

Free Molecular Heat Transfer Programs for Setup and Dynamic Updating the Conductors in Thermal Desktop

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Abstract

Thermal Desktop has the capability of modeling free molecular heat transfer (FMHT), but limitations are observed when working with large models during transient operation. To overcome this limitation, a MatLab program was developed that processes the Thermal Desktop free molecular conductors. It sets up the logic and arrays for the Thermal Desktop GUI used by SINDA/FLUINT. The theory of free molecular heating is presented along with the process required to setup the conductors, arrays, logic and Fortran subroutines for FMHT modeling in Thermal Desktop.

Background

Thermal Desktop [1] has the capability of modeling free molecular heat transfer (FMHT) by using the RadCad radiation modules. The software underneath Thermal Desktop that actually solves the equations is SINDA/Fluint [2]. The user specified surface properties can account for the accommodation coefficient of FMHT and the user has to supply a constant term to account for the rest of the conductor. Although this method is possibly useful to model a small number of FMHT conductors, it quickly becomes laborious and impractical for large transient models where the conductors change over time. This method of modeling is nonstandard given that the FMHT usually modeled is external heating [1]. These observations about the capabilities of Thermal Desktop were drawn while developing a thermal model of the test facility and telescope for the James Webb Space Telescope Project. Two requirements were identified to enable a practical FMHT modeling system useful for large FMHT models.

The first requirement is to have a semi-automated process to setup the FMHT radiation conductors. Sometimes with large models it is useful to have several radiation tasks used to setup the FMHT conductors since each task is limited to 10,000 conductors. The programs developed use arrays to store the inputs, which are limited to 10,000 entries. This can require the user to sort out duplicate conductors based on the submodel names of the surface nodes. Breaking up the free molecular heating into several radiation tasks prevent the arrays used in the logic structure from being too long. Also, the user can eliminate the small value conductors that have little impact on the heat transfer. A user will quickly realize that the number of conductors can quickly escalate to an extreme number when large numbers of surfaces or subdivisions are used. For example, three flat surfaces which have a 10 by 10 nodal subdivision will result in 30,000 FMHT conductors if all conductors are used. A MatLab model was developed that enables the sorting and elimination of FMHT conductors that are generated from Thermal Desktop.

The second need identified to enable a practical system useful for large FMHT models was to have the conductors updated as the gas pressure, gas temperature, and surface temperatures change in transient models. A logic structure and the modules to calculate the FMHT conductors were developed to update the conductor values during transient operation. This paper describes the FMHT programs developed for modeling large FMHT systems. Also, the setup and operation of the programs is presented.

Relation of Free Molecular Heating to the Different Modes of Fluid Heat Transfer

In modeling fluids, there are three regimes of heat transfer that are typically taught in engineering heat transfer classes: forced convection, natural convection and mixed forced and natural convection (see Table 1). Forced convection is the heat transfer resulting from fluid flowing over a surface. The velocity of the fluid over the surface results in energy transfer from either the fluid to the surface or vice versa depending on the difference in temperature of the fluid and surface. In this mode of heat transfer there are different correlations for both laminar and turbulent flow cases.

Natural convection is the transfer of energy, where the velocity of the fluid remote from the surface is essentially zero. The force due to gravity drives the fluid velocity near

the surface due to density differences resulting in heat transfer between the surface and fluid. Notice that natural convection can only occur when gravity is appreciable. Microgravity conditions, which are common in space environments away from planet surfaces, prevent natural convection.

Table 1. Modes of Heat Transfer for Fluids

| General Area | Heat Transfer Mode | Relevant Environment | Description |
|-------------------------------------|----------------------------------|--|---|
| Continuum ($Kn < 0.01$) | Forced Convection | Fluid flows over surface | Fluid flowing over surface results in heat transfer |
| | Natural Convection | Gravity environments where fluid away from surface has zero velocity | Body forces cause fluid flow near surface resulting in heat transfer |
| | Mixed Forced & Natural | Gravity environments where there is a flowing fluid with large temperature gradients | Both fluid flow and body forces result in an accumulated larger flow resulting in heat transfer |
| | Conduction | Microgravity conditions | With low gravity and cases where there is no forced flow, the fluid does not move so the heat transfers through the fluid by conduction |
| Mixed | Mixed Free Molecular & Continuum | Space environments with low pressure ($0.01 < Kn < 0.30$) | Between the continuum and free molecular mode where both modes are active |
| Free Molecular | Free Molecular | Space environments with low pressure ($Kn > 0.3$) | High temperature surface imparts energy into fluid molecules which travel to other low temperature surface, thus transferring energy. Intermolecular collisions are few while traversing the distance between the surfaces. |

Mixed forced and natural convection is the case where both modes of heat transfer are significant. The Grashof and Reynolds number have a relation that identifies the mixed regime:

$$\frac{Gr}{Re^2} \ll 1 : \text{forced convection only} \quad (1a)$$

$$\frac{Gr}{Re^2} \approx 1 : \text{mixed convection} \quad (1b)$$

$$\frac{Gr}{Re^2} \gg 1 : \text{natural convection only} \quad (1c)$$

$$\frac{Gr}{Re^2} \approx \frac{\text{buoyancy force}}{\text{inertial force}} \quad (1d)$$

Conduction heat transfer of fluids is another regime of heat transfer that is often overlooked in engineering heat transfer classes. This mode of heat transfer often occurs in microgravity environments where the fluid is essentially stationary. The conductor is modeled by treating the gas as a solid surface and the conductor is calculated appropriately based on the fluid properties and the cross sectional area and length between surfaces, $k \cdot A/L$.

Free Molecular heating occurs in very low density gases where the mean free path of the gas molecules is large compared to the distance between the surfaces. The Knudsen number is the ratio of the mean free path and the effective length between surfaces.

$$Kn \equiv \frac{\lambda}{L_e} \quad (2)$$

| | |
|-----------|-----------------------------------|
| Kn | Knudsen number |
| λ | mean free path |
| L_e | effective length between surfaces |

When the Knudsen number is greater than 0.30 one should use the free molecular relations to account for heat transfer. It is instructive to follow a gas molecule to see how energy is transferred between surfaces in free molecular heating. A low energy gas molecule hits the high temperature surface. The vibration of the molecules on the surface will impart greater energy into the gas molecule, typically causing it to depart the surface with a higher velocity. Given that the mean free path is large compared to the distance between the surfaces, the probability is relatively high that the gas molecule will reach the other surface without any collisions with other gas molecules. The high energy gas molecule, if the trajectory is correct, then transfers the energy to the low energy surface

by hitting the surface. The impact causes the vibration of molecules to increase on the low temperature surface. Energy is therefore transferred from the high temperature surface to the low temperature surface. Large numbers of molecules will transfer energy in this fashion resulting in a significant energy transfer.

When the Knudsen number is less than 0.30 and greater than 0.01, the mode of heat transfer is mixed containing both free molecular heating and continuum heating – one of the four types, but most likely conduction or natural convection. The magnitude of heat transfer is typically greater than the free molecular, but less than the full continuum heat transfer mode.

Theory of Free Molecular Heat Transfer

The mean free path tells the mean distance that a molecule will travel in a gas before a collision with another gas molecule will occur. The relation of the mean free path to the effective length between surfaces tells if a heat transfer process is in the free molecular mode. This ratio is the Knudsen number which is shown in equation (2). The mean free path is calculated by the following relation:

$$\lambda = \left(\frac{\mu}{p} \right) \sqrt{\frac{\pi R_u T}{2 g_c MW}} \quad (3)$$

| | |
|-----------|---|
| λ | mean free path (MFP) |
| μ | gas viscosity |
| p | gas pressure |
| R_u | universal gas constant |
| T | temperature that causes high energy collisions (T hot surface) |
| g_c | units conversion |
| MW | molecular weight |

Table 2 shows when to use the free molecular or continuum equations. Specifically, the free molecular equations should be used when the mean free path is about a third of the effective length or greater. The continuum equations should be used when the mean free path is significantly small compared to the effective length ($Kn < 0.01$). The molecules will collide with each other rapidly after hitting the surface and dissipate the energy in the fluid rather than transport the energy by direct molecular contact between the surfaces. The mixed mode is between the two cases and caution should be exercised in using the free molecular heating equations since it can give an inflated value for the heat transfer.

Table 2. Determining the Mode of Heat Transfer

| Heat Transfer Mode | Determining Factor | Equations to Use |
|---------------------------|---------------------------|---|
| Continuum | $Kn < 0.01$ | Use gas conduction, natural convection or other equations |
| Mixed Continuum & FMHT | $0.01 < Kn < 0.30$ | Use FMHT equations with caution (you will overestimate the heat transfer) |
| Free Molecular | $Kn > 0.30$ | Use FMHT equations |

The basic equation for FMHT between two surfaces is the following [3]:

$$Q = G p F_a F_{12} A_1 (T_2 - T_1) \quad (4)$$

| | |
|----------|---|
| G | G factor |
| p | gas absolute pressure |
| F_a | accommodation coefficient factor |
| F_{12} | view factor from surface number one to surface number two |
| A_1 | surface area of surface number one |
| T_1 | surface temperature of surface number one |
| T_2 | surface temperature of surface number two |

The equation is analogous to radiation heat transfer between two surfaces. This is apparent when the accommodation coefficient factor is examined. Specifically, the accommodation coefficient factor, F_a , is analogous to the F_e emissivity factor in radiation so the form of the equation can be taken from radiation handbooks. The radiation equation is the following:

$$Q = \sigma F_e F_{12} A_1 (T_2^4 - T_1^4) \quad (5)$$

| | |
|----------|--|
| σ | Stefan-Boltzmann constant |
| F_e | emissivity factor |
| F_{12} | view factor |
| A_1 | area of surface number one |
| T_2 | absolute temperature of surface number two |
| T_1 | absolute temperature of surface number one |

The equations are similar except for the fourth power. In radiation, the F_e term depends on the geometry and the emissivity of the surfaces (see table 3).

Table 3. Different Geometries and the Resulting Fe Equation for Radiation

| Type of radiation exchange | $\frac{1}{F_e}$ Equation | Comments |
|--------------------------------------|---|--|
| Two Surfaces that Form an Enclosure | $\frac{F_{12} \cdot (1 - \epsilon_1)}{\epsilon_1} + 1 + \frac{A_1 \cdot F_{12} \cdot (1 - \epsilon_2)}{\epsilon_2 \cdot A_2}$ | More general case |
| Large (Infinite) Parallel Planes | $\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1$ | $F_{12} = 1$ $A_1 = A_2$ |
| Long (Infinite) Concentric Cylinders | $\frac{1}{\epsilon_1} + \frac{1 - \epsilon_2}{\epsilon_2} \cdot \left(\frac{r_1}{r_2} \right)$ | $F_{12} = 1$ $\frac{A_1}{A_2} = \frac{r_1}{r_2}$ |
| Concentric Spheres | $\frac{1}{\epsilon_1} + \frac{1 - \epsilon_2}{\epsilon_2} \cdot \left(\frac{r_1}{r_2} \right)^2$ | $F_{12} = 1$ $\frac{A_1}{A_2} = \left(\frac{r_1}{r_2} \right)^2$ |

If we use the equation in Table 3 with two surfaces enclosing one another with a view factor of one, then the equation results in the following:

$$\frac{1}{F_e} = \frac{1}{\epsilon_1} + \frac{A_1}{A_2} \cdot \left[\frac{1}{\epsilon_2} - 1 \right] \quad (6)$$

- F_e emissivity factor
- ϵ_1 emissivity of surface number one
- ϵ_2 emissivity of surface number two
- A_1 area of surface number one
- A_2 area of surface number two

The accommodation coefficient factor is analogous to the emissivity factor. The form of the emissivity factor equation chosen will depend on the geometry. For equation (6) the accommodation coefficient factor equation is the following:

$$\frac{1}{F_a} = \frac{1}{a_1} + \frac{A_1}{A_2} \cdot \left[\frac{1}{a_2} - 1 \right] \quad (7)$$

- F_a accommodation coefficient **factor**
- a_1 accommodation coefficient based on surface number one temperature (analogous to emissivity)
- a_2 accommodation coefficient based on surface number two temperature (analogous to emissivity)

| | |
|-------|----------------------------|
| A_1 | area of surface number one |
| A_2 | area of surface number two |

The accommodation coefficient, a , is analogous to emissivity and is temperature dependent. It is the ratio of the actual energy transfer and the maximum possible energy transfer. A curve fit of the equation for helium for the temperature ranging from 20 to 300 K is the following [4]:

$$a_i = 1.30168 \cdot T_i^{-0.262249} \quad (8)$$

| | |
|-------|---|
| T_i | absolute temperature of surface i |
| a_i | accommodation coefficient for surface i |

The last term needed to calculate the FMHT for a surface is the G term which is the following:

$$G = \frac{\gamma + 1}{\gamma - 1} \cdot \sqrt{\frac{g_c R_u}{8 \pi \cdot MW \cdot T}} \quad (9)$$

| | |
|----------|--|
| γ | ratio of specific heats (based on hot surface) |
| g_c | units conversion constant |
| R_u | universal gas constant |
| MW | molecular weight |
| T | gas absolute temperature (hot surface) |

Once all terms of the free molecular equation are calculated, equation (4) can be used to find the heat transfer. The value of the conductor is the following:

$$G_{cond} = G p F_a F_{12} A_1 \quad (10)$$

Operation of Thermal Desktop

Thermal Desktop generates the free molecular conductors by using RadCad. A new radiation analysis group is generated by selecting the main menu item “Thermal” and selecting the “Radiation Analysis Groups ...” menu (see figure 1).

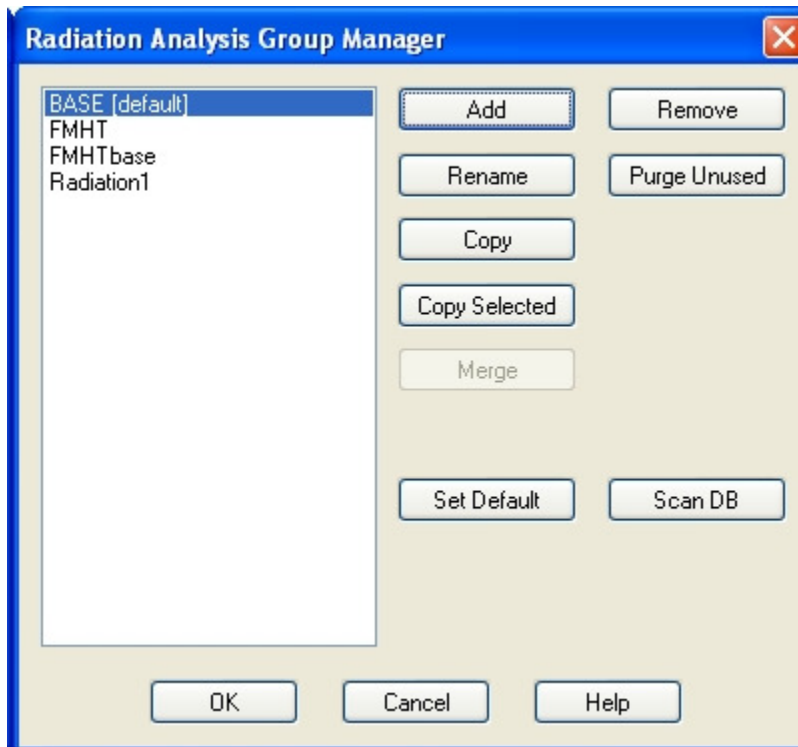


Figure 1. Radiation Analysis Group Manager Page.

Notice that three analysis groups have been added in Figure 1: FMHT, FMHTbase, Radiation1. The “BASE” group will be shown when the “Radiation Analysis Group Manager” window has been opened for the first time. The user will add additional groups as desired. **It should be noted here that the properties cannot be changed here under the “Radiation Analysis Group Manager”. It is used to add a new group, change the group name, remove groups, copy groups, purge unused groups and set the default group.** Typically, this is where the user defines the name of the RadCad radiation groups. The mode of heat transfer for the group is defined as free molecular heating under the properties menu in the “Case Set Manager” section.

Under the “Case Set Manager” menu the user can find the “Radiation Tasks” tab which brings up the page allowing the user to generate radiation tasks (see figure 2). This needs to be completed after the name has been added to the “Radiation Analysis Group Manager” as discussed above. Figure 2 shows that four Radiation tasks have been added: BASE, FMHT, FMHTbase, and Radiation1. These were added to the tasks by selecting them individually from the “Analysis Group” pull down menu (see the blue arrow in Figure 2). Next, the “Add” button is pushed to put them in the analysis group task list (see the green ellipse around the button in Figure 2). The properties of the analysis group are set by selecting the analysis group from the list and then pushing the “properties” button (see the red ellipse in Figure 2). The “Radiation Analysis Data” page pops up when the button is pushed.

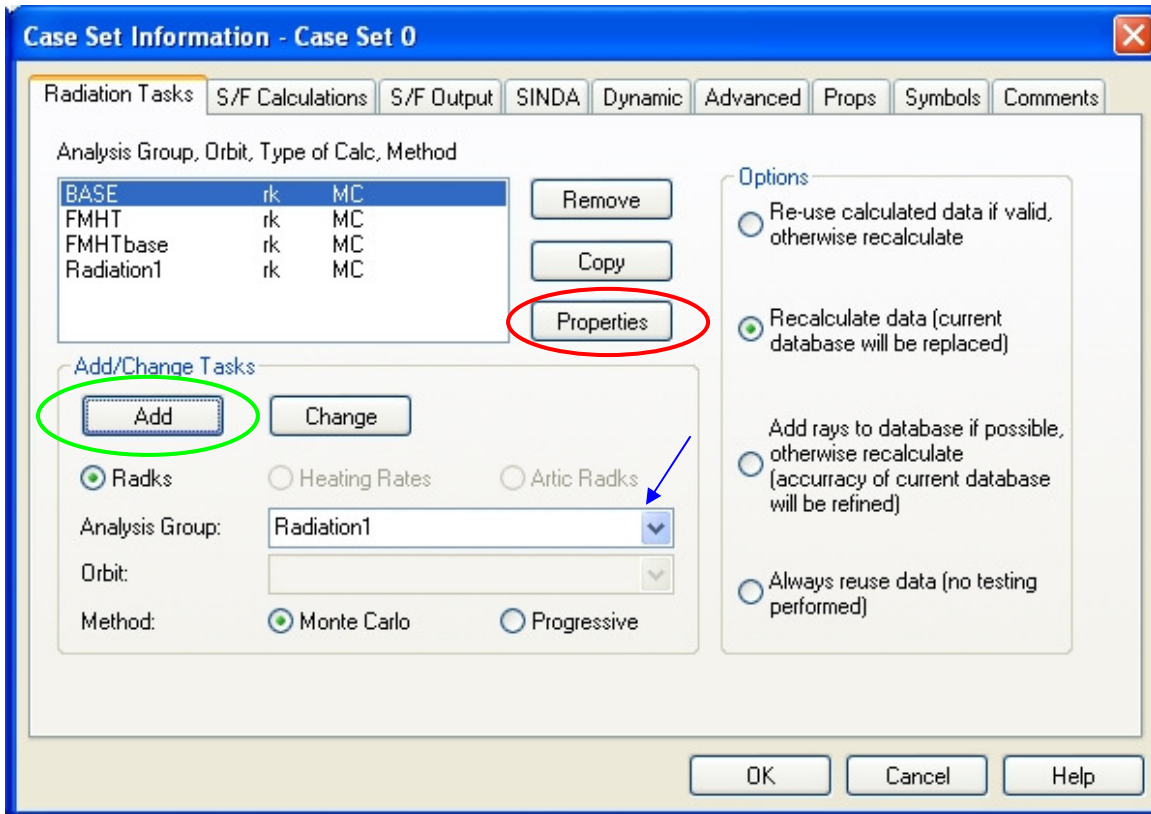


Figure 2. “Radiation Tasks” page can generate a number of radiation tasks.

The “Radiation Analysis Data” page has a number of menu tabs that allows the properties of the tasks to be set (see Figure 3). The “Control” tab page allows the number of rays shot from the nodes to be specified which defines the view factor or Bij value. Either the view factor will be calculated or the Bij value will be calculated based on the method chosen under the “Radiation Calculation” menu, when this method of calculation is chosen to generate the conductors. This menu item is under the main “Thermal” menu. The user can also specify a select number of nodes to shoot additional rays from the “Control” tab page. The energy cutoff fraction can also be specified, which will prevent the low energy conductors from being generated. The help menu on the page will explain all the options more clearly.

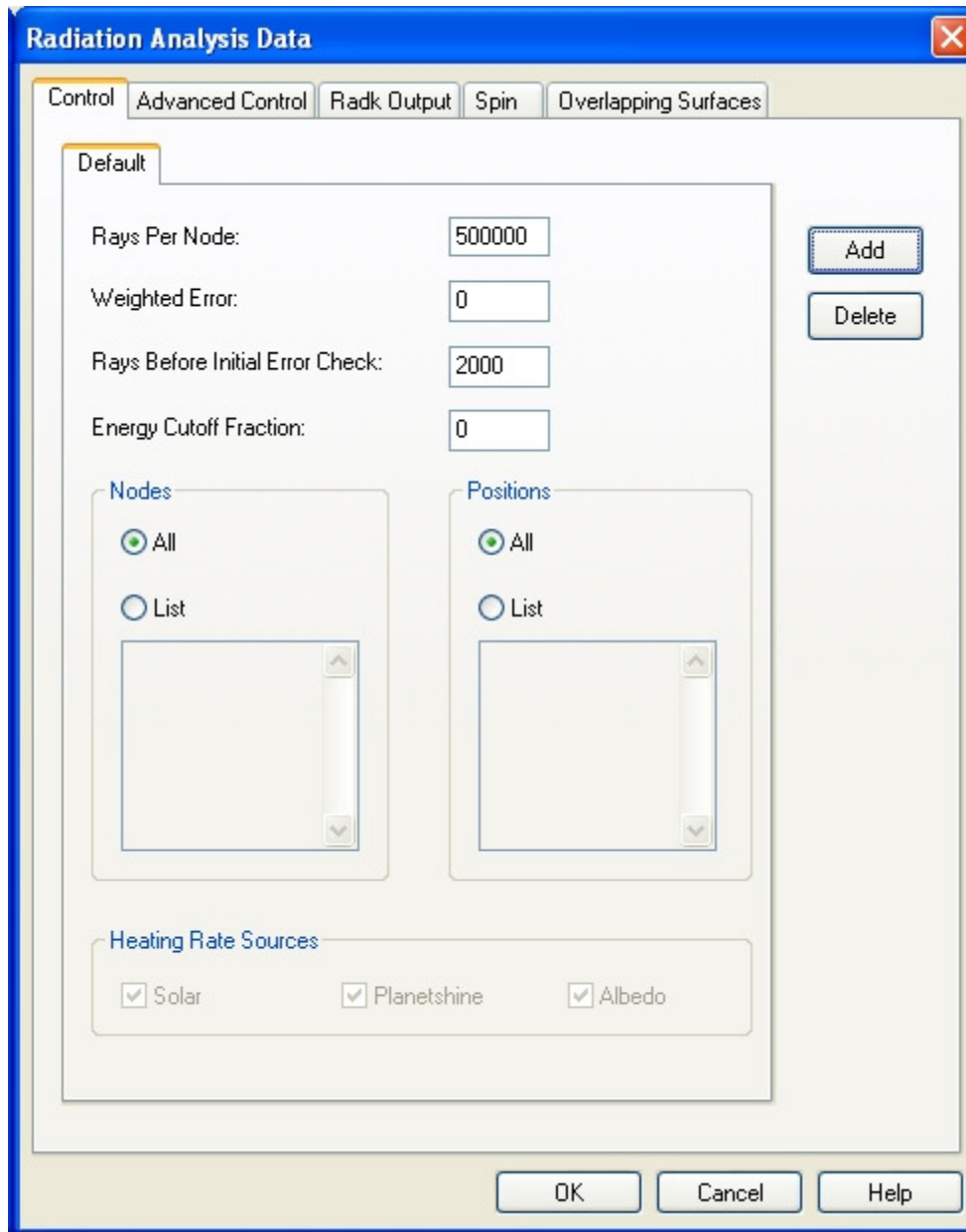


Figure 3. “Radiation Analysis Data” page sets the properties of radiation groups.

The “Radk Output” tab opens a page that can specify the radiation group to be free molecular (see Figure 4). The red ellipse in Figure 4 shows the “Free molecular Output” button. This button will bring up the popup window shown in Figure 5. The conductors can be specified to be linear which is required of free molecular conductors. The free molecular multiplier can also be specified on this window. It is unnecessary to define this multiplier when the programs defined in this paper are used. The programs will update the conductors during operation. The user needs to check the checkbox “Output RADKS as Linear Conductors” as shown in Figure 5.

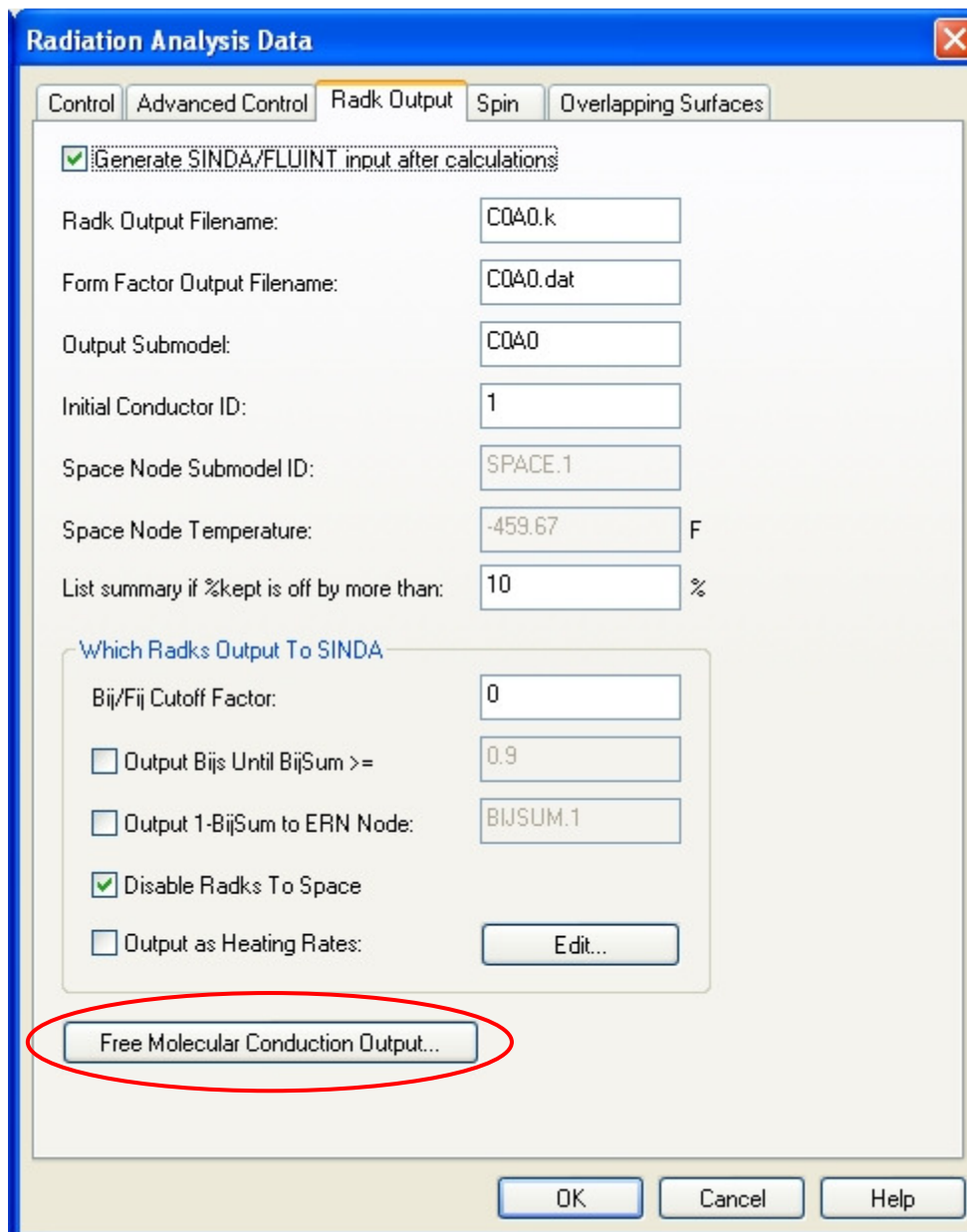


Figure 4. The “Radiation Analysis Data” page also has the tab menu page “Radk Output” which has the “Free Molecular Conduction Output” button (red ellipse highlights button).

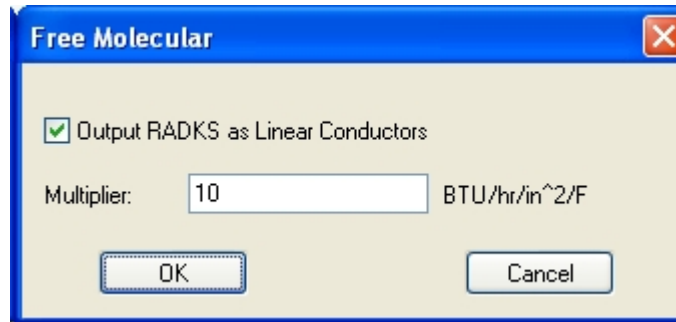


Figure 5. The “Free Molecular” popup window enables the conductors to be linear.

There are essentially two ways to generate the radiation or free molecular conductors once the radiation tasks (including free molecular tasks) are defined. The first is to use the “Radiation Calculation” menu found under the main “Thermal” menu (see Figure 6).

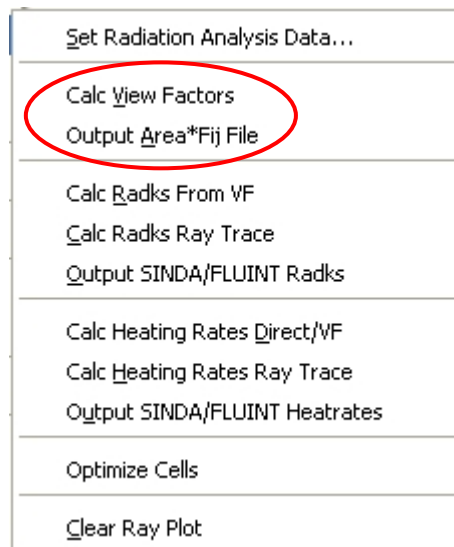


Figure 6. The menu items are found under the “Radiation Calculations” menu. The red ellipse shows the two options used to generate the area file AREAFIJ.ar and free molecular conductors file AREAFIJ.DAT for the programs in this paper.

Prior to using these options found in Figure 6, the user should apply the radiation group to the appropriate surfaces. This is accomplished by first selecting the surface and then selecting the “Edit” menu under the main “Thermal” menu. Also the “Edit” button can be selected from the toolbar button that shows a star and a pencil. When this toolbar button is highlighted the description “Edit Any Thermal Desktop Object” should be highlighted. The “Thermal Model Data” page should appear once the edit button is pushed. Under the “Radiation” tab the active surfaces are defined for each radiation or free molecular group. Figure 7 shows the “Radiation” tab of the “Thermal Model Data” page. Figure 7 shows both surfaces active for the BASE group. The groups FMHT, FMHTbase and Radiation1 are not applied to the surface of either side.

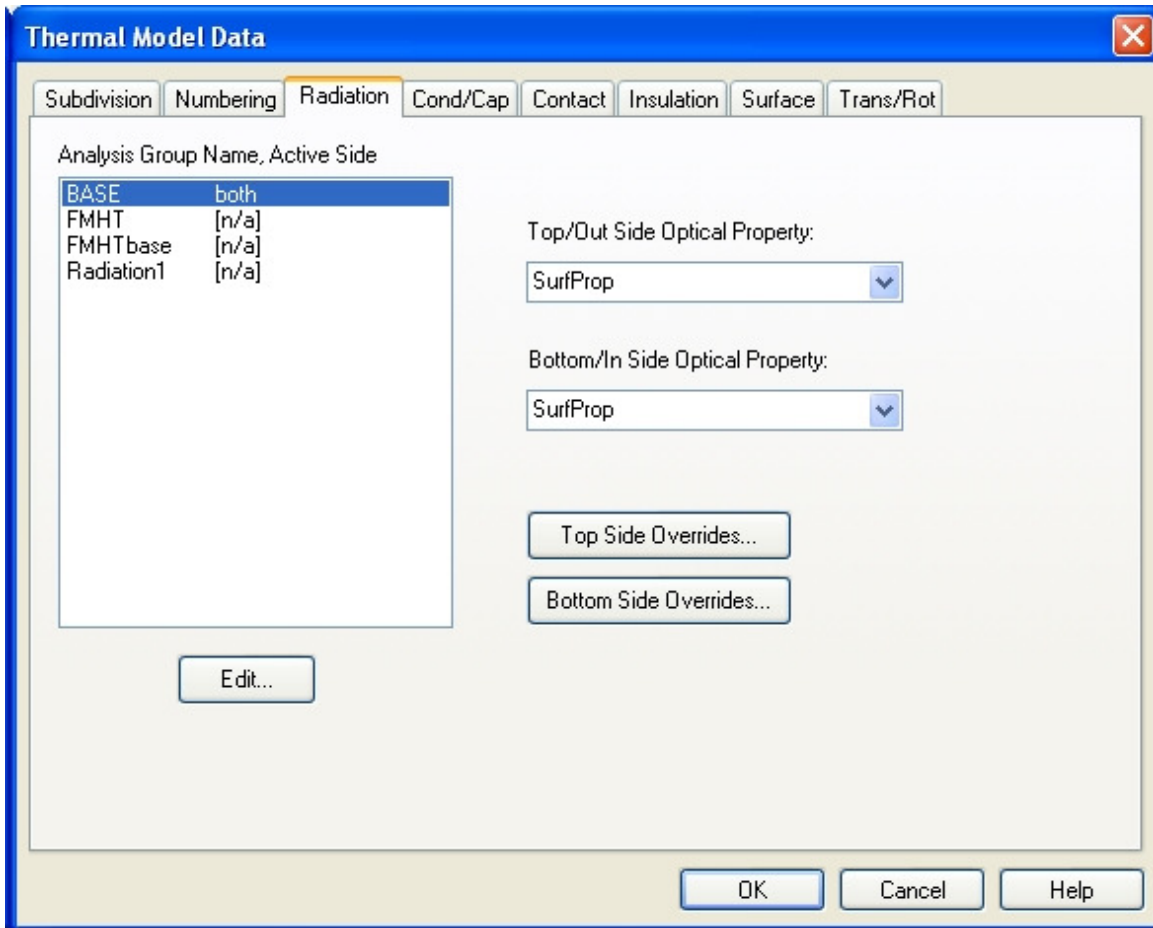


Figure 7. “Thermal Model Data” page that associates a surface with the radiation analysis group.

After the radiation groups are applied to the surfaces it is then possible to generate the output files found in Figure 6. To output the radiation or free molecular group, it must first be set as the default group under the “Radiation Analysis Group Manager” page found in Figure 1. The desired radiation or free molecular group needs to be selected and the “Set Default” needs to be pushed. Once this is complete, the menu items of Figure 6 can be selected to output files. The “Calc View Factors” menu item should be selected first followed by the “Output Area*Fij File” menu item.

The second way to generate the radiation or free molecular conductors is to use the “Case Set Manager” page. This option automates the output of the conductors, just prior to the Sinda/Fluint run. This method is not the choice when the free molecular programs presented in this paper are used. Further details about Thermal Desktop or Sinda/Fluint are found in the user manuals [1,2].

Operation of the MatLab Program

Prior to running the MatLab program FMHTPRE.m, the area file and the conductors file need to be output from Thermal Desktop. This is accomplished by selecting the “Radiation Calculation” menu under the main menu “Thermal”. The red ellipse in Figure 6 shows the two menu items. First, the user should set the default free molecular group from the “Radiation Analysis Group Manager” window (see Figure 1). All conductors are generated based on the free molecular group selected. Next, the view factors are output by selecting the first menu item which is circled in red in Figure 6. The name on the menu item is “Calc View Factors” and the file AREAFIJ.ar is output when this menu item is selected. The directory “<radiation group name>.rcf” is also generated by this task which is needed to output the conductors. For each surface, the file contains the node number and the associated area of the surface.

The next task is to generate the conductors by selecting the “Output Area*Fij File” menu item (see second menu item in red ellipse of Figure 6). The file AREAFIJ.DAT is generated by this action. Once this is complete, the user is ready to run the MatLab program FMHTPRE.m. From the command line of the MatLab window, the user should run the program FMHTPRE.m by typing in the directory and MatLab program name. For example, the user could type in “C:\Workarea\FMHT\FMHTPRE” and hit “return” to run the MatLab program from the command line if the MatLab file FMHTPRE.m is in the directory. This causes the MatLab program to execute.

The MatLab program first prompts for the base value for the array numbers. Table 4 shows a case where the base value is 500. The MatLab program next prompts for the increment value of the arrays. For the array number shown in Table 4 the increment value was 10. The arrays that are generated by the program are used with the logic in SINDA FLUINT. Once the data is generated, the arrays can be pasted into the different locations as shown in Table 4 in the “Location” column. For example, arrays 510 through 590 from Table 4 would all go in the ARRAY DATA HEADER for the specified submodel. Figure 8 shows the “SINDA” tab page in the “Case Set Information” menu where the information can be pasted manually in the ARRAY DATA of the appropriate submodel. The string array should be pasted in the CARRAY DATA of the appropriate submodel (array 600 in Table 4).

The MatLab program then prompts for the name of the submodel that contains the viscosity array. This is the array that shows how viscosity changes with temperature. It needs to be in a different submodel than arrays 510 through 590. Table 4 shows the value of 555. This number can be selected arbitrarily, but it must not conflict with the other arrays. The program next prompts for the input and output file names. The input files must exist and contain the information that was previously generated (see Figure 6). Also, MatLab must recognize the directories and the files. The output file name can be whatever the user desires, but it must not overwrite another file name. The next prompt asks the user if the header data should be processed. “No” should always be input for this prompt since the function is not needed.

TABLE 4. Arrays constructed by the MatLab program

| Array Number | Array Description | Array Type | Location |
|---------------------------|---|-------------------|--|
| User Specified (e.g. 555) | Viscosity | Real | Different submodel than 700 ARRAY DATA |
| User Specified (e.g. 333) | Array that holds pointers to all other arrays in this table. | | |
| 510 | Conductor number | Integer | ARRAY DATA of user specified submodel |
| 520 | First node number of conductor | Integer | “ |
| 530 | Second node number of conductor | Integer | “ |
| 540 | Area associated with first node number | Real | “ |
| 550 | Area associated with the second node number | Real | “ |
| 560 | View factor between surfaces | Real | “ |
| 570 | Effective length | Real | “ |
| 580 | Array that has the index of the submodel name of node 1 found in the CARRAY | Integer | “ |
| 590 | Array that has the index of submodel name of node 2 found in the CARRAY | Integer | “ |
| 600 | CARRAY data that has strings listing the submodels | String | CARRAY DATA of user specified submodel |

The next prompt is for the cutoff value for the conductors. This input enables the conductors to be eliminated from the model which are smaller than the cutoff value. The very small conductors will tend to have less impact on the model and can typically be deleted without much effect. A warning should be given here; however, since a small conductor with a very high temperature difference between the nodes can have a significant impact on the results. The user needs to use this option with care and good judgment. Also, the nodal subdivision can determine when the free molecular conductors are retained or not. This can cause important conductors to be eliminated from a model when actually the conductors have a significant impact on the results.

The user also has the option of eliminating conductors based on the names of the submodels associated with the nodes of the conductors. There are four cases where the user would want to use this option. The first case for using this option is when the user has two or more FMHT radiation tasks. Possibly there can be duplicate conductors generated from the two radiation tasks. These are identified when two conductors are found – one being in the one radiation task and the other being in the second radiation task – that have the same two nodes for the conductors. If the user is clever, the use of

submodel names can be used to eliminate duplicate FMHT conductors. The second case for using this option is when the temperatures of two different submodels are nearly the same. Rather than including these conductors and increasing the solve time, the user can eliminate them. The third case for using this option is when the temperature within a submodel is nearly the same. The user can specify that the free molecular conductors attached between the nodes of the same submodel be eliminated. Again, this will speed up the solve time. The final case is where the view factor between the surfaces of two submodels is small. The free molecular conductors can be eliminated for this case also. For example, if one submodel is far away from another and objects block the view, the user can eliminate the FMHT conductors. Engineering judgment is needed when using this option.

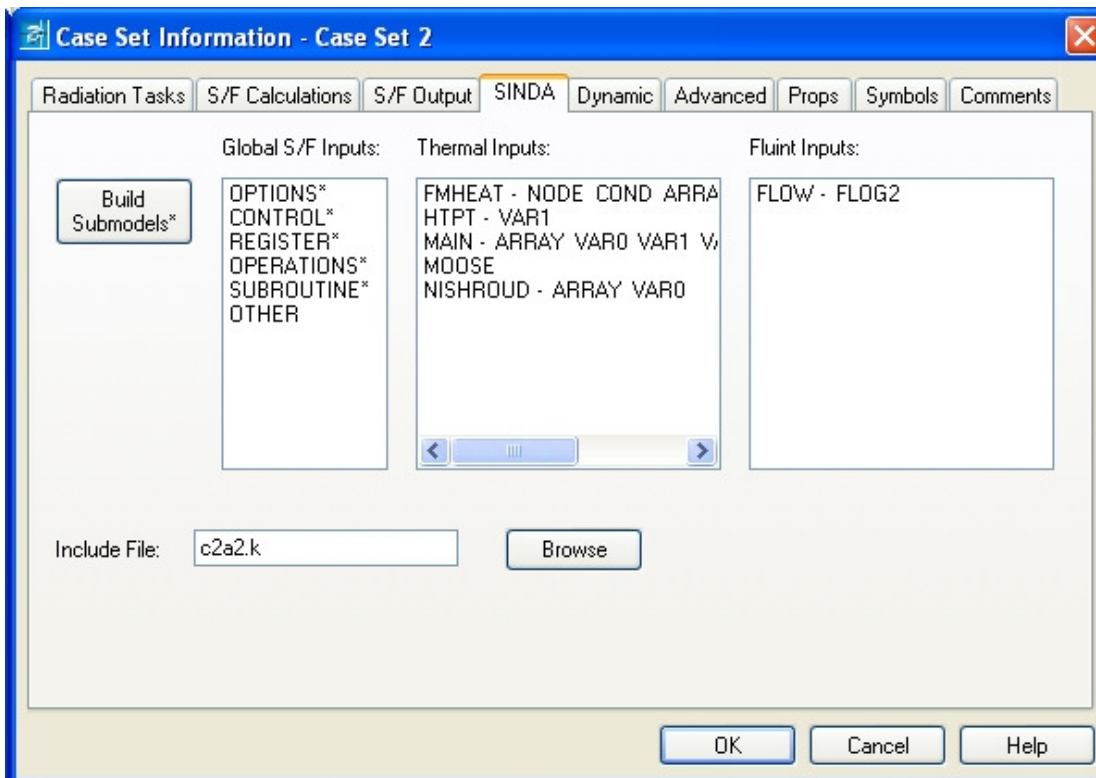


Figure 8. The SINDA tab under the “Case Set Information” page

The user also has the option of selecting the conductor numbers which will not be eliminated no matter the names of the submodels of the two nodes. This option allows for critical conductors to be retained. For example, the user may know that a specific node will become much hotter than the surrounding nodes of the same submodel. Even though these free molecular conductors were previously eliminated, if the user knows the critical FMHT conductor numbers, then these conductors can be retained. The last prompt is the option specifying the effective length based on the submodel names of the two nodes of the conductor. This is only an approximation and is used when the free-molecular Fortran subroutines check the mode of heat transfer. Ideally the user will find the distances between the surfaces of the conductors, but most the time this is not practical when there are many surfaces. The user then can input the worst case conditions

to see when the mode of heat transfer changes from free molecular to continuum. If the mode of heat transfer does change the user will need to modify the free molecular Fortran subroutines to switch the modeling so the appropriate continuum equations are used. Possibly, logic can be incorporated to turn off the free molecular submodel and to turn on another submodel of conductors which model the appropriate continuum equations. If it is known that the heat transfer mode is always in the free molecular region, it is important that the user select effective lengths appropriately so the free molecular equations are used. Currently the Fortran subroutine is setup to apply a factor of 100 to the free molecular conductor value. This was arbitrarily chosen and the user may want to change this factor.

Setup of Thermal Desktop for Modeling Dynamic Free Molecular Heat Transfer

Once the output files are generated in MatLab the user has to manually insert portions of the data in the correct “Global Sinda Inputs” and “Thermal Inputs” sections of Thermal Desktop (see Figure 8). Table 4 shows the different arrays that are generated in the output file. The submodel name where the conductors are placed is the third input specified in the MatLab program FMHTPRE.m. This submodel name is where the conductors should be copied from the output file. If the arrays found in Table 4 were generated in the output file, then arrays 510, 520, 530, 540, 550, 560, 570, 580, 590, 600 and 333 will be copied to the array data of the appropriate submodel. Figure 9 shows the different header names used in a SINDA submodel. The conductors should be copied to the “Conductor” header inputs page while the arrays should be copied to the “Array” header inputs page (see figure 9). Array 600 should be copied to the “Carray” header, while the viscosity array should be copied to the appropriate submodel that the user supplied in the fourth input to the MatLab program FMHTPRE.m. The array should be copied to the “Array” header page of that submodel. All the calls to the subroutine “ARYTRN” should be copied to the global SINDA/FLUINT input “OPERATIONS” page (see Figure 8). The calls to “ARYTRN” put the memory locations of the pointers of the arrays into array 333 to enable the rapid updating of the conductors. The call to the Fortran subroutine FMHTCOND should be located where the user wants the conductors updated, since this module does the updating. For a steady state run this should be in VARIABLES 0. For a transient run, the location is in VARIABLES 0, but the user may opt to speed up the solve time by putting the call in the OUTPUT header (see Figure 9). The conductors will only update as often as the output calls are called. The “SINDA Control Information” page controls the length of time between output calls.

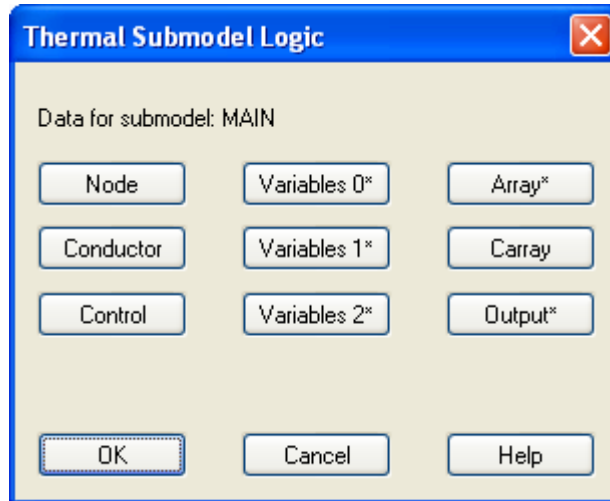


Figure 9. The Headers used for submodel MAIN. This menu is activated by double clicking on the submodel name under the “Thermal Inputs” section observed in the previous figure.

Fortran modules were written to automate the updates to the conductors. There are three main subroutines: KNNUM, FMHT, and FMHTCOND. The first subroutine calculates equations (2, 3). It finds the Knudsen number to determine the mode of heat transfer. The second subroutine FMHT calculates the conductor value. The equations (4, 8, 9, 10) are solved as well as the generalized accommodation coefficient factor based on Table 3. One important assumption of this subroutine is that the gas is helium. Equation (8) needs modification if another gas besides helium is used. FMHTCOND is the master subroutine that does the actual updating of all the conductors. Figure 10 shows the general logic structure. It calls KNNUM to determine the mode of heat transfer, and then calls subroutine FMHT for each conductor. If the mode of heat transfer is mixed or FMHT, the conductor value calculated by subroutine FMHT is used. If the mode is continuum the conductor is multiplied by 100. This factor was arbitrarily chosen so the user may want to modify this value. Another possible modification is for the user to have two submodels: one to model the free molecular heating and the other the continuum. The user would have to setup the logic in subroutine FMHTCOND to shut off and on the appropriate submodels, depending on the type of heating.

Once the Thermal Desktop model is setup, the analysis can begin by activating Thermal Desktop. SINDA/FLUINT runs underneath the Thermal Desktop GUI solving the model. Careful setup of the FMHT model will prevent excessive solve times.

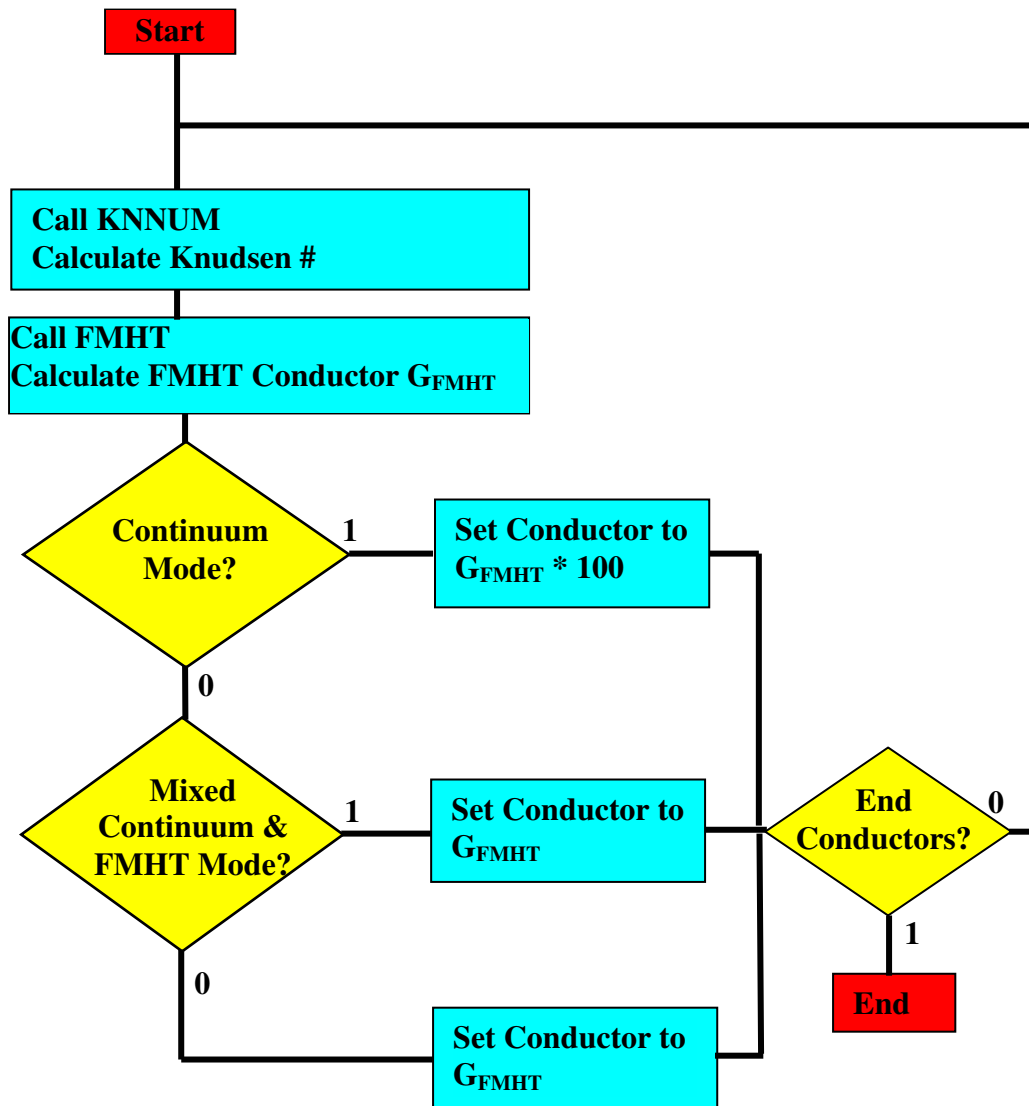


Figure 10. Current Logic structure of subroutine FMHTCOND.

Conclusion

The programs, arrays and logic structure were developed to enable the dynamic update of conductors in thermal desktop. The MatLab program FMHTPRE.m processes the Thermal Desktop conductors and sets up the arrays. The user needs to manually copy portions of the output to different input regions in Thermal Desktop. Also, Fortran subroutines are provided that perform the actual updates to the conductors. The subroutines are setup for helium gas, but the equations can be modified for other gases. The maximum number of free molecular conductors allowed is 10,000 for a given radiation task. Additional radiation tasks for FMHT can be generated to account for more

conductors. Modifications to the Fortran subroutines may be warranted, when the mode of heat transfer is in the mixed or continuum mode. The FMHT Thermal Desktop model should be activated by using the “Case Set Manager” once the model is setup. Careful setup of the model is needed to avoid excessive solve times.

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