GRAPHICAL MODEL BUILDERS FOR SPACECRAFT THERMAL DESIGN

Ron Behee
Network Analysis Inc

Brandon Paulsen
Space Dynamics Laboratory
Utah State University

ABSTRACT

SINDA is a network-type thermal analyzer that utilizes nodes and conductors to model thermal systems. In the past these models have been built in a text editor, but during the last decade graphical modelers have taken over most SINDA model generation, especially in the spacecraft thermal design area. This paper discusses the various technologies that these graphical modelers employ along with the advantages and disadvantages of the various philosophies they use.

Graphical model builders for SINDA can be divided into two basic types, network model builders and geometric model builders. Network model builders use a graphical interface to create the nodes and conductors of a network model directly. Geometric model builders use geometry which is meshed or divided into nodes and conductors. These geometric model builders can use two different technologies, finite elements or geometric shapes. Finite element meshers are those such as MSC.Patran[1] or FEMAP[2] and they divide the geometry into small elements. Shaped based model builders such as Thermica or TSS use geometric shapes that are supported by thermal radiation and orbital heating programs. These shapes include such geometries as cylinders, spheres or rectangles.

The relative advantages and disadvantages of these methods are discussed in this paper.

INTRODUCTION

SINDA is a network thermal analyzer that is especially good for solving nonlinear transient heat transfer problems such as those found in spacecraft thermal design. Being a network thermal analyzer, models are built using nodes that represent thermal masses and conductors representing conduction, convection, radiation and fluid flow. This network approach allows complex systems to be simplified and reduced to a simple network thermal model with a few dozen or a few hundred nodes, but seldom more. These models traditionally have been built in a text editor, but now are sometimes built using a network-type graphical tool.

For many thermal models, especially those involving surface-to-surface radiation, it is desirable to use a geometric model builder that will automatically generate the nodes and conductors of a network model based on 3D geometry. These graphical model builders fall into two categories, finite element (FE) meshing type and those that are a part of a thermal radiation code and utilize geometric primitive shapes such as a sphere or cylinder. FE meshing-type model builders frequently turn curved surfaces into a series of flat plates and as a result produce many more surfaces than those using shapes. Shape-type model builders maintain the curvature, but cannot model any arbitrary geometry such as what typically comes from a CAD system. These shapes are used by the thermal radiation code for computing the geometric view factors, radiation exchange factors and orbital fluxes.

While it may be faster to generate hundreds, thousands or even hundreds of thousands of nodes and conductors using either type of geometric model builder, the actual SINDA file that results is typically so detailed that it provides little physical insight to the thermal system being modeled compared to the simplified network approach. Both the simplified network approach and geometric approach using either FE's or shapes are valid and have their relative advantages and disadvantages. The remainder of this paper will discuss these methods in detail, explain how to choose a method for constructing a SINDA thermal model, and discuss why a combination of methods may actually be the best choice.

APPROACHES TO BUILDING SPACECRAFT THERMAL MODELS

NETWORK APPROACH

As previously explained, SINDA is a network thermal analyzer. The network is more of a symbolic representation of the physical system and contains a wealth of thermal information and insight into the thermal system being modeled. For example, consider a transmitter mounted to a radiator panel on a spacecraft as shown below. The transmitter can be lumped into a single node. In this case let's assume it has a thermal mass of 10 watt-hrs/deg C. This means if one puts 10 watts into this node for 1 hour it will go up 1 degree C. This gives the thermal engineer physical insight into the time response of this device. Let's further assume the transmitter is mounted to the radiator panel with a 1.5 deg C/watt thermal resistance. This tells the thermal engineer that for every watt that flows from the transmitter to the panel, the delta T will be 1.5 degrees. So for 10 watts, the transmitter will be running 15 deg C above the panel temperature. Simply looking at a SINDA thermal model may yield tremendous information concerning the thermal performance of the system being modeled.

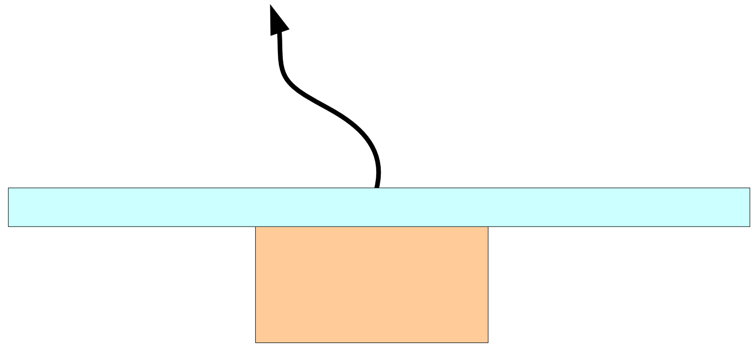


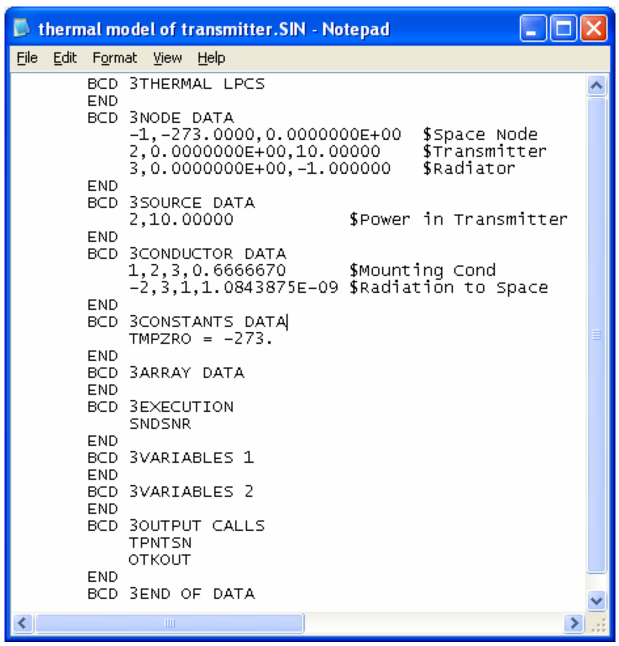
Figure 1.1 Transmitter on a Radiator Panel

There are two basic approaches one can use in building simplified symbolic models:

1. Use a text type tool such as a text editor.
2. Use a graphical tool designed to build network models.

Text Editors for Network Models

For the example in the figure above, the system could be modeled with a node for the transmitter (SINDA diffusion node with thermal mass), one for the radiator panel (no mass arithmetic node) and a boundary node to represent space. A listing of this model is shown displayed in a text editor in Figure 1.2 below.




```
        BCD 3THERMAL LPCS
        END
        BCD 3NODE DATA
            -1,-273.0000,0.0000000E+00   $Space Node
            2,0.0000000E+00,10.00000     $Transmitter
            3,0.0000000E+00,-1.000000    $Radiator
        END
        BCD 3SOURCE DATA
            2,10.00000           $Power in Transmitter
        END
        BCD 3CONDUCTOR DATA
            1,2,3,0.6666670      $Mounting Cond
            -2,3,1,1.0843875E-09 $Radiation to Space
        END
        BCD 3CONSTANTS DATA
            TMPZRO = -273.
        END
        BCD 3ARRAY DATA
        END
        BCD 3EXECUTION
            SNDSNR
        END
        BCD 3VARIABLES 1
        END
        BCD 3VARIABLES 2
        END
        BCD 3OUTPUT CALLS
            TPNTSN
            OTKOUT
        END
        BCD 3END OF DATA
```

Figure 1.2 SINDA/G Thermal model in Text Editor

Other text tools such as the customized Microsoft Excel template which is part of the SINDA/G Office Tool Kit [3] can also be used. The Excel link to SINDA/G as shown below is basically a glorified text editor that formats the SINDA/G input file automatically, launches SINDA from within Excel and will create plots of the transient results.

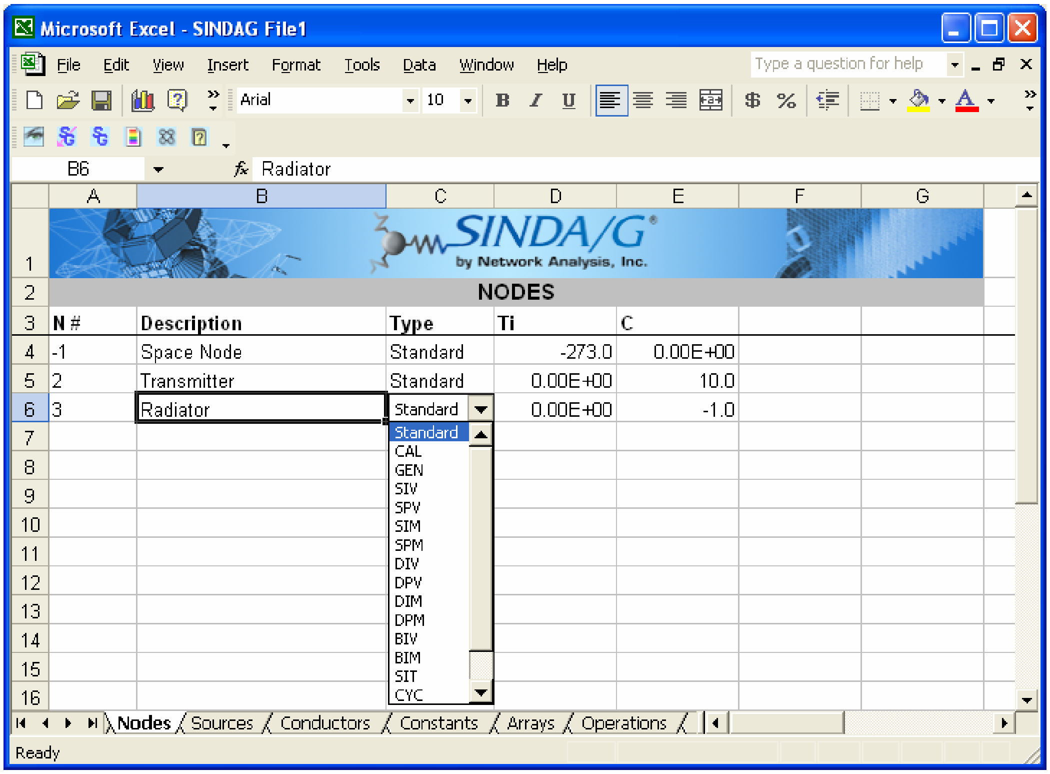


Figure 1.3 SINDA/G Thermal Model in Microsoft's Excel

Graphical Tools for Network Models

In recent years graphical tools have been developed to create SINDA network models. One such tool is a Microsoft Visio add-on that allows models to be built, run and post-processed entirely within the Visio environment. This product is part of the SINDA/G[4] Office Toolkit. Using a graphical tool such as this one allows the engineer to simply drag nodes, conductors, tables and powers onto a page and the SINDA/G model is built automatically. Results such as heat flow through conductors and node temperatures can be seen graphically.

Even if a more detailed thermal model needs to be created to add more detail, these simplified network models should be the starting place for all thermal analysis because of the insight they provide into the thermal system being modeled.

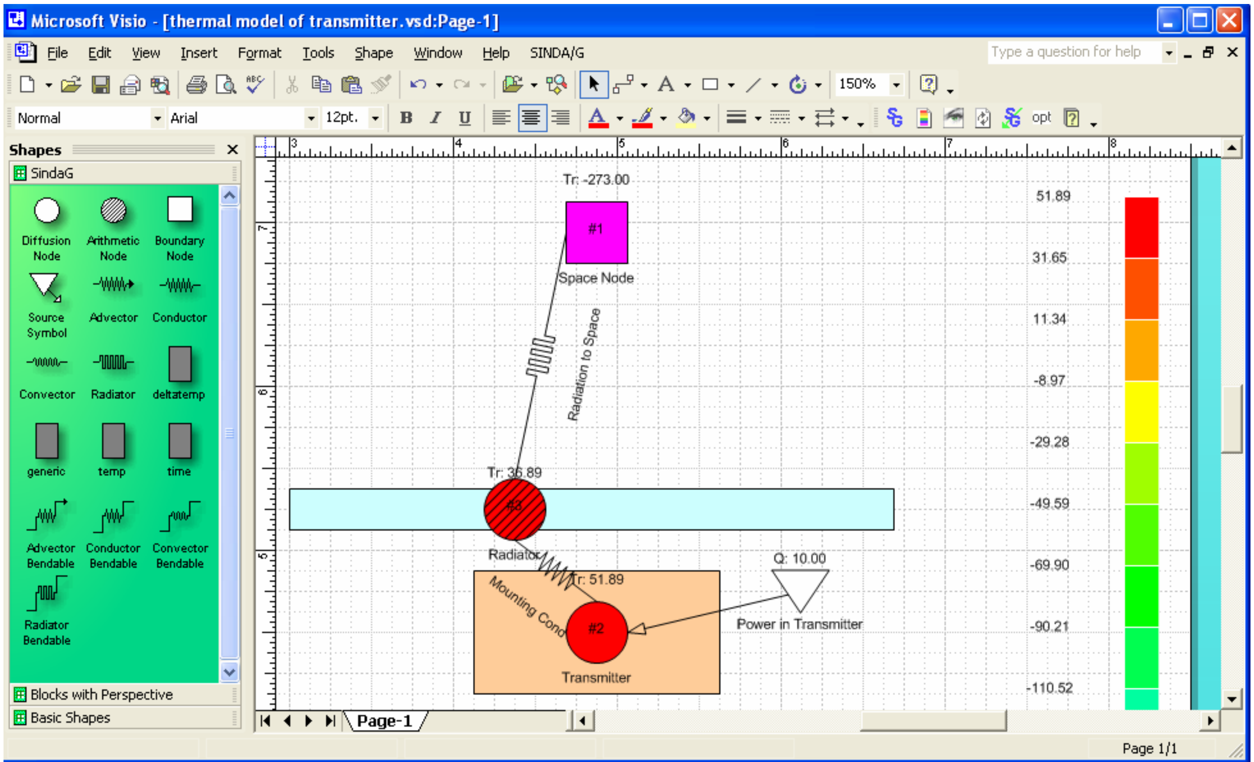


Figure 1.4 SINDA/G Thermal Model in Microsoft's Visio

GEOMETRIC APPROACH

The geometric approach is sometimes referred to as a graphical approach, but since graphical approaches can be applied to network models, the term *geometric* approach is actually more correct. This approach uses geometry to automatically compute nodes and conductors. This geometry can be input in the modeler or some modelers can import CAD data to minimize the recreation of geometry.

Geometric model builders come in two basic types, those that mesh geometry into finite elements and those that use geometric primitives such as a cylinder, disk, quadrangle or sphere as the basic building blocks to create the geometry.

Finite Element Meshing Type Model Builders

Finite element type model builders are have been used for years by structural engineers building NASTRAN or ANSYS type structural FEA models. This type of model builder sometimes requires a CAD system to create the geometry or a built-in CAD-like geometry builder. Design Space from ANSYS Inc or COSMOS Works from Solid Works are examples of FEA model builders that require a CAD system to work in conjunction with the mesher and post processor that are parts of these packages. FEMAP from EDS and Patran from MSC are examples of model builders that have interfaces to CAD but can also create full 3D geometries from within these products.

Below is an example of CAD data that was imported into FEMAP from the Unigraphics CAD system. Notice how the thermal model was somewhat simplified, meshing over the small holes and ignoring some small shape details. Thermal models are not as sensitive to these small details as structural model are, so the engineer can simplify the model.

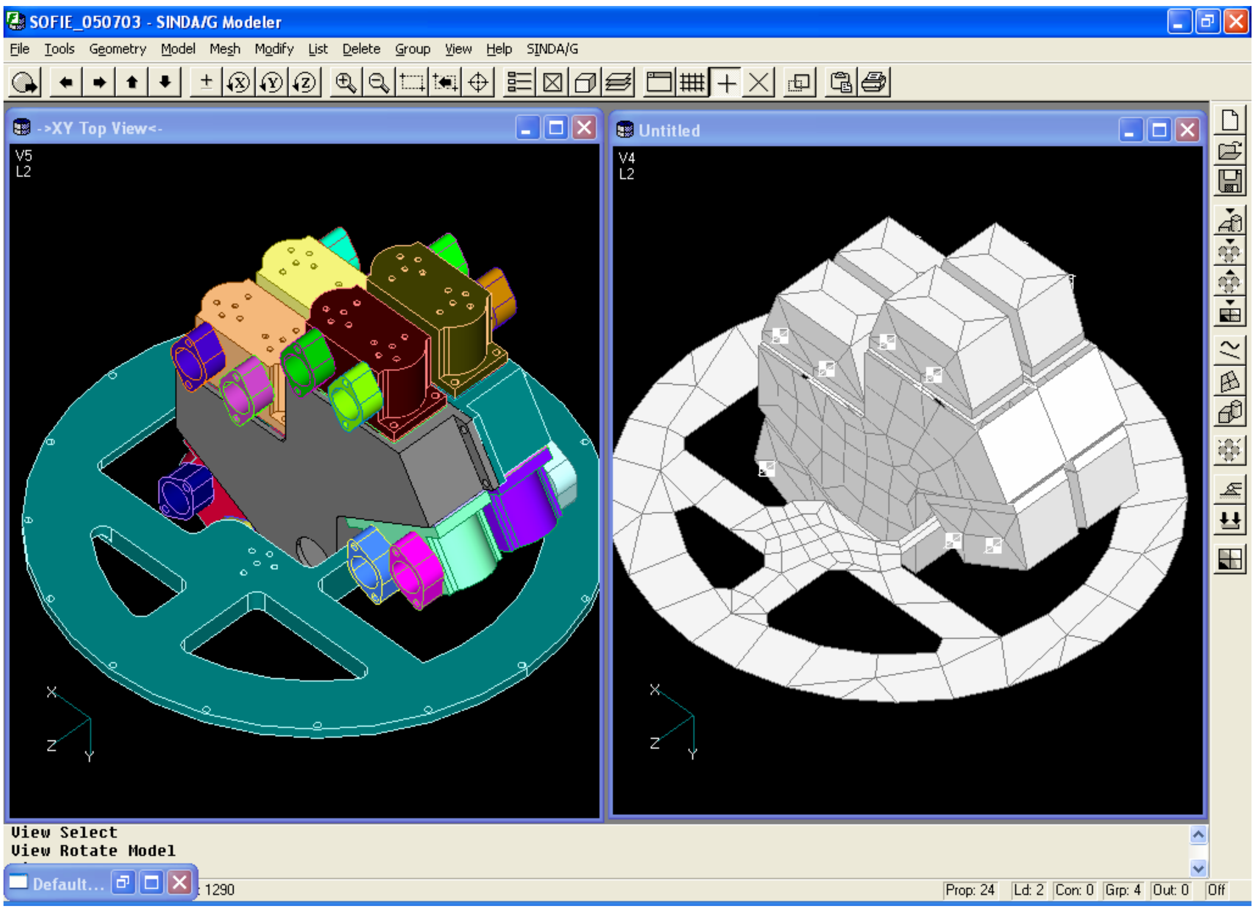


Figure 1.5 Thermal Model Based on CAD Files

Shape-Based Model Builders

Shape-based model builders build the entire model out of primitives such as rectangles, cylinders, spheres, etc. These primitives are the shapes supported by thermal radiation codes, and each shape-based model builder is tied to one of these codes. These primitives have a basic thermal mesh associated with them, such as a cylinder divided into 8 nodes around the circumference and 4 along the length.

Because curved surfaces are transferred to the thermal radiation code with true geometric shapes, the radiation model is more accurate and typically much smaller than when the same model is built using a FE mesher type model builder.

An example of a simple shape that is difficult to build in a shape-based model builder is a cylinder with a hole in one side such as the instrument shown in Figure 1.6. This part was actually created in FEMAP, which is a FE meshing-type model builder and then transferred to Thermica, which is a shape-based model builder. While most of Thermica's shapes have curvature, it does support quadrangles and triangle shaped flat plates. The disadvantage of using a FE meshing type program is that they produce numerous flat plates that increase the model size. While SINDA/G can solve large models fairly quickly, radiation codes typically are limited to a few thousand surfaces and have long run times. Notice the object names of each part on the left windows. Each of these objects, such as the cover (yellow) is composed of numerous small flat plates.

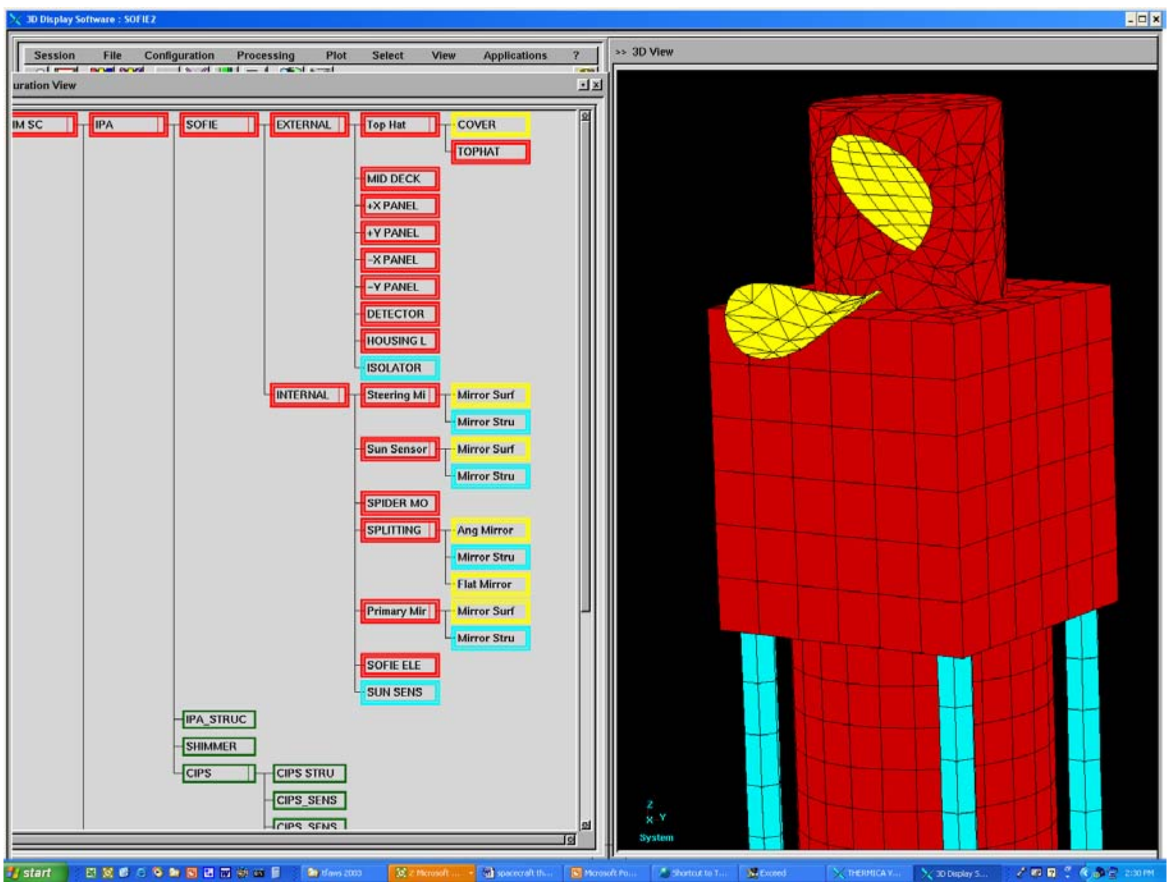


Figure 1.6 Cylindrical Instrument with Circular Hole in Side

It is possible to combine the best of both modelers by building part of it in an FE model builder, and then once this is transferred to a shape-based model builder, add any larger shapes such as a cylinder or sphere as true shapes while still keeping the more finely meshed plates.

Advantages and disadvantages of FE type meshers and shape based model builders

Many people ask, "Which is better, a shape-based model builder or FE meshing type modeler?" The answer is "both". Each method has their relative advantages and it sometimes useful to combine both in one model.

Below are some general comments concerning these type types of model builders:

FE meshing type model builder

- Good connection to CAD
- Good connection to FEA structural/fluid programs
- Typically flat plate connection to radiation/orbital heating programs
- Models solids, orthotropic materials and laminate materials

Shape-based model builders

- Poor connection to CAD
- Poor connection to FEA programs
- Excellent full-shape connection to radiation/orbital heating programs
- Usually models surfaces only with isotropic plates

CONCLUSIONS

Network thermal models give tremendous insight into the thermal system being modeled. Graphical tools for creating these network models help document the model and facilitate building this type of thermal model. The creation of a simplified network model should be the first step one takes in the thermal analysis process. Then, if needed, a more comprehensive model can be created using a geometric model builder

Shape-based radiation models offer quick solutions that are helpful in performing trade studies and optimization analyses. During the early stages of satellite and instrument development programs, the thermal engineer will need to explore various surface coatings and geometry combinations. Shape-based models allow the thermal engineer to quickly change geometry and surface properties without having to re-work intricate meshes.

As the design matures, many odd shapes will begin to appear in the spacecraft or instrument geometry that are not easily modeled with native shapes. However, the native shapes should not be thrown aside altogether. For example, in the following model of the conceptual design of the SOFIE instrument onboard the AIM spacecraft, the SOFIE instrument is modeled with high-fidelity finite elements. Notice that the remaining items in the model, such as the spacecraft and other instruments, are approximated by large single-element surfaces. This allows for relatively quick solutions when running worst case hot and cold cases, compared with using finite elements to approximate all of the peripheral geometry.

Figure 1.7 SOFIE Instrument Onboard the AIM Spacecraft

ACKNOWLEDGEMENTS

The Authors acknowledge the Space Dynamics Laboratory at Utah State University in Logan Utah for their support in providing the thermal model used in this paper.

REFERENCES

1. MSC.Patran – is a registered trademark of MSCSoftware Inc.
2. FEMAP – is a registered trademark of EDS Corporation
3. SINDA/G Office Tool Kit – software product by Network Analysis Inc.
4. SINDA/G – is a registered trademark of Network Analysis Inc.

CONTACTS

Ron Behee – Network Analysis Inc – ron@sinda.com

Brandon Paulsen – Space Dynamics Lab – Brandon.Paulsen@sdl.usu.edu