ROLE OF IAC IN LARGE SPACE SYSTEMS THERMAL ANALYSIS

G.K. Jones, J.T. Skladany, and J.P. Young
Goddard Space Flight Center
Greenbelt, Maryland

INTEGRATED ANALYSIS CAPABILITY (IAC)

To produce practical, alternative large space structure configurations, design analysts must have highly adaptable and efficient computer analysis programs to evaluate critical coupling effects that can significantly influence spacecraft system performance. These coupling effects arise from the varied parameters of the spacecraft systems, environments, and forcing functions associated with disciplines such as thermal, structures, and controls. Adverse effects can be expected to significantly impact system design aspects such as structural integrity, controllability, and mission performance.

One such neeeded design analysis capability is a software system that can "integrate" individual discipline computer codes into a highly user-oriented/interactive-graphics-based analysis capability. This "integration" of computer codes must be done in a manner that will greatly accelerate interdisciplinary data flow by maximizing use of modern data handling techniques and new generation computer systems. By providing this type of computer-assisted interdisciplinary design analysis capability, the analyst will be afforded a rapid and efficient system to minimize solution turnaround time as well as having basic solution capabilities hitherto unavailable.

Therefore, the purpose of the integrated analysis capability is to provide new system analysis capability wherein coupling effects of multidisciplinary design drivers can be rapidly evaluated and design alternatives assessed.

The IAC system can be viewed as being the following two products (see fig. 1):

a. Core framework system which serves as an "integrating base" whereby users can readily add desired analysis modules. The IAC is explicitly being designed so as to greatly ease the task of interfacing new analysis modules.

b. Self-contained interdisciplinary system analysis capability having a specific set of fully integrated multidisciplinary analysis programs that deal with the coupling of thermal, structures, controls, antenna radiation performance, and instrument optical performance disciplines.

Use of the IAC will be adaptable to the full range of design process stages starting at the definition phase and progressing to the final design verification stage.

INTEGRATED ANALYSIS CAPABILITY

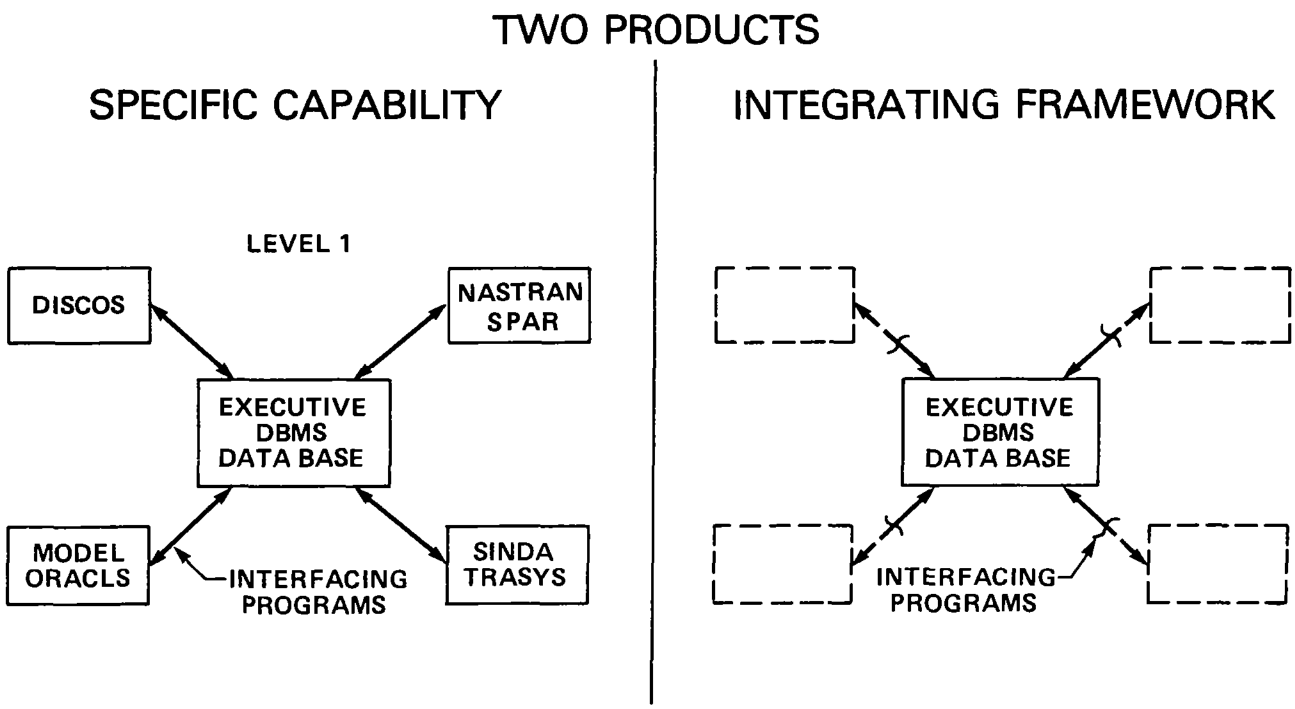


Figure 1

IAC SOLUTION PATHS

Much of the required technical capability of the IAC can be described as being part of one or more distinct "solution paths" (fig. 2). Each path is actually a class of solutions which consists of a number of selectable options and variations, rather than a rigidly predefined and automated process. An engineer-in-the-loop mode of operation is therefore possible and, in fact, is emphasized. Currently, five such solution paths have been defined. The standalone (uncoupled) operation of each technology or major technical module is defined to be Solution Path I. Paths II through V involve an increasing degree of interdisciplinary coupling and correspondingly greater complexity. Solution Path II provides thermal deformations via the coupling of a thermal analyzer such as SINDA, NASTRAN, or SPAR with a structural analyzer such as NASTRAN or SPAR. Obviously, a major coupling task is to handle the generally incompatible thermal and structural models. Path III accomplishes a structural/control analysis in either the frequency or time domain by providing required modal data from a structural analyzer to a system dynamics analyzer module such as DISCOS. Solution Path IV provides a time domain structural/control analysis, including a time-varying but quasi-static thermal loading; i.e., thermal loads are unaffected by the dynamic motions. Paths I-IV are to be fully implemented within the Level 1 program. Finally, Path V provides a fully coupled analysis in the frequency domain, and is directed at problems such as thermal flutter of long spacecraft members. This last solution path requires development and verification of new analysis technology such as thermal mode solution technique.

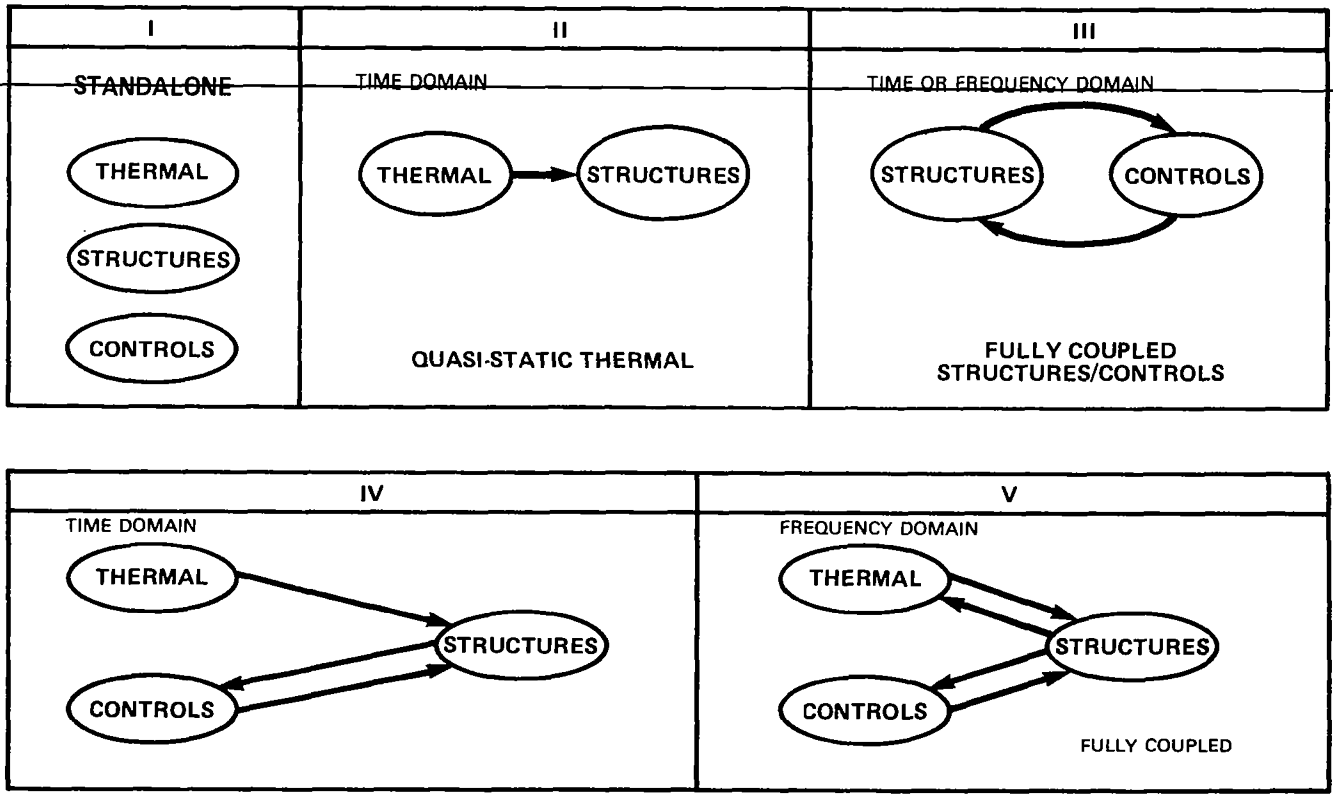


Figure 2

IAC ARCHITECTURE

The IAC design has an architectural plan not too unlike any common database-dependent software system consisting of data-handling capability and unified system executive encircled by application programs and a key supportive interactive graphics module (fig. 3). The diagram also shows the required interface to IPAD via use of the RIM database manager. A very important aspect of the IAC system, as indicated by the "OTHER" module block, is that specific attention is being given to making the system "open-ended" by facilitating the effort necessary to add other analysis capabilities. One design criterion for the early IAC release levels is to incorporate, where possible, analysis modules that are considered "industry standard." The most notable exceptions to this criterion are the SAMSAN and MODEL control system analysis-related programs which are currently being developed at the Goddard Space Flight Center. Creation of the interface programs, shown as the broad arrows A - G, constitutes a major part of the total IAC development activity. The bulk of the remaining task has centered around building up the total data handling and executive systems.

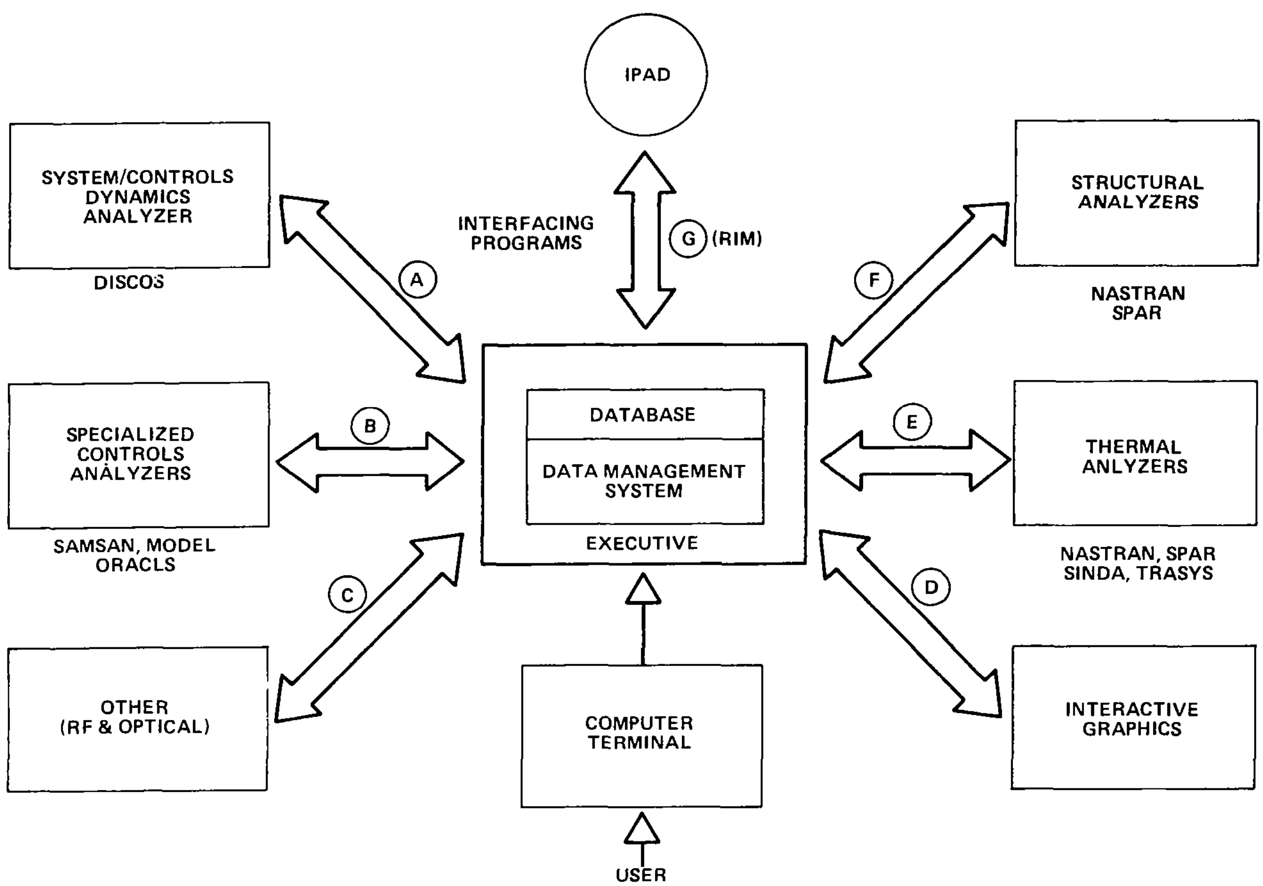
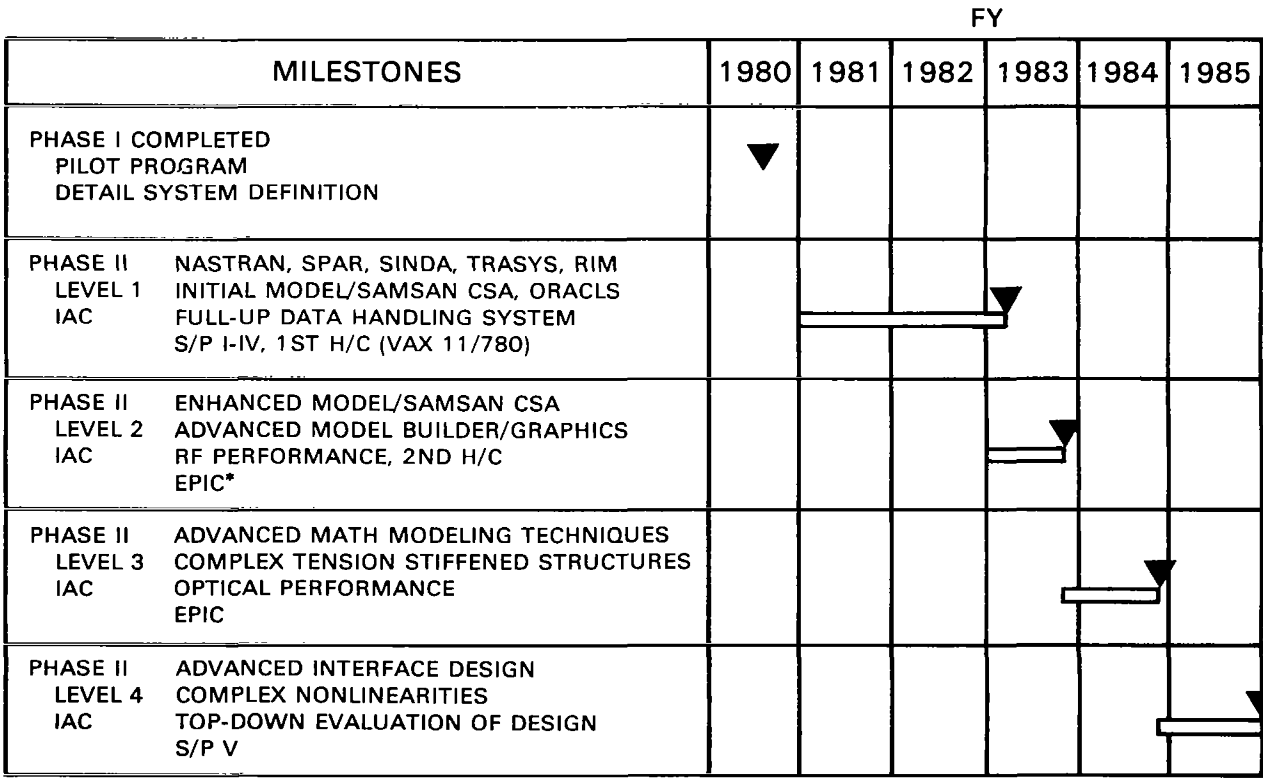


Figure 3

IAC DEVELOPMENT PLAN

Figure 4 gives a picture of the projected staged level delivery schedule of the IAC through FY 1985. In addition, a FY 1980 accomplishment is shown as the completion of Phase I and delivery of a pilot program and a detail system definition. The Level 1 through Level 4 IAC systems are shown as being completed on approximately 1-year intervals starting in early FY 83. Each level will successively incorporate additional capability as briefly noted in the chart. For definition of the solution paths (S/P) I-V as shown, refer to figure 2. The first host computer (H/C) will be the DEC VAX 11/780 super minicomputer manufactured by Digital Equipment Corporation. The second H/C has not yet been selected. Selection will be delayed as long as possible to allow the current-generation computer user market to develop further. Since a significant class of large space structures appears to be of a complex tension-stiffened (T/S) member type of construction, the Level 3 IAC is projected to contain solution algorithms unique to such structures. The need for an improved capability to analyze for geometric nonlinearities is anticipated and is projected for incorporation into the Level 4 IAC. After several years of usage, more effective ways of integrating the technical analysis modules will undoubtedly become known. In addition, after such usage experience it may well be advantageous to "pause" and re-evaluate the total IAC design concept from a top-down software design point of view. Therefore, provision for these tasks is shown during the Level 4 development period.



*Enhanced Plug-In Capability

Figure 4

MAJOR THERMAL MODULES

The four major thermal analyses modules are presented in figure 5. The NASTRAN thermal analyzer (NTA) and SPAR thermal analyzer perform steady-state and transient thermal analyses. Both use the finite-element solution technique. Their main advantage is that they compute temperatures at points which are completely analogous to structural grid points. Their major drawback is their limited acceptance by the thermal community.

The SINDA program is a finite-difference thermal analyzer. It has a wide range of options and capabilities, and unlike the NTA it is widely accepted by the thermal community. The major drawback is the lack of direct compatibility with the structural model.

TRASYS is probably the most widely used radiation analysis system. It calculates all the parameters dealing with radiation, including black-body view factors, interchange factors, and complete absorbed fluxes from the Sun and planets throughout an orbit.

- NTA — NASTRAN THERMAL ANALYZER
- SINDA — SYSTEMS IMPROVED NUMERICAL DIFFERENTIAL ANALYZER
- TRASYS — THERMAL RADIATION ANALYSIS SYSTEM
- STA — SPAR THERMAL ANALYZER

Figure 5

THERMAL INTERFACES REQUIRED

The existence of a number of thermal programs establishes the need for some thermal interfaces (fig. 6). The NASTRAN-to-SINDA link is basically a conversion of the structural model to a SINDA thermal model.

The TRASYS/NASTRAN link is envisioned as a two-way link. First TRASYS must be able to accept model data in NASTRAN format, and secondly the output from TRASYS must be converted to NTA format. A link from TRASYS to SINDA exists as part of standard TRASYS output.

Finally, a link from SINDA output back to the structural model must be provided in order to perform a structural analysis with thermal data included. MIMIC (model integration via mesh interpolation coefficients), which is a program that derives point-wise spatial interpolation coefficients, will transform temperature data from one set of nodes to another.

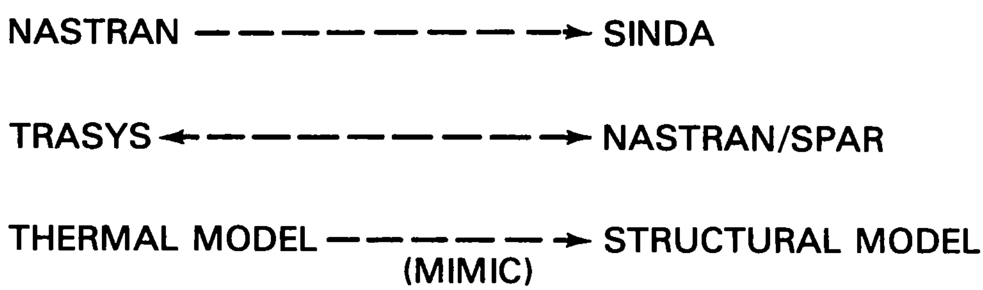


Figure 6

THERMAL MODULE CAPABILITIES

The combination of several thermal programs is required because no one program exists which performs all the required functions (fig. 7). The analyzers (e.g., SINDA, NTA) generally do not calculate the radiant inputs to the thermal model. That is, in general, a special-purpose program such as TRASYS is required to provide the radiant energy to the model from the Sun and planets. In addition, most of the analyzers contain (at best) only a limited capability to calculate radiant interchange factors. Some additional capability in this area has recently been added to the MSC NASTRAN by the addition of the VIEW program. The SPAR program is shown open-ended because currently there is significant on-going activity to extend SPAR capabilities.

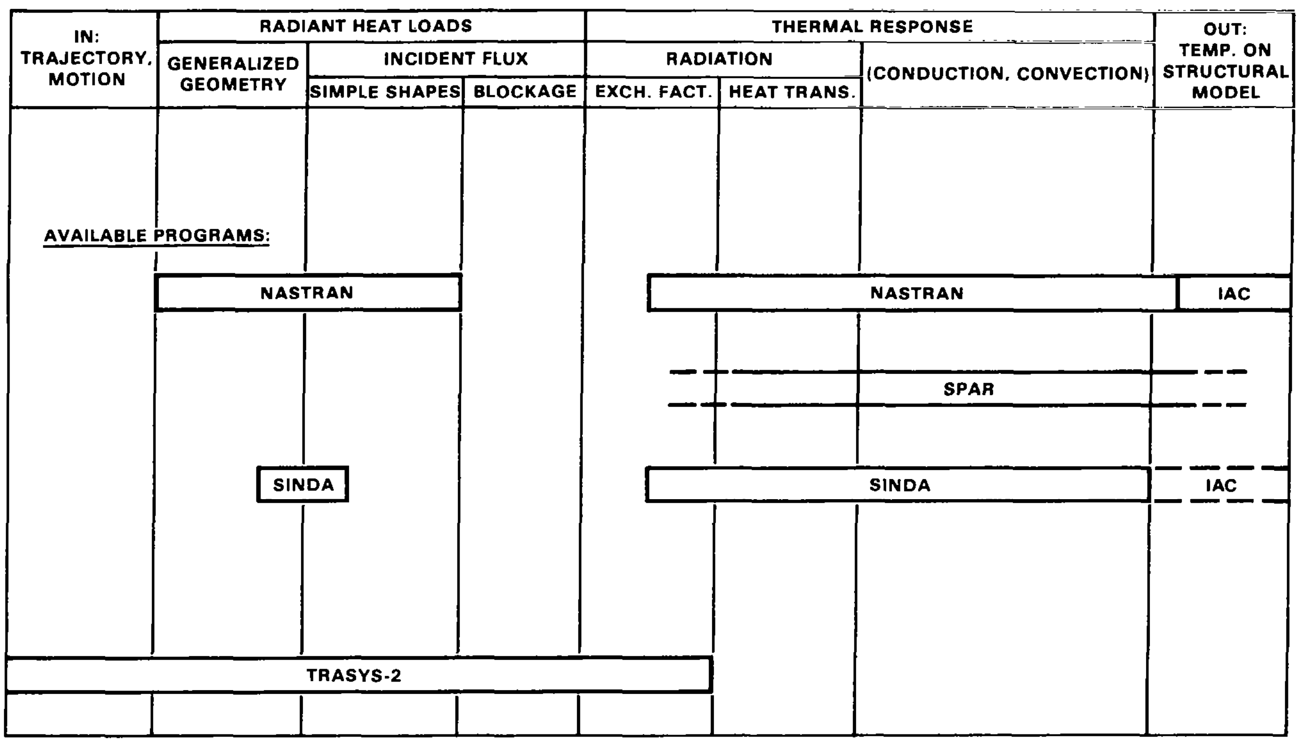


Figure 7

THERMAL ANALYSIS MODULES AND DATA FLOW

The thermal process is envisioned as beginning with a basic finite-element structural model (fig. 8). Engineering intervention is required to add some thermal data at this point. From this point, part of the data is transferred to the region where the radiant interchanges are computed. Meanwhile the user now has a choice as to which thermal analyzer he wishes to run. If he chooses SINDA, the finite-element data must be converted to a finite-difference format. Once the thermal analyzer has been run, its output can be converted to temperatures at the structural model grid points so that further processing can occur.

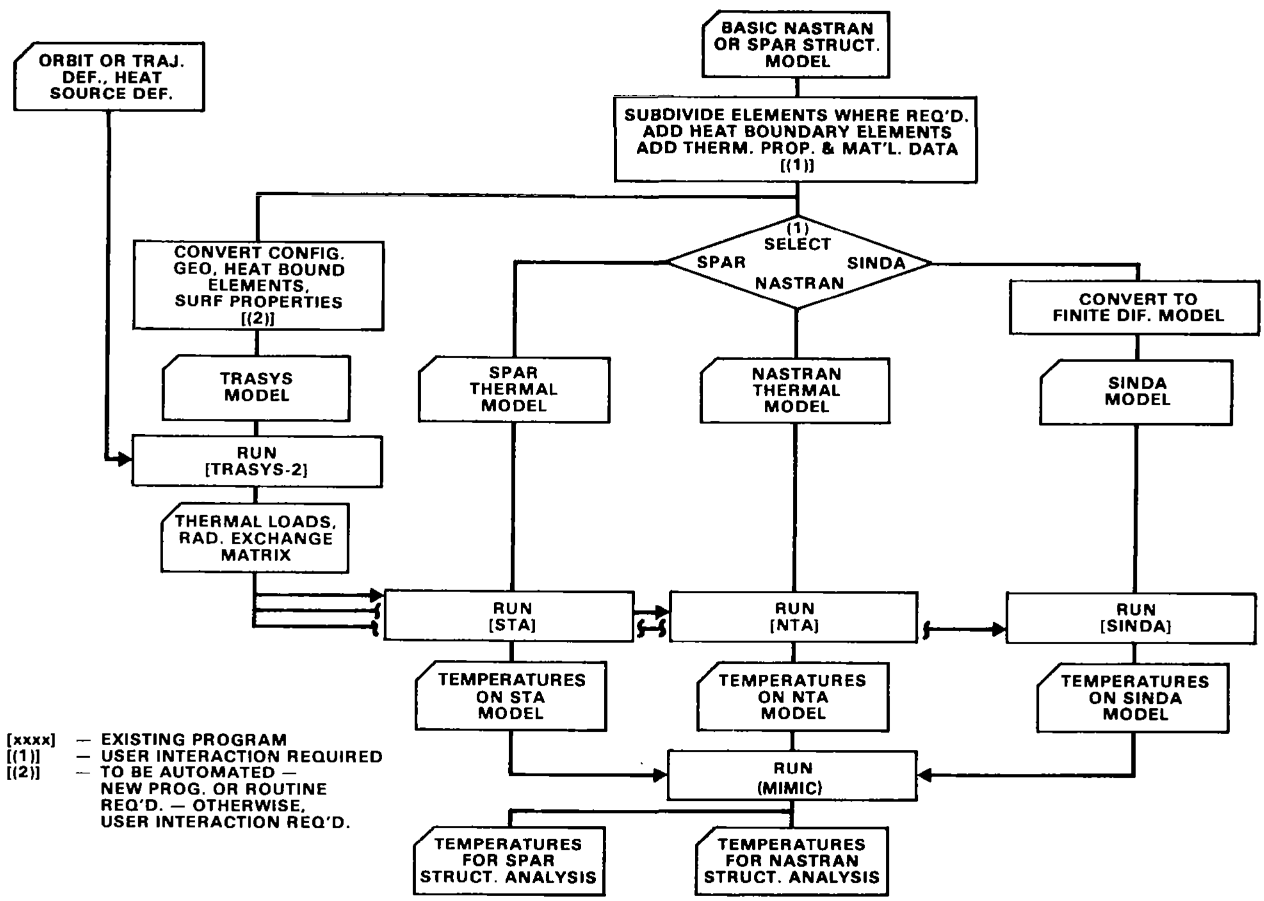


Figure 8

THERMAL ANALYSIS VIA THERMAL MODES

The investigation of the concept of thermal modes was intially motivated by a desire to be able to include thermal effects in coupled-structure thermal-controls stability analyses. Conventional thermal analysis methods are ill-suited for such coupled-system dynamic analysis. This technique also appeared to have considerable potential for problem size truncation in transient thermal analyses. In this application, it was spectulated that a large number of thermal modes could be discarded prior to performing the transient analysis with little effect on the results (fig. 9).

WHY :

1. **POTENTIAL FOR PROBLEM SIZE TRUNCATION**
2. **APPLICATION TO COUPLED THERMAL-STRUCTURE-CONTROLS PROBLEMS**

Figure 9

ACTIVITY TO DATE

Much of the work on thermal modes presented herein was performed by a contractor, John Anderes, of Swales and Associates. Papers and reports were reviewed and several different thermal mode formulations were investigated. The CAVE (conduction analysis via eigenvalues) formulation was used in the CAVE III thermal analysis code developed for LaRC by Grumman Aerospace Corportion. In a recent paper (ref. 1), H. P. Frisch of GSFC presented a formulation of the thermal heat balance equation for thermal mode solution that included linearized radiation. This reported activity has resulted in the formulation of a more generalized thermal mode technique, as described in figure 10, that was implemented using NASTRAN combined with DMAP to obtain the desired matrix data. Then a general-purpose matrix code, titled FLAME, was used to solve the matrix equation for nodal tempertures. Two test problems were defined and solved:

1. A 10-node slab problem was selected from the CAVE III report. This one-dimensional problem had only conduction coupling.

2. A 55-node parabolic dish antenna model was available from previous IAC studies. This 3-dimensional problem had both conduction and nonlinear radiation coupling.

- REVIEW OF SEVERAL DIFFERENT THERMAL MODE FORMULATIONS
  - CAVE (LaRC)
  - FRISCH (GSFC)
- IMPLEMENTATION OF CODE TO FIND THERMAL MODES AND TO SOLVE THE RESULTING MODAL EQUATIONS
  - NASTRAN THERMAL ANALYZER, DMAP
  - FLAME
- TRIAL SOLUTIONS AND COMPARISONS WITH CONVENTIONAL TECHNIQUE
  - SLAB, 10 NODE, ONE DIMENSION, CONDUCTION
  - PARABOLIC DISH, 55 NODE, 3-D, CONDUCTION & RADIATION

Figure 10

TECHNIQUE

The basic thermal equation used in this investigation was the formulation developed for the NASTRAN thermal analyzer (NTA) (fig. 11). This formulation supports both linear and nonlinear radiation coupling. In this formulation the nonlinear radiation terms are included on the right side of the equation in a forcing function role. The right side of the equation was set equal to zero and the eigenvalue and eigenvectors were determined using the EISPAK eigensolvers in FLAME. These eigenvalues and temperature patterns (eigenvector) may be physically interpreted by considering a structural analogy. If an undamped structure is physically deformed into one of its structural mode shapes and then released, it will vibrate indefinitely with that shape at the frequency of that mode. Likewise, if a structure is given an initial thermal pattern (distribution) of one of its thermal modes, referenced to some mean temperature, the transient nodal temperatures will decay to the mean temperature with a time constant equal to the reciprocal of the eigenvalue. During this transient period, the thermal pattern will maintain its original shape and only its magnitude will change.

- BASIC EQUATION:

$$B\dot{T} + KT = P + N(T)$$

T — NODAL TEMPERATURES
B — HEAT CAPACITANCE MATRIX
K — HEAT CONDUCTION PLUS LINEARIZED RADIATION MATRIX
P — THERMAL INPUT MATRIX
N — NON LINEAR RADIATION TERMS

- SET RIGHT SIDE EQUAL TO ZERO AND ASSUME A SOLUTION:

$$T = \phi e^{-\lambda t}$$

- THE REDUCED EQUATION IS THEN:

$$\left\{ B^{-1} K - \lambda I \right\} \phi = 0$$

- USE EIGENSOLVER TO GET

λ_i — EIGENVALUES (DECAY CONSTANTS)
ϕ_i — EIGENVECTORS (TEMPERATURE PATTERNS)

Figure 11

PARABOLIC DISH MODEL

Two thermal transient problems were solved via thermal modes. The more complex analysis used an NTA model of a parabolic dish (fig. 12). The model contained 55 grid points and the analysis included both conduction and nonlinear radiation coupling. Topologically the model consisted of a parabolic dish, a feed assembly, and a pedestal which is partially obscured in this hidden-line plot.

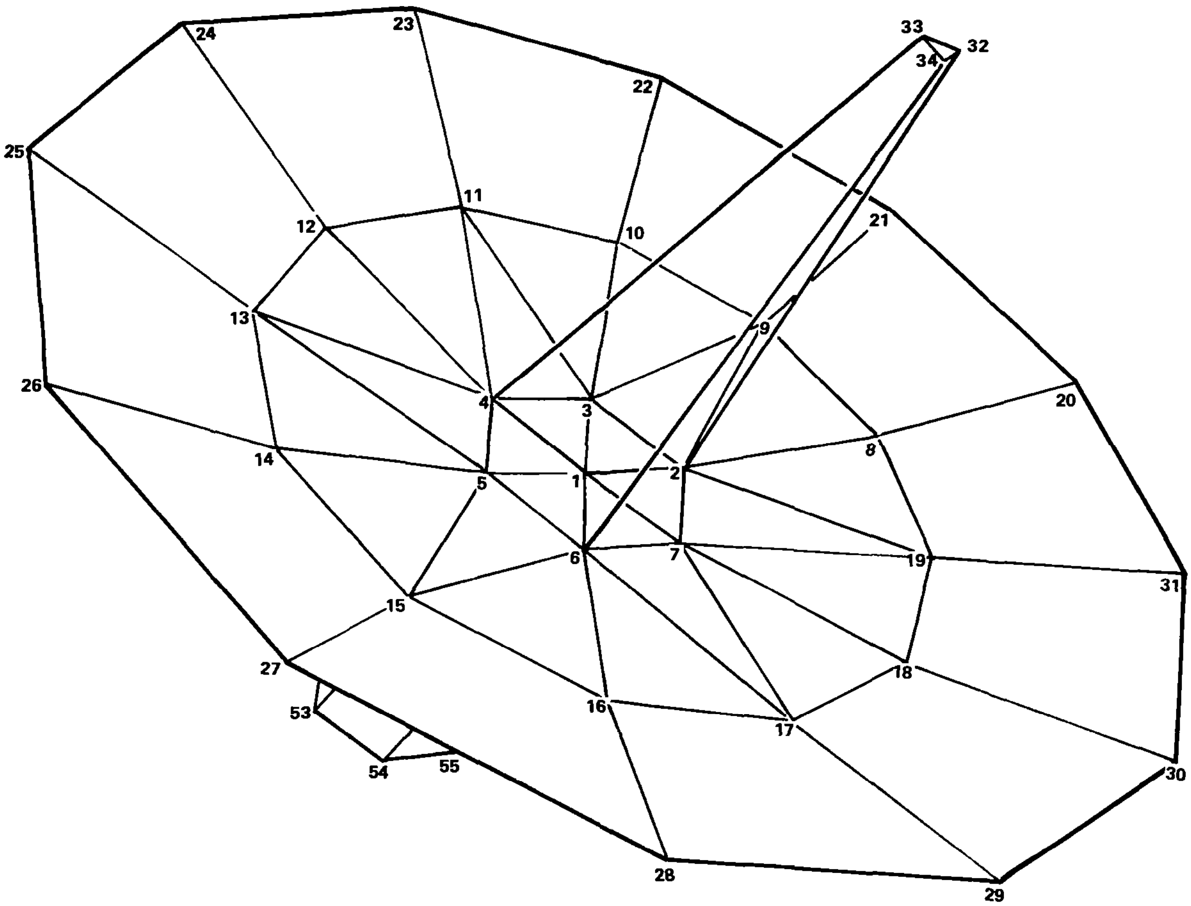


Figure 12

PARABOLIC DISH-THERMAL MODE 1

The visualization of thermal modes on a conventional black-and-white graphic terminal would be difficult. For this study we used the MOVIE.BYU graphics software together with a 512 x 512 color raster display system. The first thermal mode of the parabolic dish is shown in figure 13. The lightest shade (maximum yellow) represents +1° and the darkest shade (maximum blue) represents -1°. The black lines on the plot are contour lines representing 0.5° increments. The decay constant for this mode is 1.6×10^5 sec. The decay constants for the other 54 modes range from 0.59×10^5 sec to 0.0039×10^5 sec.

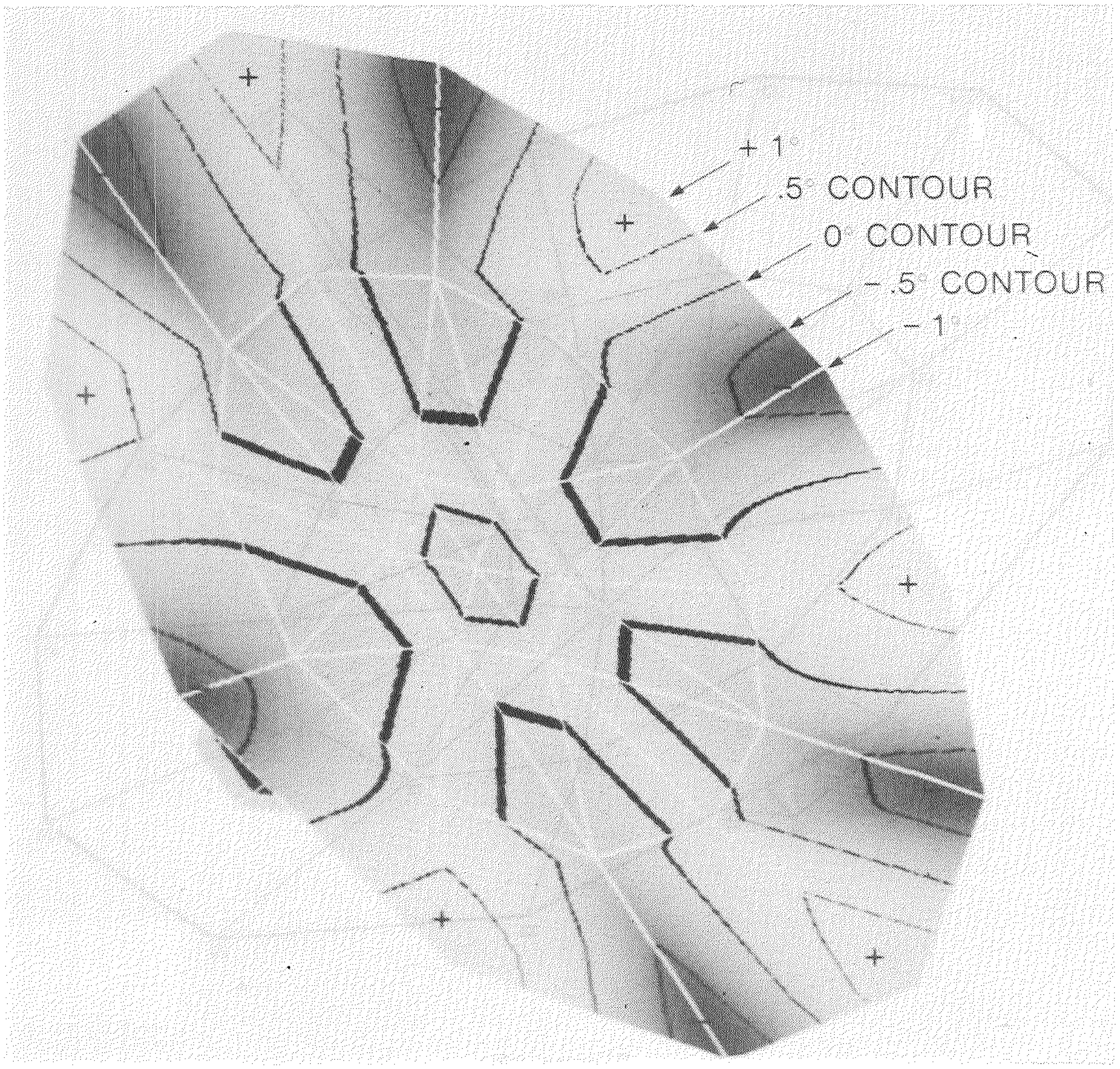


Figure 13

The antenna dish transient problem consisted of calculating the temperature changes of the dish from an initial temperature of 23.5° with in-orbit flux input and nonlinear radiation (fig. 14). The modal solution using all thermal modes (55) was found to match exactly the solution found via conventional analysis. Computer runs investigating the effects of truncating the modal set are in progress. For example, the predicted response of the pedestal end points using the lower 36 modes almost exactly matches the results using all 55 thermal modes. At this point in time, however, we have developed no firm criteria to select modes to be retained.

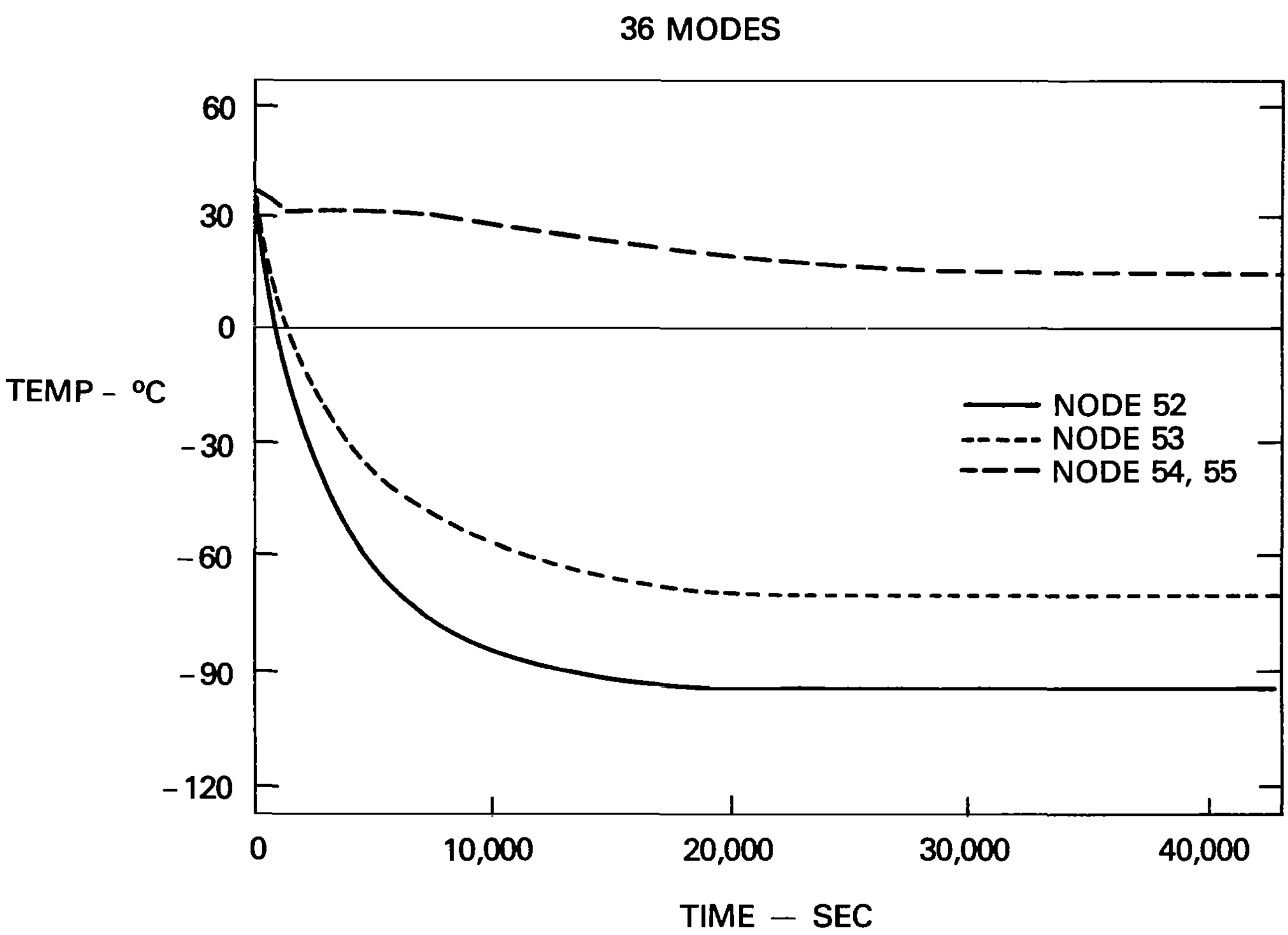


Figure 14

RUN TIME PERFORMANCE-PARABOLIC DISH

Presented in figure 15 is a comparison of the CPU time involved in three different analyses of the antenna dish (that is, conventional method, thermal mode using all 55 modes, and thermal mode using the first 36 thermal modes). As was expected, truncation of the modal set reduces the CPU run time. Surprisingly, the modal solution using all 55 modes was somewhat quicker than the conventional direct solution. At this point in time the thermal mode technique shows promise of being more efficient than the conventional direct solution, but additional experience using thermal modes must be obtained before any firm conclusions can be reached.

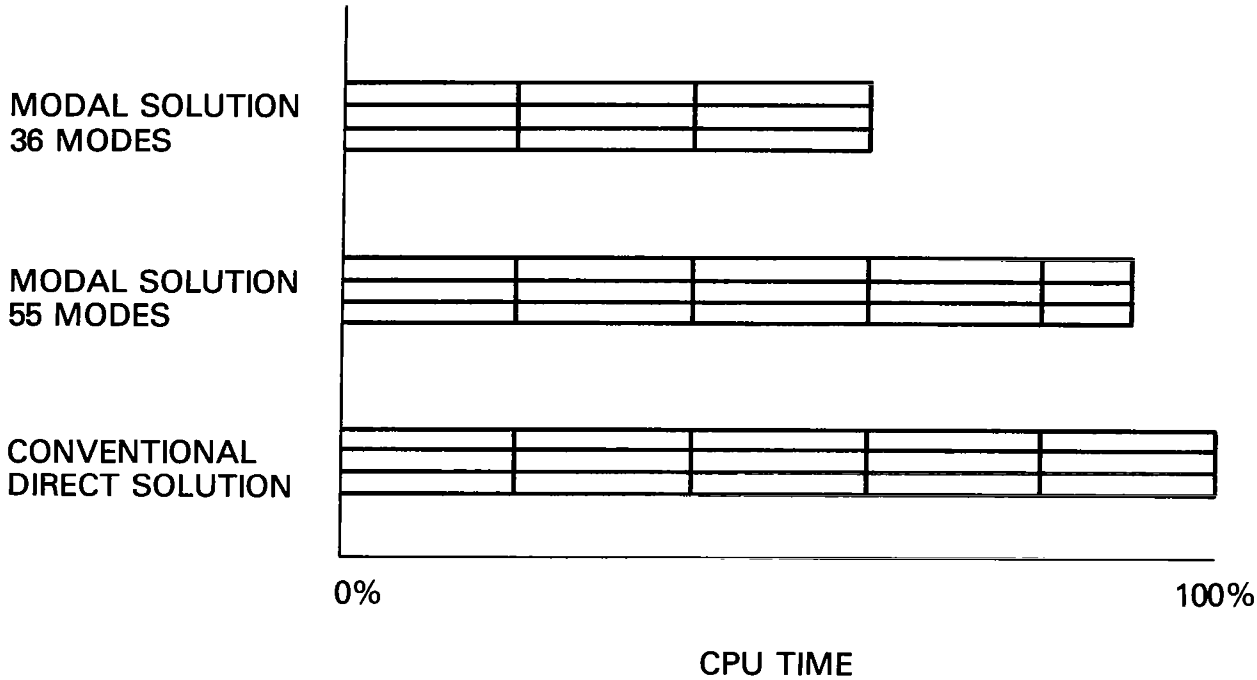


Figure 15

ANTICIPATED FUTURE ACTIVITY

With the completion of this study, the fundamental validity, practicality, and means for implementation of the thermal mode process have been demonstrated. Projected future activity will consist of evaluating the technique on larger real-world problems, developing an understanding of the mode selection process, and developing interfaces to other thermal analysis codes, i.e., SPAR and SINDA (fig. 16).

- EVALUATE TECHNIQUE FOR LARGER REAL WORLD PROBLEMS
- DEVELOP UNDERSTANDING TO ENABLE EFFICIENT MODE SELECTION
- DEVELOP INTERFACES TO OTHER THERMAL ANALYSIS CODES (I.E., SPAR, SINDA)

Figure 16

REFERENCE

1. Frisch, H. P.: Thermally Induced Response of Flexible Structures: A Method for Analysis. J. Guidance and Control, Vol. 3, No. 1, Jan. - Feb. 1980.