NASA Technical Memorandum 85638

NASA-TM-85638 19830021033

INTERACTIVE ANALYSIS OF A LARGE APERTURE EARTH OBSERVATIONS SATELLITE

Robert L. Wright, Dariene D. DeRyder,

Melvin J. Ferebee, Jr. and John C. Smith

May 1983

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

INTERACTIVE ANALYSIS OF A LARGE
APERTURE EARTH OBSERVATIONS SATELLITE

Robert L. Wright, Dariene D. DeRyder, and Melvin J. Ferebee, Jr.
NASA Langley Research Center
Hampton, Virginia 23665

and

John C. Smith
University of Virginia
Charlottesville, Virginia 22901

Abstract

A system level design and analysis has been conducted on an Earth Observation Satellite (EOS) system using the Interactive Design and Evaluation of Advanced Spacecraft (IDEAS) computer-aided design and analysis program. The IDEAS program consists of about 40 user-friendly technical modules and an interactive graphics display.

The reflector support system and feed mast of the EOS spacecraft are constructed with a box-truss structural concept, a lattice configuration which can be packaged for delivery in a single Shuttle flight and deployed in orbit. The deployed spacecraft consists of a 120-m by 60-m parabolic reflector, a 120-m-long support structure, and a 30-m feed arc beam on the focal axis. The spacecraft was modeled for structural, thermal, and control systems analysis and structural elements were designed. On-orbit dynamic and thermal loading analyses were conducted and spacecraft weights were determined.

Introduction

An advanced Earth Observation Satellite (EOS) system is being studied for Earth, oceanic, and atmospheric observational resource missions in the 1990's. The satellite system would use microwave radiometer measurements to provide information for crop yield forecasting, climate prediction, coastal productivity, hydrology, water quality, and coastal dynamics. Such missions require day/night/all-weather operations, contiguous high resolution mapping, global coverage, and multiparametric sensing, hence, the need for a large microwave antenna with an accurately defined surface. The mission and performance requirements used in the studies of the Earth Observation Satellite systems are outlined in table I. Spacecraft design requirements dictated packaging for a single Shuttle launch to place the EOS spacecraft in a Sun-synchronous orbit with a 5-year lifetime. A pointing accuracy of ± 0.07 degrees absolute is required for the Earth pointing spacecraft.

1

Numerous structural design concepts, both deployable and erectable, have been identified as candidates for the EOS spacecraft (refs. 1 to 4). The box-truss concept (developed by Martin Marietta Aerospace) possesses a number of attractive features, namely: 1) deployment is sequential and linear; and 2) the truss support structure is inherently stiff and is the subject of this study. The box-truss concept is characterized by a series of cubes joined together to form the lattice-structure of the spacecraft. An artist concept of the fully deployed spacecraft is shown in figure 1, and consists of a 120-m by 60-m parabolic reflector, a 120-m-long support structure and a 30-m feed arc beam on the focal axis.

EOS Mission and Spacecraft Description

Mission Definition

The EOS spacecraft was designed for multidiscipline missions. A group of compatible sensors share the large antenna spacecraft to obtain remote sensing data to achieve combined Earth, ocean and coastal zone, and atmospheric observations. The sensor package consists of microwave radiometers providing day/night and near all-weather observations in the 1 to 37 GHz region, as well as sensors operating in the visible and IR regions. A list of potential observations from large microwave radiometers and their application is given in table II.

Measurement requirements for Earth observation missions include day/night, all-weather operations, contiguous coverage, ground resolution of less than 1 km, revisit frequency from one visit per day to one visit per week, and experiment life greater than 5 years. The corresponding performance requirements of the spacecraft are listed in table I.

Spacecraft Description

Lattice work or a combination of repeating structures and tension cable designs have been identified as ideal candidates for the structural support system of future large antenna systems. These concepts are lightweight, packaged simply, are easily deployed or assembled on orbit, and are inherently stiff. The lattice concepts include repeating structures such as the tetrahedral truss, box-ring, and box-truss. The radial rib is a repeating cantilevered system and the hoop-and-column typifies the tension stabilized concept. Finite-element models of these concepts are shown in figure 2. Each of these concepts has been the object of investigation for various space missions. The Microwave Radiometer Spacecraft (MRS) study of references 1 and 2 investigated the use of tetrahedral concepts for a mission to measure soil moisture for global crop forecasting. All five concepts were studied and compared in references 3 and 4 for Land Mobile Satellite System (LMSS) missions. The box truss was selected for the analysis of the current EOS mission since its deployment is sequential and linear with resultant bending stresses that are well within the allowable envelope for the graphite epoxy members (ref. 4) and the entire spacecraft can be packaged in a single Shuttle flight.

The antenna design for the EOS mission is based on a number of considerations. An offset-fed reflector operating in a pushbroom mode reduces aperture blockage and minimizes scattered radiation. The aperture size is dictated by the lowest operating frequency, the spatial resolution requirement, and number of feed beams. A spherical/parabolic reflector provides a line of focus for the multiple beams, such that each feed sees a specified spot on the reflector and, subsequently, a specified spot on the ground.

To match these considerations with the mission requirements of table I, the box-truss structural configuration of figure 3 was developed. The box-truss geometry consists of a series of cubes joined together to form the lattice structure of the spacecraft. The individual cubes, 15 m on each side, are designed such that the horizontal tubes are hinged and fold against the non-folding vertical tubes for packaging. The deployment sequence from reference 5 for the box-truss spacecraft is shown in figure 4. Pretensioned telescoping tapes extend from each corner (both in the plane of the faces and across the cube diagonals) to stabilize the deployed cube. Both the tubular members and the telescoping tapes are constructed of graphite. The deployed spacecraft consists of a 120-m by 60-m spherical/parabolic reflector, a 120-m-long feed support mast, and a 30-m feed arc beam on the focal axis. The antenna surface is spherical in the 120-m direction (with a radius of 232-m) and parabolic in the 60-m direction, with a focal length of 116.1 m. The spacecraft is pitched forward 19.33 degrees about the y-axis to align the spacecraft inertial axis perpendicular to the Earth, as shown in figure 5.

Although a number of different structural member types are used in the EOS structure, only three classes will be described. The surface or horizontal folding members are cylindrical in cross section with a diameter of 8.33 cm and have a wall thickness of 0.066 cm and are constructed of layers of graphite cloth or tape and epoxy. However, the wall thickness is increased at the interface of the feed mast and antenna support structure. The vertical members are square tubes of graphite epoxy laminate, 2.54 cm on a side with 5.08 cm fins projecting outward 45 degrees from each corner for strength. Wall and fin thickness for the vertical members is 0.127 cm. All surface and vertical members are designed with a safety factor of 1.25. The diagonal members are pretensioned telecoping cables in a unique rod and slide fitting. The cords of internal diagonals are 0.66 cm in diameter, while the exterior diagonal cables are 0.81 cm in diameter to provide greater stiffness in the plane of the horizontal surface tubes (the vertical tubes have a greater mass than the surface tubes). Details may be found in reference 5.

IDEAS Program

The systems analysis of the box-truss concept is conducted with the Integrated Design and Evaluation of Advanced Spacecraft (IDEAS) computer-aided design and analysis program (ref. 2), which was developed for rapid evaluation of systems concepts and technology needs for future advanced spacecraft such as large antennas, platforms, and space stations. The IDEAS program is an expansion of the Large Advanced Space Systems program (ref. 6) and consists of 40 technical modules and an interactive graphics display linked by the AVID

data base management system (ref. 7), as shown in figure 6. The IDEAS program is described in more detail in reference 8.

A single analyst at an interactive terminal can rapidly model the structure and design and analyze the total spacecraft and mission. On-orbit environmental computational algorithms are coupled with design and analysis modules for rapid evaluation of a spacecraft design or computing designs.

Weight and Packaging Analysis

Weight

Weight and structural analyses were conducted on the EOS spacecraft by interactively exercising the individual synthesizer modules and the general truss synthesizer module of the IDEAS program. A mass properties report for the EOS spacecraft is given in table III. The total mass consists of a lumped subsystem mass, and the masses of the spacecraft structure and propulsion system.

The lumped subsystem and propulsion system masses, developed in the system study of reference 5, are used in the present study. Total subsystem mass was 4569 kg, with the major contributors being slewing propulsion (1265 kg), power (840 kg), orbit transfer propulsion (886 kg), and electronics and feed system (827 kg), with 2603 kg for the structural elements, 93 kg for the midlink and hinges, 335 kg for the mesh, and 265 kg for the corner and end hinges. Since the GTS module will only model circular elements, the section properties of the finned vertical members, surface tube members, diagonals and other non-circular shapes were converted. The total mass of an element was maintained and the wall thickness of the circular element was adjusted. Average values of Ix and Iy were used in the calculations.

The computed spacecraft total mass of 7865 kg differed from the spacecraft mass of reference 5, by 230 kg. The comparison is shown in figure 7. The difference is due primarily to the mass of the cube corner fittings.

Packaging

The total spacecraft mass of 7865 kg is well within the Shuttle payload capacity of 29,000 kg. Maximum packing density for the Shuttle is 98.3 kg/m^3 (based on a Shuttle volume of 300 m^3). Packing density for the EOS spacecraft is 26.2 kg/m^3 and, therefore, "volume critical." The overall length of the stowed EOS spacecraft is 17.8 m and the width is 3.75 m. The Shuttle bay dimensions are 18.29 m long and 4.57 m wide.

Thermal Analysis

A thermal analysis was conducted on the EOS spacecraft at 32 points during the worst case baseline non-Sun synchronous, 60-degree inclination orbit. The thermal analysis (TA) module computes heating rates and radiation

4

equilibrium temperatures for each structural element at a given position in the spacecraft orbit. Heat sources include an Earth albedo, Earth radiation, solar radiation, and the element's reradiation of heat absorbed. Typical heating rates on the horizontal and vertical tubes and the cables in the beam are shown in figure 8. The heating rates are observed to go to zero during the shadow period. The vertical tubes are noted to rise sharply after exit from the shadow to a peak of about 1500 W/m^2 and then drop to a value of 300 W/m^2, followed by a second rise just prior to entry into the Earth's shadow. This oscillatory effect is due to the change in angle of the vertical elements with the Sun-spacecraft line. The hottest points occur when the element is perpendicular to the Sun-spacecraft line and the heating rate decreases as the element comes more in line with (parallel to) the Sun-spacecraft line.

The average temperature of each element is calculated by determining the orientation of the spacecraft element with respect to the Earth and Sun and using the calculated heat fluxes due to all heat sources. The module then performs an integration of temperatures from a beginning point in the orbit to the desired point in the orbit. A table of temperatures is created and stored for future reference. For the present study, the maximum and minimum temperatures on the spacecraft are tabulated in table IV for 16 points in the orbit. Due to the inclination and low altitude (720 km) of the orbit, it is observed that the spacecraft lies in the Earth's shadow during a major portion of the orbit (approximately 38 percent of the orbit). During this time, the spacecraft cools to a low temperature of about 190° K. However, the temperature on the hottest elements rises about 100° K during the first 5 minutes after exit from the shadow. Reference 9 describes a color graphics technique for visualizing the temperature variations on the spacecraft and a detailed analysis of the orbital thermal analysis on the EOS spacecraft.

Dynamic Analysis

A dynamic analysis was performed on the EOS structural model using the Structural Analysis Program (SAP). Natural frequencies and mode shape were calculated for a free-free structure. The frequencies and mode shapes can be found in table V and figures 9 through 11, respectively. Corresponding frequencies and mode shapes from reference 5 are presented for comparison.

The first flexible-body fundamental frequency for the EOS spacecraft was 0.8888 Hz, compared to 0.874 Hz for the spacecraft of reference 5. The mode shape associated with this frequency is a bending of the feed mast and an oscillation of the dish about the x-axis as shown in figure 9.

This lattice structure is very stiff, relative to similar structures of previous studies. In reference 5, the first fundamental frequency of the four offset feed structural concepts studied was less than 0.1 Hz. The natural frequency of the reflector only in these concepts was an order of magnitude higher than the total spacecraft, leading to the conclusion that offset feed masts that are essentially supported at one end tend to drive the system

natural frequencies downward. Thus, for the EOS study, one of the design criterion was to stiffen the feed mast to match the natural frequency of the reflector.

Second and third fundamental frequencies are shown in figures 10 and 11 and listed in table V. Again, the results from the present study matched the data of reference 5. The second mode is characterized by a flexure of the feed mast and reflector dish about the line of intersection. The third mode shows a torsional rotation of the feed mast and reflector.

Concluding Remarks

A system-level interactive design and analysis has been conducted on a large aperture Earth Observation Satellite (EOS) computer-aided design and analysis program. A box-truss structural concept which can be packaged for delivery in a single Shuttle flight and deployed in space was analyzed. On-orbit dynamic and thermal loadings and total spacecraft weight were determined.

The total spacecraft mass of 7827 kg is well within the Shuttle capability of 29,000 kg and easily fits into the cargo bay.

Temperatures on the spacecraft vary from 334° K at the hottest point in the orbit to a low of 183° K just prior to exit from the Earth's shadow. It is noted that the temperatures on the spacecraft rise rapidly ($\sim 100°$ K) during the first 5 minutes after exit from the Earth's shadow.

The first fundamental frequency for the spacecraft was determined to be 0.8888 kg which is very stiff relative to similar lattice structural spacecraft. Additional weight savings could be made by lightening the structural elements (reducing wall thickness) without adversely impacting the structural stiffness.

Author Biography

Robert L. Wright, Aero-Space Technologist in the Space Systems Division, at NASA Langley Research Center, received his bachelor of science degree in Aeronautical Engineering from the University of Virginia in 1958. Before joining the NASA Langley Research Center staff in 1961, he served in the U.S. Navy.

In February 1970, he was named Staff Assistant to the Assistant Director for Flight Projects, and in October 1970, he was appointed Staff Assistant to the Director for Space. In December 1972, he was named Technical Assistant to the Viking Project Manager. From May 1974 to August 1976, he was Division Executive to the Chief, Space Applications and Technology Division at NASA Langley Research Center. He assumed his present position in August 1976 and is responsible for the analysis, definition, and development of future large spacecraft concepts for flight on Shuttle missions.

He received a NASA Special Achievement Award in July 1974, is the author or co-author of 42 technical reports and presentations, and has made 150 presentations to the general public.

References

1. Wright, Robert L., (ed.): The Microwave Radiometer Spacecraft - A Design Study. NASA RP-1079, 1981.

2. Garrett, L. Bernard: Interactive Design and Analysis of Future Large Spacecraft Concepts. AIAA Paper 81-1177, June 1981.

3. Ferebee, Melvin J., Jr.; Wright, Robert L.; and Farmer, Jeffrey T.: Weight and Structural Analysis of Four Structural Concepts for a Land Mobile Satellite System. SAWE Paper 1456, May 1982.

4. Ferebee, M. J., Jr.; Garrett, L. B.; and Farmer, J. T.: Interactive Systems Analysis of a Land Mobile Satellite System. AIAA Paper 83-0219, January 1983.

5. Herbert, James J.; Postuchow, J. R.; and Schartel, Wilfred A.: Technology Needs of Advanced Earth Observation Spacecraft. Martin Marietta Aerospace Company, Report MCR 81-630, March 1983.

6. Leondis, A. F.: Large Advanced Space System (LASS) Computer Program. AIAA Paper 79-0904, May 1979.

7. Wilhite, A. W. and Rehder, J. J.: AVID: A Design System for Technology Studies of Advanced Transportation Concepts. AIAA Paper 79-0872, May 1979.

8. Garrett, L. Bernard and Ferebee, Melvin J., Jr.: Comparative Analysis of Large Antenna Spacecraft Using the IDEAS System. AIAA Paper 83-0798-CP, May 1983.

9. Wright, Robert L.; DeRyder, Dariene D.; and Palmer, Michael T.: Orbital Thermal Analysis of Lattice Structural Spacecraft Using Color Video Display Techniques. AIAA Paper 83-1460, June 1983.

Table I. Mission and Performance Requirements.

a) Mission Requirements.

REQUIREMENTS	IMPLIES
DAY/NIGHT OPERATION	OPERATE LOWER FREQUENCIES (1-10 GHz)
GLOBAL COVERAGE	PASSIVE SYSTEM
MULTIPARAMETER SENSING	OPERATE AT VARIOUS FREQUENCIES
CONTIGUOUS MAPPING	⟨ WIDE GROUND SWATH / ORBIT PARAMETERS
OPERATIONAL ENVIRONMENTAL MONITORING	
ALL WEATHER OPERATION	LOWER FREQUENCIES

b) Performance Requirements.

MEASUREMENT REQUIREMENT	PERFORMANCE REQUIREMENT
	RADIOMETER
6 MEASURANDS	3 FREQ. BANDS, APPROX. 1, 2, AND 4 GHz
LAND, WATER, ICE RADIATIONS	BRIGHTNESS TEMP. T_B, 200 TO 350 K
6 MEASURAND ACCURACIES	PRECISION, ΔT_B < 1 K
RESOLUTION, < 1 KM	BEAM WIDTH, < 0.1° (ALTITUDE DEPENDENT)
COVERAGE, CONTIGUOUS	WIDE SWATH, > 200 BEAMS
	ORBITAL PARAMETERS
EXPERIMENT LIFETIME, > 5 YEARS	ALTITUDE MIN., 600 KM
REPEAT, 1/DAY TO 1/WEEK	ALTITUDE MAX., 1400 KM
COVERAGE - OVER FARM BELTS AND COASTAL ZONES	INCLINATION, 60° AND ≈98°
REPEAT PRECISION	ALT. DECAY, < 0.1 SWATH/REPEAT EQUIV.

Table II. Potential Observations.

APPLICATION	SOIL MOIST	WATER SURF TEMP	SALINITY	POLLUTANTS	SEA STATE	ICE
CROP YIELD	3					
CLIMATE PRED	2	2	1		2	3
COASTAL PRODUCTIVITY		3	3	2	1	1
HYDROLOGY	2					2
WATER QUALITY			1	3	1	
COASTAL DYNAMICS		2	1	2	3	

Table III. Mass Properties Report.

	Mass, kg	
	Present Study	From reference 5
Subsystem		
Slewing Propulsion	1265	1265
Power	840	840
Orbital Transfer Propulsion	886	886
Electronic and Feed System	827	827
Science	751	751
Structure		
Structural Members	2603	2574
Mid Link Hinges	93	104
Corner Fittings	265	53
Mesh	335	335
Total	7865	7635

Table IV.   Temperature Data.

a)   Complete Orbit.

Orbital Position, radians	Temperature, ° K	
	Max.	Min.
0.00	334	264
0.3927	334	259
0.7854	331	257
1.1781	325	253
1.5708	319	248
1.9635	316	237
Enters at 2.010 rad.		
2.3562	243	212
2.7489	215	201
3.1416 Shadow	203	194
3.5343	198	188
3.9270	196	185
4.3197	195	183
Exits at 4.371 rad.		
4.7124	299	218
5.1051	318	233
5.4978	326	250
5.8905	332	256
6.2831	334	264

b)   At Exit from Shadow.

Time from exit, Min.	Orbital position, radians	Temperature ° K	
		Max.	Min.
-0.05	4.3361	194	182
0.0	4.3710	209	192
0.5	4.4059	247	193
1.0	4.4408	245	193
1.5	4.4757	258	195
2.0	4.5106	276	198
2.5	4.5455	277	199
3.0	4.5804	282	203
3.5	4.6153	289	207
4.0	4.6503	293	211
4.5	4.6852	296	215
5.0	4.7124	299	218

Table V. Dynamic Analysis Summary.

	Frequency, Hz	
	Present Study	From Reference 5
First	0.874	0.8888
Second	1.046	1.004
Third	1.436	1.124

a) Artist's Concept.

120 m

15 m

60 m

116.1 m

234.8 m R

30 m
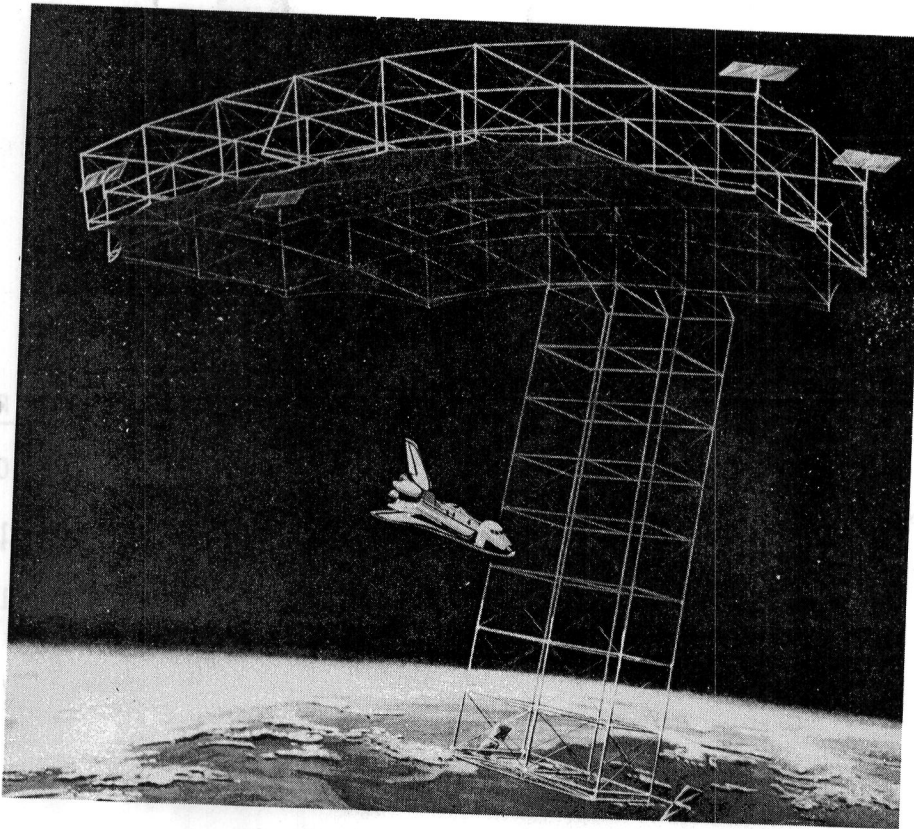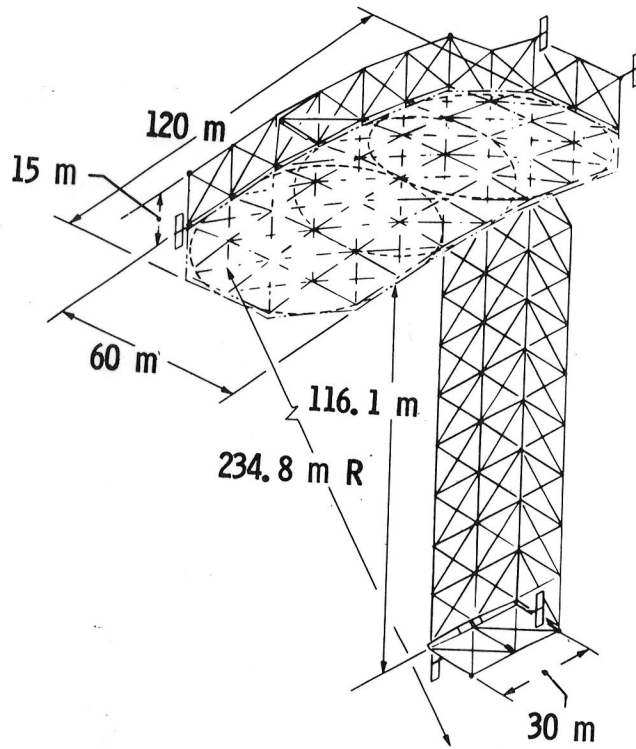
b) Box Truss Configuration.

Figure 1. EOS Spacecraft.

HOOP AND COLUMN

BOX TRUSS

TETRAHEDRAL TRUSS

RADIAL RIB

BOX RING TRUSS
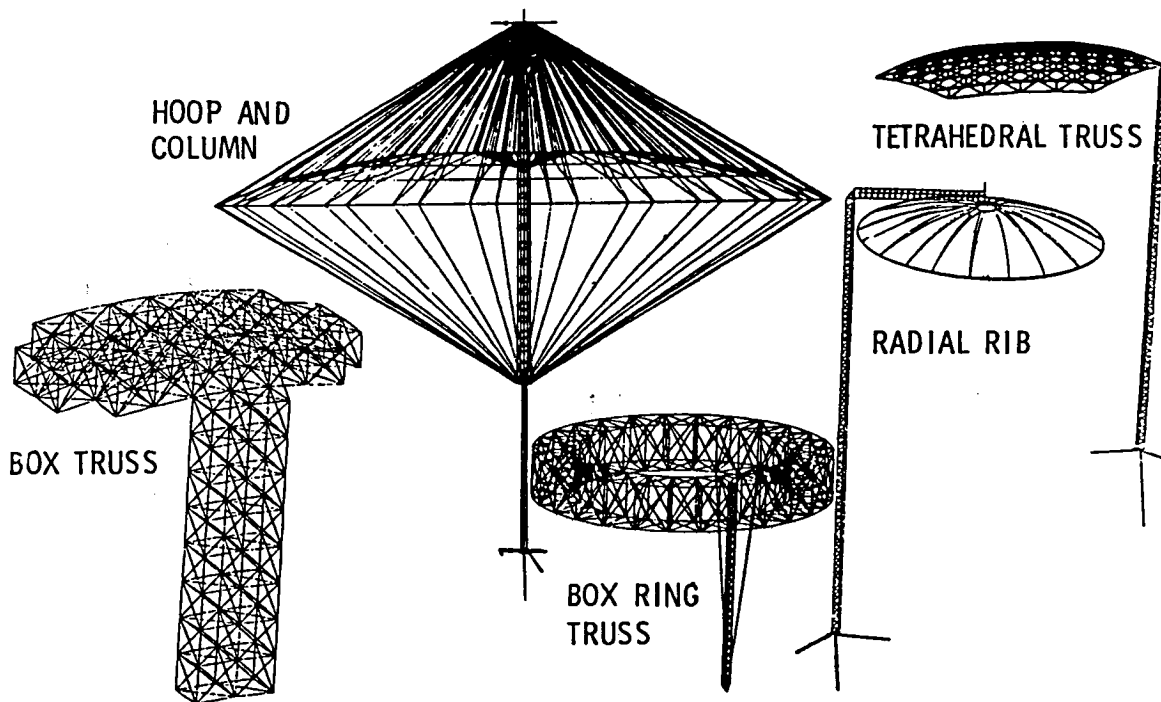
Figure 2. Antenna Structural Concepts.

DEPLOYED TRUSS

CUBE

EXTERNAL DIAGONAL

STANDOFFS

SURFACE TUBE

FRAME

INTERIOR DIAGONAL

STOWED FRAME

VERTICAL MEMBER

CORNER FITTING

MIDLINK HINGE
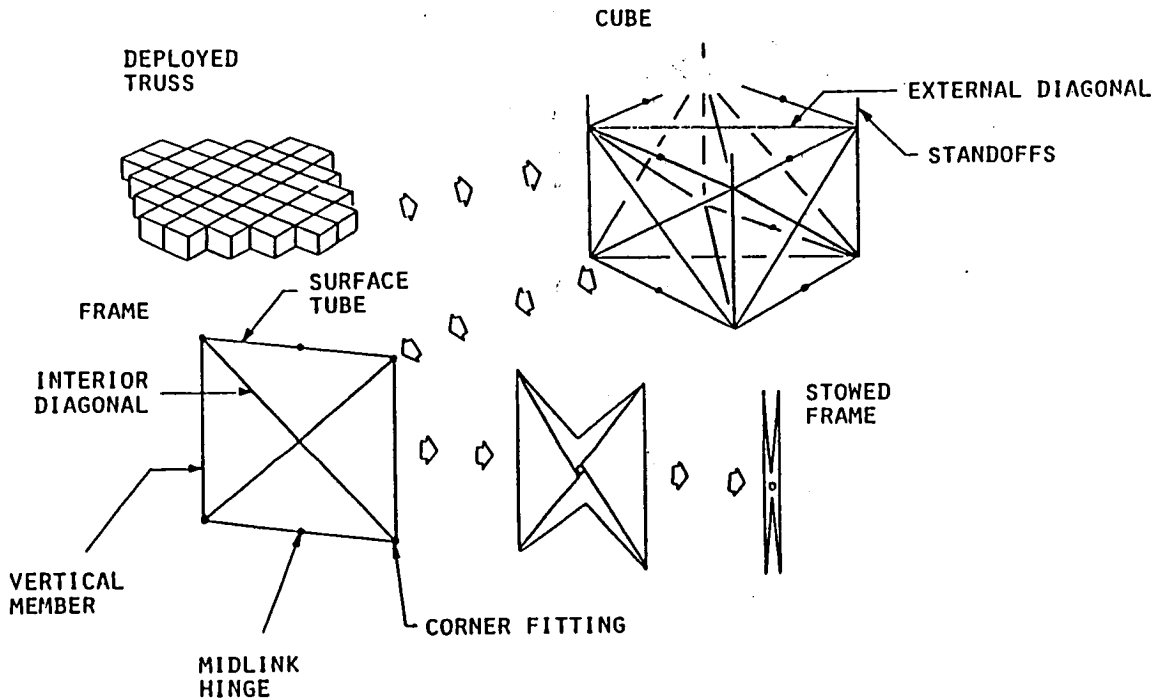
Figure 3. Box Truss Structural Elements.

STOWED

15 m

1

2

3

4
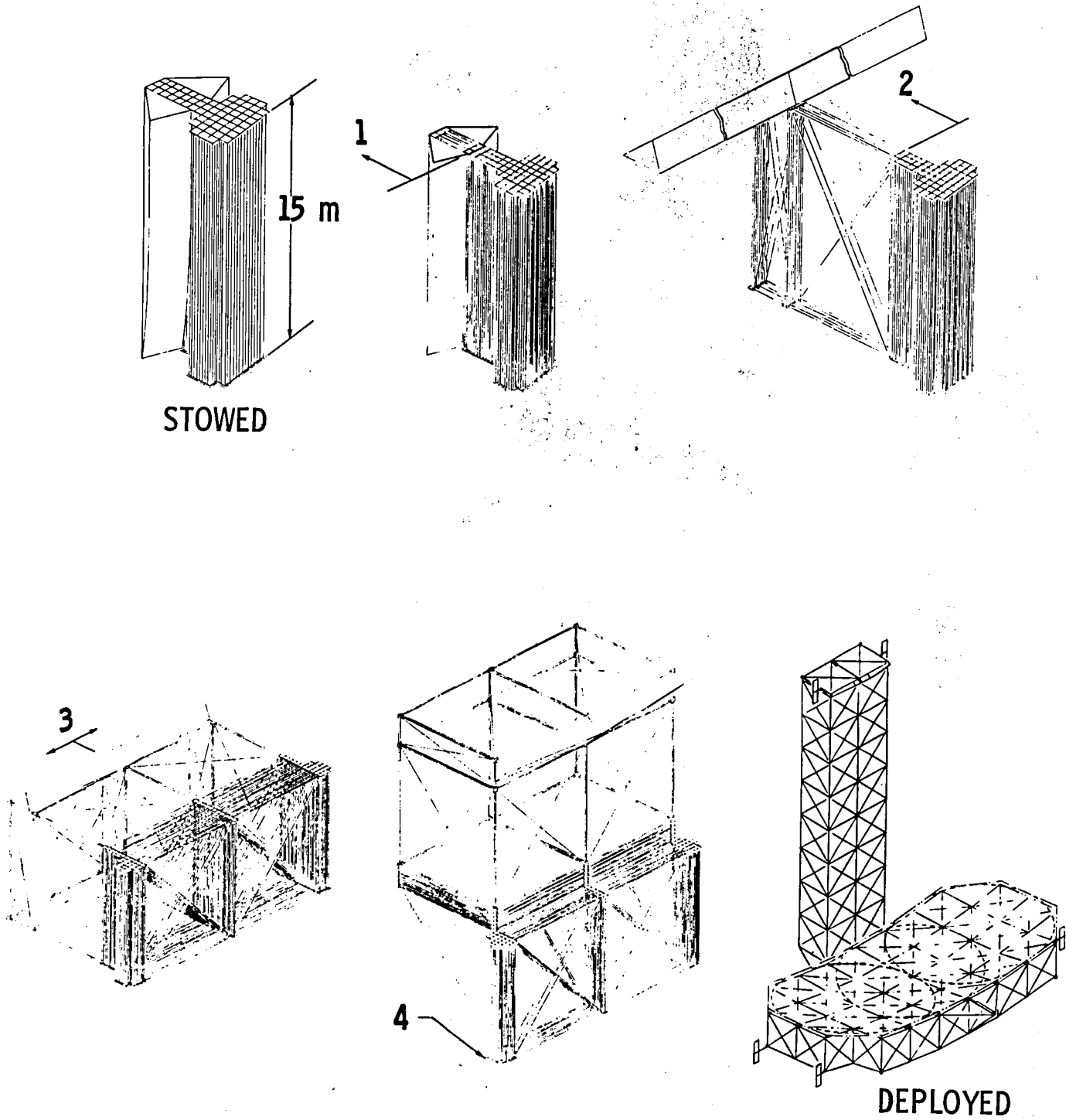
DEPLOYED

Figure 4.   Deployment Sequence.

14
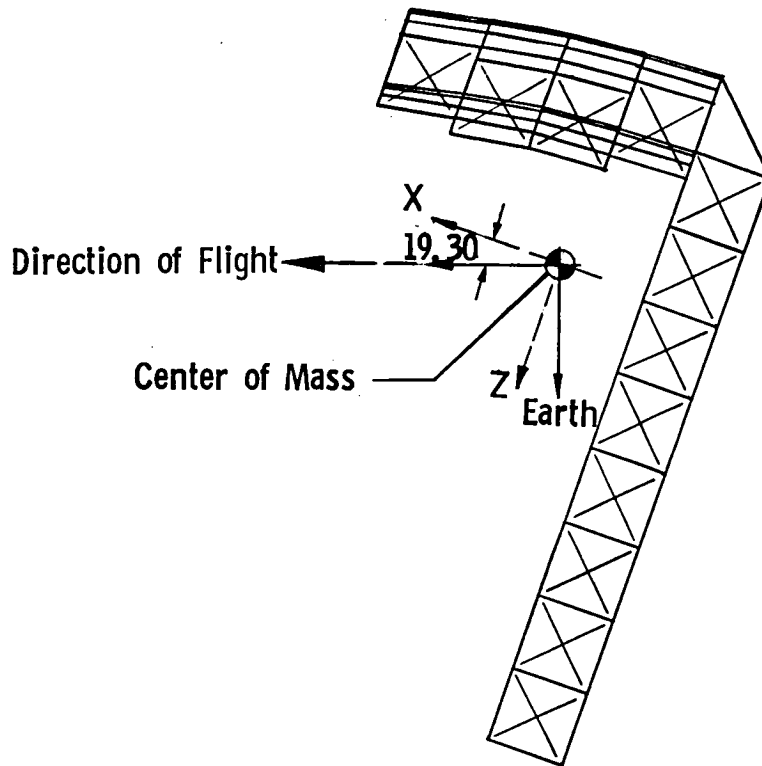
Figure 5. Spacecraft Orientation.
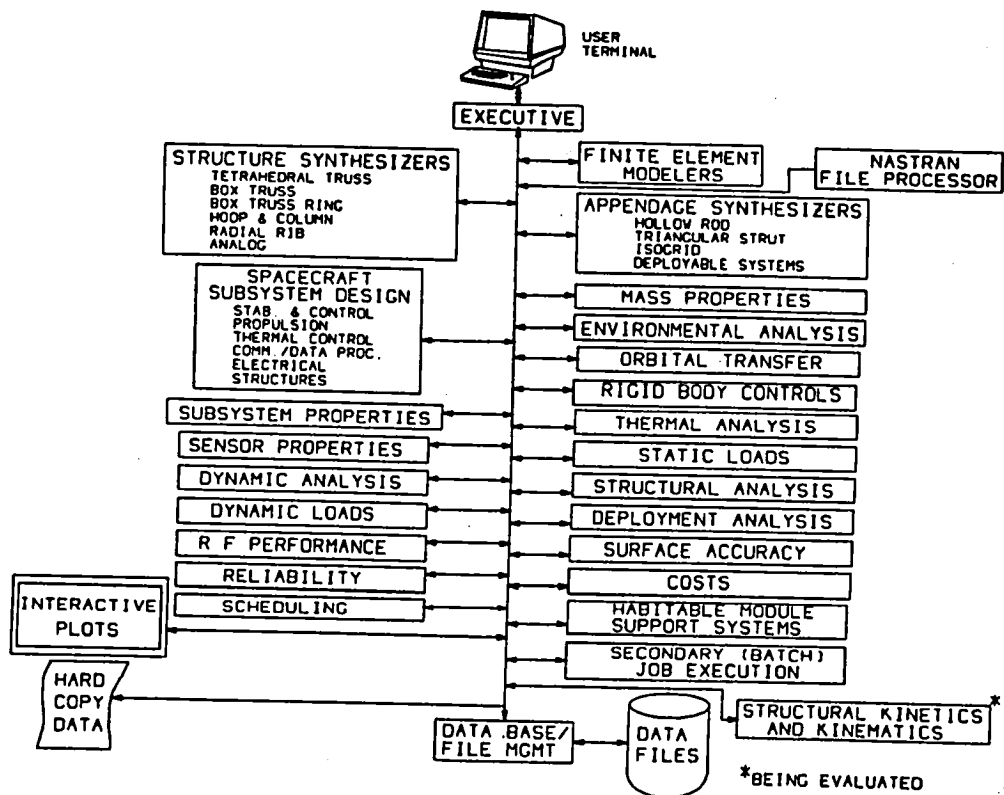
Figure 6. IDEAS Software.
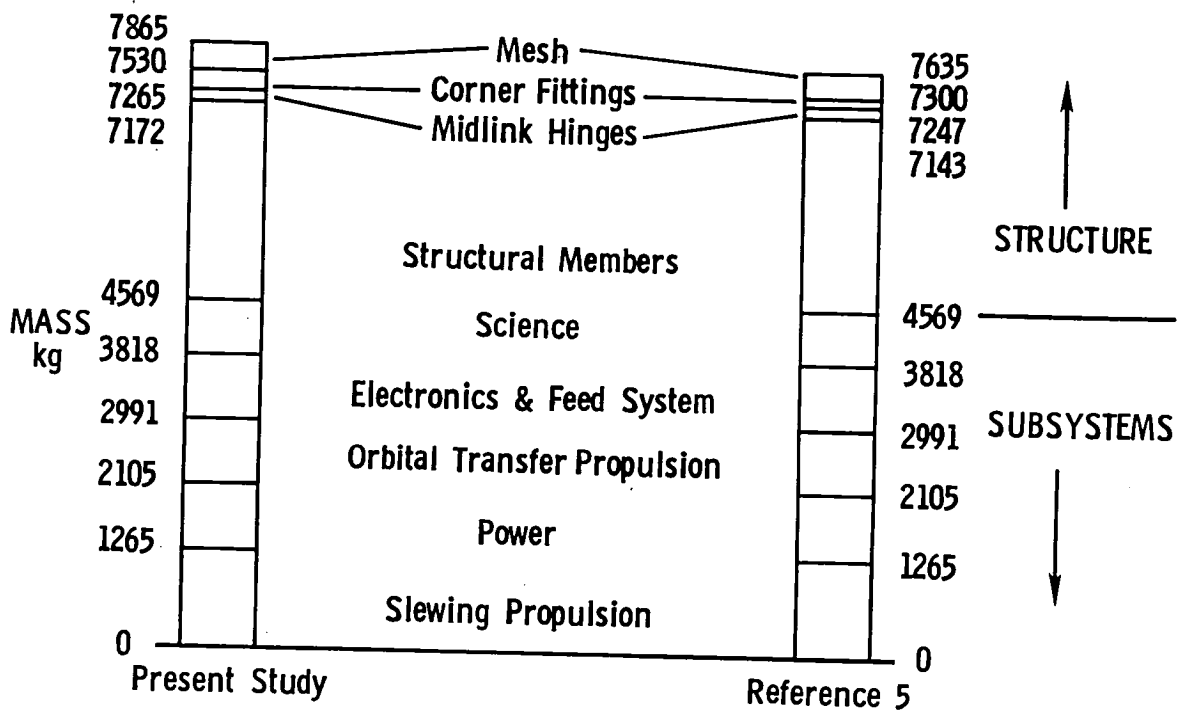
Figure 7. Spacecraft Mass Summary.
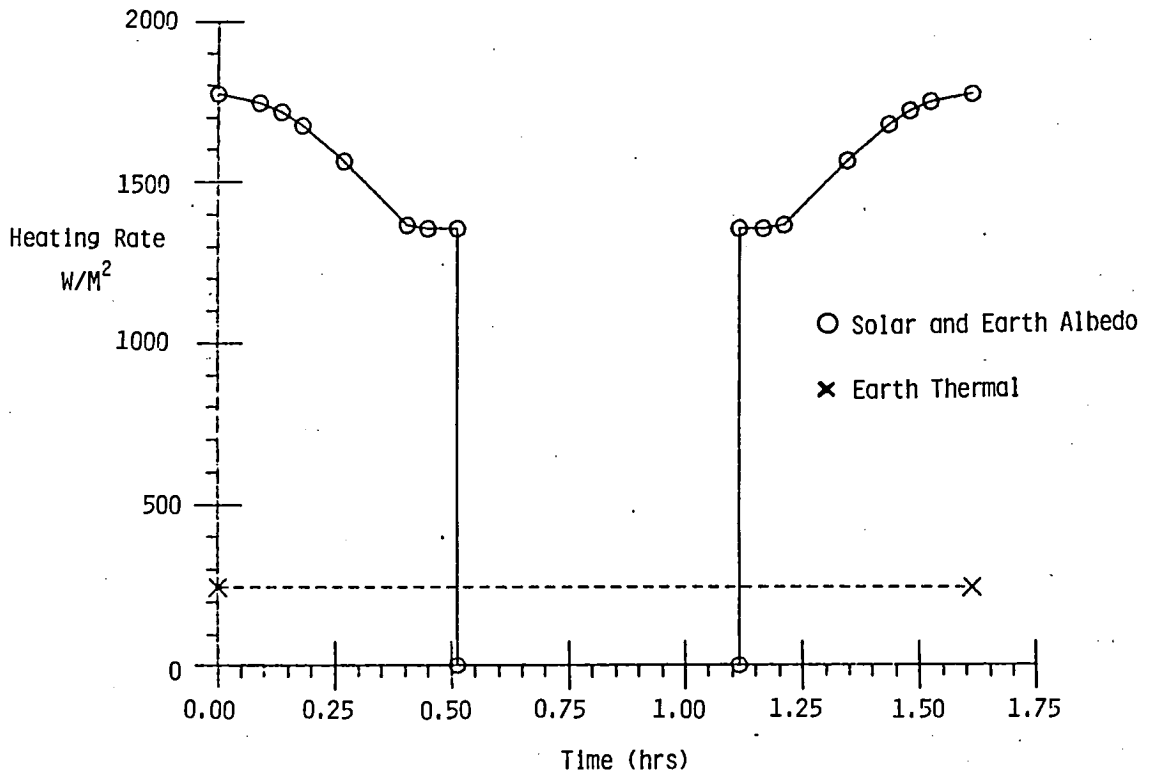
a) **Horizontal Surface Tube.**
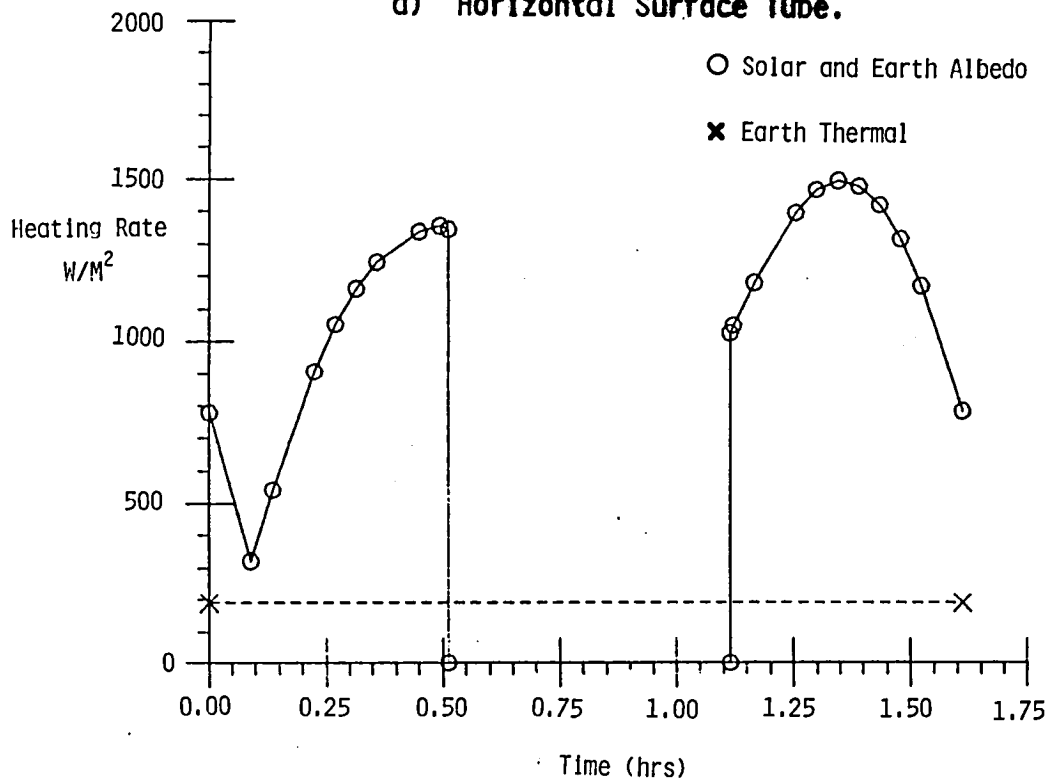
b) **Vertical Tube.**

Figure 8. Structural Element Heating Rates.

O   Solar and Earth Albedo

X ¡Earth Thermal

c)   Horizontal Cable.

O Solar and Earth Albedo

X Earth Thermal
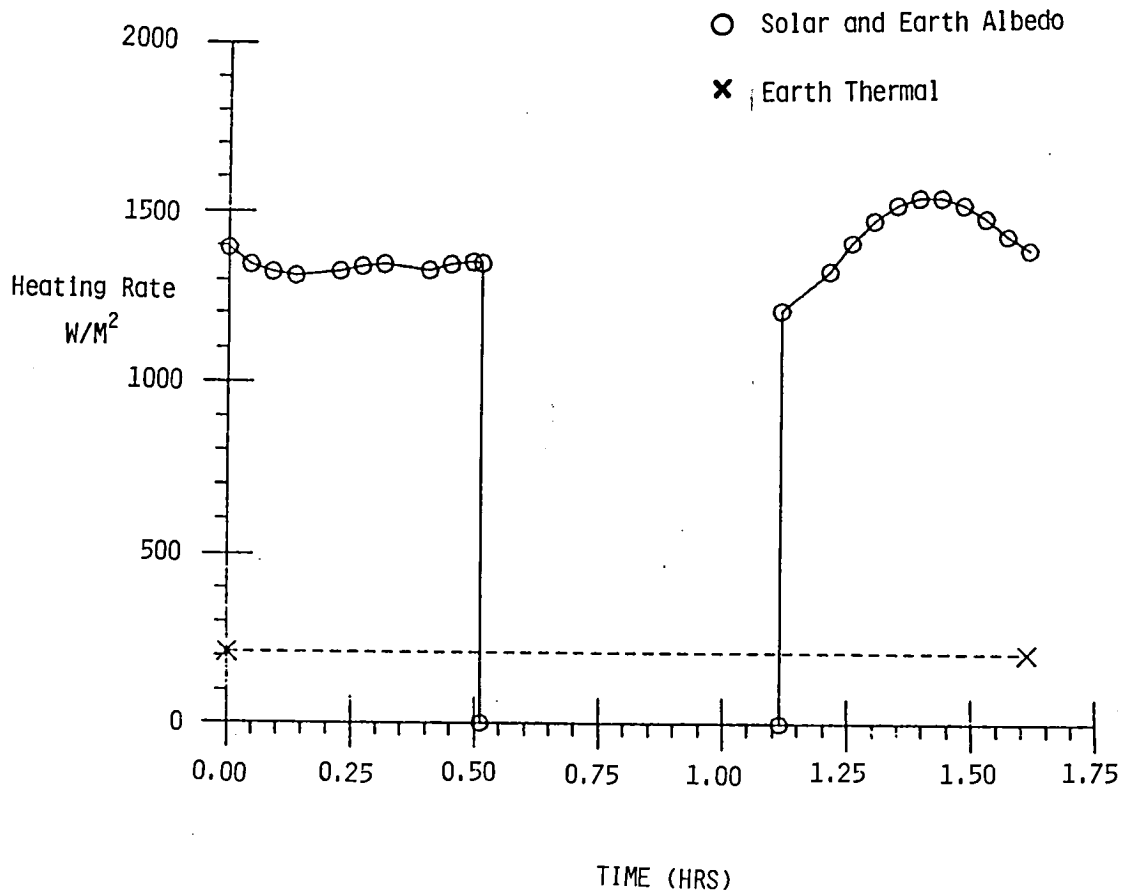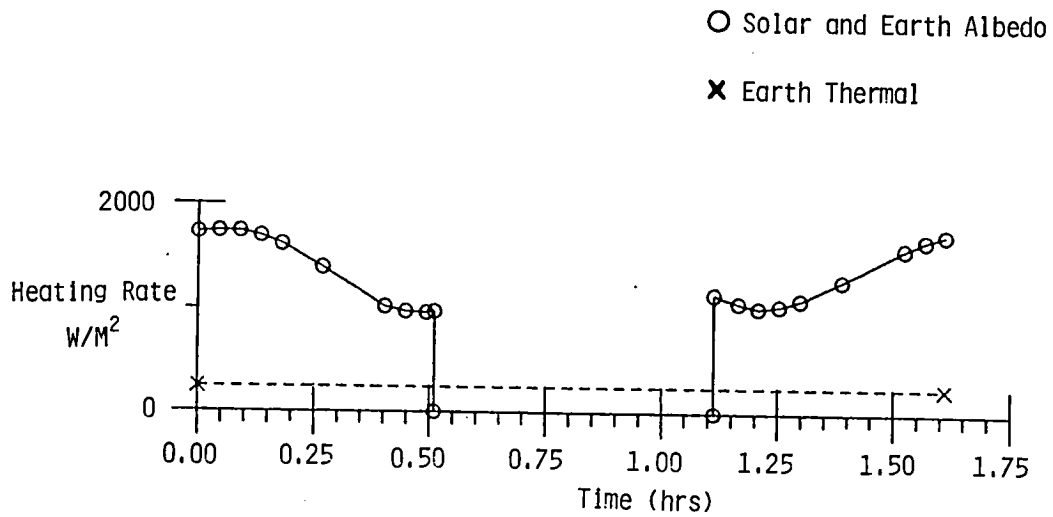
d)   Vertical Cable.

Figure 8.   Concluded.
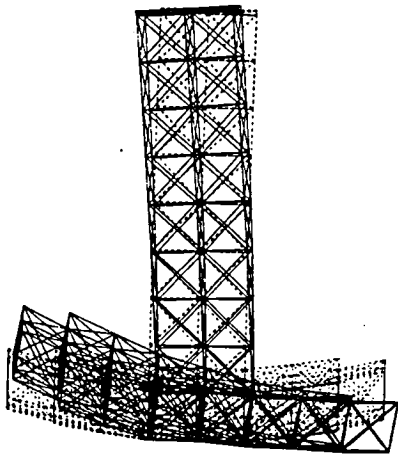
FREQUENCY 0.874 Hz
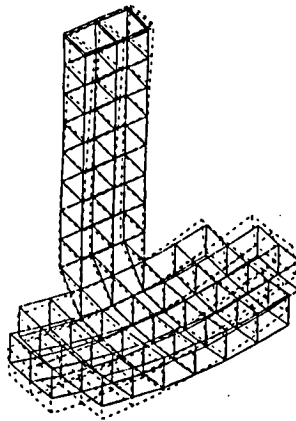
FREQUENCY 0.8888 Hz

a) Present Study.
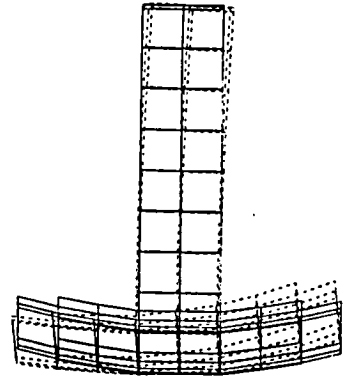
b) From Reference 5.

Figure 9.   First Fundamental Frequency.
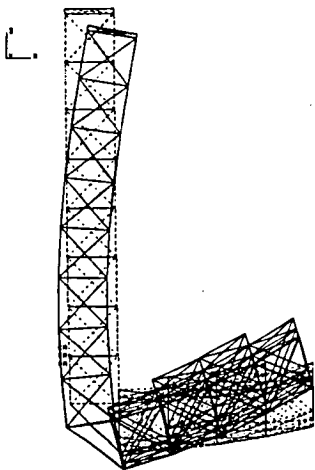
FREQUENCY 1.046 Hz
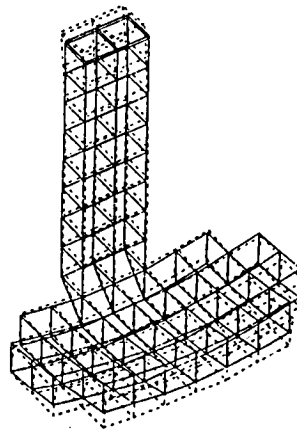
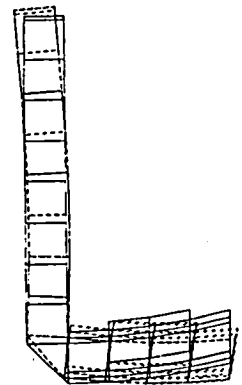FREQUENCY 1.004 Hz

a) Present Study.

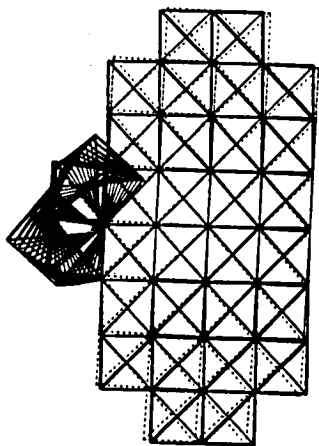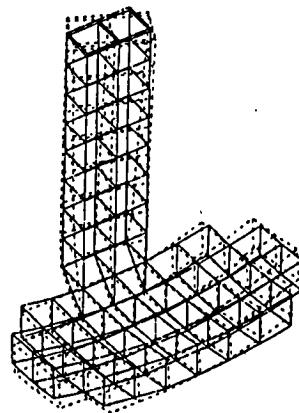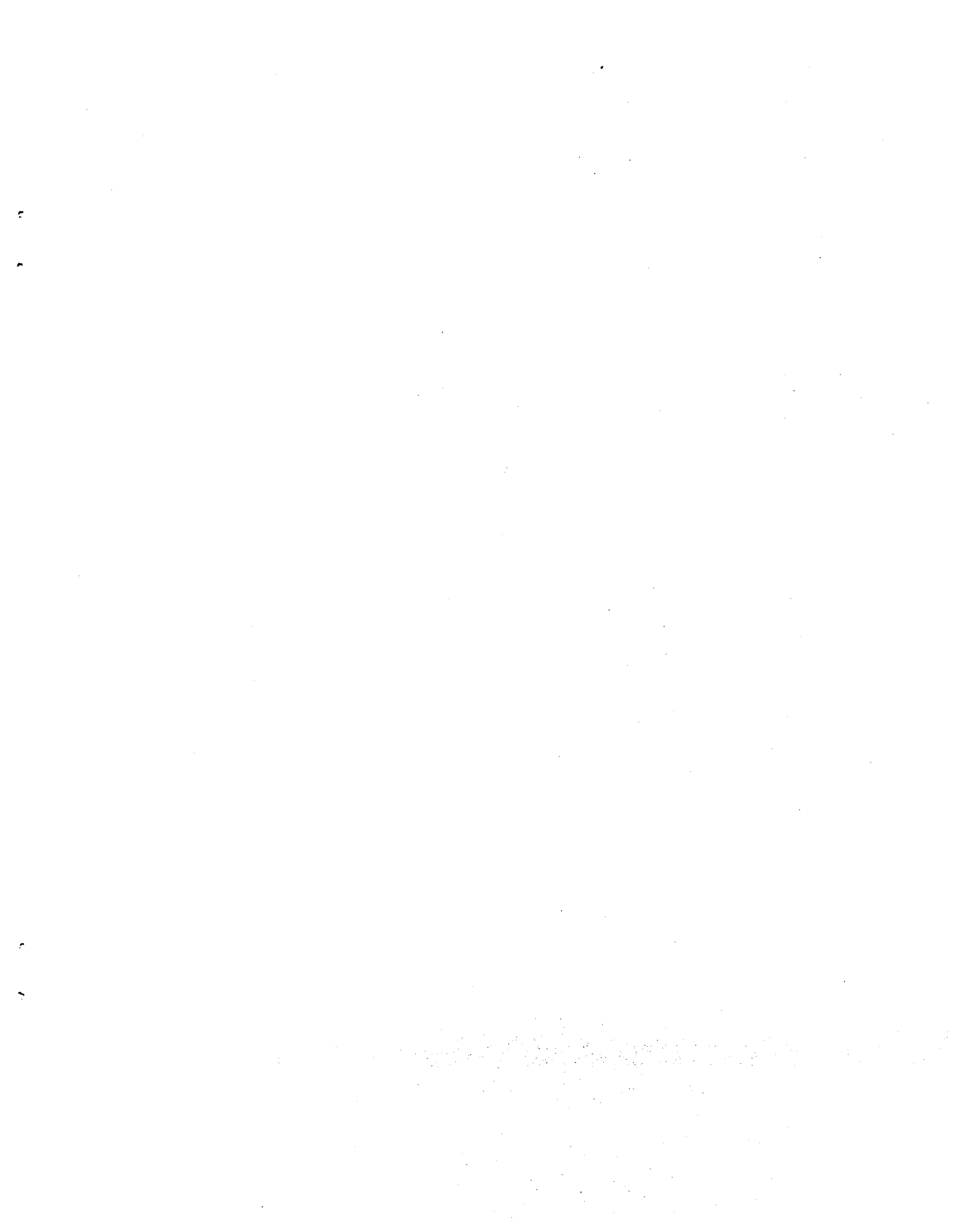b) From Reference 5.

Figure 10.   Second Fundamental Frequency.

FREQUENCY 1.436 Hz   FREQUENCY 1.124 Hz

a) Present Study.   b)   From Reference 5.

Figure 11.   Third Fundamental Frequency.

1. Report No. NASA TM-85638	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Interactive Analysis of a Large Aperture Earth Observations Satellite		5. Report Date May 1983
		6. Performing Organization Code 506-62-23-01
7. Author(s) Robert L. Wright, Dariene D. DeRyder, Melvin J. Ferebee, Jr., and John C. Smith		8. Performing Organization Report No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Virginia 23665		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A system level design and analysis has been conducted on an Earth Observation Satellite (EOS) system using the Interactive Design and Evaluation of Advanced Spacecraft (IDEAS) computer-aided design and analysis program. The IDEAS program consists of about 40 user-friendly technical modules and an interactive graphics display.

The reflector support system and feed mast of the EOS spacecraft are constructed with a box-truss structural concept, a lattice configuration which can be packaged for delivery in a single Shuttle flight and deployed in orbit. The deployed spacecraft consists of a 120-m by 60-m parabolic focal axis. The spacecraft was modeled for structural, thermal, and control systems analysis and structural elements were designed. On-orbit dynamic and thermal loading analyses were conducted; spacecraft weights and developmental and first unit costs were determined.

17. Key Words (Suggested by Author(s)) Spacecraft design Large space structures technology Spacecraft antennas Microwave radiometer	18. Distribution Statement Unclassified - Unlimited Subject Category 18
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	22. Price A02