conductance multiplier.
- KT is the conductance multiplier interpolated from optional Card 9 table EXP. `EXP` = blank defaults to `KT = 1`. The dependent variable on table EXP's TABTYPE Card must be `COND`.
- $A_{TC}(N1)$ is the area of the overlap of `N1` onto `N2`.

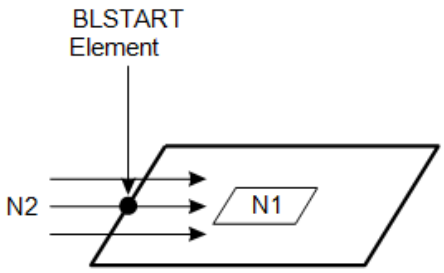
`NEARC1` (or `3000`)

- If `N1` is planar, h is calculated assuming it lies on the wall of a duct with fully developed duct flow.
- If `N1` is a beam element, h is calculated with free cylinder in cross flow correlations.
- If `N1` is a lump mass element, h is calculated with sphere in free flow correlations.



`NEARC4` (or `3003`)

- `h` is calculated using a flat plate in free stream correlation. The distance to the leading edge of the plate is the length of the flow path from the center of the hydraulic element `N2` to the first upstream `BLSTART` element.
- If there are no `BLSTART` elements specified, the leading edge is at the most upstream element.
- `N1` must be planar.



`NEARC12` (or `3012`) is similar to `NEARC1`, but the length of the boundary layer from the beginning of the duct is taken into account.

- The boundary layer starts at the nearest upstream `BLSTART` element.

`NEARC13` (or `3013`) is similar to `NEARC1`, but 2-node beam elements are treated not as beams perpendicular to the flow, but as equivalent area shell elements parallel to the flow (i.e. as if they were on the pipe wall).

The Free Convection Options

The following `NEARC` options are associated with free convection and Card 5a hydraulic elements.

Additional available free convection options are the Card 6a NEARF and FREE convection options.

The `N1` elements must be shell elements. Except for the `NEARC10`, `CONCYL`, `CONSPH`, `CAVITY`, and `CAVITYH` options, the `N2` elements may be 2-node hydraulic elements or 1-node `AMBIENT` elements.

The fluid is assumed to be a gas, and the free convection conductance is computed with:

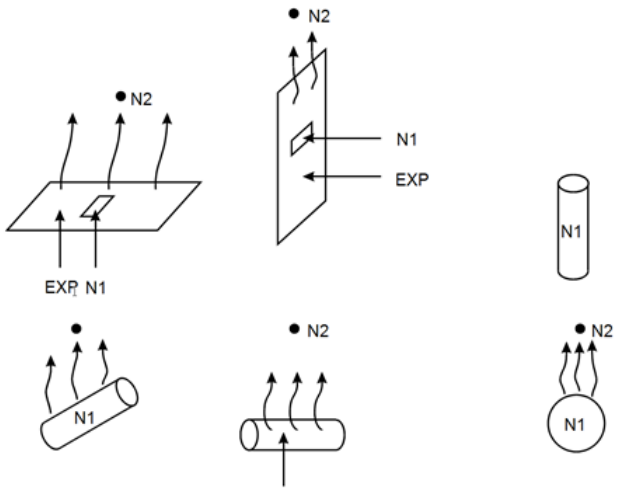
$$G = h * A_{TC}(N1) * HN1$$

where:

- h is the computed free convection heat transfer coefficient.
- $HN1$ is a constant multiplier.
- $A_{TC}(N1)$ is the area the overlap of `N1` onto `N2`.

`NEARC6 (or 3100)`: For this option a characteristic element is defined, and TMG automatically selects the correlation appropriate for the characteristic element's geometry from the following correlation types:

- top surface of a horizontal flat plate
- top surface of an angled flat plate
- one side of a vertical flat plate
- horizontal rods
- vertical rods
- angled rods
- spheres



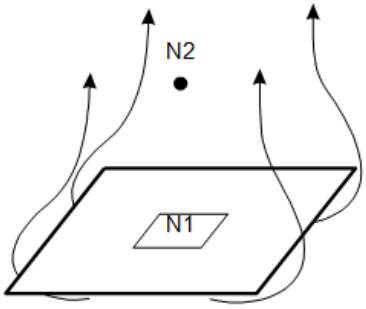
For the `NEARC6` option the relative vertical positions of the `N1` and `N2` elements is important. Free convection is driven by gravity, therefore the `N1` elements must be hotter than the `N2` elements and be positioned below them, or they must be cooler and above them.

`EXP` is the characteristic element whose shape determines the correlation type and characteristic length.

`EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`NEARC9` (or `3104`): This option assumes free convection upward from the bottom surface of a hot horizontal plate, or downward from the top surface of a cold plate.

The relative vertical positions `N1` and `N2` are important. Free convection will only occur if `N1` is hotter than `N2` and is below it, or is colder and above it.

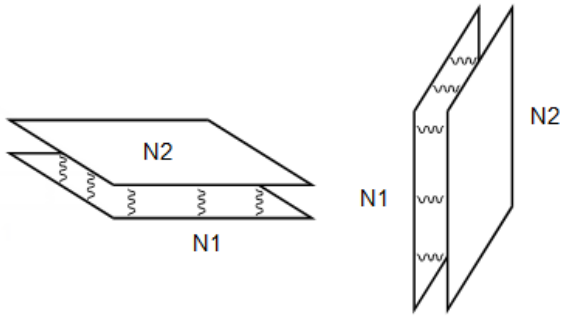


`EXP` is the characteristic element whose shape determines the correlation type and characteristic length. `EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`NEARC10` (or `3105`): This option models recirculation between two closely spaced parallel plates boxed in at their edges, whose areas are large compared to the distance separating them (e.g. two circuit boards).

`N1` and `N2` must both be horizontal or vertical. If they are otherwise oriented, a warning message is printed and a vertical or horizontal assumption is made.

The recirculating fluid properties are defined on the Card 5a AMBIENT elements.



`EXP` is the characteristic element whose shape determines the correlation type and characteristic length. `EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`NEARC16` (or `3500`): This is the preferred option for most applications. It is similar to `NEARC6`, except that the relative vertical position of the `N2` and `N1` elements is not taken into account. The `N2` element is considered to "surround" the `N1` elements, therefore free convection will always occur.

If `N1` is a horizontal plate colder than `N2`, the `NEARC9` correlation is used, i.e. the cold air will flow downwards from the top surface of the plate.

`EXP` is the characteristic element whose shape determines the correlation type and characteristic length. `EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`NEARC19` (or `3504`): This is similar to the `NEARC9` option, except that the relative vertical position of `N1` and `N2` is not taken into account. Free convection will always occur, since `N2` is considered to "surround" `N1`.

If `N1` is colder than `N2`, the `NEARC6` correlation (convection from the top surface of a plate) is used.

`EXP` is the characteristic element whose shape determines the correlation type and characteristic length. `EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`NEARCIN` (or `3107`): Free convection couplings from the inside surface of a box `N1` to an internal hydraulic element `N2` are calculated.

The orientation of the surface normal of `N1` with respect to the gravity vector determines the correlation used.

If the convecting surface is the roof of a box (the surface normal points downward), the `NEARC6` correlation is used, and `N2` is assumed to lie below `N1`. Convection will occur if `N1` is colder than `N2`.

If the convecting surface is the floor of a box (the surface normal points upward), the `NEARC6` correlation is used, and `N2` is assumed to be above `N1`. Convection will occur if `N1` is warmer than `N2`.

If the convecting surface is the wall of a box (the surface normal points sideways), the `NEARC16` correlation is used. Convection in this case will always occur.

`EXP` is the characteristic element whose shape determines the correlation type and characteristic length. `EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`NEARCOUT` (or `3108`): Free convection couplings from the outside surfaces of a box `N1` to a surrounding fluid (hydraulic element `N2`) are calculated.

The orientation of the surface normal of `N1` with respect to the gravity vector determines the correlation used.

If the convecting surface `N1` is the bottom of a box (the surface normal points downward), the `NEARC19` correlation is used. Convection will always occur.

If the convecting surface is the roof or side of a box (the surface normal points sideways or upward), the `NEARC16` correlation is used. Convection will always occur.

`EXP` is the characteristic element whose shape determines the correlation type and characteristic length. `EXP` should be a planar, spherical, or beam element with the shape of the full convecting surface on which `N1` is located. `EXP` may also be the code `SELF`, in which case the characteristic element is `N1` itself.

`PLATE` (or `3801`): A free convection coupling from the top/bottom/both side(s) of element(s) `N1` on a plate is created to hydraulic or `AMBIENT` element `N2`.

`EXP` is the characteristic length=area/perimeter of the plate. Alternatively, `EXP` may be the code `SELF`, in which case the vector components `VX`, `VY`, and `VZ`, as well as the characteristic length are calculated from the geometry of the group `N1`.

`N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

P1 may be the code TOP , BOTTOM , or BOTH , indicating the side of the plate that convects. If P1 is BOTH , two separate thermal couplings are created, one from each side of the plate.

VX , VY , VZ are the directional components of the vector of the surface normal of the plate.

PLATEH (or 3802): A free convection coupling from the top/bottom/both side(s) of element(s) N1 on a horizontal plate is created to hydraulic or AMBIENT element N2 .

N1D may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

EXP is the characteristic length = area/perimeter of the plate. Alternatively, EXP may be the code SELF , in which case the vector components VX , VY , and VZ , as well as the characteristic length are calculated from the geometry of the group N1 .

P1 may be the code TOP , BOTTOM , or BOTH , indicating the side of the plate that convects. If P1 is BOTH , two separate thermal couplings are created, one from each side of the plate.

VX , VY , VZ are the directional components of the vector of the surface normal of the plate.

SPHERE (or 3803): A free convection coupling from element(s) N1 on the surface of a sphere is created, convecting to hydraulic/ AMBIENT element N2 .

N1D may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

EXP is the diameter of the sphere.

CYLINDER (or 3804): A free convection coupling from element(s) N1 on the surface of a cylinder is created, convecting to hydraulic/ AMBIENT element N2 .

N1D may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`EXP` is the diameter of the cylinder.

`P1` must be the length of the cylinder.

`VX`, `VY`, `VZ` are the directional components of the axis vector of the cylinder.

`INCCHNL` (or `3805`): A free convection coupling from the element(s) `N1` on the inner surface of either wall of an inclined open parallel plate channel is created, convecting to hydraulic element `N2`.

`N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`EXP` is the distance between the walls of the channel.

`P1` is the length of the channel.

`VX`, `VY`, `VZ` are the directional components of the vector of the surface normal of the walls of the channel.

`CAVITY` (or `3806`): A free convection coupling from the element(s) `N1` on one wall of an inclined closed parallel plate cavity is created, convecting to the nearest element `N2` on the other wall of the `N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`EXP` is the distance between the walls of the cavity. If `VX` is the code `SELF`, then `P1`, `VX`, `VY`, `VZ` are automatically calculated from the elements `N1`.

`P1` is the length of the cavity.

`VX`, `VY`, `VZ` are the directional components of the vector of the surface normal of the walls of the cavity.

`CAVITYH` (or `3807`): A free convection coupling from the element(s) `N1` on one wall of a horizontal closed parallel plate cavity is created, convecting to the nearest element `N2` on the other wall of the cavity.

`N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`EXP` is the distance between the walls of the cavity. If `VX` is the code `SELF`, then `P1`, `VX`, `VY`, `VZ` are automatically calculated from the elements `N1`.

`P1` is the length of the cavity.

`CONCYL` (or 3`808`): A free convection coupling from the element(s) `N1` on the outer cylinder of two concentric horizontal cylinders is created, convecting to the nearest element `N2` on the inner cylinder.

`N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`EXP` is the diameter of the outer cylinder.

`P1` is the diameter of the inner cylinder.

`CONSPH` (or `3809`): A free convection coupling from the element(s) `N1` on the outer sphere of two concentric spheres is created, convecting to the nearest element `N2` on the inner sphere.

`N1D` may be 0 or the material ID of the convecting fluid. If it is zero, the fluid properties are obtained from the HYDENV Card.

`EXP` is the diameter of the outer sphere.

`P1` is the diameter of the inner sphere.

The CFD NEARC21 - NEARC44 and NEARCB1-NEARCB4 Options

These options are used to couple convecting printed circuit board elements to adjacent fluid elements for the ESC product. A number of special conditions apply:

The `NEARC21-24` and `NEARCB1-4` options define convective couplings between the board and the fluid. `N1S` should be the group name for the board, `N2S` should be the group name for the fluid. They create couplings between the board and the fluid equal to:

$$G = A(N1)_{overlap} * h * HN1$$

where:

- $A(N1)_{overlap}$ is the area of the board element overlapping the area of the corresponding fluid element, **less** the area of all the components between the fluid and board elements.
- h is the heat transfer coefficient calculated by TMG.
- $HN1$ is a user-specified multiplier.
- G is the conductance between the board and nearest fluid element.
- $N1F$ is the surface roughness value assigned to the circuit board for the `NEARC21` - `NEARC24` and `NEARCB1-4` options only.
- $N1D$ defines the type of mesh correction to be applied to the convective couplings for the `NEARC21 - NEARC24` and `NEARCB1-4` options only.
- $N1D = 0$ no mesh correction.
- $N1D = 1$ forced convection mesh correction.
- $N1D = 2$ natural convection mesh correction.
- $N1D = 3$ automatic determination of mesh correction.
- $KODE$ may be `NEARC21`, `NEARC22`, `NEARC23`, or `NEARC24`.

`NEARC21` (`3921`) or `NEARCB1` (`3931`)

`NEARC21` (`3921`) or `NEARCB1` (`3931`) calculates convective couplings with `h(KODE, EXP) = 1` from the positive side of the board

---

`NEARC22` (or `3922`) or `NEARCB2` (`3932`) is similar to `NEARC21`, except that the couplings are from the negative side of the board.

`NEARC23` (or `3923`) or `NEARCB3` (`3933`) is similar to `NEARC21`, except that `h` is computed by TMG.

`NEARC24` (or `3924`) or `NEARCB4` (`3933`) is similar to `NEARC22`, except that `h` is computed by TMG.

The only difference between the `NEARCBx` and `NEARC2x` options is the method of calculating the overlap area. The code of the thermal coupling for both on the file MODLF CNF Card will be `3921-3924`.

The `NEARC41-44` options define the association between the components and the boards. `N1S` should be a group name for components; `N2S` should be the group name for the board they lie on.

> **Note**
>
> The matching of the NEARC4x and NEARC2x components Cards is important. NEARC41 Cards will be associated only with NEARC21 Cards; NEARC42 Cards will be associated with NEARC22 Cards, etc.

The `NEARC41-44` option creates couplings between the component and the fluid equal to:

$$G = A(N1) * h * HN1$$

where:

- $A(N1)$ is the area of the component.
- h is the heat transfer coefficient calculated by TMG. The roughness value and mesh correction flag used to calculate `h` is the one specified for the corresponding board elements on the NEARC21 Card.
- $HN1$ is a user-specified multiplier.
- $KODE$ may be `NEARC41`, `NEARC42`, `NEARC43`, or `NEARC44`.

`NEARC41` (or `3941`) specifies components for `NEARC21` couplings on positive side of board.

`NEARC42` (or `3942`) specifies components for `NEARC22` couplings on negative side of board.

`NEARC43` (or `3943`) specifies components for `NEARC23` couplings on positive side of board.

`NEARC44` (or `3944`) specifies components for `NEARC24` couplings on negative side of board.

Example

```
AREA 1 5 2 7 4 .36 CONV
$ CONVECTIVE CONDUCTANCES ARE CREATED BETWEEN ELEMENTS
$ 1 AND 7, 3 AND 11, 5 AND 15, WITH MAGNITUDES = AREAS
$ OF 1, 3, AND 5 MULTIPLIED BY .36.

AREA BOXTOP 0 0 BOARD1 0 1.6 NEARA
$ CONDUCTANCES ARE CREATED BETWEEN THE ELEMENTS OF
$ BOXTOP AND THE NEAREST ELEMENTS OF BOARD1,
$ MAGNITUDE = AREA(BOXTOP)(1.6)

AREA BOXTOP 0 0 AMBIENT 0 .36 CONV
$ CONVECTIVE CONDUCTANCES ARE CREATED BETWEEN THE
$ ELEMENTS OF BOXTOP AND THE SINGLE ELEMENT AMBIENT

AREA GLUE 0 0 0 0 (.03/.001) INTER
$ THE ELEMENTS OF GLUE (CONNECTING TWO SOLID ELEMENTS)
$ ARE INTERFACE RESISTANCE ELEMENTS, WITH THERMAL
$ CONDUCTIVITY OF .03 AND THICKNESS OF .001

AREA PLATE 0 0 AIR 0 FREE .33
$ FREE CONVECTION COND. ARE CREATED BETWEEN THE
$ ELEMENTS OF PLATE & AIR

AREA BOARD 0 0 FLUID 0 1 NEARC1
$ FORCED CONVECTION CONDUCTANCES CALCULATED
$ FOR ELEMENTS OF BOARD

AREA WALL 0 0 AIR 0 1 NEARC6 101
$ FREE CONVECTION CONDUCTANCES FROM THE WALLS OF A BOX
$ TO THE AIR THE CHARACTERISTIC ELEMENT IS ELEMENT 101

AREA BOARD1 0 0 BOARD2 0 1 NEARC10 SELF
$ FREE CONVECTION CONDUCTANCES CALCULATED BETWEEN
$ TWO BOARDS
```

Card 6f - MESH Redefinition – Optional

`L`, `M`, `ERR`, `gpname`

This option defines the MESH elemental subdivision parameter for subsequent thermal coupling and radiation calculations, until a new MESH Card is encountered. The global MESH parameter is defined on Card 2a – Program Control Card – Required.

`L` is the code `MESH` (or `14`)

`M` may be:

= `ERROR` (or `-3`), or

= `RESET` (or `-2`), or

= `SINGLEONLY` (or `-4`), or

= `TOLERANCE` (or `-5`), or

= integer value

`M` = `ERROR:` For this option the MESH value for subsequent radiation calculations is calculated from the value of `ERR`, where `ERR` is the target residual view factor for each element.

$$\mathrm{ERR} = 1 - \sum_{i} \mathrm{VF}_{ij}$$

where:

- VF_{ij} is the view factor from element i to element j

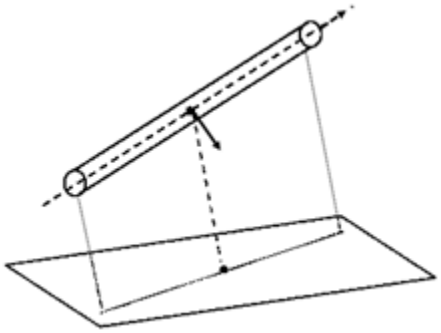
`ERR` should be between 0 and 1. Lower `ERR` values (e.g. `.02`) will result in higher MESH values, and vice versa.

This option is not valid for Card 6e thermal coupling calculation request. If a thermal coupling request is encountered while this option is active, it will be performed with the Card 2a MESH value.

`M` = `RESET`: subsequent radiation requests are performed with the Card 2a MESH value, until another MESH Card is encountered.

Subsequent Card 6e thermal coupling calculation requests are performed such that only a single conductance is calculated for each element in the primary `N1` group, even when the element overlaps several other elements.

- `ERR` = `OVERLAP:` subsequent Card 6e thermal coupling calculations are performed with the provision that no thermal couplings are created for elements that do not overlap. The overlap test is done by projecting the primary element N1 onto the secondary element `N2` . gpname specifies the normal used for the projection of `N1` onto `N2` . If gpname is PRIMARY, the overlap test uses the primary element normal for the projection. If gpname is SECONDARY or blank, the overlap test uses the secondary element normal for the projection. The surface normal of a beam element is perpendicular to the beam axial direction, and lies on the surface formed by the beam axial direction, and the line joining the CG of the primary element and the CG of secondary element.



- `ERR` = `OVERFLP:` As with the `ERR = OVERLAP` option, subsequent Card 6e thermal coupling calculations are performed with the proviso that no thermal couplings are created for elements that do not overlap. With this option, the overlap test uses the secondary element normal for the projection of the primary element onto the secondary element. In addition, the primary `N1` and secondary `N2` groups on Card 6e are interchanged if the average area of the primary group is greater than the average area of the secondary group, and the thermal coupling is of the NEAR type. This is done to minimize heat flow concentration effects. If the primary `N1` and the secondary `N2` groups are interchanged, the overlap test uses the original primary element normals for the projection of the primary elements onto the secondary elements. This option is not recommended.

`M` = `SINGLEONLY` : This Card is ignored for radiation requests and is used only for thermal coupling requests.

- `ERR` = `ON:` This addresses the case when common elements exist in both the primary N1 and secondary N2 groups in a subsequent request. If a coupling is created between two elements which occur in both the primary N1 and secondary N2 groups, then its value is multiplied by .5, in order to compensate for the possible creation of duplicate thermal couplings.
- `ERR` = `OFF` : This is the default option. For subsequent Card 6e thermal coupling requests duplicate thermal couplings may be calculated for the same element if the primary and secondary groups N1 and N2 have common elements.

- `gpname` is ignored.

`M` = `TOLERANCE:` this Card is used only for subsequent Card 6e proximity-dependent (NEARx option) thermal coupling requests.

- `ERR` is a tolerance value. A thermal coupling will be calculated only if:

$$\mathrm{D} < \mathrm{ERR}\sqrt{\min(A1, A2)}$$

where:

- D is the distance between the primary `N1` and secondary `N2` elements
- $A1, A2$ are the areas of the primary `N1` and secondary elements `N2`

- `gpname` is ignored.

`M=` integer value

This option defines the MESH value explicitly.

`M` may be an integer from `0` to `20`, and sets the value of the MESH parameter.

- `ERR` = `SUNRAYS` : This is a global parameter, all collimated solar spectrum calculations are performed with the specified `MESH` = `M` value.
- `ERR` = `EARTH:` This is a global parameter, all Earth view factor and albedo factor calculations are performed with the specified `MESH` = `M` value.
- `ERR` = `GROUPNAME:` This is a global parameter, all view factor and heat flux view factor calculations involving any element of the group `gpname` are performed with the specified **M** value. This option is not supported with the Hemicube method.
- `ERR` = `SPACE:` This is a global parameter, all view factors to the Card 5d SPACE elements are performed with the specified `MESH` = `M` value.
- `ERR` = `OVERLAP:` Subsequent Card 6e thermal coupling calculations are performed with the proviso that no thermal couplings are created for elements that do not overlap. The overlap test is done by projecting the primary element N1 onto the secondary element `N2` . `gpname` specifies the normal used for the projection of N1onto N2. If `gpname` is PRIMARY, the overlap test uses the primary element normal for the projection. If

`gpname` is SECONDARY or blank, the overlap test uses the secondary element normal for the projection. The surface normal of a beam element is the perpendicular to the beam axial direction that lies on the surface formed by the beam axial direction and the line joining the CG of the primary element and the CG of secondary element.

- `ERR` = `OVERFLP:` As with the `ERR` = `OVERLAP` option, subsequent Card 6e thermal coupling calculations are performed with the proviso that no thermal couplings are created for elements that do not overlap. With this option, the overlap test uses the secondary element normal for the projection of the primary element onto the secondary element. In addition, the primary `N1` and secondary `N2` groups on Card 6e are interchanged if the average area of the primary group is greater than the average area of the secondary group, and the thermal coupling is of the NEAR type. This is done to minimize heat flow concentration effects. If the primary `N1` and the secondary `N2` groups are interchanged, the overlap test uses the original primary element normals for the projection of the primary elements onto the secondary elements. This option is not recommended.

Notes

In general, higher MESH values result in more accurate computations.
Unless otherwise specified, Card 6f overrides the default Card 2a MESH parameter.
For a discussion of how the MESH parameter subdivides an element, see Card 2a - Program Control Card – Required.

In the following example, all radiation calculations are performed with `MESH=2`, with the following exceptions:

1. For element 100 the targeted view factor sum error is `.02`.
2. For the elements of the group CRITICAL, `MESH=3` is used.
3. All solar spectrum calculations are performed with `MESH=4`.
4. Card 6e thermal couplings will be created with a single coupling only.

Example

```
MESH ERROR .02
VFS1ALL 100
MESH 3 GROUPNAME CRITICAL
MESH 2
VFSALL
MESH RESET
AREA N1 0 0 N2 0 1 NEARA
MESH 4 SUNRAYS
SOLSALL 0 0 0 0
```

Card 6g - Symmetric View Factors Request Card – Optional

`L` , `KODE`

`L` = `SYMVREQ` (or `15`)

A combination of Cards 6g, Card 6h, Card 6o, and Card 6a VFx1ALL Cards may be used to calculate view factors for geometrically symmetric models more efficiently, by taking into account the model's symmetry. Card 6g sets the view factor merging flags.

`KODE` is the symmetric view factor merging flag.

`KODE` = `ARCOMB` (or `1`) merges the view factors and areas of the symmetric elements.This option should be used if all the boundary conditions and the calculated temperatures are also expected to be symmetrical. The symmetric elements defined on Card 6h - Symmetric Elements List Card – Optional should also be merged with Card 7 - Element Merging and Renumbering Cards.

`KODE` = `REST` (or `3`) creates the remaining view factors of the model with no view factor merging. This option should be used if the calculated temperatures are not expected to be symmetrical.

Example

```
SYMVREQ ARCOMB
$ SYMMETRIC VIEW FACTORS WITH ELEMENT MERGING
SYMNODES 11 12 13 14
$ N1 ELEMENT IS 11, 11,12,13,14 ARE SYMMETRIC
SYMNODES 21 22 23 24
$ N1 ELEMENT IS 21, 21,22,23,24 ARE SYMMETRIC
VFS1ALL 11
VFS1ALL 21
$ VIEW FACTORS FOR N1 ELEMENTS ARE CALCULATED
```

Card 6h - Symmetric Elements List Card – Optional

This Card specifies a symmetrical model's properties for symmetric view factor calculations.

`L, N1, N2, N3,....NN`	Option 1
`L, GENER, N1S, INC1, N1N, INC2, N2N`	Option 2

`L` = `SYMNODES` (or `16`)

`N1` is the `N1` row element.

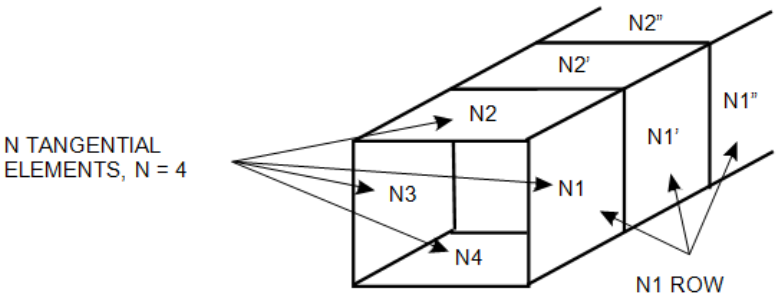
`N2, N3...NN` are the elements symmetrical with respect to the `N1` row element.

There is a maximum of 15 elements per Card, but Card 6o Continuation Cards may be used to extend this.

`N1S, INC1, N1N, INC2, N2N`

`N1S` is the Starting Element for Option 2. Option 2 creates `N2N` Cards 6h, each `N1` row element incremented by INC2. Each Card 6h contains `N1N` elements, incremented by `INC1`. The generated Cards have the format:

```
SYMNODES, N1S, N1S+INC1, ....N1S+(N1N-1)*INC1
SYMNODES, N1S+INC2, N1S+INC2+INC1,....N1S+INC2+(N1N-1)*INC1
.
.
SYMNODES, N1S+(N2N-1)*INC2,.....N1S+(N2N-1)*INC2+(N1N-1)*INC1
```



Notes

For globally axisymmetric models see Card 9 - AXISYMM Axisymmetric Element Creation Card - Optional). Cards 6g and 6h need not be specified, they are automatically generated.
Cards 6g and 6h may be used for view factor calculations only, not for other types of radiation view factors.

Modeling symmetrical models

1. Create a symmetric model, with `N` tangential elements located at each level along the axis of the model (see diagram).
2. Choose a row of elements and call it the `N1` row. Each `N1` row element must have `N–1` other corresponding elements.
3. Specify with Cards 6h that elements `N1` , `N2` , `N3` , `....NN` , `N1'` , `N2'` , `N3'` , `.... NN'` , `N1''` , `...` etc. are symmetric elements.
   There must be a Card 6h defined for each level, and all the elements of the model must be listed on Cards 6h. Each Card 6h must have exactly `N` elements on it, and the first element must be an `N1` row element.
4. Calculate all the view factors for each `N1` row element with Card 6a VFx1ALL Cards. This creates a partial set of view factors, for example the view factor from `N2` to `N3` will not be computed.

   TMG will automatically create the rest of the symmetric view factors. If the Card 6g the ARCOMB option is specified, create Card 7 Merging Cards to merge elements
   `N1` , `N2` , `...NN` into element `N1` , elements `N1'` , `N2'` , `...NN'` into element `N1'` , etc.

Example

```
1 0 0 0
GEN 3 2 1 3 1 0 0 0 1 0
GEN3RD 2 10 0 0 1
```

```
$ CARD 4 NODES – THE CARTESIAN GLOBAL
$ COORDINATE SYSTEM IS IN EFFECT
-1
1 0 M1 0 P1  1 11 12  2
2 0 M1 0 P1 11 14 15 12
3 0 M1 0 P1  4  5 15 14
4 0 M1 0 P1  4  1  2  5
11 0 M1 0 P1  2 12 13  3
12 0 M1 0 P1 12 15 16 13
13 0 M1 0 P1  5  6 16 15
14 0 M1 0 P1  5  2  3  6
$ CARD 5 ELEMENTS, 1,2,3,4 ARE SYMMETRIC,
$ AND 11,12,13,14 ARE SYMMETRIC.
-1
SYMVREQ ARCOMB
$ CARD 6G, THE ELEMENTS WILL BE MERGED,
$ ONE CARD 6H PER STATION, ALL ELEMENTS ARE LISTED
SYMNODES 1 2 3 4      $ ELEMENT 1 IS AN N1 ROW ELEMENT
SYMNODES 11 12 13 14  $ ELEMENT 11 IS AN N1 ROW ELEMENT
VFN1ALL 1             $ VIEW FACTORS FOR N1 ELEMENT 1
VFN1ALL 11            $ VIEW FACTORS FOR N1 ELEMENT 11
-1
1 2 3 4               $ CARDS 7 MERGE ELEMENTS.
11 12 13 14
-1
```

Card 6j - View Factor Merging Card

`L`, `NM`, `NN2`, `NN3`, `NN4`,...	Option 1
`L`, `GENER`, `N1S`, `INC1`, `N1N`, `INC2`, `N2N`	Option 2
`L`, `NAME1`	Option 3
`L`, `NM`, `NAME2`	Option 4

`L` = `VFMERGE` (or `18`)

`N1S`, `INC1`, `N1N`, `INC2`, `N2N`

`N1S` is the Starting Element for Option 2. Option 2 creates N2N Cards 6j, each starting with an `N1` element incremented by `INC2`. Each Card 6j contains `N1N` elements, incremented by `INC1`. The generated Cards have the format:

```
VFMERGE, N1S, N1S+INC1, ....N1S+(N1N-1)*INC1
VFMERGE, N1S+INC2, N1S+INC2+INC1,....N1S+INC2+(N1N-1)*INC1
.
.
VFMERGE, N1S+(N2N-1)*INC2,.....N1S+(N2N-1)*INC2+(N1N-1)*INC1
```

`NAME1`, `NAME2` are group names.

`NM` is an element number.

Notes

1. For Option 1 Card 6j merges the view factors, solar view factors, albedo factors, and Earth view factors of elements `NM`, `NN2`, `NN3`, `..` A new element `NM` is created, with an area equal to the sum of the areas. The radiative surface properties are set to the area–averaged values.
2. For Option 3 the elements of `NAME1` are merged with the starting element of `NAME1`. The starting element is the first element defined on the Card 9 group name NAME Card, or, for Simcenter 3D models, the lowest element number defined.
3. For Option 4 all the elements of group `NAME2` are merged into element `NM`. A new element `NM` is created, with an area equal to the sum of the areas. The radiative surface properties are set to the area–averaged values.
4. Card 6j differs from Card 7 in that element merging is performed for the radiative properties only. This is useful for reducing the size of the view factor matrix to be inverted by the GRAYB module. However, it results in less accurate radiative conductances.
5. Corresponding Card 7 Merging Cards should be present whenever Card 6j is used, to merge the non-radiative model parameters.
6. The use of the Card 7 Merging Card is recommended instead of Card 6j.

Example

```
VFMERGE 1 2 3 4
VFMERGE,GENER,1,1,5,10,2 INTO 1.
$ ELEMENTS 2,3, AND 4 MERGED INTO 1.
$ ELEMENTS 2,3,4,5 MERGED
$ ELEMENTS 12,13,14,15 MERGED INTO 11.
```

Card 6k - Orbit Definition Card – Optional

`L` , `ORIENT` , `ALB` , `NINT` , `SUNDECL` , `ORBINCL` , `E` , `SMAR` , `OMEGA` , `ANGPER` , `PER` , `N1`

This Card generates equivalent Card 6b - Solar View Factor Request Card – Optional and Card 6d - Earth Card – Optional from the orbital parameters. Additional optional orbital parameters may be defined on that card that immediately follow: Card 6l - Additional Orbital Parameters ORBADD Card – Optional. The planet does not have to be Earth.

`L` is an orbit generation code. `L` may be `ORBS1` , `ORBN1` , `ORBSALL` , or `ORBNALL` .

`ORBS1` (or `19`) generates them with shadowing.

`ORBN1` (or `20`) generates them with no shadowing.

`ORBSALL` (or `21`) generates them for all elements with shadowing. `N1 = blank` .

`ORBNALL` (or `22`) generates them for all elements with no shadowing. `N1 = blank` .

`ORIENT` is the vehicle coordinate system orientation flag. Different orientation flags may not be mixed within a single data deck. `ORIENT` may be `PLANET` , `SUN` , `SURFACE` , or `STAR` .

`PLANET` (or `0`): the vehicle coordinate system is planet oriented. Its X axis points towards the center of the planet. Its Z axis is in the Northern half–space or in the plane of the equator. Its Y axis lies in the orbit plane.

`SUN` (or `1`): the vehicle coordinate system is sun oriented. Its X axis points towards the sun. Its Z axis lies in the plane formed by the Sun vector and the North vector, such that it is positive Northward. Its Y axis completes the right–handed set.

`SURFACE` (or `2`): the vehicle coordinate system is attached to the surface of the planet, and rotates with it. Its X axis points towards the center of the planet. Its Z axis points North and its Y axis points West. Only solar vectors are computed for this option; planet view factors are not computed.

`STAR` (or `3`): the vehicle coordinate system is star oriented. Its X axis points towards a star. Its Z axis lies in the Sun–North plane, positive Northward. Its Y axis completes the right–handed set. The star's coordinates are defined on the ORBSADD Card.

`ALB` is the albedo value, e.g. `.35`.

If `ALB = 0`, solar view factors with eclipse will be calculated without Earth or albedo factors.

`ALB` is ignored for `ORIENT=SURFACE`.

`NINT` is the number of equally spaced subintervals into which the Card 6l orbit interval `STARTANGLE` to `ENDANGLE` is divided.

The number of orbital positions is `NINT` + `1` + twice the number of eclipse points. Two calculations are performed for each eclipse point, one on each side of it, separated by a `.1` degree interval.

`SUNDECL` is the sun's declination angle in degrees. `SUNDECL` is the angle between the sun vector, which points towards the sun, and the equatorial plane.

`SUNDECL` is `> 0` in the Northern and < 0 in the Southern hemispheres. For Earth, `−23.44 ≤ SUNDECL ≤ 23.44`, and is `= 0` at equinox.

`ORBINCL` is the orbit inclination angle in degrees, i.e. the angle between the orbit plane and the equatorial plane.

`ORBINCL` is positive counterclockwise when looking towards the planet's center from the orbit ascending node.

`ORBINCL` equals the latitude for `ORIENT=SURFACE`.

`E` is the orbit eccentricity, `0` ≤ `E` ≤ `1`.

`E = 0` is a circular orbit.

`E` is ignored for `ORIENT` = `SURFACE`.

`SMAR` is the orbit semi major axis ratio, i.e. the ratio of the length of the orbit's semi major axis to the planet's radius.

Earth's radius is `3441` nautical miles = 3963 miles = 6378 kilometers.

`SMAR` is ignored for `ORIENT` = `SURFACE`.

`OMEGA` is the angle between the reference line, which is the projection of the sun vector onto the equatorial plane (local noon), and the orbit ascending node, in degrees, measured in the equatorial plane. (Clarification note: this is not the same as the Right Ascension of Ascending Node, which is the angle measured from the Vernal Equinox, nor the Geographic Longitude of Ascending Node, which is the angle measured from the Prime Meridian.)

`OMEGA` is positive when the equatorial plane is viewed from the North Pole (measured "East" from the reference line).

`OMEGA` is ignored for `ORIENT` = `SURFACE`.

`ANGPER` is the periapsis angle in degrees, i.e. the angle between the ascending node and the perigee, measured in the orbit plane. Periapsis is the point in the orbit closest to the planet.

`ANGPER` is positive in the direction of the spacecraft's motion.

`ANGPER` is ignored for `ORIENT` = `SURFACE`.

`PER` is the period of the orbit in appropriate time units.

`PER` is the length of a day for `ORIENT` = `SURFACE`.

`N1` is the element (or elements if `N1` is a group name) for which the calculations are performed.

`N1` must be blank for the `ORBSALL` and `ORBNALL` options.

Notes

If a planet's radius R_P and acceleration of gravity at its surface `G` (`6378` km and `9.81 m/sec2` for Earth) are known, then the orbital period can be calculated:

$$PER = 2\pi\left(\frac{R_p}{G}\right)^{\frac{1}{2}}(SMAR)^{\frac{3}{2}}$$

The maximum and minimum altitudes above the center of the planet are:

$$HP = SMAR(1-E)RP \quad at\ periapsis$$
$$HP = SMAR(1-E)RP \quad at\ apoapsis$$

Example

```
ORBSALL PLANET 0 12 0 0 0 6.625 180 0 24.0
```

The spacecraft is in a geosynchronous (SMAR = `6.625`, PER = `24`) equatorial (`ORBINCL = 0`) orbit, during equinox (`SUNDECL = 0`). Solar eclipse calculations with shadowing (`L = ORBSALL`), but no Earth view factor or albedo factor calculations (`ALB = 0`) are performed every 2 hours (`NINT = 12`), plus just before and just after entering and exiting eclipse. The vehicle coordinate system's X axis points towards the Earth, its Z axis North, and its Y axis West (`ORIENT = PLANET`).

Example

```
ORBSALL SURFACE 0 12 -23.5 45.55 0 0 0 0 24
```

The vehicle coordinate system is anchored to Earth at latitude of `45.5` degrees (Montreal).

Card 6l - Additional Orbital Parameters ORBADD Card – Optional

`L` , `STARTANGLE` , `ENDANGLE` , `TIMEI` , `ANGX` , `ANGY` , `ANGZ` , `ORDER` , `DANGX` , `DANGY` , `DANGZ` , `OMEGASTAR` , `PHISTAR` , `THETASTAR`

A Card 6l must follow a Card 6k Orbit Definition Card. If absent, all its parameters default to `0.` `ENDANGLE` defaults to 360 degrees.

`L` is the code `ORBADD` (or `23`).

`STARTANGLE` is the initial orbit position in degrees.

`STARTANGLE` is measured in the orbit plane, starting from the periapsis, and is positive in the direction of the motion of the spacecraft.

For `ORIENT=SURFACE` , `STARTANGLE` is the number of degrees the planet has rotated from local midnight for the start of the orbit. For a 6:00 AM start `STARTANGLE` should be 90 degrees.

`ENDANGLE` is the final orbit position in degrees.

`ENDANGLE` is measured in the orbit plane, starting from the periapsis, and is positive in the direction of the motion of the spacecraft.

For `ORIENT=SURFACE` , `ENDANGLE` is the number of degrees the planet has rotated from local midnight for the end of the orbit. For a 5:00 PM end `ENDANGLE` should be 255 degrees.

`TIMEI` is the `TIME` parameter value at `STARTANGLE` .

If `ENDANGLE-STARTANGLE = 360` , `TIMEI` must be `0` , i.e. a full orbit must start at `TIMEI = 0` .

`ANGX` , `ANGY` , `ANGZ` are the angles in degrees which define the orientation of the vehicle coordinate system (as defined by the ORIENT on Card 6k) at `TIME = TIMEI` with respect to the global (model's) coordinate system.

If the two coordinate systems coincide and are stationary relative to each other, i.e. `DANGX` , `DANGY` , `DANGZ` are blank, then `ANGX` , `ANGY` , `ANGZ` , and `ORDER` must also be blank.

`ORDER` determines the order of the rotations by which the vehicle coordinate system is rotated into the global (model's) coordinate system. `ORDER` may be the codes:

- `XYZ` , `XZY` , `YXZ` , `YZX` , `ZXY` , or `ZYX`
- (or 1 to 6), defining the axes of rotation in the order the rotations are performed.

For example, if `ORDER` is `XZY` , to arrive at the global coordinate system you must first rotate counterclockwise about the vehicle coordinate system's X axis by `ANGX` , then next about the new Z axis by `ANGZ` , then about the new Y axis by `ANGY` .

`DANGX` , `DANGY` , `DANGZ` are the rotational angle increments in degrees for `ANGX` , `ANGY` , `ANGZ` after one complete orbit.

If these are blank or zero, the vehicle coordinate system is fixed with respect to the global coordinate system.

For example, the rotation `AX(t)` about the X axis at `TIME = t` is computed with:

$$AX(t) = ANGX + DANGX\left(\frac{t - TIMEI}{PERIOD}\right)$$

`OMEGASTAR` is the angle of the vernal equinox in degrees from the Reference Line. The vernal equinox is a vector along the line of intersection of the ecliptic and equatorial planes, pointing in the direction where the sun crosses the equator going Northwards.

`PHISTAR` is the angle between the projection of the star vector on the equatorial plane and the angle of the vernal equinox measured counter clockwise when looking southwards.

`THETASTAR` is the angle between the vector pointing towards the star and the North vector.

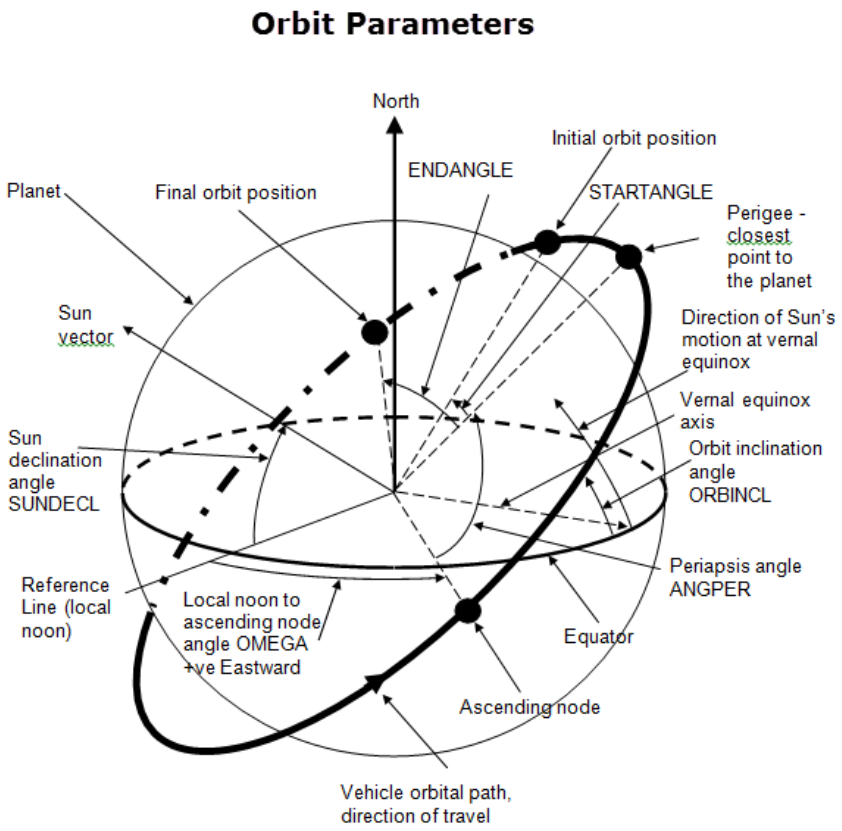
Example

```
ORBSALL PLANET 0 12 0 0 0 6.625 180 0
24.0      $ CARD 6K EXAMPLE


ORBADD 0 360 0 0 90 180 ZYX            $ S/C ORIENTATION IN ORBIT
```

The spacecraft is in geosynchronous (`SMAR = 6.625, PERIOD = 24`) equatorial (`ORBINCL = 0`) orbit, during equinox (`SUNDECL = 0`). Solar eclipse calculations with shadowing (`L = ORBSALL`), are performed every 2 hours (`NINT = 12`), plus just before and just after entering and exiting eclipse. No Earth view factor or albedo factor calculations are performed (`ALB = 0`). The vehicle coordinate system's X axis points towards the Earth, its Z axis North, and its Y axis West (`ORIENT = PLANET`).

The spacecraft's Z axis points away from the Earth, its Y axis is positive in the direction of the motion (towards East), and its X axis points southward. To get to the model's coordinate system, the vehicle coordinate system is rotated 180 degrees counterclockwise about its Z axis, then 90 degrees counterclockwise about its new Y axis.



Card 6m - Minimum Allowable View Factor VFMIN Card – Optional

`L` , `VAL`

`L` = `VFMIN` (or `24`)

`VAL` is a value. `0 ≤ VAL ≤ 1`

Notes

1. This Card sets a minimum value for unshadowed view factors, default = `1.0E-10`.
   If the estimated value of a view factor is `< VAL` for both elements, that view factor is not calculated. If it is calculated, and is `< VAL`, it is not written on file VUFF.
2. The value of `VAL` is in effect until a subsequent VFMIN Card is encountered.
3. A VFMIN Card can considerably speed up view factor calculations for large models. However, care should be exercised in setting the value of `VAL`, since it can significantly affect the energy balance. A rule of thumb is that `VAL < 1/10N` is safe, where `N` is the number of elements in the model (or enclosure).
4. The difference between the Card 2a RK parameter and the VFMIN Card is that VFMIN prevents the calculation of small view factors, thus reduces run–time of the VUFAC module, while the RK parameter eliminates small radiative couplings caused by small gray body view factors for Gebhardt's Method.

Both the VFMIN and RK options should be used together to save CPU time, since small radiative couplings will still be created by the GRAYB module, even though there may not be any small view factors in the model.

For the Card 9 PARAM OPPENHEIM option the `RK` parameter is not available, only VFMIN is effective.

Example

```
VFMIN .001          $ SETTING VAL FOR VIEW FACTORS OF ENCLOSURE 1
VFS12 ENC1 ENC1
VFMIN .0001         $ SETTING VAL FOR VIEW FACTORS OF ENCLOSURE 2
VFS12 ENC2 ENC2
```

Card 6n - Heat Flux View Factor Requests to Radiative Sources – Optional

`L` , `N1` , `N2` , `POWER` , `TIME` , `AFLAG` , `REVN1` , `REVN2` , `POWERIR` , `THETA` , `PHI` , `ARRAYNO` , `DIRFLAG`

`L` = the type of heat flux view factor request.

`L` may be:

`SOURCES12` (or `25`) calculates a heat flux view factor from source element(s) `N1` to element(s) `N2` with shadowing.

If `N1` and `N2` are both group names, all the heat flux view factors from the elements of `N1` to the elements of `N2` will be calculated.

`SOURCEN12` (or `26`) is the same as `SOURCES12` with no shadowing.

`SOURCESALL` (or `27`) calculates all the heat flux view factors for source element(s) `N1` with shadowing, starting with the heat flux view factor to `N2`. `N2 = 0` calculates all the heat flux view factors for source element(s) `N1`.

If `N1` is a group name, all the heat flux view factors for the elements of that group will be calculated.

`SOURCENALL` (or `28`) is the same as `SOURCESALL` with no shadowing.

`N1` is the radiative source. `N1` may be an element number or a group name.

`N2` is the element or group name of the element(s) for which the heat flux view factors are calculated. `N2` must be set to 0 for the `SOURCESALL` and `SOURCENALL` Cards.

`POWER` is the value of the solar spectrum heat load per unit time emitted by the `N1` source elements. `POWER` may not be negative. To ensure that the specified amount of solar spectrum radiation is emitted by the `N1` source elements and none of it is re-absorbed by them due to reflection, their absorptivity value will be set to zero in the POWER module.

If `POWER` is `Tn`, where `n` is a table number (e.g. `T10`), and n is a table whose dependent variable is `QNODE`, and `TIME` is `CONSTANT`, then the `POWER` value will be interpolated from the table `n` by the Analyzer during run time.

For multispectral runs (Card 9 PARAM SPECTRA Card) the values of `POWER` and `POWERIR` are multiplied together to yield the heat load per unit time. If the sources are wavelength-dependent, either `POWER` or `POWERIR` must reference a table specifying the wavelength dependence.

`TIME` specifies the time value when the heat flux view factors are defined. `TIME` may also be the flag `CONSTANT` (or `-99990`). If `TIME` is blank, it defaults to `CONSTANT`.

`AFLAG` determines whether the values specified in the `POWER` and `POWERIR` fields are emitted heat loads per unit area**,** per element, or emitted by all the elements `N1`.

`= ABSOLUTE` (or `0`)

For this option `POWER` and `POWERIR` are the emitted power values for the element `N1`.

`= AREA` (or `1`), or

For this option `POWER` and `POWERIR` are the emitted power per unit area values for the element `N1`.

`= TOTAL` (or `2`),

For this option, if:

- `POWER` or `POWERIR` are of the form `Tn`, and
- table `n` has the independent variable `EID`, or it has the independent variable `OPERAT` and the dependent variable `TABLE`, and
- one of the tables listed in n has the independent variable `EID`,
- then the heat load is calculated according to the following formula:

$$H(I) = F\frac{\Omega(I)AREA(I)}{\sum_{i}^{N1}\Omega(i)AREA(i)}$$

where:

- $H(I)$ is the heat load emitted per unit time by the radiating source element I, where I is a member of the group `N1`
- $'\Omega(I)$ is the value interpolated from the table n for element I
- $AREA(I)$ is the area of element I
- F is a multiplying factor, which is obtained by interpolation from the non-EID table if the independent variable is OPERAT. If the independent variables is EID, then `F=1`.

For the `TOTAL` option `N1` must be a group name.

`= blank`, which defaults to `AREA`.

`= INCABSOLUTE` (or `3`), or

`= INCAREA` (or `4`), or

`= INCTOTAL` (or `5`)

`INCABSOLUTE`, `INCAREA`, and `INCTOTAL` behave the same way as the `ABSOLUTE`, `AREA`, and `TOTAL` options, except that instead of view factors being calculated and written on `VUFF`, heat loads are written on `MODLF`. The magnitude of the heat loads is equal to what the elements would have absorbed had they all been perfectly black.

`REVN1` may be `0`, blank, an element ID, or a group name. The reverse sides of the `REVN1` element(s) are added to the `N1` source elements.

`REVN2` is applicable for `L = SOURCES12` or `SOURCEN12`, otherwise it must be blank or 0. `REVN2` may be 0 or an element or a group name, and the reverse sides of the `REVN2` element(s) are added to the `N2` elements.

`POWERIR` is the IR spectrum heat load per unit time emitted by the source element(s). To ensure that the specified amount of IR spectrum radiation is emitted by the `N1` source elements and none of it is re-absorbed by them due to reflection, their emissivity value will be set to zero in the POWER module.

If `POWERIR` is `Tn` or `-n`, where n is a table number (e.g. `T10` or `-10`), and n is a table whose dependent variable is `QNODE`, and `TIME` is `CONSTANT`, then the `POWERIR` value will be interpolated from the table n by the Analyzer during run time.

For multispectral runs (Card 9 PARAM SPECTRA Card) the values of `POWER` and `POWERIR` are multiplied together to yield the heat load per unit time. If the sources are wavelength-dependent, either `POWER` or `POWERIR` must reference a table specifying the wavelength dependence.

`THETA` is optional. If `THETA` is present, the sources send out only collimated rays. If `THETA` is not present, they send out rays in all directions.

`THETA` is the angle in degrees between the direction of the collimated rays and the element surface normal. If `THETA` is not zero, then the elemental material coordinate system must be defined with Card 9 MATVEC Cards.

If the source element `N1` is a 1-node element, or `DIRFLAG` is `1`, then `THETA` is interpreted to be in the global coordinate system.

`PHI` is the angle in degrees between the projection of the collimated rays' direction vector onto the material coordinate system's XY plane and the X-vector of the material coordinate system, measured positive in the counterclockwise direction.

If `THETA` is not zero, then the elemental material coordinate system must be defined with Card 9 MATVEC Cards.

If the source element `N1` is a 1-node element, or `DIRFLAG` is `1`, `PHI` is interpreted to be in the global coordinate system.

`ARRAYNO` is optional, and if specified, is the number of an array that contains a distribution vs angle data.

If `ARRAYNO` is specified, the source `N1` is considered to be direction-dependent. The angular distribution in the table is normalized over all solid angle such that the total power specified in the `POWER` and `POWERIR` fields is respected. Without the `ARRAYNO` table referenced, the diffuse source will provide a Lambertian power distribution.

By specifying angular dependence in the table, other distributions can be defined. The intensity emitted by the radiative heat source in a given direction is calculated by multiplying the `POWER` and `POWERIR` values by the normalized value interpreted from the array, times the multiplier specified by `AFLAG`.

The array must be specified with Card 9 ARRAYTYPE and ARRAYDATA Cards. The first independent variable must be `DIR_INC`, the second independent variable must be `ANG_INC`, and the dependent variable must be `MULTIPLIER`.

A MATVEC Card must also be specified for each `N1` source element to specify the material directional properties. `DIR_INC` is the angle in degrees of the emitted ray with respect to the material X axis, and `ANG_INC` is the angle in degrees of the emitted ray with respect to the material Z axis.

If `ARRAYNO` is specified, the values of `THETA` and `PHI` are ignored.

`DIRFLAG`

If `DIRFLAG` is blank or zero, then `THETA` and `PHI` are interpreted to be defined in the `N1` elements' material coordinate system. If `DIRFLAG` is 1, then `THETA` and `PHI` are interpreted to be in the global coordinate system.

Notes

This Card calculates heat flux view factors from radiative sources such as light sources. The calculation procedure is analogous to that of solar loads, with the heat flux view factors replacing the solar view factors. The following procedure should be used to calculate radiative heat loads from source elements.

1. Define the radiative source elements geometrically. Assign them a group name (e.g. SOURCES) with a Card 9 NAME Card.
2. Request all the view factors with a Card 6a VFSALL Card.
3. Request the heat flux view factors with a Card 6n SOURCES Card. Set `N1` to the source group name, and specify the `POWER` and `POWERIR` parameters. Optionally, you may wish to specify the `TIME` and `AFLAG` parameters.
4. Set the Card 2a `M` parameter to `194 (= 2+64+128)`, plus whatever other options you wish to run. These options request that the VUFAC should be run to calculate the view factors and the heat flux view factors and that the POWER module should be run to calculate the heat loads and write them on file MODLF.

When heat flux view factors are written on file VUFF, the value in the view factor field is the calculated heat flux view factor multiplied by the `POWER` parameter.

Example

```
SOURCES1ALL SOURCES 0 1.6
$ RADIATIVE HEAT FLUX VIEW FACTORS ARE
$ CALCULATED TO ALL THE ELEMENTS FROM
$ SOURCE ELEMENTS CALLED SOURCES. THE
$ EMITTED HEAT LOAD HAS A VALUE OF 1.6
$ PER UNIT AREA.

SOURCES12 SOURCA 2 2.5 10 ABSOLUTE
$ RADIATIVE HEAT LOADS ARE CALCULATED FROM
$ SOURCE SOURCA TO ELEMENT 2 TO AT TIME = 10.
$ THE EMITTED HEAT LOAD FROM THE ELEMENTS OF
$ SOURCA HAS A VALUE OF 2.5 PER ELEMENT.
```

Card 6o - Symmetric Elements List Continuation Card – Optional

`L`, `N2`, `N3`, `....NN`

`L` = `SYMNCONT` (or `29`)

`N2`, `N3`, `....NN` are the elements of the symmetric model that are symmetrical with respect to the `N1` element defined on a previous Card 6h - Symmetric Elements List Card – Optional.

There is a maximum of 15 elements per Card, but any number of Card 6o Continuation Cards may be used.

This Card is useful if the model's symmetry is greater than 15 – fold, i.e. if not all the symmetric elements fit on a single Card 6h. Any number of elements may be placed on a series of Cards 6o.

Example

```
$ THE FOLLOWING CARDS DESCRIBE A MODEL WITH
$ 35-FOLD SYMMETRY
SYMVREQ ARCOMB
SYMNODES 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
SYMNCONT 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
SYMNCONT 31 32 33 35 35
SYMNODES 101 102 103 104 105 106 107 108 109 11 111 112 113 114
SYMNCONT 115 116 117 118 119 120 121 122 123 124 125 126 127 128
SYMNCONT 129 130 131 132 133 135 135
```

Card 6p - Spinning Definition in Orbit Card – Optional

`L`, `NPOS`, `VECTOR`

This card is used to specify spinning of a spacecraft or a portion of a spacecraft in orbit.

This card must follow the ORBADD card 6l of the corresponding orbit definition.

`L` is the code `ORBSPIN` (or `30`)

`NPOS` is the number of positions per spin. The minimum `NPOS` value is 2.

`VECTOR` is the vector number referencing VECTOR card 9. This vector defines the spinning axis.

Notes

The ORBSPIN card is always associated with an orbit definition from ORBIT Cards 6k and an ORBADD Card 6l, or an ORBDEF Card 6t. The ORBSPIN card must follow the ORBADD Card 6l or the ORBDEF Card 6t of the corresponding orbit definition.

If an ORBSPIN card is specified, `SPIN1` or `SPINALL` cards are generated by the DATACH module for every orbit position specified in the corresponding orbit definition.

If an ORBSPIN card is specified, the solar, earth, albedo, and black body view factors are averaged over each spin position.

Example 1

```
ORBSALL PLANET 0.35 12 0 0 0 1.1 0 0 3.6E+03

ORBADD 0 360 0 0 0 0 XYZ 0 0 0

ORBSPIN 8 1 $ THE ORBSPIN CARD DEFINIES SPINNING FOR THE WHOLE MODEL.
```

Example 2

```
ORBDEF1 1 S1 EARTH NADIR PVEL BUS 0

ORBDEF2 1 8.64E+04 6.37E+09 9810 ON .3 FLUX 2.36E+02 FLUX 0

ORBDEF3 1 1.3772E+03 SUNDECL 0 0 0 0 0 0

ORBDEF4 1 CLASSIC AMIN 1.9E+09 ECC 0 45.000 0 LTIME 18

ORBDEF5 1 0 0 -1 -1 0 0 1 0 0

ORBDEF6 1 FULL AN 0 0 360 12

ORBDEF7 1 0 0 0 0 0 0 0

ORBSPIN 8 2
```

```
$ THE ORBSPIN CARD DEFINES 8 POSITIONS FOR FRONT SIDES OF THE ELEMENT GROUP ‘BUS’

$ OVER WHICH THE VIEW FACTORS ARE AVERAGED. THE SPINNING AXIS IS VECTOR 2.
```

Card 6q - Spinning Request Card – Optional

`L` , `N1` , `NPOS` , `VECTOR` , `TIME`

This card is used to define spinning request for a model or a portion of a model.

`L` is the type of spinning request. `L` may be `SPINALL` or `SPIN1` .

`SPINALL` (or `32`) calculates all solar, earth, albedo, and black body view factors for a model that is in a spinning motion.

`SPIN1` (or `31`) calculates all solar, earth, albedo, and black body view factors for elements `N1` that are in a spinning motion.

`N1` is a group name for SPIN1 option. It is `0` for the `SPINALL` option.

`NPOS` is the number of positions per spin. The minimum `NPOS` value is `2` .

`VECTOR` is the vector number referencing VECTOR card 9. This vector defines the spinning axis.

`TIME` is either blank or the flag `CONSTANT` . `TIME =` blank defaults to `CONSTANT` .

Notes

If an `SPIN1` or `SPINALL` card is specified, the solar, earth, albedo view factors, and black body view factors are averaged over each spin position.
If two or more objects, defined on different SPIN1 cards, are spinning then it is assumed that these objects are moving at the same spin rate.

Spinning is not allowed on more than one spin axis.
If SPIN1 cards have different number of spinning positions, a single `NPOS` value (the maximum of all) will be used for all cards.
Spinning can be used in a model along with other features, such as articulation, ray-tracing, thermal couplings, hemicube and deterministic methods for view factor calculation, etc.

Example

```
SPINALL 0 8 10 CONSTANT

VECTOR 10 0, 0, 0, 0, 0, 1

$ THE MODEL SPINS ABOUT VECTOR 10
```

Card 6r - View Factor Request Cards in an Enclosure – Optional

`L` , `N1` , `N2` , `FLAG1` , `FLAG2`

`L` is the type of view factor calculation request. `L` may be `VFSENC` or `VFNENC` .

`VFSENC` (or `33`) calculates all the view factors with shadowing in an enclosure specified by `N1` , `N2` and `FLAG1` . Only the elements belonging to the enclosure are checked for potential shadowing, potentially resulting in considerable CPU savings.

`VFNENC` (or `34`) is the same as VFSENC with no shadowing.

`N1` may be an element number a group name, or `0` . `N1` specifies the elements whose front surfaces belong to the enclosure.

`N2` may be an element number a group name, or `0` . `N2` specifies the elements whose reverse sides belong to the enclosure. The `N2` elements' reverse sides are specified on Card 9 REVNODE or REVNOM Cards.

`FLAG1` may be blank, `0`, or `SPACE`.

`SPACE` (or `-4`)

`SPACE` specifies that the enclosure contains the space elements as well as the elements specified by `N1` and `N2`.

`FLAG2` may be blank, `0`, or `VFTRACE`.

If `FLAG2` is `VFTRACE`, then ray-tracing is performed on the specular and transparent elements of the enclosure according to the rules described for the `VFTRACE` option of Card 6a.

Notes

The `VFSENC` and `VFNENC` requests are very similar to the view factor request of Card 6a. For more information, see Card 6a - View Factor Request Cards – Optional.

Example

```
VFSENC FRONT BACK SPACE
$ ALL VIEW FACTORS IN AN ENCLOSURE DEFINED BY THE FRONT
$ SURFACES OF THE ELEMENTS FRONT, THE REVERSE SIDES
$ OF THE ELEMENTS BACK, AND THE SPACE ELEMENT ARE CALCULATED.
```

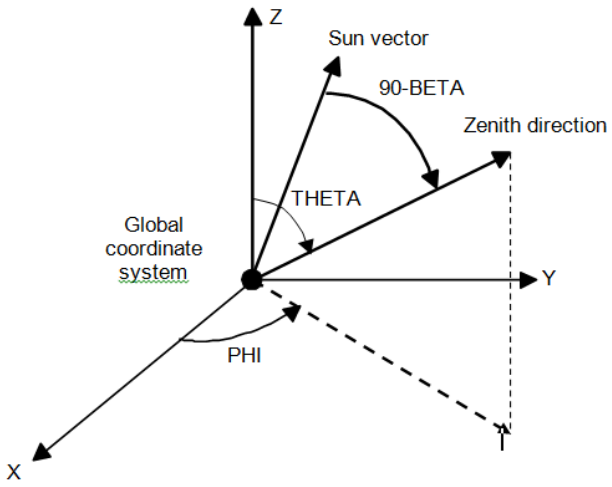
Card 6s - Diffuse Sky View Factor Request Card – Optional

`L`, `N1`, `N2`, `THETA`, `PHI`, `BETA`, `DIFFSKY`, `REFLG`, `PSUN`, `TIME`

`L` is `SKY` (or `36`)

`N1` is the element number or group name of the elements whose front surface will receive diffuse radiation from the sky.

`N2` is the element number or group name of the elements whose reverse surface will receive diffuse radiation from the sky. Reverse sides can be created with Card 9 REVNODE Card.



`THETA` is the angle in degrees the vector point towards zenith makes with the global Z axis.

`PHI` is the angle in degrees the projection onto the global XY plane of the vector pointing towards zenith makes with the global X axis. The counterclockwise direction is positive.

`BETA` is the solar altitude angle in degrees, the angle from the horizontal to the sun vector.

`DIFFSKY` is the diffuse sky factor ratio, i.e. the diffuse sky flux on a horizontal plate divided by the direct normal solar flux.

`REFLG` is the ground reflectance.

`PSUN` is the value of the solar flux attenuated by the atmosphere incident upon a surface.

If `PSUN` is 0, the card 2a `PSUN` value will be used.

If `PSUN` is `Tn` or `-n`, where n is a table number (e.g. `T10 or -10`), and `n` is a table whose dependent variable is `QNODE`, and `TIME = CONSTANT`, then the `PSUN` value will be interpolated from the table n by the Analyzer during run time.

`TIME` is the `TIME` value when the solar heat flux occurs.

Notes

This card computes the diffuse incident solar spectrum flux from the sky as well as that reflected from the ground. The equation used is:

$$Indicent\,flux = I_d + I_r$$

where:

- I_d is the sky diffusse radiation.
- I_r is the ground reflected radiation.

$$I_d = PSUN \times DIFFSKY \times VF_{sky}$$

where VF_{sky} is view factor between the surface and the sky. In case of explicit sky modeling using EXSKY parameter in Card 9 - PARAM Parameter Card - Optional, the view factor is computed from the sky model. Otherwise:

$$VF_{sky} = \frac{1 + \cos\Omega}{2}$$

$$I_r = REFLEG \times I_{tH} \times VF_g$$

$$I_{tH} = PSUN(DIFFSKY + \sin\beta)$$

where:

- I_{tH} is the total horizontal irradiation.
- VF_g is a view factor between the surface and the ground.

In case of explicit earth modeling using EXEARTH parameter in Card 9 - PARAM Parameter Card - Optional, the view factor is computed from the earth model. Otherwise:

$$VF_g = \frac{1 - \cos\Omega}{2}$$

where Ω is the surface elevation angle, for example, the angle between the element surface normal and zenith. The reference for the equation is found in: ASHRAE Handbook, HVAC Applications 1995, SI edition, p. 30.1 to 30.5. This card generates equivalent ALB Cards on the VUFF file. When the explicit sky option is activated the shadowing effects is computed. Otherwise, shadowing calculations are not performed. Incident solar fluxes are not computed with this card, they need to be computed separately using the Card 6b - Solar View Factor Request Card – Optional. You can flag elements that cannot receive fluxes computed with this card using the NOSOLAR option in Card 9 - PARAM Parameter Card - Optional.

Card 6t - ORBDEF1-ORBDEF7 Orbit and Attitude Modeling Request Cards – Optional

The ORBDEF1-ORBDEF7 Cards define an orbit and attitude modeling request.

```
ORBDEF1 ID SHADOPT PNAME V1OPT V2OPT FRONTGRP REVGRP

ORBDEF2 ID PLPERIOD PLRADIUS PLGRAV PLIRFLAG ALB IROPT1 IRVAL1 IROPT2 IRVAL2 IROPT3
IRVAL3 IROPT4

ORBDEF3 ID SOLFLUX SOLOPT SV1 SV2 SV3 SV4 SV5 SV6

ORBDEF4 ID BETA BETAOPT ALRADVAL BETAANGLE (beta angle orbit option), or

ORBDEF4 ID GEOSYNC LONGVALUE (geosynchronous orbits option), or
ORBDEF4 ID ORBTYPE ALTOPT1 ALT1 ALTOPT2 ALT2 ORBINCL ANGPER ANOPT ANVAL (for CLASSIC,
SUNSYNC, SHUTTLE OR MOLNIYA options)

ORBDEF5 ID V1X V1Y V1Z V2X V2Y V2Z SATDIR SATLAT RASUN

ORBDEF6 ID SEGTYPE STARTPOS STARTANGLE TIMEI ENDANGLE NINT

ORBDEF7 ID ROTX ROTY ROTZ ROTRATE STARRA STARDECL ROTFLAG
```

All fields are required on all the Cards, except for the FRONTGRP and REVGRP on ORBDEF1, which may be blank. If the value in a field is to be ignored, specify 0.

A simpler alternate method is available in Cards 6k and 6l.

It is helpful to reference the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional when perusing these cards.

`ID` is the orbit and attitude modeling request number. ID is an integer value common to all associated ORBDEF Cards.

ORBDEF1: Major Orbit Parameters

`ID SHADOPT PNAME V1OPT V2OPT FRONTGRP REVGRP`

FIELD	VALUE	DESCRIPTION
`ORBDEF1`	ORBDEF1 or 41	mnemonic
`ID`	integer	ID number
`SHADOPT`	`S1`	Shadowing for some elements
	`N1`	No shadowing for some elements
	`SALL`	Shadowing for all elements
	`NALL`	No shadowing for all elements
`PNAME`	`MERCURY`	Planet Mercury
	`VENUS`	Planet Venus
	`EARTH`	Planet Earth
	`MARS`	Planet Mars
	`JUPITER`	Planet Jupiter
	`SATURN`	Planet Saturn
	`URANUS`	Planet Uranus
	`NEPTUNE`	Planet Neptune
	`PLUTO`	Planet Pluto

	`GENERIC`	Generic planet
	`MOON`	Moon
`V1OPT`	`NADIR`	vector1 points to the nadir
	`SUN`	vector1 points to the Sun
	`STAR`	vector1 points in the star direction
	`PVEL`	vector1 points in the velocity vector direction
	`PNORMAL`	vector1 points along the orbit normal
	`NORTH`	vector1 points North
	`SOUTH`	vector1 points South
`V2OPT`	`PVEL`	vector2 points close to the positive velocity vector direction
	`PNORMAL`	vector2 points close to the positive orbit normal direction
	`NORTH`	vector2 points close to the North direction
	`SOUTH`	vector2 points close to the South direction
	`NADIR`	vector2 points close to the nadir direction
	`SUN`	vector2 points close to the Sun direction
	`STAR`	vector2 points close to the star direction

FRONTGRP	mnemonic or integer	Element ID or group ID of front facing elements
REVGRP	mnemonic or integer	Element ID or group ID of reverse facing elements

SHADOPT is the shadowing option to be used for the selected elements.

PNAME is the planet name around which the spacecraft orbits. This field has the following effects:

- For planets other than the Moon or Mercury, the dark side IR radiation value is assumed to be the same as the sunlight side radiation value. For the Moon and Mercury, an interpolation is performed between the sunlight and dark sides, based on the algorithm described on Card 9 PARAM PIRSUBSOLAR Card.
- For the planet Earth, options exist to specify the time of the year when the orbit occurs. In addition, it is necessary to specify only either the sun declination angle or the sun right ascension angle, as opposed to other planets, where both need to be specified. The reason is that the maximum and minimum sun declination angles are know to be 23.44 degrees.

V1OPT is the flag for target1, the target with which vector1 is aligned. vector1 is the first of two vectors fixed with respect to the spacecraft (global) coordinate system needed to specify the alignment of the spacecraft with respect to the orbit.

The components of vector1 are specified on the ORBDEF5 Card.

If no rotation is specified on ORBDEF7, the spacecraft is so oriented that vector1 is always locked onto target1.

If a rotation is specified on ORBDEF7, vector1 is aimed at its target only at time = 0. At subsequent times, the spacecraft is rotated about the rotation axis by the rate specified on ORBDEF7.

V2OPT is the flag for target2, the target towards which vector2 is aimed. vector2 is the second of two vectors fixed with respect to the spacecraft (global) coordinate system needed to specify the alignment of the spacecraft with respect to the orbit.

The components of vector2 are specified on the ORBDEF5 Card.

The spacecraft will be aligned to minimize the angular deviation between `vector2` and the spacecraft-to-target2 vector. However, it may not be achievable to have perfect alignment between the spacecraft-to-target2 vector and vector2. Then, the spacecraft will be oriented with respect to the orbit that:

- The spacecraft-to-target2 vector always lies in the plane of vector1 and a vector2.
- The dot product of the spacecraft-to-target2 vector and vector2 is always positive. If this is not possible, an error message will be issued.

`FRONTGRP` is the single element ID or the group name of the front facing elements for which the orbital fluxes are to be calculated.

This field should blank if the `SHADOPT` is `NALL` or `SALL`.

This field should be 0 if only a reverse group is selected.

`REVGRP` is a single element ID or the group name of the elements for whose reverse sides orbital fluxes are to be calculated.

The field should be blank or 0 if no reverse sides are to be included in the orbital flux calculations.

If both `FRONTGRP` and `REVGRP` are blank or 0, and `SHADOPT` is `S1` or `N1`, then orbital positions are computed, in case the orbit is referenced in an articulation object, but orbital heating is not taken into account.

ORBDEF2: Planet Parameters

`ID PLPERIOD PLRADIUS PLGRAV PLIRFLAG ALB IROPT1 IRVAL1 IROPT2 IVAL2 IROPT3 IRVAL3 IROPT4`

FIELD	VALUE	DESCRIPTION
`ORBDEF2`	`ORBDEF2` or `42`	Mnemonic
`ID`	integer	ID number

PLPERIOD	real	Planet period value
	STATIONARY	The planet does not rotate
PLRADIUS	real	Planet radius value
PLGRAV	real	Planet gravity constant value
PLIRFLAG	OFF	Planet albedo and IR radiation are not calculated
	ON	Planet albedo and IR radiation are calculated
ALB	real	Albedo value. Alternatively, ALB may be of the form Tn, where n is a table number, referencing a TABTYPE Card, or an array number, referencing an ARRAYTYPE Card. The dependent variable on the TABTYPE Card must be ALBEDO, and the independent variable LATITUDE, LONGITUDE, or TIME. The dependent variable on the ARRAYTYPE Card must be ALBEDO, and the independent variables LATITUDE and LONGITUDE. Latitude and longitude must be defined in degrees. If a table is specified, the Card 9 PARAM EXEARTH flag must also be set.
IROPT1	FLUX	Sunlight side planet IR radiation is specified as flux
	TEMP	Sunlight side planet IR radiation is specified as temperature

IRVAL1	real	Sunlight side planet IR radiation value. Alternatively, if IROPT1 is set to FLUX, IRVAL1 may be of the form Tn, where n is a table number, referencing a TABTYPE Card, or an array number, referencing an ARRAYTYPE Card. The dependent variable on the TABTYPE Card must be PIR, and the independent variable LATITUDE, LONGITUDE, or TIME. The dependent variable on the ARRAYTYPE Card must be PIR, and the independent variables LATITUDE and LONGITUDE. Latitude and longitude must be defined in degrees.
IROPT2	FLUX	dark side planet IR radiation is specified as flux
	TEMP	dark side planet radiation is specified as temperature
IRVAL2	real	dark side planet IR radiation value. Alternatively, if IROPT2 is set to FLUX, IRVAL2 may be of the form Tn, where n is a table number, referencing a TABTYPE Card, or an array number, referencing an ARRAYTYPE Card. The dependent variable on the TABTYPE Card must be PIR, and the independent variable LATITUDE, LONGITUDE, or TIME. The dependent variable on the ARRAYTYPE Card must be PIR, and the independent variables LATITUDE and LONGITUDE. Latitude and longitude must be defined in degrees.
IROPT3	LN	Local noon is the longitude from which the prime meridian for the selected celestial body is referenced

	`ME`	March equinox is the longitude from which the prime meridian for the selected celestial body is referenced
	`AN`	Ascending node is the longitude from which the prime meridian for the selected celestial body is referenced
`IRVAL3`	real	Angle from the reference longitude to the prime meridian
`IROPT4`	`CCW`	Counterclockwise rotation orientation for the generic planet
	`CW`	Clockwise rotation orientation for the generic plane

`PLPERIOD` is the period of the planet's rotation i.e the time in seconds for a complete rotation around its axis of rotation. For Earth this value is 86400 seconds. If you set `PLPERIOD` to `STATIONARY`, the planet does not rotate.

`PLRADIUS` is the planet radius value. For Earth this value is 6370.32 km.

`PLGRAV` is the planet surface gravity value. For Earth this value is 9.81 m/s^2.

`PLIRFLAG` is the flag to indicate whether the planet IR and albedo are to be calculated or not.

`ALB` is the Planet albedo value. For Earth, the average value is 0.3.

`IROPT1` is the flag to specify how the planet IR radiation value is specified (flux or temperature).

`IRVAL1` is the IR radiation value (in flux or temperature units) for the sunlight side of the planet.

`IROPT2` is the flag to specify how the planet IR radiation value is specified for the dark side of the planet (flux or temperature).

`IRVAL2` is the IR radiation value (in flux or temperature units) for the dark side of the planet. The interpolation between the dark and sunlight side is done according to the algorithm described on the Card 9 PARAM PIRSUBSOLAR Card.

`IROPT3` is the flag to specify the longitude from which the prime meridian for the selected celestial body is referenced.

`IRVAL3` is the angle from the reference longitude defined by `IROPT3` to the prime meridian. The angle should be between 0 and 360 degrees, and it is measured counterclockwise.

`IROPT4` is the flag to specify the generic planet rotation for longitude-dependent calculations.

> **Note**
>
> For the Sun Planet Vector orbit type the independent variable can only be time. It cannot be longitude and/or latitude.

ORBDEF3: Solar and Orbit Parameters

`ID SOLFLUX SOLOPT SV1 SV2 SV3 SV4 SV5 SV6`

FIELD	VALUE	DESCRIPTION

`ORBDEF3`	`ORBDEF3` or `43`	mnemonic or 43
`ID`	integer	ID number
`SOLFLUX`	real	Solar flux value
	integer	Solar flux table number for `SOLOPT=TABLE`
`SOLOPT`	`SUNDECL`	SV1 is sun's declination angle in degrees
	`MEQUI`	Planet is Earth, time is March equinox
	`JSOL`	Planet is Earth, time is June solstice
	`SEQUI`	Planet is Earth, time is September equinox
	`DSOL`	Planet is Earth, time is December solstice
	`SUNRA`	Planet is Earth, `SV1` is sun right ascension angle in degrees
	`DAY`	Planet is Earth, `SV1` is day number for Earth for year (year=1999)
	`GMT`	Planet is Earth, `SV1` is day value
	`TABLE`	`SOLFLUX` is a solar flux table number
`SV1`	integer	Day number for S `OLOPT=DAY` or `SOLOPT=GMT`
	real	Angle in degrees for `SOLOPT=SUNDECL, SOLOPT=SUNRA`
	0	For all other `SOLOPT` options

SV2	integer	Month for GMT option
SV3	integer	Year for GMT option
SV4	integer	Hour for GMT option
SV5	integer	Minutes for GMT option
SV6	integer	Seconds for GMT option

SOLFLUX is the incident solar flux value of the planet, or table number of the time dependent solar flux value defined in Card 9 TABTYPE Card.

If a table is defined, the dependent parameter on the TABTYPE Card must be QNODE, and the independent parameter must be TIME.

SOLOPT is the flag for defining the sun's angular position with respect to the planet.

For planets other than Earth SOLOPT = SUNDECL must be used, and it is also necessary to define the sun right ascension angle on ORBDEF5 Cards.

SV1 : This field specifies the:

- Day number if SOLOPT = GMT (Greenwich Mean Time) or SOLOPT = DAY .
  Sun declination angle value in degrees for SOLOPT = SUNDECL .
  - This is the angle in degrees between the sun vector, which points towards the sun, and the equatorial plane. It is > 0 in the Northern and < 0 in the Southern hemispheres. For Earth, the sun's declination angle is between ± 23.44 degrees. Refer to the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional.

  Sun's right ascension angle in degrees for SOLOPT = SUNRA .
  - The sun right ascension angle is the angle measured eastward from the vernal equinox axis in the Earth's equatorial plane to the projection of the sun vector onto the equatorial plane.
  - The vernal equinox is the time when the apparent position of the sun crosses the equator moving from south to north. The vernal equinox axis is a line from the Earth's center to the point where the sun crosses the equator moving from south to north.

`SV1` must be `0` for all other options.

`SV2` is month if SOLOPT = GMT, otherwise it must be 0.

`SV3` is year if SOLOPT = GMT, otherwise it must be 0.

`SV4` is hour if SOLOPT = GMT, otherwise it must be 0.

`SV5` is minutes if SOLOPT = GMT, otherwise it must be 0.

`SV6` is seconds if SOLOPT = GMT, otherwise it must 0.

ORBDEF4: Orbit Parameters for CLASSIC, SUNSYNC, SHUTTLE OR MOLNIYA options

```
ID ORBTYPE ALTOPT1 ALT1 ALTOPT2 ALT2 ORBINCL ANGPER ANOPT ANVAL
```

FIELD	VALUE	DESCRIPTION
`ORBDEF4`	`ORBDEF4` or `44`	Mnemonic
`ID`	integer	ID number
`ORBTYPE`	`CLASSIC`	Classical Orbit
	`SUNSYNC`	Sun Synchronous Orbit

	`SHUTTLE`	Shuttle Orbit
	`MOLNIYA`	Molniya Orbit
`ALTOPT1`	`AMIN`	Minimum orbit altitude
	`AMAX`	Maximum orbit altitude
	`RMIN`	Minimum orbit radius
	`RMAX`	Maximum orbit radius
	`ECC`	Orbit eccentricity
	`PER`	Orbit period
`ALT1`	real	`ALTOPT1` value
`ALTOPT2`	`AMIN`	Minimum orbit altitude
	`AMAX`	Maximum orbit altitude
	`RMIN`	Minimum orbit radius
	`RMAX`	Maximum orbit radius
	`ECC`	Orbit eccentricity
	`PER`	Orbit period
`ALT2`	real	`ALTOPT2` value

ORBINCL	real	Orbit inclination in degrees
ANGPER	real	Periapsis angle in degrees
ANOPT	LTIME	Local time value at ascending node
	LNOON	Angle between local noon and ascending node
	RAAN	Right ascension angle of the ascending node
	LONGAN	Geographic longitude of ascending node
	LONGSAT	Longitude of S/C
ANVAL	real	Value defined by ANOPT

ORBTYPE is the flag to specify the type of orbit.

ALTOPT1 is the first of two flags necessary to specify the elliptical shape of the orbit.

ALT1 is the orbit shape parameter value corresponding to ALTOPT1.

ALTOPT2 is the second of two flags necessary to specify the elliptical shape of the orbit.

ALT2 is the orbit shape parameter value corresponding to ALTOPT2.

`ORBINCL` is the orbit inclination angle in degrees, which is the angle between the North vector and the normal to the orbit plane.

When the orbit is so viewed that the spacecraft travels in the counterclockwise direction, the orbit normal points towards the viewer. If it travels in the clockwise direction, the orbit normal points away from the viewer.

The ascending node is the point in planet's equatorial plane where the spacecraft crosses the equator moving from South to North.

ORBINCL is positive counterclockwise when looking towards the planet's center from the orbit ascending node. The orbit ascending node is the point where the orbit crosses the equatorial plane going Northwards. Refer to the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional.

`ANGPER` is `Periapsis` angle in degrees, which is the angle in the plane of the spacecraft's orbit between the ascending node and the perigee of the orbit, measured in the direction of motion of the spacecraft.

It is positive in the direction of motion of the spacecraft. Refer to the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional.

`ANOPT` is the flag specifying the nature of the ascending node value.

If `ANOPT = LTIME`, `ANVAL` is the local time value in hours (`0-24`) at the ascending node position in the orbit.

If `ANOPT = LNOON`, `ANVAL` is the angle in degrees of the ascending node from local noon. It is measured in the equatorial plane from the reference line to the ascending node, and is positive in the counterclockwise direction when the equatorial plane is viewed from the North Pole. It is the same as the angle OMEGA on the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional.

- The reference line is the projection of the sun vector onto the equatorial plane. Refer to the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional.
  The sun vector points towards the sun. If `ANOPT = RAAN`, `ANVAL` is the right ascension angle of the ascending node in degrees. Refer to the diagram in Card 6l - Additional Orbital Parameters ORBADD Card – Optional.
- The right ascension angle is the angle measured Eastward from the vernal equinox axis in the Earth's equatorial plane to the ascending node.
- The vernal equinox is the time when the apparent position of the sun crosses the equator moving from south to north. The vernal equinox axis is a line from the Earth's center to the point where the sun crosses the equator moving from South to North.
- The ascending node is the point in planet's equatorial plane where the spacecraft crosses the equator moving from South to North.

If `ANOPT = LONGAN`, `ANVAL` is the geographic longitude of the ascending node in degrees, measured from the Prime Meridian. The Prime Meridian is the line longitude at which longitude is 0 degrees.

If `ANOPT = LONGSAT`, then `ANVAL` is the longitude of the spacecraft in degrees at the time specified in fields `SV1-SV6` of the ORBDEF3 Card. This option is valid only if `SOLOPT = GMT` on the ORBDEF3 Card.

`ANVAL` is the ascending node value corresponding to the `ANOPT` option.

ORBDEF4

`ID BETA BETAOPT ALRADVAL BETAANGLE` (beta angle orbit option), or

FIELD	VALUE	DESCRIPTION
`ORBDEF4`	`ORBDEF4` or `44`	mnemonic
`ID`	integer	ID number
`ORBTYPE`	`BETA`	Orbit beta angle mnemonic
`BETAOPT`	`ALT`	Orbit altitude mnemonic
	`RADIUS`	Orbit radius mnemonic
`ALRADVAL`	real	Betaopt value
`BETAANGLE`	real	Beta angle (orbit inclination in degrees)

`BETAOPT` is the flag specifying the nature of `ALRADVAL`.

`ALRADVAL` is the altitude or radius value corresponding to `BETAOPT`.

`BETAANGLE` is the beta angle value in degrees. The beta angle is the minimum angle between the orbit plane and the sun vector.

`BETAANGLE` must be between `-90` and `+90` degrees.

`BETAANGLE > 0` occurs when the spacecraft travels in the counterclockwise direction in its orbit when viewed from the sun, and `BETAANGLE < 0` occurs when it travels in the clockwise direction.

ORBDEF4: geosynchronous orbits option

`ID GEOSYNC LONGVALUE`

FIELD	VALUE	DESCRIPTION
`ORBDEF4`	`ORBDEF4` or `44`	mnemonic
`ID`	integer	ID number
`ORBTYPE`	`GEOSYNC`	Geosynchronous orbit
`LONGVALUE`	real	Longitude value in degrees

`LONGVALUE` is the sub-spacecraft longitude value when `SOLOPT = GMT` on the ORBDEF3 Card. Otherwise it should be 0. The rationale for this is that for the geosynchronous option there is no ascending node value, `LONGVALUE` is used only for the orbital display option.

ORBDEF5: Spacecraft Orientation Parameters

`ID V1X V1Y V1Z V2X V2Y V2Z SATDIR SATLAT RASUN`

FIELD	VALUE	DESCRIPTION
`ORBDEF5`	`ORBDEF5` or `45`	mnemonic
`ID`	Integer	ID number
`V1X`	real	X component of vector1 in the global coordinate system
`V1Y`	real	Y component of vector1 in the global coordinate system
`V1Z`	real	Z component of vector1 in the global coordinate system
`V2X`	real	X component of vector2 in the global coordinate system
`V2Y`	real	Y component of vector2 in the global coordinate system
`V2Z`	real	Z component of vector2 in the global coordinate system
`SATDIR`	1	For `ORBDEF4 ANOPT = LONGSAT`, S/C is ascending at the LONGSAT position
	2	For `ORBDEF4 ANOPT = LONGSAT`, S/C is descending at the LONGSAT position
`SATLAT`	real	S/C latitude (active for `ORBDEF4 ANOPT = LONGSAT`)

`RASUN`	real	Right ascension angle of the sun in degrees

`V1X` is the `X` coordinate of vector1 on `ORBDEF1` in the global coordinate system.

`V1Y` is the `Y` coordinate of vector1 on `ORBDEF1` in the global coordinate system.

`V1Z` is the Z coordinate of vector1 on `ORBDEF1` in the global coordinate system.

`V2X` is the X coordinate of vector2 on `ORBDEF1` in the global coordinate system.

`V2Y` is the Y coordinate of vector2 on `ORBDEF1` in the global coordinate system.

`V2Z` is the Z coordinate of vector2 on `ORBDEF1` in the global coordinate system.

`SATDIR` is the flag specifying whether the spacecraft is ascending or descending when `ORBDEF4 ANOPT = LONGSAT`. Otherwise it should be 0.

`SATLAT` is the spacecraft latitude in degrees if `ORBDEF4 ANOPT = LONGSAT`. Otherwise it should be 0.

`RASUN` is the sun right ascension angle value in degrees if `ORBDEF3 SOLOPT = SUNDECL` for planets other than Earth `(ORBDEF1 PNAME = EARTH)`. Otherwise it should be 0.

The sun right ascension angle is the angle measured eastward from the Vernal equinox axis in the planet's equatorial plane to the projection of the sun vector onto the equatorial plane.

The vernal equinox is the time when the apparent position of the sun crosses the equator moving from south to north. The vernal equinox axis is a line from the Earth's center to the point where the sun crosses the equator moving from South to North.

ORBDEF6 : Full or Partial Orbit Parameters

`ID SEGTYPE STARTPOS STARTANGLE TIMEI ENDANGLE NINT`

FIELD	VALUE	DESCRIPTION
`ORBDEF6`	`ORBDEF6` or `46`	mnemonic
`ID`	Integer	ID number
`SEGTYPE`	`FULL`	Full orbit
	`PARTIAL`	Partial orbit
`STARTPOS`	`AN`	S/C starting position is defined w/rt ascending node
	`DN`	S/C starting position is defined w/rt descending node
	`LN`	S/C starting position is defined w/rt local noon
	`LM`	S/C starting position is defined w/rt local midnight
	`PE`	S/C starting position is defined w/rt perigee
	`AP`	S/C starting position is defined w/rt apogee
`STARTANGLE`	Real	S/C starting angle w/rt the starting position

`TIMEI`	Real	Initial computational time
`ENDANGLE`	Real	S/C end angle w/rt starting position
`NINT`	Integer	Number of orbital position or negative of table number value

`SEGTYPE` is the flag specifying whether the orbit is full or partial.

`STARTPOS` is the flag specifying the position from which the start angle (and end angle for a partial orbit) is referenced.

Refer to the diagram in Card 6l – Additional Orbital Parameters ORBADD Card – Optional for the illustration of the PE option.

For ORBDEF4 Card GEO option, only the `LN` and `LM` options are valid.

`STARTANGLE` is the angle in degrees of the start position from the reference point defined in STARTPOS. The angle is measured in the orbit plane and is positive in the direction of motion of the spacecraft.

`TIMEI` is the analysis time associated with the start angle of partial orbits. For full orbits it should be 0.

`ENDANGLE` is the angle in degrees of the end position from the reference point defined in STARTPOS for partial orbits. The angle is measured in the orbit plane and is positive in the direction of motion of the spacecraft. For full orbits it should be 0.

`NINT` is the number of equal angular intervals at which the orbital fluxes will be calculated.

If the angle positions are specified in a table, then:

- `NINT` must be `< 0` , and then the abs(`NINT`) is a table number defined in Card 9 TABTYPE and TABDATA Cards containing the angular positions.

- On the TABTYPE Card, the dependent variable must be `ROTAT`, and the independent variable must be `TIME`. On the TABDATA Cards the dependent variable must be an angle in degrees, while the value of the independent variable is ignored (it does not have to be time).

ORBDEF7:Spacecraft Rotation Parameters

`ID ROTX ROTY ROTZ ROTRATE STARRA STARDECL ROTFLAG`

FIELD	VALUE	DESCRIPTION
`ORBDEF7`	`ORBDEF7` or `47`	Mnemonic
`ID`	integer	ID number
`ROTVX`	real	X component of the rotation vector in S/C coordinate system
`ROTVY`	real	Y component of the rotation vector in S/C coordinate system
`ROTVZ`	real	Z component of the rotation vector in S/C coordinate system
`ROTRATE`	real	Rotation of the S/C per orbit
`STARRA`	real	Star right ascension angle
`STARDECL`	real	Star declination
`ROTFLAG`	0	Constant rate
	Integer	Table number specifying variable rate S/C angular rotation

`ROTVX` is the X component of the spacecraft rotation vector in the global coordinate system. Otherwise it should be 0.

`ROTVY` is the Y component of the spacecraft rotation vector in the global coordinate system. Otherwise it should be 0.

`ROTVZ` is the Z component of the spacecraft rotation vector in the global coordinate system. Otherwise it should be 0.

`ROTRATE` is the rotation in degrees per complete orbit of the spacecraft about the specified axis of rotation. If there is no rotation, it should be 0.

`STARRA` is the star right ascension angle value in degrees if `ORBDEF1 V1OPT = STAR or V2OPT = STAR`. Otherwise it should be 0.

The star right ascension angle is the angle measured eastward from the vernal equinox axis in the planet's equatorial plane to the projection of the star vector onto the equatorial plane.

The vernal equinox is the time when the apparent position of the sun crosses the equator moving from south to north. The vernal equinox axis is a line from the Earth's center to the point where the sun crosses the equator moving from south to north.

`STARDECL` is the star declination in degrees if `ORBDEF1 V1OPT=STAR or V2OPT=STAR`. If not applicable it should be 0.

The star declination angle is an angle in degrees measured from planet's equatorial plane to the star vector. It is positive northward and negative southward and is between -90 and +90 inclusively.

The star vector points to the star.

`ROTFLAG` is the table number if the rotation rate is defined via a rotation vs time table.

The table should be defined with a `ROTAT` vs TIME TABTYPE Card. If no table specified, `ROTFLAG` should be 0.

Card 6u - DIURNAL1-6 Solar Heating Modeling Request Cards – Optional

This set of Cards defines a diurnal solar heating modeling request. Each request consists of six DIURNAL Cards, labeled DIURNAL1 – DIURNAL6.

A diurnal heating request calculates solar and other heat flux view factors for a model located on a planet's surface.

```
DIURNAL1 ID SHADOPT PNAME V1OPT V2OPT FRONTGRP REVGRP
DIURNAL2 ID V1X V1Y V1Z V2X V2Y V2Z
DIURNAL3 ID LATITUDE SOLOPT VAL1 VAL2
DIURNAL4 ID FLUXOPT VAL1 VAL2 VAL3 VAL4 VAL5
DIURNAL5 ID NINT CALCOPT LOCTIME1 LOCTIME2 LOCTIME3
DIURNAL6 ID STARTOPT FINALOPT TIMEVAL SV1 SV2 SV3 FV1 FV2 FV3
```

All fields are required on all the Cards, except when otherwise specified. If the value in a field is to be ignored and cannot be blank, it must be zero.

`ID` is the request number and is an integer value common to all associated DIURNAL Cards.

DIURNAL1

`ID SHADOPT PNAME V1OPT V2OPT FRONTGRP REVGRP`

FIELD	VALUE	DESCRIPTION
`DIURNAL1`	`DIURNAL1` (or `61`)	Mnemonic.
`ID`	Integer	Request ID number.
`SHADOPT`	`S1`	Calculations are done with shadowing for requested elements.
	`N1`	Calculations are done without shadowing for requested elements.

FIELD	VALUE	DESCRIPTION
	SALL	Calculations are done with shadowing for all elements.
	NALL	Calculations are done without shadowing for all elements
PNAME	MERCURY	Planet is Mercury.
	VENUS	Planet is Venus.
	EARTH	Planet is Earth.
	MARS	Planet is Mars.
	JUPITER	Planet is Jupiter.
	SATURN	Planet is Saturn.
	URANUS	Planet is Uranus.
	NEPTUNE	Planet is Neptune.
	PLUTO	Planet is Pluto.
	MOON	Planet is the Moon.
	GENERIC	Generic planet
V1OPT	SUN	vector1 points towards the Sun.
	NORTH	vector1 points North.

FIELD	VALUE	DESCRIPTION
	SOUTH	vector1 points South.
	EAST	vector1 points East.
	WEST	vector1 points West.
	ZENITH	vector1 points towards the zenith.
	GRAVITY	vector1 points towards the planet center.
V2OPT	SUN	vector2 points approximately towards the Sun.
	NORTH	vector2 points approximately towards North.
	SOUTH	vector2 points approximately towards South.
	EAST	vector2 points approximately towards East.
	WEST	vector2 points approximately towards West.
	ZENITH	vector2 points approximately towards the zenith.
	GRAVITY	vector2 points approximately towards the planet center.
FRONTGRP	Group name or integer	Element ID or group name of front facing elements.
REVGRP	Group name or integer	Element ID or group name of elements whose reverse side is to be included.

`SHADOPT` is the shadowing option to be used for the selected elements.

`PNAME` is the planet name.

For planets other than the Earth, both the sun declination angle and the sun right ascension angle must be specified.

For planets other than Earth, the PNAME field has no effect, and is used for display purposes only.

For Earth, only the sun declination angle needs to be specified.

`V1OPT` is the flag for target1, the target vector1 is aligned with. vector1 is the first of two vectors fixed with respect to the model's global coordinate system needed to specify the orbit.

The model is so oriented that vector1 is locked onto target1.

The components of vector1 are specified on the DIURNAL2 Card.

`V2OPT` is the flag for target2, the target towards which vector2 is aimed. vector2 is the second of two vectors fixed with respect to the global coordinate system.

A plane defined by vector1 and the origin-to-target2 vector is created.

The model is so oriented that vector2 lies in this plane, and the angle between vector2 and the origin-to-target2 vector is minimal.

The components of vector2 are specified on the DIURNAL2 Card.

`FRONTGRP` is the element ID or the group name of the elements for whose front side the fluxes are to be calculated.

Should be blank or 0 if the `SHADOPT` is `NALL` or `SALL`.

This field should be 0 if only a reverse group is selected.

`REVGRP` is the element ID or the group name of the elements for whose reverse sides fluxes are to be calculated.

Should be blank or 0 if the `SHADOPT` is `NALL` or `SALL`.

Should be blank or 0 if no reverse sides are to be included in the orbital flux calculations.

Example

```
DIURNAL1 ID NALL/SALL PNAME V1OPT V2OPT
DIURNAL1 3 S1 EARTH SUN NORTH FRONTARR
DIURNAL1 3 S1 EARTH SUN NORTH 0 REVARR
DIURNAL1 3 SALL EARTH EAST NORTH
```

DIURNAL2

`ID V1X V1Y V1Z V2X V2Y V2Z`

FIELD	VALUE	DESCRIPTION
`DIURNAL2`	`DIURNAL2` (or `62`)	mnemonic.
`ID`	Integer	Request ID number.
`V1X`	Real	X component of vector1 in the global coordinate system.
`V1Y`	Real	Y component of vector1 in the global coordinate system.
`V1Z`	Real	Z component of vector1 in the global coordinate system.
`V2X`	Real	X component of vector2 in the global coordinate system.
`V2Y`	Real	Y component of vector2 in the global coordinate system.
`V2Z`	Real	Z component of vector2 in the global coordinate system.

Example

```
DIURNAL2 3 1.0 1.0 1.0 2.0 3.0 4.0
```

DIURNAL3

```
ID LATITUDE SOLOPT VAL1 VAL2
```

FIELD	VALUE	DESCRIPTION
DIURNAL3	DIURNAL3 (or 63)	Mnemonic
ID	Integer	Request ID number.
LATITUDE	Real	Latitude in degrees.
SOLOPT	SUNDECL	When Planet is set to Earth, VAL1 is the sun's declination in degrees.
	MEQUI	When Planet is set to Earth, time is March equinox.
	JSOL	When Planet is set to Earth, time is June solstice.
	SEQUI	When Planet is set to Earth, time is September equinox.
	DSOL	When Planet is set to Earth, time is December solstice.
	SUNRA	When Planet is set to Earth, VAL1 is solar right ascension angle in degrees.
	DAY	When Planet is set to Earth, VAL1 is the day number for year 1999.

	DATE	When Planet is set to Earth, VAL1 is the day number and VAL2 is the month number for year 1999.
	OTHER	For a planet other than Earth, VAL1 is the sun declination angle and VAL2 is the sun right ascension angle.
VAL1	Integer	Day number for the DAY and DATE values.
	Real	Sun declination angle in degrees for the SUNDECL and OTHER values. Sun right ascension angle in degrees for the SUNRA value.
	0 or blank	For all other SOLOPT values.
VAL2	Integer	Month number for the DATE value.
	Real	Sun right ascension angle in degrees for other planets.
	0 or blank	For all other SOLOPT values.
RPLANET	Real	Planet mean radius.
ALTITUDE	Real	Altitude above ground.

LATITUDE is the latitude angle in degrees of the model's location on the planet.

SOLOPT is the flag for defining the sun's angular position with respect to the planet

For planets other than Earth, use the SOLOPT values.

VAL1 can be:

Day number in the year 1999 if `SOLOPT = DAY`.

Month number in the year 1999 if `SOLOPT = DATE`.

Sun declination in degrees if `SOLOPT = SUNDECL and SOLOPT = OTHER`. The sun's declination is the angle between the solar vector and the equatorial plane, positive northwards.

Solar right ascension angle in degrees if `SOLOPT = SUNRA`.

- The solar right ascension angle is the angle measured eastward in the Earth's equatorial plane, from the vernal equinox axis to the projection of the sun vector, onto the equatorial plane.
- The vernal equinox is the time when the apparent position of the sun crosses the equator moving from south to north. The vernal equinox axis is the line from the Earth's center to the point where the sun crosses the equator moving from south to north.

Must be blank or 0 for all other values.

`VAL2` can be:

Month number in the year 1999 if `SOLOPT = DATE`.

Solar right ascension angle in degrees if `SOLOPT = OTHER`.

Must be blank or 0 for all other values.

Example

```
DIURNAL3 3 44.6 OTHER 48.0 20.0
DIURNAL3 3 44.6 DATE 27 1
DIURNAL3 3 44.6 DAY 27
DIURNAL3 3 44.6 SUNRA 12.5
```

DIURNAL4

`ID FLUXOPT VAL1 VAL2 VAL3 VAL4 VAL5 VAL6`

FIELD	VALUE	DESCRIPTION

DIURNAL4	DIURNAL4 (or 64)	Mnemonic.
ID	Integer	Request ID number.
FLUXOPT	NOATT	No atmospheric attenuation.
	ATT	Atmospheric attenuation occurs and is evaluated with the atmospheric extinction coefficient method.
	TABLE	VAL1 is a solar flux table number.
	TURB	Atmospheric attenuation occurs and is evaluated with the altitude and turbidity method.
VAL1	Real	Apparent solar radiation value if FLUXOPT=ATT, and the solar flux value for FLUXOPT=TURB.
	Integer	Solar flux table number if FLUXOPT = TABLE.
VAL2	Real value	Atmospheric extinction coefficient if FLUXOPT=ATT and turbidity factor for FLUXOPT=TURB. 0 therwise it is unused.
VAL3	Real value	Clearness factor if FLUXOPT=ATT and cleaness index if FLUXOPT=ATT or FLUXOPT=TURB. Otherwise it is unused.
VAL4	Real value	Diffuse sky radiation factor if FLUXOPT=ATT. Otherwise it is unused.
VAL5	Real value	Albedo value if FLUXOPT=ATT or FLUXOPT=TURB. Otherwise it is unused.

VAL6	FACTOR	Controls the overcast conditions method. VAL3 is a cleaness factor.
	INDEX	Controls the overcast conditions method. VAL3 is a cleaness index.
	0 or blank	If FLUXOPT=NOATT or FLUXOPT=TABLE.

FLUXOPT specifies the type of solar flux calculation option.

VAL1 can be:

The value of the solar flux outside the atmosphere if FLUXOPT=NOATT or FLUXOPT=TURB.

The table number of the time-dependent solar flux value defined In Card 9 TABTYPE Card for FLUXOPT=TABLE.

The “apparent solar flux” defined in the ASHRAE Fundamentals Handbook, Edition 1997, pp. 29.17 for F LUXOPT=ATT ,

If a table-dependent solar flux is defined, the dependent parameter in the TABTYPE Card must be QNODE, and the independent parameter must be TIME.

VAL2 is the atmospheric extinction coefficient value if FLUXOPT = ATT. The direct normal irradiation at the Earth’s surface of a plate normal to the sun is defined to be:

$$Irradiation = \frac{VAL1}{e^{\frac{VAL2}{sin(\beta)}}}$$

where β is the angle between the horizon and the sun vector is found in the table of ASHRAE Handbook, HVAC Applications 1995, SI edition, p. 30.2.

VAL2 is the Linke turbidity factor if FLUXOPT = TURB. The direct normal irradiation, at the Earth’s surface of a plate normal to the sun, is defined as:

$$Irradiation = \frac{VAL1}{e^{(0.8662 \cdot VAL2 \cdot m \cdot \delta_R(m))}}$$

where:

- m is the relative optical air mass.
- $\delta_R(m)$ is the Rayleigh optical thickness at air mass m is found in Suri, Marcel, and Jaroslav Hofierk, Transactions in GIS 8.2 ,2004, p. 175-190.

`VAL3` is the clearness factor value if `FLUXOPT = FACTOR`, otherwise it is blank or 0.

The clearness factor is the ratio between the actual clear day direction radiation intensity at a specific location, and the intensity calculated for the standard atmosphere at the same location and date. The refference for cleaness factoris found in ASHRAE Handbook, 1995, HVAC Applications, pp. 30.5. Clearness values `> 1` indicate a very dry and clear sky, for example, a sky at high altitudes. Conversely, Clearness values < `1` indicate very hazy and humid conditions.

`VAL3` is the clearness index value if `FLUXOPT = INDEX`. The clearness index is the ratio of radiation on a horizontal surface to the extraterrestrial radiation. The clearness index is employed to estimate solar radiation under overcast conditions using the Solar Energy Research Institute method is found in Maxwell, E.L. ,1987,Solar Energy Research Institute, United States.

`VAL4` is the diffuse sky radiation factor if FLUXOPT = ATT, otherwise it should be blank or 0.

This is the ratio of the diffuse solar flux originating from the sky incident upon a horizontal plate to the direct attenuated solar flux incident upon a plate normal to the sun vector. (cf table 1 ASHRAE Handbook, 1995, HVAC Applications, p30.2)

`VAL5` is the albedo value if `FLUXOPT = ATT or TURB`, otherwise, it is blank or 0.

Albedo is the fraction of the solar radiation reflected from the nearby ground.

`VAL6` specifies the type of clearness values that are defined for VAL3.

Example

```
DIURNAL4 3 ATT 1.188116E+03  1.559929E-01 1.000000E+00  7.115684E-02  3.060000E-01
FACTOR
DIURNAL4 3 NOATT 1100.0
```

```
DIURNAL4 3 TABLE 10
```

DIURNAL5

`ID NINT CALCOPT LOCTIME1 LOCTIME2 LOCTIME3`

FIELD	VALUE	DESCRIPTION
`DIURNAL5`	`DIURNAL5` (or `65`)	Mnemonic.
`ID`	Integer	Request ID number.
`NINT`	Integer	Number of calculation if `CALCOPT = TIME`.
	`1`	For `CALCOPT = CTE`.
`CALCOPT`	`CTE`	The diurnal flux is calculated for a single position defined in fields `LOCTIME1-3` as the local solar time.
	`TIME`	Multiple calculation positions are required as defined with the DIURNAL6 cards are present.
`LOCTIME1`	Integer	Hour of the local solar time position. Valid only if `CALCOPT=CTE` and the planet is Earth.
	Real	Angle in degrees along a constant latitude plane, measured from local midnight, in the direction of planet's rotation. Valid only if CALCOPT=CTE and the planet is not Earth.
`LOCTIME2`	Integer	Minutes of the local solar time position. Valid only if `CALCOPT=CTE` and the planet is Earth.
`LOCTIME3`	Integer	Seconds of the local solar time position. Valid only if `CALCOPT=CTE` and the planet is Earth

`NINT` is the number of calculation intervals in the diurnal heating request for `CALCOPT = TIME`. If C`ALCOPT = CTE`, then `NINT` should be 1.

`CALCOPT` is the calculation option, either CTE (constant time) or TIME.

If `CALCOPT = CTE`, the `LOCTIME1`, `LOCTIME2` and `LOCTIME3` fields define the local solar time position. For this option, the DIURNAL6 Card is not needed.

If `CALCOPT = TIME`, a Card6 DIURNAL6 is necessary to define additional diurnal heating request parameters.

`LOCTIME1` is the hours of local solar time if the planet is Earth. Used only for `CALCOPT = CTE`.

Local solar time is the time elapsed since local midnight.

If the planet is not Earth, LOCTIME is the angular position in degrees measured from local midnight in the direction of the planet's rotation at constant latitude. Used only for `CALCOPT = CTE` option.

`LOCTIME2` is the minutes of the local solar time if the planet is Earth. Used only for `CALCOPT = CTE`.

`LOCTIME3` is the seconds of the local solar time if the planet is Earth. Used only for `CALCOPT = CTE`.

Example

```
DIURNAL5 3 1 CTE 11 23 45
DIURNAL5 3 12 TIME
```

DIURNAL6

`ID STARTOPT FINALOPT TIMEVAL SV1 SV2 SV3 FV1 FV2`

FIELD	VALUE	DESCRIPTION
`DIURNAL6`	`DIURNAL6` (or `66`)	Mnemonic
`ID`	Integer	Request ID number.
`STARTOPT`	`LSTIME`	Fields SV1-3 define the start of the diurnal heating request.
	`SUNRISE`	The diurnal start position is at sunrise.
	`ANGLE`	The diurnal start position is at SV1 degrees from local midnight.
	`Blank`	A complete day is simulated and all subsequent fields must be blank.
`FINALOPT`	`LSTIME`	Fields FV1-3 define the final position of the diurnal heating request.
	`SUNSET`	The diurnal heating end position is at sunset.
	`ANGLE`	The diurnal heating end position is at FV1 degrees from local midnight.
`TIMEVAL`	Real	Time value at the diurnal heating start position.
`SV1`	Integer	Hour value of the local solar time at start of diurnal heating request. `STARTOPT = LSTIME` only.
	Real	Start position in degrees from local midnight. `STARTOPT = ANGLE` only.
`SV2`	Integer	Minute value of the local solar time at the start position. `STARTOPT = LSTIME` only.

SV3	Integer	Second value of the local solar time at start position. STARTOPT = LSTIME only.
FV1	Integer	Hour value of the local solar time at the end position. FINALOPT = LSTIME only.
	Real	End position in degrees from local midnight. FINALOPT = ANGLE only.
FV2	Integer	Minute value of the local solar time at the end position. FINALOPT = LSTIME only.
FV3	Integer	Second value of the local solar time at the position. FINALOPT = LSTIME only.

STARTOPT specifies whether the starting position of the diurnal heating request is defined in terms of local solar time, at sunrise, or in degrees from local midnight.

- If STARTOPT = LSTIME, then the fields SV1-SV3 define the starting position of the diurnal heating request in terms of local solar time.
- If STARTOP = SUNRISE, the start position is at the sunrise.
- If STARTOPT = ANGLE, then SV1 is the angle in degrees from local midnight to the start position. This angle is measured in the direction of the planet's rotation at constant latitude.
- If a complete day is simulated, then this field and the rest of the fields should be blank.

FINALOPT specifies whether the final position of the diurnal heating request is defined in terms of local solar time, at sunset, or in degrees from local midnight.

If FINALOPT = LSTIME, then the fields FV1-FV3 define the final position of the diurnal heating request in terms of local solar time.

If FINALOPT = SUNSET, the diurnal heating request ends at sunset.

If FINALOPT = ANGLE, then FV1 is the angle in degrees from local midnight to the end position of the diurnal heating request. This angle is positive when measured in the direction of the planet's rotation at constant latitude.

`TIMEVAL` is the time value at the start position.

`SV1`

If `STARTOPT = LSTIME`, then `SV1` is the hour value of the local solar time at the start position.

If `STARTOPT = ANGLE`, then `SV1` is the angle in degrees from local midnight to the starting position. This angle is positive when measured in the direction of the planet's rotation at constant latitude.

`SV2` is the minute value of local solar time at the start position for `STARTOPT = LSTIME`. Otherwise, it should be zero or blank.

`SV3` is the seconds value of local solar time at the start position for `STARTOPT = LSTIME`. Otherwise, it should be zero or blank.

`FV1`

If `FINALOPT = LSTIME`, then `FV1` is the hours value of the local solar time at the end position.

If `FINALOPT = ANGLE`, then `FV1` is the angle in degrees from local midnight to the end of the diurnal heating request. This angle is positive when measured in the direction of the planet's rotation at constant latitude.

`FV2` is the minutes value of local solar time at the end position for `STARTOPT = LSTIME`. Otherwise, it should be zero or blank.

`FV3` is the seconds value of local solar time at the end position for `STARTOPT = LSTIME`. Otherwise, it should be zero or blank.

Example

```
$ For FULL DAY:
DIURNAL6 3
$ For PARTIAL DAY:
DIURNAL6 3 LSTIME LSTIME 0.0 0 0 0 12 0 0
DIURNAL6 3 LSTIME SUNSET 3600.0 1 0 0
DIURNAL6 3 LSTIME ANGLE 0.0 1 0 0 45.0
DIURNAL6 3 SUNRISE LSTIME 0.0 0 0 0 12 0 0
DIURNAL6 3 SUNRISE SUNSET 0.0
DIURNAL6 3 SUNRISE ANGLE 0.0 0 0 0 90.0
DIURNAL6 3 ANGLE LSTIME 0.0 30.0 0 0 12 0 0
DIURNAL6 3 ANGLE SUNSET 0.0 0.0
DIURNAL6 3 ANGLE ANGLE 0.0 10.0 0
```

Card 6v - Hemicube View Factor Method Activation Card - Optional

This Card toggles the use of the hemicube method to calculate view factor requests.

If toggled `ON`, the HEMIVIEW module calculates view factor requests which follow this Card. If toggled OFF, view factors are calculated using the VUFAC module.

To use the HEMIVIEW module, you must have a graphics card and operating system which supports the OpenGL graphics library, and you must have an active graphics display.

During activation of the HEMIVIEW module, a small graphics window will appear which on your display, which is used to calculate the view factors.

`L, TOGGLE, WINSIZE, OPTION`

`L` = `HEMI (or 35)`

`TOGGLE`

= `ON` (or `4`)

- all following VFS12, VFSALL, VFS1ALL, VFSENC Cards will be processed using the HEMIVIEW module.

= `OFF` (or `5`)

- all following VFS12, VFSALL, VFS1ALL, VFSENC Cards will be processed using the VUFAC module

---

`WINSIZE` is the window size in pixels along each side of the square graphics window used by the hemicube method. More pixels yield greater accuracy, but result in increased computation time. The default and recommended value is 128.

`OPTION` specifies the hemicube/analytical method hybrid option. Currently, only `OPTION=1` is supported.

= `1` performs only pure hemicube calculations

Card 6 - View Factor, Solar View Factor, Earth, Orbit, and Convective Conductance Request Cards – Optional

Card 6 data consists of requests for the VUFAC module to calculate thermal couplings, or geometrical radiation parameters, which may be view factors, solar view factors, Earth view factors, or albedo factors. To run VUFAC, on Card 2a `M = 2` must be specified.

For an element to be recognized by the VUFAC module it must be a SURFACE or a hydraulic element. If an element is referenced on a Card 9 PARAM NORAD Card, it will not take part in radiation calculations, but will be recognized for thermal coupling calculations.

If duplicate radiation parameters are written on file VUFF because of sequential runs, only the last ones will be considered valid. However, all the duplicated thermal couplings written on file MODLF are considered to be valid.

Card 6w - Monte Carlo Method Activation Card - Optional

This card toggles the use of the Monte Carlo method to calculate view factor requests, radiative heating requests, orbital heating, and diurnal heating requests.

If toggled ON, the VUFAC module uses the Monte Carlo method to calculate view factor requests, radiative heating requests, orbital heating and diurnal heating requests which follow this Card. If toggled OFF, these view factors are calculated using the deterministic subdivision method.

The Monte Carlo method can calculate view factors, orbital view factors, heat flux view factors, radiative couplings, or heat loads. It does so by sampling rays in random directions and following the ray paths to their termination.

`L` , `TOGGLE` , `NRAYS` , `RAY_OPTION,` `VFTYPE` , `SEED` , `ERR` , `CL`

`L` = `MONTECARLO`

`TOGGLE`

= `ON` : all following Card 6 VFS12, VFSALL, VFS1ALL, VFSENC, SOURCExxx, DIURNALx, ORBIT, ORBDEFx, EARTHx, and SOLxxx cards will be processed by the VUFAC module using the Monte Carlo method.

= `OFF` : all following cards will be processed with the VUFAC module using the standard deterministic subdivision method.

The Monte Carlo method will not be active until it is toggled back on again.

`NRAYS` = number of rays to be launched.

Depending on the `RAY_OPTION` flag, the number of rays to be launched to or from an element will be either `NRAYS` (absolute) or `NRAYS` per unit area. For view factor requests and radiative source requests, `NRAYS` specifies the number of rays launched from each element. For environmental heating requests (solar, earth, orbit, or diurnal heating requests), `NRAYS` specifies the number of rays launched to each element.

`RAY_OPTION`

= `AREA` : `NRAYS` rays per unit area are launched from or (in the case of environmental heating requests) to the element.

= `ABSOLUTE` : `NRAYS` rays are launched per element.

= `ERROR` : The ray density control is based on error criterion, i.e. more rays are launched until the specified error criterion `ERR` is satisfied to within a confidence level **CL** percentage.

`VFTYPE`

= `VF` :View factors will be computed with the Monte Carlo method. This includes blackbody view factors, ray-traced view factors, heat flux view factors, earth, albedo, and solar view factors, provided those requests follow this card.

= `HTFRAD` : Radiative couplings and heat loads will be computed with the Monte Carlo method. View factor requests result in the direct computation of radiative couplings. Heat flux view factor requests and environmental heating requests result in the direct computation of radiative heat loads.

`SEED:` This value sets the pseudo-random number generator seed for the following Monte Carlo request. The seed is the first in number in a unique sequence of pseudo-random numbers, so re-using the same seed will yield identical results between runs (assuming identical TMG versions are run). The seed can be modified to study convergence of the Monte Carlo results. If the seed value is not entered, a default of zero is used.

`ERR`

If `RAY_OPTION` = `ERROR` , then `ERR` is the error criterion value.

`CL`

If `RAY_OPTION` = `ERROR` , then `CL` is the confidence level value expressed in percentage.

Notes

When the Monte Carlo option is active, ray tracing is automatically performed to all specular, diffuse, and transparent elements.

When `VFTYPE` = `HTFRAD` , and view factors are requested with Card 6a VF type Cards, then radiative couplings are computed directly from the Monte Carlo ray tracing technique by the VUFAC module. This results in a radiative conductance matrix similar to that generated by using Gebhardt's method from view factor data.

When `VFTYPE` = `HTFRAD` , and heat flux view factors are requested with SOURCE or ORB type Cards, radiative heat loads are computed directly from the Monte Carlo ray tracing technique by the VUFAC module, and written as HTF cards into MODLF.

It is possible to mix methods, e.g. to compute radiative couplings of some radiative enclosures with the HTFRAD option, and then to the Monte Carlo method `OFF`, and to compute black body view factors for other enclosures. If you have selected the Oppenheim method, TMG will automatically use the Oppenheim method only for the enclosures for which black body view factors have been calculated.
The default maximum number of rays cast per element is 20,000. This can be modified with the advanced Card 9 option `GPARAM 4 305 NMAX`.
The Monte Carlo method makes use of a pseudo-random number generator. To modify the seed value for the random number generator, use the advanced option `GPARAM 4 294 N`.

Example

```
The following is a TMG model with two different enclosure type view factor requests:
$
$ 1 - BUS_ENCLOSURE
$
MONTECARLO ON 10000 ABSOLUTE VF
VFSENC BUS_ENC 0
MONTECARLO OFF
$
$ 2 - MIDDLE_ENCLOSURE
$
MESH ERROR 9.000000E-01
VFSENC MIDDLE_ 0
$
```

The first TMG radiation request is an enclosure request which computes black body view factors between the elements in group “`BUS_ENC”`. It computes the black body view factors using the Monte Carlo ray tracing method, by casting 10,000 rays randomly from each element in the enclosure.

The second TMG radiation request is an enclosure request which computes black body view factors between the elements of group “`MIDDLE_”`. It does not use the Monte Carlo method, rather, TMG’s standard deterministic subdivision method is used.

Card 6 - GPU Radiation Activation Card - Optional

This card activates the graphics processing unit (GPU) to calculate radiation requests using the VFRTGPU module.

To use the VFRTGPU module, you must have an NVIDIA graphics card. NVIDIA GPUs with the Kepler microarchitecture or later are supported. However, Pascal microarchitecture version or later graphics card are recommended.

`L` = `VFRTGPU (` or `35)`

`TOGGLE`

= `ON (` or `4)`

- VFS12, VFSALL, VFS1ALL, VFSENC Cards are processed to calculate view factor requests using the VFRTGPU module. For more information see, Card 6a - View Factor Request Cards – Optional.

= `OFF (` or `5)`

- View factors are not calculated.

`VFTYPE`

= `0` : Black body view factors are computed using the Monte Carlo method.

= `1` : Radiative conductances are computed using the ray-tracing Monte Carlo method.

`NRAYS` = Specifies the number of rays that are launched from an element.

Example

```
$ Radiation(1)
MESH RESET
VFRTGPU ON 0 666
VFS12 "Radiation(1) - Region Radiating from Top Side" "Radiation(1) - Region Radiating
from Top Side" 0 0 0 SPACE
VFRTGPU OFF
```

Card 6x - Thermal Coupling Rotational Periodicity Card - Optional

This Card specifies that thermal couplings should be rotationally periodic. This means that an average angle is computed between the primary and secondary group of the thermal coupling, about the specified axis of rotation. The secondary group is rotated back by that angle before thermal couplings are calculated.

`L` , `TOGGLE` , `XO` , `YO` , `ZO` , `XDIR` , `YDIR` , `ZDIR`

`L` = `ROTATE` (or `67`)

`TOGGLE`

= `ON` (or `4`): all subsequent thermal couplings will be treated as rotationally periodic.

= `OFF` (or `5`): all subsequent thermal couplings will be treated normally.

`XO` , `YO` , `ZO` specifies the start location of the axis vector.

`XDIR` , `YDIR` , `ZDIR` specifies the direction of the axis vector.

Example

```
$ GROUP2 is to be rotated about the z axis by the average angle between GROUP1 and
$ GROUP2 before the thermal coupling is calculated.
ROTATE ON 0.0 0.0 0.0 0.0 0.0 1.0
AREA GROUP1 0 0 GROUP2 0 1.000000E+02 NEARA
ROTATE OFF
```

Card 7 - Element Merging and Renumbering Cards

`M, NN2, NN3, NN4,...`	Option 1 element list maximum 13 elements per Card
`NAME1, NAME2`	Option 2 maximum 2 group names

`NAME1`	Option 3 single group name
`NM, NAME2`	Option 4 element + group name
`NAME1, NN2`	Option 5 group name + element
`GENER, N1S, INC1, N1N, INC2, N2N`	Option 6 element generation

Element merging/renumbering by the MEREL module consists of assigning one or more elements the element number of the starting element and automatically combining their conductances, capacitances, and heat loads. The resulting temperature will be the average of the merged elements.

Element merging should be used only if the elements are closely coupled, or are expected to have similar temperatures.

Element merging can reduce solution time by reducing the size of the model, and by eliminating high conductances that cause ill–conditioning.

Notes

- For Option 1 elements `NN2` , `NN3` , `NN4,..` are merged into element `NM` .
- For Options 2, `NAME1` and `NAME2` are group names and `NM` and `NN2` are element numbers. `NAME1` may not start with the letter C.
- For Options 2, 3, and 5 the elements of `NAME1` and `NAME2` are merged with the starting element of `NAME1` . The starting element is the first element defined on the Card 9 group name NAME Card, or, for Simcenter 3D models, the lowest element number defined.
- For Option 4 all the elements are merged into element `NM` .
- Option 6 generates N2N Option 1 format Cards, each with `N1N` elements:

  ```
  $
  N1S, N1S+INC1,....N1S+(N1N-1)INC1
  N1S+INC2, N1S+INC2+INC1,...N1S+INC2+(N1N-1)INC1
  N1S+(N2N-1)INC2,N1S+INC1+(N2N-1)INC2,..N1S+(N1N-1)INC1+(N2N-1)INC2
  $
  ```

  `INC1` is the element number increment between the elements on the same line (between elements to be merged).
  `N1N` is the number of elements in each line (maximum 13).

`INC2` is the element number increment between the generated Cards (increment between elements to be merged to).

`N2N` is the number of Cards generated.

- Elements may be merged to the nearest physical element with Card 6e NEARM option.
- Elements connected with a conductance value `> 1.0E10` are automatically merged.
- The elements created by the Card 5d Space Element Card, and the reverse elements created with the Card 9 REVNODE Card are automatically merged.
- The temperatures of the merged elements are recovered by the automatic creation of follower conductances. During the Analyzer run, the merged elements become SINK elements. This option may be disabled with the Card 9 PARAM NOMRECOV Card.
- Hydraulic elements and Card 9 MCV elements may not be merged into other elements. However, other elements may be merged into them.
- If elements with temperature-dependent specific heats or capacitances are merged, it is important to ensure that they all reference the same specific heat table.

Example

```
10, 4, 5
$ ELEMENTS 4 AND 5 MERGED INTO ELEMENT 10
GENER, 201, 1, 3, 10, 3
$ ELEMENTS 202 AND 203 MERGED INTO 201
$ ELEMENTS 212 AND 213 MERGED INTO 211
$ ELEMENTS 222 AND 223 MERGED INTO 221

BOX1,BOX2
$ ELEMS ASSOCIATED WITH CARD 9 NAMES BOX1
$ AND BOX2 ARE MERGED INTO THE STARTING
$ ELEMENT OF BOX1
```

Card 8 - Element Elimination Cards – Optional

`NE1, NE2, ...`	Option 1 - list of elements
`NAME1`	Option 2 - group name

`GENER, N1S, INC1, N1N, INC2, N2N`	Option 3 - element generation

Element elimination by the MEREL module consists of the creation through substructuring a smaller but equivalent conductance–capacitance thermal model. For more information, see Card 9 - PARAM Parameter Card - Optional.

Notes

Option 1 eliminates the elements `NE1`, `NE2`, ... from the model. The maximum number of elements per Card is 13.

Option 2 eliminates elements of `NAME1`. `NAME1` may not start with the letter C.

Option 3 generates `N2N` Element Elimination Cards, each containing N1N elements. The format is identical to the one described on Card 7.

Example

```
1,5,8,10   $
ELEMENTS 1,5,8, AND 10 ARE ELIMINATED FROM THE MODEL.
```

Card 9 - ADDREMOVE Additional or Removal Criteria Definition Card

KODE, N1, T1, T2

`KODE` = `ADDREMOVE` (or `120`)

`N1` is the element number or group name to which additional or removal criteria is applied.

`T1` may be:

= `NAME` (or `1`)

= `SELECTION` (or `2`)

= `CRITERION` (or `3`)

= `ADDITION_CRITERION` (or `4`)

= `ADDITION_DELTA_TYPE` (or `5`)

= `ADDITION_DELTA_TIME` (or `6`)

= `REMOVAL_CRITERION` (or `7`)

= `REMOVAL_DELTA_TYPE` (or `8`)

= `REMOVAL_DELTA_TIME` (or `9`)

`T1` = `NAME` specifies the name of the ADDREMOVE card. `T2` is a name string.

`T1` = `SELECTION` specifies the selection of elements to which the additional or removal criteria is applied. `T2` is a group name or an element number.

`T1` = `CRITERION` specifies the addition time when the solver adds or removes the physical properties of elements. Time is specified in `T2`. Time must be inside the range of solution time.

`T1` = `ADDITION_CRITERION` specifies the value of addition time when the solver adds the physical properties of elements. The value is specified in `T2.`

`T1` = `ADDITION_DELTA_TYPE` specifies the process type of the elements addition.

- `T2` may be `RAMP` or `SPECIFY`.
- `T2 = RAMP`: Specifies a linear addition of the physical properties of the elements until the end of a current solution step.
- `T2 = SPECIFY`: Specifies the period of time which user defined for addition of the physical properties of the elements.

`T1` = `ADDITION_DELTA_TIME` specifies the time interval to add the physical properties of the elements. The value is specified in `T2 .` If the value of delta time is greater than the time remaining in the solution step, then the solver computes the `ADDITION_DELTA_TIME` as the solution step time minus the current time. The solver takes the delta time as the remaining time to the next solution step.

`T1` = `REMOVAL_CRITERION` specifies the value of time when the solver removes the physical properties of elements. The value is specified in `T2`.

`T1` = `REMOVAL_DELTA_TYPE` specifies the process type of the elements removal.

- `T2` may be `RAMP` or `SPECIFY`.
- `T2 = RAMP`: Specifies a linear removal of the physical properties of the elements until the end of a current solution step.
- `T2 = SPECIFY`: Specifies the period of time which user defined for removal of the physical properties of the elements. The time value must be less than the remaining time in the current solution step.

`T1` = `REMOVAL_DELTA_TIME` specifies a time interval to remove the physical properties of the elements. The value is specified in `T2 .`

Notes

Any element selected in an Element Add/Remove simulation object is added or removed as specified in the simulation object. The addition criteria and the removal criteria time can be specified together. The removal time must be greater than the addition time plus the addition delta time. The addition time can be greater than the start time of the solution. This implies that the element is not added from the start of the solution until the addition time.

Example

```
$ Case2
NAME2 Case2 Case2
NAME Case2            8          8          1
ADDREMOVE 2 NAME "Case2"
ADDREMOVE 2 SELECTION "Case2"
ADDREMOVE 2 CRITERION TIME
ADDREMOVE 2 ADDITION_CRITERION  5.000000E+00
ADDREMOVE 2 ADDITION_DELTA_TYPE SPECIFY
ADDREMOVE 2 ADDITION_DELTA_TIME  9.000000E+00
```

Card 9 - ALIGN Align Vector Definition - Optional

KODE, N1, T1, T2, T3

`KODE` = `ALIGN` (or `62`)

`N1` is a joint number (`N1` from a Card 9 JOINT Card).

`T1` is the orbit dependent direction defined on a Card 6t `ORBDEF1` Card (NADIR, SUN, STAR, PVEL, PNORMAL, NORTH or SOUTH) which vector `T2` is aligned with.

`T2` is a vector number (`N1` from Card 9 - VECTOR Vector Definition Card - Optional).

`T3` may be:

- ALL for all defined orbit and modeling requests, or
- An ID number from an ORBDEF Card for single orbit and attitude modeling requests.

Notes

The ALIGN option minimizes the angle between the align vector and the vector to the object being pointed to, while respecting the constraints of the rotational joint. It requires Card 9 ARTICUT, JOINT, VECTOR and Card 6 orbit definition Cards to be present in INPF. An orbit is defined with either Card 6t ORBDEF cards, or Card 6b SOL card and Card 6d EARTH card.

Example

```
$ ALIGN VECTOR 2 WITH NORTH FOR ALL ORBITS
JOINT         1 REVOLUT 0 1
VECTOR        1 0 0 0 -1 0 0
VECTOR        2 0 0 0 0 1 0
ARTICUT       1 SHELLS
```

Card 9 - ARPARAM Articulation Parameters - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `ARPARAM` (or `51`)

`N1` is the parameter type. It can only be `TIME`.

`T1` is the starting time of the articulation movement.

`T2` is the ending time of the articulation movement.

`T3` is the interval of time when calculations of time-dependent view factors and radiative conductances are to be calculated for analysis.

Notes

When an ORBIT card is present in the input file, the articulation parameter card is not considered. The start time, end time and time interval are superseded by the values in the `ORBIT` card.

Example

```
ARPARAM TIME 0 10 0.5
$ ARTICULATION STARTS AT TIME 0, AND ENDS AT TIME 10.
$ TIME DEPENDENT RADIATIVE CONDUCTANCES
$ ARE CALCULATED AT EVERY HALF SECOND
```

Card 9 - ARRAYDATA Array Variable Definition Card - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `ARRAYDATA` (or `54`)

`N1` is the array number. An array cannot have the same number as a table in the model.

`T1` is the value for the first independent variable (`X`)

`T2` is the value for the second independent variable (`Y`)

`T3` is the value for the dependent variable (`Z`)

Notes

This card defines the data points for array `N1` for linear interpolation.
The data must represent a fully populated table, that is if there are n X values and m Y values in the data there must be (m `x` n) ARRAYDATA Cards, for every X value there must be m Y values etc.
Each array must have a single ARRAYTYPE, and one or more ARRAYDATA cards, and may be referenced from MAT Cards or INTERP cards.
When data is required outside of the user supplied range the appropriate extreme data point(s) are used. No extrapolation occurs.
If the dependent variable is angle of incidence then the dependent variable must lie in the range `0` through `90` .
If the dependent variable is direction of incidence then the dependent variable must lie in the range `-180` through `+180` . Data outside of this range will be mapped into it.

Card 9 - ARRAYTYPE Array Variable Definition Card - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `ARRAYTYPE` (or `53`)

`N1` is the array number. An array cannot have the same number as a table in the model.

`T1` is the code for the first independent variable (`X`)

`T2` is the code for the second independent variable (`Y`)

`T3` is the code for the dependent variable (`Z`)

Mnemonic code	Equivalent number code	Description of the code	Dependent variable	Independent variable
`ALBEDO`	`142`	Albedo value	**X**	
`ABSORPTIVITY`	`45`	Solar absorptivity	**X**	
`ANG_INC`	`120`	Angle of incidence of a ray		**X**
`ANG_REF`	`122`	Angle of reflection of ray		**X**

`BRDF`	`46`	Value of the bidirectional reflectance distribution function at `ANG_INC` and `ANG_REF`. Note that the `BRDF` array must be fully populated. `BRDF` are used only in conjunction with the Monte Carlo `HTFRAD` ray tracing option. Input `BRDF` data is normalized by `TMG` so that the integral of the probability density over all angles equals one.	**X**	
`CAP`	`3`	`CAP` is the capacitance of a single element.	**X**	
`COND`	`1`	`COND` is the current conductance **value** (linearized if non-linear) if it is used as the independent variable. `COND` is a conductance multiplier when it is used as the dependent variable. The original conductance value is multiplied by the value interpolated from the table.	**X**	
`CPP`	`2015`	`CPP` is the specific heat at constant pressure at the element. The independent variable must be one of the following: ▪ `TEMP` ▪ `TIME` ▪ `PTOTAL` ▪ Combination of those (if used in a bivariate fluid material). Referenced `CPP` from Card 9 - MAT Material Property Definition Card - Optional.	**X**	
`CURRENT`	`30`	`CURRENT` is a current boundary condition specified for an electrical resistance element.	**X**	

DIR_INC	121	Direction of incidence of a ray		X
DELTAPT	2003	DELTAPT is the total pressure rise if it is referenced as **dependent** variable from a PROP FANPUMP Card. DELTAPT is positive if there is a total pressure rise over the element, and it describes a flow boundary condition. DELTAPT is the total pressure **drop** if it is referenced from a PROP DUCT or PROP FLOWRES Card as the independent variable, positive if there is a total pressure drop over the element.	X	
E	18	E is the emissivity of an element. The independent variable code must be TEMP or TIME or ANG_INC or DIR_INC. Should be referenced from Card 9 - MAT Material Property Definition Card - Optional.	X	
ELECRES	31	ELECRES is the electrical resistivity specified for an electrical resistance element.	X	
FLOWRES	2002	FLOWRES is the hydraulic flow resistance multiplier referenced by a PROP FLOWRES or PROP DUCT Card.	X	
KTHERM	2017	KTHERM is the thermal conductivity of an element. The independent variable element must be the same as the dependent variable element, it should be referenced from Card 9 - MAT Material Property Definition Card - Optional.	X	
LATITUDE	140	Latitude value		X
LONGITUDE	141	Longitude value		X

MASSFL	2005	MASSFL is the mass flow through a 2-node hydraulic element. If referenced from a FANPUMP or STREAM element, it must be the dependent variable and is then a flow boundary condition. If referenced from a PROP DUCT or PROP FLOWRES Card, it must be the independent variable. It is considered positive in the reference forward direction of the element.	X	
MULTIPLIER	84	MULTIPLIER is a multiplier value interpolated from the array.	X	
PABS	2025	PABS is the absolute pressure at a hydraulic element.		X
PIR	143	PIR is the planet IR radiation. It is the emissive power per unit area leaving the surface of the planet.	X	
PTOTAL	2008	PTOTAL is the total pressure at a hydraulic element. If used as the dependent variable, it must be referenced by a PSINK element, and is considered to be a boundary condition.	X	X
QNODE	4	QNODE is the heat load into an element. If it is the independent variable, it is considered to be the total heat load into the element. If it is the dependent variable, it is summed with all other heat loads into the element, and is a boundary condition.	X	
RHOAMB	2012	RHOAMB is the density of the ambient fluid.	X	
RHO	2018	RHO is the density of the element referenced from Card 9 - MAT Material Property Definition Card - Optional.	X	
SPECULAR	83	Solar specular reflectivity of a surface	X	

`TEMP`	`2`	`TEMP` is the temperature of an element. If used as the dependent variable, the element must be a SINK or an AMBIENT element. If used as the independent variable, and the dependent variable is a conductance, the average temperatures of the two ends of the conductance are used as the independent variable.	**X**	**X**
`TIME`	`0`	`TIME` is the time value during a transient run. TIME is considered to be periodic, with a period equal to the (largest-smallest) time value in the table.		**X**
`TPHASE`	`40`	`TPHASE` is the phase change temperature of an element.	**X**	
`TPRIME`	`101`	`TPRIME` is the temperature value of the first element of the conductance. If a Card 6e thermal coupling references a table whose independent variable is `TPRIME`, the independent variable will be the temperature of the `N1` (primary) element		**X**
`TRANSMISS`	`82`	Solar transmissivity of a surface	**X**	

`USER1ARR`
 	
`USER2ARR`
 	
`...`
 	
`USER9ARR`
	`91-99`	`USER1ARR…USER9ARR` are codes for table interpolation to be used with the `CALL USERARRAY` routine in a Card 10 user-written subroutine.		**X**

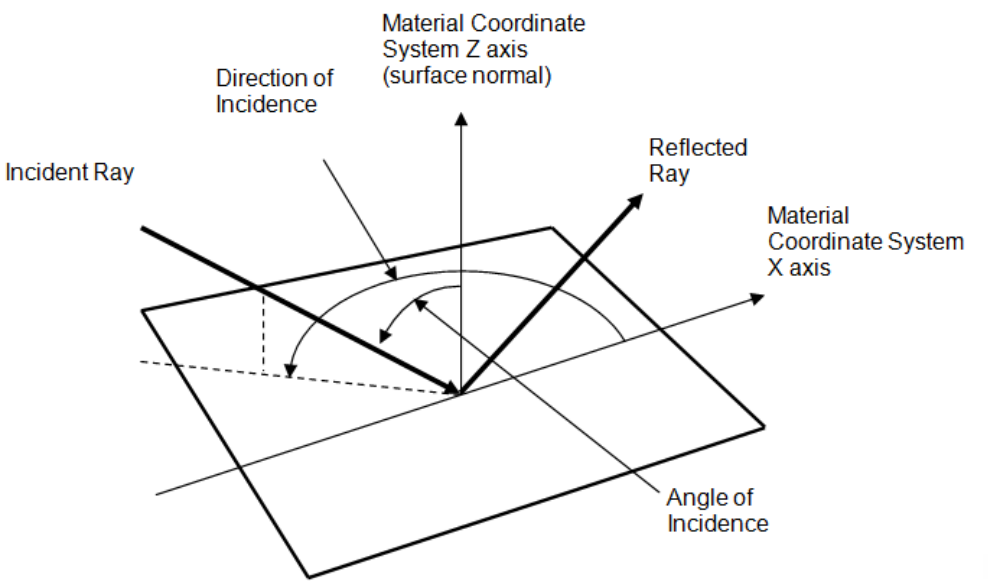
VELOC	2007	VELOC is the flow velocity through the hydraulic element. If referenced from a PROP FANPUMP Card it must be the dependent variable and is a flow boundary condition.	X	
VISC	2016	VISC is fluid viscosity. The independent variable must be one of the following: • TEMP • TIME • PTOTAL • Combination of those (if used in a bivariate fluid material). The table should be referenced from Card 9 - MAT Material Property Definition Card - Optional.	X	
VOLTAGE	29	VOLTAGE is voltage boundary conditions specified for an electrical resistance element.	X	
VOLUME	2004	VOLUME is volume flow through the hydraulic element. If referenced from a PROP FANPUMP Card, it must be the dependent variable and is a flow boundary condition. If referenced from a PROP DUCT or PROP FLOWRES Card, it must be the independent variable. It is considered positive in the referenced forward direction of the 2-node element.	X	
WAVELENGTH	116	WAVELENGTH is the wavelength value at which the spectrum-dependent dependent variable is defined. WAVELENGTH must be defined in microns μ, where 1 μ=1.E-6m.	X	
WAVELENGTHNUMBER	116	WAVELENGTHNUMBER is an integer (1,2,3..) used as the independent variable to define a wavelength-dependent spectrum. The dependent variable must be WAVELENGTH or TEMP.	X	X

Notes

This card describes the nature of the dependent and independent variables for array `N1`

Each array must have a single `ARRAYTYPE` , and one or more `ARRAYDATA` cards, and may be referenced from MAT Cards or INTERP cards.

If the dependent variables are `SPECULAR` or `TRANSMISS` , then the independent variables must be `ANG_INC` or `DIR_INC` . In this case angle-dependent surface properties are defined, and ray-tracing is performed. The material property coordinate system must be defined with MATVEC Cards, and Angle and Direction of incidence are defined in the following figure:



Example

```
$
$ Define angle-dependent specular
$ reflectivity
$
ARRAYTYPE 1 DIR_INC ANG_INC SPECULARITY
$
ARRAYDATA 1 -0.18E+03 0.00E+00 .10E+00
ARRAYDATA 1 -0.18E+03 0.45E+02 .10E+00
ARRAYDATA 1 -0.18E+03 0.60E+02 .10E+00
```

```
ARRAYDATA 1 -0.18E+03 0.90E+02 .10E+00
$
ARRAYDATA 1 -0.10E+02 0.00E+00 .40E+00
ARRAYDATA 1 -0.10E+02 0.45E+02 .40E+00
ARRAYDATA 1 -0.10E+02 0.60E+02 .40E+00
ARRAYDATA 1 -0.10E+02 0.90E+02 .40E+00
$
ARRAYDATA 1  0.00E+00 0.00E+00 .50E+00
ARRAYDATA 1  0.00E+00 0.45E+02 .50E+00
ARRAYDATA 1  0.00E+00 0.60E+02 .50E+00
ARRAYDATA 1  0.00E+00 0.90E+02 .50E+00
$
ARRAYDATA 1  0.10E+02 0.00E+00 .60E+00
ARRAYDATA 1  0.10E+02 0.45E+02 .60E+00
ARRAYDATA 1  0.10E+02 0.60E+02 .60E+00
ARRAYDATA 1  0.10E+02 0.90E+02 .60E+00
$
ARRAYDATA 1  0.18E+03 0.00E+00 .90E+00
ARRAYDATA 1  0.18E+03 0.45E+02 .90E+00
ARRAYDATA 1  0.18E+03 0.60E+02 .90E+00
ARRAYDATA 1  0.18E+03 0.90E+02 .90E+00
$
$ Bidirectional reflectivity example
$
ARRAYTYPE 2 ANG_INC ANG_REF BRDF
ARRAYDATA 2   0.0   0.0  0.8
ARRAYDATA 2   0.0  44.9  0.8
ARRAYDATA 2   0.0  45.0  0.0
ARRAYDATA 2   0.0  90.0  0.0
$
ARRAYDATA 2  44.9   0.0  0.8
ARRAYDATA 2  44.9  44.9  0.8
ARRAYDATA 2  44.9  45.0  0.0
ARRAYDATA 2  44.9  90.0  0.0
$
ARRAYDATA 2  45.0   0.0  0.0
ARRAYDATA 2  45.0  44.9  0.0
ARRAYDATA 2  45.0  45.0  0.8
ARRAYDATA 2  45.0  90.0  0.8
$
ARRAYDATA 2  90.0   0.0  0.0
ARRAYDATA 2  90.0  44.9  0.0
ARRAYDATA 2  90.0  45.0  0.8
ARRAYDATA 2  90.0  90.0  0.8
$
$ Angle-dependent emissivity
$
```

```
ARRAYTYPE 14 ANG_INC DIR_INC E
ARRAYDATA 14  0.000000E+00 -1.800000E+02  5.000000E-01
ARRAYDATA 14  0.000000E+00  1.800000E+02  5.000000E-01
ARRAYDATA 14  4.500000E+01 -1.800000E+02  6.000000E-01
ARRAYDATA 14  4.500000E+01  1.800000E+02  6.000000E-01
ARRAYDATA 14  9.000000E+01 -1.800000E+02  7.000000E-01
ARRAYDATA 14  9.000000E+01  1.800000E+02  7.000000E-01
$
```

Arrays may be used to define bivariate fluid properties, in particular coupled pressure-temperature dependence of :

- Mass density (`RHO`)
- Thermal conductivity (`KTHERM`)
- Specific heat (`CPP`)
- Viscosity (`VISC`)

The following example shows an array that defines a bivariate `CPP:`

Example

```
$ Water bivariate formula example   $
ARRAYTYPE 51 TEMP PTOTAL CPP
ARRAYDATA 51  0.000000E+00  1.000000E+02  4.240000E+09
ARRAYDATA 51  0.000000E+00  5.500000E+02  4.420000E+09
ARRAYDATA 51  0.000000E+00  1.000000E+03  4.600000E+09
ARRAYDATA 51  6.342500E+01  1.000000E+02  4.240000E+09
ARRAYDATA 51  6.342500E+01  5.500000E+02  4.420000E+09
ARRAYDATA 51  6.342500E+01  1.000000E+03  4.600000E+09
```

Card 9 - ARTICUT Articulation Definition - Optional

KODE, N1, T1, T2, T3

`KODE` = `ARTICUT` (or `49`)

`N1` is the joint number.

`T1` is a group name containing the articulating elements.

`T2` is the speed of rotation or translation. If the speed is table-dependent, `T2` should be the mnemonic `Tn` (or the negative number `-n`), where `n` is the table number referencing `TABTYPE` and `TABDATA` Cards.

`T3` is a table multiplier (if `T2` is a table), otherwise it is ignored. If `T2` is not a table, `T3` may be blank.

Notes

The articulation definition is used with a joint definition card 9 `JOINT`. The joint number of the articulation card is associated with the same joint number of the joint definition card.
The group of elements refers to the elements of that joint only and not to the child joints. Refer to Card 9 - JOINT Articulation Joint Definition - Optional.
If `T2` references a table `Tn`, in which the independent variable is `TIME`, then the time values listed in `Tn` are considered additional articulation times.

Example

```
ARTICUT 20 ARTICGRP 5.
JOINT   20 REVOLUTE 0 10
VECTOR  10 0. 0. 0. 0. 0. 1.
$ ELEMENTS IN GROUP ARTICGRP ROTATE AT A SPEED OF 5. DEGREES
$ PER SECOND ABOUT VECTOR NUMBER 10
```

Note

For articulation requests with time dependent articulation parameters, if no movement occurs between two articulation times, the thermal solver does not compute the radiation request at the new time step but uses the results from the previous time step. You can compute the radiation request at each articulation time step even when no movement occurs using the `PARAM ORBRAD` option in the Card 9-PARAM.

Card 9 - AXISYMM Axisymmetric Element Creation Card - Optional

`KODE, N1, T1, T2`

`KODE` = `AXISYMM` (or `31`)

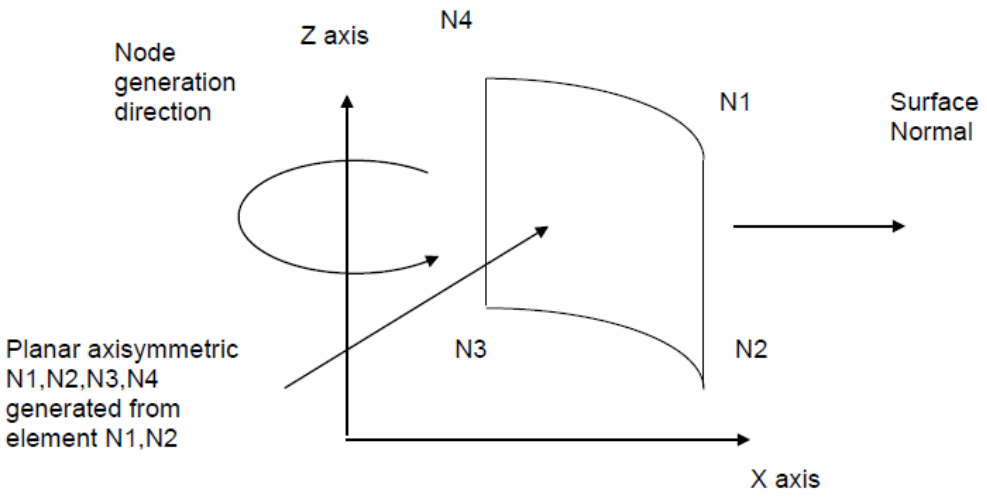
`N1`

If `N1` is a group name, all its elements are axisymmetric.

If `N1` = 0, the axisymmetry is global.

`T1` is the number of axisymmetric elements to be generated for radiation calculations for each axisymmetric element about the axis of revolution. `T1` should be `≥ 8` if radiation calculations are performed, default `= 8.` Axisymmetric elements may have 1 to 4 nodes.

Element Generation Convention for the Default XZ Option



`T2` is a code that defines the axis of revolution and plane in which the elements must lie. `T2` is optional, if it is not present, the `X Z` option is used. The axis of revolution must be one of the global `X`, `Y,` or `Z` axes.

`= XZ` then the elements must be defined on the `+X` side of the `XZ` plane, and the rotation will be counterclockwise about the `Z` axis. This is the default.

`= YZ` then the elements must be defined on the `+Y` side of the `YZ` plane, and the rotation will be counterclockwise about the `Z` axis.

`= XY` then the elements must be defined on the `+X` side of the `XY` plane, and the rotation will be counterclockwise about the `Y` axis.

`= ZY` then the elements must be defined on the `+Z` side of the `ZY` plane, and the rotation will be counterclockwise about the `Y` axis.

`= YX` then the elements must be defined on the `+Y` side of the `YX` plane, and the rotation will be counterclockwise about the `X` axis.

`= ZX` then the elements must be defined on the `+Z` side of the `ZX` plane, and the rotation will be counterclockwise about the `X` axis.

`= X` then the elements and the `X` axis must lie on the same plane, and the rotation will be counterclockwise about the `X` axis.

`= Y` then the elements and the `Y` axis must lie on the same plane, and the rotation will be counterclockwise about the `Y` axis.

`= Z` then the elements and the `Z` axis must lie on the same plane, and the rotation will be counterclockwise about the `Z` axis.

Notes

1. Internal Element Generation for Radiation Calculations
   - For radiation calculations each 1- and 2-node axisymmetric element with an emissivity `≥ 0` generates `T1` internal shell and beam elements in the counterclockwise direction about the axis of revolution. The first generated element is assigned the axisymmetric element number, the others are assigned to unused

element numbers reported in the report log file. A 1-node axisymmetric element generates `T1` beam elements, a 2-node axisymmetric element generates `T1` shell elements. The generated elements are merged with the axisymmetric element once the radiation parameters have been calculated.

- Hydraulic and 3 and 4-node elements are not expanded.
- The Card 5d SPACE Card generates `3*` `T1` very large elements forming a closed cylinder about the origin for radiation calculations.
- The radiative surface properties of the axisymmetric elements are passed to the generated elements.

2. Surface Normals of Axisymmetric Elements

   Care should be taken with radiation calculations that the surface normals point in the correct directions. The direction of the surface normal of an expanded element is determined by the orientation of the nodes of its axisymmetric element with respect to the axis of revolution.

This is done by first identifying the direction vector of the axisymmetric element, which is from node 1 to node 2.

Next, the surface normal vector of the axisymmetric element is computed. This is the cross product (`*`) of the direction vector and the vector normal to the plane. For the default convention, the plane normal is the Y-axis, hence the element surface normal will be the direction vector `*Y` axis. The element surface normal lies in the `XZ` plane, and when it is revolved with the axisymmetric element it defines the orientations of the expanded element surface normals.

Another way of visualizing the surface normal direction of the axisymmetric element is that if the direction vector of the axisymmetric element points in the same direction as the axis vector (i.e. their dot products are positive), and the axisymmetric element lies in the `+XZ` plane, the surface normal points inwards towards the axis. If their dot products are negative (as in diagram), the surface normal points away from the axis If their dot products are zero, then if the direction vector points in the `+X` direction, the surface normal points in the +Z direction, if the direction vector points in the `-X` direction, the surface normal points in the `-Z` direction.

If a 2-node axisymmetric shell elements lies on a solid, the surface normal of its front side will be automatically oriented so that it points out of the solid.

3. Physical Properties of Axisymmetric Elements

   Special considerations apply to the PROP Cards:

   - For 1-node axisymmetric elements PROP BEAM should be specified.
   - For 2-node axisymmetric elements PROP SHELL should be specified.
   - For 3-4 node planar axisymmetric elements no PROP Card should be specified.

4. Additional Considerations

   - Axisymmetric elements are both geometrically and thermally axisymmetric with respect to the axis of revolution, i.e. there can be no tangential thermal gradients.
   - The model's symmetry is used to enhance the efficiency of the radiation calculations. Internally the Card 6 VFSALL/VFNALL Cards are replaced with equivalent `VFS1ALL` and `VFN1ALL` Cards. View factors are calculated only for the axisymmetric elements, the view factors for the expanded elements are generated from symmetry considerations. The view factors of the expanded elements are then merged.
   - If view factor calculations are requested with VFS1ALL or VFN1ALL Cards, the results may be erroneous, unless a VFSALL request is also present.
   - Circular elements may not be specified with XCIRC Cards for an axisymmetric model.

- For conduction , capacitance, and Card 6e AREA Card calculations each axisymmetric element is assumed to have the fully revolved shape about the axis of revolution.
- Elements may be specified to be non-axisymmetric with the Card 9 PARAM NOAXISYM Card.
- If there is more than one AXISYMM card in the model, then the groups `N1` must be exclusive.
- If `N1 = 0` , then all elements that are not part of other AXISYMM cards will be expanded according to the global AXISYMM card.

Example

```
AXISYMM 0 8
$ THE THERMAL MODEL IS GLOBALLY AXISYMMETRIC WITH
$ RESPECT TO THE GLOBAL Z AXIS.
```

Card 9 - CONTROLLER Controller Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE = CONTROLLER` (or `140`) defines a heater or fan controller entity.

`N1` is the `CONTROLLER` card ID.

`T1` is:

`= NAME (or 1)`

`= SENSOR_SELECTION (or 2)`

`= HEATER_SELECTION (or 3)`

`= TYPE (or 4)`

`= HEAT_DISTRIBUTION (or 5)`

`= ACTIVEHEATER (or 6)`

`= SENSOR_METHOD (or 7)`

`= SET_POINT (or 8)`

`= CUT_IN (or 9)`

`= CUT_OFF (or 10)`

`= HEAT_MAGNITUDE (or 11)`

`= GAIN (or 12)`

`= INTEGRAL (or 13)`

`= DERIVATIVE (or 14)`

`= BIAS (or 15)`

`T1 = NAME` specifies the controller name in `T2`.

`T1 = SENSOR_SELECTION` is the element number or group name of the temperature sensor specified in `T2`. If `T2` is a group name, a sensor is placed on all the elements of the group.

`T1 = TYPE` specifies the controller type in `T2`.

- `T2 = HEATER` specifies that controller acts as a thermal load.
- `T2 = THERMOSTAT` specifies the thermostat that controls heat input to the elements of the heater. It functions as a binary switch: activates or deactivates the heater based on the sensor temperature.
- `T2 = ACTIVEHEATER` specifies the active heater controller that controls thermal loads based on parameters you define and the temperature of sensor elements. The heater controller can be proportional or PID.
- `T2 = FAN` specifies the active fan controller for the flow boundary conditions. The controller checks the temperature of the sensor each time step and activates the fan when the temperature rises above the cut-in temperature and deactivates it when the temperature falls below the cut-off temperature.
- `T2 = THERMFANCTRL` specifies the controller that is used in flow boundary conditions as a type `FAN` and a thermal load as `THERMOSTAT` simultaneously.

`T1 = HEATER_SELECTION` is the element number or group name of the thermostat's heater specified in `T2`. If `T2` is a group name, a heater is placed on all the elements of the group. This option is available only for the `HEATER` type.

`T1 = HEAT_DISTRIBUTION` specifies the heat input value in `T2`. This option is available only for the `HEATER` type.

- `T2 = ABSOLUTE` specifies the heat input value `HEAT_MAGNITUDE` in `T3` for each element.
- `T2 = AREA` specifies the heat input value `HEAT_MAGNITUDE*area(HEATER_SELECTION)` for each planar, beam, or lump mass element.
- `T2 = VOLUME` specifies the heat input value `HEAT_MAGNITUDE*volume(HEATER_SELECTION)` for each solid element.
- `T2 = TOTAL` specifies the total heat input `HEAT_MAGNITUDE` for elements or group in `HEATER_SELECTION`.

`T1= HEAT_MAGNITUDE` specifies the heat input value. This option is available only for the `HEATER` type.

- If the magnitude is constant, then its value is specified in `T2`.
- If the magnitude is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn`, for example, `T25` where n is a table number referencing the `TABTYPE` or `FIELDTYPE` cards. The dependent variable on the `TABTYPE` card must be `COND`.
- If the magnitude is computed using an expression, then `T2` is an expression multiplier and `T3` has the form En, for example, `E25` where n is an expression number referencing the `EXPRESSION` card.

`T1 = SENSOR_METHOD` specifies the method in `T2` how the sensor temperature is computed.

- `T2 = AVERAGE` identifies the arithmetic mean of elemental temperatures within the sensor selection.
- `T2 = MIN` identifies the minimum elemental temperature within the sensor selection.
- `T2 = MAX` identifies the maximum elemental temperature within the sensor selection.

`T1 = CUT_IN` is the thermostat's cut-in temperature. This option is available only for `THERMOSTAT` or proportional type of `ACTIVEHEATER`.

`T1 = CUT_OFF` is the thermostat's cut-off temperature. This option is available only for `THERMOSTAT` or proportional type of `ACTIVEHEATER`.

`T1 = ACTIVEHEATER_TYPE` specifies the active heater controller type in T2. This option is available only for `ACTIVERHEATER`.

- `T2 = PROPORTIONAL`: thermostat acts as a proportional controller. The heat input Q to the heaters follows the relationship:

$$Q = 0 \qquad T > CUT\_OFF$$

$$Q = \frac{Q_{HTR}(CUT\_OFF - T)}{CUT\_OFF - CUT\_IN} \qquad CUT\_IN \geq T \geq CUT\_OFF$$

$$Q = Q_{HTR} \qquad T < CUT\_IN$$

  where Q_{HTR} is the heat input to the heaters.

- `T2 = PID`: thermostat acts as PID controller defined as a constant value or time-dependent table. The heat input Q to the heaters is computed as follows:

$$e(t) = SET\_POINT - T$$

$$Q = Q_{HTR}\left(GAIN(e(t)) + INTEGRAL\int_0^t e(t)dt + DERIVATIVE\frac{de(t)}{dt} + BIAS\right) \quad 0 \leq Q \leq QHTR$$

`T1 = GAIN` specifies the gain parameter for the `PID` type.

`T1 = INTEGRAL` specifies the integral constant for the `PID` type.

`T1 = DERIVATIVE` specifies the derivative constant for the `PID` type.

`T1 = BIAS` specifies offset for the `PID` type.

`T1 = SET_POINT` specifies the target temperature only for the `PID` type. This temperature is used to calculate the error e(t)= `SET_POINT` -*T*, where *T* is the temperature of a given element at time t.

Example

```
CONTROLLER 1 NAME Thermostat1
```

```
CONTROLLER 1 SENSOR_SELECTION Thermo1
CONTROLLER 1 TYPE THERMOSTAT
CONTROLLER 1 CUT_IN  4.000000E+01
CONTROLLER 1 CUT_OFF  5.000000E+01
CONTROLLER 1 SENSOR_METHOD AVERAGE
```

Card 9 - CURVE Cards – Optional

`KODE` , `N1` , `T1` , `T2` , `T3`

`KODE` = `CURVE` (or `109`)

`N1` is the CURVE ID that uniquely identifies the curve.

Cards with the same ID reference the same curve.

`T1` may be:

= `NAME` (or `1`)

= `POINTS` (or `2`)

`T1` = `NAME` : The name of the curve is specified in `T2` .

`T1` = `POINTS`

`T2` indicates the starting Card 9 - CURVEPOINT Cards - Optional.

`T3` indicates the ending Card 9 - CURVEPOINT Cards - Optional.

Card 9 - CURVEPOINT Cards - Optional

This card specifies the point used in the CURVE card.

`KODE` , `N1` , `T1`

`KODE` = `CURVEPOINT` (or `108`)

`N1` is the unique `CURVEPOINT ID`

`T1` = `X` `Y` `Z`

- `T2` = numeric value of `X` coordinate
- `T3` = numeric value of `Y` coordinate
- `T4` = numeric value of `Z` coordinate

Card 9 - CYCLIC_SYMMETRY Cyclic Symmetry Definition- Optional

`KODE, N1, T1, T2, T3, T4`

`KODE` = `CYCLIC_SYMMETRY` (or `127`) defines cyclic symmetry rotational periodicity that is created between source and target groups.

`N1` is the `CYCLIC_SYMMETRY` card ID. Cards with the same ID reference the same cyclic symmetry definition.

`T1` may be:

= `NAME` (or `1`)

= `SELECTION_SOURCE` (or `2`)

= `SELECTION_TARGET` (or `3`)

= `SELECTION_SOLID` (or `10`)

= `SELECTION_FLUID` (or `12`)

`= SELECTION_COAT` (or `11`)

`= RADIATION (` or `4)`

= `AXIS (` or `5)`

`= INSTANCES(` or `6)`

`= RESOLUTION(` or `9)`

`= OVERLAP(` or `7)`

`= OVER_DIR(` or `8)`

`T1 = NAME` indicates the name for the cyclic symmetry boundary condition that is specified in `T2`.

`T1 = SELECTION_SOURCE` specifies a selection of cyclic source elements. The selection is represented by the group name in `T2`.

`T1 = SELECTION_TARGET` specifies a selection of cyclic target elements. The selection is represented by the group name in `T2`.

`T1 = SELECTION_SOLID` specifies a selection of cyclic solid polygon body. The selection is represented by the group name in `T2`.

- If `SELECTION_SOLID` is specified then material properties, such as heat capacity and thermal conductivity, are multiplied by the number of instances specified in `INSTANCES`.

`T1 = SELECTION_FLUID` specifies a selection of cyclic fluid polygon body. The selection is represented by the group name in `T2`.

- If `SELECTION_FLUID` is specified then material properties, such as heat capacity and thermal conductivity, are multiplied by the number of instances specified in `INSTANCES`.

`T1 = SELECTION_COAT` specifies a selection of the shell elements on the top of the polygon body. The selection is represented by the group name `T2`.

- If `SELECTION_COAT` is specified then all convective areas that are specified by the `SELECTION_COAT` group are multiplied by number of instances specified in `INSTANCES`.

`T1 = RADIATION` specifies a group of elements that contain defined thermo-optical properties that extended in space about the axis of rotation, specified in `AXIS` by the number of instances specified in `INSTANCES`.

`T1 = AXIS` is the axis of rotation. `T2` may be an integer that represents the ID of a referenced Card 9 VECTOR card, or GLOBAL referencing Card 9 GLOBAL_AXIS card.

`T1 = INSTANCES` specifies the number of instances in `T2`. It represents the number of times the geometry is duplicated around the axis of rotation.

`T1 = RESOLUTION` specifies the coupling resolution option in `T2`, in which `T2` may be `ONETOONE, COARSE, MEDIUM, FINE, VERYFINE,` or `FINEST`.

`T1 = OVERLAP` connects only overlapping elements between the source and target element selections which is activated in `T2.` The `T2` may be `ON` or `OFF`.

`T1 = OVER_DIR` specifies the overlap projection in `T2` if the connect only overlapping elements is `ON`.

- If the direction of the overlap is along the normal of source elements, then `T2 = PRIMARY`.
- If the direction of the overlap is along the normal of target elements, then `T2 = SECONDARY`.

Example

```
CYCLIC_SYMMETRY 1 NAME Cyclic Symmetry-stage1
CYCLIC_SYMMETRY 1 SELECTION_SOURCE Cyclic_
```

```
CYCLIC_SYMMETRY 1 SELECTION_TARGET CyclicS
CYCLIC_SYMMETRY 1 SELECTION_SOLID Cyclicy
CYCLIC_SYMMETRY 1 SELECTION_COAT Cyclicm
CYCLIC_SYMMETRY 1 RADIATION
CYCLIC_SYMMETRY 1 AXIS 2
CYCLIC_SYMMETRY 1 INSTANCES 72
CYCLIC_SYMMETRY 1 RESOLUTION MEDIUM
CYCLIC_SYMMETRY 1 OVERLAP ON
CYCLIC_SYMMETRY 1 OVER_DIR SECONDARY
```

Card 9 - DESCRIP Character String Descriptor Cards - Optional

`KODE1, N1, T1`
`KODE2, N1, T2, T3, T4, T5, T6`
`KODE3, N1, T7, T8, T9, T10, T11, T12, T13`

`KODE1` = `DESCRIP` (or `36`)

`N1` is a descriptor number

`T1` is a character string up to 40 characters long assigned to number `N1`. The string can be accessed from within Card 10 USERF and USER1 user-written subroutines with a `CALL DESCRIP` statement.

`KODE2` = `DESCAD1` (or `55`)

`T2`, `T3` are 8-character descriptor strings, such as `SINK` or `CONSTANT` associated with the DESCRIP Card.

`T4` , `T5` , `T6` are all optional group names associated with the DESCRIP Card.

`KODE3` = `DESCAD2` (or `56`)

`T7, T8, T9, T10, T11, T12,`
`T13` are all optional constants associated with the DESCRIP Card.

Example

```
DESCRIP 46 BOISSY-NUEVO CORRELATION $ THE CHARACTER STRING "BOISSY-NUEVO
$ CORRELATION" IS ASSIGNED THE DESCRIPTOR NUMBER 46.
```

Card 9 - DUCTINOUT Duct Inlet/Outlet Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `DUCTINOUT` (or 131) defines flow parameters on duct nodes to model fluid movement in a duct network.

`N1` is the `DUCTINOUT` card ID. Cards with the same ID reference the same duct inlet/outlet definition.

`T1` may be:

`= NAME (or 1)`

`= SELECTION (or 2)`

`= VELOCITY (or 3)`

`= VOLUMEFLOW (or 4)`

`= MASSFLOW (or 5)`

`= PRESSURERISE (or 6)`

`= STATICPRESSURE (or 7)`

`= TOTALPRESSURE (or 8)`

`= TEMPERATURE (or 9)`

`= EXTTOTALPRESSURE (or 10)`

`T1` = `NAME` indicates the duct inlet or outlet name that is specified in T2.

`T1` = `SELECTION` specifies the duct inlet or outlet 0D elements. The selection is represented by the group name in `T2`.

`T1` = `VELOCITY` specifies a fluid velocity at the duct inlet or outlet.

- If the velocity is constant, then its value is specified in `T2`.
- If the velocity is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing `TABTYPE` or `FIELDTYPE` cards with dependent variable as `VELOC`.
- If the velocity is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing `EXPRESSION` card with dependent variable as `VELOC`.

`T1` = `VOLUMEFLOW` specifies a volume flow rate through the duct inlet or outlet.

- If the volume flow rate is constant, then its value is specified in `T2`.
- If the volume flow rate is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `VOLUME`.
- If the volume flow rate is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card with dependent variable as `VOLUME`.

`T1` = `MASSFLOW` specifies a mass flow through the duct inlet or outlet.

- If the mass flow is constant, then its value is specified in `T2`.
- If the mass flow is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `MASSFL`.
- If the mass flow is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card with dependent variable as `MASSFL`.

`T1 = PRESSURERISE` specifies the change in pressure across the inlet or outlet.

- If the pressure rise is constant, then its value is specified in `T2`.
- If the pressure rise is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `DELTAPT`.
- If the pressure rise is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card with dependent variable as `DELTAPT`.

`T1 = STATICPRESSURE` specifies a static gauge fluid pressure at the duct inlet or outlet.

- If the static pressure is constant, then its value is specified in `T2`.
- If the static pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `PRESSURE`.
- If the static pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card with dependent variable as `PRESSURE`.

`T1 = TOTALPRESSURE` specifies a total gauge fluid pressure at the duct inlet or outlet.

- If the total pressure is constant, then its value is specified in `T2`.
- If the total pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `PRESSURE`.
- If the total pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card with dependent variable as `PRESSURE`.

`T1 = TEMPERATURE` specifies a temperature at the duct inlet or outlet.

- If the temperature is constant, then its value is specified in `T2`.
- If the temperature is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `TEMP`.

- If the temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card with dependent variable as `TEMP`.

`T1` = `EXTTOTALPRESSURE` specifies an external total pressure at the duct inlet or outlet.

- If the external total pressure is constant, then its value is specified in `T2`.
- If the external total pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards with dependent variable as `PRESSURE`.
- If the external total pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card with dependent variable as `PRESSURE`.

Example

```
DUCTINOUT 4 NAME "Velocity (Duct In-Out - Expression)"
DUCTINOUT 4 SELECTION "Velocity"
EXPRESSION 5 VELOC ( 1.0 + ( 0.1 * cos( ( ( ( 360.0 * (time) ) * 5.0 ) / 1.0 ) *
0.0174533 ) ) ) * 1000
DUCTINOUT 4 VELOCITY  1.000000E+00 E5
DUCTINOUT 4 TEMPERATURE  1.000000E+01
```

Card 9 - DUCTLABEL Duct Label Definition - Optional

`KODE, N1, T1, T2`

`KODE = DUCTLABEL` (or `125`) specifies a boundary condition ID for a selection of elements that the solver uses to create output of their flow physical quantities.

`N1` is the boundary condition ID specified in the Duct Label simulation object.

`T1` is:

`= NAME` (or `1`)

`= SELECTION` (or `3`)

`T1 = NAME` specifies the Duct Label simulation object name in `T2`.

`T1 = SELECTION` specifies a selection of 1D fluid elements to which the Duct Label simulation object is applied. The selection is represented by the group name `T2.`

Example

```
$ Duct_Flow_BC(1)
NAME2 Duct_Flow_BC(1) Duct_Flow_BC(1)
NAME Duct_Flow_BC(1)          10          13          1
DUCTLABEL 18 NAME "Duct_Flow_BC(1)"
DUCTLABEL 18 SELECTION "Duct_Flow_BC(1)"
```

Card 9 - EAREAED Area Proportional Edge Conductance - Optional

`KODE, N1, T1, T2, T3, T4, T5, T6, T7`

`KODE` = `EAREAED` (or `46`)

`N1` is an element number.

`T1` is an edge number, as defined in the diagram associated with the Card 9 - FREEFACE Element Free Face Generation Card - Optional. If the area proportional edge conductance is applied to a beam or axisymmetric shell, then `T1` is ignored. If the area proportional edge conductance is applied to a shell or axisymmetric solid, then `T1` is the edge number for which the conductance is applied.

`T2` is `0`.

`T3` is the table number referencing TABTYPE and TABDATA Cards that define the temperature distribution of the reference temperature of the conductance.

`T4` is 0.

`T5` is a length or area proportional nominal convective coefficient or a nominal emissivity for radiative coupling.

For convective coupling, `T5` is the nominal convective coefficient divided by the length of the edge of a beam or shell or the revolved area of the edge of an axisymmetric shell or an axisymmetric solid.

For radiative coupling, `T5` is the nominal emissivity of the beam, shell, axisymmetric shell or axisymmetric solid element.T6

`T6` is the code `CONVASN` for convective coupling or `RADASN` for radiative coupling.

`T7` is the table number referencing `TABTYPE` and `TABDATA` cards that defines the variation of the convective coefficient for the `CONVASN` option, or the variation of emissivity for the `RADASN` option. `T7` is left blank for constant convective coefficient or constant emissivity.

Notes

When an EAREAED card is specified, a coupling is created from the element to a reference temperature described by table `T3`. This table can only be expressed as temperature versus time. For constant reference temperature, only one value must be specified in the table.
For the CONVASN option, the convective coefficient is created by multiplying coefficient `T5` by the length or area of the element and the interpolated value from table `T7` if any. This table can only be expressed as conductance versus temperature.
For the RADASN option, the reference emissivity specified by `T5` is multiplied by the interpolated value from table `T7` if any. This table can only be expressed as conductance versus temperature.

When a convective or radiative coupling is created at an edge of a shell or an axisymmetric solid, a new beam or axisymmetric shell element is created and used to apply the coupling.

Examples

```
EAREAED 10 3 0 15 0 2.5 CONVASN
TABTYPE 15 TEMP TIME
TABDATA 15 20.  0.
$ A CONVECTIVE COUPLING OF 2.5 PER UNIT LENGTH IS APPLIED BETWEEN EDGE 3 OF
$ SHELL ELEMENT 10 AND A.  CONSTANT REFERENCE TEMPERATURE OF 20.
EAREAED 20 0 0 25 0 0.5 RADASN 30
TABTYPE 25 TEMP TIME
TABDATA 25 0.   0.
TABDATA 25 10.  1.
TABTYPE 30 COND TEMP
TABDATA 30 0.8  0.
TABDATA 30 1.0  10.
$ A RADIATIVE COUPLING OF NOMINAL EMISSIVITY OF 0.5 IS APPLIED TO BEAM ELEMENT 20.
$ THE EMISSIVITY VARIES FROM 0.8 TO 1.0 AND IS MULTIPLIED BY THE NOMINAL VALUE.
$ THE REFERENCE TEMPERATURE VARIES FROM 0 TO 10.
```

Card 9 - EAREAFA Area Proportional Face Conductance - Optional

KODE, N1, T1, T2, T3, T4, T5, T6, T7

`KODE` = `EAREAFA` (or `47`)

`N1` is an element number.

`T1` is a face number as defined in the diagram associated with the Card 9 - FREEFACE Element Free Face Generation Card - Optional. If the area proportional face conductance is applied to a shell, then `T1` is ignored. If the area proportional face conductance is applied to a solid, then `T1` is the face number for which the conductance is applied.

`T2` is `0`.

`T3` is the table number referencing TABTYPE and TABDATA cards that defines the temperature distribution of the reference temperature of the conductance.

`T4` is `0`.

`T5` is an area proportional nominal convective coefficient or a nominal emissivity for radiative coupling. For convective coupling, `T5` is the nominal convective coefficient divided by the area of the face of the shell or the solid. For radiative coupling, `T5` is the nominal emissivity of the shell or solid element.

`T6` is the code `CONVASN` for convective coupling or `RADASN` for radiative coupling.

`T7` is the table number referencing TABTYPE and TABDATA cards that defines the variation of the convective coefficient for the `CONVASN` option or the variation of emissivity for the `RADASN` option. `T7` is left blank for constant convective coefficient or constant emissivity.

Notes

When an EAREAFA card is specified, a coupling is created from the element to a reference temperature described by table `T3`. This table can only be expressed as temperature versus time. For constant reference temperature, only one value must be specified in the table.
For the `CONVASN` option, the convective coefficient is created by multiplying coefficient `T5` by the area of the face of element and the interpolated value from table `T7`, if any. This table can only be expressed as conductance versus temperature.
For the `RADASN` option, the reference emissivity specified by `T5` is multiplied by the interpolated value from table `T7`, if any. This table can only be expressed as conductance versus temperature.
When a convective or radiative coupling is created at a face of solid, a new shell element is created on the face and used to apply the coupling.

Examples

```
EAREAFA 10 3 0 15 0 2.5 CONVASN
TABTYPE 15 TEMP TIME
TABDATA 15 20.  0.
$ A CONVECTIVE COUPLING OF 2.5 PER UNIT AREA IS APPLIED
$ BETWEEN FACE 3 OF SOLID ELEMENT 10 AND A CONSTANT
$ REFERENCE TEMPERATURE OF 20.
EAREAFA 20 0 0 25 0 0.5 RADASN 30
TABTYPE 25 TEMP TIME
TABDATA 25 0.   0.
TABDATA 25 10.  1.
TABTYPE 30 COND TEMP
TABDATA 30 0.8  0.
TABDATA 30 1.0  10.
$ A RADIATIVE COUPLING OF NOMINAL EMISSIVITY OF 0.5 IS
$ APPLIED TO SHELL ELEMENT 20. THE EMISSIVITY VARIES
$ FROM 0.8 TO 1.0 AND IS MULTIPLIED BY THE NOMINAL
$ VALUE. THE REFERENCE TEMPERATURE VARIES
$ FROM 0. TO 10.
```

Card 9 - ELEMQED Element Edge Heat Fluxes - Optional

KODE, N1, T1, T2, T3, T4

`KODE` = `ELEMQED` (or `43`)

`N1` is an element number.

`T1` is the element edge number as defined in the diagram associated with the Card 9 - FREEFACE Element Free Face Generation Card - Optional.

If the edge heat flux is applied to a beam or axisymmetric shell, then `T1` is ignored. If the edge heat flux is applied to a shell or axisymmetric solid, then `T1` is the edge number for which the heat flux is applied.

`T2` is the heat flux at the first end of the edge.

`T3` is the heat flux at the last end of the edge.

`T4` is:

- the code `CONSTANT` if the heat flux is not table-dependent.
- a table number referencing TABTYPE and TABDATA cards for table-dependent heat flux.

Notes

For beam and shell elements, heat fluxes `T2` and `T3` are expressed as total heat per length. For axisymmetric shell and axisymmetric solid elements, `T2` and `T3` are expressed as total heat per area where the area is the surface area of the revolved edge. Heat flux cannot be applied to any other element type. The total heat load is given by $\frac{T2+T3}{2}$ multiplied by the length of the edge or the area of the revolved edge. For table-dependent heat flux, this nominal value is multiplied by the value interpolated from the table. When heat flux is applied to an edge of a shell or axisymmetric solid, a new beam of axisymmetric shell is created and the total heat is applied to this element as required.

Examples

```
ELEMQED 10 0 2.5 3.0 CONSTANT
ELEMQED 20 3 0.6 0.7 10
TABTYPE 10 QNODE TEMP
TABDATA 10 100.  0.
TABDATA 10 200.  100.
$ AN AVERAGE HEAT FLUX OF 2.75 IS APPLIED TO BEAM
$ ELEMENT 10 NOMINAL HEAT FLUX OF .65 FOR ELEMENT 20
$ HEAT FLUX IS MULTIPLIED BY INTERPOLATED
$ VALUE. HEAT FLUX VARIES FROM 100 to 200
$ OVER TEMPERATURE RANGE 0 TO 100.
```

Card 9 - ELEMQEL Element Heat Generation - Optional

KODE, N1, T1, T2

`KODE` = `ELEMQEL` (or `42`)

`N1` is an element number.

`T1` is the heat load into `N1`.

`T2` is:

- the code `CONSTANT` for constant heat load, or
- a table number referencing TABTYPE and TABDATA cards for table-dependent heat load.

Notes

For table-dependent heat load, the total heat load into element `N1` is the nominal heat load `T1` multiplied by the value interpolated from table `T2` for table-dependent heat load.

Example:

```
ELEMQEL 10 2.5 CONSTANT
$ AN HEAT LOAD OF 2.5 IS APPLIED TO ELEMENT 10
ELEMQEL 20 .8 10
TABTYPE 10 QNODE TEMP
TABDATA 10 3.10.
TABDATA 10 3.5   100.
$ HEAT LOAD ON ELEMENT 20 VARIES FROM 3. TO 3.5 OVER
$ TEMPERATURE RANGE OF 10 TO 100 AND IS MULTIPLIED BY
$ NOMINAL VALUE OF .8
```

Card 9 - ELEMQFA Element Face Heat Fluxes - Optional

KODE, N1, T1, T2, T3, T4

`KODE` = `ELEMQFA` (or `44`)

`N1` is an element number.

`T1` is the element face number as defined in the diagram associated with the FREEFACE Card. See Card 9 - FREEFACE Element Free Face Generation Card - Optional for more information.

If the face heat flux is applied to a shell element, then `T1` is ignored. If the face heat flux is applied to a solid, then `T1` is the face number for which the heat flux is applied.

`T2` is the shell option. If the heat flux is applied to a face of a shell, then `T2` is `1`. If it is applied to the reverse side of a shell it is 2. If it is applied to a face of a solid, then `T2` is `0`.

`T3` is the face heat flux applied to the element.

`T4` is:

- the code `CONSTANT` if the heat flux is not table-dependent.
- a table number referencing TABTYPE and TABDATA cards for table-dependent heat flux.

Notes

Element face flux can only be applied to shell and solid elements.
The total heat load is given by the heat flux multiplied by the area of the face of the element. For table-dependent heat flux, this nominal value is multiplied by the value interpolated from the table.
When heat flux is applied to a face of a solid, a new shell element is created at that face and the total heat is applied to this element as required.

Example

```
ELEMQFA 10 0 1 3.0 CONSTANT
$ A CONSTANT HEAT FLUX OF 3 IS APPLIED
$ TO SHELL ELEMENT 10
ELEMQFA 20 4 0 2.5 10
```

```
$ NOMINAL HEAT FLUX OF 2.5 ON FACE 4
$ OF SOLID ELEMENT 20.
TABTYPE 10 QNODE TEMP
TABDATA 10 10.   0.
TABDATA 10 20.   10.
$ HEAT FLUX IS MULTIPLIED BY INTERPOLATED VALUE.
$ HEAT FLUX VARIES
FROM 10 to 20 OVER TEMPERATURE
$ RANGE 0 TO 10.
```

Card 9 - ELVARTHICK Element Variable Thickness Data - Optional

`KODE, N1, T1, T2, T3, T4, T5, T5, T6, T7, T8`

`KODE` = `ELVARTHICK` (or `121`)

`N1` is an element number.

`T1-T8` are the nodal thickness values.

- For a linear three-sided element, `T1-T3` are populated with the thickness values for corner nodes, and `T4-T8` are empty.
- For a parabolic three-sided element, `T1-T3` are populated with the thickness values for corner nodes, `T4-T6` are populated with the thickness values for midside nodes, and `T7-T8` are empty.
- For a linear four-sided element, `T1-T4` are populated with the thickness values for corner nodes, and `T5-T8` are empty.
- For a parabolic four-sided element, `T1-T4` are populated with the thickness values for corner nodes, and `T5-T8` are populated with the thickness values for midside nodes.

> **Note**
>
> This card defines variable nodal thicknesses for 2D elements.

Example

```
$ Element Variable Thickness Data
$ ------------------------------
$
ELVARTHICK 1  0.000000E+00  1.000000E+00 -1.000000E+00
$ 1 is a linear three-sided element
ELVARTHICK 2  1.000000E+00  0.000000E+00 -1.000000E+00
ELVARTHICK 3  1.000000E+00  2.000000E+00  0.000000E+00  1.500000E+00  1.000000E+00  5.00
0000E-01
$ 3 is a parabolic three-sided element
ELVARTHICK 4  2.000000E+00  1.000000E+00  0.000000E+00  1.500000E+00  5.000000E-01  1.00
0000E+00
ELVARTHICK 5  0.000000E+00  1.000000E+00  2.000000E+00  1.000000E+00
$ 5 is a linear four-sided element
ELVARTHICK 6  0.000000E+00  1.000000E+00  0.000000E+00 -1.000000E+00  5.000000E-01  5.00
0000E-01 -5.000000E-01 -5.000000E-01
$6 is a parabolic four-sided element
```

Card 9 - EXPPLUGIN User-written Plugin File - Optional

Specifies a user-written plugin file to load for expression functions

KODE, N1

`KODE` = `EXPPLUGIN` (or `105`)

N1 provides the full absolute path of a user-written plugin file to be loaded for expression evaluations. Each such file contains definitions and enables the use of user-written registered functions that can be referenced in solver expressions, in the current run. If the thermal solver is not able to load the plugin file indicated in INPF, it extracts the plugin name by removing the file name's extension. Depending on the platform (.dll for Windows and .so for Linux) it adds the appropriate extension and searches for the plugin file in the folder specified by the UGII_CAE_PLUGIN_DIR environment variable.

Notes

When multiple plugin files are to be loaded, multiple EXPPLUGIN cards, one per file, should be used.

Example

```
EXPPLUGIN "d:/dir1/subdir1/userplugin1.dll"
```

Card 9 - EXPRESSION Symbolic Expression Definition Card - Optional

KODE, N1, T1, T2

`KODE` = `EXPRESSION` (or `100`)

`N1` is the expression number.

An expression cannot have the same number as a table or array in the model. An expression number can be referenced the same way as a table number in most of the places where a table number is accepted. Expressions are mainly supported for the cards and definitions (including emissivity and heat transfer coefficients) where the actual evaluation of the expression or table is done in (or postponed until) the Analyzer module execution. Those normally include, but may not be limited to, INTERP, SINK, PSINK, QNODE, and RELTEMP cards, material properties, thermal couplings, as well as various fields in VOID_NONGEOM, VOID_REGION, TSTREAM, and ZONE_CONVECTION cards.

Expression numbers can also be referenced as dependent variable values in TABDATA cards for tables whose dependent and independent variable types (in TABTYPE card) are TABLE and OPERATION, respectively. This is supported provided that such a TABLE-OPERATION table is not referenced from another expression. For places where a table with number `n` can be referenced using `Tn` or `-n` convention, you can also use the `En` notation, which is an equivalent intended for cases when n is an expression number.

`T1` is the code for the dependent variable type, which has the same meaning and can accept the same values as the dependent variable type in TABTYPE cards

For a list of supported types and for their descriptions, see Card 9 - TABDATA Analyzer Table Data Cards - Optional.

`T2` is the symbolic expression string, which could be either enclosed in double quotes (“) or left unquoted. The expression string consists of:

- Constants
- Operators

- Backed variables
- Built-in functions
- Table references (fields)registered functions
- Punctuation (parentheses and if/then/else statements)

For example:

$$\text{EXPRESSION 9 TEMP } \cos(0.3E2 * \text{time}) * \text{VT}(1) * \text{fd}(\text{``FieldName}(1)\text{ ''}) * \text{thickness}/67.89$$

where

- time and thickness are examples of backed variables
- $\cos$ is a built-in function
- VT is a registered function
- fd is a reference to a table for a field named $\text{``FieldName}(1)\text{ ''}$
- $0.3E2$, 67.89, 1, and $\text{``FieldName}(1)\text{ ''}$ are constants

The expression strings in the INPF should not contain any unit specifications, such as "[`mm/sec`]". All unit conversions should be done before the expression string is written to the INPF file. In that expression string all quantities are assumed to be in the same units as in other INPF cards.

Expression constants can be of type:

- integer (*e.g.* `257`)
- real (*e.g.* `0.` `1`, `1E6`, `2.3d4`)
- boolean (true or false or various capitalized versions of those)
- string (enclosed in quotes, *e.g.*, "`string 1(a)#$%^&`")

Those are also the types used in arguments or return values of expression functions.

Expression operators include standard mathematical operators (+, -, *, /, and ^ for power), comparison operators (==, !=, <, >, <=, >=), and boolean operators (!, &&, ||). The meaning of those operators (except using ^ for power) is the same as in C or C++ programming languages.

The built-in function symbols include:

- abs
- acosine
- asine
- atangent
- atangent2 (two arguments, x and y)
- ceiling (returns integer for a real argument)
- cos
- floor (returns integer for a real argument)
- hypcos
- hypsin
- hyptan
- log

- log10
- max
- minimum
- mod
- pi (pi constant, 3.14159.., no arguments)
- round (returns integer for a real argument)
- sin
- sqrt
- tan

Note that in the INPF file expression strings, all angular quantities in arguments or return values of those built-in functions should be in degrees, not radians (*e.g.*, `cos(90.0)` is the cosine of a 90 degree angle).

Expression backed variables is an Analyzer-supported set of variable names to access various quantities in the expression evaluation context (that is for a given element or conductance number to which the expression is applied at a given moment in the solve integration time) that can be used as independent variables. Many of those names have a corresponding equivalent (with the same definition) in the list of possible independent variable types for TABTYPE cards. For more information on the types, see Card 9 - TABDATA Analyzer Table Data Cards - Optional. They include:

Variable name	TABTYPE equivalent	Meaning
`contact_pressure`	`THMCPRES`	Contact pressure
`fluid_temperature`		Fluid temperature at associated fluid element
`gap_distance`	`THMCDISP`	Gap distance
`heat_flow_rate`	`QNODE`	Heat flow rate
`mass_flow_rate`	`MASSFL`	Mass flow rate at associated fluid element
`nx`		x component of the unit normal vector for the associated surface element
`ny`		y component of the unit normal vector for the associated surface element
`nz`		z component of the unit normal vector for the associated surface element

`pressure`	`PTOTAL`	Total fluid pressure at associated fluid element
`radius`		Radius value at element CG
`rotational_speed`		Rotational speed at element CG
`swirl_velocity`		Swirl velocity at element CG
`temperature`	`TEMP`	Temperature
`temperature_difference`	`TDIFF`	Temperature difference
`thermal_capacitance`	`CAP`	Thermal capacitance
`thickness`		Shell element thickness
`time`	`TIME`	Simulation time
`velocity`	`VELOC`	Flow velocity
`volume_flow_rate`	`VOLUME`	Volume flow rate
`x`		x coordinate at element CG
`y`		y coordinate at element CG
`z`		z coordinate at element CG

Expression fields (table references) have the form `fd(...)`, which is a symbolic function call with a string argument (double-quoted) containing the name of the corresponding table. That name should be defined using an EXPTAB card, which associates the name to a table number. For simple table names (without spaces or special characters), you can

put those names (without quotes) directly in expressions as variable names, such as backed variables without wrapping them in `fd(...)` calls.

Example

```
EXPRESSION 14 QNODE 2.0*(fd("Field Name (1)"") + Table2)
EXPTAB  15 "Field Name (1)"
EXPTAB  16 Table2
TABTYPE 15 VALUE EID
TABDATA 15 ...
TABTYPE 16 VALUE TIME
TABDATA 16 ...
```

Parentheses, with any number of matching "(" `and` ")", could be used to structure an expression. The if-then-else construct can be used according to the following syntax:

$$\text{if } < \text{expr1} > \text{ then } < \text{expr2} > \text{ else } < \text{expr3} >$$

For example:

$$\text{EXPRESSION 46 COND if (gap\_distance} > 0) \text{ then fd(``Table8 '') else fd(``Table9 '')}$$

Note that spaces are required before and after each of the "if", "then", and "else" keywords.

Other functions, besides the built-in functions and `fd(...)` fields, should be registered in the expression evaluation system by loading plugins (dynamic library files loaded at run time by the solver) that contain definitions (names, numbers and types of mandatory and optional arguments, type of the return value) and implementations of those functions. A generally available standard set of registered functions is supported through solver built-in plugins that are distributed with the thermal solver executables. Those ones include general function, solution-dependent function, and fluid properties function plugins. Other functions that are not part of that pre-supplied set can be registered by loading additional user-provided plugins specified by EXPPLUGIN cards.

Registered functions can have required and optional arguments (parameters) or no arguments. In the latter case, the parentheses "()" should still follow the function name. When optional arguments for a given function are not provided, then their function-specific defaults are used. For example, possible uses of required and optional arguments of the function `ABS2REL` could be:

Example

```
ABS2REL(300.0)
ABS2REL(300.0,0.99*radius)
ABS2REL(300.0,radius,0.5*rotational_speed)
ABS2REL(300.0,radius,rotational_speed,0,0.5*
```

```
swirl_velocity)
```

To set a desired optional argument (*e.g.*, the third one) one should also provide all of the preceding ones (*e.g.*, the first two).

Note that when there are expressions with significant sensitivity to temperature through backed variables or registered functions and/or there are expressions with critical interdependencies (an expression result on one boundary condition depends on the quantities on another boundary condition which is governed by another expression), then use of the fully implicit integration method setting for GRADNT field on Card 2b is recommended for increased accuracy and consistency of the results.

Registered functions from the general category include:

Function name	Required parameters	Output
`KU`	Temperature value to be converted to Kelvin units	Converts a temperature value from the solve units to degrees Kelvin and returns it as a unitless quantity.
`R`	Name of a named point	Returns the radius from the current rotation axis to a named point.
`THICK`	Name of a named point	Returns the local shell thickness at a named point.
`X`	Name of a named point	Returns the `X` coordinate of a named point.
`Y`	Name of a named point	Returns the `Y` coordinate of a named point.
`Z`	Name of a named point	Returns the `Z` coordinate of a named point.

Registered functions from the solution dependent category include:

Function name	Required parameters	Optional parameters	Output
`CHRS`	TSTREAM card ID		Returns the convective heat flux for stream ID.

CHRV	VOID_REGION card ID		Returns the convective heat flux for void ID.
CHRZ	ZONE_CONVECTION card ID		Returns the convective heat flux for zone ID.
DR	Name of a named point		Returns the change in radius of a named point from the current rotation axis due to structural displacement.
DX	Name of a named point		Returns the change in coordinate X of a named point due to structural displacement.
DY	Name of a named point		Returns the change in coordinate Y of a named point due to structural displacement.
DZ	Name of a named point		Returns the change in coordinate Z of a named point due to structural displacement.
GAPD	Name of a named point		Returns the local gap distance at a named point.
MF	Name of a named point		Returns the local mass flow at a named point.
ONEOF	Double precision values		Returns the first value that is defined from two or more arguments.
PR	Three double-precision values		Returns the first argument that is defined from one required and two optional arguments. During evaluation, it generates a printout of the arguments.

PWR	TSTREAM card ID		Returns the power input from feeding the specified stream into a void.
PWRV	Mass flow from the void to another void, THERMAL_VOID c ard ID		Returns the power input from feeding the specified void into another void.
RLD	Name of the CURVE defined by the Card 9 - CURVE Cards – Optional		Returns the closest distance to the curve.
RS	Name of a named point		Returns the local rotational speed at a named point.
SA	TSTREAM card ID		Returns the element selection area for stream ID.
SAC	TSTREAM card ID		Returns the corrected convecting area for stream ID.
SAC2	TSTREAM card ID		Returns the corrected convecting area of one side of a two-sided stream ID.
SMO	TSTREAM card ID		Returns the outlet mass flow for stream ID.
SP	TSTREAM card ID		Returns the pressure for stream ID.
SSV	TSTREAM card ID		Returns the swirl velocity for stream ID.
STI	TSTREAM card ID		Returns the total absolute or relative inlet temperature for stream ID.
STMO	TSTREAM card ID		Returns the outlet metal temperature for stream ID.

STO	TSTREAM card ID		Returns the total absolute or relative outlet temperature for stream ID.
TEMP	Name of a named point		Returns the local solid temperature at a named point.
TEMPF	Name of a named point		Returns the local fluid temperature at a named point.
THRS	TSTREAM card ID		Returns the total convective heat flux plus the heat pickup for stream ID.
THRV	VOID_REGION card ID		Returns the total convective heat flux plus the heat pickup for void ID.
THRZ	ZONE_CONVECTION card ID		Returns the specific heat ratio of a fluid at the given temperature for zone ID.
VA	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the element selection area for void ID or one of its regions.
VAC	VOID_REGION card ID		Returns the corrected convecting area for void ID.
VP	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the pressure for void ID or one of its regions.
VSV	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the swirl velocity for void ID or one of its regions.
VT	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the total absolute or relative temperature for void ID or one of its regions.
ZA	ZONE_CONVECTION card ID		Returns the element selection area for convecting zone ID.

ZAC	ZONE_CONVECTION card ID		Returns the corrected convecting area for zone ID.
ZP	ZONE_CONVECTION card ID		Returns the pressure for convecting zone ID.
ZSV	ZONE_CONVECTION card ID		Returns the swirl velocity for convecting zone ID.
ZT	ZONE_CONVECTION card ID		Returns the total absolute or relative temperature for convecting zone ID.

Note that for the functions that return pressure, swirl, or temperature for convecting zone, void, or stream BCs (ZT, ZP, etc), when there are spatial variations of that quantity along the BC, then the output result is the maximum value over those spatial variations. In the functions where temperature is returned, the temperature is either total absolute or total relative temperature, depending on the type of rotational effects specified in the ROT_FXS option of the ROT_FX card, referenced in the given BC.

Registered functions from the additional solution dependent category include:

Function name	Required parameters	Optional parameters	Output
ABS2REL	Total absolute temperature	Radius, rotational speed, fluid swirl velocity, fluid material index	Returns the total relative temperature of an input total absolute temperature.
ABS2REL_SR	Total absolute temperature	Radius, rotational speed, fluid swirl ratio, fluid material index	Returns the total relative temperature of an input total absolute temperature.

`HTCFORCE`	Hydraulic radius, correlation type (`PLATE`, `PLATE_ENV`, `DUCT`, `DUCT_FULL`)	Characteristic length, fluid velocity, convection side	Returns the heat transfer coefficient for the specified forced convection correlation. Depending on the specified correlation type, different equations are used: • For `PLATE` correlation, the thermal solver uses equations for the NEARC4 option. • For `PLATE_ENV` correlation, the thermal solver uses equations for the FORCEDPASN option. You must also specify the convection side: 1, 2, or 3 respectively indicating that the top, bottom, or both plate sides convect. For two-layer shells and multi-layer shells, the thermal solver only computes and returns the top side heat transfer coefficient regardless of the specified convection side. • For `DUCT` correlation, the thermal solver uses equations for the NEARC12 option. • For `DUCT_FULL` correlation, the thermal solver uses equations for the NEARC1 option. These options are described in Card 6e - Thermal Coupling Request Card - Optional and Forced Convection Conductances.

`HTCFREE`	Correlation type (`HORIZONTAL` , `INCLINED`), convection side (`TOP` , `BOTTOM` , `BOTH`)	Characteristic length, perimeter	Returns the heat transfer for the specified free convection correlation. Depending on the specified correlation type, different equations are used: • For `HORIZONTAL` correlation, the thermal solver uses equations for the PLATEH and PLATEHASN options. • For `INCLINED` correlation, the thermal solver uses equations for the PLATE and PLATEASN options. The convection side indicates which plate sides convect: top, bottom, of both sides. For two-layer shells and multi-layer shells, the thermal solver only computes and returns the top side heat transfer coefficient regardless of the specified convection side. These options are described in Card 6e - Thermal Coupling Request Card - Optional and Free Convection Conductances.
`MIX`	TSTREAM card ID, TSTREAM card ID	Up to 8 more TSTREAM card IDs	Returns the temperature that results from mixing the flows of two or more streams.
`MMIX`	TSTREAM card ID, TSTREAM card ID	Up to 8 more TSTREAM card IDs	Returns the mass flow rate that results from mixing the flows of two or more streams.
`REL2ABS`	Total relative temperature	Radius, rotational speed, fluid swirl velocity, fluid material index	Returns the total absolute temperature of an input total relative temperature.

REL2ABS_SR	Total relative temperature	Radius, rotational speed, fluid swirl ratio, fluid material index	Returns the total absolute temperature of an input total relative temperature.
REL2REL	Total relative temperature, rotational speed at input, fluid swirl velocity at input	Rotational speed at output, fluid swirl velocity at output, radius, fluid material index	Converts the input total relative temperature at input rotational speed and swirl velocity to the equivalent output relative temperature at output (or current) rotational speed and swirl velocity. Both relative temperatures are evaluated at the same rotation radius.
REL2REL_SR	Total relative temperature, rotational speed at input, fluid swirl ratio at input	Rotational speed at output, fluid swirl ratio at output, radius, fluid material index	Converts the input total relative temperature at input rotational speed and swirl ratio to the equivalent output relative temperature at output (or current) rotational speed and swirl ratio. Both relative temperatures are evaluated at the same rotation radius.

Registered functions from the fluid properties category include:

Fluid Function	Required parameters	Optional parameters	Output
CONDFL	Temperature	Fluid material index	Returns the thermal conductivity at a specified temperature for the fluid material.
DENSFL	None	Temperature, pressure, fluid material index	Returns the mass density at a specified temperature for the fluid material.

`ENTHFL`	Temperature	Fluid material index	Returns the specific enthalpy at a specified temperature for the fluid material.
`GAMMAFL`	Temperature	Fluid material index	Returns the ratio of specific heats at a specified temperature for the fluid material.
`RE`	None	Temperature, radius, rotational speed, pressure, fluid material index	Calculates the local rotational Reynolds number for the fluid material.
`SPECFL`	Temperature	Fluid material index	Returns the specific heat at constant pressure of the fluid at a specified temperature for the fluid material.
`VISCFL`	Temperature	Fluid material index	Returns the dynamic viscosity at a specified temperature for the fluid material.

KODE, N1, T1, T2

`KODE` = `EXPRESSION` (or `100`)

`N1` is the expression number.

An expression cannot have the same number as a table or array in the model. An expression number can be referenced the same way as a table number in most of the places where a table number is accepted. Expressions are mainly

supported for the cards and definitions (including emissivity and heat transfer coefficients) where the actual evaluation of the expression or table is done in (or postponed until) the Analyzer module execution. Those normally include, but may not be limited to, INTERP, SINK, PSINK, QNODE, and RELTEMP cards, material properties, thermal couplings, as well as various fields in VOID_NONGEOM, VOID_REGION, TSTREAM, and ZONE_CONVECTION cards.

Expression numbers can also be referenced as dependent variable values in TABDATA cards for tables whose dependent and independent variable types (in TABTYPE card) are TABLE and OPERATION, respectively. This is supported provided that such a TABLE-OPERATION table is not referenced from another expression. For places where a table with number `n` can be referenced using `Tn` or `-n` convention, you can also use the `En` notation, which is an equivalent intended for cases when n is an expression number.

`T1` is the code for the dependent variable type, which has the same meaning and can accept the same values as the dependent variable type in TABTYPE cards

For a list of supported types and for their descriptions, see Card 9 - TABDATA Analyzer Table Data Cards - Optional.

`T2` is the symbolic expression string, which could be either enclosed in double quotes (“) or left unquoted. The expression string consists of:

- Constants
- Operators
- Backed variables
- Built-in functions
- Table references (fields)registered functions
- Punctuation (parentheses and if/then/else statements)

For example:

$$\text{EXPRESSION 9 TEMP } \cos(0.3E2 * \text{time}) * \text{VT}(1) * \text{fd}(\text{``FieldName}(1)\text{ ''}) * \text{thickness}/67.89$$

where

- time and thickness are examples of backed variables
- cos is a built-in function
- VT is a registered function
- fd is a reference to a table for a field named ``FieldName(1) "
- 0.3E2, 67.89, 1, and ``FieldName(1) " are constants

The expression strings in the INPF should not contain any unit specifications, such as “[`mm/sec`]”. All unit conversions should be done before the expression string is written to the INPF file. In that expression string all quantities are assumed to be in the same units as in other INPF cards.

Expression constants can be of type:

- integer (*e.g.* `257`)
- real (*e.g.* `0. 1`, `1E6`, `2.3d4`)
- boolean (true or false or various capitalized versions of those)
- string (enclosed in quotes, *e.g.*, "`string 1(a)#$%^&`")

Those are also the types used in arguments or return values of expression functions.

Expression operators include standard mathematical operators (+, -, *, /, and ^ for power), comparison operators (==, !=, <, >, <=, >=), and boolean operators (!, &&, ||). The meaning of those operators (except using ^ for power) is the same as in C or C++ programming languages.

The built-in function symbols include:

- abs
- acosine
- asine
- atangent
- atangent2 (two arguments, x and y)
- ceiling (returns integer for a real argument)
- cos
- floor (returns integer for a real argument)
- hypcos
- hypsin
- hyptan
- log
- log10
- max
- minimum
- mod
- pi (pi constant, 3.14159.., no arguments)
- round (returns integer for a real argument)
- sin
- sqrt
- tan

Note that in the INPF file expression strings, all angular quantities in arguments or return values of those built-in functions should be in degrees, not radians (*e.g.*, `cos(90.0)` is the cosine of a 90 degree angle).

Expression backed variables is an Analyzer-supported set of variable names to access various quantities in the expression evaluation context (that is for a given element or conductance number to which the expression is applied at a given moment in the solve integration time) that can be used as independent variables. Many of those names have a corresponding equivalent (with the same definition) in the list of possible independent variable types for TABTYPE cards. For more information on the types, see Card 9 - TABDATA Analyzer Table Data Cards - Optional. They include:

Variable name	TABTYPE equivalent	Meaning

contact_pressure	THMCPRES	Contact pressure
fluid_temperature		Fluid temperature at associated fluid element
gap_distance	THMCDISP	Gap distance
heat_flow_rate	QNODE	Heat flow rate
mass_flow_rate	MASSFL	Mass flow rate at associated fluid element
nx		x component of the unit normal vector for the associated surface element
ny		y component of the unit normal vector for the associated surface element
nz		z component of the unit normal vector for the associated surface element
pressure	PTOTAL	Total fluid pressure at associated fluid element
radius		Radius value at element CG
rotational_speed		Rotational speed at element CG
swirl_velocity		Swirl velocity at element CG
temperature	TEMP	Temperature
temperature_difference	TDIFF	Temperature difference

`thermal_capacitance`	`CAP`	Thermal capacitance
`thickness`		Shell element thickness
`time`	`TIME`	Simulation time
`velocity`	`VELOC`	Flow velocity
`volume_flow_rate`	`VOLUME`	Volume flow rate
`x`		x coordinate at element CG
`y`		y coordinate at element CG
`z`		z coordinate at element CG

Expression fields (table references) have the form `fd(...)`, which is a symbolic function call with a string argument (double-quoted) containing the name of the corresponding table. That name should be defined using an EXPTAB card, which associates the name to a table number. For simple table names (without spaces or special characters), you can put those names (without quotes) directly in expressions as variable names, such as backed variables without wrapping them in `fd(...)` calls.

Example

```
EXPRESSION 14 QNODE 2.0*(fd("Field Name (1)"") + Table2)
EXPTAB  15 "Field Name (1)"
EXPTAB  16 Table2
TABTYPE 15 VALUE EID
TABDATA 15 ...
TABTYPE 16 VALUE TIME
TABDATA 16 ...
```

Parentheses, with any number of matching “(” `and` “)”, could be used to structure an expression. The if-then-else construct can be used according to the following syntax:

$$\text{if} < \text{expr1} > \text{then} < \text{expr2} > \text{else} < \text{expr3} >$$

For example:

EXPRESSION 46 COND if (gap_distance > 0) then fd(‘‘Table8 ") else fd(‘‘Table9 ")

Note that spaces are required before and after each of the “if”, “then”, and “else” keywords.

Other functions, besides the built-in functions and `fd(...)` fields, should be registered in the expression evaluation system by loading plugins (dynamic library files loaded at run time by the solver) that contain definitions (names, numbers and types of mandatory and optional arguments, type of the return value) and implementations of those functions. A generally available standard set of registered functions is supported through solver built-in plugins that are distributed with the thermal solver executables. Those ones include general function, solution-dependent function, and fluid properties function plugins. Other functions that are not part of that pre-supplied set can be registered by loading additional user-provided plugins specified by EXPPLUGIN cards.

Registered functions can have required and optional arguments (parameters) or no arguments. In the latter case, the parentheses “()” should still follow the function name. When optional arguments for a given function are not provided, then their function-specific defaults are used. For example, possible uses of required and optional arguments of the function `ABS2REL` could be:

Example

```
ABS2REL(300.0)
ABS2REL(300.0,0.99*radius)
ABS2REL(300.0,radius,0.5*rotational_speed)
ABS2REL(300.0,radius,rotational_speed,0,0.5*
swirl_velocity)
```

To set a desired optional argument (*e.g.*, the third one) one should also provide all of the preceding ones (*e.g.*, the first two).

Note that when there are expressions with significant sensitivity to temperature through backed variables or registered functions and/or there are expressions with critical interdependencies (an expression result on one boundary condition depends on the quantities on another boundary condition which is governed by another expression), then use of the fully implicit integration method setting for GRADNT field on Card 2b is recommended for increased accuracy and consistency of the results.

Registered functions from the general category include:

Function name	Required parameters	Output
`KU`	Temperature value to be converted to Kelvin units	Converts a temperature value from the solve units to degrees Kelvin and returns it as a unitless quantity.

`R`	Name of a named point	Returns the radius from the current rotation axis to a named point.
`THICK`	Name of a named point	Returns the local shell thickness at a named point.
`X`	Name of a named point	Returns the `X` coordinate of a named point.
`Y`	Name of a named point	Returns the `Y` coordinate of a named point.
`Z`	Name of a named point	Returns the `Z` coordinate of a named point.

Registered functions from the solution dependent category include:

Function name	Required parameters	Optional parameters	Output
`CHRS`	TSTREAM card ID		Returns the convective heat flux for stream ID.
`CHRV`	VOID_REGION card ID		Returns the convective heat flux for void ID.
`CHRZ`	ZONE_CONVECTION card ID		Returns the convective heat flux for zone ID.
`DR`	Name of a named point		Returns the change in radius of a named point from the current rotation axis due to structural displacement.
`DX`	Name of a named point		Returns the change in coordinate `X` of a named point due to structural displacement.

DY	Name of a named point		Returns the change in coordinate Y of a named point due to structural displacement.
DZ	Name of a named point		Returns the change in coordinate Z of a named point due to structural displacement.
GAPD	Name of a named point		Returns the local gap distance at a named point.
MF	Name of a named point		Returns the local mass flow at a named point.
ONEOF	Double precision values		Returns the first value that is defined from two or more arguments.
PR	Three double-precision values		Returns the first argument that is defined from one required and two optional arguments. During evaluation, it generates a printout of the arguments.
PWR	TSTREAM card ID		Returns the power input from feeding the specified stream into a void.
PWRV	Mass flow from the void to another void, THERMAL_VOID c ard ID		Returns the power input from feeding the specified void into another void.
RLD	Name of the CURVE defined by the Card 9 - CURVE Cards – Optional		Returns the closest distance to the curve.
RS	Name of a named point		Returns the local rotational speed at a named point.

SA	TSTREAM card ID		Returns the element selection area for stream ID.
SAC	TSTREAM card ID		Returns the corrected convecting area for stream ID.
SAC2	TSTREAM card ID		Returns the corrected convecting area of one side of a two-sided stream ID.
SMO	TSTREAM card ID		Returns the outlet mass flow for stream ID.
SP	TSTREAM card ID		Returns the pressure for stream ID.
SSV	TSTREAM card ID		Returns the swirl velocity for stream ID.
STI	TSTREAM card ID		Returns the total absolute or relative inlet temperature for stream ID.
STMO	TSTREAM card ID		Returns the outlet metal temperature for stream ID.
STO	TSTREAM card ID		Returns the total absolute or relative outlet temperature for stream ID.
TEMP	Name of a named point		Returns the local solid temperature at a named point.
TEMPF	Name of a named point		Returns the local fluid temperature at a named point.
THRS	TSTREAM card ID		Returns the total convective heat flux plus the heat pickup for stream ID.
THRV	VOID_REGION card ID		Returns the total convective heat flux plus the heat pickup for void ID.

THRZ	ZONE_CONVECTION card ID		Returns the specific heat ratio of a fluid at the given temperature for zone ID.
VA	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the element selection area for void ID or one of its regions.
VAC	VOID_REGION card ID		Returns the corrected convecting area for void ID.
VP	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the pressure for void ID or one of its regions.
VSV	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the swirl velocity for void ID or one of its regions.
VT	VOID_NONGEOM card ID	VOID_REGION card ID	Returns the total absolute or relative temperature for void ID or one of its regions.
ZA	ZONE_CONVECTION card ID		Returns the element selection area for convecting zone ID.
ZAC	ZONE_CONVECTION card ID		Returns the corrected convecting area for zone ID.
ZP	ZONE_CONVECTION card ID		Returns the pressure for convecting zone ID.
ZSV	ZONE_CONVECTION card ID		Returns the swirl velocity for convecting zone ID.
ZT	ZONE_CONVECTION card ID		Returns the total absolute or relative temperature for convecting zone ID.

Note that for the functions that return pressure, swirl, or temperature for convecting zone, void, or stream BCs (ZT, ZP, etc), when there are spatial variations of that quantity along the BC, then the output result is the maximum value over those spatial variations. In the functions where temperature is returned, the temperature is either total absolute or total relative temperature, depending on the type of rotational effects specified in the ROT_FXS option of the ROT_FX card, referenced in the given BC.

Registered functions from the additional solution dependent category include:

Function name	Required parameters	Optional parameters	Output
`ABS2REL`	Total absolute temperature	Radius, rotational speed, fluid swirl velocity, fluid material index	Returns the total relative temperature of an input total absolute temperature.
`ABS2REL_SR`	Total absolute temperature	Radius, rotational speed, fluid swirl ratio, fluid material index	Returns the total relative temperature of an input total absolute temperature.

`HTCFORCE`	Hydraulic radius, correlation type (`PLATE` , `PLATE_ENV` , `DUCT` , `DUCT_FULL`)	Characteristic length, fluid velocity, convection side	Returns the heat transfer coefficient for the specified forced convection correlation. Depending on the specified correlation type, different equations are used: • For `PLATE` correlation, the thermal solver uses equations for the NEARC4 option. • For `PLATE_ENV` correlation, the thermal solver uses equations for the FORCEDPASN option. You must also specify the convection side: 1, 2, or 3 respectively indicating that the top, bottom, or both plate sides convect. For two-layer shells and multi-layer shells, the thermal solver only computes and returns the top side heat transfer coefficient regardless of the specified convection side. • For `DUCT` correlation, the thermal solver uses equations for the NEARC12 option. • For `DUCT_FULL` correlation, the thermal solver uses equations for the NEARC1 option. These options are described in Card 6e - Thermal Coupling Request Card - Optional and Forced Convection Conductances.

`HTCFREE`	Correlation type (`HORIZONTAL` , `INCLINED`), convection side (`TOP` , `BOTTOM` , `BOTH`)	Characteristic length, perimeter	Returns the heat transfer for the specified free convection correlation. Depending on the specified correlation type, different equations are used: • For `HORIZONTAL` correlation, the thermal solver uses equations for the PLATEH and PLATEHASN options. • For `INCLINED` correlation, the thermal solver uses equations for the PLATE and PLATEASN options. The convection side indicates which plate sides convect: top, bottom, of both sides. For two-layer shells and multi-layer shells, the thermal solver only computes and returns the top side heat transfer coefficient regardless of the specified convection side. These options are described in Card 6e - Thermal Coupling Request Card - Optional and Free Convection Conductances.
`MIX`	TSTREAM card ID, TSTREAM card ID	Up to 8 more TSTREAM card IDs	Returns the temperature that results from mixing the flows of two or more streams.
`MMIX`	TSTREAM card ID, TSTREAM card ID	Up to 8 more TSTREAM card IDs	Returns the mass flow rate that results from mixing the flows of two or more streams.
`REL2ABS`	Total relative temperature	Radius, rotational speed, fluid swirl velocity, fluid material index	Returns the total absolute temperature of an input total relative temperature.

REL2ABS_SR	Total relative temperature	Radius, rotational speed, fluid swirl ratio, fluid material index	Returns the total absolute temperature of an input total relative temperature.
REL2REL	Total relative temperature, rotational speed at input, fluid swirl velocity at input	Rotational speed at output, fluid swirl velocity at output, radius, fluid material index	Converts the input total relative temperature at input rotational speed and swirl velocity to the equivalent output relative temperature at output (or current) rotational speed and swirl velocity. Both relative temperatures are evaluated at the same rotation radius.
REL2REL_SR	Total relative temperature, rotational speed at input, fluid swirl ratio at input	Rotational speed at output, fluid swirl ratio at output, radius, fluid material index	Converts the input total relative temperature at input rotational speed and swirl ratio to the equivalent output relative temperature at output (or current) rotational speed and swirl ratio. Both relative temperatures are evaluated at the same rotation radius.

Registered functions from the fluid properties category include:

Fluid Function	Required parameters	Optional parameters	Output
CONDFL	Temperature	Fluid material index	Returns the thermal conductivity at a specified temperature for the fluid material.
DENSFL	None	Temperature, pressure, fluid material index	Returns the mass density at a specified temperature for the fluid material.

`ENTHFL`	Temperature	Fluid material index	Returns the specific enthalpy at a specified temperature for the fluid material.
`GAMMAFL`	Temperature	Fluid material index	Returns the ratio of specific heats at a specified temperature for the fluid material.
`RE`	None	Temperature, radius, rotational speed, pressure, fluid material index	Calculates the local rotational Reynolds number for the fluid material.
`SPECFL`	Temperature	Fluid material index	Returns the specific heat at constant pressure of the fluid at a specified temperature for the fluid material.
`VISCFL`	Temperature	Fluid material index	Returns the dynamic viscosity at a specified temperature for the fluid material.

Card 9 - EXPTAB Table name for referencing in expressions

KODE, N1, T1

```
KODE = EXPTAB
```

`N1` is the table or array number for the TABTYPE, TABDATA, ARRAYTYPE, or ARRAYDATA cards to which the given EXPTAB card refers to.

`T1` is the name under which the specified table can be referenced in symbolic expression EXPRESSION cards. That name string could be either enclosed in double quotes (“) or left unquoted.

Note

The dependent variable type of the tables referenced through EXPTAB cards in expressions is ignored. Hence the generic dependent variable type VALUE is normally used.

Example

```
TABTYPE 12 VALUE TIME
TABDATA 1.0 0.0
EXPTAB 12 "Table 1(a)"
EXPRESSION 13 TEMP 2.0*fd("Table 1(a)")
```

Card 9 - EXT_SOLVER External Solver Definition - Optional

The external solver boundary condition simulation object will translate to the following INPF card.

`KODE` , `N1` , `T1` , `T2` , `T3`

`KODE` = `EXT_SOLVER` (or `110`): defines a boundary condition that passes values from the Pre/Post model to the inlets and outlets of an external CFD model.

`N1` is the EXT_SOLVER card ID.

Cards with the same ID reference the same External Solver Boundary Condition.

`T1` may be:

= `ANGULAR_RATE` (or `6`)

= `BC_NAME` (or `1`)

= `MASSFLOW` (or `4`)

= `PRESSURE` (or `5`)

= `SOLVER_NAME` (or `2`)

= `SWIRL_VELOCITY` (or `7`)

= `TEMPERATURE` (or `3`)

= `HEATPICKUP` (or `8`)

= `GAP_DISTANCE` (or `9`)

= `LENGTH` (or `10`)

= `UNITLESS` (or `11`)

`T1` = `ANGULAR_RATE` (or `6`):

- Specifies the rotation angular rate that the thermal solver transfers to the CFD model.
- If the angular rate is constant, then its value is specified in `T2`.
- If the angular rate is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card.
- If the angular rate is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `ROTATION`.

`T1` = `BC_NAME` (or `1`): The user-defined external boundary condition name is specified in `T2` as a string between quotes.

`T1` = `MASSFLOW` (or `4`): Specifies the mass flow that the thermal solver transfers to the CFD model.

- If the mass flow is constant, then its value is specified in `T2`.

- If the mass flow is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card.
- If the mass flow is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `MASSF`.

`T1` = `PRESSURE` (or `5`): Specifies the fluid pressure that the thermal solver transfers to the CFD model.

- If the pressure is constant, then its value is specified in `T2`.
- If the pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card.
- If the pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `PTOTAL`.

`T1` = `SOLVER_NAME` (or `2`): The external solver modeling object name is specified in `T2` as a string between quotes.

`T1` = `SWIRL_VELOCITY` (or `7`): Specifies the swirl velocity that the thermal solver transfers to the CFD model.

- If the swirl velocity is constant, then its value is specified in `T2`.
- If the swirl velocity is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card.
- If the swirl velocity is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `VELOC`.

`T1` = `TEMPERATURE` (or `3`): Specifies the fluid temperature that the thermal solver transfers to the CFD model.

- If the temperature is constant, then its value is specified in `T2`.
- If the temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing the EXPRESSION card.
- If the temperature is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `TEMP`.

`T1` = `HEATPICKUP` (or `8`): Specifies the heatpickup that the thermal solver transfers to the CFD model.

- If the heatpickup is constant, then its value is specified in `T2`.
- If the heatpickup is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `HTFL`.

`T1` = `GAP_DISTANCE` (or `9`): Specifies the gap distance that the thermal solver transfers to the CFD model.

- If the gap distance is constant, then its value is specified in `T2`.
- If the gap distance is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `THMCDISP`.

`T1` = `LENGTH` (or `10`): Specifies the length that the thermal solver transfers to the CFD model. The value is specified in `T2`.

- If the length is constant, then its value is specified in `T2`.
- If the length is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards.

`T1` = `UNITLESS` (or `11`): Specifies the unitless value that the thermal solver transfers to the CFD model.

- If the length is constant, then its value is specified in `T2`.
- If the length is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards.

Example

```
$ External Solver Boundary Condition
EXT_SOLVER 3 BC_NAME "sc_mesh(123)"
EXT_SOLVER 3 SOLVER_NAME "Dummy"
EXT_SOLVER 3 TEMPERATURE -1.501500E+02
EXT_SOLVER 3 MASSFLOW 4.560000E+05
EXT_SOLVER 3 PRESSURE 7.890000E+05
EXT_SOLVER 3 ANGULAR_RATE 1.350000E+02
EXT_SOLVER 3 SWIRL_VELOCITY 2.460000E+02
EXT_SOLVER 3 HEATPICKUP 2.460000E+02
EXT_SOLVER 3 GAP_DISTANCE 2.460000E+02
EXT_SOLVER 3 LENGTH 2.460000E+02
EXT_SOLVER 3 UNITLESS 2.460000E+02
```

Card 9 - FIELDCSYS

This card specifies the local coordinate systems supported in the interpolation methods in Card 9 - FIELDINTERP.

`KODE, T1, T2, T3, T4`

`KODE = FIELDCSYS`

`T1` can be:

- CARTESIAN (or `CYLINDRICAL` or `SPHERICAL`) that specifies the type of local CSYS.
- `ORIGIN`
- `XDIR`
- `YDIR`

T2 is:

- Specifies the X coordinate of local CSYS origin when `T1` is `ORIGIN`.
- Specifies the X coordinate of the X axis for the local CSYS when `T1` is `XDIR`.
- Specifies the X coordinate of the Y axis for the local CSYS when `T1` is YDIR `.`

T3 is:

- Specifies the Y coordinate of local CSYS origin when `T1` is `ORIGIN`.
- Specifies the Y coordinate of the X axis for the local CSYS when `T1` is `XDIR`.
- Specifies the Y coordinate of the Y axis for the local CSYS when `T1` is YDIR `.`

T4 is:

- Specifies the Zcoordinate of local CSYS origin when `T1` is `ORIGIN`.
- Specifies the Z coordinate of the X axis for the local CSYS when `T1` is `XDIR`.
- Specifies the Z coordinate of the Y axis for the local CSYS when `T1` is YDIR `.`

Card 9 - FIELDDATA Spatial and non-spatial field types definition

This card specifies the input row line for raw data for spatial fields, whose dependent and independent variables types are specifed in Card 9 - FIELDTYPE Spatial and non-spatial field data interpolation. The method of interpolation is specified in Card 9 - FIELDINTERP. Depending on the variables types, the solver treats tables that are specified in cartesian, cylindrical, spherical coordinate system.

```
KODE, T1, N1, IND1, IND2, IND3, IND4
```

KODE = FIELDDATA ID

T1 is the spatial field number.

N1 is the dependent variable value. The dependent variable can be any variable supported in Card 9 - ARRAYDATA Array Variable Definition Card - Optional and Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

IND1...IND4 are the independent variable values. The maximum number of supported independent variables is 4.

Card 9 - FIELDINTERP

This card specifies the supported interpolation methods for the 1-D, 2-D, and 3-D spatial fields, described in Card 9 - FIELDTYPE Spatial and non-spatial field data interpolation.

```
FIELDINTERP ID METHOD
```

ID is the label ID of the table.

`METHOD` is the specified interpolation method supported for 1-D, 2-D, 3-D and 4-D spatial fields that are identified in the following tables.

1-D spatial field

The following are the interpolotion methods supported for 1-D spatial fields, including those 1-D spatial fields that are referenced in a table of fields.

Method	Interpolation type
LINEAR	Linear
AKIMA	Linear
AKIMA72	Akima72
CUBIC	Cubic
NNEIGHBOR	Nearest Neighbor
INVERSE	Inverse Distance Weighting

2-D and 3D spatial fields

The following are the interpolation methods supported for 2-D and 3-D spatial fields, including those 2-D and 3-D spatial fields referenced in a table of fields:

Method	Interpolation type
DELAUNAYF	Fast Delaunay
DELAUNAYM	Medium Delaunay

Method	Interpolation type
DELAUNAYA	Accurate Delaunay
NNEIGHBOR	Nearest Neighbor
ANEIGHBOR	Approximate Nearest Neighbor
RENKASHEPARD	Renka's Modified Shepard
INVERSE	Inverse Distance Weighting

Card 9 - FIELDOPTIONS

This card specifies the options supported from the interpolation methods in Card 9 - FIELDINTERP.

`KODE, T1, N1, N2`

`KODE=FIELDOPTIONS`

`T1` = ID

`N1` can be:

- `ALGORITHM` is a keyword to specify the interpolation algorithm for the LINEAR method
- `APPROXRADIUS` is a keyword for the search radius as a fraction of the diagonal used for the INVERSE method.
- `APPROXNUMBER` is a keyword for the fraction of all points used for the INVERSE method.
- `APPROXTOLERANCE` is a keyword for the nearest neighbor tolerance used for the ANEIGHBOR and INVERSE methods.
- `SHIFT` is a keyword for the independent value shift for the LINEAR method.
- `DIVISOR` is a keyword for the independent value divisor for the LINEAR method.
- OUTSIDE.

N2 can be:

- `LINEAR_LINEAR` (or `LOG_LINEAR`, o r `LINEAR_LOG`, or `LOG_LOG`) that is the interpolation algorithm used for the LINEAR method.
- CONSTANT or UNDEFINED or EXTRAPOLATE for the treatment of points that lay OUTSIDE of the field independent variables ranges.
- A number from 0 to 1 for APPROXRADIUS, APPROXNUMBER and APPROXTOLERANCE.
- Any real number for SHIFT and DIVISOR options specified above.

Card 9 - FIELDTYPE Spatial and non-spatial field data interpolation

This card specifies internal codes for dependent and independent variables for the spatial field specified in Card 9 - FIELDDATA Spatial and non-spatial field types definition.

```
KODE, T1, N1, IND1, IND2, IND3, IND4
```

`KODE` = `FIELDTYPE`

`T1` is the table ID.

`N1` is the code for dependent variable. The dependent variable can be any variable supported in Card 9 - ARRAYTYPE Array Variable Definition Card - Optional and Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

`IND1` ... `IND4` are the codes for the independent variables.

The maximum number of independent variables that you can define is 4.

The maximum number of independent variables is 4, of which 3 are spatial independent variables.

Supported spatial fields

The FIELDTYPE and FIELDDATA cards are used for 1-D. 2-D, 3-D, and 4-D tables and can support any of the following domains:

- Cylindrical: PHI (1D field), AXIAL or Z (1D field), RADIUS-AXIAL (2D field), RADIUS-AXIAL-THETA (3D field)
- Spherical: THETA-PHI (2D field), RADIUS-THETA-PHI (3D field)
- Cartesian: X or Y or Z (1D field), X-Y or Y-Z or X-Z (2D field), X-Y-Z (3D field)
- Time as an independent variable that can be used with any 1D-2D-3D spatial tables. Thus, addition of time leads to the specification of table of fields in time.

Card 9 - FMHDEF - Free Molecular Heating Request Cards - Optional

The FMHDEF1-FMHDEF3 Cards define a free molecular heating (FMH) request.

`FMHDEF1` , `ID` , `SHADOPT` , `TIME` , `FRONTGRP` , `REVGRP`

`FMHDEF2` , `ID` , `HEATFLUXMODE` , `FLUX` , `VELOCITY` , `DENSITY`

`FMHDEF3` , `ID` , `FMHACC` , `HEATFLUXDIR` , `VECX` , `VECY` , `VECZ` , `TX` , `TY` , `TZ`

`ID` is the free molecular heating request number. ID is an integer value common to all associated FMHDEF Cards.

FMHDEF1, ID, SHADOPT, TIME, FRONTGRP, REVGRP

FIELD	VALUE	DESCRIPTION
`FMHDEF1`	FMHDEF1 or 68	mnemonic
`ID`	integer	ID number
`SHADOPT`	FMHS1	Shadowing for some elements
	FMHSALL	Shadowing for all elements
`TIME`	Real value	Time value

	CONSTANT	Flag CONSTANT
	Blank	blank (SHADOPT=FMHSALL) defaults to CONSTANT
FRONTGRP	mnemonic or integer	Element ID or group name of front facing elements
REVGRP	mnemonic or integer	Element ID or group name of reverse facing elements

FMHDEF2, ID, HEATFLUXMODE, FLUX, VELOCITY, DENSITY

FIELD	VALUE	DESCRIPTION
FMHDEF2	FMHDEF2 or 69	mnemonic
ID	integer	ID number
HEATFLUXMODE	FLUX	The heat flux is entered by the user
	VELOCITY_DENSITY	The velocity and density are entered by the user
	DENSITY	The density is entered by the user while the velocity is calculated from orbit
	ALTITUDE_DENSITY	The density is altitude dependent. The altitude and the velocity are calculated from orbit.
FLUX	Real value	Value for constant flux
	Table	Table for time dependent flux
VELOCITY	Real value	Value for constant velocity

	Table	Table for time dependent velocity
`DENSITY`	Real value	Value for constant density
	Table	Table for time dependent density

FMHDEF3, ID, FMHACC, HEATFLUXDIR, VECX, VECY, VECZ, TX, TY, TZ

FIELD	VALUE	DESCRIPTION
`FMHDEF3`	FMHDEF3 or 70	mnemonic
`ID`	integer	ID number
`FMHACC`	Real value	FMH accommodation factor
`HEATFLUXDIR`	VECTOR	Direction defined by vector VECX, VECY, VECZ or table TX, TY, TZ
	ORBIT	Direction obtained from orbit definition

Note

The incident flux q_i generated by free molecular heating is $0.5 * \rho * \mathrm{V}^3$
Where:

- ρ is the atmospheric density
- *V* is the spacecraft's velocity

The amount of heat absorbed (q_a) is equal to the incident flux multiplied by the accommodation coefficient, α; 0 ≤ α ≤ 1.
$q_a = \alpha \times q_i$

Example

```
$ ----------------------
$ Free Molecular Heating
$ ----------------------
$
MONTECARLO ON 2000 ABSOLUTE HTFRAD 0
```

```
FMHDEF1 1 FMHSALL CONSTANT
FMHDEF2 1 FLUX  1.000000E+02 NONE 0 NONE 0
FMHDEF3 1 1.000000E+00 VECTOR 1.0 1.0 1.0 T42 T43 T44
MONTECARLO OFF
```

Card 9 - FREEFACE Element Free Face Generation Card - Optional

KODE, N1, T1, T2, T3, T4, T5, T6, T7, T8, T9

`N1` is a group name. The elements generated by this Card will be assigned this group name.

`T1` is a flag `=` `0` or `1` . `T1` = `0` means the element generated by this Card cannot radiate, `T1` = `1` means they can. If the generated elements are beams or lump masses they cannot radiate.

`T2` is an element number on whose face/edge an element is to be generated.

`T3` is the face/edge number associated with element `T2` .

`T4` is an element number on whose face/edge an element is to be generated (optional).

`T5` is the face/edge number associated with element `T4` .

`T6` is an element number on whose face/edge an element is to be generated (optional).

`T7` is the face/edge number associated with element `T6` .

`T8` is an element number on whose face/edge an element is to be generated (optional).

`T9` is the face/edge number associated with element `T8`.

Notes

This Card generates elements on the faces or edges of specified elements. The generated elements are all assigned the group name `N1`, which may be used in the same way as other group names defined on the Card 9 NAME Cards.

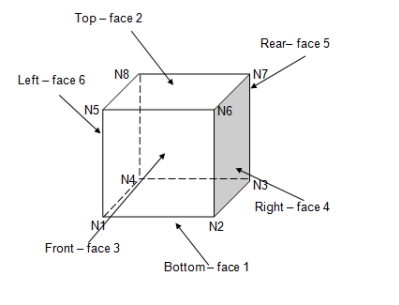
The orientation of shell elements generated on faces of solid elements is such that the shell elements face outwards. This allows them to radiate, provided the underlying element has a proper emissivity defined, and provided the generated element is not flagged as non-radiating with a Card 9 PARAM NORAD Card. Shell elements between generated between two solid elements, beams, and lump masses cannot radiate.

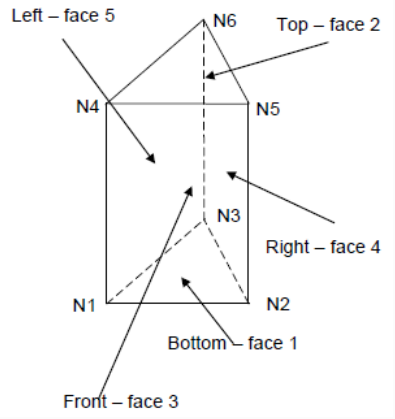
In case an element already exists on a specified face, a new element will not be created. Instead, the existing element will be added to the group `N1`.

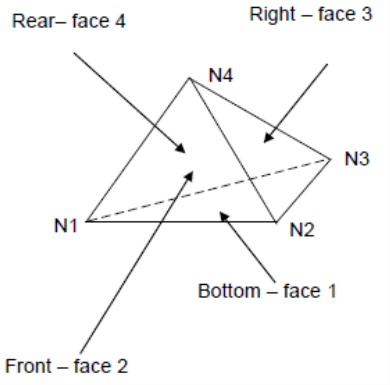
If multiple FREEFACE requests exist for the same element face, only a single element will be generated, and it will be added to all the specified group names.

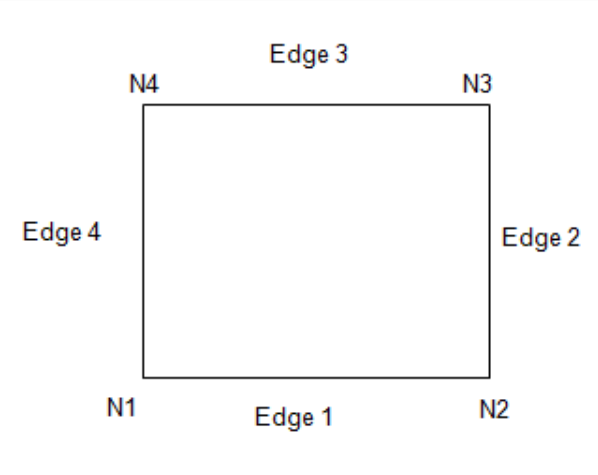
A generated beam is assigned a surface area equal to the thickness of the underlying shell, and a generated lump mass is assigned the surface are of the underlying beam. If the generated beam or lump mass is connected to more than one element, it is randomly assigned the surface area of the one of the underlying elements.

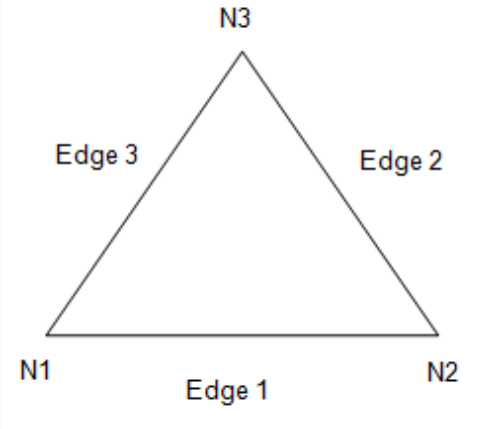
The numbering convention for the free faces and edges in relation to the nodes is as follows











Card 9 - GENERIC Generic Entity Cards - Optional

```
GENERIC1 N1 String1
GENERIC2 N1 String2
GENERIC3 N1 Group1
GENERIC4 N1 Group2
GENERIC5 N1 R1, R2, R3, R4, R5, R6, R7, R8
GENERIC6 N1 I1, I2, I3, I4, I5, I6
```

`N1` is the ID associated with the `GENERIC` Cards.

`String1` is a character string if 80 characters or less.

`String2` is a character string if 80 characters or less.

`GRP1` is group name in NAME2 long format. It must exist in the INPF. Card `GENRIC3` is optional.

`GRP2` is group name in NAME2 long format. It must exist in the INPF. Card `GENRIC4` is optional.

`R1-R8` are up to 8 real characters associated with the generic entity.

`I1-I8` are up to 8 integer characters associated with the generic entity.

Notes

This Card defines a set of generic entities for the model. The generic entities may be accessed from the Analyzer in a user-written subroutine with `CALL GENERIC`.

Example

```
GENERIC1 5 This is string 1
GENERIC2 5 This is string 2
GENERIC3 5 This is group name 1
GENERIC4 5 This is group name 2
GENERIC5 5 111.0 112.0 113.0 114.0 115.0 116.0 117.0 118.0
GENERIC6 5 121 122 123 124 125 126 127 128
NAME2 NAME1 This is group name 1
NAME2 NAME2 This is group name 2
```

The following example shows how to define a directional radiance using the ID associated with RADIANCE_DIRECTION. Radiance of an element is described in Card 9 - PRINT Analyzer Printout Codes - Optional.

Example

```
GENERIC1 5 RADIANCE_DIRECTION
GENERIC5 5 1.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
1.000000E+00  30.000000E+00  0.000000E+00
```

where:

- The `R1` , `R2` and `R3` values in `GENERIC5` are the reference directional vector components X, Y and Z, respectively.
- The values `R4` , `R5` and `R6` define the components for the rotation axis X, Y and Z, respectively.
- The `R7` value defines the rotation angle.

If an axis of rotation and an angle value are specified, the thermal solver computes the radiance for several angles. The reference directional vector rotates on an angle `R7` counterclockwise around the axis of rotation, until a full 360 degree rotation is covered.

Card 9 - GLOBAL_AXIS Global Axis of Revolution - Optional

KODE, N1

`KODE` = `GLOBAL_AXIS` (or `102`)

`N1` is the axis of revolution is represented by Card 9 VECTOR card. The ID of the referenced Card 9 - VECTOR Vector Definition Card - Optional is specified in `N1` .

Example

```
$
$ --------------------------------------
$ Thermal Rotational Periodicity Objects
$ --------------------------------------
$
$ Thermal Rotational Periodicity(2)
ROTPER 3 TYPE RADIATIVE
ROTPER 3 AXIS GLOBAL
ROTPER 3 ANGLE  6.000000E+01
$
GLOBAL_AXIS  7
VECTOR  7  0.0  0.0  0.0  1.0  0.0  0.0
$
```

Card 9 - GLOBALCYC_AXIS Cyclic Symmetry Axis of Revolution - Optional

`KODE, N1, T1, T2`

`KODE` = `GLOBALCYC_AXIS` (or `113`)

`N1` is the axial axis of revolution that is represented by Card 9 VECTOR card. The ID of the referenced Card 9 - VECTOR Vector Definition Card - Optional is specified in `N1`.

`T1` is the radial axis of revolution that is represented by Card 9 VECTOR card. The ID of the referenced Card 9 - VECTOR Vector Definition Card - Optional is specified in `T1`.

`T2` is the tangential axis of revolution that is represented by Card 9 VECTOR card. The ID of the referenced Card 9 - VECTOR Vector Definition Card - Optional is specified in `T2`.

Example

```
$
$ -------------------------------------
$ Thermal Rotational Periodicity Objects
$ -------------------------------------
$
GLOBALCYC_AXIS  1 2 3
VECTOR 1  0.000000E+00  0.000000E+00  0.000000E+00  1.000000E+00  0.000000E+00
0.000000E+00
VECTOR 2  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  1.000000E+00
0.000000E+00
VECTOR 3  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
1.000000E+00
```

Card 9 - GPARAM Parameter Card - Optional

KODE, N1, T1, T2

This Card defines or overrides run-time parameters for the model.

`KODE` = `GPARAM` (or `41`)

`N1` is an internal number referring to a TMG module.

`T1` is the parameter index in module `N1`.

`T2` is the parameter value.

Note

GPARAM cards are used to activate advanced thermal parameters. A list of these is given in the example below.

Example

```
GPARAM  0  21  1   $ The thermal postprocessor processes REPORTER Cards.
GPARAM  0  35  1   $ indicates that TMG refreshes REPORTER Cards on surfaces.
GPARAM  0  36  1   $ indicates REPORTER Cards are refreshed.
GPARAM  1  153  1   $ Flag for file handling when REPORTER Cards are refreshed.
GPARAM  1  313  0   $ Creates a perfect contact coupling using large conductances
relative to other conductances between groups of elements specified in perfect contact
requests.
GPARAM  4  420  0   $ Allow all elements to shadow.
GPARAM  4  420  1   $ Limit shadowing checks to the requested enclosure.
GPARAM  12  725  0   $ Use first order formulation for quadrilateral shells.
GPARAM  12  792  0   $ Do not account for conduction in hydraulic fluid flow.
GPARAM  12  861  1   $ indicates the thermal solver will compute heatflow and/or view
factor REPORTER Cards.
GPARAM  12  1055 1   $ Activates Petukhov correlation for laminar and turbulent fully
developed duct flow.
GPARAM  12  1084  1   $ Printout times match integration times.
```

```
GPARAM  12  1281  4   $ The thermal solver will use 4 threads in matrix assembly
parallelization.
GPARAM  12  1484  1   $ Do not apply extrapolation limitation to the nodal temperatures
used in computing the error estimates.
GPARAM  12  1485  1   $ Wherever two or more BCs intersect do not actually compute the
error estimates on the closest (to the intersection nodes) three layers of elements.
Apply to these elements an error estimate inherited from the inner neighbors.
GPARAM  12  1563  1   $ Activates Sieder-Tate's correlations for laminar developing duct
flow.
GPARAM  38  15  0   $ Use first order formulation for quadrilateral shells.
GPARAM  56  28  1   $ Activate on-screen rendering for the hemicube method.
GPARAM  56  30  0.05   $ Sum of disposed radiation view factors less than 0.05.
GPARAM  1000  72  -2   $ Equivalent to PARAM CAPDIST OFF.
```

Card 9 - GRAVITY Gravity Definition Cards - Optional

KODE, N1, T1, T2, T3

`KODE` = `GRAVITY` (or `98`)

`N1` is the GRAVITY card ID. Cards with the same ID reference the same Gravity definition.

`T1` may be:

= `X` (or `1`)

= `Y` (or `2`)

= `Z` (or `3`)

= `MAGNITUDE` (or `4`)

`T1` = `X` or `Y` or `Z` represents the `X` or `Y` or `Z` components of the gravity vector. If a component is constant, then its value is specified in `T2.` If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`)

where `n` is a table number referencing TABTYPE and TABDATA cards. The dependent variable on the TABTYPE card must be NUMBER, and the independent variable is TIME.

`T1` = `MAGNITUDE` is the magnitude of the gravity acceleration. If the magnitude is constant, then its value is specified in `T2`. If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE and TABDATA cards. The dependent variable on the TABTYPE card must be NUMBER, and the independent variable is TIME.

- When the MAGNITUDE card is present in a GRAVITY definition, it overrides the magnitude of the gravity vector defined through the `X`, `Y`, and `Z` components. In this case, the components provide the gravity direction only. When the MAGNITUDE card is not present in a GRAVITY definition, both the gravity direction and magnitude are derived from the `X`, `Y`, and `Z` components of the gravity vector.

Notes

If a GRAVITY definition is present, it overrides the gravity magnitude and direction in the HYDENV card. If more than one GRAVITY definition is present, a warning is issued and only the first definition is retained.

Example

```
GRAVITY 1 X 0.0
GRAVITY 1 Y 0.0
GRAVITY 1 Z -1.0
GRAVITY 1 MAGNITUDE 1.0 T25
TABTYPE 25 NUMBER TIME
TABDATA 25 9.81 0.0
```

Card 9 - GROUP - Optional

References a group of selected nodes or elements.

KODE, N1, T1, T2

`KODE` = `GROUP` (or `103`)

`N1` is the GROUP card ID.

`T1` may be:

= `DESCRIPTION` `(` or `3)`

= `ELEMENTS` `(` or `2)`

= `NODE` `(` or `1)`

`T1` = `DESCRIPTION` `(` or `3)` specifies the name of the GROUP in `T2`

`T1` = `ELEMENTS` `(` or `2)` specifies that the GROUP contains selected elements.

`T1` = `NODE` specifies that the GROUP contains selected nodes.

`T2` : If `T1` is `NODE` or `ELEMENT` then `T2` will have the form of `Ln`, which references the `LABELLIST` card with ID `n`. `LABELLIST Ln` will contain the list of nodes (if `T1` is `NODE)` or elements (if `T1` is `ELEMENT`) labels `.`

Example

```
GROUP 5 named BOX contains elements 1 through 24, 30, 35, and 40.
GROUP               5        DESCRIPTION          BOX
GROUP               5        ELEMENT              L29
LABELLIST          29         1         24          1
LABELLIST          29        30         40          5
```

Card 9 - HEAT_LOAD Heat Load Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `HEAT_LOAD` (or `124`) defines a heat load to a selection of elements or a group name.

`N1` is the HEAT_LOAD card ID. Cards with the same ID reference the same Heat Load simulation object.

`T1` is:

`= NAME` (or `1`)

`= SELECTION` (or 2)

`= TYPE` (or `3`)

`= MAGNITUDE` (or `4`)

`= DISTRIBUTION` (or `5`)

`= MULTILAYER` (or `6`)

`T1 = NAME` specifies the Heat Load simulation object name in `T2`.

`T1 = SELECTION` specifies a selection of elements on which the Heat Load simulation object is applied. The element selection is represented by the group name `T2`.

`T1 = TYPE` specifies the heat load type in `T2`.

- `T2 = LOAD` (or `1`) specifies a heat load on the selected elements.
- `T2 = FLUX` (or `2`) specifies a heat load, per unit area, on the selected elements.
- `T2 = GENERATION` (or `3`) specifies a heat load, per unit volume, on the selected elements. For planar and beam elements, the volume is calculated by multiplying the length or area by the cross-sectional area or thickness.

`T1 = MAGNITUDE` specifies the heat load value in `T2`.

- If the heat load is constant, then its value is specified in `T2`.
- If the heat load is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`), where `n` is a table number referencing TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card is the `HEAT_LOAD`.
- If the heat load is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing the EXPRESSION card.

  If the heat load type `LOAD` is not distributed per element, it is redistributed among the selected group elements in proportion to their areas or volumes as:

$$Q(1) = T2\frac{\Omega(T2, X(I))AV(I)}{\sum_{i}^{n} AV(i)}$$

where:

- $AV(I)$ is either the volume (for solid elements), or area of element `I` (for shells and beams), or unity (for non-dimensional elements), where `I` is a member of the selected group elements. All the elements of the selected group must be of the same type, for example, do not mix solid and non-solid elements.
- $Q(I)$ is the heat load to element `I`, which is a member of the selected group.
- $\Omega(T2, X(I))$ is the interpolated variable, where `T2` is a table.
- n is the number of selected elements.

If `T2` is a spatial table (field or EID dependent), then $Q(I)$ is calculated with a weighting factor $\Omega(I)$ that is interpolated from this table:

$$Q(I) = T2\frac{\Omega(I)AV(I)}{\sum_{i}^{n} \Omega(i)AV(i)}$$

When `T2` includes a reference to an expression, either directly or through a table, then each spatial field, referenced in that expression is normalized by a factor that makes the area-weighted average of that field equal to one. The averaging is performed over the selected elements group.
If the selected group is a single element, the heat load is applied to the element.

`T1 = DISTRIBUTION` specifies that the `LOAD` type is distributed per elements in `T2`.

- If the heat load is distributed per element over the selected elements, then `T2 = PER_ELEMENT` (or `1`).

`T1= MULTILAYER` specifies the layer for multilayer elements in `T2`. Non-homogeneous multilayer elements are specified on LAYER Cards, and homogeneous multilayer elements are specified on PROP Cards.

- If the heat load is applied to the top layer, then `T2` = `TOP` (or `1`).
- If the heat load is applied to the middle layer, then `T2 = MIDDLE` (or `2`).
- If the heat load is applied to the bottom layer, then `T2 = BOTTOM` (or `3`).
- If the heat load is applied to all layers, then `T2 = ALL` (or `4`).
- If the heat load is applied to a specified layer, then `T2 = SPECIFY` (or `5`). `SPECIFY` identifies the layer number in `T3` and is counted from the top layer. For example, `T3 = 1` is the same as `T3 = TOP`.

Example

```
$ Heat_LOAD_BC(1)
NAME2 Heat_LOAD_BC(1) Heat_LOAD_BC(1)
NAME Heat_LOAD_BC(1)        380         15          1
```

```
HEAT_LOAD 1 NAME "Heat_LOAD_BC(1)"
HEAT_LOAD 1 SELECTION "Heat_LOAD_BC(1)"
HEAT_LOAD 1 TYPE LOAD
HEAT_LOAD 1 MAGNITUDE 15
HEAT_LOAD 1 DISTRIBUTION PER_ELEMENT
HEAT_LOAD 1 MULTILAYER SPECIFY 1
```

Card 9 - HEAT_PIPE Heat Pipe Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE = HEAT_PIPE` (or 129) defines a heat pipe to a selection of elements or a group name.

`N1` is the HEAT_PIPE card ID. Cards with the same ID reference the same Heat Pipe simulation object.

`T1` is:

= `NAME(` or `1)`

= `SELECTION(` or `2)`

= `HTC_EVAPORATION(` or `3)`

= `HTC_CONDENSATION(` or `4)`

= `QMAX(` or `5)`

= `COND(` or `6)`

= `TMIN(` or `7)`

= `TMAX(` or `8)`

`T1 = NAME` specifies the Heat Pipe simulation object name in `T2`.

`T1 = SELECTION` specifies a selection of elements on which the Heat Pipe simulation object is applied. The element selection is represented by the group name `T2.`

`T1 = HTC_EVAPORATION` specifies an evaporation heat transfer coefficient in `T2`.

- If the evaporation heat transfer coefficient is constant, then its value is specified in `T2`.
- If the evaporation heat transfer coefficient is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards.
- If the evaporation heat transfer coefficient is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1 = HTC_CONDENSATION` specifies a condensation heat transfer coefficient in `T2`.

- If the condensation heat transfer coefficient is constant, then its value is specified in `T2`.
- If the condensation heat transfer coefficient is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards.
- If the condensation heat transfer coefficient is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1 = QMAX` (optional) specifies the maximum heat flux in `T2`.

- If the maximum heat flux is constant, then its value is specified in `T2`.
- If the maximum heat flux is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`), where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card is `COND`.
- If the heat load is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1= COND` (optional replacement of `HTC_EVAPORATION` or `HTC_CONDENSATION` settings) specifies the total conductance in `T2`.

- If the total conductance is constant, then its value is specified in `T2`.
- If the total conductance is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`), where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card is `QNODE`.

- If the total conductance is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1 = TMIN` (optional) specifies the minimum temperature in `T2` . If the heat pipe vapor temperature goes below `TMIN,` then the heat flow through that heat pipe is turned off.

`T1 = TMAX` (optional) specifies the maximum temperature in `T2` . If the heat pipe vapor temperature goes above `TMAX,` then the heat flow through that heat pipe is turned off.

Example

```
HEAT_PIPE 300 NAME "Heat Pipe(1)"
HEAT_PIPE 300 SELECTION "Thermal Stream(1)"
HEAT_PIPE 300 HTC_EVAPORATION 1.0E+5
HEAT_PIPE 300 HTC_CONDENSATION 1.0E+5
HEAT_PIPE 300 QMAX 1.0E+5 T5
HEAT_PIPE 300 TMIN -100.0
HEAT_PIPE 300 TMAX 600.0
HEAT_PIPE 300 COND 1.0E+7 T6
```

Card 9 - HYDENV Hydraulic Element Environment Definition Card - Optional

KODE, N1, T1, T2, T3, T4, T5, T6

`KODE` = `HYDENV` (or `25`)

`N1` is the absolute (not gauge) value of the static pressure of the Card 5 AMBIENT elements. `N1` also defines the zero gauge pressure and the standard pressure values at which the densities on the MAT Cards are defined. The nominal value for 1 atmosphere in `SI` units is `101,351 Newtons/m2.`

`T1` is the temperature of the Card 5a AMBIENT elements and the standard temperature at which the fluid densities on MAT Card are defined. The nominal room temperature value in `SI` units is `20C` .

`T2` is the magnitude of the acceleration of gravity, `9.81 m/sec2` in `SI` units.

`T3` is the angle in degrees between the model's global Z axis and the gravity vector. Down is considered positive (i.e. if the Z axis points upwards, `T3` should be `180`).

`T4` is the angle in degrees between the X axis and the projection of the gravity vector on the global XY plane.

`T5` is optional – it may be the code `SAMEMAT`, or blank, or `0`. If `T5` is `SAMEMAT`, then the buoyancy forces for hydraulic networks are calculated by assuming the material of the AMBIENT element is the same as the material of the hydraulic element, and the buoyancy forces are driven solely by their temperature difference. For this option, it is not necessary to define a Card 5a AMBIENT element.

`T6` is optional. If `T6` is `SAMEMAT`, then `T6` may take on the format `Tn` (e.g. `T136)`, were n is the number of a temperature vs time table, defined with a TABTYE and TABDATA Cards, describing the temperature of the AMBIENT environment. This is used for buoyancy calculations only.

Notes

This Card defines the properties of the ambient environment for hydraulic elements. It is mandatory if Card 5a hydraulic elements are present in the model.

Example

```
HYDENV 101351 20 9.81 180 0 SAMEMAT
$ AMBIENT ENVIRONMENT DEFINED IN SI UNITS
```

Card 9 - IMMERSEDDUCTS Immersed Ducts Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE = IMMERSEDDUCTS ( or 122)`

`N1` is the IMMERSEDDUCTS card ID. Cards with the same ID reference the same Immersed Ducts simulation object.

`T1` may be:

= `NAME ( or 1)`

= `FLUID_SELECTION ( or 2)`

= `HTC ( or 3)`

`T1` = `NAME` specifies the Immersed Ducts simulation object name in `T2` .

`T1` = `FLUID_SELECTION` specifies a selection of 1D fluid elements to which the Immersed Ducts simulation object is applied. The selection is represented by the group name `T2.`

`T1` = `HTC` specifies a heat transfer coefficient for the convection between the selected 1D fluid elements and the surrounding solid elements.

- If the heat transfer coefficient is constant, then its value is specified in `T2` .
- If the heat transfer coefficient is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` , for example, `T25` where n is a table number referencing the TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `COND` .
- If the heat transfer coefficient is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` , for example, `E25` where n is an expression number referencing the EXPRESSION card.

Example

```
$ Immersed Ducts(1)
NAME2 Immerse Immersed Ducts(1)
NAME Immerse          1         10          1
IMMERSEDDUCTS 1 NAME "Immersed Ducts(1)"
```

```
IMMERSEDDUCTS 1 FLUID_SELECTION "Immersed Ducts(1)"
IMMERSEDDUCTS 1 HTC  1.000000E+08 0
```

Card 9 - INCLAXI Include Axisymmetric Elements Definition Card - OBSOLETE

KODE, N1

`KODE` = `INCLAXI` (or `58`)

`N1` is a group name.

Notes

This Card causes the axisymmetric elements generated for radiation calculations from the axisymmetric elements of group `N1` to also be included in the group `N1`. For an explanation of the axisymmetric element creation card, see the Card 9 - AXISYMM Axisymmetric Element Creation Card - Optional.
The INCLAXI Card is useful for creating thermal couplings between axisymmetric elements and non-axisymmetric elements. In this case, the Card PARAM AXIMERGE is also useful.

The following example shows how the INCLAXI Card could be used together with PARAM AXIMERGE and AXISYMM to couple a group of non-axisymmetric elements to a group of axisymmetric elements generated from a group of axisymmetric elements.

Example

```
--Card 6--
$
$ Card 6e thermal coupling between non-axisymmetric GROUP1 and axisymmetric
$ GROUP2 elements
$
AREA GROUP1 0 3 GROUP2 0 1 NEARC23
$
--Card 9–
$
$ Axisymmetric Card which expands all axisymmetric elements into 8 axisymmetric elements
$
AXISYMM 0 8
$
$ GROUP1 are elements that are not axisymmetric
```

```
$
PARAM NOAXISYM GROUP1
$
$ GROUP2 elements are automatically axisymmetric elements because of the
$ AXISYMM Card above.
$
INCLAXI GROUP2
$
$ The following merges all the axisymmetric elements in GROUP2 with the original
$ axisymmetric elements.
$
PARAM AXIMERGE
```

Card 9 - INTERP Analyzer Table Interpolation - Optional

KODE, N1, T1, T2, T3, T4, T5, T6

`KODE` = `INTERP` (or 7)

`N1` is the element number, group name, or conductance number of the dependent variable. The interpolated variable is applied on `N1`.

If `N1` is a group name, the interpolated variable is applied on all the elements of the group, and `T1` should be 0.

`T1` is the element number, group name, or conductance number of the independent variable.

If `T1` is a group name, the value of the independent variable is averaged over the elements of that group.

`T1 = 0` defaults to `T1 = N1.`

`T2` is a table or expression number.

`T3` may be a multiplying factor for the interpolated variable. The dependent variable `Y(I)` at element I is computed by interpolation from the table `T2` by:

$$Y(I) = T3\Omega(T2, X(T1, I))$$

where:

- $Y(I)$ is the computed dependent variable at element `I`
- $X(T1, I)$ is the independent variable at elements `I` and `T1`
- I is an element number that is part of the group `N1`
- $\Omega(T2)$ represents the result of the interpolation procedure over table `T2`

`T3` may be the code `AREA` (or `1E36`), in which case the interpolated variable `Y(I)` is multiplied by the area of `I`.

$$Y(I) = T4\Omega(T2, X(I))AREA(I)$$

`T3` may be the code `VOLUME` (or `3E36`), in which case the interpolated variable `Y(I)` is multiplied by the volume of `I`. For planar and beam elements the volume is calculated by multiplying the length or area by the cross-sectional area or thickness.

$$Y(I) = T4\Omega(T2, X(I))VOLUME(I)$$

`T3` may be the code `TOTAL` (or `2E36`), in which case the interpolated variable (e.g. heat load) is redistributed among the elements of group `N1` in proportion to their areas or volumes.

$$Y(I) = T4\frac{\Omega(T2, X(I))AV(I)}{\sum_{i}^{N1} AV(i)}$$

where:

- $AV(I)$ is either the volume (for solid elements) or area of element I (for shells and beams), or unity (for non-dimensional element), where `I` is a member of the `N1` group. For the TOTAL option all the elements of group `N1` must be of the same type, i.e. solid and non-solid elements may not be mixed.

If table `T2` a spatial table (field or EID dependent), then `Y(I)` is calculated with a weighting factor `Ω(I)` interpolated from this table:

$$Y(I) = T4\frac{\Omega(I)AV(I)}{\sum_{i}^{N1}\Omega(i)AV(i)}$$

`T4` is a multiplying factor for the interpolated variable, effective only if `T3` = `AREA`, `VOLUME`, or `TOTAL`. For all other options it defaults to 1.

`T5` specifies the layer for multilayer elements:

= `0` or blank indicates that the element is not a multilayer. For non-uniform multilayers, `T5 = 0` or blank is identical to `T5 = TOP`. For uniform multilayers, `T5 = 0` or blank is identical to `T5 = MIDDLE`.

= `TOP` indicates that heat load is applied to the top layer.

= `MIDDLE` indicates that the heat load is applied to the middle layer.

= `BOTTOM` indicates that the heat load is applied to the bottom layer.

= `ALL` indicates that the heat load is applied to all layers.

= `SPECIFY` or `FROMBOT` indicates that the heat load is applied to the `T6` th layer.

`T6` is the layer number counted from the bottom layer of the multilayer. It is only used if `T5` = `SPECIFY` or `FROMBOT`.

Notes

- The value of the dependent variable is calculated by linear table interpolation at each Analyzer iteration or time step and multiplied by `T3` or `T4.`
- Table `T2` is defined with TABTYPE or FIELDTYPE Cards. TABTYPE and FIELDTYPE Cards define the type of the independent and dependent variables. TABDATA and FIELDDATA Cards contain the table data. Alternatively, `T2` may reference a bivariate array defined by ARRAYTYPE and ARRAYDATA Cards.
- A conductance-dependent variable `Y(N1)` is evaluated differently from the above procedure:

$$Y(I) = T3\Omega(T2, X(T1, I))GORIG$$

- where:

- `GORIG` is the conductance parameter calculated from geometry by the `COND`, `GRAYB`, or `VUFAC` modules, or created with XCOND Cards.
- `N1` is the conductance number. The conductance number may be specified on XCOND Cards, or it may be automatically assigned. For this case, it may be obtained from the report log file with a `PRINT HFGROUP` printout.
- For this option, the TABDATA Cards of table `T2` should contain a conductance multiplier. The dependent variable code on the TABTYPE Card of table `T2` must be `COND.`

For more information on how the table data carried through to the SINDA file on file FMODLF, see the REFORM Module.
In addition to INTERP Cards, tables may also be referenced from Card 6e thermal couplings, user-written subroutines, PROP Physical Property Cards, and MAT Material Property Cards.

Example

```
INTERP 2 1 3 3.0
TABTYPE 3 QNODE TEMP
TABDATA 3 2 4
TABDATA 3 8 10
$ INTERPOLATES HEAT LOAD TO ELEMENT 2 AS A FUNCTION
$ OF TEMP OF ELEMENT 1. FOR A TEMP OF 7.0 THE
$ CALCULATED HEAT LOAD = 15
$ = 3*((7-4)/(10-4)*(8-2)+2)
```

Card 9 - JOINT Articulation Joint Definition - Optional

KODE, N1, T1, T2, T3

`KODE` = `JOINT` (or `50`)

`N1` is the joint number.

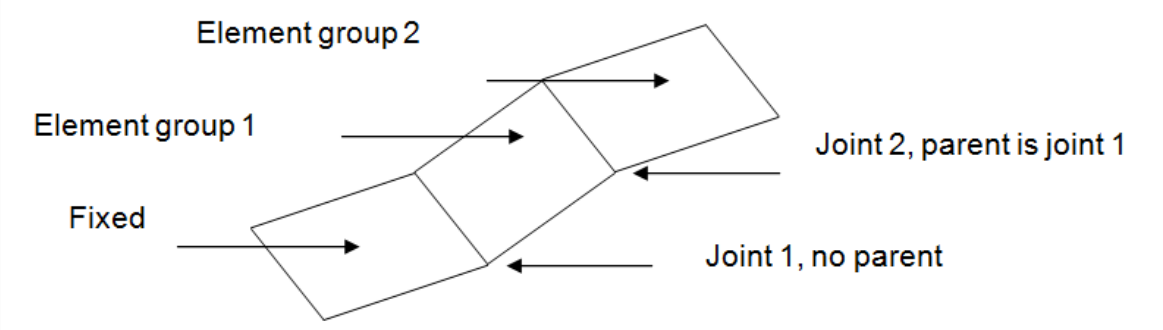
`T1` is the joint type. It can be REVOLUTE for a rotational joint or TRANSLATIONAL for a translational joint.

`T2` is a parent joint number. The parent joint number is zero when the joint is a primary joint. See below.

`T3` is a vector number. For a rotational joint, the elements rotate about the given vector. For a translational joint, the elements move along the given vector. For more information, see Card 9 - VECTOR Vector Definition Card - Optional.

Notes

The movement of an articulating member is defined by both ARTICUT and JOINT Cards. An articulation may consist of multiple joints. These joints form a chain.
An example of such a joint chain is a robotic arm. The multi-joint articulation is handled by assigning a parent to a joint to represent the relative movement. A parent of a joint can have its own parent. Only the first joint in a chain has no parent.



The joint definition is used with an articulation definition card 9 ARTICUT. The joint number of the joint definition card is associated with the same joint number of the articulation definition card.

Example

```
ARTICUT 1 ARTICG1 5.
JOINT   1 REVOLUTE 0 1
VECTOR  1 0. 0. 0. 0. 0. 1.
$
$ ELEMENTS IN GROUP ARTICG1 ROTATE AT A SPEED OF 5 DEGREES PER SECOND ABOUT
$ VECTOR 1.
$
ARTICUT 2 ARTICG2 10.
JOINT   2 REVOLUTE 1 2
```

```
VECTOR  2 1. 0. 0. 0. 0. 1.
$
$ ELEMENTS IN GROUP ARTICG2 ROTATE AT A SPEED OF 10 DEGREES PER SECOND ABOUT
$ VECTOR 2 RELATIVE TO ELEMENTS OF GROUP ARTICG1. THE ABSOLUTE MOVEMENT OF JOINT 2
$ IS THE MOVEMENT OF JOINT 2 RELATIVE TO JOINT 1 PLUS THE MOVEMENT OF JOINT 1.
```

Card 9 - JUNCTION_3DFLOW Ducts/Streams Junction to 3D flow definition - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE = JUNCTION_3DFLOW` (or `134`) defines the ducts/streams junction to 3D flow entity.

`N1` is the `JUNCTION_3DFLOW` card ID. Cards with the same ID reference the same ducts/streams to 3D flow junction.

`T1` may be:

= `NAME` (or 1)

`= FLUID_SELECTION` (or 2)

`= DUCT_ELEMENT` (or 3)

`= DUCT_NODE` (or 4)

= `TYPE` (or 5)

= `TRANSFER` (or 6)

`= ENTRY` (or 7)

`T1` = `NAME` indicates the name for the ducts/streams junction that is specified in `T2`.

`T1 = TYPE` indicates the flow direction that is specified in `T2`.

`T2` may be:

- `T2 = INFLOW` (or 1) indicates that the flow is entering into the 3D fluid domain.
- `T2 = OUTFLOW` (or 2) indicates that the flow is leaving the 3D fluid domain.

`T1 = TRANSFER` indicates the transfer option that is specified in `T2`.

`T2` may be:

- `T2 = MASS` (or 1) indicates that the mass flow is transferred between the junction and the 3D fluid domain.
- `T2 = PRESSURE` (or 2) indicates that the absolute pressure is transferred between the junction and the 3D fluid domain. `T3` specifies the absolute pressure value. `T4` specifies the table or expression used to calculate pressure instead of junction pressure.

`T1 = DUCT_NODE` specifies the duct node that is connected to the junction.

`T2` may be:

- `T2 = FLOW_SIDE` (or 1) indicates the node attached to the 3D CFD domain. `T3` is the 0D element number.
- `T2 = TMG_SIDE` (or 2) indicates the node attached to the 1D duct domain. `T3` is the 0D element number.

`T1 = DUCT_ELEMENT` specifies the duct element, specified in `T2,` that is connected to the junction. `T2` is the element number.

`T1 = ENTRY` specifies that a duct or a stream, specified in `T2`, is connected to the junction.

`T2` may be:

- `T2 = STREAM` (or 1) indicates a stream connected to the junction. `T3` is the thermal stream ID.
- `T2 = DUCT` (or -1) indicates a duct label connected to the junction. `T3` is the duct label ID.

Example

```
JUNCTION_3DFLOW 1 NAME "Junction-OutM"
JUNCTION_3DFLOW 1 TYPE OUTFLOW
JUNCTION_3DFLOW 1 TRANSFER MASS
JUNCTION_3DFLOW 1 DUCT_NODE FLOW_SIDE 339472
JUNCTION_3DFLOW 1 DUCT_NODE TMG_SIDE 339473
```

```
JUNCTION_3DFLOW 1 DUCT_ELEMENT 339474
JUNCTION_3DFLOW 1 ENTRY STREAM 4
JUNCTION_3DFLOW 1 ENTRY DUCT 1
```

Card 9 - JUNCTION Thermal Streams Junction Definition - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE = JUNCTION` (or `128`) defines the junction to connect thermal streams.

`N1` is the `JUNCTION` card ID. Cards with the same ID reference the same thermal streams junction.

`T1` may be:

= `NAME` (or `2`)

= `INLET` (or `1`)

= `OUTLET` (or `-1`)

`T1` = `NAME` indicates the name for the thermal streams junction that is specified in `T2`.

`T1 = INLET` specifies an inlet of the thermal boundary condition, indicated in `T3`, is connected at the thermal stream junction. `T2 = STREAM` indicates thermal streams are connected in the junction. `T3` is the internal index (from 1 to 20) and `T4` is `uid` UI label.

`T1 = OUTLET` specifies an outlet of the thermal boundary condition, indicated in `T3`, is connected at the thermal stream junction. `T2 = STREAM` indicates thermal streams are connected in the junction. `T3` is the internal index (from 1 to 20) and `T4` is `uid` UI label.

Example

```
JUNCTION 1 NAME "3To4-5"
JUNCTION 1 INLET STREAM 1 5
JUNCTION 1 OUTLET STREAM 1 3
```

Card 9 - KEEPDEL Element Keep/Delete Cards - Optional

KODE, N1, T1, T2

`KODE` = `KEEPDEL` (or `15`)

`N1` is an element number, or a group name.

`T1` is another element number, or `0`. `T1` must be `0` if `N1` is a group name.

`T2` may be:

`= DELETE (` or -1): All references to elements `N1` through `T1` will be deleted by the DATACH module, including Card 5 elements on INPF, the XCOND and XCAP Cards, and all references from files VUFF, MODLF, and MODLCF.

- `N1 = T1 = 0` defaults to all elements.

`= KEEP (` or 1): This option is similar to DELETE, except that only the elements `N1` through `T1` are kept, all others are deleted. All conductances or view factors with `N1` through `T1` as one of their elements, are kept.

- In case of conflict between KEEP and DELETE requests, the KEEP option prevails. For example, if one element of a conductance is to be kept while the other is to be deleted, the conductance is kept.
- `N1 = T1 = 0` defaults to all elements.

= `ALBDEL (` or `-13)` deletes all albedo heat loads from VUFF.

`= BVFDEL (` or `-10)` deletes all view factors from VUFF.

`= CAPDEL (` or `-5)` deletes capacitances from MODLF and INPF for elements `N1` through `T1`. `N1 = T1 = 0` defaults to all elements.

`= CAPMDEL (` or `-19)` deletes capacitances from `MODLF` only (not INPF`)` for elements `N1` through `T1`. `N1 = T1 = 0` defaults to all elements.

`= CONDDEL (` or `-6)` deletes all conductive conductances from MODLF.

`= CONDEL (` or `-2)` deletes conductive conductances, thermal couplings, and hydraulic flow resistances from MODLF and INPF for elements `N1` through `T1`. `N1 = T1 = 0` defaults to all elements.

`= EVFDEL (` or `-14)` deletes all Earth view factors from VUFF.

`= HTFALBDEL (` or `-15)` deletes all albedo heat loads from MODLF.

`= HTFIRDEL (` or `-16)` deletes all Earth IR radiative heat loads from MODLF.

`= HTFSOLDEL (` or `-12)` deletes all solar heat loads from MODLF.

`= HTFSOLDEL (` or `-12)` deletes all solar heat loads from MODLF.

`= HVFDEL (` or `-20)` deletes all heat flux view factors in all spectra from VUFF.

`= NEARCDEL (` or `-8)` deletes all thermal couplings from MODLF created with the Card 6e NEARCx options.

`= NEARXDEL (` or `-7)` deletes all thermal couplings and conductances including (radiative conductances) from MODLF created with the Card 6e NEARx, CONV, RAD, COND, CSERIES, RSERIES, and `FREE` options, but not those created with the NEARCx options.

`= QDEL (` or `-4)` deletes all radiative heat loads from MODLF.

`= RADDEL (` or `-3)` deletes radiative conductances from MODLF for elements `N1` to `T1`, except those created by Card 6e radiative thermal couplings. `N1 = T1 = 0` defaults to all elements.

`= SVFDEL (` or `-11)` deletes all solar view factors from VUFF.

Example

```
KEEPDEL BOX 0  KEEP
$ ONLY ELEMENTS OF BOX WILL BE KEPT
$
KEEPDEL 30 35  DELETE
$ ELEMENTS 30 THROUGH 35 WILL BE DELETED
$
KEEPDEL 1 9999 RADDEL
$ ALL RADIATIVE CONDUCTANCES DELETED
$
KEEPDEL 1 8CONDEL
$ ALL CONDUCTIVE CONDUCTANCES CONNECTED TO 1 THROUGH 8
$ DELETED FROM MODLF & MODLCF
$
KEEPDEL 20 30  QDEL
$ ALL HEAT LOADS TO 20 THROUGH 30 WILL BE
$ DELETED FROM FILES MODLF AND MODLCF
$
KEEPDEL 0 0SVFDEL
$ ALL SOLAR VIEW FACTORS DELETED FROM VUFF
```

Card 9 - LABELLIST - Optional

References a list of labels.

KODE, N1, T1, T2, T3

`KODE` = `LABELLIST` (or `104`)

`N1` is the `LABELLIST ID.`

`T1` is a label number. `LABELLIST` `N1` will contain labels `T1` through `T2`, in increments of `T3`. The labels could be element or node labels.

`T2` is a label number.

`T3` is a label number increment or is blank, in which case `T3 = 1`

Example

```
LABELLIST 29 contains labels 1 through 24, 30, 35, and 40.
LABELLIST          29          1          24          1
LABELLIST          29         30          40          5
```

Card 9 - LAYER Layer Property Definition Card - Optional

A LAYER Card defines the layer properties of non-homogeneous multilayer Card 5 shell elements.

`KODE, N1, T1, T2, T3, T4, T5, T6, T7, T8`

`KODE = LAYER (or 67)`

`N1` is the LAYER Card ID. Must be the same as the associated PROP Card ID of the top element in the layer.

`T1` is layer number. `T1` must be `> 1`, since it references the layer below the top layer.

`T2` is the MAT Card ID of the layer, in the form `Mn`, where `n` is the ID number.

`T3` is the PROP Card ID of the layer in the form `Pn`, where n is the ID.

`T4` is the OPTICAL Card ID of the front side of the layer, in the form `On`, where `n` is the ID. Must be zero if not used.

`T5` is the OPTICAL Card ID of the reverse side of the layer, in the form `On`, where `n` is the ID. Must be zero if not used.

`T6` is the is the principal material angle in degrees for orthotropic materials, measured relative to the principal material axis of the top layer, as defined on its it MATVEC Card. This requires that if a layer is orthotropic, the top layer should also be specified as an orthotropic element. Must be zero if not used.

`T7` is the heat transfer coefficient that determines the magnitude of the transverse conductive coupling between the layers.

If `T7` is not zero, a conductive coupling of magnitude `G` is created between the element and the element of the layer above it.

$$G = AREA(element)T7$$

If `T7` is zero, but the thermal conductivity of the element and the element above it are not, the transverse conductance is calculated from the layer thicknesses and thermal conductivities:

$$G = \frac{AREA(element)}{\frac{t_{layer}}{2KTHERM_{layer}} + \frac{t_{layer\_above}}{2KTHERM_{layer\_above}}}$$

If `T7` is zero or blank, and either the thermal conductivity of the layer, or that of the layer above, is table-dependent, then, instead of creating a single conductance between the two layers, an additional calculation point is inserted between the layers, and a transverse conductance is created between this calculation point and the layer, and between this point and the layer above.

If `T7` has the value `1.E-20` or less, then no thermal coupling is created between the layers.

`T8` defines the magnitude of the radiative conductance between the layer and the layer above.

If `T8` is neither zero nor blank, then a radiative conductance of magnitude G_{rad} is created between the layers:

$$G_{rad} = AREA(element)T8$$

If `T8` is zero or blank, and emissivities are defined for both the top surface of the layer and the reverse side of the layer above, view factors will be automatically requested between the layers. View factors from inner layers are calculated only to adjacent layers, and are set to unity.

If `T8` has the value `1.E-20` or less, then no radiative thermal coupling is created between the layers.

Description

Non-homogeneous multilayer elements are shell elements with different layers. Each layer may have different optical, physical, and material properties. Radiation, in-plane conduction, and conduction to an adjacent layer are supported by each layer.

By contrast, all layers of homogeneous multilayer elements (defined with non-zero field `T3` on a PROP Card for shell elements) have the same material and physical properties, the layers cannot radiate to each other, and in-plane conduction is supported only on the central layer.

The following are the highlights of the way non-homogeneous multilayer elements are handled in TMG:

- An element is defined to be a non-homogeneous multilayer element if it has LAYER Cards defined. The LAYER Card ID (field `N1`) must be the same as the PROP Card ID of the top layer.
- Each LAYER Card generates a shell element behind the top layer, with MAT, OPTICAL, and PROP Card properties defined on the LAYER Card. The properties of the top layer are obtained from its own MAT, OPTICAL, and PROP Cards. The top layer does not have a LAYER Card.
- Each internal layer's element is generated at the center of the layer, while each external (top and bottom) layer's element is generated on its outer surface. Example: for a 4-layer element, with thicknesses `t1`, `t2`, `t3`, and `t4`, the distances from top to bottom between the elements will be `(t1+t2/2)`, `(t2/2+t3/2)`, `(t3/2+t4)`. Note that the total thickness adds up to `t1+t2+t3+t4.`
- If a reverse side is specified on a Card 6 radiation request, e.g. on a Card 6r - View Factor Request Cards in an Enclosure – Optional it will be interpreted to be the reverse side of the bottom layer.
- Reverse side elements for a layer are generated if its reverse side optical properties are defined on its OPTICAL or MAT Cards. For the top layer a reverse side may also be defined by a REVNODE Card.
- If a layer can conduct laterally, it will conduct to the corresponding layer of an adjacent multilayer element. For example, the third layer of a multilayer element conducts to an adjacent multilayer element's third layer.
- "Hanging" layers do not conduct laterally – e.g. if a multilayer element has 4 layers and the adjacent element has only 3 layers, the 4th layer will not conduct the adjacent element.
- A layer's thermal conductivities may be specified to be constant or table-dependent, isotropic or orthotropic.
- A beam element is connected to a multilayer element is considered to be connected to all its layers, i.e. a "short" is formed connecting the layers.
- A layer of a non-homogeneous multilayer element may not be specified to be a multilayer element.

- Temperature and heat load boundary conditions may be applied to specific layers. For more information, see Card 9 - SINK Elements - Optional and Card 9 - QNODE Heat Loads - Optional Cards.
- The surface normals of adjacent non-homogeneous multilayer elements sharing common nodes should be oriented in a consistent direction, for example they should not point in opposite directions.

The following is an example of a 3-layer non-homogeneous multilayer element, with the referenced MAT, PROP, and OPTICAL Cards.

Example

```
PROP 2 SHELL .6          $ PROP Card of top layer
LAYER 2 2 M4 P6 O5 O6 0  $ Second layer of elements referencing PROP Card 2
LAYER 2 3 M4 P6 O5 O6 0  $ Third layer
MAT 4 KTHERM .67         $ MAT Card of the layers
OPTICAL 5 E .5           $ Front optical property
OPTICAL 6 E .6           $ Rear optical property
PROP 6 SHELL 3.7         $ PROP Card of the layers
```

Card 9 - MATCHANGE Material Property Change Card - Optional

The MATCHANGE Card specified material properties for elements. It overrides material properties specified on MAT Card.

KODE N1 T1 T2

`KODE` = `MATCHANGE` (or `63`)

`N1` is the element number or group name whose material properties are to be changed. If `N1` is of the 7-character format `_Mxxxxx,` where `xxxxx` is a MAT Card number (e.g. for MAT Card number 13 this would be `_M00013`) then the properties of the elements associated with MAT Card `xxxxx` will be changed.

`T1` is the material property code (e.g. ABSORPTIVITY). For material property codes, see Card 9 - MAT Material Property Definition Card - Optional.

`T2` is the material property value (e.g. .5). For rules on material property values, see Card 9 - MAT Material Property Definition Card - Optional.

Note

Emissivity override may reference an expression in **`T2.`**

The following independent variables are supported in expressions for emissivity overrides:

- fluid_temperature
- heat_flow_rate
- mass_flow_rate
- pressure
- radius
- rotational_speed
- temperature
- temperature_difference
- thermal_capacitance
- thickness
- time
- volume_flow_rate
- x
- y
- z

For more information on expressions, see Card 9 - EXPRESSION Symbolic Expression Definition Card - Optional.

Example

```
$ The absorptivity of element 500 is specified to be 500.
$
MATCHANGE 500 ABSORPTIVITY .5
$
$ The thermal conductivity of elements of group HEATER is specified to be .92
$
MATCHANGE HEATER KTHERM .92
```

Card 9 - MATLIST Additional Fluid Material List - Optional

KODE, N1, T1, T2

`KODE` = `MATLIST` (or `102`)

`N1` is the MATLIST card ID. Cards with the same ID reference the same Material List.

`T1` may be:

`= FLUID1` (or `1`)

`= FLUID2` (or `2`)

`= FLUID3` (or `3`)

`= FLUID4` (or `4`)

`= FLUID5` (or `5`)

`T2` is the material ID of the additional fluid material.

Card 9 - MAT Material Property Definition Card - Optional

A MAT Card defines the material properties of Card 5 elements. If a property is not defined, the default values apply.

KODE, N1, keyword, value

`KODE` = `MAT` (or `32`)

`N1` is the material number.

`keyword` is the keyword for the property specified.

Keyword	Description
ABLAT	If value is ≠ 0, then the material can ablate. Only multilayer shells and solids can ablate. TPHASE and HTLAT must be specified for ablative materials. If $1 > \text{ABLAT} > 0$, (e.g. .5) then the material ablates, i.e. burns up during phase change. For homogeneous multilayer shells, once a shell layer has ablated, its conductance to adjacent layers is increased by a factor of 100,000, and its in-plane conductance and capacitance are set to 1.E-6 times its value. Similarly, once a solid element has ablated, its thermal conductivity is increased by a factor of 100,000, and its thermal capacitance is set to 1.E-6 times its value. If value > 1 and value is an integer, it is interpreted to be the material ID for the ablated phase. For this case charring is assumed to occur during ablation, and the material properties of the charred material are defined by value. A set of MAT Cards with material ID=value must be present for this option.
ABSORPTIVITY	Surface absorptivity in solar spectrum.
CAPAPH	Specific heat above phase change temperature, may not be table-dependent. To specify a table-dependent specific heat above the phase change temperature, specify the specific heat to be table-dependent.
COEFFTHERM	Thermal expansion coefficient of the material. Not used.
CONVAR	Specified variable that check for material conversion. The keyword is TEMP.
CONVTO	Enables properties with material ID= N1 to convert to properties with material ID=value.
CONVTH	Specified threshold value of the conversion variable.

Keyword	Description
`CPP`	Specific heat value at constant pressure. The nominal value for air in SI units is `1007 Nm/Kg/C`. For water it is `4187 Nm/Kg/C`. For aluminum it is `1088 Nm/Kg/C,` and for steel `669 Nm/Kg/C.`
`E`	Emissivity `E` may be replaced by the keyword NORAD (or `-2.34`) for materials that do not radiate.
`ELECRES`	Electrical resistivity of material. Default is 0.
`RSPECIFIC`	Specific gas constant of material.
`HTLAT`	Latent heat per unit mass at phase change temperature.
`IRSPEC`	Surface specularity in the IR spectrum.
`IRTRANS`	Surface transmissivity in the IR spectrum.

Keyword	Description
`IREXTINCT`	IR spectrum extinction coefficient. If this property is specified for a solid element, then during ray tracing calculations the IR spectrum strength of each ray traveling through the element is diminished by a fraction equal to: $1 - e^{(-IREXTINCT * LENGTH)}$ where $LENGTH$ is the length of the path of the ray through the element. $IREXTINCT$ is ignored for shell, beam or lump mass elements. If a non-zero `IREXTINCT` or `SOLAREXTINCT` property is specified for a solid element, it is automatically surface coated with transparent shell elements with reverse sides. The reduction in the value of the ray strength is considered to be due to absorption by the solid. The power absorbed in the solid element is assigned to the surface coated shell elements, rather than to the solid element itself.

Keyword	Description
IREFFRONT	Index of refraction on the front surface of a transparent material for both the IR and solar spectra. If IREFFRONT is not specified, or is specified to be zero, it defaults to 1. For shell elements, IREFFRONT is the index of refraction on the front surface, and IREFBACK on the reverse side. The bending of a light going through the element ray and incident on the front surface a transparent element is calculated with Snell's Law: $sin(thetaback) = \frac{IREFFRONT}{IREFBACK} sin(thetafront)$ where $thetafront$ is the angle between the incident ray and the surface normal $thetaback$ is the angle between the transmitted ray and the surface normal If $sin(thetaback) > 1$, transmission is not possible, and full reflection occurs. Each surface of solid elements with $IREFFRONT > 1$ is automatically surface coated with two transparent shell elements: one facing the element, and one facing away. The index of refraction of the element facing the solid is assigned the value of $IREFFRONT$, and its reverse side is assigned the $IREFFRONT$ value of the adjacent element. The $IREFBACK$ value is ignored for solid elements. If there is no adjacent solid element, or the adjacent solid element does not have an index of refraction value specified, then it is assumed to be a free surface, and the reverse side is assigned an index of refraction value of unity. If the index of refraction through a solid is not uniform, a curved path is calculated for a ray traveling through the solid.
IREFBACK	Index of refraction on the back surface of a transparent material. If $IREFBACK$ is not specified or is set to 0, it defaults to $IREFFRONT$. $IREFBACK$ is ignored for solid elements.
IRSCATTER	Specifies the infrared spectrum scattering coefficient in a semi-transparent material. This is also sometimes referred to as the infrared spectrum macroscopic scattering cross section. The units of the scattering coefficient are length^{-1}. Used only with Monte Carlo ray tracing.

Keyword	Description
`IRREDIFF`	Infrared diffuse reflectivity. This value is only used when Monte Carlo ray tracing is to be performed and a BRDF table is to be specified for the bidirectional reflectivity of the material. The value should point to a table number.
`KTHERM`	Thermal conductivity. A nominal value for air in SI units is `.0263 W/m/C`. For water it is `.603 W/m/C,` for pure aluminum `249 W/m/C`, for steel `31 W/m/C`.
`KXX`	Orthotropic or anisotropic thermal conductivity in the material X direction, which is defined on MATVEC Cards. For each orthotropic element the material's orientation vectors must be defined on a corresponding MATVEC Card.
`KYY`	Orthotropic or anisotropic thermal conductivity in the material Y direction, which is defined on MATVEC Cards.
`KZZ`	Orthotropic or anisotropic thermal conductivity in the material Z direction, which is defined on MATVEC Cards.
`KXY`	Anisotropic thermal conductivity in the material XY direction.
`KXZ`	Anisotropic thermal conductivity in the material XZ direction.
`KYZ`	Anisotropic thermal conductivity in the material YZ direction.

Keyword	Description
`PHASE`	Property describing phase of a material. May be `SOLID`, `LIQUID`, `GAS`, or `DAMAGE`. Option `DAMAGE` flags the material as damage interface material and is only valid for cohesive elements. The solver treats damage interface elements by assuming perfect contacts between their upper and lower faces, ignoring their other properties.
`POISSONRATIO`	Poisson's ratio for an isotropic material.

`POISSONRATIO12`
 	
`POISSONRATIO23`
 	
`POISSONRATIO13`
	Poisson's ratio for an orthotropic material.

`REMISS`	Emissivity of the reverse side of an element. Default value is `-2.34`. If $\text{REMISS} \geq 0$ is specified, reverse side elements will be automatically created for all the elements of this MAT Card similarly to the Card 9 REVNODE Card `T1=0` option, where the reverse and front sides are automatically merged, and the element numbers of the reverse sides are automatically assigned. In case of conflict with a reverse side specified on an existing REVNODE or REVNOM Card, the REVNODE or REVNOM Card definition will prevail.
`RABSORP`	Absorptivity of reverse side of element. Default value is `-2.34`.
`RSOLSPEC`	Solar spectrum specularity on reverse side of element Default value is 0.

Keyword	Description
`RIRSPEC`	IR spectrum specularity on reverse side of element. Default value is 0.
`RHO`	Density. For hydraulic elements, this is the density of the fluid at the standard temperature and pressure defined on the HYDENV Card. The nominal value for air in `SI` units is `1.207 Kg/m`^{3} at a pressure of `101,351 Newtons/m`^{2} and temperature of `20 C`. For water it is `1000 Kg/m`^{3}`.` For aluminum it is `2,700 Kg/m`^{3}, and for steel `7,850 Kg/m`^{3}. If the density of a hydraulic element is table-dependent, its `PHASE` value should be flagged as `LIQUID.` The thermal solver supports only constant density for `SOLID` elements. If the density of a `SOLID` element is provided by a temperature-dependent mass density table, the density at the interpolation temperature is computed using the following Card: `GPARAM 1 335 T2` where `T2` is the user-defined interpolation temperature in `Kelvin`.
`SATRHO`	Saturation density of fluid. Used for CFD calculations only, e.g. when the saturation density of water is specified as a function of temperature for condensation analysis.

Keyword	Description
SOLAREXTINCT	Solar spectrum extinction coefficient. If this property is specified for a solid element, then during ray tracing calculations the solar spectrum strength of each ray traveling through the element is diminished by a fraction equal to: $1 - e^{(SOLAREXTINCT * LENGTH)}$ where $LENGTH$ is the length of the path of the ray through the element. $SOLAREXTINCT$ is ignored for shell, beam or lump mass elements. If a non-zero $IREXTINCT$ or $SOLAREXTINCT$ property is specified for a solid element, it is automatically surface coated with transparent shell elements with reverse sides. The reduction in the value of the ray strength is considered to be due to absorption by the solid. The power absorbed in the solid element is assigned to the surface coated shell elements, rather than to the solid element itself.
SOLARSCATTER	Specifies the solar spectrum scattering coefficient in a semi-transparent material. This is also sometimes referred to as the solar spectrum macroscopic scattering cross section. The units of the scattering coefficient are length^{-1}. Only used when Monte Carlo ray tracing is to be performed.
SOLREDIFF	Solar diffuse reflectivity. This value is only used when Monte Carlo ray tracing is to be performed and a BRDF table is to be specified for the bidirectional reflectivity of the material. The value should point to a table number.
SPECULARITY	Surface specularity in solar spectrum.
TPHASE	Phase change temperature for phase change material.

Keyword	Description
`TPHASERANGE`	Specifies the range of temperature ΔT over which the phase change occurs. $T1 + \Delta T = T2$ where $T1$ is the low end of the temperature range ΔT is the temperature range $T2$ is the high end of the temperature range $T1$ must be specified in the TPHASE card.
`TRANSMISS`	Surface transmissivity in solar spectrum.
`VISC`	Dynamic viscosity for 1-node hydraulic elements only. A nominal value for air in `SI` units is `1.85E-5 Nsec/m`^{2}, for water `.001 Nsec/m`$_2$. Default = `0`.
`YOUNGMODULUS`	Young's modulus for an isotropic material.

`YOUNGMODULUS1`
`YOUNGMODULUS2`
`YOUNGMODULUS3`
	Young's modulus for an orthotropic material.

`value` is the specified value for the material property. If not specified, the default values are zero, except for the following:

Keyword	Default value
`E`	`NORAD (or -2.34)`
`PHASE`	`SOLID (or 1)`
`TPHASE`	`1.E6`

If material is table or array dependent, for example its properties are described in table `n`, then value may be the mnemonic `Tn` (e.g. `T210` for table or array `210`).

For multispectral runs, the IR spectrum properties only (`E, IRSPEC`, etc.) may be defined to be spectrum-dependent, where the dependent variable on the TABTYPE Card is `WAVELENGTH`. Within the same run, radiative properties may be defined to have constant IR and solar properties, or be wavelength dependent. TMG will automatically create the appropriate wavelength-dependent tables from IR and solar properties for multispectral runs where necessary, and the appropriate constant solar and IR properties from spectrum-dependent properties for non-multispectral runs. For more information, see Card 9 - PARAM Parameter Card - Optional.

Note

For each MAT Card `N1` the 7-character group name _`M0000N1` (e.g. `_M00016` for MAT Card 16) is automatically created.

Example

```
$ CARD 5
101 SURFACE M2 0 P4 1 2 3 4
$ ELEMENT 101  HAS PROPERTIES DEFINED WITH MAT CARD 2
$ AND PROP CARD 4
|
$ CARD 9
PROP 4 PLANAR 1.6
$ ELEMENTS WHICH REFERENCE PROP CARD 4 HAVE
$ A THICKNESS OF 1.6
$
MAT 2 RHO 2.6
MAT 2 CPP 7.8
```

```
MAT 2 E .6
MAT 2 ABSORPTIVITY .4
MAT 2 KTHERM 1.4
$ ELEMENTS WHICH $REFERENCE MAT CARD 2 HAVE
$ DENSITY=2.6, SP. HEAT=7.8, EMISSIVITY=.6,
$ ABSORPTIVITY=.4 AND THERMAL CONDUCTIVITY = 1.4
$
MAT 3 KTHERM T2
TABTYPE 2 KTHERM TEMP
TABDATA 2 .6 -100
TABDATA 2 .5 0
TABDATA 2 .5 100
$ THERMAL CONDUCTIVITY OF MATERIAL 3 IS
$ TEMP. DEPENDENT, DEFINED ON TABLE 2
$
$  This example shows infrared and solar diffuse reflectivity pointing to the
$  same BRDF table.
$
MAT 1 IRREDIF T002
MAT 1 SOLREDI T002
ARRAYTYPE 2 ANG_INC ANG_REF BRDF
ARRAYDATA 2   0.0   0.0  0.8
ARRAYDATA 2   0.0  44.9  0.8
ARRAYDATA 2   0.0  45.0  0.0
ARRAYDATA 2   0.0  90.0  0.0
$
ARRAYDATA 2  44.9   0.0  0.8
ARRAYDATA 2  44.9  44.9  0.8
ARRAYDATA 2  44.9  45.0  0.0
ARRAYDATA 2  44.9  90.0  0.0
$
ARRAYDATA 2  45.0   0.0  0.0
ARRAYDATA 2  45.0  44.9  0.0
ARRAYDATA 2  45.0  45.0  0.8
ARRAYDATA 2  45.0  90.0  0.8
```

Card 9 - MATVEC2 Material Orientation Definition Card - Optional

The MATVEC2 Card defines the material's directions in the global coordinate system for plane stress, plane strain, axisymmetric, and chocking elements.

If there are no corresponding orthotropic thermal conductivities defined, the MATVEC2 Card is ignored.

KODE, N1, T1, T2

`KODE` = `MATVEC2` (or `114`)

`N1` is an element number or a group name to which the MATVEC2 Card applies.

`T1` is the angle THETA (degrees), which is the angle the material's thermal conductivity in the Xmat direction makes with the global X-axis.

`T2` is either the code `XY` or `ZX`. If `T2` is `XY`, then THETA is measured from the global X-axis and rotated about the positive Z-axis (Figure 1). If `T2` is `ZX`, then THETA is measured from the global X-axis and rotated about the negative Y-axis (Figure 2).

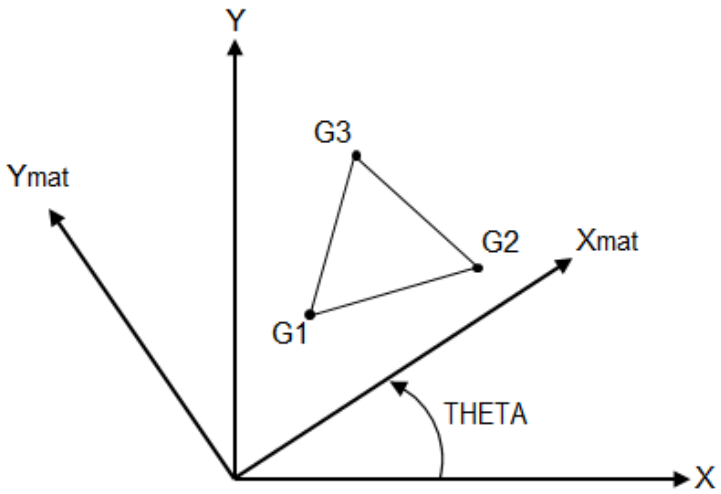


Figure 1

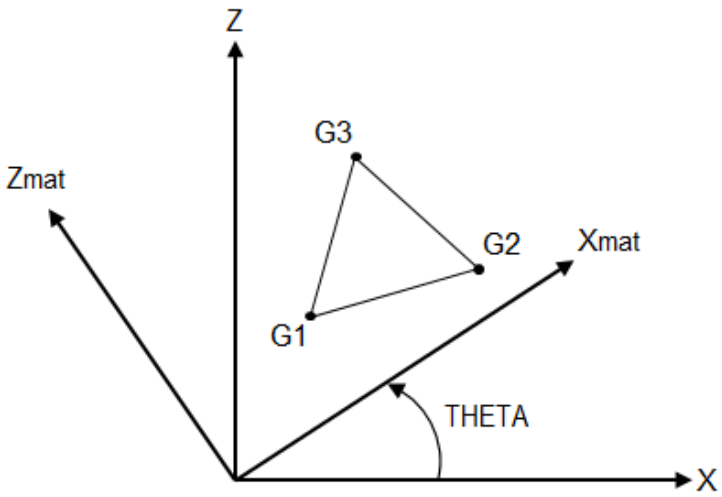


Figure 2

Example

```
$ FOR ELEMENT 425, THE ANGLE BETWEEN THE MATERIAL DIRECTION AND THE GLOBAL X-AXIS IS 30
DEGREES
MATVEC2  425  30  XY
```

Card 9 - MATVEC Material Orientation Definition Card - Optional

The MATVEC Card defines the material orientation of the principal axes of the thermal conductivities `KXX`, `KYY`, `KZZ` of an orthotropic/anisotropic element whose values are defined on a MAT Card.

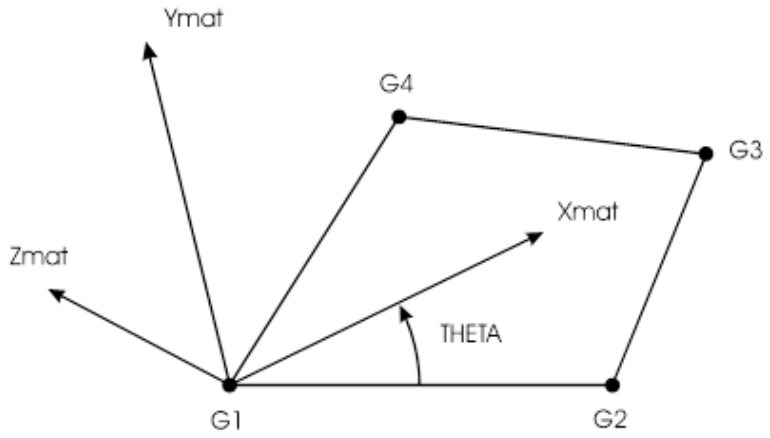
If there are no corresponding `KXX`, `KYY`, `KZZ` properties defined, the MATVEC Card is ignored.

KODE, N1, T1, T2, T3, T4

`KODE` = `MATVEC` (or `35`)

`N1` is an element number or a group name to which the MATVEC Card applies.

Option 1

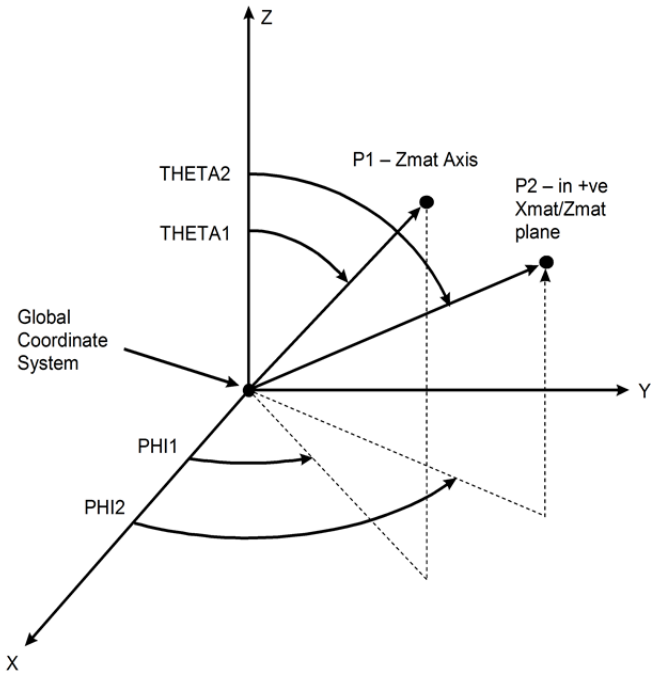


Defines the element material's principal directions in the element's local coordinate system.

`T1` is the angle THETA (degrees), which is the angle the material's thermal conductivity in the Xmat direction makes with nodes 1 and 2. The material's thermal conductivity in the Ymat direction lies in the plane of the element.

`T2-T4` must all be blank.

Option 2



Defines the material's directions in the global coordinate system. Two vectors `P1` and `P2` are defined in the spherical global coordinate system. `P1` defines the material's `Zmat` axis, while `P2` lies on the material's `XmatZmat` plane on the `+Xmat` side of the plane.

`T1` is `THETA1`, the angle in degrees `P1` makes with the global Z axis.

`T2` is `PHI1`, the angle in degrees the projection of `P1` onto the global XY plane makes with the global X axis.

`T3` is `THETA2`, the angle in degrees `P2` makes with the global Z axis.

`T4` is `PHI2`, the angle in degrees the projection of `P2` onto the global XY plane makes with the global X axis.

Example

```
$CARD 5
345 SURFACE M1 0 P1 1 2 3 4
$ ELEMENT 345 THERMAL CONDUCTIVITIES DEFINED
$ ON MAT CARD 1
|
|
$CARD 9
MAT 1 0 0 0 0 12 13 14
$ MATERIAL 1 IS ORTHOTROPIC, WITH THERMAL
$ CONDUCTIVITIES OF 12, 13, AND 14 IN THE
$ MATERIAL'S X, Y, AND Z DIRECTIONS.
$
MATVEC 345 5 10 15 20
$ ELEMENT 345 HAS ITS MATERIAL AXES
$ DEFINED IN GLOBAL SPHERICAL COORDINATES
```

Card 9 - MCV Moving Control Volume Fluid Elements - Optional

`KODE, N1, T1, T2`

`KODE` = `MCV` (or `28`)

`N1` is an element number, or a group name.

`T1` is an element number or 0, which defaults to `T1 = N1`. If `N1` is a group name, `T1` must be 0.

`T2` is the capacitance flow rate, used for steady-state analysis only. `T2` may be blank and is ignored for transient analysis.

Notes

The MCV Card defines the elements `N1` through `T1` to be MCV (Moving Control Volume) fluid elements.
The temperature of an MCV element is calculated by computing its heat balance as it moves downstream to its next location.
The MCV method provides an alternative to the standard SCV (Stationary Control Volume) method for modeling one-dimensional pipe or duct fluid flow.
The SCV method assumes the elements are stationary, and one-way conductances are used to model the heat carried into an element by the moving fluid. One-way conductances can be defined directly with XCOND Cards, or are automatically created for hydraulic networks. Where possible, the SCV method should be used to model fluid flow.
The major advantage of the MCV method is that it can model fluid flow with phase change, by defining the phase change properties of the element with PHASE or MAT Cards. Otherwise, it is a much more cumbersome technique.
With the MCV method, a special numbering sequence must be used. MCV fluid elements must be sequentially numbered in ascending order in each flow branch. Fluid flows from the lowest to the highest element number.
If transient analysis is performed with MCV Cards:

- All elements must be separated by equally spaced time intervals. The integration time step `DT` specified on Card 2b must be the time it takes for the fluid to flow to the next downstream element.
- Only the `-3` forward differencing or the `-2` exponential forward differencing techniques may be specified on Card 2b.
- Capacitances must be specified as usual for all MCV elements. Capacitances may be calculated from geometry or specified on XCAP Cards. Capacitances are ignored in steady-state analysis.

If steady-state analysis is performed, it is necessary to specify the `T2` parameter on the MCV Card. `T2` must be the mass rate of flow times the specific heat of the fluid (`Btu/sec/F` or `W/C`).
Fluid branching may be modeled with MCV elements. The first element in a branch must be connected to the main stream with a XCOND FOLLOWER Card.
MCV elements must not be merged or renumbered with Card 7.
MCV elements may not be used with the ILU solver.

Example

```
XCAP 3 7 3
$ ELEMENTS 3 TO 7 HAVE CAPACITANCES OF 3.0
$
MCV 3 7
$ ELEMENTS 3 TO 7 ARE MCV FLUID ELEMENTS.
$ THE FLUID FLOWS FROM ELEMENT 3 TO 4, ETC.
```

Card 9 - NAME2 - Group Name Description - Optional

KODE, N1, T1

`KODE` = `NAME2` (or `59`)

`N1` is a short format group name.

`T1` is the long format of the group name. It must not exceed 80 characters.

Notes

This Card associates a description with the group name of `N1`, specified on the Card 9 - NAME Cards - Optional.
This Card associates long format group names with their short format versions, since a short format group name cannot exceed 7 characters.
When referencing a group name on a Card you may use either the short format of the group name specified on a Card 9 - NAME Cards - Optional, or the long format specified on NAME2 Card. If the long format is used, the group name must be enclosed in double quotes (“). See examples below.
In case the long format is used on the Card to reference a group, and the long format name contains a double quote, it must be preceded by a backslash (\).

Example

```
NAME2 TOPLOAD Heat load on box cover
NAME TOPLOAD 101 105
QNODE TOPLOAD 1.6 CONSTANT
$
NAME SIDELD 201 207
NAME2 SIDELD Side load
QNODE "Side load" 1.7
$
NAME2 BOTLOAD Heat load on the "bottom" of the box
QNODE "Heat loads on the \"bottom\" of the box"
```

Card 9 - NAME Cards - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE` = `NAME` (or `21`)

`N1` is the group name of a group of elements. Group names must be specified with 7 characters or less. Valid characters are printable ASCII, except for comma and space. Valid group names must start with a letter.

`T1` is an element number or another group name.

If `T1` is an element number, the group `N1` will contain elements `T1` through `T2`, in increments of `T3`.

If `T1` is a group name, then the group `N1` includes with all the elements of `T1` .

`T2` may be:

- an element number `> T1`.
- blank, in which case `T2 = T1.`
- the code `ALL` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but all the layers of their non-homogeneous multilayers.
- the code `BOTTOM` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but the bottom layer of their non-homogeneous multilayers.
- the code `FROMBOTTOM` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but layer number `T3` counting from bottom of their non-homogeneous multilayers.
- the code `FROMTOP` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but layer number `T3` counting from top of their non-homogeneous multilayers.
- the code `MIDDLE` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but the middle layer of their non-homogeneous multilayers.
- the code `REV` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but their reverse sides.
- the code `TOP` for the case when `T1` is a group name. For this case `N1` will include not the elements of group `T1`, but the top layer of their non-homogeneous multilayers.

`T3` is an element number increment or is blank, in which case `T3 = 1.`

If `T2` is the code `FROMTOP` or `FROMBOTTOM`, then `T3` is a layer number.

`T4` is the optional specified group ID.

Notes

An element may be assigned many group names. During printout the name that comes first alphabetically is printed.
If a nonexistent Card 5 geometrical element is referenced with group name, it is ignored.

Example

```
NAME BOXA
100 200
$ THIS CARD ASSOCIATES THE ELEMENTS 100 - 200
$ WITH THE NAME BOXA.
REVNODE BOXA 1000 .1 .1
$ THIS DEFINES THE PROPERTIES OF THE REVERSE
$ SIDES OF THE ELEMENTS OF BOX
```

In this example if a Card 5 element in the 100-200 range does not exist, its reverse side is not created.
If a group name references a range of Card 9 non-geometrical elements (e.g. on Card 9 - QNODE Heat Loads - Optional) , all those elements will be created.

Example

```
QNODE BOXA 100 CONSTANT
```

This will create constant heat loads to all the elements of BOXA (100-200, see above). If an element has not been defined previously, this Card will create it.
Where only a single element is acceptable, (e.g. for the element number of the dependent variable on an INTERP Card), a group name is interpreted as the first element of that group name.
The long format of the group name is specified on the NAME2 Card. If the long format is used, it must be enclosed in double quotes (“). For examples, see
Card 9 - NAME2 - Group Name Description - Optional.
It is possible to use the NAME Card to ensure that TMG-created elements start only above a certain number. For example, `NAME KEEPOUT 1 100000` will ensure that all TMG-created elements will have element ID’s > 100000.

Example

```
VFS12 OUTSIDE ALL
$ CARD 6A REQUESTS ALL VIEW FACTORS FROM
$ OUTSIDE OF A BOX
```

```
$
AREA OUTSIDE 0 0 SPACE 0 1.0 CONV
$ CARD 6E COUPLINGS FROM ELEMENTS  1001-1500
$ TO SPACE ELEMENT 2001
$
QNODE TOP 1.6 CONSTANT
$ CARD 9 HEAT LOAD INTO ELEMENT 101
$
SINK SPACE -273 CONSTANT
$ CARD 9 2001 IS A SINK ELEMENT
$
REVNODE INSIDE 1000 .8 0
$ CARD 9 ELEMENTS 1001-1500 DEFINED
$
NAME OUTSIDE 1001 1500   $ CARD 9 NAME CARDS
NAME ALL 1 3000
NAME TOP 101
NAME BOX1 101 200
NAME BOX2 201 300
NAME SPACE 2001
NAME INSIDE 1 500
NAME FLUIDS 10 20
NAME BOX BOX1             $ THE NAME BOX IS ASSOCIATED
NAME BOX BOX2             $ WITH ELEMENTS 101-200, 201-300.
```

Card 9 - NODEQ Nodal Heat Source - Optional

KODE, N1, T1, T2

`KODE` = `NODEQ` (or `48`)

`N1` is a node number.

`T1` is the heat load into `N1`.

`T2` is the code `CONSTANT` for constant heat load, or a table number referencing Card 9 - TABTYPE Table Variable Type Definition Card - Optional and Card 9 - TABDATA Analyzer Table Data Cards - Optional for table-dependent heat load.

Notes

For table-dependent heat load the total heat load into node `N1` is the nominal heat load `T1` multiplied by the value interpolated from table `T2` for table-dependent heat load.
The nodal heat load is redistributed to connecting elements for the thermal analysis.

Example

```
NODEQ 10 2.5 CONSTANT
$ AN HEAT LOAD OF 2.5 IS APPLIED TO NODE 10
NODEQ 20 .8 10
TABTYPE 10 QNODE TEMP
TABDATA 10 3.10.
TABDATA 10 3.5   100.
$ HEAT LOAD ON NODE 20 VARIES FROM 3. TO 3.5 OVER
$ TEMPERATURE RANGE OF 10 TO 100 AND IS MULTIPLIED
$ BY NOMINAL VALUE OF .8
```

Card 9 - NODESINK Sink Nodes - Optional

KODE, N1, T1, T2, T3

`KODE` = `NODESINK` (or `45`)

`N1` is the sink node number.

`T1` is the shell option. `T1` is 0 if the sink node is applied at a node of a solid element. `T1` is 1 if the sink node is applied at a node of a shell element.

`T2` is the temperature of the sink node.

`T3` is `CONSTANT` for constant sink node temperature.

Notes

Sink node temperatures are distributed to elements by the DATACH module. New beam elements are created at edges of shells and new shell elements are created at faces of solids when required.
When sink node temperatures are translated to sink element temperature, the sink element temperature is the average of all sink node temperatures of the element.
Sink element temperature always takes precedence over sink node temperature. As an example, if a shell exists at a face of a solid with a sink element temperature and sink node temperatures exist at every node of the shell, the sink element temperature will be used.

Example

```
NODESINK 10 0 30. CONSTANT
$ NODE 10 HAS A TEMPERATURE OF 30
```

Card 9 - OPTICAL Surface Properties - Optional

KODE, N1, T1, T2

`KODE` = `OPTICAL` (or `65`)

`N1` is the ID of the optical surface property.

`T1` is code of the property. `T1` may be the code for any surface optical property (e.g. `ABSORPTIVITY`, `E`, etc.) described on the Card 9 - MAT Material Property Definition Card - Optional.

`T2` is the value of the property. If the property is table-dependent, `T2` may take the form `Tn`, where n is the table number (e.g. `T6` for table or array 6).

Notes

The OPTICAL Card provides an alternate way of specifying front and reverse side optical surface properties for elements. To define the front side properties of an element, the OPTICAL Card must be referenced in the FRONTOPTPROP field of a Card 5a. To define the reverse side properties of an element, the OPTICAL Card must be referenced in the REVOPTPROP field of the Card 5a. For more information, see Card 5a - Element Cards – Optional.

Properties such as `TRANSMISSIVITY`, `IRTRANS`, etc., which apply to both sides, are obtained from the OPTICAL Card that defines the front side properties and are ignored when defined on the reverse side on an element.

Example

```
$ Card 5 element with front and reverse side optical properties specified
256 REVOPTPROP=11 M6 13 P6 11 12 13 14
|
$ Corresponding optical properties 11 and 13
OPTICAL 11 E .4
OPTICAL 11 ABSORPTIVITY .7
OPTICAL 13 E .7
OPTICAL 13 ABSORPTIVITY .5
```

Card 9 - PARAM Parameter Card - Optional

This Card defines several run-time parameters for the model.

`KODE, N1, T1, T2, T3, T4`

`KODE = PARAM` (or `22`)

`N1`

`= ACCEL` (or `3`)

= ADDBEAMENDS (or 111)

= ALPHA (or 17)

= ANADOMDEC (or 131)

= ANALYZVERSION (or 55)

= ANARSLT (or 136)

= AUTOCOAT (or 47)

= AUTODELTAT (or 134)

= AXIMERGE (or 75)

= BACKTOBACK (or 60)

= BCSUMMARY (or 145)

= CAPDIST (or 72)

= CHECKPOINT (or 49)

= CINDA (or 65)

= CNVGTRA (or 37)

= COINCNODE (or 90)

= COMPILE (or 84)

= COMPRESS (or 36)

= COND (or 28)

= CONDENS (or 89)

= CSOLVE (or 32)

= `DOMDEC` (or `126`)

= `DUCTHEADLOSS` (or `153`)

= `DTEMPMAX` (or `86`)

= `ELECUPDATE` (or `43`)

= `ELEMENTALBC` (or `148`)

= `ELEMTYPE` (or `115`)

= `ELIM1WAY` (or `117`)

= `ENGBAL` (or `10`)

= `ESATAN` (or `66`)

= `ESATANTMG` (or `108`)

= `EXEARTH` (or `68`)

= `EXPRESSION` (or `149`)

= `EXSKY` (or `138`)

= `FASTRANSIENT` (or `44`)

= `FEM` (or `152`)

= `FEMCOND` (or `141`)

= `FEMNODALBC` (or `150`)

= `FIELDSDIRECTORY (or 212)`

= `FSICOUPLING` (or `146`)

= `FLAGPOLE` (or `70`)

= HEIDI (or 25)

= HYBRID (or 22)

= HYDEXPT (or 127)

= HYDLOOP (or 29)

= HYDDAMP (or 42)

= ILU (or 27)

= INITIME (or 125)

= LASTTIMEONLY (or 99)

= LOCALDAMP (or 112)

= MAXNODEID (or 133)

= MODCOND (or 56)

= MPIALL

= MPIVUFAC (or 120)

= MPIHEMIVIEW (or 121)

= MPIRSLTPOST (or 123)

= NEGCOND (or 26)

= NEVADA (or 50)

= NLOOP (or 2)

= NOAXISYM (or 23)

= NOBUOY (or 15)

= NOELREC (or 58)

= NOEMIT (or 59)

= NOMRECOV (or 14)

= NONIDEAS (or 54)

= NORAD (or 13)

= NOSHADOW (or 12)

= NOSOLAR (or 67)

= NOTCONN (or 98)

= ORBRAD (or 139)

= OPPENHEIM (or 45)

= OPPMERGE (or 80)

= ORIGINALSTREAM (or 147)

= PATCH (or 77)

= PDMAX (or 21)

= PECONV (or 61)

= PIRSUBSOLAR (or 52)

= QUARTIC (or 4)

= RADDOMDEC (or 124)

= RADSOLVE (or 118)

= REDUCE (or 69)

= `RESTART` (or `91`)

= `RESTARTDIR` (or `91`)

= `RETRANS` (or `36`)

= `REVINC` (or `88`)

= `RUNSINDA` (or `74`)

= `SCRMESG` (or `38`)

= `SINDA` (or `62`)

= `SINDA85` (or `64`)

= `SINKBND` (or `128`)

= `SOLIDACC` (or `1`)

= `SPECTRA` (or `102`)

= `SUBSTR` (or `5`)

= `TC_CONVECT` (or `144`)

= `TDEPORTHO` (or `116`)

= `TDIFS` (or `18`)

= `TEMPCONDITION` (or `114`)

= `TEMPTARGET` (or `119`)

= `TIMETABLE` (or `140`)

= `THERMOSTAT` (or `110`)

= `THIN` (or `9`)

`= TMGVERSION` (or `113`)

`= TRASYS` (or `63`)

`= UNITS` (or `73`)

`= USERDLL` (or `109`)

= `UPDATEOPTICAL` (or `137`)

`= USRCNDADD` (or `51`)

`= VFADJUSTALL` (or `92`)

Options

`PARAM ACCEL n T2`

`PARAM ACCEL OFF`

`PARAM ACCEL CHEBY`

This option is OBSOLETE.

This option sets some of the iteration convergence accelerator parameters for Analyzer if the conjugate gradient solver is not used (Card 9 PARAM ILU OFF must be present).

If the `n` and `T2` parameters are specified, Aitken's accelerator is used. Every n'th iteration (default = `6`) the ratio `r` between the last two temperature changes is computed for each element `i`

$$r = \frac{T_{i,n} - T_{i,n-1}}{T_{i,n-1} - T_{i,n-2}}$$

Then, if `-1 < r < 1`, a new temperature is extrapolated using the formula for summing an infinite geometric series:

$$T_{i,new} = T_{i,n-2} + \frac{T_{i,n-1} - T_{i,n-2}}{1 - r}$$

`1/(1-r)` is the acceleration multiplier. Its maximum permitted value is `T2.` The default for `T2` is `50`.

If `T1` = `OFF,` the accelerator is disabled.

If `T1` = `CHEBY,` the Chebyshev accelerator is used instead of Aitken's. This method is based on computing accelerator parameters from the maximum and minimum eigenvalues of the convergence matrix. It is preferable to Aitken's Method for difficult, hard-to-converge models and for models with hydraulic elements.

`PARAM ADDBEAMENDS`

This option creates two zero thickness quadrilateral shell elements at the free ends of radiating beams with `emissivity` = `0` and `absorptivity` = `0` facing outward. Their purpose is to close the ends of beams, to create radiative blockages for other elements. Since beam cross-sections are assumed to be circular, and the elements fit in the circle, their areas do not fully cover the beam ends.

`PARAM ALPHA T1`

This option sets the explicit-implicit weighting factor `ALPHA` to `T1` for transient runs with the Card 2b GRADNT = - 5 option. At each integration time step the temperature at time `t + dt` is computed by:

$$T(t + dt) = T(t) + (1 - ALPHA)\frac{dT(t)}{dt} + ALPHA\frac{dT(t + dt)}{dt}$$

`T1` must be bounded by 0 and 1. `T1 = 0` defines a fully explicit and `T1 = 1` a fully implicit algorithm.

If a `PARAM ALPHA` Card is not present, the default is `ALPHA` = `1`.

`PARAM ANADOMDEC T1`

This option activates distributed memory (MPI) parallel processing in the Analyzer module using domain decomposition approach. Each Analyzer process runs in its separate domain specific directory. Those directories are automatically created as `mayampi_tmpdir1,2,..` subdirectories in the main run (solution) directory path (that path should exist on all the machines in the run, but it does not have to be on a network shared location.) Before

launching the Analyzer module the domain decomposition (`DOMDEC`) module is run to partition the model into domains. Each domain has only a portion of the model's full set of elements and conductances in its `MODLCF` file, which is written to the domain's directory. The DOMDEC module also converts other input files of the Analyzer to their domain-specific versions that are placed in the domains' directories. Upon the analyzer run completion the domain's chunks of each of the solve results files (`TEMPF` , `tmgrslt` . `dat` , etc) are merged into the corresponding single (united) file in the main run directory. This option can be combined with parallel view factor calculations but not with `PARAM DOMDEC` or `PARAM RADDOMDEC` options. Compared to the `PARAM DOMDEC` option the `PARAM ANADOMDEC` method is applied to the Analyzer module only (`GRAYB` , `POWER` , and `MEREL` are run in serial) but provides more complete parallelization of that module and has no special restrictions on the models with which it can be used or on how the models are partitioned (for example, a single radiative enclosure could be split between multiple domains).

`PARAM ANALYZVERSION T1`

This option allows a different version of the analyzer module to be run. `T1` is a number > `0` , e.g. 6, in which case the executable `tmg/exe/analyz6.exe` will be run, instead of `tmg/exe/analyz.exe.`

`PARAM ANALRSLT T1`

This option performs the postprocessing of thermal solve results from the ANALYZER module instead of running the RSLTPOST module separately. It passes the results directly to the RSLTPOST routines instead of using the `tmgrslt.dat` file to read and write the results. The `tmgrslt.dat` file can still be written if needed.

`T1` = `0` (or blank) Performs RSLTPOST processing from the ANALYZER main execution thread rather than in a separate thread. It does not write the `tmgrslt.dat` file to a disk.

`T1` = `-1` Deactivates the `PARAM ANARSLT` option so that the results are written directly to the `tmgrslt.dat` file, then it reads the tmgrslt.dat file and performs the postprocessing in the RSLTPOST module.

`T1` = `1` Performs the RSLTPOST processing in a separate thread concurrently with the ANALYZER computations of the main execution thread.

`T1` = `2` Writes the thermal results from memory to the `tmgrslt.dat` file in the main thread.

`T1` = `3` Writes the `tmgrslt.dat` file in the main thread and performs the RSLTPOST processing in a separate thread.

`T1` = `4` Writes the `tmgrslt.dat` file in a separate thread while keeping the RSLTPOST processing in the main thread.

`T1` = `5` Writes the result to the `tmgrslt.dat` file and performs the RSLTPOST post processing in two separate independent threads concurrently with the ANALYZER computations.

- If the `PARAM ANARSLT` option is used in combination with distributed-memory parallel processing in ANALYZER (with `PARAM ANADOMDEC`), then parallel processing will be enabled in RSLTPOST as well. The RSLTPOST parallelization in this case follows the same methodology as for `PARAM MPIRSLTPOST`. That is, different time steps are processed on different processes. To prevent clashes between inter-process communication of the ANALYZER and RSLTPOST threads on the same process, the RSLTPOST execution will be restricted to the main thread in each process. That is, settings `T1` = `1`, `3`, `5` above are automatically replaced with `T1` = `0`, `2`, `4`, respectively.

`PARAM AUTOCOAT T1`

This option performs automatic surface coating on free edges and surfaces of specified elements. Free edges of shells are covered with beams whose surface areas are set to the thicknesses of the shells, and free surfaces of solids are covered with zero thickness shells. The material properties of the coating elements are set to the material properties of the elements they coat.

No new element will be created on a free surface or edge that is already covered by an element.

The surface normals of free surfaces point outwards.

If `T1` is a group name, only the elements of `T1` are surface coated. The newly created elements are assigned the group name `T1`.

If `T1` is a blank, all elements are surface coated.

If `T1` is `OFF`, then all other `PARAM AUTCOAT` Cards are rendered null.

If `T1` is `_SOLIDS`, then all solid elements (and only solid elements) will be surface coated. No group names will be associated with the surface coated elements.

`PARAM AUTODELTAT T1 T2 T3`

This option specifies and activates all the required parameters for automatic handling of the time step size used by the solver during transient runs.

`T1` specifies the error estimate.

`T2` defines the minimal integration time step size the solver uses during transient runs. If the minimum time step overwrites the minimum time step specified in CARD 2B, a warning is issued.

`T3` defines the maximum integration time step size the solver uses during transient runs.

`PARAM AXIMERGE`

This option merges all axisymmetric elements generated for radiation calculations into the axisymmetric elements themselves for thermal coupling calculations. See Card 9 - INCLAXI Include Axisymmetric Elements Definition Card - OBSOLETE for more information. This option is OBSOLETE.

`PARAM BACKTOBACK`

This option creates reverse sides element with `REVNODE` Cards from all back-to-back Card 5 shell elements that share the same nodes but whose surface normals point in opposite directions.

`PARAM BCSUMMARY`

This option enables printing of tables that summarize the thermal and fluid properties of the Thermal Streams, Thermal Convecting Zones, and Thermal Voids. This table is displayed in the standard log and the verbose log files.

`PARAM CAPDIST T1 T2`

If `T1` is blank, then for the element CG method, this option redistributes capacitances and heat loads of solid elements only from the CG to the boundary elements, and eliminates the conductances from the CG to the boundaries. This is the default option.

If `T1` is `SUBDIV`, then the solid element is further subdivided into subelements with capacitances assigned to the faces of the subelements. This creates a denser conductance matrix and increases the accuracy of transient solutions (but not steady-state solutions), with a corresponding increase in CPU time.

If `T1` is `OFF`, then the redistribution of the capacitances from the CG for solid elements does not occur. The capacitance and the elemental heat load are lumped at the CG, not at the boundary elements, and conductances from the CG to the boundary elements are created. This was the default option in previous releases.

`T2` is a group name or element number, valid if `T1` is `SUBDIV`. In that case, only the elements specified in `T2` are subdivided.

`PARAM CENTRIFUG T1 T2 T3 T4 T5 T6 T7 T8`

This option specifies that a group of solid or hydraulic elements undergo rotation about an axis.

If the elements specified are hydraulic elements, a centrifugal body force is applied to the specified hydraulic elements.

If the elements specified are solid elements, then advection is assumed to occur between the adjacent elements. 1-way conductances are created between the adjacent solid elements.

`T1` is a group name specifying the elements. If `T1` = `0`, the centrifugal force applies to all hydraulic elements and advective 1-way conductances are created between all solid elements.

`T2` is the frequency of revolution multiplied by `2*Pi.` For example, if the frequency of rotation is 600 rpm, then `T2` would be `2*Pi*600/60` = `62.8 Rad/sec`. The centrifugal effect on a 2-node hydraulic element is calculated by:

$$\text{Pressure} = T2^2 \rho \frac{(r_2^2 - r_1^2)}{2}$$

- ρ is the density of the fluid
- r_1, r_2 are the perpendicular distances from the ends of a 2 node hydraulic element to the axis of revolution.

  `T3`, `T4`, `T5` are the i, j, k, components of a vector along the axis of revolution. If the vector points out of the paper, the direction of rotation is considered to be counterclockwise in the plane of the paper when looking at the paper.

`T6`, `T7`, `T8` are the global x, y, z coordinates of a point along the axis of revolution.

The magnitude G1way of the 1-way advective conductance created between two adjacent solid elements is:

$$G1\text{way} = \rho C_p vol$$

where:

- C_p is the specific heat of the material of the element that lies upstream

- vol is the volume the boundary element between the adjacent solids sweeps out in unit time when rotating at `T2`.

`PARAM CHECKPOINT T1 T2`

This option allows the creation of a checkpoint file at the completion of the run.

`T1` is an identity number that is appended to the name of the checkpoint file. For example, if `T1 = 300`, the checkpoint file is called `CHECKPNT300`.

`T2` is a flag = `0` or `1`. If `T2` = `1`, a command line-driven interface is automatically run with each stand-alone checkpoint run allowing the user to modify specified entities.

A checkpoint file contains the dump of all the data in memory of the Analyzer at the completion of the run.

If the file is renamed `CHKPNT`, then the Analyzer can be re-run in a standalone mode using only the `tmg/exe/analyz.exe` and file `CHKPNT`. This allows the user to create stand-alone self-running objects of complete thermal models.

`PARAM CINDA T1 T2 T3 T4`

This option creates a `CINDA` format output.

`T1` must be 0. `T1` may be a blank if `T2` is blank.

`T2` is an optional file name, on which the CINDA format output is written. If `T2` is blank, the output is written on file `FMODLF`.

`T3` and `T4` are two element numbers, `T4` > `T3`. If these are specified, TMG will attempt to create internal element numbers (e.g. boundary elements for the `COND` module, Oppenheim elements, etc.) within these limits.

`PARAM CNVGTRA`

This option allows the TMG CFD product to be halted during the Analyzer run if the PAUSE button is pressed.

`PARAM COINCNODE T1`

This option allows the merging of coincident nodes if they fall within a tolerance radius of `T1` of each other.

`PARAM COMPILE LAHEY`

This option specifies that the `LAHEY` Fortran compiler should be used to compile user-written subroutines.

`PARAM COMPRESS`

This option specifies that the properties of the hydraulic elements are calculated using compressible flow properties.

`PARAM COND NEW T2`

This option specifies what method is used to calculate conductive conductances. If the card is specified, the element CG method is used. If the card is omitted, the element center method is used. `T2` is a flag.

`T2` = blank (default) is the same as `T2` = `3.`

`T2` = `1` is the old (OBSOLETE) version of element CG method, characterized by no conductances between the CG and the boundary elements.

`T2` = `2` is another OBSOLETE implementation of the element CG method.

`T2` = `3` is the up-to-date implementation of the element CG method.

`PARAM CONDENS T1`

This option is used for TMG CFD calculations only. It indicates that condensation and evaporation is modeled. `T1` represents the material number for the condensate (e.g. water).

`PARAM CSOLVE T1 T2`

This option enables the coupled solver for TMG CFD.

`T1` is a flag determining the coupled solver option.

`T1` = `2` is the thermal only solution.

`T1` = `3` is the coupled solution, with sequential coupling option (OBSOLETE).

`T1` = `4` is the coupled solution, with concurrent coupling option.

`T2` is an optional flag that indicates the flow solver type.

`T2` = `1`, the serial flow solver is used (OBSOLETE).

`T2` = `2`, the parallel flow solver is used.

`PARAM DOMDEC T1`

This Card is the same as `PARAM RADDOMDEC` except that the domain decomposition is extended so that the non-radiative elements and conductances are divided between domains as well, instead of being duplicated in full on every domain. Instead of separate/independent linear solves in the Analyzer module for different domains, a common parallel linear solve is done. In contrast to the `PARAM RADDOMDEC` option, the current option is meaningfully applicable to conduction-dominated models as well.

`T1` is an optional integer value that sets the level of overlap between the domains (if the field is empty, it defaults to 1). Value of 0 means that no additional domain overlap is introduced. Increasing the level of domain overlap by 1 means that each domain will be extended by a layer of out-of-domain elements that are directly connected (through non-radiative conductances) to the given domain elements. Increasing that value can improve iterative convergence of the `ILU-BiCGStab` linear solve, but it also increases the memory requirement and per-iteration computational cost for each domain.

`PARAM DTEMPMAX T1 T2`

This option is OBSOLETE. `PARAM AUTODELTAT` is the preferred option.

This option allows the integration time step to increase during transient runs.

`T1` is the maximum allowable temperature change in a given integration time step. You can specify `T1` in a time-dependent table. For more information, see Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

`T2` is the maximum allowable integration time step. `T2` = `0` or blank defaults to the Card 2b `TF` parameter, i.e. the time of the run.

The minimum allowable integration time step is the Card 2b `DT`, parameter, or the integration time step calculated from a table.

The algorithm first estimates the temperature change for each element. The integration time step value is then proportionally increased until the maximum estimated temperature change reaches `T1`, provided that:

- The slopes of all time-dependent boundary conditions are unchanged within the integration time step.
- Phase change does not occur on any element during the integration time step.
- The maximum estimated temperature change is `≤ T1.`

`PARAM DUCTHEADLOSS`

This option specifies a duct head loss due to curvature, bends and junctions. The duct solver computes the radius of curvature along the duct, and the angle between subsequent branches of the duct at sharp bends and junctions, based on the duct geometry. From this geometrical information, the solver computes an additional head loss and applies the loss to the duct. For more information, see Head Loss Correlations for Bends and Branches.

`PARAM ELECUPDATE T1`

This option specifies that if an electrical resistance matrix is specified, the properties of the matrix should be updated with a frequency of `T1`. Default for `T1` = `10.` For more information on electrical resistance matrices, see Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

`PARAM ELEMENTALBC`

This option changes the scheme that evaluates boundary condition properties.

With this advanced parameter:

- During the solve, swirl velocity are calculated on the element CGs.

- During post processing, auxiliary variables (Trel, Tabs, Tstat, Vrel, and Swirl) on the nodes are interpolated from corresponding elemental values.

`PARAM ELEMTYPE T1 T2 T3`

This option associates the elements of a group to a specific element type.

`T1` is a group name.

`T2` = `0`

If `T3` = `FLUIDFACE`, then the elements of group `T1` are identified as fluid faces for CFD analysis.

`PARAM ELIM1WAY T1`

This option ensures that if there is more than one 1-way conductance connected to a single element, such that the element influences the other element at the end of the 1-way conductance, then the smaller 1-way conductances are combined with the larger 1-way conductance, and the smaller 1-way conductance is replaced by a value equal to `T1` times its value. `T1` should be small number. This parameter can be used to eliminate false diffusion occurring with mesh misalignment when 1-way conductances are created with the `PARAM CENTRIFUG` option, or when a fluid velocity is specified on a PROP Card.

`PARAM ENGBAL T1 T2`

`T2` may be blank, or the code `FRACT.`

The `ENGBAL` option adds a system energy balance convergence criterion to steady-state Analyzer runs.

Without `PARAM ENGBAL` the default convergence criterion is that the maximum temperature difference between any two iterations must be < the Card 2b `GRADNT` parameter.

With `PARAM ENGBAL` the system energy balance criterion must also be fulfilled. The energy balance is equal to the sum of the heat inputs into the elements, plus the heat flowing from the sources, minus the heat flowing into the sinks, minus the heat remaining in the elements connected with one-way conductances.

If `T2` is blank, the energy balance must be < `T1`.

If `T2` is `FRACT`, the energy balance must be < `T1` times the value of heat flowing into the sink elements. With the `FRACT` option `T1 = 0.005` generally yields acceptable results.

`PARAM ESATAN T1 T2 T3 T4`

This option creates an `ESATAN` format output.

`T1` must be 0. `T1` may be a blank if `T2` is blank.

`T2` is an optional file name, on which the `ESATAN` format output is written. If `T2` is blank, the output is written on file `esatan.dat`.

`T3` and `T4` are two element numbers, `T4` > `T3`. If these are specified, TMG will attempt to create internal element numbers (e.g. boundary elements for the COND module, Oppenheim elements, etc.) within these limits.

`PARAM ESATANTMG T1 T2`

This option defines the parameters for the `ESATAN-TMG` product. `T1` is an `ESATAN` keyword, whose explanation may be found in the `ESATAN` User's Manual. `T2` may be blank, or a value.

`T1` may be `SOLVE`, then if `T2` = `1`, an end-to-end `ESAN-TMG` solve is created, if `T2` = `2`, an `ESATAN` input file is created, and if `T2` = `3`, a solution is run from the `ESATAN` input file.

`T1` may be `TIMEO`, then `T2` is the start time value.

`T1` may be `TIMEND`, then `T2` is the end time value.

`T1` may be `OUTINT`, then `T2` is the output interval value.

`T1` may be `DTIMEI`, then `T2` is the initial time step value.

`T1` may be `NLOOP`, then `T2` is the maximum iteration count value.

`T1` may be `RELXCA`, then `T2` is the temperature convergence criterion value.

`T1` may be `DAMPT`, then `T2` is the temperature damping factor value.

`T1` may be `INBALA`, then `T2` is the absolute energy balance criterion value.

`T1` may be `INBALR`, then `T2` is the relative energy balance criterion value.

`T1` may be `INBNDM`, then `T2` is the mean energy balance criterion value.

`T1` may be `ARITH`, then `T2` is the arithmetic node factor value.

`T1` may be `DTPMAX`, then `T2` is the maximum temperature change over time step value.

`T1` may be `DTROCA`, then `T2` is the temperature error bound over time step value.

`T1` may be `DTMIN`, then `T2` is the minimum time step value.

`T1` may be `DTMAX`, then `T2` is the maximum time step value.

`T1` may be `TABS`, then `T2` is the absolute temperature offset value.

`T1` may be `STEFAN`, then `T2` is the Stefan-Boltzmann constant value.

`T1` may be `CVTCA`, then `T2` is the cyclic temperature convergence criterion value.

`T1` may be `CVDTCA`, then `T2` is the cyclic temperature ROC convergence criterion value.

`T1` may be `PERIOD`, then `T2` is the cycle period value.

`T1` may be `OUTPUT`, then `T2` is the output interval value during cyclic iterations value.

`T1` may be `SOLVIT`, then the successive point iteration (steady state solver) is specified.

`T1` may be `SOLVFM`, then the sparse matrix (steady state solver) is specified.

`T1` may be `SOLVCG`, then the conjugate gradient (steady state solver) is specified.

`T1` may be `SLFRWD`, then the forward difference (transient solver) is specified.

`T1` may be `SLFWBK`, then the standard Crank-Nicolson (transient solver) is specified.

`T1` may be `SLCRNC`, then the advanced Crank-Nicolson (transient solver)is specified.

`T1` may be `SOLCYC`, then the cyclic transient solver is specified.

`PARAM EXEARTH T1 T2`

With this option, the Earth view factors and albedo factors are created not by the default method of analytical formulation and table lookup, but by explicitly modeling the section of the Earth seen by the satellite as a segment of a faceted sphere, and computing the Sun's reflections from the facets.

`T1` is the number of elements (facets) in the tangential direction.

`T2` is the number of elements in the radial direction.

Although this method is more compute-intensive, it provides more accurate shadowing computations for the albedo calculation than with the default method.

When specular surfaces exist on the satellite, both albedo factors and Earth view factors are ray-traced. This is not the case for the default method, where only incident solar radiation is ray-traced.

`PARAM EXPRESSION T1`

This option represents all angular quantities in symbolic expressions as radians.

`T1` is a keyword `RADIANS`. When it is not specified, the angular quantities are in degrees.

`PARAM EXSKY T1 T2`

With this option the sky dome is modeled explicitly.

`T1` is the number of elements (facets) in the tangential direction.

`T2` is the number of elements in the radial direction.

`PARAM FASTRANSIENT T1`

This is an OBSOLETE option. Use `PARAM TDIFS` instead.

`PARAM FEM`

This option activates the finite element formulation.

`PARAM FEMCOND`

This option activates the finite element formulation to calculate heat conductance for bulk solids and shells.

`PARAM FEMNODALBC`

This option activates the finite element treatment of convective boundary conditions, such as convecting zones, streams, and voids.

`PARAM FIELDSDIRECTORY T1`

This option specifies the directory path to the field files. The software automatically writes the interpolated solid temperature on convective and immersed ducts in fields files in the specified directory path.

`PARAM FSICOUPLING T1 T2`

This option provides the coupling type for the fluid and structure interaction.

`T1` is the keyword `NONE` or `ONEWAY`.

- If `T1` = `NONE`, then there is no interaction between the fluid and the structure.
- If `T1` = `ONEWAY`, then fluid parameters, such as pressure affect the structure.

`T2` is a group name for the flow surface elements that are in contact with the structure.

`PARAM FLAGPOLE`

This option provides conductive paths between elements that are joined with a flagpole and hinge-door topologies. By default, TMG does not provide a thermal conductive path between elements for these topologies.

The `PARAM FLAGPOLE` option is only applicable with the element CG method, activated by the `PARAM COND NEW` flag.

A flagpole topology occurs when a beam element is joined to a solid or a shell at a corner only. Exceptions to flagpole topologies are:

- When the beam is non-conducting.
- The attached shell is non-conducting.
- The beam is connected with both its nodes to a shell.
- The beam is flagpole-connected to a shell but the shell has one or more conductive beams running along its edge, and one of these beams is connected to the beam.
- If a beam is attached to a combination of solids and shells at a node, it is assumed to be attached only to a single solid. If it is attached to more than one shell at a node, it is considered to be attached to only one shell.

Once the flagpole situation is identified, a connection is made by merging the 1-node lump mass boundary element to the appropriate boundary element of the other element. This is identified as follows:

- If the other element is a conductive shell, the lump mass is merged to the center of one of the boundary elements at the shell's edges.
- If the other element is a solid, then the lump mass boundary element is merged to the CG of the shell boundary element on the face of the solid.

A hinge-door topology occurs when a shell is attached to one or more solids at only two of its nodes. Exceptions to hinge-door topologies are:

- The shell is non-conducting.
- The solid has a conductive shell on its surface joining the hinge-dooring shell at its nodes.
- The shell is a boundary element to another solid, i.e. it is fully connected with all its nodes to the surface of another solid.

The hinge-door topology is addressed by identifying the beam boundary element at the nodes, and joining this to an appropriate surface boundary element of the solid.

`PARAM HEIDI T1`

This option splits every quadrilateral element into two triangular elements. `T1` is an increment (e.g. 1000) such that if element N is a quadrilateral element, it is split into two triangular elements `N` and `N` + `T1`. The details of the split are written on file HEIDISPLIT by the DATACH module.

`PARAM HYDEXPT`

This option models each hydraulic element with an exponential temperature profile along the element length.

`PARAM HYDLOOP T1`

This option specifies that the maximum number of hydraulic loop iterations must not exceed `T1`. The default is 100.

`PARAM HYDDAMP T1`

This option specifies the damping parameter `T1` for the hydraulic network. Default = Card 2b `DT` parameter.

`PARAM HYBRID`

This is an OBSOLETE option which specifies that the hybrid solver should be used if a steady state run is being performed.

The hybrid solver is a combination of the substructuring option and the iterative solver. All elements connected by only linear conductances are automatically eliminated, creating a smaller model, which is then solved iteratively. The temperatures of the full model are then recovered at the end of the run.

The `PARAM HYBRID` option is equivalent to the `PARAM SUBSTR RADNODES` option. It is ignored for transient runs.

`PARAM ILU LFIL T2 T3 T4`

This is a recommended option which activates the `ILU` preconditioned conjugate gradient solver. When this option is used, the default `PARAM ACCEL` parameter is automatically set to `OFF`.

The conjugate gradient solver is the default option.

`LFIL` is the maximum number of terms generated for each row of the preconditioning matrix. `LFIL` defaults to `10`.

`LFIL` = `-1` generates a diagonal preconditioning matrix.

`LFIL` = `-2` generates a unit preconditioning matrix.

Higher `LFIL` values are more suitable for ill-conditioned matrices and increase the likelihood of convergence but require more CPU time. If convergence does not occur after 100 iterations within the conjugate gradient solver, the `LFIL` value is automatically increased by 10, until convergence is achieved.

`T2` is optional. It defines the conjugate gradient solver iteration convergence criterion.

`T3` is optional. It defines the maximum number of allowable iterations. The default is `100`.

`T4` is optional. It defines the convergence norm method, either MAX or L2.

The conjugate gradient iterations are considered converged if the norm of the residual of vector `[A]{x}-{b}` divided by the norm of the vector {b} is less than `T2`. Once the convergence criterion is satisfied, an additional convergence criterion must also be satisfied: the difference in temperatures between iterations must be less than the amount specified by `PARAM TDIFS` (alternately specified by GRADNT in Card 2b for steady-state runs). This additional temperature difference convergence criterion has a stabilizing effect on the outer iteration convergence. You can deactivate it using the advanced parameter `GPARAM 12 1394 0` in Card 9 - GPARAM Parameter Card - Optional.

`PARAM INITIME T1`

This option specifies the initial times at which the Analyzer module evaulates the temperature and/or water density. This paramater lets you change the default start time.

`T1` is the integer value from a previous solution from which the results are used as initial conditions.

`PARAM LASTTIMEONLY`

This option specifies that only a single printout is created for a transient run at the end of the run. It overrides all other options.

`PARAM LOCALDAMP T1 T2`

This option allows the specification of iteration damping parameters for selected elements only, as opposed to globally, as specified on Card 2b. `T1` is an element number or group name, and `T2` is the iteration damping parameter that overrides the Card 2b value for the selected elements.

`PARAM MAXNODEID T1`

`T1` is the largest label for user-defined nodes in the model.

`PARAM MODCOND T1 T2 T3`

This option modifies the conductances for odd-shaped elements with the element CG method.

Odd-shaped elements yield negative conductances. Large negative conductances can have two undesirable effects: convergence problems, and in unrealistic temperatures on the boundaries of the element. The latter is aggravated when the boundary lies on a free surface and can convect or radiate, and the thermal gradients in the element are large.

To address this problem, the negative conductances of odd-shaped elements are automatically clipped during Analyzer runs, and a warning message is written to the verbose log file `.`

- `T1` sets the clipping threshold for elements that have a free surface boundary. The largest negative conductance in the element is clipped such that its absolute value will not exceed `T1` times the sum of the conductances of the elements it is connected to.
- `T1` must be ≥ `0`. `T1 = 0` defaults to `1`. `T1` < `1` modify more elements, `T1` > `1` modify fewer elements.
- `T2` sets the clipping threshold for elements that do not have a free surface boundary. `T2` must be ≥ `0`. `T2` = `0` or `T2` = blank defaults to `10`.
- `T3` multiplies the default `T1` and `T2` values by `T3.`

`PARAM MPIALL`

This option activates distributed memory parallel processing for `HEMIVIEW` and `VUFAC` modules, using the message passing interface (MPI) protocol for inter-processor communication, with the purpose of reducing the CPU time of view factor computations. This Card is a substitute for `PARAM MPIHEMIVIEW` and `PARAM MPIVUFAC` Cards. The parallel run can use either a single machine with multiple processors/cores or an interconneted set of multiple machines with one or more processors on each. This option requires a file named `mayampi.hosts`, which is present in the thermal solve run directory. That file lists the host names of the machines which are used for the parallel run, one host name per line. The first line contains the name of the machine that the solve is launched from (the

master machine). When multiple processes are used on any of the machines then that machine is listed multiple number of times (on multiple lines). The total number of parallel processors launched equals the number of lines in the `mayampi.hosts` file. The TMG installation directory path should be valid on all of the machines in the run, which is achieved by either placing the TMG executables in the same path on each machine local drive or installing TMG in a network shared location. The solve run directory does not have to be valid/accessible on any of the machines except the master one. The machines in the same parallel run should have compatible operating systems: one should neither mix Linux and Windows machines nor combine 32-bit with 64-bit machines. `HEMIVIEW` and `VUFAC` parallel processing uses dynamic load balancing, which allows efficient use of machines of different performance characteristics in the same run: faster machines receive more work load than the slower ones. For multi-host runs on Linux platform a secure shell installation (`ssh` command) should be available and configured to run without password prompt (that is, passwordless `ssh` should be enabled). On Windows platforms, one also needs to install MPICH2 (version 1.4.1p1) on each machine so that the MPICH2 process manager (SMPD) service is active on all the machines of the run (http://www.mpich.org/).

`PARAM MPIVUFAC T1 T2`

This Card activates the distributed-memory parallel processing feature for the VUFAC module to reduce the CPU time of view factor computations. Different view factors and related quantities (e.g. solar view factors) are computed concurrently on different machines or different CPUs of the same machine.

- `T1` is a mandatory integer value, and is set to the number of processes of the parallel run.
- `T2` is optional. It is the name of the file that allows the specification of the machine host names, one per line. Multiple processors/cores on the same host are specified by repeating the name of the host multiple times in the file.
- If `T2` is blank, then a default machine file named `mayampi.hosts` is first required in the run directory. The number of lines in the machine file is equal or larger than the requested number of processes `T1`.

The same machine setup and machine file requirements apply as for the `PARAM MPIALL` option.

`PARAM MPIHEMIVIEW T1 T2`

This Card activates the distributed-memory parallel processing feature for the `HEMIVIEW` module to reduce the CPU time of view factor computations. Different view factors are computed concurrently on the graphic cards of different machines.

- `T1` is a mandatory integer value, and is set to the number of processes of the parallel run.
- `T2` is optional. It is the name of the file that allows the specification of the machine host names, one per line. Multiple processors/cores on the same host can be specified by repeating the name of the host multiple times in the file.

- If `T2` is blank, then a default machine file named `mayampi.hosts` is first required in the run directory. The number of lines in the machine file should be equal or larger than the requested number of processes `T1`.

The same machine setup and machine file requirements apply as for the `PARAM MPIALL` option.

`PARAM MPIRSLTPOST T1 T2`

This Card activates the distributed-memory parallel processing feature for the `RSLTPOST` module to reduce the CPU time of the postprocessing computations. The data from different time steps of a transient run is postprocessed concurrently on different parallel processes.

`T1` is a mandatory integer value, and is set to the number of processes of the parallel run.

`T2` is optional. It is the name of the file that allows the specification of the machine host names, one per line. Multiple processors/cores on the same host is specified by repeating the name of the host multiple times in the file. If `T2` is blank, then a default machine file named `mayampi.hosts` is first required in the run directory. The number of lines in the machine file should be equal or larger than the requested number of processes `T1`.

The same machine setup and machine file requirements apply as for the `PARAM MPIALL` option. The current Card is best used with multiple processes on a single machine. If the same machine file is used as for `PARAM MPIALL` in a parallel run with multiple hosts having multiple cores each, then one can limit the `RSLTPOST` parallel processing to the master machine by listing all the master machine processes in the first lines of the machine file and then setting the `T1` value to the number of the master machine processes.

`PARAM NEGCOND`

This option allows the `COND` module using the element center method to write negative conductive conductances in the file `MODLF`, instead of merging the two connected elements together.

`PARAM NEVADA T1 T2 T3 T4`

This option creates a `NEVADA` format output.

`T1` is equal to 0. `T1` may be a blank if `T2` is blank.

`T2` is an optional file name, on which the `NEVADA` format output is written. If `T2` is blank, the output is written on file `nevada.ren`.

`T3` and `T4` are two element numbers, `T4` > `T3`. If these are specified, TMG solver attempts to create internal element numbers (e.g. boundary elements for the COND module, Oppenheim elements, etc.) within these limits.

`PARAM NLOOP T1 T2`

If the `T2` field is empty, this option sets the maximum number of iterations during transient runs in an integration time to `T1`. The default is 100. Convergence is achieved if the maximum temperature difference between two subsequent iterations is less than the value set by the `PARAM TDIFS` Card, with the default value of `0.001.`

If the `T2` field is set to `STEADYSTATE`, then `T1` is the maximum number of iterations for the solution control STEP cards with the steady state solution type. Otherwise, the steady state equivalent of `PARAM NLOOP` is the Card 2b `TF` parameter.

`PARAM NOAXISYM T1`

This option defines the group `T1` for non-axisymmetric elements, which allows the inclusion of non-axisymmetric elements in an axisymmetric model.

`PARAM NOBUOY T1`

This specifies that buoyancy pressures are not calculated for the hydraulic elements `T1`. `T1` is an element number or a group name.

when `T1` is blank, buoyancy is ignored for all elements.

`PARAM NOELREC`

This option is similar to `PARAM NOMRECOV.` When Card 8 element elimination or `PARAM SUBSTR` substructuring is performed, then the temperatures of the eliminated elements are not recovered. This results in a smaller file MODLCF and avoiding post-processing, in which all temperatures are required.

`PARAM NOEMIT T1`

This option specifies that the element(s) `T1` and their reverse side elements cannot emit or receive radiation in the IR spectrum, or shadow other elements in all spectral bands, during radiation calculations of the VUFAC module. `T1` is a single element or a group name.

If reverse sides are defined with `REVNOM` or `REVNODE` Cards for the element(s) `T1`, they are considered as non-emitting and non-shadowing. View factors are not calculated for elements `T1` and their reverse sides, hence radiative couplings or radiative heat flux view factors are not calculated.

This option is similar to `PARAM NORAD`. A possible use for `PARAM NOEMIT` is to define a set of perfectly transparent "mask" elements, which fix the ray-tracing calculation mesh for all elements behind them.

`PARAM NOMRECOV T1`

`T1` is blank or a group name.

With this option the temperatures of the merged elements of Card 7 are not recovered during Analyzer runs. By default, they are automatically recovered. When `T1` is blank, none of the merged elements' temperatures are recovered. When `T1` is a group name, only the temperatures of the elements specified in the group are not recovered.

This option reduces the size of the output but should not be used when any sort of post-processing is required, in which the temperatures of all the elements are used.

`PARAM NONIDEAS T1 T2 T3 T4`

This option identifies the nodes or elements between `T2` and `T3` that were not created by your CAE software.

`T1` is `ELEMENT` or `NODE`.

`T2` is the starting element or node number.

`T3` is the ending element or node number. Blank or zero defaults to `T2.`

`T4` is an increment. Blank or zero default to 1.

`PARAM NORAD T1 T2`

This specifies that the front sides of element(s) `T1` and the reverse sides of element(s) `T2` are not considered in any radiative calculations by the VUFAC module. They cannot emit or receive any radiation or shadow any other elements in all spectral bands. It is the equivalent of specifying `NORAD` in Card 5a geometrical element, which is the emissivity.

`T1` and `T2` are single elements, or 0, or group names.

For the sake of backward compatibility, when `T2` is blank, both the front and reverse sides of element(s) `T1` are considered as non-radiating.

`PARAM NOSHADOW T1`

This specifies that the element(s) `T1` and their reverse sides (defined with `REVNOM` or `REVNODE` Cards) cannot shadow during radiation calculations of the VUFAC module. `T1` is a single element, or a group name.

`PARAM NOSOLAR T1 T2`

This specifies that the front sides element(s) `T1` and the reverse sides of element(s) `T2` do not have any solar, Earth or albedo view factors calculated to them. However, they still shadow for Orbital, Sun or Earth requests. `T1` and `T2` are single elements, 0, or group names.

`PARAM NOTCONN T1`

This specifies that element(s) `T1` are not connected to other elements. The temperatures of the `T1` elements are not used in calculating average, Min, or Max temperatures, and all `T1` elements and their nodes are flagged as `PARAM NONIDEAS`. `T1` is an element or a group name.

`PARAM ORBRAD`

This option activates the old method for computing the radiation request for all articulation times, even when no movement occurs between two articulation times. The thermal solver computes view factors in radiative enclosures and thermal couplings, which contain articulating elements.

`PARAM OPPENHEIM T1`

This option specifies that radiative couplings that are created with Oppenheim's Method instead of Gebhardt's Method if Card 2a `M = 4`. This is the recommended option.

For each radiating element, `I,` a corresponding Oppenheim element, `I` + `T1,` is created. A radiative coupling between `I` and its Oppenheim element is created with a magnitude equal to `Area(I)*emissivity(I)/(1-emissivity(I)).`

The view factors `VFIJ` between elements `I` and `J` are transformed into radiative couplings equal to `Area(I)*VFIJ` between the corresponding Oppenheim elements `I` + `T1` and `J` + `T1.`

In case of element number conflict, an unused element number is assigned to the Oppenheim element instead of `I` + `T1`.

The Card 2a `RK` parameter is ignored.

Oppenheim's Method has several advantages over Gebhardt's Method.

1. Temperature-dependent emissivities are modeled exactly and efficiently, since only the radiative coupling between the element and its Oppenheim element needs to be updated.
2. The costly matrix inversion process necessary for Gebhardt's Method is bypassed.
3. The radiation matrices to be solved tend to be much smaller, resulting in faster solution time.
4. The storage of the large gray body view factor matrix on file `VUFF` is bypassed.

For transient runs it is suggested that an implicit integration method should be employed, because of the presence of the many zero-capacitance Oppenheim elements solution times are costly with explicit techniques.

`PARAM OPPMERGE T1`

This option specifies that the Oppenheim elements of those elements that are merged should also be merged to speed up runs. `T1` is `OFF` or blank (the default). When `T1` is `OFF`, the Oppenheim elements are not merged. By default, the Oppenheim elements are merged.

`PARAM ORIGINALSTREAM`

This option changes the scheme that forms connections between the fluid stream elements created by the thermal solver and the wall elements selected in the two-sided thermal stream.

With this advanced parameter, the length of the fluid stream is equal to the length of the longest wall element selection of the two selections in the two-sided thermal stream. The connections between wall elements and fluid stream elements are formed by finding the closest fluid stream element to the line perpendicular to selected wall element.

`PARAM PATCH T1 T2`

This option merges adjacent Oppenheim elements in the MEREL module into a “patch” on both the front and reverse sides of elements to reduce the temperature calculation time in the Analyzer module. The elements merged all center around a common node. Typically, 5-10 adjacent Oppenheim elements are merged. This option usually reduces the number of radiative conductances in large models by an order of magnitude, with generally only a slight reduction in accuracy.

Oppenheim elements are merged based on the following conditions:

- The elements associated with them are co-planar within a specified tolerance value.
- Their parent elements have the same emissivities.
- The topology is not that of a fence or a flagpole.

One form of inaccuracy introduced by the merging of the Oppenheim elements is a “false diffusion” type heat flow between elements within a patch, caused by the elements’ common connection to the same Oppenheim element. This is usually negligible if the adjacent elements have similar temperatures. To reduce the false diffusion effect, negative corrective radiative conductances are introduced between elements within a patch. However, no corrective conductances are introduced when they have temperature-dependent emissivities.

Any number of PARAM PATCH Cards may be used.

`T1` may be:

- A numerical value (e.g. 10), which specifies the angular tolerance in degrees. If `T1` is blank or = `0`, `T1` default to `15` degrees. Adjacent elements whose surface normals differ by > `T1` degrees do not have their Oppenheim elements patched together.
- The code `NOPATCH`, in which case `T2` must be an element number or a group name. This specifies the elements, which are excluded from patching.

- The code `ONEPATCH`, in which case `T2` is a group name. This option ensures that the Oppenheim elements of the elements specified in `T2` are patched together.
- The code `PATCHMAX` specifies a maximum area threshold criterion for patching adjacent Oppenheim elements. `T2` is a group name. The smallest elemental area in `T2` becomes the area threshold criterion. Elements with areas greater than this value do not have their Oppenheim elements patched together. The objective of this criterion is to prevent large elements from being patched together.
- The code `PATCHSET` specifies a set of elements that are only patched to each other. `T2` is a group name specifying these elements. Any number of PARAM PATCH PATCHSET Cards may be present in the model.

`PARAM PDMAX T1`

This option specifies the convergence parameter for the pressure/flow solution of the hydraulic network.

If `T1` > `0`, convergence occurs when the maximum total pressure difference between iterations is less than `T1,` and no conductance clipping is performed. Lower `T1` values increase the accuracy of the solution.

If this Card is not present or `T1` = `0` or blank, `T1` defaults to 1% of the maximum total pressure difference in the model.

If `T1` < `0`, then convergence occurs when the maximum total pressure difference between iterations is < `abs(T1)` times the maximum total pressure difference in the model, and no conductance clipping is performed.

Convergence of the hydraulic network is observed with the PRINT HYDTRACE Card.

`PARAM PECONV T1 T2 T3 T4`

This option specifies a periodic convergence criterion for transient runs. When a transient run is cyclical with a period `T2`, convergence occures if the maximum temperature difference on any element of the list between last two cycles is less than `T1`. The run is then terminated.

If `T3` is blank or equal to `0`, only the results of the last cycle are written on file `tmgrslt.dat`. If `T3` = `1`, then all the results are written on `tmgrslt.dat.`

If `T4` is blank or equal to `0`, then the list of elements on which the convergence is checked contains all elements. If `T4` is an element or a group name, then the list of elements contains only that element or elements that are in the

group. You can also replace `T4` by a generic entity of type CYCLIC_TEMP to check the convergence on the elements specified through the generic entity, GENERIC Card.

`T2` should be ≤ the final time value specified on Card 2b `TF`.

`PARAM PIRSUBSOLAR T1`

This option specifies `T1`, the ratio of the IR emissive power of a planet at its subsolar point to its IR emissive power on the side opposite the subsolar point. This is used in planetary IR radiative heat flux calculations. Default for `T1` is 1.

The IR radiative heat fluxes incident on an element is calculated with:

$$Incident\ Flux = PIR\left(EVF + \frac{(T1-1)ALB}{AL} \right)$$

where:

- PIR is the planet emissive power in the subsolar point.
- ALB is the albedo factor.
- AL is the albedo value.
- EVF is the planet view factor.

This option is useful when the planet surface temperature is a strong function of the incident solar radiation. For example, on the Moon. This option is automatically invoked when the planet dark side IR radiation value is different from the planet sunlight side IR radiation value, on the Card 6t ORBDEF1 Card.

`PARAM QUARTIC`

With this option, if radiative conductances are present, the Analyzer solves a quartic equation for each element at each iteration to calculate elemental temperatures. Otherwise, the radiative conductances are linearized using the current temperature values.

`PARAM QUARTIC` can increase stability and reduce the number of iterations needed to achieve solution. It should be used if some of the elements radiate at high temperatures or over large temperature differences. If the temperature differences are small, however, its overhead can increase solution run time.

This option is OBSOLETE and is automatically disabled if the conjugate gradient solver is used.

`PARAM RADDOMDEC`

This Card activates domain decomposition method of parallel processing of radiative conductances in GRAYB, POWER, MEREL, and Analyzer modules to enable solutions of large multi-enclosure radiative models that may require more memory than is available on a single machine. The original radiative model with multiple radiative enclosures will be decomposed and solved as a coupled set of submodels (domains) distributed over multiple directories on multiple machines. The model partitioning/decomposition are done automatically, by grouping radiative enclosures into domains, in which their memory requirements in nearly equal. While the set of radiative conductances is split (without overlap) between different domains, all the non-radiative conductances of the full model are passed in their entirety to each of the domain. This makes this option best suited for predominantly radiative models. This method is currently not supported (is automatically disabled) for models with spinning, articulation, CFD-coupled solves, or user1 subroutines.

The `PARAM RADDOMDEC` card requires an additional input file named `tmgdomdec.setup` in the main run directory (where the simulation starts). The file contains an alternating sequence of machine host names and absolute paths to domain-specific run directories, as

```
hostname1

/abs/path/dir1

hostname2

/abs/path/dir2

…
```

Here each directory path is defined locally with respect to the machine listed on the preceding line, even if that path is not directly accessible/mounted on other machines. This simplifies use of local/scratch disks for the distributed run. The main run directory should be accessible for reading and writing from every machine in the list. Note that the main run directory differs from the directory of the first (or any) domain. If the lowest level directory (e.g. `“dir1” in “/abs/path/dir1”`) does not exist, it is created automatically, provided the upper level directory (`“/abs/path/”`) exists. The paths in the list should differ between each other in the physical location they correspond to, but not necessarily in their specification strings (e.g. when on same-named local disks of different machines).

The active MPI environment is required for all machines listed in the `tmgdomdec.setup`, with the same requirements as for the `PARAM MPIALL` option.

The number of host/directory entries in the `tmgdomdec.setup` input file determines the maximum allowed number of domains. The actual number of domains used depends on the number and relative sizes of enclosures in the model and cannot be larger than the total number of enclosures or much larger than the total number of view factors divided by the number of view factors in the largest enclosure.

Action of this PARAM card is independent of (does not affect, is not affected by, and can be freely intermixed with) other parallel processing PARAM cards (`PARAM MPIALL` , `PARAM MPIVUFAC` , `PARAM MPIHEMI` , `PARAM MPIRSLTPOST`). While other parallel processing options are designed primarily for performance improvement, the present card aims to overcome the limitations on the model size (particularly on the number of radiative conductances) that are imposed by a single-machine memory limit. Depending on the model, the current method may not give any performance gain or could increase the overall execution time compared to if the same model is run without this `PARAM` on (due to a larger number of iterative updates and linear solves). But it enables execution of large models that do not fit into memory of any single machine the user may have available.

This option changes the standard execution flow in the following way. After the VUFAC module completes, the auxiliary DOMDEC module runs to partition the original model into domains and to setup run directories and input files for running GRAYB, POWER, MEREL, and Analyzer modules for each domain. Each of those modules then run in parallel via `MPICH2` implementation of message passing interface (MPI), with different MPI processes running in different run directories. After completion of the Analyzer run, the solve results data are gathered in the main run directory. The postprocessing module (RSLTPOST) will proceed as for a regular undistributed run.

The DOMDEC module analyzes inter-element connectivity information (read from VUFF, MODLF, tmggeom.dat `,` and tmg49.dat files) and partitions the element list so that each element is assigned a single domain index. The connectivity matrix (“graph”) is constructed so that any two elements, which are connected in any of the following ways:

- Radiative or follower conductance.
- Merge card.
- Free face card.
- Different layers of the same multilayer element.
- Front and reverse side of a transparent element.

are forced to belong to the same domain, by being merged into the same element (“vertex”) of the connectivity graph. Each vertex of the connectivity graphs is assigned a weight, mainly based on the number of view factors it encapsulates. To make domains as nearly equal in their total weights (numbers of view factors) as possible within reasonable computation time, the connectivity graph is partitioned using the METIS library ["*A Fast and High Quality Multilevel Scheme for Partitioning Irregular Graphs*". George Karypis and Vipin Kumar, SIAM Journal on Scientific Computing, Vol. 20, No. 1, pp. 359-392, 1999]. The obtained domains are then internally sorted by their size (the first domain is the largest). If any domains could be merged so that the resulting new domain is not larger than the largest existing one, that will be done as well. The partitioning step of the DOMDEC module writes the partitioning information to file partition.dat, which lists domain index for each element number, distinguishing radiative elements by negative sign of their domain index.

The DOMDEC module is launched via MPI with different processes starting in the main run directory. After the partitioning step above completes (done only on the first process), the partitioning information is broadcasted to all other processes. Each process then reads the full `VUFF` and `MODLF` files from the main run directory and writes its own reduced (filtered) domain-specific copies of those files to the corresponding domain run directory. Other necessary TMG files (`tmggeom.dat,` `tmg49.dat` , etc) as well as partition.dat file are copied unmodified from the main directory to the distributed directories.

In spite of being launched via `MPI` (for easier management of distributed execution), each process of GRAYB, POWER, and MEREL modules runs essentially as if it were a regular serial run but applied to the domain-specific `VUFF` and `MODLF` files, without any internal communication between processes (no MPI calls used). For those modules, the `PARAM RADDOMDEC` card is only taken into account when processing `QNODE` cards in the MEREL module, which reads the partitioning information and excludes heat load (`HTF`) cards for out-of-domain radiative elements from writing to the `MODLF` file of its domain, to prevent double counting of those heat loads in the Analyzer module.

The main interaction between different domains occurs at the Analyzer stage (via MPI calls). For optimal convergence, all elements of the model (even elements of other domains) are solved on every domain. The main difference from the undistributed run is that all the missing radiative conductances of each out-of-domain element are replaced by one effective conductance (equal to the sum of missing radiative conductances) from the element to an effective sink element (whose temperature is set as radiative-conductance-averaged temperature of the elements that would be connected to the given element through the missing conductances). In this way, the missing radiative conductances are accounted for via corrections to the diagonal elements and the right hand sides of the linearized heat balance equation. This implementation allows a given radiative element to have radiative conductances from more than one domain. For each radiative element, its heat load will be calculated as a sum of heat load contributions from all domains. The inter-domain synchronization of temperatures and the matrix correction terms is performed after each complete linear solve for temperatures.

The Analyzer temperature solve results for all the elements of the full model (with partial exception for Oppenheim elements, see below) are written only by the first MPI process in the first domain directory. Upon completion of the Analyzer run, those files and some related ones (`TEMPF` , `GTEMPF` , `PRESSF` , `tmgrslt.dat` , `tmgrslt2.dat` , the report log file, `QNODEF` , `groups.unv`) are copied to the main directory.

Oppenheim elements are created independently on different domains (assigned zero domain index) and their element numbers and temperatures are meaningful only with respect to their corresponding domains (rather than the full model). The `TEMPF` file in the main directory includes Oppenheim elements (and their temperatures) from the first domain only.

Each distributed TMG module starts with empty the verbose log file in the domain-specific directories. After the module completes, its the verbose log file outputs in each directory are appended to the common the verbose log file in the main run directory, domain after domain, in the order of domain enumeration. The information written to the report log file stays in the domain-specific directories, with only the first domain's the report log file being copied to the main directory. While the full updated domain-specific `VUFF` , `MODLF` , `MODLCF` , and `tmggeom.dat` files are not gathered the report log fileback in the main directory, the extra `HTF` cards and the view factor sums written in the distributed runs are appended to the main directory `MODLF` and `tmggeom.dat` files, respectively, for postprocessing.

`PARAM RADSOLVE`

This option calculates temperatures in the Analyzer model by solving the radiative and non-radiative matrices separately, passing boundary conditions back and forth. It is particularly effective with large radiative models, and ones where large radiative temperature differences and nonlinearities cause convergence problems. It is limited to non-articulating models using the Oppenheim's Method.

When the results are output, the Oppenheim element temperatures are transformed into equivalent far-field radiative temperatures, with a corrective heat load for energy balance.

`PARAM RADSOLVE` is automatically activated with wavelength-dependent (PARAM SPECTRA Card) models.

Using this option is often more efficient because:

- The radiation matrix is solved in T^4, not `T`, which makes it well-behaved and linear. The non-radiation matrix is always solved in `T`. When the two matrices are combined, they need to be solved in `T`, which makes the resulting matrix non-linear. Thus, the `PARAM RADSOLVE` option in effect eliminates radiative non-linearities, which makes it particularly effective for reducing the number of iterations when the radiation matrix is very non-linear, e.g. near cryogenic temperatures.
- `PARAM RADSOLVE` is very effective when the model is ill-conditioned. This is because the radiation part of the matrix is very seldom ill-conditioned, but the radiation part is usually much larger than the solid part. Ill-conditioning requires larger preconditioning matrices with higher fill-in values, which reduces the performance of the solution. Using the `PARAM RADSOLVE` option confines the high-fill-in preconditioner to the much smaller solid portion of the matrix, resulting better solver performance.

`PARAM REDUCE T1 T2 T3`

This option creates a reduced finite-difference conductance/capacitance model between user-specified groups of elements during the Analyzer run.

`T1` is a group name of elements that are condensed into a finite difference node with label `T2` in the reduced model.

The reduced model is written out at the end of the run onto file INPF.reduced in INPF format.

Model creation:

- For a reduced model of n finite-difference nodes there must be `n` `PARAM REDUCE` Cards in the model, each specifying a separate group and label.
- Care should be taken that all elements of the model are specified on a `PARAM REDUCE` Card, none should be left out. In case some are left out, TMG assigns a single aggregate group for all left-out non-sink elements, and a separate group for each left-out SINK element.
- SINK elements of different temperatures should be specified in their own groups and should not be mixed with non-SINK elements. SINK elements of the same temperature may be grouped together.
- The reduced model contains:

- TINIT Cards that specify the average temperature of the group at the printout interval.
- QNODE and XCAP Cards containing the total heat inputs and capacitances of the groups at the time of the printout. For transient runs these may be written with time-dependent tables.
- XCOND RAD Cards to model direct radiative conductance paths between the groups. Their values are calculated by computing the heat flow through the radiative conductances between the groups of elements and dividing by the `SIGMA*(TI**4-TJ**4)`. For transient runs these may be written with time-dependent tables.
- XCOND COND Cards to model direct conductive paths. Their values are computed by calculating the heat flow between the groups through all direct conductive paths and dividing by the temperature difference between them. For transient runs, these may be written with time-dependent tables.
- XCOND COND Cards to model conductance paths not included in the direct conductance and radiative paths. For transient runs these may be written with time-dependent tables.
- If `T3=1`, XCOND FOLLOWER conductances to recover the temperatures of the original model. If this option is specified, care should be taken that the node number `T2` is different from any element label in the model.
- SINK Cards to specify the temperature of temperature boundary condition groups. For transient runs these may be written with time-dependent tables.
- NAME Cards associating the group names with the assigned labels.
- A PRINT 0 0 SUBTEMP Card to automatically create a file tmgtempe.unv to recover element temperatures.

The following example will create a three-node finite difference model between the three groups `SPACE`, `ANTENNA`, and `DECK`.

- `PARAM REDUCE SPACE 2001`
- `PARAM REDUCE ANTENNA 1`
- `PARAM REDUCE DECK 2`

`PARAM RESTART T1 T2 T3`

This option governs the reuse and recalculation of different thermal model parameters during restarts. The Card 2a M parameter must = `231`.

- `T1` is a mnemonic defining the type of thermal model parameter. `T1` may be:
  - `COND_CAP_FLUID` for conductive conductances, capacitances, and hydraulic resistances calculated by the COND module, and the thermal model parameters with the mnemonics `CON`, `CAP`, and `HYD` on file `MODLF.`
- `THERMAL_COUPLINGS` for thermal couplings calculated by Card 6e AREA Cards of the types:

`CONV, COND, RAD, VIEW, NEAR, CSERIES, RSERIES, NEARA, NEARAS, NEARS, NEARAR, INTER, NEARM, NEARP, SOLAR, NEARFOL, NEARLP, ABS, XCOND, CONVLP, RADTOT, MERGE, NEARVF, NEARTOT, NEARRES, NEARA1W, RESISTA, CONV1W, INTERTO, RAD2, NEARAR2, RADTOT2, NEARAR3, INTER2, INTER2T, INTERB, INTERBTOT`

and the thermal model parameters with the mnemonic `CNF` on file `MODLF.`

- `CONVECTION_COUPLINGS` for thermal couplings calculated by Card 6e AREA Cards of the types:

`NEARAFU, NEARC1, NEARC4, NEARC5, NEARC12, NEARC13, FREE, NEARF, NEARC6, NEARC7, NEARC8, NEARC9, NEARC10, NEARCIN, NEARCOUT, NEARC16, NEARC19, PLATE, PLATEH, SPHERE, CYLIND, INCCHNL, CAVITY, CAVITYH, CONCYL, CONSPH, NEARC21, NEARC22, NEARC23, NEARC24, NEARC41, NEARC42, NEARC43, NEARC43, NEARC44, NEARCB1, NEARCB2, NEARCB3, NEARCB4`

and the thermal model parameters with the mnemonic `CNF` on file `MODLF.`

- `BLACK_BODY_VIEW_FACTORS`
  - For view factors calculated the `VUFAC` and `HEMIVIEW` modules by requests of the types Card 6a and 6r, and the thermal model parameters with the mnemonics `BVF` on file `VUFF.`
  - If previously calculated black body view factors were calculated with the ray-tracing VFTRACE option, and specular and transparent properties are present, they should be reused only if the specular and transparent properties have not changed from the previous run.
- `RADIATIVE_CONDUCTANCES`
  - For radiative conductances are calculated by the GRAYB module, and the thermal model parameters with the mnemonic `RAD` on file `MODLF.`
- `ORBITAL_VIEW_FACTORS`
  - For orbital view factors, calculated with Card 6 requests of the type Card 6b, 6d, 6k, 6l, 6n, 6s, 6t, and 6u, and the thermal model parameters with the mnemonics `EVF`, `EVR`, `ALB`, `ALR`, `SVF` on file `VUFF`.
  - If specular and transparent properties are present, previously calculated orbital view factors should be reused only if the specular and transparent properties have not changed from the previous run.
- `HEAT_FLUX_VIEW_FACTORS`

    - For heat flux view factors, calculated with Card 6 requests of the type Card 6n, and the thermal model parameters with the mnemonics `HVF` and `HVI` on file `VUFF.`
    - If specular and transparent properties are present, previously calculated heat flux view factors should be reused only if the specular and transparent properties have not changed from the previous run.
- `ORBIT_HEAT_FLUXES`
    - For orbital heat loads calculated with the Card 2a `M` = `32`, `M` = `64`, and `M` = `128` options, and the thermal model parameters mnemonic `HTF` on file `MODLF.`
    - `T2` is a flag governing the retention and reuse, or deletion of these parameters on files `VUFF` or `MODLF`. `T2` may be the mnemonic:
        - `REUSE`
        - `DELETE`
    - If only `REUSE` options are present, all parameters other than the ones specified to be reused are deleted.
    - If only `DELETE` options are present, all parameters other than the ones specified to be deleted are reused.
    - In case of a conflict between the `REUSE` and `DELETE` options, the `REUSE` option prevails.
    - `T3` is a flag governing the recalculation or non-recalculation of these parameters. `T3` may be the mnemonic:
        - `CALC` or
        - `NOCALC`

`PARAM RESTARTDIR T1`

This option specifies the name of the directory `T1` where the restart files `VUFF`, `MODLF`, and `tmggeom.dat` are located if a restart is being performed.

`PARAM RETRANS T1`

This option redefines the laminar to turbulent transition Reynolds Number for duct flow to `T1`. The default transition Reynolds Number is `2300.`

`PARAM REVINC T1`

This option specifies the reverse side increment `T1` for all elements whose reverse side properties are defined on MAT Cards. The reverse side of element `I` will be `I+T1`. If this Card is not present, the reverse side numbering is automatically assigned.

`PARAM RUNSINDA`

This option allows you to run any one of the `SINDA` versions, or `ESATAN`, to calculate temperatures instead of the Analyzer module. You have to customize the script `tmg/com/runsinda.com` or `tmg/com/runsinda.cmd`, and remember to specify the SINDA version with a `PARAM SINDA` or `PARAM SINDA85` Card.

`PARAM SCRMESG`

This option writes error/warning messages onto the screen for TMG CFD instead of the verbose log file.

`PARAM SINDA T1 T2 T3 T4`

This option creates an old COSMIC SINDA format output.

`T1` must be `0`. `T1` may be a blank if `T2` is blank.

`T2` is an optional file name, on which the `SINDA` format output is written. If `T2` is blank, the output is written on file `FMODLF`.

`T3` and `T4` are two element numbers, `T4` > `T3.` If these are specified, TMG will attempt to create internal element numbers (e.g. boundary elements for the COND module, Oppenheim elements, etc.) within these limits.

`PARAM SINDA85 T1 T2 T3 T4`

This option creates a `SINDA` format output.

`T1` must be `0`. `T1` may be a blank if `T2` is blank.

`T2` is an optional file name, on which the `SINDA85` format output is written. If `T2` is blank, the output is written on file `sinda85.dat`.

`T3` and `T4` are two element numbers, `T4` > `T3`. If these are specified, TMG will attempt to create internal element numbers (e.g. boundary elements for the COND module, Oppenheim elements, etc.) within these limits.

`PARAM SINKBND`

This option merges all boundary elements of a sink element to the original sink element. This has the effect of sinking all of those boundary elements to the sink temperature.

`PARAM SOLIDACC`

With this option, the conductive conductances of hexahedral or wedge-shaped solid elements that do not have unique element centers are calculated accurately by the COND module for the element center option. For the recommended element CG option this option is ignored.

A solid element is will not have a unique element center if on one of its surfaces the perpendiculars from the edges do not meet at a single point. With `PARAM SOLIDACC` conductances are calculated by subdividing the element into tetrahedral sub-elements. The sub-element's element center closest to the solid element's CG is chosen as the element center, and all other sub-elements' element centers are eliminated with the star-delta transformation.

If a `PARAM SOLIDACC` Card is not present (the default option), a unique element center is assumed near the CG for odd-shaped solid elements. This yields fewer conductances, but creates a less accurate conductance matrix.

If the only solid elements present are tetrahedral, brick-shaped, or regular wedge-shaped, a `PARAM SOLIDACC` Card is not used.

`PARAM SPECTRA T1 T2 T3 T4 T5 T6 T7 T8`

This option specifies that radiative couplings and radiative heat fluxes are calculated using spectrum-dependent optical properties in a multispectral run, instead of the standard gray-body assumption with two (IR and solar) bands. Multispectral runs should be specified only if wavelength-dependent optical properties are present, and more accurate results are desired.

A separate radiative coupling matrix for radiative heat transfer between elements is created for each band in the IR spectrum, and separate radiative heat loads is created for each band in the total spectrum.

`T1` specifies the number of bands into which the total spectrum is subdivided:

- `T1` must be `> 1` for a multispectral run.
- If `T1` = `0`, a standard gray body run is performed, just as if a `PARAM SPECTRA` Card was not present. Radiative couplings are calculated only for the IR spectrum, and radiative heat fluxes are calculated only in the IR and solar spectra. A `PARAM SPECTRA` Card's presence is necessary for gray body runs only if wavelength-dependent optical properties are present in the model to transform their properties into the equivalent solar and IR spectrum properties.
- `T1` may take the form of `Tn` (e.g. `T3`), where n is a table number that specifies the wavelength breakpoints between the bands. The number of bands is then computed from the table.
  - The independent variable on the `TABTYPE` Card must be `WAVELENGTHNUMBER.`
  - The dependent variable must be `TEMP` or `WAVELENGTH`.
  - If the dependent variable is `TEMP`, then an equivalent wavelength is calculated for each temperature specified in the table, using Wien's law for a radiating black body.
  - If the dependent variable on the `TABTYPE` Card is `WAVELENGTH`, then the values on the `TABDATA` Card must be specified in units of μ (microns), where μ=1×10^{-8} m.

`T2` is the constant in the equation for Planck`s spectral energy distribution, value 14387.69 μK or 25897.84 μR.

`T3` specifies the method by which the spectrum is subdivided when `T1 > 0.`

- The radiative spectrum is considered to range from $0- > \lambda_{\max}$ and $\lambda_{\max} - > 1000\lambda_{\max}$, where $\lambda_{\max}$ is defined by `T3`. The spectrum $0- > \lambda_{\max}$ is subdivided according to a method defined by `T3`, `T5`, and `T6`.
- For `T3` = `MAXMINWAVE, T5` is the minimum wavelength of interest and `T6` is the maximum wavelength of interest $\lambda_{\max}$, specified in μ (microns). The spectrum $0- > \mathrm{T5}$ is a single band. The spectrum $\mathrm{T5} - > \lambda_{\max}$ is subdivided into T1 bands, with breakpoints chosen to avoid bands that would not radiate significantly. The spectrum $\lambda_{\max} - > 1000\lambda_{\max}$ is a single band.
- For `T3` = `MAXMINTEMP, T5` and `T6` are the minimum and maximum temperatures of interest. For example, these may be specified to be room and lamp temperatures for models where radiative heating with lamps is calculated. The first band $0- > \lambda_{\min}$ and the last band $\lambda_{\max} - > 1000\lambda_{\max}$ are computed so that each one of them radiate a power equal to `1/T1` using the spectral distribution for a black body at temperatures `T5` and `T6`. The spectrum $\lambda_{\min} - > \lambda_{\max}$ is subdivided into `T1-2` bands. The breakpoints between $\lambda_{\min}$ and $\lambda_{\max}$ are chosen to avoid "dead bands", i.e. bands that do not radiate significantly.
- For `T3` = `EQPOWER`, $\lambda_{\max}$ is calculated from temperature `T5`, and the spectrum $0- > \lambda_{\max}$ is subdivided into `T1-1` bands. $\lambda_{\max}$ is then chosen that each band radiates the same power at the black body at temperature `T5`. `T6` is ignored.
- For `T3` = `EQBAND`, `T5` is the maximum wavelength of interest $\lambda_{\max}$, specified in μ. The spectrum $0- > \lambda_{\max}$ is subdivided into `T1-1` equal bands, and the spectrum $\lambda_{\max} - > 1000\lambda_{\max}$ is a single band.

`T4` is a wavelength value in μ (microns) that defines the breakpoint between the solar and IR spectra. `T4` has a number of uses.

- `T4` permits the specification of optical properties using the standard gray body values in the IR and solar spectra. It is not necessary to specify all optical properties as wavelength-dependent. For multispectral runs, for each pair of constant IR and solar spectrum optical properties (`E` and `ABSORPTIVITY)` , (`IRSPEC` and `SPECULARITY`), (`IRTRANS` and `TRANSMISSIVITY)` , (`IREXTINCT` and `SOLAREXTINCT`), (`IRSCATTER` and `SOLARSCATTER`), (`IRREDIFF` and `SOLREDIFF`), TMG creates equivalent wavelength-dependent property tables for each of the bands. For example, for an absorptivity-emissivity pair of properties, the emissivity value in the table in the wavelength band λ_i to λ_{i+1} where $\lambda_{i+1} \leq T4$ is set to the solar absorptivity value, in the band where $\lambda_i \geq T4$ is set to the emissivity value, and in the band where $\lambda_i < T4 > \lambda_{i+1}$ it is a weighted average of the emissivity and absorptivity.
- **Note**: Wavelength-dependent optical properties should be defined only with IR spectrum mnemonics, not solar spectrum mnemonics. Thus, `ABSORPTIVITY` should not be defined as a function of wavelength, while `E` can be.
- For gray-body runs (`T1=0`) if wavelength-dependent optical properties are present, they are transformed into equivalent gray body solar and IR properties with `T4` .
- Radiative heat loads into elements from radiative sources (Card 6 SOURCE Cards) are calculated for all the bands in the spectrum $0- > 1000\lambda_{max}$.
- Radiative couplings for radiative heat transfer between elements are not calculated with discrete bands in the spectrum $0- > \lambda_i$ where $\lambda_i \leq T4$. In other words, minimal radiation is assumed to occur in the solar spectrum. The fraction of radiation emitted by an element is summed with the lowest radiating band. To permit radiation in all bands, you specify the ALLBAND option for `T8` .
- `T4` is used to modify the orbital solar spectrum (solar heat input and albedo) calculations. First, an internal power vs wavelength table is created from published measured solar data. Next, this table is modified so that the power emitted in the bands with the range λ_i to λ_{i+1} , where $\lambda_i \geq T4$, is set to 0, and is summed with the largest band where $\lambda_{i+1} \leq T4$. Last, the table is non-dimensionalized to create a constant weighting factor for each band, where the weighting factor represents the fraction of energy emitted in that band.
- `T4` is used to modify the Earth IR spectrum for orbital calculations. First, an internal power vs wavelength table is created from the specified Card 2a PIR for the Earth. Next, an equivalent Earth temperature is calculated, assuming an Earth emissivity of `.612` . Next, a power vs wavelength table is created for this spectrum using Planck's Law. Next, the table is modified that the power emitted in the bands defined by the range λ_i to $\lambda_{i+1} \leq T4$, where, is set to 0, and is summed with the lowest band where $\lambda_i > T4$. Last, the table is non-dimensionalized to create a constant weighting factor for each band, where the weighting factor represents the fraction of energy emitted in that band.
- `T4` = `0` defaults to $T4 = 3\mu$.

`T5` The interpretation of `T5` depends on the mnemonic `T3`. It is $\lambda_{\max}$ for `EQBAND ,` the black body temperature and `EQPOWER`, the minimum temperature of interest for `MAXMINTEMP ,` and the minimum wavelength of interest for `MAXMINWAVE.`

`T6` The interpretation of `T6` depends on the mnemonic `T3`. It is the maximum temperature of interest for `MAXMINTEMP` and the maximum wavelength of interest for `MAXMINWAVE.`

`T7` is optional:

- If present, it must be a table specified as `Tn` (e.g. `T5`), where `n` is the table number in which the weighting factors for the spectrum-dependence of the sun is defined on `TABTYPE` and `TABDATA` Cards. The dependent variable on the `TABTYPE` Card must be `PSUN`, and the independent variable must be `WAVELENGTH.`
- The solar power magnitude in a particular band is calculated by interpolating a weighting factor from the table, and multiplying it by the `PSUN` value specified for that particular Card 6 request.
- If is `T7` = `0,` an internally generated solar power table is used.

T8 may be blank, or

- `SINGLEIRSPECTRUM,` in which case all the radiative couplings will be merged into a single band, or
- `ALLBANDS,` in which case all the bands radiate, including those in the solar spectrum.

`PARAM SUBSTR T1 T2 T3`

This option requests the MEREL module to reduce the number of elements with substructuring, and it specifies the elements not to be eliminated.

Substructuring is a process that reduces the size of the model to be solved by performing a series of star-delta transformations before solving for temperatures. The information to recover the eliminated elements' temperatures is written on file `MODLCRF`.

`T1` is:

- The element number or group name of element(s) not to be eliminated, or
- The code `RADNODES` (or `-2.34`), in which case none of the elements connected to a radiative conductance is eliminated, or
- 0 or blank if any element may be eliminated.

`T2` is blank or may be:

- `GSUM` (or `33`), in which case those elements whose conductance sums is > `T3` are eliminated.

- `RCMIN` (or 31), in which case all elements with RC values < `T3` are eliminated, including zero-capacitance elements. RC is the element's capacitance divided by sum of its conductances.
- `CMIN` (or `32`), in which case all elements with capacitance values < `T3`, including zero-capacitance elements, are eliminated.

`T3` may be a value associated with `T2` = `GSUM, RCMIN,` or `CMIN`, or is blank.

The Analyzer calculates the temperatures of the eliminated elements of the reduced model in a single iteration at each printout interval.

Several `PARAM SUBSTR` Cards may be used simultaneously.

The elements to be eliminated are selected as follows:

- All elements specified on Card 8 and the `T2` elimination criteria are eliminated.
- Sink elements, `MCV` elements, phase change elements, hydraulic elements, elements referenced on `INTERP` or `THERMST` Cards, and elements connected with one-way or non-linear non-radiative conductances are automatically kept.
- The element(s) of `T1` are kept, even if a `T1` element is requested to be eliminated on a Card 8 or by one of the `T2` elimination criteria.
- If all the elements in a steady-state run are candidates for elimination, a single `PARAM SUBSTR` Card with `T1 = T2 = T3 = blank` will eliminate all the elements.

Substructuring can reduce Analyzer run times by solving a smaller and less ill-conditioned model that has larger RC values. Substructuring is especially useful when:

- High-conductance elements are eliminated in an ill-conditioned model.
- Zero capacitance and small-RC elements that govern the integration time step are eliminated for transient analysis.

If the eliminated elements are connected to radiative conductances, the Card 2a `SIGMA` and `TLIN` parameters must be specified.

Elements referenced in user-written subroutines must be kept by specifying them on a `T1` parameter.

Substructuring results are exact if the following conditions are met:

- The elements to be eliminated are joined to other elements by conductive conductances only, or by radiative conductances only, or by a mixture of the two with an exact value for `TLIN`.
- Steady-state analysis is used.
- The `PARAM THIN` option is not used.

If transient analysis is performed and non-zero capacitance elements are eliminated, the substructuring process will not be exact, since the order of the differential equations describing the model is changed. However, the error will generally be small if the eliminated element capacitances are comparatively small or their rates of change of temperature are small.

For `SINDA` models, only the temperatures of the reduced model will be calculated. The recovery information on file `MODLCRF` is not transmitted to the `SINDA` file on file `FMODLF`.

`PARAM TC_CONVECT`

This option excludes the thermal coupling elements from the convection to environment when the thermal coupling and convection to environment boundary conditions are on the same selection.

`PARAM TDEPORTHO T1`

With this Card `T1` specifies the criterion for updating temperature-dependent orthotropic conductances. By default these conductances are updated only when the maximum temperature change for any temperature-dependent orthotropic element exceeds 20 degrees. Increasing this value speeds up Analyzer runs, decreasing this value increases the accuracy.

`PARAM TDIFS T1 T2`

This Card specifies the temperature iteration convergence criterion for steady-state runs, and transient runs when an implicit technique (Crank-Nicolson or backward) is used.

Convergence is achieved if the maximum temperature difference for any element between two subsequent iterations is < `abs` (`T1`). This criterion is used both in the outer (nonlinear) iteration loop as well as in the linear solver activated by `PARAM ILU.`

The steady state `T1` default is the Card 2b `GRADNT` parameter, the transient default is `0.001`.

`T2` specifies how the convergence criterion is applied.

- If `T2` is blank or `ALL`, `T1` applies to all elements.
- If `T2` is `CAPONLY, T1` applies only to elements with non-zero capacitances.
- If `T2` is `NONOPPENHEIM, T1` applies only to non-Oppenheim elements only.

- If `T2` is `IDEASONLY, T1` applies only to Card 5 elements.
- If `T2` is an element number, `T1` applies only to that element.
- If `T2` is a group name, `T1` applies only to that group name.
- If `T2` is `STEADYSTATE`, `T1` applies only to the solution control STEP cards with the steady state solution type.

Multiple `PARAM TDIFS` Cards may be used. In case of conflict, the tighter convergence criterion specified for the element is used.

`PARAM TEMPCONDITION`

This Card ensures that at printout times no element temperature falls below the minimum SINK temperature or initial temperature. It is possible for an element temperature to fall below the minimum allowable temperature if the element is highly distorted, or because other nonlinearities occur.

`PARAM TEMPDIFFTARGET T1 T2`

This Card creates an additional stopping criterion for transient runs. `T1` is an element number or group name of element(s), and `T2` is a temperature difference. The run is considered to be completed when the difference in average temperature of `T1` between two consecutive transient timesteps is less than `T2`.

`PARAM TEMPTARGET T1 T2`

This Card creates an additional stopping criterion for transient runs. `T1` is an element number or group name of element(s), and `T2` is a temperature. The run is considered to be completed when the average temperature of `T1` reaches the temperature `T2` either from above or below.

`PARAM TIMETABLE T1 T2`

This Card controls the interpolation method of time-dependent tables when the time lies outside of the table range.

- If the keyword is `PERIODIC` (or `0`), the table values are periodic for the times larger than the last table entry. For times smaller than the first table entry, the solver uses the lower bound value.

- If the keyword is `TRUNCATE` (or `1`), the solver uses the lower bound value for times smaller than the first table entry, and the upper bound value for times larger than the last table entry.

`PARAM THERMOSTAT T1 T2 T3`

This is a global flag for thermostats and is used only if Card 9 `THERMST` Cards are present. The following options are available:

- If `T1` is the code `AVGTEMP`, then all the heater elements are set to the average temperature of the Thigh and Tlow values specified on the `THERMST` Card. This is a simple way to calculate heater power requirements. This is the default option for steady-state analysis if there are Card 9 `THERMST` Cards present but no `PARAM THERMOSTAT` Card. Note that this can result in negative heat loads on the heaters, when the heater temperatures are below those of the environment.
- If `T1` is the code `PROPORTIONAL`, then all the thermostats are replaced by proportional controllers, with the temperature limits equal to the Thigh and Tlow values specified on the `THERMST` Card. Care should be taken for this option during steady-state analysis to use a low value for the Card 2b `DT` relaxation parameter to prevent oscillation of the solution.
- If `T1` is the code `Q_EQUIV`, then, if a steady-state run is performed, TMG will automatically perform multiple runs to calculate through sensitivity analysis the heater powers required to keep the sensors at the average of the Thigh and Tlow temperatures specified on the THERMST Card. If there are `N` thermostats in the model, `N` runs will be performed.
- `T2` is the temperature convergence criterion used for convergence for the `Q_EQUIV` option. By default `T2` is `0.1` degrees. Otherwise it is ignored.
- `T3` is the maximum number of iterations performed for the `Q_EQUIV` option. Otherwise it is ignored. `T3` defaults to `10`. If the model has no non-linear conductances, there should be only two iterations

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`PARAM THIN T1`

This option eliminates insignificant conductances in the MEREL module. A conductance is considered insignificant if:

$$G_{ij} < T1^{*}GSUM_{i}, \text{ and}$$
$$G_{ij} < T1^{*}GSUM_{j},$$

Where:

- G_{ij} s the conductance between elements i and j
- $GSUM_{i}$ is the sum of the conductances to element i

- $GSUM_j$ is the sum of the conductances to element `j`

Radiative conductances are linearized with the Card 2a `SIGMA` and `TLIN` parameters during the thinning out process.

`T1` values above `0.01` should be used with caution; too many eliminated conductances may result in degradation of accuracy.

Thinning can considerably reduce the run times of the Analyzer module if there are too many insignificantly small conductances present.

This option also eliminates negative conductances, so it should be used with caution when the `PARAM COND NEW` option is in effect.

`PARAM TMGVERSION T1`

This option sets the defaults for a particular version number. For example, if a set of default parameters were changed in TMG version 13 from version 12, the Card `PARAM TMGVERSION 12` will reset those parameters to those of version 12. The objective is to be able to perform comparison runs between two versions to evaluate the effects of a change in defaults.

`PARAM TRASYS T1 T2 T3 T4`

This option creates a `TRASYS` format output.

`T1` must be 0. `T1` may be a blank if `T2` is blank.

`T2` is an optional file name, on which the `TRASYS` format output is written. If `T2` is blank, the output is written on file `FMODLF`.

`T3` and `T3` are two element numbers, `T4` > `T3`. If these are specified, TMG will attempt to create internal element numbers (e.g. boundary elements for the COND module, Oppenheim elements, etc.) within these limits.

`PARAM UNITS T1 T2 T3 T4 T5 T6`

This option specifies to TMG what units are being used.

`T1` is a numerical code, not in use at this time.

`T2` is the number of model's length units that are in a meter. For example, if the model's length units are in inches, `T2` = `39.37`

`T3` is the number of the model's force units that are in a Newton. For example, if the model's force units are Kgf, then `T3` = `1/9.81` = `0.1019`

`T4` is the model's temperature scaling factor with respect to Centigrade. For example, if the model's temperature units are in Fahrenheit or Rankin, `T4` = `1.8`

`T5` is the model's temperature offset for absolute zero. For example, if the model's temperature units are in Centigrade, `T5` = `-273.15`

`T6` is the model's time scaling units with respect to seconds. For example, if the model's time is in hours, then `T6` = `3600.`

The model's units can be accessed from a user-written subroutine with `CALL TUNITS`. For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional.

`PARAM UPDATEOPTICAL T1 T2 T3 T4`

This option accounts for the changes in the surface optical properties, caused by forming a condensation film over a surface.

`T1` specifies the calculation method type of the surface optical properties. There are currently two methods supported by the solver.

If `T1` = `0`, the first calculation method is used, where the transmissivity and specular reflectivity of the film layer are defined as a function of film thickness for irradiation and solar spectrums**.** The transmissivity and specular reflectivity are defined, while the software calculates the emissivity/absorptivity.

If `T1` = `1`, the second calculation method is used, where the index of refraction and extinction coefficient of the film layer are defined as a function of wavelength. The film optical properties are automatically calculated by the thin-film analysis algorithm.

In both methods, the combined transmissivity, t, and reflectivity, r, of media 1 and 2 are calculated as follows:

$$t_{12} = t_1 \cdot t_2$$

$$r_{12} = r_1 + t_1^2 \cdot r_2$$

`T2` is the film type. If `T2` = `0`, then the film is incoherent. If `T2` = `1`, the film is coherent. The default value is `1`. This option is only applicable to the second method.

`T3` is the film thickness threshold for updating the optical properties.

`T4` is the film thickness change rate threshold between two consecutive time steps.

> **Note**
>
> All surface optical properties in the model should be defined using the "Advanced Thermo-Optical Properties", such as emissivity/absorptivity, transmissivity, and specular reflectivity. The value of emissivity/absorptivity cannot be 0 or 1. It must be between 0.01 and 0.99.

Example of the first method

```
PARAM UPDATEOPTICAL 0 1 1.E-10 1.E-10
$
TABTYPE 40 FT_IRSPEC FILMTHICKNESS
TABDATA 40  0.00  1.000000E-07
TABDATA 40  0.00  1.500000E-07
TABDATA 40  0.00  2.000000E-07
TABTYPE 41 FT_IRTRANS FILMTHICKNESS
TABDATA 41  0.990  1.000000E-07
TABDATA 41  0.985  1.500000E-07
TABDATA 41  0.980  2.000000E-07
TABTYPE 43 FT_SPECULARITY  FILMTHICKNESS
TABDATA 43  0.00  1.000000E-07
TABDATA 43  0.00  1.500000E-07
TABDATA 43  0.00  2.000000E-07
TABTYPE 49 FT_TRANSMISSIVITY  FILMTHICKNESS
TABDATA 49  0.990  1.000000E-07
TABDATA 49  0.985  1.500000E-07
TABDATA 49  0.980  2.000000E-07
```

Example of the second method

```
PARAM UPDATEOPTICAL 1 1 1.E-10 1.E-10
$
TABTYPE 160 IREFFILM WLENGTH
TABDATA 160 1.396       0.0000002
TABDATA 160 1.373       0.000000225
TABDATA 160 1.362       0.00000025
TABTYPE 161 EXTFILM WLENGTH
TABDATA 161 6.911504    0.0000002
TABDATA 161 2.736676    0.000000225
TABDATA 161 1.683894    0.00000025
```

`PARAM USERDLL`

This option allows you to bypass the use of the required Fortran compiler for user-written subroutines. Instead, it allows you to use another Fortran compiler. A `dll` will be created, and automatically linked into the code.

An important limitation: You MUST have the following defined in your user-written subroutine:

`DOUBLE PRECISION T, TIME, DT`

Also, only TMG subroutines documented in the Reference Manual may be called.

`PARAM USRCNDADD`

This option signals to the Analyzer that the user-written subroutine `USER1` is called with `KODE` = `5,` and a set of new conductances are to be added to the Analyzer conductance matrix at run-time. For more information, see the `CALL ADDCOND` option in Card 10 - User-Written Subroutines USER1 and USERF - Optional.

`PARAM VFADJUSTALL`

This option allows the proportional adjustment of all view factors when the Card 2a `KSP` = `3000000` option is specified. Without this option only unshadowed view factors are adjusted. The benefit of using this option is that it increases the likelihood that after adjustment all the elements' view factors sum to 1.

Example

```
PARAM SOLIDACC
$ CONDUCTIVE CONDUCTANCES BETWEEN ODD-SHAPED
$ SOLID ELEMENTS WILL BE ACCURATELY CALCULATED
$
PARAM NLOOP 200
$ THE NLOOP PARAMETER IS SET TO 200
$
PARAM ACCEL 10 100
$ THE ACCELERATOR PARAMETERS ARE REDEFINED
$
PARAM QUARTIC
$ THE FOURTH ROOT IS FOUND AT EACH ITERATION
$
PARAM SUBSTR KEY GSUM .1
PARAM SUBSTR 0 RCMIN .01
PARAM RECOVER
$ SUBSTRUCTURING AND RECOVERY ARE PERFORMED.
$ THE ELEMENTS ASSIGNED TO KEY ARE KEPT.
$ ELEMENTS WITH GSUM > .1 AND RCMIN < .01
$ ARE ELIMINATED.
$
PARAM ENGBAL .001
$ THE ENERGY BALANCE MUST BE < .001 AT CONVERGENCE
$
PARAM ENGBAL .01 FRACT
$ ENERGY BALANCE MUST BE < .01 OF HEAT FLOW INTO SINKS
```

Card 9 - PELTIER Peltier Device Card - Optional

`KODE, GRPCOLD, GRPHOT, NPOLE, SEEBECK, GEOM, ELECRES, VOLT, CURRENT, KTHERM`

`KODE` = `PELTIER` (or `60`)

`GRPCOLD` is the group name of the cooled side elements of the Peltier device.

`GRPHOT` is the group name of the other ("hot") side elements of the Peltier device.

`NPOLE` is the number of poles of the Peltier device.

`SEEBECK` is the value of the Seebeck coefficient of the Peltier device material.

If `SEEBECK` is of the form `Tn` (e.g. `T5`), then n is a table number from which the Seebeck coefficient is interpolated. The table must be defined with Card 9 TABTYPE and TABDATA Cards. The independent variable may be TEMP, which is interpreted to be the average temperature of the hot and cooled sides, or TIME, and the dependent variable must be `SEEBECK` .

If `SEEBECK` is of the form `En` (e.g. `E5`), then n is an expression number from which the Seebeck coefficient is evaluated.

`GEOM` is the value of the geometrical parameter (Area/length of each semiconductor element) associated with the Peltier device.

`ELECRES` is the value of the electrical resistivity of the Peltier device material.

If `ELECRES` is of the form `Tn` (e.g. `T7`), then n is a table number from which the electrical resistivity is interpolated. The table must be defined with Card 9 TABTYPE and TABDATA Cards. The independent variable may be TEMP, which is interpreted to be the average temperature of the hot and cooled sides, or TIME, and the dependent variable must be `ELECRES` .

If `ELECRES` is of the form `En` (e.g. `E7`), then n is an expression number from which the electrical resistivity is evaluated.

`VOLT` is the value of the applied voltage of the Peltier device. If `VOLT is > 0` , it is understood to be applied to the cooled side.

Either `VOLT` or `CURRENT` must be zero.

The relation between current and voltage in the Peltier device [13] is given as:

$$CURRENT = \left(\frac{VOLTAGE}{2NPOLE} - SEEBECK(T_{hot} - T_{cooled}) \right) \frac{GEOM}{ELECRES}$$

- If `VOLT` is of the form `Tn` (e.g. `T7`), then `n` is a table number from which the voltage is interpolated. The table must be defined with Card 9 TABTYPE and TABDATA Cards. The independent variable may be `TEMP`, which is interpreted as the average temperature of the hot and cooled sides, or TIME, and the dependent variable must be VOLTAGE.
- If `VOLT` is of the form `En` (e.g. `E7`), then n is an expression number from which the applied voltage is evaluated.

`CURRENT` is the value of the current applied to the cooled side of the Peltier device.

Either `VOLT` or `CURRENT` must be zero.

If `CURRENT` is of the form `Tn` (e.g. `T7`), then `n` is a table number from which the current is interpolated. The table must be defined with Card 9 TABTYPE and TABDATA Cards. The independent variable may be `TEMP`, which is interpreted to be the average temperature of the hot and cooled sides, or TIME, and the dependent variable must be `CURRENT`.

If `CURRENT` is of the form `En` (e.g. `E7`), then n is an expression number from which the applied current is evaluated.

`KTHERM` is the value of the thermal conductivity of the Peltier device.

If `KTHERM` is of the form `Tn` (e.g. `T90`), then n is a table number from which the thermal conductivity is interpolated as a function of the average temperature of the hot and cooled sides. The table must be defined with Card 9 TABTYPE and TABDATA Cards. The independent variable must be `TEMP`, and the dependent variable must be `KTHERM`.

If `KTHERM` is of the form `En` (e.g. `E90`), then n is an expression number from which the thermal conductivity is evaluated.

Note:

- You can also model more complex Peltier device phenomena, with the `CALL PELTIER` function with Card 10 user-written subroutines.

- The software defines a conductive coupling of value $2(NPOLE)(GEOM)(KTHERM)$ between the cooled and hot sides.

This Card specifies the parameters for a Peltier device. Using these parameters, the Analyzer module calculates the appropriate heat inputs to the cooled and hot sides of the device. The heat input QC applied to the cooled side and QH applied to the hot side of the device is calculated by:

$$QC = 2NPOLE\left(-SEEBECK^{*}CURRENT^{*}(T_{cooled} + T_{abs}) + \frac{CURRENT^{2}ELECRES}{2GEOM} \right)$$

$$QH = 2NPOLE\left(-SEEBECK^{*}CURRENT^{*}(T_{hot} + T_{abs}) + \frac{CURRENT^{2}ELECRES}{2GEOM} \right)$$

where T_{abs} is the temperature offset from absolute zero.

Example

```
$ CONSTANT COEFFICIENT PELTIER DEVICE
PELTIER TCOLD THOT 127 2.02E-4 .00052 1.0E-5 12. 0 1.51
$
$ TABLE-DEPENDENT PELTIER DEVICE
PELTIER TCOLD THOT 127 T1003 .00052 T1001 12. 0 T1002
TABTYPE 1003 SEEBECK TEMP
TABDATA 1003 1.94E-4 -273
TABDATA 1003 1.94E-4  0
TABDATA 1003 2.02E-4 25
TABDATA 1003 2.10E-4 75
TABDATA 1003 1.79E-4 200
TABTYPE 1001 ELECRES TEMP
TABDATA 1001 9.2E-6 -273
TABDATA 1001 9.2E-6  0
TABDATA 1001 1.76E-5 200
TABTYPE 1002 KTHERM TEMP
TABDATA 1002 1.61 -273
TABDATA 1002 1.61 0
TABDATA 1002 2.09 200
```

Card 9 - PHASE Phase Change Elements - Optional

`KODE, N1, T1, T2, T3`

`KODE = PHASE` (or `4`)

`N1` is the phase change element number, or a group name.

`T1` is the phase change temperature.

`T2` is the value of the element's latent heat.

`T3` is the ratio of the thermal capacitance above the phase change temperature to the thermal capacitance below the phase change temperature. If a temperature-dependent capacitance is specified in a table, this value is automatically updated.

Notes

This Card provides an alternate method of defining phase change properties for both geometric and non-geometric elements. The preferred method of defining phase change properties for geometric elements is through MAT Cards.

The capacitance of the `N1` element(s) must be non-zero, they may be either created by the COND module from geometry or defined on XCAP Cards. The capacitance is interpreted to be the capacitance value below the phase change temperature.

Phase change elements may be used in transient analysis, or in steady-state analysis with MCV elements to model phase change in fluid flow.

Example

```
XCAP 62 0 12
PHASE 62 50 80 2
```

Element 62 is a phase change element which has a phase change temperature of 50 degrees, latent heat of 80, and thermal capacitances of 12 and `2*12 = 24` below and above the phase change temperature respectively.

Card 9 - POINT Named Point Definition - Optional

`KODE, N1, T1, T2, T3 T4`

`KODE` = `POINT` `(` or `99)` defines a user-defined named point

`N1` is the POINT card ID.

Cards with the same ID reference the same Named Point.

`T1` may be:

= `NAME` `(` or `1)`

= `XYZ` `(` or `2)`

- `T1` = `NAME` : name of the point is specified in `T2` .
- `T1` = `XYZ` : The cartesian coordinates of the point are `T2` , `T3` , `T4.`

Card 9 - PRINT Analyzer Printout Codes - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `PRINT` (or `6`)

`N1` may be:

- an element number (element from), or a group name. In either case, different parameters are printed out during Analyzer runs.

- of the format `Gn` (e.g. `G5`), where `n` is the ID of Card 9 GROUP card. In this case, CAE results are printed out on the referenced nodes or elements of group `Gn`.

`T1` is an element number (element to), or `0`, which defaults to `T1` = `N1`, or a group name.

`T2` Options

`ABSHEAT` (or `16`) prints the absorbed heat values of the group names of `N1` since the beginning of a transient run to the verbose log file. `N1` must be a group name, it cannot be an element number.

The absorbed heat values Q_{abs} are calculated by the formula:

$$Q_{abs}(t) = \sum (C_j(t)T_j(t) - C_j(t0)T_j(t0))$$

where

- j is an element belonging to the group
- $t0$ is the time at the start of the run
- t is the current time
- C_j is the capacitance of element `j`
- Q_{abs} is the absorbed heat value
- T_j is the temperature of element j

For sink elements, Q_{abs} is the total heat absorbed by the sink element from the beginning of the run.

`APPTEMP` (or `115`) prints the apparent temperature of an element to the CAE results file. The apparent temperature of an element is equal to $(\text{emissivity} * *.25 * (\text{T(IOPP)} + \text{TABS}) - \text{TABS})$, where T(IOPP) is the temperature of its Oppenheim element, and TABS is the absolute temperature.

`CAP` (or `3`) prints the capacitances for elements `N1` through `T1` to the report log file.

`COND` (or `1`) prints the conductance values with conductance numbers to the report log file.

`CONN` (or `6`) prints the connectivity model to the CAE results file.

`COUPLAREA (or 206)` prints the coupled area ratio results to CAE results file, that shows the the ratio of the primary element convective area over the primary element area that participate in a thermal coupling.

`ELABSFL` (or `119`) prints elemental absorbed radiative fluxes to the CAE results file.

`ELCHF` (or `176`) prints elemental convective heat fluxes to the CAE results file.

`ELCRHTC (or 197)` prints the elemental area corrected heat transfer coefficients to the CAE results file.

`ELCONVAREA` (`or 199`) prints the elemental convective areas to the CAE results file.

`ELCONVTHICK` (`or 201`) prints the elemental convective thicknesses to the CAE results file.

`ELDENS` (or `137`) prints elemental fluid densities to the CAE results file.

`ELADBTTEMP(` or 217) prints adiabatic wall temperatures to the CAE results file.

`ELDUCT_SWIRL_RATIO` (or 213) prints elemental swirl ratios for 1D fluid elements to the CAE results file.

`ELDUCTTEMP` (or `153`) prints elemental temperatures for 1D fluid elements in CAE format to the CAE results file.

`ELDUCT_TOTTEMP_ABS` (or 209) prints elemental total absolute temperatures for 1D fluid elements to the CAE results file.

`ELDUCT_TOTTEMP_REL` (or 211) prints elemental total relative temperatures for 1D fluid elements to the CAE results file.

`ELECTRICAL` (or `104`) prints electrical network calculation results to the CAE results file and in TEMPF format to POWERDENSITY.

`ELERRMAX` (or `164`) prints elemental local temperature error estimates to the CAE results file.

`ELFLUIDWALL` (or `161`) prints elemental fluid temperatures on walls, for thermal streams, thermal convecting zones and thermal voids to the CAE results file.

`ELGRAD` (or `65`) prints elemental thermal gradient to the CAE results file.

`ELHBAL` (or `67`) prints elemental heat balances to the CAE results file.

`ELHTC` (or `74`) prints elemental heat transfer coefficients to the CAE results file.

`ELHTF` (or `63`) prints elemental conductive heat flux vectors (thermal gradient times elemental thermal conductivity times thickness) to the CAE results file.

`ELINCFL` (or `120`) prints elemental incident radiative fluxes to the CAE results file.

`ELMASSFL` (or `78`) prints elemental mass flows and elemental mass flow vectors to the CAE results file.

`ELORBFL` (or `76`) prints elemental orbital heat fluxes to the CAE results file.

`ELORBVF` (or `77`) prints elemental solar, albedo, and Earth view factors to the CAE results file.

`ELPRESS` (or `72`) prints elemental total pressures to the CAE results file.

`ELQUAL` (or `105`) prints elemental quality for phase change elements to the CAE results file.

`ELREN` (or `70`) prints elemental Reynolds Numbers to the CAE results file.

`ELRCPROD` (or `118`) prints elemental RC products, i.e. element's capacitance divided by the sum of its conductances, to the CAE results file.

`ELREFFL` (or `121`) prints elemental reflected radiative fluxes to the CAE results file.

`ELSWIRLVEL` (or `166`) prints the elemental swirl velocity values for all boundary conditions to the CAE results file.

`ELTEMP` (or `61`) prints element temperatures to the CAE results file.

`ELTMAX` (or `106`) prints elemental maximum and minimum temperatures and times of their occurrence to the CAE results file.

`ELTOTF` (or `107`) prints elemental heat loads and fluxes to the CAE results file.

`ELTOTTEMP_ABS` (or `155`) prints the elemental total absolute temperature values on walls, for all boundary condition requests to the CAE results file.

`ELTOTTEMP_REL` (or `159`) prints the elemental total relative temperature values on walls, for all boundary condition requests to the CAE results file.

`ELTOTTEMP_STAT` (or `160`) prints the elemental total static temperature values on walls, for all boundary condition requests to the CAE results file.

`ELTRNFL` (or `122`) prints elemental transmitted radiative fluxes to the CAE results file.

`ELTRVTGR` (or `143`) prints elemental transverse temperature gradients on multilayers to the CAE results file.

`ELVEL` (or `68`) prints elemental fluid velocities to the CAE results file.

`ELVFENV` (or `157`) prints element environmental view factors to the CAE results file.

`ELVFSUM` (or `75`) prints elemental view factor sums to the CAE results file.

`ELWALLVEL (or 195)` prints the elemental wall velocity values for thermal convecting zones, thermal streams, thermal voids selection boundary conditions to the CAE results file.

`FLUENCE` (or `117`) prints elemental fluences to the CAE results file.

The fluence of an element is the total energy input into the element, which is accumulated over time.

It is equal to the integral over time (from 0 to t) of `q/A`, where t is time, q is the power or heat load from both radiative and non-radiative sources, and `A` is the element area.

`GRP2GRP` (or `81`) prints heat flows to the report log file between groups `N1` and `T1`, both of which must be group names. This option is similar to the `HFGROUP` option, and is useful for model debugging.

`T1` may be the symbol `*`, in which case the heat flows from the group `N1` to all the elements in the model will be printed.

`T1` may be the keyword `_SINKS`, in which case the heat flows from the group `N1` to all the sink elements or groups are calculated.

Heat flows through the different modes of heat transfer are calculated as follows:

1. Conductive heat flows are calculated only between groups that have direct conductive heat paths between each other, i.e. they share common edges or surfaces.
2. Convective heat flows are calculated by summing the heat flows through the non-radiative thermal couplings between the two groups.
3. Radiative heat flows are calculated by summing the heat flows through the radiative thermal couplings, plus the direct radiative couplings calculated by Gebhardt's Method.
   If Oppenheim's Method was used to calculate radiative heat transfer, a two-step method is used to calculate the heat flows. In step 1, all non-Oppenheim elements are set to be sinks of temperature of zero, except for the `N1` elements, which are set to their proper temperatures. The temperatures of all Oppenheim elements are then computed with the CG solver, and `QN1T1`, the heat flow from `N1` to `T1`, is calculated. In step 2, all non-Oppenheim element temperatures are set to zero except for the temperatures of the group `T1`, and `QT1N1`,

the heat flow from `T1` to `N1`, is calculated. The net radiative heat flow between the two groups is `QN1T1 – QT1N1`.

4. Average temperatures of the groups are calculated by simple averaging.
5. The equivalent radiative, convective, or conductive conductances are calculated by dividing the appropriate heat flow between the groups by the difference in their average temperatures. In cases where large temperature gradients exist within a given group, this may yield counterintuitive results.

The functionality is identical to the `CALL GRP2GRP` option in the card 10 user-written subroutine.

`HFGROUP` (or `12`) prints the heat flows through each conductance. The conductances are grouped by element number for easy model troubleshooting.

`HFGROUP` also prints out details of the calculations for the hydraulic elements present in the model, and if there are electrical elements present (see Card 9 - TABTYPE Table Variable Type Definition Card - Optional, it also prints out details of the voltage drop and power dissipation calculations.

`HYDTRACE` (or `81`) prints to the screen and to the report log file the convergence behavior of the hydraulic solution loop.

`ILUTRACE` (or `80`) prints to the screen and to the report log file the convergence behavior of the conjugate gradient solution loop.

`IRRADILD` (or `128`) prints elemental irradiance heat load to the CAE results file.

`IRRADIFL` (or `129`) prints elemental irradiance heat flux to the CAE results file.

The net radiative heat flux leaving a surface is equal to the difference between the radiosity and the irradiance:

$$\text{Qnet} = \text{Quot} - \text{Qin}$$

The radiosity of a surface `Qout` is the outgoing radiative heat flux that consists of the emitted and reflected flux from that surface.

The irradiance of a surface `Qin` is the incident radiative heat flux from all other surfaces.

$$Quot = \varepsilon\sigma T^4 + \rho Qin$$

where:

- ε is the surface emissivity,
- σ is the Stefan-Boltzmann constant,
- T is the absolute surface temperature,
- ρ is the surface reflectivity.

`MASSFL` (or `2005`) prints the mass flow through hydraulic elements `N1` through `T1` to the report log file.

`NDADBTTEMP` (or 218) prints the nodal adiabatic wall temperatures to the CAE results file.

`NDCHF` (or `177`) prints nodal convective heat fluxes to the CAE results file.

`NDCONVAREA` (`or 200`) prints the nodal convective areas to the CAE results file.

`NDCONVTHICK` (or 202) prints the nodal convective thicknesses to the CAE results file.

`NDCRHTC (or 198)` prints the nodal area corrected heat transfer coefficients to the CAE results file.

`NDDENS` (or `138`) prints nodal fluid densities to the CAE results file.

`NDDISP` (or `178`) prints the nodal displacements to the CAE results file.

`NDDUCT_SWIRL_RATIO` (or 214) prints nodal swirl ratio for 1D fluid elements to the CAE results file.

`NDDUCT_TOTTEMP_ABS` (or 210) prints nodal total absolute temperatures for 1D fluid elements to the CAE results file.

`NDDUCT_TOTTEMP_REL` (or 212) prints nodal total relative temperatures for 1D fluid elements to the CAE results file.

`NDDUCTTEMP` (or `154`) prints nodal temperatures for 1D fluid elements to the CAE results file.

`NDERRMAX` (or `165`) prints nodal local temperature error estimates to the CAE results file.

`NDFLUIDWALL` (or `162`) prints nodal fluid temperatures on walls, for thermal streams, thermal Convecting Zones and thermal Voids to the CAE results file.

`NDGRAD` (or `66`) prints the nodes' thermal gradient to the CAE results file.

`NDHTC` (or `168`) prints the nodal heat transfer coefficients to the CAE results file.

`NDHTF` (or `64`) prints nodal conductive heat flux vectors to the CAE results file.

`NDMASSFL` (or `79`) prints the nodal mass flows and elemental mass flow vectors to the CAE results file.

`NDPRESS` (or `73`) prints the nodes' total pressures to the CAE results file.

`NDREN` (or `71`) prints the nodes' Reynolds Numbers to the CAE results file.

`NDSWIRLVEL` (or `167`) prints the nodal swirl velocity values for all boundary condition requests to the CAE results file.

`NDTEMP` (or `62`) prints the node temperatures to the CAE results file.

`NDTOTTEMP_ABS` (or `174`) prints the nodal total absolute temperature values on walls, for all boundary condition requests to the CAE results file.

`NDTOTTEMP_REL` (or `175`) prints the nodal total relative temperature values on walls, for all boundary condition requests to the CAE results file.

`NDTOTTEMP_STAT` (or `156`) prints the nodal total static temperature values on walls, for all boundary condition requests to the CAE results file.

`NDTRVTGR` (or `144`) prints nodal transverse temperature gradients on multilayers to the CAE results file.

`NDVEL` (or `69`) prints the nodes' fluid velocities to the CAE results file.

`NDWALLVEL ( 196)` prints the nodal wall velocity values for thermal convecting zones, thermal streams, thermal voids selection boundary conditions to the CAE results file.

`NETRADLD` (or `124`) prints elemental net radiative heat load to the CAE results file.

`NETRADFL` (or `125`) prints elemental net radiative heat flux to the CAE results file.

`PRESS` (or `111`) prints the total pressure values for hydraulic elements `N1` through `T1` to the report log file.

`QNODE` (or `4`) prints the heat loads to the elements `N1` through `T1` to the report log file.

`QUAL` (or `14`) prints the quality (the fraction of the element in its higher temperature phase) values for phase change elements to the report log file.

`RADIANCE` (or `114`) prints the radiance of an element to the CAE results file. The radiance of an element is equal to Boltzmann's constant `*(T(IOPP)+TABS)**4/PI,` where `T(IOPP)` is the temperature of its Oppenheim element.

Notes

The thermal solver computes the radiance of an element based on the element's normal. You can define a directional radiance using the Card 9 - GENERIC Generic Entity Cards - Optional.

`RADIOSLD` (or `126`) prints elemental radiosity heat load to the CAE results file.

`RADIOSFL` (or `127`) prints elemental radiosity heat flux to the CAE results file.

`RCPROD` (or `11`) prints the RC products to the report log file for transient runs at the beginning of the run. This is useful for determining which element will create `RCMIN` and thereby govern the integration time step.

`RTRACE` (or `103`) prints the results of ray-tracing for specular or transparent elements onto file `TRACEF`.

`SUBTEMP` (or `83`) prints element temperatures to the CAE results file during an Analyzer run. This is very similar to the `ELTEMP` option, which, however, creates the file subsequent to an Analyzer run.

`TEMP` (or `2`) prints the temperatures for elements `N1` through `T1` to the report log file.

`THERMCONN(or 205)` prints the connection between the primary and secondary elements that participate in a thermal coupling to the CAE results file. The color of connections refers to unique thermal coupling.

`TRACE` (or `15`) prints to the screen and to the report log file the iteration number and maximum temperature of each iteration to track convergence. For transient runs the printout can become very large.

`VFGROUP` (or `102`) prints the view factors for elements `N1` through `T1` to the report log file.

`T3` is an integer that represents the thermal output request ID of the PRINT card. A thermal output request is referenced by the keyword `PRINT` of the STEP cards. For a given solution step, a combination of the global PRINT cards having a thermal output request IDs referenced in the field PRINT of the STEP cards are active.

If `T3` is blank, the PRINT card is part of the GLOBAL thermal output request.

Example

```
PRINT 1 20 QNODE
```

```
$ HEAT LOADS TO ELEMENTS 1 THROUGH 20 PRINTED
$
PRINT 1 9999 TEMP
$ TEMPERATURES OF ELEMENTS 1 THROUGH 9999 ARE PRINTED
```

Card 9 - PROP Physical Property Definition Cards - Optional

This Card defines the physical properties of Card 5a - Element Cards - Optional, where applicable.

`KODE, N1, T1, T2, T3, T4, T5, T6, T7, T8`

`KODE` = `PROP` (or `33`)

`N1` is the physical property number, referenced on Card 5a - Element Cards - Optional.

`T1` is code:

- `AMBIENT` (or `-2452`) for `AMBIENT` elements
- `BEAM` (or `1`) for 2-node `BEAM` elements
- `BLSTART` (or `-2451`) for 1-node `BLSTART` hydraulic elements
- `COHESIVE` (or `3`) for `COHESIVE` elements. This option is used for `SOLID` elements of a 6-noded linear wedge, an 8-noded linear hexahedron, a 15-noded parabolic wedge, or a 20-noded parabolic hexahedron type. When calculating their conductive or other size dependent properties, their thickness (distance between the upper and lower faces) will be replaced by the value given in the `T2` field.
- `DUCT` (or `-2000`) for 2-node `DUCT` hydraulic elements
- `FLOWCON` (or `-2450`) for 1-node `FLOWCON` hydraulic elements
- `FLOWRES` (or `-2002`) for 2-node `FLOWRES` hydraulic elements
- `FLOWSEC` (or `-2450)` for 1-node `FLOWSEC` hydraulic elements
- `FANPUMP` (or `-2003`) for 2-node `FANPUMP` hydraulic elements
- `LAMINATE` (or `4`) for `LAMINATE` ply elements
- `LUMP` (or `0`) for `LUMP` mass elements
- `MIDSIDE` (or `-11`) for elements that specifies the `MIDSIDE` nodes of parabolic elements
- `SHELL` (or `2`) for planar 3- and 4-node `SHELL` elements
- `STREAM` (or `-2003`) for 2-node `STREAM` hydraulic elements

For LUMP, BEAM, SHELL, COHESIVE and LAMINATE elements

`T2`

is the volume of 1-node elements.

is the cross-sectional area of beam elements.

is the thickness of shell and cohesive elements. Note: Thickness is ignored for damage interface cohesive elements.

is the ply ID for `LAMINATE` elements.

may be blank, which defaults to 0.

`T3`

is the surface area of a lump mass element.

is the surface area per unit length of a beam element.

is the ply angle

may be blank, which defaults to 0.

is the number of layers for `SHELL` elements, must be an odd number. This option creates homogeneous multilayer shell elements in the MEREL module, which have the following properties:

- The shell element is subdivided into `T1` layers, where `T1` is an odd number. The layers are equidistant from each other.
- The original shell element number is assigned to the middle layer, new element numbers are created for all additional layers. The layer numbers are written to the report log file.
- The in-plane thermal conductive paths are assigned to the middle layer.
- The capacitance of the element is equally subdivided between all the layers.
- A heat load applied to the element becomes applied to the top layer of the element. However, if the element is transparent in either the solar or IR spectra, the heat load is evenly distributed among the layers.
- Thermal couplings, equal to `(area of element)*(thermal conductivity)/distance` are created between the layers.
- The top and bottom layers are determined by the element orientation, such that the element normal will face out of the top layer.
- Thermal couplings and radiative conductances attached to the element are redefined to be attached to the top and bottom layers of the element.

Note

You may define nonhomogeneous multilayer shell elements with the Card 9 LAYER Card. Unlike homogeneous multilayer elements, nonhomogeneous multilayer elements support in-plane conduction and radiation between the layers.

`T4` is blank, or is the fluid flow velocity for the element.

If `T4` is not blank and the element center method is specified, the COND module will calculate equivalent 1-way conductances between adjacent element CG's to model the fluid flow. If the element CG method is specified, the CONDN module will calculate 1-way conductances between the boundary elements and the element CG.

The magnitude of the 1-way conductance is equal to `T4*T2*RHO*CP*L`

where

- `RHO` and `CP` are the density and specific heat of the material.
- `L` is the length of the projection onto a line perpendicular to the flow direction of the common side for the element center method, or boundary element for the element CG method.

If the element is a beam element, the fluid flow is assumed to be parallel to the beam.

The fluid flow direction is specified in `T5` and `T6`.

`T5` may be blank.

If `T4` is not blank, and `T6` is not the code `MATVEC`, then `T5` is the angle in degrees between the fluid flow direction vector and the global Z axis.

If `T6` is the code `MATVEC,` then flow direction is in the plane of the element. `T5` is then the angle in degrees from the material's X axis in the direction of the material's Y axis that specifies the flow direction.

`T6` may be blank.

If `T4` is not blank and `T6` is not the code `MATVEC`, then `T6` is the angle in degrees between the projection of the fluid flow direction vector onto the global XY plane and the global X axis.

`T7` may be blank.

If `T7` is not blank, `T7` is the nonstructural mass for `LUMP` elements, nonstructural mass per unit length for `BEAM` elements, and nonstructural mass per unit area for `SHELL` elements. The total mass of the element is the volume of the element times its density, plus its nonstructural mass. The capacitance of the element is calculated by multiplying its total mass with its specific heat.

`T8` may be blank.

If `T8` is not blank, `T8` is additional capacitance for `LUMP` elements, additional capacitance per unit length for BEAM elements, and additional capacitance per unit area for `SHELL` elements. The total mass of the element is the volume of the element times its density, plus its nonstructural mass. The capacitance of the element is calculated by multiplying its total mass with its specific heat, and summing it with the additional capacitance calculated from `T8`.

For FLOWSEC, BLSTART and AMBIENT hydraulic elements

`T2` is the duct cross-sectional area.

If `T2` = 0 the cross-sectional area is set to the surface area of element `T4`.

For AMBIENT elements the cross-sectional area is set to `1.E22`.

`T3` is the hydraulic diameter.

If `T3` and `T4` are both blank or 0, the hydraulic diameter is computed from the cross-sectional area `T2`, assuming a square cross-section.

If `T4` is not blank, the hydraulic diameter is obtained from `T4`.

For AMBIENT elements the hydraulic diameter is set to `1.E11`

`T4` is the element number of a Card 5 planar element with the duct's cross-sectional profile.

If `T4` is not blank, the hydraulic diameter and cross-sectional area are both computed from the shape of element `T4`.

If `T2`, `T3`, and `T4` are all blank or zero, the properties are obtained from the immediately upstream `FLOWSEC` or `BLSTART` element.

`T5` is the head loss of the flow through the element.

If the element is connected to a single hydraulic element, i.e. it is at the end of the chain, the head loss will be applied to the `DUCT` or `FLOWRES` element connected to it. If the element is connected to two or more `DUCT` or `FLOWRES` elements, half the head loss will be applied to each of the connected elements.

`T6` is ignored, may be blank.

`T7` is ignored, may be blank.

`T8` is ignored, may be blank.

For FLOWRES, DUCT, and FANPUMP hydraulic elements

`T2`

For `FLOWRES` and `DUCT` elements `T2` is a flow resistance multiplier. If `T3` is blank for `FLOWRES` elements, `T2` reduces to the constant head loss factor KLOSS.

For `FANPUMP` elements `T2` multiplies the total pressure rise, mass flow, volumetric flow, or velocity value interpolated from Table `T3`.

`T2` = `0` or blank defaults 1.

`T3` is a table or expression number.

`T3` is optional for `FLOWRES` and `DUCT` elements. If present, it defines a table-dependent flow resistance (or head loss factor) multiplier, and the dependent variable on the TABTYPE Card must be `FLOWRES`.

`T3` is required for `FANPUMP` elements/. It defines the flow boundary conditions (mass flow, volumetric flow, velocity, or total pressure rise). The dependent variable on the TABTYPE or EXPRESSION Card must be `MASSFL`, `VOLUME`, `VELOC`, or `DELTAPT`.

`T4` is ignored for non-`DUCT` elements, may be blank.

For `DUCT` elements, `T4` represents the absolute wall roughness (or sand-grain roughness) value on the wall off the hydraulic element. The flow resistance and heat transfer coefficients will be appropriately modified as a function of this roughness value. Smooth walls should be specified with `T4 = 0.`

`T5` is ignored for non-`DUCT` elements, may be blank.

For `DUCT` elements that are not straight, `T4` represents the radius of curvature. The flow resistance and heat transfer coefficients will be appropriately modified as a function of the curvature of the element.

`T6` is ignored, may be blank.

`T7` is ignored, may be blank.

`T8` is ignored, may be blank.

For FLOWCON hydraulic elements

All fields are ignored. The PROP FLOWCON card is only used to mark 1-node elements as belonging to a stream network.

For STREAM hydraulic elements

`T2` is a multiplier of the total mass value value interpolated from table `T3`.

`T2` = `0` or blank defaults to `1`.

`T3` is a table number or blank. If set, it defines the mass flow boundary condition. The dependent variable on the TABTYPE card must be `MASSFL`.

Note

For each PROP Card N1 the 7-character group name `_P0000N1` (e.g. `_P00016` for PROP Card 16) is automatically created.

Example

```
$ CARD 5
101 0 M2 0 P4 1 2 3 4
$ CARD 5A ELEMENT 101 HAS ITS PROPERTIES DEFINED WITH
$ MAT CARD 4 AND PROP CARD 5
|
$ CARD 9
PROP 4 SHELL 1.6
$ ALL CARD 5A ELEMENTS WHICH REFERENCE
$ PROP CARD 4 HAVE A THICKNESS OF 1.6
```

Card 9 - PROTECTIVE_LAYER Protective Layer Definition - Optional

`KODE, N1, T1, T2`

`KODE = PROTECTIVE_LAYER` (or `123`) defines a boundary condition that adds a thermal barrier coating, on top of thermal elements for protective layer heat transfer modeling.

`N1` is the PROTECTIVE_LAYER card ID. Cards with the same ID, reference the same Protective Layer.

`T1` may be:

= `NAME` (or `1`)

= `SELECTION` (or `2`)

= `MATERIAL` (or `3`)

= `THICKNESS` (or `4`)

= `SUBLAYERS` (or 6)

= `OPTICAL` (or `5`)

`T1` = `NAME` specifies the Protective Layer simulation object name in `T2`.

`T1` = `SELECTION` specifies a selection of thermal elements on which the Protective Layer simulation object is applied. The selection is represented by the group name `T2.`

`T1` = `MATERIAL` specifies the material ID in `T2`.

`T1` = `THICKNESS` specifies the layer thickness value in `T2`.

- If the thickness is constant, then its value is specified in `T2`.
- If the thickness is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn`, for example `T39`, where n is a table number referencing the TABTYPE and FIELDTYPE cards.

`T1` = `SUBLAYERS` specifies the number of sublayers per layer in `T2`. For more information, see Protective layer in finite element method.

`T1` = `OPTICAL` specifies the ID of optical properties of the referenced OPTICAL card in `T2`.

Example

```
PROTECTIVE_LAYER 1 NAME "3Layers"
PROTECTIVE_LAYER 1 SELECTION "3Layers"
PROTECTIVE_LAYER 1 MATERIAL 6
PROTECTIVE_LAYER 1 THICKNESS  1.000000E-01
PROTECTIVE_LAYER 1 SUBLAYERS 1
PROTECTIVE_LAYER 1 MATERIAL 7
PROTECTIVE_LAYER 1 THICKNESS  2.500000E-01 T39
PROTECTIVE_LAYER 1 SUBLAYERS 3
PROTECTIVE_LAYER 1 MATERIAL 8
PROTECTIVE_LAYER 1 THICKNESS  7.500000E-01
PROTECTIVE_LAYER 1 SUBLAYERS 5
PROTECTIVE_LAYER 1 OPTICAL 2
```

Card 9 - PSINK Pressure Sink Definition Cards - Optional

`KODE, N1, T1, T2`

`KODE = PSINK` (or `27`)

`N1` is an element number, or a group name.

`T1` is the pressure boundary condition value expressed as gauge (not absolute) pressure for hydraulic element(s) `N1`.

`T1` may be the code `FPRESSF` (or `-1.E5`), in which case, the pressure values are read from file PRESSF, which must be present.

`T2` may be:

- `TOTAL` or blank, then `T1` is the total pressure boundary condition value expressed as gauge (not absolute) pressure for hydraulic element(s) `N1`.
- `STATIC` or blank, then `T1` is the static pressure boundary condition value expressed as gauge (not absolute) pressure for hydraulic element(s) `N1`.

Note

The thermal solver does not support the static pressure boundary condition with a gas as the fluid material.

Notes

You can define pressure boundary conditions for Card 5a hydraulic elements either with PSINK Cards or AMBIENT elements.
For open-ended flow paths that start and end with an AMBIENT element, the total pressure and temperature boundary conditions should be defined with AMBIENT elements and the HYDENV Card.
For open-ended paths there is no need to explicitly define an AMBIENT element because one is automatically created.
If an element's pressure boundary condition is specified through the INTERP card using a table or in a user-written subroutine, the element must be flagged as a PSINK element.
Only a single PSINK Card may be present in the data deck if the FPRESSF option is used.

Example

```
PSINK 181 0.0 STATIC
INTERP 181 0 19 1.0
TABTYPE 19 PTOTAL TIME
TABDATA 19 5.056759949E+02 0.000000E+00
```

Card 9 - PSPROP1 Plane Stress Elements for Blades Card - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `PSPROP1` (or `95`)

`N1` is the ID of the PSPROP1 card.

`T1` is a group name whose elements are specified as plane stress elements.

`T2` is the number of instances (or blades).

`T3` is a code that defines the axis of revolution and the plane in which the plane stress elements lie.

= `XZ` : the elements lie on the ZX plane and the axis of rotation is the Z-axis.

= `YX` **:** the elements lie on the XY plane and the axis of rotation is the X-axis.

Example

```
PSPROP1 1 "1 - QUAD4 Plane Stress ZX" 5 XZ
```

Card 9 - PSPROP2 Plane Stress Elements for Holes and Bolts Card - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE` = `PSPROP2` (or `97`) defines plane stress elements for holes and bolts.

`N1` is the `PSPROP2` card ID.

`T1` is:

`= SELECTION` (or `1`)

`= INSTANCES` (or `2`)

`= TYPE` (or `3`)

`= DIRECTION` (or `4`)

`= RADIUS` (or `5`)

`= CENTER1` (or `6`)

`= CENTER2` (or `7`)

`T1` `=` `SELECTION` specifies a selection of elements on holes and bolts, which are represented by the group name `T2`.

`T1` `=` `INSTANCES` specifies the number of holes or bolts in `T2`.

`T1` `=` `TYPE` specifies the type in `T2`.

- If type is a Hole, then `T2` = `1`.
- If type is a Bolt, then `T2` = `2`.

`T1` `=` `DIRECTION` defines the axis of revolution and the plane, in which the plane stress elements are positioned.

- If the elements are positioned on the ZX plane and the axis of rotation is the Z-axis, then `T2` = `XZ` (or `0`).
- If the elements are positioned on the ZY plane and the axis of rotation is the Z-axis, then `T2` = `YZ` (or `1`).
- If the elements are positioned on the YX plane and the axis of rotation is the Y-axis, then `T2` = `XY` (or `2`).
- If the elements are positioned on the YZ plane and the axis of rotation is the Y-axis, then `T2` = `ZY` (or `3`).
- If the elements are positioned on the XY plane and the axis of rotation is the X-axis, then `T2` = `YX` (or `4`).
- If the elements are positioned on the XZ plane and the axis of rotation is the X-axis, then `T2` = `ZX` (or `5`).
- If the elements and the Z-axis of rotation are positioned on the same plane, then `T2` = `Z` (or 6).
- If the elements and the Y-axis of rotation are positioned on the same plane, then `T2` = `Y` (or `7`).
- If the elements and the X-axis of rotation are positioned on the same plane, then `T2` = `X` (or `8`).

`T1` = `RADIUS` specifies the radius of the hole or bolt in `T2`.

`T1` = `CENTER1` specifies the coordinates of the first point that defines the hole or bolt axis in `T2`, `T3`, and `T4`, which are the X, Y, and Z coordinates, respectively.

`T1` = `CENTER2` specifies the coordinates of the second point that defines the hole or bolt axis in `T2`, `T3`, and `T4`, which are the X, Y, and Z coordinates, respectively.

Example

```
PSPROP2 3 SELECTION "QUAD8 Plane Stress XY"
PSPROP2 3 INSTANCES 6
PSPROP2 3 TYPE 1
PSPROP2 3 DIRECTION YX
PSPROP2 3 RADIUS  1.000000E-06
PSPROP2 3 CENTER1  8.250000E+01  8.578644E-01  0.000000E+00
PSPROP2 3 CENTER2  8.250000E+01  2.914214E+01  0.000000E+00
```

Card 9 - PSPROP3 Chocking Elements

`KODE, N1, T1, T2, T3, T4`

`KODE` = `PSPROP3` (or `111`)

`N1` is the ID of the PSPROP3 card.

`T1` is a group name whose elements are specified as chocking elements.

`T2` is the gap thickness. If the thickness has the form `Tn`, where `n` is a table number (e.g. `T26`), then `n` is a table whose dependent variable is `THICKNESS` and independent variable is `EID`, refer to Card 9 - TABTYPE Table Variable Type Definition Card - Optional for details.

`T3` is the number of gaps.

`T4` is a code that defines the axis of revolution and the plane in which the chocking elements lie.

= `XZ` , the elements lie on the ZX plane and the axis of rotation is the Z-axis.

= `YX` , the elements lie on the XY plane and the axis of rotation is the X-axis.

Notes

The element reference in the Card 9 - PROP Physical Property Definition Cards - Optional has the corresponding thickness table that incorporates the gap information included in the following example.

Example

```
PSPROP3 1 "1 - TRI3 Chocking XY" 1.000000E+01 4 YX
$
$ Physical property 2 [Chocking Property]
PROP 2 SHELL T26 0 0.0 0.0 0.0  0.000000E+00 0.0
TABTYPE 26 THICKNESS EID
TABDATA 26 1.928828E+02 1
TABDATA 26 2.372701E+02 2
TABDATA 26 1.928829E+02 3
```

Card 9 - QNODE Heat Loads - Optional

`KODE, N1, T1, T2, T3, T4, T5`

`KODE` = `QNODE` (or `1`)

`N1` is an element number, or a group name.

`T1` is the specified heat load, or heat load/area, or heat load/volume into `N1`.

`T2` may be:

- the specified time when the heat load occurs (this option is not recommended). `T2` may not be `< 0`, unless `T2` = - `99990`.
- the code CONSTANT (or `-99990`) for constant heat loads. If `T2` is blank it defaults to CONSTANT.
- the form `Tn` (e.g. `T6`), where `n` is a table number specified by TABTYPE and FIELDTYPE Cards, and table `n` specifies a heat load multiplier. The total heat load will then be equal to the value interpolated from table `Tn`, times `T1`, times the geometrical multiplying factor computed from `T3`.
- the form `En` (e.g. `E6`), where `n` is an expression number specified by EXPRESSION card, and expression `n` specifies a heat load multiplier. The total heat load will then be equal to the value evaluated from expression `En`, times `T1`, times the geometrical multiplying factor computed from `T3`.

`T3` may be:

- blank, `ABSOLUTE,` or 0.
  `T1` is the heat load into element `N1`.
- `AREA` (or `1E36`)
  `T1` is the heat load per unit area into element `N1`.
- `LENGTH` (or `4E36`)
  `T1` is the heat load per unit length into element `N1`. This is applicable to beam elements only.
- `TOTAL` (or `2E36`)
  The heat load is redistributed among the elements of group `N1` in proportion to their areas or volumes

$$Q(1) = T1 \frac{\Omega(T2, X(I))AV(I)}{\sum_{i}^{N1} AV(i)}$$

where:

- $AV(I)$ is either the volume (for solid elements) or area of element I (for shells and beams), or unity (for non-dimensional element), where `I` is a member of the `N1` group. All the elements of group `N1` must be of the same type, i.e. solid and non-solid elements may not be mixed.
- $Q(I)$ is the heat load to element `I`, which is a member of the group `N1`.
- $\Omega(T2, I)$ is the interpolated variable where `T2` is a table.

If `T2` is a spatial table (field or EID dependent), then $Q(I)$ is calculated with a weighting factor $\Omega(I)$ interpolated from this table:

$$Q(I) = T1 \frac{\Omega(I)AV(I)}{\sum_{i}^{N1} \Omega(i)AV(i)}$$

When `T2` includes a reference to an expression, either directly or through a table, then each spatial field, referenced in that expression is normalized by a factor that makes the area-weighted average of that field equal to one. The averaging is performed over the `N1` element group.

If `N1` is a single element, the heat load is applied to the element.

- `VOLUME` (or `3E36`)
  `T1` is the heat load per unit volume into element `N1`. For planar and beam elements the volume is calculated by multiplying the length or area by the cross-sectional area or thickness.

`T4` specifies the layer for multilayer elements. Non-homogeneous multilayer elements are specified on LAYER Cards, homogeneous multilayer elements are specified on PROP Cards.

`= 0`, blank, or `TOP`, the element is not multilayer or heat load is applied to the top layer.

`= MIDDLE` – heat load is applied to the middle layer.

`= BOTTOM` – heat load is applied to the bottom layer.

`= ALL -` heat load is applied to all the layers.

`= SPECIFY` – heat load is applied to the `T5` th layer, as counted from the bottom layer. `T4` = `1` is the same as `T4` = `BOTTOM.`

T5 is the jayer number for `4` = `SPECIFY`.

Notes

Orbital radiative heat loads calculated from geometry are automatically summed by the MEREL module with those specified on QNODE Cards.

A `T2` parameter value other than CONSTANT or a table number is not recommended if orbital heat loads are also calculated. This is because it is necessary to match with `T2` all the orbital time parameters on QNODE Cards, otherwise errors can result.

To work around this problem, it is recommended that you specify time-dependent heat loads on tables with INTERP, TABTYPE, and FIELDTYPE Cards, or with user-written subroutines. This will avoid the problem of matching all the time values if orbital heat loads are also calculated.

Example

```
QNODE 14 30 CONSTANT
$ HEAT LOAD OF 30 IS ADDED TO ELEMENT 14
QNODE 14 30 8 AREA
$ A HEAT LOAD = 30*AREA(14) IS ADDED TO ELEMENT 14 AT TI
```

Card 9 - RELTEMP Relative Temperature Correction - Optional

`KODE, N1, T1`

`KODE` = `RELTEMP` (or `85`)

`N1` is an element number or group name to which relative temperature correction will be applied.

`T1` may be:

- a constant relative temperature correction.

- of the format `Tn` (e.g. `T5`), where n is a table number referencing a table whose dependent variable is `TEMP`.
- of the format `En` (e.g. `E5`), where n is an expression number referencing EXPRESSION card.

Notes

The `T1` field will be used to calculate relative temperature correction ΔT for all elements in `N1`. If a given element has a nonzero `ΔT`, then in the heat balance equations in the Analyzer solve, all the RELTEMP card relevant heat flows will use that element temperature shifted by ΔT, i.e. taking $T + \Delta T$ instead of T. The relevant heat flows include heat flows through convective thermal couplings as well as through all couplings between hydraulic elements and non-hydraulic elements.
Relative temperature corrections are typically used in rotating machinery applications.

Example

```
$ A relative temperature correction of 5.5 is applied to element 200.
RELTEMP 200 5.5
$ A relative temperature correction of 7.0 is applied to the elements
$ of group GROUP1.
RELTEMP GROUP1 7.0
```

Card 9 - RENUMN, RENUME Node and Element Renumbering - Optional

`KODE, N1, T1, T2, T3, T4, T5`

`KODE` = `RENUMN` (or `39`), for which nodes are renumbered, or

`KODE` = `RENUME` (or `38`), for which elements are renumbered

`N1` is an element or node number `T1` is renumbered to.

`T2` is an element or node number `T3` is renumbered to.

`T4` is an element or node number `T5` is renumbered to.

Note

This Card permits elements and nodes to be renumbered for post-processing. There is a maximum of 6 element pairs to a Card.

Example

```
RENUMN 80005 101 80006 406 80008 203
$ NODE 101 IS RENUMBERED TO 80005, NODE 406
$ IS RENUMBERED TO 8008 ETC.
```

Card 9 - REPEAT Additional Card Generation - Optional

`KODE, N1, T1, T2`

`KODE = REPEAT` (or `11`)

`N1` is an element or conductance number limit

`T1` is an element or conductance number increment

`T2` is an element or conductance number increment

Notes

This card will generate a number of additional copies of the previous Card 9 Card in the data deck, provided the previous Card 9 Card is an XCOND, XCAP, SINK, or QNODE Card.
If the previous Card's `N1` parameter is `N1P`, then additional Cards will be generated with `N1` increasing in the series `N1P`, `N1P+T1`, `N1P+2T1`,... `N1`. For XCOND Cards, if the previous Card's `T1` parameter is `T1P`, then the corresponding `T1` parameters generated will be `T1P`, `T1P+T2`, `T1P+2*T2`,....etc.

Example

```
SINK 30 0 CONSTANT
REPEAT 33 1
```

will internally generate the following cards:

Example

```
SINK 30 0 CONSTANT
SINK 31 0 CONSTANT
SINK 32 0 CONSTANT
SINK 33 0 CONSTANT
```

Card 9 - REPORTER for Group Reports - Optional

The REPORTER Card creates an output of different group properties and writes it onto a file. The report on a given group property provides the average, maximum and minimum values of the property requested.

`KODE, N1, T1, T2, T3, T4, T5`

`KODE` = `REPORTER` (or `70`)

`N1` is the REPORTER Card type.

= `PRINT`, the report is written onto GroupReport.html. For steady-state runs, a single output is produced. For transient runs, report outputs are written at each printout time and orbit calculation time of the run.

= `TRACK` , the report is written onto TrackReportThermal.csv. Report outputs are written at each integration time. `T1` must be GRTEMP. A graphical output is available as well to display the temperature variation during run time.

`T1` is the group property requested. It can take the following codes:

- `GRTEMP` : Temperatures
- `GRLOAD` : Heat loads
- `GRFLUX` : Heat fluxes
- `GRPROP` : Physical properties
- `GRORBVF` : Orbital or source view factors
- `GRPHASE` : Phase change quality
- `GRDUCT` : Duct flow data
- `GRHEATMAPS` : Heat maps – heat flows between different groups connected to group `T2`
- `GRTDIF` : Temperature difference between groups `T2` and `T3`
- `GRHEATFLOW` : Heat flow between groups `T2` and `T3`
- `GRVIEWFACT` : View factors and RadK's between groups `T2` and `T3`
- ---

`T2` is a group name.

`T3` is a second group name for the GRTDIF, GRHEATFLOW, GRVIEWFACT options.

`T4` may be blank or `Tupperlimit` for `N1=PRINT` and `T1=GRTEMP` . If the maximum temperature of `T2` exceeds `T4` , the output line in the html report is highlighted in red.

`T5` may be blank or `Tlowerlimit` for `N1=PRINT` and `T1=GRTEMP.` If the minimum temperature of `T2` is below `T4` , the output line in the html report is highlighted in blue.

Card 9 - REVNODE or REVNOM Reversed Element Creation - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE = REVNODE` (or `13`), if the element is merged with its reversed side element, or

`KODE = REVNOM` (`1013`) if no merging is performed.

`N1` is the element or group name whose reverse side is created

---

`T1` is the element number increment. The element number of the reversed element will be `N1 + T1.` For `T1 = 0`, the reverse side element number is automatically assigned.

`T2` is the emissivity of the reversed element.

If `T2` = SAME (or `-99`), all its IR spectrum properties are set to the same value as that of element `N1`.

If `T2` = MAT (or `-98`), then all the reverse side properties, including solar spectrum properties, will be obtained from the reverse side properties of the MAT or OPTICAL Card of the element `N1`.

`T3` is the absorptivity of the reversed element.

If `T3` = `SAME` (or `-99`), its absorptivity is set to the same value as that of element `N1`.

If a solar transmissivity is specified on the front side of the element, TMG will automatically set the solar transmissivity of the reverse side to the same value.

`T4` is a group name for the reverse elements created, or is blank.

Notes

This Card creates a reverse side element for each Card 5 element `N1`. Each new element has the same nodes as `N1`, but their order is reversed, i.e. the reverse side element's surface normal will point in the opposite direction from `N1`. Reverse side elements for beams and lump masses are not created.
REVNODE Cards are used to define reverse side elements for radiative enclosures.
The reverse element's thermal conductivity and specific heat are set to 0.
If an element `N1` is specified as non-shadowing with a PARAM NOSHADOW Card, its reverse side will also be non-shadowing.

Examples

```
REVNODE 100 1000 .06 SAME
$ REVERSE ELEMENT 1100 IS CREATED, E = .06,
$ ABSORPTIVITY = SAME AS 100, AND THE TWO ARE MERGED
$
REVNODE 100 5000 .06 .15
$ REVERSE ELEMENT 5100 OF ELEMENT 100 IS CREATED WITH
$ E = .06 AND ABSORPTIVITY = .15, AND THE TWO ARE MERGED
$
REVNOM TOP 5000 .06 .15
$ REVERSE ELEMENTS ARE CREATED FOR THE ELEMENTS
$ ASSOCIATED WITH TOP, AND ARE NOT MERGED
```

Card 9 - ROT_FX Rotational Effects Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `ROT_FX` (or `86`)

`N1` is the ROT_FX card ID. Cards with the same ID reference the same rotational effects definition.

`T1` may be:

= `ROT_FXS` (or `121`): The type of rotation effects is specified in `T2`.

- `T2` may be either `NEGLECT_ROT` (neglect wall rotations) or `CORRECT_ROT` (correct for wall rotations) or `RELTEMP_REF` (relative temperature reference frame).

= `SWIRL` (or `125`) indicates the type of swirl to be used for total temperature corrections.

- `T2` may be either `VELOCITY` (swirl velocity) or `RATIO` (swirl ratio) or `DEL_TEMP` (relative temperature difference).

= `SWIRL_DEL_TEMP` (or `124`): A relative temperature difference is specified for total temperature corrections.

- If the relative temperature difference is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `TEMP`.
- If the relative temperature difference is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card.

= `SWIRL_RATIO` (or 123) is a swirl ratio that is specified for total temperature corrections.

- If the swirl ratio is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `NUMBER`.
- If the swirl ratio is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

= `SWIRL_VELOCITY` (or `122`) is a swirl velocity that is specified for total temperature corrections.

- If the swirl velocity is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `VELOC`.
- If the swirl velocity is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form En (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

= `FLOW_ROTATION_STATIONARY_STRUCTURES ( or 6)` specifies how the rotation speed value for the case of a fluid adjacent to a stationary wall to account for swirl velocity in the fluid is defined in `T2`.

- `T2` may be either `ROT_SPEED,` which is specified rotation speed value, or `AUTOMATIC,` which is a rotation speed value computed by the thermal solver.
- If `T2 = AUTOMATIC,` the thermal solver finds the maximum rotation velocity among rotation wall elements connected to the stationary wall through the fluid elements.

= `ROT_SPEED (or 7)` specifies the rotation speed value in `T2.`

- If the rotation speed value is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `NUMBER`.
- If the rotation speed value is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

Example

```
$ ------------------
$ Rotational effects
$ ------------------
ROT_FX 1 ROT_FXS RELTEMP_REF
ROT_FX 1 SWIRL VELOCITY
ROT_FX 1 SWIRL_VELOCITY 2.000000E+04
```

Card 9 - ROTATION Rotation Load Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `ROTATION` (or `89`)

`N1` is the ROTATION card ID. Cards with the same ID reference the same rotation load definition.

`T1` may be:

= `ANGULAR_RATE` (or `4`): The rotation angular rate is specified.

- If the angular rate is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing TABTYPE and TABDATA cards.
- The dependent variable on the TABTYPE card must be `ROTATION`, and the independent variable is `TIME`.

= `AXIS` (or `3`): The axis of rotation is represented by a Card 9 VECTOR card. The ID of the referenced VECTOR card is specified in `T2`.

= `SELECTION` (or `2`): The rotation load is applied to the elements of group `T2.`

= `TYPE` (or `1`): The type of rotation load is specified in `T2`. If `T2` = `GLOBAL`, then the rotation load is applied to all elements. If `T2` = `LOCAL`, then the rotation load is applied to a selection subset of elements.

Example

```
$ -------------
$ Rotation Load
$ -------------
ROTATION 2 TYPE GLOBAL
ROTATION 2 AXIS 1
ROTATION 2 ANGULAR_RATE  5.729578E+04
VECTOR 1  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
1.000000E+00
```

Card 9 - ROTPER Thermal Rotational Periodicity Definition - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE` = `ROTPER` (or `87`)

`N1` is the ROTPER card ID. Cards with the same ID reference the same rotational periodicity definition.

`T1` may be:

= `ANGLE` (or `5`) The rotation angle in degrees that is used to duplicate the geometry around the axis of rotation is specified in `T2`. The equivalent number of instances is 360 divided by `T2`.

= `AXIS` (or `3`) is the axis of rotation. `T2` may be an integer that represents the ID of a referenced Card 9 VECTOR card, or GLOBAL referencing Card 9 GLOBAL_AXIS card.

= `INSTANCE` (or `4`) The number of instances is specified in `T2`. It represents the number of times the geometry is duplicated around the axis of rotation.

- The rotation angle between two consecutive instances is 360 degrees divided by the number of instances `T2`.

= `OVER_DIR` (or `8`) For rotational periodicity of type CONDUCTIVE, when the connect only overlapping elements is ON, the overlap projection direction is specified in `T2`.

- The normal of the primary or secondary elements is used to determine the overlap area. `T2` may be PRIMARY or SECONDARY.

= `OVERLAP` (or `7`) For rotational periodicity of type CONDUCTIVE, the option to connect only overlapping elements between the primary and secondary regions can be activated.

- `T2` may be ON or OFF.

= `RESOLUTION` (or `6`) For rotational periodicity of type CONDUCTIVE, the resolution of the coupling that connects the primary and secondary regions is specified in `T2`.

- `T2` may be ONETOONE or COARSE or MEDIUM or FINE or VERYFINE or FINEST.

= `SELECTION` (or `2`) For rotational periodicity of type CONDUCTIVE, `T2` and `T3` are group names associated with the Primary Region and the Secondary Region selections, respectively.

= `TYPE` (or `1`) is the type of rotational periodicity. `T2` may be CONDUCTIVE or RADIATIVE.

Note

In a thermal rotational periodicity definition, either INSTANCE or ANGLE must be specified.

Example

```
$
$ ---------------------------------------
$ Thermal Rotational Periodicity Objects
$ ---------------------------------------
$
$ Thermal Rotational Periodicity(2)
ROTPER 3 TYPE RADIATIVE
ROTPER 3 AXIS 1
ROTPER 3 ANGLE  6.000000E+01
```

Card 9 - SINK Elements - Optional

`KODE, N1, T1, T2, T3, T4, T5`

`KODE = SINK` (or `5`)

`N1` is the sink element number, or a group name.

If `N1` is a group name, all its elements become sink elements.

If `N1` is '`*`', and `T1` is `FTEMPF`, then all the element specified on file `T3` will be sinks with temperature history specified on file `T3`.

`T1` may be:

- the temperature of the sink element, or
- the code `FTEMPF` (or `-10000`), and the temperatures are read from file specified in `T3`.

`T2` is the time when `T1` occurs (this option is not recommended, and if used, `T2` may not be `< 0`), or

T2 may be blank or the code CONSTANT, for which T1 is constant.

If T2 is '*', its value is ignored.

T3 may be blank or a file name.

If T3 is a file name, and T1 is FTEMPF, then the temperatures are read from file T3. File T3 must have file TEMPF format.

If T3 is blank, and T1 is FTEMPF, then the temperatures are read from file T3. File T3 must have file TEMPF format.

T4 specifies the layer for multilayer elements. Non-homogeneous multilayer elements are specified on LAYER Cards, homogeneous multilayer elements are specified on PROP Cards.

= 0, blank, or TOP, the element is not multilayer or temperature is applied to the top layer.

= MIDDLE – temperature is applied to the middle layer.

= BOTTOM – temperature applied to the bottom layer.

= ALL – temperature is applied to all the layers.

= SPECIFY – temperature is applied to the T5'th layer from the bottom. T4=1 is the same as T4=BOTTOM.

T5 is the layer number for T4 = SPECIFY.

Notes

A sink element's temperature is a boundary condition for the thermal model, which can be changed in the user-written subroutine or with INTERP Cards.
A sink element temperature should not be adjusted with a follower conductance.
It is recommended that time-dependent sink element temperatures be specified on tables with INTERP, TABTYPE, and TABDATA Cards, and not with the T1 parameter.
A sink element is flagged internally in the Analyzer by a negative capacitance. Thus, a sink element may be changed to a non-sink element with a specified capacitance during a run, by changing its capacitance value. This may be accomplished only in a user-written subroutine.

Sink temperature definitions should not be at absolute zero. This is physically unrealistic, and will cause convergence problems.

Examples

```
SINK 30 0 CONSTANT
$ ELEMENT 30 IS DEFINED AS A SINK ELEMENT
$
INTERP 30 0 1 1
$ ELEMENT 30 IS REFERENCED ON TABLE 1
TABTYPE 1 TEMP TIME
$ TABLE 1 DEFINES A TIME-VARYING HISTORY
$
TABDATA 1 20 0
$ ELEMENT 30 HAS TEMP. OF 20 AT TIME 0
$
TABDATA 1 40 100
$ ELEMENT 30 HAS TEMP. OF 40 AT TIME 100
$
SINK 20 100 CONSTANT
$ ELEMENT 20 HAS A TEMPERATURE 100.0
```

Card 9 - STEP Solution Steps Control Card - Optional

The STEP cards allow you to set up a solution sequence so that different stages of the same simulation use different settings for the solution type (transient or steady state), integration time step, and printing step control. If present, they override the corresponding settings (`DTP` , `DT` , `TST` , `TF`) of the Analyzer Control Card 2b. The simulation stages corresponding to different STEP cards are executed in the order that those cards are written in the INPF file.

`KODE, N1, T1, T2, T3`

`KODE` = `STEP` (or `94`)

`N1` is the STEP card ID. Cards with the same ID reference the same Solution Step.

`T1` may be:

= `AUTODELTAT` (or `11`)

= `DTEMPMAX` (or `4`)

= `DTMAX` (or `6`)

= `DTMIN` (or `5`)

= `ENDTIME` (or `2`)

= `INCREMENTS` (or `10`)

= `NAME` (or `9`)

= `OUTPUT` (or `7`)

= `PRINT` (or `8`)

= `TIMESTEP` (or `3`)

= `TYPE` (or `1`)

- `T1` = `AUTODELTAT`: When automatic time stepping is used, the temperature error tolerance (i.e. maximum temperature error estimate) is specified in `T2.`
- `T1` = `DTEMPMAX`: This method is OBSOLETE.
  When automatic time stepping is used, the maximum allowable temperature change of the PARAM DTEMPMAX method is specified in `T2.`
- `T1` = `DTMAX` is the upper limit on the integration time steps obtained during automatic time stepping is specified in `T2`.
- `T1` = `DTMIN` is the lower limit on the integration time steps obtained during automatic time stepping is specified in `T2.`
- `T1` = `ENDTIME` specifies the value of end time of the solution step in `T2`.
- For steady state steps this is the time point where the steady state simulation is to be performed for the given step.

If the step is of type transient when it covers the transient integration time interval from the end time of the previous STEP card to the current step end time.
The end time values of the first and last step are taken to be the initial and final time of the simulation and they override the `TST` and `TF` fields of Card 2b

- `T1` = `INCREMENTS` : If the TIMESTEP option is set to AUTOMATIC, the integration time step upper limit is defined as the number of increments throughout the time duration of the solution step.
  Therefore, the maximum integration time step is the solution step duration time divided by the number of increments. This number of increments is specified in `T2` .
- `T1` = `NAME` : The solution step user-defined name is specified in `T2` .
- `T1` = `OUTPUT`
  If `T2` = `ALL` (or `4`) then result printout will be performed at all integration and coupling time steps between the thermal and structural solvers.
  If `T2` = `COUPLED` (or `3`) then result printout will be performed only at coupling times between the thermal and structural solvers.
  If `T2` = `END` (or `2`), then result printout is done only at the end time of the solution step.
  If `T2` = `YES` (or `1`) then result printout will be performed at each integration time step.
- `T1` = `PRINT` : The thermal output request ID that should be used for the given STEP card is specified in `T2` , unless it is set to GLOBAL (or -1).
- `T1` = `TIMESTEP` specifies how the transient integration time step is to be determined for the given solution step.
  If `T2` = `DT` (or `4`) then the integration time step is a constant value given in `T3` . If `T2 = AUTOMATIC` (or `5`) then the integration time step is determined automatically using the PARAM AUTODELTAT method.
  If `T2` = `NUMBER` (or `3`) then the integration time step is a constant value equal to the total duration of the current time step interval (from previous solution step end time to the current solution step end time) divided by the integer value provided in `T3` (if that value is `0` or absent then it will be taken as `1`).
- `T1` = `TYPE` defines the solution type for the given step. If `T2 = STEADY` (or `1`) then the given step will be treated as steady state. If `T2 = TRANSIENT` (or `2`) or blank then the step is to be treated as transient.

Example

```
$
$ Solution Steps
$
STEP 1 TYPE TRANSIENT
STEP 1 ENDTIME  0.000000E+00
```

```
STEP 1 TIMESTEP NUMBER 100
STEP 1 OUTPUT END
STEP 1 PRINT GLOBAL
$
STEP 2 TYPE TRANSIENT
STEP 2 ENDTIME  2.500000E+04
STEP 2 TIMESTEP DT 0.5
STEP 2 OUTPUT YES
STEP 2 PRINT GLOBAL
```

Card 9 - SYMM Symmetry Definition Card - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE = SYMM` (or `40`)

`N1` is the code `MIRROR` (or `32`)

`T1` should be 0.

`T2` is a node number.

`T3` is a node number

`T4` is a node number

Notes

This Card defines the plane of symmetry for a mirror-symmetrical model. The plane is defined by nodes `T2`, `T3`, `T4`. The positive side of the plane is the one where nodes `T2`, `T3`, `T4` are seen in a counterclockwise order.

The model is assumed to be symmetrical both geometrically and thermally. The effect of the Card is to create equivalent Card 7 Merging Cards for the symmetrically located elements

.

Example

```
SYMM MIRROR 0 101 102 103
$ THE MODEL HAS MIRROR SYMMETRY WRT  PLANE DEFINED
$ BY NODES 101, 102, 103
```

Card 9 - SYSCOOR Card - Optional

This card references a coordinate system.

`KODE, N1, T1, T2, T3, T4`

`KODE = SYSCOOR` or (`106`)

`N1` is the SYSCOOR ID number

`T1` may be:

= `AXIS1` (or `2`)

- `T2, T3, T4` are the coordinates of the 1st axis of the coordinate system

= `AXIS2` (or `3`)

- `T2` , `T3, T4` are the coordinates of the 2nd axis of the coordinate system

= `ORIGIN` (or `1`)

- `T2` , `T3` , `T4` are the coordinates of the origin of the coordinate system

Card 9 - TABDATA Analyzer Table Data Cards - Optional

`KODE, N1, T1, T2, T3`

`KODE = TABDATA` (or `9`)

`N1` is the table number

`T1` is the value of the dependent variable

`T2` is the value of the independent variable

`T3` (optional) is the table number of the TABDATA Cards associated with the TABTYPE Card. If `T3` is blank, the table number of the TABDATA Cards associated with the TABTYPE Cards is `N1`.

Notes

This Card defines the data points of table `N1` for linear interpolation by the Analyzer. Their order in the data deck must be such that the independent variable `T2` is monotonically increasing. Tables with a single data point return a constant value.
If the independent variable is time**,** then the table is interpreted to be periodic, with a period equal to the (largest-smallest) time value in the table.
Tables may be referenced from INTERP Cards, Card 10 user-written subroutines, Card 6e AREA Cards, MAT Material Property Cards, and PROP Physical Property cards.
The nature of the data contained in a table is specified on its TABTYPE Card.
It is a good policy to extend tables beyond their expected range, to ensure that during iteration the Analyzer does not exceed the table. If a table is exceeded its last value is used and an error message is written to [Simulation name]_verbose.log.
For the special case when the independent variable code on the corresponding TABTYPE Card is OPERAT, and the dependent variable code is TABLE, the TABDATA Card may outline a sequence of operations involving interpolation, addition, subtraction, multiplication, division, and thermostat. For this option, the dependent

variable must be a table number on the TABDATA Card, and the independent variable may be the code `INTERP`, `ADD`, `SUBTRACT`, `MULTIPLY`, `DIVIDE`, and `THERMST`. For a description of this, see the **Notes** section in Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

Example

```
INTERP 3 2 6 1
TABTYPE 6 QNODE TEMP
TABDATA 6 22.6 100
TABDATA 6 16.7 1000
$ TABLE 6 CONTAINS TEMPERATURE DEPENDENT HEAT LOADS
$ FOR ELEMENT 3. THE HEAT LOAD VARIES FROM 22.7
$ TO 16.7 OVER THE TEMPERATURE RANGE 100 TO 1000
```

Card 9 - TABTYPE Table Variable Type Definition Card - Optional

`KODE, N1, T1, T2`

`KODE = TABTYPE` (or `8`)

`N1` is the table number.

`T1` is the code for the dependent variable type.

`T2` is the code for independent variable type.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`ALBEDO`	`72`	`ALBEDO` is Albedo value.	Dep.
`CAP`	`3`	`CAP` is the capacitance of an element.	Both
`COND`	`1`	`COND` is the current linearized conductance value, if used as the independent variable. `COND` is a conductance multiplier when it is used as the dependent variable. The original conductance value is multiplied by the value interpolated from the table.	Both
`CPP`	`2015`	`CPP` is the specific heat at constant pressure at the element. The independent variable must be `TEMP` or `TIME` and referenced from a MAT Card.	Dep.
`CURRENT`	`30`	`CURRENT` is a current boundary condition specified for an electrical resistance element.	Dep.
`DELTAPT`	`2003`	`DELTAPT` is the total pressure rise if it is the dependent variable for a FANPUMP hydraulic element. `DELTAPT` is a flow boundary condition and is considered positive if there is a total pressure rise over the element. `DELTAPT` is the total pressure drop if it is used as the independent variable for a DUCT or FLOWRES element. `DELTAPT` is then considered positive if there is a total pressure drop over the element. The table should be referenced from a PROP DUCT, PROP FLOWRES, or PROP FANPUMP Card.	Both

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
DT	16	DT is the integration time step for transient runs.	Dep.
DTEMPMAX	59	DTEMPMAX is the maximum allowable temperature change during a transient run. See the description of the Card 9 - PARAM Parameter Card - Optional. The independent variable must be TIME.	Dep.
DTP	17	DTP is the printout time interval for transient runs.	Dep.
E	18	E is the emissivity of an element. The independent variable code must be TEMP or TIME. The table should be referenced from Card 9 - MAT Material Property Definition Card - Optional.	Dep.
EID	130	EID is the element number of the dependent variable.	Ind.
ELECRES	31	ELECRES is the electrical resistivity specified for an electrical resistance element.	Dep.
EY	193	EY is the Young's modulus of the given material.	Dep.
FLOWRES	2002	FLOWRES is the hydraulic flow resistance multiplier. The table should be referenced from a PROP FLOWRES or PROP DUCT Card.	Dep.
HTFL	19	HTFL is heat flow through a conductance.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`INDEX`	`141`	`INDEX` is an index of a parameter value in specifying a list of parameters of a function. The dependent variable must be `PARAMETER`.	Ind.
`KTHERM`	`2017`	`KTHERM` is the thermal conductivity of an element.	Dep.
`KXX`	`2019`	`KXX` is the orthotropic or anisotropic thermal conductivity in the material X direction.	Dep.
`KYY`	`35`	`KYY` is the orthotropic or anisotropic thermal conductivity in the material Y direction.	Dep.
`KZZ`	`36`	`KZZ` is the orthotropic or anisotropic thermal conductivity in the material Z direction.	Dep.
`KXY`	`2020`	`KXY` is the anisotropic thermal conductivity in the material XY direction.	Dep.
`KXZ`	`2021`	`KXZ` is the anisotropic thermal conductivity in the material XZ direction	Dep.
`KYZ`	`2022`	`KYZ` is the anisotropic thermal conductivity in the material YZ direction.	Dep.
`LATITUDE`	`123`	`LATITUDE` is the latitude value.	Ind.
`LONGITUDE`	`185`	`LONGITUDE` is the longitude value.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`MASSFL`	`2005`	`MASSFL` is the mass flow through a 2-node hydraulic or stream element. If used as the dependent variable, then the table is a flow boundary condition for a FANPUMP or STREAM element. The table should be referenced from a PROP FANPUMP or PROP STREAM Card. If used as the independent variable the table must reference a `DUCT` or `FLOWRES` hydraulic element. It is considered positive in the reference forward direction of the element.	Both
`NUMBER`	`118`	`NUMBER` is a dimensionless quantity. It can be used with any type of dependent variable. It is mainly intended for use as a multiplier in table operations.	Dep.
`NU`	`194`	`NU` is the Poisson's ratio of the given material.	Dep.
`OPERAT`	`135`	`OPERAT` is an operation, independent variable on TABTYPE. See **Notes** below.	Ind.
`PABS`	`2025`	`PABS` is the absolute pressure at a hydraulic element.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`PARAMETER`	`120`	`PARAMETER` is a value of arbitrary dimensionality to describe a list of parameters of a function. The independent variable is a parameter index. The meaning and dimensionality of each `PARAMETER` value is determined by the type of function which references the PARAMETER vs. INDEX table. The independent variable must be `INDEX`.	Dep.
`PDYN`	`2010`	`PDYN` is the dynamic pressure $\texttt{RHOV}^2\texttt{/2}$ at a hydraulic element.	Ind.
`PIR`	`47`	`PIR` is the planet IR radiation. It is the emissive power per unit area leaving the surface of the planet.	Dep.
`PRINT`	`58`	`PRINT` is an option, where a printout is created during transient runs for all the time points specified in the table. The independent variable should be `TIME`. An `INTERP` Card should be specified. The value of the dependent variable on the TABDATA card is ignored, only its sign matters. If the dependent variable is < `0`, then calculations will be made at the corresponding time step value, but no printout will occur. If the dependent variable is ≥ `0`, then printout will occur.	Dep.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`PSTATIC`	`2009`	`PSTATIC` is the static pressure at the hydraulic element.	Ind.
`PSUN`	`46`	`PSUN` is the Card 2a solar power per unit area parameter at a particular time value. Independent variable must be `TIME`.	Dep.
`PTOTAL`	`2008`	`PTOTAL` is the total pressure at a hydraulic element. If used as the dependent variable, the table must point to a `PSINK` element, and is considered to be a boundary condition.	Both
`QNODE`	`4`	`QNODE` is the heat load into an element. If it is used the independent variable, it is considered to be the total heat load into the element. If it is used as the dependent variable, it is summed with all other heat loads into the element, and is a boundary condition.	Both
`REDUCT`	`2006`	`REDUCT` is the Reynolds Number based on hydraulic diameter.	Ind.
`RELENGT`	`2013`	`RELENGT` is the Reynolds Number for a hydraulic element based on the distance from the start of the boundary layer to the element's CG. The boundary layer is considered to start at the immediately upstream `BLSTART` element.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`RHOAMB`	`2012`	`RHOAMB` is the density of the ambient fluid for hydraulic elements.	Both
`RHO`	`2018`	`RHO` is the density of the element referenced from Card 9 - MAT Material Property Definition Card - Optional.	Both
`ROTATION`	`32`	`ROTATION` is the angular rotation of an element in degrees.	Dep.
`SEEBECK`	`60`	`SEEBECK` is the temperature-dependent Seebeck coefficient.	Dep.
`TABLE`	`117`	`TABLE` is a table number, interpolated variable.	Dep.
`TDIF`	`22`	• `TDIF` is the absolute value of the temperature difference between the elements of a single conductance. • It can be used only when a conductance number references the conductance. • The dependent variable must be `COND`.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`TEMP`	`2`	`TEMP` is the temperature of an element. If used as the dependent variable, the element must be a `SINK` or `AMBIENT` element. If used as the independent variable, and the dependent variable is a conductance, and the conductance number is the dependent variable value on the INTERP Card, then: • If the independent variable value on the INTERP Card is the same as the dependent variable value, then average temperatures of the two ends of the conductance are used as the independent variable. • If the independent variable value on the INTERP Card is different from the dependent variable value, then temperatures of the independent variable value will be used as the independent variable.	Both
`TEMPX`	`119`	`TEMPX` is the mean value of the solver calculated temperatures of all elements whose IDs are listed in the independent variable column of the table. This is meant for using element temperatures in table operations. The values in the dependent variable columns are ignored. The independent variable must be `EID`.	Dep.
`THICKNESS`	`2023`	`THICKNESS` is the thickness of an element.	Dep.
`THMCDISP`	`139`	`THMCDISP` is a contact gap distance for contact thermal couplings in thermomechanical coupling runs. The dependent variable must be `COND`.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`THMCPRES`	`140`	`THMCPRES` is a contact gap pressure for contact thermal couplings in thermomechanical coupling runs. The dependent variable must be `COND`.	Ind.
`TIME`	`0`	`TIME` is the time value during a transient run. The table is considered to be periodic, with a period equal to the (largest-smallest) time value in the table.	Ind.
`TPHASE`	`40`	`TPHASE` is the phase change temperature of an element.	Dep.
`TPRIME`	`101`	`TPRIME` is the temperature value of the first element of the conductance. If a Card 6e thermal coupling references a table whose independent variable is `TPRIME`, the independent variable will be the temperature of the `N1` (primary) element.	Ind.
`TRANS`	`33`	`TRANS` is the translation of a point in units of length.	Dep.
`USERF`	`43`	`USERF` is a code for invoking a user-written function. For this option, the value of the dependent variable is evaluated with a user-written subroutine instead of table interpolation. For more information, Card 10 - User-Written Subroutines USER1 and USERF - Optional.	Ind.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var

`USER1ARR`
`USER2ARR`
`|`
`USER9ARR`
	`91-99`	`USER1ARR...USER9ARR` are codes for table interpolation to be used with the `CALL USERARRAY` routine in a Card 10 user-written subroutine. For more information, Card 10 - User-Written Subroutines USER1 and USERF - Optional.	Ind.

`VALUE`	`126`	`VALUE` is the quantity of arbitrary or unknown type. This is intended for tables referenced from symbolic expressions through EXPTAB cards.	Dep
`VELOC`	`2007`	`VELOC` is the flow velocity through the hydraulic element. If the table referenced from a PROP FANPUMP Card it must be the dependent variable and is a flow boundary condition. If the table is referenced from a `PROP DUCT` or `PROP FLOWRES` element, it must be the independent variable. Velocity is considered positive in the referenced forward direction of the 2-node element.	Both
`VISC`	`2016`	`VISC` is fluid viscosity. The independent variable code must be `TEMP` or `TIME`. The table should be referenced from a MAT Card.	Dep.

Mnemonic Code	Equiv. Num. Code	Description of the Code	Dep. or Ind. Var
`VOLTAGE`	`29`	`VOLTAGE` is voltage boundary conditions specified for an electrical resistance element.	Dep.
`VOLUME`	`2004`	`VOLUME` is volume flow through the hydraulic element. If the table referenced from a PROP FANPUMP Card, it must be the dependent variable and is a flow boundary condition. If the table referenced from a PROP DUCT or PROP FLOWRES Card, it must be the independent variable. The volume flow is considered positive in the referenced forward direction of the 2-node element.	Both

Notes

This Card describes the nature of the dependent and independent variables of table `N1`.
Each table must be specified with a single TABTYPE and one or more TABDATA Cards.
Tables may be referenced from within user-written subroutines, Card 6e thermal coupling Cards, and from INTERP, PROP, and MAT Cards.
The dependent and independent variables allowed in various boundary conditions can be referenced indirectly through `TABTYPE[ID] TABLE OPERATION` and/or `TABTYPE[ID] TABLE TIME`.

Table Operations:
A sequence of interpolation, addition, subtraction, multiplication, and division operations on an element parameter may be performed with a single table if the table independent variable is `OPERAT`, and the dependent variable is TABLE on the TABTYPE Card. On the corresponding TABDATA Card the dependent variable must be table number, and the independent variable must be the mnemonic `INTERP, ADD`, `SUBTRACT`, `MULTIPLY`, `DIVIDE`, `HTCMOD1` or `THERMST`. The first operation on the TABDATA Card must be INTERP.
This is best illustrated with an example:

```
INTERP 403 0 6 3.8

TABTYPE 6 TABLE OPERAT

TABDATA 6 7 INTERP
```

```
TABDATA 6 8 ADD

TABTYPE 7 QNODE TIME

TABDATA 7 6.2 0

TABTYPE 8 QNODE TIME

TABDATA 8 3.0 0
```

The heat load of `34.96` to element `403` is evaluated from table 6 as follows:

First, the value of `6.2` is computed by interpolation from table 7. Next, the value of `3.0` is computed by interpolation from table 8, and added to the value of `6.2`, yielding `9.2`. Finally, the result is multiplied by `3.8`, yielding the value of `34.96`.

Heat Transfer Correction (`HTCMOD1`)

The table operation with `HTCMOD1` (Heat Transfer Correction) mnemonic is only applicable to TABLE OPERATION tables that define conductances or conductance multipliers. That operation acts as a multiplier in the table operation sequence (similarly to `MULTIPLY` or `THERMST`). The multiplier form is the following:

$$h = h_0 C \left(\frac{T_{wall} + T_{aw}}{2T_{ref}} \right)^{exp1} |T_{wall} - T_{aw}|^{exp2}$$

Where

- C is the "Multiplier" number
- exp1 is the "Temperature Ratio Exponent"
- exp2 is the "Temperature Difference Exponent"
- T_{ref} is the "Reference Temperature"
- T_{wall} is the "wall temperature" (first element of the conductance)
- T_{aw} is the temperature of the other element of conductance

The first and second elements of the conductance normally come from primary and secondary selections of elements in thermal couplings. Parameters C, exp1, exp2, and T_{ref} are specified by the table whose ID is given in the independent variable value position of the `HTCMOD1` line. The dependent and independent variable types of that referenced table should be `PARAMETER` and `INDEX` and it should have 4 TABDATA lines, in which the independent variable values should be 1, 2, 3, 4 and the dependent variable values should be the values of C, exp1, exp2, and Tref parameters, respectively.

The `HTCMOD1` usage can be illustrated with the following example:

```
TABTYPE  18  TABLE OPERATION
TABDATA  18  19  INTERP
TABDATA  18  20  MULT
TABDATA  18  21  HTCMOD1

TABTYPE  19  COND  EID
```

```
TABDATA  19  9.995997E+02  9
TABDATA  19  9.995146E+02  10
TABDATA  19  9.998522E+02  11
TABDATA  19  9.998270E+02  12
TABDATA  19  9.999520E+02  13
TABDATA  19  9.999585E+02  14
TABDATA  19  9.999659E+02  15
TABDATA  19  9.999886E+02  16

TABTYPE  20  COND  TIME
TABDATA  20  2.500000E+07  0.000000E+00
TABDATA  20  5.000000E+07  1.000000E+02
TABDATA  20  1.000000E+08  1.000000E+03

TABTYPE  21  PARAMETER  INDEX
TABDATA  21  R1  1
TABDATA  21  R2  2
TABDATA  21  R3  3
TABDATA  21  R4  4

Where R1..R4 are the following:

R1 = C is the "Multiplier" number
R2 = exp1 is the "Temperature Ratio Exponent"
R3 = exp2 is the "Temperature Difference Exponent"
R4 = Tref is the "Reference Temperature"
```

Another example to illustrate the usage of the mnemonic `THERMST`:

```
THERMST  177  0  40.0  100.0  1001  ID
QNODE  235  1.0  T101  ABSOLUTE
TABTYPE  101  TABLE  OPERAT
TABDATA  101     1  INTERP
TABDATA  101  1001  THERMST
TABTYPE  1  QNODE  TIME
TABDATA  1  25.0  0.0
```

A heat load of `1.0`, applied to element `235`, is multiplied by the value interpolated from table operation `101`. The first operation is an interpolation that returns a heat load multiplier of `25.0`, which is subject to a thermostat identified with ID `1001` through the second operation. Thermostat `1001` is a dead zone thermostat with element `177` as a sensor, a cut-in temperature of `40` and a cut-off temperature of `100`.

Table Time:

The `TABLE TIME` usage can be illustrated with the following example:

```
TSTREAM 1 HEATPICKUP  1.000000E+00 T85
...
TABTYPE 85 TABLE TIME
TABDATA 85 80  0.000000E+00
TABDATA 85 83  5.000000E+01
TABTYPE 80 QNODE EID
TABDATA 80  7.000000E+00 1
TABDATA 80  5.000000E+00 2
TABDATA 80  7.000000E+00 3
TABDATA 80  5.000000E+00 4
TABDATA 80  7.000000E+00 5
TABDATA 80  7.000000E+00 6
TABDATA 80  7.000000E+00 7
TABDATA 80  7.000000E+00 8
TABDATA 80  7.000000E+00 9
TABDATA 80  7.000000E+00 10
TABDATA 80  5.000000E+00 11
TABDATA 80  5.000000E+00 12
TABDATA 80  5.000000E+00 13
TABDATA 80  5.000000E+00 14
TABDATA 80  5.000000E+00 15
TABDATA 80  5.000000E+00 16
TABTYPE 83 QNODE EID
TABDATA 83  8.000000E+00 1
TABDATA 83  6.000000E+00 2
TABDATA 83  8.000000E+00 3
TABDATA 83  6.000000E+00 4
TABDATA 83  8.000000E+00 5
TABDATA 83  8.000000E+00 6
TABDATA 83  8.000000E+00 7
TABDATA 83  8.000000E+00 8
TABDATA 83  8.000000E+00 9
TABDATA 83  8.000000E+00 10
TABDATA 83  6.000000E+00 11
TABDATA 83  6.000000E+00 12
TABDATA 83  6.000000E+00 13
TABDATA 83  6.000000E+00 14
TABDATA 83  6.000000E+00 15
TABDATA 83  6.000000E+00 16
```

In this example `, HEATPICKUP` is specified by the table `85`, which is also `TABLE TIME`. Table `80` corresponds to initial time `0.0`, and table `83` corresponds to time `50.0`. Time between `0.0` and `50.0` is linear interpolation between values given by tables `80` and `83`. These tables represent the heat load versus EID.

The heat load of 7.2 to element 7 at time 10 is evaluated as follows:

First, the value 7.0 is computed by interpolation from table 80. Next, the value 8.0 is computed by interpolation from table 83. Interpolation for time 10, between 7.0 associated with time 0, and 8.0 associated with time 50, yields 7.2

Electrical resistance elements

1. An element is specified to be an electrical resistance element by referencing it on an INTERP Card that points to a table whose dependent variable is the `ELECRES` electrical resistivity, or specifying the electrical resistivity on a Card 9 MAT Card. Electrical resistances will be automatically calculated for these elements using the conduction shape factors calculated by the `COND` module.
2. Electrical resistance elements form an electrical network. At each iteration or time step voltage, current, and electrical power dissipations will automatically be performed for the electrical network.
3. The frequency with which the power dissipation of the electrical resistance elements is updated is specified on `PARAMELECUPDATE` Card.
4. Conductances for the electrical network may also be specified with a Card 6e AREA thermal couplings that reference an `ELECRES` table. The magnitude of the electrical resistance is the electrical resistance interpolated from the table divided by the calculated thermal coupling value.

   An example of this the Card 6e NEARA coupling. If the Card references a table in its EXP field whose dependent variable is `ELECRES` , then the magnitude of the electrical resistance calculated between the N1 and N2 elements will be:

   $$R_{elec} = \frac{ELERCES}{A(N1)HN1}$$

   Where
   - R_{elec} is the electrical resistance calculated between the N1 and N2 elements.
   - $A(N1)$ is the area of the N1 element.
   - $HN1$ is the multiplier specified on the Card.
   - $ELECRES$ is the electrical resistivity interpolated from the table.
5. Voltage and/or current boundary conditions may be specified with `CURRENT` and `VOLTAGE` tables. At least one voltage boundary condition must be specified for each separate electrical network.
6. Voltage drops are written onto file voltages.unv, and if the `PRINTHFGROUP` option is present, to report log file. Power dissipation is written onto file POWERDISS.unv.

Example

```
TABTYPE 12 QNODE TEMP
TABDATA 12 10 0
TABDATA 12 20 10
$ TABLE 12 CONTAINS HEAT LOAD VS TEMP DATA
```

Card 9 - TEMPERATURE - Optional

`KODE, N1, T1, T2, T3`

`KODE = TEMPERATURE` (or 133) constrains temperature on elements or on fluid duct nodes.

`N1` is the `TEMPERATURE` card ID. Cards with the same ID reference the same temperature definition.

`T1` may be:

= `NAME` (or 1)

= `SELECTION` (or 2)

= `MAGNITUDE` (or 3)

= `FROM_FILE` (or 4)

= `FROM_DIRECTORY` (or 5)

`T1` = `NAME` indicates the name for the temperature constraint that is specified in `T2` .

`T1` = `SELECTION` specifies a selection of elements or fluid duct nodes where the temperature constraint is applied. The selection is represented by the group name in `T2` .

`T1` = `MAGNITUDE` specifies the temperature value in `T2` .

- If the temperature is constant, then its value is specified in `T2` .
- If the temperature is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`), where `n` is a table number referencing TABTYPE or FIELDTYPE cards.
- If the temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing the EXPRESSION card.

`T1` = `FROM_FILE` reads the temperature from the file given in `T2`. `T2` must have file in `TEMPF` format.

`T1` = `FROM_DIRECTORY` reads the temperature from the file named `TEMPF` located in directory `T2.`

Examples

```
$ Temperature(1)
TEMPERATURE 6 NAME "Temperature(1)"
TEMPERATURE 6 SELECTION "Temperature(1)"
TEMPERATURE 6 MAGNITUDE  3.400000E+01
```

Card 9 - THERMAL_COUPLING Card - Optional

`KODE, N1, T1, T2, T3, T4, T5`

`KODE = THERMAL_COUPLING` (or `126`) defines a thermal coupling entity.

`N1` is the `THERMAL_COUPLING` card ID.

`T1` is:

`= NAME (or 1)`

`= SELECTION (or 2)`

`= TYPE (or 3)`

`= SIDE (or 6)`

`= SIDE_FREE (or 18)`

`= TYPE (or 3)`

`= MAGNITUDE (or 4)`

`= METHOD (or 7)`

`= OVERLAP_PROJECTION (or 5)`

`= RESOLUTION (or 21)`

`= ROUGHNESS (or 22)`

`= FLUID_TEMPERATURE (or 24)`

`= MESH_CORRECTION (or 23)`

`= ROT_FX (or 25)`

`= ADIABATIC_WALL_TEMP_FOR_HTC (or 26)`

`= WALL_TEMP (or 28)`

`= RECOVERY_FACTOR (or 27)`

`T1 = NAME` specifies the thermal coupling name in `T2`.

`T1 = SELECTION`: the thermal coupling is applied to a selection of elements that are represented by the group name in `T3`. The selected element is specified in `T2`. `T2` may be:

- `T2 = PRIMARY` (or `1`) specifies the primary elements.
- `T2 = SECONDARY` (or `2`) specifies the secondary elements.

`T1 = SIDE`: the thermal coupling is applied to a side of selected elements. The selected element is specified in `T2`. The side type is indicated in `T3`.

`T2` may be:

- `T2 = PRIMARY` specifies the primary elements.
- `T2 = SECONDARY` specifies the secondary elements.

`T3` may be:

- `T3 = TOP` indicates the top side of the selected elements.
- `T3 = BOTTOM` indicates the bottom side of the selected elements.

`T1 = SIDE_FREE`: the convection for environment is applied to a side of selected elements indicated in `T2`.

`T2` may be:

- `T2 = TOP` indicates the top side of the selected elements.
- `T2 = BOTTOM` indicates the bottom side of the selected elements.
- `T2 = BOTH` indicates the top and bottom sides of the selected elements.

`T1 = TYPE` specifies the thermal coupling type in `T2`.

- `T2 = HTC` specifies the heat transfer coefficient for convection between the primary elements and secondary elements.
- `T2 = CONDUCTIVE_GAP` specifies conductances G = (k × A) / L between the primary elements and secondary elements, where L is the distance to the secondary element along the primary element's surface normal.
- `T2 = EDGE_CONTACT` specifies an edge-to-edge conductance, $G = C_l \times L$, between the primary elements and secondary elements, where C_l is the conductance per length, and L is the edge length.
- `T2 = PERFECT_CONTACT` specifies a perfect contact coupling between the primary elements and secondary elements.
- `T2 = TOTAL_CONDUCTANCE` specifies a total conductance, G, to describe the quantity of heat that flows from the hotter element to the cooler element per degree of temperature difference, between the primary and secondary elements.
- `T2 = TOTAL_RESISTANCE` specifies a total resistance, R, to describe the temperature rise between the primary and secondary elements.
- `T2 = XCOND` specifies a total conductance between a set of primary elements and a non-geometric element.
- `T2 = XRESIST` specifies a total resistance between a set of primary elements and a non-geometric element.
- `T2 = XCONV` specifies a heat transfer coefficient between a set of primary elements and a non-geometric element.
- `T2 = EDGE_XCONV` specifies an edge-to-edge conductance between a set of primary elements and a non-geometric element.
- `T2 = TOTAL_CONDUCTANCE_LEGACY` specifies a total conductance between the primary and secondary elements when the LEGACY_COUPLING_OVERLAP advanced parameter is defined.
- `T2 = TOTAL_RESISTANCE_LEGACY` specifies a total resistance between the primary and secondary elements when the LEGACY_COUPLING_OVERLAP advanced parameter is defined.
- `T2 = AXI_SOLID_INTERFACE_SLIP` specifies a conductance G = h × A between fluid and solid elements for an axisymmetric solid interface boundary condition that is defined with the slip wall treatment.

- `T2 = AXI_SOLID_INTERFACE_ROUGH` specifies a conductance G = h × A between fluid and solid elements for an axisymmetric solid interface boundary condition that is defined with a surface roughness.
- `T2 = CONVECTION_TO_ENVIRONMENT` specifies convection properties the software uses to model the convection to environment.
- `T2 = CONVECTION_COUPLING` specifies the heat transfer coefficient for convection between the convection region selection (`PRIMARY SELECTION`) and the fluid ducts selection (`SECONDARY SELECTION`).
- `T2 = DUCT_NODE_COUPLING` specifies the heat transfer coefficient for convection between the convection region selection (`PRIMARY SELECTION`) and the fluid duct nodes (`SECONDARY SELECTION`).

`T1 = MAGNITUDE` specifies the value of the coupling type, except for the `PERFECT_CONTACT` .

- If the coupling type is constant, then its value is specified in `T2` .
- If the coupling type is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` , for example, `T25` where n is a table number referencing the TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `COND` .
- If the magnitude is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` , for example, `E25` where `n` is an expression number referencing the EXPRESSION card.

`T1 = METHOD` specifies the thermal coupling method in `T2` .

- `T2 = STACK` specifies the stack method, which defines conductances between PCB stacks.
- `T2 = PROJECTIVE_INTERSECTION` specifies the projective intersection method, which computes the exact overlap area between two sets of elements.
- `T2 = ELEMENT_SUBDIVISION` specifies the element subdivision method, which defines conductances between primary and secondary elements using proximity or overlap methods.

`T1 = OVERLAP_PROJECTION` the direction of overlap projection is specified in `T2` .

- If the direction of overlap projection is along the normal of primary element, then `T2 = PRIMARY` .
- If the direction of overlap projection is along the normal of secondary element, then `T2 = SCONDARY` .
- If the direction of the overlap projection is specified by a vector, then `T2 = VECTOR` , where `T3` , `T4` , and `T5` are the X, Y, and Z components of the vector.

`T1 = RESOLUTION` specifies the coupling resolution option in `T2` , where `T2` may be `ONE-TO-ONE` , `COARSE` , `MEDIUM` , `FINE` , `VERY FINE` , `FINEST` , or `RESET` . With the `RESET` option, no subdivision is performed, and only a single conductance is calculated for each element.

`T1 = ROUGHNESS` specifies the roughness height for the axisymmetric solid interface boundary condition in `T2`.

`T1 = FLUID_TEMPERATURE` specifies the convecting fluid temperature for convection to environment in `T2.`

`T1 = MESH_CORRECTION` specifies the type of mesh correction that is applied to the axisymmetric solid interface boundary condition in `T2`.

- `T2 = 0` specifies no mesh correction.
- `T2 = 1` specifies forced convection mesh correction.
- `T2 = 2` specifies natural convection mesh correction.
- `T2 = 3` specifies automatic mesh correction.

`T1 = ROT_FX` accounts for total temperature effects due to rotation. The ID of the referenced `ROT_FX` cards is specified in `T2`.

`T1 = ADIABATIC_WALL_TEMP_FOR_HTC` specifies the calculations of adiabatic wall temperature for heat transfer is defined in T2.

- `T2` may be either `TEMPERATURE`, which is a specified value for an adiabatic wall temperature, or `AUTOMATIC`, which is an adiabatic wall temperature value computed by the thermal solver.
- If `T2 = AUTOMATIC,` the thermal solver uses the adiabatic wall temperature in heat transfer calculations as follows:

$$T_{aw} = T_s + RF\frac{v_{rel}^2}{2C_p}$$

where:

- T_s is the static temperature.
- $RF = Pr_{film}^{1/3}$ is the recovery factor that is computed by the thermal solver, or can be specified in `RECOVERY_FACTOR`.
- Pr is the Prandl number calculated at $T_{film} = \frac{1}{2}(T_\omega - T_f)$.
- $v_{rel} = abs(u - v_\phi)$ is the relative tangential velocity, where u is a wall tangential velocity and v_ϕ is a swirl velocity.
- C_p is the specific heat at the fluid temperature T_{film}.

`T1 = WALL_TEMP` specifies a value for an adiabatic wall temperature in `T2.`

- If the adiabatic wall temperature is constant, then its value is specified in `T2`.

- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `NUMBER`.
- If the adiabatic wall temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` h as the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1 = RECOVERY_FACTOR` specifies a value for the recovery factor, which is used to compute the adiabatic wall temperature, in `T2.`

- If the recovery factor is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `NUMBER`.
- If the recovery factor is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

Example

```
$ Thermal Coupling(1)
THERMAL_COUPLING 1 NAME "Thermal Coupling(1)"
THERMAL_COUPLING 1 SELECTION PRIMARY "Thermal Coupling(1) - Primary Region"
THERMAL_COUPLING 1 SELECTION SECONDARY "Thermal Coupling(1) - Secondary Region"
THERMAL_COUPLING 1 SIDE PRIMARY TOP
THERMAL_COUPLING 1 SIDE SECONDARY BOTTOM
THERMAL_COUPLING 1 RESOLUTION MEDIUM
THERMAL_COUPLING 1 TYPE HTC
THERMAL_COUPLING 1 MAGNITUDE  2.800000E+06
THERMAL_COUPLING 1 OVERLAP_PROJECTION VECTOR -5.773503E-01  5.773503E-01  5.773503E-01
```

Card 9 - THERMST Analyzer Thermostat Definition - Optional

Note

Use improved CONTROLLER Card to model the thermostat, or heater controller, or fan controller.

`KODE, N1, T1, T2, T3, T4, T5, T6, T7, T8, T9, T10`

`KODE` = `THERMST` (or `10`)

`N1` is the element number or group name of the thermostat's temperature sensor. If `N1` is a group name, then the sensor temperature is considered to be the average of the `N1` elements.

`T1` is the element number or group name where the thermostat's heater(s) are located. If `T1` is a group name, a heater is placed on all the elements of the group.

`T2` is the thermostat's cut-in temperature. If `T6` is PID, i.e. the thermostat acts as a PID controller, then `T2` is the set point of the controller defined as a constant value or time-dependent table.

`T3` is the thermostat's cut-off temperature, `T3 > T2` for heater control and `T3 < T2` for cooler control.

`T4` may be:

= 0 or blank, then the thermostat controls the total heat input into the element `T1`, including additional heat loads not specified in `T4`.

= value, then it is a heat input, and the thermostat controls only this heat input to the element. If this value takes on the form `Tn` (e.g. `T576`), then `n` is a table number of a QNODE vs TIME table, specifying the time-dependent heat load value to the heaters.

If `T5=FAN`, then `T4` is not a heat input, but rather a user-assigned thermostat ID.

If `T5=ID`, then `T4` is not a heat input, but rather a user-assigned thermostat ID, that can be referenced in a table operation.

`T5` is a mnemonic that characterizes the heat input `T4` into element `T1` if `T4 > 0`.

= `ABSOLUTE`, then the heat input value `T4` is specified for each element `T1`.

= `AREA`, then the heat input value `T4*area(T1)` is specified for each planar, beam or lump mass element `T1`, and a heat input value of `T4*volume(T1)` is specified for each solid element `T1`.

= `TOTAL`, then the elements of group `T1` receive the total heat input `T4`.

= `FAN`, then the thermostat controls no heaters, and `T4` is a user-assigned element ID.

`T6` may be the code `PROPORTIONAL`, in which case the heat input Q to the heaters follows the relationship:

$$Q = 0 \qquad T(N1) > T3$$

$$Q = \frac{QHTR(T3 - T(N1))}{T3 - T2} \qquad T2 \geq T(N1) \geq T3$$

$$Q = QHTR \qquad T(N1) < T2$$

or it may be blank, in which case a thermostat with a dead zone is modeled, and:

$$Q = 0 \qquad T(N1) \geq T3$$
$$Q = QHTR \qquad T(N1) \leq T3$$
$$Q = intermediate \qquad T3 > T(N1) > T2$$

or it may be the code PID, in which case a proportional PID controller is modeled. The heat inputs Q to the heaters are calculated as follows:

$$e(t) = T2 - T(N1)$$
$$Q = QHTR\left(T7(e(t)) + T8\int_0^t e(t)dt + T9\frac{de(t)}{dt} + T10\right) \qquad 0 \leq Q \leq QHTR$$

where $QHTR$ is the heat input to the heaters, defined by `T4` and `T5`.

`T7` is the gain if a PID controller is specified in `T6`, otherwise it is ignored.

`T8` is the integral constant if a PID controller is specified in `T6`, otherwise it is ignored.

`T9` is the derivative constant if a PID controller is specified in `T6`, otherwise it is ignored.

`T10` is the bias if a PID controller is specified in T6, otherwise it is ignore

Notes

If T6 is blank, the thermostat models a dead zone between the cut-in and cut-out temperatures, in which the ON/OFF state of the heater does not change. The heater is switched ON if the sensor temperature is below the cut-in temperature, and is switched OFF if the sensor temperature is above the cut-out temperature.

If `T6` is `PROPORTIONAL`, then the thermostat acts like a proportional controller between the temperatures `T2` and `T3`.

For cooler control, the negative heat load `T4` must be of the form `Tn`, that references a table of `QNODE` versus `TIME`.

A number of options exist for handling thermostats in steady state, all defined on a Card 9 PARAM THERMOSTAT Card. If a PARAM THERMOSTAT Card is not present, one is automatically created with the AVGTEMP option. With this option, the heaters are defined to be SINK elements, with the average temperature of the cut-in and cut-off temperatures. This is an approximation, but it allows the calculation of heat flows into the heaters for the defined conditions.

Example

```
QNODE HEATERS 5
THERMST SENSOR1 HEATERS 70 72
$ A thermostat operating between temperatures 70 and 72 degrees turns ON and OFF
$ the heat load of 5 units to the elementS HEATERS. The temperature is sensed at
$ the element SENSOR1.
$
THERMST SENSOR1 HEATERS 70 72 100 TOTAL
$ A thermostat operating between temperatures 70 and 72 degrees turns ON and OFF a
$ total  heat load of 100 to the elementS HEATERS. The temperature is sensed at
$ the element SENSOR1. the individual elements will  receive heat inputs in
$ proportion to their areas.
```

Card 9 - TINIT Initial Temperatures - Optional

`KODE, N1, T1, T2, T3, T4, T5`

`KODE = TINIT` (or `14`) defines initial temperatures for the Analyzer run or the SINDA data deck. There are three input options:

Option 1

`N1` is an element number or a group name for the elements whose initial temperatures are specified.

`T1` is another element number or `0`. `T1` must be `0` if `N1` is a group name.

`T2` is a starting temperature for elements `N1` through `T1`, if `T3` is zero.

If `T2` is zero, then `T3` may be of the format `:`

- `Tn`, where n is a table number.
- `En`, where n is an expression number referencing EXPRESSION card.

`T4-T5` are ignored.

Option 2

`N1` is the code `FILE`.

`T1` is a filename from which the temperatures are read. The file must have file TEMPF format.

`T2-T5` are ignored.

Option 3

`N1` is the code `STEADYSTATE`.

- If this option is used, and Card 2b specifies a transient run, then a steady state run will be performed before the transient run with the options `T1-T5` to calculate the initial temperatures.

`T1` is the equivalent of the Card 2b GRADNT parameter.

`T2` is the equivalent of the Card 2b DTP parameter.

`T3` is the equivalent of the Card 2b DT parameter.

`T4` is the equivalent of the Card 2b TST parameter.

`T5` is the equivalent of the Card 2b TF parameter.

Notes

By default starting temperatures are read from file TEMPF. If file TEMPF is not present, zero starting temperatures are assumed.
If TINIT Cards are present, they overwrite TEMPF.
For sink elements you must define temperatures on SINK Cards. Where they conflict with the TINIT Cards, the SINK Card definitions prevail.
Initial temperatures should not be at absolute zero. This is physically unrealistic, and may cause convergence problems.

Example

```
TINIT 1 20 15.0
$ ELEMENTS 1 THROUGH 20 HAVE STARTING TEMPF OF 15
$
TINIT 25 0 30.0
$ ELEMENT 25 HAS A STARTING TEMP OF 30 DEGREES
$
TINIT BOX 0 30
$ THE ELEMENTS OF BOX HAVE STARTING TEMP OF 30
$
TINIT FILE TEMPPREV
$ STARTING TEMPS ARE READ FROM FILE TEMPPREV
$
$Spatially varying: TINIT  GroupName  0  0  T25
TABTYPE  25  TEMP  EID
TABDATA  25  Value  Label
Expression: TINIT  Groupname  0  0  E47
EXPRESSION  47  [Expression]
```

Card 9 - TOTTEMP Total Temperature Effects Definition - Optional

`KODE, N1, T1, T2, T3, T4`

`KODE = TOTTEMP` (or `93`) defines total temperature effects on fluid duct elements.

`N1` is the TOTTEMP card ID. Cards with the same ID reference the same Total Temperature Effects definition.

`T1` may be:

= `ROT_FX` (or `2`)

= `ROT_FXA(` or 3) or `ROT_FXB` (or 4)

= `ROT_FXAB` (or 5)

= `SELECTION` (or `1`)

`T1` = `ROT_FX` : The fluid duct temperatures are corrected for rotational effects. The ID of the referenced `ROT_FX` cards is specified in `T2.`

- This card is required for one-sided total temperature effects.

`T1` = `ROT_FXA or ROT_FXB` is similar to `ROT_FX.`

- `ROT_FXA` and `ROT_FXB` reference the rotational effects for the first and second side of the two-sided total temperature effects, respectively.

`T1` = `ROT_FXAB` : The fluid duct temperatures are corrected for rotational effects.

- The ID of the referenced `ROT_FX` cards is specified in `T2`. This card is defined for two-sided total temperature effects with the same rotational effects for both sides.

`T1` = `SELECTION:` Total temperature effects are applied to a selection of elements.

- `T2` is a group name or element number of the fluid duct element(s).
- `T3` is an optional group name that you specify for the convecting wall elements. For two-sided total temperature effects, it represents the group name of the convecting wall elements of the first side.
- For two-sided total temperature effects, `T4` is an optional group name that you specify for the convecting wall elements of the second side.
- When the `T3` and `T4` are not specified, the thermal solver searches for the duct connections to the wall, and creates the selection from wall elements. The rotational effects are the same for both sides and are specified in `ROT_FXAB` card.

Card 9 - TSTREAM Thermal Stream Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `TSTREAM` (or `88`)

`N1` is the TSTREAM card ID. Cards with the same ID reference the same Thermal Stream.

`T1` may be:

= `AXIAL` (or `23`)

= `CIRCUMFERENTIAL` (or `22`)

= `CONNECT` (or `33`)

= `CSYS` (or `18`)

= `DIRECTION` (or `2`)

= `ELINLET` or `ELINLETA` or `IDINLET` or `IDINLETA` (or `16`)

= ELINLETB or IDINLETB (or 17)

= FLOWREVERSE (or 9)

= FACTOR or FACTORA (or 27)

= FACTORB (or 28)

= HEATPICKUP or HEATPICKUPA (or 14)

= HEATPICKUPB (or 1 5)

= HTC or HTCA (or 7)

= HTCB (or 8)

= LABELLIST or LABELLISTA (or 34)

= LABELLISTB (or 35)

= MASSFLOW (or 4)

= MAT_LIST (or 21)

= MATERIAL (or 3)

= NAME (or 24)

= NDINLET or NDINLETA (or 31)

= NDINLETB (or 32)

= PRESSURE (or 6)

= OVERRIDE or OVERRIDEA (or 29)

= OVERRIDEB (or 30)

= RADIAL (or 20)

= `ROT_FX` or `ROT_FXA` (or `12`)

= `ROT_FXB` (or `13`)

= `SELECTION` (or `1`)

= `TINLET` (or `5`)

= `THICK` or `THICKA (or 25)`

= `THICKB (or 26)`

`T1` = `AXIAL` references the axial component of the thermal stream on faces with cylindrical components. The axial component is specified in `T2.`

`T1` = `CIRCUMFERENTIAL` references the circumferential component of the thermal stream on faces with cylindrical components. The circumferential component is specified in `T2.`

`T1` = `CONNECT` indicates the parameters that are calculated from connected streams in `T2. T2` may be:

`= MASS` indicates the mass flow is computed.

`= TEMP` indicates the thermal stream inlet temperature is computed.

`= REVMASS` indicates the reverse mass flow is computed.

`= REVTEMP` indicates the thermal stream reverse inlet temperature is computed.

`T1` = `CSYS`: The ID of the referenced SYSCOOR card (coordinate system) is specified in `T2`.

`T1` = `DIRECTION`: For thermal streams on faces, a direction is specified for the stream elements.

- The X, Y, and Z components of the vector representing the stream direction are specified in `T2, T3`, and `T4`, respectively.

`T1` = `ELINLET` or `ELINLETA`: For thermal streams on edges, the ID of the first element of the stream is specified in `T2`.

- If the stream is two-sided, then `T2` is the first element ID in the first side of the stream.

T1 = ELINLETB is similar to ELINLETA. It specifies the ID of the first element in the second side of a two-sided stream on edges.

T1 = FLOWREVERSE indicates that flow reversal can be activated. If the original mass flow becomes negative, then the flow reversal conditions are activated.

- T2 may be MASSFLOW or TINLET.
- T2 = MASSFLOW: If the massflow of the flow reversal conditions is constant, then its value is specified in T3.
- T2 = TINLET: If the inlet temperature of the flow reversal conditions is constant, then its value is specified in T3.
- If it is table dependent, then T3 is a table multiplier and T4 has the form Tn (e.g. T25) where n is a table number referencing TABTYPE or FIELDTYPE cards.
- The dependent variable for TINLET on the TABTYPE card must be TEMP.
- The dependent variable for MASSFLOW on the TABTYPE card must be MASSFL.
- If the inlet temperature or massflow of the flow reversal conditions is calculated using an expression, then T2 is an expression multiplier and T3 has the form En (e.g. E25) where n is an expression number referencing EXPRESSION card.

T1 = HEATPICKUP or HEATPICKUPA or HEATPICKUPB: Additional heat pickup in the fluid flowing in the stream is specified, as a heat power per unit area of the thermal stream selection. HEATPICKUPA is similar to HEATPICKUP. HEATPICKUPA and HEATPICKUPB specify the heat pickup for the first and second side of the two-sided thermal stream, respectively.

- If the heat pickup is constant, then its value is specified in T2.
- If the heat pickup is table dependent, then T2 is a table multiplier and T3 has the form Tn (e.g. T25) where n is a table number referencing TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be QNODE.
- If the thermal stream is two-sided, then HEATPICKUP specifies the same heat pickup for both sides of the stream.
- If the heat pickup is calculated using an expression, then T2 is an expression multiplier and T3 has the form En (e.g. E25) where n is an expression number referencing EXPRESSION card.

T1 = HTC or HTCA or HTCB: A heat transfer coefficient connecting the selected elements with the stream is specified. If the heat transfer coefficient is constant, then its value is specified in T2. HTCA is similar to HTC. HTCA and HTCB specify the heat transfer coefficient for the first and second side of the two-sided thermal stream, respectively.

- If the heat transfer coefficient is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `COND`.
- If the thermal stream is two-sided, then `HTC` specifies the same heat transfer coefficient for both sides of the stream.
- If the heat transfer coefficient is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1` = `LABELLIST or LABELLISTA:` For thermal streams on edges, indicates in `T2` the ID of the LABELLIST card containing ordered element selection for the side of the stream.

- If the stream is two-sided, then `T2` is the ID of the LABELLIST card containing ordered elements selection for the first side of the stream.

`T1` = `LABELLISTB:` indicates in `T2` the ID of the LABELLIST card containing ordered elements selection for the second side of the two-sided stream on edges.

`T1` = `MASSFLOW:` A massflow is specified for the thermal stream. If the massflow is constant, then its value is specified in `T2`.

- If the massflow is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `MASSFL`.
- If the massflow is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1` = `MAT_LIST`: Additional fluid materials are defined. The ID of MATLIST card, which lists these additional fluid materials, is specified in `T2`.

`T1` = `MATERIAL`: The material ID of the primary fluid material in the thermal stream is specified in `T2`.

`T1` = `NAME`: The load name is specified in `T2`.

`T1 = NDINLET` indicates the first node for one-sided streams on edges.

`T1 = NDINLETA` indicates the first node on the side A for two-sided streams on edges.

`T1 = NDINLETB` indicates the first node on the side B for two-sided streams on edges.

`T1` = `PRESSURE` : A pressure is specified for the thermal stream. If the pressure is constant, then its value is specified in `T2` .

- If the pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `PTOTAL` .
- If the pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing EXPRESSION card.

`T1` = `RADIAL` references the radial component of the thermal stream on faces with cylindrical components. The radial component is specified in `T2` .

`T1` = `ROT_FX` : The stream temperatures are corrected for rotational effects.

- The ID of the referenced ROT_FX cards is specified in `T2` . If the thermal stream is two-sided, then `ROT_FX` references the same rotational effects for both sides of the stream.

`T1` = `ROT_FXA or ROT_FX B` : Similar to `ROT_FX` , `both ROT_FXA` and `ROT_FXB` reference the rotational effects for the first and second side of the two-sided thermal stream, respectively.

`T1` = `SELECTION:` The thermal stream is applied to a selection of elements. `T2` is a group name or an element number.

- If the stream is two-sided, `T3` is a group name or an element number for the second side.

`T1` = `TINLET` : An inlet temperature is specified for the thermal stream. If the inlet temperature is constant, then its value is specified in `T2` .

- If the temperature is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `TEMP` .
- If the inlet temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1 = THICK` : The area for internal edges is specified. This input is used to compute the convective area when the Thermal Stream is applied to internal edges.

- If thicknesses are subtracted, then `T2 = SUB` .
- If thicknesses are added, then `T2 = ADD` .

`T1` = `THICKA or THICKB` : Similar to `THICK` , both `THICKA` and `THICKB` reference the thickness treatment for the first and second side of a two-sided stream, respectively.

`T1` = `FACTOR` : An area correction factor is specified. This input corrects the convective area.

- If the area correction factor is constant, then its value is specified in `T2` .
- If the area correction factor is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE and FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `NUMBER` .
- If the area correction factor is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1` = `FACTORA or FACTORB` : Similar to `FACTOR` , both `FACTORA` and `FACTORB` reference the area correction factor for the first and second side of a two-sided stream, respectively.

`T1 = OVERRIDE` : An area override is specified. This input overrides the convective area.

- If the area override is constant, then its value is specified in `T2` .
- If the area override is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE and FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `NUMBER` .
- If the area override is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1` = `OVERRIDEA or OVERRIDEB` : Similar to `OVERRIDE` , both `OVERRIDEA` and `OVERRIDEB` reference the area override for the first and second side of a two-sided stream, respectively.

Thermal steam face-to-edge

In the following example, the face-to-edge thermal stream is a special combination of a two-sided stream, where side A is an edge and side B is a face.

- `ELINLETA` and `NDINLETA` are specified for the side A.
- `DIRECTION` is specified for the side B.

Example

```
TSTREAM 36 NAME "Stream 36"
```

```
TSTREAM 36 SELECTION "Stream 36" "Stream 36 1"
LABELLIST 39 60773 60781 1
TSTREAM 36 LABELLISTA 39
TSTREAM 36 DIRECTION 2.540000E+01 0.000000E+00 0.000000E+00
TSTREAM 36 ELINLETA 60773
TSTREAM 36 NDINLETA 19224
```

Card 9 - VARIABLE Variable Definition Card - Optional

`KODE, N1, T1`

`KODE` = `VARIABLE` (or `29`)

`N1` is a symbolic variable name. The variable name must start with a % sign, and must not exceed 29 characters.

`T1` is the value of the symbolic variable.

Notes

You can use symbolic variables anywhere in the data deck, except for Cards 1 and 2. Once a symbolic variable is encountered, it is replaced with its value.
If you use symbolic variables in NAME Cards and other variable Cards its definition must occur before its usage. Otherwise, it may occur anywhere.
You can access symbolic variables by the Card 10 user-written subroutine. For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional.

Example

```
VARIABLE %AREA .5
VARIABLE %HEATIN .7
VARIABLE %XVAR 3.7
XCOND 101 102 %XVAR COND
QNODE 5 (%HEATIN*%AREA) CONSTANT
$ HEAT LOAD TO ELEMENT 5 = .35
```

Card 9 - VECTOR Vector Definition Card - Optional

`KODE, N1, T1, T2, T3, T4, T5, T6`

`KODE` = `VECTOR` (or `52`)

`N1` is the vector number.

`T1, T2, T3` are the X, Y and Z coordinates of first point of vector.

`T4, T5, T6` are X, Y and Z components of the vector that define the direction.

Notes

A vector Card defines the rotations or translational parameters for an articulating joint as well as the spinning axis for spinning spacecraft. VECTOR Cards are referenced from JOINT and ORBSPIN Cards.

Example

```
VECTOR 1 0. 0. 0. 0. 0. 1.
$ VECTOR 1 HAS ITS ORIGIN AT ZERO AND IS ORIENTED
$ IN THE Z DIRECTION.
```

Card 9 - VOID_NONGEOM Void Non-Geometric Element Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `VOID_NONGEOM` (or `90`) defines a void non-geometric element that can be used as part of one or more thermal void zones.

`N1` is the VOID_NONGEOM card ID. Cards with the same ID reference the same non-geometric element.

`T1` may be:

= `CAP_METHOD` (or `4`)

= `CAPACITANCE` (or `3`)

= `HEAT_LOAD` (or `2`)

= `MAT` (or `1`)

= `MAT_LIST` (or `7`)

= `NAME` (or 9)

= `REGION` (or 8)

= `VOLUME` (or `5`)

`T1` = `CAP_METHOD`: This card describes the capacitance method specified for the VOID non-geometric element. `T2` may be:

- `T2` = `NONE`: The VOID non-geometric element has no capacitance.
- `T2` = `SPECIFY_CAP`: The VOID non-geometric element capacitance is explicitly defined. Its value is specified in a separate VOID_NONGEOM card with `T1` = `CAPACITANCE`.
- `T2` = `SPECIFY_VOL`: The VOID non-geometric element capacitance is computed based on the volume of the element (specified in a separate VOID_NONGEOM card with `T1` = `VOLUME`) and on the material properties (density and specific heat).
- The material ID is specified in a separate VOID_NONGEOM card with `T1` = `MAT`.

`T1` = `CAPACITANCE` : A capacitance is defined for the VOID non-geometric element.

- If the capacitance is constant, then its value is specified in `T2` .
- If the capacitance is table dependent, then `T2` is a table multiplier, and `T3` has the form `Tn` (e.g. `T25`) where n is the table number referencing TABTYPE and TABDATA cards. The dependent variable on the TABTYPE card must be `CAP,` and the independent variable can be either `TEMP` or `TIME` .
- If the capacitance is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`), where `n` is an expression number referencing an EXPRESSION card.

`T1` = `HEAT_LOAD` : A heat load is applied to the VOID non-geometric element.

- If the heat load is constant, then its value is specified in `T2` .
- If the heat load is table dependent, then `T2` is a table multiplier, and `T3` has the form `Tn` (e.g. `T25`) where n is the table number referencing TABTYPE and TABDATA cards.
- When the heat load is variable, the dependent variable on the TABTYPE Card must be `QNODE` and the independent variable can be `TEMP` , or `CAP` , or `TIME` .
- If the heat load is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing an EXPRESSION card.

`T1` = `MAT` : Defines the primary material of the void non-geometric element. Its ID is specified in `T2` .

`T1` = `MAT_LIST` : Additional fluid materials are defined. The ID of Card 9 - MATLIST Additional Fluid Material List - Optional, which lists these additional fluid materials, is specified in `T2` .

`T1` = `NAME` : The load name is specified in `T2` .

`T1` = `REGION` : Specifies a void region which is attached to the void non-geometric element. `T2` is the void region index (from 1 to 20), and `T3` is the uid of that void region.

- The contents of the void region will be written to the Card 9 - VOID_REGION Thermal Void Region Definition - Optional.

`T1` = `VOLUME` : A volume is defined for the void non-geometric element.

- If the volume is constant, then its value is specified in `T2` .
- If the volume is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`), where `n` is a table number referencing TABTYPE and TABDATA cards. The dependent variable on the TABTYPE card must be `VOLUME` , and the independent variable is `TEMP` or `TIME` .
- If the volume is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing an EXPRESSION card.

Example

```
VOID_NONGEOM 3 MAT 2
VOID_NONGEOM 3 HEAT_LOAD 1.000000E+07
VOID_NONGEOM 3 CAP_METHOD SPECIFY_CAP
VOID_NONGEOM 3 CAPACITANCE  1.000000E+10
```

Card 9 - VOID_REGION Thermal Void Region Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `VOID_REGION` (or `91`) defines a void region that creates a thermal coupling between a group of selected elements and a void non-geometric element.

`N1` is the VOID_REGION card ID, which is the uid in the solver XML file. Cards with the same ID reference the same void region.

`T1` may be:

= `HTC` `(` or `4)`

= `FACTOR (` or `8)`

= `NAME` `(` or `6`)

= `OVERRIDE (` or `9)`

= `PRESSURE` (or `3`)

= `ROT_FX` (or `5`)

= `SELECTION` (or `1`)

= `THICK(` or `7)`

= `VOID_ELEM` (or `2`) Note: This option supports the INPF format for pre-NX11 voids, and is described in more detail in the `T1 = VOID_ELEM` description.

`T1` = `HTC` : A heat transfer coefficient connecting the void region selection with the associated void non-geometric element is specified.

- If the heat transfer coefficient is constant, then its value is specified in `T2`.
- If the heat transfer coefficient is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing the TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `COND.`
- If the heat transfer coefficient is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing the `EXPRESSION card.`

`T1 = FACTOR` : An area correction factor is specified. This input corrects the convective area.

- If the area correction factor is constant, then its value is specified in `T2`.
- If the area correction factor is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T 25`) where n is a table number referencing the TABTYPE and FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `NUMBER`.
- If the area correction factor is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1 = NAME :` The region name is specified in `T2 .`

`T1 = OVERRIDE` : An area override is specified. This input overrides the convective area.

- If the area override is constant, then its value is specified in `T2`.
- If the area override is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE and FIELDTYPE cards.

- The dependent variable on the TABTYPE card must be `NUMBER`.
- If the area override is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1` = `PRESSURE`: A pressure is specified for the void region.

- If the pressure is constant, then its value is specified in `T2`.
- If the pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `PTOTAL`.
- If the pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing the EXPRESSION card `.`

`T1` = `ROT_FX`: The void region temperatures are corrected for rotational effects.

- The ID of the referenced ROT_FX cards is specified in `T2`.

`T1` = `SELECTION`: The void region is made up of a selection of elements that are represented by the group name `T2`.

`T1 = THICK`: The area for internal edges is specified. This input is used to compute the convective area when the void region is applied to internal edges.

- If thicknesses are subtracted, then `T2 = SUB`.
- If thicknesses are added, then `T2 = ADD`.

`T1 = VOID_ELEM:` The void region selection is coupled to a void non-geometric element represented by the `VOID_NONGEOM` cards. The ID of the referenced the `VOID_NONGEOM` cards is specified in T2.

- This specification of the void region supports the INPF format for pre-NX11 voids. It will still be supported, but if this line is present, then no REGION cards may exist in the corresponding the VOID_NONGEOM cards, and none of the references to void expression functions may reference regions.

Example

```
$ ------------------
$ Thermal Void Loads
$ ------------------
$
VOID_NONGEOM 3 MAT 2
VOID_NONGEOM 3 HEAT_LOAD  1.000000E+01
VOID_NONGEOM 1 CAP_METHOD SPECIFY_CAP
VOID_NONGEOM 3 VOLUME  0.000000E+00
VOID_NONGEOM 3 CAPACITANCE  0.000000E+00
VOID_NONGEOM 3 REGION 1 101
VOID_NONGEOM 3 REGION 2 202
$
$ ------------
$ Void Regions
$ ------------
$
$ Thermal Void(1)
NAME2 Thermal Thermal Void(1)
NAME Thermal        801       1200       1
$
$ Void Region1
VOID_REGION 101 SELECTION Thermal
VOID_REGION 101 PRESSURE  1.013250E+05
VOID_REGION 101 HTC  5.000000E+04
VOID_REGION 101 ROT_FX 1
ROT_FX 1 ROT_FXS NEGLECT_ROT
ROT_FX 1 SWIRL DEL_TEMP
ROT_FX 1 SWIRL_DEL_TEMP  0.000000E+00
$ Void Region2
NAME2 Therma_ Thermal Void(2)
NAME Therma_       1201       1600          1
VOID_REGION 202 SELECTION Therma_
VOID_REGION 202 PRESSURE  1.013250E+05
VOID_REGION 202 HTC  1.000000E+05
VOID_REGION 202 ROT_FX 2
ROT_FX 2 ROT_FXS NEGLECT_ROT
ROT_FX 2 SWIRL DEL_TEMP
ROT_FX 2 SWIRL_DEL_TEMP  0.000000E+00
```

Card 9 - WDINIT Initial Water Mass Accumulation per Unit Area – Optional

`KODE, N1, T1, T2, T3`

`KODE` = `WDINIT` (or `61`) defines initial water mass accumulation per unit area. There are two input options:

Option 1

`N1` is an element number or a group name for the elements whose initial water mass accumulation is specified.

`T1` is another element number or 0. `T1` must be 0 if `N1` is a group name.

`T2` may be:

- A constant initial water mass accumulation per unit area, on the front side of elements `N1` through `T1`.
- Of the format `Tn`, where n is a table number `.`

`T3` may be:

- A constant initial water mass accumulation per unit area, on the reverse side of elements `N1` through `T1`.
- Of the format `Tn`, where n is a table number `.`

Option 2

`N1` is the code FILE.

`T1` is a file name from which the initial water mass accumulation is read. The file must have file WATERDENSF format.

`T2-T3` are ignored.

Example

```
$Spatially varying:
WDINIT  GroupName  0  T26  T27
```

```
TABTYPE  26  VALUE  Label
TABTYPE  27  VALUE  Label
```

Card 9 - XCAP Capacitances - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `XCAP` (or `2`)

`N1` is an element number, or a group name.

`T1` is an element number or 0. `T1 = 0` defaults to `T1 = N1`. If `N1` is a group name, `T1` must be 0.

`T2` is the capacitance value of the elements `N1` through `T1` or of group `N1`.

`T3` may be:

= `AREA` (or `1.E36`) in which case the capacitance generated will be equal to `T2*area` of element, or

= `LENGTH` (or `4.E36`) in which case the capacitance generated will be equal to `T2*length` of beam element, or

= `VOLUME` (or `3.E36)`, in which case the capacitance generated will be equal to `T2*volume` of element, or is blank.

Notes

This Card specifies capacitances for elements `N1` through `T1`. Alternatively, capacitances may be calculated from geometry by specifying non-zero specific heats and densities on MAT Cards for Card 5a elements. Capacitances calculated from geometry are summed with those specified on XCAP Cards by the MEREL module.

Example

```
XCAP 3 5 3
$ ELEMENTS 3,4, AND 5 HAVE CAPACITANCES OF 3.0
```

Card 9 - XCIRC Circular Element Definition Card - Optional

`KODE, N1, T1, T2, T3`

`KODE` = `XCIRC` (or `17`)

`N1` is an element number, or a group name.

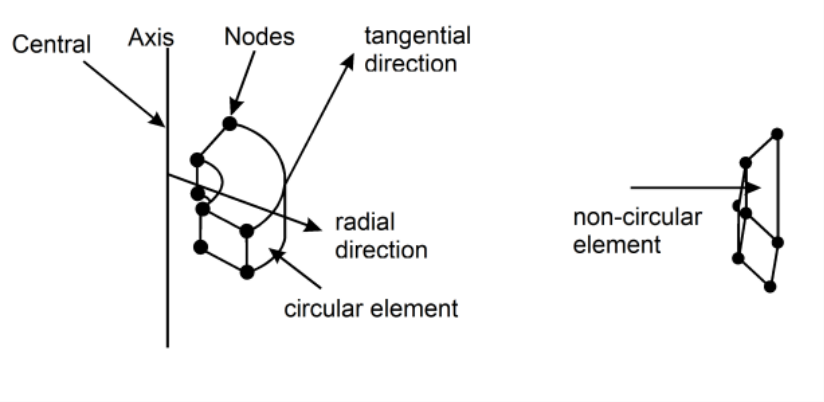
`T1` is another element number, or 0 if N1 is a group name.

`T2` is a node number.

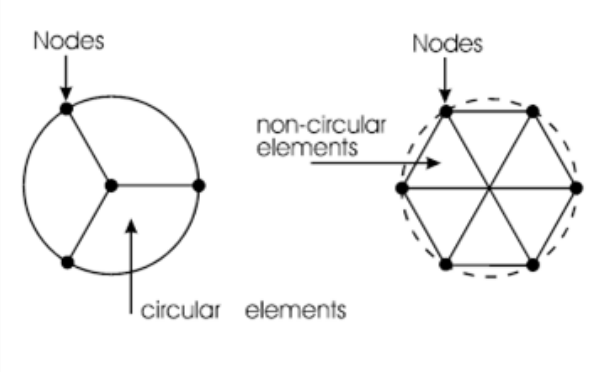
`T3` is another node number.

Notes

This Card defines Card 5 elements `N1` through `T1` to be circular elements whose central axis runs through nodes `T2` and `T3`.



- Conductive conductances for circular elements are calculated assuming temperature gradients are logarithmic in the radial direction and linear in the tangential direction. As a special case, if a node of a circular element falls on the central axis the radial temperature gradient in the element is assumed to be linear in order to avoid a singularity.
- You can use circular elements to efficiently model circular geometries such as thick-walled pipes. For example, to accurately describe the surface of a cylinder of unit radius with non-circular elements, you need at least 8 tangential elements. With circular elements you can accurately model the cylinder with as few as 3 tangential elements.
- Lump mass and beam elements are not considered to be circular elements.



- For view factor calculations performed by the VUFAC module, each circular element is subdivided into a number of flat elements such that the angle subtended by an edge of a flat element does not exceed 45 degrees. If, however, an edge of a circular element exceeds 135 degrees that edge is subdivided into three equiangular line segments. View factors thermal couplings are calculated for these flat elements separately, and are then summed to yield the view factor and thermal coupling of the circular element.
- It is important to remember that view factor calculations assume uniform illumination over the element. If the circular element subtends too large an angle, this condition may not be fulfilled, and inaccurate results are obtained.
- Circular elements may **not** be defined as orthotropic elements.
- It is highly recommended that circular elements have shapes that have edges along the radial and tangential directions.

- Circular elements may not be specified with XCIRC Cards for an axisymmetric model.

Card 9 - XCOND Conductances - Optional

`KODE, N1, T1, T2, T3, T4, T5, T6`

`KODE` = `XCOND` (or `3`)

`N1` is an element number, or a group name. If `N1` is a group name, a conductance of value `T2` is generated between all the elements of the `N1` and the element(s) of `T1`.

`T1` is another element number, or a group name. If `T1` is a group name, a conductance of value `T2` is generated between the element(s) of the `N1` and the elements of `T1`.

`T2` is the value of the conductance between elements `N1` and `T1`.

`T3` is a code or a conductance number, or a table number.

`1WAYC` (or `2)` creates a one-way conductive conductance between elements `N1` and `T1`. `N1` will be affected by `T1`, but `T1` will not be affected by `N1`.

- You can model fluid flow with one-way conductive conductances, where `N1` is the downstream element, `T1` is the upstream element, and `T2` is the mass rate of flow times the fluid's specific heat (e. g. `Btu/sec/F)` flowing into element `N1` from `T1`.
- If a chain of 1-WAYC conductances is present, they should all be of the same magnitude, and start and end in a SINK element. If this rule is not followed, an energy imbalance will be shown in the verbose log file.

`1WAYR` (or `3`) creates a one-way radiative conductance of value `T2 = (area* emissivity * gray body view factor)` between elements `N1` and `T1`. `N1` will be affected by `T1`, but `T1` will not be affected by `N1`.

`CNVSN` (or `8`) adds a linear conductance between elements `N1` and `T1`.

- The value of this conductance at run time is `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the element `N1` and this sink element.

`CNVASN` (or `9`) adds a linear conductance between elements `N1` and `T1`.

- The value of this conductance at run time is area (`N1`) times `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the element `N1` and this sink element.

`CNVSNR` (or `10`) adds a linear conductance between the reverse side of element `N1` and element `T1`.

- The value of this conductance at run time is `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the reverse side of element `N1` and this sink element.

`CNVASNR` (or `11`) adds a linear conductance between the reverse side of element `N1` and element `T1`.

- The value of this conductance at run time is area (`N1`) times `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the reverse side of element `N1` and this sink element.

`COND` (or `0`) creates a linear conductive conductance of value `T2` between elements `N1` and `T1`.

`CSERIES` (or `5`) adds a conductive conductance of value `T2` in series with the linear conductances between elements `N1` and `T1`, to reduce their value. This option can model contact conductances.

`FOLLOWER` (or `4`) automatically makes `T1` into a sink element with the temperature of `N1`. `T1` should not be defined with a SINK Card.

- `T2` is ignored.

`FREE` (or `7`) creates a free convection conductance between elements `N1` and `T1`. The heat flow through it is calculated with:

$$Q_{N1T1} = T2(TN1 - TT1)(TN1 - TT1)^{T4}$$

where:

- $TN1$ is the temperature of element `N1`
- $TT1$ is the temperature of element `T1`
- Q_{N1T1} is the heat flow through the conductance by the Analyzer module.
- $T4$ = blank defaults to T4 = 0.25.

`RAD` (or `1`) creates a radiative conductance with `T2 = (area * emissivity * gray body view factor)` between elements `N1` and `T1`.

`RADSN2` (or `13`) adds a radiative conductance between elements `N1` and `T1`.

- The value of this conductance at run time is area (`N1`) times emissivity(`N1`) times `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the element `N1` and this sink element.
- RADSN3 (or 12) adds a radiative conductance between elements `N1` and `T1`.
- The value of this conductance at run time is area (`N1`) times `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the element `N1` and this sink element.

`RADSNR2` (or `15`) adds a radiative conductance between the reverse side of element `N1` and element `T1`.

- The value of this conductance at run time is = $(\text{area(N1)}) * (\text{emissivity of reverse side of N1}) * (\text{T2}) * (\text{the value interpolated from table T4})$.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.

- The conductance is then created not between `N1` and `T1`, but between the reverse side of element `N1` and this sink element.

`RADSNR3` (or `14`) adds a radiative conductance between the reverse side of element `N1` and element `T1`.

- The value of this conductance at run time is area (`N1`) times `T2` times the value interpolated from table `T4`.
- If `T5` is neither zero nor blank, then it is interpreted to be the ID of a temperature vs time table.
- This table defines the temperature history of a sink element whose element number is defined at run-time.
- The conductance is then created not between `N1` and `T1`, but between the reverse side of element `N1` and this sink element.

`RSERIES` (or `6`) adds a radiative conductance of $\mathrm{T2} = (\text{area} * \text{emissivity} * \text{gray body view factor})$ in series with the radiative conductances between elements `N1` and `T1`.

`T3 > 15` a conductive conductance of value `T2` is created between elements `N1` and `T1` with the conductance number `T3`.

`T3 < -15` a radiative conductance with `(area * emissivity * gray body view factor) value = T2` is created between elements `N1` and `T1` with the conductance number abs (`T3`).

- The `T3 > 15` and `T3 < 15` options pre-assign conductance numbers which are otherwise automatically assigned, so the conductances are referenced by user-written subroutines or INTERP Cards.

`T4` is an exponent associated with a free convection conductance, or blank, or a table number associated with CNV-type conductances.

`T5` is a table number associated with CNV-type conductances.

`T6` is the number of DESCRIP Card associated with the XCOND Card (optional).

Example

```
XCOND 3 4 2 COND
$ CONDUCTIVE CONDUCTANCE OF VALUE 2.0 BETWEEN 3 AND 4
$
```

```
XCOND 5 6 7 RAD
$ RADIATIVE CONDUNCTANCE OF VALUE 7 BETWEEN 5 AND 6
$
XCOND 8 9 0 FOLLOWER
$ ELEMENT 9 FOLLOWS THE TEMPERATURE OF ELEMENT 8
$
XCOND 1 2 .5 FREE .33
$ FREE CONVECTION CONDUNCTANCE BETWEEN 1 AND 2
```

Card 9 - ZONE_CONVECTION Thermal Convecting Zone Definition - Optional

`KODE, N1, T1, T2, T3`

`KODE = ZONE_CONVECTION` (or `92`) defines a boundary condition that creates a convection coupling between a group of selected elements and a fluid environment.

`N1` is the ZONE_CONVECTION card ID. Cards with the same ID reference the same Thermal Convection Zone.

`T1` may be:

= `FACTOR` (`or` `11`)

= `HTC` (or `5`)

= `HTFL` (or `8`)

= `MAT` (or `2`)

= `MAT_LIST` (or `7`)

= `NAME` (or 6)

= `PRESSURE` (or `3`)

= `ROT_FX` (or `6`)

= `SELECTION` (or `1`)

= `TEMPERATURE` (or `4`)

= `THICK (or 10)`

= `OVERRIDE` (or 12)

`= ADIABATIC_WALL_TEMP_FOR_HTC (or 14)`

`= WALL_TEMP (or 16)`

`= RECOVERY_FACTOR (or 15)`

`T1` = `HTC`: A heat transfer coefficient for the convection between the selected elements and the fluid environment is specified.

- If the heat transfer coefficient is constant, then its value is specified in `T2`.
- If the heat transfer coefficient is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing the TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `COND`.
- If the heat transfer coefficient is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1` = `HTFL`: A heat flux is specified for the thermal convection zone.

- If the heat flux is constant, then its value is specified in `T2`.
- If the heat flux is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing the TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `HTFL`.
- If the heat flux is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1` = `MAT`: The material ID of the primary fluid environment is specified in `T2`.

`T1` = `MAT_LIST` : Additional fluid materials are defined. The ID of MATLIST card, which lists these additional fluid materials, is specified in `T2` . `T1` = `NAME` : The solution step user-defined name is specified in `T2` .

`T1` = `NAME` : The load name is specified in `T2` .

`T1` = `PRESSURE` : A pressure is specified for the thermal convecting zone.

- If the pressure is constant, then its value is specified in `T2` .
- If the pressure is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `PTOTAL` .
- If the pressure is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1` = `ROT_FX` : The thermal convecting zone temperatures are corrected for rotational effects. The ID of the referenced ROT_FX cards is specified in `T2` .

`T1` = `SELECTION` : The thermal convecting zone is applied to a selection of elements that are represented by the group name `T2` .

`T1` = `TEMPERATURE:` A temperature is specified for the fluid environment.

- If the temperature is constant, then its value is specified in `T2` .
- If the temperature is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where `n` is a table number referencing the TABTYPE or FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `TEMP` .
- If the temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where `n` is an expression number referencing the EXPRESSION card.

`T1 = THICK` : The area for internal edges is specified. This input is used to compute the convective area when the Thermal Convecting Zone is applied to internal edges.

- If thicknesses are subtracted, then `T2 = SUB.`
- If thicknesses are added, then `T2 = ADD.`

`T1 = FACTOR` : An area correction factor is specified. This input corrects the convective area.

- If the area correction factor is constant, then its value is specified in `T2` .

- If the area correction factor is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE and FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `NUMBER.`
- If the area correction factor is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing the EXPRESSION card.

`T1 = OVERRIDE` : An area override is specified. This input overrides the convective area.

- If the area override is constant, then its value is specified in `T2` .
- If the area override is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing the TABTYPE and FIELDTYPE cards.
- The dependent variable on the TABTYPE card must be `NUMBER.`
- If the area override is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25)` where n is an expression number referencing the EXPRESSION card.

`T1 = ADIABATIC_WALL_TEMP_FOR_HTC(or ?)` specifies how an adiabatic wall temperature for heat transfer calculations is defined in T2.

- `T2` may be either `TEMPERATURE` (specified value for an adiabatic wall temperature), or `AUTOMATIC` (an adiabatic wall temperature value is computed by the thermal solver).
- If `T2 = AUTOMATIC,` the thermal solver computes the adiabatic wall temperature and use it in heat transfer calculations as follows:

$$T_{aw} = T_s + RF\frac{v_{rel}^2}{2C_p}$$

where:

- T_s is the static temperature.
- $RF = Pr_{film}^{1/2}$ is the recovery factor that is computed by the thermal solver, or can be specified in `RECOVERY_FACTOR` .
- Pr is the Prandl number calculated at $T_{film} = \frac{1}{2}(T_\omega - T_f)$.
- $v_{rel} = abs(u - v_\phi)$ is the relative tangential velocity, where u is a wall velocity and v_ϕ is a swirl velocity.
- C_p is the specific heat at the fluid temperature T_{film} .

`T1 = WALL_TEMP` specifies a value for an adiabatic wall temperature in `T2.`

- If the adiabatic wall temperature is constant, then its value is specified in `T2` .

- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `NUMBER`.
- If the adiabatic wall temperature is calculated using an expression, then `T2` is an expression multiplier and `T3` h as the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

`T1 = RECOVERY_FACTOR` specifies a value for the recovery factor, which is used to compute the adiabatic wall temperature, in T2.

- If the recovery factor is constant, then its value is specified in `T2`.
- If it is table dependent, then `T2` is a table multiplier and `T3` has the form `Tn` (e.g. `T25`) where n is a table number referencing TABTYPE or FIELDTYPE cards. The dependent variable on the TABTYPE card must be `NUMBER`.
- If the recovery factor is calculated using an expression, then `T2` is an expression multiplier and `T3` has the form `En` (e.g. `E25`) where n is an expression number referencing EXPRESSION card.

Example

```
$ Thermal Convecting Zone(1)
NAME2 Thermal Thermal Convecting Zone(1)
NAME Thermal 328 345 1
ZONE_CONVECTION 1 SELECTION "Thermal Convecting Zone(1)"
ZONE_CONVECTION 1 MAT 2
ZONE_CONVECTION 1 PRESSURE 2.000000E+03
ZONE_CONVECTION 1 TEMPERATURE 1.0 T16
ZONE_CONVECTION 1 HTC 1.0 T8
ZONE_CONVECTION 1 HTFL 1.0 T8
ZONE_CONVECTION 1 ROT_FX 1
```

Card 10 - user written subroutines

Card 10 includes the following user written subroutines:

USER1 that can access thermal model parameters in the TMG solver. `USER1` is an optional FORTRAN 77 user-written subroutine that is automatically compiled and loaded with the Analyzer at run time. The USER1 routines and functions can query and modify the thermal model during the solve.

USERF is a user defined table substitution option for table interpolation within TMG.

For a complete description, see the *Thermal Solver API Manual.*

Section 2: Files

Using CAE software and the input cards described in this guide certain files are created during a TMG run. The main input file to TMG is INPF. Results are written to VUFF, MODLF, FMODLF, `tmgrslt.dat`, `tmggeom.dat`, and the report and verbose log files.

For a file to be executed, it must be present at the start of the run. For restart runs, file tmggeom.dat needs to be present. See description of Card 2a – Program Control Card – Required. Scratch files used by TMG have the prefix `scx`, `SCX` or `SC`, such as `SCX01`, `SCX09`, etc. and are deleted after the run.

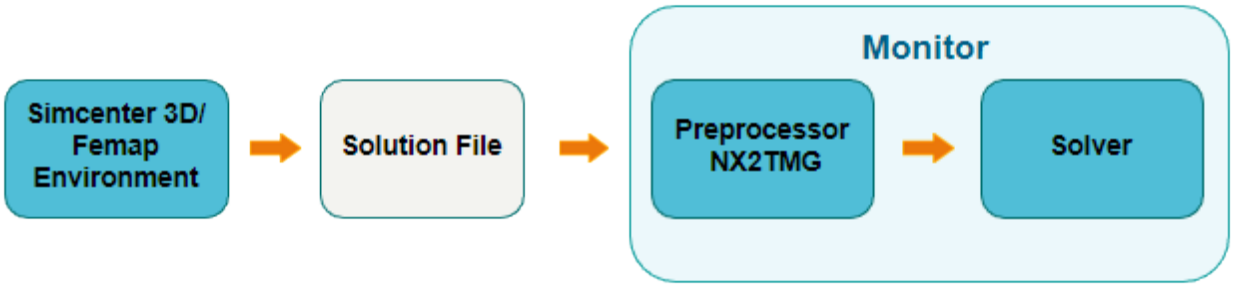
The thermal model is built using the supported CAE software. The results are solved and displayed within the software using the built-in pre and post-processing functionality. This section describes the data exchange files that are generated during this type of solve.

Thermal-flow data exchange files

Solution file

<simulation/model name>-<solution/analysis name>.xml

The file contains the model and solution definition. The model definition includes meshes, elements, and model properties. The solution definition includes the boundary conditions and solution settings.

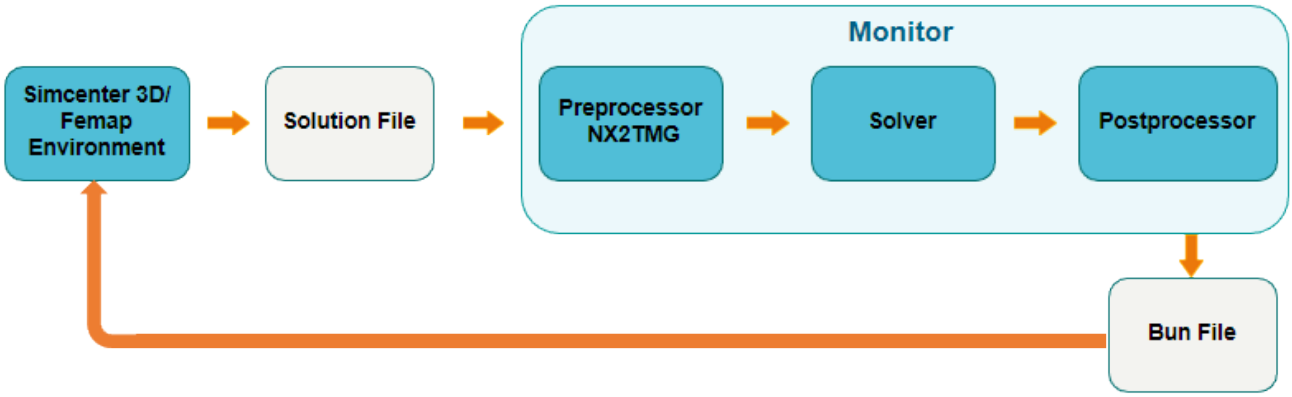


The CAE software launches the Monitor, where the file data is processed and prepared in a format (INPF file) that the thermal solver require to perform the solve.

Bun file

<simulation/model name>-<solution/analysis name>.bun

A post-processing file that contains the solver results, which is translated to binary. This file is used by the software to generate a post-processing interpretation of the solution, such as contours and graphs.

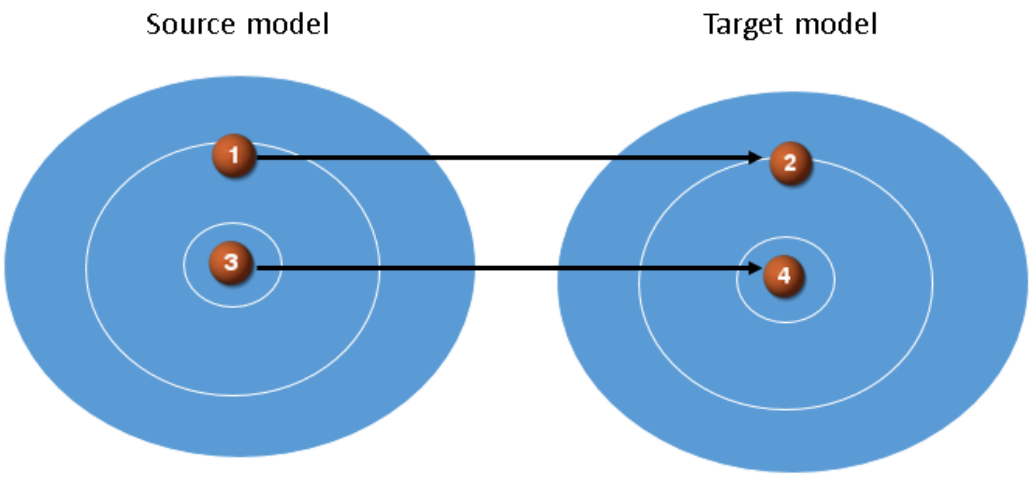


In the Monitor, after the thermal solver performs the analysis, the solver sends the file to a post-processor that converts the information to a bun file. You can import and load the file in your CAE software to review the derived results for post-processing.

Mapping file

<simulation name>-<solution name>.map

A mapping file is used by the solution file to retrieve the regions where mapping is defined in the source and target models. It also includes information about the mapping zones defined for the source and target model, such as thermal, transverse gradient, and axisymmetry mapping zones.



(1) is the mesh flow association region.

(2) is the mesh target region.

(3) is the source mesh flow mapping zone.

(4) is the target mesh flow mapping zone.

Log files

<simulation/model name>-<solution/analysis name>.log

A log file that contains information, such as warnings and error messages, and iterative convergence data generated by the Solution Monitor during an analysis.

<simulation/model name>-<solution/analysis name>_report.log

A log file that contains calculation details. This file is always appended to the solution. This file replaces the old REPF file.

<simulation/model name>-<solution/analysis name>_verbose.log

A log file that contains messages regarding thermal solver routines, including their timing and memory statistics and verbose messages. This file replaces the old MSFG file.

The thermal solver has the capability of displaying different levels of messaging in the log files,

- Level 1 only displays fatal errors.
- Level 2 displays fatal errors and warning messages.
- Level 3 displays fatal errors, warnings, and information messages. This is the default.

When you include the LEVEL OF VERBOSENESS OF MESSAGING OUTPUT advanced parameter into your solution, you can display:

- Level 4 displays fatal errors, warnings, information messages, and key information from different thermal solver routines including convergence traces. The level 4 information is written to the verbose log file.
- Level 5 displays level 4 information and MPI secondary ranks. It also resolves messages by boundary conditions. All extra information from level 5 is written only to the verbose log file.

For levels 4 and 5, you can also request the timing and memory information in thermal solver modules that support it when you include the INCLUDE TIMING INFO IN VERBOSE OUTPUT and INCLUDE MEMORY INFO IN VERBOSE OUTPUT advanced parameters, respectively.

Error file

<simulation name>-<solution name>.err

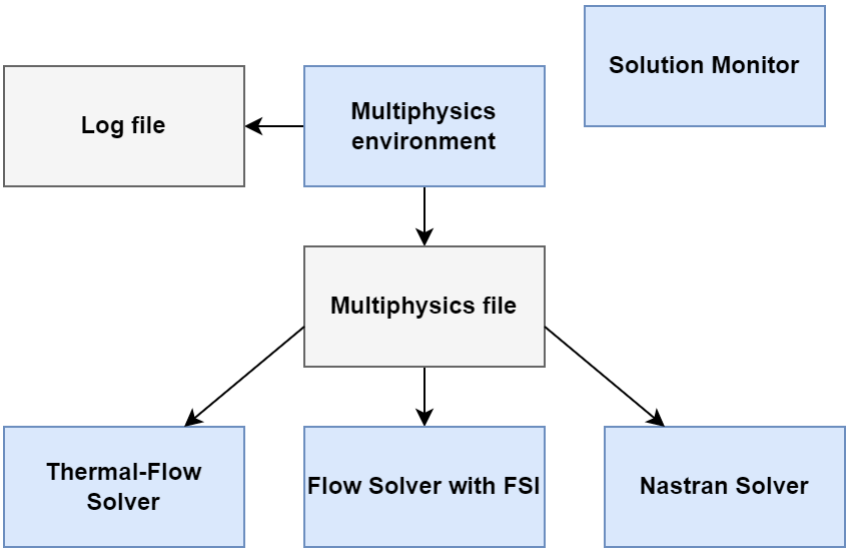
An error file that identifies the error number for a solve, if applicable. An error number that is different from 0 indicates that that the solve completed with a fatal error.

This file only identifies the error number. You can retrieve the full error message from the log file.

Multiphysics files

<simulation name>-<solution name>.mpdat

<simulation name>-<solution name>.mplg



Simcenter 3D generates a multiphysics data input file (*<simulation name>-<solution name>.mpdat*) when two or more solvers are selected for an analysis in the Simcenter 3D Multiphysics solver environment. The thermal and flow solvers can be combined with structural solvers for a full multiphysics or fluid-structure interaction (FSI) analysis. For available solvers, see the Simcenter 3D help.

The multiphysics data input file generated for a coupled solution includes a section for the Multiphysics environment, and for each solver used. In the Multiphysics environment section, parameters are defined that the Multiphysics environment uses to manage convergence between the solvers. The solver-specific sections specify the solver name, the solution type, the name and location of the solution files, and solvers' internal parameters.

The Multiphysics environment generates a log file (*<simulation name>-<solution name>.mplg*) that includes warnings and error messages, and information on the sequential or iterative convergence.

Co-simulation files

<Simulation file name>-<Solution name>.json

The file contains the mapping information of the exchanged variables between the thermal and the external solvers.

<Simulation file name>-<Solution name>_<External solver>_Co-simulation.log

A log file that contains the co-simulation information, such as warnings and error messages, the external solver file location, the exchanged variables and the time steps at which the solvers exchange data.

TMG FLOWCHART

INPUT	EXECUTABLE	OUTPUT
`INPF`	MAIN Data checking, determines modules to be run.	`<simulation/model name>-<solution/analysis name>_verbose.log`

`INPF`	DATACH
	Data checking, orbit creation.
		`<simulation/model name>-<solution/analysis name>_verbose.log`
		
		`<simulation/model name>-<solution/analysis name>_report.log`
		
		`tmggeom.dat`

`INPF`
 	
`tmggeom.dat`
	ECHOS
	Geometry parameter calculations.
		`VUFF`
		`tmggeom.dat`

INPUT	EXECUTABLE	OUTPUT
`INPF` `tmggeom.dat`	COND Calculates capacitances, hydraulic resistances, and conductive conductances from geometry (optional).	`MODLF` `tmggeom.dat`

`INPF`
`tmggeom.dat`
	VUFAC
	Calculates view factors, solar view factors, albedo factors, Earth view factors, heat flux view factors, thermal couplings from geometry (optional).
		`MODLF`
		`VUFF`
		`<simulation/model name>-<solution/analysis name>_verbose.log`
		`<simulation/model name>-<solution/analysis name>_report.log`

`INPF`
`VUFF`
`tmggeom.dat`
	GRAYB
	Calculates radiative conductances, gray body view factor matrices from view factors (optional).
		`VUFF`
		`MODLF`
		`tmggeom.dat`

`VUFF`
`INPF`
`tmggeom.dat`
	POWER
	Calculates IR and solar spectrum heat loads from view factors and gray body view factor matrices (optional)
		`VUFF`
		`MODLF`

INPUT	EXECUTABLE	OUTPUT

`INPF`
`MODLF`
`tmggeom.dat`
	MEREL
	Model simplification, merging, substructuring, combines parameters calculated from geometry and defined on Card 9.
		`<simulation/model name>-<solution/analysis name>_report.log`
		`MODLCF`
		`tmggeom.dat`

`USER1`
`MODLCF`
`tmggeom.dat`
	ANALYZER
	Calculates temperatures and total pressures.
		`<simulation/model name>-<solution/analysis name>_report.log`
		`TEMPF`
		`PRESSF`
		`tmggeom.dat`

`INPF` `MODLCF`	REFORM Creates SINDA and TRASYS format models.	`FMODLF`
`tmgrslt.dat` `tmggeom.dat`	RSLTPOST Transforms results into I-deas Universal file format.	`UNIVERSAL FILES`

esatan.dat

`esatan.dat` is an ESATAN output format file created if Card 9 PARAM ESATAN is specified.

FMODLF

`FMODLF` contains a thermal model in `TRASYS`, or `SINDA` formats, or element or node temperatures in NASTRAN format. `FMODLF` is created if a Card 9 PARAMSINDA or PRAM TRASYS Card is present.

The REFORM module writes in `FMODLF`. `FMODLF` is always appended to.

GTEMPF

`GTEMPF` is an output file that contains node temperatures. Its format is identical to that of file `TEMPF`, except that the temperatures are node temperatures.

`GTEMPF` is created from file TEMPF and the model's geometry by the TMGINT FE to FD interpolator module.

INPF

`INPF` is the primary input file used by the DATACH module.

No input line may exceed 90 columns.

All data in `INPF` is in free format, except for the optional `NASTRAN` format section in Card 4.

MODLCF

`MODLCF` is a condensed version of file `MODLF` after addition of the Card 9 model parameters, element merging, substructuring, and combining of heat loads, capacitances, and conductances. The format of `MODLCF` is identical to that of `MODLF`, with the following exceptions:

1. For capacitances `VAL1` = capacitance value, `VAL2` always `= 1`.
2. `MODLCF` contains the additional capacitances, conductances, element sink temperatures, and heat loads specified on Card 9 XCOND, XCAP, SINK, and QNODE Cards. The Card 9 XCOND `1WAYC` conductance is written with the mnemonic `1WC`, and the `1WAYR` conductance is written with the mnemonic `1WR`.
3. There is only a single RDF Card present at the beginning of the file.
4. A series of time Cards with `MNM = TIM`, `VAL1` = time value are written at the end of the file. These contain the time values specified on Card 9 QNODE Cards and Card 6e radiation heat load requests.

5. All elements in the model are assigned a capacitance value with a `MNM = CAP` Card, which may be zero.
6. For merged elements follower conductances `MNM = FOL` are created, unless the Card 9 PARAMNOMRECOV option is specified.
7. Elements that have been eliminated with Card 8 and Card 9 PARAMSUBSTR substructuring and whose temperatures are to be calculated by the recovery process are set to be constant temperature `MNM = SNK` sink elements with a temperature of `-1.E30`.

Sink Element Temperatures

`MNM` = `SNK`

`I` = element

`J` = blank

`VAL1` = temperature of the sink element

`VAL2` = time when temperature occurs

Follower Conductances

`MNM` = `FOL`

`I` = element whose temperature is to be followed

`J` = element whose temperature follows that of element `I`

`VAL1` = `1.E-36`

MODLF

`MODLF` contains all the thermal couplings, radiative, conductive, hydraulic, and convective conductances, element capacitances, and heat loads calculated from elemental geometry and material and physical properties by the COND, GRAYB, VUFAC, and POWER modules.

`MODLF` is always appended to.

`MODLF` is by default in binary format, however, it can be translated into ASCII format using the `AS` option in the TMG Executive Menu (type `tmg as`). Both binary and ASCII formats are equally acceptable to TMG; however, the binary is preferred, because there is no loss in precision. If `MODLF` is in ASCII format, its data can be read with the format (`A3,2I6,9E11.4`).

Before each run, a run definition Card containing the run title and date is written in the format (' `RDF` ', `A80`).

`MNM` , `I` , `J` , `VAL1` , `VAL2` , `VAL3` , `VAL4` , `VAL5` , `VAL6` , `VAL7` , `VAL8` , `VAL9`

Heat Load Cards - created by the POWER and/or VUFAC modules

`MNM` = `HTF`

`I` = element receiving heat load if `I < 1E6`

- = blank if element receiving heat load is > `1E6`

`J` = blank

`VAL1` = heat load value

`VAL2` = time at which heat load occurs

`VAL3` = blank if `I < 1E6`

- = element receiving heat load if `I > 1E6`

DTM Cards extend the precision of time. When DTM cards are present, the time values referenced in other MODLF cards are replaced with real value IDs, where the corresponding actual double precision time is given by the sum of the last two fields in the DTM cards.

`MNM` = `DTM`

`I` = blank

`J` = blank

`VAL1` = real-valued ID of the time point

`VAL2` = first term of the corresponding actual time value

`VAL` = second (correction) term of the actual time value

Linear Thermal Couplings created by Card 6e COND, CONV, CONVASN, CONVLP, CONVSN, RESISTANCE, XCOND, NEAR, NEARA, NEARLP, NEARM, NEARP, NEARRES, NEARTOT and Card 9 TSTREAM, VOID_REGION, ZONE_CONVECTION options.

`MNM = CNF`

`I` = element from, must be non-hydraulic element if `I < 1E6` and `J < 1E6`

- = blank if `I` > `1E6` or `J` > `1E6`

`J` = element to if `I < 1E6` and `J < 1E6`

- = blank if `I` > 1E6 or `J > 1E6`

`VAL1` = Conductance value

- If `VAL1 = 1.234E+35,` then element `J` is merged into element `I`, and the coupling was created with the Card 6e NEARM option.

`VAL2` = hydraulic diameter of `I`

`VAL3` = `3999+10,000*IDESCRIP` where `IDESCRIP` is the descriptor ID associated with the thermal coupling specified on Card 6e N2D field, except these below:

- If `VAL3` = `13`, then the coupling was created with the Card 6e NEARM option.
- If `VAL3` = `3961`, then the coupling was created with the Card 9 TSTREAM option.
- If `VAL3` = `3962`, then the coupling was created with the Card 9 VOID_REGION option.
- If `VAL3` = `3963`, then the coupling was created with the Card 9 ZONE_CONVECTION option.

`VAL4` = area of element `I`

`VAL5` = the table number of the conductance multiplier table

`VAL6` = Area of element `I` that overlaps element `J`

`VAL7` = is a combined number, `VAL7=JJ+ITSTEP*100`

- `ITSTEP` is the articulation time step number, if it is an articulating thermal coupling. `ITSTEP=0` for non-articulating thermal couplings.
- `JJ` is code equal to `0`, `1`, `10`, or `11`. If `JJ`:
- = `0`, then the `+ve` side of `I` is coupled to the `+ve` side of `J`
- = `1`, then the `-ve` side of `I` is coupled to the `+ve` side of `J`
- = `10`, then the `+ve` side of `I` is coupled to the `-ve` side of `J`
- = `11`, then the `-ve` side of `I` is coupled to the `-ve` side of `J`

`VAL8` = blank if `I < 1E6` and `J < 1E6`

- = element from if `I ≥ 1E6` or `J ≥ 1E6`

`VAL9` = blank if `I < 1E6` and `J < 1E6`

- = element to if `I ≥ 1E6` or `J ≥ 1E6`

Forced convection conductances created by Card 6e FORCEDPASN, FORCEDCASN, and FORCEDSASN options.

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`

- = blank if `I ≥ 1E6` or `J ≥ 1E6`

`J` = element to if `I < 1E6` and `J < 1E6`

- = blank if `I ≥ 1E6` or `J ≥ 1E6`

`VAL1` = Area of elements I times Card 6e HN1 value

`VAL2` = Fluid velocity

`VAL3` = `10,000*IDESCRIP + code`, where `IDESCRIP` is the descriptor ID associated with the thermal coupling specified on Card 6e N2D field, and code defines the type of conductance and the relative vertical relationships of elements `I` and `J`. `code` may be:

- = `3836` for the FORCEDPASN option, if the element convects from the top surface
- = `3837` for the FORCEDCASN option
- = `3838` for the FORCEDSASN option

`VAL4` = characteristic length for the FORCEDPASN option

- = diameter FORCEDCASN and FORCEDSASN options

`VAL5` = `0`

`VAL6` = Material ID of fluid

`VAL7` = `0` as a rule

- = `1` for the BOTTOM option of the FORCEDPASN option

`VAL8` = blank if `I < 1E6` and `J < 1E6`

- = element from if `I ≥ 1E6` or `J ≥ 1E6`

`VAL9` = blank if `I < 1E6` and `J < 1E6`

- = element to if `I ≥ 1E6` or `J ≥ 1E6`

Forced Convection Conductances created by Card 6e NEARC1, NEARC4, NEARC12 options.

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`, must be non-hydraulic element.

= blank if `I ≥ 1E6` or `J ≥ 1E6`

`J` = element to if `I < 1E6` and `J < 1E6`

= blank if `I ≥ 1E6` or `J ≥ 1E6`

`VAL1` = Overlapping area of elements `I` and `J` times Card 6e HN1 value

`VAL2` = hydraulic diameter of `I`

`VAL3` = conductance type code + `10,000*IDESCRIP` where `IDESCRIP` is the descriptor ID associated with the thermal coupling specified on Card 6e N2D field. The conductance type code may be:

- = `3000 NEARC1 DUCT` flow.
- = `3001 NEARC1 DUCT` flow for beam element.
- = `3002 NEARC1 DUCT` flow for lump mass element.
- = `3003 NEARC4` Flat plate in free stream.
- = `3012 NEARC12 DUCT` flow with entrance effects.

`VAL4` = area of element `I`

`VAL5` = the table number of the conductance multiplier table.

`VAL6` = Area of element I that overlaps element `J`

`VAL7` = is code equal to `0,1,10,` or `11`. If `VAL7`:

- = `0`, then the `+ve` side of `I` is coupled to the `+ve` side of `J`.
- = `1`, then the `-ve` side of `I` is coupled to the `+ve` side of `J`.
- = `10`, then the `+ve` side of `I` is coupled to the `-ve` side of `J`.
- = `11`, then the `-ve` side of `I` is coupled to the `-ve` side of `J`.

`VAL8` = blank if `I < 1E6` and `J < 1E6`

- = element from if `I ≥ 1E6` or `J ≥ 1E6`

`VAL9` = blank if `I < 1E6` and `J < 1E6`

- = element to if `I ≥ 1E6` or `J ≥ 1E6`

Free convection conductances created by Card 6e FREECONVASN, PLATEASN, PLATEHASN, SPHEREASN, CYLINDASN options.

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = `(Area of element I)*(Card 6e HN1 value)`.

`VAL2` = Angle of tilt in degrees between the vertical plane and the plane of the characteristic element for the PLATEASN and CYLINDASN options.

- = `0` for FREECONVASN, PLATEHASN, and SPHEREASN options.

`VAL3` = `10,000*IDESCRIP` + `code`, where `IDESCRIP` is the descriptor ID associated with the thermal coupling specified on Card 6e N2D field, and code defines the type of conductance and the relative vertical relationships of elements `I` and `J`. Code is:

- = `3831` for the PLATEASN and PLATEHASN options
- = `3833` for the SPHEREASN option
- = `3835` for the CYLINDASN option

`VAL4` = characteristic length for the PLATEASN, PLATEHASN options

- = diameter for SPHEREASN and CYLINDASN options

`VAL5` = `0`

- = `0` for SPHEREASN, CYLINDASN options

`VAL6` = Material ID of fluid

`VAL7` = `0` as a rule

- = `1` for the BOTTOM option of the PLATEASN and PLATEHASN options

`VAL8` = blank if `I < 1E6` and `J < 1E6`.

- = element from if I `≥ 1E6` or `J ≥ 1E6`.

`VAL9` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Free Convection Conductances created by Card 6e NEARF and FREE options

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = Overlapping area of elements `I` and `J` times Card 6e HN1 value.

`VAL2` = Free convection exponent.

`VAL3` = `10,000*IDESCRIP` where `IDESCRIP` is the descriptor ID associated with the thermal coupling specified on Card 6e N2D field.

`VAL4` = area of element `I`.

`VAL5` = ignored.

`VAL6` = Area of element `I` that overlaps element `J`.

`VAL7` = is code equal to `0`, `1`, `10`, or `11`. If `VAL7`:

- = `0`, then the `+ve` side of `I` is coupled to the `+ve` side of `J`.
- = `1`, then the `-ve` side of `I` is coupled to the `+ve` side of `J`.
- = `10`, then the `+ve` side of `I` is coupled to the `-ve` side of `J`.
- = `11`, then the `-ve` side of `I` is coupled to the `-ve` side of `J`.

`VAL8` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL9` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Free Convection Conductances created by Card 6e NEARC6, NEARC9, NEARC10, NEARC16, NEARC19, NEARCIN, and NEARCOUT options.

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`, must be non-hydraulic element.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`. Except for `NEARC10`, `J` is a hydraulic element.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = Overlapping area of elements `I` and `J` times Card 6e HN1 value.

`VAL2` = hydraulic diameter.

`VAL3` = Code defining type of conductance, type of characteristic element, angle of tilt, and relative vertical positions of elements `I` and `J`.

- = `3104 NEARC9` Horizontal plate, downward facing. Element `J` is above element `I`.
- = `3105 NEARC10` Vertical recirculating cavity.
- = `3106 NEARC10` Horizontal recirculating cavity. Element `J` is above element `I`.
- = `3109-3199 NEARC6`. Characteristic length is calculated from geometry of characteristic plate element. Element `J` is above element `I`. The angle between the vertical and its projection onto the plate is `VAL3-3109` degrees.
- = `3209-3299 NEARC6`. Characteristic length is calculated from geometry of characteristic beam element. Element `J` is above element `I`. The angle of axis of the beam element from the vertical is `VAL3-3209` degrees.
- = `3304 NEARC9` Horizontal plate, downward facing. Element `I` is above element `J`.
- = `3306 NEARC10` Horizontal recirculating cavity. Element `I` is above element `J`.
- = `3309-3399 NEARC6` Characteristic length is calculated from geometry of characteristic plate element. Element `I` is above element `J`. The angle of between the vertical and its projection onto the plate is `VAL3-3309` degrees.
- = `3409-3499 NEARC6` Characteristic length is calculated from geometry for characteristic beam element. Element `I` is above element `J`. The angle of the beam element from the vertical is `VAL3-3409` degrees.

- = `3509-3599 NEARC16` Characteristic length is calculated from geometry for characteristic plate element. The relative vertical positions of elements `I` and `J` are ignored. The angle between the vertical and its projection onto the plate is `VAL3-3509` degrees.
- = `3609-3699 NEARC16` Characteristic length is calculated from geometry for beam. The relative vertical positions of elements `I` and `J` are ignored. The angle between the vertical and its projection onto the plate is `VAL3-3609` degrees.

`VAL4` = area of element `I`.

`VAL5` = characteristic length.

`VAL6` = Area of element `I` that overlaps element `J`.

`VAL7` = is code equal to `0`, `1`, `10`, or `11`. If `VAL7`:

- = `0`, then the `+ve` side of `I` is coupled to the `+ve` side of `J`.
- = `1`, then the `-ve` side of `I` is coupled to the `+ve` side of `J`.
- = `10`, then the `+ve` side of `I` is coupled to the `-ve` side of `J`.
- = `11`, then the `-ve` side of `I` is coupled to the `-ve` side of `J`.

`VAL8` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL9` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Free Convection Conductances created by Card PLATE, PLATEH, SPHERE, CYLINDER, INCCHNL, CAVITY, CAVITYH, CONCYL, and CONSPH options

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`, must be non-hydraulic element.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`. For PLATE, PLATEH, SPHERE, CYLINDER options element `J` is a hydraulic element.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = Overlapping area of elements `I` and `J` times Card 6e HN1 value.

`VAL2` = Angle of tilt in degrees between the vertical and the plane of the characteristic element for PLATE, CYLINDER, INCCHNL, and CAVITY options.

- = `0` for PLATEH, SPHERE, CAVITYH, CONCYL, CONSPH options.

`VAL3` = `10,000*IDESCRIP` + `code`, where `IDESCRIP` is the descriptor ID associated with the thermal coupling specified on Card 6e N2D field, and code defines the type of conductance and the relative vertical relationships of elements `I` and `J`. Code is:

- = `3821` for the PLATE and PLATEH options, if the element convects from the top surface.
- = `3841` for the PLATE and PLATEH options, if the element convects from the bottom surface.
- = `3803` for the SPHERE option.
- = `3804` for the CYLINDER option.
- = `3805` for the INCCHNL option.
- = `3806` for the CAVITY and CAVITYH options.
- = `3808` for the CONCYL option.
- = `3809` for the CONSPH option.

`VAL4` = characteristic length for the PLATE, PLATEH options.

- = diameter for SPHERE and CYLINDER options.
- = spacing for the CAVITY, CAVITYH, INCCHNL options.
- = smaller diameter for CONCYL and CONSPH options.

`VAL5` = `1` for TOP options of PLATE and PLATEH

- = `2` for BOTTOM options of PLATE and PLATEH
- = `0` for SPHERE, CYLINDER and CAVITYH options
- = larger diameter for CONCYL, CONSPH options
- = length for INCCHNL and CAVITY options

`VAL6` = The material number of the convecting fluid for the PLATE, PLATEH, SPHERE, CYLINDER, INCCHNL CAVITY, CAVITYH, CONCYL, and CONSPH options.

`VAL7` = code equal to `0`, `1`, `10`, or `11`. If `VAL7`:

- = `0`, then the `+ve` side of `I` is coupled to the `+ve` side of `J`.
- = `1`, then the `-ve` side of `I` is coupled to the `+ve` side of `J`.
- = `10`, then the `+ve` side of `I` is coupled to the `-ve` side of `J`.
- = `11`, then the `-ve` side of `I` is coupled to the `-ve` side of `J`.

`VAL8` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL9` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or J `≥ 1E6`.

CFD conductances - created the Card 6e NEARC21-4, NEARC41-4 options

`MNM` = `CNF`

`I` = element from if `I < 1E6` and `J < 1E6`, board or component element.

= blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`, CFD element.

= blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = Overlapping area of element `I` times `HN1` value.

`VAL2` = roughness coefficient.

`VAL3` = code defining the type of conductance

- = `3921` board to fluid conductance is specified with Card 6e NEARC21 option.
- = `3922` board to fluid conductance is specified with Card 6e NEARC22 option.
- = `3923` board to fluid conductance is specified with Card 6e NEARC23 option.
- = `3924` board to fluid conductance is specified with Card 6e NEARC24 option.
- = `3941` board to fluid conductance is specified with Card 6e NEARC41 option.

- = `3942` board to fluid conductance is specified with Card 6e NEARC42 option.
- = `3943` board to fluid conductance is specified with Card 6e NEARC43 option.
- = `3944` board to fluid conductance is specified with Card 6e NEARC44 option.

`VAL4` = code for evaluating the heat transfer coefficient - same as N1D code on Card 6e.

`VAL5` = table number for table multiplier.

`VAL6` = area of element `I` that overlaps element `J`.

`VAL7` = code equal to `0`, `1`, `10`, or `11`. If `VAL7`:

- = `0`, then the `+ve` side of `I` is coupled to the `+ve` side of `J`.
- = `1`, then the `-ve` side of `I` is coupled to the `+ve` side of `J`.
- = `10`, then the `+ve` side of `I` is coupled to the -ve side of `J`.
- = 11, then the `-ve` side of `I` is coupled to the `-ve` side of `Je`

`VAL8` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL9` = blank if `I < 1E6` and `J` < 1E6.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Conductive Conductances created by the COND module

`MNM` = `CON`

`I` = element from if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = conductance value.

`VAL2` = element number from which the conductances were calculated, if element CG method was used.

`VAL3` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL4` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

One-way Conductive Conductances created by the COND module

`MNM` = `CON`

`I` = blank

`J` = blank

`VAL1` = conductance value.

`VAL2` = 0

`VAL3` = downstream element number

`VAL4` = negative of upstream element number

Radiative Conductances created by GRAYB module

`MNM` = `RAD`

`I` = element from if `I < 1E6` and `J < 1E` 6.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = area `*` emissivity of element `I*` gray body view factor between `I` and `J`.

`VAL2` = `1.0`.

`VAL3` = `1.0`.

`VAL4` = `1.0`.

`VAL5` = `-1.E36` if non-articulating radiative couplings. For articulating radiative couplings VAL5 is the TIME value when the coupling occurs.

`VAL6` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL7` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Radiative Thermal Couplings created by VUFAC module

`MNM` = `RAD`

`I` = element from if `I < 1E6` and `J < 1E6`.

= blank if `I` ≥ 1E6 or `J` ≥ 1E6.

`J` = element to if `I < 1E6` and `J < 1E6`.

= blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = area of element `I`.

`VAL2` = emissivity of element `I`.

`VAL3` = `-12300` if the positive side of `I` is coupled to the positive side of `J`.

`VAL3` = `-12301` if the negative side of `I` is coupled to the positive side of `J`.

`VAL3` = `-12310` if the positive side of `I` is coupled to the negative side of `J`.

`VAL3` = `-12311` if the negative side of `I` is coupled to the negative side of `J`.

`VAL4` = gray body view factor.

`VAL5` = `-1.E36`

`VAL6` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL7` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Capacitances created by the COND module.

`MNM` = `CAP`

`I` = element if `I < 1E6`.

- = blank if `I ≥ 1E6`.

`J` = blank

`VAL1` = element area or volume.

`VAL2` = capacitance per unit area or per unit volume.

`VAL3` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

Hydraulic Resistance created by COND module.

`MNM` = `HYD`

`I` = upstream element if `I < 1E6` and `J < 1E6`.

= blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = downstream element if `I < 1E6` and `J < 1E6`.

= blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = flow resistance multiplier divided by length. For FLOWRES elements the length is assumed to be `1`.

`VAL2` = blank if `I < 1E6 and J < 1E6`.

- = element from if `I > 1E6 or J > 1E6`.

`VAL3` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥ 1E6`.

Series Conductances created by the Card 6e INTER Cards.

`MNM` = `COS`

`I` = element from if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`J` = element to if `I < 1E6` and `J < 1E6`.

- = blank if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL1` = conductance value.

`VAL2` = zero or the descriptor ID number of specified on the Card 6e N2D parameter.

`VAL3` = conductance multiplier table number (optional).

`VAL4` = blank if `I < 1E6` and `J < 1E6`.

- = element from if `I ≥ 1E6` or `J ≥ 1E6`.

`VAL5` = blank if `I < 1E6` and `J < 1E6`.

- = element to if `I ≥ 1E6` or `J ≥` 1E6.

nevada.ren

`nevada.ren` contains the NEVADA format output file. It is created by the REFORM module when a Card 9 PARAM NEVADA Card is present.

POWERDENSITY

`POWERDENSITY` contains the power dissipation density of electrical elements (if they exist) in TEMPF format. See Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

POWERDENSITY.unv

`POWERDENSITY.unv` contains the power dissipation density of electrical elements (if they exist) in I-deas Universal file format.

PRESSF

`PRESSF` contains the computed total pressure `PT(I)` and mass flow values `MASSFL(I)` for all the hydraulic elements in the model.

Data is written in format:

```
(I7,2E15.7)
```

and the data fields contain `I`, `PT(I)`, `MASSFL(I)` for element `I`.

- If `I` = - `99999`, then `PT(I)` represents the printout time.
- If a Card 9 PSINK FPRESSF Card is present, all the hydraulic elements are defined to be PSINK elements, with the constant pressures and constant mass flows read from file PRESSF.

QNODEF

`QNODEF` is an output file that contains elemental heat inputs. Its format is identical to that of file `TEMPF`.

`QNODEF` is created by the Analyzer at each printout interval.

sinda85.dat

`sinda85.da` t is a SINDA85 format output file created if Card 9 PARAM SINDA85 is specified.

TEMPF

File `TEMPF` contains the calculated temperatures at the end of a run. The Analyzer writes data on `TEMPF` at the printout intervals defined by the Card 2b DTP parameter. Alternatively, other software may create `TEMPF` . e.g. SINDA, for post-processing by TMG.

`TEMPF` is used for post-processing by the TMGINT, FRONT, and REFORM modules.

Data is written on `TEMPF` in format:

`(I10,1PE23.15)`

If at the start of a run a file `TEMPF` is present, its data is used as the initial temperatures. If Card 9 TINIT Cards are also present, the temperatures of the TINIT Cards override those of file `TEMPF` .

If it is not present, or contains an incomplete set of data, the Analyzer for the undefined elements assumes zero initial temperatures.

`I` , `TEMP(I)`

- `I` is the element number.
- `TEMP(I)` is the temperature of element `I` .
- If `I` is `-99999` , `TEMP(I)` is the printout time value for subsequent temperatures.

tmggeom.dat

`tmggeom.da` t is a binary file that contains information about the geometrical and other parameters of the model.

If restarts are performed `tmggeom.dat` should be present.

tmgrslt.dat

`tmgrslt.dat` is a binary file that contains the computed parameters of the Analyzer and the GRAYB module that can be displayed.

`tmgrslt.dat` is processed by the RSLTPOST module to create the following I-deas Universal files:

- `tmgabsf.unv` absorbed orbital heat fluxes.
- `tmgincf.unv` incident orbital heat fluxes.
- `tmgreff.unv` reflected orbital heat fluxes.
- `tmgtotf.unv` total orbital heat fluxes.
- `tmghtf.unv` elemental heat fluxes.
- `tmghtfn.unv` nodal heat flux.
- `tmgtempe.unv` contains elemental temperatures.
- `tmgtempn.unv` nodal temperatures.
- `tmggrade.unv` elemental temperatures.
- `tmggradn.unv` nodal thermal gradients.
- `tmghbal.unv` elemental heat balance.
- `tmgvele.unv` elemental fluid velocity.
- `tmgveln.unv` nodal fluid velocity.
- `tmgrene.unv` elemental Reynolds Number.
- `tmgrenn.unv` nodal Reynolds Number.
- `tmgprese.unv` elemental total pressures.
- `tmgpresn.unv` nodal total pressures.
- `tmghtc.unv` elemental heat transfer coefficient sum.
- `tmgvfsum.unv` elemental view factor sums.
- `tmgorbvf.unv` elemental albedo & Earth view factors.
- `tmgconn.unv` connectivity matrix.
- `tmgmasseunv` elemental mass flows.
- `tmgmassn.unv` nodal mass flows.

TRACEF

File `TRACEF` contains the results of ray-tracing for specular and transparent surfaces. It is created only if a Card 9 PRINT 0 0 RTRACE Card is present in `INPF`. It is written in format (`I8` , `1P` , `11E16` . `8`). The data format is:

`IEL,VAL1,VAL2,VAL3,VAL4,VAL5,VAL6,VAL7,VAL8`

- `IEL` is the element number that is hit. If `IEL=0` , and `VAL1 = -99990` , then `VAL2` is the time value for the following trace.
- `VAL1` is the strength of the ray in the solar spectrum
- `VAL2` is the strength of the ray in the IR spectrum
- `VAL3` is the optical path length for the ray from its origin.
- `VAL4` is the total distance the ray has traveled.
- `VAL5` is the X-coordinate of the ray where it hits.
- `VAL6` is the Y-coordinate of the ray where it hits.
- `VAL7` is the Z-coordinate of the ray where it hits.
- `VAL8` is the value of the index of refraction of the element it hits.

voltages.unv

`voltages.unv` is a universal file created by the Analyzer whenever electrical elements are present.

VUFF

`VUFF` contains the model geometry elemental properties written by `ECHOS` , the view factors, heat flux view factors, solar view factors, albedo factors, and Earth view factors written by VUFAC, and the IR and solar spectrum gray body view factor matrices written by GRAYB.

VUFF is always appended.

`MNM, I, J, AR, E, TSA, VF, TIME, DD`

`MNM` = the mnemonic code for the Card. All Cards except for `MNM` = `NGR` , `MNM` = `AXM` , and `MNM` = `RDF` can be read with the format (`A3` , `2I6` , `3E11` . `4` , `F11` . `7` , `2E11` . `4`)

= `AXM` for expansion of axisymmetric profile elements written by the DATACH module. `MNM` = `AXM` can be read with the format (`A3` , `10I6`).

= `ALB` for albedo factors written by the VUFAC module.

= `ALR` for albedo factors calculated with ray-tracing written by the VUFAC module.

= `BVF` for view factors written by the VUFAC module.

= `EVF` for Earth view factors written by the VUFAC module.

= `EVM` for Earth view factors modified values when the value of PIRSUBSOLAR > PIR.

= `EVR` for Earth view factors calculated with ray-tracing written by the VUFAC module.

= `GRD` for node coordinates X, Y, Z written by the ECHOS module.

= `HVF` for solar spectrum heat flux view factors written by the VUFAC module.

= `HVI` for IR spectrum heat flux view factors written by the VUFAC module.

= `IGM` for the IR spectrum gray body view factor matrix.

= `NCC` for the element center for circular elements written by the ECHOS module.

= `NCG` for the element's C.G written by the ECHOS module.

= `NDC` for the element center for non-circular elements written by the ECHOS module.

= `NGR` for the node numbers for an element written by the ECHOS module. `MNM` = `NGR` can be read with the format (`A3` , `10I6`).

= `NPR` for the elemental properties written by the ECHOS module.

= `NRM` for the element's surface normal written by the ECHOS module. For beam elements NRM is the axial unit vector pointing from node 1 to node 2.

= `SVF` for solar view factors written by the VUFAC module.

= `SGM` for the solar spectrum gray body view factor matrix.

= `RDF` for run definition Cards.

At the start of each run, a run definition Card written by the MAIN module containing the run title and date is written in the format (' `RDF` ', `A80`)

The Card 9 NAME group names, starting element, increment, and ending element, and group name number are written on file VUFF by the DATACH module with the format (' `RDFGROUPNAMES` ', `1X` , `A7` , `I9` , `I12` , `2I10`)

The Card 9 VARIABLE symbolic variable names and values are written on file VUFF by the DATACH module with the format (' `RDFVARIABLENAME` ', `1X` , `A31` , `E15` . `8`)

= `REV` for reverse elements written by the DATACH module.

`I` is:

= element from, or

= blank for nodes.

= the profile element number for `MNM` = `AXM` .

`J` is:

= blank, or

= element to, or

= element number of the radiative source for heat flux view factors, or

= node number for GRD.

= the number of nodes for NGR.

= the first expanded element number for `MNM` = `AXM` . The fourth field represents the last expanded element number, and the fifth field represents the increment.

= the reverse element number for `MNM` = `REV` .

`AR` is:

= area or volume of element `I`, or

= X coordinate for `GRD`, `NDC`, `NCG`, `NCC`, or `NRM`.

`E` is:

= emissivity of element `I`.

- If `E` = `-2.34`, the element is recognized by the VUFAC module for area-proportional conductance calculations, but not for radiation.
- If `E < 0`, it is not recognized by the VUFAC module at all.
- If `E` = `-1.23`, it is assigned an area = `0`.

= `Y` coordinate for `GRD`, `NDC`, `NCG`, or `NRM`.

`TSA` is:

= `TSA` parameter (combined radiative solar spectrum property) of element `I`.

= `Z` coordinate for `GRD`, `NDC`, `NCG`, `NCC`, or `NRM`.

`VF` is:

= view factor from `I` to `J` if `MNM = BVF` and `MNM = HVF` and `TIME = -1.E36`

= gray body view factor from `I` to `J` if `MNM` = `SGM` or `IGM`

= solar view factor if `MNM = SVF`

= albedo factor if `MNM = ALB`

= Earth view factor if `MNM = EVF`

= thermal conductivity times cross-sectional area, or thermal conductivity times thickness, or thermal conductivity (for solid elements) of element `I` if `MNM = NPR`

= `-1E30` if `MNM = NPR` for elements that are the reverse sides of other elements created by the Card 9 REVNODE Card, and for SPACE elements created with Card 5d.

This ensures that follower conductances are created to recover the temperatures of these elements after they are

merged.

If `VF < -1.E28`, and `MNM=NPR`, then the element I is not recognized by the COND module for conduction calculations.

`TIME` is:

= time at which the view factor (`MNM = BVF`), solar view factor (`MNM = SVF`), Earth view factor (`MNM = EVF`), heat flux view factor (`MNM = HVF`), or albedo factor (`MNM = ALB`) occurs.

`TIME` is = `-1.E36`, `-1.1E36`, or `-1.2E36` for view factors (`MNM = BVF`) that will be used only for radiative conductance and gray body view factor calculations and are constant over time.

`TIME` = `-1.1E36` on a BVF Card is a flag indicates that the view factor was calculated with ray-tracing using the solar spectrum surface properties. The value in the AR field is equal to the area of the element multiplied by the factor (`1-solar spectrum specularity/transparency`). The values in the `E` and `TSA` fields are equal to the emissivity and absorptivity of the element divided by the factor `1/(1-solar spectrum specularity/transparency)` respectively. If no IR spectrum properties were specified for the model, the view factors of this Card are considered valid for both the solar and IR spectra. If IR spectrum properties were calculated for the model, the view factors of this Card are considered valid for the solar spectrum only.

`TIME = -1.2E36` is a flag indicates that the view factor was calculated with ray-tracing using the IR spectrum surface properties. The value in the AR field is equal to the area of the element multiplied by the factor (`1-IR spectrum specularity/transparency)` . The values in the E and TSA fields are equal to the emissivity and absorptivity of the element divided by the factor `1/(1-IR spectrum specularity/transparency)` respecti vely.

`TIME = -1.E36` for gray body view factors `(MNM = SGM and MNM = IGM)` .

= specific heat*density value of for solid element `I`, or specific heat*density*thickness value for planar element `I`, or specific `heat* density*cross-sectional area` for beam element `I` if `MNM = NPR` .

`DD` is:

= hydraulic diameter of the element for MNM = NPR.

= shadowing flag if `MNM = BVF` . `DD = 0` if the view factor was calculated with shadowing, and `DD = 1` if it was calculated without shadowing.

WATERDENSF

`WATERDENSF` contains the accumulated water mass per unit are on the front and reverse sides of the element.

Data is written in format:

`(I7,2E15.7)`

and the data fields contain `I`, water mass per unit area accumulated on front side of `I`, and water mass per unit area accumulated on reverse side of `I`.

If `I = -99999`, then the first field represents the printout time.

Section 3: Modules

Analyzer Module

Function

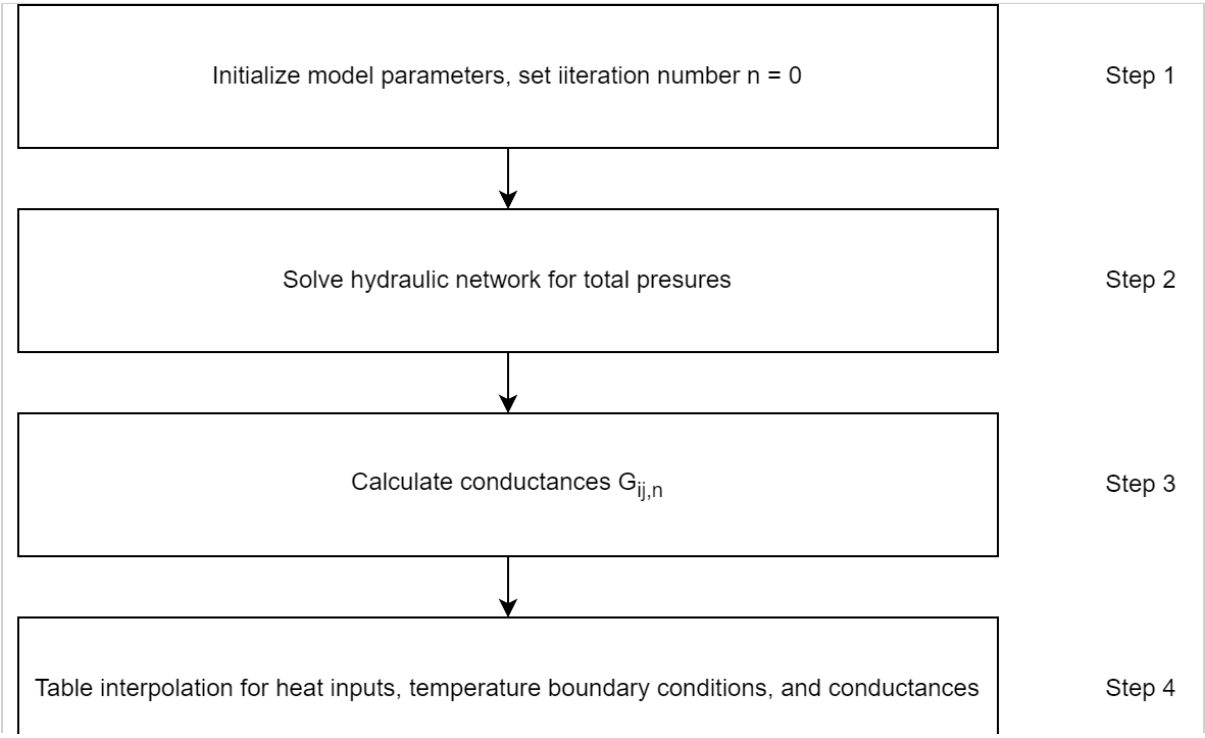
The Analyzer module calculates steady state or transient temperatures and total pressures for thermal/hydraulic models. Heat paths are specified as thermal conductances, fluid flow paths as flow resistances. Boundary conditions specified are elemental heat loads, mass flows, sink temperatures, and total pressures.

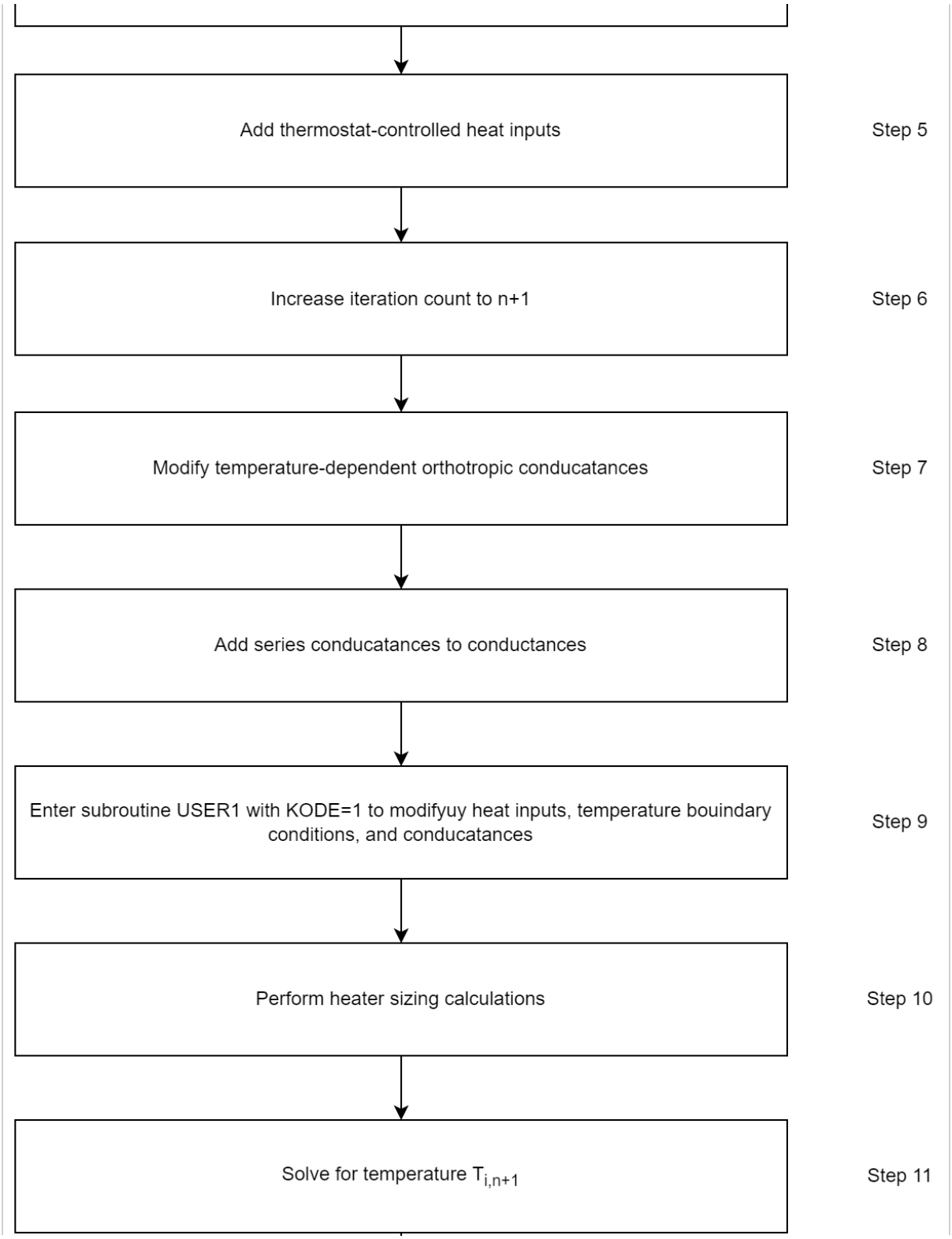
Parameters may be varied during solution time through table interpolation and with user–written FORTRAN subroutines.

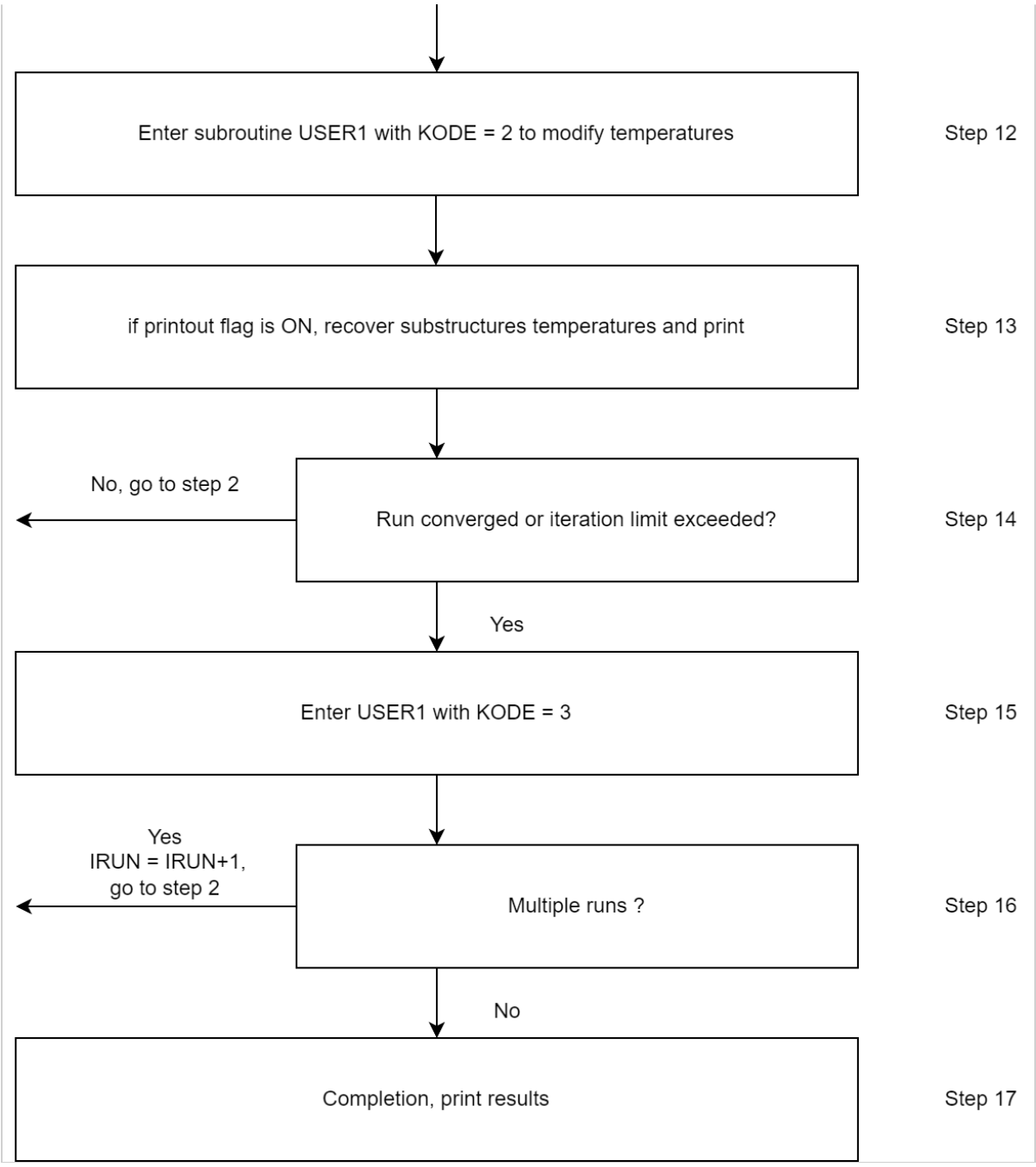
The Analyzer is run if a Card 2b Analyzer Control Card is present.

Steady State Analysis

If Card 2b GRANT ≥ 0, steady state analysis is performed. The temperatures of non-sink elements are calculated iteratively. The flowchart of the steady-state algorithm is as follows:




Add thermostat-controlled heat inputs
Step 5
Increase iteration count to n+1
Step 6
Modify temperature-dependent orthotropic conducatances
Step 7
Add series conducatances to conductances
Step 8
Enter subroutine USER1 with KODE=1 to modifyuy heat inputs, temperature bouindary conditions, and conducatances
Step 9
Perform heater sizing calculations
Step 10
Solve for temperature $T_{i,n+1}$
Step 11



Step 1: Initialization

Initial values are assigned to all the element temperatures, conductances, and heat inputs.

The initial temperatures default to zero unless a file TEMPF is present, or initial temperatures have been specified with Card 9 TINIT Cards, in which case these define the initial temperatures.

For multilayer elements, the layer temperatures are initialized to the temperature of the middle layer.

The temperatures of unitialized Oppenheim elements are initialized at the average temperature of the elements the Oppenheim element is connected to.

If the element CG method is used, the boundary element temperatures are initialized to the weighted average temperatures of the elements they are connected to.

For more information on initialization of hydraulic elements, see Hydraulic Elements.

Time `t` at the start of the run is defined by the Card 2b `TST` parameter.

If Card 9 PARAM USRCNDADD is present, the user-written subroutine is entered with `KODE=5`. At this time, you can add new conductances to the conductance matrix.

If the element CG method is used, large negative conductances are modified according to the values set by Card 9 PARAM MODCOND.

Step 2: Calculation of Total Pressures for Hydraulic Elements

Total pressures of hydraulic elements are calculated for the current iteration (please refer to the Hydraulic Elements section).

Step 3: Calculation of Conductances

Convective and free convection conductances associated with hydraulic elements are updated as described in the Hydraulic Elements section.

One-way conductances for hydraulic networks are updated by multiplying the mass flow values flowing through DUCT and FLOWRES elements with the specific heat.

Conductive conductances for hydraulic elements are calculated from the CG to the boundary.

$$G = \frac{2A_{DUCT}KTHERM}{L}$$

where:

- G is the conductance from the CG to the boundary
- A_{DUCT} is the duct cross-section
- L is the length of the duct
- $KTHERM$ is the thermal conductivity of the fluid

Free convection conductances specified on Card 6e and not associated with hydraulic elements are calculated with:

$$G_{ij,n} = GF_{ij}(T_{i,n} - T_{j,n})^{EXP}$$

where:

- $G_{ij,n}$ is the value of the conductance between elements i and j at iteration n
- i, n refers to the property of element i at iteration n
- $T_{i,n}$ is the temperature of element i at iteration n
- $T_{j,n}$ is the temperature of element j at iteration n
- GF_{ij} is the free convection conductance parameter
- EXP is the specified exponent

Step 4: Table Interpolation

Next, linear table interpolations are performed. Heat inputs, SINK temperatures, and table-dependent conductances are evaluated. For further details please refer to Card 9 INTERP, TABDATA, and TABTYPE Cards.

If the independent variable is greater than the largest value in the table, the last dependent variable is used, and a warning message is issued. If the independent variable is smaller than the smallest value in the table, the first dependent variable is used. In other words, the first and last values of the table are extended beyond the table limits.

If electrical elements are present, the electrical network is solved for voltage and current. The power dissipation in the electrical network is computed and summed with other heat inputs specified for the electrical elements. For further details please refer to the Card 9 TABTYPE Card.

If the Card 9 PARAM CAPDIST OFF Card is not present, and the default element CG formulation is used, then the heat loads on solid elements are redistributed from the CG to the boundary elements. For tetrahedra, a uniform weighting factor is used. For wedges and hexahedra, the weighting factors are proportional to the areas of the boundary elements.

Step 5: Add Thermostat-controlled Heat Inputs

Thermostats are transformed into proportional controllers. For proportional controllers, the heat input Q to the heaters follows the following relationship:

$$
\begin{aligned}
Q &= 0 && T(N1) > T3 \\
Q &= \frac{QHTR(T3 - T(N1)}{T3 - T2} && T2 \geq T(N1) \geq T3 \\
Q &= QHTR && T(N1) < T2
\end{aligned}
$$

where:

- $T(N1)$ is the sensor temperature
- $QHTR$ is the maximum heater power
- $T3$ is the cut-out temperature for the proportional controller
- $T2$ is the cut-in temperature of the heater

Step 6: Increase Iteration Count to n+1

Step 7: Modify Temperature-dependent Orthotropic Conductances

If orthotropic materials are present, all conductances associated with orthotropic elements are recalculated, provided the maximum temperature change of an orthotropic element has not exceeded 20 degrees. This value can be set with the Card 9 PARAM TDEPORTHO Card.

Step 8: Series Conductances

If series or interface conductances (Card 6e INTER, INTERTOT, INTER2, INTER2TOT Card) are present the conductances the interface element is connected to are modified.

Step 9: Entering USER1 with KODE = 1

Next, the optional user–written subroutine `USER1` is entered with `KODE = 1`. You can modify conductances, heat loads, etc. before calculating temperatures. For further details, please refer to Card 10 User–Written Subroutine.

Step 10: Perform Heater Sizing Calculations

If a Card 9 THERMST Card is present, and if the `T1` is the code `Q_EQUIV`, then a sensitivity analysis is performed to calculate the heater heat loads required to keep the sensors at the average of the Thigh and Tlow temperatures specified on the THERMST Card.

Step 11: Calculation of Temperatures

The undamped temperature estimate $T_{iest,n+1}$ for iteration $n+1$ is calculated according to the method outlined in the section on the conjugate gradient solver below.

Next, the temperatures $T_{i,n+1}$ for all elements i for the next iteration $n+1$ are computed with damping from $T_{i,n+1}$

$$T_{i,n+1} = (1 - DT)T_{i,n} + T_{iest,n+1}\,DT$$

where:

- DT is the iteration damping factor from Card 2b, default = 0.5.
- $T_{iest,n+1}$ is the temperature estimate at iteration $n+1$ calculated with the CG solver.

Sink element and MCV element temperatures are not altered. Sink element temperatures may be altered through table interpolation or in `USER1.`

Step 12: Entering USER1 with KODE = 2

Once temperatures are calculated, `USER1` is entered with $KODE = 2$. This gives the option to alter some of the calculated temperatures.

For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional.

Step 13: Printout and Recovery of Eliminated Element Temperatures

Next, a check is made to determine whether the printout flag is set. The printout flag is set either with the Card 2b DTP parameter or through PRTFLG in `USER1.`

If the printout flag and substructuring are performed through Card 8 element elimination or Card 9 PARAM SUBSTR Cards, the temperatures of the eliminated elements are recovered.

The temperature recovery matrix is read in from file MODLCRF, and the heat loads of the eliminated elements are redistributed in the order the elements were eliminated, according to the method described in the section on the MEREL Module. Then, the temperatures `T_{i,n+1}` of each eliminated elements i are computed in the reverse order they were eliminated.

Next, printout is performed according to the specifications of Card 9 PRINT Cards. At every printout a set of results are written on files QNODEF, [Simulation name]_report.log, PRESSF, TEMPF, tmgrslt.dat and the verbose log file.

Step 14: Convergence Check

Next, a run completion check is performed. A run is considered completed if the maximum number of iterations (defined on Card 2b TF parameter) is exceeded, or if convergence occurs.

Convergence occurs if the maximum temperature difference between two subsequent iterations is less than the Card 2b GRADNT parameter, default = `0.001`.

If the Card 9 PARAM ENGBAL system energy balance criterion is set, this criterion must also be met for convergence to occur. For each sink element `i` a heat flow $QSINK_i$ is computed:

$$QSINK_{i,n+1} = Q_{i,n+1} GTSUM_{i,n+1} - T_{i,n+1} GSUM_{i,n+1}$$

where:

- $QSINK_{i,n+1}$ is the heat flowing into (or out of) the sink element i at iteration $n+1$.
- $GSUM_{i,n}$ is the sum of conductances $G_{ij,n}$ for element i
- $GTSUM_{i,n}$ is the sum of the $T_{j,n} G_{ij,n}$ for element i
- $GSUMC_{i,n}$ is the sum of non-radiative conductances for element i
- $GSUMR_{i,n}$ is the sum of all GR_{ij}'s for element i
- $GTSUMC_{i,n}$ is the sum of the $T_{j,n}\ G_{ij,n}$ for all non-radiative conductances for element i
- $GTSUMR_{i,n}$ is the sum of the $T_{j,n}\ ^4GR_{ij}$ for all radiative conductances for element i

To satisfy the system energy balance criterion the following criterion must be met:

$$|QSINK_{IN} - QSINK_{OUT} - QTOT| < T1$$

Where:

- $QSINK_{IN}$ is the sum of the heat flows into the sink elements
- $QSINK_{OUT}$ is the sum of the heat flows out of the sink elements
- $QTOT$ is the sum of the heat loads into the elements
- $T1$ is either an absolute value, defined on the Card 9 PARAM ENGBAL Card, or is a specified fraction of $QSINK_{IN}$.

If convergence has not occurred, the cycle start again at Step 2.

Step 15: Enter USER1 with KODE = 3 for Multiple Runs

Once the run is completed, `USER1` is entered with $KODE = 3$. At this time you can specify additional steady-state or transient runs by setting a flag in the array IR. For further details, please refer to Card 10 User-Written Subroutines.

If an additional run is specified, the program continues at Step 2 of either the steady state or transient algorithms.

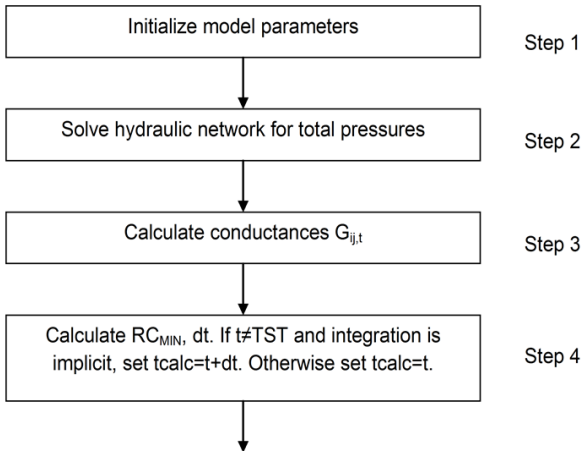
If there are subsequent runs, a printout on files TEMPF `n`, PRESSF `n`, and QNODEF `n` is created, where `n` is the run number.

Step 16: Completion

If the run is completed, a final printout is performed.

Transient Network Analysis

If Card 2b GRADNT = `-2`, `-3`, `-4`, or `-5`, transient analysis is performed using the following algorithm:



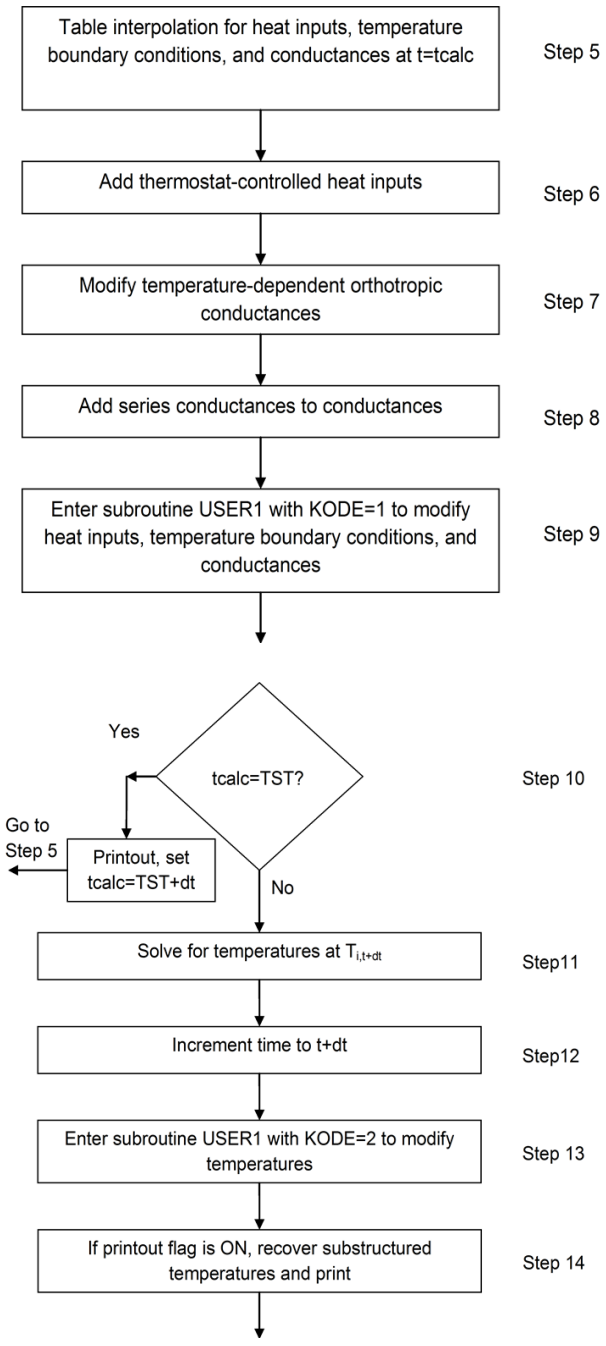
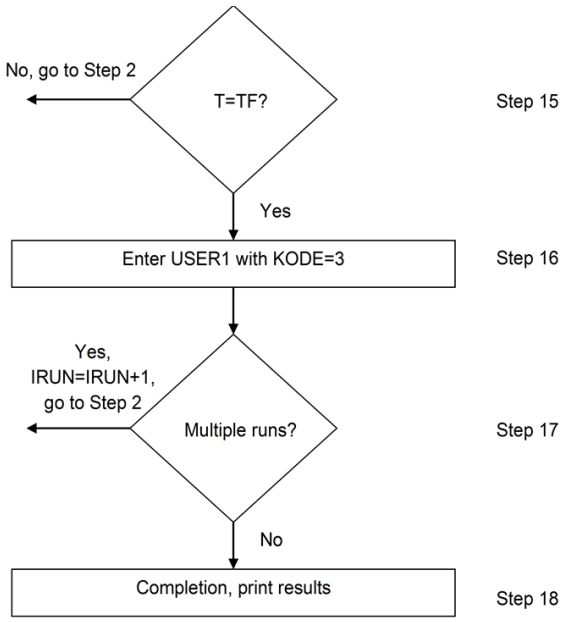


Table interpolation for heat inputs, temperature boundary conditions, and conductances at t=tcalc
Step 5
Add thermostat-controlled heat inputs
Step 6
Modify temperature-dependent orthotropic conductances
Step 7
Add series conductances to conductances
Step 8
Enter subroutine USER1 with KODE=1 to modify heat inputs, temperature boundary conditions, and conductances
Step 9
Yes
tcalc=TST?
Step 10
Go to Step 5
Printout, set tcalc=TST+dt
No
Solve for temperatures at $T_{i,t+dt}$
Step11
Increment time to t+dt
Step12
Enter subroutine USER1 with KODE=2 to modify temperatures
Step 13
If printout flag is ON, recover substructured temperatures and print
Step 14



Step 1: Initialization

Initial values are assigned to all the element temperatures, conductances, and heat inputs.

The initial temperatures default to zero unless a file TEMPF is present, or initial temperatures have been specified with Card 9 TINIT Cards, in which case these define the initial temperatures.

For multilayer elements, the layer temperatures are initialized to the temperature of the middle layer.

The temperatures of unitialized Oppenheim elements are initialized at the average temperature of the elements the Oppenheim element is connected to.

If the element CG method is used, the boundary element temperatures are initialized to the weighted average temperatures of the elements they are connected to.

For more information on initialization of hydraulic elements, see Hydraulic Elements.

If Card 9 PARAM USRCNDADD is present, the user-written subroutine is entered with `KODE=5`. At this time, you can add new conductances to the conductance matrix.

Time `t` at the start of the run is defined by the Card 2b `TST` parameter.

If the element CG method is used, large negative conductances are modified according to the values set by Card 9 PARAM MODCOND.

Conductive conductances for hydraulic elements are calculated from the CG to the boundary.

$$G = \frac{2A_{DUCT}KTHERM}{L}$$

where:

- G is the conductance from the CG to the boundary
- A_{DUCT} is the duct cross-section
- L is the length of the duct
- $KTHERM$ is the thermal conductivity of the fluid

Step 2: Calculation of Total Pressures for Hydraulic Elements

Total pressures of hydraulic elements are calculated for the current time step. For more information, see Hydraulic Elements.

Step 3: Calculation of Conductances

Convective and free convection conductances associated with hydraulic elements are updated as described in the Hydraulic Elements section.

One-way conductances for hydraulic networks are updated by multiplying the mass flow values flowing through DUCT and FLOWRES elements with the specific heat.

Free convection conductances specified on Card 6e and not associated with hydraulic elements are calculated with:

$$G_{ij,t} = GF_{ij}(T_{i,t} - T_{j,t})^{EXP}$$

where:

- $G_{ij,t}$ is the value of the conductance between elements i and j
- $_{i,t}$ refers to the property of element i at time t.
- $T_{i,t}$ is the temperature of element i
- $T_{j,t}$ is the temperature of element j
- GF_{ij} is the free convection conductance parameter
- EXP is the specified exponent

Step 4: Calculation of Integration Time Step dt, tcalc, and RC_{MIN}

Next, the integration time step `dt` is calculated, according to the specification of the Card 2b DT parameter.

$$\text{If } DT > 0, dt = DT$$
$$\text{If } DT = 0, dt = \frac{RC_{MIN}}{2}$$
$$\text{If } DT < 0, dt = |DT| \frac{RC_{MIN}}{2}$$

where:

- RC_{MIN} is the smallest value of in the model
- $GSUM_{i,t}$ is the sum of conductances $G_{ij,t}$ for element i

Next, dt is checked to see if $t + dt$ exceeds the time of the next printout interval, defined by the DTP and TF parameters of Card 2b. If $t + dt$ is too large, dt is appropriately reduced.

The parameter $tcalc$ is defined. $tcalc$ is the time value at which the heat loads and temperature boundary conditions are evaluated. For implicit methods when calculation the temperatures at time $t + \alpha dt, tcalc$ is $t + \alpha dt$ where:

α is the explicit-implicit weighting factor, between `0` and `1`.

For Crank-Nicolson $\alpha = .5$, for forward and exponential forward differencing $\alpha = 0$ and for backward differencing $\alpha = 1$

When the initial values are to be printed, $tcalc$ is set to TST.

Step 5: Table Interpolation at t=tcalc

Next, linear table interpolations are performed. Heat inputs, SINK temperatures, and table-dependent conductances are evaluated. For more information see Card 9 - INTERP Analyzer Table Interpolation - Optional , Card 9 - TABDATA Analyzer Table Data Cards - Optional, and Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

If the independent variable is greater than the largest value in the table, the last dependent variable is used, and a waning message is issued. If the independent variable is greater than the smallest value in the table, the first dependent variable is used. In other words, the first and last values of the table are extended beyond the table limits.

If electrical elements are present, the electrical network is solved for voltage and current. The power dissipation in the electrical network is computed and summed with other heat inputs specified for the electrical elements.

If series or interface conductances (Card 6e INTER Card) are present the appropriate conductance values are modified.

If the Card 9 PARAM CAPDIST OFF Card is not present, and the default element CG formulation is used, then the heat loads and capacitances of solid elements are redistributed from the CG to the boundary elements. For tetrahedra, a uniform weighting factor is used. For wedges and hexahedra, the weighting factor are proportional to the areas of the boundary elements.

Step 6: Thermostats

Next, if thermostats or PID controllers have been specified on Card 9 THERMST Cards, the heat load to each heater element is checked as to whether it should be zero or not.

For PID controllers, the heat input Q to the heaters is calculated using the following equations:

$$e(t) = T2 - T(N1)$$

$$Q = QHTR\left\{T7e(t) + T8\int e(t)dt + T9\frac{de(t)}{dt} + T10\right\} \qquad 0 \le Q \le QHTR$$

where:

- $QHTR$ is the maximum heat input to the heaters.
- $T2$ is the controller's set point
- $T7$ is the controller's gain
- $T8$ is the integral constant
- $T9$ is the derivative constant
- $T10$ is the bias

For thermostats, a heater element is turned ON if the temperature $T_{i,t}$ of the sensor element falls below the cut–in temperature of the thermostat. It is turned OFF if the sensor element temperature is above the cut–off temperature. If the sensor element temperature is between the cut–in and cut–off temperatures, the heater's ON/OFF status is not altered.

For proportional controllers, the heat input Q to the heaters follows the following relationship:

$$\begin{aligned} Q &= 0 && T(N1) > T3 \\ Q &= \frac{QHTR(T3 - T(N1))}{T3 - T2} && T2 \ge T(N1) \ge T3 \\ Q &= QHTR && T(N1) < T2 \end{aligned}$$

where:

- $T(N1)$ is the sensor temperature
- $QHTR$ is the maximum heater power
- $T3$ is the cut-out temperature for the proportional controller
- $T2$ is the cut-in temperature of the heater

Step 7: Modify Temperature-dependent Orthotropic Conductances

If orthotropic materials are present, all conductances associated with orthotropic elements are recalculated, provided the maximum temperature change of an orthotropic element has not exceeded 20 degrees.

Step 8: Series Conductances

If series or interface conductances (**Card 6e INTER**, **INTERTOT**, **INTER2**, **INTER2TOT** Card) are present the conductances the interface element is connected to are modified.

Step 9: Entering USER1 with KODE = 1

Next, the optional user–written subroutine `USER1` is entered with `KODE = 1`. You can modify conductances, heat loads, sink temperatures, and capacitances before calculating **temperatures**.

For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional.

Step 10: If tcalc=TST, initial printout is performed

$tcalc$ is then incremented to $TST + \alpha dt$, and the program loops to Step 5 to recalculate boundary conditions.

Step 11: Calculation of Temperatures

Next, the temperatures at time $t + dt$ are calculated:

Explicit techniques (GRDNT = -2 and GRADNT = -3)

For the exponential forward differencing technique:

$$T_{i.t+dt} = T_{i,t}(TEQ_{i,t} - T_{i,t})(1 - e)^{\frac{-dt}{\tau_{i,t}}}$$
$$TEQ_{i,t} = \frac{Q_{i,t} + GTSUM_{i,t}}{GSUM_{i,t}}$$
$$\tau_{i,t} = \frac{C_{i,t}}{GSUM_{i,t}}$$

where:

- $\tau_{i,t}$ is the time constant of the element
- $TEQ_{i,t}$ is the equilibrium temperature the element would reach if all its neighboring element temperatures were constant.
- $GSUM_{i,t}$ is the sum of conductances $G_{ij,t}$ for element i at time t
- $GTSUM_{i,t}$ is the sum of the $T_{j,t}G_{ij,t}$ for element i at time t
- $GSUMC_{i,t}$ is the sum of non-radiative conductances for element i at time t
- $GSUMR_{i,t}$ is the sum of all for element i at time t.
- $GTSUMC_{i,t}$ is the sum of GR_{ij}'s for all non-radiative conductances for element i at time t

- $GTSUMR_{i,t}$ is the sum of the $T_{j,t}{}^4 GR_{ij}$ for all radiative conductances for element i at time t

For the forward differencing technique:

$$T_{i,t+dt} = T_{i,t} + (TEQ_{i,t} - T_{i,t})(\frac{dt}{\tau_{i,t}})$$

Implicit Techniques (GRADNT = −4 and GRADNT = −5)

For the implicit techniques all temperatures are calculated iteratively.

The implicit techniques are unconditionally stable if the explicit–implicit weighting factor $\alpha > .5$

If the default conjugate gradient solver is used, $T_{iest,t+dt,n+1}$ is calculated using the technique described below, where:

$T_{iest,t+dt,n+1}$ is the estimated temperature of element i at iteration $n+1$ without damping calculated with the conjugate-gradient technique.

All parameters used at time $t+dt$ are calculated using temperature and conductance values at iteration n

Next, damping is used to calculate the new set of temperatures:

$$T_{i,t+dt,n+1} = T_{iest,t+dt,n+1} TRDMP + (1 - TRDMP) T_{i,t+dt,n}$$

where:

- $T_{i,t+dt,n+1}$ is the temperature estimate of element i at iteration $n+1$
- $TRDMP$ is the transient damping parameter defined on Card 2b.

During iteration only the radiative conductances are updated, all other conductances are evaluated at `t`.

The maximum number of iterations defaults to `100`, and may be overridden on the Card 9 PARAM NLOOP Card. If the maximum number of iterations is reached, a warning message is written to the verbose log file.

If the Card 9 PRINT TRACE flag was set, the highlights of the current iteration are printed to the screen as well as to the report log file.

Convergence is achieved when the maximum temperature difference between two subsequent iterations is less than the product TDIFS * TRDMP.TDIFS may be set on the Card 9 PARAM TDIFS Card, its default value `= 0.001`.

Initial temperature estimation for the implicit techniques

To accelerate convergence, the first iteration, $T_{i,t+dt,1}$ is estimated from the past behavior of the equilibrium temperature of the element.

$$T_{i,t+dt,1} = T_{i,t} + (TEQ_{i,t} - TEQ_{i,t-dtp,1})(\frac{dt}{dtp})$$

where:

- dtp is the previous integration time step

Phase Change Calculations

Next, the temperatures of phase change elements modeled with Card 9 PHASE or MAT Cards are appropriately adjusted to account for the energy absorbed by the latent heat of absorption.

For the explicit techniques this adjustment occurs at the completion of the first iteration only. For the implicit techniques it occurs at the completion of each iteration.

The adjustment is as follows:

1. For each phase change element a quality $QUAL_{i,t+dt}$ is defined, which is the fraction of the element in its hotter phase. Initially, $QUAL_{i,t+dt}$ is set to $QUAL_{i,t}$. If $T_{i,t}$ is below the phase change temperature, $QUAL_{i,t} = 0$. If $T_{i,t}$ is above the phase change temperature, $QUAL_{i,t} = 1$.

2. A check is performed to see if phase change effects should be considered. Phase change effects are not considered if both $T_{i,t}$ and $T_{i,t+dt}$ both lie on the same side of the phase change temperature.

3. If phase change is considered, the energy flowing into the element over the integration time step is partitioned into three components: energy that affects its temperature below the phase change temperature, energy that affects its quality at the phase change temperature, and energy that affects its temperature above the phase change temperature.

   Using these three values, the temperature and the quality of the phase change element are appropriately adjusted.

Ablative elements are a subset of phase change elements. Once an ablative element enters its higher temperature phase, a determination is made whether it is considered to have burned up or merely changed properties.

If the ABLAT parameter on the MAT card points to a change in material properties, the thermal conductivity capacitance are appropriately adjusted. If, instead, the element is considered to have burned up, then the capacitance is reduced by a factor of 1.E-6. For solid elements thermal conductivity is increased by a factor of 1.E5, for shell elements the in-plane thermal conductivity is set to zero, and the out-of-plane thermal conductivity is increased by a factor of 1.E5.

Step 12: Increment time to t+dt

Step 13: Entering USER1 with KODE = 2

Once temperatures are calculated, USER1 is entered with `KODE = 2`. This gives you the option to alter some of the calculated temperatures.

For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional

Step 14: Printout and Recovery of Substructured Element Temperatures

Next, the status of the printout flag is checked. The printout flag may be specified either through the Card 2b DTP parameter or through PRTFLG in USER1. If the printout flag has not been set, TMG proceeds to the next step.

If the printout flag has been set and substructuring had been performed through Card 8 element elimination or Card 9 PARAM SUBSTR Cards, the temperatures of the eliminated elements is recovered.

Next a printout is performed according to the specifications of Card 9 PRIN**T** Cards. At every printout a set of results are written to the report and verbose log files. The elemental heat loads are written on file QNODEF, and the temperatures on file TEMPF at the completion of the run. Total pressures and mass flows are written on file PRESSF.

Step 15: Run Completion Check

Next, a run completion check is performed. A transient run is considered completed if t equals the Card 2b TF parameter.

Step 16: Enter USER1 with KODE = 3 for Multiple Runs

Once the run is completed, `USER1` is entered with $\mathrm{KODE} = 3$ You can specify additional steady–state or transient runs, by setting a flag in the array IR. For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional

Step 17: Check for Multiple Runs

If an additional run is specified, the program re–enters at either Step 2 of the steady state or transient algorithm.

Step 18: Completion, Print Results

If there are subsequent runs, a printout on files TEMPFn, PRESSFn, and QNODEFn is created, where n is the run number.

Conjugate-Gradient Solver

The CG solver uses the biconjugate gradient stabilized technique to solve for temperatures. The equations are placed into the matrix format:

$$[\mathrm{GG}]\{\mathrm{T}_{\mathrm{t+dt,n+1}}\} = \{\mathrm{B}\}$$

where:

- $[\mathrm{GG}]$ is the conductance matrix
- $\{T_{i,t+dt,n+1}\}$ is the temperature vector estimate at conjugate iteration $n+1$ and time $t+dt$ without damping.
- $\{B\}$ is the right-hand side vector

Derivation of the conductance matrix GG

The energy balance equation for a transient run to be solved iteratively at iteration $n+1$ and time $t+dt$ for element i can be cast in the form:

$$\frac{-C_{i,t}(T_{i,t+dt,n+1}-T_{i,t})}{dt} + Q_{i,t+\alpha dt}(1-\alpha)(\sum T_{j,t}GC_{ij} - T_{i,t}\sum GC_{ij} +$$
$$\sum(T_{j,t}+T_{ABS})^4 GR_{ij} - (T_{i,t}+T_{ABS})^4 \sum GR_{ij}) + \alpha(\sum T_{j,t+dt,n+1}GC_{ij}$$
$$-T_{i,t,+dt,n+1}\sum GC_{ij}) + \sum(T_{j,t+dt,n+1}+T_{ABS})^4 GR_{ij}(-T_{i,t+dt,n+1}+T_{ABS})^4 \sum GR_{ij}) = 0$$

where:

- GC_{ij} is the sum of the non-radiative conductances between i and j.
- n is the current iteration value
- $C_{i,t}$ is the capacitance of the element.
- $T_{i,t+dt,n+1}$ is the temperature of element i at time $t+dt$ and iteration $n+1$. The objective is to solve for $T_{i,t+dt,n+1}$
- $T_{i,t}$ is the temperature of element i at time t.
- GR_{ij} is the radiative conductance parameter for a radiative coupling between elements i and j, equal to its (Boltzmann's Constant)(area)(emissivity)(gray body view factor) product value.
- α is the explicit-implicit weighting factor, between 0 and 1. For Crank-Nicolson $\alpha = .5$ for forward and exponential forward differencing $\alpha = 0$ and for backward differencing $\alpha = 1$. For steady state analysis $\alpha = 1$.
- dt is the integration time step. For steady state analysis dt = infinity.
- T_{ABS} is the absolute value of absolute zero.

Since the equation is non-linear, the Newton-Raphson Method is used. A first-order Taylor series expansion for $\sum(T_{j,t+dt,n+1} + T_{ABS})^4 GR_{ij}$ about $T_{j,t+dt,n}$ and for $\sum(T_{j,t+dt,n+1} + T_{ABS})^4 \sum GR_{ij}$ about $T_{i,t+dt,n}$ is performed:

$$\sum(T_{j,t+dt,n+1} + T_{ABS})^4 GR_{ij} = \sum GR_{ij}(T_{j,t+dt,n} + T_{ABS})^4 +$$
$$\sum 4GR_{ij}(T_{j,t+dt,n} + T_{ABS})^3 (T_{j,t+dt,n+1} + T_{j,t+dt,n})(T_{i,t+dt,n+1} + T_{ABS})^4 \sum GR_{ij}$$
$$= (T_{i,t+dt,n} + T_{ABS})^4 \sum GR_{ij} + 4(T_{i,t+dt,n} + T_{ABS})^3 (T_{i,t+dt,n+1} - T_{i,t+dt,n}) \sum GR_{ij}$$

Substituting into the energy balance equation yields:

$$\frac{-C_{i,t}(T_{i,t+dt,n+1} - T_{i,t})}{dt} + Q_{I,t+\alpha dt} +$$
$$(1-\alpha)(\sum T_{j,t} GC_{ij} - T_{i,t} \sum GC_{ij} + \sum(T_{j,t} + T_{ABS})^4 GR_{ij} -$$
$$(T_{i,t} + T_{ABS})^4 \sum GR_{ij}) + \alpha(\sum T_{j,t+dt,n+1} GC_{ij} - T_{i,t+dt,n+1} \sum GC_{i,j} +$$
$$\sum GR_{ij}(T_{j,t+dt,n} - T_{ABS})^4 \sum G4R_{ij}(T_{j,t+dt,n} + T_{ABS})^3 (T_{j,t+dt+n} - T_{j,t+dt,n})$$
$$(T_{i,t+dt,n} + T_{ABS})^4 \sum GR_{ij} - 4(T_{i,t+dt,n} + T_{ABS})^3 (T_{i,t+dt,n+1} - T_{i,t+dt,n,1}) \sum GR_{ij}) = 0$$

Recasting this equation into the matrix form:

$$[GG]\{T_{t+dt,n+1}\} + \{B\}$$

yields:

$$B_i = -\frac{\frac{C_{i,t}T_{i,t}}{dt} + Q_{i,t+\alpha dt}}{\alpha} + (\frac{1}{\alpha} - 1)(\sum GC_{ij}(T_{j,t} - T_{i,t}) + \sum GR_{ij}((T_{j,t} + T_{ABS})^4 -$$
$$(T_{i,t} + T_{ABS})^4)) + \sum GR_{ij}(-(T_{j,t+dt,n} + T_{ABS})^4 + 4(T_{j,t+dt,n} + T_{ABS})^3 T_{j,t+dt,n} +$$
$$(T_{i,t+dt,n} + T_{ABS})^4 - 4(T_{i,t+dt,n} + T_{ABS})^3 T_{i,t+dt,n})$$

when `i` is not equal to `j:`

$$GG_{ij} + GC_{ij} + 4GR_{ij}(T_{i,t+dt,n} + T_{ABS})^3$$

when `i = j`:

$$GG_{ij} = -\frac{C_{i,t}}{\alpha dt} - \sum GC_{ij} - 4(T_{i,t+dt,n} + T_{ABS})^3 \sum GR_{ij}$$

where:

- GG_{ij} is the matrix term of the i'th row and j'th column

- B_i is the right hand side

For sink temperatures:

$$GG_{ii} = -1$$
$$B_i = -T_{i,t}$$

The matrix is solved with the biconjugate-stabilized version of the conjugate gradient technique (Ref. 2). The matrix convergence parameters can be set on **Card 9** PARAM ILU.

Convergence is considered to be achieved if the value of the norm of the expression below is `< T2`.

$$\left| \frac{[GG\{T\}-\{B\}]}{B} \right| < T2$$

where:

- $T2$ is a convergence parameter specified on Card 9 PARAM ILU. $T2$ defaults to `1.E-8.`

To accelerate convergence, an approximate inverse matrix is used as a preconditioner. The preconditioning matrix is created using the Incomplete Lower-Upper factorization method. LFIL is the maximum number of terms in each row of the preconditioning matrix, and its initial value defaults to 10. LFIL may be redefined on a **Card** 9 PARAM ILU Card.

The preconditioning matrix is created once every 10 iterations for steady-state runs, and once every 10 integration time steps for transient runs. In addition, before every solution the diagonal terms of the GG matrix are checked to see if they have changed since the last time the preconditioning matrix was updated. If they have changed by more than 100%, the preconditioning matrix is automatically updated.

If the conjugate gradient solver does not converge after 100 iterations, one of two actions is taken. If the pattern of convergence is good, then the maximum number of allowable iterations is increased to 200, 300, etc. If the pattern of convergence is not good, then the LFIL value of the preconditioning matrix is automatically increased in increments of 10 to a maximum value of 200, and the preconditioning matrix is re-created until convergence is achieved.

If the forward differencing or exponential forward differencing methods are specified, then only a single iteration per time step is used as the default. This assumes that the conductance matrix remains constant during the integration time step.

Hydraulic Elements

The function of hydraulic elements is to model mass and heat transport and the associated free and forced convection mechanisms in 1-dimensional duct network fluid flow.

Each hydraulic element belongs to two coupled networks: the pressure/flow hydraulic network and the temperature/heat flow thermal network. The element is connected to the hydraulic network with flow resistances, and to the thermal network with convective and 1–way conductances.

The two networks are bidirectionally coupled because convective and 1–way conductances are functions of the mass flow through the element, and buoyancy forces, density, and flow resistances are functions of temperature.

Two types of hydraulic elements may be specified Card 5a: 1–node AMBIENT, `FLOWSEC`, and `BLSTART` elements, and 2–node `DUCT`, `FLOWRES`, and `FANPUMP` elements.

1-node hydraulic elements

A 1–node `FLOWSEC` hydraulic element defines the cross–sectional properties (area and hydraulic diameter) at its location.

A `BLSTART` element is similar to a `FLOWSEC` element, except that it also defines the start of the boundary layer for convective conductance calculations.

An `AMBIENT` element is a very large area pressure and temperature sink element used to define a flow boundary condition.

2-node hydraulic elements

A 2–node hydraulic element defines the total pressure drop or total pressure rise across it.

A `DUCT` element models length–dependent pressure drops.

A `FLOWRES` element models length–independent pressure drops.

Mass flow, volume flow, velocity, and total pressure rise boundary conditions are defined on `FANPUMP` elements.

The center of each 2–node hydraulic element is automatically connected to the upstream and downstream 1–node hydraulic elements with two equal hydraulic flow resistances and 1–way fluid flow thermal conductances.

Optionally, convective conductances between 2–node hydraulic elements and other thermal elements may be defined with the Card 6e NEARCx options.

Flow branches

A flow branch is a series of connected 2-node hydraulic elements ending in either a 1–node hydraulic element or in a junction with two or more flow branches.

The same forward direction should be specified for all the 2-node hydraulic elements in a flow branch, i.e. from node 1 to node 2. This is the assumed initial flow direction in the flow branch.

In case of a direction inconsistency in the assumed flow direction, the orientation of a hydraulic element will be automatically reversed and a warning message will be given. Flow reversals due to pressure changes will also be automatically be computed.

Each hydraulic element must have its cross–sectional and flow properties defined, for a 2–node hydraulic element these are defined by the 1–node elements at its ends.

To define cross-sectional and flow properties for a flow branch, it is sufficient to specify a single 1-node hydraulic element at the most upstream location. New downstream `FLOWSEC` hydraulic elements with the same cross–sectional and fluid properties will be automatically created until a new `FLOWSEC` or `BLSTART` element is encountered.

AMBIENT elements

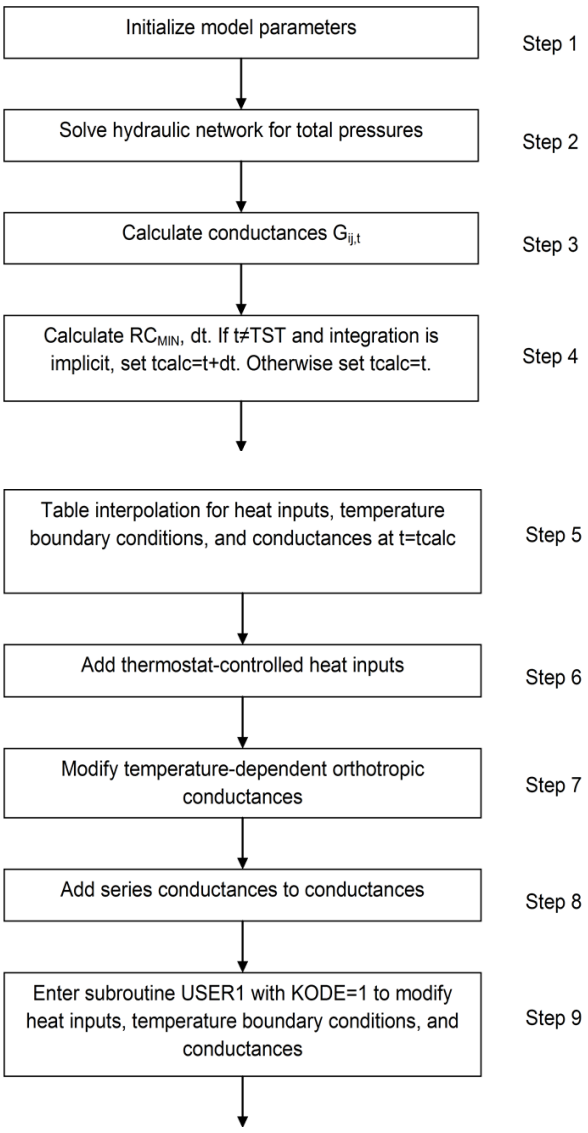
Each hydraulic element must have a path to either an `AMBIENT` element, or to an element whose total pressure is fixed with a Card 9 PSINK Card.

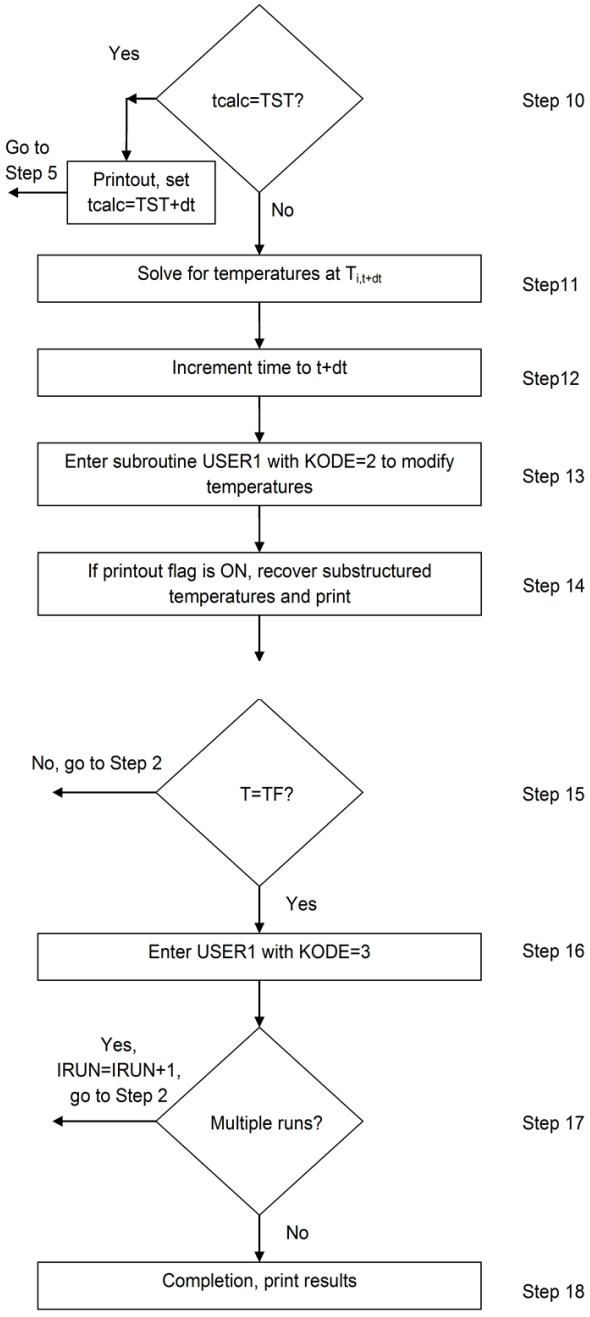
Models with hydraulic elements must have at least one `AMBIENT` element defined.

The hydraulic environment (ambient temperature, static pressure) must be defined with a Card 9 HYDENV Card. These will define the boundary conditions for `AMBIENT` elements.

`AMBIENT` element at the dangling ends of a flow branches will be automatically created unless a `FLOWSEC` or `BLSTART` element is specified there.

If Card 2b GRADNT = `-2` , `-3` , `-4` , or `-5` , transient analysis is performed using the following algorithm:


Initialize model parameters
Step 1
Solve hydraulic network for total pressures
Step 2
Calculate conductances $G_{ij,t}$
Step 3
Calculate RC_{MIN}, dt. If t≠TST and integration is implicit, set tcalc=t+dt. Otherwise set tcalc=t.
Step 4
Table interpolation for heat inputs, temperature boundary conditions, and conductances at t=tcalc
Step 5
Add thermostat-controlled heat inputs
Step 6
Modify temperature-dependent orthotropic conductances
Step 7
Add series conductances to conductances
Step 8
Enter subroutine USER1 with KODE=1 to modify heat inputs, temperature boundary conditions, and conductances
Step 9



Step 1: Initialization

Initial values are assigned to all the element temperatures, conductances, and heat inputs.

The initial temperatures default to zero unless a file TEMPF is present, or initial temperatures have been specified with Card 9 TINIT Cards, in which case these define the initial temperatures.

For multilayer elements, the layer temperatures are initialized to the temperature of the middle layer.

The temperatures of unitialized Oppenheim elements are initialized at the average temperature of the elements the Oppenheim element is connected to.

If the element CG method is used, the boundary element temperatures are initialized to the weighted average temperatures of the elements they are connected to.

For more information on initialization of hydraulic elements, see Hydraulic Elements.

If Card 9 PARAM USRCNDADD is present, the user-written subroutine is entered with `KODE=5`. At this time, you can add new conductances to the conductance matrix.

Time `t` at the start of the run is defined by the Card 2b `TST` parameter.

If the element CG method is used, large negative conductances are modified according to the values set by Card 9 PARAM MODCOND.

Conductive conductances for hydraulic elements are calculated from the CG to the boundary.

$$G = \frac{2A_{DUCT}KTHERM}{L}$$

where:

- G is the conductance from the CG to the boundary
- A_{DUCT} is the duct cross-section
- L is the length of the duct
- $KTHERM$ is the thermal conductivity of the fluid

Step 2: Calculation of Total Pressures for Hydraulic Elements

Total pressures of hydraulic elements are calculated for the current time step. For more information, see Hydraulic Elements.

Step 3: Calculation of Conductances

Convective and free convection conductances associated with hydraulic elements are updated as described in the Hydraulic Elements section.

One-way conductances for hydraulic networks are updated by multiplying the mass flow values flowing through DUCT and FLOWRES elements with the specific heat.

Free convection conductances specified on Card 6e and not associated with hydraulic elements are calculated with:

$$G_{ij,t} = GF_{ij}(T_{i,t} - T_{j,t})^{EXP}$$

where:

- $G_{ij,t}$ is the value of the conductance between elements i and j
- $_{i,t}$ refers to the property of element i at time t.
- $T_{i,t}$ is the temperature of element i
- $T_{j,t}$ is the temperature of element j
- GF_{ij} is the free convection conductance parameter
- EXP is the specified exponent

Step 4: Calculation of Integration Time Step dt, tcalc, and RC_{MIN}

Next, the integration time step `dt` is calculated, according to the specification of the Card 2b DT parameter.

$$\text{If } DT > 0, dt = DT$$
$$\text{If } DT = 0, dt = \frac{RC_{MIN}}{2}$$
$$\text{If } DT < 0, dt = |DT|\frac{RC_{MIN}}{2}$$

where:

- RC_{MIN} is the smallest value of in the model
- $GSUM_{i,t}$ is the sum of conductances $G_{ij,t}$ for element i

Next, dt is checked to see if $t + dt$ exceeds the time of the next printout interval, defined by the DTP and TF parameters of Card 2b. If $t + dt$ is too large, dt is appropriately reduced.

The parameter $tcalc$ is defined. $tcalc$ is the time value at which the heat loads and temperature boundary conditions are evaluated. For implicit methods when calculation the temperatures at time $t + \alpha dt, tcalc$ is $t + \alpha dt$ where:

α is the explicit-implicit weighting factor, between `0` and `1`.

For Crank-Nicolson $\alpha = .5$, for forward and exponential forward differencing $\alpha = 0$ and for backward differencing $\alpha = 1$

When the initial values are to be printed, $tcalc$ is set to TST.

Step 5: Table Interpolation at t=tcalc

Next, linear table interpolations are performed. Heat inputs, SINK temperatures, and table-dependent conductances are evaluated. For more information see Card 9 - INTERP Analyzer Table Interpolation - Optional , Card 9 - TABDATA Analyzer Table Data Cards - Optional, and Card 9 - TABTYPE Table Variable Type Definition Card - Optional.

If the independent variable is greater than the largest value in the table, the last dependent variable is used, and a waning message is issued. If the independent variable is greater than the smallest value in the table, the first dependent variable is used. In other words, the first and last values of the table are extended beyond the table limits.

If electrical elements are present, the electrical network is solved for voltage and current. The power dissipation in the electrical network is computed and summed with other heat inputs specified for the electrical elements.

If series or interface conductances (Card 6e INTER Card) are present the appropriate conductance values are modified.

If the Card 9 PARAM CAPDIST OFF Card is not present, and the default element CG formulation is used, then the heat loads and capacitances of solid elements are redistributed from the CG to the boundary elements. For tetrahedra, a uniform weighting factor is used. For wedges and hexahedra, the weighting factor are proportional to the areas of the boundary elements.

Step 6: Thermostats

Next, if thermostats or PID controllers have been specified on Card 9 THERMST Cards, the heat load to each heater element is checked as to whether it should be zero or not.

For PID controllers, the heat input Q to the heaters is calculated using the following equations:

$$e(t) = T2 - T(N1)$$

$$Q = QHTR\left\{T7e(t) + T8\int e(t)dt + T9\frac{de(t)}{dt} + T10\right\} \qquad 0 \le Q \le QHTR$$

where:

- $QHTR$ is the maximum heat input to the heaters.
- $T2$ is the controller's set point
- $T7$ is the controller's gain
- $T8$ is the integral constant
- $T9$ is the derivative constant
- $T10$ is the bias

For thermostats, a heater element is turned ON if the temperature $T_{i,t}$ of the sensor element falls below the cut–in temperature of the thermostat. It is turned OFF if the sensor element temperature is above the cut–off temperature. If the sensor element temperature is between the cut–in and cut–off temperatures, the heater's ON/OFF status is not altered.

For proportional controllers, the heat input Q to the heaters follows the following relationship:

$$\begin{aligned} Q &= 0 && T(N1) > T3 \\ Q &= \frac{QHTR(T3 - T(N1))}{T3 - T2} && T2 \geq T(N1) \geq T3 \\ Q &= QHTR && T(N1) < T2 \end{aligned}$$

where:

- $T(N1)$ is the sensor temperature
- $QHTR$ is the maximum heater power
- $T3$ is the cut-out temperature for the proportional controller
- $T2$ is the cut-in temperature of the heater

Step 7: Modify Temperature-dependent Orthotropic Conductances

If orthotropic materials are present, all conductances associated with orthotropic elements are recalculated, provided the maximum temperature change of an orthotropic element has not exceeded 20 degrees.

Step 8: Series Conductances

If series or interface conductances (**Card 6e INTER**, **INTERTOT**, **INTER2**, **INTER2TOT** Card) are present the conductances the interface element is connected to are modified.

Step 9: Entering USER1 with KODE = 1

Next, the optional user–written subroutine `USER1` is entered with `KODE = 1`. You can modify conductances, heat loads, sink temperatures, and capacitances before calculating **temperatures**.

For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional.

Step 10: If tcalc=TST, initial printout is performed

$tcalc$ is then incremented to $TST + \alpha dt$, and the program loops to Step 5 to recalculate boundary conditions.

Step 11: Calculation of Temperatures

Next, the temperatures at time $t + dt$ are calculated:

Explicit techniques (GRDNT = -2 and GRADNT = -3)

For the exponential forward differencing technique:

$$T_{i.t+dt} = T_{i,t}(TEQ_{i,t} - T_{i,t})(1 - e)^{\frac{-dt}{\tau_{i,t}}}$$
$$TEQ_{i,t} = \frac{Q_{i,t} + GTSUM_{i,t}}{GSUM_{i,t}}$$
$$\tau_{i,t} = \frac{C_{i,t}}{GSUM_{i,t}}$$

where:

- $\tau_{i,t}$ is the time constant of the element
- $TEQ_{i,t}$ is the equilibrium temperature the element would reach if all its neighboring element temperatures were constant.
- $GSUM_{i,t}$ is the sum of conductances $G_{ij,t}$ for element i at time t
- $GTSUM_{i,t}$ is the sum of the $T_{j,t}G_{ij,t}$ for element i at time t
- $GSUMC_{i,t}$ is the sum of non-radiative conductances for element i at time t
- $GSUMR_{i,t}$ is the sum of all for element i at time t.
- $GTSUMC_{i,t}$ is the sum of GR_{ij}'s for all non-radiative conductances for element i at time t
- $GTSUMR_{i,t}$ is the sum of the $T_{j,t}{}^4GR_{ij}$ for all radiative conductances for element i at time t

For the forward differencing technique:

$$T_{i,t+dt} = T_{i,t} + (TEQ_{i,t} - T_{i,t})(\frac{dt}{\tau_{i,t}})$$

Implicit Techniques (GRADNT = −4 and GRADNT = −5)

For the implicit techniques all temperatures are calculated iteratively.

The implicit techniques are unconditionally stable if the explicit–implicit weighting factor $\alpha > .5$

If the default conjugate gradient solver is used, $T_{iest,t+dt,n+1}$ is calculated using the technique described below, where:

$T_{iest,t+dt,n+1}$ is the estimated temperature of element i at iteration $n+1$ without damping calculated with the conjugate-gradient technique.

All parameters used at time $t + dt$ are calculated using temperature and conductance values at iteration n

Next, damping is used to calculate the new set of temperatures:

$$T_{i,t+dt,n+1} = T_{iest,t+dt,n+1}TRDMP + (1 - TRDMP)T_{i,t+dt,n}$$

where:

- $T_{i,t+dt,n+1}$ is the temperature estimate of element i at iteration $n+1$
- $TRDMP$ is the transient damping parameter defined on Card 2b.

During iteration only the radiative conductances are updated, all other conductances are evaluated at `t`.

The maximum number of iterations defaults to `100`, and may be overridden on the Card 9 PARAM NLOOP Card. If the maximum number of iterations is reached, a warning message is written to the verbose log file.

If the Card 9 PRINT TRACE flag was set, the highlights of the current iteration are printed to the screen as well as to the report log file.

Convergence is achieved when the maximum temperature difference between two subsequent iterations is less than the product $\text{TDIFS} * \text{TRDMP.TDIFS}$ may be set on the Card 9 PARAM TDIFS Card, its default value `= 0.001`.

Initial temperature estimation for the implicit techniques

To accelerate convergence, the first iteration, $T_{i,t+dt,1}$ is estimated from the past behavior of the equilibrium temperature of the element.

$$T_{i,t+dt,1} = T_{i,t} + (TEQ_{i,t} - TEQ_{i,t-dtp,1})(\frac{dt}{dtp})$$

where:

- dtp is the previous integration time step

Phase Change Calculations

Next, the temperatures of phase change elements modeled with Card 9 PHASE or MAT Cards are appropriately adjusted to account for the energy absorbed by the latent heat of absorption.

For the explicit techniques this adjustment occurs at the completion of the first iteration only. For the implicit techniques it occurs at the completion of each iteration.

The adjustment is as follows:

1. For each phase change element a quality $QUAL_{i,t+dt}$ is defined, which is the fraction of the element in its hotter phase. Initially, $QUAL_{i,t+dt}$ is set to $QUAL_{i,t}$. If $T_{i,t}$ is below the phase change temperature, $QUAL_{i,t} = 0$. If $T_{i,t}$ is above the phase change temperature, $QUAL_{i,t} = 1$.

2. A check is performed to see if phase change effects should be considered. Phase change effects are not considered if both $T_{i,t}$ and $T_{i,t+dt}$ both lie on the same side of the phase change temperature.

3. If phase change is considered, the energy flowing into the element over the integration time step is partitioned into three components: energy that affects its temperature below the phase change temperature, energy that affects its quality at the phase change temperature, and energy that affects its temperature above the phase change temperature.

Using these three values, the temperature and the quality of the phase change element are appropriately adjusted.

Ablative elements are a subset of phase change elements. Once an ablative element enters its higher temperature phase, a determination is made whether it is considered to have burned up or merely changed properties.

If the ABLAT parameter on the MAT card points to a change in material properties, the thermal conductivity capacitance are appropriately adjusted. If, instead, the element is considered to have burned up, then the capacitance is reduced by a factor of 1.E-6. For solid elements thermal conductivity is increased by a factor of 1.E5, for shell elements the in-plane thermal conductivity is set to zero, and the out-of-plane thermal conductivity is increased by a factor of 1.E5.

Step 12: Increment time to t+dt

Step 13: Entering USER1 with KODE = 2

Once temperatures are calculated, USER1 is entered with `KODE = 2`. This gives you the option to alter some of the calculated temperatures.

For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional

Step 14: Printout and Recovery of Substructured Element Temperatures

Next, the status of the printout flag is checked. The printout flag may be specified either through the Card 2b DTP parameter or through PRTFLG in USER1. If the printout flag has not been set, TMG proceeds to the next step.

If the printout flag has been set and substructuring had been performed through Card 8 element elimination or Card 9 PARAM SUBSTR Cards, the temperatures of the eliminated elements is recovered.

Next a printout is performed according to the specifications of Card 9 PRIN**T** Cards. At every printout a set of results are written to the report and verbose log files. The elemental heat loads are written on file QNODEF, and the temperatures on file TEMPF at the completion of the run. Total pressures and mass flows are written on file PRESSF.

Step 15: Run Completion Check

Next, a run completion check is performed. A transient run is considered completed if t equals the Card 2b TF parameter.

Step 16: Enter USER1 with KODE = 3 for Multiple Runs

Once the run is completed, `USER1` is entered with $\mathrm{KODE} = 3$ You can specify additional steady–state or transient runs, by setting a flag in the array IR. For more information, see Card 10 - User-Written Subroutines USER1 and USERF - Optional

Step 17: Check for Multiple Runs

If an additional run is specified, the program re–enters at either Step 2 of the steady state or transient algorithm.

Step 18: Completion, Print Results

If there are subsequent runs, a printout on files TEMPFn, PRESSFn, and QNODEFn is created, where n is the run number.

Conjugate-Gradient Solver

The CG solver uses the biconjugate gradient stabilized technique to solve for temperatures. The equations are placed into the matrix format:

$$[\mathrm{GG}]\{\mathrm{T}_{\mathrm{t+dt,n+1}}\} = \{\mathrm{B}\}$$

where:

- $[\mathrm{GG}]$ is the conductance matrix
- $\{T_{i,t+dt,n+1}\}$ is the temperature vector estimate at conjugate iteration $n+1$ and time $t+dt$ without damping.
- $\{B\}$ is the right-hand side vector

Derivation of the conductance matrix GG

The energy balance equation for a transient run to be solved iteratively at iteration $n+1$ and time $t+dt$ for element i can be cast in the form:

$$\frac{-C_{i,t}(T_{i,t+dt,n+1}-T_{i,t})}{dt} + Q_{i,t+\alpha dt}(1-\alpha)(\sum T_{j,t}GC_{ij} - T_{i,t}\sum GC_{ij} +$$
$$\sum(T_{j,t}+T_{ABS})^4 GR_{ij} - (T_{i,t}+T_{ABS})^4 \sum GR_{ij}) + \alpha(\sum T_{j,t+dt,n+1}GC_{ij}$$
$$-T_{i,t,+dt,n+1}\sum GC_{ij}) + \sum(T_{j,t+dt,n+1}+T_{ABS})^4 GR_{ij}(-T_{i,t+dt,n+1}+T_{ABS})^4 \sum GR_{ij}) = 0$$

where:

- GC_{ij} is the sum of the non-radiative conductances between i and j.
- n is the current iteration value
- $C_{i,t}$ is the capacitance of the element.
- $T_{i,t+dt,n+1}$ is the temperature of element i at time $t+dt$ and iteration $n+1$. The objective is to solve for $T_{i,t+dt,n+1}$
- $T_{i,t}$ is the temperature of element i at time t.
- GR_{ij} is the radiative conductance parameter for a radiative coupling between elements i and j, equal to its (Boltzmann's Constant)(area)(emissivity)(gray body view factor) product value.
- α is the explicit-implicit weighting factor, between 0 and 1. For Crank-Nicolson $\alpha = .5$ for forward and exponential forward differencing $\alpha = 0$ and for backward differencing $\alpha = 1$. For steady state analysis $\alpha = 1$.

- dt is the integration time step. For steady state analysis dt = infinity.
- T_{ABS} is the absolute value of absolute zero.

Since the equation is non-linear, the Newton-Raphson Method is used. A first-order Taylor series expansion for $\sum(T_{j,t+dt,n+1} + T_{ABS})^4 GR_{ij}$ about $T_{j,t+dt,n}$ and for $\sum(T_{j,t+dt,n+1} + T_{ABS})^4 \sum GR_{ij}$ about $T_{i,t+dt,n}$ is performed:

$$\sum(T_{j,t+dt,n+1} + T_{ABS})^4 GR_{ij} = \sum GR_{ij}(T_{j,t+dt,n} + T_{ABS})^4 +$$
$$\sum 4GR_{ij}(T_{j,t+dt,n} + T_{ABS})^3 (T_{j,t+dt,n+1} + T_{j,t+dt,n})(T_{i,t+dt,n+1} + T_{ABS})^4 \sum GR_{ij}$$
$$= (T_{i,t+dt,n} + T_{ABS})^4 \sum GR_{ij} + 4(T_{i,t+dt,n} + T_{ABS})^3 (T_{i,t+dt,n+1} - T_{i,t+dt,n}) \sum GR_{ij}$$

Substituting into the energy balance equation yields:

$$\frac{-C_{i,t}(T_{i,t+dt,n+1} - T_{i,t})}{dt} + Q_{I,t+\alpha dt} +$$
$$(1-\alpha)(\sum T_{j,t} GC_{ij} - T_{i,t} \sum GC_{ij} + \sum(T_{j,t} + T_{ABS})^4 GR_{ij} -$$
$$(T_{i,t} + T_{ABS})^4 \sum GR_{ij}) + \alpha(\sum T_{j,t+dt,n+1} GC_{ij} - T_{i,t+dt,n+1} \sum GC_{i,j} +$$
$$\sum GR_{ij}(T_{j,t+dt,n} - T_{ABS})^4 + \sum 4GR_{ij}(T_{j,t+dt,n} + T_{ABS})^3 (T_{j,t+dt,n+1} - T_{j,t+dt,n}) +$$
$$(T_{i,t+dt,n} + T_{ABS})^4 \sum GR_{ij} - 4(T_{i,t+dt,n} + T_{ABS})^3 (T_{i,t+dt,n+1} - T_{i,t+dt,n}) \sum GR_{ij}) = 0$$

Recasting this equation into the matrix form:

$$[GG]\{T_{t+dt,\,n+1}\} + \{B\}$$

yields:

$$B_i = -\frac{\frac{C_{i,t}T_{i,t}}{dt} + Q_{i,t+\alpha dt}}{\alpha} + (\frac{1}{\alpha} - 1)(\sum GC_{ij}(T_{j,t} - T_{i,t}) + \sum GR_{ij}((T_{j,t} + T_{ABS})^4 -$$
$$(T_{i,t} + T_{ABS})^4)) + \sum GR_{ij}(-(T_{j,t+dt,n} + T_{ABS})^4 + 4(T_{j,t+dt,n} + T_{ABS})^3 T_{j,t+dt,n} +$$
$$(T_{i,t+dt,n} + T_{ABS})^4 - 4(T_{i,t+dt,n} + T_{ABS})^3 T_{i,t+dt,n})$$

when `i` is not equal to `j:`

$$GG_{ij} = GC_{ij} + 4GR_{ij}(T_{j,t+dt,n} + T_{ABS})^3$$

when `i = j`:

$$GG_{ij} = -\frac{C_{i,t}}{\alpha dt} - \sum GC_{ij} - 4(T_{i,t+dt,n} + T_{ABS})^3 \sum GR_{ij}$$

where:

- GG_{ij} is the matrix term of the i'th row and j'th column
- B_i is the right hand side

For sink temperatures:

$$GG_{ii} = -1$$
$$B_i = -T_{i,t}$$

The matrix is solved with the biconjugate-stabilized version of the conjugate gradient technique (Ref. 2). The matrix convergence parameters can be set on **Card 9** PARAM ILU.

Convergence is considered to be achieved if the value of the norm of the expression below is `< T2`.

$$\left| \frac{[GG\{T\}-\{B\}]}{B} \right| < T2$$

where:

- $T2$ is a convergence parameter specified on Card 9 PARAM ILU. $T2$ defaults to `1.E-8.`

To accelerate convergence, an approximate inverse matrix is used as a preconditioner. The preconditioning matrix is created using the Incomplete Lower-Upper factorization method. LFIL is the maximum number of terms in each row of the preconditioning matrix, and its initial value defaults to 10. LFIL may be redefined on a **Card** 9 PARAM ILU Card.

The preconditioning matrix is created once every 10 iterations for steady-state runs, and once every 10 integration time steps for transient runs. In addition, before every solution the diagonal terms of the GG matrix are checked to see if they have changed since the last time the preconditioning matrix was updated. If they have changed by more than 100%, the preconditioning matrix is automatically updated.

If the conjugate gradient solver does not converge after 100 iterations, one of two actions is taken. If the pattern of convergence is good, then the maximum number of allowable iterations is increased to 200, 300, etc. If the pattern of convergence is not good, then the LFIL value of the preconditioning matrix is automatically increased in increments of 10 to a maximum value of 200, and the preconditioning matrix is re-created until convergence is achieved.

If the forward differencing or exponential forward differencing methods are specified, then only a single iteration per time step is used as the default. This assumes that the conductance matrix remains constant during the integration time step.

Hydraulic Elements

The function of hydraulic elements is to model mass and heat transport and the associated free and forced convection mechanisms in 1-dimensional duct network fluid flow.

Each hydraulic element belongs to two coupled networks: the pressure/flow hydraulic network and the temperature/heat flow thermal network. The element is connected to the hydraulic network with flow resistances, and to the thermal network with convective and 1–way conductances.

The two networks are bidirectionally coupled because convective and 1–way conductances are functions of the mass flow through the element, and buoyancy forces, density, and flow resistances are functions of temperature.

Two types of hydraulic elements may be specified Card 5a: 1–node AMBIENT, `FLOWSEC`, and `BLSTART` elements, and 2–node `DUCT`, `FLOWRES`, and `FANPUMP` elements.

1-node hydraulic elements

A 1–node `FLOWSEC` hydraulic element defines the cross–sectional properties (area and hydraulic diameter) at its location.

A `BLSTART` element is similar to a `FLOWSEC` element, except that it also defines the start of the boundary layer for convective conductance calculations.

An `AMBIENT` element is a very large area pressure and temperature sink element used to define a flow boundary condition.

2-node hydraulic elements

A 2–node hydraulic element defines the total pressure drop or total pressure rise across it.

A `DUCT` element models length–dependent pressure drops.

A `FLOWRES` element models length–independent pressure drops.

Mass flow, volume flow, velocity, and total pressure rise boundary conditions are defined on `FANPUMP` elements.

The center of each 2–node hydraulic element is automatically connected to the upstream and downstream 1–node hydraulic elements with two equal hydraulic flow resistances and 1–way fluid flow thermal conductances.

Optionally, convective conductances between 2–node hydraulic elements and other thermal elements may be defined with the Card 6e NEARCx options.

Flow branches

A flow branch is a series of connected 2-node hydraulic elements ending in either a 1–node hydraulic element or in a junction with two or more flow branches.

The same forward direction should be specified for all the 2-node hydraulic elements in a flow branch, i.e. from node 1 to node 2. This is the assumed initial flow direction in the flow branch.

In case of a direction inconsistency in the assumed flow direction, the orientation of a hydraulic element will be automatically reversed and a warning message will be given. Flow reversals due to pressure changes will also be automatically be computed.

Each hydraulic element must have its cross–sectional and flow properties defined, for a 2–node hydraulic element these are defined by the 1–node elements at its ends.

To define cross-sectional and flow properties for a flow branch, it is sufficient to specify a single 1-node hydraulic element at the most upstream location. New downstream `FLOWSEC` hydraulic elements with the same cross–sectional and fluid properties will be automatically created until a new `FLOWSEC` or `BLSTART` element is encountered.

AMBIENT elements

Each hydraulic element must have a path to either an `AMBIENT` element, or to an element whose total pressure is fixed with a Card 9 PSINK Card.

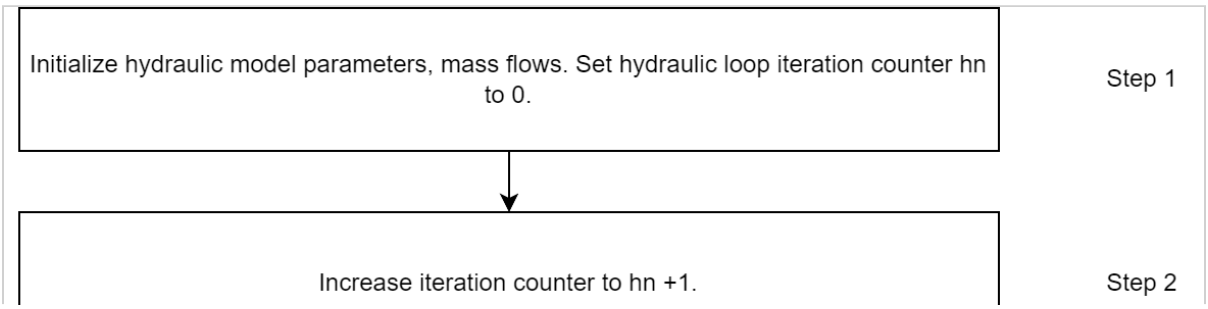
Models with hydraulic elements must have at least one `AMBIENT` element defined.

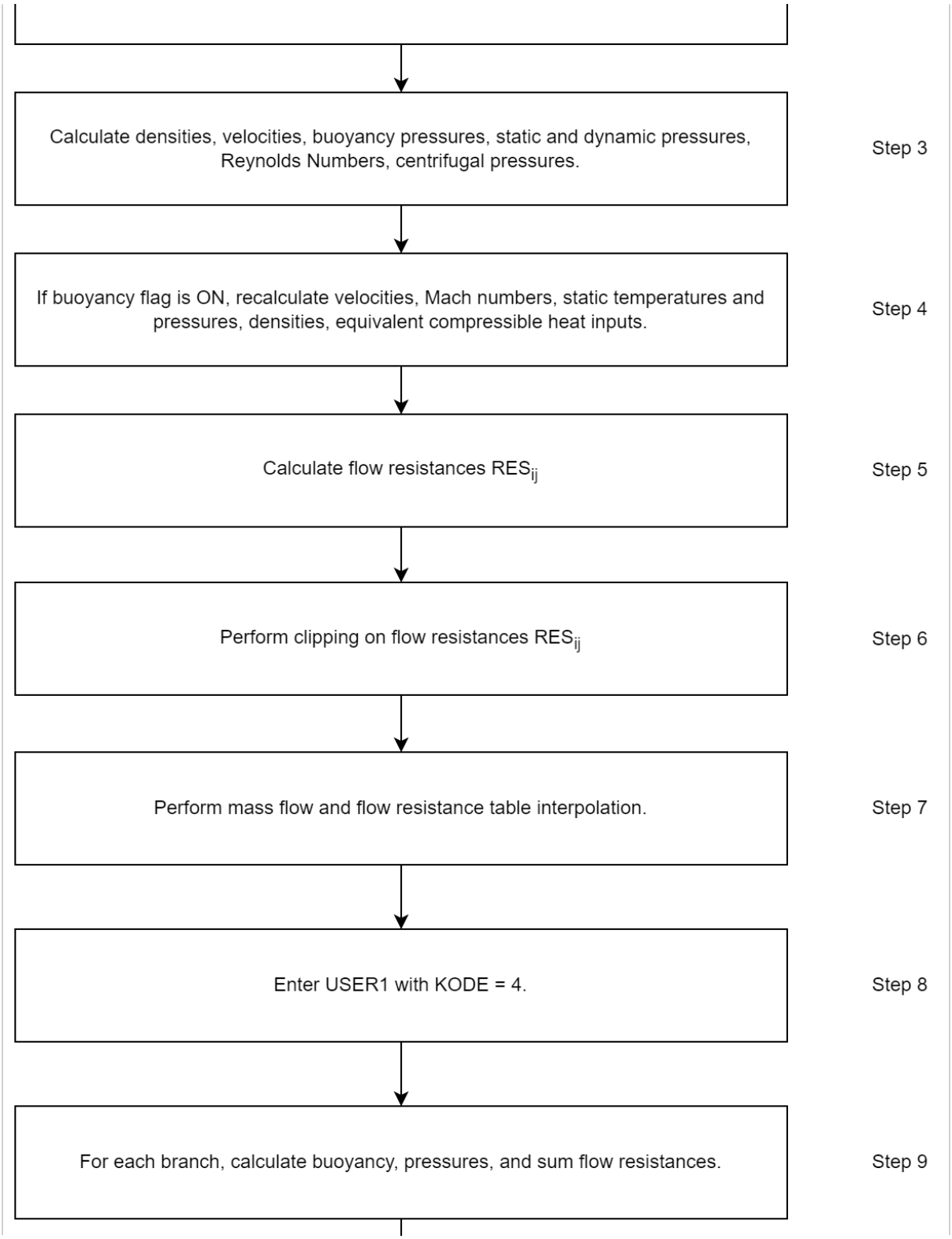
The hydraulic environment (ambient temperature, static pressure) must be defined with a Card 9 HYDENV Card. These will define the boundary conditions for `AMBIENT` elements.

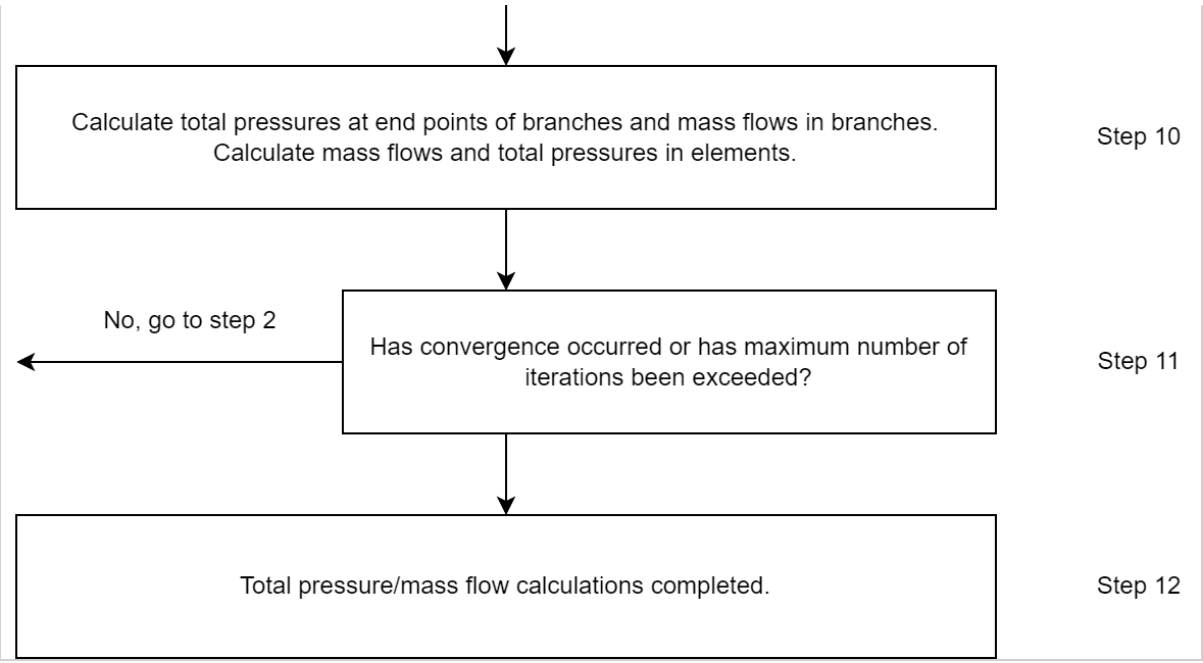
`AMBIENT` element at the dangling ends of a flow branches will be automatically created unless a `FLOWSEC` or `BLSTART` element is specified there.

Hydraulic Network Analysis

At each iteration or time step (see Steady State Analysis: Step 2 of the Steady State Analysis Flowchart) the hydraulic pressure-flow network is solved. The following algorithm is used:




Calculate densities, velocities, buoyancy pressures, static and dynamic pressures, Reynolds Numbers, centrifugal pressures.
Step 3
If buoyancy flag is ON, recalculate velocities, Mach numbers, static temperatures and pressures, densities, equivalent compressible heat inputs.
Step 4
Calculate flow resistances RES_{ij}
Step 5
Perform clipping on flow resistances RES_{ij}
Step 6
Perform mass flow and flow resistance table interpolation.
Step 7
Enter USER1 with KODE = 4.
Step 8
For each branch, calculate buoyancy, pressures, and sum flow resistances.
Step 9



Step 1: Initialization

If mass flows have been calculated in a previous time step or iteration, then the previously calculated values are used.

If no mass flows have yet been calculated for any of the hydraulic elements, all mass flows $MASSFL_{IJ}$ are initialized for 2–node hydraulic elements with a duct Reynolds Number = 10000.

The first time the hydraulic loop is entered, the initial total pressures PT of non–PSINK elements are set to zero and the initial static pressures P_S are set to zero gauge pressure.

Step 2: Increase Iteration Counter

The iteration counter is increased.

Step 3: Calculate Densities, Buoyancy Forces, etc.

Next, if the mass flow through a flow resistance is entirely due to buoyancy forces, to increase the stability of the solution the change in mass flow from that of the previous iteration is multiplied by the Card 2b damping factor DT or TRDMP.

Next, the duct Reynolds Numbers are computed.

$$Re_{duct} = \frac{MASSFL_{IJ} D_{duct}}{A\mu}$$

D_{duct} is the hydraulic diameter of the element

A is the cross–sectional area of the element

μ is the viscosity of the fluid

$MASSFL_{IJ}$ is the mass flow through a hydraulic flow resistance between elements I and J

RE_{duct} is the duct Reynolds Number

The mass flows are then checked to see whether they fall outside the limits of $1 < RE_{duct} < 10^8$. If the mass flows fall outside this limit, they are appropriately adjusted.

Next, if the compressible flow option (Card 9 PARAM COMPRESS) is not specified, the density for gases is computed using the Ideal Gas Law:

$$\rho = \frac{P_S}{R_U(T + T_{ABS})}$$

where:

- ρ is the density at the element
- P_S is the static pressure
- T is the temperature of the element
- T_{ABS} is the absolute temperature
- R_U is the Universal Gas Constant

$$\mathrm{R_U} = \frac{\mathrm{P_{SENV}}}{\rho_{\mathrm{nominal}}(\mathrm{T_{ENV}} + \mathrm{T_{ABS}})}$$

- $\mathrm{T_{ENV}}$ is the standard temperature defined on the Card 9 HYDENV Card
- $\mathrm{P_{SENV}}$ is the standard pressure defined on the CARD 9 HYDENV Card
- ρ is the nominal fluid density defined on the Card 9 MAT Card for the AMBIENT elements

For liquids the change in density = 0.

Next, in order to avoid large solution oscillations, a check is performed to see whether the change in density from that of the previous value brings the new computed density below 25% of the nominal density specified on the MAT Card for the element. If it does, the change in density is clipped. Then, the change in density is damped by multiplying it with the Card 2b DT or TRDMP parameter.

Next, the buoyancy pressure rise over each 2-node hydraulic element is computed:

$$DELTA_{PB} = g(\rho - \rho_{ambient})DELTA_{HEIGHT}$$

where:

- $DELTA_{PB}$ is the buoyancy pressure increase over the element.
- g is the acceleration of gravity, defined on the Card 9 HYDENV Card.
- $\rho_{ambient}$ is the density of the ambient air at standard temperature and pressure, defined on Card 5a AMBIENT Card's MAT Card.
- $DELTA_{HEIGHT}$ is the difference in elevation between the two ends of the 2–node hydraulic element.

Next, the flow velocities are computed:

$$\mathrm{V} = \frac{\mathrm{MASSFL_{IJ}}}{\mathrm{A}\rho}$$

where:

- V is the velocity

Next, the dynamic pressures are computed:

$$\mathrm{P_D} = \frac{\rho \mathrm{V}^2}{2}$$

where:

- $\mathrm{P_D}$ is the dynamic pressure

Next, the static pressures are recomputed:

$$P_S = P_T - P_D$$

Centrifugal effects calculation

If a Card 9 PARAM CENTRIFUG Card is specified, $DELTA_{PB}$ is calculated by:

$$\mathrm{DELTA_{PB}} = \frac{\omega^2 \rho_{CG} (H1^2 - H2^2)}{2}$$

where:

- ρ_{CG} is the density at the CG of the element
- ω is the circular frequency of the centrifugal force
- $H1, H2$ are the perpendicular distances of the two ends of the hydraulic element from the axis of rotation.

Step 4: Compressible Flow Calculations

If the compressible flow option is specified with Card 9 PARAM COMPRESS, the density and static pressure calculations take into account compressible effects for all elements with Mach numbers > .1. For elements with Mach numbers > .1, the following procedure is followed.

First, for each two-node hydraulic element I, the upstream velocity, density, and static pressure are calculated from the upstream temperature, mass flow, and total pressure:

$$P_{SU} = \frac{2PT_U A_U + 2\sqrt{PT_U{}^2 A_U{}^2 - 2MASSFL_{IJ}{}^2 R_U (T_U + T_{ABS})}}{4A_U}$$

$$\rho_U = \frac{2PT_U A_U + 2\sqrt{PT_U{}^2 A_U{}^2 - 2MASSFL_{IJ}{}^2 R_U (T_U + T_{ABS})}}{(4A_U R_U (T_U + T_{ABS}))}$$

$$V_U = \frac{4MASSFL_{IJ} R_U (T_U + T_{ABS})}{(2PT_U A_U + 2\sqrt{PT_U{}^2 A_U{}^2 + 2MASSFL_{IJ}{}^2 R_U (T_U + T_{ABS})})}$$

where:

- V_U is the upstream velocity,
- A_U is the upstream cross-sectional area,
- ρ_U is the upstream density
- T_U is the upstream temperature
- P_{SU} is the upstream static pressure
- PT_U is the upstream total pressure
- $MASSFL_{IJ}$ is the mass flow through the hydraulic element
- T_{ABS} is the absolute temperature
- R_U is the Universal Gas Constant

Next, the upstream Mach number is calculated using the ratio of the specific heats and the upstream temperature:

$$MACH_U = \frac{V_U}{\sqrt{k_{ratio} R_U (T_U + T_{ABS})}}$$

where:

- $MACH_U$ is the upstream Mach number,
- k_{ratio} is the ratio of the specific heat at constant pressure to the specific heat at constant volume (fixed at 1.4),

Next, the upstream stagnation temperature is computed:

$$T_{SU} = (T_U + T_{ABS})(1 + \frac{(k_{ratio} - 1) MACH_U{}^2}{2})$$

where:

- T_{SU} is the upstream stagnation temperature

Next, the net heat input per unit mass flow for the hydraulic element `I` is computed:

$$Q_{unit} = \frac{Q_I + GTSUM_I - T_I GSUM_I - MASSFL_{IJ} C_P (T_U - T_I)}{MASSFL_{IJ}}$$

where:

- C_p is the specific heat for the element.
- Q_{unit} is the net heat input per unit mass flow for the hydraulic element
- $GTSUM_I$ is the sum of the conductances times connected element temperatures for element `I`
- Q_I is heat input into hydraulic element `I`
- $GSUM_I$ is the sum of the conductances of element `I`
- Q_I is the net heat input per unit mass flow for the hydraulic element `I`
- T_I is the temperature of element `I`

Next, the downstream stagnation temperature is T_{SD} computed:

$$T_{SD} = T_{SU} + \frac{Q_{unit}}{Cp}$$

where:

- T_{SD} is the downstream stagnation temperature. T_{SD} is only affected by the heat input into the flow.

Next, the equivalent friction parameter K_{LOSSEQ} for the hydraulic element is computed. For non-FANPUMP elements:

$$K_{LOSSEQ} = K_{loss}$$

and for FANPUMP elements:

$$K_{LOSSEQ} = K_{LOSS} + \frac{PT_D - PT_U}{P_D}$$

where:

- PT_D is the downstream total pressures of the FANPUMP element.
- K_{LOSSEQ} is the equivalent friction parameter
- K_{LOSS} is the head loss factor
- P_D is the dynamic pressure of the element at its narrower end

Next, the differential equation for $M^2(x)$, the square of the Mach number at a normalized distance `x` along the hydraulic element is solved:

$$\frac{dM^2(x)}{dx} = \left(\frac{M^2(x)(1+\frac{(k_{ratio}-1)M^2(x)}{2}}{1-M^2(x)}\right)\left(-2\ln\left(\frac{A_D}{A_U}\right)+1n\left(\frac{T_{SD}}{T_{SU}}\right)+k_{ratio}M^2(x)\left(1n\left(\frac{T_{SD}}{T_{SU}}\right)+KLOSSEQ\right)\right)$$

where

- A_D is the downstream cross-sectional area.
- $M^2(x)$ is the square of the Mach number at a distance `x` in the element

Applying the boundary condition:

$$M^2(0) = {MACH_U}^2$$

where:

- $MACH_U$ is the upstream Mach number.

The downstream Mach number is then computed from:

$$MACH_D = \sqrt{M^2(1)}$$

where:

- $MACH_D$ is the downstream Mach number

The following limitation is imposed:

$$0 < MACHD < 1$$

When choke flow $(MACH_D \sim 1)$ occurs, a warning message is written to the verbose log file.

Next, the downstream temperature T_D is estimated:

$$T_D = (T_U + T_{ABS}) \frac{\left(1 + (\frac{k_{ratio}-1)MACH_U^2}{2}\right)}{T_{SU}\left(1 + \frac{(k_{ratio}-1)^2}{2}\right)} - T_{ABS}$$

where:

- T_D is the downstream temperature.

Next, the downstream static pressure P_{SD} is calculated:

$$P_{SD} = P_{SU} A_U MACH_U \frac{\sqrt{\frac{T_D+T_{ABS}}{T_U+T_{ABS}}}}{A_D MACH_D}$$

where:

- P_{SD} is the downstream static pressure
- P_{SU} is the upstream static pressure

Next, the downstream velocity is computed:

$$V_D = MACH_D \sqrt{k_{ratio} R_U (T_D + T_{ABS})}$$

where:

- V_D is the downstream velocity

Next, the downstream density is computed from:

$$\rho_D = \frac{MASSFL_{IJ}}{V_D A_D}$$

where:

- ρ_D is the downstream density.

Next, in order to compute the downstream temperature using the standard temperature computational routines Q_{CD} is computed:

$$Q_{CD} = (\rho C_p (T_D - T_U) - Q_{unit}) MASSFL_{IJ}$$

where:

- Q_{CD} is an equivalent compressible heat input value which is applied to the immediately downstream 1-node hydraulic element to account for the compressible heating effects. Q_{CD} is summed with all the other heat inputs into the downstream element.

Next, the downstream total pressure is estimated:

$$PT_D = P_{SD} + \frac{\rho_D V_D^2}{2}$$

where:

- PT_D is the downstream total pressure

Next, the flow resistance RES_{IJ} is computed for the duct:

$$RES_{IJ} = \frac{P_{TU} - P_{TD}}{MASSFL_{IJ}}$$

where:

- RES_{IJ} is the value of the hydraulic flow resistance.

Next, the friction heating effects on the wall are computed. Due to friction, under adiabatic conditions the wall temperature will approximately equal the temperature of the stagnation temperature of the fluid. To model this effect, first the difference between the static and dynamic temperatures is computed for the 2-node hydraulic element I:

$$TDIFF_I = (T_I + T_{ABS})(k_{ratio} - 1)\frac{MACH_U^2}{2}$$

where:

- $TDIFF_I$ is the difference between the temperature and stagnation temperature of the fluid at the center of the element.

Next, for each wall element connected to the fluid element with convective conductance an additional heat input Q_{WALLI} is computed.

$$Q_{WALLI} = GSUM_I TDIFF_I$$

where:

- Q_{WALLI} is the corrective heat input applied element I to account for the friction heating effects. To maintain energy conservation, Q_{WALLI} is also subtracted from Q_I.

Step 5: Calculation of Hydraulic Flow Resistances RES_{IJ}

Next, if compressibility effects are not taken into account, flow resistances RES_{IJ} are computed as described in Evaluating Hydraulic Flow Resistances for Incompressible Flows.

Step 6: Clipping RES_{IJ}

If the fractional change between two subsequent iterations in the value of a hydraulic flow resistance is greater than the hydraulic iteration damping parameter defined with Card 9 PARAM HYDDAMP (or the Card 2b DT or TRDMP parameter if a PARAM HYDDAMP is not present), the change in the flow resistance is appropriately clipped. This is done to avoid solution oscillations.

Step 7: Table Interpolation

Next, table interpolations are performed. Table interpolation may be used to multiply computed hydraulic flow resistances (see the section on Evaluating Hydraulic Flow Resistances below), and to calculate FANPUMP mass flows and pressure rises.

Each 2–node FANPUMP element must reference a table, which is used to specify velocities, mass flows, or total pressure rise as a function of mass or volume flow through the element.

Velocities and volume flows are transformed into mass flows using the fluid density and FANPUMP cross–sectional area values. These in turn are transformed into a mass flow couple $-MASSFL_{IJ}$ at the inlet and $+MASSFL_{IJ}$ at the outlet 1-node elements of the FANPUMP element.

The FANPUMP element itself has an infinite hydraulic flow resistance.

The total pressure at the center of the FANPUMP element is estimated to be the average value of the total pressures at the end elements.

If total pressure rise DELTA PT as a function of mass flow is specified for a FANPUMP element, first the mass flows in and out of the end elements are computed from the current estimates of the flow resistances from the ends of the FANPUMP element and the total pressures of the elements they are joined to. Then, the $DELTA_{PT}$ value over the FANPUMP element is interpolated from the table using the average of these mass flow values. The PT_{CG} value at the CG of the FANPUMP element is estimated to be the average of the total pressures values of the end elements. Last, the total pressures of the end elements are then computed to be $PT_{CG} + DELTA_{PT}/2$, and $PT_{CG} - DELTA_{PT}/2$ the end elements are defined to be pressure sink elements.

Step 8: Entering USER1 with KODE = 4

Next, the user–written subroutine is entered with $KODE = 4$. At this time, you can alter hydraulic flow resistances and total pressures for sink elements.

Step 9: Branch Buoyancy Pressure Calculations

Next, the total buoyancy pressures δ, the total flow branch flow resistances RES_{TOT}, and the buoyancy–driven mass flow $MASSFL_{PB}$ are computed for each flow branch.

$$MASSFL_{PB} = \frac{DELTA_{PBTOT}}{RES_{TOT}}$$

where:

- $MASSFL_{PB}$ is the computed mass flow through the flow branch due to buoyancy effects in the flow branch.
- $DELTA_{PBOT}$ is the sum of the buoyancy pressures in the flow branch computed by summing the buoyancy pressures of each element over the branch.
- RES_{TOT} is the total hydraulic flow resistance of the flow branch.

Once $MASSFL_{PB}$ is computed, it is modeled as a mass flow couple $+MASSFL_{PB}$ and $-MASSFL_{PB}$ mass flow boundary conditions are added at the beginning and end 1-node elements of the flow branch.

Step 10: Calculation of Total Pressures and Mass Flows in Branches

Once the mass flow inputs and total pressure values for the pressure sink elements are defined, the matrix is simplified by reducing it to flow branches. Here the flow branches are as defined above, with the exception that the endpoints of a FANPUMP element are considered to consist of the start of a new flow branch. The purpose of the simplification is to reduce the size of the matrix to be solved.

The simplification consists of summing the flow resistances in a flow branch.

Next, the total pressures at the endpoints of each flow branch are computed from the mass balance equation, i.e. the sum of the mass flows into each hydraulic element must be zero.

$$MASSIN_{IE} + \sum_{JE} MASSFL_{IE,JE} = 0$$

$$MASSFL_{IE,JE} = \frac{PT_{JE} - PT_{IE}}{RES_{IE,JE}}$$

hence:

$$MASSIN_{IE} + \sum_{JE} (PT_{JE} - PT_{IE}) RES_{IE,JE} = 0$$

where:

- $_{IE,JE}$ are 1-node elements at the ends of a flow branch
- $MASSIN_{IE}$ is the impressed mass flow into element I, computed from FANPUMP elements and from $MASSFL_{PB}$ couples.
- PT_{IE}, PT_{JE} are the total pressure values at elements $_{IE}$ and $_{JE}$ where
- $MASSFL_{IE,JE}$ is the mass flow through hydraulic flow resistance $RES_{IE,JE}$

This matrix equation is solved by a conjugate–gradient sparse matrix inversion routine.

Calculation of Mass Flows through Elements

Next, the total pressures PT_I for each element I in each branch are calculated from the computed total pressures PT_{IE} and PT_{JE}. Starting from the end IE, the first total is computed:

$$PT_I = PT_{IE} + MASSFL_{IE,JE} RES_{I,JE}$$

and so on.

Next, the mass flows are computed:

$$MASSFL_{IJ} = MASSFL_{IE.JE}$$

Step 11: Checking for Convergence

Next, if no clipping has been performed on any conductances, the maximum total pressure change for any element from that of the previous iteration is evaluated and is compared with PDMAX, the maximum allowable total pressure change for convergence to have occurred. PDMAX defaults to 1% of the difference between the maximum and minimum total pressure values in the model, but may be overridden on a Card 9 PARAM PDMAX Card.

If the solution has not converged, the sequence of steps from Step 2 onwards are repeated.

If the solution has not converged after the maximum number of iterations, a warning message is printed to the verbose log file. The maximum number of iterations defaults to 100, however this may be overridden by a PARAM HYDLOOP Card. Convergence trace may be printed out with the PRINT HYDTRACE Card.

Evaluating Hydraulic Flow Resistances for Incompressible Flows

Hydraulic resistances are modeled with 2–node hydraulic elements. FLOWRES elements model length–independent pressure drops, while DUCT elements model length–dependent pressure drops. For both, the non–linear flow resistance is determined by the K_{LOSS} parameter.

$$PT_I - PT_J = K_{LOSS} P_D = RES_{IJ} MASSFL_{IJ}$$

hence:

$$RES_{IJ} = \frac{K_{LOSS} P_D}{MASSFL_{IJ}}$$

where:

- K_{LOSS} is the head loss factor

For FLOWRES elements the K_{LOSS} parameter is defined by:

$$K_{LOSS} = K_{PROP} K_{TABLE}$$

where:

- K_{PROP} is the nominal head loss factor specified on the PROP Card
- K_{TABLE} is a multiplying factor interpolated from table (default = 1)

For DUCT elements K_{LOSS} is computed from:

$$K_{LOSS} = K_{PROP} K_{TABLE} R_F$$

where:

- R_F is the flow resistance factor computed for the element.

Three types of DUCT element configurations are possible: straight ducts, diffusers (where the flow widens), and nozzles (where the flow contracts). The flow direction and the ratio of the areas of the 1–node elements at its ends determine the type of DUCT element configuration.

Straight Ducts

For straight ducts fully developed duct flow is assumed, and R_F is computed from:

$$R_F = \frac{4fL}{D_{duct}}$$

where:

- f is the Fanning friction factor
- D_{duct} is the hydraulic diameter of the duct = 4A/U
- A is the cross–sectional area of the duct
- U is the perimeter of the duct
- L is the length of the duct

In evaluating f, rectangular cross–section ducts are assumed.

For laminar flow f is computed with the following approximate relationship (derived from data presented in Thermal Computations for Electronic Equipment by Gordon N. Ellison, Van Nostrand Reinhold Co., 1984).

$$f = \frac{24 - 10\left(\frac{D_{duct}^2}{A}\right)}{Re_{duct}} \text{ for } 1 < Re_{duct} < 2300$$

For turbulent flow the following approximate relationships are used:(Handbook of Heat Transfer Fundamentals, 2nd. Ed., by Rohsenow, Hartnett, and Ganic, McGraw-Hill, 1985):

$$f = \frac{.079}{Re_{duct}^{1/4}} \text{for } 2300 < Re_{duct} < 30000$$

$$f = \frac{.046}{Re_{duct}^{1/5}} \text{for } 30000 < Re_{duct} < 1.E6$$

Nozzles and Diffusers

For nozzles and diffusers the angles α and β are defined (Handbook of Hydraulic Resistance – Coefficients of Local Resistance and of Friction by I.E. Idel'chick, 1960):

$$\alpha = 2\tan\left(\frac{SE1-SE2}{2L_D}\right)$$
$$\beta = 2\tan\left(\frac{SI1-SI2}{2L_D}\right)$$

where:

- $SE1$ is the larger side of the exit
- $SE2$ is the larger side of the inlet
- $SI1$ is the smaller side of the exit
- $SI2$ is the smaller side of the inlet
- L_D is the length of the nozzle or diffuser

α is assumed > β. If $\alpha < \beta$, the two are reversed. α can take on a maximum value of 40 degrees. If α > 40 degrees, α = 40 degrees is used.

Next, a friction coefficient is defined:

$$\Psi_{FR} = \frac{f}{16}\left(1-\left(\frac{A1}{A2}\right)^2\right)\left(\frac{1}{\sin(\frac{\alpha}{2})}+\frac{1}{\sin(\frac{\beta}{2})}\right)$$

for $\beta > .5$ degrees, and

$$\Psi_{FR}\left(\frac{f}{4\sin(\frac{\alpha}{2})}\right)\left(\left(\frac{SE1}{SI2}\right)\left(1-\frac{A1}{A2}\right)=\frac{1}{2}\left(1-\left(\frac{A1}{A2}\right)^2\right)\right)$$

for $\beta < .5$ degrees.

where:

- $A1$ is the area at the narrower end
- $A2$ is the area at the larger end
- Ψ_{FR} is the friction coefficient

For diffusers, a shock and an expansion coefficient are defined at the narrower end:

$$\Psi_{EXP} = 4\tan\left(\frac{\alpha}{2}\right)^{1.25}$$
$$Z_{EXP} = \Psi_{EXP}\left(1-\frac{A1}{A2}\right)^2 \text{ for Reduct} > 2300$$
$$Z_{EXP} = 0 \qquad \text{for Reduct} < 2300$$

where:

- Ψ_{EXP} is the shock coefficient
- Z_{EXP} is the expansion coefficient

Then the flow resistance factor for a diffuser is:

$$R_F = 4\Psi_{FR} + Z_{EXP}$$

For nozzles a length to hydraulic diameter ratio is defined:

$$R_{LD} = \frac{L}{D1}$$

where:

- $D1$ is the hydraulic diameter at the narrower end
- R_{LD} is the length to hydraulic diameter ratio

Next, an interpolation parameter R_{INT} is computed:

$$\begin{aligned} R_{INT} &= .5 - 4R_{LD} && \text{for } 0 < R_{LD} < .05 \\ R_{INT} &= .4 - 2R_{LD} && \text{for } .05 < R_{LD} < .15 \\ R_{INT} &= .1 && \text{for } .15 < R_{LD} \end{aligned}$$

Next, the parameter is Z' defined and the flow expansion coefficient Z_{EXP} is calculated:

$$\begin{aligned} Z' &= 0.5 - R_{INT}(\frac{\alpha}{50}) && \text{for } \alpha < 50 \\ Z' &= R_{INT} + \frac{(0.5 - R_{INT})(\alpha - 50)}{180 - 50} && \text{for } \alpha > 50 \\ Z_{EXP} &= Z'\left(1 - \frac{A1}{A2}\right)^2 && \text{for } \mathrm{Re}_{duct} > 2500 \\ Z_{EXP} &= Z'\left(1 - \frac{A1}{A2}\right)^2 \left(\frac{(\mathrm{Re}_{duct} - 2300}{200}\right) && \text{for } 2300 < \mathrm{Re}_{duct} < 2500 \\ Z_{EXP} &= 0 && \text{for } \mathrm{Re}_{duct} < 2300 \end{aligned}$$

Then the flow resistance factor for a nozzle is:

$$R_F = 4\Psi_{FR} + Z_{EXP}$$

Duct Geometry Consideration for Rough and Curved Ducts

For fully developed flow through straight, smooth ducts, TMG currently supports a wide range of friction factor and heat transfer correlations for different duct geometries. Corresponding reliable correlations for rough or curved ducts do not exist for all these geometries. Indeed, the only comprehensive set of correlations is for ducts with circular cross sections

(pipes). To fully extend TMG's geometry dependent correlations to rough and curved ducts, the following approximations are made:

$$f_{rough} = f_{smooth}\left(\frac{f_{rough,\ circular}}{f_{smooth,\ circular}}\right)$$

i) The coefficient for the rough duct is the coefficient for the smooth duct of the appropriate geometry times the ratio of the rough and smooth coefficients for circular geometry. i.e.,

$$f_{curved} = f_{straight}\left(\frac{f_{curved,\ circular}}{f_{straight,\ circular}}\right)\frac{\pi\phi R}{180L}$$

ii) As above, the coefficient for the curved duct is the coefficient for the straight duct of the appropriate geometry, times the ratio of the curved and straight coefficients for circular geometry.

$$NU_{rough} = NU_{smooth}\left(\frac{NU_{rough,\ circular}}{NU_{smooth,\ circular}}\right)$$

An extra factor is also used to account for the increased length of the curved duct compared to the straight-line distance between the end nodes of the duct. i.e.,

$$NU_{curved} = NU_{straight}\left(\frac{NU_{curved,\ circular}}{NU_{straight\ circular}}\right)\frac{\pi\phi R}{180L}$$

where:

- ϕ is the angle of the bend in degrees,
- R is the radius of curvature of the bend, and
- L is the straight-line distance between the end nodes of the element.

iii) The coefficients for circular geometry given above are evaluated using the hydraulic diameter of the duct.

All correlations given in sections 3 to 5 are for circular ducts. Additionally, it is approximated that the flow is fully developed.

Rough Duct Correlations

Friction Factors

i.) Laminar Flow: Re `< 2300`

In the case of purely laminar flow, the roughness has no influence on the friction factor, which is given by:

$$f = \frac{16}{Re}$$

Re is the Reynolds number, given by $\mathrm{Re} = \frac{D_h u_m}{\upsilon}$.

ii.) Turbulent Flow Re ≥ 4000

It is noted that the experiments of Nikuradse are often cited as having identified three different friction factor regimes during turbulent flow in rough pipes. These experiments, however, were performed using smooth pipes with grains of sand of “uniform” size glued to them. His results are not typical for the roughness typically found in commercial rough pipes. Therefore, the results of Colebrooke, on which the Moody diagram is based are used over those of Nikuradse.

$$\mathrm{f_{smooth}} = \left[1.56351\mathrm{n}\left(\frac{\mathrm{Re}}{7.0}\right)\right]^{-2}$$

ii.a) For smooth circular pipes, the friction factor is of the form . The most suitable correlation in t his regime is that given by Colebrook,

ii.b) For rough pipes, the friction factor correlation is of the form.

$$\mathrm{f} = \mathrm{f}\left(\frac{\varepsilon}{\mathrm{D_h}}, \mathrm{Re}\right)$$

The correlation by Jain is the most accurate explicit formula that approximates the original implicit correlation by Colebrooke.

iii.) Transition to Turbulent Flow: $2300 < \mathrm{Re} < 4000$

$$\mathrm{f_{rough}} = \left[3.4841 - 1.7372\ 1\mathrm{n}\left(\frac{2\varepsilon}{D_h} + \frac{42.5}{\mathrm{Re}^{0.9}}\right)\right]^{-2}$$

There is little accurate data for this region. We would like a function which creates a continuous transition from laminar to turbulent conditions. We use a linear joining function between the laminar and turbulent friction factors, given by:

$$\begin{aligned}\mathrm{f} &= \mathrm{f_{2300}} + \left(\frac{\mathrm{Re} - 2300}{4000 - 2300}\right)(\mathrm{f_{4000}} - \mathrm{f_{2300}}) \\ &= 6.956 \text{ x } 10^{-3} + \left(\frac{\mathrm{Re} - 2300}{1700}\right)(\mathrm{f_{4000}} - 6.956 \text{ x } 10^{-3})\end{aligned}$$

$\mathrm{f_{4000}}$ depends on the roughness.

Nusselt Numbers

The Nusselt number in rough ducts is only significantly different from smooth ducts in non-laminar flow conditions.

$$\frac{f_{rough}}{f_{smooth}} \leq 4$$
$$\frac{f_{rough}}{f_{smooth}} \geq 4$$

The following correlation is used for $Re > 2300$.

$$\frac{Nu}{Nu_s} = \left(\frac{f_{rough}}{f_{smooth}}\right)^n = 4^n$$

where

$$n = 68Pr^{0.215} \quad Pr \leq 6$$
$$n = 1 \quad Pr > 6$$

Curved Duct Correlations

Head Loss Coefficients

The pressure loss in a bend can be calculated with the total loss coefficient K as

$$\Delta P = K\frac{\rho u^2}{2}$$

where K is given by:

$$K = \frac{4f_{curved}L}{D_h} = \frac{4fL}{D_h} + K^* = \frac{4f}{D_h}\left(\frac{\pi\phi R}{180}\right) + K^*$$

Correlations for bends are generally given for K, f_{curved}, or K^*. Here, we transform all correlations into expressions of the form $f_{curved}/f_{straight}$ using the relations

$$\frac{f_{curved}}{f_{straight}} = \frac{K}{\frac{4f}{D_h}\left(\frac{\pi\phi R}{180}\right)}$$

and

$$\frac{f_{curved}}{f_{straight}} = \frac{K^* + \frac{4f}{D_h}\left(\frac{\pi\phi R}{180}\right)}{\frac{4f}{D_h}\left(\frac{\pi\phi R}{180}\right)}$$

i.) Laminar Flow: $Re < 2300$

The Dean number is defined as

$$De = \mathrm{Re}\left(\frac{R}{a}\right)^{-1/2}$$

where $a = D_h/2$. The following correlations are given by Idelchik for laminar flow:

$$50 < \mathrm{De} < 600 \qquad f_{curved} = 5.0\,\mathrm{Re}^{-0.65}\left(\frac{R}{a}\right)^{-0.175}$$

$$600 < \mathrm{De} < 1400 \qquad f_{curved} = 2.6\,\mathrm{Re}^{-0.55}\left(\frac{R}{a}\right)^{-0.225}$$

$$1400 < \mathrm{De} < 5000 \qquad f_{curved} = 1.25\,\mathrm{Re}^{-0.45}\left(\frac{R}{a}\right)^{-0.275}$$

ii.) Turbulent Flow: $Re > 2300$

Ito gives correlations for bends of discrete angles of 45, 90 and 180 degrees, while Idelchik gives more dubious looking correlations in general. The Idelchik correlations are, however within about 20% of the Ito correlations. The Ito correlations are used preferentially over Idelchik's, in the range of validity. They are:

$$\mathrm{Re}\left(\tfrac{R}{a}\right)^{-2} < 91 \qquad K = 0.00873\,B\phi\left(0.0075 + 0.0076\left\{\mathrm{Re}\left(\tfrac{R}{a}\right)^{-2}\right\}^{-0.25}\right)\left(\tfrac{R}{a}\right)^{1/2}$$

$$\mathrm{Re}\left(\tfrac{R}{a}\right)^{-2} > 91 \qquad K = 0.00241\,B\phi\,\mathrm{Re}^{-0.17}\left(\tfrac{R}{a}\right)^{0.84}$$

where

$$\phi = 45^\circ \qquad B = 1.0 + 14.2\left(\frac{R}{a}\right)^{-1.47}$$

These correlations are valid over the range $2\mathrm{x}10^4 < \mathrm{Re} < 4\mathrm{x}10^5$ and $2 < R/a < 15$. They are used with angles ϕ plus or minus 1 degree of the given discrete values (i.e., 44 to 46 degrees, 89 to 91 degrees, and 179 to 181 degrees).

$$\phi = 90^\circ, \left(\frac{R}{a}\right) > 19.7 \qquad B = 1.0$$
$$\phi = 90^\circ, \left(\frac{R}{a}\right) < 19.7 \qquad B = 0.95 + 17.2\left(\frac{R}{a}\right)^{-1.96}$$
$$\phi = 180^\circ \qquad B = 1.0 + 116.0\left(\frac{R}{a}\right)^{-4.52}$$

Outside of this range of validity, the Idelchik correlation is used:

where for

$$K^* = B\left[0.051 + 0.38\left(\frac{a}{R}\right)\right]$$
$$\phi \le 70^\circ, \qquad B = 0.9\sin(\phi)$$
$$70^\circ < \phi \le 89.9, \qquad B = 0.84573 + 0.0077135(\phi - 70)$$
$$89.9^\circ < \phi < 90.1, \qquad B = 1.0$$
$$90.1^\circ \le \phi < 100.0, \qquad B = 1.0 + 0.0088889(\phi - 90)$$
$$100.0^\circ \le \phi \le 180.0, \qquad B = 0.7 + 0.35\frac{\phi}{90}$$

Heat Transfer Correlations

There appears to be no sufficiently general correlations for heat transfer coefficients in curved ducts. Observations are that for modest values of R/a, heat transfer in a 90 degree bend is increased by about 20%, and heat transfer in a 180 degree bend is increased by about 30%. As R/a gets higher, the effect should lessen, since the duct will become more and more “straight-like”. The following correlation is proposed:

$$\frac{Nu_{curved}}{Nu_{straight}} = 1.0 + (0.0028\phi - 6.2\,\mathrm{x}10^{-6}\phi^2)\left(\frac{R}{a}\right)^{\frac{-0.133\phi}{180}}$$

Head Loss Correlations for Bends and Branches

Head loss in sharp duct bends

The thermal solver uses the following correlation to compute head loss in sharp bends proposed by Hager:

$$K_{LOSS} = 2\left(1 - cos\left(\frac{3}{4}\alpha\right)\right)$$

where α is the angle of the duct bend.

Head loss in duct branches

In complex hydraulics networks, the duct flow can be divided from one duct to multiple branches, or combined from multiple number of branches to another number of branches in junctions. Due to flow redirection and cross-sectional changes at such junctions, additional head losses have to be taken into account.

i.) The thermal solver uses the following head loss correlation in the common outflow branch, when N branches are combined into one branch:

$$K_{LOSS} = \frac{1}{2}\left(1 + \left(\frac{MASSFL_{in\_1}}{MASSFL_{out}}\right)^2 - \sum_{i=1,N} 2\left(\frac{MASSFL_{in\_i}}{MASSFL_{out}}\right)^2 \cos(\alpha_i)\right)$$

where:

- α_i is the angle between inflow branch and the outflow branch.
- $MASSFL_{in}$ is the mass flow in inflow branch.
- $MASSFL_{out}$ is the mass flow in the common outflow branch.

This correlation is proposed based on a comparison between the correlations of Hager, Crane and Idelchik and numerical flow simulations.

The resulting resistance at the junction for the outflow branch is:

$$RES = \frac{K_{LOSS} P_{Dout}}{MASSFL_{out}}$$

where P_{Dout} is the dynamic pressure in the common outflow branch.

ii.) In all other cases, with any number of inflow branches and any number of outflow branches, the thermal solver uses correlations for diverging flow proposed by Bassett. First, the thermal solver identifies the inflow branch with largest mass flow, and uses it as the reference inflow branch. Then, depending on the angles α_i between outflow branches i and the reference inflow branch, the thermal solver uses the added loss correlations for each flow branch:

For $\alpha_i = 0°$, the solver uses the following correlation:

$$K_{LOSS\_i} = \frac{4}{5}\left(1 - \frac{MASSFL_{out\_i}}{MASSFL_{in}}\right)\left(\frac{1}{2} - \frac{MASSFL_{out\_i}}{MASSFL_{in}}\right)$$

For all other angles, the solver uses the following correlation:

$$K_{LOSS\_i} = 1 - 2\left(\frac{MASSFL_{out\_i}}{MASSFL_{in}}\right)\cos\left(\frac{3}{4}\alpha_i\right) - \left(\frac{MASSFL_{out\_i}}{MASSFL_{in}}\right)^2$$

The resulting resistance at the junction for outflow branch is:

$$RES = \frac{K_{LOSS\_i} P_{Din}}{MASSFL_{out}}$$

where P_{Din} is the dynamic pressure in the reference inflow branch.

One-way Conductance

For each flow resistance, a one–way conductance is created to model the heat transported by the fluid. The direction of the conductance is in the direction of the flow, and is updated every iteration. Flow reversals are automatically taken into account. The magnitude of the conductance is:

$$G_{IJ} = \rho A V C_p$$

where:

- G_{IJ} is the magnitude of the one–way conductance

All properties are evaluated at the narrower end of a nozzle or a diffuser, unless it is a straight duct, in which case they are evaluated at the inlet.

Convective Conductance associated with Hydraulic Elements

Free and forced convection convective conductances associated with hydraulic elements are defined with the Card 6e NEARCx options.

Three types of forced convection options can be specified: NEARC1, NEARC12 and NEARC4.

Five types of free convection conductances can be specified: NEARC6, NEARC16, NEARC9, NEARC19, and NEARC10.

For all except the NEARC10 option, a convective conductance is created between a solid surface element and a hydraulic element. For the NEARC10 option it is created between two parallel plates.

The heat flow through a convective conductance is described by:

$$Q_{NSNH} = G_{NSNH}(T_{NS} - T_{NH})$$
$$G_{NSNH} = hA_{NS}H_{NS}K_{TABLE}$$

where:

- NS is the surface element
- NH is the hydraulic element
- $QNSNH$ is the heat flowing between NS and NH
- T_{NS}, T_{NH} are the temperatures of NS and NH

- G_{NSNH} is the convective conductance between NS and NH
- h is the heat transfer coefficient computed by TMG
- A_{NS} is the area of element NS
- H_{NS} is a user–specified multiplier, default = 1
- K_{TABLE} is a user–specified multiplier interpolated from a table, = 1 for default and for free convection

Forced Convection Conductances

Forced Convection Conductances comprises the following options:

`NEARC1`

`NEARC12`

`NEARC4`

`FORCEDPASN`

`FORCEDCASN`

`FORCEDSASN`

`NEARC1, NEARC12, FORCEDCASN, FORCEDSASN` Options

`NEARC1` and `NEARC12` are the most comprehensive of the forced convection options. They automatically selects different convective conductance correlations as a function of the element and duct geometries.

If NS is a planar element, then:

$$\mathrm{Pr} = \frac{C_p \mu}{KTHERM}$$

$$Nu_{DT} = .023\,\mathrm{Re}_{duct}^{0.8}\,\mathrm{Pr}^{.33333}$$

$$TR = \frac{\mathrm{Re}_{duct} - 2000}{300} \qquad \text{for } 2000 < \mathrm{Re}_{duct} < 2300$$

$$TR = 0 \qquad \text{for } \mathrm{Re}_{duct} < 2000$$

$$TR = 1 \qquad \text{for } \mathrm{Re}_{duct} > 2300$$

$$Nu_{DL} = 7.89 - \frac{4.56 D_{duct}^2}{A_{duct}} \qquad \text{for} \frac{D_{duct}^2}{A_{DUCT}} < 1.02, \text{rectangular ducts}$$

$$Nu_{DL} = 4.0 \qquad \text{for} \frac{D_{duct}^2}{A_{duct}} > 1.02, \text{circular ducts}$$

$$Nu_{DL} = Nu_{DT} TR + (1 - TR) Nu_{DL}$$

where:

- Nu_D is the duct Nusselt number for fully developed duct flow.
- $KTHERM$ is the thermal conductivity of the fluid.
- Re_{duct} is the duct Reynolds Number, defined at the narrower end.
- D_{duct} is the duct hydraulic diameter, evaluated at the narrower end for nozzles or diffusers.
- A_{duct} is the duct cross–sectional area, evaluated at the narrower end for nozzles or diffusers.
- Pr is the fluid's Prandtl Number.
- h_{mult} is a length-correction factor = 1 for NEARC1, where fully developed flow is assumed.

For the `NEARC12` option h_{mult} is evaluated as a function of X/D_{duct}, where X is the distance from the element NS to the start of the boundary layer, which is at the nearest upstream BLSTART element, or, if one is not defined, the most upstream element.

The following table presents h_{mult} for the turbulent case ($Re_{duct} > 2300$) (Fig. 26, PP 7–34, of Handbook of Heat Transfer Fundamentals, 2nd. Ed., by Rohsenow, Hartnett, and Ganic, McGraw–Hill, 1985).

X/D_{duct}	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	>10.0
h_{mult} (turb)	2.2	2.4	1.85	1.45	1.4	1.32	1.23	1.2	1.15	1.05

For the laminar case, the following relationship is used (Eqns. 41 and 42, PP 7–22, of Handbook of Heat Transfer Fundamentals, 2nd. Ed., by Rohsenow, Hartnett, and Ganic, McGraw–Hill, 1985):

$$X^+ = \frac{2X}{D_{duct} PrRe_{duct}}$$

$$h_{mult} = \left(\frac{1.356}{X^{+0.333}} - 0.7\right)\left(\frac{1}{3.66}\right) \qquad \text{for } X^+ < 0.02$$

$$h_{mult} = \left(3.657 + \frac{9.461}{(1000X^+)^{0.488} e^{28.6X^+}}\right)\left(\frac{1}{3.66}\right) \text{for } X^+ > 0.02$$

If NS is a beam element, then the correlation for a cylinder in cross flow (Thermal Analysis and Control of Electronic Equipment by Allan D. Kraus and Avram Bar–Cohen, hemisphere, 1993) is used:

$$Nu_{NS} = Pr^{0.4}(0.4\sqrt{Re_{NS}} + 0.06Re_{NS}^{.67}) \qquad \text{for } Re_{NS} > 100$$

$$Nu_{NS} = 0.35Pr^{0.4} + Pr^{0.4}(0.4\sqrt{Re_{NS}} + 0.06Re_{NS}^{.67}) \qquad \text{for } Re_{NS} < 100$$

$$Re_{NS} = \frac{\rho V D_{NS}}{\mu}$$

$$h = \frac{Nu_{NS} KTHERM}{D_{NS}}$$

where:

- Nu_{NS} is the Nusselt of element NS
- D_{NS} is the diameter of the element
- Re_{NS} is the Reynolds number at the element

This correlation is also used for the `FORCEDCASN` option.

If the element is a sphere (Thermal Analysis and Control of Electronic Equipment by Allan D. Kraus and Avram Bar–Cohen, hemisphere, 1993):

$$Nu_{NS} = 2 + Pr^{0.4}(0.4\sqrt{Re_{NS}} + 0.06Re_{NS}^{0.67})$$

$$h = \frac{Nu_{NS} KTHERM}{D_{NS}}$$

This is also the correlation used for the FORCEDSASN option.

`NEARC4` options

This correlation calculates the heat transfer coefficient using the flat plate in free stream correlation (Thermal Analysis and Control of Electronic Equipment by Allan D. Kraus and Avram Bar–Cohen, Hemisphere, 1993):

$$Nu_X = 0.332 PR^{0.333} {Re_X}^{0.5} \quad \text{for } Re_X < 2E5$$
$$TURBFR = \frac{Re_X - 2E5}{1E5} \quad \text{for } 2E5 < Re_X < 3E5$$
$$Nu_x = 0.332(TURBFR)Pr^{0.333} {Re_X}^{0.5} + 0.0288(1 - TURBFR)Pr^{0.333} {RE_X}^{0.8} \quad \text{for } 2E5 < Re_X < 3E5$$
$$Nu_X = 0.0288 Pr^{0.333} {Re_X}^{0.8} \quad \text{for } Re_X > 3E5$$
$$Re_X = \frac{\rho XV}{\mu}$$
$$h = \frac{Nu_X KTHERM}{X}$$

$\mathrm{Nu_X}$ is the plate Nusselt number

$\mathrm{RE_X}$ is the plate Reynolds number

`FORCEDPASN` Option

For this option the following correlations are used (Holman, J.P., Heat Transfer, 7th ed., McGraw Hill Book Company, New York, 1990):

$$Nu = 0.664 Pr^{0.333} Re^{0.5} \quad \text{for } Re < 4E5$$
$$TURBFR = \frac{Re - 4E5}{2E5} \quad \text{for } 4E5 < Re < 6E5$$
$$Nu = 0.664(TURBFR)Pr^{0.333} Re^{0.5} + 0.037(1 - TURBFR)Pr^{0.333} Re^{0.8} \quad \text{for } 4E5 < Re < 6E5$$
$$Nu = 0.037 Pr^{0.333} Re^{0.8} \quad \text{for } Re > 6E5$$
$$Re = \frac{\rho LV}{\mu}$$
$$h = \frac{NuKTHERM}{L}$$

where:

- L is the length of the plate in the direction of the flow.

Free Convection Conductances

For free convection, the heat flow through a convective conductance is described by:

$$\mathrm{Q_{NSNH}} = \mathrm{G_{NSNH}}(\mathrm{T_{NS}} - \mathrm{T_{NH}})$$
$$G_{NSNH} = h_{EXP} A_{NS} H_{NS}$$

where:

- Q_{NSNH} is the heat flowing NS and NH
- T_{NS} , T_{NH} are the temperatures of NS and NH
- G_{NSNH} is the convective conductance between NS and NH his the heat transfer coefficient computed by TMG
- A_{NS} is the area of element NS
- H_{NS} is a user–specified multiplier, default = 1
- EXP is the number of the characteristic element, from which the characteristic length L is calculated
- h is the calculated free convection heat transfer coefficient

In h convection occurs only if:

- The surface element is hotter than the fluid element, and the fluid element is above the surface element.
- The surface element is colder than the fluid element, and the fluid element is below the surface element.
- The fluid element surrounds the surface element.

Free convection conductances are calculated only for gases. Free convection in liquids may be modeled with the Card 6e NEARA option.

All of the correlations defined below were obtained from (Handbook of Heat Transfer Fundamentals, 2nd. Ed., by Rohsenow, Hartnett, and Ganic, McGraw–Hill, 1985).

The following parameters are defined for the fluid:

$$A_A = \frac{g\rho^2 Cp}{T_A \mu KTHERM}$$

$$Ra = A_A \, abs(T_{NS} - T_{NH}) L^3$$

$$RC_L = \frac{.6705}{\left(1 + \left(\frac{.492}{Pr}\right)^{.5625}\right)^{.44444}}$$

$$RC_{TH} = .14 \text{ for } Pr < 1000$$

$$RC_{TH} = .15 \text{ for } Pr > 1000$$

$$RC_{TV} = \frac{.13Pr^{.22}}{(1 + .61Pr^{.81})^{.42}}$$

$$RC_{TC} = \frac{.077 + \log_{10}(100Pr)(.108 - .077)}{2.301} \qquad \text{for } Pr < 2$$

$$RC_{TC} = \frac{.109 - \log_{10}(.5Pr)(.109 - .088)}{3} \qquad \text{for } Pr > 2$$

$$RC_{TS} = .075 + \log_{10}(100Pr)(.110 - .074) \qquad \text{for } Pr < 2$$

$$RC_{TS} = .111 - \frac{\log_{10}(.5Pr)(.111 - .086)}{3} \qquad \text{for } Pr > 2$$

where:

- T_A is the absolute temperature of the convecting element.
- Ra is the Rayleigh number
- L is the characteristic length of the element
- g is the acceleration of gravity
- $KTHERM$ is the thermal conductivity of the fluid
- μ is the viscosity of the fluid
- C_p is the specific heat of the fluid
- P_r is the fluid's Prandtl Number

The NEARC6 and NEARC16 Options

These options calculate free convection conductances for horizontal, vertical, and angled plates, horizontal, vertical, and angled rods, and spheres.

For each conductance request a characteristic element is specified. The characteristic element generally needs to be an element that has the shape and size of the full wall on which the element is located. The shape, size, and orientation of the characteristic element, not the convecting element itself, determines the correlation selected.

For the NEARC6 option, free convection takes place only if the NS element is hotter than the NH element and is below it, or it is colder and is above it. The NS element is the solid element, the NH element is the fluid element.

For the NEARC16 option (except for the horizontal flat plate correlation), their relative positions of `NS` and `NH` are ignored, the fluid is assumed to surround the convecting element.

Free Convection from a Sphere (SPHERE, NEARC6, NEARC16, SPHEREASN options)

$$\mathrm{NU_T} = \mathrm{RC_{TS}Ra}^{.333}$$
$$NU_L = 2.0 + .878 RC_L Ra^{.25}$$
$$NU_{NS} = (NU_T{}^6 + NU_L{}^6)^{1/6}$$

$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the characteristic length, the diameter of the sphere
- NS is located on the solid
- NH is the fluid

Free Convection from a Vertical Flat Plate (NEARC6, NEARC16, PLATE, PLATEASN options)

A plate is considered vertical if it is within 10 degrees of the vertical.

$$\mathrm{NU_L} = \frac{2.8}{1\mathrm{n}\left(1+\frac{2.8}{\mathrm{RC_L Ra}^{.25}}\right)}$$
$$NU_T = RC_{TV} Ra^{.3333}$$
$$NU_{NS} = (NU_L{}^6 + NU_T{}^6)^{(1/6)}$$

$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the characteristic length, which is the height of the plate

For the NEARC6 option convection occurs only if $\mathrm{T_{NS}} > \mathrm{T_{NH}}$ and NS is below NH, or if $\mathrm{T_{NS}} < \mathrm{T_{NH}}$ and NS is below NH.

For the NEARC16 and PLATE TOP/BOTTOM/BOTH options the fluid is assumed to surround the plate and convection always occurs.

For the PLATE BOTH option, two separate convective thermal couplings are created, one from each side of the plate.

Free Convection from the Top Surface of a Horizontal Plate (NEARC6, NEARC16, PLATE, PLATEH, PLATEASN, PLATEHASN options)

A plate is considered horizontal if it is within 5 degrees of the horizontal.

$$\mathrm{NU_{TT}} = .835\mathrm{RC_L}\mathrm{Ra}^{.25}$$

$$NU_L = \frac{1.4}{1n\left(1+\frac{1.4}{NU_{TT}}\right)}$$

$$NU_T = RC_{TH}\,Ra^{.3333}$$

$$NU_{NS} = (NU_L{}^{10} + NU_T{}^{10})^{.1}$$

$$h = \frac{NU_{NS}KTHERM}{L}$$

where:

- L is the characteristic length, equal to the area of the plate divided by its perimeter.

If $\mathrm{T_{NS}} > \mathrm{T_{NH}}$ and NS is above NH, or if $\mathrm{T_{NS}} < \mathrm{T_{NH}}$ and NS is above NH, then:

- For the NEARC16, PLATE TOP and PLATEH TOP options the NEARC9 correlation is used.
- For the NEARC6 option $\mathrm{h} = 0$ and convection does not take place.

Free Convection from plates at an angle (NEARC6, NEARC16, and PLATE, PLATEASN options)

The plate angle must be more that 10 degrees from the vertical, otherwise the vertical correlation is used. The plate also must be more than 5 degrees from the horizontal, otherwise the horizontal correlation is used.

For the NEARC6, NEARC16, and PLATE TOP options, if $\mathrm{T_{NS}} > \mathrm{T_{NH}}$, the plate convects upward, and the following correlation is used:

$$RC_T = RC_{TV}\cos(ANG)^{.333} \qquad \text{for } -90 < ANG < \arctan\left(\left(\frac{RC_{TV}}{RC_{TH}}\right)^3\right)$$

$$RC_T = RC_{TH}\sin(ANG)^{.333} \qquad \text{for } \arctan\left(\left(\frac{RC_{TV}}{RC_{TH}}\right)\right) < ANG < 90$$

$$NU_{L2} = \frac{2.8}{1n\left(1+\frac{2.8}{RC_L\cos(ANG)^{.25}Ra}\right)}$$

$$NU_{L1} = \frac{1.4}{1n\left(1+\frac{1.4}{.835RC_L Ra^{.25}}\right)}$$

$$NU_L = max(NU_{L1}, NU_{L2})$$

$$NU_T = RC_T Ra^{.3333}$$

$$NU_{NS} = (NU_L{}^6 + NU_T{}^6)^{(1/6)}$$

$$h = \frac{NU_{NS}KTHERM}{L}$$

where:

- ANG is the angular deviation from the vertical in degrees
- L is the characteristic length, which is the length of the line formed when the gravity vector is projected onto the plate.

For the NEARC6, NEARC16, and PLATE TOP options, if $T_{NS} < T_{NH}$ then $h = 0$.

For the PLATE BOTTOM option, the following method is used to calculate h:

First, the h_1 is calculated for an upward facing plate, with Ra replaced by Rasin(ANG).

Next, h_3 is calculated for the downward facing plate, with Ra replaced by Rasin(ANG).

Next, h_3 is calculated for the vertical plate correlation, with Ra replaced by Racos(ANG).

Finally, $h = \max(h_1, h_2, h_3)$ is computed.

Free Convection from Horizontal Cylinders (NEARC6, NEARC16, CYLINDER, CYLINDASN options)

A cylinder is considered horizontal if it lies within 10 degrees of the horizontal.

$$\mathrm{NU_{TT}} = .772\mathrm{RC_L}\,\mathrm{Ra}^{.25}$$
$$NU_T = RC_{TC}\,Ra^{.333}$$
$$Rf = 1 - \frac{.13}{NU_{TT}{}^{.16}}$$
$$NU_L = \frac{2Rf}{1n\left(1+\frac{2Rf}{NU_{TT}}\right)}$$
$$NU_{NS} = (NU_L{}^{3.3} + NU_T{}^{3.3})^{.3}$$

$$h = \frac{NU_{NS}KTHERM}{L}$$

where:

- L is the characteristic length, which is the diameter of the cylinder.

Free Convection from Vertical Cylinders (NEARC6, NEARC16, CYLINDER, CYLINDASN options)

A cylinder is considered vertical if it is within 10 degrees of the vertical.

$$\mathrm{NU_{TT}} = \mathrm{RC_L Ra}$$

$$NU_L = \frac{2.8}{1n\left(1+\frac{2.8}{NU_{TT}}\right)}$$

$$NU_T = RC_{TV}\, Ra^{.3333}$$
$$NU_p = (NU_L{}^6 + NU_T{}^6)^{(1/6)}$$
$$\xi = \frac{2L}{D_c NU_{TT}}$$

$$NU_{NS} = \frac{.9\xi NU_p}{1n(1+.9\xi)} \quad for\ \frac{L}{D_c} < 10$$
$$Ra_s = Ra\left(\frac{D_c}{L}\right)^4$$
$$NU_{NS} = \frac{1.8L}{D_c 1n\left(1+\frac{1.8}{RC_L Ra_S{}^{.25}}\right)} \quad for\ \frac{L}{D_c} > 10$$
$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the characteristic length, the height of the cylinder
- DC is the diameter of the cylinder

Free Convection from Cylinders at an Angle (NEARC6, NEARC16, CYLINDER, CYLINDASN options)

A cylinder is considered to be at an angle if it is more than 10 degrees away from the horizontal and more than 10 degrees away from the vertical.

$$R_p = \frac{2L_c}{Lcot(ANG)}$$

$$NU_{TT} = \left(.772 + \frac{.228}{1+.676R_p{}^{1.23}}\right)\left(sin(ANF) + \left(\frac{L}{L_c}\right)cos(ANG)\right)^{.25} RC_L Ra^{.25}$$

$$NU_{NS} = \frac{1.8}{1n\left(1+\frac{1.8}{NU_{TT}}\right)}$$

$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the characteristic length, the diameter of the cylinder
- LC is the length of the cylinder
- ANG is the angular deviation from the vertical in degrees

Free Convection from the Bottom of a Horizontal Plate (NEARC9, NEARC19, PLATE BOTTOM and PLATEH BOTTOM, PLATEASN BOTTOM, PLATEHASN BOTTOM options)

$$NU_{TT} = \frac{.527Ra^{.2}}{\left(1+\left(\frac{1.9}{Pr}\right)^{.9}\right)^{(2/9)}}$$

$$NU_L = \frac{2.5}{1n\left(1+\frac{2.5}{NU_{TT}}\right)}$$

$$NU_{NS} = NU_L$$

$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the characteristic length, which is the area of the plate divided by its perimeter

If $T_{NS} > T_{NH}$ and NS is above NH, or if $T_{NS} < T_{NH}$ and NS is above NH, then:

- For the NEARC9 option $h = 0$ and convection does not take place.
- For the NEARC19, PLATE BOTTOM, and PLATEH BOTTOM, PLATEASN BOTTOM, PLATEHASN BOTTOM options convection takes place, but the NEARC6 option's horizontal flat plate correlation is used. The plate is assumed to be completely surrounded by the fluid.

Convection Between Two Large Parallel Plates (NEARC10, CAVITY, CAVITYH options)

This correlation calculates the free convection coefficient between two closely spaced parallel plates, joined at their edges to create an enclosed cavity. The fluid properties used are those specified on the AMBIENT element's MAT Card.

`NH` here represents not the fluid element but the plate element on the other wall.

Correlation for vertical cavities (NEARC10, CAVITY):

For $\mathrm{Pr} < 1$:

$$\mathrm{NU_{CT}} = \left(1 + \frac{.104\mathrm{Ra}^{.293}}{\left(1+\left(\frac{6310}{\mathrm{Ra}}\right)^{1.36}\right)^{3}}\right)^{.3333}$$

$$NU_L = .242\left(\frac{RaL}{HEIGHT}\right)^{.273}$$

$$NU_T = .0605Ra^{.333}$$

For $\mathrm{Pr} > 1$

$$\mathrm{NU_{CT}} = 1$$

$$NU_L = .36Pr^{.051}\left(\frac{L}{HEIGHT}\right)^{.36}Ra^{.25}$$

$$NU_T = .084Pr^{.051}\left(\frac{L}{HEIGHT}\right)^{.1}Ra^{.3}$$

$$NU_{NS} = max(NU_{CT}, NU_L, NU_T) \quad for\ Ra\left(\frac{HEIGHT}{L}\right)^3 < 4.E12$$

$$NU_{NS} = .039Ra^{(1/3)} \quad for\ Ra\left(\frac{HEIGHT}{L}\right)^3 > 4.E12$$

$$h = \frac{NU_{NS}KTHERM}{L}$$

Correlation for horizontal and vertical cavities (NEARC10, CAVITYH, CAVITY):

If hot plate is on top, cold plate is on bottom:

$$\mathrm{NU_{NS}} = 1$$

$$\mathrm{RK1} = \left(\frac{1.44}{1 + \frac{.018}{\mathrm{Pr}} + \frac{.00136}{\mathrm{Pr}^2}} \right)$$

$$RK2 = 75e^{\left(\frac{1.5}{\sqrt{Pr}} \right)}$$

$$BB = \frac{Ra^{.333}}{RK2}$$

$$NU_{NS} = 1 + delt\left(1 - \frac{1708}{Ra}\right)(RK1 + 2BB(1 - 1n(BB))) + delt\left(\left(\frac{Ra}{5830}\right)^{.3333} - 1\right)$$

$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the characteristic length, the distance between the plates
- HEIGHT is the height of the characteristic element
- TNS, TNH are the temperatures of the two elements
- $\mathrm{delt(X)} = \mathrm{X\ for\ X} > 0$
- $\mathrm{delt(X)} = 0\ \mathrm{for\ X} < 0$

If the cavity is inclined, the following correlation is used (NS is assumed to be bottom plate, NH is top plate, and H is length of cavity):

$$\mathrm{HL} = \frac{\mathrm{H}}{\mathrm{L}}$$
$$\tau_{crit} = 25 \; for \; HL < 1$$
$$\tau_{crit} = 53 \; for \; 1 \leq HL < 3$$
$$\tau_{crit} = 60 \; for \; 3 \leq HL < 6$$
$$\tau_{crit} = 63 \; for \; 6 \leq HL < 12$$
$$\tau_{crit} = 70 \; for \; 12 \leq HL$$
$$\tau = 90 - ANG \quad for \; T_{NS} > T_{NH}$$
$$\tau = 90 + ANG \quad for \; T_{NS} < T_{NH}$$
$$a = delt\left(1 - \frac{1708}{Racos(\tau)}\right)$$
$$b = 1.44delt\left(1 - \frac{1708sin(1.8\tau)^{1.6}}{Racos(\tau)}\right) \; for \; 1.8\tau < 180 \; degrees$$
$$c = delt\left(\left(\frac{Racos(\tau)}{5830}\right)^{.3333} - 1\right)$$
$$d = 1.44delt\left(1 - \frac{1708}{Racos(\tau)}\right)$$
$$e = delt\left(\left(\frac{Ra}{5830}\right)^{.3333} - 1\right)$$
$$NU_1 = 1 + ab + c$$
$$NU_2 = max(NU_{CT}, NU_L, NU_T)$$
$$NU_3 = 1 + 1.44de$$
$$NU_4 = NU_1\left(\frac{NU_4}{NU_3}\right)^{\left(\frac{\tau}{\tau_{crit}}\right)} (sin(\tau_{crit}))^{\left(\frac{\tau}{4\tau_{crit}}\right)}$$
$$NU_{NS} = NU_1 \; for \; HL > 12 \; and \; \tau < \tau_{crit}$$
$$NU_{NS} = NU_4 \; for \; HL < 12 \; and \; \tau < \tau_{crit}$$
$$NU_{NS} = NU_2 sin(\tau)^{.25} \quad for \; 90 \; degrees < \tau > \tau_{crit}$$
$$NU_{NS} = 1 + (NU_2 - 1)sin(\tau) \quad for \; 90 \; degrees < \tau < 180 \; degrees$$
$$h = \frac{NU_{NS}KTHERM}{L}$$

Free Convection between Horizontal Concentric Cylinders (CONCYL option)

For this option the convection is assumed to take place on the surface of the outer cylinder, therefore h is calculated as convecting from the outer to the inner cylinder.

$$L = \frac{D_O - D_I}{2}$$

$$Ra_c = \frac{1n\left(\frac{D_O}{D_I}\right)^4 Ra}{L^3\left(D_O{}^{(-.6)} + D_I{}^{(-.6)}\right)}$$

$$F = .386\left(\frac{PrRA_c}{.861+Pr}\right)^{.25}$$

$$h = \frac{FKTHERMD_I}{LD_O}$$

where:

- D_O is the outer diameter
- D_I is the inner diameter

Free Convection between Concentric Spheres (CONSPH option)

For this option the convection is assumed to take place on the surface of the outer sphere, therefore h is calculated as convecting from the outer to the inner sphere.

$$L = \frac{D_O - D_I}{2}$$

$$Ra_S = \frac{RaL}{(D_O D_I)^4 (D_O{}^{(-1.4)} + D_I{}^{(-1.4)})^5}$$

$$F = .74\left(\frac{PrRa_S}{.861+Pr}\right)^{.25}$$

$$h = \frac{FD_I KTHERM}{LD_O}$$

where:

- D_O is the outer diameter
- D_I is the inner diameter

Free Convection from walls of an open inclined channel (INCCHNL option) and a hydraulic element

If the inclined channel is horizontal, then the horizontal cavity option is used. NS is here considered to be an element on either wall of the channel.

$$\mathrm{Ra_{ANG}} = \frac{\mathrm{RaLcos(ANG)}}{\mathrm{H}}$$

$$NU_{NS} = \frac{1}{\sqrt{\left(\frac{576}{Ra_{ANG}{}^2}\right)} + \frac{2.87}{\sqrt{Ra_{ANG}}}}$$

$$h = \frac{NU_{NS} KTHERM}{L}$$

where:

- L is the distance between the walls
- H is the length of the channel
- ANG is the angular deviation from the vertical in degrees

ANS2TMG Module

Function

The ANS2TMG module transforms the ANSYS version 5 finite element model to TMG input file format or TMG geometry interpolation file VUFFE format.

Module Operation

ANS2TMG accepts ANSYS version 5 FE model in ASCII file format, which can be generated from ANSYS by issuing the `CDWRITE` command.

For ANSYS version 5.5 you should include the `UNBLOCKED` option with the `CDWRITE` command.

To translate an ANSYS FE model file into TMG input file format:

1. Create a TMG format include file, containing boundary conditions, analysis control and other data. Call this file inpf.inc
2. Name your ANSYS input file file.cdb
3. Run the TMG Executive Menu from the operating system, and select the "`RA - Merge ANSYS and TMG files and run TMG`". This operation will create a TMG input file INPF and run it.

To create TMG geometry interpolation file VUFFE format for temperature mapping postprocessing by the tmgint module by selecting "`BI - Build interpolator geometry file`" option.

ANS2TMG translates the following ANSYS FE model identities into TMG FD model:

- ANSYS FE nodes are translated into TMG nodes.
- ANSYS thermal elements are translated into TMG elements. The ANSYS element types translated are: `SURF19`, `SURF22`, `LINK32`, `LINK33`, `PLANE35`, `SHELL57`, `SELL63`, `PLANE67`, `LINK68`, `PLANE77`, `SOLID70`, `MASS71`, `SOLID87`, and `SOLID90`.
- `SURF19` and `SURF22` are translated only when temperature has been defined as one of their degrees of freedom.
- The extra nodes from surface effect elements and higher order elements are ignored.
- ANSYS thermal material property data are translated into TMG Card 9 MAT Cards. The material properties translated are: density DENS, specific heat C, thermal conductivities KXX, KYY and KZZ, radiation emissivity EMIS. TMG will automatically assign a default solar absorptivity of `-1E6` for each MAT Card.

For temperature-dependent material properties corresponding Card 9 TABTYPE and TABDATA Cards are generated. Thermal conductivity, C, and EMIS are translated into corresponding TABTYPE Card KTHERM, CPP and E codes. Density is always assumed to be constant.

ANSYS real constants are translated into TMG Card 9 PROP Physical Property Cards.

COND and CONN2 Modules

Function

The COND and CONN2 modules create capacitances, hydraulic resistances, and conductive conductances from geometry for the element center method. The COND and CONN2 modules are considered obsolete and the use of the CONDN module with the element CG method is recommended. Output is written on file MODLF.

Conductive Conductance Calculations

Conductances are computed between elements if their thermal conductivities are > 0. Elements may have the following shapes:

- Point (lump mass elements),
- Line (beam elements),
- Planar (triangular and quadrilateral elements).
- Solid (tetrahedron, wedge, and hexahedron).
- Conductances between elements are calculated by a four-step technique:

Step 1: Location of the Element Center and Elemental Subdivision

First, the element center locations are determined.

For lump masses the element center is at the node.

For beam elements the element center is at the CG. The element center of a beam is unique.

For triangular elements the element center is at the meeting of the perpendicular bisectors of the edges. The element center of a triangle is unique.

Planar quadrilateral elements are divided into two triangular sub-elements by connecting the opposite corners that form the largest angle sum.

The element center of a quadrilateral is unique if the perpendicular bisectors of all the sides meet at a common point. This is the case with regularly shaped quadrilaterals, such as rectangles and isosceles trapezoids. If the element center is unique, the element has only a single sub-element.

If a quadrilateral does not have a unique element center, the element center of the sub-element closest to the element CG is chosen to be the element center of the element.

If a Card 9 PARAM SOLIDACC Card is present, or the material is orthotropic, solid elements are subdivided into tetrahedral sub-elements. The element center of each sub-element is found at the meeting of the perpendiculars erected from the element centers of its surfaces.

A solid element has a unique element center if the element centers of all the sub-elements coincide. This occurs when each surface has a unique element center. This is so for elements whose surfaces are regular, i.e. triangles, rectangles, or isosceles trapezoids.

Thus, tetrahedra have unique element centers, while wedges and hexahedra do only if all its surfaces are regular shapes.

Solid elements with a unique element center have only a single sub-element.

If a solid element does not have a unique element center, the element center of the sub-element closest to the element CG is chosen to be the element center of the element.

If there is no Card 9 PARAM SOLIDACC Card present (the default option), the solid element is not subdivided, and a unique element center is assumed near its CG. This option yields fewer but less accurate conductive conductances.

Where possible, elements with regular shapes should be used. This minimizes the number of conductances, thus speeding up solution times, and maximizes accuracy.

Note that for certain element shapes (e.g. a triangle with an obtuse angle) the element center may fall outside the element. See diagram and discussion below.

Step 2: Calculation Sub-element Conductances

Next, the sub-elemental conductances G_i to the sub-element's boundaries are computed.

$$G_i = \frac{KA}{L}$$

where K is:

- the thermal conductivity,

L is:

- the distance from the element center to the ends of a beam,
- the length of the perpendicular to the element's edge for a planar shell element
- the length of the perpendicular to a surface for a solid element
- is zero for a beam lying on the edge of a shell, or for a shell on the surface of a solid.

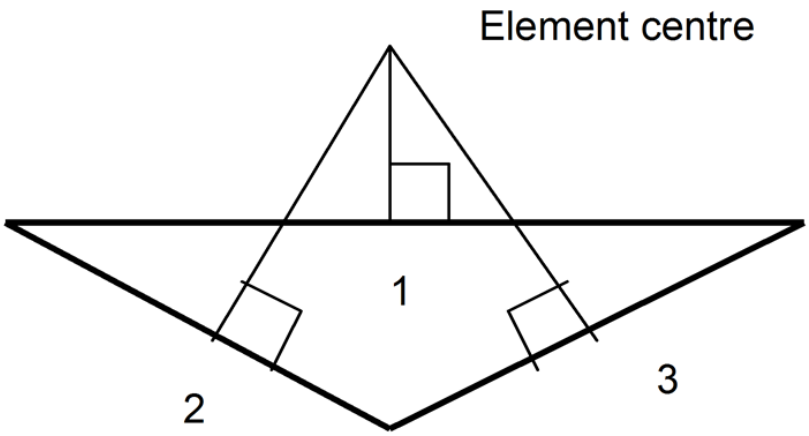
A is:

- the cross-sectional area for a beam,
- the (thickness)*(boundary length) for a planar shell element,
- the boundary surface area of the surface for a solid element,

G_i is the elemental conductance for sub-element i.

Note

When the element center falls outside the sub-element (e.g. for an obtuse angled triangle) L and G_i will be negative. In the example below, the conductance between side 1 and the element center will be negative.



Thick shell approximation

If solid elements have large (> 5) aspect ratios, i.e. they are thin as opposed to chunky, the thick shell approximation is used.

The aspect ratio is defined as the longest edge divided by the approximate thickness.

To calculate the approximate thickness value, the thickness direction is first found: this is the direction with the smallest average edge length. The average edge length in the thickness direction is then used as the approximate thickness.

For wedge elements the thickness direction is the one from one triangular face to the other.

In-plane conductances are then calculated as if the solid element were planar with a thickness equal to the mean thickness of the solid element.

The through-thickness conductance is calculated as if the solid element were solid with a unique element center.

Step 3: Calculation of Conductances Between Sub-Elements

Next, the conductances between the element centers of connected sub-elements are calculated.

Sub-elements are considered connected if they share common nodes along a face or an edge.

Lump mass elements may be connected only to beam elements. Beam elements may be connected only to lump mass or other beam elements. Planar elements may be connected to lump mass elements or other beam elements along a common node, or they may be connected to planar elements if they share both nodes of an edge. Solid elements may be connected to planar elements or to other solid elements.

For elements that meet only one other element at a boundary (e.g. solid joined to another solid), the conductances are summed in series:

$$G_{ij} = \frac{1}{\left(\frac{1}{G_i} + \frac{1}{G_j}\right)}$$

where:

- G_{ij} is the computed conductance between sub-elements i and j
- G_i is the conductance between the element center of sub-element i and the common boundary.
- G_j is the conductance between the element center of sub-element j and the common boundary,

If the sub-element meets meet more than one element at the boundary (e.g. three or more shell sub-elements sharing a common edge), the conductances between the sub elements are calculated by eliminating the boundary using the star-delta transformation for multi-branched stars:

$$G_{ij} = \frac{G_i G_j}{\sum_k G_k}$$

where:

- G_k is a conductance joined the boundary from sub-element k.

Negative conductances

If the element center of sub-element i falls outside its boundaries, a $G_i < 0$ will be computed, possibly resulting $G_{ij} < 0$.

If it falls inside another sub-element within the same element and $G_{ij} < 0$, the two sub-element element centers will be merged and a warning message will be issued about approximate conductances.

If it falls outside the element, a warning message is issued, and the conductance is replaced by a very large value, which will result in element merging by the MEREL module.

A sub-element's element center falling outside the element also cause problems if the adjacent element it falls in has a different thermal conductivity or a different thickness. Incorrect conductances will then result.

Step 4: Elimination of Sub-Elements

Last, the sub-elements whose element centers are not the element centers of the element are eliminated by the CONN2 module. The elimination is performed by the star-delta transformation process, as described above.

A side-effect of the star-delta elimination is that a large number of very small conductances may be generated between non-adjacent elements. To reduce their number, model thinning is performed in the CONN2 module to eliminate insignificant conductances.

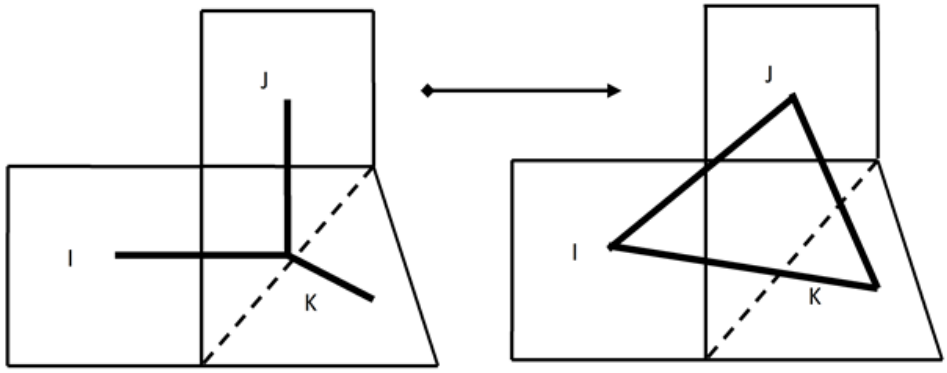
A conductance G_{ij} between elements i and j is considered insignificant if the following criteria are met:

- i and j do not share a common edge or boundary.
- $G_{ij} < .001 * G_{itot}$
- $G_{ji} < .001 * G_{itot}$

where:

- G_{itot} is the sum of the conductances of element i
- G_{jtot} is the sum of the conductances of element j

The method by which conductances are created between non-adjacent elements is shown below. The boundary joining the two sub-element of element m is eliminated through the Y-delta transform, resulting in couplings between non-adjacent element i and j. Although the conductance map does not look physically realistic, it is mathematically correct.



Eliminating a sub-element can yield conductances between non-adjacent elements

For certain geometries, e.g. when two obtuse or right angled triangles are joined by their longest edges, a negative or infinite conductance may be computed. A warning message then is issued, and the conductance is replaced by a very large value, which will result in element merging by the MEREL module.

Circular elements

If the element is defined to be a circular element with a Card 9 XCIRC card, the element is re-mapped before the element center is located. The curved element is unfolded and stretched so that the calculated conductances will account for a logarithmic temperature variation in the radial direction.

Orthotropic Materials

If a solid element has an orthotropic thermal conductivity, then element is first proportionally stretched in the element's material X, Y, and Z directions by the factors, $\sqrt{(k_{yy}k_{zz})}$, $\sqrt{(k_{xx}k_{zz})}$, $\sqrt{(k_{yy}k_{xx})}$ respectively before the conductance calculation, and the thermal conductivity value is set to 1.

If a planar element has an orthotropic thermal conductivity, then element is first proportionally stretched in the element's material X and Y directions by the factors $\sqrt{k_{yy}}$, $\sqrt{k_{xx}}$ respectively before the conductance calculation, and the thermal conductivity value is replaced by the value $\sqrt{(k_{yy}k_{xx})}$

Axisymmetric Elements

If an element is an axisymmetric solid, it is treated as a planar element in the XZ plane that is stretched in the X direction by:

$$2\pi\frac{(X\max - X\min)}{\log\left(\frac{X\max}{X\min}\right)}$$

and in the Z direction by:

$$\pi(X\max - X\min)$$

If it is an axisymmetric shell with a thickness t, it is treated as a beam with an equivalent cross-section of:

$$\frac{2\pi(X\max - X\min)}{\log\left(\frac{X\max}{X\max}\right)}$$

where:

- Xmax and Xmin are the maximum and minimum X (radial) dimensions of the element.

If the material is also orthotropic, it is first stretched along the orthotropic axes as described above.

Capacitance Calculations

Capacitance calculations are performed only for elements that have specific heats > 0. An elemental capacitance is calculated by multiplying the $(\mathrm{volume})*(\ \mathrm{specific\ heat})*(\mathrm{density})$.

Hydraulic resistance calculations

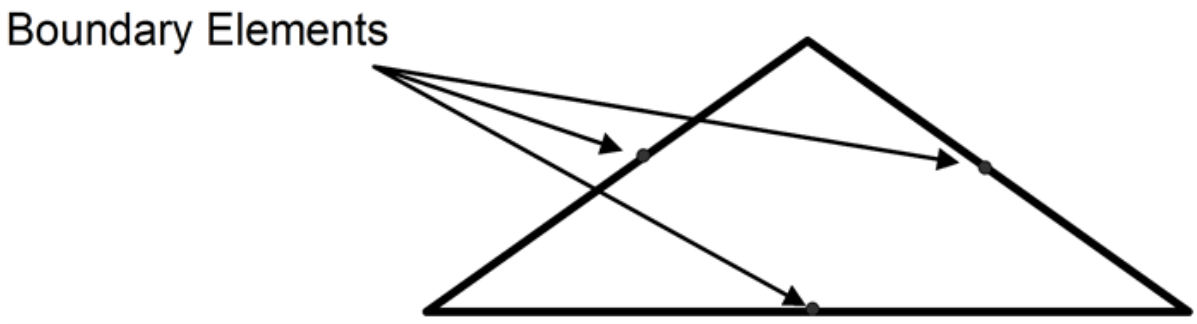
Two hydraulic resistances are calculated between the CG of each 2-node hydraulic element and the 1-node hydraulic elements at its boundary. The value of the hydraulic resistance written on file MODLF with $\mathrm{MNM} = \mathrm{HYD}$ is the flow resistance multiplier from the element PROP Card divided by the distance between the CG of the element and its ends.

CONDN Module

Function

The CONDN module creates capacitances, hydraulic resistances, and conductive conductances from geometry. Its functionality is identical to the COND module, but its approach is different. Whereas COND directly creates conductances between element centers, CONDN creates special boundary elements on each solid element's surfaces, planar element's edges, and beam element's ends, and creates conductances between the centers of gravity (CG's) of the element and these boundary elements.

> **Note**
>
> If PARAM FEMCOND is activated, the thermal solver omits the calculation of conductance conductances.



CONDN is activated by Card 2a M = 1 and Card 9 PARAM COND NEW. Output is written on MODLF.

Creation of Boundary Elements

Boundary elements are the equivalent to:

- zero thickness shell elements created on the surfaces of solid elements,
- zero radius beam elements on the edges of shell elements, and
- zero radius lump mass elements on the end of beam elements.

Boundary elements are not created if the surface or edge on which it is to be created is already occupied by another element, or if the element on which it is to be created has zero thermal conductivity.

Elemental Conductances for Beams

The elemental conductance of a beam connects the CG of the beam to the boundary elements at its endpoints and is calculated with:

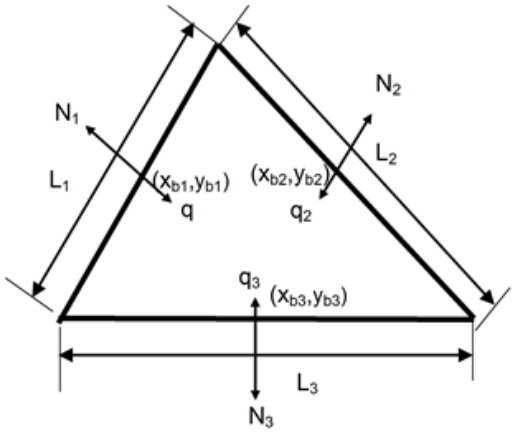
$$G_{ij} = \frac{KA}{L}$$

where:

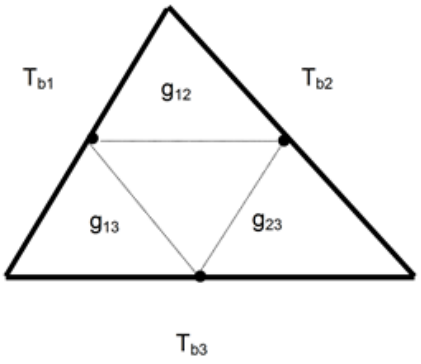
- G_{ij} is the conductance between the ends of the beam,
- k is the thermal conductivity,
- L is the distance from the element CG to one of the nodes,
- A is the cross-sectional area.

Elemental Conductances for Triangles

To create the elemental conductances of a triangle the first step is to create a conductance matrix between only the boundary element CG's.



Element geometry



Conductance matrix between boundary elements

A linear internal temperature field is assumed within the element:

$$T(x, y) = a_1 + a_2 x + a_3 y$$

The boundary element temperatures T_{b_i} are defined at the midpoints of the edges:

$$T(x_{b_i}\, y_{b_i}) = T_{b_i} \qquad i = 1, 2, 3$$

Substituting the boundary element temperatures into temperature field equation, the weighting factors e_{ij} of the coefficients a_1, a_2, a_3 can be evaluated:

$$a_1 = e_{11} T_{b_1} + e_{12} T_{b_2} + e_{13} T_{b_3}$$
$$a_2 = e_{21} T_{b_1} + e_{22} T_{b_2} + e_{23} T_{b_3}$$
$$a_3 = e_{31} T_{b_1} + e_{32} T_{b_2} + e_{33} T_{b_3}$$

From the geometry of the element the coefficients b_i and c_i of the unit edge normal vectors $\mathbf{N_i}$ at the boundary elements and the length L_i of each boundary element can be evaluated:

$$\mathbf{N}_1(x_{b1}, y_{b1}) = b_1 \mathbf{i} + c_1 \mathbf{j}$$
$$\mathbf{N}_2(x_{b2}, y_{b2}) = b_2 \mathbf{i} + c_2 \mathbf{j}$$
$$\mathbf{N}_3(x_{b3}, y_{b3}) = b_3 \mathbf{i} + c_3 \mathbf{j}$$

The temperature gradient vector is constant over the triangle, and is expressed by:

$$\mathbf{T}' = a_2 \mathbf{i} + a_3 \mathbf{j}$$

Expanding yields:

$$\mathrm{T}' = e_{21} T_{b1} + e_{22} T_{b1} + e_{23} T_{b3} + e_{31} T_{b1} + e_{31} T_{b2} + e_{32} T_{b2} + e_{33} T_{b3}$$

If the element has a thickness t and thermal conductivity k, then using Fourier's Law the heat flow q_i into element at each boundary element can be evaluated using the dot product of the temperature gradient vector and the edge normal vector:

$$q_i = -ktL_i \mathbf{T'} \cdot \mathbf{N}\mathrm{i}(xb_i, yb_i)$$

Expanding yields:

$$q_1 = -ktL_1(b_1(e_{21} T_{b1} + e_{22} T_{b2} + e_{23} T_{b3}) + c_1(e_{31} Tb_1 + e_{32} T_{b2} + e_{33} T_{b3}))$$
$$q_2 = -ktL_2(b_2(e_{21} T_{b1} + e_{22} T_{b2} + e_{23} T_{b3}) + c_2(e_{31} Tb_1 + e_{32} T_{b2} + e_{33} T_{b3}))$$
$$q_3 = -ktL_3(b_3(e_{21} T_{b1} + e_{22} T_{b2} + e_{23} T_{b3}) + c_3(e_{31} Tb_1 + e_{32} T_{b2} + e_{33} T_{b3}))$$

Collecting terms:

$$q_1 = (-ktL_1)(T_{b1}(b_1e_{21} + c_1e_{31}) + T_{b2}(b_1e_{22} + c_1e_{32}) + T_{b3}(b_1e_{23} + c_1e_{33}))$$
$$q_2 = (-ktL_2)(T_{b1}(b_1e_{21} + c_1e_{31}) + T_{b2}(b_1e_{22} + c_1e_{32}) + T_{b3}(b_1e_{23} + c_1e_{33}))$$
$$q_3 = (-ktL_3)(T_{b1}(b_1e_{21} + c_1e_{31}) + T_{b2}(b_1e_{22} + c_1e_{32}) + T_{b3}(b_1e_{23} + c_1e_{33}))$$

However, the q_i 's can also be expressed in terms of conductances between the boundary elements using Kirchoff's Law:

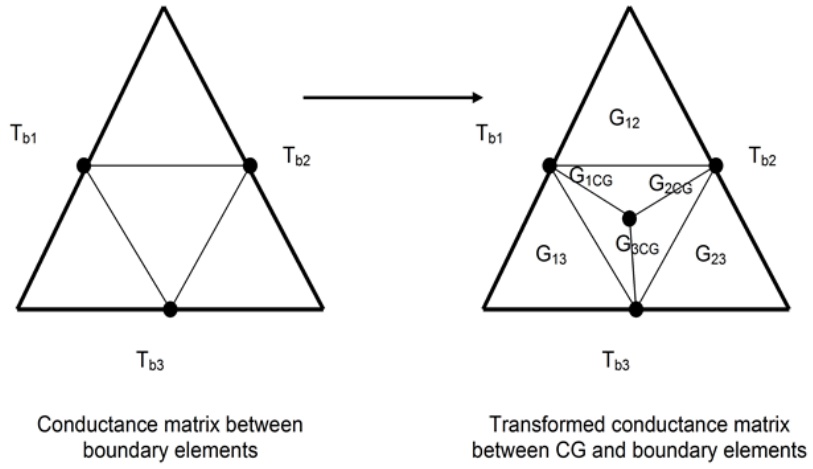
$$q_1 = g_{12}(T_{b1} - T_{b2}) + g_{13}(T_{b1} - T_{b3})$$
$$q_2 = g_{12}(T_{b2} - T_{b1}) + g_{23}(T_{b2} - T_{b3})$$
$$q_3 = g_{23}(T_{b3} - T_{b2}) + g_{13}(T_{b3} - T_{b1})$$

Equating the above two sets of equations yields the expressions for g_{ij} :

$$g_{12} = ktL_1(b_1e_{22} + c_1e_{32})$$
$$g_{13} = ktL_1(b_1e_{23} + c_1e_{33})$$
$$g_{23} = ktL_2(b_2e_{23} + c_2e_{33})$$

This conductance matrix is between the boundary elements only, and does not connect them to the CG.

Optionally, of the Card 9 PARAM CAPDIST OFF is present, the conductance matrix is transformed into a conductance matrix between the element CG and the boundary element.



Conductance matrix between boundary elements

Transformed conductance matrix between CG and boundary elements

The two conductance matrices are equivalent, but the conductance matrix from the CG has 6 conductances, whereas the matrix between the boundary elements has only 3.

To calculate the additional conductances from the CG to the boundary elements, it is recognized that the temperature at the CG of the triangle if the triangle has a linear temperature gradient is equal to the average temperature of the midpoints of the sides. This is possible only if:

$$G_{1CG} = G_{2CG}$$
$$G_{1CG} = G_{3CG}$$

An additional constraint we impose is that the root mean square value of the sum of the conductances between the boundary elements is minimized. This yields the following equations:

$$\partial \frac{(G_{12}^2 + G_{13}^2 + G_{23}^2)}{\partial (G_{1CG})} = 0$$

The star-delta transformation is used to provide the other 3 equations:

$$\frac{G_{1CG}+G_{2CG}}{G_{1CG}+G_{2CG}+G_{3CG}} + G_{12} = g_{12}$$
$$\frac{G_{1CG}+G_{3CG}}{G_{1CG}+G_{2CG}+G_{3CG}} + G_{13} = g_{13}$$
$$\frac{G_{2CG}+G_{3CG}}{G_{1CG}+G_{2CG}+G_{3CG}} + G_{23} = g_{23}$$

For an equilateral triangle the element center method and the element CG method provide identical results.

Elemental Conductances for Tetrahedra

The derivation of the conductance matrix for a tetrahedron is very similar to the derivation for a triangle. The first step is to create a conductance matrix between the boundary element CG's.

A linear internal temperature field is assumed within the element:

$$T(x, y, z) = a_1 + a_2 x + a_3 y + a_4 z$$

The boundary element temperatures T_{b_i} are defined at the midpoints of the edges:

$$T(x_{bi}, y_{bi}, z_{bi}) = T_{bi} \qquad i = 1, 2, 3, 4$$

Substituting the boundary element temperatures into temperature field equation, the weighting factors e_{ij} of the coefficients a_1 , a_2 , a_3 , a_4 can be evaluated:

$$a_1 = e_{11}T_{b_1} + e_{12}T_{b2} + e_{13}T_{b_3} + e_{14}T_{b_4}$$
$$a_2 = e_{21}T_{b_1} + e_{22}T_{b2} + e_{23}T_{b_3} + e_{24}T_{b_4}$$
$$a_3 = e_{31}T_{b_1} + e_{32}T_{b2} + e_{33}T_{b_3} + e_{34}T_{b_4}$$
$$a_4 = e_{41}T_{b_1} + e_{42}T_{b2} + e_{43}T_{b_3} + e_{44}T_{b_4}$$

From the geometry of the element the coefficients b_i , c_i , d_i , of the unit surface normal vectors $\mathbf{N_i}$ at the boundary elements and the area A_i of each boundary element can be evaluated:

$$\mathbf{N}_1(x_{b1}, y_{b1}, z_{b1}) = b_1\mathbf{i} + c_1\mathbf{j} + d_1\mathbf{k}$$
$$\mathbf{N}_2(x_{b2}, y_{b2}, z_{b2}) = b_2\mathbf{i} + c_2\mathbf{j} + d_2\mathbf{k}$$
$$\mathbf{N}_3(x_{b3}, y_{b3}, z_{b3}) = b_3\mathbf{i} + c_3\mathbf{j} + d_3\mathbf{k}$$
$$\mathbf{N}_4(x_{b4}, y_{b4}, z_{b4}) = b_4\mathbf{i} + c_4\mathbf{j} + d_4\mathbf{k}$$

The temperature gradient vector is constant over the element, and is expressed by:

$$\mathbf{T}' = a_2\mathbf{i} + a_3\mathbf{j} + a_4\mathbf{k}$$

Expanding yields:

$$\begin{aligned}\mathrm{T}' =&(e_{21}T_{b1} + e_{22}T_{b2} + e_{23}T_{b3} + e_{24}T_{b4})\mathrm{i}\\ &+(e_{31}T_{b1} + e_{32}T_{b2} + e_{33}T_{b3} + e_{34}T_{b4})\mathrm{j}\\ &+(e_{41}T_{b1} + e_{42}T_{b2} + e_{43}T_{b3} + e_{44}T_{b4})\mathrm{k}\end{aligned}$$

If the element has thermal conductivity k , then using Fourier's Law the heat flow q_i into element at each boundary element can be evaluated using the dot product of the temperature gradient vector and the surface normal vector:

$$q_i = -kA_i(\mathbf{T}' \cdot \mathbf{N}\mathrm{i}(x_{bi}, y_{bi}, z_{bi}))$$

Expanding yields:

$$q_1 = -kA_1(b_1(e_{21}T_{b1} + e_{22}T_{b2} + e_{23}b_{b3} + e_{24}T_{b4}) + c_1(e_{31}T_{b1} + e_{32}T_{b2} + e_{33}b_{b3} + e_{34}T_{b4}) + d_1(e_{41}T_{b1} + e_{42}T_{b2} + e_{43}T_{b3} + e_{44}T_{b4}))$$
$$q_2 = -kA_2(b_2(e_{21}T_{b1} + e_{22}T_{b2} + e_{23}b_{b3} + e_{24}T_{b4}) + c_2(e_{31}T_{b1} + e_{32}T_{b2} + e_{33}b_{b3} + e_{34}T_{b4}) + d_2(e_{41}T_{b1} + e_{42}T_{b2} + e_{43}T_{b3} + e_{44}T_{b4}))$$
$$q_3 = -kA_3(b_3(e_{21}T_{b1} + e_{22}T_{b2} + e_{23}b_{b3} + e_{24}T_{b4}) + c_3(e_{31}T_{b1} + e_{32}T_{b2} + e_{33}b_{b3} + e_{34}T_{b4}) + d_3(e_{41}T_{b1} + e_{42}T_{b2} + e_{43}T_{b3} + e_{44}T_{b4}))$$
$$q_4 = -kA_4(b_4(e_{21}T_{b1} + e_{22}T_{b2} + e_{23}b_{b3} + e_{24}T_{b4}) + c_4(e_{31}T_{b1} + e_{32}T_{b2} + e_{33}b_{b3} + e_{34}T_{b4}) + d_4(e_{41}T_{b1} + e_{42}T_{b2} + e_{43}T_{b3} + e_{44}T_{b4}))$$

Collecting terms:

$$q_1 = -kA_1(T_{b1}(b_1e_{21} + c_1e_{31} + d_1e_{41}) + T_{b2}(b_1e_{22} + c_1e_{32} + d_1e_{42}) + T_{b3}(b_1e_{23} + c_1e_{33} + d_1e_{43}) + T_{b4}(b_1e_{24} + c_1e_{34} + d_1e_{44}))$$
$$q_2 = -kA_2(T_{b1}(b_2e_{21} + c_2e_{31} + d_2e_{41}) + T_{b2}(b_2e_{22} + c_2e_{32} + d_2e_{42}) + T_{b3}(b_2e_{23} + c_2e_{33} + d_2e_{43}) + T_{b4}(b_2e_{24} + c_2e_{34} + d_2e_{44}))$$
$$q_3 = -kA_3(T_{b1}(b_3e_{21} + c_3e_{31} + d_3e_{41}) + T_{b2}(b_3e_{22} + c_3e_{32} + d_3e_{42}) + T_{b3}(b_3e_{23} + c_3e_{33} + d_3e_{43}) + T_{b4}(b_3e_{24} + c_3e_{34} + d_3e_{44}))$$
$$q_4 = -kA_4(T_{b1}(b_4e_{21} + c_4e_{31} + d_4e_{41}) + T_{b2}(b_4e_{22} + c_4e_{32} + d_4e_{42}) + T_{b3}(b_4e_{23} + c_4e_{33} + d_4e_{43}) + T_{b4}(b_4e_{24} + c_4e_{34} + d_4e_{44}))$$

However, the q_i 's can also be expressed in terms of conductances between the boundary elements using Kirchoff's Law:

$$q_1 = g_{12}(T_{b1} - T_{b2}) + g_{13}(T_{b1} - T_{b3}) + g_{14}(T_{b1} - T_{b4})$$
$$q_2 = g_{12}(T_{b2} - T_{b1}) + g_{23}(T_{b2} - T_{b3}) + g_{24}(T_{b2} - T_{b4})$$
$$q_3 = g_{23}(T_{b3} - T_{b2}) + g_{13}(T_{b3} - T_{b1}) + g_{34}(T_{b3} - T_{b4})$$
$$q_4 = g_{14}(T_{b4} - T_{b1}) + g_{24}(T_{b4} - T_{b2}) + g_{34}(T_{b4} - T_{b3})$$

Equating the above two sets of equations yields the expressions for g_{ij} :

$$g_{12} = kA_1(b_1e_{22} + c_1e_{32} + d_1e_{42})$$
$$g_{13} = kA_1(b_1e_{23} + c_1e_{33} + d_1e_{43})$$
$$g_{14} = kA_1(b_1e_{24} + c_1e_{34} + d_1e_{44})$$
$$g_{23} = kA_2(b_2e_{23} + c_2e_{33} + d_2e_{43})$$
$$g_{24} = kA_2(b_2e_{24} + c_2e_{34} + d_2e_{44})$$
$$g_{34} = kA_3(b_3e_{24} + c_3e_{34} + d_3e_{44})$$

This conductance matrix is between the boundary elements only, and does not connect them to the CG. The elemental heat loads and capacitances are distributed to the four boundary elements with a weighting factor proportional to the sum of the conductances to the boundary element.

$$C_1 = \frac{C_{tet}(g_{12}+g_{13}+g_{14})}{g_{12}+g_{13}+g_{14}+g_{23}+g_{24}+g_{34}}$$
$$C_2 = \frac{C_{tet}(g_{12}+g_{23}+g_{24})}{g_{12}+g_{13}+g_{14}+g_{23}+g_{24}+g_{34}}$$
$$C_3 = \frac{C_{tet}(g_{13}+g_{23}+g_{34})}{g_{12}+g_{13}+g_{14}+g_{23}+g_{24}+g_{34}}$$
$$C_4 = \frac{C_{tet}(g_{14}+g_{24}+g_{34})}{g_{12}+g_{13}+g_{14}+g_{23}+g_{24}+g_{34}}$$

If the Card 9 PARAM CAPDIST OFF option is present, the matrix is transformed into a conductance matrix between the element CG and the boundary elements. The two conductance matrices are equivalent, but the conductance matrix from the CG has 10 conductances, whereas the matrix between the boundary elements has only 6. For this option, the elemental heat load and capacitance are concentrated at the CG.

To calculate the four additional conductances, we use the fact that the CG temperature is equal to the average of the four temperatures at the CG's of the sides. This is possible only if:

$$G_{1CG} = G_{2CG}$$
$$G_{1CG} = G_{3CG}$$
$$G_{1CG} = G_{4CG}$$

An additional constraint we impose is that the root mean square value of the sum of the conductances between the boundary elements is minimized. This yields the following equation:

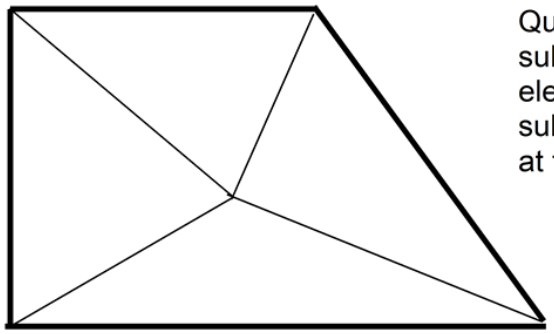
$$\partial \frac{(G_{12}^2 + G_{13}^2 + G_{14}^2 + G_{23}^2 + G_{34}^2)}{\partial (G_{1CG})} = 0$$

The star-delta transformation provides the other 6 equations:

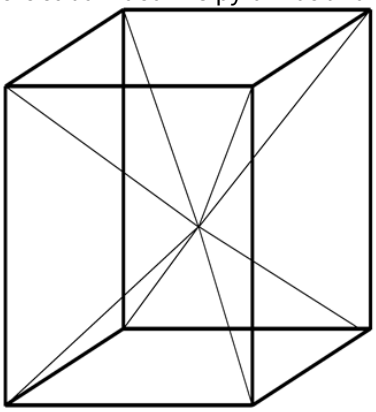
$$\frac{G_{1CG}G_{2CG}}{G_{1CG}+G_{2CG}+G_{3CG}+G_{4CG}} + G_{12} = g_{12}$$
$$\frac{G_{1CG}G_{3CG}}{G_{1CG}+G_{2CG}+G_{3CG}+G_{4CG}} + G_{13} = g_{13}$$
$$\frac{G_{1CG}G_{4CG}}{G_{1CG}+G_{2CG}+G_{3CG}+G_{4CG}} + G_{14} = g_{14}$$
$$\frac{G_{2CG}G_{3CG}}{G_{1CG}+G_{2CG}+G_{3CG}+G_{4CG}} + G_{23} = g_{23}$$
$$\frac{G_{2CG}G_{4CG}}{G_{1CG}+G_{2CG}+G_{3CG}+G_{4CG}} + G_{24} = g_{24}$$
$$\frac{G_{3CG}G_{4CG}}{G_{1CG}+G_{2CG}+G_{3CG}+G_{4CG}} + G_{34} = g_{34}$$

Calculation of Elemental Conductances for Quadrilaterals, Wedges, Pyramids, and Hexahedra

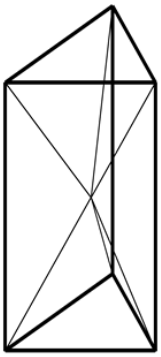
To calculate the conductance matrix for quadrilaterals, hexahedra and wedges these elements are first divided into triangular, tetrahedral and pyramidal subelements.



For a quadrilateral the diagonally opposite nodes with the larger sum of the internal angles are connected.
Each hexahedron is subdivided into 6 pyramids with lines joining the CG of the hexahedron to each of the corners. Each wedge is subdivided in 3 pyramids and 2 tetrahedra by joining the CG of the element to the corners.



Subdivision of a hexahedron



Subdivision of a wedge

For each sub-element a conductance matrix is constructed similar to the procedure described above for triangles and tetrahedra, with the following exceptions:

- For wedges, pyramids, and hexahedra, the location of the calculation points on external faces is at the CG of the face.
- At internal faces the boundary condition of matching the heat fluxes is used.
- The conductance matrix of pyramidal elements and sub-element is derived by sub-dividing the pyramid into two tetrahedra, and applying the following conditions:
    - The sum of the heat flows through the adjacent side of the two tetrahedra is zero.
    - The thermal gradient normal to the quadrilateral face is the same for both tetrahedra (uniform heat flux on the quadrilateral face).
    - The temperature at the CG of the quadrilateral face is equal to the area-weighted average temperature of the CG's of the two triangles subdividing that face.

The element conductance matrix is assembled by eliminating the calculation point at the CG of the internal faces using the star-delta transform. This yields a conductance matrix between the boundary elements.

For quadrilaterals the resulting conductance matrix is further transformed by creating four more conductances between the CG and the boundary elements in the manner described above for the tetrahedron with the PARAM CAPDIST OFF option, by minimizing the root mean square value of the conductances between the boundary elements. The weighting factors for the conductances from the CG to the boundary elements are derived by assuming a parabolic temperature distribution within the element.

The resulting size of the conductance matrix is 10 conductances for quads, 10 conductances for wedges and 15 conductances for hexes.

For wedges and hexes, the capacitance and elemental heat loads are redistributed to the boundary elements at analysis time, for quads they remain concentrated at the CG.

Optionally, if the Card 9 PARAM CAPDIST OFF is present, the conductance matrix between the boundary elements is transformed into a conductance matrix between the CG of the element and boundary elements, including conductance terms from the CG to the boundary elements. This is done in a manner similar to the method described above for the triangle and the tetrahedron, with an important exception. The root mean square value of the conductances between the boundary elements is minimized as before, however, the conductances between the CG and the boundary elements are not equal. For a solid element:

$$\frac{G_{iCG}}{G_{jCG}} = \frac{A_i D_j sin(\theta_i)}{A_j D_i sin(\theta_j)}$$

and for a quadrilateral:

$$\frac{G_{iCG}}{G_{jCG}} = \frac{L_i D_j sin(\theta_i)}{A_j L_i sin(\theta_j)}$$

where:

- D_i is the distance between the element CG and the CG of the boundary element
- θ_i is the angle between the line joining the CG of the element to the boundary element and the surface normal of the boundary element.

This approach yields a conductance matrix identical to that of the element center method for rectangles and brick elements.

Interface Conductances

If an interface conductance between two adjacent elements is specified with a Card 6 INTER, ITERTOT, INTER2, INTER2TOT option, two parallel boundary elements are created on the adjacent elements by splitting the nodes of the interface element. The interface conductance equal to the area of the boundary element times the interface conductance is then created connecting the two boundary elements.

If more than two elements are connected to the interface element, then conductances will be created between all the elements with a value equal to the total interface conductance value divided by the total number of elements.

Parabolic Elements

Parabolic and linear elements are treated identically, the extra nodes on parabolic elements are only used in temperature recovery stage.

Temperature-dependent thermal conductivities

If an element has a non-linear thermal conductivity specified in a table, a nominal value of 1 is used in the conductance calculation and the resulting conductances are multiplied by the interpolated conductance value during the Analyzer run.

Orthotropic Materials

If a solid element has an orthotropic thermal conductivity, then element is first proportionally stretched in the element's material X, Y, and Z directions by the factors $\sqrt{(k_{yy}k_{zz})}$, $\sqrt{(k_{xx}k_{zz})}$, $\sqrt{(k_{yy}k_{xx})}$ respectively before the conductance calculation, and the thermal conductivity value is set to 1.

If a planar element has an orthotropic thermal conductivity, then element is first proportionally stretched in the element's material X and Y directions by the factors $\sqrt{k_{yy}}$, $\sqrt{kxx}$ respectively before the conductance calculation, and the thermal conductivity value is replaced by the value $\sqrt{(k_{yy}k_{xx})}$.

Axisymmetric Elements

If an element is an axisymmetric solid, it is treated as a planar element in the XZ plane that is stretched in the X direction by:

$$\frac{2\pi(X\max - X\min)}{\log(\frac{X\max}{X\min})}$$

and in the Z direction by:

$$\pi(X\max - X\min)$$

If it is an axisymmetric shell with a thickness t, it is treated as a beam with an equivalent cross-section of:

$$\frac{2\pi(X\max - X\min)}{\log(\frac{X\max}{X\min})}$$

where:

- $X\max$ and $X\min$ are the maximum and minimum X (radial) dimensions of the element.

If the material is also orthotropic, it is first stretched along the orthotropic axes as described above.

Capacitance Calculations

Capacitance calculations are performed only for elements that have specific heats > 0. An elemental capacitance is calculated by:

$$\text{Capacitance} = (\text{volume})(\text{specific heat})(\text{density})$$

Hydraulic Resistance Calculation

Two hydraulic resistances are calculated between the CG of each 2-node hydraulic element and the 1-node hydraulic elements at its boundary. The value of the hydraulic resistance written on file MODLF with MNM = HYD is the flow resistance multiplier from the element PROP Card divided by the distance between the CG of the element and its ends.

Comparison between CONDN and COND modules

The following provides a brief comparison between the COND and CONDN conduction modules.

- CONDN creates conductances between boundary elements, whereas COND also creates conductances between element centers. For regular rectangular meshes, CONDN creates a much denser mesh.
- CONDN is more tolerant of odd element shapes.
- For meshes which contain irregular elements CONDN generally produces more accurate temperatures, especially if the thermal model includes radiation or convection effects. This is because that CONDN module allows TMG to calculate temperatures at the CG's of the surface elements, which more accurately represent the average surface temperature of the radiating or convecting elements. In addition, the conductance matrix derivation for solid elements is much more accurate that that of COND, and CONDN allows the creation of negative conductances, while COND does not.

GRAYB Module

Function

The GRAYB module creates the radiative conductances (Card 2a `M = 4)` and the IR (`M = 16`) and solar spectrum (`M = 8`) gray body view factor matrices.

The radiative conductances may be calculated using the recommended Oppenheim's Method (activated with Card 9 PARAM OPPENHEIM) or Gebhardt's Method.

The radiative conductances are written on file MODLF, and the gray body view factor matrices on file VUFF.

The Gray Body View Factor

Radiative heat transfer between elements i and j is described by:

$$Q_{ij} = \sigma \mathrm{E}_i A_i VFG_{ij}(T_i^4 - T_j^4)$$
$$= -\sigma \mathrm{E}_j A_j VFG_{ji}(T_j^4 - T_i^4)$$

where:

- Q_i is the net radiative heat load from element i to element j.
- σ is Stefan-Boltzmann's constant.
- T_i, T are the absolute temperatures of elements i and j.
- E_i, E_j are the emissivities of elements i and j, defined on MAT Cards.
- A_i, A_j are the surface areas of elements i and j.
- VFG_{ij} is the gray body view factor from i to j, which is the fraction of the emitted or reflected radiant heat load leaving the surface i and absorbed by j after multiple diffuse reflections from all the elements.
- VFG_{ji} is the gray body view factor from j to i.

An important property associated with the gray body view factor is reciprocity:

$$EiA_iVFG_{ij} = EjA_jVFG_{ji}$$

Note the similarity to the view factor reciprocity property:

$$A_iVF_{ij} = A_jVF_{ji}$$

Another important property of the gray body view factor is that the sum of the gray body view factors for any element i is unity:

$$\sum_j VFG_{ij} = 1$$

The gray body view factor and the view factor are identical in an enclosure where all the elements are black.

An important difference between the view factors and the gray body view factors is that while self-view factors are zero for non-concave surfaces, gray body self-view factors are generally not zero, since reflections cause the elements to re-absorb some of the radiation that leaves their surfaces.

In the IR spectrum gray body view factor calculation the absorptivity is equal to the emissivity.

For solar spectrum calculations the emissivity values are replaced by the solar absorptivity values.

Enclosures

The GRAYB module separates elements into enclosures. An enclosure is defined to be a set of elements that view each other and only each other.

The advantages of enclosures are:

- Efficiency - the size of the radiation matrix to be inverted is reduced for Gebhardt's Method.
- Model debugging - the elements belonging to each enclosure are written to the report log file. This can be used to verify that improper couplings between enclosures are not present.

KSP and the Residual View Factor R_i

The residual view factor R_i for element i is:

$$R_i = 1 - \sum VF_{ij}$$

The ideal value of R_i is `0`. Departures from this may occur because of the approximations in view factor calculations, or when an improper enclosure is defined, e.g. when i sees the back of another element. Very large departures are usually an indication of an improper model.

The physical effect of $R_i > 0$ is to reduce the radiation leaving i, in effect making the surface more "concave".

TMG provides three methods of compensating for $R_i \neq 0$

Create a self-view factor ($KSP = 0$).

- The effect of creating a self-view factor may be viewed as assuming the element is concave. Some of the radiation is incident on i itself, which is then reflected to the elements it sees in proportion to the view factors times the reflectivity

Setting the residual view factor to an element ($KSP > 0$, KSP = element number).

- If $KSP > 0$, R_i is connected to element KSP, provided a view factor from that enclosure to element KSP already exists. If it is does not, R_i is set to the self-view factor. This prevents the unwanted leakage of radiation from inside an enclosure to an element it cannot see.
- A new very large black element KSP is created in the enclosure.
- If $KSP > 0$, for each element i where $R_i < 0$ the $KSP = 0$ option is used.
- If $KSP = 2E6$, the space element number obtained from the Card 5d SPACE Card is substituted for the code 2E6.

Approximate proportional adjustment of the view factors ($KSP = 3E6$).

This is the **recommended** option.

With this option, adjustment of the shadowed view factors only is performed iteratively to minimize the maximum R_i. The unshadowed view factors are assumed to be exact because it is assumed they were calculated with the accurate Exact Contour Integral Technique.

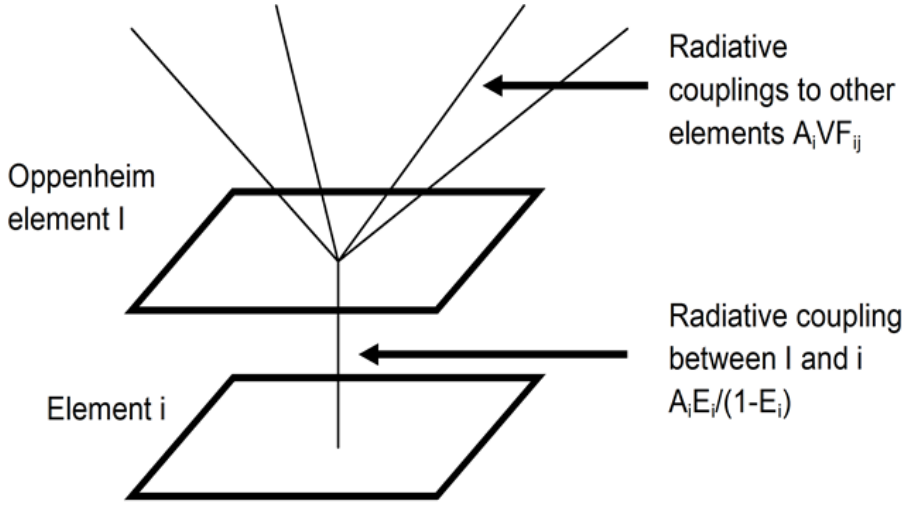
At each iteration each shadowed view factor VF_{ij} is multiplied by the factor:

$$\frac{1}{1 - R_i \frac{A_j}{A_i + A_j} - R_j \frac{A_i}{A_i + A_j}}$$

The R_i 's are re-evaluated during each iteration. The iterations are halted when the maximum R_i is minimized.

Oppenheim's Method

Oppenheim's Method, or otherwise known as the radiosity method, is the recommended approach. Oppenheim's Method consists of creating an artificial "Oppenheim element" I for each radiating element i, which may be visualized as an imaginary element floating above element i, and intercepting all radiation to it.



A radiative coupling equal to

$$\frac{A_i E_i}{1 - E_i}$$

is created between I and i, and each view factor VF_{ij} is transformed into a radiative coupling $A_i VF_{ij}$ between I and the Oppenheim element J of j.

Oppenheim's Method is an alternative to Gebhardt's Method for calculating radiative couplings. It has several advantages:

- Temperature-dependent emissivities are handled more accurately and efficiently. This is because during temperature calculations only the radiative conductance $A_i E_i/(1 - E_i)$ between the Oppenheim element and the element itself needs to be modified.
- CPU performance is generally much improved for two reasons: the matrix inversion process of Gebhardt's Method is bypassed, and the number of radiative couplings is much generally much smaller. This is because in a given enclosure Gebhardt's Method creates a radiative coupling between every element, even if they cannot view each other.
- Accuracy is improved because the RK elimination of insignificant radiative couplings is bypassed.
- File sizes are generally smaller.

Note: With Oppenheim's Method significant performance degradation can be expected during transient analysis with the explicit forward differencing method. This is because the Oppenheim elements are assigned zero capacitance, and the forward differencing method requires a full steady-state solution for the surface elements at each integration time step.

However, no accuracy degradation is observed with the implicit time integration methods.

Oppenheim's Method is invoked by specifying Card 9 PARAM OPPEHEIM `T1`. The corresponding Oppenheim element I for each element i are then assigned an element number equal to $i + T1$. In case of numbering conflict, an unused element number is assigned.

Gebhardt's Method

Gray body view factors between the elements are calculated by Gebhardt's Method (Ref. 2). This method assumes that the radiation emitted by i and absorbed by j after multiple diffuse reflections is equal to the absorbed portion of the radiation directly incident upon j, plus the radiation reflected by all surfaces:

$$VFG_{ij} = E_j VF_{ij} + \sum_k VF_{ik}(1 - E_k)VFG_{kj}$$

The reflected radiation is assumed to be reflected perfectly diffusely, i.e. it is reflected in proportion to the view factors of the element. If only geometric view factors are present on the VUFF file, then even if an element has specular reflectivity, its reflectivity is treated as perfectly diffuse.

If ray-traced view factors are present on VUFF through the use of the VFTRACE option, the equivalent reduced diffuse properties of the view factor matrix are used for elements that have specular or transmissive surface properties. In this case, the specular and transmissive effects have been accounted for during the ray-tracing procedure.

The RK Parameter

Excessively weak radiative conductances calculated with Gebhardt's Method may be eliminated or connected to element Card 2a KSP through the use of a non-zero Card 2a RK parameter. For each element i and j the largest gray

body view factors not connected to a Card 5d space element VFG_{imax} and VFG_{jmax} are found, and only those radiative conductances whose gray body view factors fulfill the two inequalities:

$$VFG_{ij} > |RK| VFG_{i\ max}$$
$$VFG_{ji} > |RK| VFG_{j\ max}$$

are written on file MODLF. All others are considered insignificant.

The double inequality is necessary because when $A_i << A_j$ the conductance may be insignificant for j but very important for i.

If $RK > 0$ the insignificant radiative conductances are not written on file MODLF, unless the coupling is to space.

If $RK < 0$ and $KSP \neq 0$ each insignificant coupling is replaced by two equivalent couplings, one from element i and one from element j, to element KSP, provided KSP is not a Card 5d space element. This technique is similar to the one described in (Ref. 1).

The gray body view factor matrices are not affected by RK.

It is necessary to exercise care with $RK > 0$ to avoid eliminating an excessive number of radiative couplings. $RK = 1$ eliminates all radiative couplings.

$RK = 0$ defaults to $RK = 1.\mathrm{E} - 4$.

Module Operation

1. The module reads from file VUFF all the areas, emissivities, and the appropriate spectrum view factors.
2. If view factors are duplicated, the last one is used.
3. The elements are separated into enclosures.
4. The residual view factors are computed and, depending on the value of KSP, view factor adjustment is performed.
5. Radiative couplings are calculated, either with Oppenheim's Method or Gebhardt's Method.
6. If Gebhardt's Method is specified, insignificant radiative couplings are eliminated or joined to KSP.
7. The radiative couplings are written on file MODLF with the mnemonic `MNM = RAD`.
8. If the gray body matrices are being calculated with Gebhardt's Method, they are written on file VUFF with the mnemonic `MNM = IGM` for the IR spectrum and `MNM = SGM` for the solar spectrum.

For this operation, very small gray body view factors, where:

$$VFG_{ij} < 1.\mathrm{E}{-}6$$
$$VFG_{ji} < 1.\mathrm{E}{-}6$$

are ignored

Angle Dependent Surface Properties

For an element with angle dependent specular reflectivity or transmissivity the diffuse reflectivity is calculated as:

$$\rho_{di} = 1 - \varepsilon_i - \rho_{si}$$
or
$$\rho_{di} = 1 - \varepsilon_i - \tau_i$$

Where:

- ρ_{di} is the diffuse reflectivity,
- ρ_{si} is the average specular reflectivity, calculated by averaging the data in the array, and
- τ is the average transmissivity, calculated by averaging the data in the array.

HEMIVIEW Module

Function

The HEMIVIEW module calculates diffuse blackbody view factors using the hemicube method, which allows computer graphics hardware to accelerate the calculations.

All HEMIVIEW module requests start with Card 6v HEMI ON and end with HEMI OFF. Between these Cards is the body of the HEMIVIEW requests. Details of the calculations are written to the verbose and report log files. Results are written on file VUFF.

Difference between HEMIVIEW and VUFAC

The VUFAC module calculates view factors with a combination of the contour integration and Nusselt sphere methods, using automatic elemental subdivision algorithm when shadowing occurs. View factors between elements are calculated one at a time. If shadowing occurs, the number of calculations required to compute the view factors varies roughly as the cube of the number of elements, which is very Cpu intensive.

The HEMIVIEW module is much faster. It uses computer graphics techniques to graphically render the radiating elements onto the five sides of a hemicube (a half-cube) placed at the CG of an element, called the emitting element. The view factors from the emitting element to the other elements, called the receiving elements, are determined by post-processing the graphical images of the receiving elements projected onto each of the hemicube sides. The

hemicube method is fast for two reasons: the number of renderings is linearly proportional to the number of elements, and the rendering calculations are performed with specialized fast graphics cards.

The accuracy of the hemicube method is limited by the pixel resolution of the drawing area.

How it Works

Cohen and Greenberg first proposed the hemicube algorithm, in which the five sides of an imaginary hemicube cover an element such that the center of the cube is at the centroid of the emitter element i (Figure 1a), and the top plane of the cube is parallel to the plane of the element. The faces of the hemicube are divided into equal size squares, referred to as pixels, with areas of dA. Each element j, called the receiver element, is graphically projected onto the faces of the hemicube, with the focus of the projection on the centroid of emitter element i. This projection is easily and efficiently performed within computer graphics hardware, with each hemicube face containing the rendered image of a section of the model.

Each receiver element j is assigned a unique color, and a depth-buffer algorithm (Z-buffer) ensures that only the visible parts of overlapping elements appear in the final image. The rendered images on the five hemicube surfaces comprise the images of all the elements of the model surrounding the emitter element i. The pixel colors of these five images are post-processed to calculate the view factors of the emitter i to each element.

Figure 1 (a and b) depicts two elements being rendered onto the surface of a hemicube, and the resulting pixel colors after the rendering process.

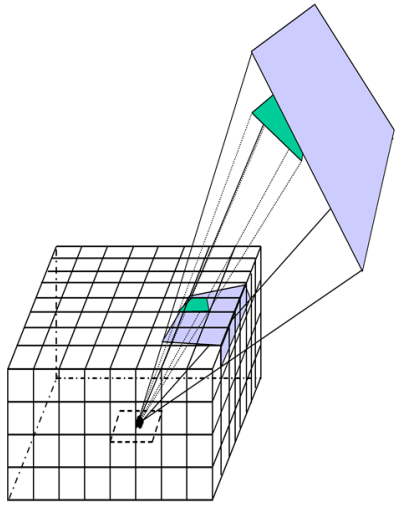


Figure 1. (a) Projection of two elements onto the Hemicube

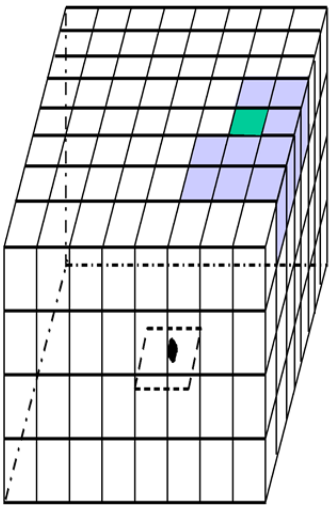


Figure 1. (b) Pixel-resolution image of the elements on the Hemicube faces

Calculation of View Factors

Each pixel is associated with a pre-computed delta view factor ΔF_p ,

$$\Delta F_p = \frac{\cos\theta_{ip}\cos\theta_p}{\pi r^2}\Delta A_p \qquad (1)$$

where the geometry is shown in Figure 2.

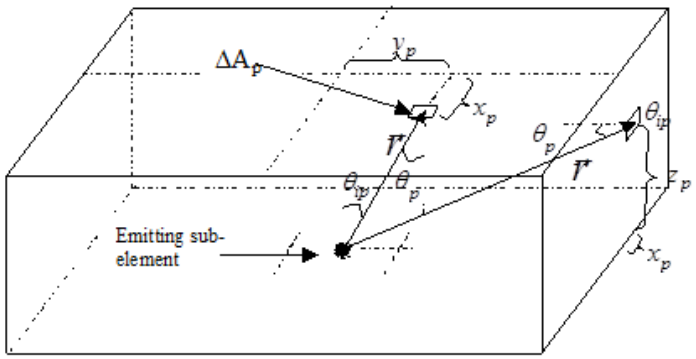


Figure 2: Geometry for determining pixel delta view

The vector r is from the eye position (CG of the emitting element i) to the CG of the pixel under consideration. θ_{ip} is the angle between r and the emitter element normal. θ_p is the angle between r and the normal to the hemicube plane on which the pixel lies.

A pixel's contribution to the view factor (Equations 3 & 5), is derived by assigning a local (x, y, z) coordinate system to the hemicube, and making the hemicube a unit height. Then, for pixels on the top plane of the hemicube,

$$|r| = \sqrt{x_p^2 + y_p^2 + 1}, \cos\theta_{ip} = \cos\theta_p = \frac{1}{r} \qquad (2)$$

Upon substitution of the above equation into Eq. (1), the view factor contribution of each pixel becomes:

$$\Delta F_p = \frac{\Delta A_p}{\pi(x_p^2 + y_p^2 + 1)^2} \qquad (3)$$

for top plane pixels of uniform area ΔA. Similarly, for the side plane pixels,

$$|r| = \sqrt{y_p^2 + z_p^2 + 1}, \cos\theta_{ip} = \frac{z_p}{r}, \cos\theta_p = \frac{1}{r} \qquad (4)$$

which yields:

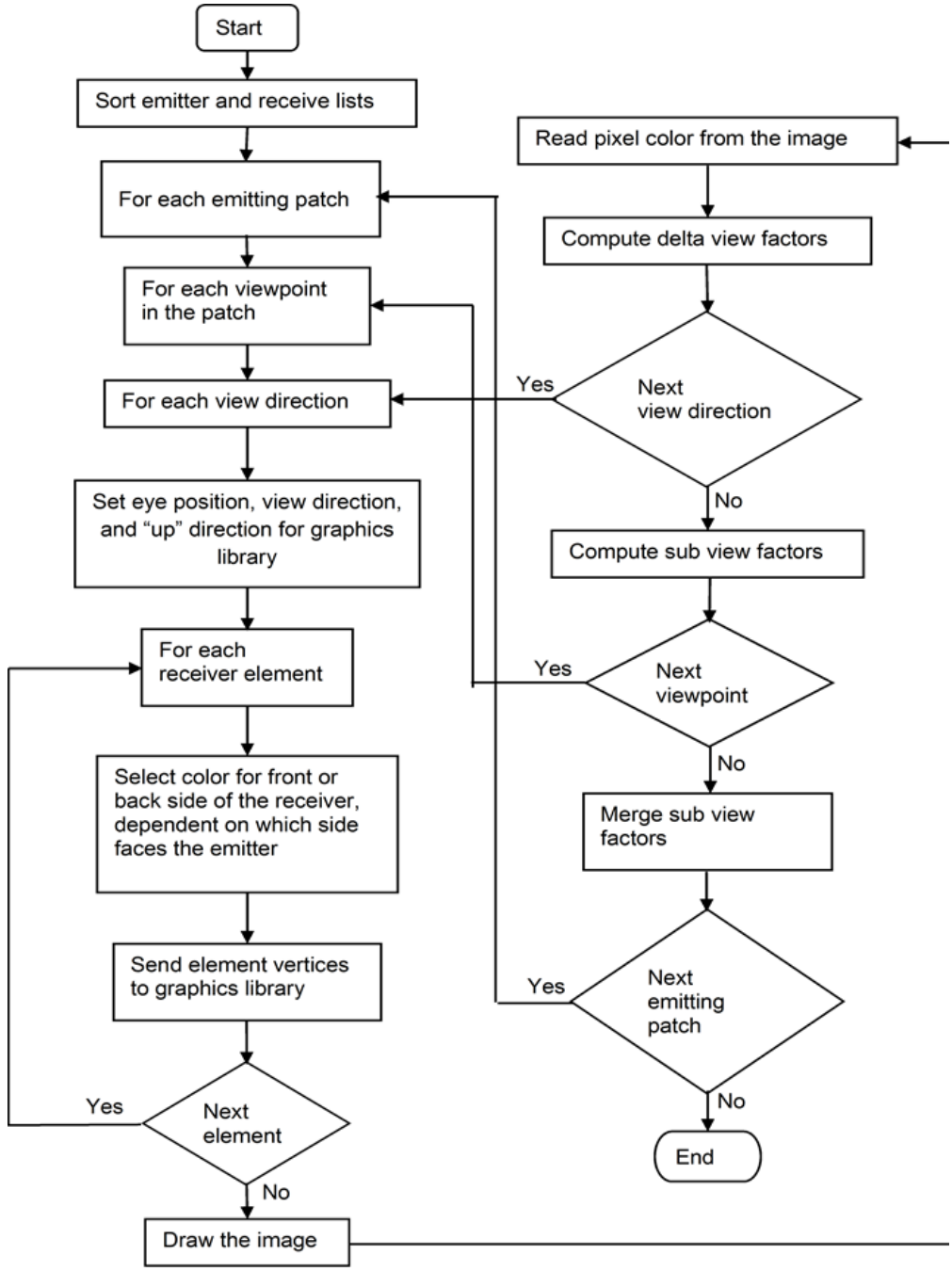
$$\Delta F_p = \frac{z_p \Delta A_p}{\pi(y_p^2 + z_p^2 + 1)^2} \qquad (5)$$

The Rendering Procedure

The rendering procedure is depicted in detail in Figure 3. First, the eye position, view direction, viewing frustum dimensions, and image plane location parameters are defined. The eye position is at the CG of the emitter element i. The view direction is perpendicular to each of the viewing planes, i.e. the sides of the hemicube. The top surface of the viewing frustum is a side of the hemicube, the bottom surface is a corresponding square or half-square located at the emitter CG.

Next, the colors and vertex coordinates of the j elements are processed for rendering. Each receiver element, as well as its reverse side, is assigned a different color. Finally, a “draw” command is issued, and the graphic hardware draws the receiver element images on the five rendering planes, as seen from the position and perspective of the CG of the emitter element i.

Workflow of image rendering in HEMIVUE


Start
Sort emitter and receive lists
For each emitting patch
For each viewpoint in the patch
For each view direction
Set eye position, view direction, and "up" direction for graphics library
For each receiver element
Select color for front or back side of the receiver, dependent on which side faces the emitter
Send element vertices to graphics library
Next element
Yes
No
Draw the image
Read pixel color from the image
Compute delta view factors
Next view direction
Yes
No
Compute sub view factors
Next viewpoint
Yes
No
Merge sub view factors
Next emitting patch
Yes
No
End

Once these initial parameters are set, the algorithm loops over all the sides and all the receiver elements j, projecting them onto the five sides.

If a reverse side is not defined, it is still projected onto the rendering planes, but the view factor to it are discarded and a warning message is issued.

For greater accuracy and efficiency, only view factors from smaller to larger elements are considered.

After the image is rendered, the view factors are computed by summing the pixels of different colors in each of the five views. The contribution of a pixel to the view factor f_{ij} between elements i and j of the hemicube view l (Equations 3 & 5) is computed with:

$$f_{i-j} = \sum_{l}^{5} \sum_{k} \Delta F_k^l H_{jk} \qquad (6)$$

where

- ΔF_{lk}^l is the delta view factor for pixel k of hemicube view l and H_{jk} is the Heaviside function which equals 1 when the color of pixel k matches the color of element j, and 0 otherwise.

Using the MESH Parameter

The accuracy of a view factor calculated with the hemicube method decreases if two elements are close together, i.e. if the view factor between them is large.

If one does not use a Card 6f MESH ERROR setting, then for each element i the following iterative procedure is employed. First, all the view factors are calculated with no elemental subdivision, i.e. the emitter element is not subdivided. Next, an evaluation is performed. If a view factor seen through the top viewing plane is > .03, or the view factor seen through the side viewing plane is > 0.3, a second run is performed, with the MESH parameter specified by the user. If desired, one can bypass this check of view factor values and enforce unconditional use of the specified MESH parameter by activating an Advanced Solver Parameter (EMS) or specifying the Card 9 GPARAM 56 38 1.

If a Card 6f MESH ERROR value is defined, then, regardless of the above MESH parameter setting, the mesh size for the elemental subdivision is determined automatically for each element so that the view factor sum error would be approximately within the given MESH ERROR set tolerance. This is the recommended option since it allows maintaining consistent accuracy throughout a model with different element sizes and configurations in it, while also minimizing the computational cost to achieve a given overall accuracy level. The MESH ERROR algorithm uses a view factor sum error estimate that is based on view factor values calculated without elemental subdivisions, distances from a given element to its surrounding elements, and the area of the given element. That error estimate uses a view-factor weighted direction average of estimated view factor errors for all emitter-receiver element pairs for a given emitter element.

The final view factor is calculated by summing the view factors of all the sub-elements:

$$f_{i-j} = \frac{1}{A_i} \sum_{m} f_{i-j}^m dA_{il} \qquad (7)$$

where

- dA_l is the m'th incremental area of emitter element i
- f_{i-j}^{m} is the view factor for the m'th incremental area of element i to element j.

For more information on how the subdivision is performed as a function of the MESH parameter, see VUFAC Module .

Choosing the Winsize Parameter

The rendering window size is specified by the Card6v WINSIZE parameter. WINSIZE defines the number of pixels that can be drawn on the screen, and hence affects the accuracy of the view factor calculations, the maximum number of elements that can be drawn, and total CPU time the module may take.

The total number of pixels for the top view is `WINSIZE*WINSIZE`, for the side view is `WINSIZE`^{2}`/2.` The maximum number of colors (and hence the maximum number of elements that can be drawn, i.e. seen by a given element) is 5*WINSIZE^2. Please note that more elements than this can exist in a model, provided that some of these elements shadow each other.

A larger WINSIZE value will increase the accuracy of the calculation but will also increase the CPU time. The default WINSIZE value is 128, which corresponds to a maximum of 49,152 elements that can be seen by any given element through one of the viewing planes.

Allowable Element Types

For the Allowable Element Types, see the description of the VUFAC Module.

Ray-Tracing

If ray-tracing is specified in the radiation request with the VFTRACE flag, the HEMIVIEW module will calculate black body view factors without ray-tracing. Ray-tracing, however, will be performed by the VUFAC module.

Operational Modes

The HEMIVIEW module has two different operational modes: On-Screen and Off-Screen. In the Off-Screen mode there are options to use either the graphic card based rendering (to take advantage of hardware acceleration in the graphics card) or software based rendering (for cases where the loss of hardware acceleration can be compensated by better parallel processing performance or, on Linux platform, for use on machines that don't have graphics cards or the X-server running).

In On-Screen mode, a fixed size window is popped-up in the top corner of the left hand side of the screen and the images are directly rendered to the window. This window must not be obscured, and it cannot be resized. A disadvantage of the On-Screen mode is that it is less robust. The window must not be obscured, the computer cannot be locked, and no screen saver can be activated while the module is running. The On-Screen mode is currently available

only on Windows platforms, as a non-default option. It can be activated either through an Advanced Solver Parameter (HOR), or through specifying the Card 9 GPARAM 56 28 1.

In the Off-Screen mode, no popped-up window can be seen and the images are rendered directly to either the memory of the graphics card or the Cpu memory. On UNIX platforms, the graphic card is used through the pBuffer, which allows hardware accelerated rendering. On Windows platforms, by default, this is done with DIB (Device-Independent Bitmaps), which use software-based rendering without hardware acceleration in the graphic card. For graphic cards that support Windows-specific WGL pbuffer extension to OpenGL, the hardware accelerated rendering can be enabled in the Off-Screen mode on Windows platforms by specifying Card 9 GPARAM 56 28 -1. For newer graphic cards that support OpenGL Frame Buffer Objects (FBO) through the GL_EXT_framebuffer_object OpenGL extension, an FBO-based Off-Screen mode can be used for hardware accelerated rendering on both Windows and Linux platforms, by specifying Card 9 GPARAM 56 28 -2. Only one of those Card 9 GPARAM 56 28 X settings should be used in a given run.

On Windows and Linux platforms, there is also an off-screen mode that exploits software rendering (in the Cpu memory) via the OSMesa API of the Mesa 3D Graphics Library (www.mesa3d.org). That option uses a different HEMIVIEW executable, which is statically linked to the OSMesa library and does not have any dependencies on either the presence of the graphic card or the X server running or the X libraries availability on the machines. To activate that option one can either add GPARAM 0 47 1 to Card 9 or set environment variable TMG_HEMI_OSMESA to ON.

When the graphic card based rendering is used, one may not get a performance advantage from HEMIVIEW multiprocessing with multiple HEMIVIEW processors per machine because those processes would be competing for the same graphic card resources.

For HEMIVIEW performance diagnostics in different operational modes one can also use Card 9 GPARAM 56 41 1 setting, which will activate printing of some of the HEMIVIEW key timing statistics to the run standard output (not to the verbose log file).

Remote Rendering

It is possible to specify rendering on a remote graphic card on a network. To do this, with either the On- or Off-Screen modes, the DISPLAY environmental variable must be properly set. Remote rendering is slower than local, especially on UNIX platforms, because X server is invoked to perform a series of actions such as encoding and decoding Open-GL commands, and the rendering is indirect.

The most frequently encountered problem with remote rendering is the availability of the remote graphics card, especially on UNIX platforms. Often access to the card is not permitted, or there is no active display available. To enable access control on UNIX platforms, the local user must run ‘`xhost + host_name`’ where host_name is the machine name from which the connection request to the graphic card is made.

Another problem often encountered with remote rendering is the unavailability of the display. The display is not available when the remote computer is off, when there is no local login session running using the local graphic card, or when the number of clients or graphic applications using the graphics card has reached its allowable limit.

Any remote graphics card on the network can be used by HEMIVIEW. A robust procedure is used to ensure the availability of a graphics card. If the desired graphics card is not local, and is not defined with the user’s $DISPLAY variable, it can be specified by the environmental variable TMG_HEMI_DISP. HEMIVIEW first checks if TMG_HEMI_DISP is defined. If it is, HEMIVIEW tries to connect to it. If it is not defined, or the access to it is denied, HEMIVIEW tries to use the

local display, i.e., the graphics card on the local host machine, the machine on which TMG is running. If this graphics card is not accessible, HEMIVIEW tries to use the display specified by the environment variable DISPLAY as the last resort. If no display is available after the above three steps, a FATAL error is issued and HEMIVIEW terminates.

MAIN, DATACH and ECHOS Modules

Function

The MAIN module reads the Card 2 Program Control Cards, and determines what modules are to be run. It then creates a procedure file SCX34 that runs the appropriate modules.

The DATACH module:

- Checks the input data on file INPF for errors.
- Transforms the nodes into the global coordinate system.
- Creates elements and nodes from element and node generation Cards and Card 9 AXISYMM Cards.
- Transforms NASTRAN format data into TMG input format.
- Replaces file TEMPF if there are Card 9 TINIT Cards present.
- Eliminates elements or conductances with Card 9 KEEPDEL Cards.
- Create equivalent solar and Earth view factor Cards from Card 6 Orbit Generation Cards.
- Automatically creates 1-node hydraulic at ends of 2-node hydraulic elements that do not already have them.
- Creates REVNODE and REVNOM reverse side elements.
- Creates space elements.

ECHOS calculates each element's CG, element center, area or volume, hydraulic diameter, and surface normal, and writes it on file VUFF, along with the location of the nodes.

MEREL Module

Function

The MEREL module performs element merging and elimination. MEREL creates the condensed model file MODLCF from file MODLF and Cards 7, 8, and 9.

Model Condensation

The following options exist:

- Automatic combination
- Element merging or renumbering
- Substructuring
- Model thinning

Automatic Combination

The MEREL module automatically combines all parallel radiative (and conductive conductances, and sums all capacitances and heat loads.

Element Merging

Element merging creates a simplified thermal model by merging elements whose temperatures are expected to be similar. Element merging is performed for:

- elements specified on Card 7,
- elements connected with a linear conductance value $\geq 1.E10$
- elements connected by the Card 6e NEARM option,
- elements for which an infinite or negative conductance was calculated by the COND module,
- reverse side elements created with the Card 9 REVNODE option,
- the elements created by the Card 5d SPACE Card.

For all except the REVNODE and SPACE Card follower conductances (`MNM = FOL`) are written on file MODLCF to recover the merged elements' temperatures.

If the Card 9 PARAM NOMRECOV option is specified, no follower conductances are created for the merged elements.

Element merging is identical to element renumbering. When j is merged to i, all references to j are replaced by a reference to i, and parallel linear and radiative conductances, capacitances, and heat loads are combined.

The elements of non-linear conductances (e.g. hydraulic resistances, convective conductances) are renumbered, but they are not added in parallel with each other.

Elements are renumbered in all references to Card 9 INTERP Cards, PHASE Cards, SINK element Cards, and THERMST Cards.

The following type of elements may not be merged with other elements:

- Card 5e hydraulic elements.
- Card 9 MCV elements.

However, other elements may be merged to them.

Substructuring

After element merging, substructuring is performed if Cards 8 are present or a Card 9 PARAM SUBSTR Card is present.

Substructuring reduces the thermal model to a smaller mathematically equivalent one by eliminating specified elements. Their temperatures are recovered at each printout interval.

First, a list of elements to be eliminated is created:

- Sink elements, MCV elements, phase change elements, hydraulic elements, elements referenced on INTERP or THERMST Cards, and elements connected with one-way or non-linear convective conductances are not eliminated.
- The elements T1 specified on the PARAM SUBSTR Card are not eliminated.
- On PARAM SUBSTR GSUM Cards elements with $G_{ksum} > T3$ are eliminated. G_{ksum} is the conductance sum of k.
- On PARAM SUBSTR T2 RCMIN Card, elements with capacitance $/G_{ksum} < T3$ are eliminated, including zero-capacitance elements.
- On PARAM SUBSTR T2 CMIN Cards elements with capacitance values $< T3$, including zero-capacitance elements, are eliminated.
- Card 8 elements are eliminated.
- If the PARAM SUBSTR RADNODES option or the equivalent PARAM HYBRID option is used, all elements with radiative conductances are not eliminated.

In case of conflict , the element is not eliminated.

Next, the total conductance G_{ksum} for each element k to be eliminated is calculated:

$$G_{ksum} = \sum G_{ik}$$

Radiative conductances are linearized with the Card 2a TLIN parameter:

$$G_{ik} = \sigma VFG_{Ki} TLINA_k EK$$

where:

- $TLIN = (Ti^4 - Tk^4)/(T_i - T_k)$
- $TLIN$ is the estimate specified on Card 2a,
- G_{ik} is the conductance between elements i and k,
- T_k is the estimated average absolute temperature of k,
- T_i is the estimated average absolute temperature of the elements connected to k,
- A_k , A_i are the areas of elements k and i
- E_i , E_k , are the emissivities of elements k and i,
- VFG_{ik} , VFG_{ki} are the gray body view factors from elements k to i and i to k,
- σ is the Stefan-Boltzmann constant from Card 2a.

Next, new equivalent conductances are calculated between elements i and j:

$$G_{ij} = G_{ik} G_{jk} / G_{ksum}$$

where:

- i, j are elements connected to element k,
- G_{ij} is the new equivalent conductance between elements i and j.
- G_{ij} set to be a radiative conductance if the smaller of G_{ik} and G_{jk} is a radiative conductance.

- G_{ij} is set to be a conductive conductance if the smaller of them is a conductive conductance.

The heat load into element k is redistributed among the connected elements:

$$Q_I(t) = Q_k(t)(G_{ik}/G_{ksum})$$

where:

- $Q_k(t)$ is the heat load into element i at time t,
- $Q_i(t)$ is the new redistributed heat load into element i at time t.

The capacitance of element k is redistributed among the connected elements with:

$$C_{pi} = C_{pk}(G_{ik}/G_{ksum})$$

where:

- C_{pi} is the new additional capacitance redistributed to element i,
- C_{pk} is the capacitance of element k.

As each element k is eliminated, G_{ksum}, the element numbers i of the connected elements, and the connecting conductances G_{ik} are written on the recovery file MODLCRF, in the order the elements k are eliminated. This is the temperature recovery matrix used by the Analyzer to recover the temperatures of the eliminated elements at each printout interval.

The eliminated elements k are written on file MODLCF as sink SNK elements of constant temperature `- 1.E30`. This is a flag to the Analyzer that the temperatures of these elements are to be calculated with the recovery process.

Accuracy of the Substructuring Process

The substructuring process yields a mathematically exact equivalent thermal model for steady state analysis if for each element k:

- all connected conductances are conductive, or
- all connected conductances radiative, or

If an element k is connected to a mixture of conductive and radiative conductances, the error introduced by an incorrect estimate of TLIN will be small if the element is either linear conductance or radiative conductance dominated.

An error is introduced when the capacitances are redistributed, since this changes the order of the system of differential equations that describes the model. This error is small if:

$$dTC_{pk}/(G_{ksum}T_M) << 1$$

where:

- dT is the maximum/ temperature rate of change element k would experience if it were not eliminated,

- T_M is the maximum temperature change element k would experience if it were not eliminated.

Purpose of Substructuring

The purpose of substructuring is to speed up solution time. Substructuring is best used in the following areas:

- Eliminating troublesome high-conductance elements that cause ill-conditioning to the conductance matrix and hence slow down iteration.
- Eliminating troublesome zero-capacitance elements that cause the transient analysis to slow down, or low-capacitance elements that govern the integration time step. This type of small time constant element is eliminated with the minimum error.

Substructuring may slow down solution time when the number of conductances is increased. To avoid this, in a given region eliminate as many connected elements as possible, and use the PARAM THIN option to eliminate insignificant conductances.

Model Thinning

After element merging and substructuring, model thinning is performed if requested on a Card 9 PARAM THIN Card. This eliminates insignificant conductances from the matrix, in order to speed up solution time. Insignificant conductances may arise from specifying an excessively small Card 2a RK value, from too many odd-shaped solid elements, and as a result of substructuring.

A conductance is considered insignificant if the following two conditions are met:

$$G_{ij} < G_{isum} T1$$
$$G_{ij} < G_{jsum} T1$$

where:

- G_{ij} is the conductance between elements i and j
- $T1$ is the user-specified thinning parameter
- G_{isum} is the sum of the conductances to element i
- G_{jsum} is the sum of the conductances of element j

Radiative conductances are linearized with `TLIN`.

Computing coupling area for plane stress, chocking and axisymmetric elements

When a convective or radiative thermal coupling is created on plane stress or chocking elements, it is important to consider the coupling area. For plane stress elements, the computation depends on its geometrical information, such

as inspecting the section of the hole surface that the specific element in this section will be used for the coupling area. For chocking elements, the coupling area corresponds to the equivalent axisymmetric area minus the gap areas.

Moreover, when coupling involves an axisymmetric edge at the junction of an axisymmetric element and a plane stress element, the coupling area is corrected as follows.

$$A_{corrected} = (2\pi R - Nt)/(2\pi R)$$

where:

- R is the radius (distance to the axisymmetric axis) associated to the axisymmetric edge.
- N is the number of instances of the plane stress element.
- t is the thickness of the blade.

This correction removes the junction section between the plane stress and the axisymmetric elements that should not be part of the thermal coupling.

NEVADA Module

The NEVADA module converts a NEVADA input deck into an equivalent I-deas Universal file. This translator consists primarily of a pre-processor which reads and parses a NEVADA data deck, a finite element mesher and a post processor which writes the surface mesh and material properties to an I-deas Universal file.

The NEVADA to I-deas Universal file translator can be invoked through the TMG Executive Menu

The user is prompted for:

NEVADA input file name

- TMG universal output file name
- NEVADA translation control parameters

Currently there exists 3 translation control parameters :

- `nomask` : Specifying this parameter will cause the translator to skip NEVADA mask surfaces. The default is to translate NEVADA mask surfaces to the I-deas Universal file.

- `nodiv` : By default, the NEVADA translator will subdivide any NEVADA surface into multiple TMG elements, including NEVADA TRIANGLE and QUADRILATERAL surfaces. This process is required in order to guarantee reasonable aspect ratios for the resulting CAE software elements. However, specifying this parameter will deactivate the NEVADA translator subdivision parameter for NEVADA TRIANGLE and QUADRILATERAL surfaces only.

- `oneelem` : Specifying this parameter will deactivate the NEVADA translator subdivision parameter for all NEVADA surfaces, consequently, each NEVADA surface will be translated as a single TMG element. Use of this parameter should be avoided.

The NEVADA surface properties block is converted into an equivalent TMG material. The following NEVADA properties are supported:

- Absorptance (Solar)
- Emittance (IR)
- Specularity (Solar)
- Transmittance (Solar)

The NEVADA surface description block is converted into equivalent TMG nodes, elements and groups. Each NEVADA surface is meshed individually into multiple TMG finite elements. The number of finite elements created is dependent on the surface type. As a general rule, the resulting finite elements are created in such a way as to limit element distortion.

The following NEVADA surface types are currently supported:

- Triangle
- Quadrilateral
- Ellipse
- Sphere
- Cylinder
- Cone
- Paraboloid
- Box
- Polygon
- Offset paraboloid

NEVADA surface normals are translated as follows:

- NEVADA surface normal “IN” translated to an equivalent TMG element.
- NEVADA surface normal “OUT” translated to a TMG element with reversed node connectivity.
- NEVADA surface normal “BOTH” translated to an equivalent TMG element along with a corresponding reverse node definition.

In general, since a NEVADA surface will be composed of multiple TMG elements, there will not be a one-to-one correspondence between the NEVADA surface node number and the TMG element label. The TMG labels are generated in sequential order beginning at 1. However, in order to allow the NEVADA user easy access to the original NEVADA surfaces once inside CAE software, two (2) groups are created for each NEVADA surface generated; the first is named after the NEVADA surface name and the second after the NEVADA surface node number.

The concept of mask nodes is not recognized by TMG, however, the NEVADA translator will read in both NEVADA ordinary and mask nodes. The corresponding TMG elements will be of a different color, depending whether or not they correspond to ordinary nodes (green) or mask nodes (yellow). This color distinction between the TMG elements allows easy modification of the TMG model.

The NEVADA Intermediate Coordinate System (ICS) block is also supported and will support any number of nested ICS definitions.

POWER Module

Function

The POWER module calculates IR and solar spectrum radiative heat loads from the orbital view factors, heat flux view factors, and view factors of file VUFF. The heat loads are written on file MODLF.

Module Operation

The following outlines the steps of the algorithm:

First, the view factor matrix is read in from VUFF (`MNM = BVF`).

- If `TIME=-1.0E36` on the BVF Card, then the view factor applies to both to the IR and solar spectra.
- If `TIME=-1.1E36` on the BVF Card, then the view factor was calculated by ray-tracing with the VFTRACE option and it applies to the solar spectrum only.
- If `TIME=-1.2E36` on the BVF Card, then the view factor was calculated by ray-tracing with the VFTRACE option and it applies to the IR spectrum only.

Next, the view factors are adjusted using the Card 2a `KSP parameter` (For information on minimizing view factor deviations from unity, refer to the Gray Body View Factor section in the GRAYB Module). However, the method differs slightly from that employed in the GRAYB module: All view factors are adjusted, not only the view factors calculated without shadowing. The reciprocity relationship of the view factors is still maintained after this adjustment.

Next, the view factors are scaled to ensure their sum becomes 1. The reciprocity relationships between them is no longer maintained at this stage.

Next, for each element i, the effective properties τ_{ieff} , ρ_{ieff} , and E_{ieff} are calculated from the surface properties and self-view factors. The effective properties are the surface properties of the element adjusted for self-reflection and self-transmission. For table-dependent emissivities, the first emissivity value of the table is used to calculate these parameters. Note that for temperature-dependent emissivity tables, this will in general be the emissivity value for the lowest temperature.

For source elements, E_{ieff} is set to zero, to ensure none of the emitted heat flux is reabsorbed by the source itself.

$$\rho_{ieff} = \frac{(-1+V_{ii})(1-\tau_i-E_i-(1-\tau_i-E_i)(1-\tau_i-E_{ir})V_{irir}+\tau_i{}^2V_{irir}}{-1+(1-\tau_i-E_{ir})V_{irir}+V_{ii}(1-\tau_i-E_i)-V_{ii}(1-\tau_i-E_i)(1-\tau_i-E_{ir})V_{irir}+V_{ii}\tau_i{}^2V_{irir}}$$

$$E_{ieff} = \frac{-(E_i-E_i(1-\tau_i-E_{ir})V_{irir}+E_{ir}V_{irir}\tau_i)}{(-1+(1-\tau_i-E_{ir})V_{irir}+V_{ii}(1-\tau_i-E_i)-V_{ii}(1-\tau_i-E_i)(1-\tau_i-E_{ir})V_{irir}+V_{ii}\tau_i{}^2V_{irir})}$$

$$\tau_{ieff} = \frac{\tau(-1+V_{irir})}{(-1+(1-\tau_i-E_{ir})V_{irir}+V_{ii}(1-\tau_i-E_i)-V_{ii}(1-\tau_i-E_i)(1-\tau_i-E_{ir})V_{irir}+V_{ii}\tau_i{}^2V_{irir})}$$

$\tau_{ieff} = 0$ *if the view factors were calculated with ray-tracing*

$$M_{ii} = \frac{1}{(1-V_{ii})}$$

$$M_{irir} = \frac{1}{(1-V_{irir})}$$

where:

- τ_{ieff} is the effective transmissivity of element i
- ρ_{ieff} is the effective reflectivity of element i
- E_{ieff} is the effective absorptivity of element i
- M_{ii} is a multiplier associated with element i
- M_{irir} is a multiplier associated with the reverse side of element i
- V_{ii} is the self-view factor of element i
- V_{irir} is the self-view factor of the reverse side of element i
- τ_i is the transparency of element i
- E_i is the absorptivity of element i
- E_{ir} is the absorptivity of the reverse side of element i

Next, the distribution matrix D is created. The terms D_{ij} consist of the sum of the reflectivity and transmissivity terms.

$$D_{ij} = M_{ii}\rho_{ieff}V_{ij} + M_{irir}\tau_{ieff}V_{irj} \qquad i \neq j$$

$$D_{ij} = 0 \qquad i = j$$

where:

- V_{irj} is the view factor from the reverse side of element i to element j
- V_{ij} is the view factor from the front side of element i to element j

Next, the heat flux view factors are read in from VUFF. Optionally, these may be put through an adjustment algorithm to ensure the total energy specified on the Card 6 SOURCE Card is maintained.

Next, for each heat flux view factor the energy packets qq_i, qq_{itrace}, qq_{iabs}, and qq_{inc}, qq_{ispec}, qq_{itrans} and are calculated.

$$
\begin{aligned}
qq_i &= PSA_i V_i \\
qq_{itrance} &= PSA_i V_i(\tau_i + \rho_{si}) && \textit{for raytraced heat flux view factors} \\
qq_{itrace} &= 0 && \textit{for non-raytraced heat flux view factors} \\
qq_{iabs} &= E_i qq_i \\
qq_{itrans} &= qq_i \tau_i && \textit{for non-raytraced heat flux view factors} \\
qq_{itrans} &= 0 && \textit{for raytraced heat flux view factors} \\
qq_{ispec} &= 0 && \textit{for raytraced heat flux view factors} \\
qq_{ispec} &= qq_i \rho_{si} && \textit{for non-raytraced heat flux view factors} \\
qq_{inc} &= \frac{(qq_i - qq_{itrace} - qq_{tabs} - qq_{itrans} - qq_{ispec})}{1 - E_i}
\end{aligned}
$$

where:

- qq_{inc} is the contribution to the total incident diffuse flux on element i of the heat flux view factor `V_i`.
- qq_{iabs} is the portion of the incident flux absorbed by element `i`.
- V_i is the heat flux view factor, albedo factor, Earth view factor, or heat flux view factor to the element.
- A_i is the area of the element. For elements for which the Card 6 VFMERGE option was used, this is the merged area of the element.
- PS is the emitted power per unit area of the source element. PS is the PSUN parameter defined on Card 2a or on the Solar View Facto Request card for solar or albedo calculations, and the Card 2a PIR parameter for IR spectrum calculations. PS=1 for heat flux view factor calculations because Vi already includes the source element's emited power per unit area.

Next, a special case is addressed. If ray-tracing was **not** performed on heat flux view factors (this occurs if file VUFF MNM=EVF or `MNM=ALB`, i.e. albedo and Earth view factors calculated without the PARAM EXEARTH option), and element `i` is specular or transparent, then qq_{itrans} is redistributed among the elements `j` the reverse side of `i` sees, and qq_{ispec} is redistributed among the elements `j` element i sees. The redistribution weighting factor used is the view factor from the reverse sides of element `i` to `j`, and the view factor from `i` to `j` respectively. The redistributed heat flux is considered as incident on element `j`.

An approximation is made here: if the element `j` is transparent, then the portion of the redistributed energy packet that would be transmitted through element `j` will be absorbed by element `j`.

Now we have initialized the process, and calculated all the diffusely incident fluxes qq_{iinc}. Next, the diffusely incident flux for each element `i` is redistributed to all the elements it sees through reflection or transmission.

$$
\begin{aligned}
qq_{iabs,new} &= qq_{iabs} + \sum_j qq_{jinc} D_{ji} E_{ieff} \\
qq_{iinc} &= \sum_j qq_{jinc} D_{ji}
\end{aligned}
$$

where:

- qq_{iabs} is the new total absorbed energy calculated for `i`
- qq_{iinc} is the new diffusely incident energy calculated for `i`
- E_{ieff} is the effective absorptivity of element `i`

For the first iteration, the transmissive portion of the D matrix is set to zero. The rationale for this is that all incident heat fluxes are considered to have been ray-traced, and thus transmission has already been taken into account.

The above redistribution process continues iteratively until a maximum of 30 iterations, or until the absorbed energy is 99.99% of the total initial incident energy. If this convergence criterion is not reached, then the remaining unabsorbed energy is redistributed to all the element in proportion to their computed absorbed energies.

Output

To output the calculated heat inputs on file MODLF, first the string:

`'RDF COLLIMATED SOLAR LOADS'` or

`'RDF IR LOADS'` or

`'RDF DIFFUSE SOLAR LOADS'`

is written. The heat inputs and the appropriate TIME values when they occur are then written on file MODLF with the mnemonic (`MNM = HTF`).

REFORM Module

Function

The REFORM module transforms the conductance-capacitance model on file MODLCF into SINDA or ESATAN formats, or the geometry model into TRASYS or NEVADA formats. The formatted models are written on file FMODLF.

SINDA Output Format

If Card 2a `N = 1` , capacitances, conductances, heat loads, and sink element temperatures are written on FMODLF in SINDA format. Only the SINDA TITLE DATA, NODE DATA, CONDUCTOR DATA, SOURCE DATA, ARRAY DATA, and VARIABLES 1 DATA blocks are written.

You can also create SINDA85 format on file sinda85.dat by specifying a Card 9 PARAM SINDAVER SINDA85.

TITLE DATA BLOCK

The Card 1 Title Data Card is entered here.

NODE DATA BLOCK

Zero-capacitance elements become arithmetic nodes with a capacitance value = `– 1.0`.

Some versions of SINDA require that at least one diffusion node (element with a non-zero capacitance) to be present. Therefore, if only arithmetic nodes are present, TMG will make the first arithmetic node into a diffusion node with a capacitance value of `1.E – 10.`

The group name of the element is entered on the comment field with a `$` sign.

If Card 8 element elimination or Card 9 PARAM SUBSTR substructuring is performed, only the reduced model is written into the NODE DATA BLOCK. The information to recover the temperatures of the eliminated elements is not transmitted by TMG to SINDA.

If elements are merged with Card 7, the merged element numbers are written in the NODE DATA BLOCK, and their temperatures are recovered.

You can model temperature-dependent specific heats by specifying the table number on the MAT Card and running the COND module. The elements will be flagged with as SIV. Table data will be translated into array data, with the array number set to the table number.

Initial temperature values default to `0`, unless they are defined on Card 9 TINIT Cards, or are present on file TEMPF.

Card 9 SINK elements are translated into boundary nodes.

CONDUCTOR DATA BLOCK

Conductors are numbered sequentially starting with the Card 2a IST parameter value.

Radiative conductors are multiplied by the Card 2a SIGMA value.

You can model temperature-dependent thermal conductivities by entering the thermal conductivity table number on the Card 9 MAT Card, and running the COND module. Temperature-dependent conductors will then be flagged as SIV. The thermal conductivity data is translated into array data, with the array number set to the Card 9 table number.

TMG translates Card 6e thermal couplings into convective conductors. These are flagged as convective conductors in the comment field, and a convective conductance number array is created in the ARRAY DATA BLOCK.

Temperature-dependent thermal couplings are translated into SIV type conductors and the tables are transformed into arrays.

You can model fluid flow with Card 9 XCOND 1WAYC Cards.

SOURCE DATA BLOCK

Constant elemental heat inputs are entered here. You can create constant heat inputs with:

- Card 9 QNODE Cards, with `T2 = CONSTANT.`
- Specifying the TIME parameter on a Card 6 to be CONSTANT.

ARRAY DATA BLOCK

This block contains the following data:

- Temperature-dependent thermal conductivities and specific heats from Card 9 MAT Cards.
- Temperature-dependent thermal couplings.
- Temperature-dependent heat loads defined on Card 9 INTERP**,** TABDATA, and TABTYPE Cards.
- Time-dependent elemental heat load arrays for `TIME ≥ 0` specified on Card 9 QNODE Cards, Card 9 INTERP, TABDATA, and TABTYPE Cards, or calculated from geometry (e.g. orbital heat loads).
- Time-dependent boundary element temperatures from Card 9 SINK Cards or Card 9 INTERP, TABDATA, and TABTYPE Cards.
- Group names.

VARIABLES 1 DATA BLOCK

This block contains `CALL DA11MC` statements referencing time-dependent heat loads and boundary node temperatures.

Constant heat loads specified on

If element `N1` is defined as following the temperature of `N2` on a Card 9 XCOND FOLLOWER Card, or if the PARAM NOMRECOV option is not used and element merging is performed (which creates XCOND FOLLOWER Cards on file MODLCF), this is translated as `TN1 = TN2` .

CONSTANTS, EXECUTION, VARIABLES 2, OUTPUT DATA BLOCKS

Default or blank parameters are entered into these data blocks.

TMG Cards Not Used by REFORM

The REFORM Module ignores the following Cards when creating a SINDA deck:

- Card 2b.
- Card 5 hydraulic elements.
- Card 9 HYDENV Cards.
- Card 9 MCV Cards.
- Card 9 PHASE phase change element Cards.
- Card 9 INTERP, TABDATA, and TABTYPE Cards, except as outlined above.
- Card 9 PRINT Cards.
- Card 9 THERMST thermostat definitions.
- Card 9 PARAM NLOOP, ACCEL, QUARTIC, ENGBAL, ALPHA, NOBUOY, NOMRECOV, PDMAX, TDIFS Cards.
- Card 9 XCOND FREE and Card 6e FREE Cards.
- Card 9 XCOND Cards with `T3 > 15` or `T3 < 15`.

TRASYS Output Format

If (Card 2a `N = 2048)`, a TRASYS model is written on file FMODLF. The following rules are used:

- Lump mass elements are ignored.
- Beam elements are transformed into `TYPE = ELEM` surfaces. The surface area per unit length must be specified on the PROP Card. Furthermore, the elements may also be written as `TYPE=CY` surfaces by adding the following Card 9:

  ```
  GPARAM 7 1 1
  ```

- Triangular planar elements with emissivities `≥ 0` are transformed into `TYPE = POLY` surfaces.
- Planar quadrilateral elements with emissivities `≥ 0` are transformed into `TYPE = POLY`, `TYPE = RECT`, or `TYPE = TRAP` surfaces.
- The default is `ACTIVE = TOP`. If the reverse side of an element is created with a Card 9 REVNODE Card and the same radiative surface properties, `ACTIVE = BOTH` is used. `ACTIVE = OUT` is used for beam elements.
- Each element is assigned a TRASYS surface number, e.g. element `912` may be written as `SURFN = 2`. The association between `912` and surface number `2` is made at the end of the deck by an entry into the CORRESPONDENCE DATA block, e.g. `912 = 2`.

In order to avoid surface number conflicts, surface numbers are assigned sequentially in increments of 4 for TYPE = POLY surfaces. This is because internally TRASYS splits each ACTIVE = TOP quadrilateral POLY type surfaces into two and ACTIVE = BOTH into four sequentially numbered surfaces, making it necessary to leave space for the additional surface numbers.

In your CAE software you can create DISK, CONE, CYL, SPHERO, PARAB TRASYS surface types. To do this, generate a mapped mesh using higher order elements on a disk, cone, cylinder, spheroid, or paraboloid. Make the mesh (including the midside nodes) line up with the latitudes and longitudes, otherwise the elements will be transformed into TYPE = POLY. or other errors can result.

The orientation of the surfaces follows the standard TMG convention, i.e. if the nodes are specified in a counterclockwise order, the element faces the viewer. REFORM Module

NEVADA Output Format

If a Card 9 PARAM NEVADA Card is present, a NEVADA model is written on file `nevada.ren`.

- Lump mass and beam elements are ignored.
- Triangular planar elements with emissivities are transformed into NEVADA triangle surfaces.
- Quadrilateral planar elements with emissivities are transformed into NEVADA quadrilateral surfaces.
- The default surface normal is IN. If the reverse side of an element is created with a Card 9 REVNODE Card and the same radiative surface properties, the surface normal is BOTH.
- Each NEVADA surface label is assigned the corresponding TMG element label.
- In your CAE software you can create ELLIPSE, SPHERE, CYLINDER, CONE, PARABOLID and OFFSET PARABOLOID surface types. In order to do this, generate a mapped mesh using higher order elements on an ellipse, sphere, cylinder, cone or paraboloid. Make the mesh. However, it is imperative that the mesh (including the midside nodes) lines up with latitudes and longitudes of the underlying surface, otherwise the elements will be translated to either a TRIANGLE, QUADRILATERAL or POLYGON surface types.
- The orientation of the surfaces follows the standard TMG right hand rule convention (i.e. if the nodes are specified in a counterclockwise order, the element normal faces the viewer).

ESATAN Output Format

If a Card 9 PARAM ESATAN Card is present, then an ESATAN format thermal model is created on file `esatan.dat`. The following blocks are created:

1. `$MODEL` Data Block
   The title is read from the first line of file MODLCF.
2. `$NODES` Data Block
   Sink elements read from file MODLCF and defined on Card 9 SINK element Cards are transformed into B type boundary nodes. Other types of elements are transformed into D type diffusion nodes. The element's group name is read from file INP2F and becomes the node label.
   Initial temperatures `T` are created by Card 9 TINIT Cards, and are read from file TEMPF.
   Element capacitances, calculated from geometry by the COND module or specified on Card 9 XCAP Cards, are

read from file MODLCF.
Element area A, emissivity EPS, and solar absorptivity ALP are read from file VUFF. Constant heat inputs Q are read from file MODLCF.
Time and temperature-dependent sink temperatures associated with Card 9 INTERP Cards are written as variable temperatures. Array SINKi in the `$ARRAY` Data Block is used for the interpolated temperature values, where `i` is the specified table number.
Time and temperature-dependent heat inputs associated with Card 9 INTERP Cards are written as variable heat inputs. Array HEATi in the $ARRAY Data Block is used for the interpolated heat input values, where i is the specified table number.
Element capacitances with temperature-dependent specific heats are written as variable capacitances. Array SPECIFICHEATi in the $ARRAY Data Block is used for the interpolated specific heat values, where i is the specified table number.

3. `$CONDUCTORS` Data Block
   Linear conductances read from file MODLCF and are transformed into GL type linear conductors. Linear conductances may be calculated by the COND module, by the VUFAC module with the Card 6e NEARA and CONV options, or specified on Card 9 XCOND COND Cards.
   Radiative conductances read from file MODLCF are transformed into GR type radiative conductors. Radiative conductances may be calculated from geometry by the GRAYB module, specified on Card 9 XCOND RAD Cards, or on Cards 6e with the NEARAR option.
   One–way conductances read from file MODLCF are transformed into GL type fluidic conductors. One–way conductances may be calculated by the COND module for Card 5a FLUID elements, or defined on Card 9 XCOND 1WAYC Cards.
   Follower conductances from file MODLCF, created by the MEREL module to recover the merged elements' temperatures, are transformed into GL type linear conductors. Follower conductances defined on Card 9 XCOND FOLLOWER Cards are not recognized.
   Conductive conductances with temperature-dependent thermal conductivities are written as variable conductances. Array CONDUCTIVITYi in the $ARRAY Data Block is used for the interpolated thermal conductivity values.
   Time and temperature-dependent conductances associated with Card 9 INTERP Cards are written as variable conductances. Array CONDUCTANCEi in the $ARRAY Data Block is used for the interpolated conductance values.
   Radiative conductances with temperature-dependent emissivities are written as variable conductances. Array EMISSIVITYi in the $ARRAY Data Block is used for the interpolated emissivity values.
4. `$CONSTANTS` Data Block
   TMG control parameters for steady state and transient runs are read from Card 2b and translated into equivalent ESATAN control constants.
5. `ARRAYS` Data block
   Time–dependent heat loads read from file MODLCF are transformed into QVALi arrays. These may be defined on Card 9 QNODE Cards, or may be radiative heat loads calculated from geometry by the POWER module.
   Sink element temperatures read from file MODLCF are translated into TVALi arrays. The sink elements are defined on Card SINK Cards.
   Time and temperature-dependent sink temperatures defined on TABDATA Cards are translated into SINKi arrays, where i is the specified table number.
   Time and temperature-dependent heat inputs defined on TABDATA Cards are translated into HEATi arrays, where i is the specified table number.
   Temperature dependent-specific heats defined on TABDATA Cards are translated into SPECIFICHEATi arrays, where i is the specified table number.
   Temperature-dependent thermal conductivities defined on TABDATA Cards are translated into CONDUCTIVITYi

arrays, where i is the specified table number.
Time and temperature-dependent conductances defined on TABDATA Cards are translated into CONDUCTANCEi arrays, where i is the specified table number.
Temperature-dependent emissivities defined on TABDATA Cards are translated into EMISSIVITYi arrays, where i is the specified table number.

6. `$EXECUTION` Operation Block
   If the value of GRADNT in Card 2b is positive, the steady state solver SOLVFM is called in the EXECUTION Block. If GRADNT is equal to (-2) or (-3), the forward differencing transient solver SLFRWD is called. If GRADNT is equal to (-4) or (-5), the Crank-Nicolson forward backward transient solver SLFWBK is called.
7. $OUTPUTS Operation Block
   The subroutine PRNDTB is called for the printout of the label and temperature of all nodes in a table format.

RSLTPOST Module

Function

The RSLTPOST module reads raw data generated by the thermal solver, and creates results file(s) in a format suitable to the CAD platform being used, in order to visualize thermal results in post-processing.

Nodal temperature interpolation with finite volume method

The purpose of the nodal interpolation is to obtain temperature values at the element nodes taking as input the temperatures at the solver calculation points (centers of gravity of elements and boundary elements), the heat flows through element boundaries, as well as element physical, material, and geometrical properties. One of the challenges of the TMG nodal interpolation problem is that there are many situations when it is not adequate to approximate the space distribution of temperatures around a given node with a single linear profile throughout the node-adjacent elements. Examples of such situations include (i) contacts between different conductivity materials, (ii) contacts between shells of different thickness, (iii) shells at angle (e.g. plane crossing), as well as (iv) boundaries with heat load applied to them (which means discontinuity of the heat flux vector and temperature gradient), and alike. Another requirement to the TMG nodal interpolation scheme is a good balance between accuracy/reliability and the computational performance for as many modeling situations as possible. To satisfy those requirements TMG uses an approach that could be named an adaptive piece-wise linear scheme. For accurate treatment of various special cases, such as (i)-(iv) that scheme allows multiple (element-specific) linear profile pieces to fit the temperature distribution around a given node. To avoid excessive computational overhead of that method for simpler interpolation cases the algorithms is made adaptive, so that it allows a number of different levels of approximation/simplification, with the optimal level of simplification automatically chosen for each given node, depending on the surroundings of the node.

Piece-wise linear interpolation

The TMG piece-wise linear interpolation scheme uses a linear temperature profile inside each internal element around a given node:

$$T = T_0 + T_x^{(e)}(x - x_0)/L + T_y^{(e)}(y - y_0)/L + T_z^{(e)}(z - z_0)/L$$

where:

- T_0 , x_0 , y_0 , z_0 are the temperature and coordinates of the node,
- L is a characteristic length scale
- $T_{x,y,z}^{(e)}$ and are e -dependent coefficients of the linear interpolation.

Note that in the TMG solver it is also assumed that there is a linear temperature profile inside each internal element and all the coefficients (including T_0) of that profile are fully determined by the temperatures of all the boundary elements. Yet, in the so determined coefficients, T_0 is e-dependent as well, $T_0 = T_0{}^{(e)}$, that is, there is no single well-defined value for the nodal temperature. To overcome that problem, in the above equation we impose a requirement that T_0 is not -dependent (the same T_0 value is shared between all the internal elements adjacent to the node), but when determining the coefficients $T_{x,y,z}^{(e)}$ we drop the constraint that the equation should reproduce all the boundary element temperatures of element e . We only require that it reproduces temperature values $T^{(b)}$ for the boundary elements b directly connected to the node,

$$T_0 + T_x^{(e)}(x^{(b)} - x_0)/L + T_y^{(e)}(y^{(b)} - y_0)/L + T_z^{(e)}(z^{(b)} - z_0)/L = T^{(b)}$$

where $x^{(b)}$, $y^{(b)}$, $z^{(b)}$ are the coordinates of boundary element center of gravity.

That is, we sacrifice the constraints coming from the boundary elements that are not connected to the chosen node directly, though belong to a node-adjacent internal element. That sacrifice also means that (in contrast to the TMG solver) coefficients are node-specific, i. e. for the same they can be different depending on which of the nodes of e is considered.

Since the above equations are not sufficient to determine all of the unknowns, we also require that, similarly to a real physical system, there is a proper balance of heat coming in and out of each inter-element interface (that is, a boundary element), with the contributing heat flows expressed in terms of the element linear temperature profiles. For lower dimensional elements (e.g. shells) we also add a constraint that temperature gradient is zero along the element normal.

The above-described constraints provide a complete system of equations to determine all the unknowns T_0 , $T_{x,y,z}^{(e)}$. Since that system is over-defined, it is treated as a fitting problem, using a least square fit procedure.

Adaptive choice for the level of accuracy of the interpolation method

Before using any least square fits the interpolation algorithm screens out various more trivial situations when adequate accuracy can be achieved already by much simpler means. In particular, if the input temperature range is very narrow,

so that all the temperatures of the adjacent boundary elements fall within a 10-5 oC-wide interval (and there is more than just one internal element adjacent to the node) then we'll just use a weighted average:

$$T^{(0)} = \frac{\sum_b T^{(b)}/d^{(b)2}}{\sum_b 1/d^{(b)2}}$$

without any further checks or compuations.

The next level of complexity (and the next step in the computational routine) targets situations when all the input temperatures (from the node-adjacent boundary elements) fall well onto one linear profile. For this purpose, only the 3 or 4 (depending on the dimensionality of the problem) closest boundary elements are used to obtain a guess for a possible linear profile and then it is checked how well that linear profile can reproduce the temperature values of the rest of the points. If the errors are sufficiently small (and the gradient calculation has not failed) then the guess is accepted and no further checks/computations are done. The error is judged to be sufficiently small if the following criterion is satisfied for each adjacent boundary element:

$$|T^{(b)} - \tilde{T}^{(b)}|/\left[|T^{(b)} - T^0| + \delta\right] < 0.1$$

where $\tilde{T}^{(b)}$ is the linear-profile-guess based prediction for the temperature value at the boundary element, and δ is either 0.1 of the boundary element temperature range width or is 10-3, whichever is greater.

The next step is to check if there are sufficient reasons to use the full complexity treatment. Those reasons mainly include:

1. Differences in the conductivity of the node-adjacent internal elements
2. Heat load on the boundary (nonzero right hand side in Eq. 3) meaning discontinuity of the heat flux vector at the boundary (except solar extinction situation, where such boundary-localized discontinuities would be somewhat unphysical).
3. Lower dimensional geometry with shells at some angle to each other or more than 2 internal elements sharing the same boundary element (e.g. crossing of two or more planes)
4. Contacts between shells of different thickness

If none of the above special cases are identified, then the scheme will use a reduced complexity treatment that is based on the piece-wise linear fit, but omitting the dependence of the coefficients $T^{(e)}_{x,y,z}$ on element index e. That simplification reduces the number of unknowns to 4.

Finally, if any of special cases 1-4 above are present, then the full complexity (piece-wise linear) treatment described in the previous section is applied.

Nodal temperature interpolation with finite element method

When the finite element method is used as a discretization method, the thermal solver does not perform the temperature interpolation, because it computes temperatures on nodes. The thermal solver computes elemental temperatures at the element's center of gravity by interpolating nodal temperatures using shape functions.

TMG2ANS Module

Function

The TMG2ANS module translates the TMG node temperature results on GTEMPF to ANSYS version 5 input files.

Module Operation

TMG2ANS is accessed by running the TMG executive menu from operating system and selecting "AN - Translate TMG data to ANSYS input file".

You will be prompted for the output option. You can translate TMG node temperatures into either an ANSYS PREP7 command input file `bftemp.dat` or an ANSYS POST1 command input file `dntemp.dat`, or both.

The TMG node temperature result file GTEMPF must exist, if it does not you can generate it from the TMG element temperature result file TEMPF with the TMG model interpolator TMGINT.

For transient analysis results multiple dntemp files are written, with file extensions `s01`, `s02` etc. Each file contains the result of a printout interval in the GTEMPF file.

TMG node temperatures are written as PREP BF commands on bftemp.dat to be input into the ANSYS FE model as a body force for subsequent ANSYS structural or other types of analyses.

At the end of BF commands, a PREP command `LSWRITE` is written.

For transient analysis a TIME command is written at each printout interval, followed by BF commands and an LSWRITE command. You can use a text editor to modify the ANSYS commands written in the bftemp.dat file.

TMG temperatures are written as DNSOL commands on d`ntemp.dat` and `dntemp.s01`, `dntemp.s02`, etc. For transient analysis results the printout interval associated with each result set is written as ANSYS comments. The dntemp files can then be used by ANSYS for post-processing.

TMGINT Module

Function

The TMGINT module is an interactive post–processor that can calculate node temperatures for a TMG thermal model, when the element CG method is used.

Calculation of Nodal Temperatures

Module Operation

Nodal temperature interpolation is invoked automatically when TMG is executed from the interface. TMGINT may also be invoked from the TMG Executive Menu.

To compute the nodal temperatures, TMGINT uses files VUFF, MODLF and TEMPF. Node temperatures are written onto file GTEMPF and FMODLF, plus the CAE results file.

Interpolation Process

The node temperatures of the thermal model are calculated from the element temperatures in file TEMPF. For each thermal element connected to a node, a temperature is obtained by spatial interpolation, unless the element has zero conductivity or thickness. The node temperature is the conductance-weighted average of the connected elements' temperatures. If all connected elements have a non-zero thermal conductivity, their temperatures are averaged.

If the node has a one-node element, it is assigned the element's temperature. If the node is attached to one or more sink elements, then the temperature of the node is the average temperature of the sink elements.

VFRTGPU Module

Function

The VFRTGPU module computes blackbody view factors and ray-tracing radiative conductances using the Monte Carlo method. It uses the computer Graphics Processing Unit (GPU) to accelerate the calculations.

All VFRTGPU module requests start with Card 6 VFRTGPU ON, and end with VFRTGPU OFF. Between these Cards is the body of the VFRTGPU requests. Computed outputs are written on files VUFF and MODLF.

Comparing VFRTGPU to the HEMIVIEW and VUFAC modules

The VUFAC module computes the ray-traced, non-ray-traced, and other types of view factors, using machine's Central Processing Unit (CPU). For more information on different types of view factors see, Basic concepts of view factors. Depending on the type you select, and number of view factors calculated by the solver, the view factor computations can be CPU intensive using the VUFAC module.

The HEMIVIEW module uses the machine's graphics card in conjunction with the Open Graphics Library (OGL) to compute the blackbody view factors using an imaginary hemicube. For more information, see HEMIVIEW Module. The accuracy and computation time of the hemicube method is limited by the pixel resolution of the drawing area. However, it only supports blackbody view factors.

The VFRTGPU module uses the Monte Carlo method to compute both the blackbody view factor and ray-traced radiative conductances using the machine's GPU. Depending on the number of radiative conductances that are computed in a radiation simulation, the GPU-based Monte Carlo method can perform approximately an order of magnitude faster on a supported GPU hardware compared to the other modules that compute the same amount of radiative conductances.

In raytracing, many rays are randomly cast between elements participating in the radiative exchange. The rays follow the path taken by the radiation.

The software launches several rays from each element using the Monte Carlo method. For more information, see Card 6 - GPU Radiation Activation Card - Optional.

VUFAC Module

Function

The VUFAC module calculates view factors, orbital view factors (solar view factors, albedo view factors, Earth view factors), heat flux view factors, view factor for axisymmetric modeling with plane stress, and thermal couplings.

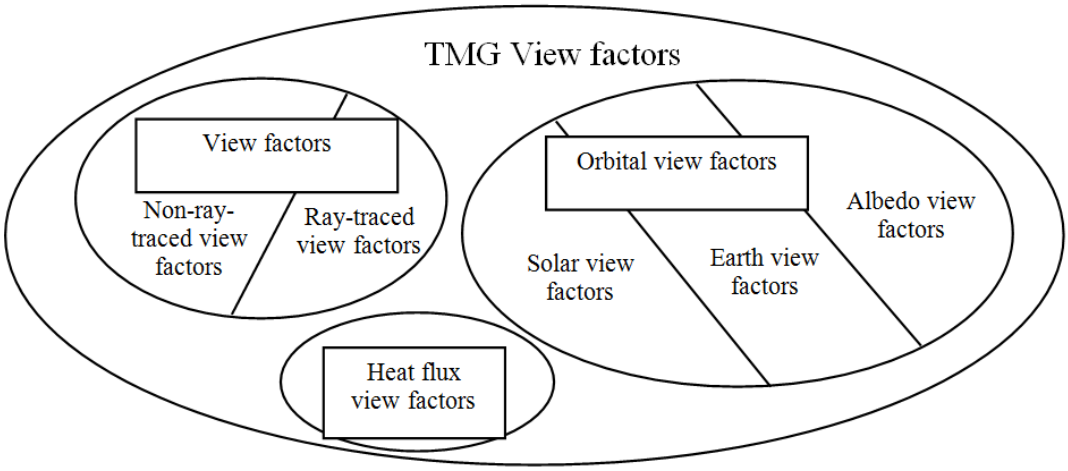
All VUFAC Module calculation requests are specified on Cards 6.

For the VUFAC module to be run, Card 2a `M` must be = `2`.

Details of the calculations (e.g. ray-tracing, shadowing surfaces used, etc.) are written to [Simulation name]_report.log. Card 2a `N = 512` disables this output. Results are written on file VUFF.

Basic concepts of view factors

Thermal Solver View factors



TMG view factors have three main classifications: view factors, orbital view factors and heat flux view factors. View factors are calculated between elements, and are subclassified into ray-traced and non-ray-traced view factors. Orbital view factors are subclassified into solar view factors, Earth view factors and albedo view factors.

All TMG view factors' magnitudes depend upon the geometric relationship between the elements, and, if there is ray-tracing involved, upon the specular and transmissive surface properties of the elements participating in the ray-tracing.

All TMG view factors are calculated by the VUFAC module. They are written on file VUFF, and are used by the GRAYB and POWER modules to calculate radiative couplings and absorbed heat fluxes using Gebhardt's or Oppenheim's Method.

Definition of the View Factor

The view factor VF_{ij} from element i to element j is defined as the fraction of the radiation emitted by i that arrives at j without any intermediate diffuse reflections (but including specular reflections and transmissions), assuming perfectly diffuse and uniform emission in all directions. View factors are subclassified into ray-traced and non-ray-traced view factors.

The non-ray-traced view factor is the view factor between the two elements if no specular reflection or transmission occurs. It depends solely upon the geometrical relationship between the two elements and the shadowing elements between them.

The ray-traced view factor is the view factor that also accounts for all specular reflections or transmissions between the two elements.

View factor calculations are requested by Card 6a View Factor Request and Card 6r View Factor Request in an Enclosure Cards. If these Cards are specified without the VFTRACE option, only non-ray-traced view factors are calculated. If these Cards are specified with the VFTRACE option, then ray-traced view factors are calculated when specularly reflective and transmissive elements are present in the model.

View factors are written on file VUFF with `MNM = BVF`. (Sometimes view factors are referred to as Black Body View Factors.)

View Factor Sum

The view factor sum is calculated in the GRAYB module, and is written to the report log file. The theoretical view factor sum for an element is 1. However, because of model geometry imperfections and approximations made during shadowing calculations, this condition is not always fulfilled.

$$\sum_{j=1}^{n} VF_{ij} = 1$$

where:

- *n* is the total number of surfaces within the enclosure
- VF_{ij} is the view factor from surface *i* to surface *j*.

The residual view factor:

```
Residual view factor = 1-view factor sum
```

is an indication of the of accuracy of the view factor calculations. Residual view factors of `-.05` to `.05` (or less) are usually acceptable.

Generally, view factor calculation accuracy may be increased by specifying higher elemental subdivision with the Card 6f MESH parameter. This can be achieved either by specifying the absolute MESH value, or the MESH ERROR criterion (see explanation below).

View Factor Reciprocity

An important view factor property is reciprocity:

$$VF_{ij} A_i = VF_{ji} A_j$$

where:

- VF_{ij}, VF_{ji} are the view factors from `i` to `j` and from `j` to `i`, and
- A_i, A_j are the areas of elements `i` and `j`.

Orbital View Factors

An orbital view factor is the view factor of an element to an orbital radiative source (sun, Earth IR, Earth albedo). An orbital view factor may be an Earth view factor, an albedo view factor, or a solar view factor.

Orbital view factors are requested by Card 6b Solar View Factor Request Cards, Card 6d Earth Cards, Card 6k and Card 6l Orbit Cards, or Card 6t ORBDEF Cards, or Card 6s SKY Cards, or Card 6u Diurnal Solar Heating Cards. The Solar View Factor and Earth Cards may be used when you want to specify specific positions of the sun and Earth at specific points in time. The Orbit, ORBDEF, SKY and Diurnal Solar Heating Cards create an environmental heating condition for which Solar View Factor and Earth Cards are generated internally within TMG from orbit specifications.

Orbital view factors are written on file VUFF. Solar view factors are written with `MNM=SVF`, Earth view factors with `MNM=EVF` or `MNM=EVR`, and albedo view factors with `MNM=ALB` or `MNM=ALR`. `EVF` and `ALB` orbital view factors are written when no ray-tracing is performed from the planet. `EVR` and `ALR` orbital view factors are written when ray-tracing is performed using the Card 9 PARAM EXEARTH option.

Heat Flux View Factors

A heat flux view factor is a view factor to a diffuse radiative heat source of arbitrary shape.

Heat flux view factors are requested by Card 6n Heat Flux View Factor Request Cards. Solar spectrum heat flux view factors are written on file VUFF with `MNM=HVF`, and IR spectrum heat flux view factors are written with `MNM=HVI`.

Allowable Element Types

Radiating elements may be defined with 1 to 4 corner nodes. The elements may be linear or parabolic.

- A 1-node element is a sphere, with a surface area defined on its PROP Card.
- A 2-node element is a circular cylinder, with a surface area per unit length defined on its PROP Card.
- A 3- or 4-node element must be planar, unless it is a parabolic element. Its surface normal orientation is defined by the ordering of its nodes on the Card 5a. If the nodes are seen in a counterclockwise order, the element faces the viewer.

To model the reverse side of a planar element, you must create a separate element with a Card 9 REVNODE or REVNOM Card, or have the reverse side properties defined on its MAT Card.

If an element has midside nodes defined, it will be considered as a parabolic element. During ray-tracing calculations the curvature of the parabolic elements will be considered when calculating the point of interception and the direction of the reflected rays.

- To be recognized by VUFAC, an element must be a Card 5a SURFACE element with a Card 9 MAT Card emissivity ≥ 0 or a NORAD flag, and must have a surface area > 0. Only elements with emissivities ≥ 0 take part in radiation calculations. Solid elements are not recognized by the VUFAC module. Hydraulic elements are recognized by the VUFAC module only for thermal coupling calculations.
- An element may be flagged as non-radiating with Card 9 PARAM NORAD or by having its emissivity defined with the NORAD flag, in which case it is ignored for radiative calculations by the VUFAC module, but is recognized for Card 6e thermal coupling calculations, even for creating radiative thermal couplings.
- An element may be flagged as non-shadowing with Card 9 PARAM NOSHADOW, in which case it will not shadow other elements during radiation calculations.
- An element may be flagged as non-emitting with a Card 9 PARAM NOEMIT, in which case neither it nor its reverse side can emit radiation or shadow radiation calculations by the VUFAC module. A use for PARAM NOEMIT is to define a set of perfectly transparent "mask" elements, which will fix the ray-tracing calculation mesh for all elements behind them.
- Elements with solar absorptivity values < 0 are not recognized for solar view factor, Earth view factor, or albedo view factor calculations.

Circular Elements

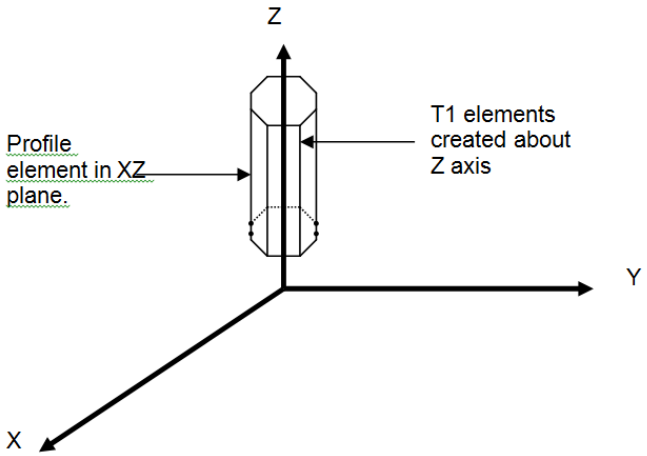
If an element is specified as circular with a Card 9 XCIRC Card, the VUFAC module approximates the circular shape of the surface by creating a number of internal flat elements. The nodes of these internally generated elements facet the surface of the circular element.

For user-defined XCIRC elements that subtend angles less than 135 degrees from the center of the circle, internal elements are created such that each one subtends an angle of no greater than 45 degrees. If the user-defined XCIRC element subtends an angle greater than 135 degrees from the center of the circle, it is subdivided into 4 elements.

The view factors and areas of the internal elements are merged to create the view factor for the circular element.

Axisymmetric Elements

If an element is specified to be axisymmetric with a Card 9 AXISYMM `T1` Card, it lies in the XZ plane. To allow the calculation of 3D radiative phenomena, `T1` planar elements rotated about the global X, Y, or Z axis are created internally in TMG by the DATACH Module for each profile element defined on the relevant plane. `T1` defaults to 8. The `T1` elements' view factors and areas are merged by VUFAC.



Warpage Angle

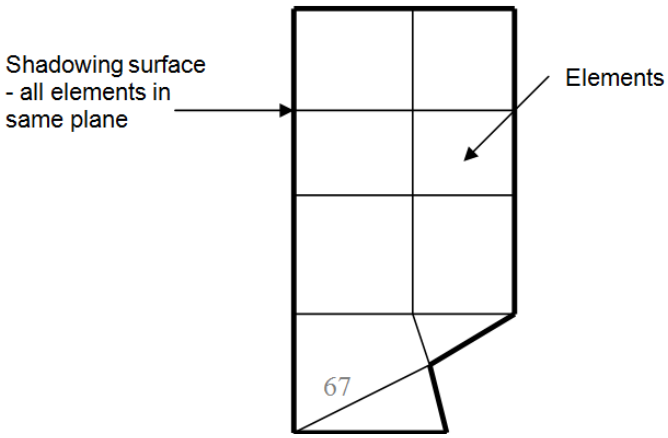
Each linear quadrilateral element has a warpage angle calculated, which is the degree of departure from planarity of the element's surface. If the element's warpage angle is greater than 0.1 degrees, it is flagged as warped. Warped elements are treated differently in a number of different procedures. It is not recommended for a model to have warped linear elements. Should the effects of element curvature be desired for ray-tracing calculations, parabolic elements should be used.

Shadowing Surfaces

To reduce the CPU time for shadowing calculations, the VUFAC module creates internal shadowing surfaces by combining adjacent elements that lie in the same plane and point in the same direction. Shadowing surfaces form n-sided polygons and may not have holes. Shadowing surfaces to reduce the CPU time for blockage calculations.

Warped quadrilateral elements are split into two separate triangular shadowing surfaces. Lump mass and beam elements also become separate shadowing surfaces.

Elements flagged as non-shadowing with a Card 9 PARAM NOSHADOW are not included in shadowing surfaces.



Elemental Subdivision Algorithm

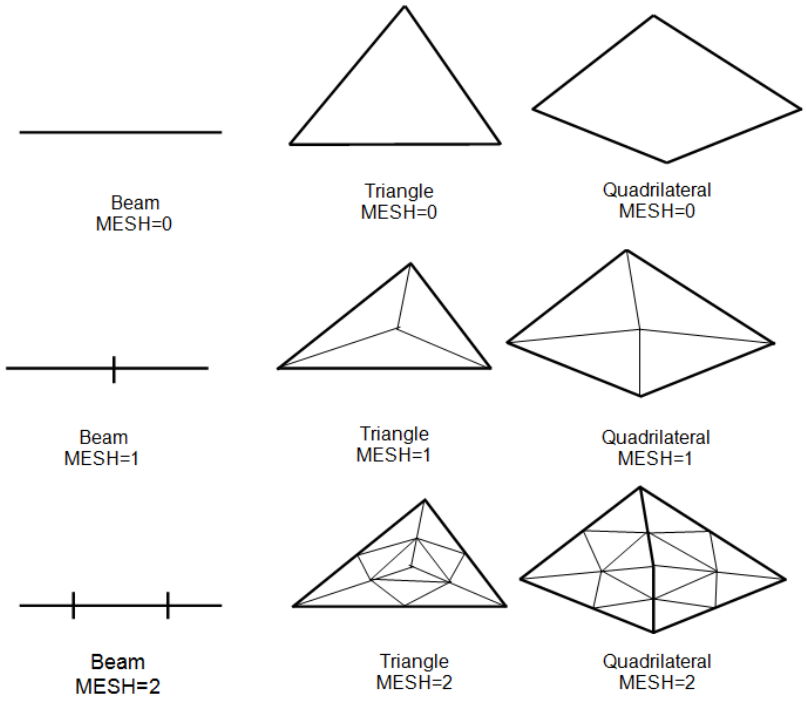
For certain operations such as shadowing checks and ray-tracing elements need to be subdivided into sub-elements.

The Card 2a or Card 6f MESH parameter governs the rules for the subdivision. A larger MESH parameter yields a larger number of sub-elements, resulting in more accurate the shadowing and ray-tracing calculations, with corresponding penalties in CPU time.

The subdivision algorithm is shown below. If `MESH > 0`, planar elements are subdivided into $MESH^2*NV$ triangular sub-elements, where NV is the number of nodes. The element's centroid is joined to each of its nodes, and each triangle thus created is subdivided into $MESH^2$ similar sub-triangles by subdividing each line segment into MESH equal parts.

Lump mass elements are not subdivided.

Beam elements are subdivided into MESH sub-elements.



If solar view factors are calculated for specular and transparent elements, the calculated MESH parameter value is multiplied by 5. This is to increase accuracy and reduce aliasing effects.

The View Factor Calculation Algorithm without Ray-Tracing

The following outline the steps by which view factors are calculated without ray-tracing.

Non-ray-traced view factors are calculated individually for each element pair i and j, following the order of the Card 6 requests.

Orbital view factors are calculated from the viewing element i to the internal representation of the environmental source (the planet or the sun), which is considered to be element j.

Heat flux view factors are calculated from viewing element i to the radiative source elements j.

Step 1: Viewing Check

Before calculating view factors or orbital or heat flux view factors a viewing check is performed. The vertices of element i are examined to see whether they can be seen by the front surface of element j. Similarly, the vertices of element j are examined if they can be seen by element i. Both conditions need to be met for the elements to see each other.

Lump mass elements cannot view each other if their nodes are coincident.

Beam elements can not view each other if their axes fall on the same straight line.

Step 2: Preliminary View Factor Magnitude Check

A preliminary view factor magnitude check is performed for view factor and heat flux view factor (but not solar view factor) calculations to see if the view factor is too small to be calculated.

The minimum acceptable threshold value is defined a Card 6m VFMIN Card, and defaults to 1.E-10.

Step 3: Preliminary Shadowing Check

If calculations with shadowing are requested, an initial shadowing check is performed on the shadowing surfaces to screen out shadowing surfaces that cannot possibly block the view of one element to the other.

With Card 6 VFxENC Enclosure Card requests only shadowing surfaces that contain elements that belong to the enclosure are considered for screening.

For this calculation lump mass and beam elements are transformed into equivalent rectangles.

Each shadowing surface is subjected to the following tests:

- A clipping test in which a rectangular box is created around the two viewing elements, using their maximum and minimum global coordinates. If the maximum and minimum coordinates of the shadowing surface fall outside the box, it cannot possibly shadow.
- The shadowing surface's vertices are examined to see if they fall behind the front surface of either of the viewing elements. If they do, the surface cannot shadow.
- If the vertices of both viewing elements fall on the same side of the shadowing surface the surface cannot shadow.

Step 4: Calculating View Factors with No Shadowing

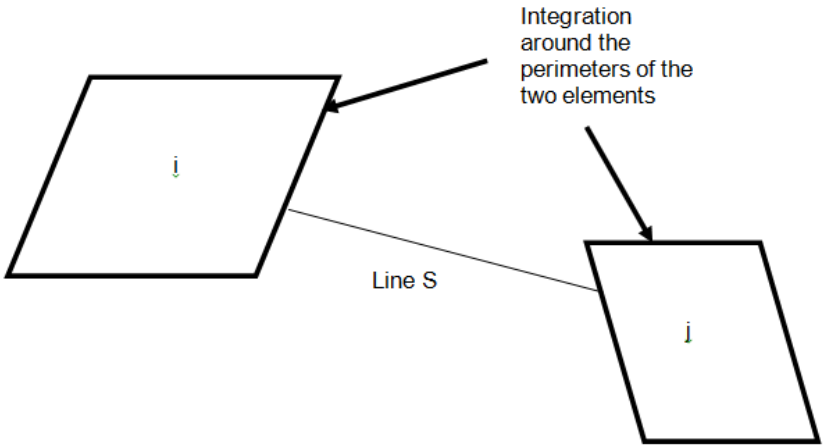
If there are no shadowing surfaces between the elements i and j, the elements are not subdivided a special algorithm for computing unshadowed view factors is used to calculate the view factor VF_{ij} between them. The algorithm uses various techniques depending on the types of elements involved.

If both viewing elements i and j are planar VF_{ij} is calculated with the contour integral technique (Ref. 1). This technique yields very accurate view factors. It consists of numerically integrating the following double integral around the perimeters of the two elements:

$$VF_{ij} = \frac{1}{2\pi Ai} \int_{Ci} \int_{Cj} 1nS(Ci, Cj) dCi dCj$$

where:

- C_i, C_j are the paths around the perimeters of elements `i` and `j`
- S is the length of a line between two points on the perimeters of elements `i` and `j`



If the plane of element `i` cuts the plane of `j`, the shape of the cut element is modified to ensure the integration is performed only over the edges of the portions that see each other.

View factors for spherical lump mass elements are calculated with an analytical expression without subdividing the sphere's surface into sub-elements.

View factors for beam elements are calculated by transforming them into equivalent surface area hexagonal tubes, and using the exact contour integral technique with the planar sides.

Once the view factor is calculated, if heat flux view factors were requested with Card 6n SOURCEx Cards, the view factor is multiplied by the POWER and POWERIR values specified on the Card before being written on VUFF.

Step 5: Calculation of the MESH Parameter

If possible shadowing surfaces have been found in Step 3, each element i and j is subdivided according to the Card 6f MESH parameter as discussed above.

The MESH parameter may be user-specified, or automatically calculated, if the Card 6f MESH ERROR ERR option is used. For this option, the MESH parameter is calculated by:

$$MESH_i = \sqrt{\frac{VF_i A_i}{(ERR)(NV)(A_j)}}$$

$$MESH_i = \sqrt{\frac{VF_i}{(ERR)(NV)}} \qquad \text{if j is not a space element}$$

$$MESH_j = MESH_i \qquad \text{if j is a space element}$$

where:

- ERR is the maximum view factor sum error specified on Card 6f
- VF_i is the maximum approximate estimated view factor between `i` and `j`, where element i is the smaller element.
- NV is average of the number of vertices of the elements i and `j`

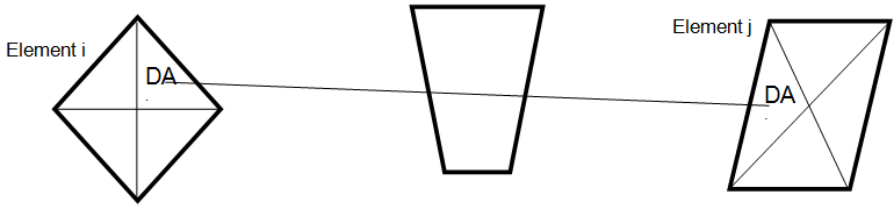
The MESH values are rounded off to the nearest integer.

Step 6: Viewing and Blockage Check for Subelements

If some shadowing surfaces have been identified as possibly shadowing, each element i and j is subdivided, and the incremental view factors DVF_{ij} from each sub-element DA_i to each subelement DA_j are calculated. The subdivision is governed by the Card 6f MESH parameter in the manner shown above.

For view factor calculations element `i` is chosen to be the element with the smaller area.

A viewing check is performed to verify that the front surface of each sub-element DA_i can see the front surface of each subelement DA_j.



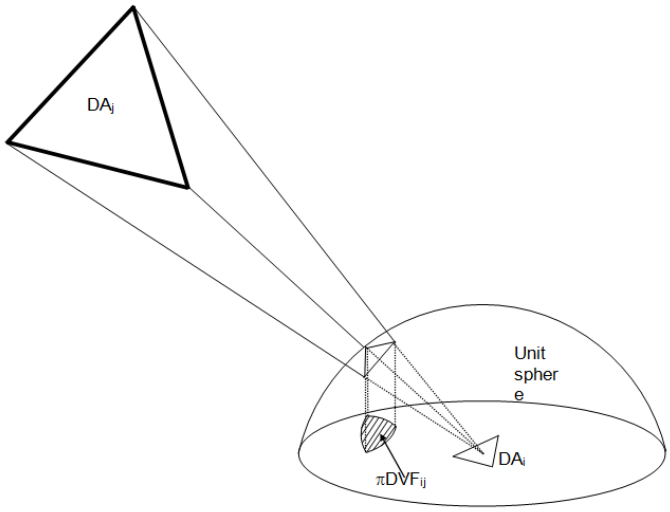
If the plane of one of the triangular sub-elements cuts through the other subelement, the shape of the second subelement is appropriately modified to allow view factor calculations between only those portions that see each other.

If either `i` or `j` is warped, then it is checked that the subelements are not shadowed by part of the warped element. The angle θ is calculated to be the angle between the vector joining the centroids of the two sub-elements and the surface normal of the warped element. Then:

$$DVF_{ij} = 0 \quad \text{if warpage angle} > \frac{\pi}{2} - \theta$$

Next, a blockage check is performed for each of the possible shadowing surfaces by checking if any of them intercepts the line joining the centroids of DA_i and DA_j. If a shadowing surface blocks, $DVF_{ij} = 0$.

Step 7: The Nusselt Sphere Technique



If both `i` and j are planar, and there is no blockage between the subelements, the Nusselt Sphere technique is used to calculate $\mathrm{DVF_{ij}}$. The Nusselt Sphere technique is used because although it is a more approximate than the contour integral technique, it requires much less CPU time.

The Nusselt Sphere uses a double projection method. First, a unit sphere (`radius=1`) is drawn around the CG of $\mathrm{DA_i}$ (whose area is smaller than $\mathrm{DA_j}$). Next, the vertices of $\mathrm{DA_j}$ are projected onto the sphere by drawing lines from the center of the sphere to the vertices. These vertex projections are then re-projected from the unit sphere onto the plane of $\mathrm{DA_i}$.

The area of this second projection equal to $\pi \mathrm{DVF}_{ij}$

The Nusselt Sphere technique is most accurate if either $\mathrm{DA}_i << \mathrm{DA}_j$ or DA_i is far away from DA_j.

If one of the elements is a beam, DVF_{ij} is calculated using the exact contour integral technique (not the Nusselt Sphere technique) between the sub-elements. This is because beam sub-elements tend to have high aspect ratios, and the assumption of small DA_i does not necessarily hold.

The incremental view factors DVF_{ij} are then summed to obtain VF_{ij} `.`

If during the shadowing checks it turns out that:

- none of the possible shadowing surfaces does in fact shadow, and
- both i and j are planar, and
- VF_{ij} is sufficiently large (hence the accuracy of the Nusselt Sphere Technique is suspect),
- then VF_{ij} is recalculated for greater accuracy with the exact contour integral technique.

If heat flux view factors were requested with Card 6n SOURCEx Cards, the view factors are multiplied by the POWER and POWERIR values specified on the Card.

Step 8: Calculation of Solar View Factors

If solar view factors are requested instead of view factors, and if Card 6d Earth Cards or Card 6k ORBIT Cards or Card 6t ORBDEF Cards are present, an eclipse check is first performed to see whether the Earth blocks the sun.

To model the sun, an internal 1-node element is created from the sun angles at a distance of `1.E6` from the origin. The blockage checks between the element i and the sun are performed as discussed above.

If there is no eclipse, the incremental solar view factor for element i to the sun is:

$$DSVF_i = \frac{\cos(\theta_{sun}) DA_i}{A_i}$$

where:

- $DSVF_i$ is the incremental solar view factor of subelement DA_i.
- θ_{sun} is the angle between the solar vector and the element's surface normal.

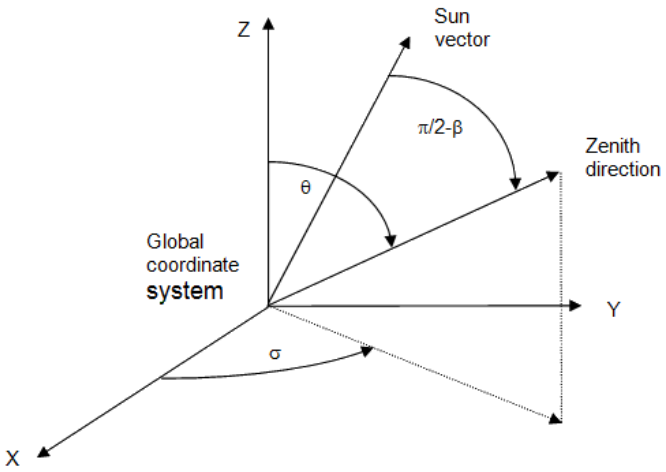
1-node elements are not subdivided. For a 1-node element:

$$SVF_i = .25$$

For a beam element:

$$DSVF_i = \frac{\sin(\theta_{axis})DAi}{\pi Ai}$$

where:



- θ_{axis} is the angle between the element's axis and the sun vector.

At the end of the view factor calculation stage, the incremental solar view factors are summed and written as an array of solar view factors SVF_i at each time interval.

Step 9: Diffuse Incident Solar Spectrum Flux from the Sky

If a Card 6s Diffuse Sky View Factor Request Card is present, then the view factor of element i to the diffuse sky as well as to the radiation reflected from the ground is calculated. The calculation is performed in the solar spectrum without any shadowing. The view factor is written on VUFF as an equivalent albedo view factor with MNM=ALB. The equation used is:

$$ALBi = \frac{PSUN}{PSUN2A}\left(\frac{DIFFSKY(1+\cos(\sigma))}{2} + \frac{DIFFSKY + \sin(\beta)(REFLG(1-\cos(\sigma))}{2}\right)$$

where:

- $PSUN$ is the value of the solar flux attenuated by the atmosphere reaching the surface.
- $PSUN$ is specified on the SKY Card.
- $PSUN2A$ is the value of the solar flux specified on Card 2a.
- $DIFFSKY$ is the diffuse sky factor ratio, i.e. the diffuse sky flux on a horizontal plate divided by the direct normal solar flux specified on the SKY Card.
- σ is the surface elevation angle, i.e. the angle between the element surface normal and zenith.
- β is the solar altitude angle in degrees, the angle from the horizontal to the sun vector.

- $REFLG$ is the ground reflectance
- ALB_i is the view factor of element i to the diffuse sky plus as the radiation reflected from the ground

Step 10: View Factor Merging

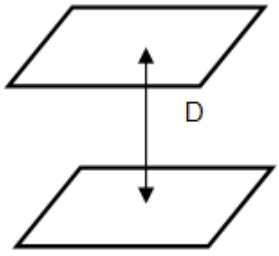
View factors may be merged with Cards 6j. However, this can significantly reduce the accuracy of radiation calculations because of the problems of non-uniform illumination discussed below.

If element merging is desired, a preferred approach is to perform element merging with Card 7, which will maintain the non-uniform illumination properties.

Special Topics

The following pages detail special topics related to the VUFAC module.

View Factor Calculation Accuracy Considerations



The following table compares the accuracy of the contour integral technique with the Nusselt Sphere Technique with `MESH = 1` and `MESH = 2`, and another popular technique called the Double Summation Technique (not used in TMG). The example is that of two parallel unit squares separated by a distance of D.

% Error vs. Separation Distance D for Two Parallel Unit Squares					
D	Contour Integral	Nusselt Sphere MESH = 1	Nusselt Sphere MESH = 2	Double Summation MESH = 1	Double Summation MESH = 2
`0.01`	`0.001`	`1.9`	`0.001`	`80000.`	`20000.`

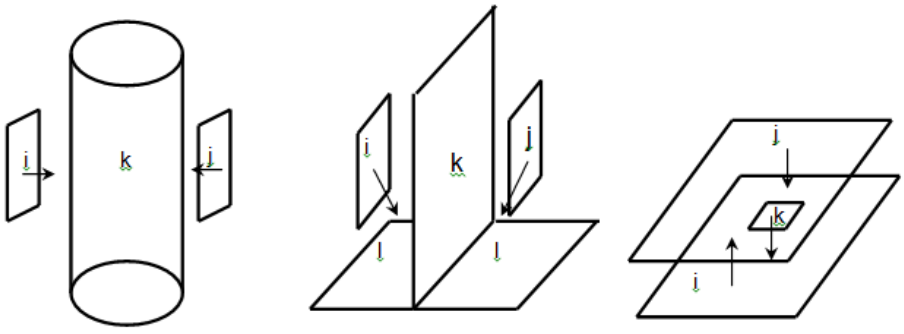
0.1	0.0002	10.6	4.7	865.	158.
1.	0.000005	5.6	1.3	8.5	1.94
10.	0	0.1	0.02	0.165	0.04

As the table shows, the accuracy of the contour integral technique is almost totally independent of geometry. The Nusselt Sphere technique has an error upper bound around 12% for `MESH = 1`, and 5% for `MESH = 2`, occurring when the elements are very close together. The double summation technique breaks down when the elements are very close together, unless they are divided into much smaller sub-elements.

Inaccuracies Due to Non-Uniform Illumination

Radiation calculations with view factors assume uniform illumination over an element, and potentially significant errors may be introduced when this assumption is not fulfilled. Three good examples of the types of errors introduced by non-uniform illumination are the cylinder blockage problem, the fence problem, and the small area seeing a large area problem.

In the cylinder blockage problem, radiation from element i cannot reach j because of blockage by cylinder k. However, if cylinder k is modeled as a single element and thus has a single reflecting surface, because of the uniform illumination assumption inherent in the view factor definition it is assumed that some of the radiation will be reflected onto j, which is clearly incorrect. To avoid this problem, if a cylinder can cause significant blockage then model its surface with a series of planar elements.



A second common error is the fence blockage problem. Here `i` and `j` cannot see each other because they are blocked by fence k. However, the edges of fence k do not line up with element `l`, which can see both `i` and `j`. Since both `i` and `j` are assumed to illuminate `l` uniformly, l will incorrectly reflect radiation from `i` to `j`. The solution here is to create a mesh so that the edge of `l` lines up with the edge of `k`, or, if this is not possible, use smaller elements along the projection of `k`.

A third common error occurs when a small area sees a large area with a large view factor. Here element k is a small black area that is very close to reflective element `i`. Element `i` in turn has a large view factor to black element `j`. Then, very little of the radiation originating from k should be reflected away from `i`, most of it should bounce back to k and be re-absorbed. However, because the radiation incident upon `i` is assumed to be uniform, and radiation is reflected in proportion to the view factors, most of the radiation from `k` will be incorrectly computed to be reflected onto and absorbed by `j`. The solution here is to subdivide element `i` into smaller sub-elements.

Highly reflective surfaces and coarse meshes generally aggravate problems due to non-uniform illumination.

Calculation of Earth View Factors without Ray-Tracing

The Earth view factor EVF_i is the element's view factor to Earth.

To calculate EVF_i, first, a preliminary viewing check is performed to see whether the element's surface sees any part of Earth. The location of the Earth is defined on a Card 6d, Card 6k, or Card 6t or Card 6u.

Lump mass and beam elements can always see Earth.

If the shadowing option is requested, a preliminary blockage check is performed to screen out the shadowing surfaces that cannot block the Earth.

If after the screening some possibly shadowing surfaces exist, the Earth Blockage Factor is calculated:

- The Earth is sub-divided into $4 * \mathrm{MESH}^2$ subelements, while element i is subdivided into $\mathrm{MESH}^2 * \mathrm{NV}$ sub-elements $\mathrm{DA_i}$.
- The view from each sub-element $\mathrm{DA_i}$ to each Earth sub-element is then examined for blockage by checking whether any of the possibly shadowing surfaces interrupts their centroids' views of each other. The technique is the same as discussed above.
- An incremental Earth view factor $\mathrm{DEVF_i}$ is calculated with the Nusselt Sphere Technique for each $\mathrm{DA_i}$.
- The Earth blockage factor is then defined as:

$$EBF_i = 1 - \frac{\sum_m \sum_k DEVF_{mkb}}{\sum_m \sum_k DEVF_{mknb}}$$

where:

- $DEVF_{mknb}$ is the incremental view factor from the m'th subelement $\mathrm{DA_i}$ of element i to the k'th subelement of Earth, calculated with the Nusselt Sphere Technique, calculated without blockage.
- $DEVF_{mkb}$ is the incremental view factor from the m'th subelement $\mathrm{DA_i}$ of element i to the k'th subelement of Earth, calculated with the Nusselt Sphere Technique, calculated with blockage.
- EBF_i is the Earth blockage factor for element i

The Earth Blockage Factor = 1 if there is full blockage, and = 0 if there is no blockage.

After the Earth Blockage Factor is calculated, the unshadowed Earth view factor is calculated with the analytical expression of (Ref. 2) for the view factor from a small planar area to a very large sphere. Cylindrical 2-node elements are approximated as equivalent surface area square cross-section rods, and lump masses are approximated as equivalent area cubes.

Then:

$$\mathrm{EFV_i} = (1 - \mathrm{EBF_i})(\text{Unshadowed Earth view factor})$$

Calculation of Albedo Factors without Ray-Tracing

The albedo view factor is defined by:

$$ALB_i = ALB \int \cos(\theta_{sun}) dVF_{iEarth}$$

where:

- ALB is the Card 6d, Card 6k, or Card 6t or Card 6u albedo value
- ALB_i is the albedo view factor of element i to the Earth
- θ_{sun} is the angle between the local Earth's surface normal and the sun vector
- dVF_{iEarth} is the incremental view factor from element i to the Earth

An Albedo Blockage Factor is calculated similarly to the Earth Blockage Factor, except that each $DEVF_i$ is multiplied by the solar illumination weighting factor.

$$ABF_i = 1 - \frac{\sum_m \sum_k SIWF_k DEFV_{mkb}}{\sum_m \sum_k SIWF_k DEFV_{mknb}}$$

where:

- $SIWF_k$ is the solar illumination weighting factor, equal to the solar view factor of the k'th Earth sub-element.
- ABF_i is the Albedo Blockage Factor for element i

The albedo blockage factor = 1 if element i does not see any part of the Earth which reflects the sun.

The unshadowed albedo view factor is calculated by interpolating the tables of (Ref. 2), using the sun angle, Earth angle, and albedo value.

Then:

$$\mathrm{ALB_i} = (1 - \mathrm{ALB_i})(\text{Unshadowed albedo view factor})$$

Ray-Tracing

The following describes TMG's methodology for handling radiation in the presence of diffuse and transparent/specular surfaces.

TMG's approach to handling a combination of diffuse, specular, and transmissive surfaces is to create a single view factor matrix to incorporate all these effects. This matrix is then used to calculate radiative couplings in the GRAYB module and heat absorption due to diffuse reflections and transmission in the POWER module with matrix methods such as Oppenheim's and Gebhardt's.

Ray-tracing is performed in the VUFAC module when creating this matrix to account for specular reflection and transmission. Ray-tracing is performed automatically for solar view and heat flux view factors. For Earth and orbital view factors to be ray-traced, the PARAM EXEARTH option must be used. For element view factors to be ray-traced, the VFTRACE option must be used with the appropriate view factor request Card. The ray-tracing methodology is summarized as follows:

- If the receiver element `j` is fully diffuse, no rays are launched, but the standard view factor calculation algorithm is used to determine the strength (magnitude) of the energy incident on `j` that comes directly from i. This strength value is then stored with element `j`.
- If the receiver element `j` is specular or transparent, multiple rays are launched from source elements `i` to partially/fully specular/transparent receiver elements j.

  Both source and receiver elements are subdivided into sub-elements using the Card 6k MESH parameter, and a ray is traced from each sub-element of element `i` to each sub-element of element `j`.

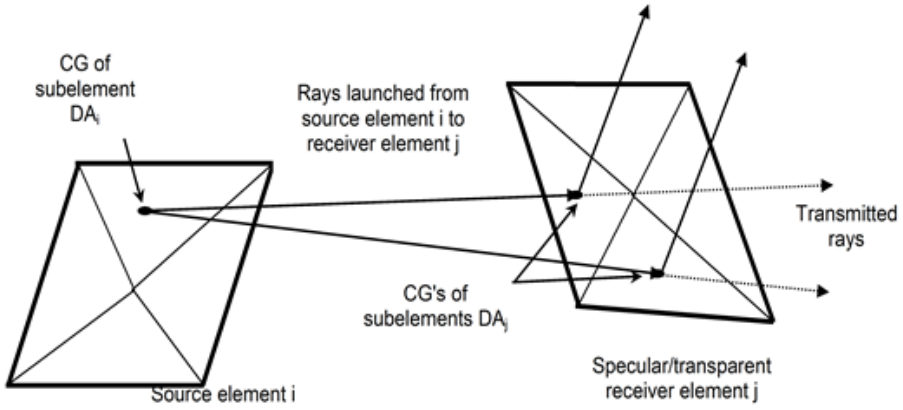
  An energy packet for each spectrum (IR and solar) is created which follows the ray. The strength (magnitude) of the energy packet is equal to the area of the launching sub-element view factor between the sub-elements. The strengths of the incident energy packets are stored for each element.

- The rays are traced through multiple reflections and/or transmissions until they encounter a fully diffuse element, and then are not further traced.

  The strengths of the incident energy packets are stored for each element.

  The strengths of the reflected/transmitted energy packets are reduced in magnitude proportional to the absorptivity and diffuse reflectivity of the elements.

- Once all elements are processed, the incident energy packets are summed to calculate the appropriate ray-traced view factors from elements `i` to `j`, including all specularly reflected and transmitted effects.



The view factor requests

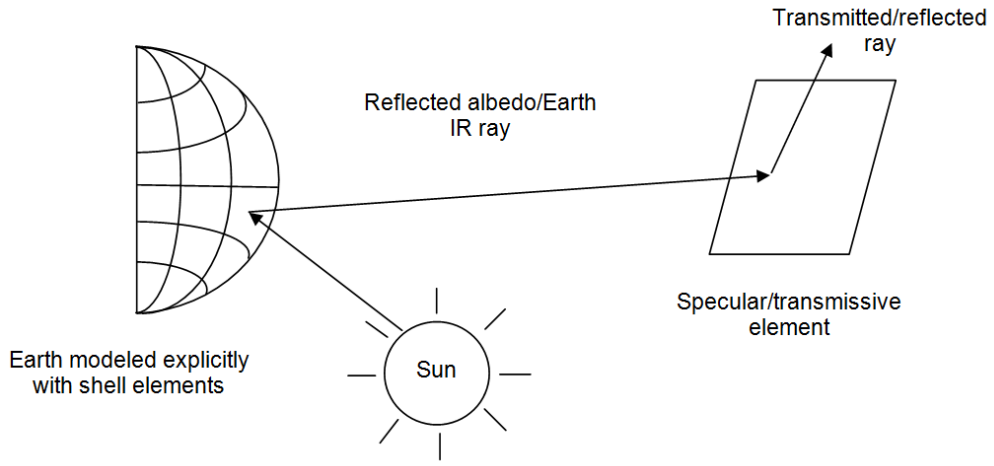
The ray-tracing process starts with a Card 6 view factor calculation request. The view factor request for which ray-tracing is done may be a:

- Card 6b Solar View Factor Request - ray-tracing is always done for solar view factors.
- Card 6n Heat Flux View Factor Request - ray-tracing is always done for heat flux view factors.
- Card 6a VFSALL View Factor Request with the VFTRACE flag.
- Card 6r Enclosure View Factor Request with the VFTRACE flag.
- Card 6k and Card 6t and Card 6u Orbit Cards: ray-tracing is always done for solar view factors; but it is only done for albedo view factors and Earth view factors if the PARAM EXEARTH option is active.

Ray-Tracing with the PARAM EXEARTH option

If the PARAM EXEARTH option is present, ray-tracing is done for Earth view factors and albedo view factors for a:

- Card 6k Orbit Definition Card
- Card 6t ORBDEF Orbit and Attitude Modeling Request Cards
- Card 6d Earth view factor requests
- With the PARAM EXEARTH flag the Earth is modeled explicitly as a separate set of shell elements for each orbital position in the appropriate location with respect to the model. For more information see Card 9 - PARAM Parameter Card - Optional, the EXEARTH option.



Choosing the source elements in a view factor request

The elements i and j for which the calculations are performed are determined by the view factor requests. Element i is chosen from the specified set of source elements, and element j is chosen from the specified set of receiver elements.

- If Card 6n heat flux view factors are requested, the set of source and receiver elements are specified on the heat flux view factor request Card.
- If solar view factors are requested through Card 6b, Card 6k, Card 6t, or Card 6u, the source element i is the sun, and the receiver elements are specified on the on the solar view factor request Cards.
- If Card 6r view factors are requested with ray-tracing in an enclosure, the source elements and the receiver elements are both specified to be all the elements in the enclosure.
- If all the view factors in the model are requested with ray-tracing through Card 6a, then the source and receiver elements are both specified to be all the elements in the model.
- If albedo and Earth view factors are requested with the PARAM EXEARTH option with Cards 6k, 6d, or 6t, the source elements are the explicitly modeled Earth elements, and the receiver elements are the ones appropriately specified on the Card.

Viewing Checks and Elemental subdivision

Steps 1 through 6 of the view factor calculation algorithm described above are followed to determine whether the two elements see each other. If element `j` is specular or transparent, the elements are subdivided as described above, even if there are no shadowing surfaces between them.

Calculation of energy packet strength

To calculate the strength of the packets associated with the ray launched from DA_i, an incremental view factor DVF_{ij} between subelements DA_i and DA_j is calculated as described above.

For each non-zero DVF_{ij}, a ray packet of strength $Strengthsol_j$ in the solar spectrum and strength $StrengthIR_j$ in the IR is launched from the CG of the subelement DA_i towards the CG of DA_j:

$Strengthsol_j = DA_i DVFi_j$	for view factor calculations
$Strengthsol_j = DA_i DVF_{ij} POWER$	for solar spectrum heat flux view factor calculations
$Strengthsol_j = DA_j DVF_{ij}$	for solar view factor calculations
$Strengthsol_j = DA_i DVF_{ij} ALB \cos(\theta_{sun})$	for albedo factor calculations with PARAM EXEARTH
$StrengthIR_j = DA_i DVFi_j$	for view factor calculations
$StrengthIR_j = DA_i DVF_{ij} POWER$	for IR spectrum heat flux view factor calculations
$StrengthIR_j = 0$	for solar view factor calculations
$StrengthIR_j = DA_i DVF_{ij}$	for Earth view factor calculations with PARAM EXEARTH

Where:

- $POWER$ is the solar spectrum energy per unit area emitted by the element i specified on Card 6n.
- $POWERIR$ is the IR spectrum energy per unit area emitted by the element i specified on Card 6n.
- ALB is the albedo value specified for the Earth.
- θ_{sun} is the angle between the solar vector and the explicitly specified Earth element.

Accuracy considerations

Accuracy and performance of ray-tracing strongly depend on the MESH parameter. The number of rays launched from an element varies as `MESH`^{4}, since the rays are launched from each DA_j subelement to each DAj subelement. The following table shows the number of rays launched from one quadrilateral element to another as a function of the MESH parameter:

Number of rays launched from quadrilateral source element `i` to quadrilateral element `j`.	
MESH	Number of rays launched
`0`	`1`
`1`	`16`

`2`	`256`
`3`	`1296`
`4`	`4096`

It is important to note that the cost of ray-tracing is only proportional to the number of specular/transparent elements in the model, since multiple rays are launched only towards them, and they are the ones that support reflected rays.

Calculation of reflected/transmitted energy packet strengths

After the ray hits a specular or transparent element `j`, one or two new rays are launched from the point where the incident ray intersects DAj.

- If element `j` is only specular or transparent but not both, a single ray is launched.
- If element j is both specular and transparent (half-silvered mirror), then two new rays are launched from DAj: one ray is transmitted and one is reflected. For each of the newly launched rays, two energy packets (one in the solar and one in the IR spectrum) are tracked, for a total of four energy packets.

The new energy packets' strengths are computed as follows:

$$
\begin{aligned}
Strengthref sol &= \rho sol_j Strengthsol_j \\
Strengthref lIR &= \rho IR_j StrengthIR_j \\
Strengthtranssol &= \tau sol_j Strengthsol_j \\
StrengthtransIR &= \tau IR_j StrengthIR_j
\end{aligned}
$$

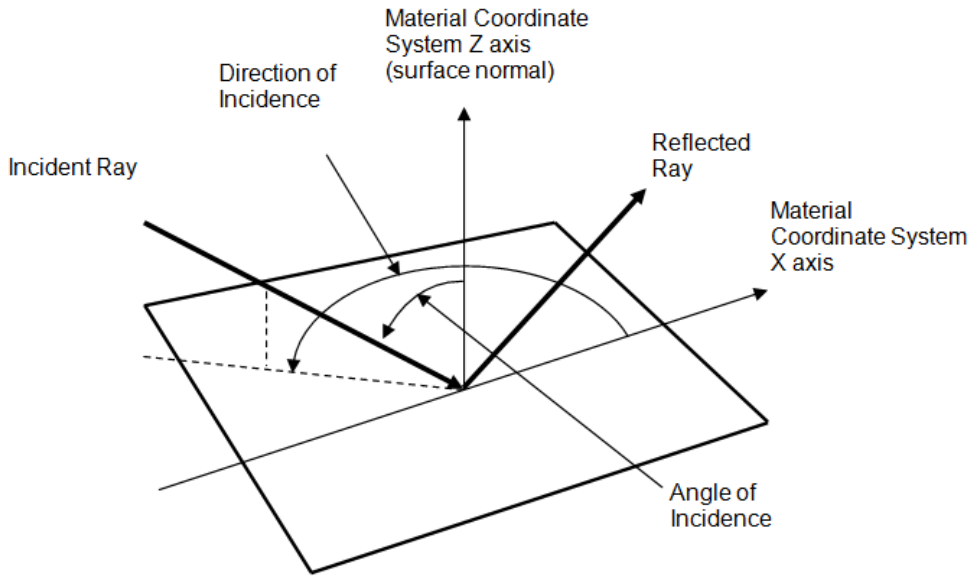
Where:

- ρsol_j is the specular reflectivity of the element j in the solar spectrum
- ρIR_j is the specular reflectivity of the element j in the IR spectrum
- τsol_j is the transparency of the element j in the solar spectrum
- τIR_j is the transparency of the element j in the IR spectrum
- $Strengthref lsol$ is the strength of the specularly reflected solar spectrum energy packet
- $Strengthref lIR$ is the strength of the specularly reflected IR spectrum energy packet
- $Strengthtranssol$ is the strength of the transmitted solar spectrum energy packet
- $StrengthtransIR$ is the strength of the transmitted IR spectrum energy packet

Angle Dependent Surface Properties

For some elements, specular reflectivity or transmissivity may be defined to be a function of angle of incidence. For these the specular reflectivity or transmissivity are determined by linear interpolation of the data in the array

referenced by the material property. If the incident angle falls outside the range defined in the array TMG uses the value at the nearest limit, it does not extrapolate.



The direction of incidence is determined by projecting the ray onto the plane defined by the element surface normal and then determining the angle between this projection and the material orientation vector for the element. Angle of incidence is the angle between the incoming ray and the surface normal.

Calculation of ray direction for reflected/transmitted rays

For specular elements j, the new direction is calculated by assuming the angle of incidence is equal to the angle of reflection with respect to the local surface normal.

For the transparent elements j, if the indices of refraction on both sides of the element are not specified or are equal, the direction of the transmitted ray is the same as the incident ray. However, if the indices of refraction are specified and are different, then a new direction for the ray's travel is calculated using Snell's Law:

$$\sin(\theta_{trans}) = \frac{I_{inc}\,\sin(\theta_{inc})}{I_{trans}}$$

Where:

- θ_{inc} is the angle the incident ray makes with the surface normal
- θ_{trans} is the angle the transmitted ray makes with the surface normal
- I_{inc} is the index of refraction on the incident side of the element (specified on Card 9 MAT Material Property Definition Card - optional)
- I_{trans} is the index of refraction on the transmitted side of the element (specified on Card 9 MAT Material Property Definition Card - optional).

The index of refraction is assumed to be spectrum-independent, the element `j` is assumed to have the same indices of refraction in both the IR and solar spectra.

If $I_{inc} > I_{trans}$ i.e. the ray goes from a dense to a less dense material, the computed $\sin(\theta_{trans})$ may be > 1. For this case the material is assumed to reflect specularly, with the specular reflectivity equal to the transmissivity of the material.

If element `j` is planar, the local surface normal is the same as the surface normal of the element.

Calculation of ray intercept and direction for curved elements

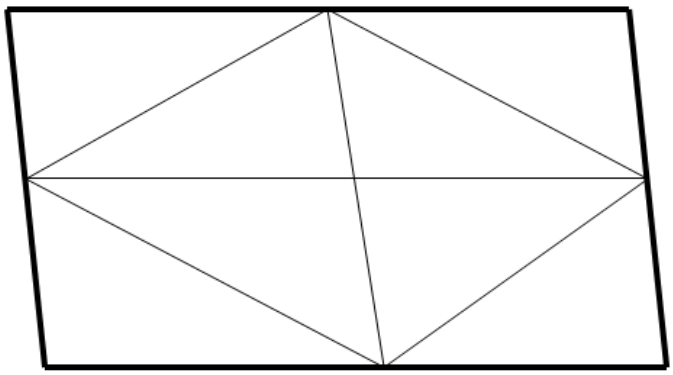
If the element is curved, a more complex algorithm is used to compute the local surface normal, the point of interception, and the new ray direction.

Curved elements are parabolic elements, defined by specifying the midside nodes of the sides with Card 5a MIDSIDE Cards.

The shape of the surface is represented using the standard finite element parabolic shape functions. These describe the variations of x, y, and z on the surface as functions of 2 parameters: `s` and `t`. The equation for the shape of the surface is defined by curve-fitting the coordinates of the nodes.

The following describes the procedure for calculating the local surface normal and the point of interception for parabolic elements:

1. Identify the sub-triangle within the element which the ray intersects.

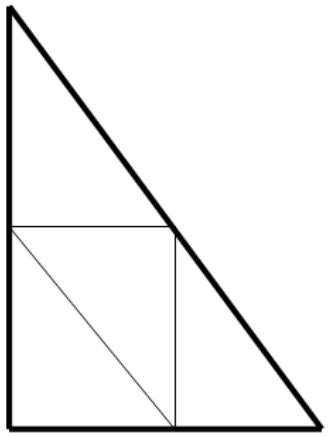


Subdivision of quadrilateral into subtriangles

2. For quadrilaterals, select point at the parametric center of the element (s=0, t=0) and determine its x, y, z coordinates. Using this point and the 8 element nodes, subdivide the quadrilateral into four quadrants. Subdivide each quadrant into two, yielding 8 subtriangles, and determine which subtriangle the ray intersects.

   If the element is a triangle, it is not subdivided, but is considered to be the intersecting subtriangle.

3. Subdivide the intersecting sub-triangle into 4 more subtriangles by connecting the midpoints of the sides. Determine which subtriangle the ray passes through. Calculate the surface normal of subtriangle and the intersection point with the ray, assuming the subtriangles are planar.



Subdivision of a triangle into subtriangles

4. Further subdivide this sub-triangle in same manner into 4 sub-triangles, and determine which of these the ray intersects. Calculate the new intersection point and surface normal for this sub-triangle, assuming the sub-triangle is planar.

   Define a tolerance parameter D:

$$D = \frac{Length\ of\ side1 + length\ of\ side2}{100}$$

5. Compare results from the subdivision of Step 2 and Step 3, and if the intersection point has moved less than D and the angular change in surface normal is less than .01 radians, then stop. Otherwise sub-divide again and start with Step 2.
6. If during the intersection calculations the ray does not intersect an element or a sub-triangle, then the element or sub-triangle is expanded in parametric space and the intersection calculation re-started. The expansion is applied recursively until an intersection is found or an internal limit is reached.

Once the point of intersection has been determined the reflected ray is calculated using the point of interception and the local surface normal. The new ray is then checked to see if it re-intersects the same element. The reflection/re-intersection procedures are repeated until a new ray does not re-intersect the element or 5 bounces are found.

In the event of failure in the curved element processing TMG resorts to using the planar approximation to the element.

Location of the next intercepted element

Once the direction and strengths of the ray launched from `j` are established, an artificial 1-node element `k'` is created at a very large distance along the ray. All the shadowing surfaces are then checked for interception of the ray

originating at DAj and ending at `k'`. If more than one shadowing surfaces intercept, the one with the point of interception closest to DAj is chosen as the intercepting surface.

Next, a search is done within the intercepting shadowing surface to identify the element `k` that is hit, and the coordinates of the interception point are computed.

If the ray is not terminated, new strength values and directions are calculated in the manner described above, and the ray further continued.

Ray termination

Ray termination occurs under the following circumstances:

- If none of the shadowing surfaces intercepts the ray, an improper model definition is assumed, and the ray is ignored and is assumed terminated in the space element.
- If view factors in an enclosure are requested, and an intercepting shadowing surface is found, but the intercepting shadowing surface is not inside the enclosure, an improper model definition is assumed and the ray is also ignored and is considered terminated.
- If the intercepted element k is diffuse, the ray-tracing for this ray is terminated.
- If the ray hits the back of an element whose reverse side is not defined, an improper model definition is assumed and the ray is terminated.
- If the energy packet strength is less than `.001` of its original strength in both spectra, the ray is terminated.

Summation of the energy packets to calculate the ray-traced view factors

Once the ray-tracing calculations are finished, the energy packets are summed to calculate the geometric view factors.

For solar view factors, albedo view factors, Earth view factors, and heat flux view factors the geometric view factor is calculated by:

$$VF_{ij} = \frac{POWER_i}{A_i} \sum_{K}^{N} DA_i \, DVF_{im} \, R_{ijk}$$

Where:

- N is the number of rays launched from source element i that arrive at element j.
- VF_{ji} is the view factor from element j to source element I
- $POWER_i$ is the power per unit area of the emitting element
  - = Card 6n POWERIR for IR spectrum heat flux view factor calculations
  - = Card 6n POWER for solar spectrum heat flux view factor calculations
  - = 1 for solar view factor calculations
  - = $ALBcos(\theta_{sun})$ for albedo view factor calculations
- R_{ijk} is the reduction factor by which the strength of the k'th ray launched from i is reduced after multiple reflections when it arrives at j
- m is the first element that the k'th ray hits

- $DA_i\,DVF_{im}$ is the strength of the k'th ray launched from i

For solar spectrum view factors, the view factor from element `i` to `j` is calculated with:

$$VF_{ij} = \sum_{K}^{N} \frac{DA_1\,DVF_{im}\,R_{ijk}}{A_i(1-\rho_{soli}-\tau_{solj})}$$

For IR spectrum view factors, the view factor from element `i` to `j` is calculated with:

$$VF_{ij} = \sum_{K}^{N} \frac{DA_1\,DVF_{im}\,R_{ijk}}{A_i(1-\rho_{IRi}-\tau_{IRj})}$$

In effect, the view factor is calculated for an area reduced by the sum of the specular reflectivity and transmissivity in each spectrum.

Ray-tracing through Solid Elements

Solid elements are by default considered to be transparent, ray-tracing is considered to occur between shell, beam and lump elements. However, if the SOLAREXTINCT or IREXTINCT properties are defined for a solid elements, ray-tracing is performed within solid elements with the following methodology:

- Surface coating. In the DATACH module, all surfaces of all solid elements with SOLAREXTINCT or IREXTINCT properties are surface coated with perfectly transparent elements, unless a shell element already exists on that surface.

  These surface coated elements will also be considered to be the boundary elements for conduction calculations.
  Reverse sides are also created for these surface coated elements, which are ignored for conduction calculations.
- The index of refraction value assigned to the front surface of a surface coated element facing a solid element is the value specified as IREFFRONT on the MAT Card for the solid element. The index of refraction of the reverse side is taken from the adjacent solid element, or, if it is a free surface, is assigned the value 1. The IREFBACK field on the MAT Card is ignored for solid elements.
- Ray strength calculation. A ray striking one of these elements will be transmitted, and the strength of the transmitted ray will be diminished as it travels through the solid by a factor equal to:

$$1 - e^{(-EXT*LENGTH)}$$

where EXT is the specified extinction coefficient. The lost radiation is written as a view factor from the original source element incident upon the surface coated element the ray hits on the far side of the solid element.

- Index of refraction. If all the surface coated elements facing a solid have the same index of refraction, the solid element is considered to have a zero index of refraction gradient, and the ray path will be straight through it. If, however, there is a variation in the index of refraction (this can be achieved with Card 9 MATCHANGE Card), then

an index of refraction gradient will be calculated for the solid element, and an appropriate curved path will be calculated for the ray traveling through the solid.

If a ray hits an internal surface coated element, it is always transmitted into the adjacent solid element. If it hits a surface coated element whose reverse side faces outwards, a determination is made based on Snell's Law (see above) on whether it exits the solid material or total internal reflection occurs.

- Once the calculations are completed, view factors and solar view factors incident upon the surface coated elements are written onto VUFF. The POWER module will calculate heat fluxes for these elements, assuming the incident rays are perfectly absorbed by the surface coated elements.

Handling of Reciprocity

In calculating view factors with ray-tracing, both VF_{ij} and VF_{ji} will in general be calculated. However, since the number of packets arriving at i from j will generally not be equal to the number of packets arriving at j from i, the reciprocity relationship $A_i VF_{ij} = A_j VF_{ji}$ will as a rule not be fulfilled. The question is, which is more accurate: VF_{ij} or VF_{ji} ?

To address this issue, if $A_i \geq 2A_j$, then VF_{ij} (the view factor from the larger element) is discarded. If $A_j \leq A_i < 2A_j$, then VF_{ij} is computed with averaging:

$$VF_{ij} = \frac{A_i VF_{ij} + A_j VF_{ji}}{2A_i} \quad \text{if } 2 \geq \frac{A_i}{A_j} \text{ and } 2 \geq \frac{A_j}{A_i}$$

$$VF_{ij} = \max(VF_{ij}) \frac{A_j VF_{ji}}{A_i} \quad \text{if } 2 < \frac{A_i}{A_j} \text{ or } 2 < \frac{A_j}{A_i}$$

Outputting of Results

The calculated view factors are written on file VUFF with the following convention:

- Solar view factors are written in the solar spectrum only with the code `MNM=SVF` .
- Ray-traced albedo view factors are written with the code `MNM = ALR` . Albedo view factors that have not been ray-traced are written with the code `MNM = ALB` .
- Ray-traced Earth view factors are written with the code `MNM = EVR` . Earth view factors that have not been ray-traced are written with the code `MNM = EVF` .
- Heat flux view factors are ray-traced in both the IR and solar spectra. Heat flux view factors in the solar spectrum are written with the code `MNM = HVF` , while heat flux view factors in the IR spectrum are written with the code `MNM = HVI` .
- Both ray-traced and non-ray-traced view factors are written with `MNM = BVF` .

  View factors that have been ray-traced in the solar spectrum are written with the code `TIME=-1.1E36` .

View factors that have been ray-traced in the IR spectrum are written with the code `TIME=-1.2E36`.

View factors which have not been ray-traced (and hence apply to both spectra) are written with the code `TIME = -1.0E36`.

- Ray-traced view factors for elements that have specular or transparent surface properties are written with their areas, emissivities, and absorptivities redefined to take into account the reduction area. The following relationships are used:

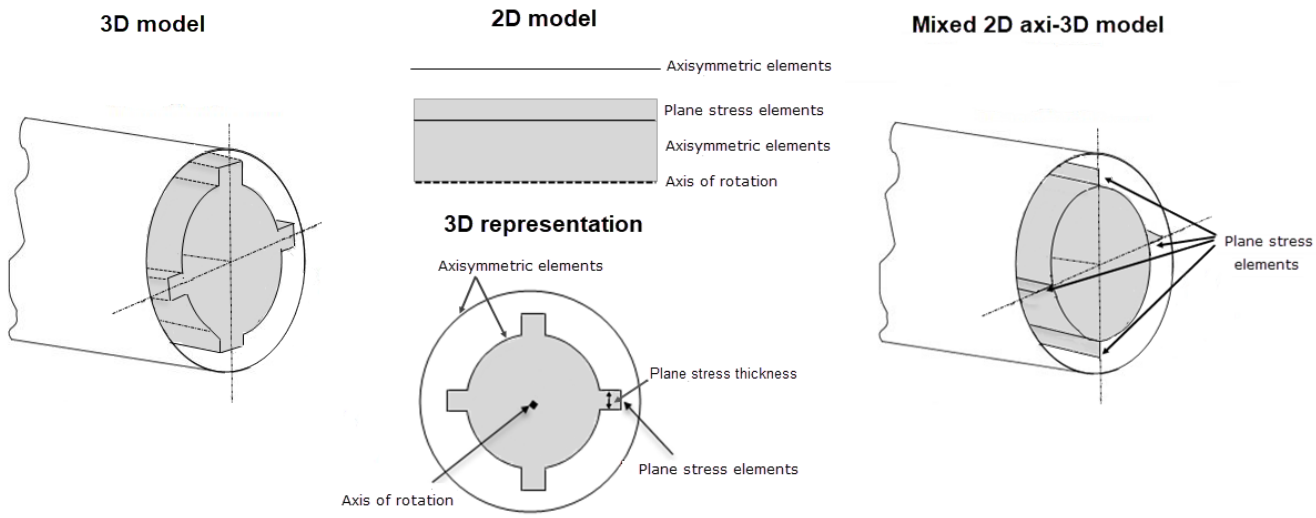
$$A_{inewsol} = A_i(1 - \rho_{soli} - \tau_{soli})$$
$$A_{inewIR} = A_i(1 - \rho_{IRi} - \tau_{IRi})$$
$$\varepsilon_{inew} = \frac{\varepsilon_i}{1-\rho_{IRi}-\tau_{IRi}}$$
$$\alpha_{inew} = \frac{\alpha_i}{1-\rho_{soli}-\tau_{soli}}$$

where

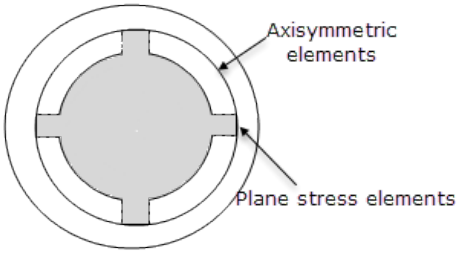
- $A_{inewsol}$ is the area written on file VUFF for solar spectrum view factors
- A_{inewIR} is the are written on file VUFF for IR spectrum view factors
- ε_{inew} is the emissivity written on file VUFF for IR spectrum view factors
- α_{inew} is the solar spectrum absorptivity written on file VUFF for solar spectrum view factors.

View factor calculation for the axisymmetric and mixed 2D axi-3D modeling with plane stress

To compute the view factor for an axisymmetric or mixed 2D axi-3D models with plane stress elements for the radiation requests, the thermal solver transfers axisymmetric elements' properties to plane stress elements. This method simplifies the full three-dimensional (3D) calculations and significantly reduces the computation time. The solver computes radiation from edges of a plane stress element, only for the Monte Carlo method, when radiation enclosures contain edges of element types, such as axisymmetric, chocking, or plane stress. The following example represents a simplified 3D model with plane stress elements.



In this model, the plane stress elements break the axisymmetry. To calculate the view factor, the thermal solver uses a simplified axisymmetric radiation treatment. It applies certain optical properties to the plane stress elements to create axisymmetric elements as shown on the following figure.



The optical properties are modified to have a transparency as follows:

$$t = \frac{2\pi R_{ps} - N t_{ps}}{2\pi R_{ps}}$$

where

- R_{ps} is the radius of top plane stress edges.
- t_{ps} is the thickness of top plane stress.
- N is the number of plane stress elements.

Depending on which side a ray originates the plane stress elements can be semitransparent or fully transparent.

- The elements are semitransparent when a ray travels from the external to the internal edges.

- The elements are fully transparent when a ray travels from the internal to the external edges.

For the view factor calculation, the thermal solver does not include the top plane stress surface that equal to Nt_{ps} , when the rays are moving outward from the internal edges.

For more information on how to calculate the view factor between the axisymmetric element, see the Axisymmetric Elements section in the Basic concepts of view factors.

Thermal coupling calculations

Thermal couplings are calculated between elements `N1` and `N2` if requested by the Card 6e Cards. The VUFAC module must recognize element `N1` . `N2` may be specified directly, or if one if the NEARx options is used, it may be automatically chosen by TMG to be the closest element to `N1` from a pre-selected group of elements.

Thermal couplings created by the Card 6e Card are written on file MODLF.

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