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THERMAL ANALYSIS RESEARCH APPLICABLE TO SPACE STATION TECHNOLOGY NEEDS

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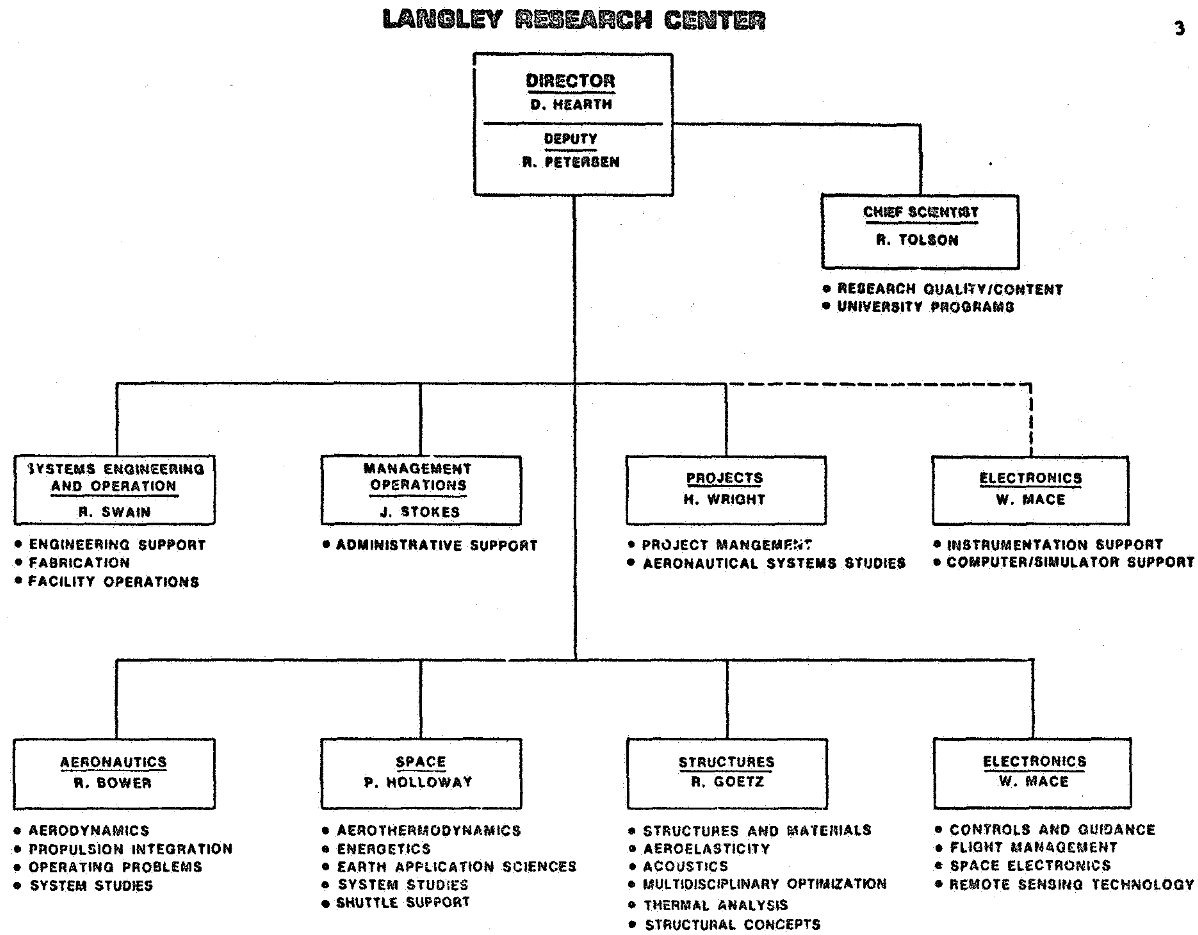
FOREWORD

This paper contains the figures and accompanying narrative material from the presentation to the thermal panel at the NASA Space Station Technology Workshop held in Williamsburg, Virginia, March 28-31, 1983. The presentation summarized thermal analysis, optimization, and software research and development at the NASA Langley Research Center which is applicable to analytical design calculations for space station structures. Topics discussed include integrated thermal-structural software, improved thermal radiation analysis, solution techniques for transient temperatures, unified thermal-structural finite elements, thermal-structural sensitivity analysis and optimization, and concept and performance analysis for heat pipes.

LANGLEY RESEARCH CENTER

The Thermal Analysis Research at Langley which will be discussed herein and is applicable to space station technology needs is being carried out primarily in the Structures Directorate. Some related thermal work which is involved with developing software for systems analysis and trade studies is the responsibility of the Space Directorate and will be briefly discussed. Figure 1 indicates the overall Langley organization, the principal missions of the organizations and particularly for the purpose of this presentation the responsibilities of the Structures and Space Directorates.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• SHUTTLE SUPPORT
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R. GOETZ
• STRUCTURES AND MATERIALS
• AEROELASTICITY
• ACOUSTICS
• MULTIDISCIPLINARY OPTIMIZATION
• THERMAL ANALYSIS
• STRUCTURAL CONCEPTS
ELECTRONICS
W. MACE
• CONTROLS AND GUIDANCE
• FLIGHT MANAGEMENT
• SPACE ELECTRONICS
• REMOTE SENSING TECHNOLOGY

Figure 1

LANGLEY R&T EFFORTS RELATED TO SPACE STATION THERMAL MANAGEMENT

gure 2 contains a breakdown showing the research and technology activities thermal-related areas being performed in the Structures and Space rectorates. The work to be described herein is primarily that of the Loads d Aeroelasticity Divsion and the Space Systems Division. Related work in e Structures and Dynamics Division and the Materials Division is being vered in other panels at this workshop.

LaRC R & T EFFORTS RELATED TO SPACE STATION THERMAL MANAGEMENT

- STRUCTURES DIRECTORATE (GOETZ)
  - LOADS AND AEROELASTICITY DIVISION (DIXON)
    - — THERMAL ANALYSIS
    - — MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION
    - — HEAT-PIPE SANDWICH STRUCTURE
  - STRUCTURES AND DYNAMICS DIVISION (CARD)
    - — GEOMETRY, GRAPHICS, DATA MANAGEMENT (IPAD)
    - — STRUCTURAL CONCEPTS
  - MATERIALS DIVISION (BLANKENSHIP)
    - — THERMAL CONTROL COATINGS
    - — COMPOSITES FOR LEO APPLICATIONS
- SPACE DIRECTORATE (HOLLOWAY)
  - SPACE SYSTEMS DIVISION (WALBERG)
    - — DESIGN STUDIES

Figure 2

ELEMENTS AND INTERACTIONS IN THERMAL-STRUCTURAL ANALYSIS

As a guide to subsequent discussions of research in thermal-structural analysis of space structures, figure 3 depicts various aspects of the analysis. Key areas of research include efficient view factor and flux calculations and proper accounting for interactions. Two important interactions cited are the need to simultaneously monitor and control the temperature distribution and shape of flexible orbiting structures such as antennas and the need to evaluate the coupling between thermal deformations and radiation view factors in flexible structures.

ELEMENTS AND INTERACTIONS IN THERMAL-STRUCTURAL ANALYSIS

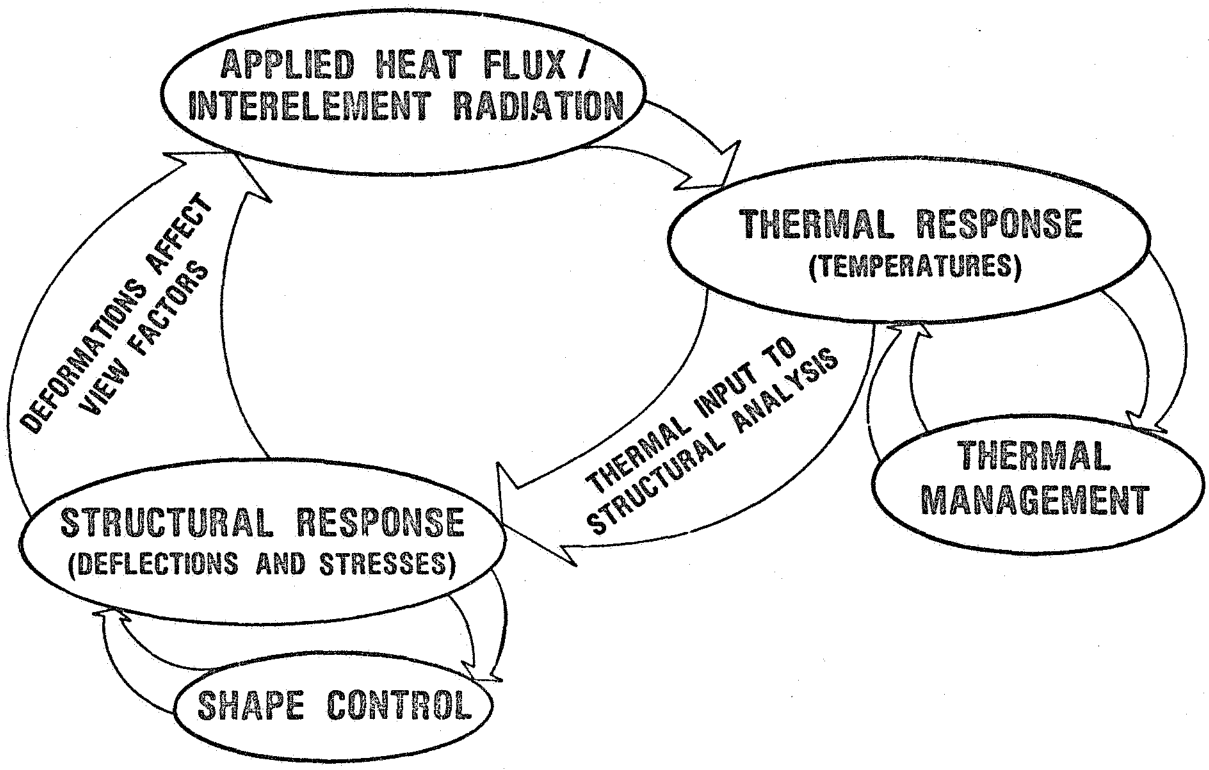


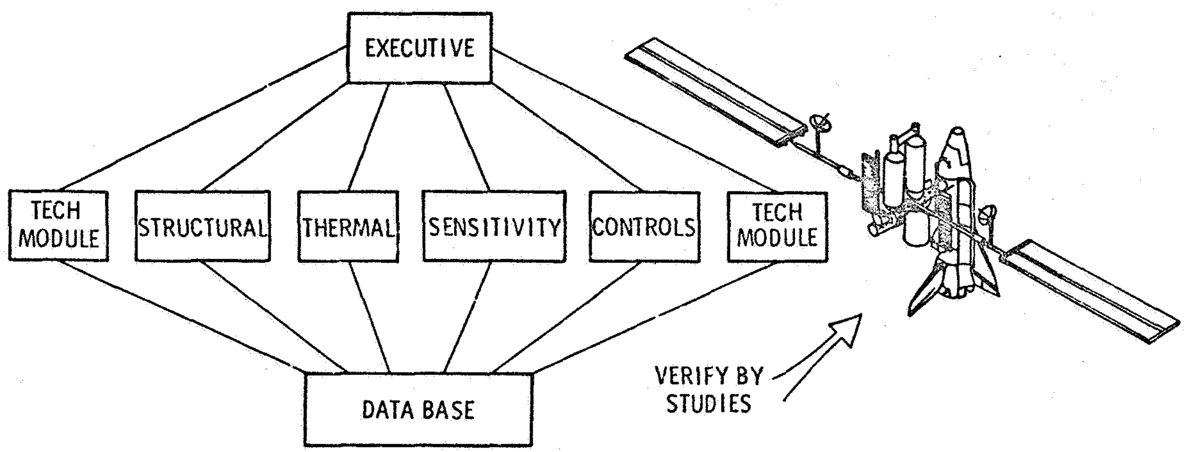
Figure 3

INTEGRATED ANALYSIS AND OPTIMIZATION

The guiding strategy for development of integrated analysis and optimization capability is to first develop sound analysis methods for thermal, structural, sensitivity derivatives, etc. The methods are used to upgrade existing capability which can in turn be integrated in a multidisciplinary analysis and optimization system (fig. 4). Design studies provide guidelines on modeling techniques for thermal-structural analysis and lead to assessments of analysis methods by comparison with available test data. These studies should not be confused with the systems and trade studies carried out by the Space Systems Division at Langley.

INTEGRATED ANALYSIS AND OPTIMIZATION

- METHOD DEVELOPMENT
- DESIGN STUDIES



- DEVELOP AND EVALUATE MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION METHODS
- MODELING GUIDELINES
- ANALYSIS/TEST CORRELATIONS

Figure 4

ELEMENTS OF RESEARCH PROGRAM FOR THERMAL ANALYSIS AND OPTIMIZATION

Figure 5 lists the elements of the research program at Langley and serves as an outline of the remainder of the presentation. A major emphasis is being placed on the implementation of the concept of integrated finite-element thermal-structural analysis. The vehicle for this implementation is the SPAR thermal analyzer. The development and incorporation of an efficient radiation view factor computational module is a principal step in this implementation. Research in improved solution methods (algorithms) and approximate techniques such as the reduced basis method is aimed at speeding up the calculation of temperatures in complex structures. Improvements in thermal modeling are focused on unified thermal structural finite elements in which the output from a thermal finite element is tailored to the requirements of the structural finite element used for the subsequent stress and deformation analysis. Sensitivity analysis methods are geared toward providing engineering data on the effect of structural or material property changes on the thermal and structural response. Thermal-structural optimization research is a subset of a larger program to apply optimization methods to multidisciplinary problems (an area being covered in the structures panel). Finally some research on the concept of heat-pipe sandwich panels and analysis methods for heat pipes is being pursued.

ELEMENTS OF RESEARCH PROGRAM FOR THERMAL ANALYSIS AND OPTIMIZATION

- SPAR THERMAL ANALYZER DEVELOPMENT
- IMPROVED RADIATION ANALYSIS
- SOLUTION METHODS FOR TRANSIENT TEMPERATURES
- APPROXIMATE THERMAL ANALYSIS TECHNIQUES
- UNIFIED THERMAL-STRUCTURAL FINITE ELEMENTS
- SENSITIVITY ANALYSIS
- THERMAL-STRUCTURAL OPTIMIZATION
- HEAT PIPE SANDWICH PANEL CONCEPT STUDIES

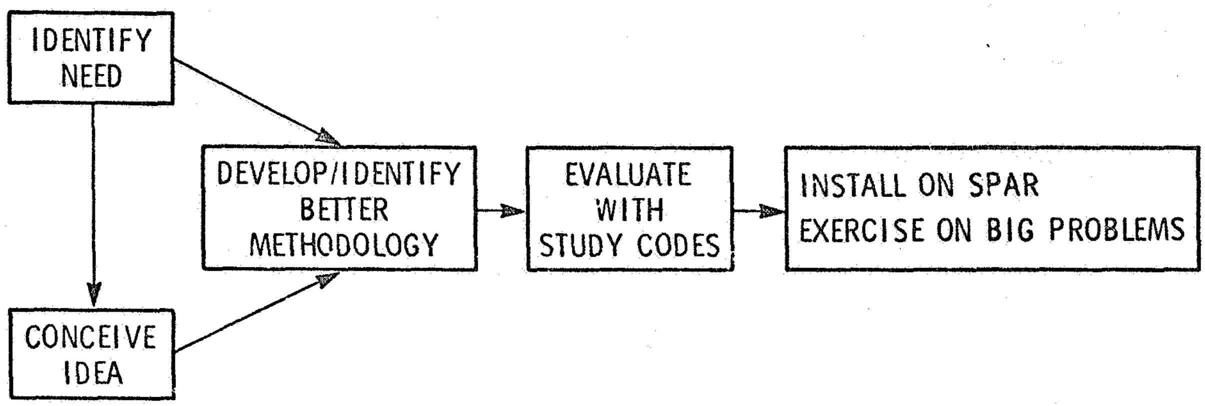
Figure 5

THERMAL-STRUCTURAL ANALYSIS CAPABILITY DEVELOPMENT

Our approach to developing and validating thermal-structural analysis capability (fig. 6) is to first identify needs and then evaluate (with small study codes) existing methods which are identified or new methods conceived to meet the needs. These evaluations are followed (provided the evaluations are encouraging) by installation in the SPAR/EAL programs so that they can be further evaluated on large problems which will challenge the methods. The capability is then ready in SPAR/EAL for further use. An example of the above process is an improved radiation view factor capability. The process has reached the final R&T step--installation of the capability in SPAR.

THERMAL-STRUCTURAL ANALYSIS CAPABILITY DEVELOPMENT

- OVERALL APPROACH



- RECENT EXAMPLE — IMPROVED RADIATION VIEW FACTOR CALCULATIONS
  - NEED — FASTER CALCULATION OF VIEW FACTORS
  - IDEA — SEVERAL NOVEL TECHNIQUES
  - BETTER METHODOLOGY — PROGRAM "VIEW" DEVELOPED UNDER NASA GRANT WITH U. OF WASHINGTON
  - EVALUATED VIEW ON LARGE LDEF THERMAL MODEL
  - VIEW BEING INSTALLED IN SPAR FY 83

Figure 6

SPAR THERMAL ANALYZER

To provide a general in-house integrated thermal-structural analysis capability the Langley Research Center has had the SPAR Thermal Analyzer developed under contract by Engineering Information Systems, Inc. (EISI). The SPAR Thermal Analyzer is a system of finite-element processors for performing steady-state and transient thermal analyses. The processors communicate with each other through the SPAR random access data base. As each processor is executed, all pertinent source data is extracted from the data base and results are stored in the data base (fig. 7).

The tabular input (TAB), element definition (ELD) and arithmetic utility system (AUS) processors are used to describe the finite-element model. The data base utility (DCU) processor operates on the data base. The plotting processors (PLTA, PLTB) provide the capability to plot the finite-element model for model verification. The thermal geometry (TGEO) processor performs geometry checking of the thermal elements and total model. The thermal processor for steady-state analysis is denoted SSTA and the transient analysis processors using the explicit algorithm, implicit algorithms with fixed time step, and implicit algorithms with variable time steps are denoted TRTA, TRTB and TRTG, respectively. In addition there are several processors not shown in the figure for extraction of thermal fluxes, system matrices and system operating characteristics.

The processors may be executed interactively or in a batch mode. A typical analysis is usually performed as a sequence of interactive and batch operations where model development and verification is performed interactively and actual thermal calculations performed in batch mode. The program operates on UNIVAC, CDC, PRIME, and VAX computers.

The dotted box at the bottome fo the figure indicates that a direct connection is available to the EAL/SPAR structural analysis program, thus providing a compatible integrated thermal-structural analysis tool.

SPAR THERMAL ANALYZER

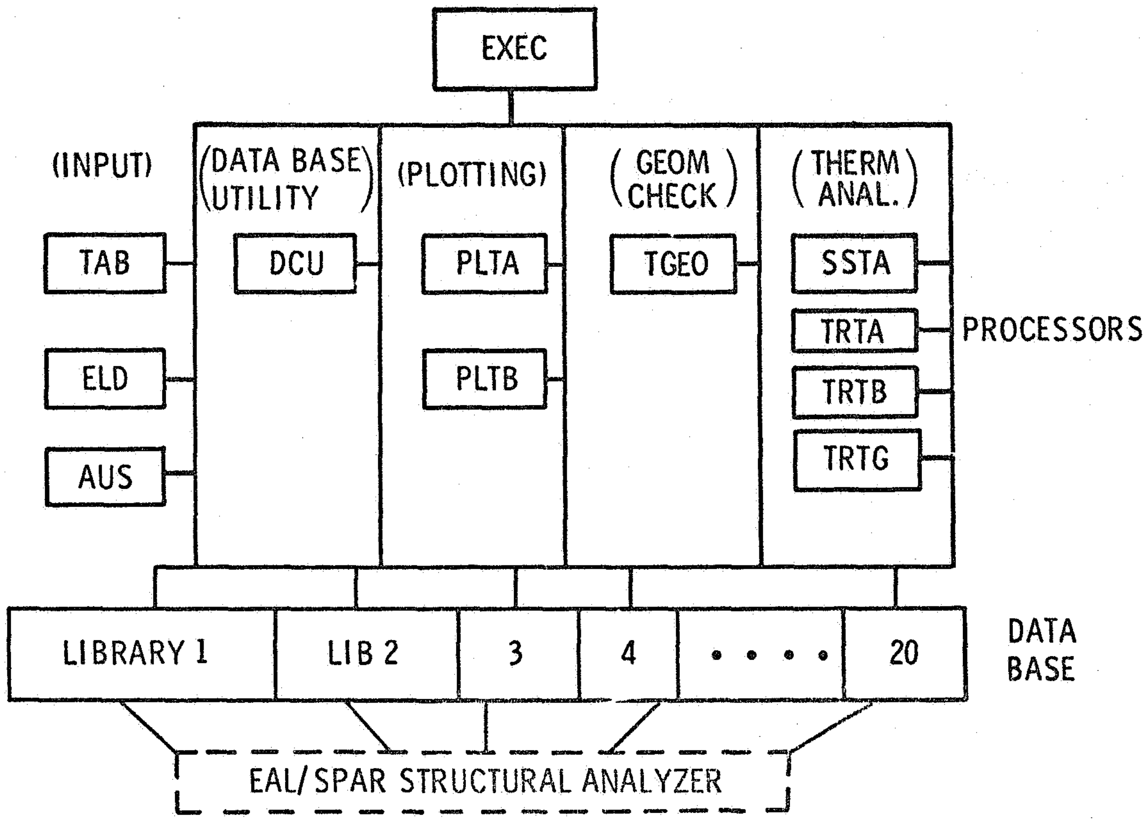


Figure 7

BASIC CAPABILITY AND CHARACTERISTICS OF SPAR

The overall capability and characteristics of the SPAR/EAL system are summarized in figure 8. The general-purpose production-level character of the system along with its flexibility make it especially useful for in-house research applications. A number of other organizations within and outside NASA are also showing interest in SPAR. Of particular note, NASA Dryden Flight Research Facility made extensive use of SPAR for Shuttle thermal analysis and have since adopted it as their primary thermal analysis computer program.

The SPAR thermal analyzer is maintained by EISI under Langley contract and new capability developed in our research program is installed in SPAR under this contract. Current and future tasks for implementation of new capability are shown in figure 9.

BASIC CAPABILITY AND CHARACTERISTICS OF SPAR/EAL

- PRODUCTION FINITE-ELEMENT PROGRAM
- STEADY-STATE AND TRANSIENT THERMAL ANALYSIS
- STATIC AND DYNAMIC STRUCTURAL ANALYSIS
- MODULAR AND INTERACTIVE
- PLOTTING CAPABILITY
- INTERNAL DATA BASE (NONRELATIONAL)
- EXPERIMENTAL ELEMENTS
- USER-CONTROLLED OPERATION SEQUENCE
- USED BY NASA (LANGLEY, DRYDEN, MSFC) AIRFORCE, INDUSTRY
- UNDER STUDY AT JOHNSON AND GODDARD

Figure 8

NEW SPAR THERMAL ANALYZER CAPABILITY

- CURRENT TASKS
  - EMBEDDED VIEW FACTOR CALCULATIONS
  - NATURAL CONVECTION
  - FLUID NETWORK PRESSURE CALCULATIONS
- FUTURE TASK
  - MULTIPHASE EFFECTS
  - THERMAL-TO-STRUCTURAL MODEL TEMPERATURE INTERPOLATION

Figure 9

NEW RADIATION VIEW FACTOR CALCULATION TECHNIQUE MORE EFFICIENT

A research grant with the University of Washington has produced an efficient view factor computer program for radiant heat transfer analysis. The program has been exercised for a thermal model of the Long Duration Exposure Facility (LDEF) payload, to be carried in the Space Shuttle (see fig. 10). To do the radiant heat transfer analysis, radiation view factors must be calculated for more than 400 internal surfaces of the payload. The view factor calculations for LDEF are complicated by the internal reinforcing structural members which produce more than 100 internal surfaces which partially block radiation between the outer surfaces. More than 60,000 view factors must be calculated. Previously, view factors were calculated using a nonoptimized, in-house computer program which based calculations on summing a large number of piecewise-constant approximations to the surface integrals which define the view factors. This computer program required about 30 hours on the CDC-6600 computer. The University of Washington program required about 30 minutes on the Cyber 203 computer. Since the Cyber 203 computer is about twice as fast as the CDC 6600, the new program decreased computer time by a factor of about 30. The increased speed in the University of Washington program is primarily due to the use of a contour integration algorithm which is considerably faster than the surface integral technique used in the in-house program. The capability to include solar radiation and umbra-penumbra effects is planned for incorporation into the view factor program. The new view factor program will be put in the COSMIC system and as previously mentioned is being incorporated into the SPAR thermal computer program.

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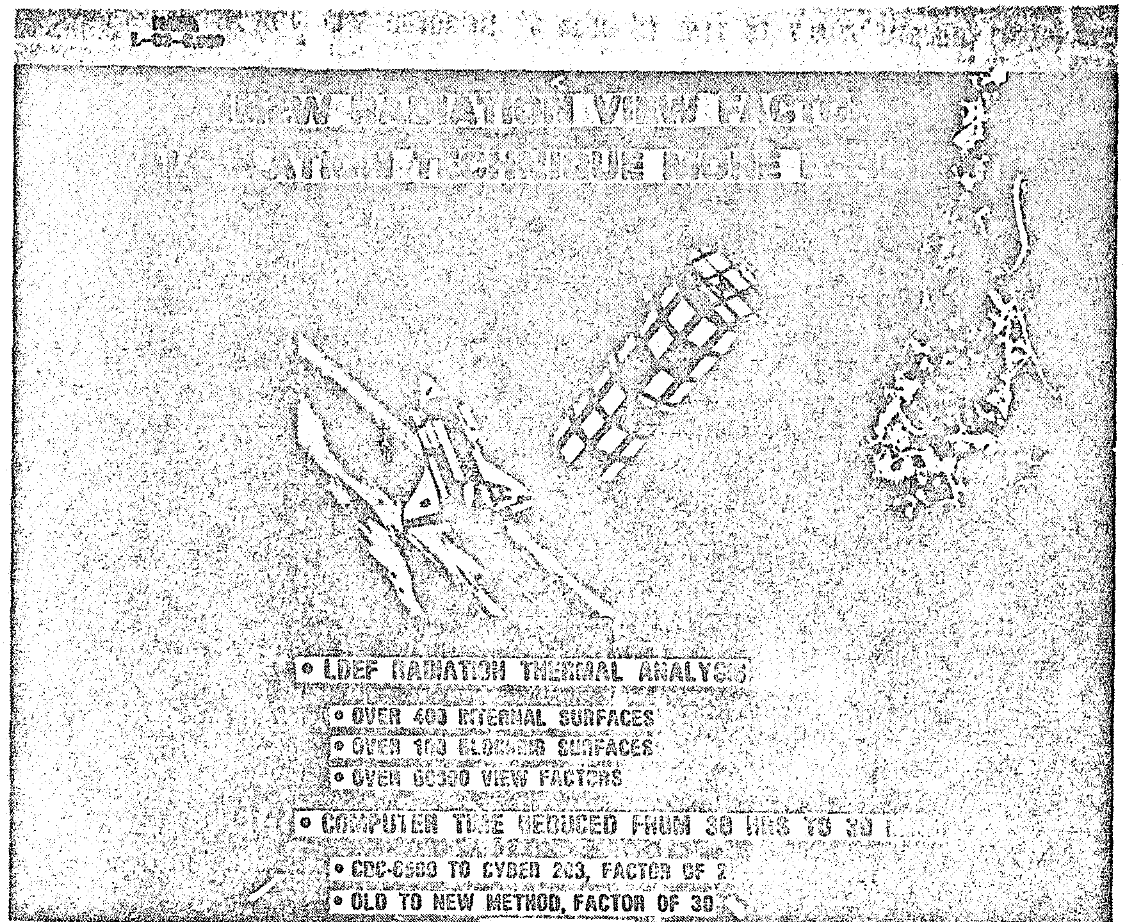

Figure 10

TRANSIENT THERMAL ANALYSIS TIME REDUCED BY IMPROVED SOLUTION METHOD

One important element of the Langley research program has been the implementation and verification of efficient solution algorithms. A set of implicit algorithms denoted GEARIB has been installed in SPAR. The desirable feature of the GEARIB technique is the ability to adaptively vary the step size throughout the temperature history. As indicated in figure 11, various algorithms were used to trace the 3500-second temperature history in a section of the Shuttle orbiter wing. Two models were considered: a two-dimensional section through the wing depth and a one-dimensional plug through the center of the two-dimensional model. Calculations for each model were carried out using explicit Euler and implicit backward differences as well as GEARIB. The explicit algorithm is burdened by the need to take small time steps (i.e., 0.1 seconds) to avoid numerical instability. The backward differences algorithm uses a larger but fixed time step of 1.0 second (determined by accuracy considerations). The GEARIB algorithm, by adaptively changing its time step to as much as 218 seconds, obtained solutions with significantly less computer time than the two previous methods. Additional results (not shown) were obtained using a lumped-parameter thermal analyzer (MITAS) and indicated that for consistent models, solution methods, and accuracy levels, SPAR and MITAS solution times are comparable. Thus, it is expected that use of GEARIB in this type of analyzer would lead to efficiency improvements similar to those obtained in the finite-element program.

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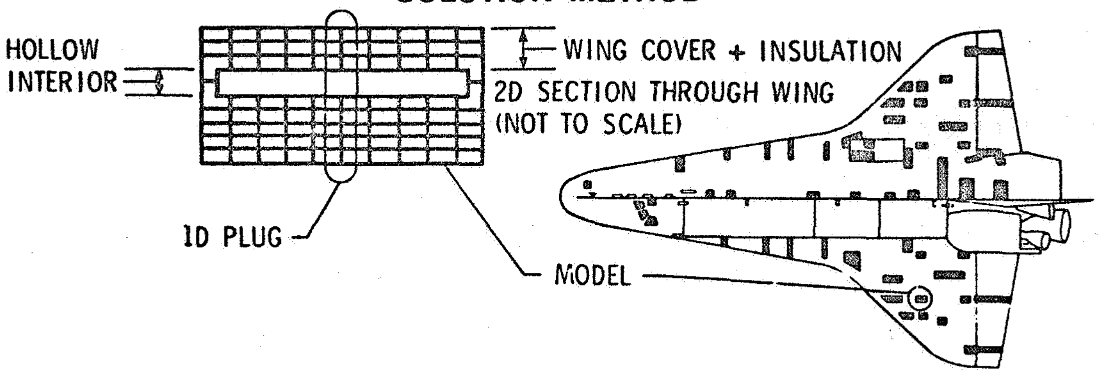
TRANSIENT THERMAL ANALYSIS TIME REDUCED BY IMPROVED SOLUTION METHOD



SOLUTION TIMES* FOR 3500 s TEMPERATURE HISTORY				
MODEL / METHOD	1D PLUG		2D SECTION	
	TIME STEP	SOLUTION TIME	TIME STEP	SOLUTION TIME
EULER-EXPLICIT	0.1	1723	0.1	3205
BACKWARD DIFFERENCES-IMPLICIT FIXED TIME STEP	1.0	256	1.0	1145
GEARIB-IMPLICIT VARIABLE TIME STEP	0.85-218	63	0.1-225	245

*ALL TIMES IN SECONDS

Figure 11

APPLICATION OF REDUCED-BASIS METHOD TO TRANSIENT THERMAL ANALYSIS

Along with implementing improved solution algorithms such as GEARIB, work has been initiated to develop approximate analysis techniques which have potential for significant reductions in solution effort. One such method is the reduced-basis technique which combines the classical Rayleigh-Ritz approximation with contemporary finite-element methods to retain modeling versatility as the degrees of freedom are reduced. The effectiveness of the method depends upon representation of local temperatures by a few modes or basis vectors. The reduced-basis technique has been successfully applied to the problem illustrated in figure 12. This problem represents a 58-in. segment of the lower surface of the Space Shuttle wing and consists of a 119-mil.-thick aluminum skin covered by 1 in. of insulation. The combined structure was modeled with two-dimensional, finite-elements with 84 node points (84 degrees of freedom). A heat pulse reasonably representative of Shuttle reentry was applied to the surface and produced temperatures where radiation becomes appreciable. Additionally, the thermal properties of the insultation are nonlinear functions of temperature and ambient pressure so that the heat transfer equations are highly nonlinear. A total of 23 thermal mode shapes were selected from solutions of two thermal eigenvalue problems: the first based on material properties evaluated for uniform temperatures at 560°R, and the second based on temperatures from a steady-state problem with averaged heating and thermal properties. The resulting temperatures are compared with temperatures obtained from a SPAR thermal analyzer solution of the full system of 84 equations. The temperature histories shown on the figure agree very well and indicate that the reduced-basis technique can approximate temperatures from the full system within 20°R over the entire heat pulse. Efforts are continuing to find the minimum number of basis vectors for acceptable temperatures and to demonstrate the technique for larger problems. Work is underway to apply the reduced-basis technique to the space antenna shown in the figure.

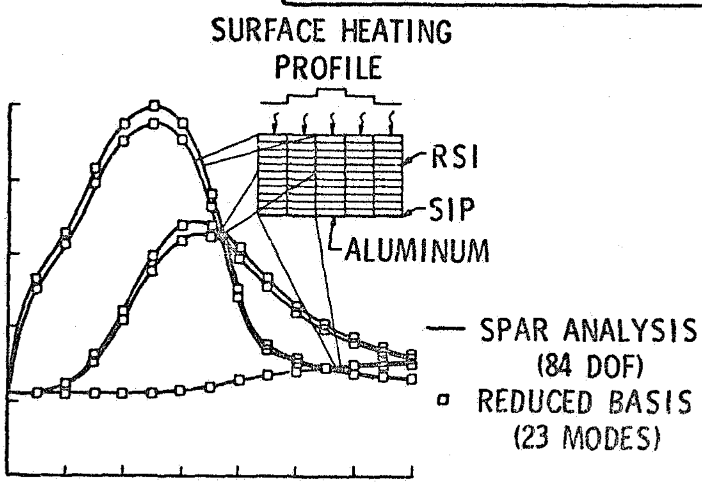
APPLICATION OF REDUCED BASIS METHOD TO TRANSIENT THERMAL ANALYSIS

$C\dot{T} + KT = Q$

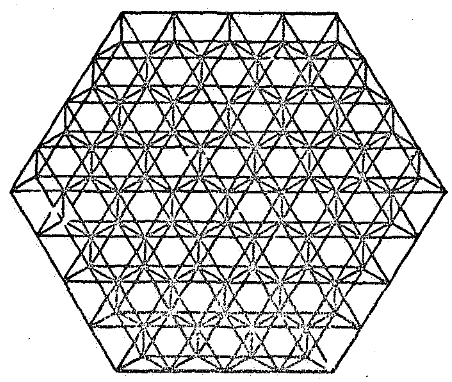
$T = \Gamma\psi$

$\bar{C}\dot{\psi} + \bar{K}\psi = \bar{Q}$

- FAR FEWER UNKNOWNS IN ψ THAN IN T
- KEY TO METHOD - CHOICE OF Γ



SHUTTLE WING BAY
(WORK COMPLETE)



RADIOMETER ANTENNA DISH -
IN PROGRESS

Figure 12

UNIFIED VERSUS CONVENTIONAL APPROACH TO THERMAL-STRUCTURAL ANALYSIS

Figure 13 illustrates the concept of unified thermal-structural finite-element analysis and how it differs from conventional thermal-structural analysis. In the conventional approach, a finite-difference (lumped parameter) analysis produces temperatures at the centroids of the lumps. The temperatures are supplied to the finite-element structural model. Before the structural analysis can be performed, it is necessary to transfer the temperatures to the grid points or elements of the finite-element grid points. Because of the difference between the thermal and structural models (they are based on different modeling philosophies and the grid points are not co-located), the temperature distributions in the structural model are not faithful representations of the distributions from the thermal analysis. In most cases, a linear representation is used. Consequently, inaccuracies in the thermal forces may be significant enough to cause large errors in structural responses.

In the unified approach, the thermal and structural analyses both use finite-element models. The two models need not be the same since interpolation can be used to transform temperatures from one finite-element gird to another. The temperature distributions from the thermal analysis are transferred to the structural analysis model and the same computer program is used for both analyses. Thus, it is possible to achieve a much higher accuracy in the calculation of the thermal forces and the resulting structural response.

The graphs in the lower center of the figure illustrate the increased accuracy resulting from a unified thermal-structural analysis of a fixed-free beam under thermal loading. The unified result is nearly coincident with the analytical solution whereas significant errors are present in the conventional solution for the reasons cited above.

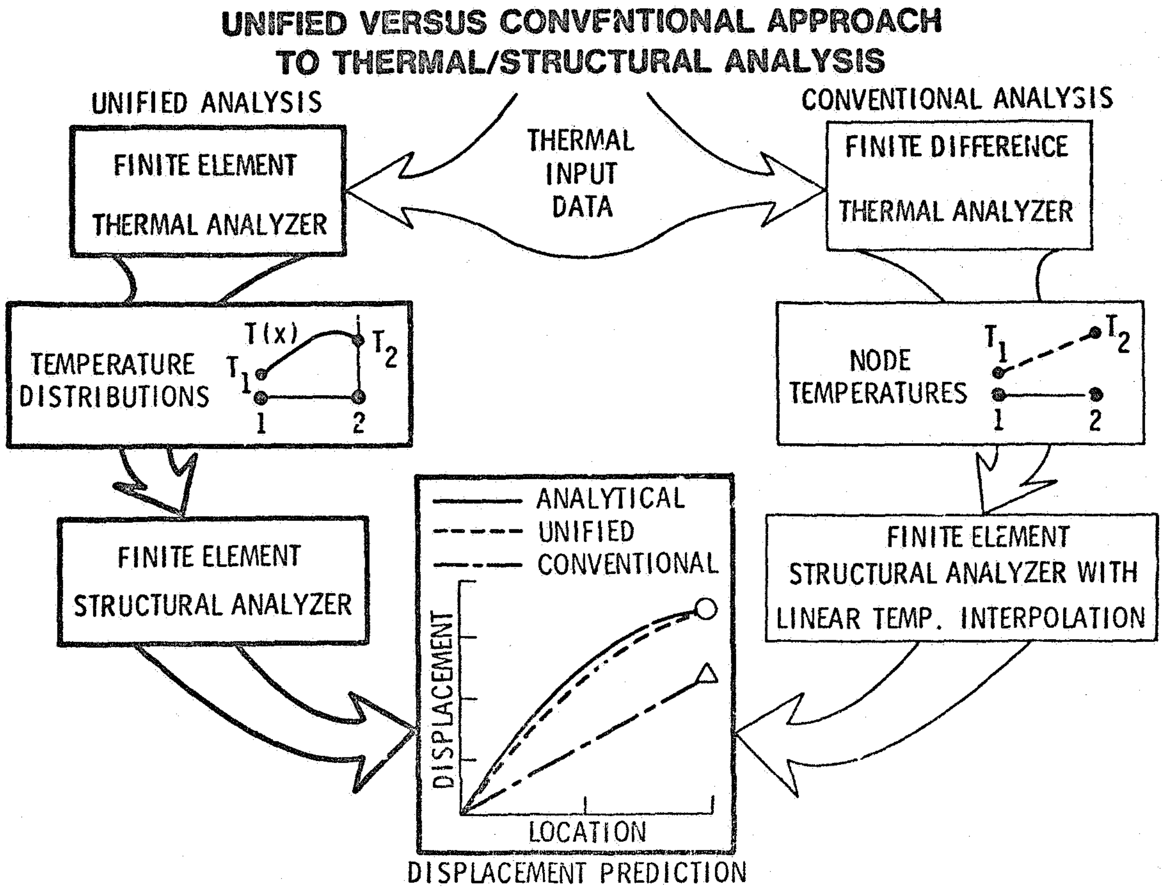

UNIFIED VERSUS CONVENTIONAL APPROACH
TO THERMAL/STRUCTURAL ANALYSIS
UNIFIED ANALYSIS
CONVENTIONAL ANALYSIS
THERMAL
INPUT
DATA
FINITE ELEMENT
THERMAL ANALYZER
FINITE DIFFERENCE
THERMAL ANALYZER
TEMPERATURE
DISTRIBUTIONS
T(x)
T1
T2
1
2
NODE
TEMPERATURES
T1
T2
1
2
FINITE ELEMENT
STRUCTURAL ANALYZER
FINITE ELEMENT
STRUCTURAL ANALYZER WITH
LINEAR TEMP. INTERPOLATION
ANALYTICAL
UNIFIED
CONVENTIONAL
DISPLACEMENT
LOCATION
DISPLACEMENT PREDICTION

Figure 13

SPACE SYSTEMS DIVISION COMPUTER-AIDED DESIGN AND ANALYSIS CAPABILITIES - IDEAS PROGRAM OVERVIEW

The IDEAS program (fig. 14) consists of 30 interdisciplinary applications modules that include structural, thermal, and control system modeling; on-orbit static, dynamic, and thermal loading analysis; structural-element design; surface accuracy analysis; antenna RF performance; and cost approximations. They reside on both mainframe and super minicomputer systems. Data files are transferable between the two computer systems. These modules are executable from remote interactive graphics terminals. Processing and data control are accomplished via simple efficient executive and data base programs and file management routines. User prompts for file names and unformatted data inputs are provided. CRT graphic displays of finite-element models and of summary information (temperature contours, element loading histograms, mode shapes, etc.) are presented to the user for immediate assessment and interactive modification of the spacecraft and/or mission as necessary.

The primary IDEAS modules and basic functions of each module are shown in figure 15. IDEAS was developed for multidiscipline spacecraft systems analysts as opposed to single discipline specialists or computer systems experts. The executive, data base/file management routines and applications modules were selected to provide a rapid, cost-effective computer-aided design and analysis capability for future large spacecraft systems concepts. The program is user friendly, prompting the analyst with queries or requests for unformatted input data, file names, processing paths, etc. The applications modules have been integrated to pass compatible, properly formatted files and data base information between single-discipline programs.

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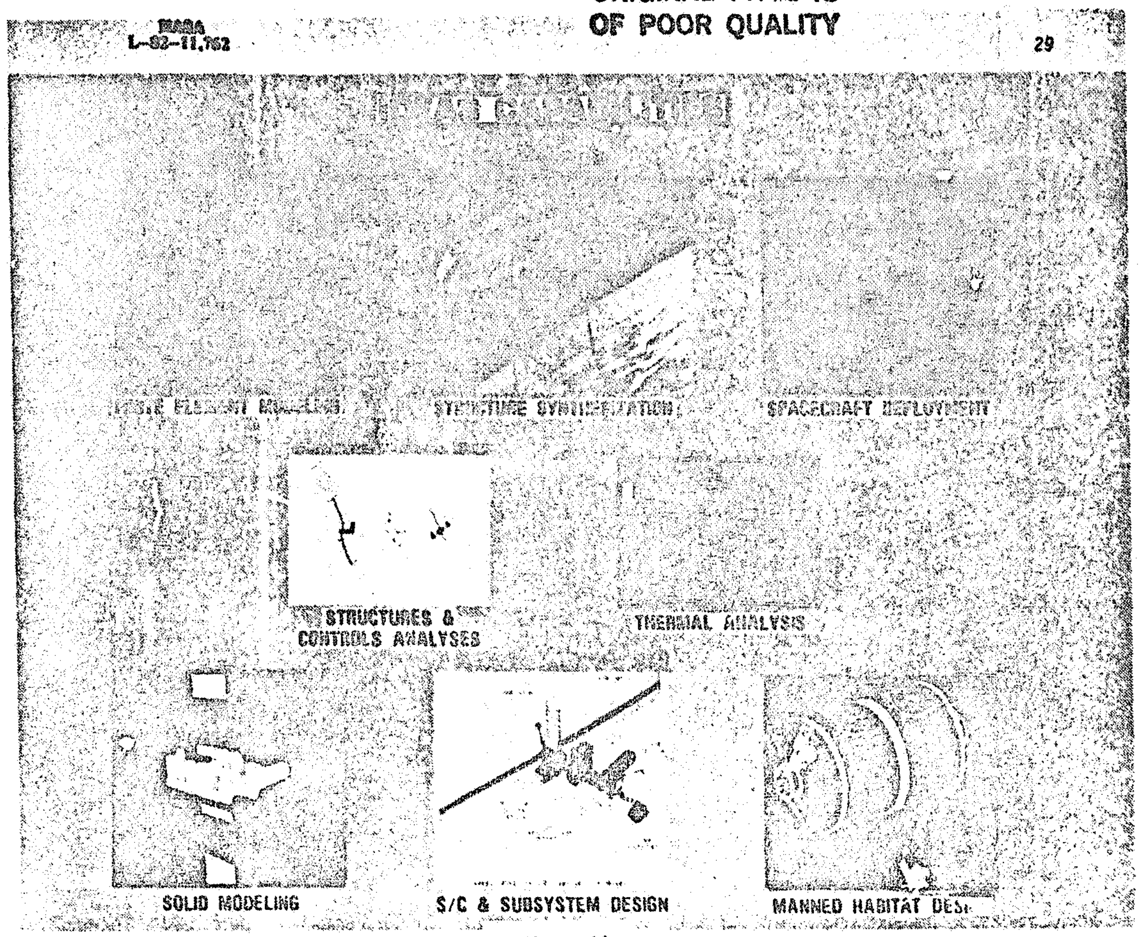

Figure 14

IDEAS

- AN INTERACTIVE COMPUTER-AIDED ENGINEERING METHODOLOGY APPLIED TO THE CONCEPTUAL DESIGN AND ANALYSIS OF ADVANCED ORBITAL SPACECRAFT
- CONSISTS OF AN INTEGRATED SET OF 40 INTERACTIVE TECHNICAL MODULES OPERATED UNDER EFFICIENT EXECUTIVE, DATA BASE AND FILE MANAGEMENT SOFTWARE
- USED BY LaRC'S SPACE SYSTEMS DIVISION TO PERFORM DESIGN EVALUATION AND PERFORMANCE ANALYSES FOR ADVANCED SPACECRAFT SYSTEMS, PAYLOAD AND MISSIONS

TECHNICAL MODULES INCLUDE

- STRUCTURAL SYNTHESIZING AND FINITE ELEMENT MODELERS
- STRUCTURAL ANALYSIS AND DESIGN
- THERMAL ANALYSIS
- CONTROLS ANALYSIS AND DESIGN
- PROPULSION SYSTEMS
- SUBSYSTEM DESIGN
- HABITABLE MODULE SUPPORT SYSTEMS
- RF PERFORMANCE
- COSTS
- RELIABILITY

SPACECRAFT EVALUATED INCLUDE

- MICROWAVE RADIOMETER SATELLITE
- LAND MOBILE SATELLITE SYSTEMS
- SOLAR POWERED SPACE LASERS
- 25 kw POWER PLATFORM
- EARTH RADIATION BUDGET SPACECRAFT
- VOICE OF AMERICA BROADCAST SATELLITE
- SINGLE PURPOSE vs LARGE MULTIMISSION
- SPACECRAFT
- SPACE STATION CONCEPTS

Figure 15

SENSITIVITY DERIVATIVES

We are developing the capability to systematically predict the change in responses such as displacements, temperatures, or stresses resulting from a change in a design variable such as a beam cross-section dimension or a shear panel thickness (fig. 16). There are three principal uses for sensitivity derivatives--optimization methods frequently require these derivatives as input to guide the search for an optimum structural design; Taylor series approximate analyses require the derivatives for use in the classic first-order Taylor series extrapolation; and sensitivity derivatives may provide useful information to designers on the effects of changing certain structural dimensions. There is a growing recognition of the need for sensitivity capability in structural analysis codes. Ford and Northrup have begun a cooperative effort to fund MacNeal-Schwendler to install sensitivity capability in NASTRAN. A series of industry visits revealed a strong interest in the quantification of the effects of material properties on thermal and structural response. This has prompted initiation of work on such a capability. At Langley, we have installed sensitivity capability into the EAL/SPAR structural analysis code. This capability has been applied to several aircraft structures and an application to a space antenna has been initiated.

SENSITIVITY DERIVATIVES

- DEFINITION - DERIVATIVE OF A RESPONSE WITH RESPECT TO A DESIGN VARIABLE
- USE OF SENSITIVITY DERIVATIVES
  - DESIGN INFORMATION AND TRENDS
  - TAYLOR SERIES EXTRAPOLATION
  - INPUT TO OPTIMIZERS
- EXAMPLES:

$\partial U/\partial v$	U = DISPLACEMENT	v = MEMBER THICKNESS
$\partial T/\partial e$	T = TEMPERATURE	e = EMISSIVITY

- GROWING RECOGNITION OF NEED IN ANALYSIS CODES
  - FORD AND NORTHRUP FUNDING MSC TO INSTALL SENSITIVITY CAPABILITY IN NASTRAN
  - ROCKWELL, TRW, GD, HARRIS CITED NEED TO KNOW SENSITIVITY OF T WITH RESPECT TO MATERIAL PROPERTIES

Figure 16

OPTIMUM DESIGN FOR THERMAL DISTORTION CONSTRAINTS

A new emphasis of our work is static control of thermal distortion in spacecraft. A contract with the Perkin-Elmer Corp. has been initiated to address the problem of controlling thermal distortion using the space telescope as a test case (fig. 17). The space telescope optical control system has severe temperature constraints and they are met by using thermal coatings and heaters which are optimally designed but in a nonautomated manner. The purpose of the present contract is to make an initial attempt to automate at least part of the design process for the heaters and coatings and to apply rigorous mathematical optimization techniques to the problem.

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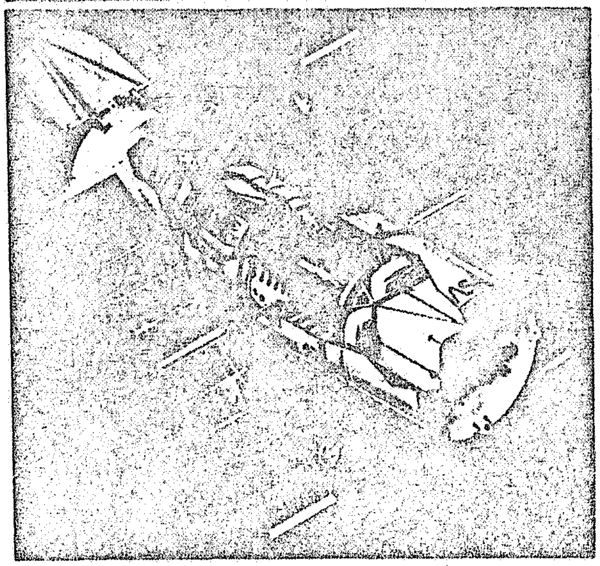
OPTIMUM DESIGN FOR THERMAL DISTORTION CONSTRAINTS



- OPTICAL CONTROL SYSTEM
- DESIGN REQUIREMENT - CHANGE IN TEMPERATURE GRADIENT BETWEEN CONSECUTIVE ORBITS NOT TO EXCEED 0.0005 °F
- CONTROL TEMPERATURES BY COATINGS, HEATERS
- DEVELOP RIGOROUS MATHEMATICAL OPTIMIZATION METHODS

SPACE TELESCOPE

Figure 17

HEAT-PIPE RESEARCH AT LANGLEY

Research in structural applications of heat pipes has been performed to demonstrate their feasibility for cooling high-speed flight structures (fig. 18). The work was initially focused on a heat-pipe cooled leading edge concept for space transportation systems. A combined analytical and test program verified the feasibility of such a concept. The work led to the development of a heat-pipe sandwich panel concept which combines the thermal efficiency of a heat pipe with the structural efficiency of a sandwich panel. A recently completed study has demonstrated the fabricability of the concept and the performance for high-temperature applications (≈1000°F). It is planned to explore the application of a heat-pipe sandwich panel to low-temperature applications such as a radiator for a space station, and reflectors for space antennas. Finally, it is planned to explore the thermal modeling of heat pipes by finite elements under a NASA grant with Georgia Tech.

HEAT PIPE RESEARCH AT LANGLEY

INITIAL

- RADIANT AND AEROTHERMAL TESTS OF HEAT-PIPE-COOLED LEADING EDGE - VERIFIED FEASIBILITY OF CONCEPT

RECENTLY-COMPLETED

- DESIGN, ANALYSIS, FABRICATION AND TESTS OF HEAT PIPE SANDWICH PANELS

PLANNED

- DEVELOPMENT OF A HEAT-PIPE FINITE ELEMENT FOR THERMAL ANLAYSIS
- DEVELOPMENT OF HIGH-CAPACITY AND VARIABLE CONDUCTANCE HEAT PIPE SANDWICH PANELS

Figure 18

HEAT-PIPE SANDWICH PANEL CONCEPT

The heat-pipe sandwich panel concept is shown schematically in figure 19. The panel consists of a wickable honeycomb core, internally wickable facesheets, and an appropriate working fluid. For high-temperature applications, the working fluid could be either cesium, potassium or sodium. During operation, heat is absorbed at the heated face by the evaporation of the working fluid. The heated vapor flows (see inset) due to a pressure differential, to the cooler face where it condenses and gives up its stored heat. The cycle is completed with the return flow of liquid condensate back to the heated face by the capillary pumping action of the wickable core. The core is perforated to allow intracellular vapor flow and is notched at both ends to allow intracellular liquid flow along the faces. The intracellular flow of both liquid and vapor is necessary to assure heat-pipe operations in the plane of the panel as well as through its depth. If intracellular flow is limited, a local panel hot spot could cause the depletion of working fluid in one region of the panel and an accumulation of fluid in another region, thus preventing normal heat-pipe operation. The faces are internally wickable to allow in-plane flow of liquid and to form a uniform film for evaporation, thus preventing local hot spots in the center of each honeycomb cell. The concept can accommodate many variations in the design of the internally wickable faces, choice of working fluid, and wickable core configuration depending on the application. The all-welded manufacturing technique eliminates concern for materials compatibility problems of the working fluid with a bonding agent. A summary of attractive features of the heat-pipe sandwich panel concept is given in figure 20.

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HEAT PIPE SANDWICH PANEL CONCEPT

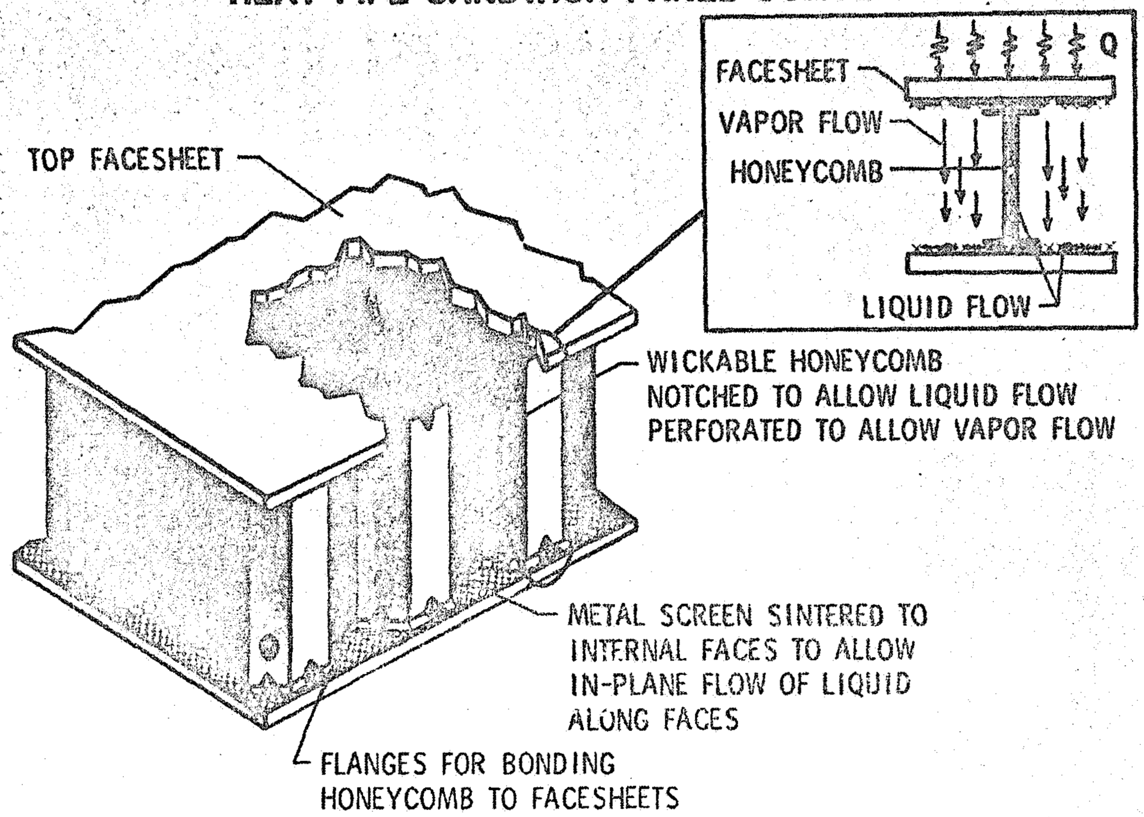

Figure 19

ADVANTAGES OF HEAT PIPE SANDWICH PANEL

COMBINES ADVANTAGES OF

SANDWICH CONSTRUCTION

- HIGH STRENGTH-TO-WEIGHT RATIO
- GOOD STIFFNESS IN EACH DIRECTION
- SMOOTH SURFACES
- RESISTANT TO BUCKLING
- HIGH LOAD CARRYING CAPACITY
- INCREASED FATIGUE LIFE

WITH

HEAT PIPES

- TRANSPORTS LARGE QUANTITIES OF HEAT
- PASSIVE (NO PUMP REQUIRED)
- ISOTHERMAL
- NO MOVING PARTS (NOISELESS)
- SELF-CONTAINED (REDUNDANCY)

HEAT-PIPE SANDWICH PANEL

- LIGHTWEIGHT AND STRONG
- FLAT - FOR BETER THERMAL CONTACT
- DISTORTION-FREE ISOTHERMAL STRUCTURE
- GOOD HEAT TRANSPORT DEVICE
- REDUNDANT - NOT SENSITIVE TO LOCAL FAILURE

Figure 20

COMPARISON OF TEMPERATURE GRADIENT HISTORIES

Potassium Working Fluid

Tests were performed to assess the performance of the heat-pipe sandwich panel with two different types of cores and three different working fluids (potassium, sodium, and cesium). Results were reported at the 21st AIAA Aerospace Sciences Meeting in a paper by Camarda and Basiulis. A representative result from that paper is shown in figure 21 which compares the thermal responses in a radiant heat test of a potassium filled test panel denoted heat pipe and a control panel denoted non heat pipe. The test indicated the excellent performance of the heat-pipe sandwich panel in reducing the peak-through-the-depth temperature difference by 46 percent.

COMPARISON OF TEMPERATURE GRADIENT HISTORIES
POTASSIUM WORKING FLUID

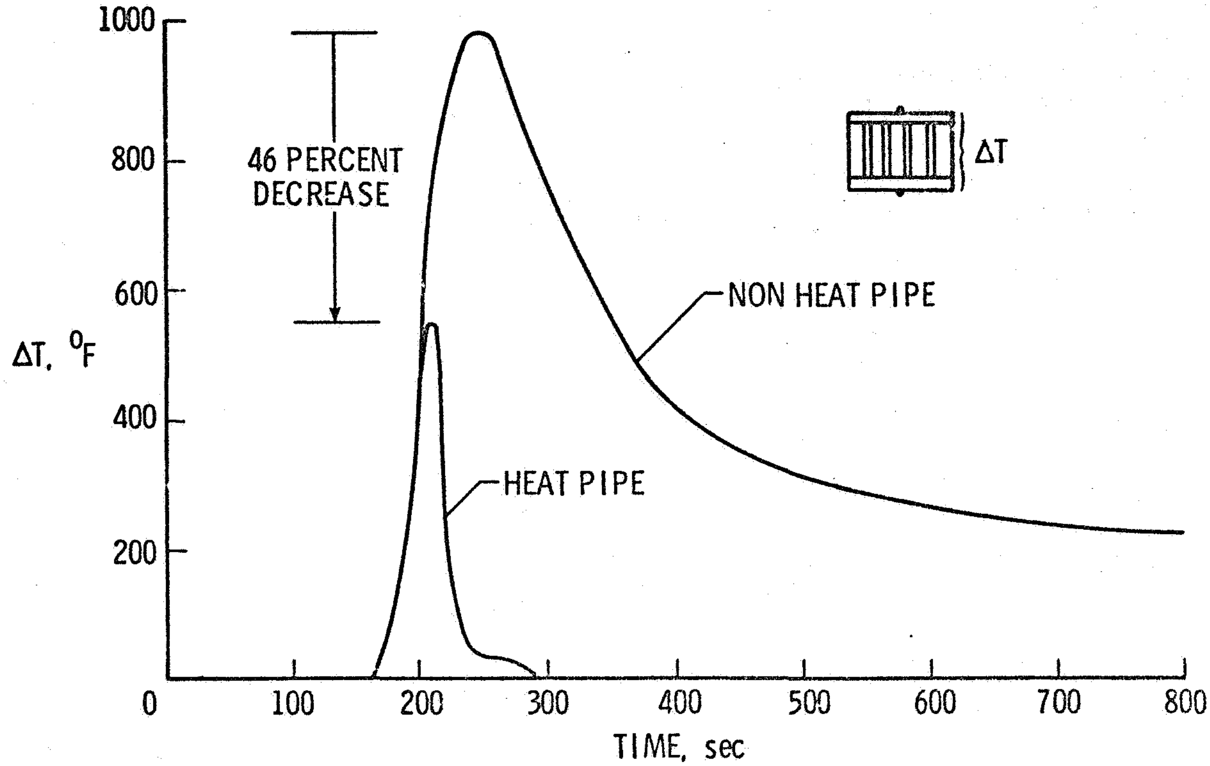

Figure 21

MODELING OF TRANSIENT HEAT-PIPE OPERATION

A research task outlined in figure 22 is aimed at the prediction of transient behavior of heat pipes under normal and adverse operating conditions. The procedure will be to develop heat-pipe mathematical models using lumped parameter methods--convert the resulting equations to finite-element form and integrate the heat pipe finite element with the remaining SPAR thermal elements in an overall model. The work is expected to be carried out under a NASA grant with Georgia Tech under the direction of Professor Colwell. Among the features of the mathematical formulation are nonlinear behavior due to temperature-dependent properties and the assumption of one-dimensional incompressible fluid flow. The adverse operating conditions will include drying, rewetting, and choking. The grant is being jointly monitored by the Loads and Aeroelasticity Division and the Space Systems Division. The capability resulting from this work will be applicable to optimization and trade studies being carried out in the Space Systems Division which are being described in the Systems/Operations Technology panel at this workshop.

MODELING OF TRANSIENT HEAT PIPE OPERATION

- GOAL - IMPROVED HEAT PIPE MODELING CAPABILITY COMPATIBLE WITH STRUCTURAL THERMAL MODELS
- APPROACH - NASA GRANT WITH GEORGIA TECH (COLWELL)
  - ADAPTATION OF LUMPED PARAMETER MODEL
- FEATURES - NONLINEAR (TEMPERATURE-DEPENDENT MATERIAL PROPERTIES)
  - ONE-DIMENSIONAL, INCOMPRESSIBLE FLUID FLOW
  - NEGLECTS START-UP FROM FROZEN, SUPERCRITICAL STATE
- JOINTLY FUNDED BY LAD, SSD AND OFFICE OF DIRECTOR
- WILL BE APPLICABLE TO OPTIMIZATION AND TRADE STUDIES

Figure 22

GRANTS AND CONTRACTS

The Langley research program represents a mix of in-house work and supported efforts through research grants and contracts. Figure 23 summarizes the thermal-oriented grants and contracts being funded by the Loads and Aeroelasticity Division. For the most part, these grants and contracts are continuations of long-term working relationships. They have fostered excellent cooperation between NASA and the outside organizations and have provided many instances of cross-fertilization of ideas and concepts which have grown into a number of significant research products.

GRANTS AND CONTRACTS

GRANT/CONTRACT NO.	ORGANIZATION/PI	SUBJECT
NSG-1266	VPI/HAFTKA	THERMAL-STRUCTURAL OPTIMIZATION
NSG-1321	ODU/THORNTON	UNIFIED THERMAL STRUCTURAL FINITE ELEMENTS
NAG-1-41	UW/EMERY	RADIATION VIEW FACTOR ANALYSIS
NAS1-14605	GWU/NOOR	APPROXIMATE THERMAL ANALYSIS
NAG-1-210	NWU/LIU	MIXED TIME-INTEGRATION METHODS FOR TRANSIENT THERMAL ANALYSIS OF STRUCTURES
NAS1-16014	EISI/WHETSTONE	DEVELOPMENT AND MAINTENANCE OF SPAR THERMAL ANALYZER
NAS1-17152	PERKIN-ELMER/ BETTINI, COSTELLO	OPTIMIZATION OF THERMAL DISTORTION CONTROL SYSTEMS

Figure 23

SURVEY OF INDUSTRY PRACTICES AND NEEDS IN THERMAL-STRUCTURAL ANALYSIS OF SPACE STRUCTURES

In January 1983, personnel of the Loads and Aeroelasticity Division visited six aerospace companies to discuss thermal-structural analysis of space structures (fig. 24). It is felt that this workshop panel would benefit from a synopsis of the observations gained during these visits. The following needs were cited:

1. Integrated thermal/structural analysis-
   Basically companies are using 10 year old technology of interfaced standard codes.

2. Sensitivity and optimization capabilities

3. Improved modeling and efficient computational techniques-
   Usually, simple elements are used which neglect the effects of joints, shading, reflections, interelement radiation, etc.

4. Sensitivities with respect to thermal/structural composite properties-
   Effect of layup, material constituents, degradation in space are not adequately defined.

5. Experimental verification of models and codes-
   Little is being done in industry or NASA.

LARGE SPACE STRUCTURES

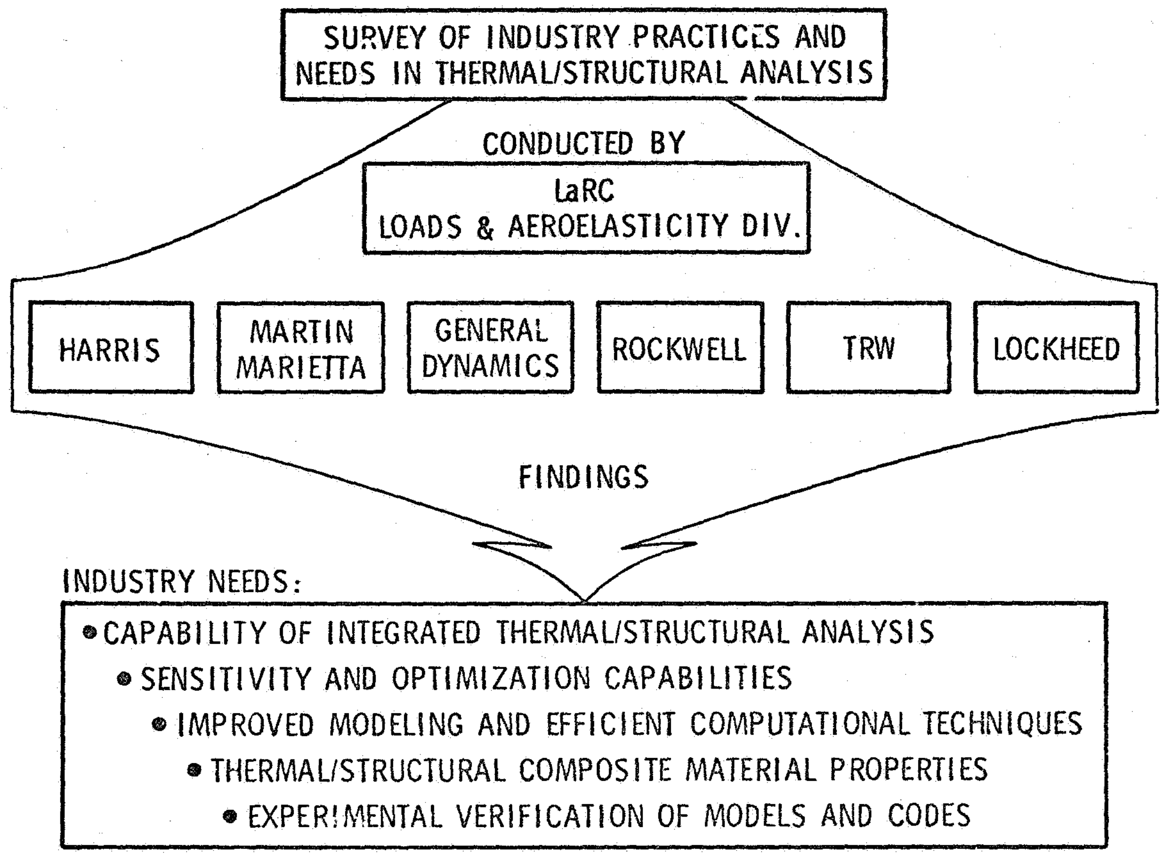

Figure 24

PLANS MARCH 1983 - MARCH 1984

This presentation is concluded by a list of planned activities for the next 12 months on topics related to the thermal area (fig. 25). It is planned to install the view factor calculation program as a processor in SPAR to move another step closer to the goal of fully integrated thermal-structural analysis. Continued application of the reduced-basis approximate-transient thermal analysis method will be focused on antennas and space station components. Development of unified finite elements will continue with an emphasis on plate and shell elements. Initial attempts will be made to apply some of the optimization procedures (discussed in the structures panel) to coupled thermal-structural design problems for spacecraft. The sensitivity analysis work will include the effect on temperatures of changes in material properties such as emissivity and absorptivity. The contract with Perkin-Elmer as well as associated in-house work will be aimed at a computerized procedure for rigorous design of systems to control thermal distortion in sensitive structures. Research on heat pipes will include an initiation of modeling efforts aimed at a finite-element representation of a heat pipe and a continuation of studies on the heat-pipe sandwich panel concepts.

PLANS — MARCH 1983 - MARCH 1984

- INSTALL RADIATION VIEW FACTOR CAPABILITY IN SPAR
- APPLY REDUCED BASIS TRANSIENT THERMAL ANALYSIS TO SPACECRAFT
- DEVELOP UNIFIED THERMAL-STRUCTURAL FINITE ELEMENTS
- INITIATE COUPLED OPTIMIZATION APPLICATIONS FOR SPACECRAFT
- SENSITIVITY ANALYSIS FOR TEMPERATURES
- COMPUTERIZED PROCEDURE FOR CONTROL OF THERMAL DISTORTION
- HEAT PIPE FINITE ELEMENT MODELING
- HEAT PIPE SANDWICH PANEL STUDIES

Figure 25