

INTERACTIVE MODELING, DESIGN AND ANALYSIS OF LARGE SPACECRAFT

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INTRODUCTION

Large space systems on the order of tens to hundreds of meters in size are projected to be operational in the future. The sizes will be driven by one or two principal considerations: economy of scale (e.g. antenna or sensor farms mounted on platforms with shared central utility supporting subsystems) or advanced systems which require large physical areas (e.g. high power solar arrays or remote sensing microwave radiometer antenna systems). These future spacecraft, unlike today's spacecraft which are generally enclosed monoque structures with a few appendages, will have large expanses of lattice (truss-like) structures with hundreds or thousands of individual connecting members. The lightweight, flexible structures will be subjected to on-orbit environmental loads (gravity gradient, thermal, low-frequency transient vibrations, etc.) which usually were ignored in past spacecraft designs. Unless efficient design and analysis capabilities are developed for these advanced structures, the engineers will be severely taxed by the modeling, design, and analysis efforts. Further, computer resources will be rapidly consumed by the use of the prevalent large, single-discipline design and analysis codes.

The purpose of this presentation is to describe an efficient computer-aided design and analysis capability which has been developed to relieve the engineer of much of the effort required in the past. The automated capabilities can be used to rapidly synthesize, evaluate, and determine performance characteristics and costs for future large spacecraft concepts. The Interactive Design and Evaluation of Advanced Spacecraft Program (IDEAS) is used to illustrate the power, efficiency, and versatility of the approach. Although the IDEAS capabilities are by no means complete, the program has reached a certain level of maturity in the use of interactive data processing capabilities and spacecraft systems analysis oriented software to guide the design of future large space systems.

The coupling of space environment modeling algorithms with simplified analysis and design modules in the IDEAS program permits rapid evaluation of competing spacecraft and mission designs. The approach is particularly useful in the conceptual design phase of advanced space missions when a multiplicity of concepts must be considered before a limited set can be selected for more detailed analysis. Integrated spacecraft systems level data and data files are generated for subsystems and mission reexamination and/or refinement and for more rigorous analyses.

**COMPUTER-AIDED DESIGN AND ANALYSIS CAPABILITIES -
IDEAS PROGRAM OVERVIEW**

The IDEAS program consists of about 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. These modules are described in detail in references 1-3. They reside on both mainframe and super mini-computer 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 1. The Aerospace Vehicle Interactive Design (AVID) program, developed by Wilhite (ref. 4) provides executive control and data base management capabilities for IDEAS. Additional procedure files and data file management routines reside in the individual IDEAS modules.

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.

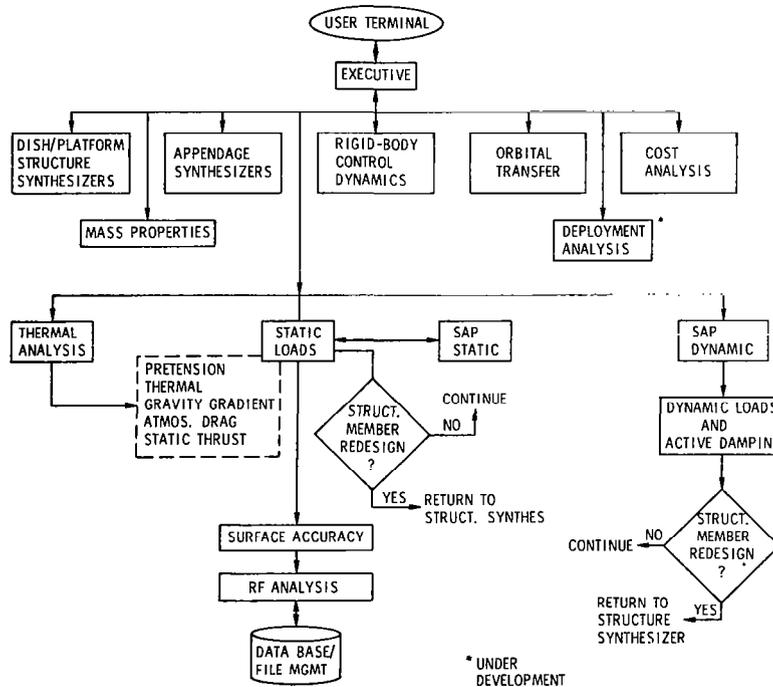


Figure 1

STRUCTURE SYNTHESIZER MODULES

The Tetrahedral Truss Structure Synthesizer (TTSS) module, developed by W. D. Honeycutt of the General Dynamics Corporation, Convair Division, is used to rapidly model flat or curved tetrahedral truss structures and to initially size the structural members. The module automatically generates the nodal geometry; the member connectivity, cross-sectional areas and masses; and the resultant finite-element model of the structure for a specified dish diameter, shape, number of bays, and a diagonal angle which defines the truss depth. The tetrahedral truss configuration and major hardware components are shown in Figure 3.

The truss structural members are assumed to be circular tubes, isogrids, or triangular truss struts. The surface and diagonal members are sized separately for Euler buckling from input material properties and initial loading conditions. Upper and lower surface members are pinned; diagonal elements may be pinned or clamped at the user's option. Structural members can be constrained to minimum material thicknesses and tube diameters so that the column buckling equations will not design members too small for practical use. An option also permits the sizing of the member (diameter and thickness) from user specified length over radius of gyration and a tube radius over thickness inputs.

The folding hinges, spiders, bearing, and end fitting masses are computed as functions of the structural member diameter. A mesh-reflective surface and the support system may be optionally included in the calculations and is automatically distributed at each nodal point on one of the surfaces. The mesh control system, used to maintain contour, is computed as a percentage of the mesh weight. A contingency mass is included which is defined as a percentage of the mass of all the structural components.

A total of 45 input variables is needed to run TTSS. The module calculates and outputs the mass of the structural components, mesh system, and total system; the center of gravity; and mass inertia properties. The displayed outputs also included structural member dimensions, hardware part counts, unit masses, total group masses, mesh area, and configuration packaging dimensions for inward and outward folded deployable surfaces.

Uniquely nameable data base and files, including a complete finite-element model of the tetrahedral truss, are created in TTSS for later use in other modules.

Structure synthesizer modules which have similar modeling characteristics as that of the tetrahedral are also incorporated in IDEAS. They include contiguous box trusses, box truss ring, radial rib, and hoop and column synthesizers. Some of these finite-element models are shown in Figures 4-6.

CONFIGURATION DEFINITIONS FOR THE TETRAHEDRAL TRUSS STRUCTURE SYNTHESIZER MODULE

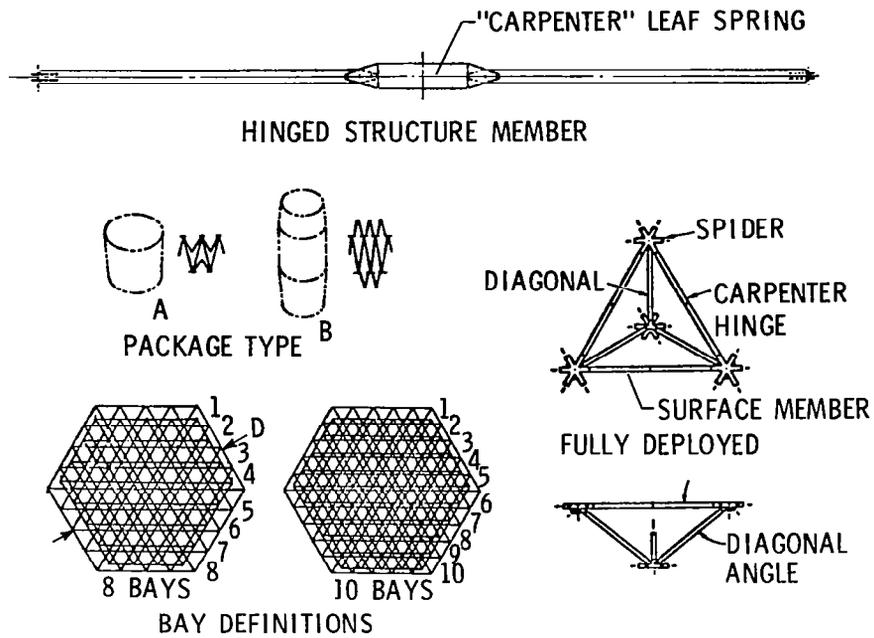


Figure 3

BOX TRUSS RING ANTENNA STRUCTURE FOR A MICROWAVE RADIOMETER SATELLITE

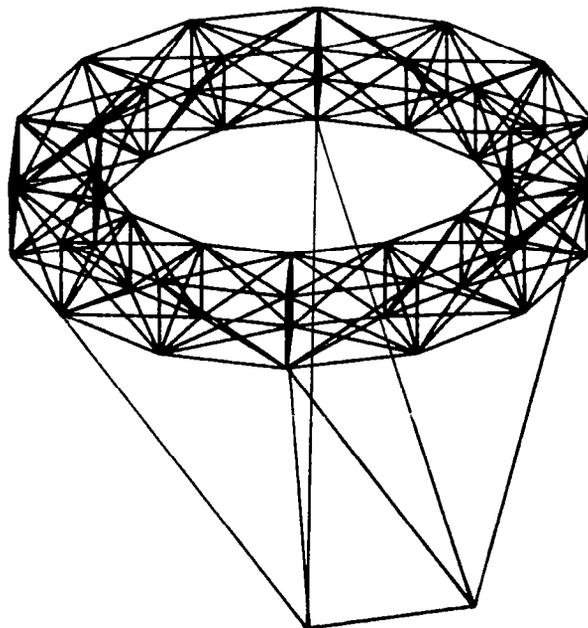


Figure 4.

**RADIAL RIB ANTENNA STRUCTURE
FOR A LAND MOBILE COMMUNICATION SATELLITE**

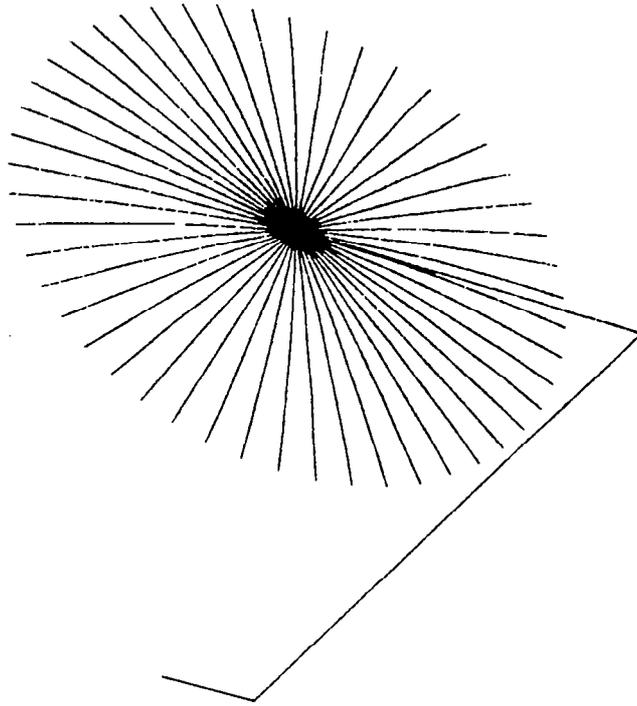


Figure 5

**HOOP AND COLUMN ANTENNA STRUCTURE
FOR A LAND MOBILE COMMUNICATIONS SATELLITE**

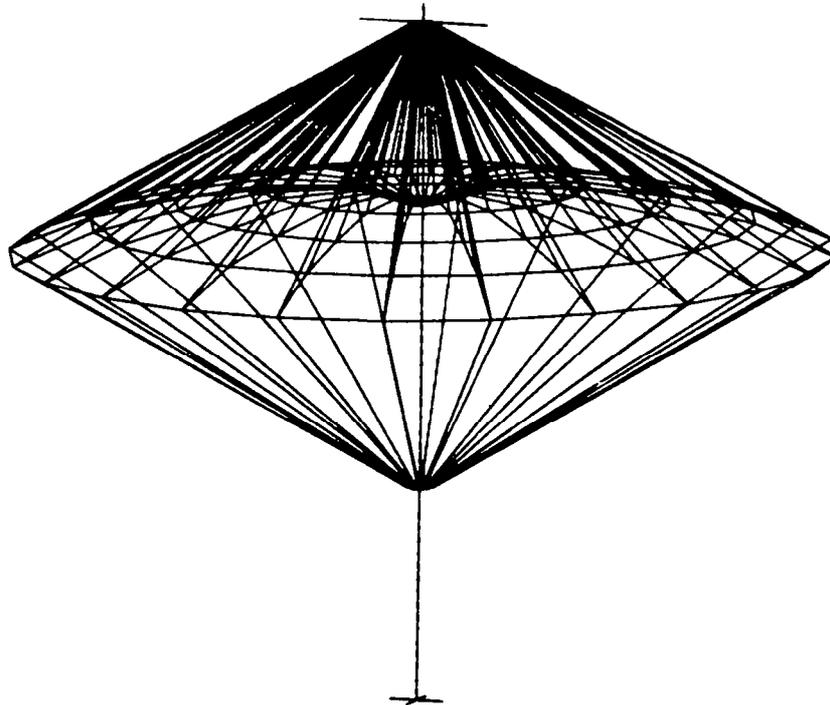


Figure 6

APPENDAGE SYNTHESIZER MODULE

The Appendage Synthesizer Module is used to complete the definition of the spacecraft structure, materials, and supporting subsystems. Required inputs include dish data files from the appropriate Structure Synthesizer Module; added structural members and connectivity, member design loads; subsystem locations, masses and areas; and mesh blockage factor. Hollow tubes, isogrids, triangular trusses (see Fig. 7), cables, and deployable astromast members are available structural appendage types. Outputs include the design of the added members; a finite-element model of the total spacecraft; an atmospheric drag approximation model; and updated mass, inertia, centers of gravity, and pressure properties. The mass-per-unit area of all elements needed for the thermal analysis is also generated in this module. The Appendage Synthesizer can be used to create spacecraft designs from keyboard input when no synthesized structure is desired. Alternatively, finite-element model data formatted by external structural analysis programs can be preprocessed and read directly into the module to save labor and time.

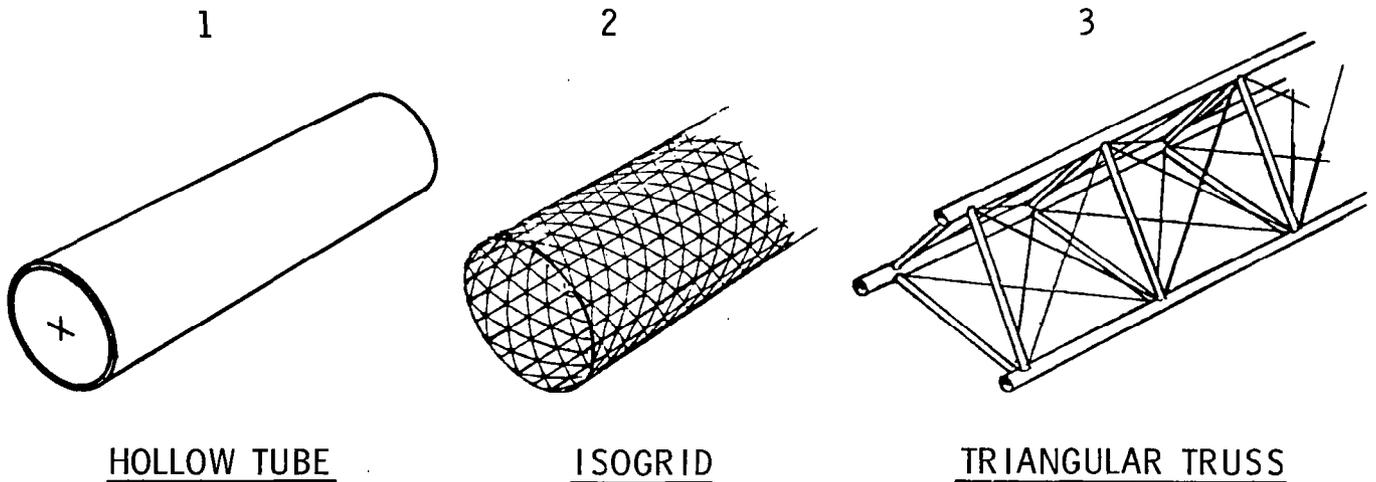


Figure 7

RIGID-BODY CONTROL DYNAMICS MODULE

The Rigid-body Control Dynamics (RCD) module calculates the on-orbit environment and maneuver forces and torques at user-specified circular orbital altitude and spacecraft orientation. The module then determines the momentum storage and desaturation requirements, and iterates the masses of the control systems, propellant, and tankage to meet the orbit-keeping, attitude control, and maneuver requirements of the spacecraft. Principal features of RCD are shown in Figure 8. The total torque and force time histories are analyzed to determine cyclic momentum for momentum exchange system sizing and accompanying momentum desaturation requirements. Momentum desaturation is accomplished by reaction control system (RCS) thrusters. RCS requirements for orbit keeping are also determined. Finally, RCS requirements are computed assuming RCS control in lieu of the momentum exchange plus desaturation systems. Technical capabilities for this module were provided by Chiarappa and Eggleston (ref. 5). References 6 and 7 also provide supporting information on satellite drag and referenced atmospheric data.

Spacecraft mass, inertia, areas, centers of gravity, and pressure are input from the synthesizer files. Those parameters are updated in RCD in accordance with the momentum exchange and propulsion systems sizing and mass computations. A total of 34 additional input variables plus a thruster force matrix are needed to run RCD. Input categories include the orbital parameters; the spacecraft orientation (inertial or Earth oriented), maneuver requirements, and pointing accuracy; the control system location and performance characteristics; and the propellant resupply periods. An arbitrary number of RCS thrusters may be located at multiple nodes. The thrust level and direction for each individual thruster is user specified. The program assumes that individual thrusters can fire in either a positive or negative direction along one of the principal axes.

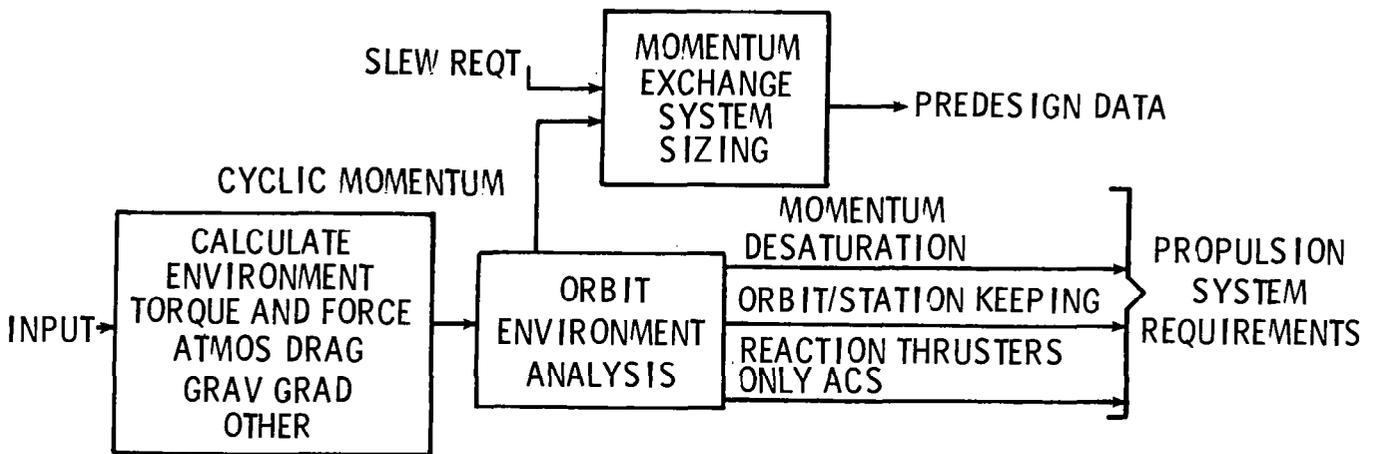


Figure 8

THERMAL ANALYSIS MODULE

The Thermal Analysis (TA) module is used to compute the radiation equilibrium temperature for each structural member at a given position in the spacecraft orbit. Technical capabilities for the module (fig. 9) were developed by G. A. Howell of the General Dynamics Corporation, Convair Division, from the original work of Ballinger and Christensen (ref. 8). Heat sources are solar radiation, Earth albedo, and Earth radiation. The thermal response of each is determined from the balance between absorption of energy from the three heat sources and reradiation of energy from the elements to deep space. The position of the members relative to the Sun and the Earth are varied at 36 intervals in the orbit. Earth shadowing is included. The members may be single or double shadowed by a translucent mesh. There is no radiation exchange or conduction between members and no shadowing of members by other members. Inputs to TA include the thermal properties of the members and mesh transmissivity constants; the finite element geometry and unit area data files from Appendage Synthesizer and/or RCD; and Sun-Earth-spacecraft geometry inputs from RCD. Outputs include the temperature of each member at a user-specified location in orbit, temperature contours of the dish upper and lower surface members, and a temperature file, TATMPS. Since one isothermal temperature is computed per member, the thermal model is completely compatible with the structural finite element model. Temperatures for each member are read into the static loads module from the TATMPS file for use in conjunction with the Structural Analysis Program for the generation of thermal loads and deflections. For 439 members, evaluated 12 minutes apart in the orbit, TA executes in 16 seconds CP time and in about 10 wall-clock minutes.

PURPOSE:

- TO COMPUTE EQUILIBRIUM HEATING RATES AND ISOTHERMAL TEMPERATURES OF EACH MEMBER IN ORBITAL ENVIRONMENT

HEAT BALANCE:

- SUN, EARTH ALBEDO, EARTH THERMAL RADIATION AND STRUCTURAL MEMBER ABSORPTION/RERADIATION
- VARIES POSITION OF MEMBERS RELATIVE TO SUN AND EARTH AT 36 INTERVALS WITHIN THE ORBIT (EARTH SHADOWING INCLUDED)
- MEMBERS ARE SHADOWED OR DOUBLE SHADOWED BY MESH

INPUTS:

- THERMAL PROPERTIES OF MEMBERS
- FINITE ELEMENT GEOMETRY, MASS/UNIT AREA DATA FILES
- SUN-EARTH-S/C GEOMETRY INPUTS FROM RCD

OUTPUTS:

- TEMPERATURE OF EACH MEMBER
- THERMAL CONTOURS
- TATMPS FILE FOR SAP STATIC

MAINFRAME STATISTICS:

- 16 SECONDS CP TIME
 - 10 MINUTES
- > 439 ELEMENTS
> 12 ORBITAL MINUTES

Figure 9

RADIAL RIB ANTENNA TEMPERATURES

Temperature contour data are shown in figure 10 for a 55-meter diameter radial rib antenna. This is one of several concepts under study for a Land Mobile Communication Satellite mission. The satellite is in a circular equatorial orbit at geosynchronous Earth orbital altitude. The satellite has been in the sunlight about 1.5 minutes after a 1.3-hour cold soak in the Earth shadow.

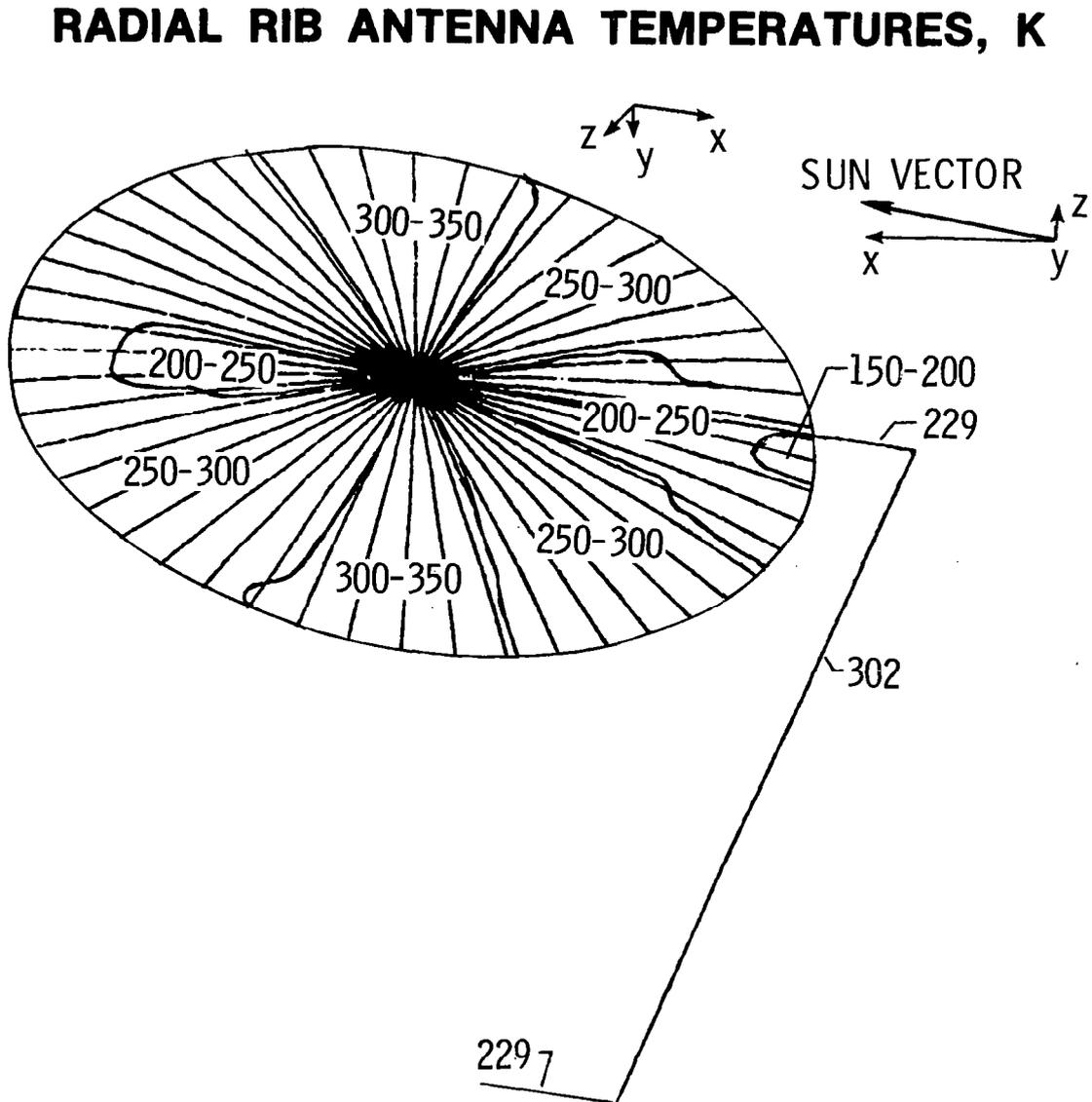


Figure 10

SELECTED MISSION AND SPACECRAFT DESIGN DETAILS

The capabilities of the IDEAS program to deal with the multidiscipline aspects of spacecraft preliminary design are illustrated by examples in the design, analysis, and parametric evaluation of an advanced spacecraft--the passive Microwave Radiometer Spacecraft (MRS) designed to perform soil moisture measurements from low-Earth orbit.

The MRS structure and supporting systems are shown schematically in Figure 11. The structure consists of a relatively stiff double-layered 750-m diameter tetrahedral truss dish (graphite epoxy composite structural members) with an RF reflective mesh (aluminized Kapton with a unit mass of 0.03 kg/m^2) attached to offsets on the concave surface. Support beams (graphite epoxy composite) and tension cables (Kevlar) provide stabilization and boresight control for the feed horns mounted on a curved beam located at the focal arc of the reflector. The spacecraft operates at a nominal altitude of 750 km. The dish points toward nadir with the feed beam oriented normal to the spacecraft velocity vector.

Attitude control is provided by a dual-ring annular momentum control device (AMCD) and eight one-newton liquid oxygen/liquid hydrogen thrusters. The AMCD rings are magnetically supported in races at the outer periphery of the convex surface of the dish to provide pitch, roll, and yaw control. Orbital velocity makeup is provided by four larger liquid oxygen/liquid hydrogen thrusters. Two are located on the dish structure providing 1,500-newtons thrust each and two are located at the extremities of the feed beam providing 500-newtons thrust each. Three propellant tanks are located on the convex side of the dish in a triangular arrangement at the three center-most nodes. Other subsystems included in the analysis are shown in Figure 11.

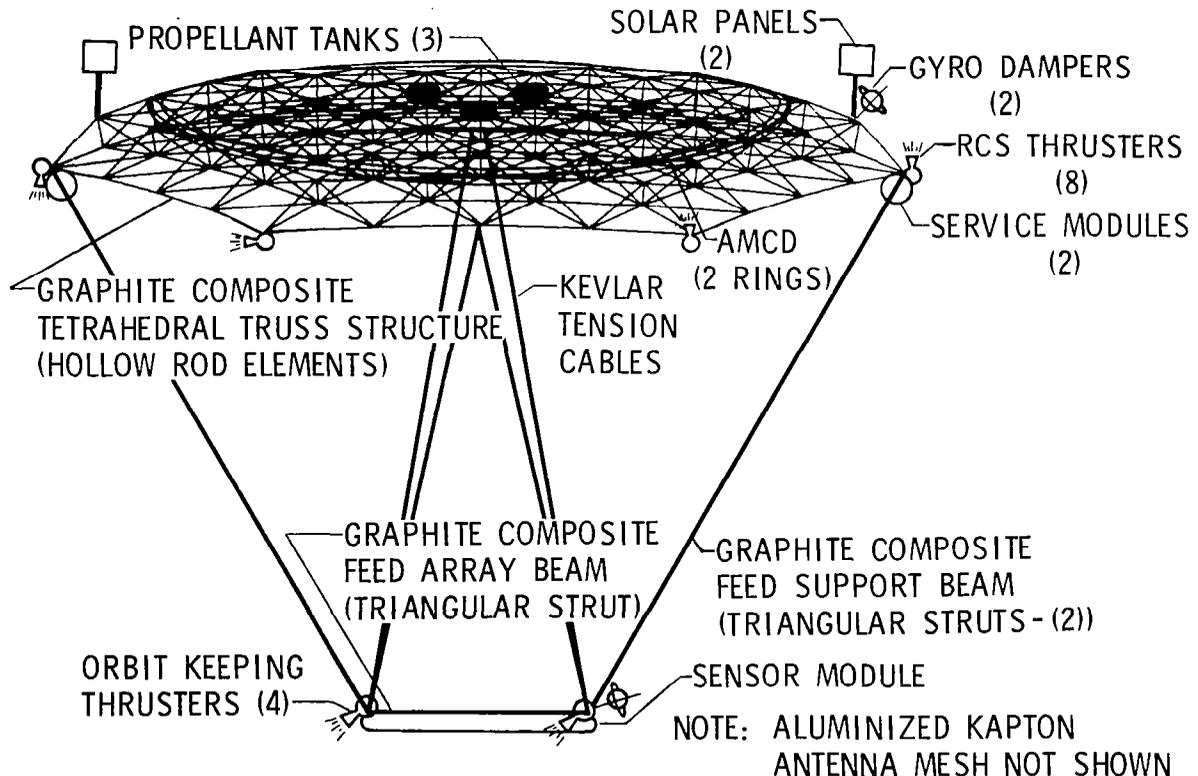


Figure 11

MICROWAVE RADIOMETER SPACECRAFT TEMPERATURE CONTOURS

Selected thermal contours for MRS dish members oriented in the same direction are shown in figure 12. The solid lines denote the structural members for which the temperature contours are applicable. Similar contours are also plotted for both concave surface members oriented in the other directions. The contours aid the analyst in rapidly visualizing approximate temperature ranges and distributions for the entire structure and are preferable in the interactive analysis to review of temperature printouts for hundreds of members.

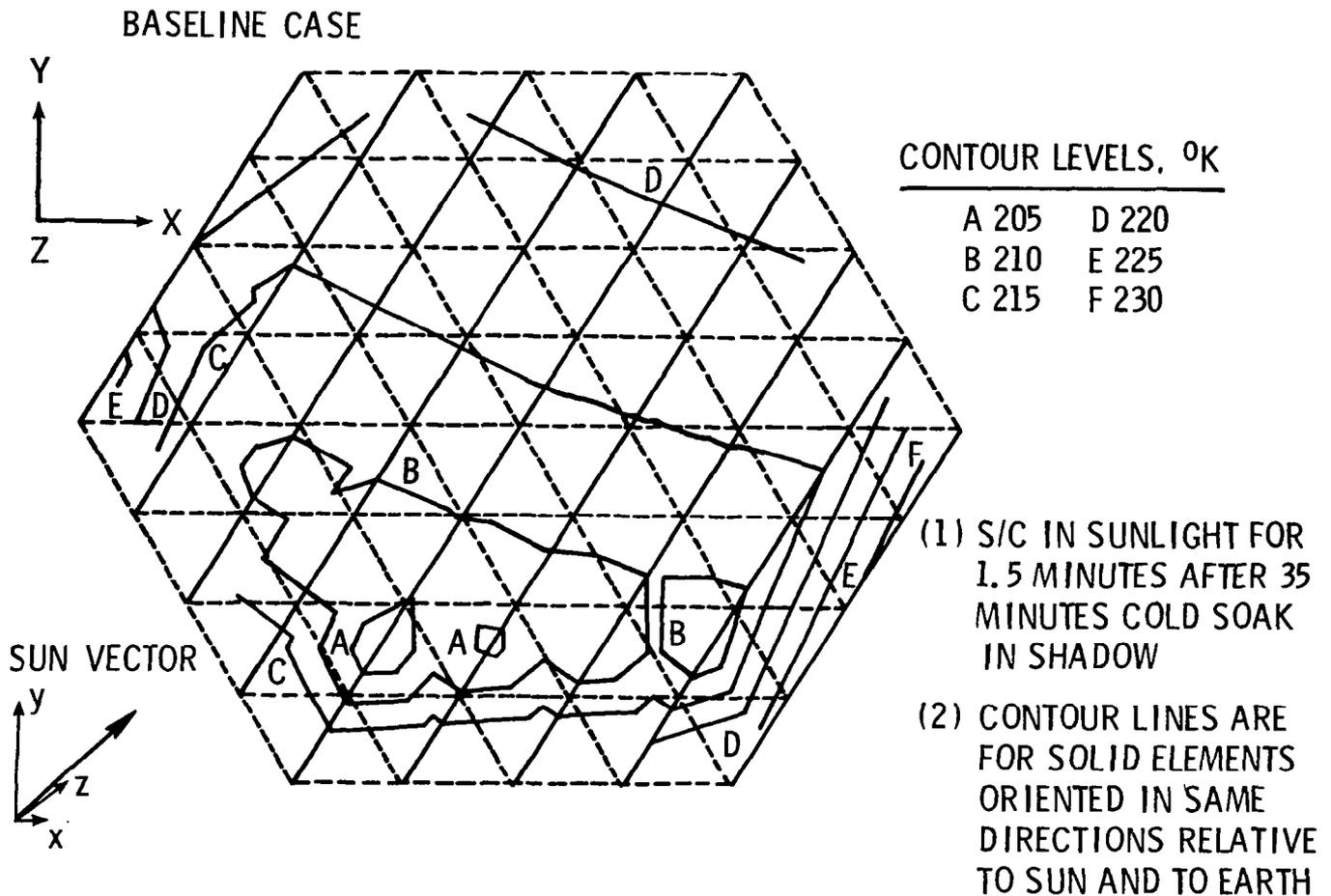


Figure 12

TEMPERATURE VARIATIONS OF THE
MICROWAVE RADIOMETER SPACECRAFT THROUGHOUT THE ORBIT

Thermal loads on the individual elements will vary throughout the orbit and it is not generally known a priori where in the orbit the loads reach the maximum. However, some insight on maximum thermal loading can be gained by calculating element temperatures and temperature differentials at selected orbital points. In this study, heating rates and temperatures of each MRS structural member were calculated in the IDEAS Thermal Analysis (TA) module at four points in the orbit:

- Point a. Orbit Anomaly Angle = 1.5 radians, time = 0.40 hours
(just prior to S/C entry into Earth shadow)
- Point b. Orbit Anomaly Angle = 3.7 radians, time = 0.98 hours
(just prior to S/C exit from Earth shadow)
- Point c. Orbit Anomaly Angle = 3.9 radians, time = 1.03 hours
(just after S/C exit from Earth shadow)
- Point d. Orbit Anomaly Angle = 5.8 radians, time = 1.53 hours
(midway in sunlight portion of orbit)

Start and end of Earth shadow were at anomaly angles of 1.6 and 3.8 radians (time 0.4239 hours and 1.005 hours), respectively. The orbit period was 1.667 hours at the 750-km altitude. Figure 13 gives summary results of maximum and minimum temperatures of the various members at each point in the orbit.

Element temperatures for Point c (just after exit of the spacecraft from Earth shadow) were selected for use in the static loads analysis. This point was selected on the combined basis of near-maximum temperature difference between elements and relatively low temperatures for all the elements.

MAXIMUM/MINIMUM ELEMENT TEMPERATURES, K

CASE	DISH MEMBERS			FEED BEAM	FEED SPT BEAM	TENSION CABLES
	CONCAVE SURF. (MESH SIDE)	CONVEX SURFACE	DIAGONAL			
A	312/232	312/237	312/236	313	312/308	310/286
B	191/183	184/183	179/176	191	179/179	180/180
C	251/201	264/196	255/214	267	261/256	262/229
D	332/324	328/324	325/300	321	298/271	301/275

Figure 13

MICROWAVE RADIOMETER SPACECRAFT ENVIRONMENTAL LOADS

SAP Static. The static-load-carrying capabilities and internal stresses in the individual structural members are evaluated in the Structural Analysis Program (SAP, ref. 9), which was originally the work of Professor Edward L. Wilson of the University of California at Berkeley, and the Static Loads (STLO) module. SAP is a general purpose structural analysis program for static and dynamic linear analyses of three dimensional structural systems. SAP static calculates nodal displacements and rotations, member forces and moments, and internal stresses for up to five separate load conditions and for the linear combination of all loads acting simultaneously. However, the program requires loading inputs to perform the analyses which are provided by the STLO module.

STLO. The STLO module operates in two parts. STLO, part 1 collects all the appropriate static loads data in a properly formatted file for SAP and generates environmental and spacecraft-induced loads for the following five loading conditions: (1) pretension; (2) thermal; (3) gravity gradient; (4) atmospheric drag; and (5) static thrust. The structural finite-element model is included in the STAMOD file. Inputs to STLO, part 1, include a full description of the mass points for the gravity gradient computations from the DYML file, the projected area approximations for the atmospheric drag loads from the Appendage Synthesizer files, the isothermal member temperatures from the Thermal Analysis module, and thrust and pretensioning forces. Following the SAP run, STLO, part 2 outputs summary data of the actual loads on the structural members, compares them to the design loads, and permits the user to redesign the elements if the actual loads differ considerably from the design loads. If many members are poorly designed, the user can instruct the program to recycle through the appropriate synthesizer modules with the updated design loads and revise the member sectional areas. If the spacecraft mass and inertia properties are significantly modified, the RCD module can redefine the control system requirements. Continuous iterations can be performed under user control until a satisfactory solution is obtained for the structural loads, member sizes, spacecraft mass, inertia and drag properties, and the control system requirements. At any step in the design and analysis process, the user may decide that he has a poor design and may revise the design or change subsystems (which may either be current space-qualified hardware or advanced technology subsystems) and continue with the design process.

The contributions of various environmental load conditions are illustrated in figures 14 and 15 for the three-load case (thermal, gravity gradient, and atmospheric drag) and for thermal load only. Note that there is little change in the loads levels or distribution from the thermal-only case to the three-load case. The environmental loads are extremely small. Minimum gage structural members designed on the basis of practical ground fabrication and handling loads are expected to have a much higher load-carrying capability.

MICROWAVE RADIOMETER SPACECRAFT STRUCTURAL MEMBER LOADS

3 ENVIRONMENTAL LOADS
(THERMAL, GRAVITY GRADIENT, DRAG)

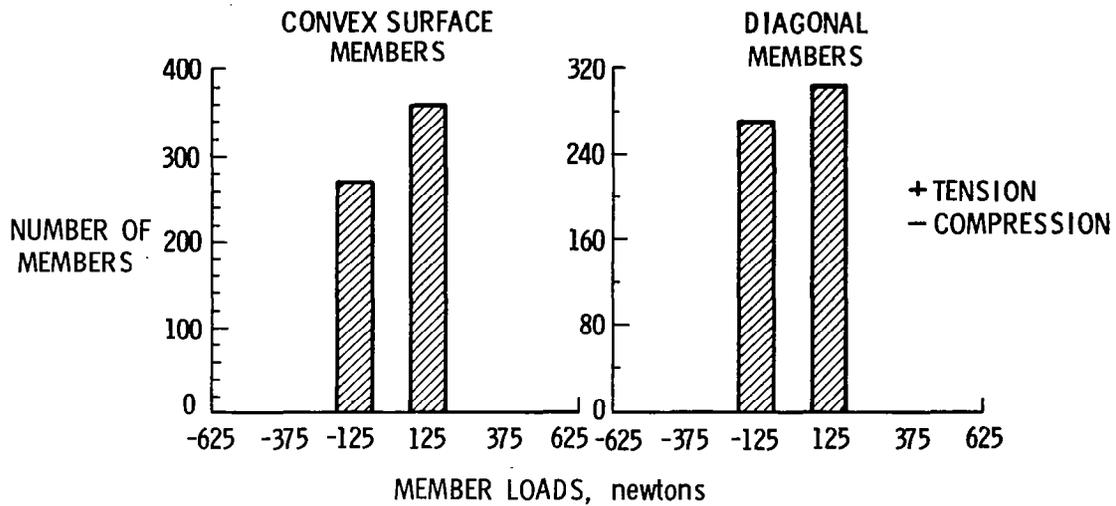


Figure 14

MICROWAVE RADIOMETER SPACECRAFT STRUCTURAL MEMBER LOADS

THERMAL ONLY

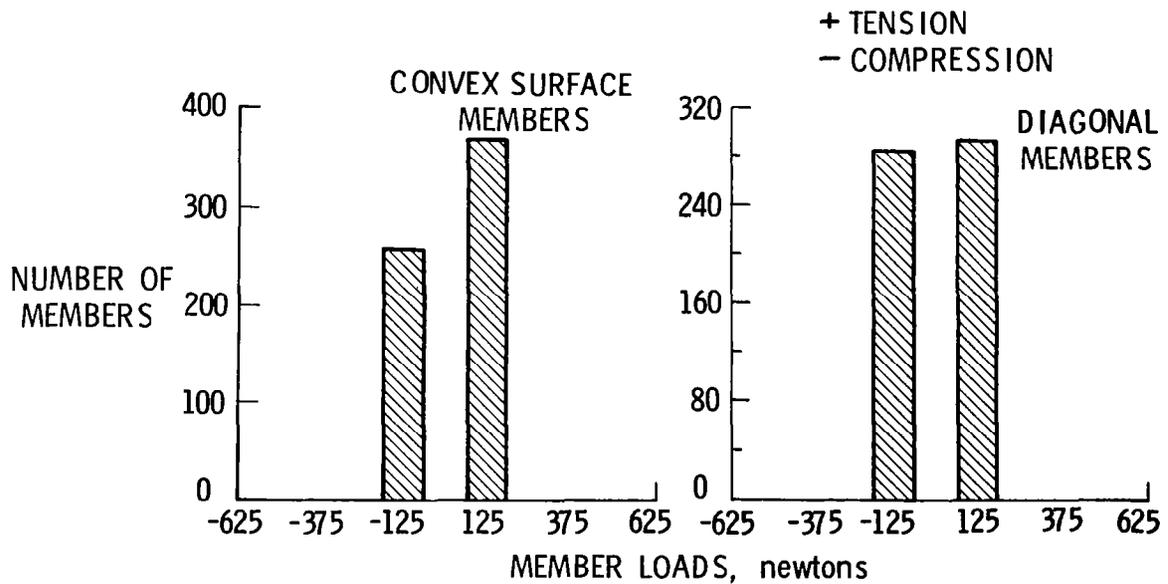


Figure 15

MICROWAVE RADIOMETER SPACECRAFT SURFACE ACCURACY

Performance must also be factored into the design evaluation process. For example, in the case of large aperture systems, surface distortions, boresight offset, and defocus are important parameters leading to the establishment of RF antenna or solar concentrator performance and figure control requirements. The IDEAS Surface Accuracy (SA) Model establishes these first-order effects on performance. SA computes the overall surface roughness (rms displacement), lines of constant derivation from an ideal surface (distortions), and changes in focal length, boresight direction, and boresight displacement for reflective surfaces. The SAP static module files supply SA with finite element model data for all original and statically displaced node point locations. SA plots the local normal displacement and distortion contours for the mesh surface nodes. The shapes of surfaces available are parabolic, spherical, or flat.

It should be noted that most spacecraft are free-free structures which require nonredundant translational constraints for purposes of static analysis. The STLO module has been coded to automatically provide nonredundant constraints at three node points on opposite corners of a tetrahedral truss dish structure (one node restrained in x, y, and z, one node restrained in x and z and one node restrained in z only) to arrive at static loads. The calculated loads and stresses are valid for the real free-free spacecraft; however, resulting static deflections at individual node points are sensitive to the method of restraint and the nodes which are restrained. The program is used to convert the artificially constrained nodal deflections into distortions that are independent of the constraints.

The MRS surface distortion contours due to the environmental loads are shown in figure 16. Defocus and boresight offset data are also shown. The resulting surface rms roughness is well within the 6-mm tolerance required for good microwave radiometry performance.

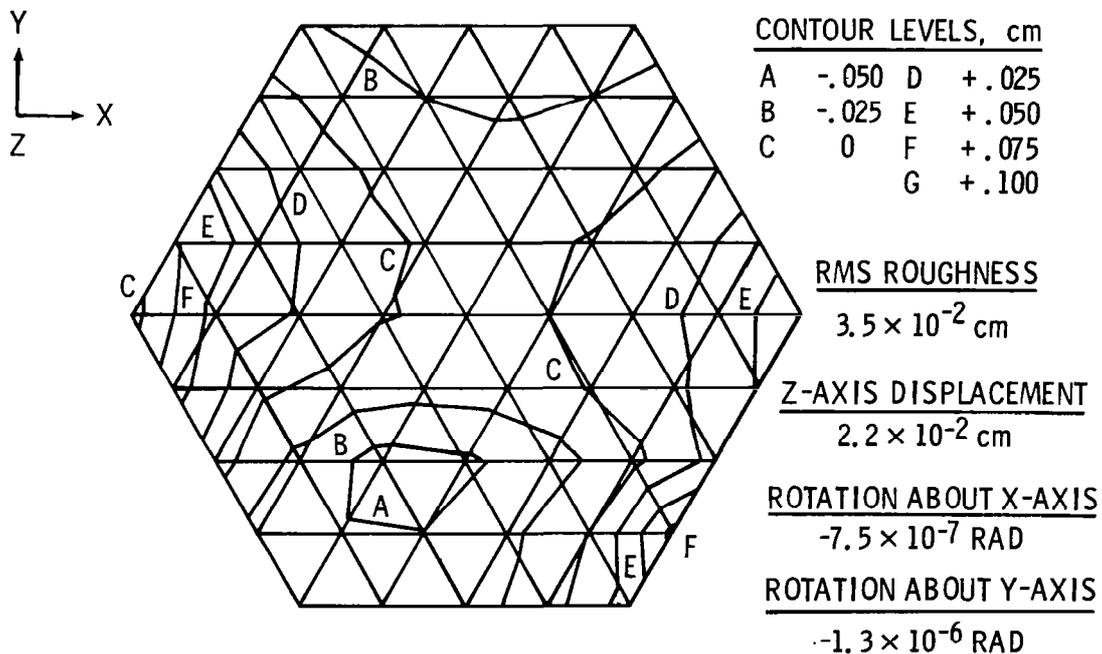


Figure 16

MICROWAVE RADIOMETER SPACECRAFT DYNAMIC ANALYSIS

In the IDEAS program the SAP Dynamic Analysis Module is used to generate modal frequencies, normalized forces, and stresses. The deflections in all cases are normalized to unit-generalized masses. All appropriate dynamic analysis data, accumulated from the structural synthesizer and other analysis modules, are combined in a properly formatted input file (DYML) for the SAP Dynamic Analysis module. An automated eigenvalue shift procedure has been employed in IDEAS to overcome most numerical instability or singularity problems associated with rigid body modes (normally there are six of these zero roots for the free-free structures). SAP outputs data on the number of modes requested by the user, including the first six rigid body modes for the linear system. A post-processor has been added to the Langley version of IDEAS to scale and plot flexible body mode shapes for the spacecraft structure.

Mode shapes for the first and fourth flexible body modes of the MRS are shown in figures 17 and 18. These figures were generated in the Interactive Plotting Module from SAP (Dynamic) solutions. The low frequencies noted in the figures are due to mast and feed beam action. The tetrahedral truss dish first flexible body frequency is an order-of-magnitude (~ 0.5 Hz) higher than the fundamental mast frequency. Although this study did not address minimum vibrational frequency or flexible-body-control-system requirements for the MRS, it should be noted that the triangular truss beams could be replaced with somewhat stiffer structural members to provide moderate increases (possibly a factor of 2 or 3) in the lower-order frequencies. However, even with technology advances in stiff, lightweight materials and structural design concepts, it is likely that these low frequencies and possibly high-amplitude vibrations will be typical of large future systems. Frequencies on the order of 0.01 to 0.1 are far below the design capabilities of space-qualified controllers/actuators and will require innovative control concepts and much more detailed analyses.

IDEAS DYNAMIC ANALYSIS
MRS BASELINE - GENERALIZED DISPLACEMENTS

$f_1 = 0.05601$ Hz
MODE 1
Y
X
Z

MAX. GENERAL DISPLACEMENTS

DX = 0.641500E-02 cm
DY = 0.186487E-03 cm
DZ = 0.332419E+00 cm

--- ORIGINAL STRUCTURE
— GENERAL DISPLACEMENT
SHAPE (EXAGGERATED)

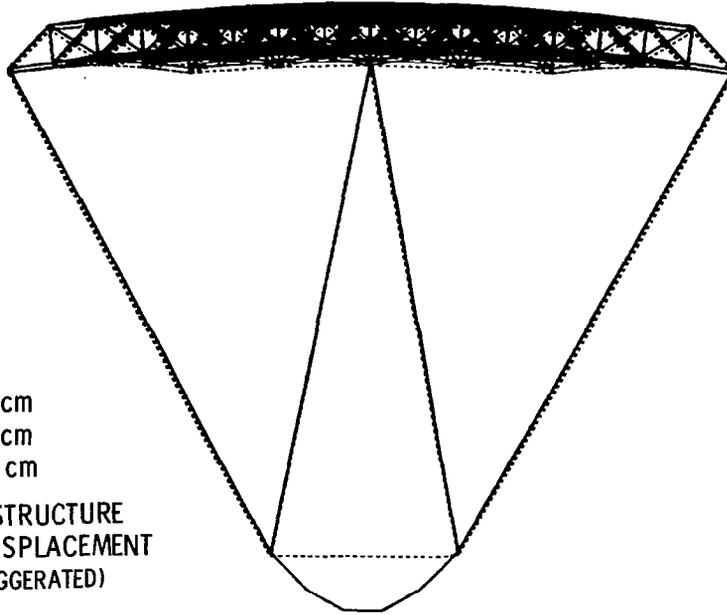


Figure 17

IDEAS DYNAMIC ANALYSIS
MRS BASELINE - GENERALIZED DISPLACEMENTS

$f_4 = 0.1000$ Hz
MODE 4
Y
X
Z

DX = 0.114351E+01 cm
DY = 0.511324E-02 cm
DZ = 0.673517E+03 cm

----- ORIGINAL STRUCTURE
— GENERAL DISPLACEMENT
SHAPE (EXAGGERATED)

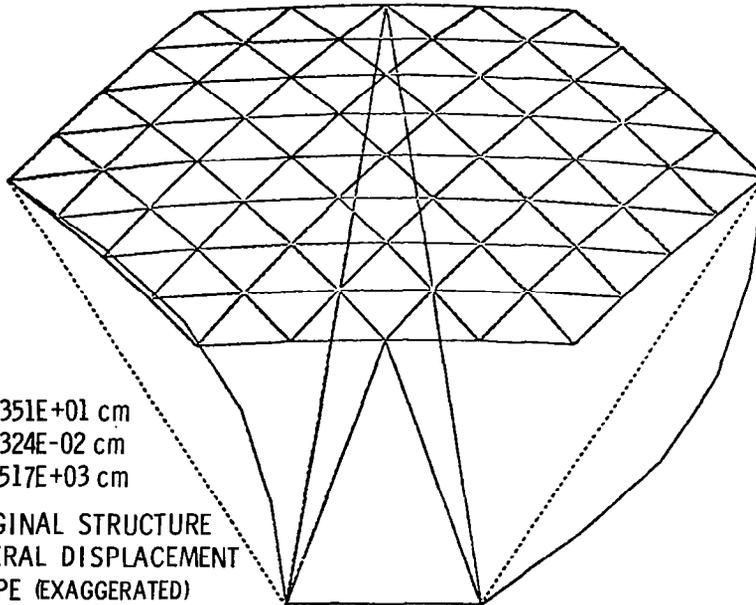


Figure 18

ADDITIONAL IDEAS CAPABILITIES

The IDEAS program has several additional capabilities for design, analysis, and evaluation of future large spacecraft concepts. These capabilities are summarized below.

Orbital Transfer. This module is used to compute the propellant required to perform an orbital plane change maneuver or to raise or lower a satellite orbit. Inputs include the satellite mass, thruster specific impulse, and initial and final orbit parameters.

RF Analysis. This module calculates the db loss for random distortions in an antenna surface. Inputs required include node point displacements or overall surface rms errors and the antenna operating frequency.

Dynamic Loads and Active Damping. Other capabilities include the Dynamic Loads (DYLO) module developed by Leondis (ref. 1) to provide dynamic deflection data at node points and dynamic loads on each member. Inputs include the flexible body modes from SAP dynamic, the finite-element files (DYML), and user-specified transient-force functions and structural damping characteristics. The use of active damping systems can be evaluated in this module.

Cost. Developmental and first unit costs are computed in the COST module principally from cost-estimating relationships. Subroutines calculated costs associated with large space structures comprised of many structural members of various types of materials and design complexity. Spacecraft subsystem costs are approximated from subsystem masses or performance data. Shuttle launch costs are based on both spacecraft/subsystem mass and on packaging volumes. On-orbit construction costs may be estimated from user inputs on construction time and crew size. All cost-estimating relationships are in 1976 dollars; however, totals costs are updatable to any subsequent year with appropriate inflation factors.

PROGRAM RUN TIMES AND THROUGHPUT STATISTICS

A 32-bay tetrahedral truss dish structure (6864 structural members) of any diameter, curvature, and truss depth can be mathematically synthesized in the Tetrahedral Truss Structure Synthesizer module in about 5 wall-clock minutes on the minicomputer system. The program incorporates all joints, pins, hinges, and mesh system and designs the structural members for a user-specified Euler buckling load. Then it generates and displays the finite-element model and summary data and writes the data and files to retrievable dish storage. The corresponding 8 Bay case (420 members) executes in 1 to 2 wall-clock minutes on the minicomputer (at 9600 Baud line rate) or about 6 wall-clock minutes and 27 seconds CP time on the mainframe (at a 1200 Baud line rate).

In general, for a typical case with about 500 structural members, the CP times for each applications module range from a few seconds to 2 minutes on the mainframe. Corresponding wall-clock times vary between 1 and 15 minutes. All modules can be run in series in 2 to 3 wall-clock hours on the mainframe. (See ref. 3 for more information on run time statistics for the individual modules.)

CONCLUDING REMARKS

Capabilities, performance, and advantages of a systems-oriented interactive computer-aided design and analysis system have been presented. A single user at an interactive terminal can create, design, analyze, and conduct parametric studies of Earth-orbiting spacecraft with relative ease. The approach is shown to be particularly useful in the conceptual design phase where various missions and spacecraft options are to be evaluated in a timely, cost-effective manner.

The Interactive Design and Evaluation of Advanced Spacecraft (IDEAS) program was developed specifically to provide spacecraft system analysts with the interactive capabilities to rapidly analyze and evaluate spacecraft performance across several disciplines. The primary emphases are on structures, thermal analyses, and controls. Simple and efficient executive data base and file management systems relieve the analyst of much of the tedium associated with computer system command protocol. Formatted data inputs reduce the possibility of input errors and greatly increase throughput capabilities. Extensive graphical displays let the analyst rapidly evaluate the results, make timely design changes, and continue in the interactive processing mode. Although the IDEAS capabilities are by no means complete, the program has reached a certain level of maturity in the use of interactive data processing capabilities and spacecraft systems analysis oriented software to guide the design of future large space systems. The coupling of space environmental modeling algorithms with first order design and analysis modules permits rapid evaluation of competing spacecraft and mission designs. Spacecraft redesign is easily accomplished and baseline designs can be altered in an orderly manner for subsystem and mission design trades. Integrated spacecraft systems level data and finite element model files are generated for more rigorous analysis.

Example problems of large flexible spacecraft in low-Earth and geosynchronous-Earth orbits have been used to illustrate some of the IDEAS capabilities. Study results lead this author to conclude that the space environmental loadings on most of the future spacecraft will be small. The structural strength requirements will be dictated by either ground-based manufacturing, assembly and testing, or launch or on-orbit deployment.

Optimally designed structures with physical sizes approaching 100 meters may have fundamental frequencies on the order of 0.01 to 0.1 Hz, which are below current control system capabilities. The desire on the part of the dynamicists to increase the structural stiffness will penalize the spacecraft design on both volume and mass basis. Further work is required in this area to achieve reasonable design compromise.

This author is also concerned with the application of some of the existing thermal analysis codes for these large structures which may have thousands of individual structural members. If some of the large conduction and radiation heat exchange computer programs are used the computer run time costs can become expensive. It is not clear that this concern has been adequately addressed by the thermal prohibitively analysis community.

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