USING UGS I-DEAS TMG™ TO SUPPORT LEGACY SINDA/TRASYS MODELS

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ABSTRACT

UGS I-deas TMG™ has been used successfully to perform thermal evaluations of many aerospace and electronic structures over the past two decades. However, given the nature of today's collaborative design environment, it is often times necessary to incorporate or integrate with models in other formats, including, but not limited to TRASYS and SINDA. For instance, a new satellite may need to include an off-the-shelf antenna available only in TRASYS/SINDA format, or a new instrument may be analyzed in TMG, but the deliverable to the customer needs to be in TRASYS/SINDA format for integration with their system model.

ATA has bridged the gap between these different software packages for several projects, and has created specialized software tools and scripts to aid in the data transfer. This paper will focus on the issues and solutions encountered when integrating legacy TRASYS/SINDA models with a TMG model, and when exporting the TMG models to TRASYS and SINDA. Generic models will be used as examples.

INTRODUCTION

UGS I-deas TMG™ has been used successfully to perform thermal evaluations of many aerospace and electronic structures over the past two decades. However, given the nature of today's collaborative design environment, it is often times necessary to incorporate or integrate with models in other formats, including, but not limited to TRASYS and SINDA.

This paper will focus on the issues and solutions encountered when integrating legacy TRASYS/SINDA models with a UGS I-deas 10 NX Series TMG™ model, and when exporting the TMG models to TRASYS and SINDA (SINDA/FLUINT and SINDA/G™). The purpose of the paper is to show how these software packages can be used together. It will also focus on techniques to improve the reliability of the integration. Also, the creation of specialized software tools and scripts will be discussed. This paper is intended to be an overview of the integration effort, and will not explore all of the possible issues. To help illustrate this integration effort, generic models will be used as examples.

UNITS ISSUES RELATED TO I-DEAS

While many in the aerospace industry use SI units (Joules, seconds, meters, °C) for thermal models, many still use English Units (BTUs, hours, in, °F), or a hybrid set of SI and English units. UGS I-deas™ does not have English Units, nor a hybrid set, although it does have the capability for the user to create his own units set. While units conversion is significant when

integrating models using different units, this issue is beyond the scope of the paper, and all of the models used in this paper (with the exception of TRASYS models, which must be in Feet) will be in SI units.

INTEGRATING TRASYS/SINDA DATA INTO TMG

The following sections shall investigate the techniques and issues of importing and integrating TRASYS and SINDA models into I-deas TMG.

TRANSLATING TRASYS MODELS TO TMG

While TMG can import geometry from TSS and ESARAD, there is no direct capability to import TRASYS data into I-deas. ATA has created a TRASYS-to-I-deas translator called TRATRAN™ to allow the import of the geometry. TRATRAN is a command-line program which requires the user to enter the input TRASYS file name, the output I-deas universal file name, and the minimum number of facets around the circumference for surfaces of revolution.

The number of facets around the circumference is required since TMG uses finite elements for radiation calculations, and a single finite element cannot model a full 360° surface. The default is 12 facets, which allows an element to span an angle of 15°. When the surface is subdivided, they are stored in an I-deas group, and can be merged together as one surface in TMG. Figure 1 shows the difference in subdividing the model with 4 and 12 elements.
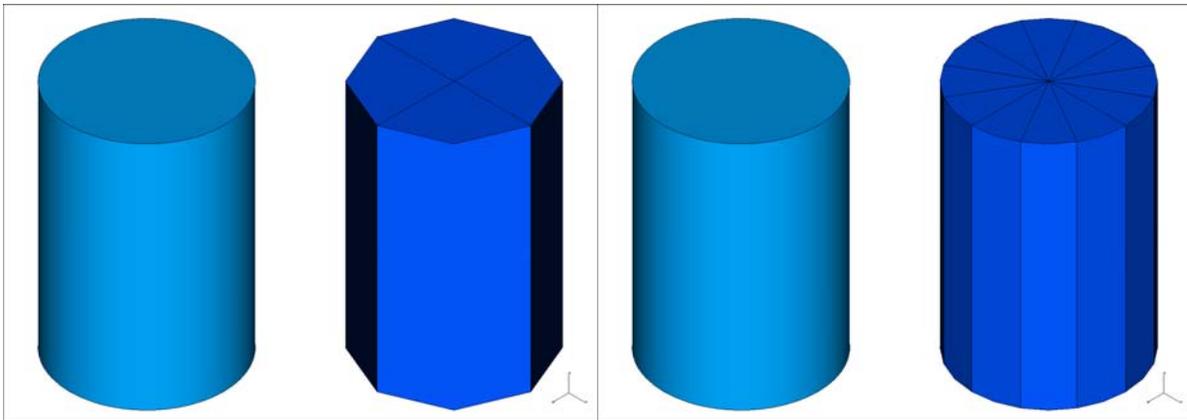
Figure 1: Differences in mesh for a closed cylinder using 4 elements around the circumference and 12 elements around the circumference.

With TRATRAN, flat surfaces (rectangles, trapezoids, boxes, polygons) are modeled with linear triangles and quadrilaterals, and surfaces of revolution (disks, cylinders, cones, spheres, paraboloids, spheroids, toroids, and ogives) are modeled with parabolic triangles and quadrilaterals. One caveat needs to be addressed concerning parabolic elements in TMG: If a surface is not specular, TMG will treat the element as linear when performing radiation calculations, ignoring the mid-side nodes. TRATRAN includes the mid-side nodes for visualization, and for potential export back to TRASYS. An example TRASYS satellite model and its I-deas counterpart are shown in Figure 2.
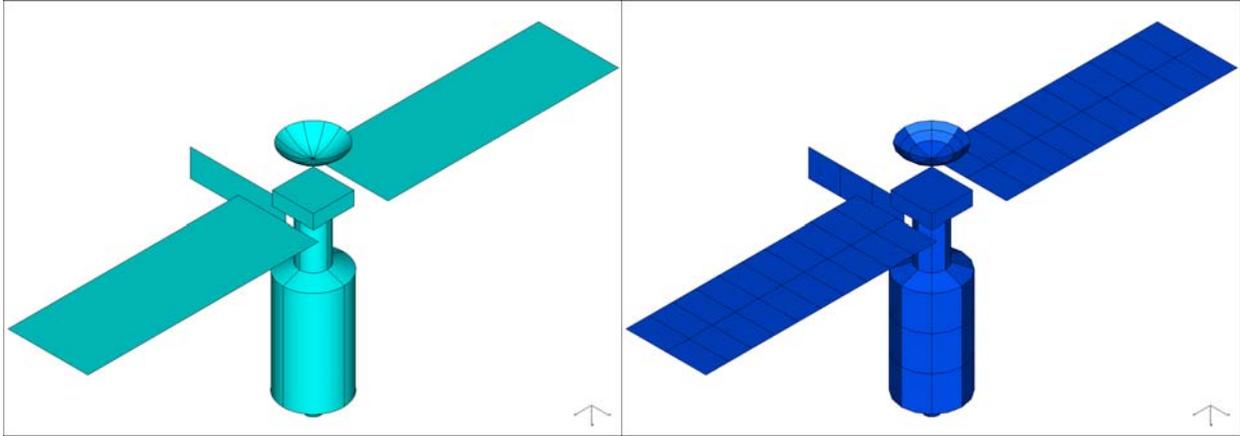
Figure 2: Example of a model translated from TRASYS to I-deas. The translated model is a combination of linear and parabolic elements.

The TRATRAN program only processes the surfaces found on the OPERATIONS BUILD card. No other OPERATIONS data, other than MODPR calls, are processed. Any view factor and orbital heating calculation data will need to be input into TMG.

One final issue is surface numbering. If there is only one sub-model, no correspondence data that merges surface, or no subdividing of surfaces of revolution, then the element numbers will remain the same as the surface numbers. Otherwise, TRATRAN will start numbering the elements at one.

Another option to convert TRASYS data into TMG is to first convert the TRASYS model to TSS format and then import the TSS model into I-deas using the native TSS-to-TMG translator.

TRANSLATING SINDA MODELS TO TMG

TMG has no direct import capabilities for SINDA models, since TMG also includes geometry, which is not available in SINDA. However, TMG does have the ability for the user to add additional conductors and capacitors to the model.

For some projects, ATA has created scripts that have converted SINDA data to TMG format. The scripts are typically written in perl or awk for UNIX or UNIX-like environments. These scripts have been written such that even the ARRAY DATA and VARIABLES 1 logic can be converted into TMG user subroutines. However, as part of the translation process, ATA had to create FORTRAN routines that convert the SINDA calls to TMG equivalents.

To shown how the script works, an example SINDA model file is shown in Figure 3. This is basically a two-node model with a single conductor between the elements, with one element having a cyclical heat load on it. An awk script was used to convert this into a TMG include file, also shown in Figure 3. The ARRAY data has been converted into FORTRAN DATA statements and the SINDA calls are translated nearly verbatim. The only change is the inclusion of the array size in the call.

3

```
                                                        -1
                                                        -1
                                                        -1
                                                        -1
                                                        -1
                                                        -1
                                                        -1
                                                        -1
                                                   XCAP     1 0 (3.9100E+04) $
       BCD 3THERMAL LPCS                           XCAP     2 0 0.0 $
       BCD 3TITLE DATA                             SINK     2  -2.6915E+02
       BCD 9SINDA Example                          XCOND     1     2 (2.0) RAD $
       END                                              -1
       BCD 3NODE DATA                                        SUBROUTINE USER1(GG,T,C,Q,QD,R,TIME,DT,IT,KODE,NOCON,MAXNO,
            1,  0.0000E+00,        3.9100E+04              +ICONV,DUM1,DUM2,DTP,TF)
           -2, -2.6915E+02,        0.0000E+00        C
       END                                               C
       BCD 3SOURCE DATA                                         DIMENSION GG(*),QD(*),T(*),C(*),Q(*),R(*),ICONV(*)
       END                                                     CHARACTER*7 NAME
       BCD 3CONDUCTOR DATA                               C
           -1,       1,       2,       2.0                     REAL A4(3)
       END                                                     REAL A5(3)
       BCD 3CONSTANTS DATA                                     DATA A4 /
           TMPIN,C                                       +0.0000E+00,4.3200E+04,8.6400E+04/
           TMPZRO,273.15                                       DATA A5 /
           SIGMA,5.669E-8                                +1.389E+03,5.391E+00,1.389E+03/
       END                                               C
       BCD 3ARRAY DATA                                         TIMEM = TIME
           4 $ TIME ARRAY                            C  UPDATE VARIABLE WHEN KODE=1
           0.0000E+00,4.3200E+04,8.6400E+04                    IF (KODE.EQ.1) THEN
           END                                                     Q1 = Q(KCONV(1))
           5 $ HEAT LOAD ARRAY FOR ELEMENT 1                      CALL DA11MC( 86400., TIMEM, A4, A5, 1.0, 3, Q1)
           1.389E+03, 5.391E+00, 1.389E+03                        Q(KCONV(1)) = Q1
           END                                                    ENDIF
       END                                                       RETURN
       BCD 3EXECUTION                                            END
 F         TIMEND= 1.7280E+05                         C==== TMG REPRESENTATION OF DA11MC =====
 F         OUTPUT= 3.6000E+03                                   SUBROUTINE DA11MC (PERIOD, TIMEM, ARRAY1, ARRAY2,
 F         DTIMEI= 6.0000E+01                             +                   RMULT, NARRAY, VAL)
           FWDBCK                                         C
       END                                                       INTEGER NARRAY
       BCD 3VARIABLES 1                                          REAL PERIOD, TIMEM, RMULT, VAL
 M         CALL DA11MC( 86400., TIMEM, A4, A5, 1.0, Q1)         REAL ARRAY1(NARRAY), ARRAY2(NARRAY)
       END                                               C
       BCD 3VARIABLES 2                                          REAL TCYCLE, FRACT
       END                                               C
       BCD 3OUTPUT CALLS                                        TCYCLE = TIMEM - PERIOD*INT(TIMEM/PERIOD)
           TPRINT                                                VAL = RMULT*TMGINT(TCYCLE,ARRAY1,ARRAY2,NARRAY)
       END                                                       RETURN
       BCD 3END OF DATA                                          END
                                                        -1
```

Figure 3: Example SINDA/G input file (left) and TMG translation of SINDA/G file (right).

Once the model data is converted, it can be added to the TMG file through the "User Include File" option.

Finally, using a script to convert the SINDA model to TMG format gives the user unlimited flexibility in creating the TMG data. For instance, the script can be modified to account for other VARIABLES 1 routines, to include temperature-dependent nodal or thermal conductivities, or even to allow for renumbering of the thermal nodes. And with a script, changes can be made quickly, without the need for recompiling, as with a more formal FORTRAN or C program. However, the user should document changes to the script.


EXAMPLE TRASYS/SINDA DATA INTEGRATION INTO TMG

An example of integration a TRASYS/SINDA model into I-deas TMG is attaching an antenna onto a satellite. For this example, the antenna is a parabolic dish and a dummy node for the satellite. The example satellite is a six-sided box. The models are shown in Figure 4.

4
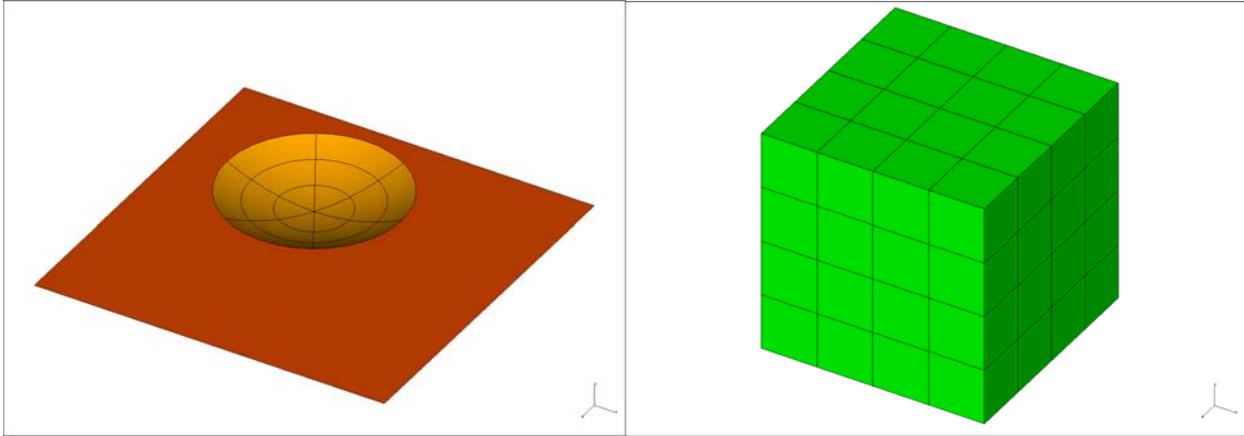
Figure 4: Example Models. Antenna Model (left) and Satellite Model (right).

The first step would be to translate the TRASYS and SINDA models to TMG format, as described above. Once the model has been translated, and the additional data required, such as orbital requests or analysis control parameters, by the user is added, a test run should be conducted to determine if the translation has been done correctly. Figure 5 shows the relative temperature difference is less than 0.5 °C for the translation.

The second step is to remove any radiation conductors and radiative heat loads from the exterior of the antenna of the translated SINDA model, and to allow TMG to calculate the radiation view factors and heat loads on the model. Again, Figure 5 shows the relative difference for the translation. In this case, the difference is 17 °C. In this case, the difference occurs because the surfaces of the antenna were converted to flat surfaces, and there is an area difference between the models. Using more surfaces than 18 to represent the antenna would reduce this error.
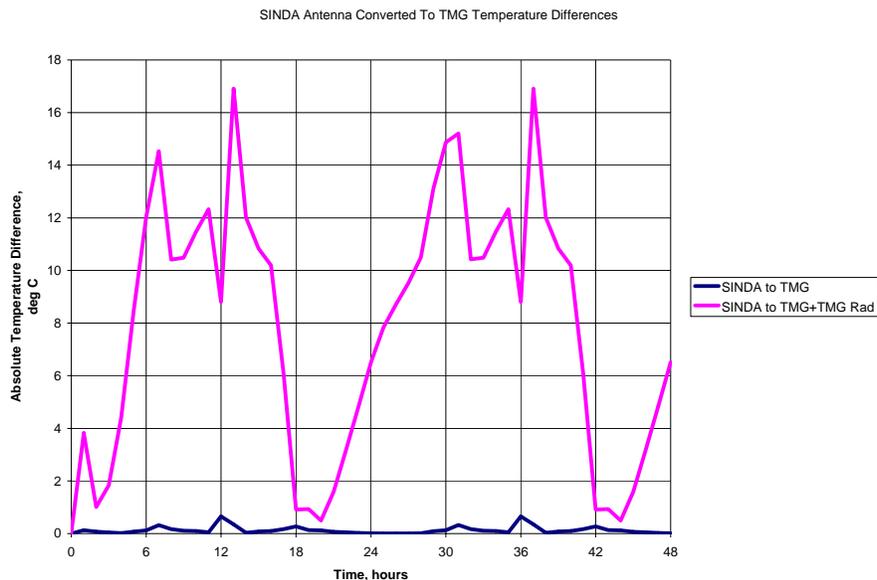
Figure 5: Temperature differences in converting model from TRASYS/SINDA to TMG.

The third step is to add the antenna to the spacecraft, preserving the element numbering on the antenna. This is important, as the translated SINDA information will not work with a

renumbered model, unless specific changes are made to the SINDA translation script. Also, any dummy spacecraft surfaces should be removed prior to combining the models. The antenna should be relocated so that it is in the correct position relative to the spacecraft (Figure 6).

The fourth step is to remove dummy spacecraft nodes and all conductors attached to these nodes from the translated and previously modified SINDA model.
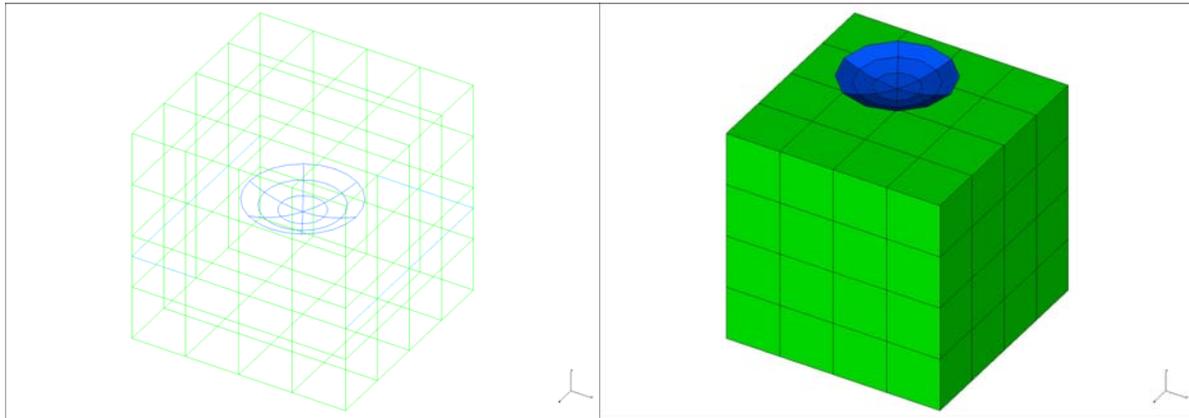
Figure 6: Reorienting the translated TRASYS model to correct location inside of I-deas. The left is the original location and the right is the corrected location.

At this point, the model can be run in TMG. View factors for the exterior of the combined spacecraft and antenna will be calculated, as well any radiative heat loads. The temperatures for one of the reflector thermal nodes are shown in Figure 7 for the SINDA/TRASYS analysis (SINDA), the translated TMG analysis (TMG 1), the translated TMG analysis with radiation conductors and heat loads calculated by TMG (TMG 2) and the combined TMG analysis (TMG Combined). The temperatures for this node are consistent with each other. The combined case shows the mass of the satellite moderates the antenna's temperature extremes.
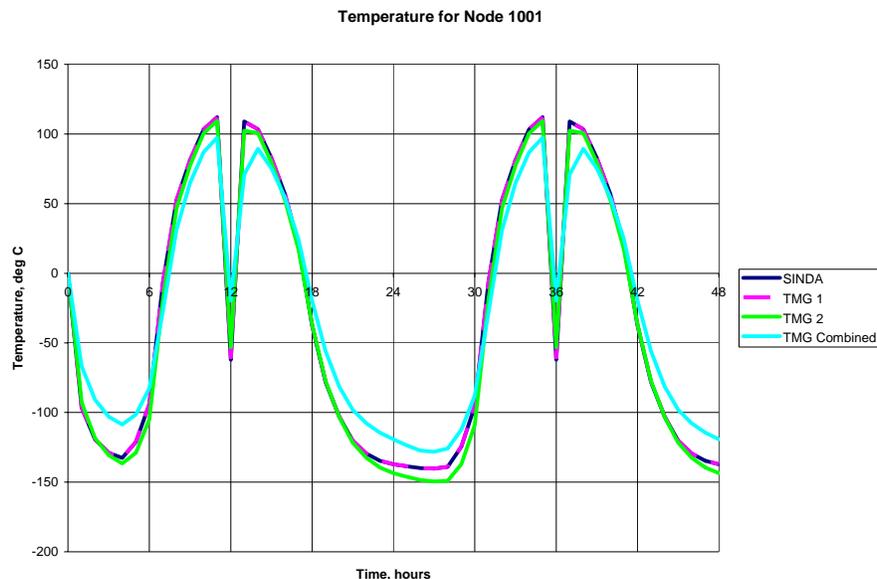
**Figure 7: Temperature profiles for an example node for the four cases.**

INTEGRATING TMG DATA INTO TRASYS/SINDA

The following sections shall investigate the techniques and issues of exporting and integrating TMG models to TRASYS and SINDA.

TRANSLATING TMG MODELS TO TRASYS

TMG has the ability to convert geometry to TSS and ESARAD without performing a thermal run. However, for TRASYS, TMG requires that the user perform a thermal analysis to create the TRASYS model. There are several items that the user should be aware of when exporting a TMG model to TRASYS.

First, TMG will convert linear triangles and quadrilaterals into rectangles, trapezoids, or polygons. TMG will convert parabolic triangles and quadrilaterals into surfaces of revolution. This translation of parabolic elements works well with disks, cones and cylinders, as shown in Figure 8. However, for doubly-curved surfaces, like spheres and paraboloids, the results are not always satisfactory, as shown in Figure 9.
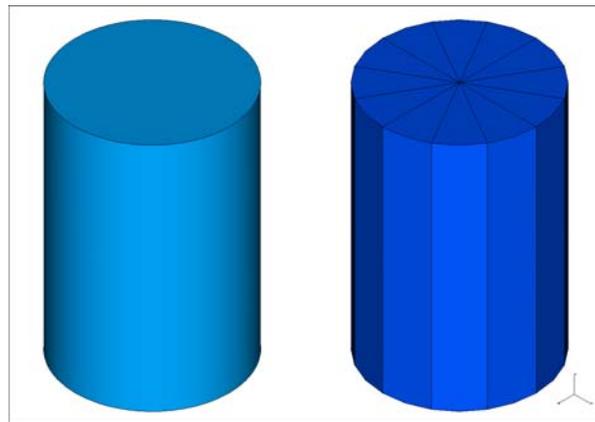
Figure 8: Example of a good TMG-to-TRASYS conversion.
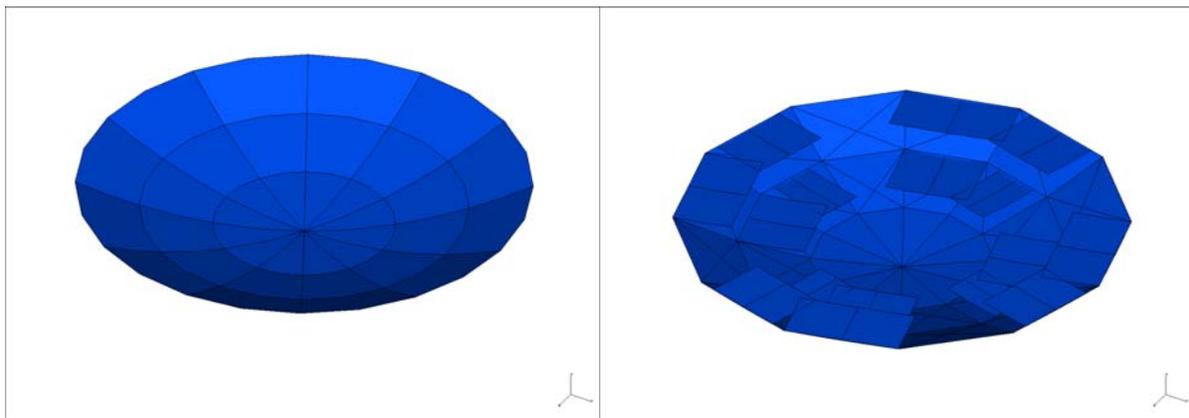
Figure 9: Example of a poor TMG-to-TRASYS conversion. On the left is the original finite element model, and on the right is the TRASYS model created by TMG.

To avoid these problems, if the user wants to create the model with surfaces of revolutions, there are two options: One, if the user is not concerned about the curvature, the model can be created with linear elements, which are accurately converted to TRASYS. Two, the user can create the surfaces using the TSS option, and convert the TSS model to TRASYS format.

Another issue that the user should be aware of is surface numbering. TMG numbers the surfaces in the range above the largest element number, and then combines the surfaces back together using correspondence data. For instance, if the model has elements 1 to 100, the surfaces will be numbered from 101 on and will be combined in the TRASYS CORRESPONDENCE data block. In some instances, the correspondence data will contain surfaces that do not exist in the model. This appears to occur to surfaces that only have one side active. These non-existence surfaces produce some warnings during the TRASYS analysis. The user can edit the correspondence data to remove these warnings.

There is also an issue with units. TMG does not convert the model from its given units to feet, nor does it add a D Card in the SURFACE DATA block to do the translation. The user will have to add the D Card to the model before analysis.

Finally, there is the issue of the view factor and orbital calculations. TMG does not translate the view factor or orbital calculations to the TRASYS model. Therefore, the user will have to input this information.

TRANSLATING TMG MODELS TO SINDA/FLUINT AND SINDA/G

To create a SINDA model, the user is required to perform a thermal analysis that creates a SINDA model as part of the output. The SINDA model can be exported in three formats: SINDA/FLUINT, SINDA/G, and CINDA (a SINDA variant used by Boeing and others).

Before exporting to SINDA, the user should be aware of the different TMG options that can affect the size and performance of the exported SINDA model. First is the different conduction models used in TMG. The default method, called the "Element CG Method", places a thermal node at the element center and at the element boundaries. For instance, a quadrilateral element will have five thermal nodes associated with it: one at the center, and four on the edges. These edge nodes may be shared with other elements. This method is good for free meshes, but has two significant issues that can affect SINDA translation: 1) it does create additional arithmetic nodes, increasing the total number of nodes by a factor of 2 or greater, and 2) it creates negative conductors, which cannot be used by some versions of SINDA, especially older versions of SINDA/FLUINT.

There is another option, called the "Element Center Method", which uses a form of Fourier's Law of Conduction. This method is good for regular or mapped meshes, but also has one major drawback: for irregular elements, the calculation point can fall outside of the element, possibly forcing it to be merged with its neighboring element. This is especially problematic if one or both of the elements are temperature-dependent, but are not the same material. A workaround for this problem is to put elements on the boundary between different temperature-dependent materials, and make these elements arithmetic.

Another consideration when creating a SINDA model is the radiation model being used. The default method used by TMG is the Oppenheim method. In this method, there is no gray body view factor matrix. Instead, additional Oppenheim thermal nodes are created for each radiation element. The view factors between the Oppenheim elements are just the black-body view factors, and the view factor between the Oppenheim element and its correspondent radiation element is $\frac{\varepsilon}{1-\varepsilon}$. This method can reduce the number of radiation conductors, but at the expense of additional arithmetic nodes. If the number of arithmetic nodes is an issue, the user can select the more traditional Gebhardt's method, which will create the gray-body matrix of radiation conductors.

Another radiation issue is the Stefan-Boltzmann constant (sigma or σ). TMG automatically includes sigma in the radiation conductor, so sigma should be set to 1.0, or a FAC card needs to be added to the SINDA file prior to the first TMG radiation conductor.

One final issue to discuss is the merging of elements, either by the "Element Center Method" or by explicit options in TMG. For compatibility with TMG, the merged elements are converted to thermal nodes in SINDA, and their temperature is set in the VARIABLES 1 block. These elements only have one conductor, and that is to itself. This will cause some versions of SINDA to issue a warning. However, they should not affect the performance of the SINDA run. If the user does not want to keep strict compatibility with TMG, or wants to simplify the model, these merged elements can be removed.

EXAMPLE TMG MODEL INTEGRATION INTO TRASYS/SINDA

An example of integrating an I-deas TMG model into TRASYS and SINDA is again attaching an antenna onto a satellite. This time, the antenna is in TMG format, and is a parabolic dish and a dummy node for the satellite. The example satellite is a six-sided box and is in TRASYS/SINDA format. These models have the same geometry as previously shown in Figure 4.

The first step would be to perform a TMG thermal analysis, requesting that the model be translated to TRASYS and SINDA TMG format, as described above. Once the model has been translated, a test SINDA run should be conducted to determine if the translation has been done correctly. Figure 10 shows the relative error for the translation, and for this case, the error is less than 0.25 °C

The second step is to remove any radiation conductors and radiative heat loads from the exterior of the antenna from the translated SINDA model, and to allow TRASYS to calculate the radiation view factors and heat loads on the model. The user will need to remember to put in any necessary units information in TRASYS, and the results of the TRASYS run should be added to the SINDA model. Again, Figure 10 shows the relative error for the translation. For this case, the error is almost 9 °C. The user should determine why there is such a significant difference, and if there is a way to remove this inconsistency. In this instance, the difference is that TRASYS calculates lower view factors to space than TMG.

TMG Antenna Converted To SINDA Temperature Differences
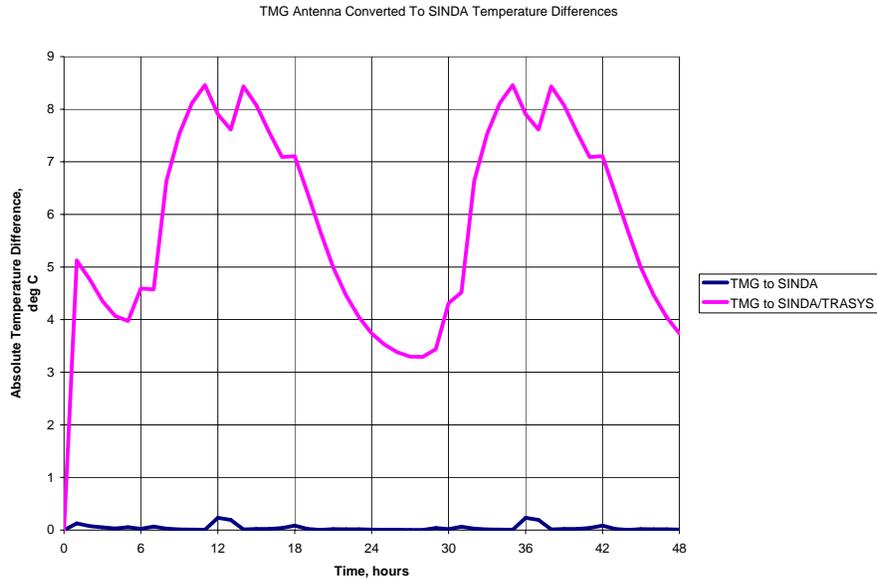
Figure 10: Temperature differences in converting model from TMG to TRASYS/SINDA.

The third step is to add the antenna to the spacecraft TRASYS model. Also, any dummy spacecraft surfaces should be removed prior to combining the models. Care should be taken to determine if the surface numbers of the antenna conflict with the spacecraft surface numbers. The antenna should be relocated so that it is in the correct position relative to the spacecraft. This can be done by changing the BCS definition for the translated model.

The fourth step is to remove any radiation conductors and radiative heat loads from the exterior of the antenna from the translated SINDA model, as view factors from the exterior will now include the surfaces of the spacecraft. Dummy spacecraft nodes and all conductors attached to these nodes should be removed.

At this point, the model can be run in TRASYS. View factors for the exterior of the combined spacecraft and antenna will be calculated, as well any radiative heat loads. These conductors and heat loads will be added to the combined SINDA model and analyzed. The temperatures for one of the reflector thermal nodes are shown in Figure 11 for the TMG analysis (TMG), the translated SINDA analysis (SINDA), the translated SINDA analysis with radiation conductors and heat loads calculated by TRASYS (TRASYS/SINDA) and the combined TRASYS/SINDA analysis (Combined). The temperatures for this node are consistent with each other. The combined case shows the mass of the satellite moderates the antenna's temperature extremes.

Temperature for Node 1001
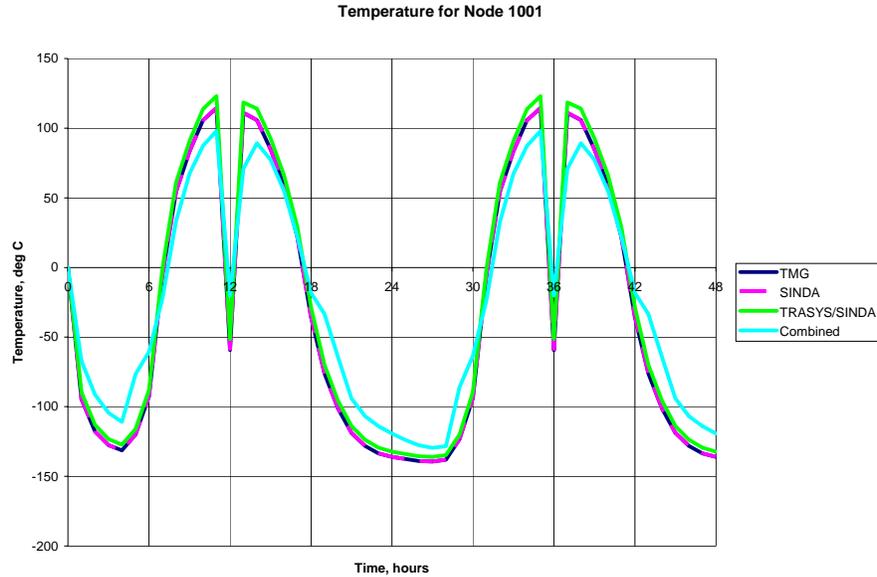
Figure 11: Temperatures profiles for an example node for the four cases.

CONCLUSIONS

In a heterogeneous analysis environment, TMG can be used with and integrated into more traditional thermal analysis codes such as SINDA and TRASYS. However, the analyst integrating the models must be aware of the issues surrounding this integration. Methods and software can improve the process and reduce the potential errors in the translation of the models.

Depending on the size of the model, and the complexity of the logic, it can take from less than a day to several weeks to convert and verify the model from one format to another. A model with only a few hundred nodes and limited logic can be converted and tested in a day or less, but a much larger model or more complex logic requires significantly more time to convert and test.

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Mr. Miskovish is currently Lead Engineer in the Eastern Region offices of ATA Engineering, Inc. and has been involved in thermal analysis for 15 years at ATA Engineering and SDRC. While specializing in the use of I-DEAS TMG, he has also used other thermal codes, such as TRASYS, SINDA, and NEVADA. He has a Master of Science in Mechanical Engineering and a Bachelor of Science in Engineering and Applied Science, both from the California Institute of Technology.

NOMENCLATURE, ACRONYMS, ABBREVIATIONS

ε	Infrared Emissivity
σ	Stephan-Boltzmann constant (5.669×10^{-8} W/m^2/K^4)