RECENT DEVELOPMENTS IN THERMAL RADIATION SYSTEM ANALYZER (TRASYS)

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SUMMARY

The Thermal Radiation Analyzer System (TRASYS) computer program remains a dynamic program. Many changes have been made in the last few years. Because of the program modularized structure it has been a building experience of adding new capabilities while keeping intact the same data input structure. The overview of the program structure and general capabilities should be sufficient background to grasp a discussion of recent developments showing the progress in the last year. Where appropriate, assessments are made of the new features. The last section discusses the application of TRASYS peripheral programs and the importance they have in developing a totally integrated thermal analysis system.

INTRODUCTION

Large and complex configurations such as the Shuttle Orbiter and its payloads have established the need for more exact definition of the thermal radiation environment for on-orbit thermal analysis. For example, the Shuttle being larger, having more extensive self-shadowing, and presenting areas with greater sensitivity to the extreme environmental conditions than found in the previous manned spacecraft programs made it evident that improved analytical tools and modeling methods would be required. The cavities created by the open payload bay doors/radiators and the payload bay with payloads contribute to very steep thermal gradients because of the trapped edge and self-shadowing effects inherent in the configuration. Other locations, which place stringent requirements on the radiation analysis tools and methods, are the unpressurized internal equipment compartments, especially the uninsulated ones such as Orbiter aft section. These areas are radiation dominated and the geometry requires greater modeling detail to predict accurate temperature levels and thermal gradients. These situations coupled with the large size and long mission scenarios have made unprecedented demands for improvements in the computational and storage efficiency for thermal radiation analyzer computer programs and for more effective utilization of these tools.

Realizing in 1970 that unique requirements would be imposed by the next generation post-Apollo spacecraft, and that existing tools would be inadequate, NASA Johnson Space Center (JSC) began preliminary design and planning for what eventually evolved as the thermal radiation analyzer TRASYS computer program (ref. 1). This computer program has been actively developed since 1972. Although the TRASYS computer program presently meets JSC needs, development continues on further improving its' capabilities and performance. Continual studies have also made substantial improvements in efficiency by identifying and educating users on more optimum methods in the application of TRASYS.

This paper will initially give a review of the program structure for those unfamiliar with the program. With this as background, basic features, recent development and support programs will be discussed.

PROGRAM STRUCTURE

When TRASYS is executed, generally two subprograms are used; a preprocessor and processor. The preprocessor performs two basic functions. First, it reads and converts the user defined model geometry in the form required by the processor. Secondly, it interprets the TRASYS psuedo Fortran code that the user specifies in the input data to define what computations are desired and the sequence in which they should be performed. Based upon this data the preprocessor generates driving logic using dynamic storage techniques with only those program segments required to obtain the requested solution. The implication of the second function is that the user may readily customize the desired solutions, thus having a very definite influence on the accuracy and computational time.

The processor is the work horse. Its function is to obtain the desired solution and output the data computed by the processor in one or more optional formats. This is accomplished by executing the code the preprocessor created.

PROGRAM CAPABILITIES AND FEATURES

TRASYS, the Thermal Radiation Analyzer System is a modularized computer program system designed to compute the total thermal radiation environment for a spacecraft in orbit. The principal end products are the radiation conductors, and total heating as function of time or averaged. The output is a lumped parameter nodal representation formatted for direct interface with a thermal analyzer. The radiation conductors account for the radiation interchange between a network of nodes that make up the geometric model defined by the user. The radiation interchange includes the direct contribution from the sun, albedo, and planet plus the intra-network reflections of this energy. Self-shadowing can be considered for the direct and reflected heat loads.

The program's major attribute is its flexible structure and margin for growth which has allowed the program to keep pace with requirements while maintaining the basic input structure.

The program includes, but is not limited to, the following features:

- 1000 node capability with extended core.
- 9 different surface types to describe geometry.
- 15 user called segments that perform specific functions, e.g., compute form factors, compute grey bodies, plot geometric model, etc.
- The user can write his own executive to customize the desired solution with numerous program segments, subroutines, and variables to choose from.

- An efficient easy to use restart capability that minimizes loss of output.

- Convenient thermal analyzer interface easily tailored to other thermal analyzers.

- Choice of form factor solution techniques: Nusselt Unit Sphere or Hybrid which automatically chooses between double summation or Nusselt Unit Sphere.

- Form factor imaging for symmetrical configurations.

- Macroinstructions include optimized application of previous flux computations.

- Self-shadowing of external flux on a discrete element basis and/or with precomputed shadow tables generated by the program.

- Accepts trajectory tape input to define orbit position and attitude.

- 3 plot segments which will plot surface node data, sun-planet-spacecraft relationship, and heating rates vs time.

- Geometric and optical properties and orbit/attitude may be a function of time.

- Pure diffuse or mixed diffuse-specular radiation property model for infrared and/or solar waveband.

The JSC TRASYS program is operational on the UNIVAC 1100 series computer with central memory that varies depending upon the model size and the largest instructional bank of the various segments mapped. The minimum core is approximately 40K decimal words.

RECENT DEVELOPMENTS

The following paragraphs spotlight the more significant changes to the JSC TRASYS program in the last year and describe their key features and/or overtones.

Ray Tracing Segment

A new infrared (IR)/solar radiation interchange segment (RTCAL) was developed for mixed diffuse-specular surfaces. The segment uses a ray tracing procedure that is conveniently integrated into the overall program structure so it has an interface with the grey body calculation (GBCAL) link similar to the real body calculation (RBCAL) link. Unlike the RBCAL link though there are no restrictions on surface type, number of nodes per surface, and number of specular reflections.

More time will be needed to evaluate and optimize the TRASYS ray tracing segment before it can be considered a viable analytical tool.

Application of Direct Incident Flux Shadow Tables

Without the use of shadow tables the direct fluxes are computed with shadowing inherently considered on a element basis. Previous timing studies have shown that up to ninety percent of the CPU time is expended in the TRASYS shadow routines when computing orbital heating rates. The application of shadow tables is one way that a significant reduction in computer time can be made because it bypasses the time consuming subroutines. Shadow tables are precomputed at specific clock and cone angles. They can be used repeatedly on subsequent runs as long as the configuration is not changed.

Shadow factors are applied in TRASYS in the following manner: For the direct solar portion of the heat flux computations the position of the sun is determined based upon the orbit and attitude input parameters. An unshadowed solar flux, after being computed, is multiplied by the shadow factor obtained via table look-up of the precomputed shadows tables. The total direct flux is the product of the unshadowed direct incident flux and the shadow factor. Similarly, the albedo and planetary flux are computed with each planet node becoming a point source and the total albedo or total planetary flux being a summation from all planet nodes.

To minimize the error associated with interpolation of shadow tables with large step functions, the program tests to ensure that the tabulated dependent values interpolated between do not exceed the tolerance for the test. If the tolerance is exceeded at any time the shadow tables are temporarily not used and the program reverts back to calculating the total incident flux to the node on an element by element basis. A separate tolerance may be specified; one for solar and one for albedo/planetary heating.

As an example of how the program executes, suppose the shadow factor solar tolerance is 0.5 and for a given sun position, the interpolation would occur between values of 0.0 and 1.0. The tolerance is exceeded so shadow tables will not be used to compute the total solar flux to that node. Opposingly, if the interpolation had been between tabulated shadow factors of 1.0 and 0.62, the shadow tables would be used.

The albedo/planetary flux computations work similarly except the table is entered and the test made using the shadow factor albedo/planetary tolerance for however many nodes the planet is divided into for a particular spacecraft node. Decreasing the tolerances will improve accuracy while increasing computer time. When shadow tables are used extensively there is the risk that some of the nodes will have excessive errors. Additional controls allow the user, with a feel for the problem, to basically eliminate any significant errors without penalizing the approach as a whole. All or selected nodes may be excluded from using shadow tables for solar and/or albedo and planetary when accuracy requirements and their sensitivity to shadowing dictate it.

As of this writing, NASA/JSC has obtained very favorable performance with the control parameters selected to never use shadow tables to compute the solar fluxes and to use them 100% of the time in albedo/planetary calculations. Typically the computer charges may be reduced by 50% while comparison of predicted temperatures showed better than 90% were less than 3°C and the maximum was 5.5°C difference.

Hybrid Form Factor Segment

A new form factor segment was developed to replace the previous double summation form factor solution. The new form factor calculation (FFCAL) link automatically chooses between a double summation method and the unit sphere method to calculate form factors. The choice between the two methods is based on a criteria involving the nearness of the node pairs. For closely adjacent nodes the unit sphere method is used for its superior accuracy in this condition. For more distant nodes the double summation method is selected because it is faster and does not suffer from the inherent accuracy problem which occurs with this method when the nodes are closely spaced. The user still retains direct control of relative accuracy with input accuracy parameters.

At NASA/JSC the new FFCAL link is becoming the primary segment to compute form factors replacing the pure unit sphere method as the mainstay, the reasons being an approximate 40% reduction in computer time, with no noticeable degradation in accuracy.

Form Factors to Space

The way in which radiation conductors are computed to space has created accuracy problems in certain situations. Normally after computing form factors and node to node interchange factors the interchange factor to space is computed implicitly utilizing the residual for conservation of energy. The screening out of small form factors, and inaccuracies in the form factors themselves affect the accuracy of the radiation conductors to space. The error will have a greater relative effect on the temperature predictions for nodes that have high form factor sums. An alternate solution is to compute form factors to space explicitly. This will eliminate the accummulative error in interchange factors that gets dumped into the space conductor. On the other hand, the fact that the form factor to space is explicitly computed does not necessarily mean the conductor to space will be better. It will be better only if the form factor to space is more accurate. Because of the sprawling nature of a space node this will not always be possible and/or practical with limited computer resources.

The procedure utilized is to generate 100 rays from the center of each element evenly distributed outward in the half space. Each ray is checked to see if it is blocked by one of the possible shadowing surfaces. With all the form factors to space known the radiation interchange to space is computed as part of the network by the GBCAL link.

Currently the form factor to space capability needs to have its characteristics evaluated to determine when it is practical to use and whether further improvements can be made.

Identical Form Factor Request Matrix

A new capability has been added which allows more than one configuration to share the same form factor request matrix. Previously, even when there was no difference in the request matrix, it was necessary to repeat it under the proper current configuration name. This change is basically a potential time saver to the user.

Restart Tape Form Factor Updates

Frequently, after a restart tape has form factors stored, it is necessary to make model changes. This makes the tape incompatible with the new model unless the node array generated with the updates is identical to the node array stored on the restart tape. This means the same node numbers, and the same sequence of nodes. Recent changes have been made which allow a model to be reduced in size and still retrieve form factors from the larger model's restart tape. The program will automatically reduce the size of the form factor file by deleting the factors to the non-existing nodes.

Nodes can also be added to a model and still read form factors from the restart tape. The new node numbers must be unique from any on the restart tape. The new nodes may be added anywhere in the Surface Data Block. The program will utilize all of the values stored on the tape and create a program request matrix to compute all the form factors required because of the additional nodes. A combination of additions and deletions is also possible. Similar requirements apply for this to be accomplished.

The above capability will allow greater utilization of the binary restart tape which is preferred over the other alternative of manually selecting applicable form factors from previous models.

Frequently there is useful form factor data on more than one incompatible restart tape. A capability is being developed that will allow up to three restart tapes to be used from which to retrieve form factors. Another aspect of restart tapes is that as models have grown and mission simulation time and complexity have increased, tape overflow problems occasionally arise. One measure taken to reduce this risk is to no longer write two complete sets of form factors to the restart tape if they are not a function of the optical properties. This occurs if there are surfaces with transmissive or specular properties. As a result the majority of models require only one set of form factors. The program has been changed to automatically read/write one or two sets as required. Provisions are made to allow restart tapes to be read from previous program versions or if property changes are made which have impacted the previous program choice.

Trajectory Tape Input

Two new macroinstructions have been developed to generate the proper executive code to read the NASA/JSC common formatted trajectory tapes. The trajectory tape input capability was developed to assist in better preflight predictions and post-flight data correlation, when the usual method of approximating the mission timeline is not sufficiently detailed to resolve critical issues. The preprocessor reads the position and attitude data from the tape and expands the code for the Operational Data Block. Consequently, it does not have to have the trajectory tape on subsequent runs and the user can customize the Operational Data Block further beyond the standard trajectory tape options. A trajectory tape used in its purest form would be very costly in computer time. This problem has been addressed to some extent but will probably warrant additional study and changes as more experience is gained.

Currently the following flexibility and degree of optimization have been implemented for a given time segment. A nominal time between positions (steps) can be specified by the user. This time interval will be adhered to unless there is a meaningful step function in the position vector to the sun or earth. The user may specify what direction cosine value qualifies as a step function. The program will recognize valid sun or earth attitude hold periods and consequently make optimum use of similar fluxes and/or planetary form factors available from previous computations. When the Shuttle is in the earth's shadow and in a earth hold attitude the program will extend the elapsed time between points to characterize the constant nature of the heating with just two points.

Extended Orbit Generator Capabilities

The orbit generator macroinstruction capability has been extended with the addition of two new arguments. One of the arguments will allow the initial time for the initial true anomaly to be specified. Previously the program assumed the time to be equal to the time since periapsis passage. This would not allow the initial true anomaly to be greater than zero without fudging the time.

The other new change will permit the user to specify the initial step number. This provides a greater flexibility to mix orbit and trajectory macroinstructions and to add new ones on subsequent runs without step number conflicts.

Source Editing

Previously orbit generation and other macroinstructions in the Operational Data Block were expanded after the source editing file was created by the pre-processor. A modification was made to include all card images generated by the macroinstructions in the source edit file. They will also be listed with edit numbers when a source listing is printed. This change will allow the user to make customized edits to these standard routines.

Possible Shadowers

Form factor blockage factors between each node pair are printed by the form factor segments and stored on the restart tape for subsequent printing. This is done because experience has shown that frequently it is easier to eyeball a blockage factor to judge the reasonableness of a suspect form factor than the form factor itself. An additional diagnostic aid is now available. A list of all possible form factor shadowing surfaces for all node pairs can be obtained with or independent of the form factor link.

Extended Core

The TRASYS program at JSC was initially developed to operate in 65K memory. As the program and models have grown there have been occasional problems mapping some of the larger links. This occurs with approximately 600-700 nodes. The newest version is an extended core version where all model size dependent variables in common will be mapped into extended core.

TRASYS ANCILLARY PROGRAMS

The major TRASYS support program available at JSC plays an important role. Several programs use the TRASYS restart tape which was designed to function not only as a restart tape but as a TRASYS interface to other programs. The programs listed are only a start in developing the full potential of utilizing the restart tape to perform tasks more efficiently external of TRASYS.

Restart Tape Print

The program will list data from selected psuedo files. It will also read and list all the header records on the restart tape. The program is used to inspect specific data, validate what is on the tape, or see whether it can be read or not.

Trajectory Print

There are two trajectory print programs; one for preflight and one for post-flight. They list all the information that is normally of interest to the Shuttle thermal analyst and in particular the TRASYS trajectory tape user.

Thermal Analyzer Total Heat

Programs are available that collect the total heat rates as a function of time from a series of restart tapes generated with orbit and/or trajectory runs. A tape/file is created with proper format for a thermal analyzer flux read routine. This approach is preferred to the alternate method provided by TRASYS of using arrays and cyclic interpolation routines. It has more flexibility and requires less storage, a critical factor in large RC network Shuttle models.

Interactive Graphics

An Adage 340 minicomputer is utilized to validate TRASYS input data, and plot the surface/node geometry. It will also plot attitude and orbit relationships. The user may interact with such functions as zoom, translation, transform and hidden lines. The value of this system can not be overestimated in time and errors saved.

CONCLUDING REMARKS

The TRASYS computer program has made significant improvements over the last year. Form factor computations times have been reduced approximately 40% and the longer flux runs have been decreased 50% when shadow tables are used. Trajectory and ray tracing capability will require further development but both have received a significant start. The basic structure of TRASYS will allow it to grow in whatever direction it needs to.

REFERENCES

1. Jensen, Carl L.; Goble, Richard G.: Thermal Radiation Analysis, TRASYS II User's Manual Revision 3 June 1981. NASA CR 161077