#9

ISSUE A

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TECHNOLOGY SURVEY OF DEPLOYABLE PARABOLIC ANTENNAS AND EXTENDIBLE HELICAL ANTENNAS FOR SPACECRAFT

APRIL, 1975

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APRIL, 1975

①

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1.0 SUMMARY

This study, undertaken for the Department of Communications, has identified two principal suppliers of deployable parabolic dish antennas for spacecraft, in the 10 ft - 16 ft. diameter range. They are:

- Lockheed Missile & Space Company, Sunnyvale, California,
- Harris Corporation, Electronic Systems Division (formerly Radiation Inc.), Melbourne, Florida.

Lockheed antennas from 6 ft. to 30 ft. diameter have been flown on many classified missions. A 30 ft. deployable Lockheed antenna is operational on ATS-6 Satellite. No Harris antennas have been flown so far, but have been qualified for flight on ground. A 12.5 ft. antenna has been developed by Harris for the TDRS Satellite and tested for NASA.

Three suppliers of extendible column helical antennas of 8 to 10 ft. range have been identified. They are:

- TRW Systems Group, Redondo Beach, California
- Astro Research Corp., Santa Barbara, California
- Fairchild Space & Electronics Co., Germantown, Maryland.

TRW have built extendible column helical antennas in the size range of interest for Fleet Satcom satellite, but all details about the antenna are classified. Astro Research are developing an antenna deployer; a 13 ft. engineering model of the deployer was developed for a TRW/USAF program.

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2.0 INTRODUCTION

This report presents the results of a technology survey undertaken for the Department of Communications, to collect technical information on deployable spacecraft antennas of the following types, and their suppliers:

i) Deployable parabolic dish antennas

ii) Extendible column helical antennas

The following companies in USA were found to be the suppliers of the antennas of interest in the present study:

(a) Deployable Parabolic Dish Antennas

- Lockheed Missile & Space Company, Sunnyvale, California
- Harris Corporation, Electronic Systems Division, (formerly Radiation Inc.), Melbourne, Florida
- General Dynamics, Convair Division, San Diego, California
- TRW Systems Group, Redondo Beach, California

(b) Extendible Column Helical Antennas

- Astro Research Corp., Santa Barbara, California
- TRW Systems Group, Redondo Beach, California
- Fairchild Space & Electronics Company, Germantown, Maryland

All these companies, except Fairchild, were visited to gain firsthand technical information. A questionnaire on the subject, included in the SOW of DOC (attached as Appendix I) was also given to the company representatives to obtain some specific information. This report is based on the information gathered from the technical discussions, responses to the questionnaire and from technical publications supplied by the various companies.

Useful discussions were also had with the following companies which are involved in the field of spacecraft antennas, but have not developed the types of antennas of interest in the present study:

- McDonnell Douglas Aircraft Corporation, Huntington Beach, California
- Jet Propulsion Laboratory, Pasadena, California
- Hughes Aircraft Company, Los Angeles, California

A detailed report on the visits to the above companies is included in Section 5.0.

3.0 COMPARISON OF CANDIDATE ANTENNAS

3.1 Deployable Parabolic Reflector Antennas

Information has been obtained from Lockheed, Harris and General Dynamics about their deployable parabolic reflector antennas. The information pertains to antenna systems developed by each company for deployable antennas and does not pertain to a specific antenna design requirement. The features of these antennas can, therefore, only be compared in a general sense. Also, information on some aspects is proprietary and is not available.

No information could be obtained from TRW about their Fleet Satcom antenna because of security classification. It was also learnt from discussions with other sources (JPL, McDonnell-Douglas, Lockheed) that development efforts by Goodyear Aerospace to develop a deployable reflector antenna had not been successful. No contact was therefore made with Goodyear Aerospace.

Main features of Lockheed, Harris and General Dynamics antennas are summarized and compared in Table I. The details are presented in subsequent Sections 4.1 through 4.3 and in Appendices.

On the basis of the information available, the following comments can be made about parabolic deployable reflector antennas:

(a) Lockheed and Harris have technical capability of supplying deployable parabolic antennas in the 10 ft - 16 ft. deployed diameter range.

(b) Lockheed antennas have been flight proven on ATS-6 Satellite and other classified missions. No Harris antenna has been flown yet, but one 12.5 ft. antenna developed for NASA has been tested and thermally qualified for flight.

(c) The stowed package of Lockheed reflector is more compact than the stowed Harris antenna. The Lockheed antenna, being a torus when stowed, can, in principle, be attached to any side of the spacecraft provided a deployable subreflector or feed is used. The Harris antenna stows in a right cylinder and has to be attached to the forward platform of the spacecraft in launch configuration. The above comments apply to the Delta 2914/3914 launch vehicle.

(d) The Harris antenna has controlled deployment. The Lockheed reflector deployment is uncontrolled and applies significant reaction forces and torques to the spacecraft during deployment. These forces can be eliminated by designing the spacecraft reflector interface such as to keep the reflector free to rotate during deployment. However, this introduces additional complexity in spacecraft and RF cable design.

(e) The Harris antenna utilizes a "double-mesh" technique which enables low surface-rms deviations to be achieved with fewer ribs and, thus, lower weight. The Lockheed antenna can produce low surface rms deviations by increasing the number of ribs. However, the gain loss in an antenna due to surface deviations can be compensated for by increased diameter. Thus, the surface rms deviation has to be considered in conjunction with other antenna design parameters.

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The Harris antenna is, according to its manufacturers, the designated design for the TDRS mission. The antenna design appears to be very complete and achieving high performance levels. With some modifications of the RF feed system to suit the Canadian Multiple Purpose Bus (MPB) mission needs and with some strengthening of the central support structure to withstand the higher vibration levels anticipated, the basic 12.5 ft. diameter antenna appears to be a good device for the Canadian MPB.

TABLE I: COMPARISON OF DEPLOYABLE PARABOLIC DISH ANTENNAS

S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
1.	Reflector Size of Candidate Antennas	4.1	12.5 ft. diameter antenna built and tested. No information on larger antennas.	Antennas of 6 ft. to 30 ft. diameter have been built.	Antennas up to 10 ft. in diameter have been built. Up to 140 ft. diameter have been designed.
2.	Deployment and Deployment Mechanism	4.2	Controlled deployment. Can be retracted. Deployed by a Mechanical Deployment System using redundant mechanical and electric torque motors.	Uncontrolled rapid deployment due to release of strain energy. Normally not retractable, however, this feature can be included in design. Deployment initiated by cutting the cables restraining the stowed system.	Uncontrolled deployment. Mechanism details not available.
3.	Stowed Size	4.3	12.5 ft. dia. fits a right cylinder 30" dia., 75" high.	10 ft. dia. - 4" X 14" dia. torus Reflector only 16 ft. - 5" X 20" dia. torus. Reflector only.	No information.
4.	Weight	4.3	12.5 ft. diameter - 25.7 lbs. excluding	10 ft. diameter - 10 lbs. 16 ft.	10 ft. - 16 lbs. 20 ft. - 39 lbs.

S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
	feed and waveguides.		feed and waveguides. -31.2 lbs. including feed and waveguides.	diameter - 28 lbs. Reflector and stowage system only.	Reflector only (Be tubes).
5.	Stowed Stiffness and Frequencies	4.3, 4.6	For 12.5 ft. dia. antenna 1st freq. (torsional) - 29.5 Hz, 2nd freq. (lateral) - 57 Hz.	10 ft. dia. - 1st freq. 25-35 Hz Reflector only.	No information.
6.	Deployed Stiffness	4.4	1st frequency (torsional) - 8.3 Hz.	10 ft. - 1st freq. (torsional) - 2.3 Hz Reflector only. 16 ft. - 1st lateral freq. - - 8-12 Hz Reflector only.	No information in 10-16 ft. diameter range. 30 ft. reflector has a freq. of 12 Hz.
7.	Deployed Inertia	4.4	No information.	<u>10 ft. dia. (f/D-0.4)</u>: Axial = 10 slug-ft^2 Lateral - 8 slug-ft^2 <u>16 ft. dia. (f/D-0.4)</u>: Axial = 50-60 slug-ft^2 Lateral = 40-50 slug-ft^2 (Reflector only)	No information.

S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
8.	Stiffness of Attach Fitting to Spacecraft Body	4.5	No information. In absence of other flexibilities judged to be greater than 100 Hz.	No information. In absence of other flexibilities judged to be greater than 100 Hz.	No information. In absence of other flexibilities judged to be greater than 100 Hz.
9.	Dynamic Environment for Design	4.7	Dynamic environment of the stowed antenna assumed to be due to Thor Delta launch vehicle. Deployed antenna to operate on a stabilized platform.	Dynamic environment of the stowed reflector is that specified for Titan IIIC launch vehicle. Deployed antenna to operate on a stabilized platform.	No specific information.
10.	Loads at the Interface with Spacecraft during Deployment	4.8	No significant loads to the spacecraft during deployment.	Reaction forces and torques applied to the spacecraft. Can be eliminated by making the hub free to rotate. Typical values of peak torque: 10 ft reflector = 40 ft-lbs. 16 ft reflector = 100 ft-lbs.	Reaction forces depend upon the attachment of the antenna to the spacecraft.

S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
11.	RMS Surface Error	4.9	Surface accuracy due to all causes in worst case orbital position - 0.038" rms with 0.63" defocussing (test values).	Maximum rms surface error in worst case orbital position - 0.120 to 0.140 in. for C-band operation. Accuracies can be improved for higher frequency operation by introducing more ribs.	10 ft - 0.029" 20 ft - 0.046"
12.	Thermal Limits for Design	4.10	Designed for Synchronous orbit conditions.	-350°F to 300°F	No information.
13.	Material Constraints due to Possible Effluent Impingement.	4.11	No information.	No information.	No information.
14.	Flight Experience and Planned Missions	4.12 and 4.19	12.5 ft. antenna for TDRS Satellite has been flight qualified for thermal environment. Not flight qualified for vibration. No antennas have been flown.	Many antennas have been flown. Details classified. A 30 ft. antenna is operating on ATS-6 Satellite.	Not flight qualified. No antenna has been flown.

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S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
15.	Feed Structure	4.13	Fixed feed structure. Conical structure with dielectric ogive radome for feed.	Feed structure design depends upon the antenna stowage and operational requirements.	No information on feed structures.
16.	Feed Design	4.14	RF aspects of feed design depends upon antenna application.	RF aspects of feed design depends upon antenna application.	RF aspects of feed design depends upon antenna application.
17.	Antenna Gain, Beam Width, etc.	4.15	12.5 ft. Reflector: <u>S-Band Operation</u> 2-2.3 GHz, Gain = 35 db, Beam width = 2.5°. <u>Ku-band Operation</u> 13.4 - 15.3 GHz: Gain = 52 db Beam width = 0.36° Estimated performance at other frequencies: 240 MHz: Gain 16.5 db, Beam width = 23° 400 MHz: Gain 21 db, Beam width = 14° 4 GHz: Gain = 41 db, Beam width = 1.6° 6 GHz: Gain = 44.5 db, Beam width = 0.9° Details in Section 4.1.	For ATS-6 30 ft. reflector, at 8.25 GHz average orbital gain - 55.5 db. No information on beam width. No information on 10-16 ft. diameter reflectors.	No information.

S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
18.	Frequency Range of Operation	4.16	Up to Ku-band (11-18 GHz).	Up to Ku-band (11-18 GHz).	Up to 15 GHz.
19.	Types of Cut-outs Allowable in the Mesh	4.17	Limited number of Cut-outs of 3" X 3" (approximately) will not affect RF performance.	No information.	No information.
20.	Level of Passive Intermodulation Products. Intermodulation product signals are generated by metal-insulator-metal junctions exposed to antenna surface when two or more transmitters are used simulataneously at different frequencies.	4.18	Depends upon antenna application. In one design, intermodulation products reduced to maintain interference below a 200 db threshold.	Depends upon antenna application.	Depends upon antenna application.
21.	Cost (ROM)	4.20	One qualification unit, one flight model and one spare for $3.0 million (approximately) - See Appendix II.	No commitment as to cost, since very dependent on spacecraft. Verbally: Development/ Qualification Model approximately $1 million.	No information.

S.No	Item	Item No. in SOW (Appendix I)	Harris (for TDRS)	Lockheed	General Dynamics
22.	Special Features		A unique "double mesh" concept is used to reduce surface error without weight penalty.	-	-
23.	Attachment to the Spacecraft		A mounting flange 26" dia. to be bolted to a flat surface or ring. Holes may have to be provided in the mounting surface for passage of waveguides and coaxial cable.	A mounting flange of 14" to 20" dia. to be bolted to a flat surface, or ring. Holes must be provided in the mounting surface for passage of waveguides and coaxial cable. Configurations exist in which the spacecraft is at the focal point and the above comments do not apply.	The reflector has a mounting pallet to be attached to the spacecraft. Similar comment, as in Harris and Lockheed, apply.

3.2 Extendible Column Helical Antennas

No information could be obtained on flight proven deployable helical antennas in the 8-10 ft. range. A deployable helical antenna made by TRW will be flown on Fleet Satcom Satellite, but the details are classified.

Some information on a helical antenna deployer developed by Astro Research Corp. has been obtained and is presented in Section 4.4. A 13 ft. long engineering model of the deployer was fabricated by Astro for a TRW/USAF program.

Fairchild Space & Electronics Co. have flown a 5.5 ft. long extendible helical antenna on the NTS-I Satellite. Limited amount of information has been supplied by Fairchild and is presented in Section 4.6.

The Astro and Fairchild antennas are compared in Table II.

Some information about a fixed helical antenna system, consisting of three helical antennas, developed by Hughes for MariSat Satellite, has been obtained and presented in Section 4.5. This antenna system is designed for operation in the UHF band (240-320 MHz) with a gain of 12.6 db.

On the basis of available information, the Astro deployer appears to be the most promising candidate for an extendible 8-10 ft. helical antenna, if the stiffness criterion of first frequency greater than (or equal to) 2 Hz is acceptable to the spacecraft control system.

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TABLE II: COMPARISON OF EXTENDIBLE COLUMN HELICAL ANTENNAS

S.No.	Item	Item No. in SOW (Appendix I)	Astro Research	Fairchild
1.	Antenna Size	4.1	10 ft. long X 13" Diameter	5.5 ft. long X 12.12" Diameter
2.	Deployment Mechanism	4.2	Antenna deployed by paying out a lanyard controlled deployment.	Uncontrolled deployment by release of the stored strain energy. Antenna deploys like a helical coil spring released from compressed state.
3.	Stowed Size, Weight, Inertia and Stiffness Distribution	4.3	Stowed Size = 13" high X 13" diameter Weight = 6-7 lbs. (including radiator element of 2 lbs.) Inertia = .062 - .078 slug-ft^2 (about base) Stiffness = No information	Stowed Size = 2.81" high X 12.12" diameter Weight = 3.3 lbs. Inertia = No information. Stiffness = No information.
4.	Deployed Inertia and Stiffness	4.4	Deployed Inertia = 6.2 to 7.15 slug-ft^2 (about base) Deployed Stiffness: Bending Stiffness = 3.5 X 10^5 lb-in^2	No information.

S.No.	Item	Item No. in SOW (Appendix I)	Astro Research	Fairchild
5.	Coefficient of Solidity as a Function of Solar Vector Angle	4.4	No information.	No information.
6.	Stiffness of Attach Fitting to Spacecraft	4.5		No information.
7.	Frequency and Mode shape of Stowed and Deployed Antenna	4.6	Deployed 1st Frequency = 2 Hz (approximately) Cantilever mode. By analysis, assuming 2 lb. radiator. Stowed	No information.
8.	Dynamic Environment for which Antenna is Designed/Developed	4.7	Typical 2000 lbs. spacecraft launched by Delta 3914 vehicle, with antenna mounted on forward platform.	Vibrated 28g rms for 3 min. each axis (X, Y and Z). Random 5-2000 Hz flat spectrum.
9.	Reaction Forces and Torques on Spacecraft during Deployment	4.8	Negligible.	No information.
10.	Lateral Tip Displacement due to Thermal Environment	4.9	0.1"	No information.
11.	Thermal Limits for Design	4.10	Synchronous orbit operation.	0°F. to 250°F. Range can be extended.

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S.No.	Item	Item No. in SOW (Appendix I)	Astro Research	Fairchild
12.	Material Constraint due to Effluent Impingement	4.11	No information.	No information.
13.	Flight Experience and Planned Mission	4.12, 4.19	Not flown. A 13 ft. engineering model built for TRW/USAF Fleet Satcom as a standby antenna.	Flown on NTS-I Satellite. To be supplied for NTS-II Satellite.
14.	Gain, Sidelobe, Polarization, etc.	4.15	No information	Gain = 12 db Side Lobes = 12 db Right Circular Polarization.
15.	Operating Frequency	4.16	UHF band	300 MHz
16.	Cost (ROM)	4.20	$30,000 approximately for an engineering prototype, without radiator element.	$15,000 (approximately).

4.0 TECHNICAL DETAILS OF CANDIDATE ANTENNAS

4.1 Harris (Radiation Inc.) Deployable Parabolic Reflector Antenna

A 12.5 ft. diameter deployable parabolic reflector antenna has been developed and tested by Harris Inc. for operation in the Ku-band (11-18 GHz). The deployed antenna is shown in Figure 1a. The mechanical and electrical characteristics of the antenna have been discussed in detail in Appendix II. These characteristics are summarized below:

RF Performance

S-Band	Transmit	Receiver
Frequency	2.025-2.120 GHz	2.200-2.300 GHz
Gain	35.33 db	36.04 db
Beam Width	2.6° (Approx)	2.4° (Approx)

Ku-Band	Transmit	Receiver
Frequency	13.40-14.05 GHz	14.60-15.25 GHz
Gain	51.67 db	52.02 db
Beam Width	0.38° (Approx)	0.36° (Approx)

The gain stated above is referenced at plane containing reflector vertex.

The estimated performance at other frequencies is as follows:

Frequency	Gain	Beam Width
240 MHz	16.5 db	23°
400 MHz	21 db	14°
4 GHz	41 db	1.6°
6 GHz	44.5 db	0.9°

Design for low intermodulation products is usually based on the uniqueness of each application, since each application frequency has unique requirements. In one of the designs, the intermodulation products were reduced to maintain interference below a 200 db threshold.

The details of the antenna gain and losses, radiation patterns in S- and Ku-band operation are given in Appendix II.

Mechanical Parameters

Deployed Diameter:	12.5 ft.
f/D:	0.417
Weight-Reflector:	25.7 lbs.
Weight-Feed:	5.5 lbs.
Package Volume (Stowed):	Right Cylinder, 30" dia. 75 inches high

Stowed resonant frequencies (tested):

Mode	Frequency, Hz
Lateral	57.0
Longitudinal	185.0
Torsional	29.4

Allowable stowed dynamic loads (analysis):

Axis	Maximum Vibration G Ultimate	Maximum Shock, G Ultimate
Lateral	25	20
Longitudinal	35	20

Deployed Resonant Frequency (minimum):	8.3 Hz, torsional
Surface Accuracy due to Manufacturing and Setting Tolerances:	0.020" (rms)

Repeatability of the Reflector Surface over Successive Deployment:	± 0.002" rms (tested)
Surface Accuracy due to all Causes in worst-case orbital position:	0.038" rms with defocussing 0.63" (tested)

Mechanical Design

The parabolic reflector surface consists of 12, 1.5" diameter, tubular aluminum ribs which shape and support the metallic mesh. A "double-mesh" technique is used to obtain high surface accuracy. The technique consists of two mesh surfaces separated by the rib thickness and tee-bars attached to the ribs. The "back" mesh is attached to the tee-bars and the "front" mesh is attached to the "back" mesh by tensioned metallic wires. By properly tensioning the connecting tie wires, the front mesh which forms the reflector surface, can be contoured to a precision parabolic shape. The tension in the connecting wires is arrived at by computer analysis and includes allowance for 1 g effect. This technique reduces the dependence of reflector surface shape on the number of ribs, thus reducing the weight of the antenna considerably.

A conical feed support structure is the primary structural member of the stowed antenna. A dielectric ogive radome is provided as an enclosure for the RF feed. The ogive geometry is selected because of its high electrical efficiency over other geometries.

The stowed antenna, shown in Figure 1b, is restrained by top and mid-section restraint systems which force the stowed antenna to act as a single stiff structural member, thereby providing a high stowed resonant frequency. The reflective surface is deployed at a controlled rate by the mechanical deployment system (MDS) shown in Figure 1c. The MDS consists of a disc-shaped carriage mounted to the moving section of a recirculating ball nut on a ball screw shaft. The carriage and the ribs are connected by linkages that transmit the force and motion required for deployment to the ribs. Redundant drive system power is supplied to the ball screw by a spring motor and two electric torque motors.

Details of the mechanical design are given in Appendix I and in Harris Inc. Report, NAS1-1144, prepared for NASA Langley Research Centre.

Information on thermal design is scant, however, it is known that ribs, conical feed and subreflector structure and part of the base are insulated from space by multilayer thermal blankets.

4.2 Lockheed Wrap-Rib Parabolic Reflector Antenna

Lockheed (LMSC) have developed deployable reflector antennas in the range of 6 to 30 ft. These antennas have been flown on classified missions. A 30 ft. deployable reflector antenna has been flown on ATS-6 spacecraft and is now operational. The 30 ft. antenna is shown in Figure 2a.

Design Description

The deployable reflector utilizes a "wrap-rib" type of design. Flexible radial ribs are attached to a skin-stressed rigid-ring central base. The ribs are pre-shaped to produce a close approximation of a parabolic cylindrical surface. Copper coated dacron mesh is attached to the ribs to form the reflecting surface. The ribs are wrapped around the central base in the stowed configuration. The stored strain energy of the ribs is utilized for deployment. Deployment is initiated when cables restraining the stowed ribs are cut by squib actuated cable cutters. Stops or locks are provided at each rib root/hub junction to approximate near rigid attachment of rib to hub in the deployed condition. The mesh and the ribs are prestressed to prevent slackening due to temperature variations in orbit.

Mechanical Characteristics

The mechanical parameters of a stowed reflector are as follows:

Diameter	Stowed Size	Reflector Weight	Moment of Inertia	Stiffness
10 ft.	4"X14" dia. Torus	10 lbs.	Less than 1 slug-ft^2	First Freq. 25-35 Hz
16 ft.	5"X20" dia. Torus	28 lbs.		

The above numbers assume C-band operation. The parameters of a deployed reflector are as follows (assuming f/D = 0.4):

		Moment of Inertia		
Diameter	Depth	Axial	Lateral	Stiffness
10 ft.	19"	10 slug-ft^2	8	First torsional frequency = 2-3 Hz
16 ft.	30"	50-60 slug-ft^2	40-50 slug-ft^2	First lateral frequency = 8-12 Hz First Torsional frequency not quoted

During deployment, the reflector applies reaction forces and torques to the spacecraft body. Typical value of peak torque for a 10 ft. antenna is 40 ft-lbs. and for a 16 ft. antenna is 100 ft-lbs. However, the deployment reaction torque can be eliminated if the hub is made free to rotate and is locked after deployment.

Isothermal RMS Tolerance (typical):	0.060" to 0.070" (rms)
Orbital Distortion:	0.0120" to 0.0140" (approx.) for C-band Reflector

If greater accuracies are required (for higher frequency operation), the reflector isothermal tolerances as low as 0.020" can be achieved by increasing the number of ribs.

RF Performance

Gain and beam width are functions of frequency and diameter. The gain loss due to the reflector surface not being a perfect paraboloid is dependent upon the number of ribs used which, in turn, depends upon the weight constraint. The ATS-6 reflector of 30 ft. diameter operating at 8.25 GHZ has an average orbital peak gain of 55.5 db, the gain loss due to imperfect paraboloid surface is less than 0.25 db.

More details of the antenna design as applicable to the 30 ft. ATS-6 antenna are given in Appendix III. Answers to the questionnaire by Lockheed are attached as Appendix IV.

4.3 General Dynamics Parabolic Expandible Truss Antenna

General Dynamics, Convair Division, have developed a parabolic expandible truss antenna (PETA) which consists of a foldable truss structure with a reflector mesh. An illustration of the folded and deployed antenna is shown in Figure 3a. The truss members are perforated tubes of Al, Ti or Be depending on the weight and cost constraints. As illustrated in Figure 3b, the number of reflector truss bays can be 4 to 10 across the major diagonal. Minimum weight in the large size reflectors is obtainable with six or eight-bay versions. As the number of bays increases, the mean surface deviation of the mesh flats, from both design and thermal distortion, decreases. Selection of the optimum number of bays is a trade-off therefore between cost and reliability on one hand, and weight and distortion on the other. The basic reflector shape is hexagonal so that the equivalent RF diameter is about 10% less than the point-to-point width.

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The antenna can be attached at the centre, edge or intermediate locations without significant penalty. The deployed antenna is quite stiff; the 30 ft. PETA reflector has a natural frequency of 12 Hz.

The PETA concept is well suited for growth to large antenna sizes - up to 600 ft. in diameter. Details of PETA characteristics are given in General Dynamics Report No. GDC DCL-69-001 attached as Appendix V. The characteristics of 10 ft. and 20 ft. antennas reported in the above reference are as follows:

Characteristics	Reflector Dia (Across Points) 10 ft.	Reflector Dia (Across Points) 20 ft.	Comments
PETA Wt. Max/Min (lb.)	25/16	71/39	Maximum Wt. is Titanium. Minimum Wt. is Beryllium
Package Size Height X Diameter (in.)	12"X9"	25"X38"	Titanium shown. Be reduces diameter by about 50%
Package Vol. (cubic ft.)	1	13	
RMS Distortion (in.)			
As Mfg.	0.016	0.016	
Max. Thermal	0.024	0.043	
Total (RSS)	0.029	0.046	In Synchronous Orbit. Titanium PETA
Peak Gain Freq. (GHz) Continuous	30	22	In Synchronous Orbit. Titanium PETA

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Characteristics	Reflector Dia (Across Points) 10 ft.	20 ft.	Comments
Peak gain freq. - 16 hrs/Day	48	36	
- 3 hrs/Day	58	54	
Natural Frequency Deployed (cps)	Large (greater than 12 Hz)	Large (greater than 12 Hz)	

4.4 Astro Helical Antenna Deployer

A deployable structure to deploy and support helical antennas from satellites is being developed by Astro Research Corp.

The structure, including the attached antenna, is deployed by simply paying out a lanyard which extends between the tip and base of the system. This is possible because three spiraled, spring-like members expand axially, self-deploying the structure while tensioning its truss-like members. The truss members include longerons which extend parallel to the axis and maintain the diameter of the structure, and diagonal members which provide the structure with shearing and torsional stiffness.

When the structure is retracted the spiral members, with the helical radiator attached to one of them, are compressed into a low-pitch helix. Stowed height for the structure, with the attached helical radiating element, is typically one-tenth of its deployed height. The truss-like support structure is made entirely of fibreglass and epoxy resin; thus, it causes no RF interference.

A 13 ft. long engineering model of the helical antenna deployer was fabricated under a TRW/USAF program.

The mechanical characteristics of the 10 ft. long X 13 in. diameter helical antenna would be as follows (by analysis):

Weight:	6 to 7 lbs. (including a 2 lb. radiator element)
Stowed Size:	13" high X 13" diameter
Bending Stiffness:	3.5×10^5 lb-in^2
Fundamental Bending Frequency:	2.0 Hz (Assuming 2.0 lbs. radiator with 6 in. radius of gyration)
Fundamental Torsional Frequency:	Greater than 2 Hz
Repeatability of the lateral position for the outboard tip:	0.2 inches
Lateral tip displacement due to thermal environment:	0.1 inches

More details of the antenna deployer are given in Appendix VI.

4.5 Hughes Helical Antenna for MARISAT

A helical antenna system consisting of three fixed helical antennas has been developed by Hughes Aircraft Co. for MARISAT Satellite. Each helical antenna is at the corner of a plane isosceles triangle of 48" side.

Some of the characteristics for the antennas are:

Operating Frequency:	240-320 MHz
Antenna Size:	40" length X 16" diameter, 32" diameter ground plane for each helical antenna
Weight:	13 lbs. (all three antennas) including the support structure.
Gain:	12.6 db, RH circular polarized, bifilar helix

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The antenna system fits in the shroud envelope of Delta 2914 and 3914 launch vehicles.

4.6 Fairchild Helical Extendible Antenna

Fairchild Space & Electronics Co. have flown a 12" dia. X 66" long helical antenna on Navigational Technology Satellite I (NTS-I) and are expected to supply a similar antenna for NTS-II. The antenna is deployed from its stowed configuration by the release of its stored strain energy. The stowed package is attached to the spacecraft interface with clips.

Some of the mechanical characteristics of the antenna are as follows:

Deployed Size:	12.12" dia. X 66" long
Stowed Size:	12.12" dia. X 2.81"
Weight:	3.3 lbs.
Stiffness:	No information available
Operating Frequency:	330 MHz
Gain:	12 db; 12 db side lobes, right circular polarization, 1.5 db axial ratio

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5.0 TRIP REPORT

5.1 Introduction

This section presents a brief trip report. Dates of visits, companies visited, personnel contacted and subjects of discussion are given in Table III in chronological order.

The following sections give more details of the visits.

TABLE III: SUMMARY OF VISITS TO THE COMPANIES DEALING WITH SPACECRAFT ANTENNAS

Date of Visit	Company Visited	Persons Contacted	Subjects Discussed - Section in this Report
March 13, 1975	Jet Propulsion Lab. Pasadena, California	Bob Freeland Telephone (213) 354-2778	JPL's survey of large deployable reflectors for the early eighties - See Section 5.2
March 14, 1975	TRW Systems Redondo Beach California	Paul Nelson Telephone, (213) 535-2150	Fleet Satcom Antenna Systems - See Section 5.3
March 14, 1975	McDonnell Douglas Corp. (MDDAC) Long Beach, California	Ed Pfarr Telephone (714) 896-3719	MDDAC proposal for Shuttle based family of antennas - See Section 5.4
March 17, 1975	Radiation Inc. of Harris Corp., Sales Office, Los Angeles, California	Bob Nelson Telephone (213) 670-5432	Harris Corp. 12.5 ft. diameter deployable reflector antenna for TDRS - See Section 5.5
March 17/18, 1975	Astro Research Santa Barbara, California	Bob Crawford Telephone (805) 963-3423	Astromast for Fleet Satcom Standby UHF helic antenna and modified version for the Canadian MPB - See Section 5.6
March 18, 1975	Hughes Aircraft Culver City, California	Al Wittmann	MARISAT spacecraft UHF helical antenna and Hughes design philosophy concerning deployables - See Section 5.7
March 19, 1975	General Dynamics, Convair Division San Diego, California	Dave Forest Telephone (714) 296-6611	GD deployable parabolic reflector - See Section 5.8

TABLE III: SUMMARY OF VISITS TO THE COMPANIES DEALING WITH SPACECRAFT ANTENNAS - Continued

Date of Visit	Company Visited	Persons Contacted	Subjects Discussed - Section in this Report
March 20, 1975	Lockheed (LMSC) Sunnyvale, California	John Hockenberry Colin Campbell John DiMonte	LMSC's deployable parabolic wrap-rib reflector - See Section 5.9
April 11, 1975	Radiation Inc. of Harris Corp. Melbourne, Florida	Gene Hegi Telephone (305) 727-5070/5210	Probable modifications required for the Canadian MPB installation - See Section 5.10
THE FOLLOWING IS A RECORD OF TELEPHONE CONVERSATIONS:			
April 8, 1975 April 21, 1975	Fairchild Space & Electronics Co. Germantown, Maryland	Gordon Smith Telephone (301) 428-6000	Fairchild's deployable helix antenna for NTS-1 & -2 Spacecraft - See Section 5.11

5.2 JPL (Pasadena, California)

Date:	May 13, 1975
Contact:	Bob Freeland
Subject:	JPL survey of large deployable reflectors for the early eighties

Only designs that are reasonably well developed are of interest to JPL in the context of their study.

Three promising suppliers were identified:

LMSC	-	Wrap-rib unfurlable reflector, space qualified
Harris Corp.	-	Folded-rib "dual-mesh" reflector, space qualified
GD (Convair)	-	Space frame supported reflector, not qualified

Generally, increased accuracy can be achieved by increasing the number of supports (ribs) to the flexible mesh.

An exception to this is the Harris "dual-mesh" type of reflector. In this design, accuracy is achieved by pre-tensioning the reflector mesh into the desired shape from the electrically passive "back mesh" by means of a very large number of interconnecting strands.

Loss of surface accuracy due to thermally induced support structure deformations is not reduced by an increase in the number of ribs nor are necessarily the zero-g effects.

Problems with demonstrating in-orbit performance on ground with any type of deployable reflector are severe. As a consequence, designs must have a substantial amount of well-founded analytic support data to convince the technical people, as well as an aura of being obviously right, to convince others.

Reliance on analytical methods will continue well into the shuttle era, although the shuttle will allow testing in space.

Feed/subreflector designs have not been included in the JPL survey; both fixed and deployable types are feasible with the LMSC design, while for the Harris design, the fixed type is logical.

Natural frequency requirements specified by the customers for the deployed reflectors are "rule-of-thumb" values aimed at ensuring absolutely no interaction with the spacecraft ACS.

5.3 TRW (Redondo Beach, California)

Date:	March 14, 1975
Contact:	Paul Nelson
Subject:	Fleet Satcom Antenna Systems

TRW declined to furnish any information on their Fleet Satfom Antenna for security reasons imposed by the Flt Satcom Project Office. Any request for information has to be directed to SAMSO/SKK; upon receiving this approval, TRW would be prepared to respond in a limited way.

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5.4 McDonnell Douglas Astronautics Company (Huntington Beach California)

Date:	March 14, 1975
Contact:	Ed Pfarr
Subject:	MDDAC proposal for a shuttle based family of antennae and other MDDAC studies

The work done for a shuttle based family of antennae involved a series of rigid reflector antennae. The most successful design from manufacturing, cost and mechanical/electrical performance point of view was a simple carbon composite dish with carbon composite back-up ribs.

From other MDDAC studies in which deployable reflectors were evaluated, the Harris Corp. "dual-mesh" reflector antenna emerged with very high marks having an efficiency comparable to that of ground based antennae, apparently, a significant achievement.

5.5 Radiation Inc. of Harris Corp., Sales Office (Los Angeles, California)

Date:	March 17, 1975
Contact:	Bob Nelson
Subject:	Harris Corp., 12.5 ft. diameter deployable reflector antenna

During this visit, the 12.5 ft. diameter deployable reflector antenna was identified as being capable of handling simultaneously UHF and SHF signals, the latter up to the Ku-band (11-18 GHz) and as being thermally qualified by ground tests at NASA-GSFC for TDRS.

NASA-GSFC is in the possession of a test report prepared by an independent company (DBA) for the TDRS project office; contact at GSFC: Len Deerkowski, (301)-982-6331.

Brochures were received, the DOC questionnaire sent to the Harris head office, and a visit to Harris Corp. was arranged.

5.6 Astro Research Corp., (Santa Barbara, California)

Date: March 17/18, 1975

Contact: Bob Crawford

Subject: Astromast for Fleet Satcom standby UHF helix antenna and modified version for the Canadian MPB.

Astro built an 11" diameter X 156" long deployable standby UHF helix antenna deployer to TRW's one for the Fleet Satcom. A minimum natural frequency criterion of 4 Hz was specified to Astro. This required Astro to introduce a system of pivoted links as a means of stiffening the deployer. These links caused "hang-ups" during deployment.

Spar ACS requirement for these units is 2 Hz for a 120" length. No pivoted links are required to meet this requirement, hence the typical preloaded cable-stiffened Astromast, which deploys reliably, can be used for the Canadian MPB.

5.7 Hughes Aircraft Co. (Culver City, California)

Date: March 18, 1975

Contact: Al Whittman

Subject: MARISAT spacecraft UHF antenna and Hughes design philosophy concerning deployables

A non-deploying, extremely light-weight (13 lbs. total including support structure) tri-helix antenna array used in the MARISAT spacecraft for signals in the 240-320 MHz range was described.

This array was fully tested on the MARISAT, a spinning spacecraft. No problem is foreseen in adapting this design to a non-spinning spacecraft, however, HAC was at the time of the visit not interested in responding to our questions.

Hughes' philosophy concerning the use of deployable structures can be summed up succinctly as, "don't, if you can do otherwise".

5.8 General Dynamics, Convair Division (San Diego, California)

Date: March 19, 1975

Contact: Dave Forest

Subject: GD deployable antenna structure

GD's design is an intermediate form between the extinct Goodyear and the extant LMSC deployable antenna.

It was only too obviously designed by structural engineers who provided it with abundant qualities of stiffness, strength, redundancy, but also, regrettably, weight. A 16 ft. diameter model using titanium as material for the collapsible truss members was viewed with awe, lifted with difficulty and left standing against the wall of GD's room of state-of-the-art exhibits.

5.9 LMSC (Sunnyvale, California)

Date: March 20, 1975

Contact:
John Hockenberry, Manager
Colin Campbell, Mechanical Design Supervisor
John DiMonte, RF Antenna Specialist

Subject: LMSC's deployable wrap-rib antenna

LMSC questionned the need for a deployable reflector for UHF band; agreed to the concept, however, if both UHF and SHF functions were required.

Operation of wrap-rib antenna was explained and demonstrated on a small 9 to 10 ft. diameter model

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which throughout its life withstood hundreds of such deployments with no apparent harm.

Scores of missions have been flown with a number of similar antennae in sizes from 9 ft. diameter upward; missions, however, are classified.

The ATS-6 spacecraft is equipped with a 30 ft. diameter 150 lb. version whose natural frequencies when deployed are approximately 10 Hz, 5 Hz and 1 Hz in axial, lateral and torsional modes, respectively.

A 14 ft. diameter reflector was built for NASA-GSFC in 1968, 1969 for the Outer Planetary Explorer mission and 2.2 GHz RF frequency. This reflector has 20 ribs made of 2014 Aluminum alloy and weighs approximately 27 lbs. Natural frequencies are approximately 0.75, 4 and 8 Hz in torsion, lateral and axial mode respectively. The GSFC Project Engineer at that time was D.F. Fitzpatrick (Telephone [301] 982-5096). This reflector may still be around at Goddard.

The rapid unfolding of the ribs will create a torque impulse of approximately 150 ft-lbs. for a duration of 3/8 to 1/2 sec. from peak to zero for this size antenna. This impulse may be almost completely contained within the antenna if the unit is despun from the spacecraft at the expense of requiring, typically, an SHF subreflector and a rotary RF joint for the UHF coaxial cable.

A large number of deployments will readily be tolerated by those reflectors. Successful deployments were made after one year of storage in stowed condition.

Thermal control consists, generally, of multilayer blanket insulation of the central hub and surface treatment (polishing) of the aluminum ribs.

5.10 Radiation Inc. of Harris Corp., (Melbourne, Florida)

Date:	April 11, 1975
Contact:	Gene Hegi
Subject:	Impact of probable modifications required for the Canadian MPB installation

In the period between the last visit (March 18) and this date, the analysis of dynamic responses of the Canadian MPB to sinusoidal vibration test inputs indicated that lateral responses of about 40 g-ult. (qual X 1.25) at the stowed antenna COM can be expected. Also, it was known that cut-outs in the reflector mesh for earth sensors will be required and a light TT&C bicone will have to be mounted on top of the communications antenna subreflector structure.

This information was conveyed to Gene Hegi who took it upon himself to seek expert opinion and respond within a two-week period.

Only classified project hardware was available in the plant, so inspection of it was not possible. However, the TDRS Project Office at GSFC has the 12.5 ft. diameter model which, probably, can be seen at Goddard. Inquiries should be directed to Len Deerkowski, GSFC TDRS Project Office, Telephone (301) 982-6331.

5.11 Fairchild Space & Electronics Co., (Germantown, Md)

Date:	April 8, 1975 April 21, 1975
Contact:	Gordon Smith
Subject:	Fairchild's deployable helix antenna for "Timation" spacecraft

After first telephone conversation, a telex containing relevant material from the DOC questionnaire was sent to Fairchild; the answers are incorporated in Table II.

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6.0 REFERENCES

i) "Deployable Reflector Design for Ku-Band Operation", NAS1-1144, Sequence No. 4317-01, prepared for NASA Langley Research Center, prepared by Electronic Systems Division of Harris Corp., Florida, September, 1974.

ii) "Deployable, Parabolic Reflectors for Ku-Band Operation", by Dr. B.C. Tankersley, Harris Corp.

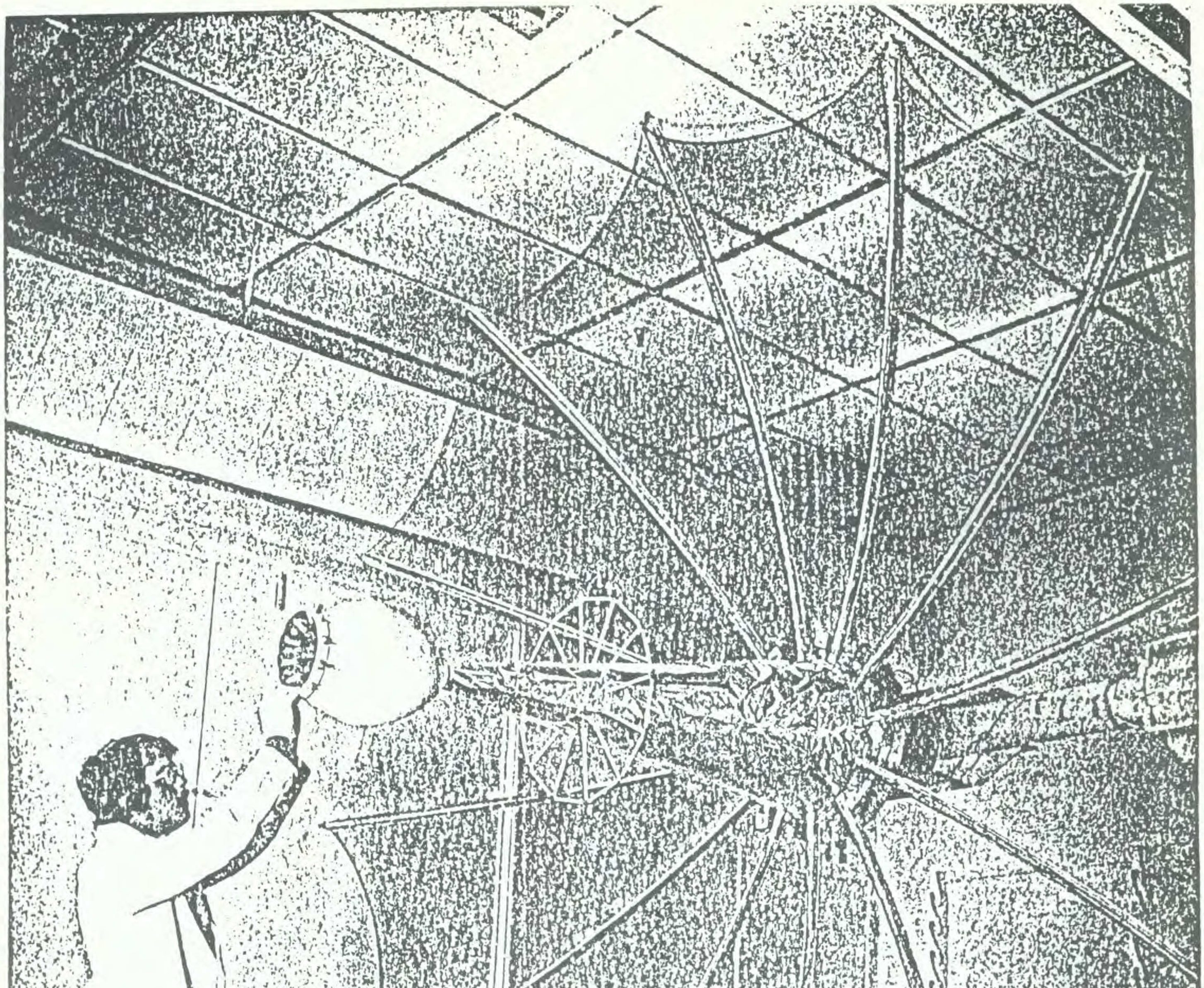

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FIGURE 1A

DEPLOYED ANTENNA (HARRIS)

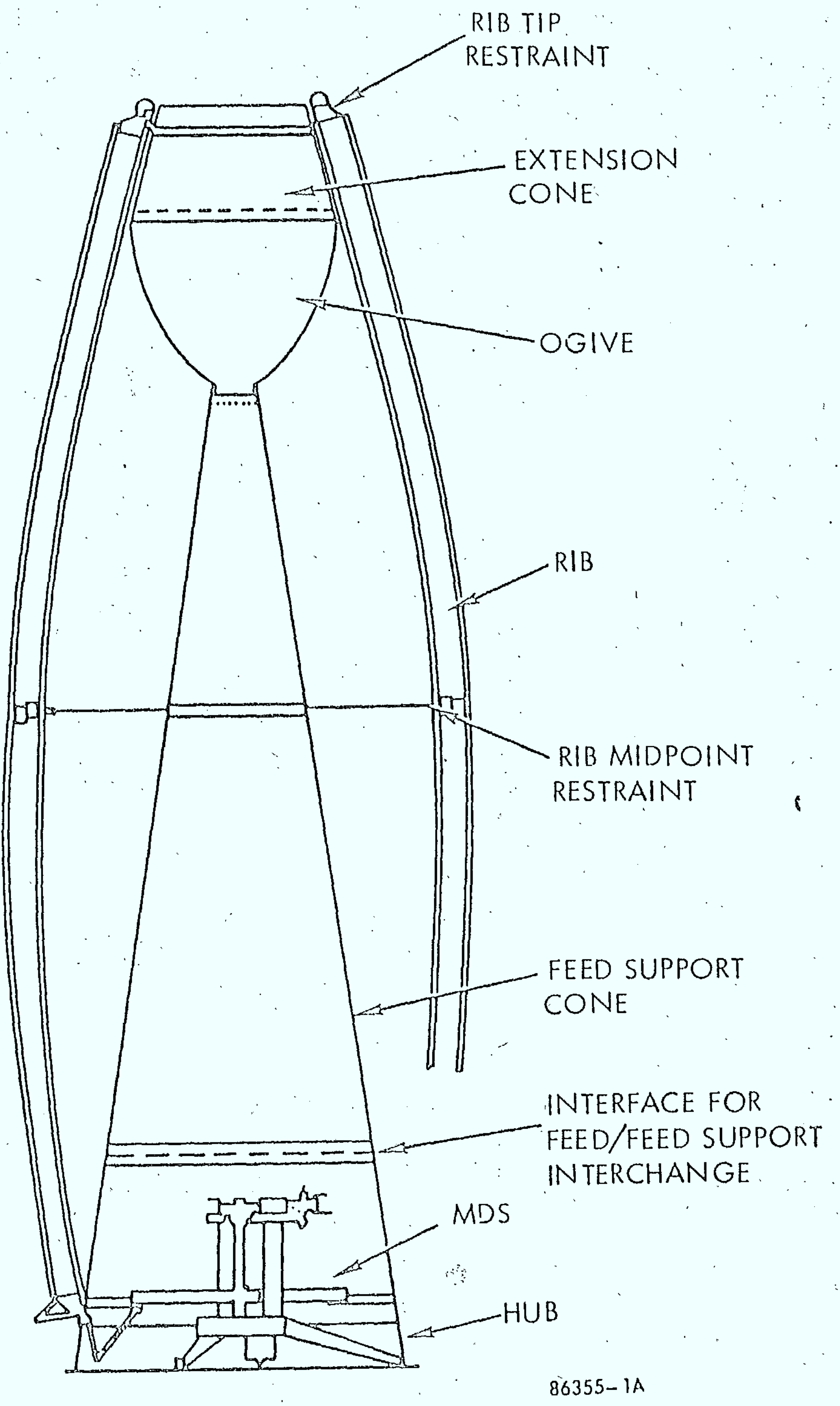
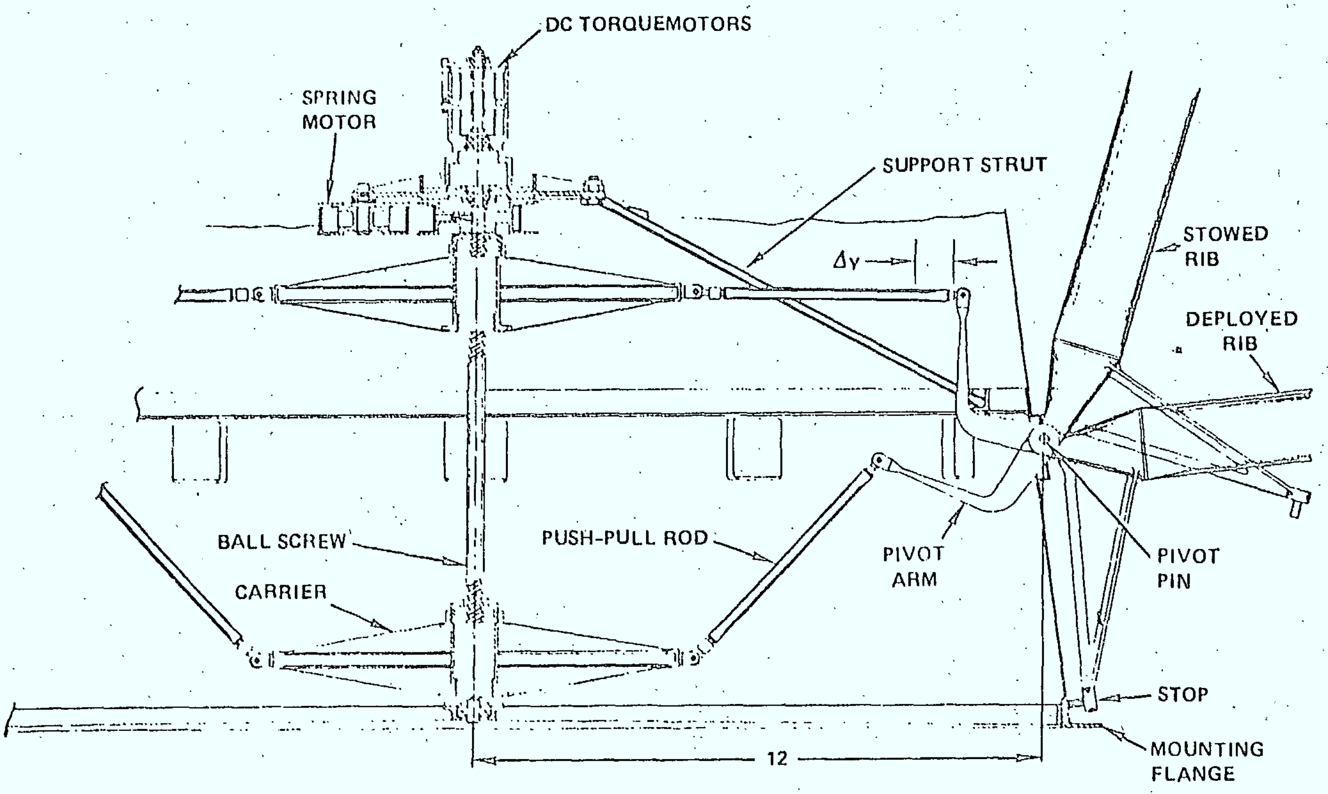


FIGURE 1b

ANTENNA IN STOWED CONFIGURATION (HARRIS)



- o CONTROLLED DEPLOYMENT
- o DRY FILM LUBRICATION
- o REMOTE FURLING

86525-12A

FIGURE 1c

MECHANICAL DEPLOYMENT SYSTEM (MDS) - HARRIS ANTENNA

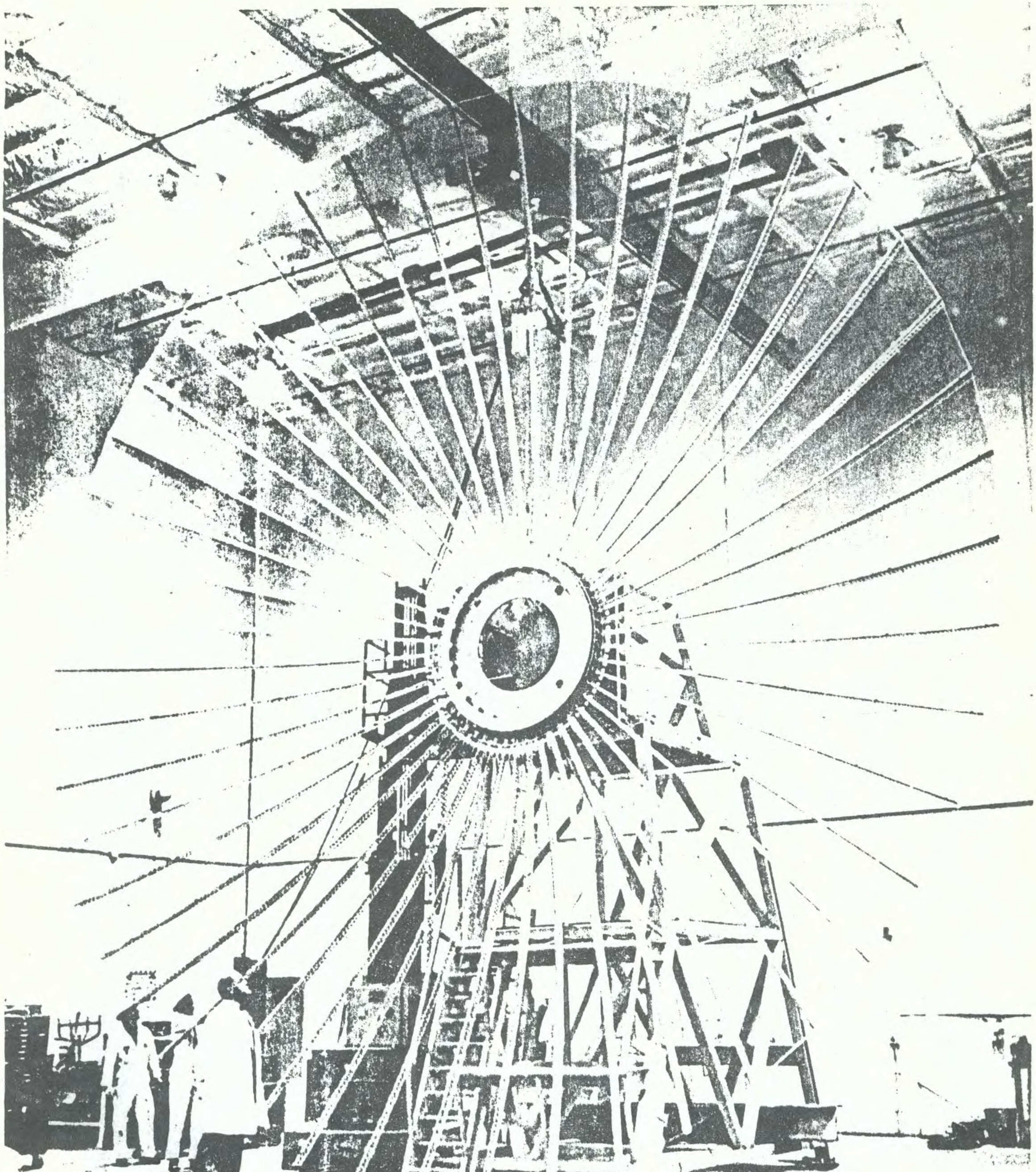


FIGURE 2a

30 FT. WRAP-RIB ANTENNA (LOCKHEED)

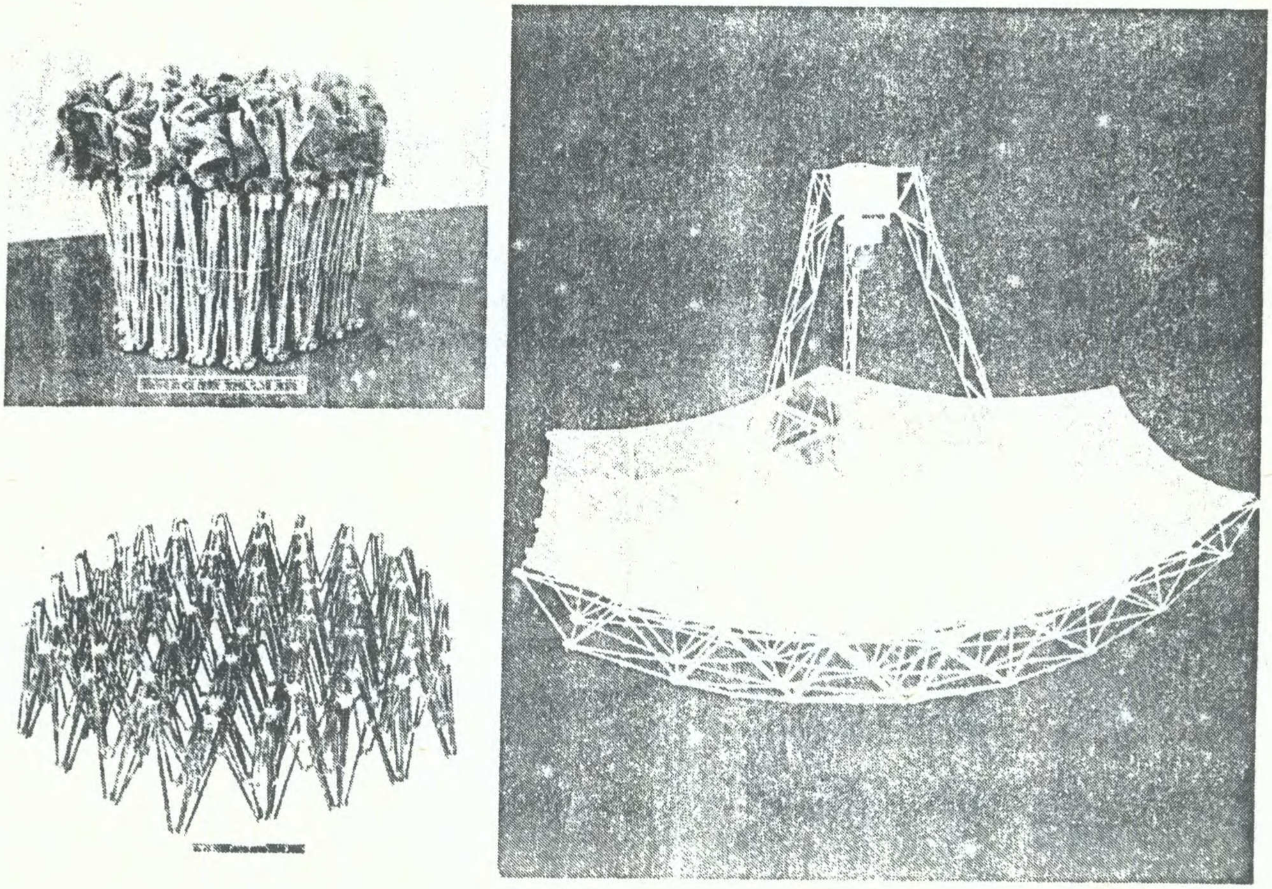
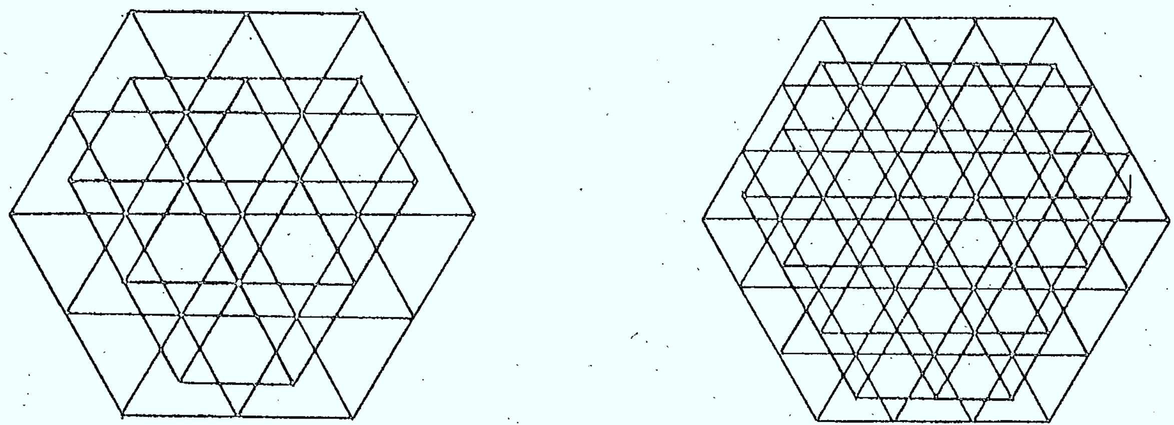


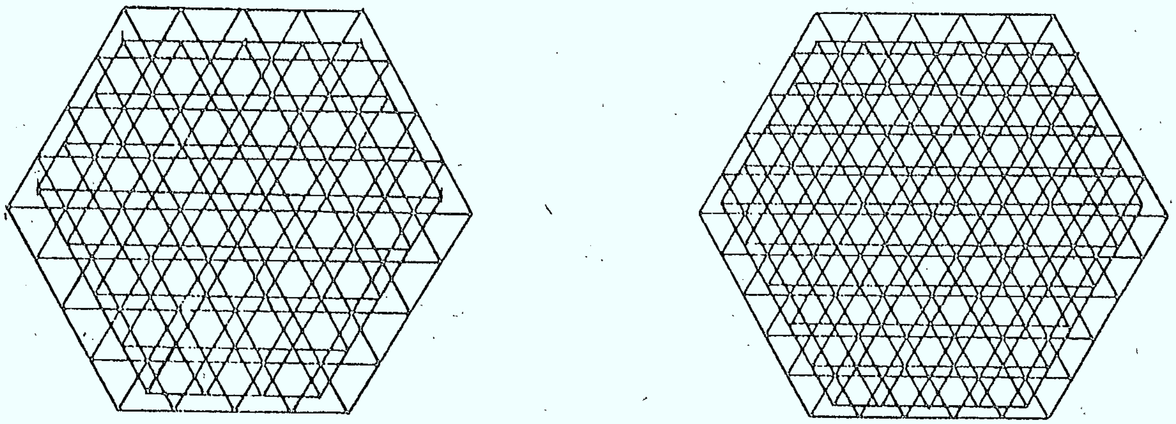
FIGURE 3a

PARABOLIC EXPANDABLE TRUSS ANTENNA (GD-CONVAIR)



4 BAYS

6 BAYS



8 BAYS

10 BAYS

FIGURE 3b

REFLECTOR TRUSS BAY CONFIGURATION (GD-CONVAIR)

APPENDIX I

PROPOSED STATEMENT OF WORK
FOR A CONTRACT WITH
SPAR AEROSPACE PRODUCTS LTD.

1.0 CONTRACT TITLE

Survey Study of:

i) Deployable Parabolic Reflectors and Feed Structures, and

ii) Extendible Helical Antennas for Satellite Antenna Applications.

2.0 CONTRACT TYPE

Study contract directed to Spar Aerospace Products Ltd., 825 Caledonia Road, Toronto, Ontario M6B 3X8.

3.0 PERSONNEL

Personnel assigned to this study shall be subject to approval by the Design Authority.

4.0 TASK DESCRIPTION

The following information will be obtained from potential vendors of deployable antenna systems of two kinds:

i) deployable parabolic dish antenna
ii) extendible column helical antenna

This information will be submitted in the form of a consolidated report. The report shall indicate information obtained from the vendor and that derived from data the vendor supplied. The associated analysis will also be included in appendix form. The contractor is also urged to include his critical comments on any or all of the vendor provided information. The following information is desired.

4.1 Candidate deployable dishes in the 10 to 16 feet deployed diameter range, and their supplier.

Candidate extendible helical antennas in the 8 to 10 feet height range, and their supplier.

4.2 The principle of operation of the mechanisms used for deployment.

4.3 The stowed configuration dimensions, weight, and inertia and stiffness distribution for different deployed diameters of the parabolic dish.

The stowed configuration dimensions, weight and inertia and stiffness distribution for different extended heights of the helical antenna.

4.4 The deployed configuration dimensions and inertia and stiffness distribution for different deployed diameters of the parabolic dish.

The deployed configuration dimensions, inertia, stiffness distribution, coefficient of solidity as a function of the solar vector angle, for different extended heights of the helical antenna.

4.5 Stiffness properties in flexure and torsion of the dish attach fitting to the spacecraft body.

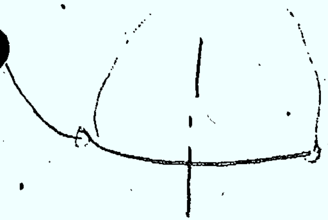
Stiffness properties in flexure and torsion of the helical antenna attach fitting to the spacecraft body.

4.6 Frequencies and mode shapes of stowed and deployed configurations for both antennas, and the associated assumptions made in arriving at these properties.

4.7 Dynamic environments for which the reflector and the helical antenna have been designed, both in the stowed and deployed conditions.

4.8 Reaction forces and torques experienced by spacecraft at attachment point during dish deployment, and column extension.

4.9 Nominal static isothermal RMS tolerance of the reflector surface along with its RMS distortion characteristics in the geostationary orbit station dynamic and thermal environment. Corresponding information for the helical antenna.



4.10 Thermal limits and thermal distortion characteristics of the reflector and the column in both the stowed and deployed configurations.

4.11 Material constraints due to possible impingement of secondary propulsion system effluent.

4.12 Missions for which the candidate reflector and helical antennas are being considered or selected.

4.13 Important details of the support structure for the feed(s) used with candidate reflectors.

4.14 A description of the feeds employed with the candidate reflectors.

4.15 Gain, beamwidth, sidelobe and polarization information of typical reflector-feed combination(s). same information for the helical antenna.

4.16 A listing of the frequency band(s) over which the candidate reflector with feeds and the helical antenna was/is designed or is feasible to operate.

4.17 An indication of the types of cut-outs in the candidate reflectors for other antennas or sensor heads.

4.18 The level of passive intermodulation products generated by the dish antenna structure. Corresponding information for the helical antenna structure.

4.19 Qualification status of design, whether flight proven, ground qualified, developed or only feasibility established.

4.20 Cost information to design, fabricate and test (functional and environmental) for a typical antenna reflector and feed.

5.0 DESIGN AUTHORITY

The Director General Space Programs, or his designate, shall be the Design Authority for this study contract. Project Officer shall be S. Ahmed.

6.0 REPORTING

One interim status report shall be made after two weeks of start of contract to indicate the contractor's work plan and status to carry out the study. A progress meeting will be held within one week of the issuance of the interim status report. Other meetings or draft materials may be required during the course of the study by the Design Authority. These will be intimated at least one week in advance to the contractor. The final report shall be furnished nine weeks after start of contract. Four copies of the interim status report and ten copies of the final report shall be delivered to the Design Authority.

7.0 CLASSIFICATION

This study contract is unclassified.

8.0 RELEASE OF INFORMATION

All information provided, compiled or developed under this study shall be the property of the Department of Communications. Such information shall not be released without the approval of the Design Authority.

9.0 CONTRACT SCHEDULE

Proposed Contract Start Date	February 17, 1975
Proposed Contract End Date	April 30, 1975
Interim Status Report	March 3, 1975
Final Report	April 18, 1975

10.0 TRANSPORTATION, TRAVEL, LIVING AND COMPUTER EXPENSES

Standard government clause for reimbursement, with limitation of these expenses to $3,000.00.

11.0 FUNDS

The total cost of this contract shall not exceed $17,000.00, including all reports and the funds identified in Clause 10. The contractor shall furnish monthly invoices to enable progress payments to be made.

APPENDIX III a.

HARRIS COMMUNICATIONS AND INFORMATION HANDLING

28 March 1975

Spar Aerospace Products, Ltd.
825 Caledonia Road
Toronto, Canada

Attention: Mr. Eric Quittner

Gentlemen:

In reference to your inquiry pertaining to 10 - 16 foot deployable antenna reflectors, I am forwarding a paper (Attachment #1) synopsizing the characteristics and parameters of our 3.8 meter Space Deployable Reflector. In addition, I am attaching (Attachment #2) the Final Report for the Deployable Reflector Design rendered to NASA/Langley Research Center. Although the developmental model was 3.8 meters, there is no constraint on the size within your desired 10 - 16 foot parameter.

For your consideration and planning, the qualification unit, flight model, and one spare unit would be in the relative order of magnitude of $3.0 million dollars if the program is considered as a "stand alone" program. From the time table indicated in your inquiry, it appears the program may run coincidental with other known requirements which could possibly render further economies that cannot at present be considered firm.

Harris Electronic Systems Division, as the leader in Space Deployable Antenna Reflectors, is pleased to have been queried per your requirement and looks forward to further involvement on this program with your firm. Should you need further information, please feel free to call the undersigned at 305/727-5089, or write

Harris Electronic Systems Division
P.O. Box 37
Melbourne, Florida 32901
Attention: Mr. Glenn Dawdy, Manager
Airborne Information Handling Systems

Very truly yours,

C. G. Dawdy, Manager
Business Development

Attachments as stated

938 - 6137 - 476 A

HARRIS CORPORATION Electronic Systems Division* P.O. Box 37, Melbourne, Florida 32901 305/727-4000
*(formerly RADIATION)

1.0 INTRODUCTION

This paper describes the Harris Spaceborne Deployable Antenna design and performance. The design described here is the "dual mesh" concept developed by Harris. The feasibility of this design for operation in the 2000 and 15,000 megahertz bands was verified by NASA in 1974 when engineers at Goddard Spaceflight Center (GSFC) subjected an engineering model to solar vaccuum tests. This engineering model was supplied by Harris under an Advanced Applications Flight Experiment (AAFE) Contract (No. 1-11444) and delivered to NASA/GSFC for the tests which simulated orbital operating conditions. Based on the results of the tests, NASA has identified the Harris dual mesh antenna in the planned Tracking and Data Relay Satellite (TDRS) baseline design for use at S and K band as the 3.8 meter Single Access Antenna.

The results of the tests at GSFC not only verified the design feasibility, but also verified the validity and accuracy of computer based design simulations. These simulations were developed by Harris and are described in Section 3.0.

The unit described here is the 3.8 meter AAFE model and performance data includes the results of the tests performed at GSFC.

The dual mesh design is a second generation antenna based on development started at Harris in 1967. Original designs utilized a single mesh approach, but the demands for improved efficiency at higher frequencies prompted the development of the dual mesh antenna.

1.1 RF Performance

The AAFE dual mesh antenna is described below and has the following characteristics:

- Shaped deployable dual mesh reflector
- RF performance characteristics as follows:

S-BAND	TRANSMIT	RECEIVER
Frequency	2025-2120 MHz	2200-2300 MHz
Gain*	35.33 dBi	36.04 dBi
Beamwidth	~2.6°	~2.4°

K_u-BAND	TRANSMIT	RECEIVER
Frequency	13.40-14.05 GHz	14.60-15.25 GHz
Gain*	51.67 dBi	52.02 dBi
Beamwidth	~0.38°	~0.36°

Our preliminary estimates of performance at 240, 400, 4000 and 6000 megahertz are as follows:

FREQUENCY	GAIN	BEAMWIDTH
240 MHz	16.5 dB	23°
400 MHz	21 dB	14°
4000 MHz	41 dB	1.6°
6000 MHz	44.5 dB	0.9°

Design for low intermodulation products is usually based on the uniqueness of each application, since each application frequency has unique requirements. Our success in eliminating intermodulation products is exhibited by a recent case where the interference was maintained below a 200 dB threshold that had been established.

1.2 S-Band Performance

Gain

In Table I, budgets for the S-band antenna gain and losses are presented. The values tabulated include all elements of the feed and reflectors, mounted forward of the main reflector, either within the feedcone support or the ogive support. The data presented is based on measurements from previous Harris programs using similar components.

---

* referenced at plane containing reflector vertex.

TABLE I

S-BAND GAIN BUDGET

PARAMETER		TRANSMIT	RECEIVE
Frequency	(MHz)	2075	2250
Aperture Area Gain	(dBi)	38.36	39.07
Losses	(dB)		
Amplitude Taper Loss		-1.34	-1.34
Spillover Loss		-0.19	-0.19
Primary Phase Loss		-0.11	-0.11
Secondary Phase Loss		-0.05	-0.05
Primary Cross-Polar. Loss		-0.04	-0.04
Secondary Cross-Polar. Loss		-0.10	-0.10
Blockage Loss		-0.24	-0.24
Mesh Reflectivity Loss		-0.07	-0.07
Ogive Radome Loss		-0.05	-0.05
Subreflector Loss		-0.10	-0.10
Feed Loss		-0.05	-0.05
Hybrid Loss		-0.15	-0.15
Cable Loss		-0.36	-0.36
Mismatch Loss		-0.18	-0.18
Antenna Gain	(dBi)	35.33	36.04

Antenna Patterns

Typical S-band patterns are presented in Figure 1.0-1a and 1.0-1b. These patterns are measured on the antenna shown in Figure 1.0-2. It consists of a 50 inch diameter mesh reflector and an S-band cavity-backed dipole feed.

1.3 K_u-Band Performance

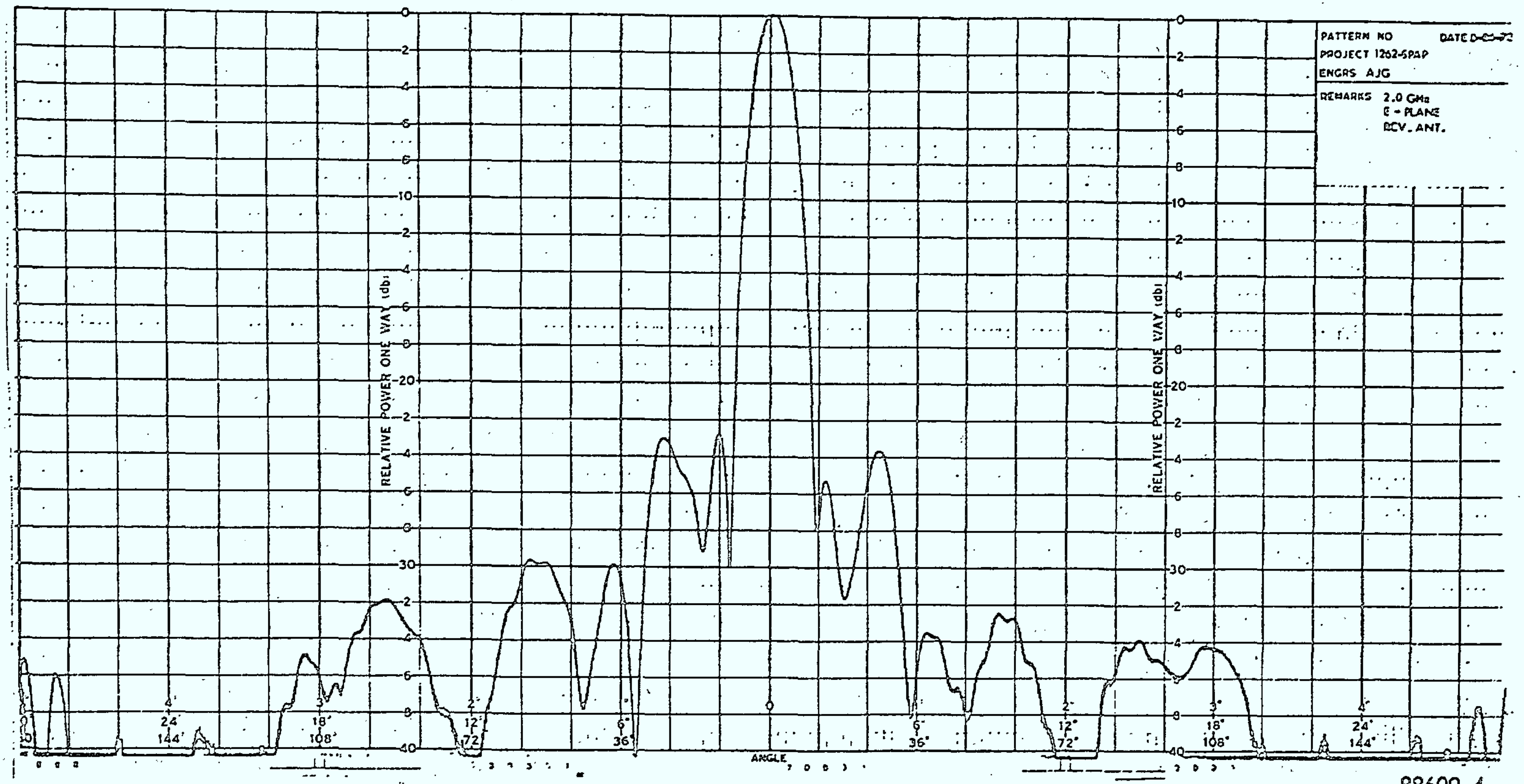
Gain

In Table II, budgets for the K_u-band antenna gain and losses are presented. The values tabulated include all elements of the feed and reflectors mounted forward of the main reflector within the feed cone or ogive support. The data presented is based on measurements and analysis from previous Harris programs using similar components.

Antenna Patterns

Figure 1.0-3 presents a typical measured K_u-band pattern. This pattern is that of a 13-foot diameter shaped solid reflector.

K_u-band patterns measured on an eight-foot diameter shaped antenna are presented in Figures 1.0-4a and 1.0-4b.



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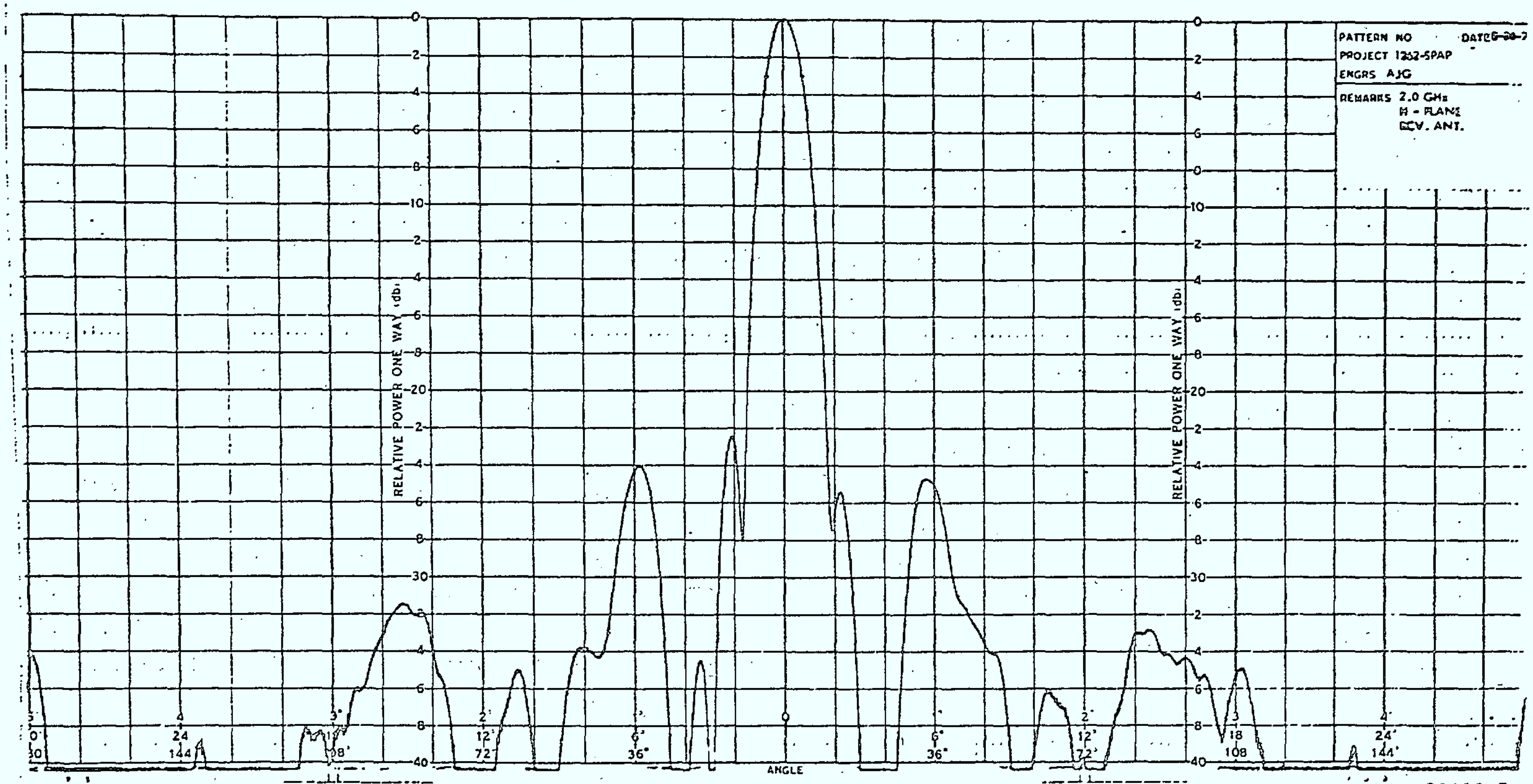
PROJECT 1262-SPAP
ENGRS AJG
REMARKS 2.0 GHz
E - PLANE
RCV. ANT.

88609-4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ENGRS AJG
REMARKS 2.0 GHz
H - PLANE
RCV. ANT.

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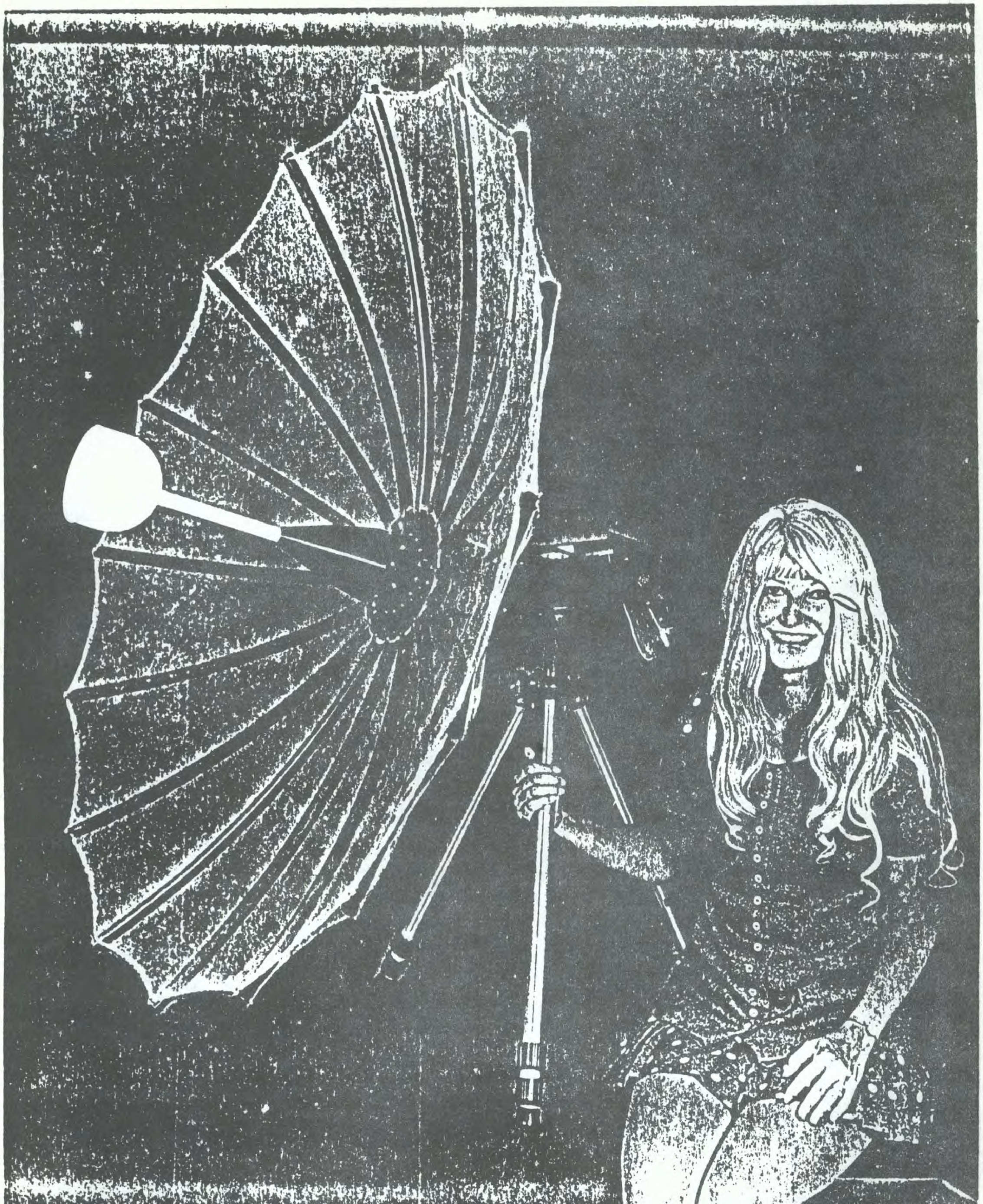
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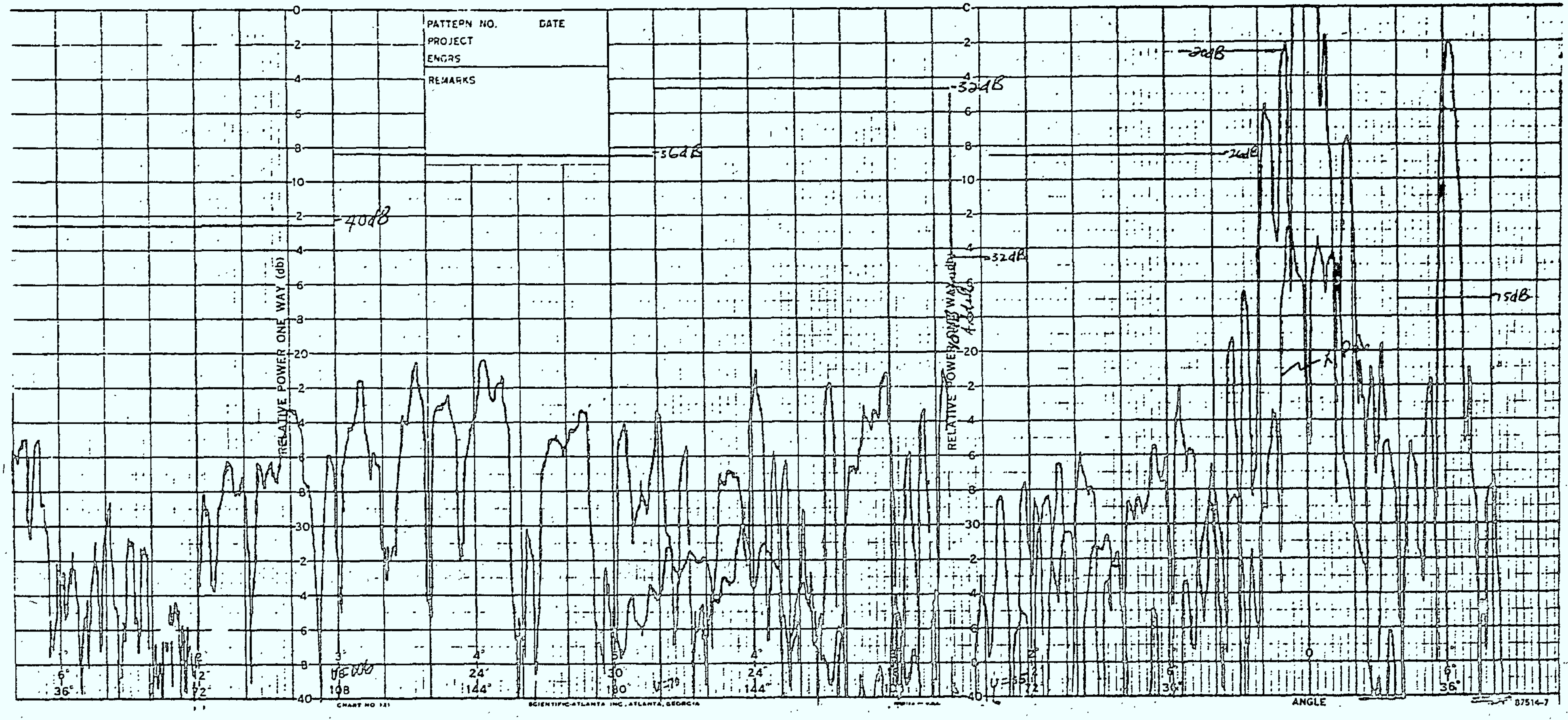
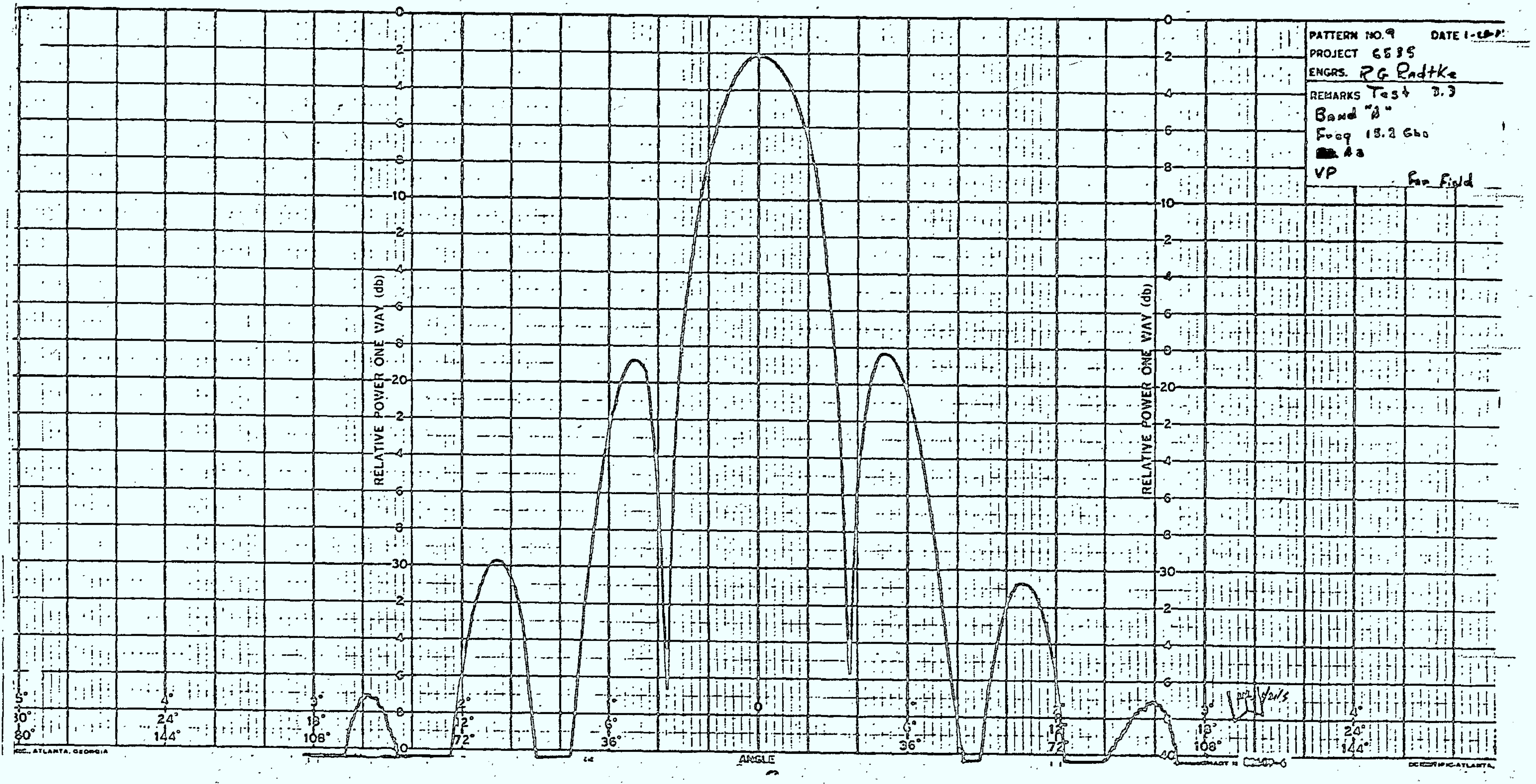
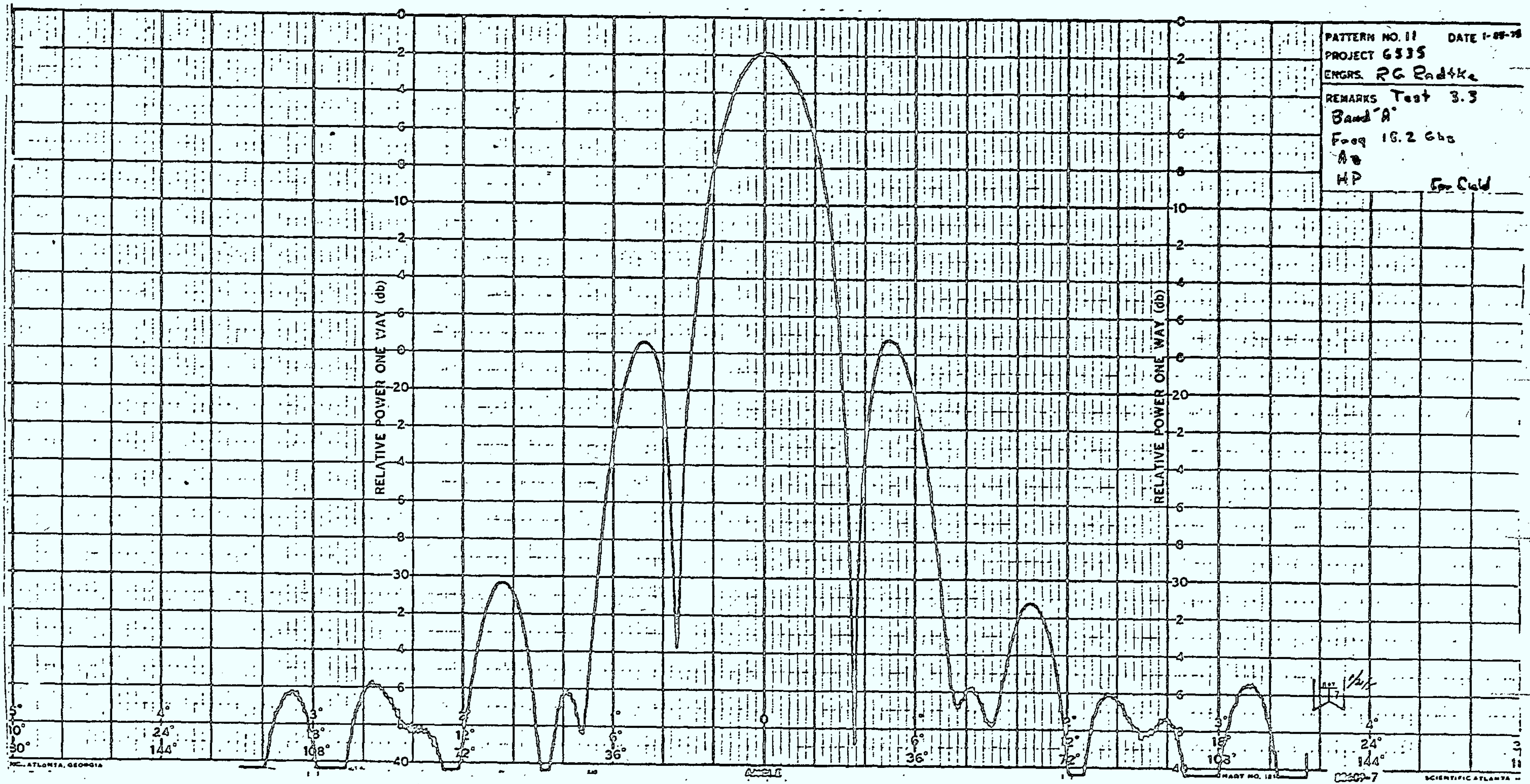

PATTERN NO.
DATE
PROJECT
ENGRS
REMARKS
RELATIVE POWER ONE WAY (db)
0
2
4
6
8
10
20
30
40
-40dB
-36dB
-32dB
-32dB
-20dB
-26dB
-15dB
6°
36°
12°
72°
3°
108
4°
24°
144°
30
180°
V=70
U=55
0
ANGLE
CHART NO 121
SCIENTIFIC-ATLANTA INC., ATLANTA, GEORGIA
87514-7



PATTERN NO. 9 DATE 1-[illegible]
PROJECT 6535
ENGRS. RG Radtke
REMARKS Test 3.3
Band "B"
Freq 18.2 Ghz
[redacted] Az
VP
Far Field



PATTERN NO. 11 DATE 1-25-75
PROJECT 6535
ENGRS. RG Radtke
REMARKS Test 3.3
Band "A"
Freq 16.2 Ghz
AB
HP
Far Field

2.0 MECHANICAL PERFORMANCE

The 3.8 meter TDRS Single Access (SA) Antenna is shown stowed in Figure 2.0-1 and deployed in Figure 2.0-2. This model demonstrated the feasibility of the dual mesh concept for the TDRS Ku- and S-band applications. Specific objectives of the NASA sponsored AAFE program was to verify the following:

1. Surface accuracy and repeatability of the dual mesh concept.
2. Verify thermoelastic methods by comparison with tests.
3. Verify dynamic analysis methods by comparison with tests.

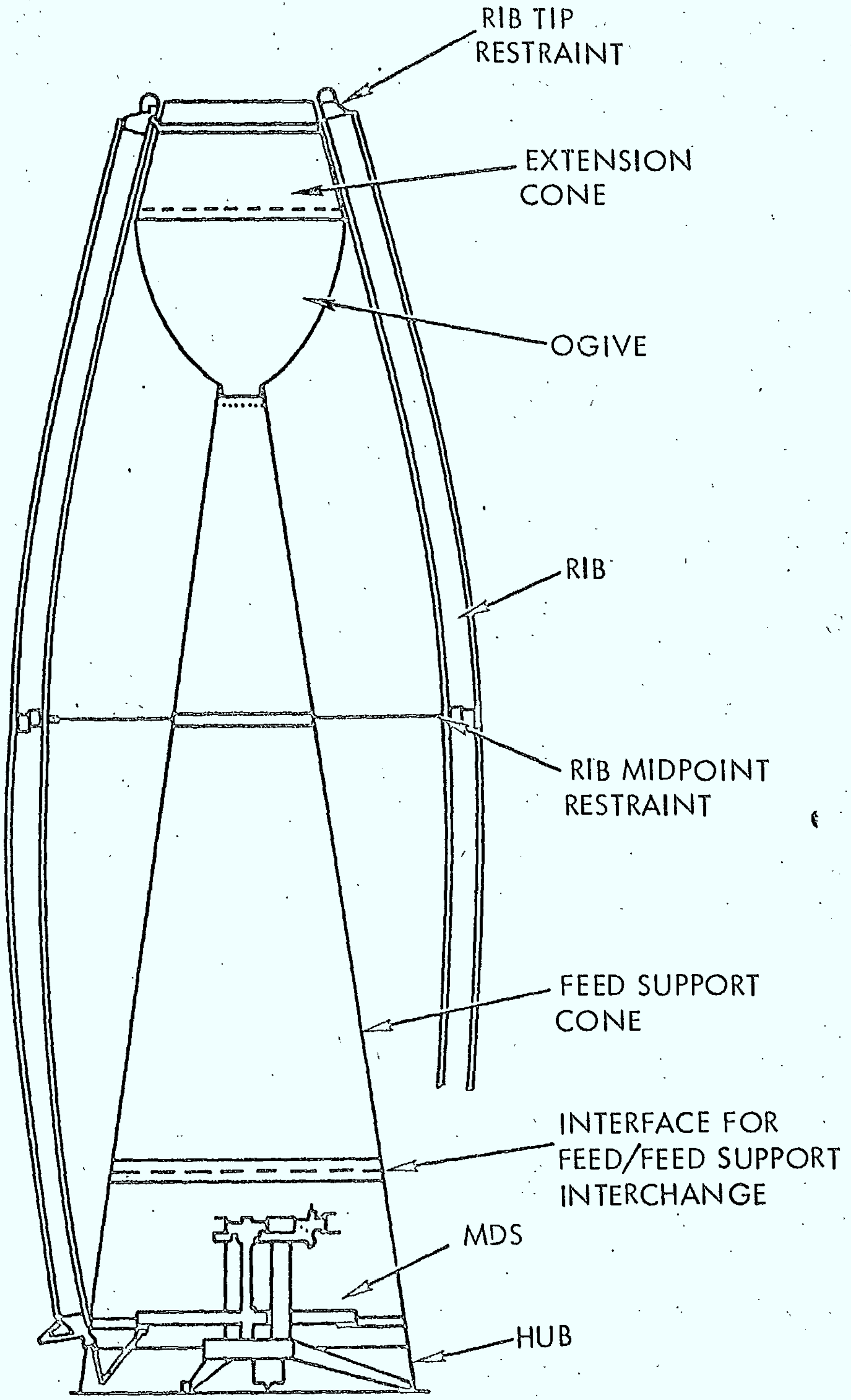
The analysis methods and test correlation results of the AAFE Antenna program are in Section 3.0.

The parabolic reflective surface of the SA antenna consists of 12, 1.5-inch diameter tubular aluminum ribs which shape and support the metallic mesh. The choice of 12 ribs was based on a trade-off of weight, surface tolerance and deployed dynamic performance. The "dual mesh" technique is used to obtain the high surface accuracy required for Ku-band operation. This technique consists of two mesh surfaces, with the rear mesh utilized as a drawing surface for contouring the front reflector mesh. The rear mesh is attached to the back of the ribs and is tied to the front mesh by tensioned wires. By properly tensioning the connecting tie wires, the reflector surface (front mesh) can be contoured to a precision parabolic shape.

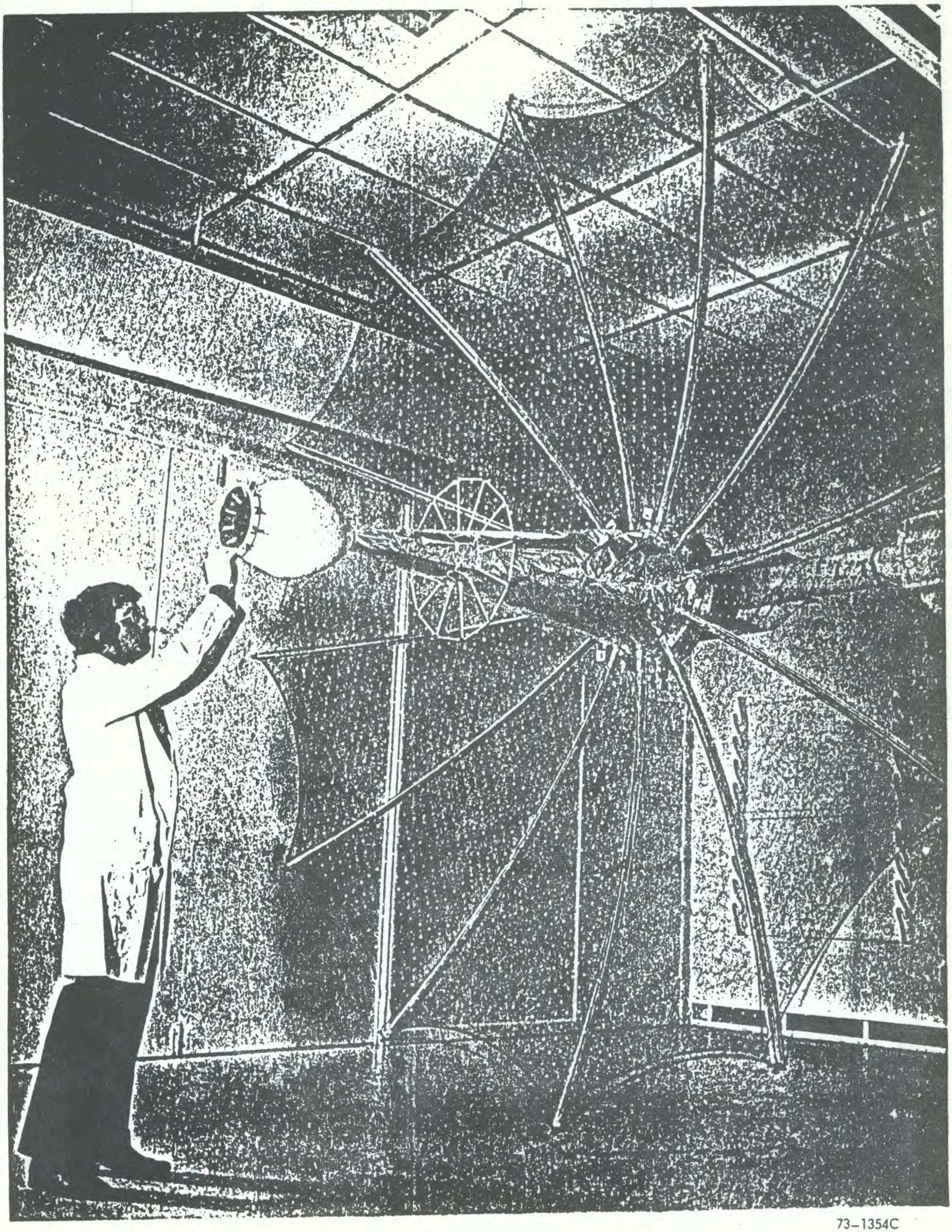
The conical feed support structure is the primary structural member of the stowed antenna. The cone was chosen since it is a very efficient structural element and since its RF blockage is no more severe than a spar system. A dielectric ogive radome is provided as an enclosure for the RF feed. The ogive geometry was selected for its high electrical efficiency and acceptable structural performance.

The stowed ribs are restrained by top and midsection restraints which cause the stowed antenna to act as a single stiff structural member, thereby providing a high stowed resonant frequency. The reflective surface is deployed at a controlled rate by the mechanical deployment system (MDS), see Figure 2.0-3. The MDS consists of a disc-shaped carriage mounted to the moving section of a recirculating ball nut on a ball screw shaft. The carriage and ribs are connected by linkages that transmit the force and motion required for deployment to the ribs. Redundant drive system power is supplied to the ball screw by a spring motor and two electric motors. The controlled deployment rate practically eliminates the transfer of any deployment forces to the spacecraft and also prevents impact loading of the ribs and mesh, thus assuring that the present parabolic surface is not distorted by the deployment action. A summary of the design parameters is shown in Table 2.0-1.

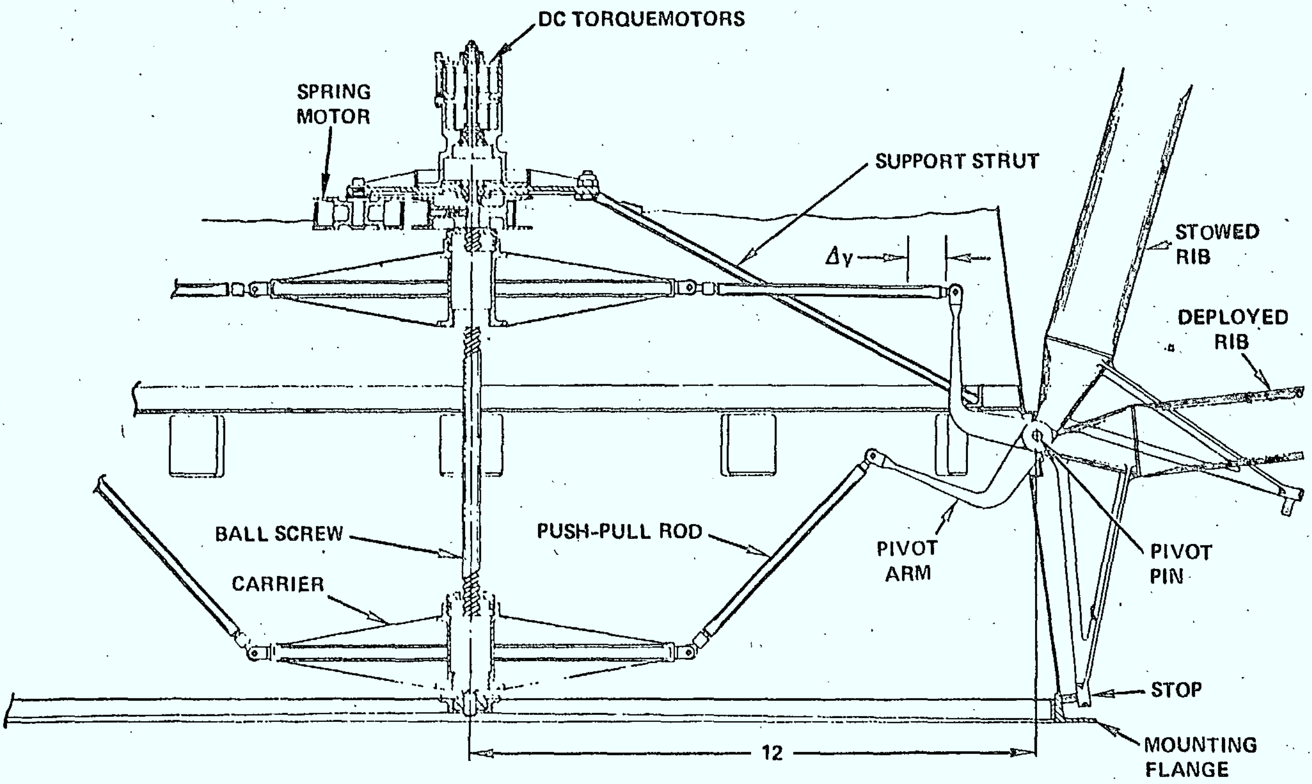
A summary of the performance characteristics of the AAFE antennas is shown in Table 2.0-2.


RIB TIP RESTRAINT
EXTENSION CONE
OGIVE
RIB
RIB MIDPOINT RESTRAINT
FEED SUPPORT CONE
INTERFACE FOR FEED/FEED SUPPORT INTERCHANGE
MDS
HUB

86355-1A



73–1354C



- CONTROLLED DEPLOYMENT
- DRY FILM LUBRICATION
- REMOTE FURLING

86525-12A

Table 2.0-1. Design Description

Element	Design Parameters
Ribs	o Number: 12
	o Diameter: 1.5 inches
	o Wall Thickness: Tapered from 0.008 (base) to 0.012 (mid) to 0.006 (tip)
	o Cross Section: Circular
	o Material: 6061-T6 Aluminum
	o Shape: Modified parabolic
	o f/D: 0.417
	o Thermal Control: Polished aluminum exterior with three layers of multilayer insulation (MLI)
Mesh (Front)	o Material: Chromel-R wire, 0.7 mil by 5 strands per end
	o Geometry: Tricot knit, 14 ends per inch
	o Coating: Electroless nickel, electroless gold, electrolytic silver and electroless gold
	o Loading: 0.02 lb/in tangential 0.01 lb/in radial
Mesh (Rear)	o Material: Chromel-R wire, 0.7 mil by 5 strands per end
	o Geometry: Raschel knit, 2 ends per inch
	o Coating: Electroless nickel covered with electroless gold
	o Loading: 0.03 lb/in tangential 0.005 lb/in radial
Center Support Structure	o Type: Truncated support cone with dielectric ogive radome

Table 2.0-1. Design Description (Continued)

Element	Design Parameters
	○ Cone Material: 6061-T6 Aluminum, 0.020 inch thick (base), stepping to 0.015 inch from the midsection to the ogive
	○ Radome: 0.01 inch thick, high modulus fiberglass and epoxy laminate skins, with phenolic (1/4-inch cell) honeycomb, 3/8 inch thick.
	○ Thermal Control: Three layers of multilayer insulation (MLI) separated by three layers of nylon net on the cone. White paint $(\alpha/\varepsilon) = 0.28/0.86$ on the radome.
	○ Attachment to Hub: Removable
Central Hub	○ Geometry: Extension of feed support cone geometry
	○ 0.050 inch thick 6061-T6 aluminum
	○ Thermal Control: 15 layers of multilayer insulation separated by 15 layers of nylon net.
Mechanical Deployment System (MDS)	○ Type: Over center type toggle action using a ball screw and carrier with linkages to each rib pivot arm. Over center condition gives positive deployed latching.
	○ Drive System: Redundant electric motor and constant torque spring motor. Primary - 2.5 inch/pound spring motor direct drive on the ball screw Secondary - Two DC torque motors integrated with a planetary gear train with 25 inch/pounds of output torque.
	○ Redundancy: Either the spring motor or dc motor is capable of deploying the antenna in a 1 G field.

Table 2.0-1. Design Description (Continued)

Launch Restraint	o Rib-to-center support cone restraint at rib midpoints using radial spars and a single hoop. Ball-and-socket joint between ribs and hoop. Preloaded by flexing the ribs. o Upper restraint provides moment joint at rib tip. Rib tips restrained and preloaded by a pretensioned, captivated cable. o Restraint Release: Two pyrotechnic cable cutters for redundancy.
Feed System	o Ku-band Cassegrain type feed, S-band apex feed. 5.5-pound weight for feed, brackets, waveguides and cabling.

Table 2.0-2. Mechanical Performance

Stowed Resonant Frequency (tested):

Mode	Frequency, hz
Lateral	57.0
Longitudinal	185.0
Torsional	29.4

Allowable Stowed Dynamic Loads (analysis):

Axis	Max. Vibration, G Ultimate	Max. Shock, G Ultimate
Lateral	25	20
Longitudinal	35	20

Total weight with 5.5 lb. feed is 31.20 lbs. (tested)

Stowed Packaging Volume is a right circular cylinder, 75 inches high and 30 inches in diameter (tested).

Probability of Successful Deployment is .9925 (analysis).

Deployed Resonant Frequency (minimum) is 8.3 Hz (tested).

Surface Accuracy due to manufacturing and setting tolerances is .020 inch RMS (tested).

Repeatability of the reflector surface over successive deployment is ±.002 inch RMS (tested).

Surface Accuracy due to all causes in worst-case orbital position is .038 inch RMS with a defocusing of .63 inch (tested).

3.0 THERMAL AND STRUCTURAL/DYNAMIC ANALYSIS

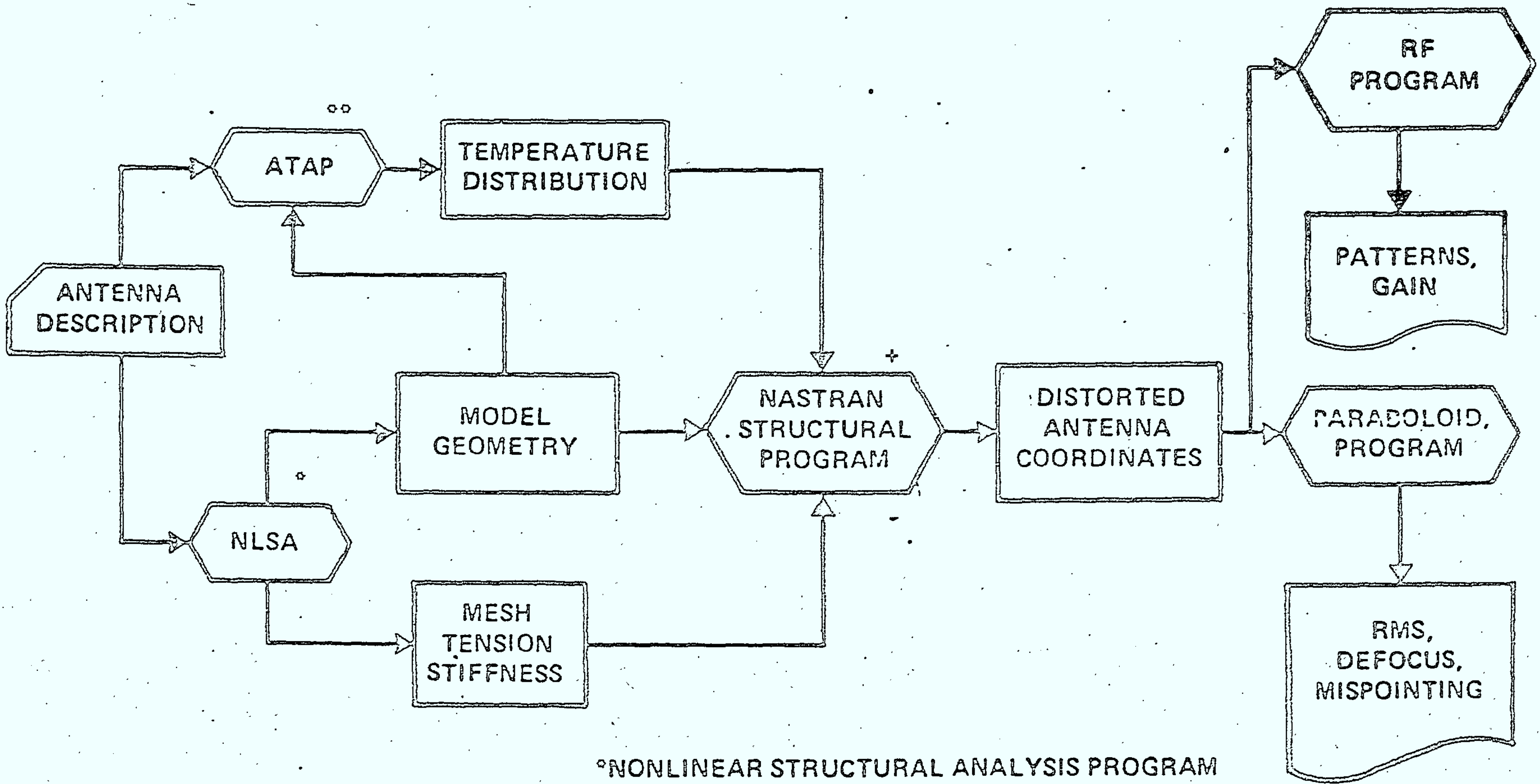
3.1 Thermal Analysis

The achievement of accurate surface accuracies in orbits/environments requires very detailed thermoelastic analyses. The thermoelastic analysis method used at Harris ESD on space deployable antenna designs is shown in Figure 3.0-1. The thermal distortion analysis is performed using the industry accepted NASTRAN program. The input models for NASTRAN are generated by two programs that were developed at Harris ESD, NLSA and ATAP. NLSA (for Nonlinear Structural Analysis) generates the structural model and model geometry including the back mesh contour, a brief description of NLSA is shown in Figure 3.0-2. ATAP (for Antenna Thermal Analyzer Program) generates the antenna temperature distribution from the antenna description input data. The distorted coordinates from NASTRAN are inputted to either of two RF analysis programs. One generates the best fit paraboloid and then computes the RMS surface accuracy, defocus and mispointing angle. The other program computes the RF secondary pattern and gain reductions.

Figure 3.0-3 shows how a reflector is typically reduced into half-gore segments for analysis through the use of cyclic symmetry. The half-gore is selected as the minimum segment of symmetry. It is then reflected about its line of intersection with the next half-gore and rotated about the Z axis to generate the entire reflector.

Figure 3.0-4 illustrates the various elements included

THERMOELASTIC ANALYSIS



°NONLINEAR STRUCTURAL ANALYSIS PROGRAM
°°ANTENNA THERMAL ANALYSIS PROGRAM
+NASA STRUCTURAL ANALYSIS PROGRAM
SYSTEM CURRENTLY RUNNING AS SHOWN
ON THE ISD U-1108 SYSTEM

FIGURE 3.0-1 Thermoelastic Analysis Flow Chart

NONLINEAR STRUCTURAL ANALYSIS PROGRAM
NLSA

- BASIC CHARACTERISTICS OF THE PROGRAM ARE:
  - O MEMBRANE AND STRINGER ELEMENTS.
  - O SMALL STRAIN-LARGE DISPLACEMENT FORMULATION TO ALLOW FOR GEOMETRIC NONLINEARITY.
  - O LOAD APPLIED IN STEPS.
  - O STIFFNESS MATRIX IS ADJUSTED AFTER EACH STEP TO ACCOUNT FOR CHANGES IN TENSIONS AND GEOMETRY.
- PROGRAM BEING EXPANDED TO INCLUDE BEAM ELEMENT AND ANALYSIS WITH MATERIAL NONLINEARITIES.

FIGURE 3.0-2 NONLINEAR STRUCTURAL ANALYSIS PROGRAM
NLSA

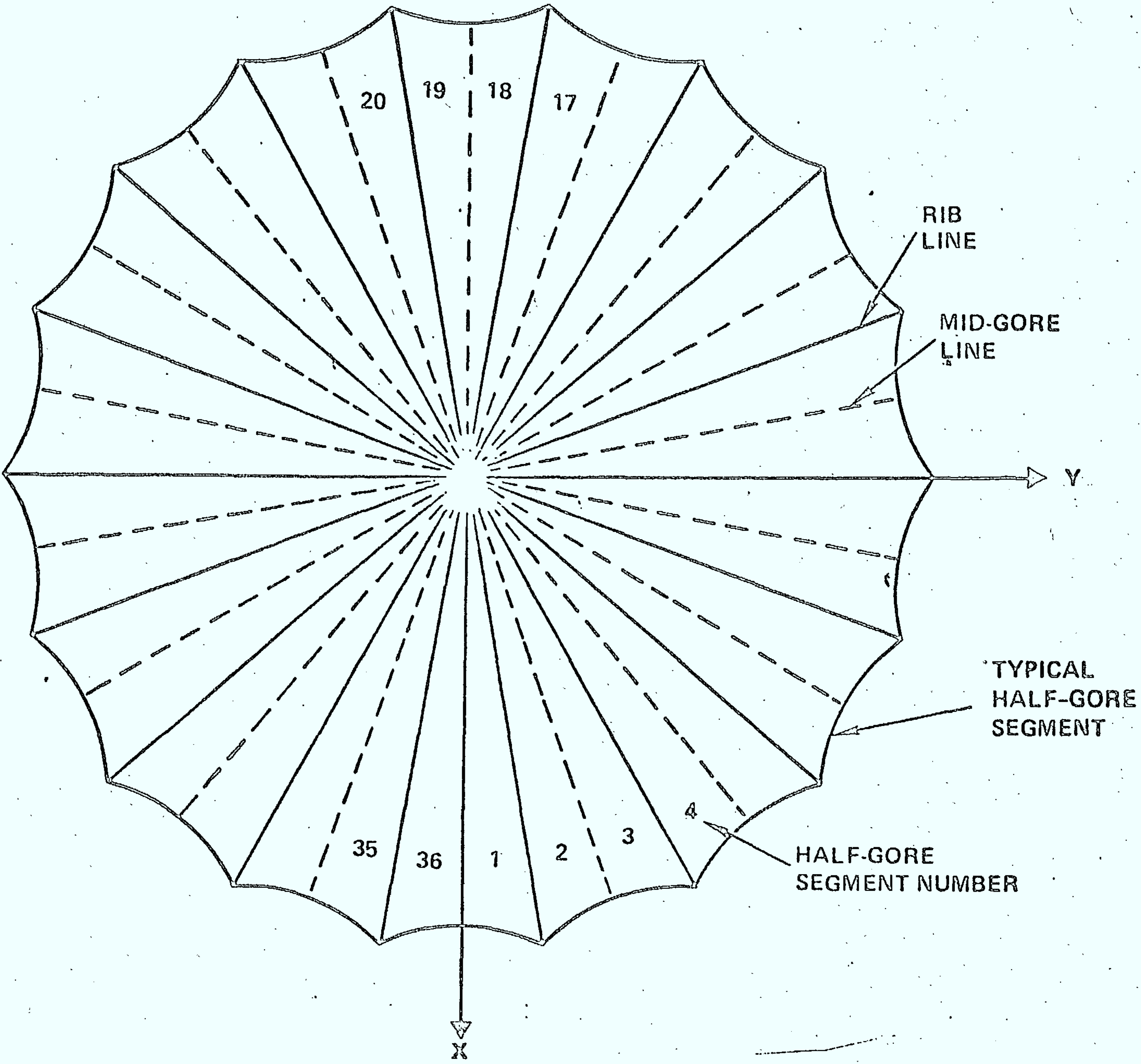
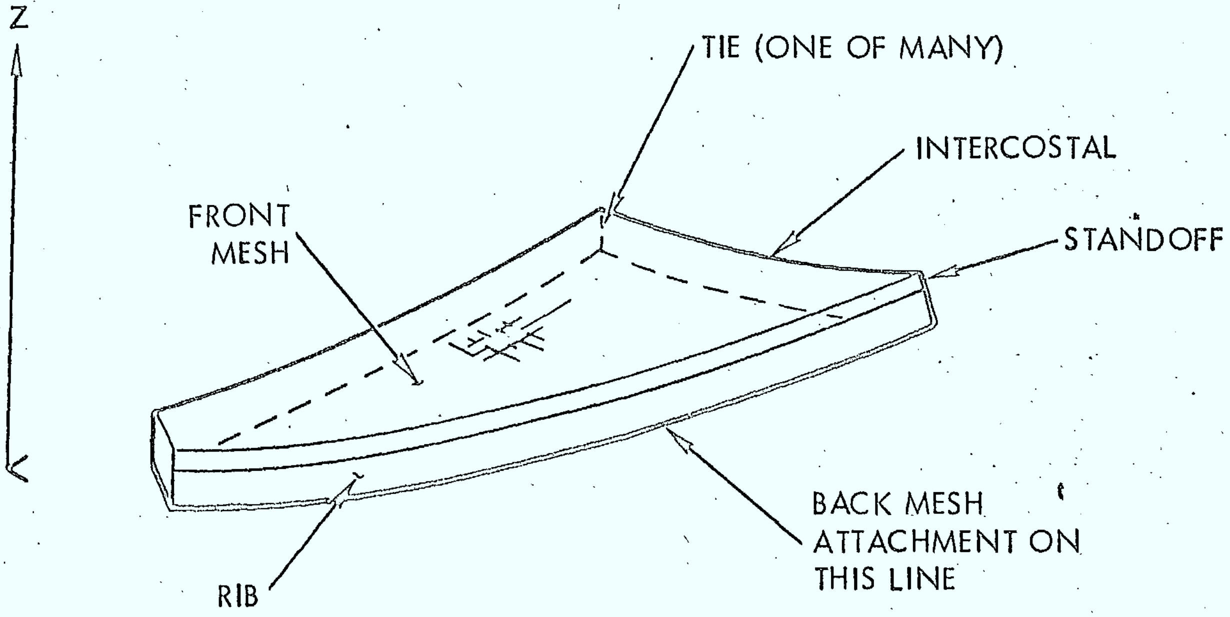


FIGURE 3.0-3

REFLECTOR DIVIDED INTO REPETITIVE HALF GORE SEGMENTS


Z
TIE (ONE OF MANY)
INTERCOSTAL
STANDOFF
FRONT MESH
BACK MESH ATTACHMENT ON THIS LINE
RIB

88460-2

with the repetitive half-gore segment model. The front and back meshes, intermesh ties, intercostal, standoffs and ribs are all included. The half-gore finite element representation of the mesh is shown in Figure 3.0-5.

3.1.1 Thermal Analysis and Test Correlation

The AAFE antenna was tested in a solar vacuum chamber at sun angles of =0° and =60°. The reflector surface was measured by the photogrammetric method in conjunction with the best fit paraboloid program. The comparison of the test and analysis results is shown in the following table.

Sun Angle, Deg.	Analysis RMS, in.	 Defocus*, in.	Test RMS, in.	 Defocus, in.
0	.037	+.46	.038	+.63
60	.022	+.37	.026	+.49

*Plus corresponds to an increase in the focal length.

3.2 Structural/Dynamic Analysis

The primary concern of the structural and dynamic analysis is attaining a very lightweight antenna that meets the stowed and deployed resonant frequency requirements and can survive the launch loads.

The computer model used for the stowed analysis is shown in Figure 3.0-6. The final dynamic analyses were performed using an eigenvalue solution to determine the five lowest resonant frequencies. The inverse iteration method in the STARDYNE computer program was used for this analysis. Preliminary analyses and tradeoff studies were performed using the Rayleigh method and the statics option available in STARDYNE. The Rayleigh method gives quick, economical and accurate results that have been validated in prior analyses and tests.

The stowed antenna mode shapes were used to apply the 25G lateral and 35G longitudinal loads for the calculation of stresses and deflections. The following factors of safety were applied to the limit loads to obtain the structural design loads.

Yield Design Load	1.15
Ultimate Design Load	1.25

To achieve a lightweight structure, the antenna is designed to attain the smallest practical margin of safety greater than zero, except where stiffness requirements dictate additional structure. The following structural elements, which are susceptible to random type failures due to manufacturing and load distribution inconsistencies, were restricted to have the following minimum margins of safety:

Antenna Part	Minimum Margin of Safety
Fasteners in shear	+.15
Bolts in tension	+.50
Fittings	+.15
Lugs	+.25
Welded and brazed joints	±.50
Epoxied joints	+.75

Rib parametric analyses were run to determine the optimum rib design that would meet a minimum frequency requirement while minimizing weight and tip deflection. A program was written using a 10-element rib that varied rib diameter, rib thickness and rib thickness taper and printed out weight, frequency, stress and deflection.

The optimum rib was then modeled for a STARDYNE eigenvalue run to determine frequencies and mode shapes. The hub stiffness was included in this model.

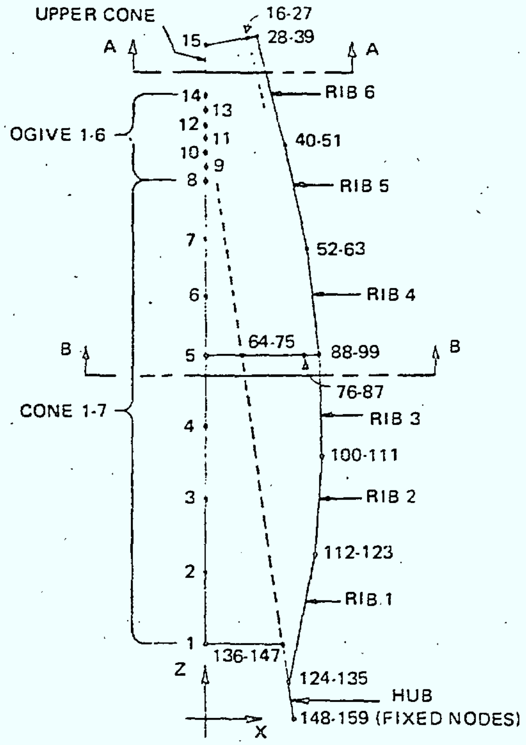
Deployment in one G at various orientations produces the highest stresses in the MDS. Forces and torques were calculated in one degree increments of motion of the MDS in both the face side and face down positions in arriving at the ultimate design and margins of safety.

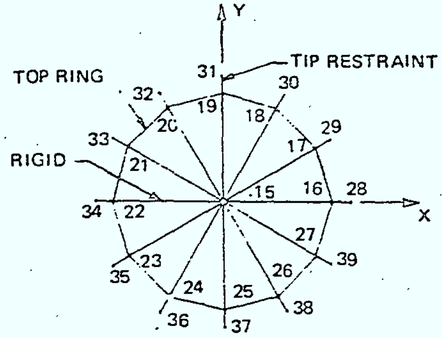
3.2.1 Dynamic Analysis and Test Correlations

The AAFE antenna was vibration tested in the lateral and longitudinal directions while stowed and in the longitudinal direction while deployed. The comparison of the resonant frequencies by test and analysis is shown in the following table:

Test Configuration	Resonant Frequency, Hz Test	 Analysis
Stowed, lateral axis	57.0	56.8
Stowed, long. axis	185.0	141.8
Deployed, long. axis	8.2	7.0

Excellent correlation was achieved in the two most important modes, stowed lateral and deployed. The computer model is under review to determine why the predicted stiffness is less than the actual in the stowed longitudinal direction.





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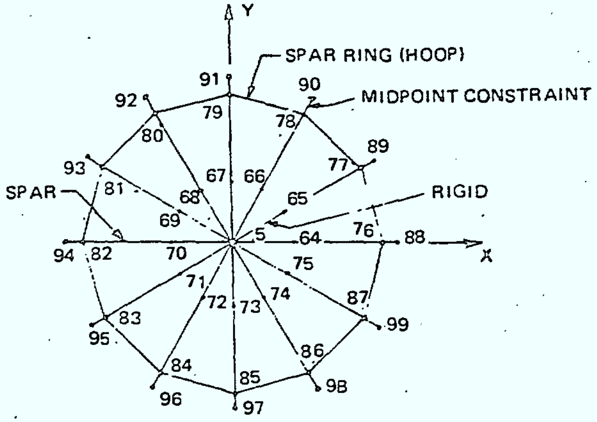
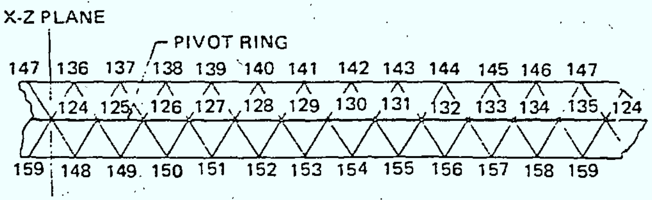
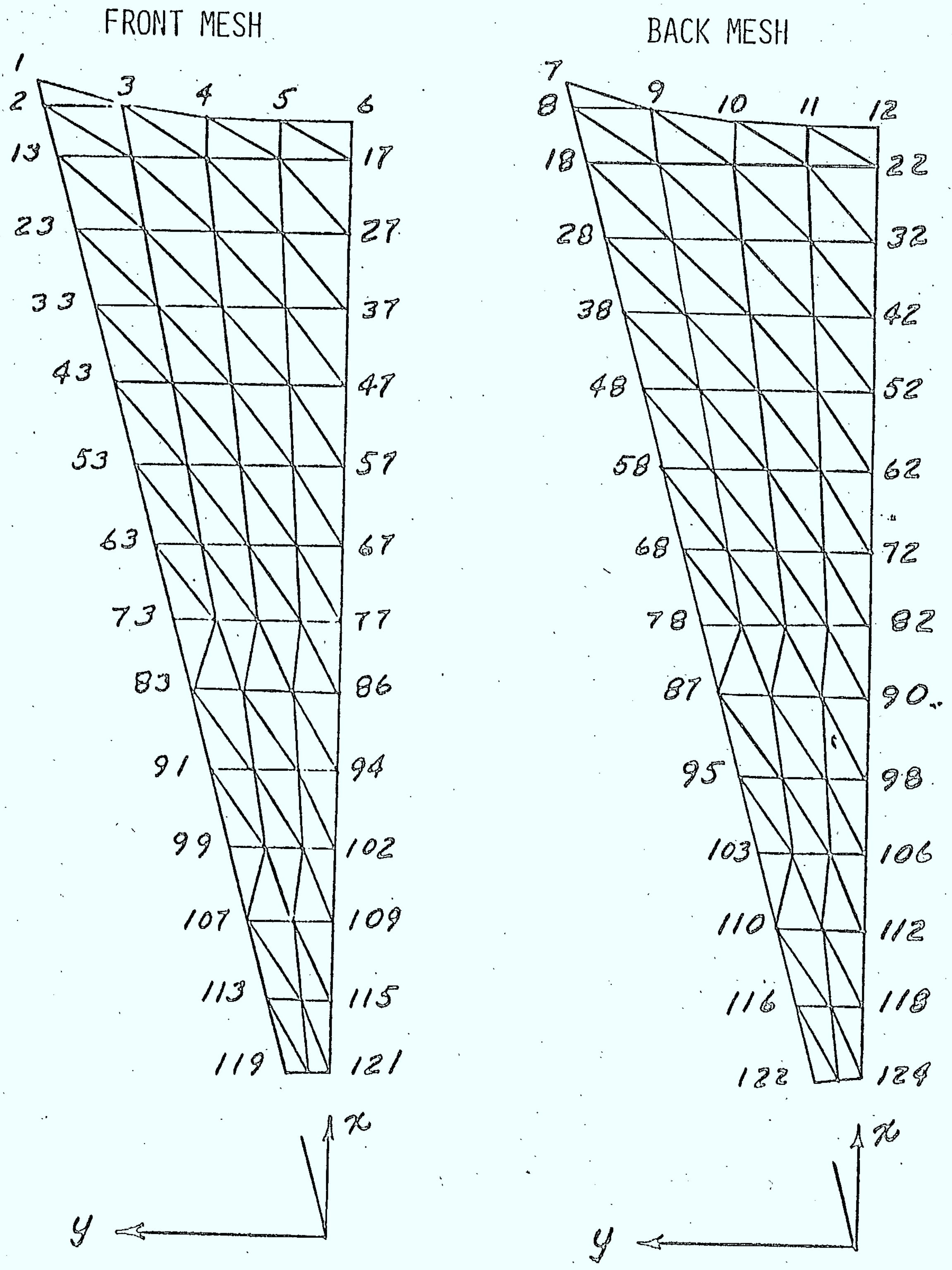


SECTION B-B



HUB DETAIL

86692–13



FRONT MESH

BACK MESH

FIGURE 3.0-5

AAFE HALF-GORE FINITE ELEMENT REPRESENTATION

APPENDIX IIb.

14 April 1975
9340-75-09

RECEIVED
[illegible] 1975
AEROSPACE MARKETING

TO: C. G. Dawdy

cc: Russ Gaspard
Bob Walters
B. C. Tankersley

FROM: J. G. Hegi

SUBJECT: VISIT OF ERIC QUITTNER, SPAR AEROSPACE

Mr. Quittner is a Section Manager/Systems Engineer with Spar Aerospace Products Limited. He is presently participating in a feasibility study for a multi-purpose Canadian satellite that has the following milestones:

Concept Definition Study (2 studies) - Start Sept. '75
Design, development phase - Start late '76 or early '77
Launch - early in 1980

This is intended to be a Canadian built satellite by Canadian companies. It will be about a 2000 pound satellite boosted by the Delta 3914.

We covered the TDRSS deployable and came up with four questions which need an "off the cuff" response from an expert. The questions and conditions follow:

1. Openings in the mesh are desired for two sensors to see through. The openings can be at any point within 30" of the center of the antenna and require an opening area of 3" x 3". The two openings must be separated by at least six inches. The question then relates to the feasibility of controlling the pattern and predicting the gain. What problems occur with such an approach?

2. The second question relates to the vibration levels that can be tolerated. A maximum of 40g's rms could occur at 35 to 40 cps during launch. Difficult but lower levels are expected at 15 to 25 cps and 40 to 50 cps due to other spacecraft resonant points.

The question relates to the ability of the stowed antenna to survive in such environments. Assumptions should include lateral excitation and complete dual feed plumbing. Can this feed cone withstand such vibration levels?

3. The third question has to do with the mounting of the TT&C antenna on the tip end of the ogive. The TT&C antenna would be an S-Band bicone on the end of a two foot mast. Is the feed cone and ogive strong enough to hold such a structure in the vibration environment described.

4. The fourth question relates to the effects of propellant combustion products upon the antenna materials. The propellant used is hydrazine and Kerosene. I don't know the products. This is the altitude control jet exhaust gases.

5. A question also came up on the area available in the deployment mechanism hub for running RF plumbing through to the spacecraft. We need to give some approximate opening dimensions with a sketch showing how it could be configured without doing structural damage to the hub.

The intention is to mount our deployable directly to the spacecraft frame with an adapter ring that mates to the presently configured hub mounts. No steering is done on the antenna alone.

Eric would like any response that we could give him by the first part of the week of 4-21-75.

JGH:lf

Attachment No. 2 28 April 1975

ANSWERS FOR SPAR AEROSPACE PRODUCTS, LTD.

DEPLOYABLE ANTENNA FOR CANADIAN COMMUNICATIONS SATELLITE STUDY

1. Providing openings in the mesh as described presents no problem mechanically. We have accomplished such openings before. To maintain the mesh tension field the holes will be elliptical with the minor axis diameter 3" in length and a slightly larger major diameter.

   Impact on gain and patterns would be evaluated analytically and by test. Similar holes of this size have made no measurable effect on past designs.

2. No problem is anticipated under the indicated random vibration loads. The basic design geometry has been more or less optimized such that stress, not stiffness, is the limiting design factor. If the levels defined present stress problems material thicknesses can be easily increased.

3. No problem is foreseen in mounting TT&C antenna on tip of ogive. Previous designs have had up to 30 lbs. mounted in this area. Feed cone and ogive designs can be made adequate for the given program requirements.

4. Not currently resolved. Current program will be doing some testing of hydrazine effects on mesh.

5. No problem expected in running through hub/MDS. Has been done on previous programs. See accompanying layout.

APPENDIX III

LMSC

ATS 30-FOOT FLEX-RIB ANTENNA

H. L. Gerwin
ATS-F and -G Project Manager
Goddard Space Flight Center
Greenbelt, Maryland

G. K. Campbell
Lockheed Missile and Space Company
Sunnyvale, California

Summary

The reflector is a self deploying 30-foot parabola which stows in a 58-inch diameter torus. It uses the stored strain energy in 48 flexible cambered ribs to deploy when a restraining cable is cut. The reflecting surface is a metal mesh stretched between the ribs. A thermal analysis of the mesh, ribs, and hub was used to obtain a distortion history which was then used to determine RF performance throughout the orbit of the spacecraft. The number of ribs to be used in the final design was determined by tests made using a simulated reflector; and, calculations indicate that torque imparted by unfurling of the antenna will be within acceptable limits.

Introduction

The first objective identified in the ATS-F and -G program is demonstration of a 30-foot deployable reflector in near geostationary orbit. As early as 1965 NASA recognized that this was a most difficult objective to achieve. Thus it funded two antenna development programs. One, called a Petaline reflector, was developed by Goodyear Aerospace Corporation of Akron, Ohio, and is shown in Figures 1 and 2. The other, called a parabolic expandable truss antenna (PETA), was developed by General Dynamics and is shown in Figures 3 and 4.

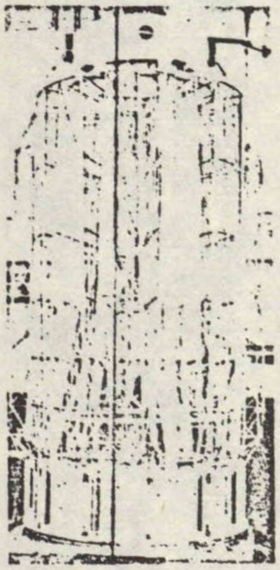


Figure 1. Stowed Condition — Goodyear Aerospace Corporation

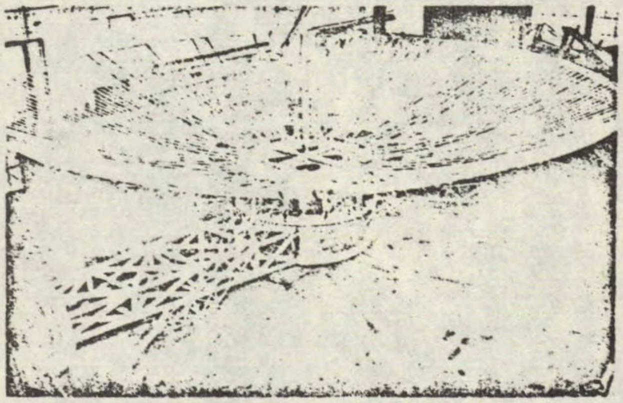


Figure 2. Deployed Condition — Goodyear Aerospace Configuration

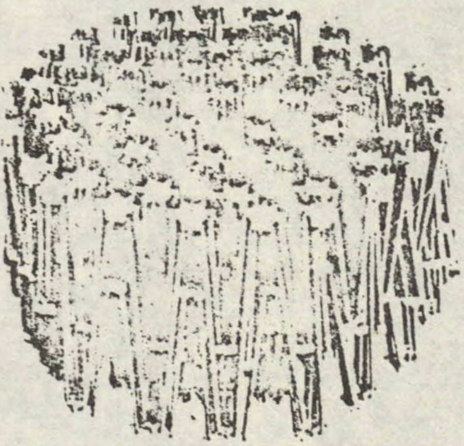


Figure 3. Stowed Condition — General Dynamics Configuration

At about the time these antenna developments were completed, the flex-rib antenna which had been developed by Lockheed Missile and Space Company, Sunnyvale, California, was declassified.

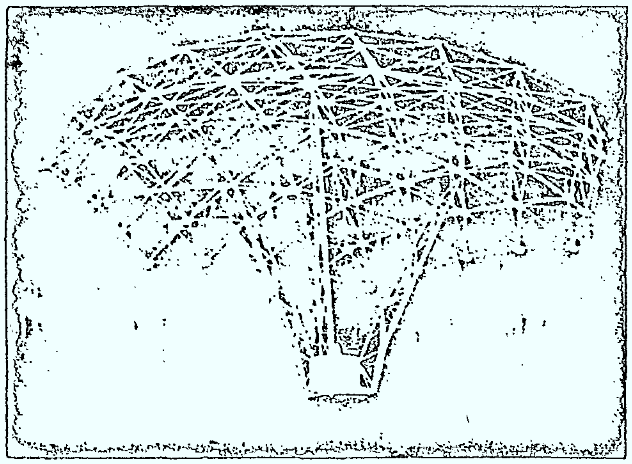


Figure 4. Deployed Condition — General Dynamics Configuration

NASA then undertook a careful comparative study to determine which of these three antenna concepts should be selected for the ATS-F and -G satellites. The Lockheed antenna was chosen largely because the design concept has excellent structural characteristics in the stowed configuration during the launch phase. It can be built as a separate module and attached to the spacecraft when ready for launch, and provides excellent performance as a reflector for frequencies up to 10 GHz.

Description

The 30-foot flex-rib antenna reflector assembly (shown in Figure 5) is a skin-stressed, rigid-ring base, flexible radial beam paraboloid. It consists of 48-flexible rib assemblies supporting an RF reflective mesh surface and a ring-shaped hub assembly which contains rib mounting, storage and deployment assemblies, and the antenna-spacecraft mounting interface. The reflective fabric is attached to the inner edge of each rib to produce the paraboloidal reflector surface. The ribs are attached to the hub through hinges that permit pivoting the ribs from their normal, radial position by 90 degrees to a tangential position relative to the hub. For stowing the reflector, the ribs are wrapped around the hub, and the fabric is folded between the ribs and wrapped on the hub between the rib spirals.

In the stowed configuration, the reflector package has approximate inside and outside diameters of 58 and 78 inches, respectively, and a height of approximately 8 inches. The reflector assembly weighs 150 pounds. A series of doors, secured by a circumferential retaining cable, close the outer periphery of this ring shaped container. Deployment of the reflector is initiated by pyrotechnically actuated redundant cable cutters. The springloaded doors open upon release of the cable and the elastic energy stored in the bent ribs cause the ribs to unwrap from the hub until they are tangent to the hub. Rib momentum insures that each rib rotates about its hinge into a radial position where it is latched. The cable remains attached to the doors to avoid interference with other components of the spacecraft. The only power required from the spacecraft system is that required to actuate the pyrotechnic device.

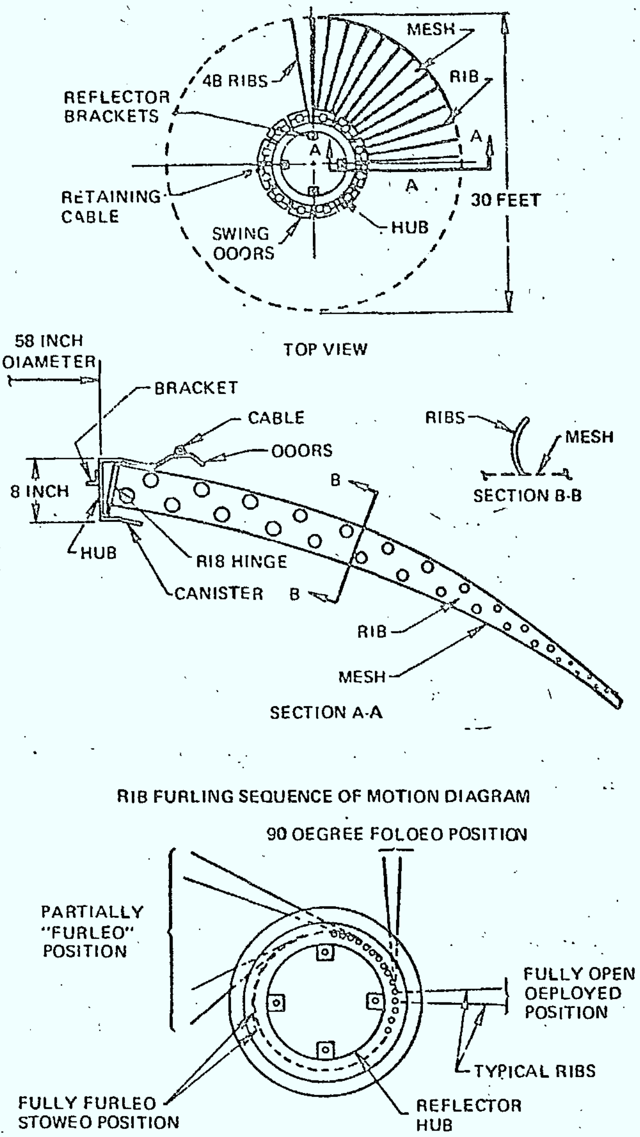


Figure 5. Flex-Rib Antenna Reflector Assembly

The reflector is designed in such a manner that the ribs exert a slight elastic force upon the mesh which maintains the latter in taut condition at all times during orbit. The ribs are thereby preloaded in a cantilever mode, always in the same direction. This preloading enables establishing the rib position with great precision while providing the required clearances in the rib hinges which would otherwise become a problem in the zero-g environment. The initial shape of the reflector is a function of the initial stress levels in the ribs and mesh, of the contour of the ribs before they are stressed, and of the rib alignment at its point of attachment to the central hub. The temperature of the mesh, ribs and hub will alter the stress conditions which in turn will alter the shape of the reflector. This is a complex structural problem, thus it was necessary to develop a computer program for use as a design tool to arrive at a final reflector design.

During the 24-hour orbital period, various members of the reflector structure will be subjected to direct sunlight or be shaded. This will significantly vary the temperature of the various structural members. By means of a thermodynamic orbital history analysis the temperature of each element node at a number of orbital times was determined. Nodal temperatures were computed at 4800-second intervals throughout the 24-hour synchronous orbit. The following information was obtained:

- o Each rib temperature history (10 nodes used per rib)
- o Each mesh panel temperature history (5 nodes used per panel)
- o Each hub/rib attachment area history (7 nodes used per rib point)

The temperatures as determined by the thermodynamic orbital history analysis were used along with the structural and material properties of the ribs, mesh, and hub to obtain a distortion history of the reflector. In turn the distortion history was used as an input to an RF-gain program to determine the RF performance throughout the orbit.

Many runs, using these computer programs were conducted to arrive at the optimum performance for a full 24-hour period.

Figure 6 shows the computed RMS deflection of the reflector over a 24-hour orbital period.

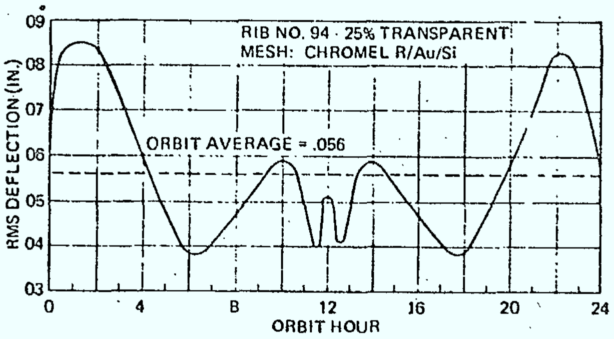


Figure 6. RMS Deflection of Reflector Over a 24-Hour Orbital Period

Figure 7 shows the computed antenna gain over the 24-hour orbital period.

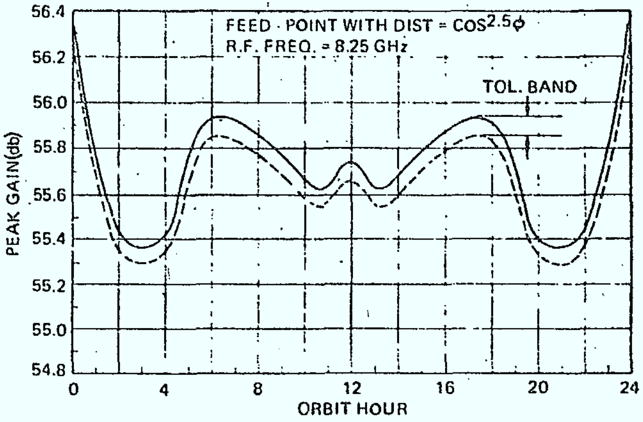


Figure 7. Antenna Gain Over a 24-Hour Orbital Period

In addition to the basic design problems discussed above, two separate items required attention. The first related to a determination of the number of ribs to be included in the final design. The peak gain performance possible from a reflector simulated by wedge shaped sections of a parabolic cylinder surface is shown by Figure 8. Loss due to this simulation is indicated on a D/λ basis; D/λ representing the diameter of the reflector in wavelengths. The D/λ term for the 30-foot ATS-F and -G reflector at

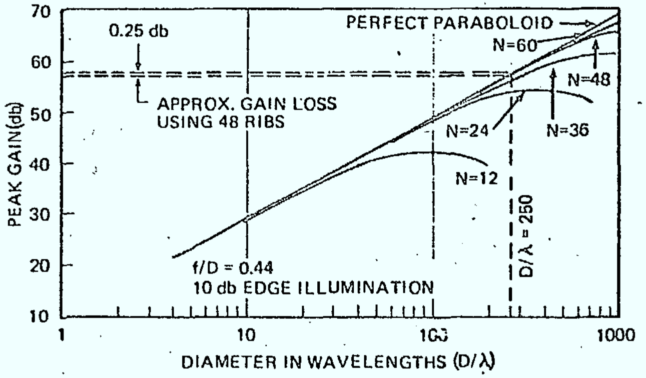


Figure 8. Peak Gain Simulated Performance of Reflector

8.25 GHz is equal to 250. For this D/λ ratio a reflector with 48 ribs is seen to closely approximate a true parabola. Fewer ribs could be used if the diameter were increased, but, generally speaking, it is more profitable from a weight standpoint to use a larger number of ribs at a smaller reflector diameter in order to meet a specific peak gain requirement. Secondly, it is more profitable from a thermal distortion standpoint to use the smallest diameter feasible in order to reduce total tip distortions of ribs due to orbital thermal history variations. In the case of the ATS-F and -G reflector with a design weight goal of 150 pounds and an average orbital peak gain including all distortions of at least 55.5 db, it appeared that the 48 rib choice with its resultant "flat panel" effect loss of 0.25 db was acceptable.

The second item requiring attention was the torque imparted by the unfurling reflector. During reflector unfurling, torques are applied to the spacecraft. They are represented by a torque profile which builds up to 950 ft-lb at the time when the reflector ribs are fully unfurled but still tangent to the hub periphery. During the 90 degree swing from tangency to full radial extension, a small resultant torque is produced by centrifugal force from the ribs rotating about their offset hub attachment hinge points. At full radial extension, the ribs will contact both extension stops and back stops (to prevent refurling) and produce maximum applied torque to the spacecraft. This value has been calculated to be less than a 3000 ft-lb peak which is acceptable loading for the ATS spacecraft structure.

In conclusion, the ATS-F and -G parabolic unfurlable reflector has an average peak gain throughout the 24-hour orbit of better than 55.5 db as illustrated by Figure 7. This gain value includes thermal distortions and the 48-panel parabolic approximation as well as the mesh property uncertainties and manufacturing tolerances.

APPENDIX IV

Lockheed
MISSILES
& SPACE
COMPANY,
INC.

In reply refer to:
LMSC-D427323
Orgn. 64-01, B/562

March 28, 1975

Mr. Eric Quittner
SPAR Aerospace Products Ltd.
825 Caledonia Road
Toronto, Ontario

Dear Mr. Quittner:

We have reviewed the list of questions that you left with us during your visit of 20 March 1975, and offer the information listed on the attached sheets. I hope this data is sufficient for your needs at this time. As your needs are definitized, we will be happy to discuss them in more detail.

Very truly yours,

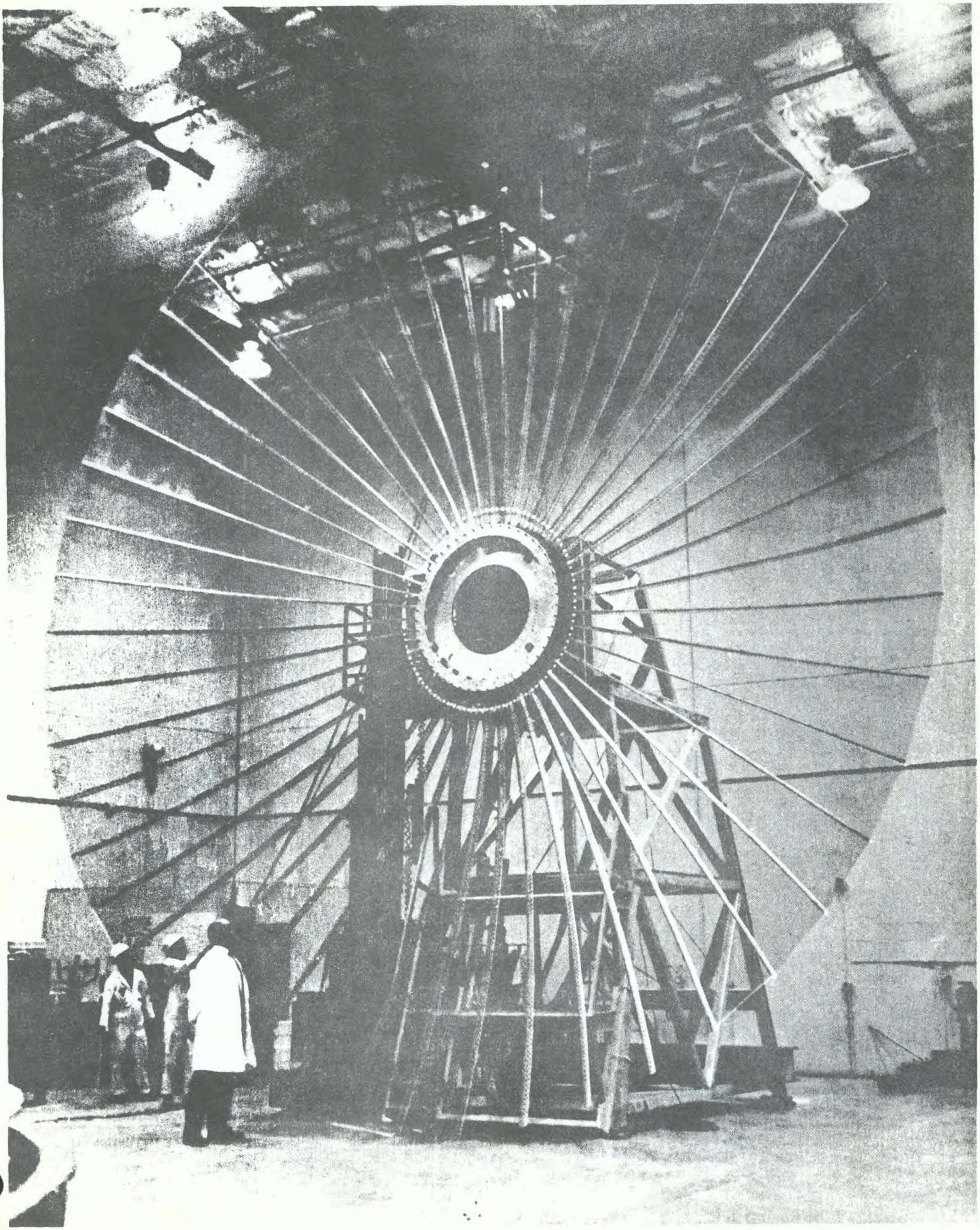
LOCKHEED MISSILES & SPACE COMPANY, INC.
SPACE SYSTEMS DIVISION

J. H. Hockenberry
Assistant General Manager
SSD Communications Systems

cc: R. L. Samuals

A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA 94088



ATTACHMENT
DATA ON DEPLOYABLE ANTENNAS

4.1 LMSC has built deployable paraboloidal reflector antennas in the range of 6 feet to 30 feet. Antennas in the range of 10 to 16 feet can be supplied for frequencies up to KuBand. LMSC has not built extendible helical antennas.

4.2 The deployable reflectors operate on the wrapped flexible rib principle, with copper coated dacron mesh for the reflecting surface. Deployment is solely by stored energy in the ribs, which are released by squib actuated cable cutters.

4.3 The physical parameters of a stowed reflector are as follows:

Diameter	Stowed Size	Reflector Weight	Moment of Inertia	Stiffness
10'	4" x 14" dia Torus	10 lbs.	Less than 1 slug-ft^2	Fm approximately 25 - 35 Hz
16'	5" x 20" dia. Torus	28 lbs.		

The feed size and weight depend on the operating frequency and coverage requirements, and since these are not stated, cannot be given here. The weight, inertia and stiffness assume C-Band.

4.4 The physical parameters of a deployed reflector are as follows (assumes F/D = 0.4):

Diameter	Depth	Moment of Inertia Axial	Moment of Inertia Rocking	Stiffness
10'	19"	10 slug ft^2	8	Fm torsional 2-3 Hz
16'	30"	50-60	40-50	Fm Rocking 8-12 Hz

4.5 The dish normally is attached rigidly to the spacecraft body. For larger diameters, the hub can be made free to rotate so the deployment torque is only that due to friction.

4.6 The natural frequency of the wrapped rib antenna is a function of the design of the ribs as well as the diameter. See answers to 4.3 and 4.4.

4.7 The dynamic environment of the stowed reflector is that specified for the Titan IIIC launch vehicle. The deployed antenna is designed to operate in space on a stabilized platform or with a rate controlled controlled gimbal system.

4.8 The reaction forces and torques are a function of number of ribs and diameter. Typical value of peak torque for a 10-foot antenna is 40 foot-pounds, and for a 16-foot antenna is 100 foot-pounds. The tolerances are a function of losses that can be tolerated.

4.9 Typical isothermal RMS tolerance is .060 to .070 inch and peak RMS orbital distortion will be approximately two times the foregoing values for a C-band reflector. If greater accuracies are required, the reflector isothermal tolerances can be as low as .020 inch.

4.10 Thermal distortion characteristics are given in 4.9. The thermal limits are -350°F to +300°F.

4.11 Normal spacecraft design does not permit direct impingement of propulsion effluents on reflectors. The materials used will not be affected in terms of rf performance, but thermal control surfaces may be degraded by effluents.

4.12 This information is classified. A 30-foot reflector is currently operating in space on the ATS-6 satellite.

4.13 Inadequate information is available to respond to this item.

4.14 Inadequate information is available to respond to this item. Feeds may be designed for any frequency from 100 MHz to 15 GHz.

4.15 Gain and beam width are function of frequency and diameter. Sidelobes are a function of illumination taper, among other things. Reflector antennas have been built and tested at LMSC with 25 db or lower side lobes. Again this is a function of operating frequency. Polarization may be either linear or circular.

4.16 Reflectors have been operated over the range from UHF to Ku-band.

4.17 Inadequate information is available to respond to this item.

4.18 No information is available on this item.

4.19 Design is flight proven. Note ATS-6.

4.20 We cannot supply this information at this time.

APPENDIX V.

HELICAL ANTENNA DEPLOYER

A new type of deployable structure has been introduced and is being developed by Astro Research Corporation, a subsidiary of Spar Aerospace Products Ltd. The structure is especially designed for deploying and supporting helical antennas from satellites.

Stowage height for the structure, with the attached helical radiating element, is typically one-tenth its deployed height. For a typical radiating helix 12 inches in diameter the support structure is 10 inches in diameter and provides ample points for permanently attaching and supporting the radiator. The truss-like support structure is made entirely of fiberglass and epoxy resin; thus, it causes no radio frequency interference.

The structure, including the attached antenna, is automatically deployed by simply paying out a lanyard which extends between the tip and base of the system. This is possible because three spiraled, spring-like members expand axially, self-deploying the structure while tensioning its truss-like members. The truss members include longerons which extend parallel to the axis and provide bending stiffness, battens which are perpendicular to the axis and maintain the diameter of the structure, and diagonal members which provide the structure with shearing and torsional stiffness.

When the structure is retracted the spiral members, with the helical radiator attached to one of them, are compressed into a low-pitch helix. Because the spiral diameter is constrained to be constant, the structure also twists slightly when retracted. In this compressed and twisted configuration, the longeron and diagonal members are deformed. However, when the structure is deployed and the deformed longerons and diagonals are straightened and tensioned, they develop axial stiffness, thereby providing the structure with shear, torsional and bending stiffnesses.

Two different types of deformable longerons have been used. One type is simply a flexible cord of fiberglass or other cord-like material that can deform easily. The stiffness such cords can develop is limited by the tensioning capability of the spirals. The other type of longeron is a chain of fiberglass/epoxy linkages that hinge to accommodate retraction. These linkages can provide greater stiffnesses than the cords for a given amount of spiral pretensioning capability, but they are a more complex and less reliable mechanism.

A 13-foot-long engineering model of the helical antenna deployer was fabricated under a TRW/Air Force program. It uses linkage-type longerons and is shown in the accompanying photographs. Without the radiator element, the structure weighs approximately five pounds. Its vibration frequency in the fundamental bending mode is about 2.5 Hz. Analysis of a similar 13-foot-long version using the cord-like longerons indicate its frequency in the same mode would be 1.3 Hz.

The previous work on this type of structure has now established its feasibility, but additional engineering and development will be required to adapt it for other specifications.

Regarding the application of this concept to the 10-foot-long Canadian UHF satellite, it is recommended that a version of it utilizing cord-like longerons be considered. The packaged height of the unit would be about 13 inches. The bending vibration frequency for such an antenna is estimated to be about 2.0 Hz. This frequency is based on the assumption that the antenna proper, including its connectors to the deployer, weighs 2.0 pounds, and that the deployer weighs 4.0 pounds.

As a budgetary estimate, an engineering prototype of the recommended deployer can be provided by Astro for approximately $30,000 (U. S.). This price includes the following:

1. Attaching a customer-provided helical radiator of constant diameter to the deployer.

2. Demonstrating the deployment characteristics of the assembly.

3. Experimentally verifying the fundamental vibration frequencies and mode shapes of the assembly.

4. Subjecting the packaged unit to the simulated vibration spectra of the 3914 Delta launch vehicle.

5. Submitting a summary engineering report on the characteristics, analysis and test results of the unit.

6. Delivery of the unit to the customer.

Answers to Spar Questions
for
Astro Helical Antenna Deployer

1. Weight of helical antenna plus Astro deployer is approximately 6 to 7 pounds.

2. Principles of operation are given by the attached discussion of the Astro deployer.

3. Stowed configuration of the deployer with its attached antenna is a right-cylindrical volume, about 13 inches in diameter and 13 inches high. Note that the 13 inch diameter is set by assuming the antenna radiator diameter to be about 13 inches. The deployer has a stowed diameter of about 10 inches. Inertias of the unit can be calculated by assuming the 6 to 7 pound mass is uniformly distributed along the units length and at a radius of gyration about the axis of about 5.4 in.

4. Not applicable.

5. Bending stiffness - 3.5×10^5 lb-in^2
   Torsional stiffness - (TBD)

6. Fundamental bending frequency - 2.0 Hz.
   Fundamental torsional frequency - greater than 2 Hz.
   We assumed a 2.0 pound antenna radiator with 6 in. radius of gyration about its axis. Also assumed local vibration frequencies of the radiator are greater than those for the fundamental bending and torsional modes.

7. The Astro deployer unit is estimated to be suitable for the launch environment of a 3914 Delta vehicle, and satellite attitude control impulses of 1.0 Hz frequency.

8. By slowly metering-out the deployer, the deployment impulse can be considered negligible.

9. Repeatability of the lateral position for the outboard tip of the deployer is estimated to be 0.2 inches.

10. Thermal lateral displacement in the thermal environment of orbit is estimated to be less than 0.1 inches. The pitch of the helical radiator can be controlled to approximately 0.1 in., assuming its pitch is about 9 inches (typical for UHF band).

11. No material constraints are foreseen.

12. The Astro deployer was considered as a contingency design for the Fleet SATCOM U. S. Air Force satellite.

13. Not applicable.

14. Not applicable.

15. RF data are dependent on the detailed design of the helical radiator. Astro has not developed such RF data.

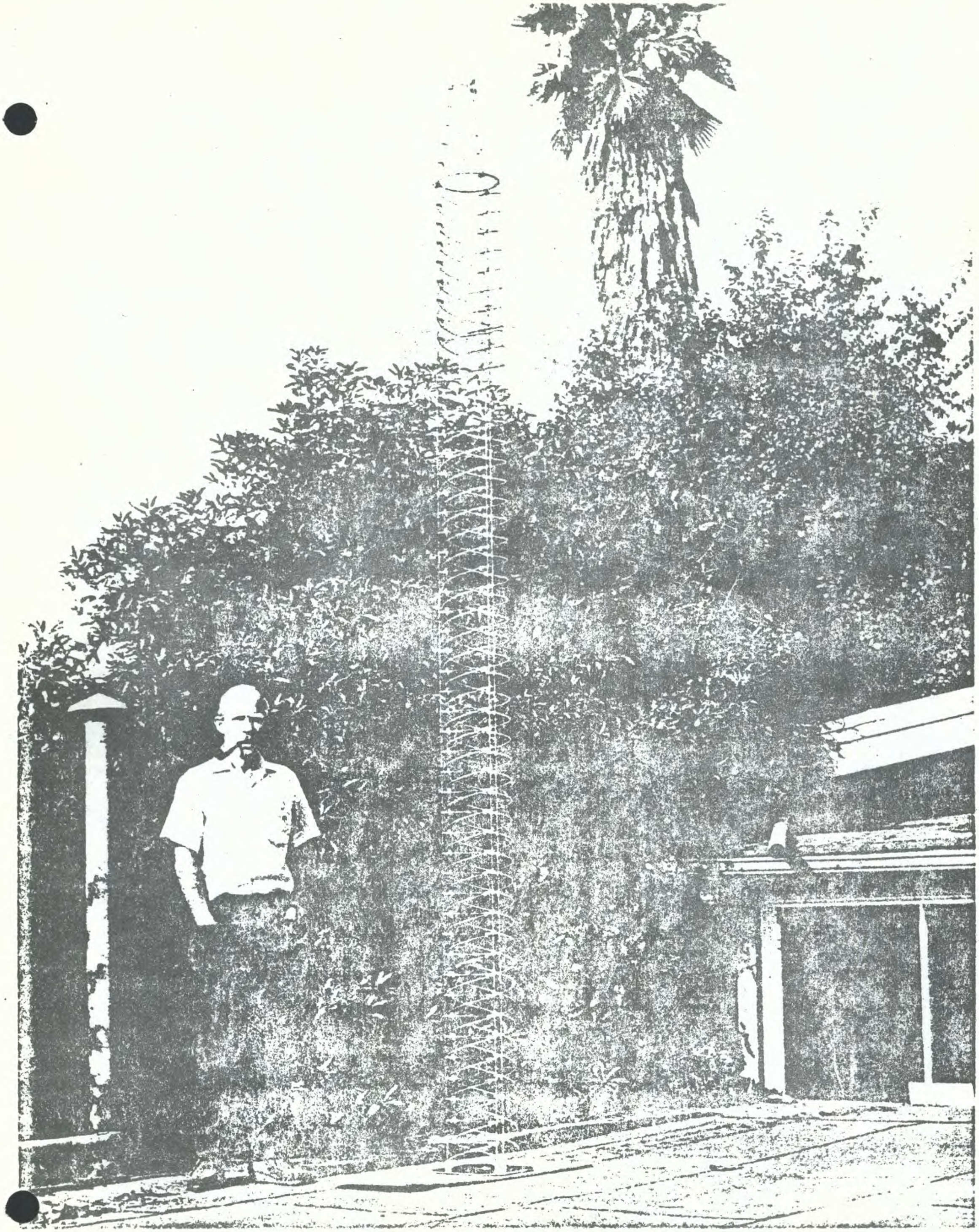
16. The Astro deployer was initially designed to deploy a UHF helical antenna.

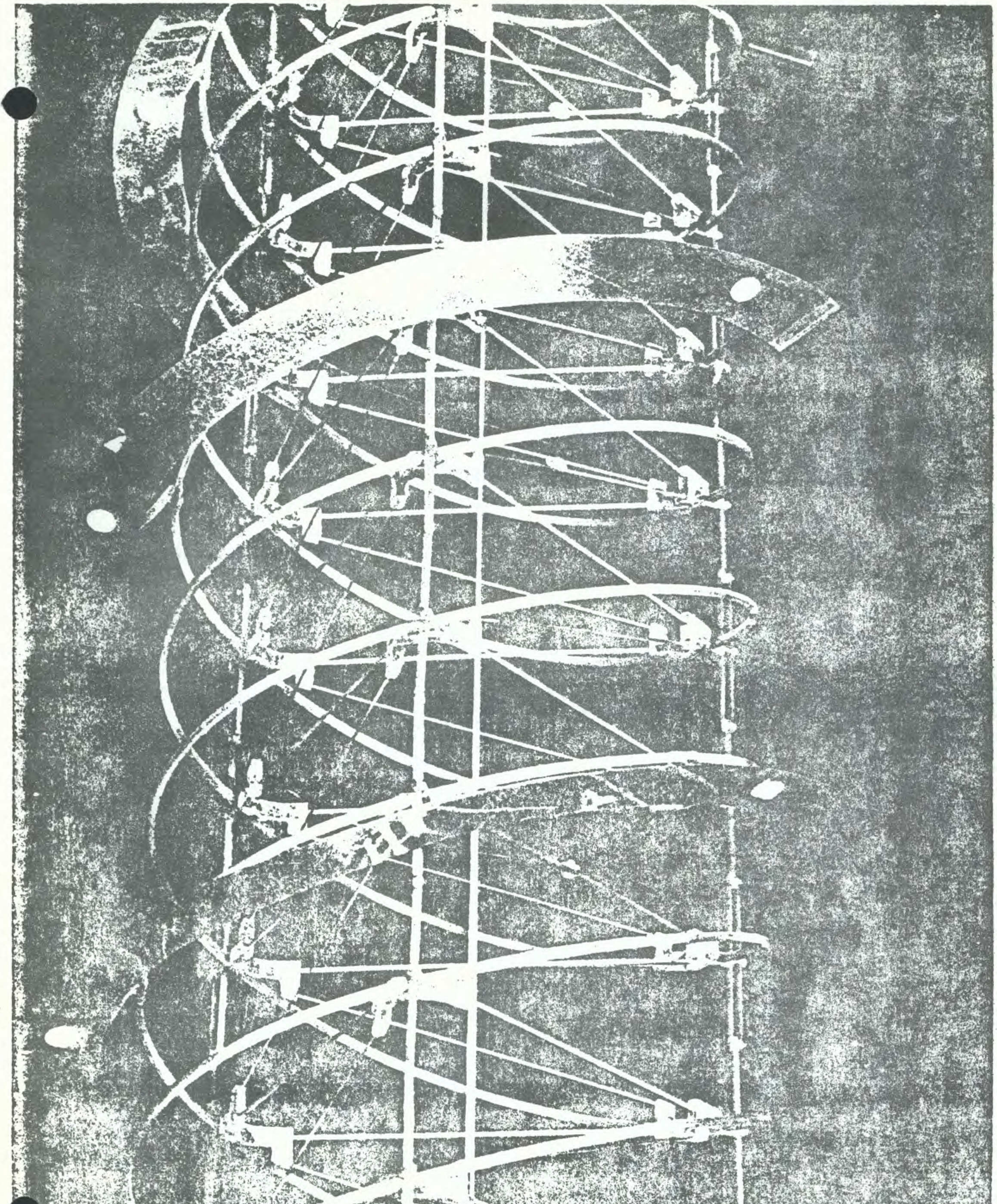
17. Not applicable.

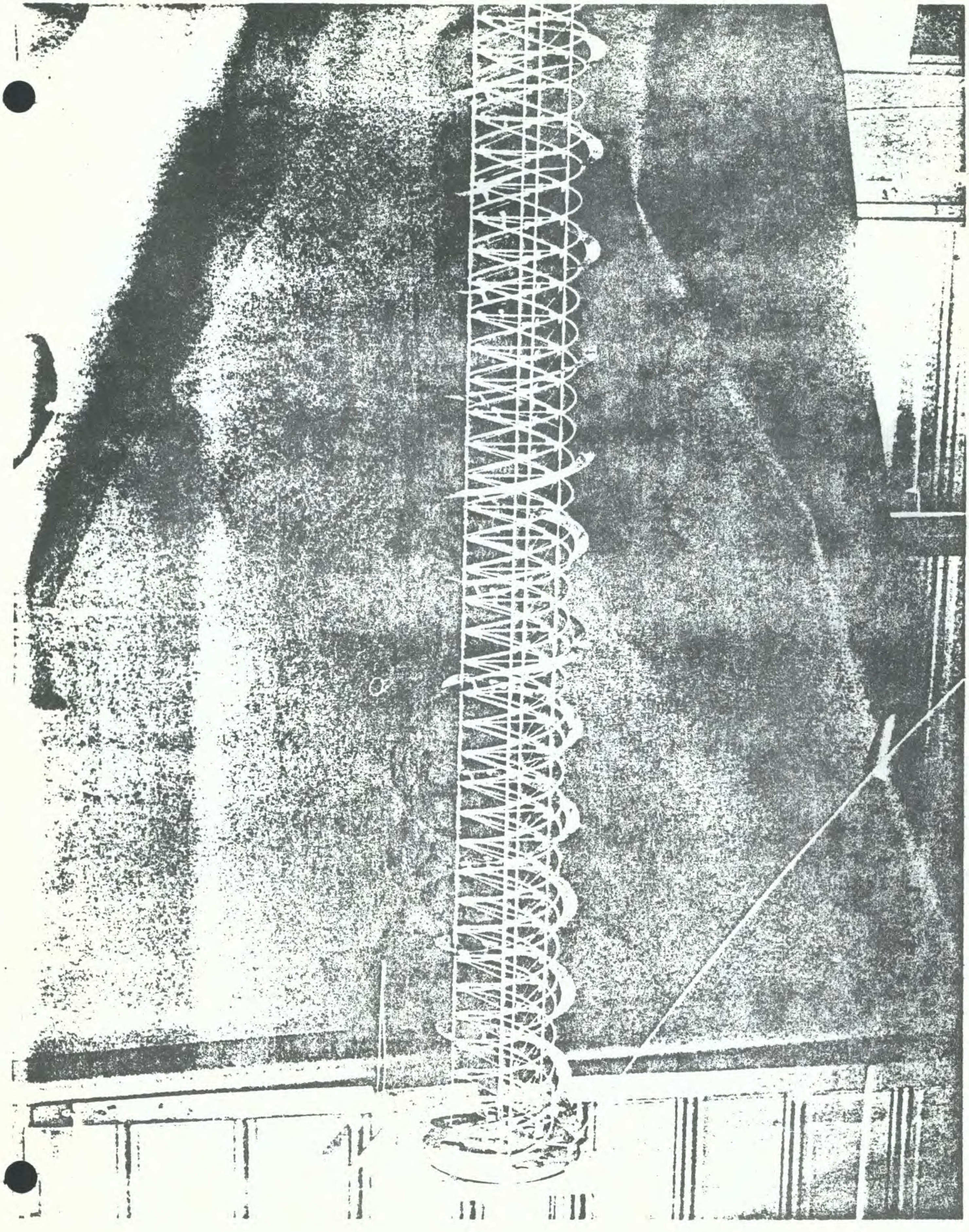
18. Intermodulation data have not been developed by Astro for helical antennas. The deployer structure is made of 100% dielectric material. Therefore, no RFI is anticipated with its use.

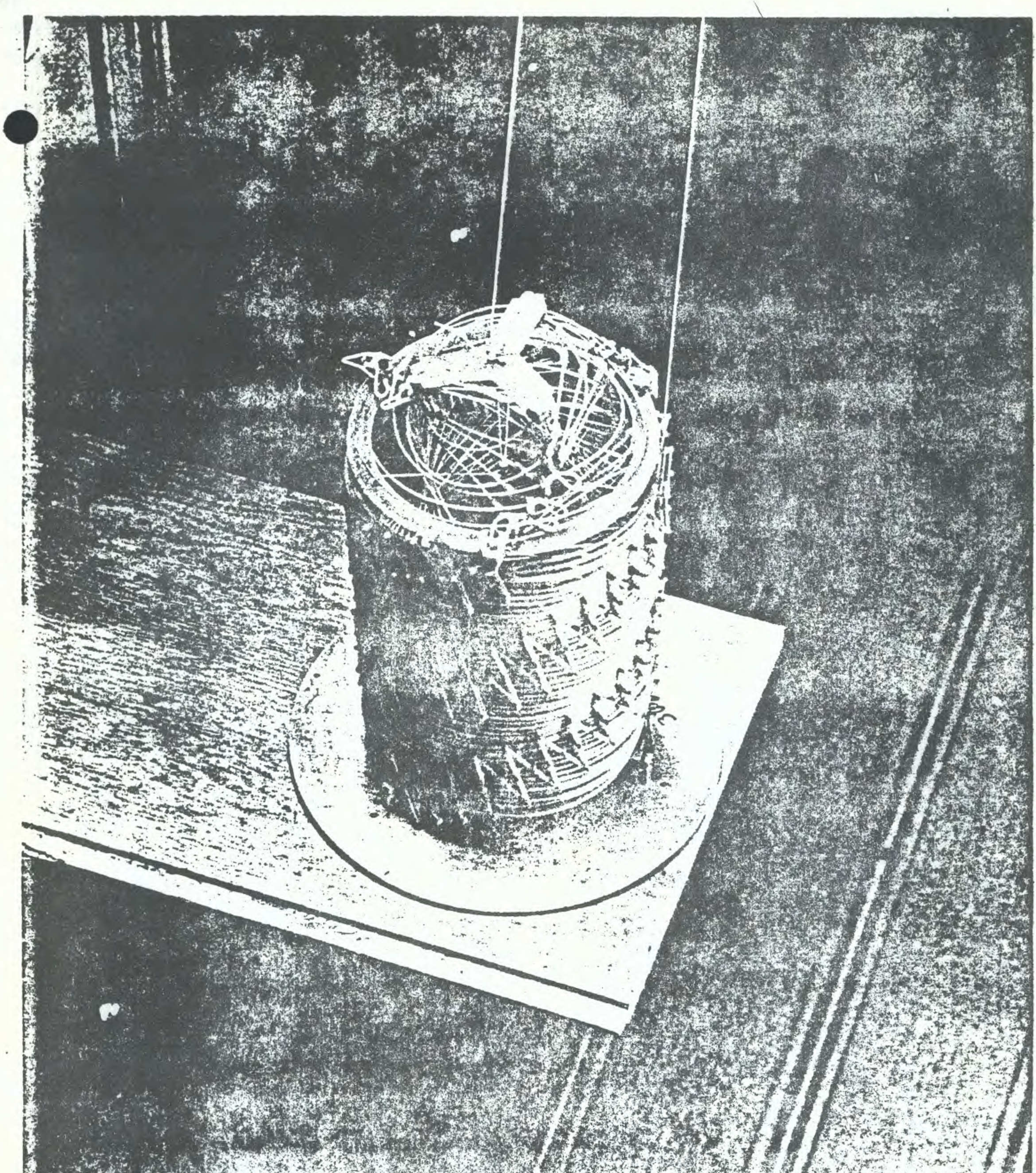
19. The Astro deployer has been previously subjected only to feasibility tests.

20. See attached description of Astro deployer for costs of fabricating, testing and delivering a helical antenna deployer.









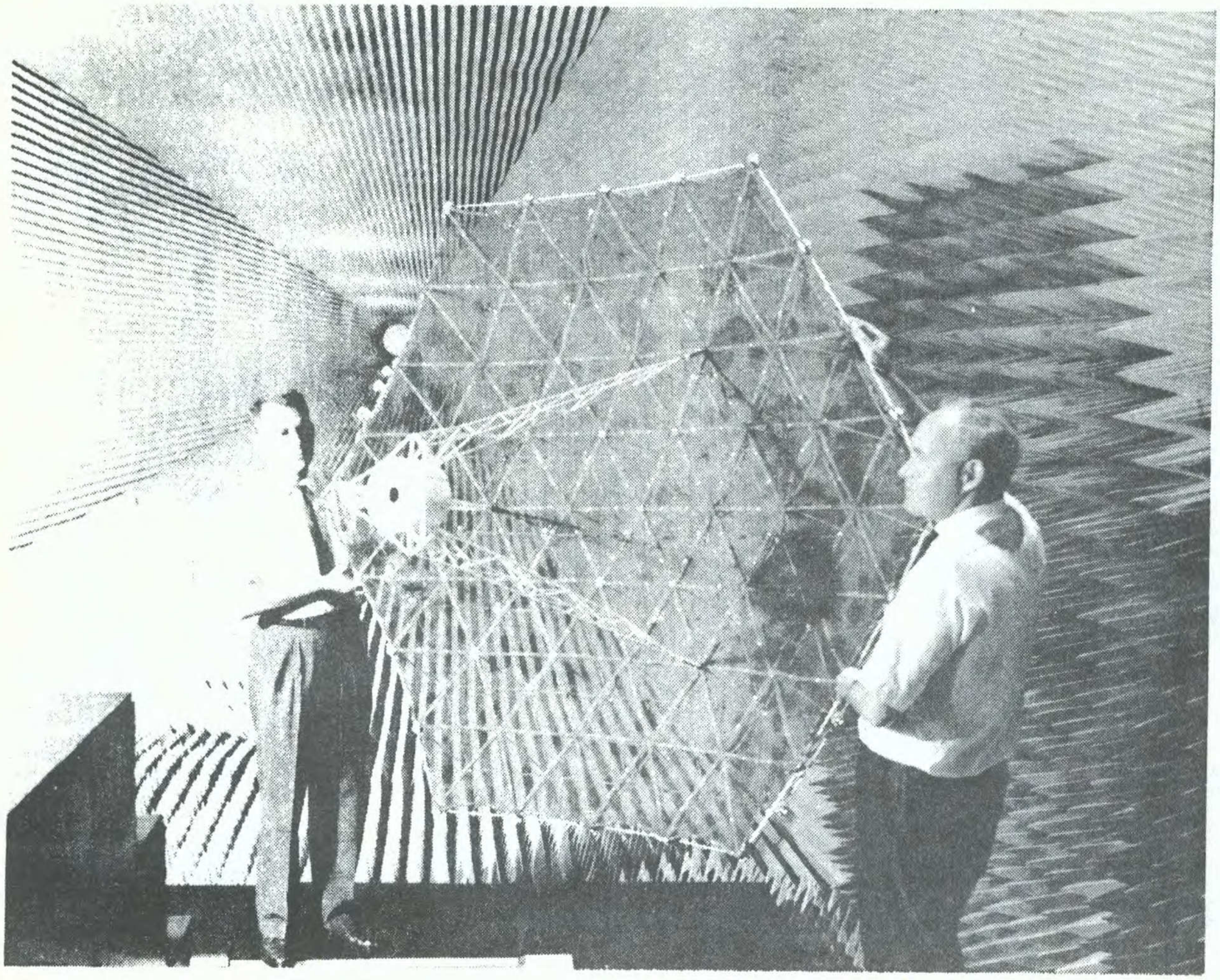
APPENDIX VI

REPORT NO. GDC DCL-69-001

EXPANDABLE TRUSS ANTENNA GROWTH CHARACTERISTICS

March 1969

Prepared by
CONVAIR DIVISION OF GENERAL DYNAMICS
San Diego, California



SUMMARY

This report presents the growth potential of the Parabolic Expandable Truss Antenna* (PETA) in terms of operating frequency, reflector size, and reflector shape. This antenna concept, developed by Convair for NASA over the past four years, has unique advantages for communications satellites proposed for the 1970 time period and beyond. Satellites for voice and television broadcast and space relay will generally operate from a geostationary orbit. Figure 1 relates the limiting PETA reflector diameter and upper operating frequency for three conditions from such an orbit. The three conditions shown are functions of the surface distortions experienced by the reflector during the 24-hour period containing the maximum dark time in a synchronous equatorial orbit. A typical distortion history is shown in Figure 2 for a 33-foot-diameter antenna.

The continuous operation limit is determined by the peak rms distortion, which occurs for only about a 30-minute period in each orbit. The 16-hour continuous operating condition is based on the elimination of the two distortion peaks which characteristically center on the side-on sun positions at 6 a.m. and 6 p.m. relative to the earth-sun vector. The intermittent condition reflects operation only during periods of minimum distortion centering on the noon and midnight positions. The three cases, therefore, determine the guaranteed minimum frequency obtainable, the nominal frequency, and the highest possible frequency obtainable. In general, nonsynchronous orbits will produce a narrower range of surface distortion centering about the nominal distortion obtained from the synchronous case. From Figure 1, the frequency limits for 30- and 100-foot-diameter antennas are:

OPERATING CONDITION	PEAK FREQUENCY LIMITATION 30-Ft. Dia.	100-Ft. Dia.
Continuous	15 GHz	4.5 GHz
Sixteen hours per day	23 GHz	7 GHz
Three hours per day	42 GHz	12 GHz

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*Convair patent pending

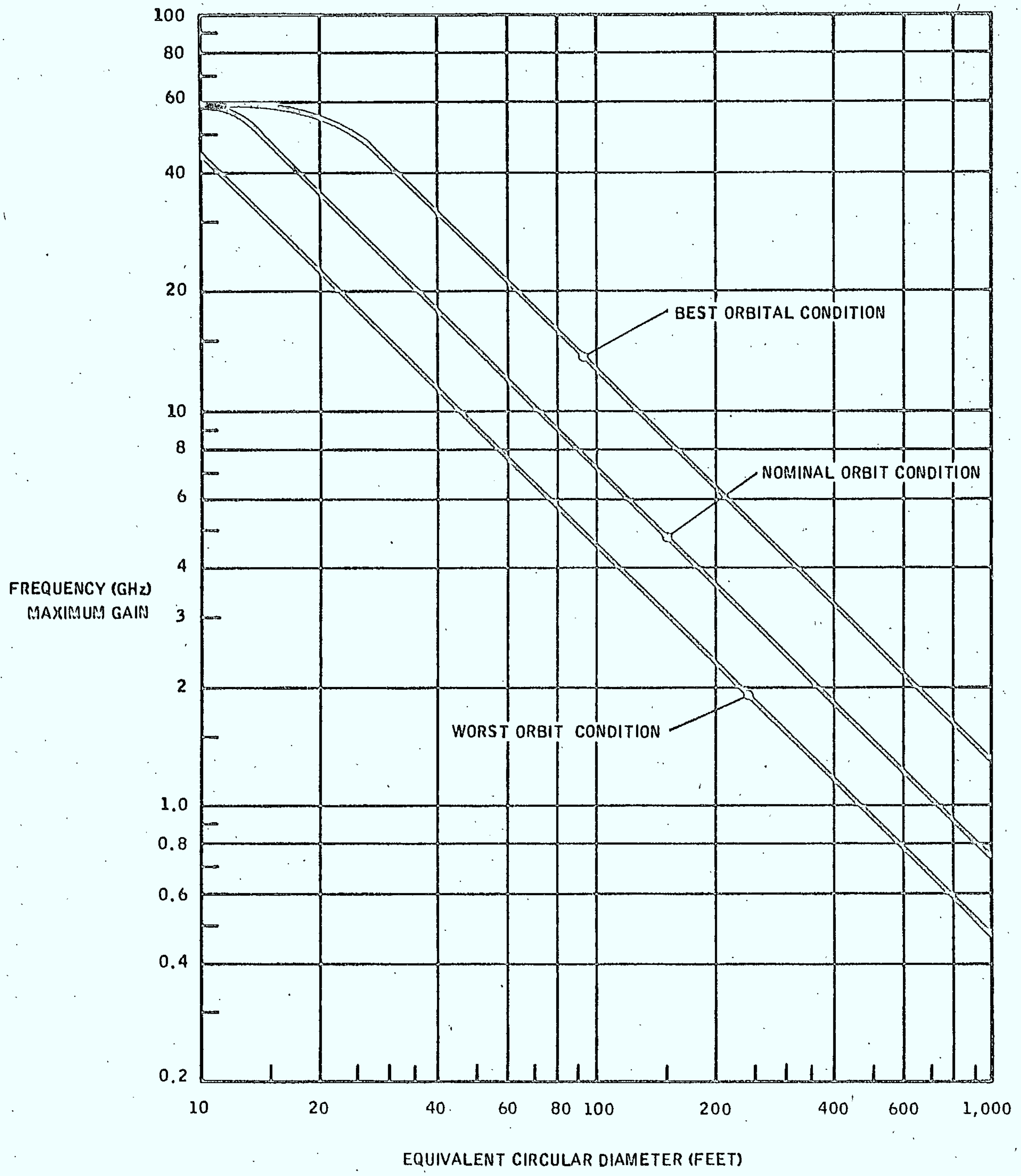


Figure 1. PETA size versus frequency limits.

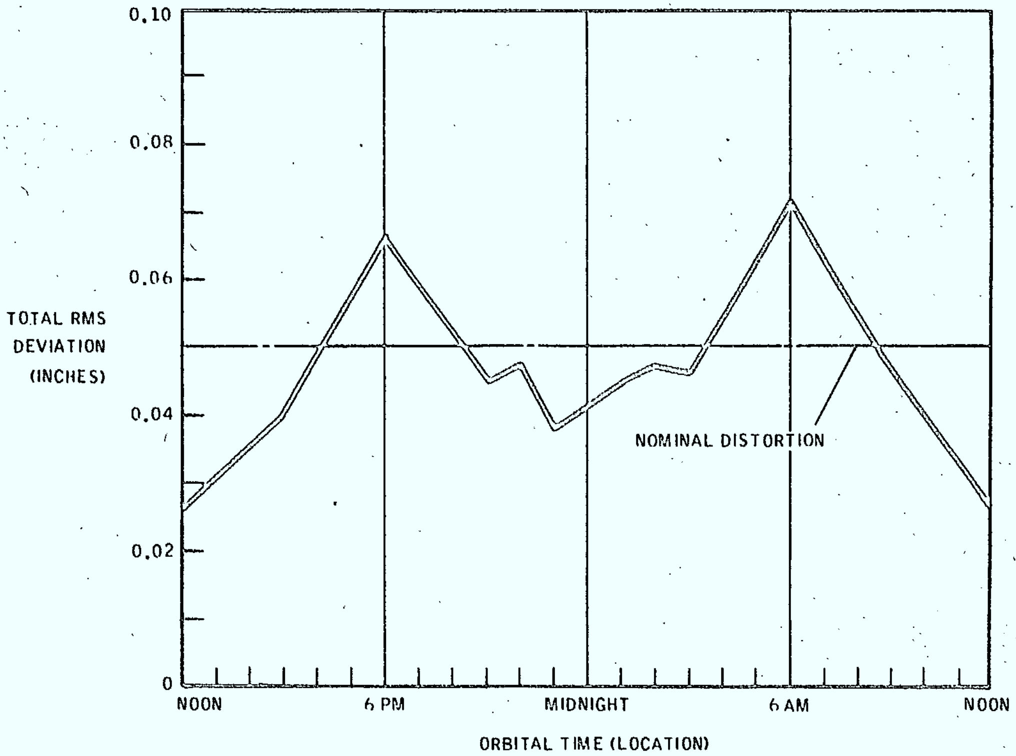


Figure 2. Distortion history — 33-foot-diameter PETA.

Many future broadcast satellites, especially for television transmission, will operate at fairly low frequencies (from UHF to perhaps four GHz). Since gain is a direct function of antenna diameter, the maximum size reflector for a given frequency is of interest. Maximum PETA diameters for various frequencies, assuming continuous operation, are:

OPERATING FREQUENCY	MAX. REFLECTOR DIA. (FT.)	GAIN
500 MHz	> 900	56 db
1.0 GHz	460	56 db
4.0 GHz	115	56 db
10.0 GHz	46	56 db

It is clear from these values that surface distortions will not limit antenna size for UHF or L-band frequencies and do not impose serious restrictions on size until operating frequencies of about 10 GHz are reached.

Orbital distortion is not the only factor which limits practical reflector size, of course. Both launch weight and package size can be critical for Atlas- or Centaur-launched satellites. Saturn V-launched satellites will usually be limited by packaged size or volume only. Both the weight and packaged size of the PETA reflector vary widely with structural configuration (number of truss bays) and truss material. The standard configuration for large size antennas is an eight-bay truss using perforated-wall, aluminum tubing. If distortions must be kept to a minimum, an eight-bay truss with perforated titanium tubing is used. For minimum weight versions, a six-bay truss using beryllium tubing is preferred. The limiting size reflector for various booster classes is given in Table 1 along with the weight of the reflector only for the three options discussed above. The sizes shown in the table are for both the normal packaging mode, in which the hinged surface struts fold inward to form a relatively flat cylinder, and for the minimum width packaging mode. One unique feature of the PETA is that, by hinging either or both sets of surface struts outward, two other packaging arrangements are possible. These are explained more fully on page 8 of the report following. These alternate arrangements produce a longer, narrow package. In the limit, a 290-foot-diameter, Type C aluminum antenna can be housed in the Saturn V envelope.

Table 1. Maximum reflector size for typical booster envelopes.

BOOSTER	MAXIMUM PACKAGE DIAMETER (IN.)	PETA TYPE	TYPE A PACKAGING PETA DIA. (FT.)	TYPE C PACKAGING PETA DIA.(FT.)
AGENA	58	8 - BAY ALUM.	32	70
		8 - BAY TITAN.	32	70
		6 - BAY BERYLL.	70	147
ATLAS OR TITAN	108	8 - BAY ALUM.	60	130
		8 - BAY TITAN.	60	130
		6 - BAY BERYLL.	130	270
SATURN V	240	8 - BAY ALUM.	134	290
		8 - BAY TITAN.	134	290
		6 - BAY BERYLL.	290	600

As shown, the PETA reflector is lightweight, has a high packaging ratio, and offers a low distortion behavior in orbit. Convair believes there are additional, unique growth advantages to the PETA concept including the following.

STIFFNESS — Several NASA studies have pointed out that large erectable structures present serious launch and orbital problems because of their low stiffness. The 30-foot PETA reflector, however, has a natural frequency of 12 cps because of the deep truss structure used. Even at 100 feet, the PETA natural frequency exceeds three cps.

BEAM SHAPING — The PETA concept is composed of a large number of structural modules. Thus, reflector shape can easily be tailored to produce noncircular beams without significant weight penalty. Versions producing highly elliptical beams, such as shown in Figure 3, are therefore feasible; multiple beams from a single reflector, as shown in Figure 4, can also be accommodated.

ATTACHMENT — The PETA may be attached at the center, edge, or intermediate locations without significant penalty. Broadcast satellites in particular may require this capability as shown in the configuration concept of Figure 5. In addition, auxiliary equipment such as reaction control jets and solar arrays may be mounted from the edges of the stiff reflector truss.

RELIABILITY — PETA reliability is the same for a 30-foot antenna as a 300-foot antenna since the same type and quantity of subcomponents are used regardless of antenna size. The reliability of an eight-bay PETA through launch and deployment is 0.994.

DEVELOPMENT COST — Since the same type and quantity of components are used in the PETA regardless of reflector size, development costs will be small once a given version is developed.

GROUND DEPLOYMENT — A simple ground support system, which involves the use of commercial Negator springs for suspension of the back surface spiders, allows the reflector to be deployed on the ground under a simulated zero-g environment. All stressed elements (hinges, mesh, springs, support cables) are designed to operate well within their elastic range, allowing repeated deployments without performance or reliability degradation.

PETA growth characteristics are listed in summary form in Table 2.

The development of the PETA concept is rapidly progressing under both NASA contract and company funds. A number of computer programs for thermal, load, stress, distortion, weights, and dynamic behavior have been developed over the last three years and are complete and in use. Other programs for special distortion cases and best-fit geometry are in work and should be completed in 1969. Detailed

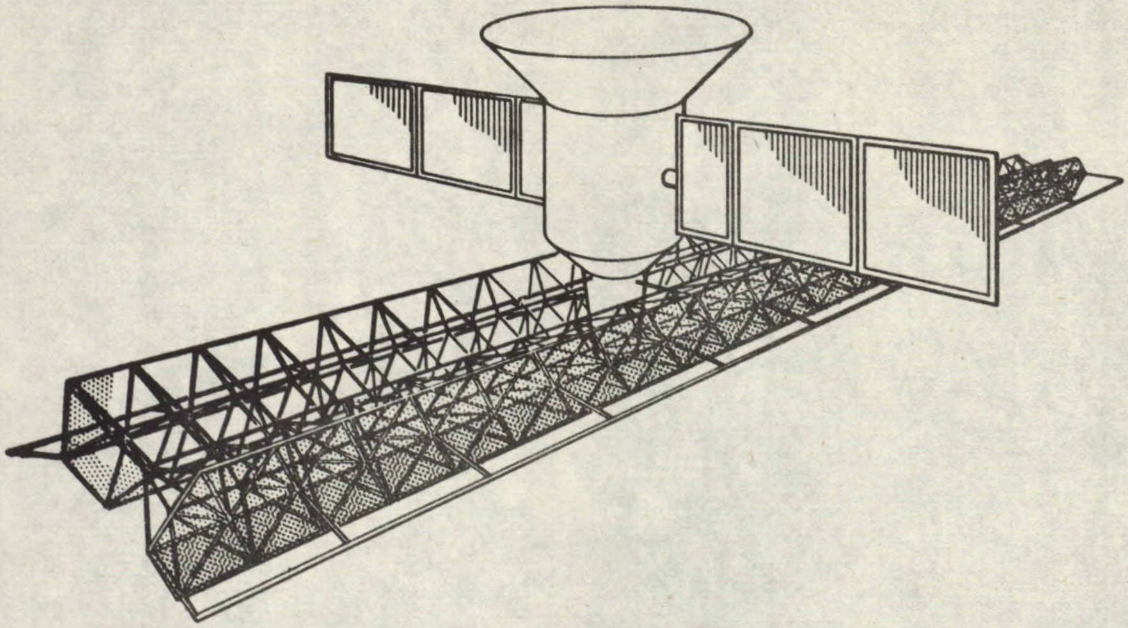


Figure 3. Elliptic beam surveillance satellite.

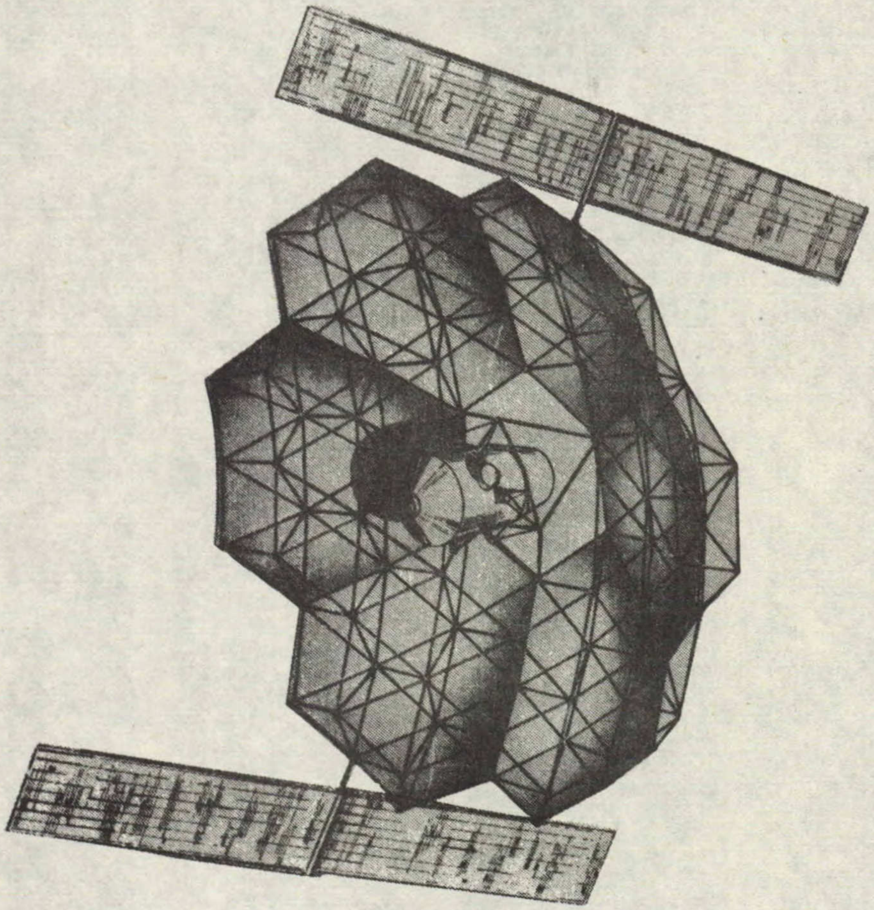


Figure 4. Six-reflector PETA antenna.

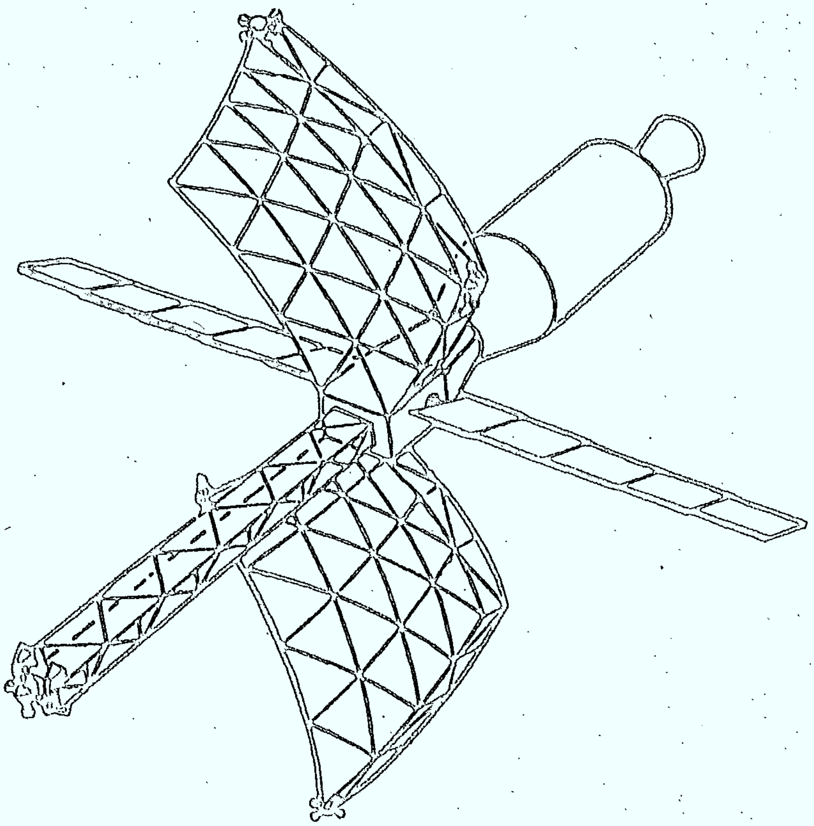


Figure 5. Shaped-beam dual-reflector configuration.

designs for 6, 10, 15, 30, 50, 70, 100, and 140-foot diameter antennas have been prepared. Two 74-inch diameter models have been built, range-tested, and deployed several hundred times with success. A tetrahedron module of a 70-foot reflector is nearing completion. This unit, constructed under NASA contract, will be deployed in a space-vacuum chamber in 1969. A 10-foot-diameter model incorporating all features of the PETA design (hinges, springs, spherical bearings, mesh support system) is being constructed under company funding and is estimated for completion in mid-1969.

In conclusion, the PETA reflector seems ideally suited for communications missions ranging from early experimental satellites such as ATS-F&G to more sophisticated operational television broadcast satellites in both potential size, weight, stiffness, and low distortion. Similarly, surveillance, tracking, and point-to-point communications missions can benefit greatly from the PETA capability for producing highly shaped beams and very narrow beamwidths coupled with a lightweight, rigid structure.

Table 2. PETA growth characteristics summary.

CHARACTERISTIC	REFLECTOR DIAMETER (FEET) ACROSS POINTS								COMMENTS
	10	20	30	50	70	100	140	300	
PETA WEIGHT MAXIMUM/MINIMUM (LB.	25 16	71 39	129 69	332 158	680 299	1,200 653	2,320 1,370	10,600 6,300	MAXIMUM WEIGHT IS TITANIUM. MINIMUM WEIGHT IS BERYLLIUM.
PACKAGE SIZE HEIGHT x DIAMETER (IN.)	12 x 9	25 x 38	37 x 56	61 x 91	86 x 126	123 x 179	172 x 250	850 x 250	TITANIUM SHOWN. BERYLLIUM REDUCES DIAMETER ABOUT 50%.
PACKAGED VOLUME (CUBIC FT.)	1	13	43	190	514	1,476	4,050	18,700	FOR TITANIUM OR ALUMINUM. BERYLLIUM ABOUT 70% LESS.
POSSIBLE PACKAGING CONFIGURATIONS	3	3	3	3	3	3	3	1	ASSUMING ONLY EXISTING BOOSTER PAYLOAD ENVELOPES
RMS DISTORTION (IN.) AS MFG. MAX. THERMAL TOTAL RMS	 0.016 0.024 0.029	 0.016 0.043 0.046	 0.016 0.062 0.064	 0.019 0.099 0.101	 0.022 0.138 0.140	 0.027 0.193 0.195	 0.035 0.269 0.270	 0.068 0.570 0.575	IN EARTH SYNCHRONOUS ORBIT - TITANIUM PETA
PEAK GAIN FREQ. (GHz) CONTINUOUS 16-HR./DAY 3-HR./DAY	 30 48 58	 22 36 54	 15 27 42	 9 14 25	 6.5 10 18	 4.3 7 13	 2.6 5.1 9.0	 1.8 2.4 4.3	IN EARTH SYNCHRONOUS ORBIT - TITANIUM PETA
NATURAL FREQUENCY DEPLOYED (CPS)	LARGE	LARGE	12	6.6	4.5	3.1	2.0	0.5	INCREASING DEPTH UPS STIFFNESS WITH SMALL WEIGHT PENALTY.
COST: DEVELOPMENT RECURRING	 625,000 250,000		 750,000 300,000			 1,650,000 1,000,000			DEVELOPMENT INCLUDES PROTO-TYPE, ENGINEERING MODEL & FULL TESTING
f/D LIMITATION	NO BASIC LIMITATION — REFLECTOR DEPTH DOES NOT AFFECT PETA PACKAGING.								AN f/D OF 0.4 IS TYPICALLY ASSUMED
POINTING ACCURACY	NO PROBLEM IF $f_0 \geq$ 2 CPS WHICH IS ACHIEVABLE IN ANY SIZE BY VARYING TRUSS DEPTH AND MATERIALS.								
PETA ATTACHMENT	PETA MAY BE MOUNTED FROM ANY THREE SPIDER FITTINGS FOR CENTER OR EDGE ATTACHMENT.								
SHAPED - BEAM ADAPTABILITY	MODULAR CONSTRUCTION ALLOWS HIGHLY ELLIPTIC BEAMS WITHOUT IMPACTING WEIGHT, PACKAGING, OR COST.								

Convair will be pleased to supply further technical and management information on the PETA concept for specific applications. Inquiries should be addressed to:

Mr. John A. Fager, Program Manager
Advanced Communications Systems
Mail Zone 581-60
P. O. Box 1128
San Diego, California 92112
Phone (714) 277-8900, Ext. 1253

INTRODUCTION

This report deals with the application of a unique antenna concept, developed by the Convair division of General Dynamics for NASA, to large-diameter space reflectors operating at frequencies above the UHF band. The initial section indicates some of the reasons why such a reflector will be required for future satellite programs.

FREQUENCY TRADEOFFS

All factors cited in the table tend to drive the frequency selection to the low end of the RF spectrum. In many cases, however, two other factors override the considerations shown. The first is the major increase in gain (for a given reflector size) that accompanies a frequency increase. The other overriding consideration is the attenuation at low frequencies from cosmic noise.

TRADEOFFS ENCOUNTERED IN SELECTING SPACE
RADAR OR COMMUNICATION FREQUENCIES

PARAMETER	FREQUENCY SENSITIVITY	REMARKS
RADAR DETECTION RANGE	$\propto \frac{1}{F}$	ASSUMING OTHER PARAMETERS FIXED, SHIFT FROM L- TO C-BAND REDUCES MAXIMUM RANGE CAPABILITY BY 50%.
WEATHER CLUTTER	$\propto F^4$ (RAIN DROP CROSS SECTION)	RAIN CLUTTER MAY OBSCURE TARGETS BECAUSE OF LARGE CLUTTER TO SIGNAL RATIO.
GROUND CLUTTER	$\propto F$	BACKSCATTERED ENERGY TENDS TO INCREASE WITH FREQUENCY – THOUGH THIS FACTOR IS HIGHLY DEPENDENT UPON SPECIFIC TERRAIN CONSIDERED.
ATMOSPHERIC LOSS – (WATER VAPOR & O_2)	$\propto F$	IN GENERAL, LOSS INCREASES WITH FREQUENCY.
TRANSMISSION LINE LOSSES	$\propto F$	LOSS INCREASES WITH FREQUENCY FOR SPECIFIC TRANSMISSION LINE TYPE
RECEIVER SENSITIVITY	$\propto F$	NOISE CONTRIBUTION OF RF AMPLIFYING & DETECTING DEVICES INCREASES WITH FREQUENCY.
RF POWER	$\propto F$	RF POWER HANDLING CAPABILITY IS LIMITED BY DECREASING COMPONENT SIZE – SMALLER TRANSMISSION LINES AND TUBES

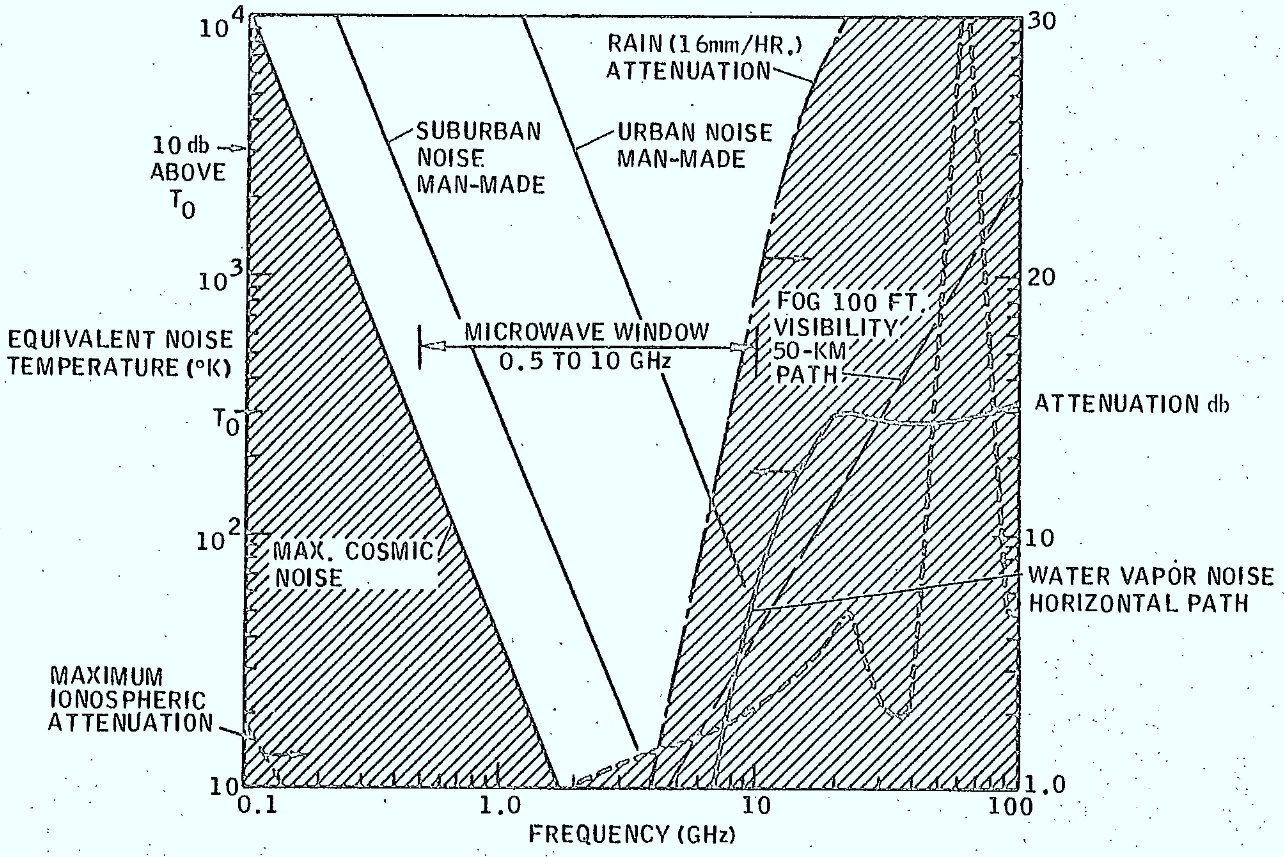
ATTENUATION AND NOISE

Electromagnetic energy traveling from space to earth (and vice versa) must propagate through the earth's ionosphere and atmosphere. This energy may also be required to traverse existing clouds and rainstorms.

The ionosphere is opaque below its critical frequency (20 to 25 MHz) and clouds become opaque above about 10 to 12 GHz. These frequencies border the microwave window, which is defined by both background noise and atmospheric attenuation profiles.

Within the 0.5-to-10 GHz window, man-made noise is severe but decreases with increasing frequency. The lowest attenuation, as shown, is at about two GHz. Noise considerations, however, can drive the frequency selection up to 10 GHz for earth communications and considerably higher for space-to-space communications.

COMPOSITE ATTENUATION & NOISE PROFILE OF SIGNIFICANT FACTORS
WHICH AFFECT EARTH - SPACE COMMUNICATION



POTENTIAL LARGE REFLECTOR UTILIZATION AREAS

The several satellite system uses listed require large reflectors for one or more of the following reasons:

1. To provide narrow beamwidth for precision position control and tracking.
2. To provide narrow beamwidth to limit territorial spillover.
3. To minimize transmitter power requirements, as in the television broadcast mission.

SPACE RADAR	EITHER MICROWAVE OR LASER – THESE PROVIDE DIRECT ONBOARD MEASUREMENT OF RANGE, RANGE RATE, ANGLE & ANGLE RATE. FACTORS USEFUL IN LANDING & RENDEZVOUS AREA. COULD BE COOPERATIVE OR NONCOOPERATIVE. USEFUL FOR SPACE RESCUE APPLICATION.
SPACE TRANSPONDER	COORDINATION OF HIGH-POWERED RADAR WITH PRECISE CLOCK CONTROLLING MODULATION & RF FREQUENCIES, MAKES EARTH & SUN-ORBITING TRANSPONDERS USEFUL AS NAVIGATIONAL DEVICES FOR EITHER SPACE OR EARTHBOUND SYSTEMS.
EARLY WARNING LONG-RANGE SURVEILLANCE	SECTOR DETECTION & WARNING MONITOR. METEOR DETECTION, OCEAN & TERRAIN SURVEILLANCE.
EARLY WARNING SPACE & MISSILE TRACK	SECTOR DETECTION, TRAJECTORY PREDICTION, THREAT EVALUATION. CAN OPERATE IN CONJUNCTION WITH IR DETECTION.
SURFACE AREA SEARCH	SECTOR DETECTION, INTRUSION DETECTION. USE TO OBSERVE SHIP MOVEMENTS & LARGE SURFACE VEHICLE MOVEMENTS (AIRCRAFT, TRUCKS, TRAINS).
GROUND MAPPING	RESOURCE SURVEY, TACTICAL WEAPON LOCATION (LARGE MISSILE INSTALLATIONS).
RE-ENTRY WEAPONS TRACKING	U.S. WEAPONS EVALUATION, PENETRATION & CONFUSION EVALUATION DEVICE.
TELEMETRY & SCIENTIFIC TRACKING	RADAR ASTRONOMY, ASTRONAUTICS COMMAND & CONTROL, DEEP-SPACE VEHICLE GUIDANCE & DATA READOUT.
CIVIL APPLICATION	AIR TRAFFIC CONTROL, MARINE TRAFFIC CONTROL, NAVIGATION, WEATHER SURVEILLANCE, EARTH RESOURCES & SCIENTIFIC R&D SUCH AS MICROWAVE RADIOMETRY AND RADIO ASTRONOMY.
COMMUNICATIONS	POINT-TO-POINT COMMUNICATION BETWEEN SMALL STATIONS, DIRECT TELEVISION BROADCAST.

PETA CONFIGURATION

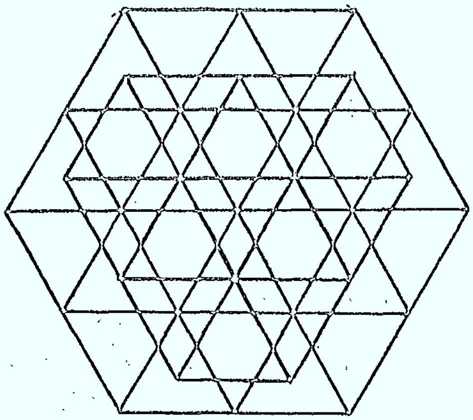
Convair's parabolic expandable truss antenna is uniquely suited to applications requiring reflectors ranging from 20 feet to more than 100 feet in diameter. Reflector weight is low, and the weight per unit aperture decreases as the antenna diameter increases. The antenna package has a small volume, and the package can be tailored to three different configurations to suit individual launch envelope requirements. Most important is the high stiffness of the reflector, which maintains a very stable structure in very large sizes and allows subsystem elements to be mounted on the reflector structure.

This section outlines the general design features and configuration options available in the basic reflector concept.

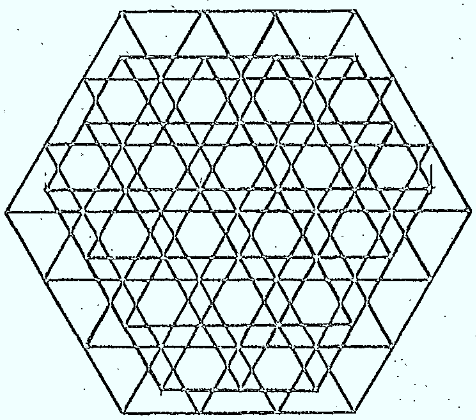
TRUSS BAY OPTIONS

As illustrated below, the number of reflector truss bays can be varied from 4 to 10 across the major diagonal. Components of the reflector are of the same design, regardless of the number of bays. The total number of subcomponents increases about 50% for each additional two-bay increase; however, reliability is reduced somewhat and cost increases. Minimum weight in the larger size reflectors is obtainable with the six- or eight-bay versions. As the number of bays increases, the mean surface deviation of the mesh flats, from both design and thermal distortion, decreases. Selection of the optimum number of bays is a tradeoff, therefore, between cost and reliability on one hand, and weight and distortion on the other.

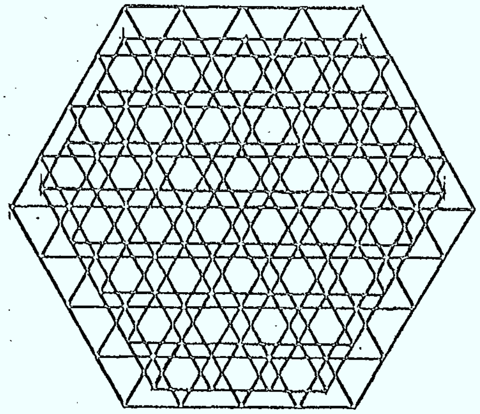
The basic reflector shape is hexagonal so that the equivalent RF diameter is about 10% less than the point-to-point width. The tubes forming the outer bays may be lengthened slightly, however, to achieve a nearly circular periphery. The modular construction also allows close approximation of highly elliptical shapes.



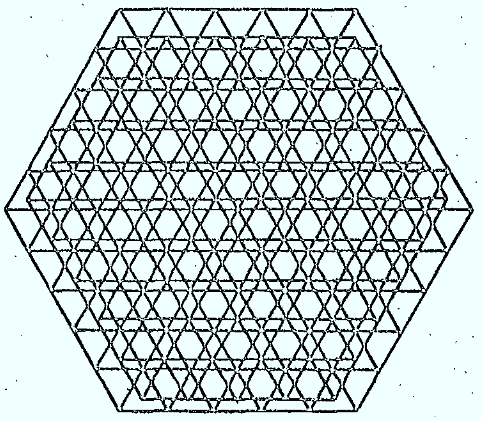
4 BAYS



6 BAYS



8 BAYS

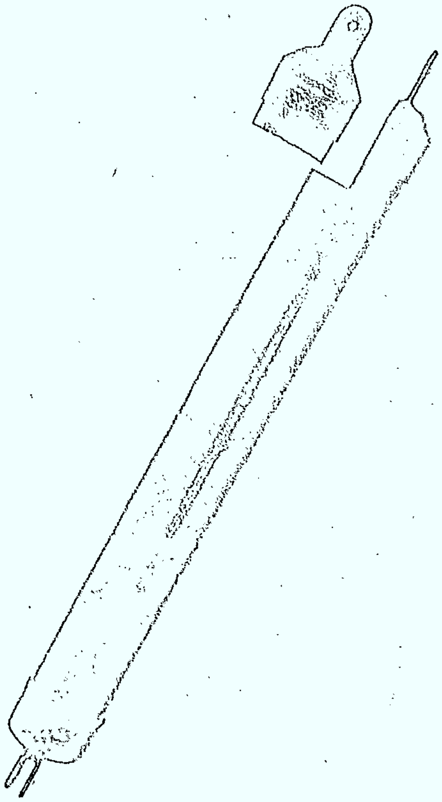


10 BAYS

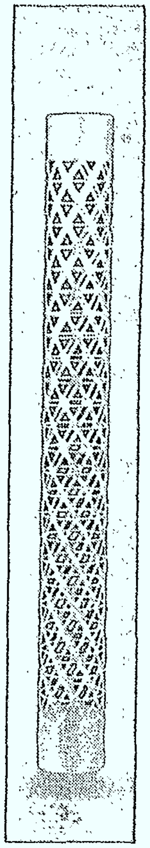
REFLECTOR MATERIAL OPTIONS

The weight, cost, thermal distortion, and packaging size of the reflector are affected by the choice of materials for the tubular struts. The following options have been studied:

1. Aluminum tubes provide the lowest cost material but result in relatively high weight and thermal distortion.
2. Perforated-wall aluminum tubes reduce thermal distortions and weight at some increase in cost.
3. Perforated-wall titanium tubes produce the lowest thermal distortions because of their transparency to solar radiation and low coefficient of expansion. The weight of this material is intermediate — between that of solid-wall and perforated-wall aluminum tubes.
4. Beryllium tubes produce a very lightweight truss with almost twice the packaging ratio of the perforated aluminum version (because of the smaller tube diameters used). Thermal distortion for the beryllium version is not as low as that of titanium, however, and the cost is significantly greater.



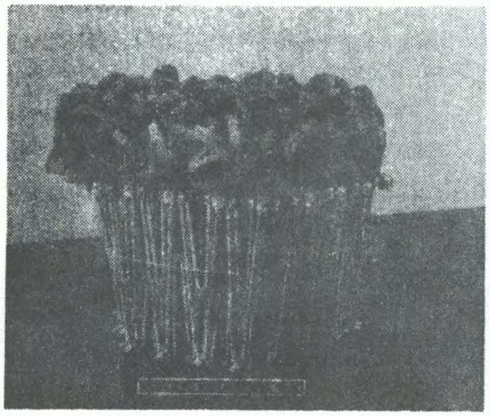
BERYLLIUM TUBE

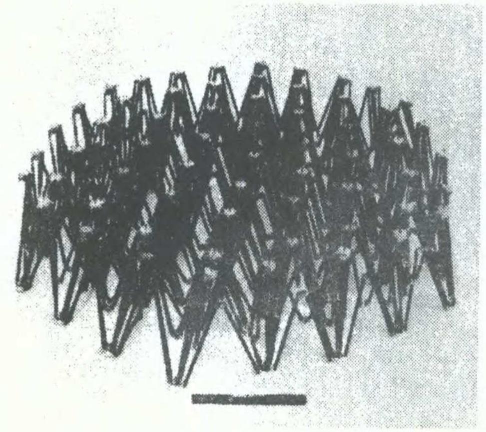


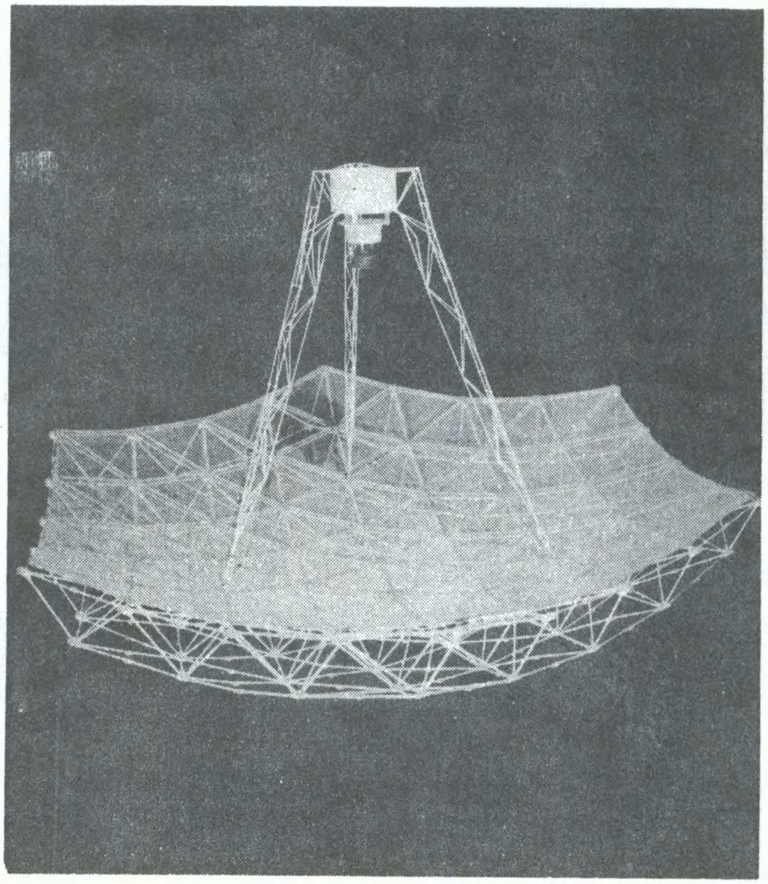
PERFORATED TUBE

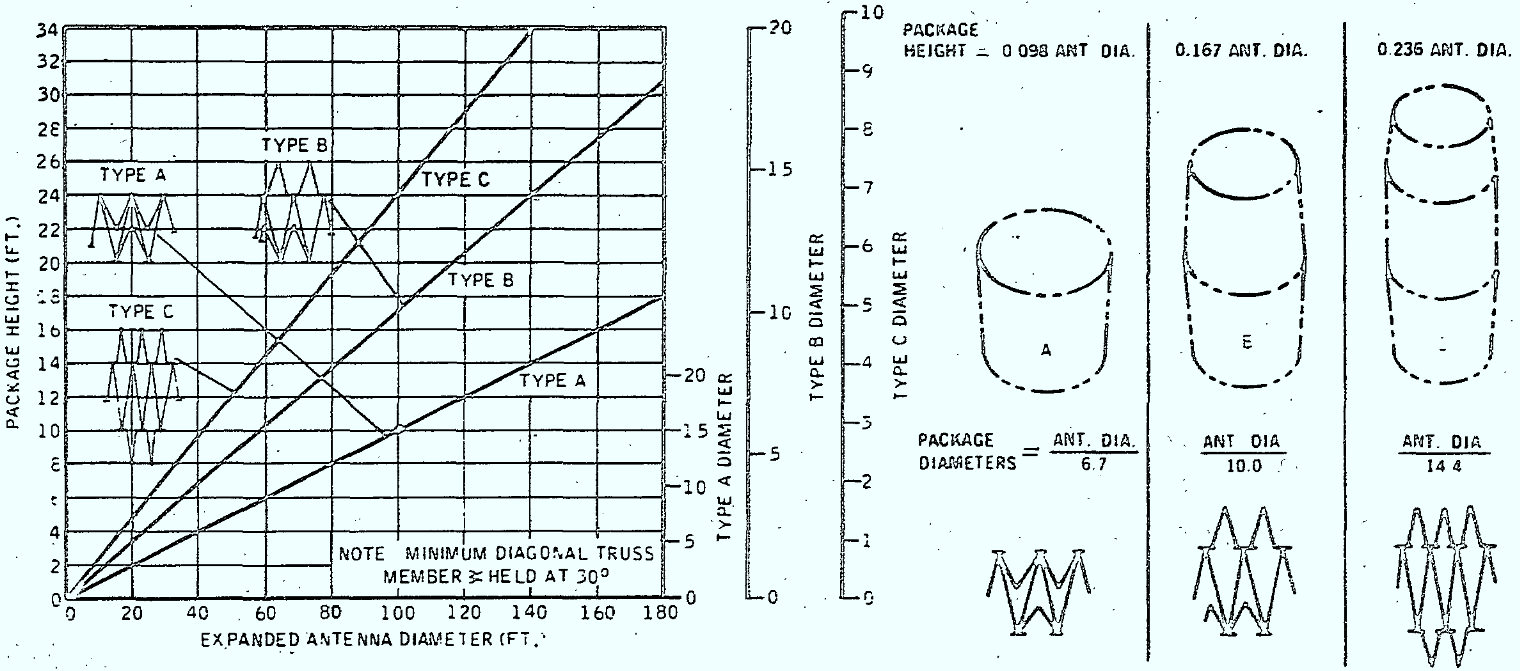
PACKAGING OPTIONS

The three packaging arrangements that can be used with the PETA are illustrated at right. Ratios shown are for an eight-bay reflector with perforated aluminum tubes and give the largest packages of any of the bay and material options. The beryllium version has a packaging ratio of 12.5:1 on diameter. The perforated titanium six-bay versions have ratios of about 6.7:1. All reflector configurations shown in this volume are the type A packaging scheme except for the 300-foot antenna, which requires type C packaging. The view below illustrates the PETA deployment sequence.









EXPANDABLE TRUSS PACKAGING PARAMETERS

PALLET DESIGN

A hold-down pallet is generally required to support the packaged antenna during launch. With the use of three captive pyrotechnic bolts, a set of shear pins on every spider leg, and a serrated "necklace" restraining band, the packaged reflector can be rigidly and securely mounted to the honeycomb pallet. The illustration on the opposite page shows the overall configuration and the spider shear pin details. This configuration uses the least pyrotechnics possible for a six-bay antenna. They are in the primary load paths for all loads. Using standard 1/8-inch-diameter tooling pins, the shear-out and bearing strength on the mating magnesium spider have a positive safety factor when the mating recess is 0.010 inch or greater. The serrated necklace restraining band design is similar to the configuration used on Atlas-Agena nose fairings.

In satellites which have an aft equipment module, the pallet can be integral with the forward module bulkhead to reduce the weight of the hold-down structure.

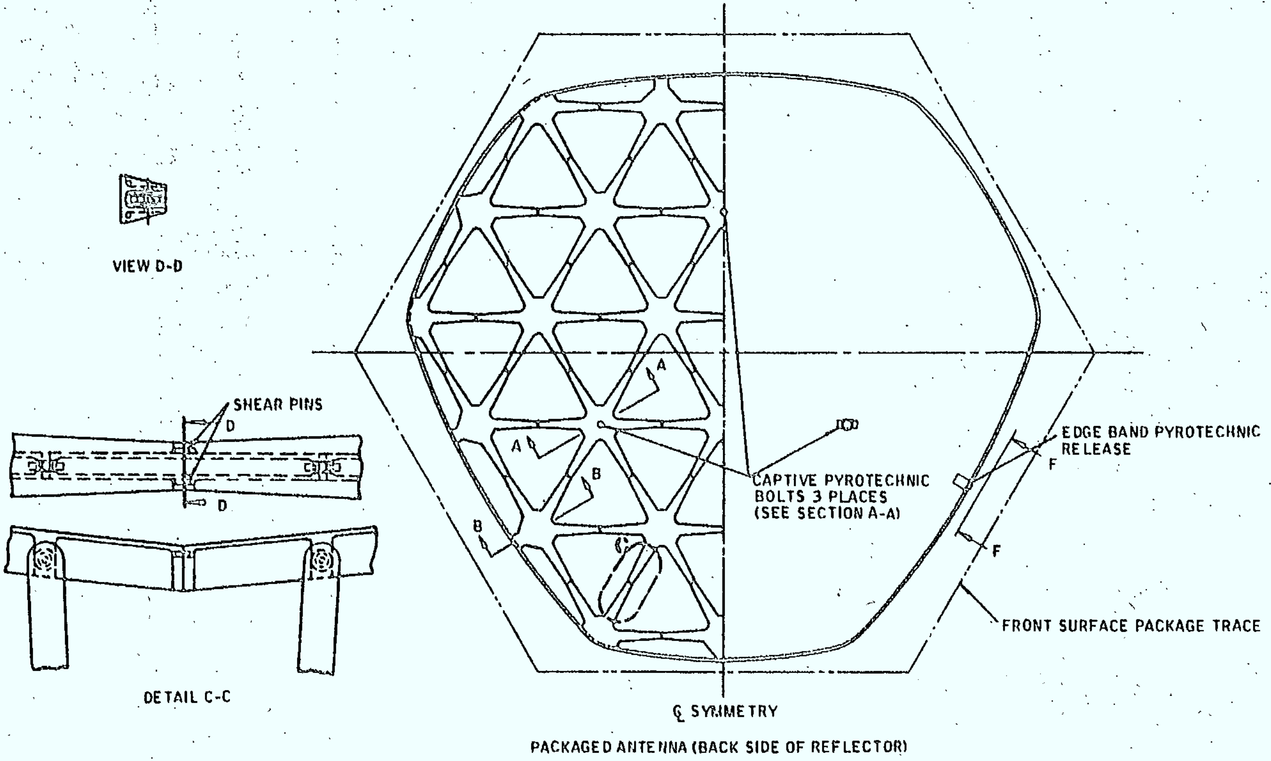
PALLET HOLD-DOWN DEVICES

The illustration opposite details the mounting of pyrotechnic devices on the spider and shows the restraining edge band assembly.

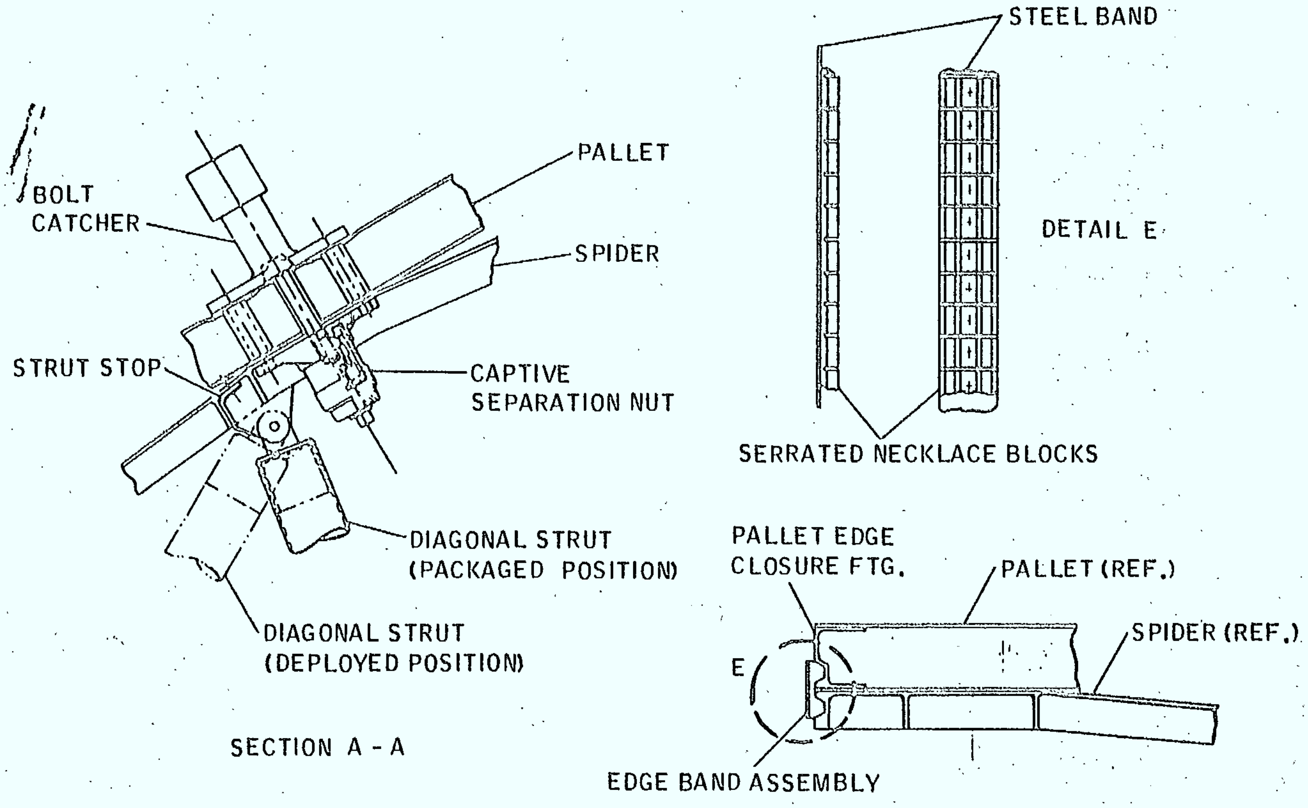
Standard separation devices — Hi-Shear, in this instance — are specified. All are commercially available units.

Construction of the serrated necklace allows it to flex, following the intersecting circular arc profile of the pallet. A spring steel band is used to back up the serrated blocks. Release of the clevis fitting holding the band separates the band from the pallet, allowing the reflector to deploy.

PALLET DESIGN

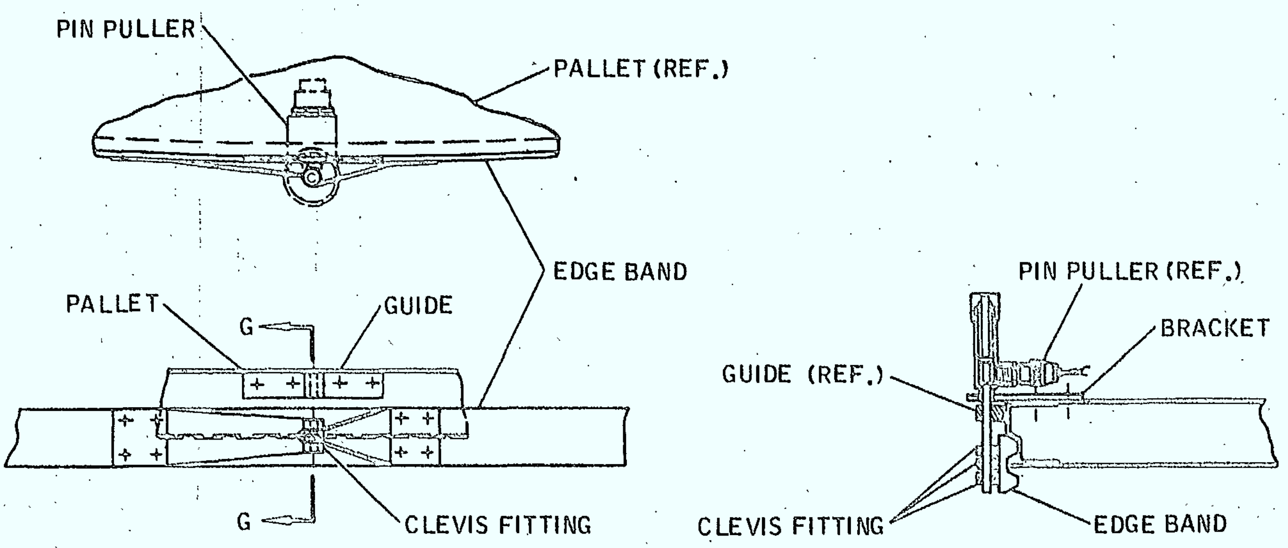


PALLET HOLD-DOWN DEVICES



SECTION B - B

PALLET BAND RELEASE



VIEW F-F

SECTION G-G

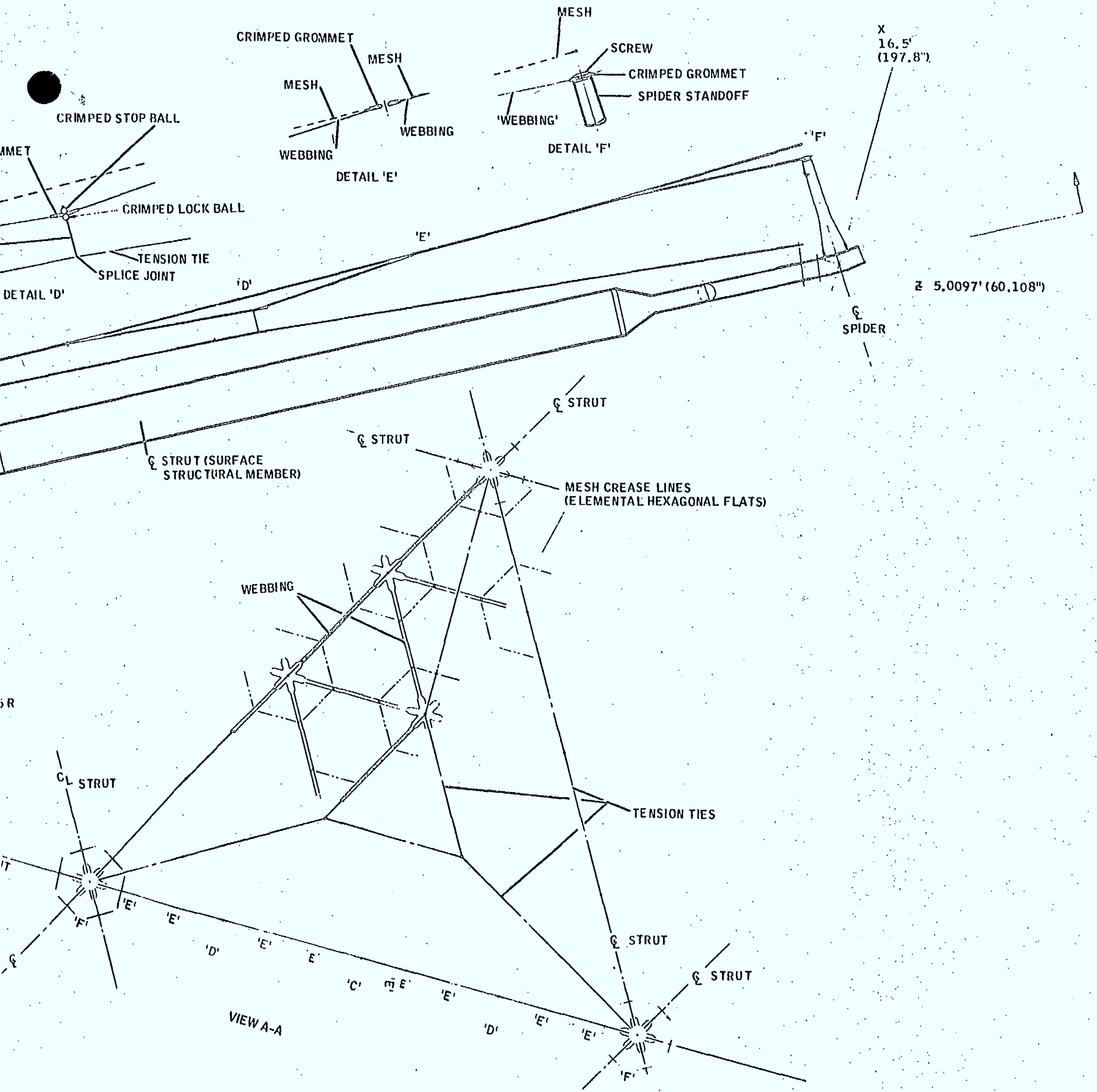
PALLET BAND RELEASE

Details of the edge band clevis fitting and release pyrotechnics are shown above. The clevis is a standard sheet-metal configuration used in many other applications. The material and gage would be similar to the spring steel used on the edge band serrated necklace. A single pyrotechnic pin-puller releases the band, initiating reflector deployment. The pin-puller is also a standard item. A guide and bracket ensure a rigid mount for the pin-puller and eliminate the possibility of the clevis binding on the pin.

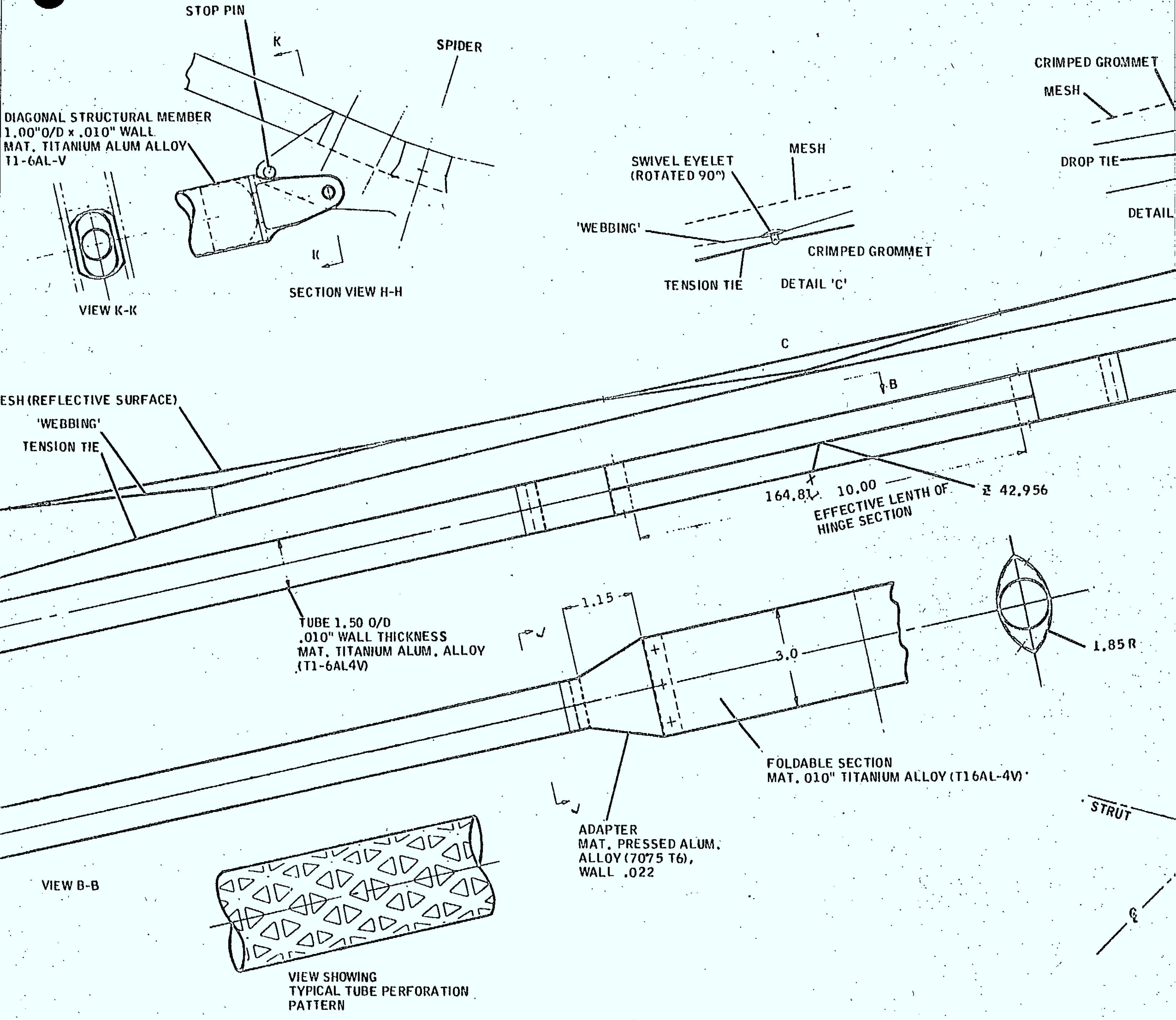
MESH SUPPORT SYSTEM

The mesh is not a true parabolic surface; rather, it is a large number of flat surface elements positioned to approximate a paraboloid. Each flat surface element, or facet, is formed by the action of the tension tie and webbing attachment system. In the antenna high-frequency design, there are 13 mesh-to-webbing ties along each surface strut. Other ties occur between struts to produce flat, hexagonal facets. Low-frequency antennas are tied only at the spiders. Facets can be adjusted by raising and lowering the tension-tie system. Thus, manufacturing tolerances and distortions are adjusted out of the reflector surface, except for the final tolerance on the accuracy of reading the adjusting mechanism. This tolerance measurement is conservatively estimated to be ±0.020 inch on any facet.

The selected mesh is a woven Chromel-R material coated with gold. This material has been extensively tested under NASA contract for mechanical and RF behavior.



Mesh Support System


STOP PIN
K
SPIDER
CRIMPED GROMMET
MESH
DIAGONAL STRUCTURAL MEMBER
1.00"O/D x .010" WALL
MAT. TITANIUM ALUM ALLOY
T1-6AL-V
SWIVEL EYELET
(ROTATED 90°)
MESH
DROP TIE
DETAIL
'WEBBING'
CRIMPED GROMMET
K
TENSION TIE
DETAIL 'C'
SECTION VIEW H-H
VIEW K-K
C
B
ESH (REFLECTIVE SURFACE)
'WEBBING'
TENSION TIE
164.81
10.00
EFFECTIVE LENTH OF
HINGE SECTION
℄ 42.956
TUBE 1.50 O/D
.010" WALL THICKNESS
MAT. TITANIUM ALUM. ALLOY
(T1-6AL4V)
1.15
3.0
1.85 R
FOLDABLE SECTION
MAT. 010" TITANIUM ALLOY (T16AL-4V)
STRUT
ADAPTER
MAT. PRESSED ALUM.
ALLOY (7075 T6),
WALL .022
VIEW B-B
℄
VIEW SHOWING
TYPICAL TUBE PERFORATION
PATTERN

F.)

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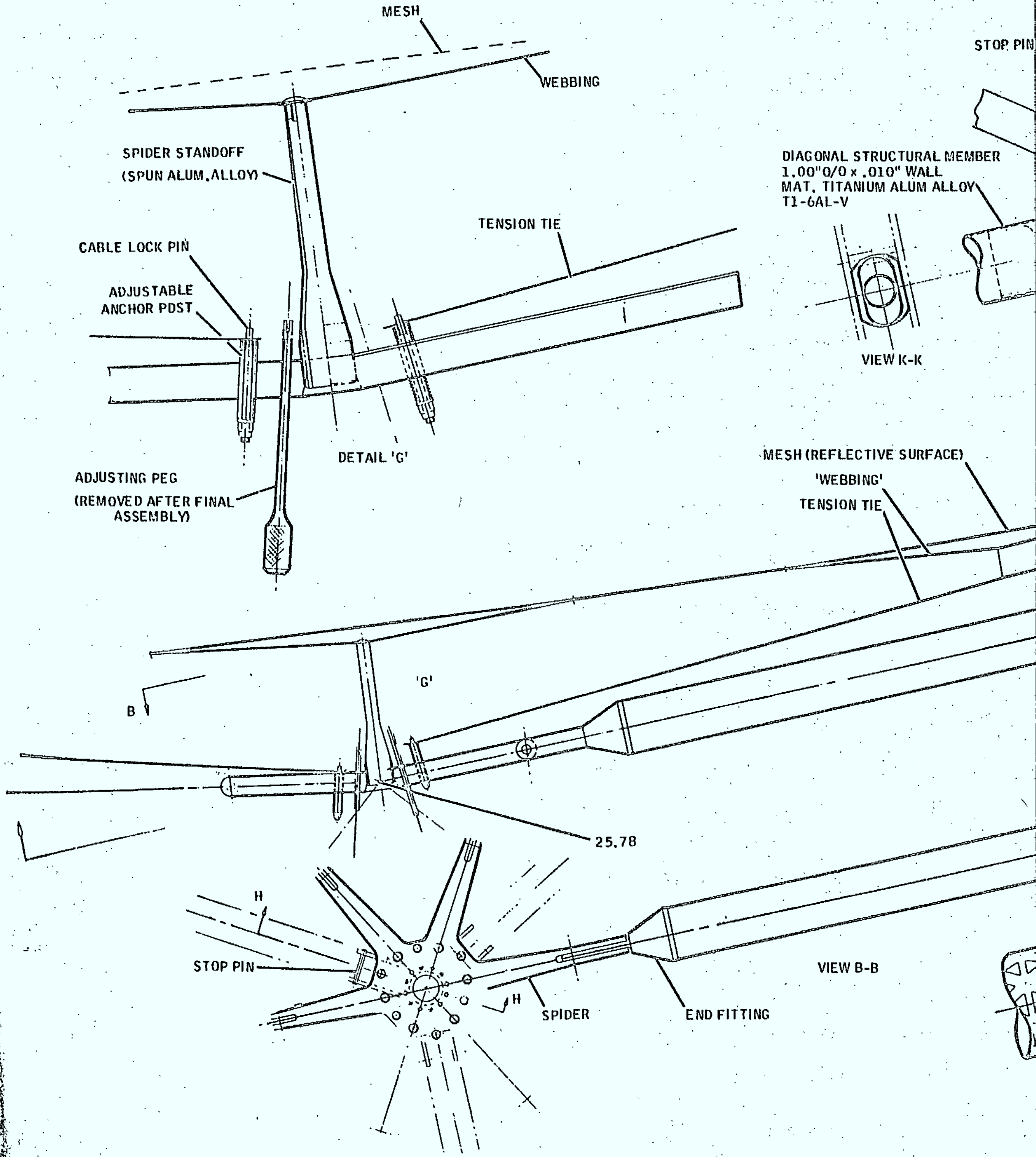
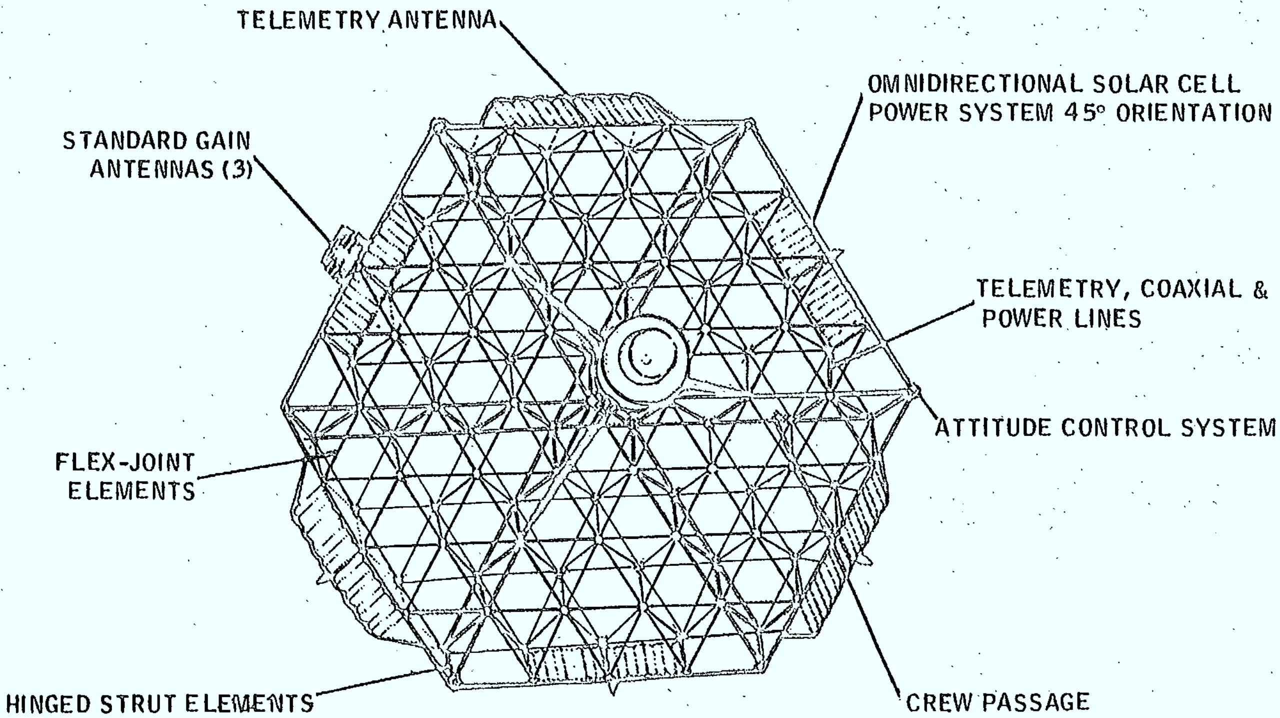


ANCILLARY EQUIPMENT INSTALLATION

One unique feature of the PETA design is the ease of mounting subsystem components directly to the truss structure. At very little increase in truss weight, elements of the solar array, attitude control and station-keeping systems, and auxiliary experiments can be easily mounted along the periphery of the truss. The illustration below and several succeeding figures show the advantages of this capability for ease of packaging and weight reduction.



SYSTEM CONFIGURATIONS

The antenna reflector is but one of many systems which must be integrated into the satellite flight package. This section illustrates a variety of configurations which satisfy differing mission requirements, but which all incorporate some version of the PETA reflector.

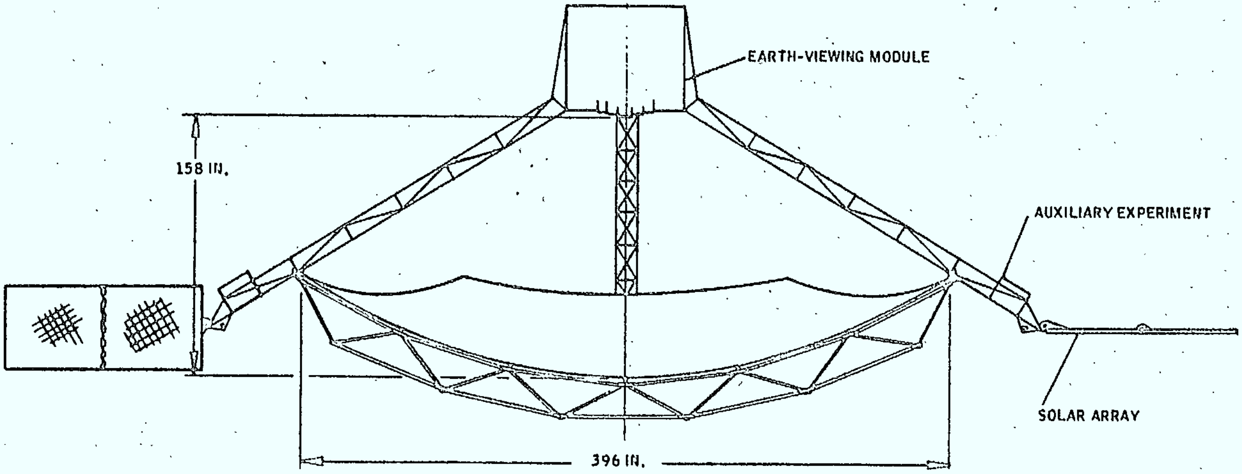
ATS-F&G CONFIGURATIONS

Several designs have been prepared by Convair to satisfy the requirements of the ATS-F&G mission. This satellite has an experimental communications mission with prime emphasis on the development of an advanced antenna concept.

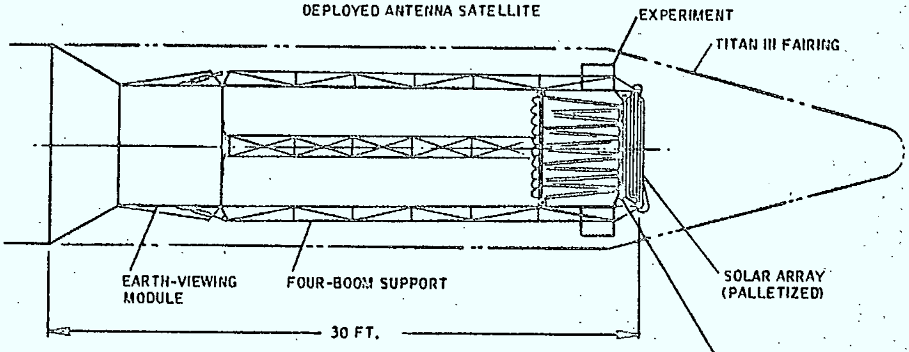
The configuration shown at right is probably the most desirable from a growth standpoint. The hinged feed boom will allow the maximum-diameter reflector to be packaged in a Titan envelope, while maintaining an efficient antenna f/D ratio. In addition, the fundamental frequency of the satellite in the packaged condition is inherently high because of the compact arrangement of the folded booms, antenna, and earth viewing module.

The configuration below is similar to the optimum version with the exception that rigid, nonfolding booms are used. This version provides somewhat more theoretical deployment reliability at an increase in weight to achieve the required high natural frequency of the booms for launch. Note the mounting of solar array and auxiliary experiments on the boom-truss intersection. This location saves significant weight overall and provides all experiments with the possibility of an earth view.

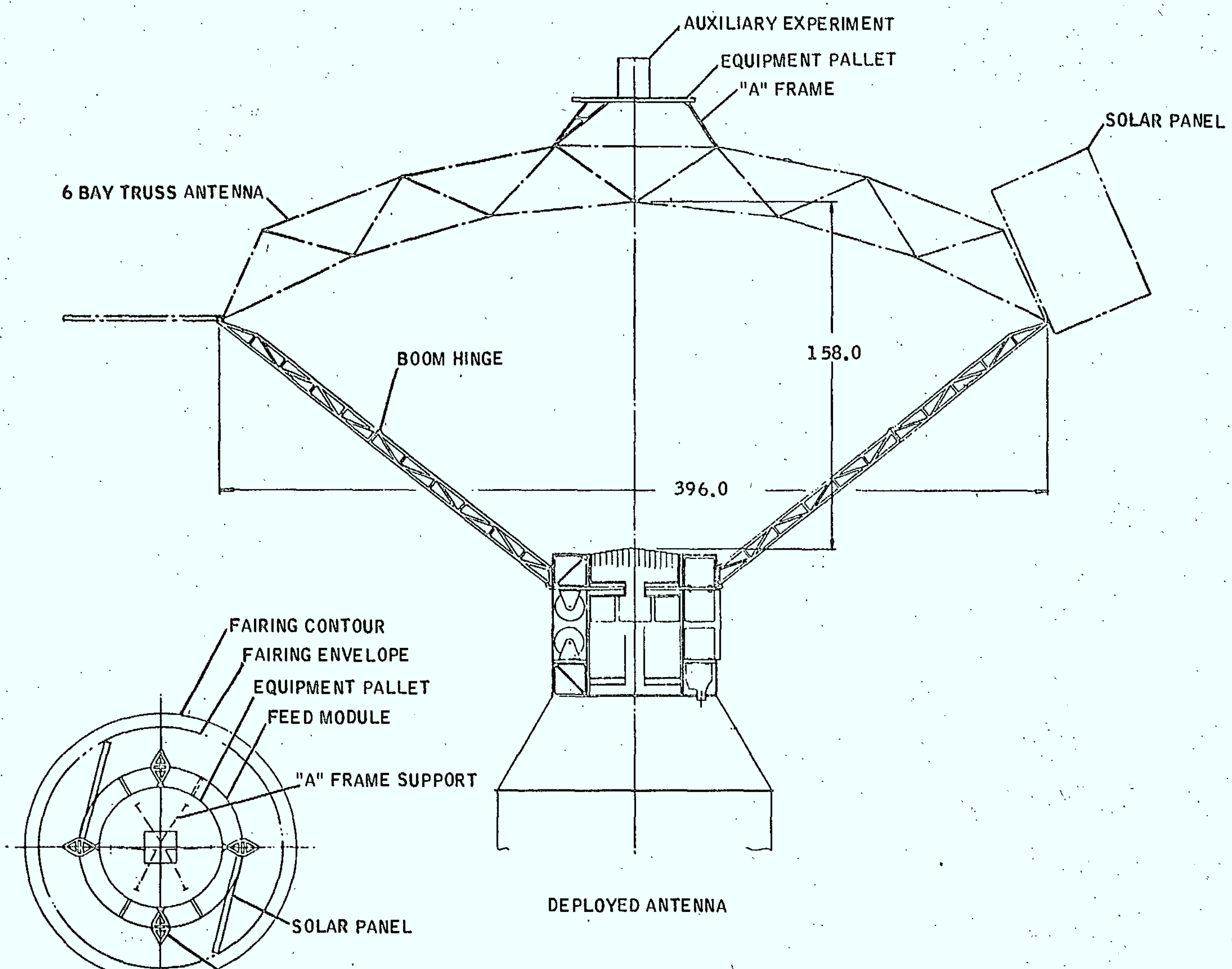
RIGID BOOM CONFIGURATION



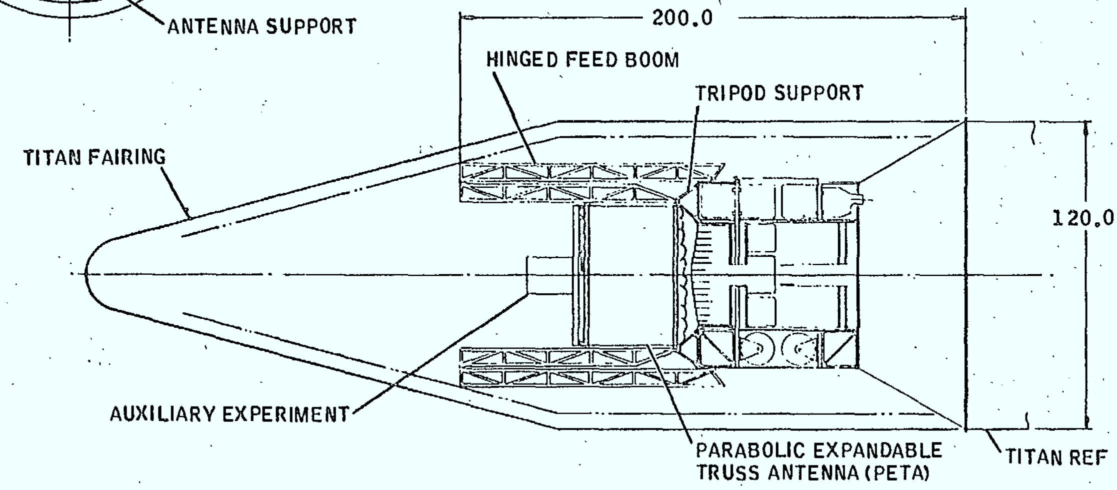
DEPLOYED ANTENNA SATELLITE



PACKAGED ANTENNA SATELLITE



DEPLOYED ANTENNA



PACKAGED ANTENNA

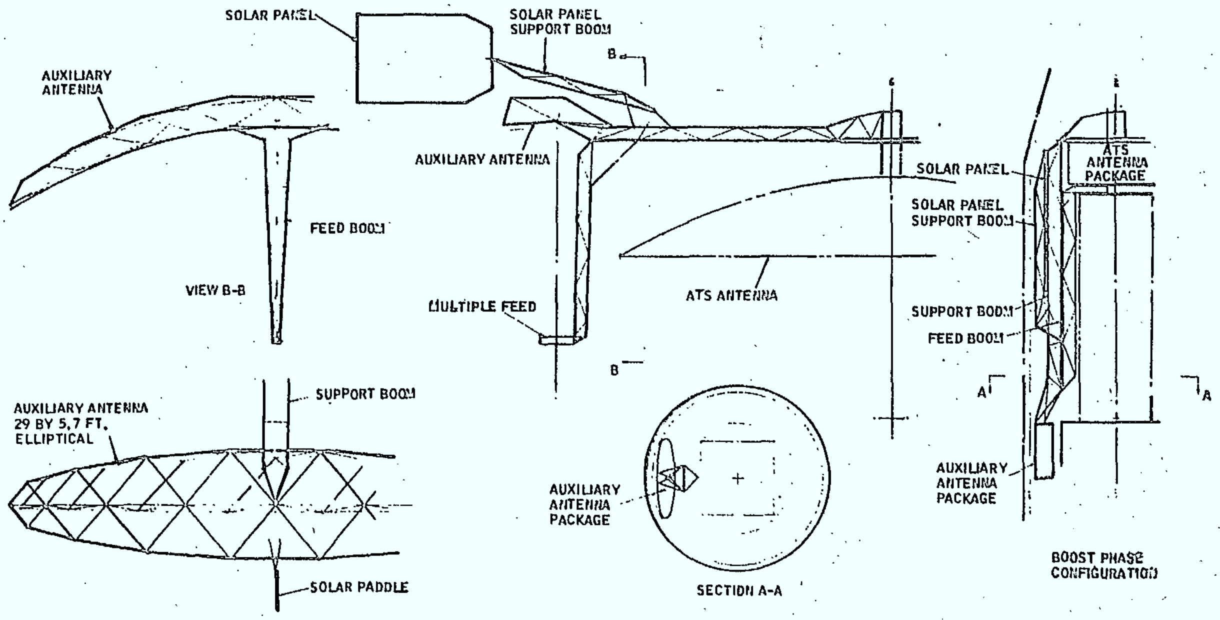
ATS WITH L-BAND ANTENNA

The drawings presented on this and the opposite page show methods of incorporating an auxiliary L-band antenna of the PETA design on the basic ATS-F&G satellite. Note that the PETA shape can be varied easily to achieve beam-shaping, as indicated by the 6 by 30-foot and 6 by 15-foot versions. Weights of the auxiliary antennas are:

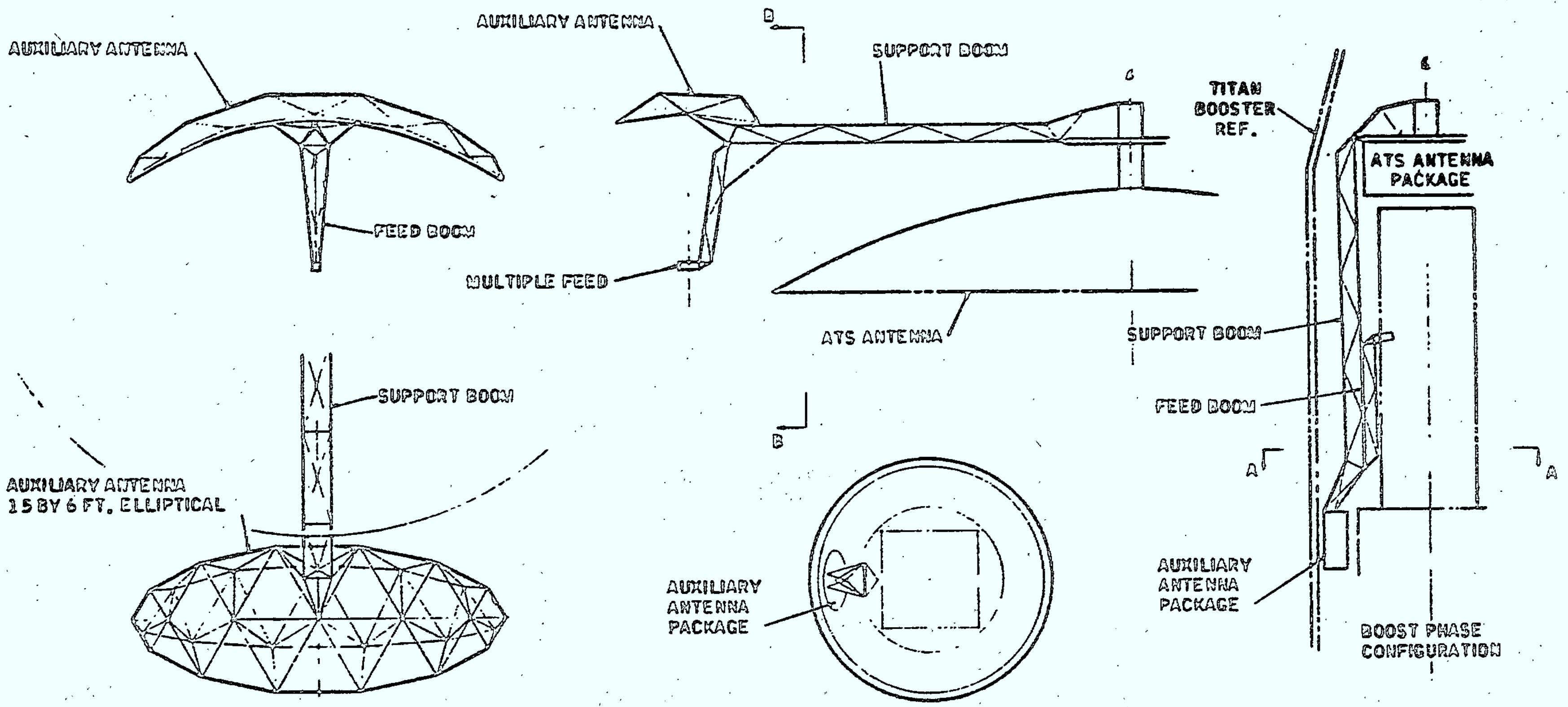
6 by 30-foot	133 lb.
6 by 15-foot	69 lb.

All weights include the auxiliary antenna feed boom and supporting structure and are based on perforated titanium tube material.

SIX-FOOT BY THIRTY-FOOT L-BAND ANTENNA



SIX-FOOT BY FIFTEEN-FOOT L-BAND ANTENNA

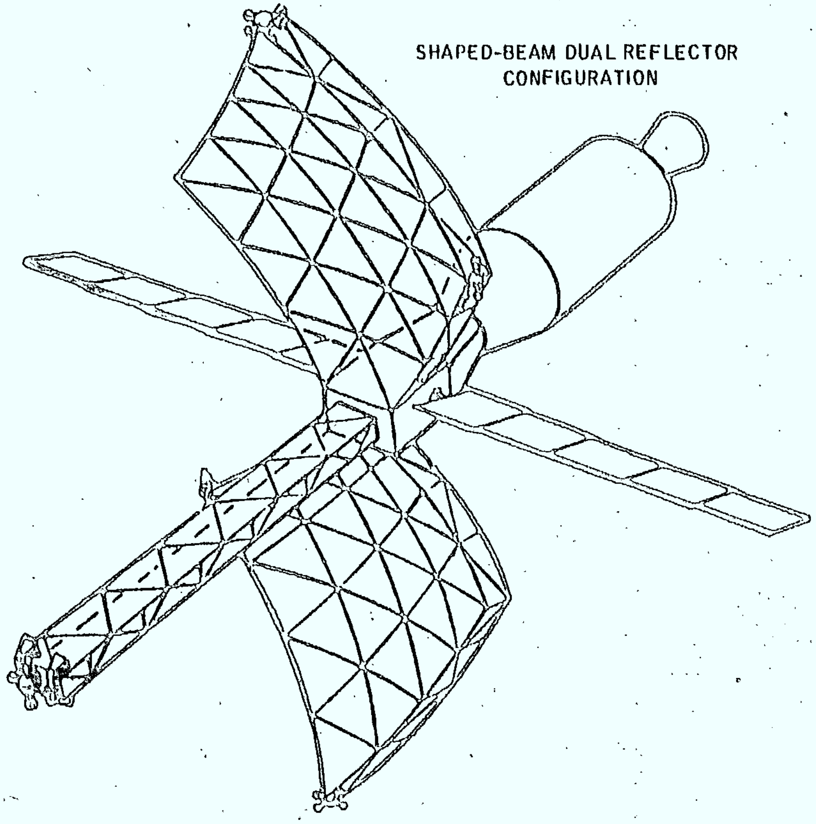


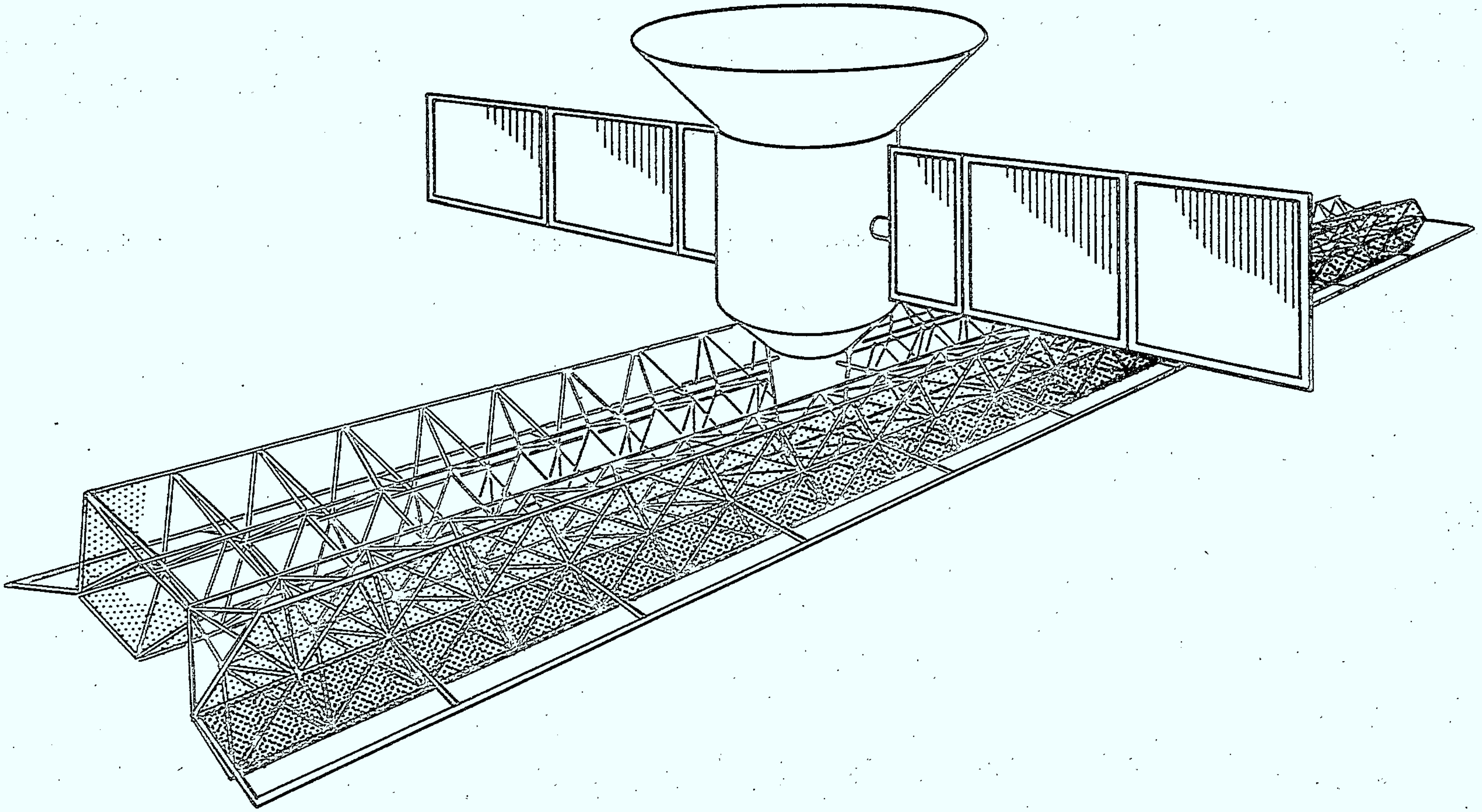
SHAPED-BEAM ANTENNA SATELLITES

The configuration shown below was originally developed for television applications involving multiple time zone coverage. The dual-reflector design could also be used as a combined L-band and S-band ATS satellite. The two diamond-shaped antennas produce an elliptical beam shape and are formed from sections of two identical, nearly concentric, 30 to 40-foot diameter parabolas. The center tower mounts four focal point feeds serving alternate areas. Prime power is supplied by rotating solar cell panels to provide peak power during the entire orbit, except for the 1.2-hour earth eclipse.

The concept shown on the facing page employs two PETA reflectors to produce extremely elliptical beams. This configuration is of interest for radar satellites operating at upper UHF frequencies. PETA size for this version is on the order of five feet wide and 100 feet long. Note that the basic modular structure is the same as for the conventional hexagonal PETA reflector.

SHAPED-BEAM DUAL REFLECTOR CONFIGURATION

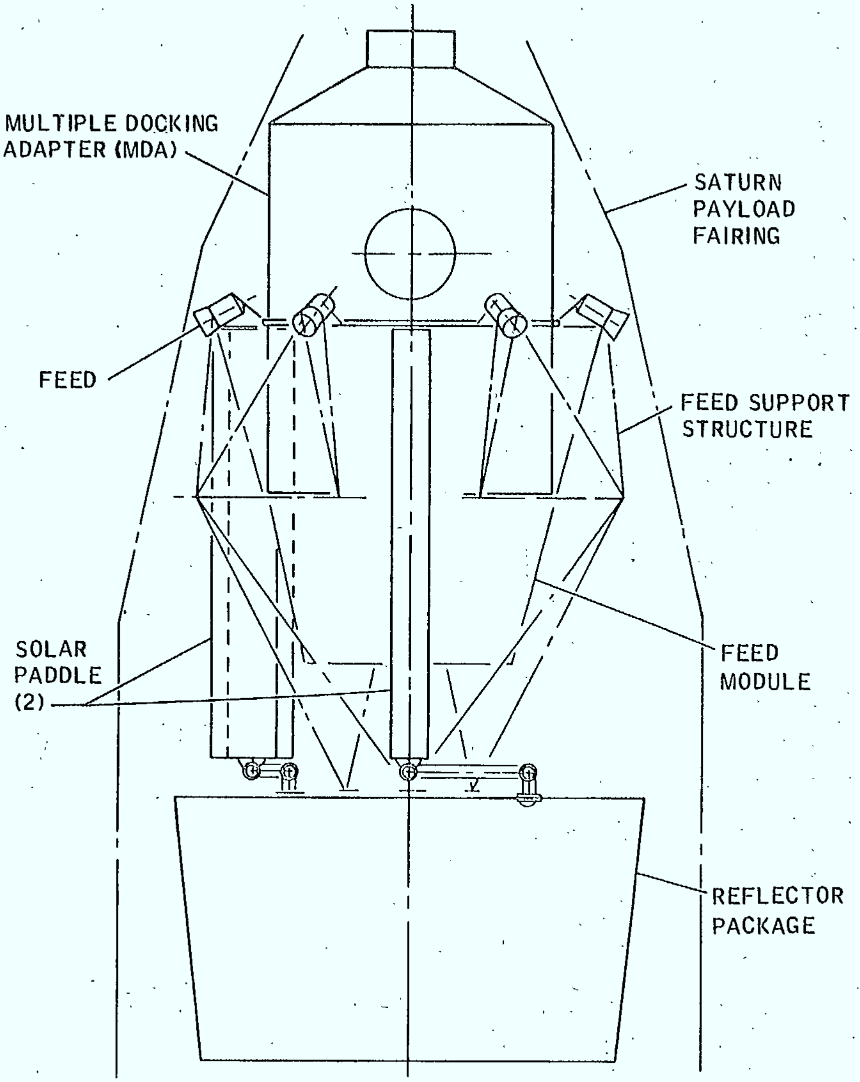


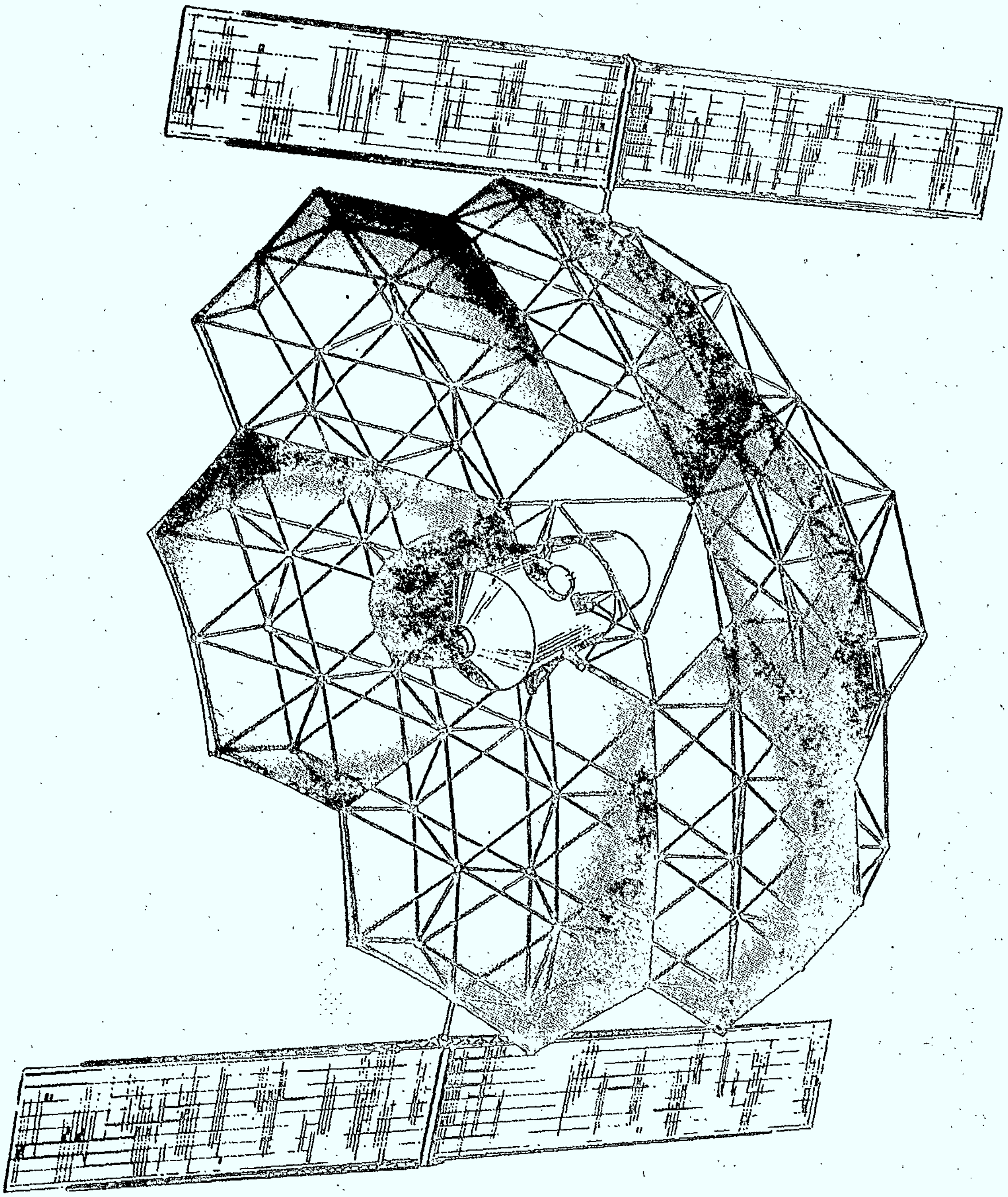


SIDE-LOOKING RADAR SYSTEM FOR EARTH RESOURCES AND MAPPING

MULTIPLE-BEAM TELEVISION ANTENNA

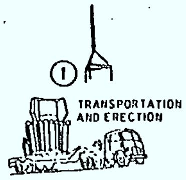
A multiple-beam PETA variation is a promising subject for television broadcast applications. A basic large PETA structure is specially contoured by varying truss strut and mesh standoff lengths to produce six circular, parabolic dishes with offset feeds. The resulting array is rigid, easily deployed, and much lighter than six separate antennas. The deployed satellite is shown at right and the packaged view below. Individual antenna diameters of 30 feet produce an overall PETA diameter of 100 feet. Smaller sizes are, of course, also feasible. The six reflectors need not all be the same diameter, so that different operating frequencies or coverage areas can be obtained.



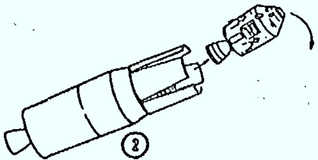


MANNED COMMUNICATIONS LABORATORY

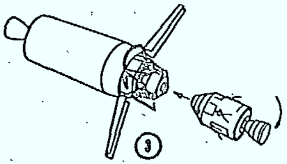
The sketch below illustrates the orbital sequence from boost to operation of a manned satellite using a 70-foot-diameter PETA reflector. Note the PETA type truss legs supporting the manned feed module and the extensive use of the reflector truss for mounting auxiliary equipment. This concept was designed as a large, manned communications laboratory.



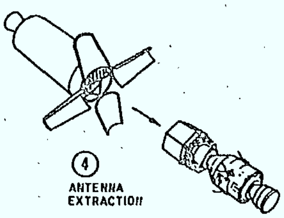
① TRANSPORTATION AND ERECTION



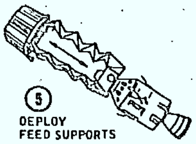
② CSM SEPARATION



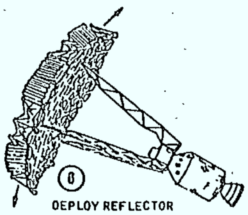
③ DOCKING



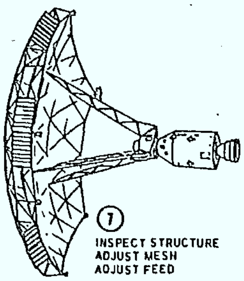
④ ANTENNA EXTRACTION



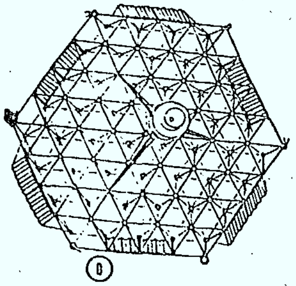
⑤ DEPLOY FEED SUPPORTS



⑥ DEPLOY REFLECTOR



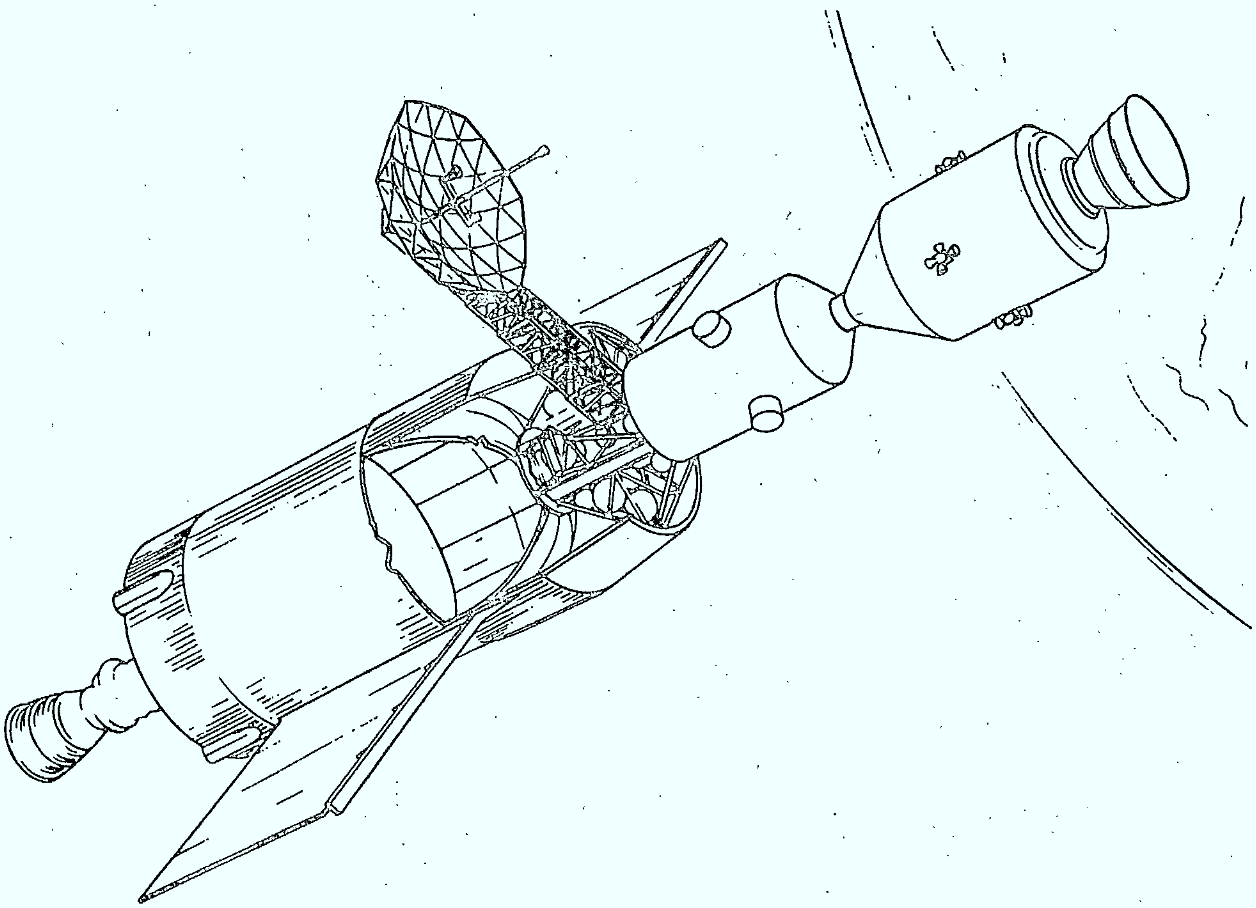
⑦ INSPECT STRUCTURE
ADJUST MESH
ADJUST FEED



⑧ PERFORM. PATTERN, NOISE, POINTING, TRANSMISSION TESTS

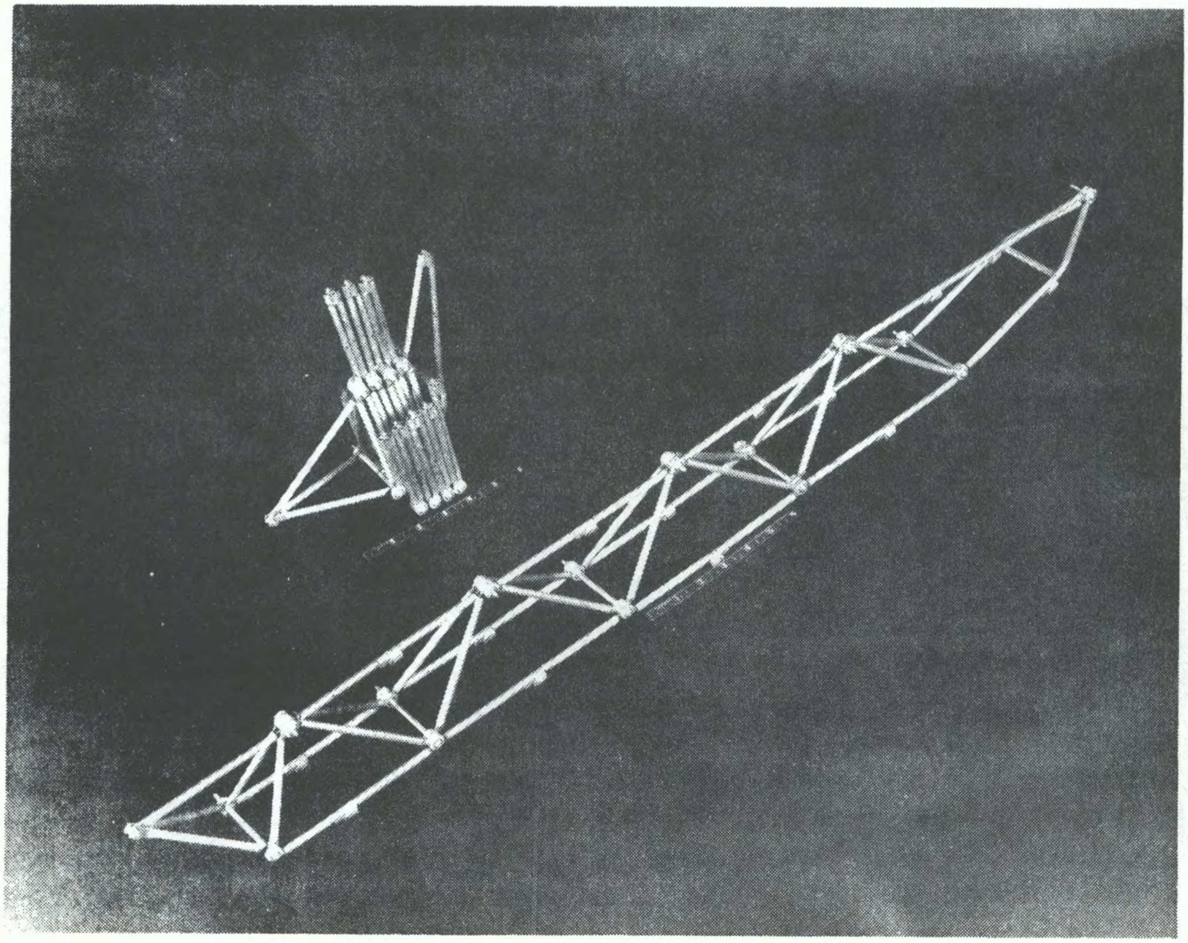
S IV B WORKSHOP ANTENNA

This concept has been proposed as a high-gain antenna which can be packaged in the engine compartment of the S IV B workshop. The antenna would be used for RF experiments from a manned laboratory and would also provide a high-gain communications link with other orbital vehicles or the ground. Note the incorporation of a three-axis gimbal mount on the PETA.



EXPANDABLE TRUSS STRUCTURES

The expandable truss concept employed for the PETA can be used for purposes other than parabolic antennas. As shown in the model below, this concept is adaptable to a folding feed support structure with high rigidity when deployed but with excellent packaging characteristics. Other uses which have been investigated include ground, lunar and space shelters, and array and helical antennas.



REFLECTOR GROWTH CONSIDERATIONS

Point designs have been studied extensively by Convair for PETA reflectors of 6, 10, 15, 30, 70, 100, and 140-foot diameter. Results of these studies, conducted under NASA and Convair funding, have been applied to project the growth considerations of the PETA in the following areas:

1. *Reflector and pallet weight.*
2. *Packaging.*
3. *Reliability.*
4. *Dynamics.*

Succeeding sections discuss the orbital distortions and RF performance of the PETA as a function of reflector size.

PREDESIGN WEIGHT PROGRAM

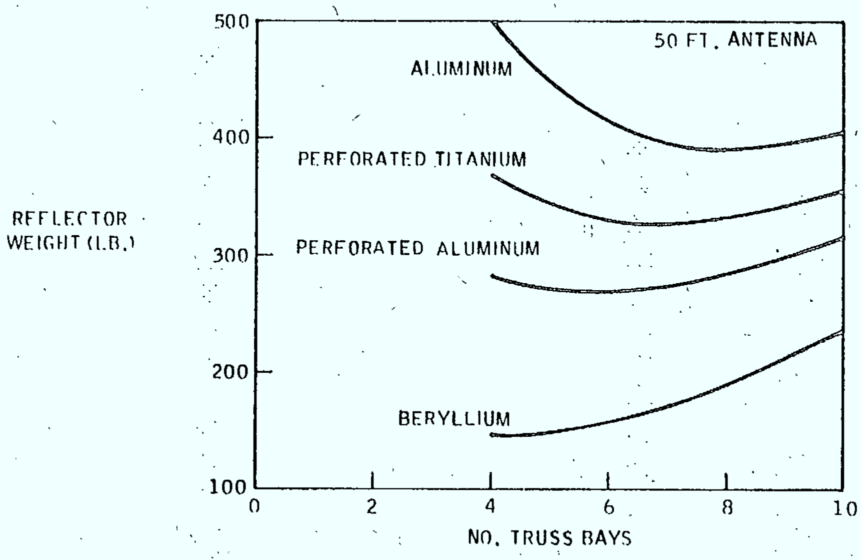
As noted earlier, the number of bays and the tube material of the reflector greatly affect its weight. Convair has written a predesign weight computer program that is used to examine the effects of these parameters on antennas up to 100 feet in diameter. The parametric charts presented in the next several illustrations are the result of some one hundred computer runs. Three-point design weights checked against the program showed correlation to within 5%, indicating high confidence in the results. A typical program printout is shown below.

```
          SURFACE STRUT TUBES WEIGHT           33.0 LB.
          DIAGONAL STRUT TUBES WEIGHT           3.9 LB.
          END FITTINGS WEIGHT                   4.0 LB.
          SPIDER FITTINGS WEIGHT                9.2 LB.
          HINGES AND SPRINGS WEIGHT            44.4 LB.      50 FT. DIA. REFLECTOR
          MESH SYSTEM WEIGHT                   39.6 LB.        BERYLLIUM TUBES
          MISC. HARDWARE WEIGHT                 4.8 LB.
          THERMAL COATINGS WEIGHT               4.1 LB.
          CONTINGENCY WEIGHT                   14.3 LB.
          TOTAL REFLECTOR WEIGHT              157.6 LB.

 AVE STRUT   DIAG STRUT   STRUT DIA.   DIAG. DIA.   SPIDER   PACK WIDTH   PACK HEIGHT
  107.00       73.00        0.97         0.56        6.6        39.6         81.7
```

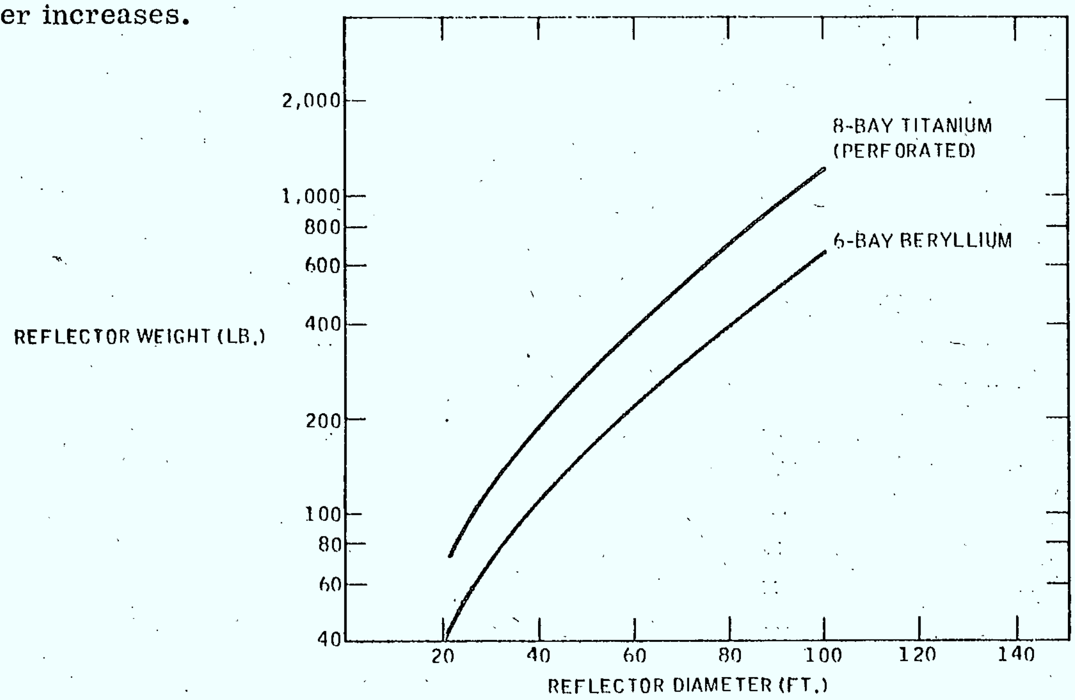
WEIGHT VARIATION WITH BAY INCREASE

It was found that the optimum weight points tend to favor larger number of bays for large antennas and fewer bays for the smaller reflectors. The plot below shows this variation for the 50-foot-diameter reflector. Beryllium versions favor fewer bays throughout the 20 to 100-foot-diameter range than do aluminum or titanium versions since tube weights are much less. Perforated titanium versions exhibit relatively small weight differences between the six and eight-bay versions within the 30 to 60-foot range of interest.



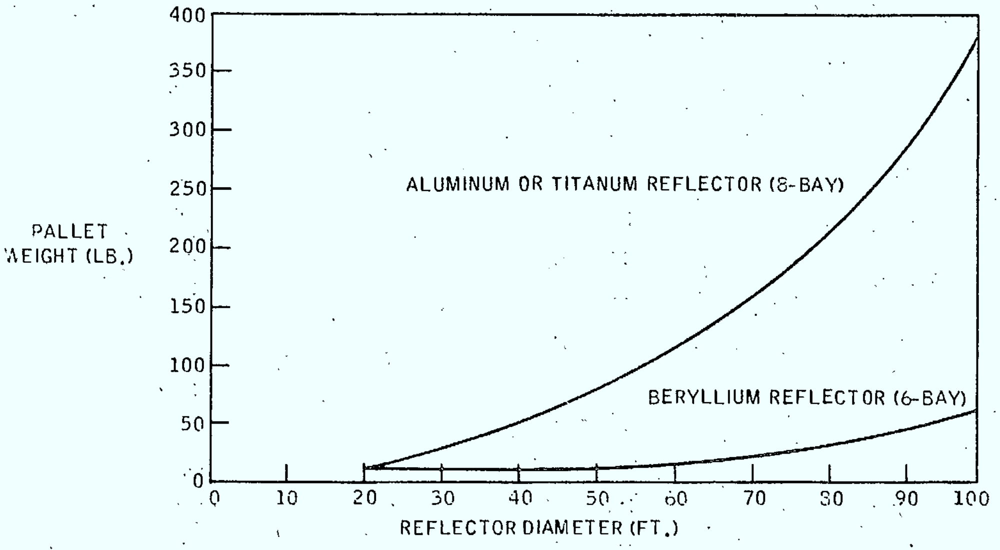
WEIGHT VARIATIONS WITH REFLECTOR SIZE

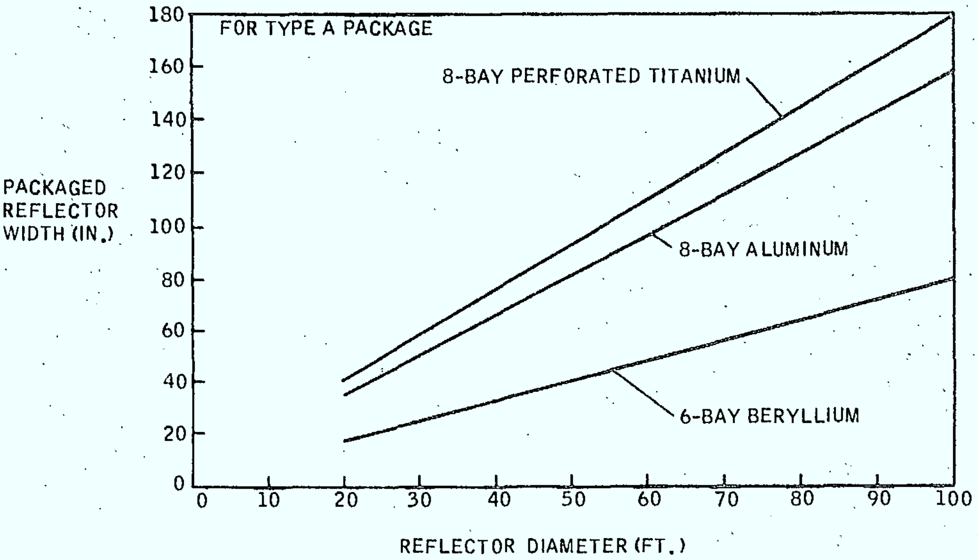
The graph below indicates the weight variation with diameter for the three most desirable overall combinations of bay size and material. The curves were plotted from computer weight data in 10-foot-diameter increments and all include a 10% contingency factor; consequently, they are considered conservative and reasonable. Note that the shape of the curves indicates a decreasing weight per unit aperture area as the diameter increases.



PALLET WEIGHT VARIATION

PETA configurations generally require a pallet similar to that illustrated on page 11. The size and weight of the pallet will increase as antenna diameter changes; the plot below indicates this variation. Pallet weights are based upon a low-deflection sandwich structure. A machined-beam configuration would probably produce significantly lower pallet weights.

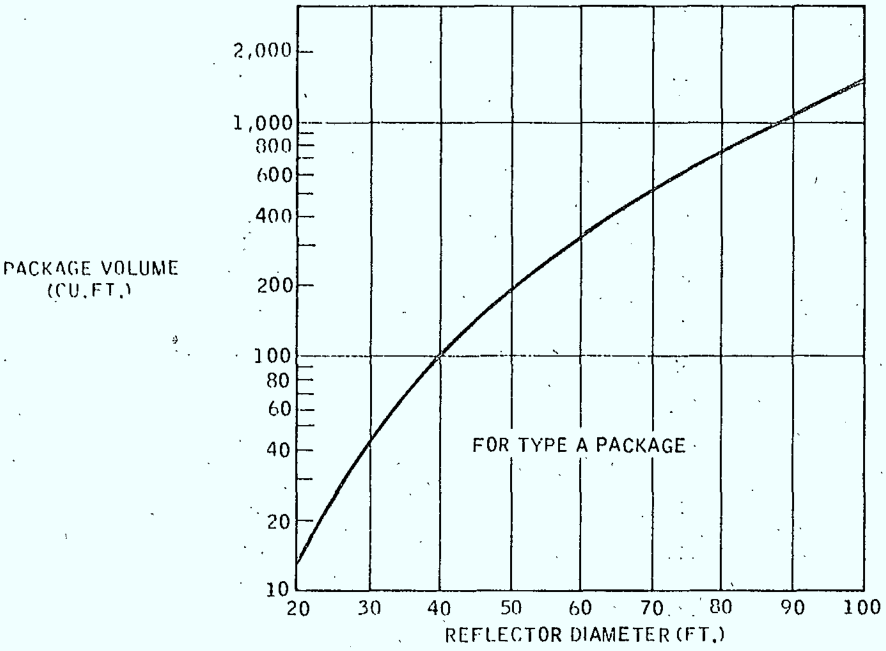




PACKAGED REFLECTOR SIZE VARIATION

Since package width depends primarily upon the diameter of the truss tubes, significant variations in package size are attainable by varying tube material. The graph above indicates these changes for beryllium, aluminum, and titanium tubes as a function of deployed reflector diameter.

The graph below translates package size for the titanium version to packaged volume. For a 54-foot reflector, package width is 98 inches; the volume is 240 cubic feet.



RELIABILITY OF DEPLOYMENT

The PETA structure is highly redundant; failure of several scattered deployment hinges or truss struts has little effect upon overall deployment or operational reliability. The table at the bottom indicates the calculated reliability of the ATS-F&G reflector in the six-bay configuration. The reliability of four-bay reflectors is slightly higher since fewer spider fittings and hinges are used, as shown below.

NO. OF BAYS	RELIABILITY
4	0.9975
6	0.9960
8	0.9938
10	0.9899

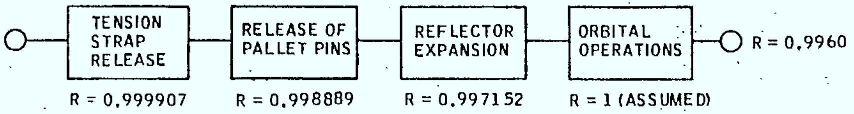
RELIABILITY PREDICTION 6-BAY PETA

	QTY.	FAILURES PER 10^6 BOOST CYCLES OF EACH PART**	FAILURES PER 10^6 DEPLOYMENTS OF EACH PART	TOTAL EXPECTED FAILURES PER 10^6 CYCLES
REFLECTOR				
SPIDER JOINT	267*	0.01	5	1,338
"CARPENTER TAPE" HINGE	180*	1.5	3.3	870
TRUSS ASSY.	1	4.8+	0	5
MESH ASSY.	1	624	15	639
TOTAL				2,852
PALLET				
RELEASE PIN	27	0.006	5	135
RELEASE PIN SPRING	27	4.5	10	392
RELEASE PIN SPRING INSERT	NO SYSTEM FAILURE UNLESS ALL FAIL BEFORE DEPLOYMENT - NEGLIGIBLE PROBABILITY.			
TENSION SPRING	2	4.5	10	29
CONNECTOR PIN	2	0.006	5	10
BRACKET PIN	2	0.006	5	10
PIN PULLER PYROTECHNIC	2	168	100	536
TENSION STRAP	2	0.48	45	91
TENSION STRAP PIN PULLER	0*		(ACTIVE REDUNDANCY)	0
ELECTRICAL CONNECTOR	5	0.4	0	2
TOTAL				1,205
CONFIGURATION TOTAL				4,057

* ADJUSTED FOR REDUNDANCY.

** ASSUMED TOTAL THRUST TIME OF 0.3 HR.

NOTE FAILURE RATES BASED ON THOSE FROM SIMILAR COMPONENTS LISTED IN FAILURE RATE DATA HANDBOOK (FARADA), USN FMSAEG, CORONA CA.



INFLUENCE OF SIZE ON NATURAL FREQUENCY

This curve of natural frequency was obtained by using linear geometric scaling, assuming that frequency varies inversely with diameter. Three-dimensional modes have been computed for a 100-foot antenna that has ACS pods and solar panels attached to the reflector rim. The lowest reflector frequency was 2.5 cps, which would drop through the two cps requirement at 125 feet diameter. A bare reflector would exhibit a frequency of two cps at about 150 feet.

Methods of increasing frequency are increasing the link cross-sectional area or increasing truss depth. It is therefore possible to achieve reasonable frequencies in very large sizes; a 300-foot antenna with $f_o \sim 2$ cps is feasible.

Convair examinations of structural characteristics of several alternative antenna system designs using the PETA reflector show that the most probable source of low-frequency modes is the feed support system. Both torsion and lateral modes are critical. Feed frequencies are shown to be lower than reflector frequencies for the ATS-F&G antenna, for example, and the values compared to system requirements were for feed (not reflector) vibrations.

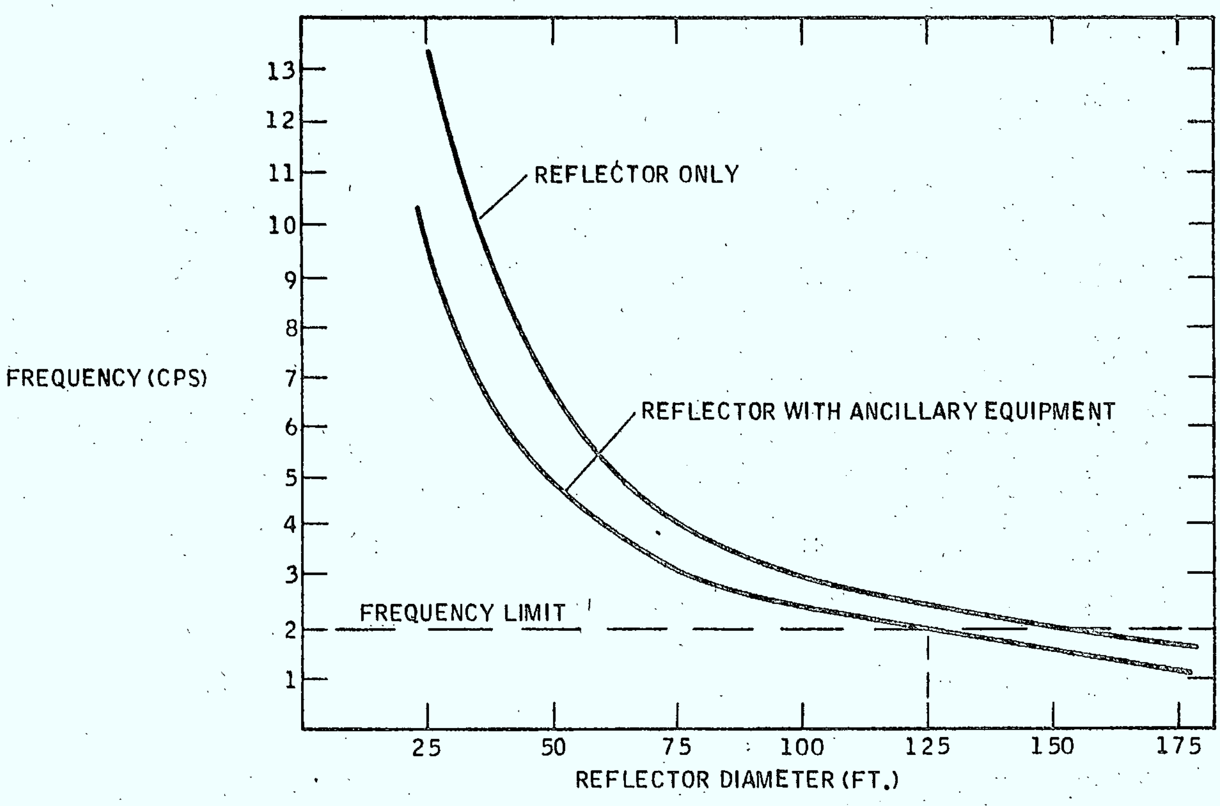
INFLUENCE OF SIZE ON NATURAL FREQUENCY — PACKAGED ANTENNA

Requirements limiting natural frequencies of the packaged antenna are set by the launch vehicle environment. Since the packaged reflector is folded and constrained with circumferential bands, its elastic characteristics are of minor importance — they are adequately represented as a single mass with elastic support. Elasticity of the support legs determines the frequencies.

Convair examined five potential ATS-F&G configurations with respect to the 10-cps lateral, 4-cps torsional, and 20-cps longitudinal requirements. Frequencies were above torsional and longitudinal minimums, but were marginal or just above lateral minimums, even though heavier and larger feed support structures were designed. Larger antennas would result in lower natural frequencies, which would be too low. One method of increasing frequency is to improve the launch environment at the antenna. Damping mechanisms can partly decouple the antenna from the booster vibrations. A more expensive method is to improve the launch vehicle — as was necessary to eliminate the pogo oscillations of manrated launch vehicles.

Use of a deploying feed support structure is a more direct and less expensive technique.

INFLUENCE OF SIZE ON NATURAL FREQUENCY, DEPLOYED 8-BAY



INFLUENCE OF SIZE ON NATURAL FREQUENCY, PACKAGED

PACKAGED FREQUENCY REQUIREMENTS SET BY LAUNCH ENVIRONMENT

NATURAL FREQUENCIES DETERMINED BY FEED SUPPORT STRUCTURE

ATS-F&G REQUIREMENTS
  10 CPS LATERAL, 4 CPS TORSIONAL, 20 CPS LONGITUDINAL

CONVAIR EXAMINED FIVE POTENTIAL ATS F&G CONFIGURATIONS:
  TORSIONAL & LONGITUDINAL ABOVE MINIMUMS
  LATERAL MARGINAL, OR JUST ABOVE, ALBEIT STRUCTURE STIFFENED

LARGER ANTENNA SIZES YIELD LOWER FREQUENCIES

METHODS OF INCREASING FREQUENCY:
  IMPROVE LAUNCH ENVIRONMENT
    DECOUPLE ANTENNA
    IMPROVE LAUNCH VEHICLE
  USE DEPLOYING FEED STRUCTURE

POINTING ACCURACY VERSUS MODAL FREQUENCY

Prediction of pointing performance for large flexible satellites with tight pointing requirements necessitates a detailed complex analysis. The effects of structural oscillations and structural feedback through the autopilot must be included. Results depend upon such system specifics as antenna size, sensor and torquer characteristics, pointing tolerance, and modal frequencies.

This data results from study of a 100-foot-diameter communications antenna using the erectable truss. Computations were made by a digital simulation which included the three vehicle rotations and component characteristics, and used modal data from a three-dimensional structural analysis. The general trend shown is that pointing accuracy degrades with decreasing modal frequency, despite autopilot compensation. Extent and seriousness of the pointing degradation will vary for different missions, satellite configurations, and antennas.

LATCHUP ANALYSIS

Two analytical techniques are used to examine reflector deployment dynamics. One technique analyzes the loads at latchup caused by link hinge velocity impact and spider deceleration. The technique is used to predict latchup loads, to size hinge springs, and to aid link design. The digital program is complete for both six and eight-bay configurations and has been used in the analysis and design of eight-bay, 70-foot-diameter, and six and eight-bay, 30-foot antennas.

Maximum bending moment along a link due to link hinge velocity impact is shown in the plot at bottom right. The titanium tube is weaker than the center hinge; consequently, the design criterion is that the tube experience a maximum of 705 inch-pounds at a velocity of 26.5 feet per second.

Another analysis technique is reflector deployment time history. It is being developed for the eight-bay reflector and for the tetrahedron to be tested under NASA contract. This technique will be used to predict loads throughout deployment, to obtain time histories of the antenna and its components, to examine energy relationships, and to compute the latchup antenna energy. The simulation is currently stepping deployment in check runs. The analysis input is mesh torque versus hinge angle.

POINTING ACCURACY VS. MODAL FREQUENCY

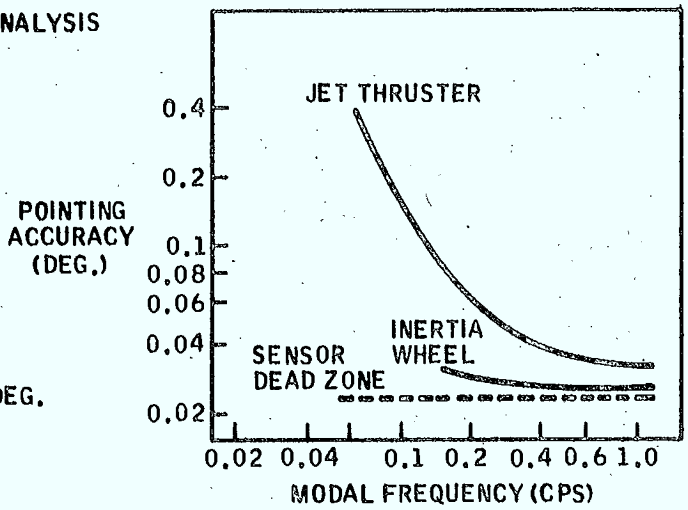
DETAILED SYSTEM SPECIFICS DEPENDENT ANALYSIS

100-FT. ANTENNA
SENSOR DEAD ZONE = 0.023 DEG.
JET THRUST = 5 LB.
INERTIA WHEEL TORQUE = 10 FT.-LB.

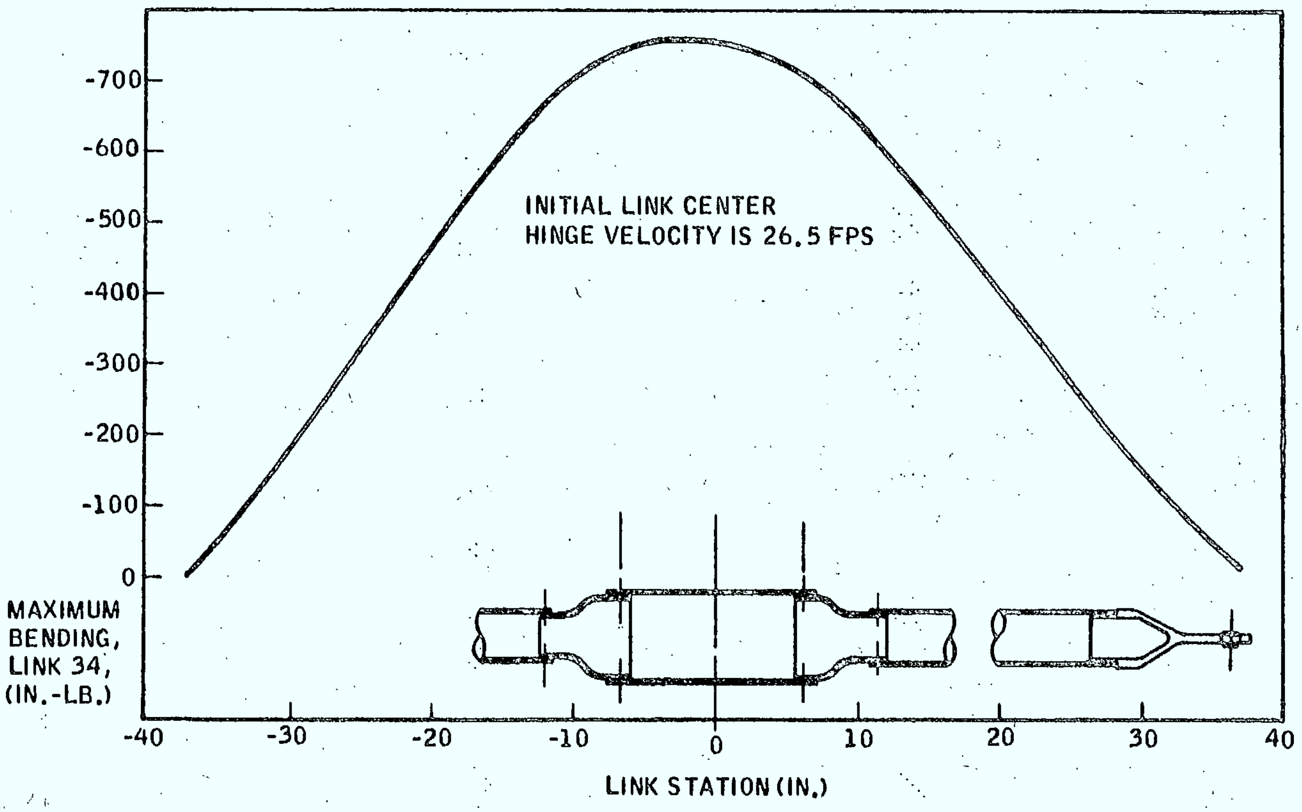
MINIMUM MODAL FREQUENCY
DUE TO FEED MOTION =
8.4 RAD./SEC. (1.3 CPS)

AUTOPILOT COMPENSATION FOR
STRUCTURAL FEEDBACK

DESIRED POINTING ACCURACY = ±0.03 DEG.



LATCHUP ANALYSIS, TYPICAL RESULTS

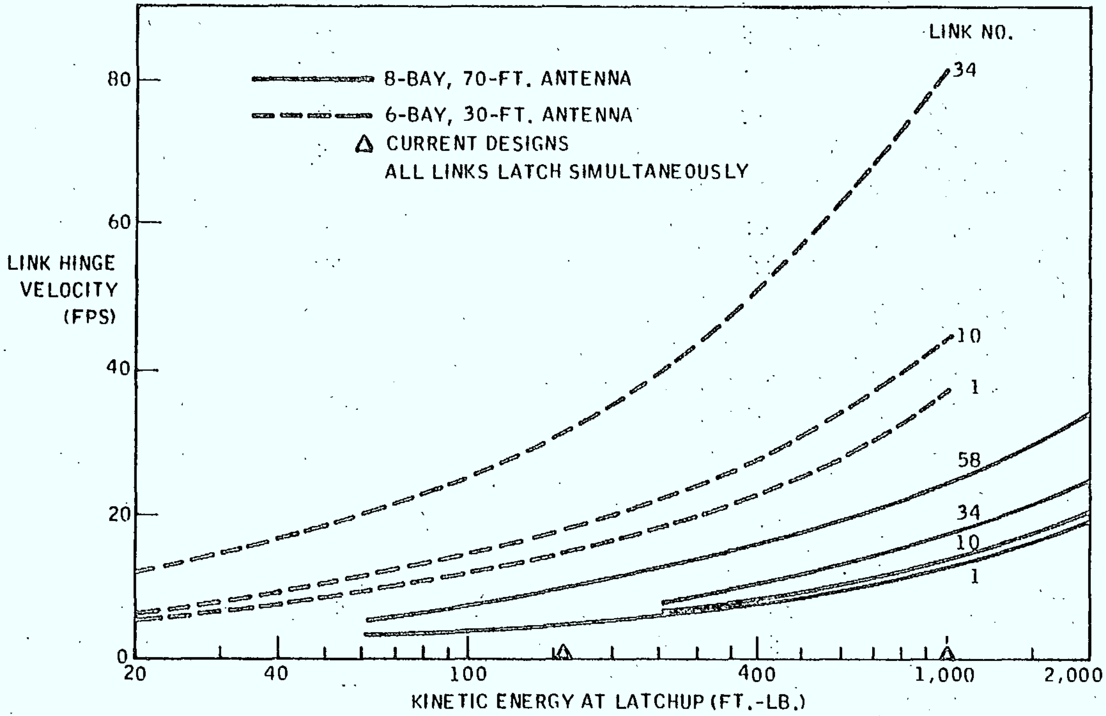


LINK HINGE VELOCITY AT LATCHUP VERSUS ENERGY

Latchup analysis procedures were completed during the fall of 1968 for both six and eight-bay configurations. The analysis has been applied to six and eight-bay, 30-foot-diameter antennas, and an eight-bay, 70-foot-diameter configuration. Typical results of the numerous computer runs are shown below for the six-bay, 30-foot, and the eight-bay, 70-foot antennas.

Link hinge velocity data (outermost eight-bay link is No. 58) shows a reasonable difference in total energy, largely because there are 153 springs in the six-bay and 276 springs in the eight-bay antenna.

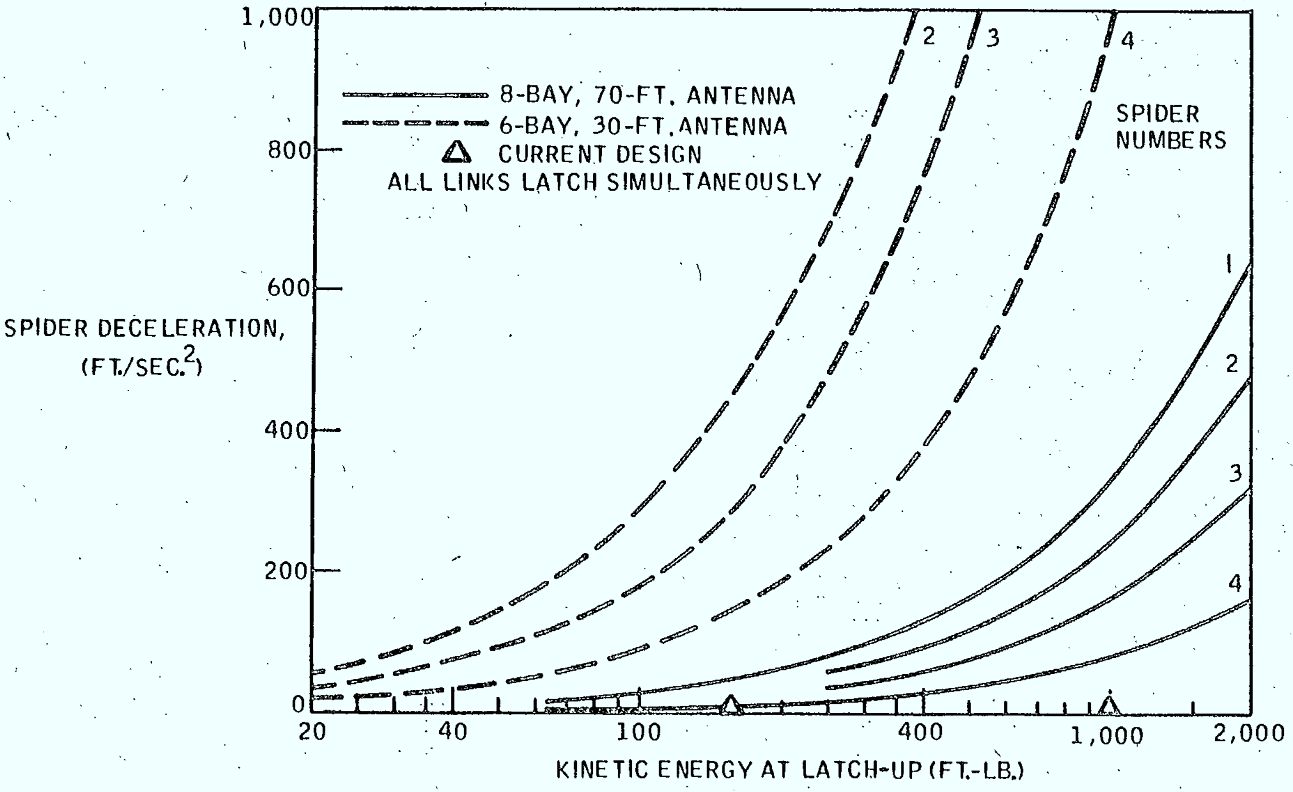
Nominal design points are shown; velocity values for the two antennas lie within a factor of two.



SPIDER DECELERATION AT LATCHUP

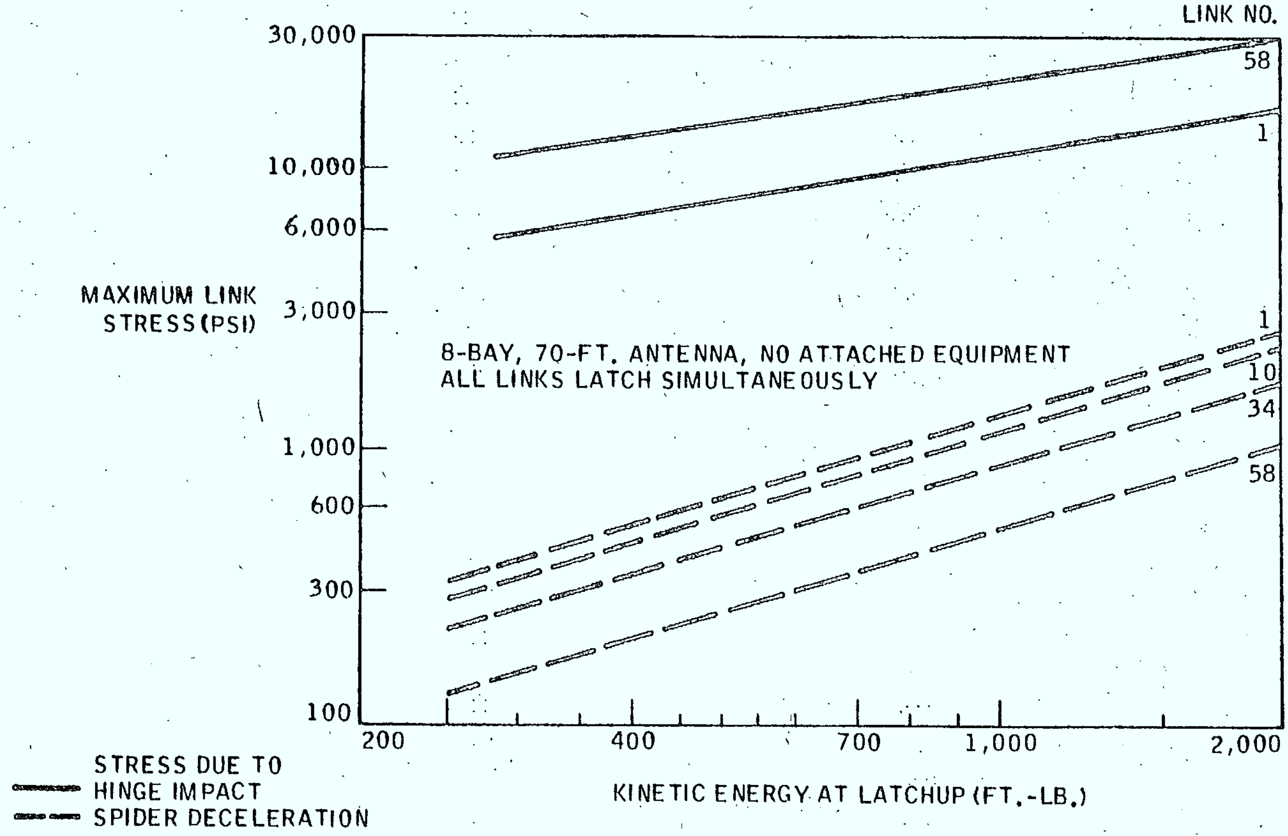
The latchup computer program computes decelerations for each spider, along with link hinge impact velocities. Typical results are shown below. Note that, again, the energies for the two configurations are quite different, but the operational values of deceleration are comparable.

Spider loads depend upon spider weights; as a result, spider weight data can be input to the program for any or all of the 109 spiders and loads calculated only for those spiders for which weights are entered.



LINK STRESS AT LATCHUP

The latchup analysis identifies two major load sources: spider deceleration and link hinge impact. The chart below compares the resulting maximum link stresses. Link 1 is in the tetrahedron to be tested in 1969. Because the link is near the center of the reflector, it experiences near-minimum hinge impact loads and near-maximum spider acceleration loads during deployment. Link 58, located near the reflector rim, experiences the maximum hinge impact load. Results show that stress levels are higher for hinge impact than for spider acceleration loads — as is usually the case for configurations of this kind that do not carry reflector-mounted equipment; e.g., ACS pods, solar panels.



THERMAL ANALYSIS AND PETA DISTORTIONS

The only significant cause of PETA performance degradation is thermal distortion of the reflector surface. Manufacturing deviations are easily controlled to relatively low levels, and distortions resulting from dynamic effects in orbit are negligible because of the stiff truss structure. This section presents a summary of the extensive thermal and distortion analyses developed in support of the RF performance analysis presented in the following section.

ORBITAL CHARACTERISTICS

Reflector surface and antenna tube element temperature predictions have been obtained for a six-bay, 33-foot-diameter, and an eight-bay, 70-foot-diameter antenna. Synchronous orbital conditions were used, and a 0-degree angle between the earth-sun vector and the orbit plane was assumed. This orbit plane/earth-sun vector orientation yields the maximum earth shadow time of about 72 minutes.

Solar and earth-thermal radiation constants of 442.4 Btu/hr.-ft.^{2} and 1.87 Btu/hr.-ft.^{2} were employed. Earth-thermal radiation was included since it limits component temperature excursions to some extent during earth-shadow period. Earth albedo radiation was neglected since its effect on component temperatures during the illuminated portion of the orbit is extremely small.

All temperature predictions are based on a + Y flight direction as shown. This flight direction was used for two reasons: (1) a large number of surface and bottom struts are nearly normal to the solar flux vector over a large portion of the orbit, and (2) the antenna is symmetrical about the Y axis. Thus, when the apparent path of the sun is in the Y-Z plane, the calculations required to determine the antenna temperature distribution are reduced by almost 50%.

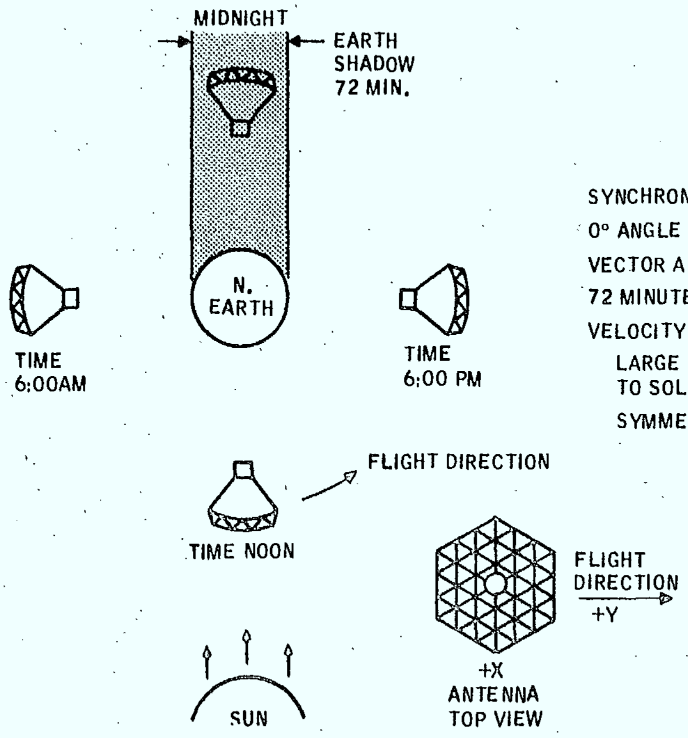
TEMPERATURE PREDICTIONS

A circular-wire square-mesh reflector surface configuration with an 80% open area was used in the analysis. For this configuration, the expression obtained for the fraction of open or void area of an element of the semitransparent reflector surface as a function of the solar incidence angle is presented in the figure at bottom right. For incidence angles less than about six degrees, the reflector surface mesh is completely opaque.

The mesh characteristics were used in a Convair-developed computer program which calculates the incident heat rates as a function of location on the reflector surface, and orientation with respect to the solar flux vector and projected area.

The incident heat rate calculations include partial or complete shadowing by other areas of the reflector surface mesh, and complete shadowing by the feed module and the earth. The feed module geometries used for the 33-foot and 70-foot antennas are presented.

ORBITAL CHARACTERISTICS



SYNCHRONOUS ORBIT

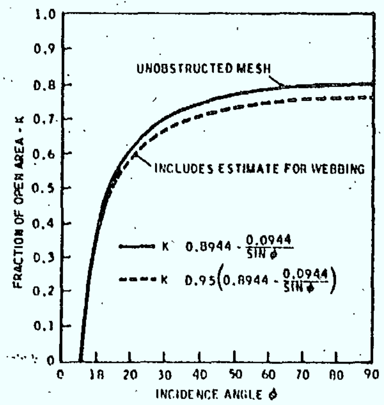
0° ANGLE BETWEEN EARTH-SUN VECTOR AND ORBIT PLANE

72 MINUTE EARTH SHADOW

VELOCITY VECTOR IN +Y DIRECTION

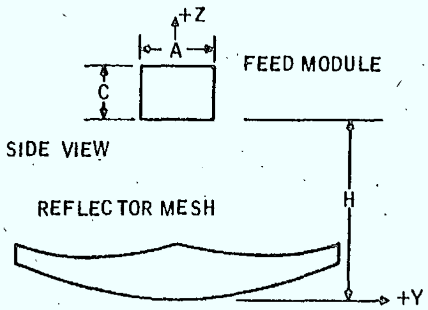
- LARGE NUMBER OF TUBES NEAR NORMAL TO SOLAR FLUX
- SYMMETRY ABOUT Y AXIS

TEMPERATURE PREDICTIONS



INCIDENT HEAT RATES

SHADOWING BY REFLECTOR MESH



SHADOWING BY FEED MODULE

ANTENNA	FEED MODULE	
(DIA.)	(H)	(A x B x C)
33.0 FT.	13.2 FT.	6.0 x 6.0 x 5.33 FT.
70.0 FT.	28.0 FT.	9.0 x 9.0 x 8.0 FT.

REFLECTOR MESH TEMPERATURE PREDICTION

Transient temperature predictions for the reflector surface mesh are based on the following characteristics:

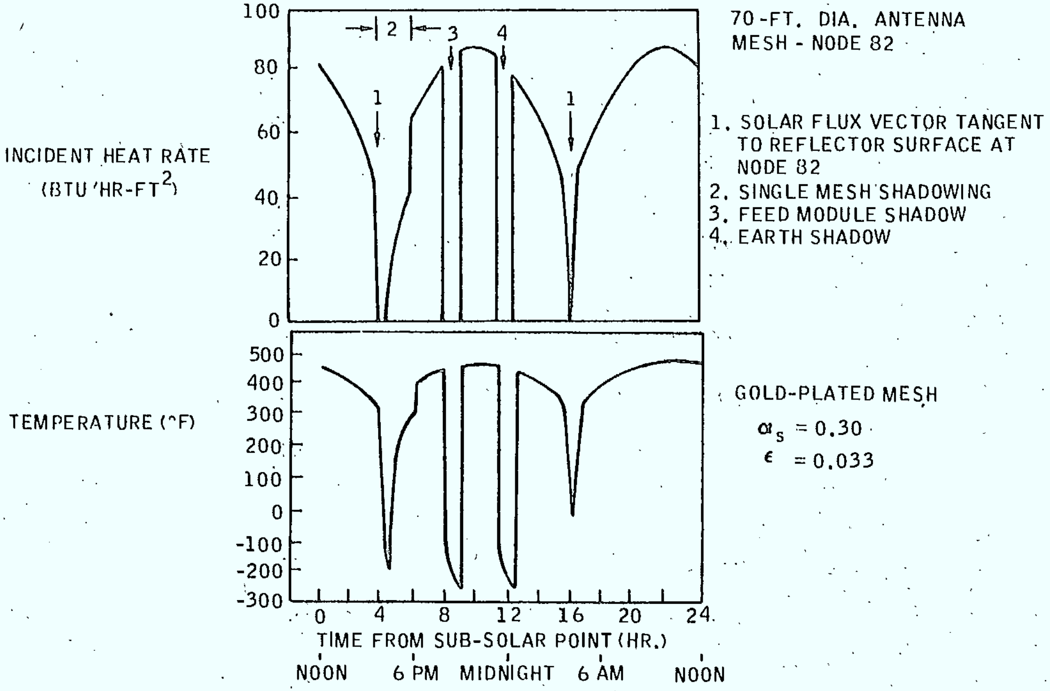
1. 80% open area
2. Opaque at low incidence angles
3. Weight = 1.35 oz./yd.^{2}
4. Specific heat = 0.107 Btu/lb.-°R
5. Solar absorptance = 0.30
6. Thermal emittance = 0.033

The solar absorptance (α_S) and thermal emittance (ϵ) is representative of the bright reflective gold-plated finish on the reflector surface mesh.

An example of the incident heat rate and the corresponding transient temperature predictions are presented for the 70-foot-diameter antenna at surface spider No. 82. Areas of interest, as indicated on the incident heat rate curve, include:

1. Solar flux vector target to reflector surface at Node 82
2. Shadowing by other portions of the reflector surface
3. Shadowing by the feed module
4. Earth's shadow

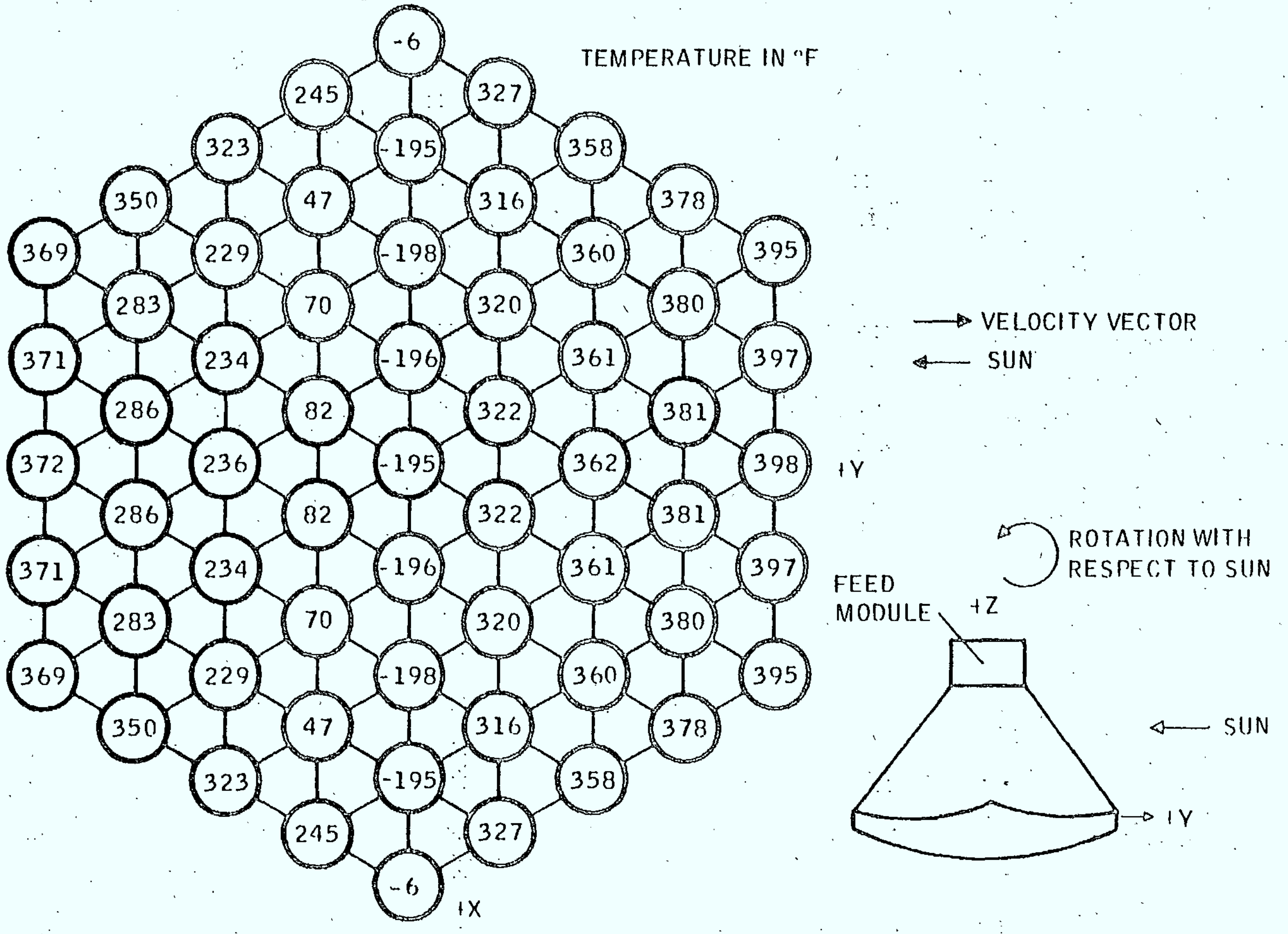
The extremely wide temperature fluctuations are caused by the high α_S/ϵ ratio and the low thermal mass.



REFLECTOR MESH TEMPERATURE DISTRIBUTION

The 70-foot-diameter reflector surface mesh temperature distribution obtained at the 6:00 a.m. orbital position is presented below. This position was found to be the worst case with respect to overall antenna distortion.

Mesh temperatures on the X axis are low since the solar flux vector is tangent to these nodes, and just prior to this orbital position, these nodes were completely shadowed by other portions of the mesh. Reflector surface locations to the left of the X axis are partially shadowed by the right half of the reflector surface.



TUBULAR ELEMENT NOMINAL TEMPERATURE

Incident heating rates for the antenna tubular elements were calculated assuming a location midway between adjoining spiders. The Convair-developed computer program used for determining the incident heating rates includes the effects of partial or complete shadowing by the reflector surface mesh, and complete shadowing by the feed module and the earth. Shadowing by the reflector surface includes single and double mesh shadowing depending on orientation with respect to the solar flux vector and the parabolic surface.

The heating rates and the transient average tube temperature predictions are based on the assumption that if the midpoint of the tube is shadowed, the whole tube is shadowed. Tube temperature predictions are for isolated elements, since the effect of the conduction heat transfer along the thin-walled tubes and across the pinned joints is negligible.

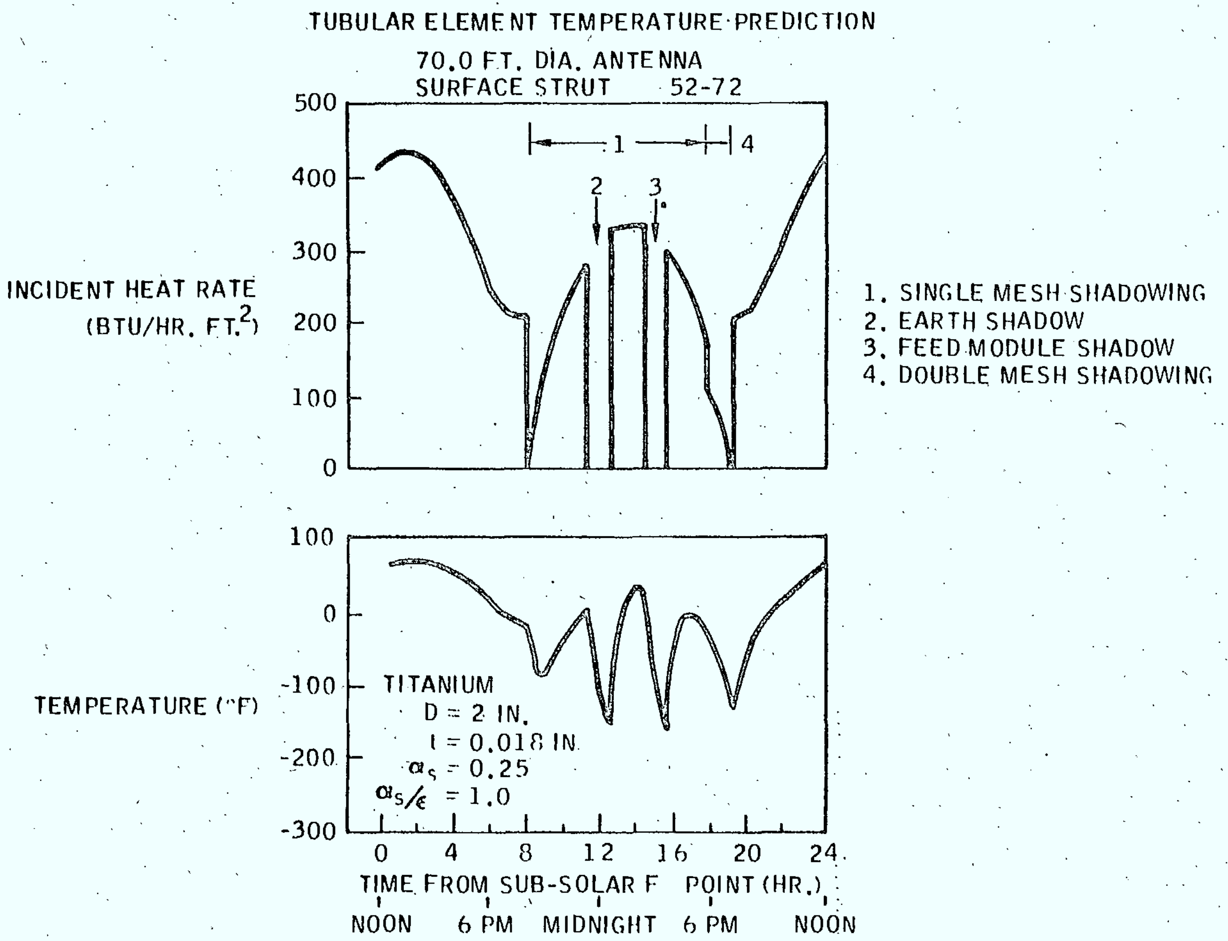
Titanium tubes having the following properties were employed.

1. Density = 0.163 lb./in.^{3}
2. Specific heat = 0.125 Btu/lb.-°R
3. Thermal conductivity = 4.2 Btu/hr.-ft.-°R

The tube sizes used in this study are presented below

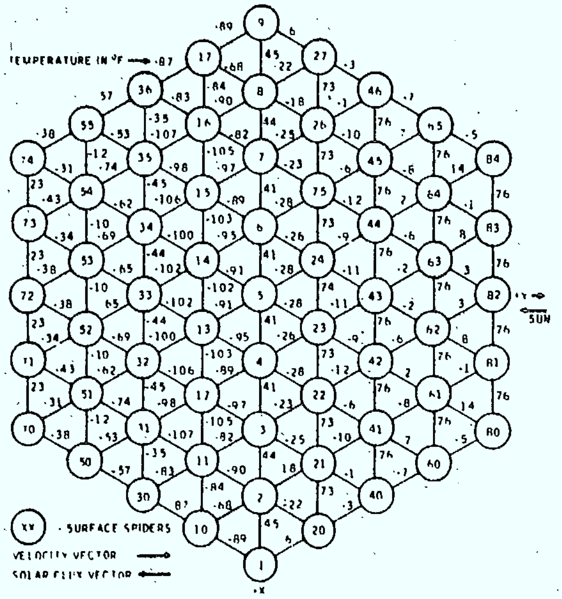
	33.0-Ft. Dia. 6 Bay (In.)	70.0-Ft. Dia. 8 Bay (In.)
Surface Struts	D = 1.5 t = 0.010	D = 2.0 t = 0.018
Diagonal Struts	D = 1.0 t = 0.010	D = 1.5 t = 0.015
Bottom Struts	D = 1.5 t = 0.010	D = 2.0 t = 0.018

An α_S/ϵ ratio of 1.0 was used since it yields a maximum average tube temperature of about +75°F (approximate fabrication temperature); α_S and ϵ values of 0.25 were used for predicting tube element temperatures. These values represent a flat reflector-type finish typical of aluminum-pigmented paints.

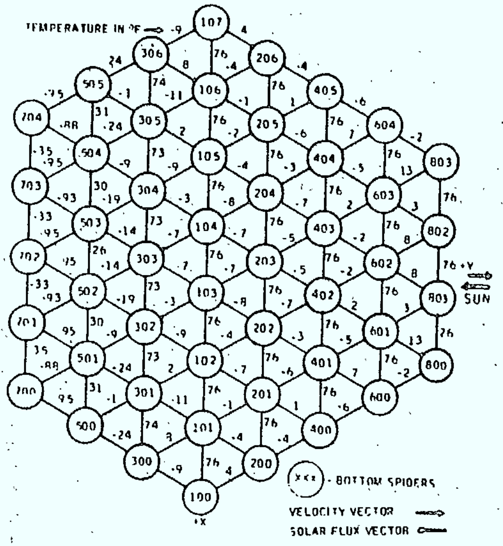


TUBULAR ELEMENTS TEMPERATURE DISTRIBUTION

The 70-foot reflector strut temperatures obtained at the 6:00 a.m. orbital position are presented. Surface strut temperatures just to the left of the X axis are very low due to the severe double-mesh shadowing occurring at this orbital position. The lowest temperatures for the diagonal and bottom struts appear closer to the left edge (-Y) of the antenna since they are located further away from the reflector mesh surface.

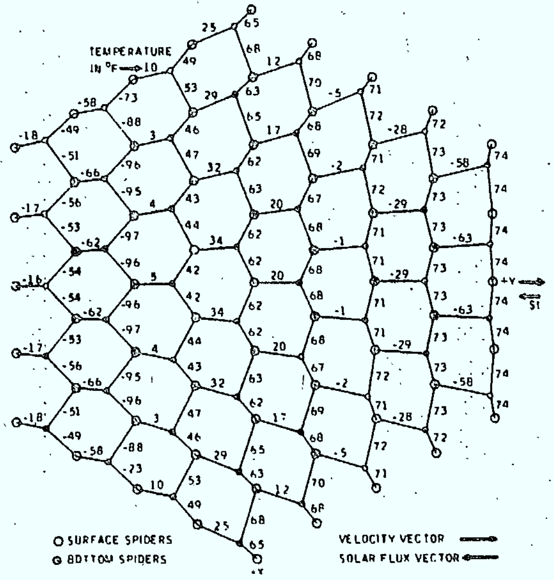


SURFACE STRUTS



BOTTOM STRUTS

DIAGONAL STRUTS

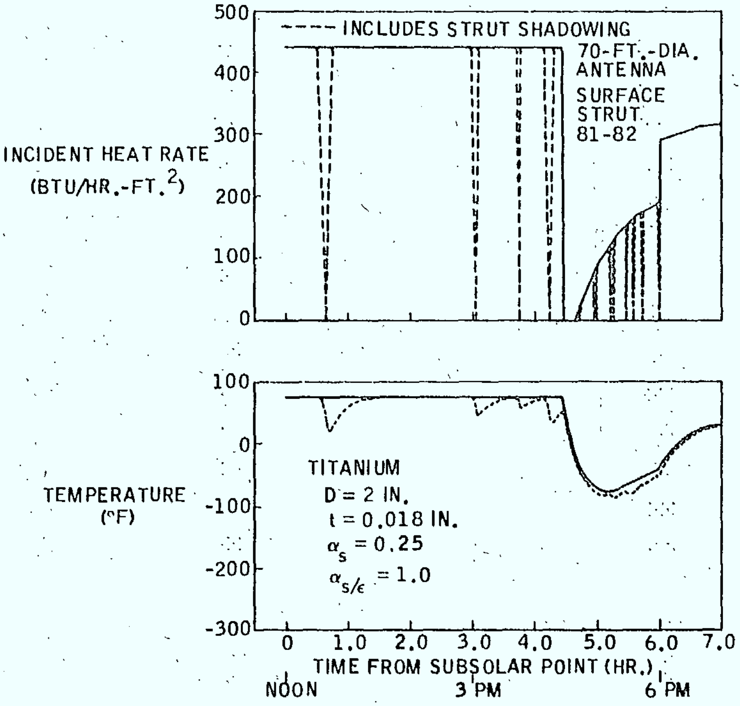


TUBULAR ELEMENT TEMPERATURE WITH SHADOWING

The major antenna strut temperature fluctuations are caused by the earth and feed module shadowing and by partial or complete shadowing by the semitransparent reflector surface mesh. Shadowing caused by other struts was not included in the temperature predictions presented above because of the complexity of the antenna configuration. In many cases, shadowing by other struts will affect only small local strut areas such as when the shadow of one strut falls across another at an angle. More severe strut shadowing does occur, however, and detailed calculations for several cases were obtained.

The typical example below shows the incident heat rate and the temperature predictions for surface strut 81-82 (70-foot antenna) during that portion of the orbit where major strut shadowing occurs. The effect of including the shadowing caused by struts which are essentially parallel to strut 81-82 is clearly indicated. The largest temperature excursions of about 50°F occur at the 12:45 p.m. and 4:15 p.m. orbital positions where the struts between bottom spiders 800 and 802 and surface spiders 61 and 63 shadow strut 81-82 (see previous illustration).

More severe shadowing occurs between diagonal struts 5-203, 33-303, 43-602, and 72-702. The differences in temperature between the shadowed and unshadowed cases for 5-203, for example, were as high as 150°F. This case is unique in that it only occurs when the apparent path of the sun is exactly in the antenna Y-Z plane. For a synchronous equatorial orbit, this case occurs at the vernal and autumnal equinoxes, or only twice a year. For all other conditions, temperature differences should be significantly less.



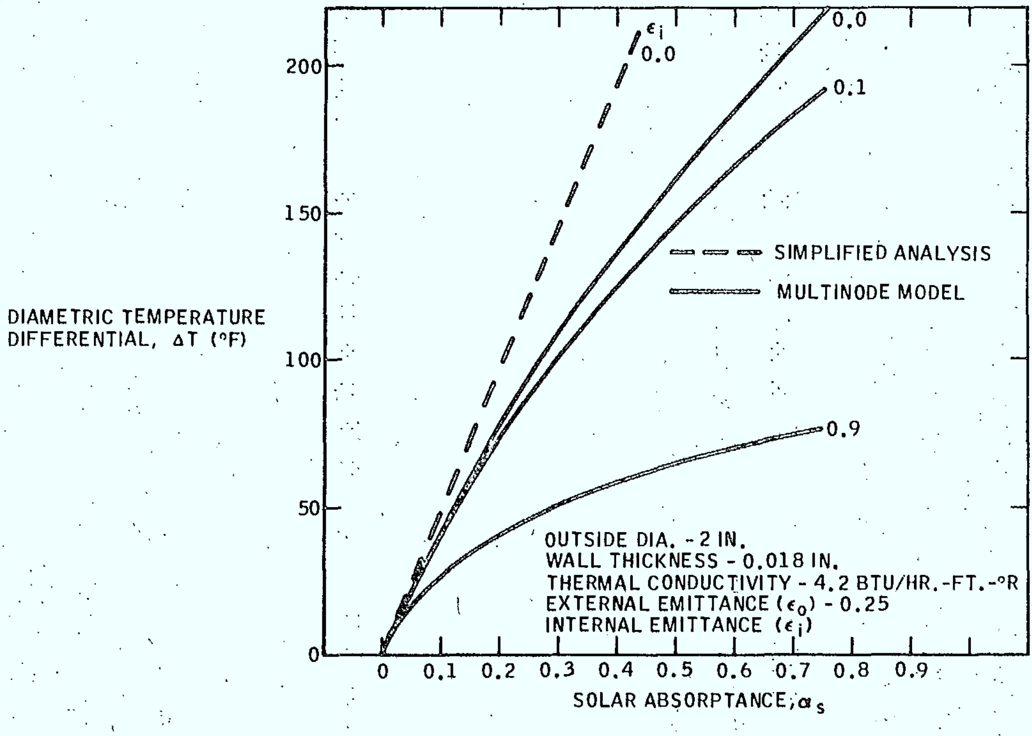
TUBULAR ELEMENT TEMPERATURE GRADIENT

The maximum equilibrium temperature gradient across thin-walled tubes can be obtained from the following equation provided the material has a high thermal conductivity or a low solar absorptance.

$$\Delta T_{max.} = \frac{D^2 \alpha_s Q_s}{4 t K}$$

The limitations on this equation are (1) no heat is transferred via radiation across internal surfaces of the tube, and (2) the temperature gradient is small enough such that for all practical purposes, heat radiated from external surfaces is equally distributed around the periphery of the tube.

Since titanium has a low thermal conductivity, a multinode thermal model was used for determining the temperature gradients. The figure shows the maximum equilibrium diametric temperature differential for a typical antenna tube. The effect of using the simplified equation is clearly indicated. For an external surface solar absorptance of 0.25, and with little or no heat transferred across internal surfaces of the tube, the diametric temperature differential is fairly high (about 85 to 95°F). A significant reduction in temperature gradient can be obtained by using a high-emittance internal surface coating as indicated.

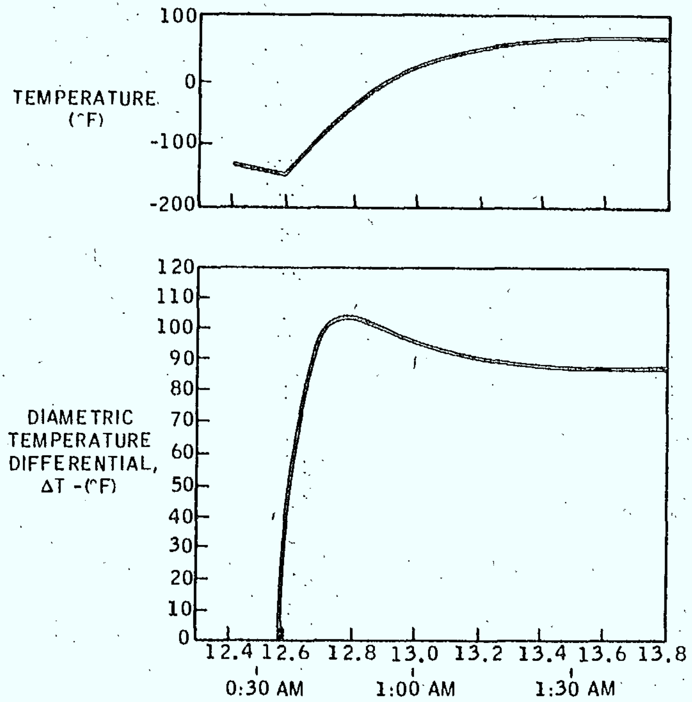


TRANSIENT DIAMETRIC TEMPERATURE DIFFERENTIAL ACROSS TUBES

The results shown in the previous figure are for equilibrium conditions and do not include the effect of transient conditions on the diametric temperature differential. A typical example of these effects is presented below. Here, the average tube temperature and the diametric temperature differential for surface strut 81-82 (70-foot antenna) are shown as a function of time during that portion of the orbit where the antenna emerges from the earth's shadow. During the rapid increase in tube temperature, the diametric temperature differential for the case considered reaches a peak value about 20% higher than that for equilibrium conditions.

It is anticipated that thermal bending of the tubular antenna elements will have very little effect on antenna distortion. The reflector surface and supporting truss distortions are affected indirectly by tube bending in that as the tube bends, the distance between the ends of the tube decreases slightly. This effect is small when compared to the effect of absolute temperature level on tube length.

Transient temperature gradients and resulting tube bending could possibly influence the dynamics of the reflector, depending on the time spans involved. Further study is required to define the effect of these thermal characteristics on reflector performance.



70-FT. DIAMETER
SURFACE STRUT 81-82
OUTSIDE DIA. - 2 IN.
WALL THICKNESS = 0.018 IN.
THERMAL CONDUCTIVITY =
4.2 BTU/HR.-FT.-°R
SOLAR ABSORPTANCE (α_s) = 0.25
EXTERNAL EMITTANCE (ϵ_0) = 0.25
INTERNAL EMITTANCE (ϵ_i) = 0.10

TUBULAR ELEMENT TEMPERATURE HISTORY

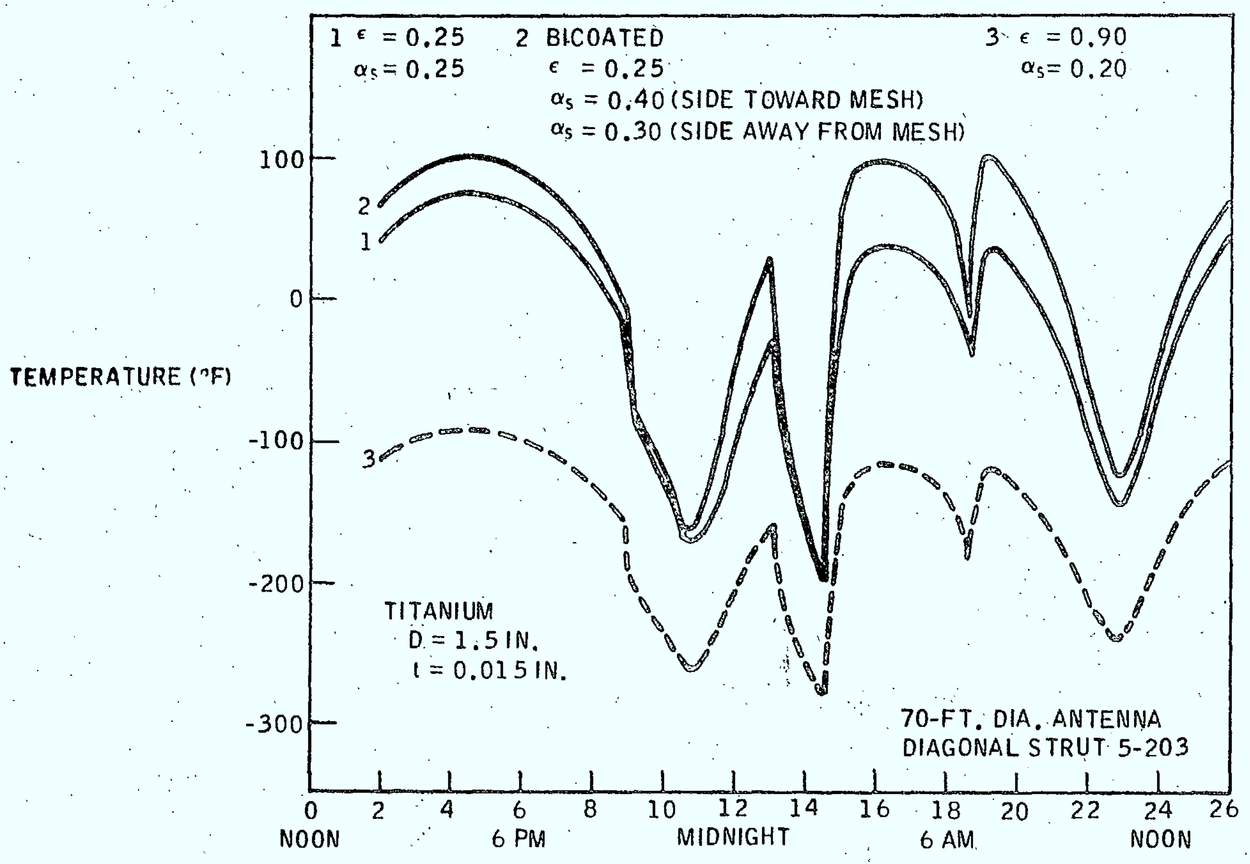
Particular care must be exercised in selection of antenna tube surface coatings. Low values of solar absorptance are required to limit distortion due to tube bending. Low values of thermal emittance are also required to limit temperature excursions during periods when elements of the antenna are either completely shadowed, or the projected area with respect to the sun is very small.

Surface properties used for predicting temperatures in this study were conservative and fairly easy to obtain. Ideally, α_S and ϵ values of 0.05 or less would probably give the best reflector performance from a thermal standpoint. Values difficult if not impossible to obtain are α_S and ϵ values of 0.05 or less, together with an α_S/ϵ ratio near 1.0.

Other coating schemes can be used to reduce distortion due to temperature differences. The figure opposite shows the results of using two different coating configurations and the comparison with those used in determining antenna distortions (α_S = 0.25, ϵ = 0.25). For the bicoated system, the α_S value was used on the side to compensate for the reflector mesh shadowing. As shown in the figure, the use of this scheme increased the temperatures, especially from about one a.m. to seven a.m., such that they are closer to the design and fabrication temperature (+68°F) over a greater portion of the orbit. For the particular coatings used, however, the difference between the maximum and minimum temperatures over the orbit increased from about 275 to 290°F. To reduce temperature excursions over an orbit, low α_S/ϵ ratios must be used. The dashed curve on the figure shows the results of using a low α_S/ϵ ratio, and high ϵ coating typical of white pigmented paints. Here, the average tube temperature is significantly below +68°F, and compensation during design and fabrication may be required. The advantage of this coating is that the differential between maximum and minimum temperatures over an orbit is decreased. For the case shown, the temperature differential decreased from 275 to 190°F.

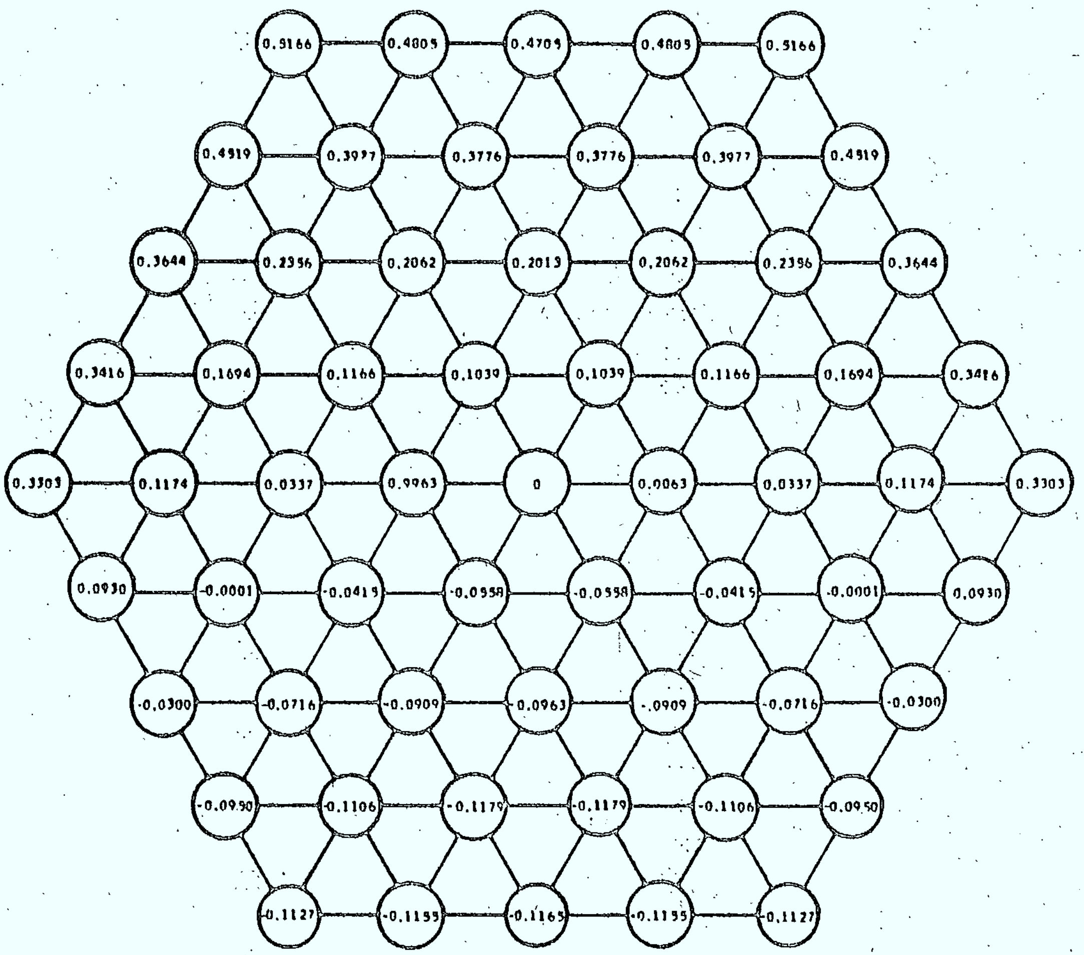
The results presented show the potential for decreasing thermal distortion through proper selection of coating configurations.

TUBULAR ELEMENT TEMPERATURE PREDICTION



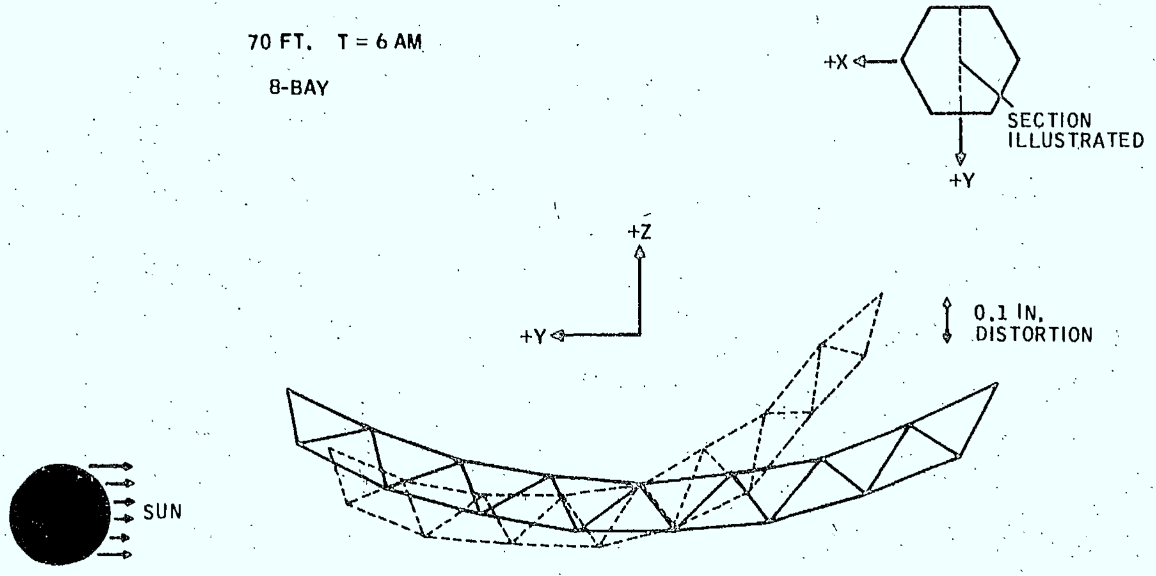
TRUSS SECTION DISTORTION

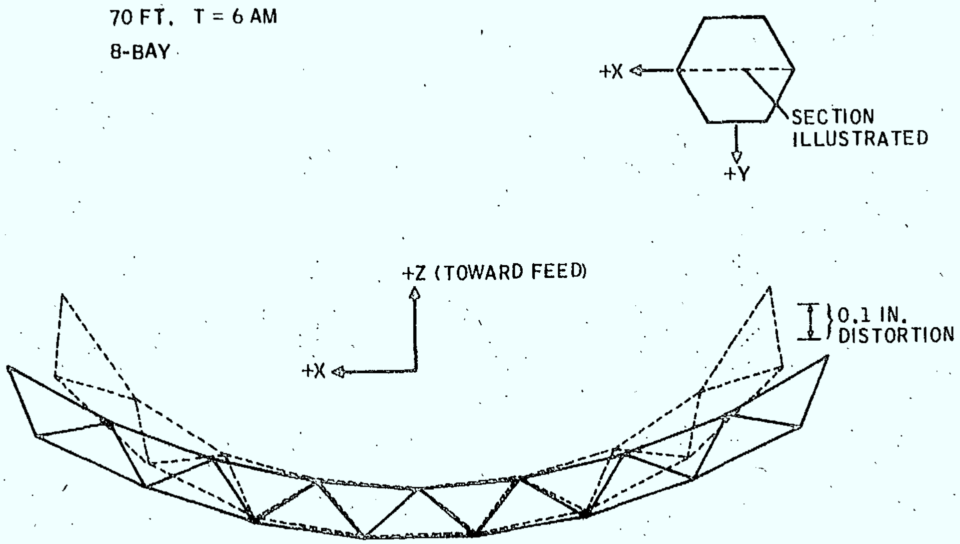
Truss thermal distortion analysis is performed with Convair's digital computer program No. 4422. The program calculates X, Y, and Z displacements, and final coordinates. It also calculates the normal displacement and half the path length change (epsilon) of the forward surface nodes. All truss deflections are relative to the center node in the forward surface. The program requires the tubular element temperature distribution previously discussed and a tubular element geometry subroutine (AGO) developed by Convair. A typical distortion pattern for a 70-foot antenna is shown below. The six a.m. case produces the most severe distortions for a synchronous orbit.



EXAMPLE OF TRUSS SECTION DISTORTION

To illustrate the physical effects of the thermal environment, examples of the distortion of two sections of the truss are shown for the 70-foot, eight-bay antenna at six a.m. Mesh shadowing causes the side of the antenna away from the sun to curl up.





TRUSS RMS THERMAL DISTORTIONS FROM ORIGINAL CONTOUR

The rms thermal distortions from the original contour are shown at right for 33-foot and 70-foot antennas for various times of the orbit. The two parameters presented are the rms of the normal displacement and the rms of half the path length change (the axial component of the normal displacement). The rms values are calculated with the following equation:

$$\text{rms} = \left[\frac{\Sigma (X_i)^2 \; W_i}{\Sigma W_i}\right]^{\frac{1}{2}}$$

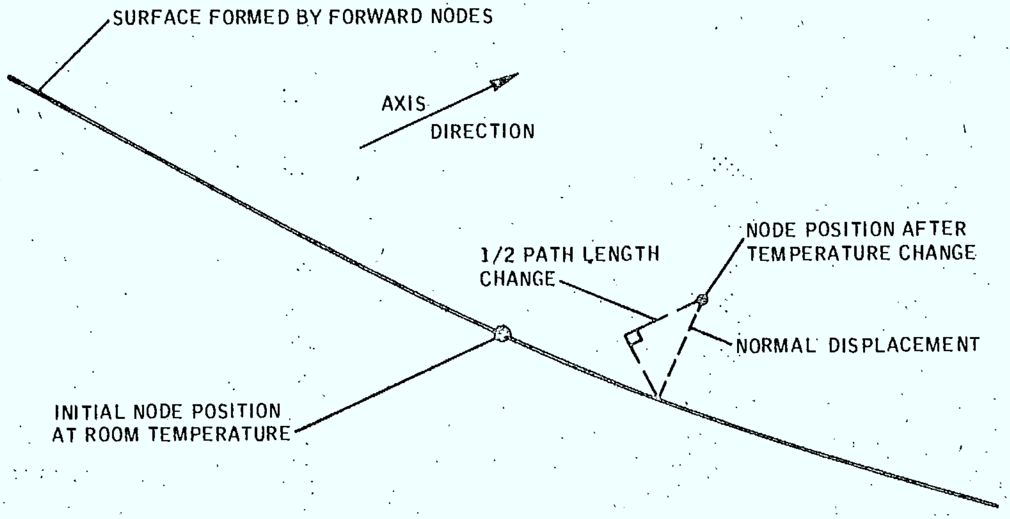
where:

X_i = ith parameter being analyzed.

W_i = ith weighting factor determined by effective area and illumination taper.

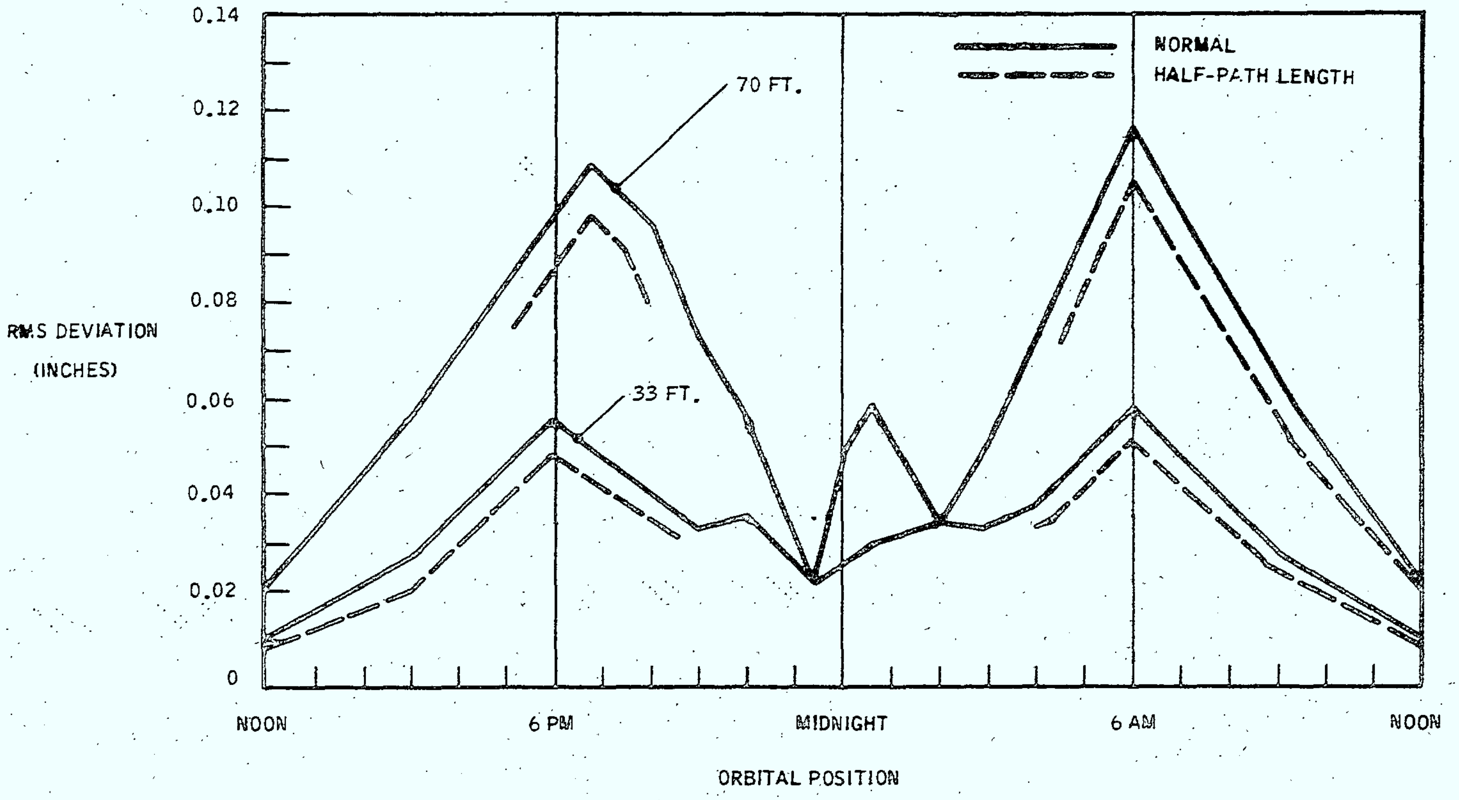
The normal displacement and half the path length change are defined in the figure below. Note that half the path length change is the axial component of the normal displacement, which is required to determine the effect of the distortions on RF performance. For an f/D ratio of 0.44, the rms half-path length change is about 10% less than the normal displacement.

NORMAL DISPLACEMENT OF A NODE



TRUSS THERMAL DEVIATIONS
8-BAY TITANIUM

$\alpha_s = 0.2, \epsilon = 0.9$

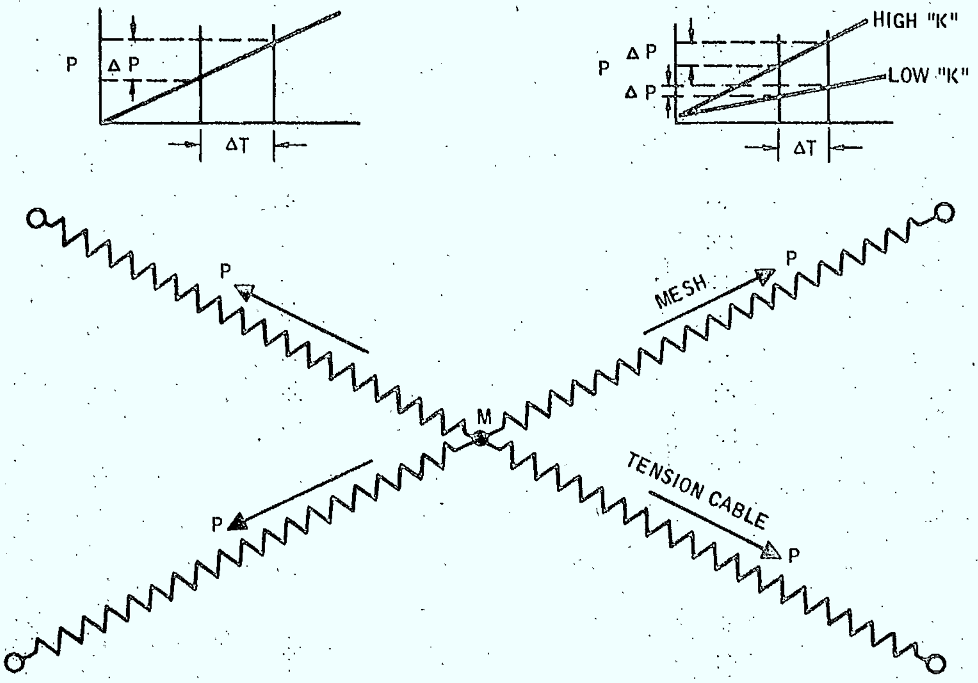


MESH THERMAL DISTORTION

As previously described, the mesh surface of the reflector experiences wide temperature variations during orbit and is generally much higher in temperature than the truss and mesh support system. Total distortions for the surface alone are low, however. The worst case for the 30-foot and 70-foot reflectors is 0.010 inch and 0.021 inch, respectively.

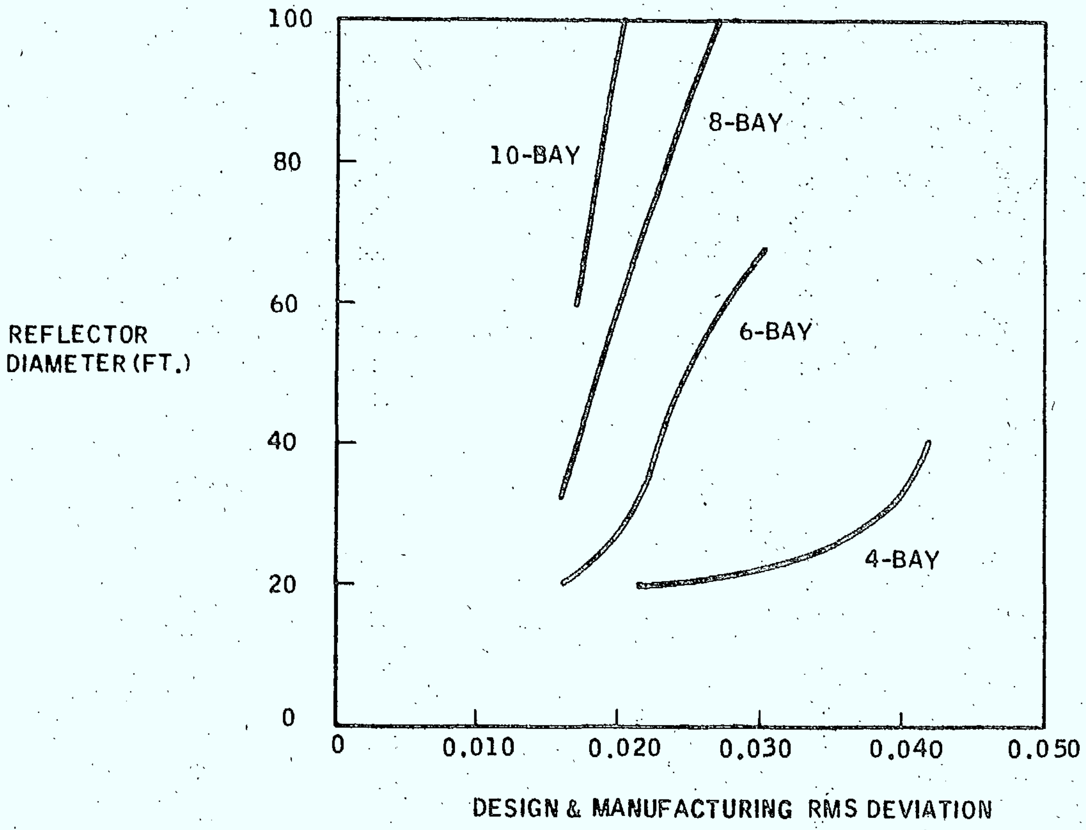
The primary factor in the low distortion of the mesh is its low spring factor. While expansion due to thermal variations may be high, the motion of point M on the figure below is dictated by the change in spring force ΔP. If the spring were of a constant-load type, such as a Negator spring, the thermal expansion would not change the position of point M. Basically, the knit woven mesh is a low spring factor material; with springs added to the adjustment cables, the effect of thermal change is greatly reduced. The gold-plated Chromel-R requires 0.02 pound per inch of material to pull it taut. The material will readily take 140 pounds per inch, which is substantially below the permanent set point in its thermal cycle variations. Since the material is entirely metallic, ultraviolet radiation or vacuum does not affect it. The low-modulus gold is plated onto the high-modulus Chromel-R. Therefore, thermal cycling will not flake off the coating. Tests at NASA-MSC substantiated this material for the Apollo lunar antenna.

MESH THERMAL DEVIATIONS
BASIC CONCEPT



DESIGN AND MANUFACTURING SURFACE DEVIATIONS

The desired parabolic contour of the mesh surface is approximated in the PETA design by producing a series of flat facets within each truss bay through the mesh support system. The inherent deviation from a true parabola depends upon the radius of curvature, which is a function of antenna diameter, and upon the size of the flat facet. As the number of bays increases, the facet size decreases for the same antenna diameter. The illustration below shows the sum of this inherent deviation and the manufacturing tolerance effect for various numbers of bays over the 20 to 100-foot-diameter range. A conservative manufacturing tolerance of ±0.020 inch has been assumed throughout. Note that the total rms deviation for the eight-bay version varies only slightly in the 30 to 60-foot-diameter range.



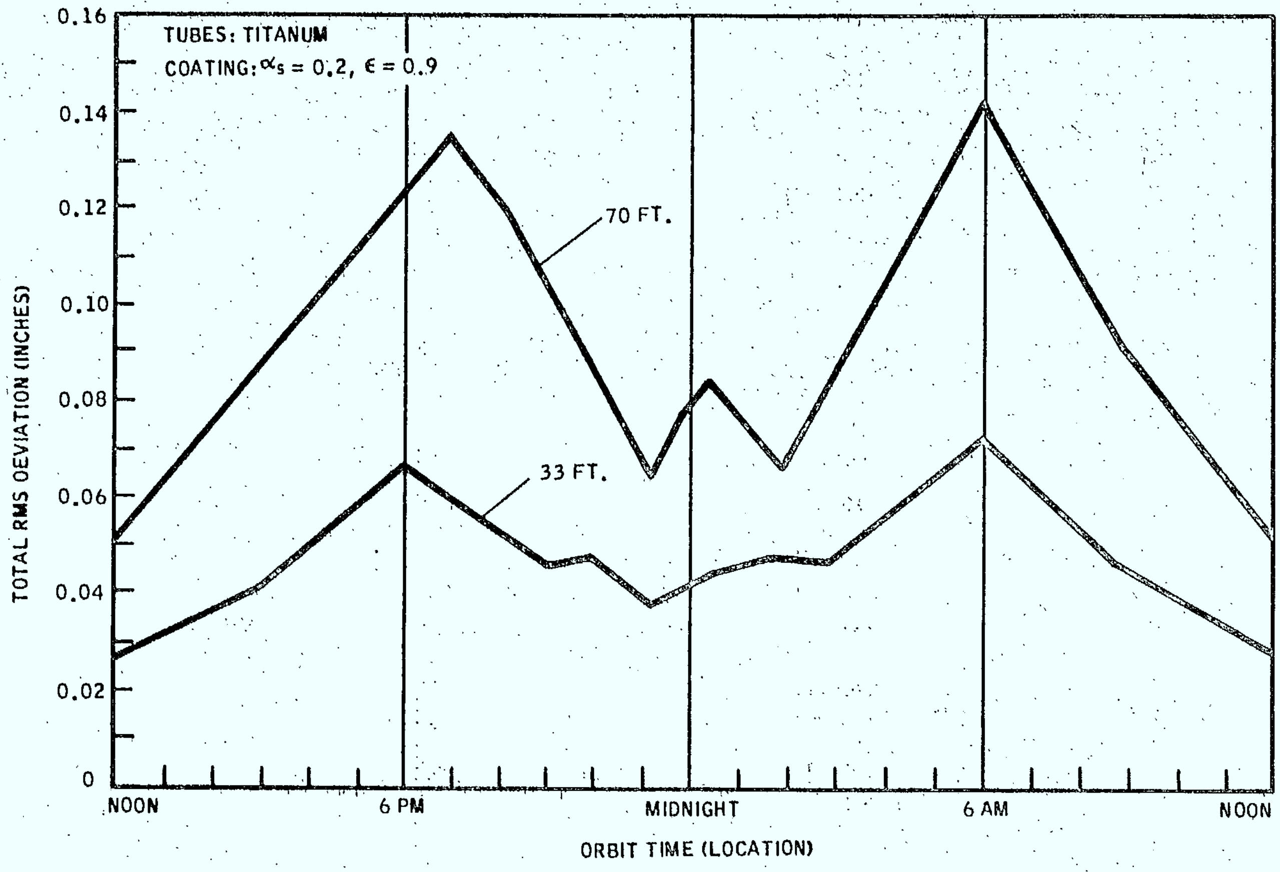
TOTAL NORMAL RMS DEVIATION VERSUS TIME

The plot below presents total normal rms deviation from the original parabolic contour as a function of time. The data is for 33-foot and 70-foot, eight-bay antennas. Total normal rms deviation includes thermal distortion of the truss and mesh and manufacturing deviations from an ideal parabolic contour.

The total rms value is determined as follows:

$$\delta_{rms} = \sqrt{(\delta_{truss} + \delta_{mesh})^2 + \delta^2_{mfg.}}$$

Except for very small antennas (up to 20 feet in diameter), the truss thermal distortion accounts for the major portion of the rms distortion.



RF PERFORMANCE

The RF performance of the PETA reflector is governed by the total rms surface distortion previously described and by the feed support structure. Thermal growth can displace the RF beam and axially defocus the antenna. Aperture blockage further degrades antenna performance by reducing the RF gain and increasing sidelobe levels.

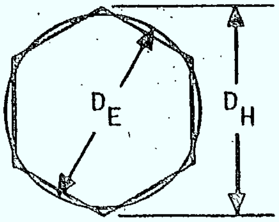
MAXIMUM FREQUENCY, GAIN AND SIZE

The figure on the facing page gives the maximum usable frequency for given antenna sizes based on mechanical and thermally induced surface deviations. Distortion data from the analyses were used in the equations:

$$f_{\text{max.}}\ (\text{GHz}) = \frac{0.94}{\sigma\,(\text{in.})}\ ;\quad G = 0.55\left(\frac{\pi D_e}{\lambda}\right)^2 e^{-\left(\frac{4\pi\sigma}{\lambda}\right)^2}$$

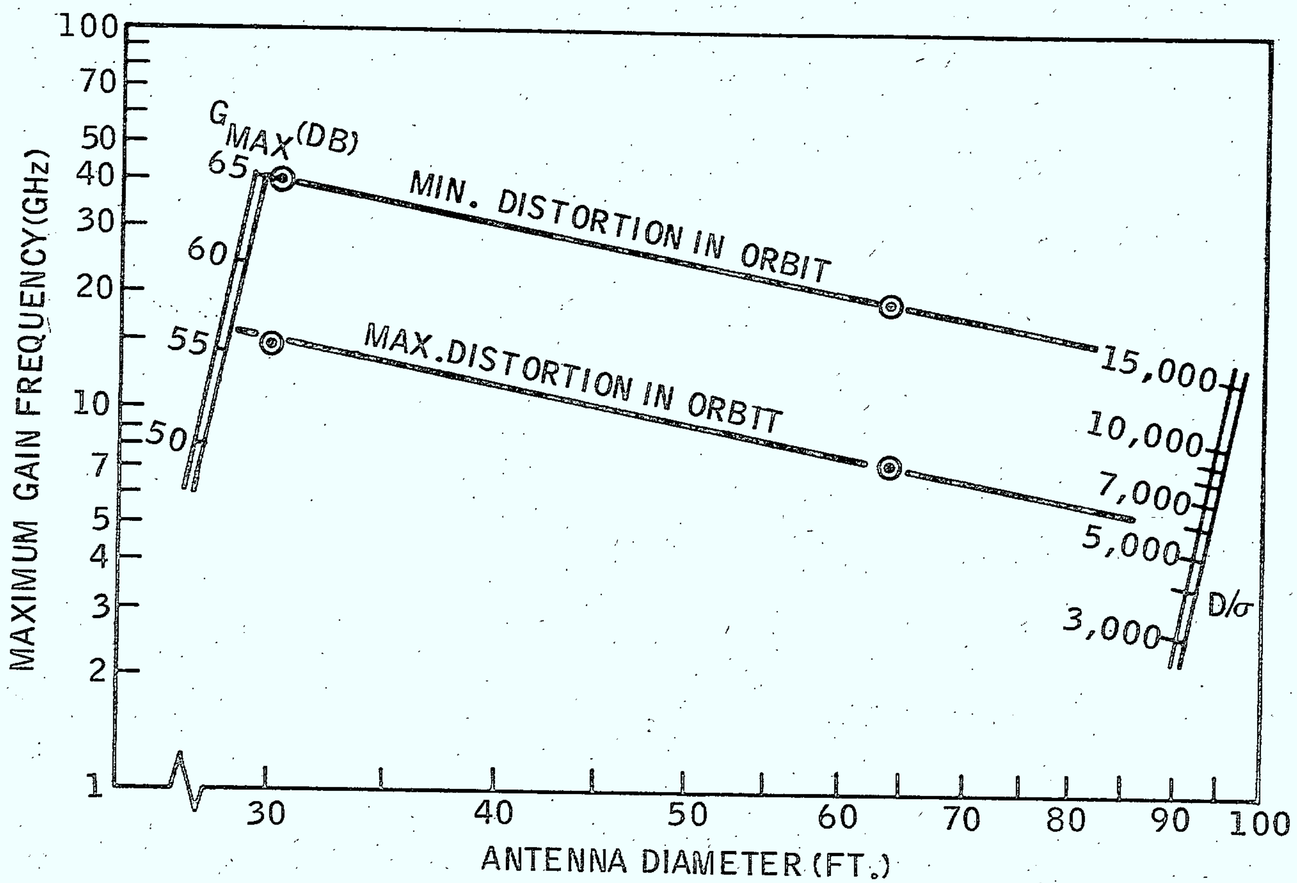
(derived from Ruze, $\lambda_{\text{min.}} = 4\pi\sigma$) to determine maximum frequencies and gain.

In this equation, σ is the rms value of the effective surface deviations. For a nominal f/D ratio of 0.44, the effective surface deviation is about 10% less than the normal displacement of the antenna surface. The values shown are for titanium tubular elements coated to produce a surface α_s/ϵ ratio of 0.22. The antenna diameter used is the equivalent circular diameter, which is about 9% less than the point-to-point reflector dimension as shown below:



EQUIVALENT CIRCULAR DIAMETER

$$D_E = 0.912\ D_H$$



MAXIMUM GAIN AND FREQUENCY CAPABILITY OF ERECTABLE
TRUSS ANTENNA IN SYNCHRONOUS ORBIT

RF BLOCKAGE EFFECTS

Placement of structural members in the antenna aperture to support feed elements, electronics, power equipment, ACS equipment, and docked spacecraft affects the antenna RF performance by increasing the sidelobe level and decreasing antenna gain. Loss in effective aperture area is illustrated opposite by the shadow regions No. 1, 2, and 3.

A large set of parameters controls the amount of blockage in these areas. Included are:

1. Feed module size
2. Feed strut
   - a. Width
   - b. Shape (tapered or constant width)
   - c. Attachment location on the reflector and on the feed module
   - d. Configuration, (bipod, tripod, etc.)
3. f/D ratio (assumed to be 0.4)
4. Illumination taper ($f(r) = 1 - a_o r^2$)
5. Reflector diameter

A computer program has been developed for the truss antenna to evaluate gain and sidelobe degradation based on expressions from Wested.*

EFFECT OF INCREASING FEED MODULE SIZE ON ANTENNA GAIN AND SIDELOBE LEVEL

In space systems, it is desirable to locate RF equipment sensors and other equipment in the antenna feed module. RF performance degradation from feed module aperture blockage increases significantly above normalized diameters of 0.1. For 30 and 70-foot antennas, this allows three-foot and seven-foot modules respectively. Illumination taper also affects RF performance, increasing degradation with increasing taper (a_o). Large normalized blockage diameters (0.2) negate tapering effects to achieve low sidelobe levels.

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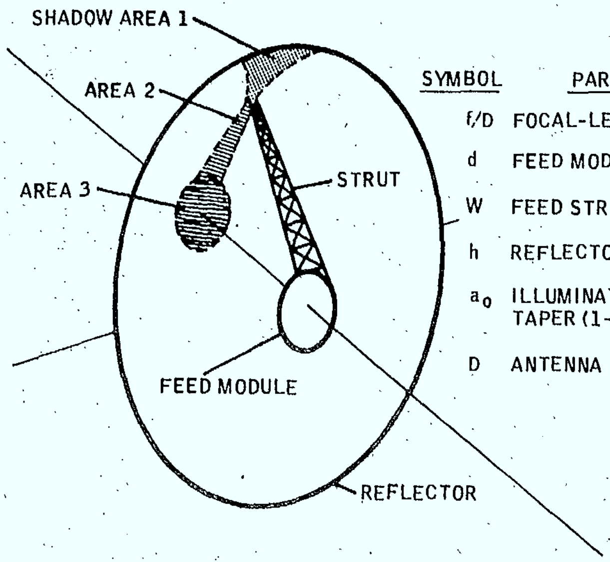
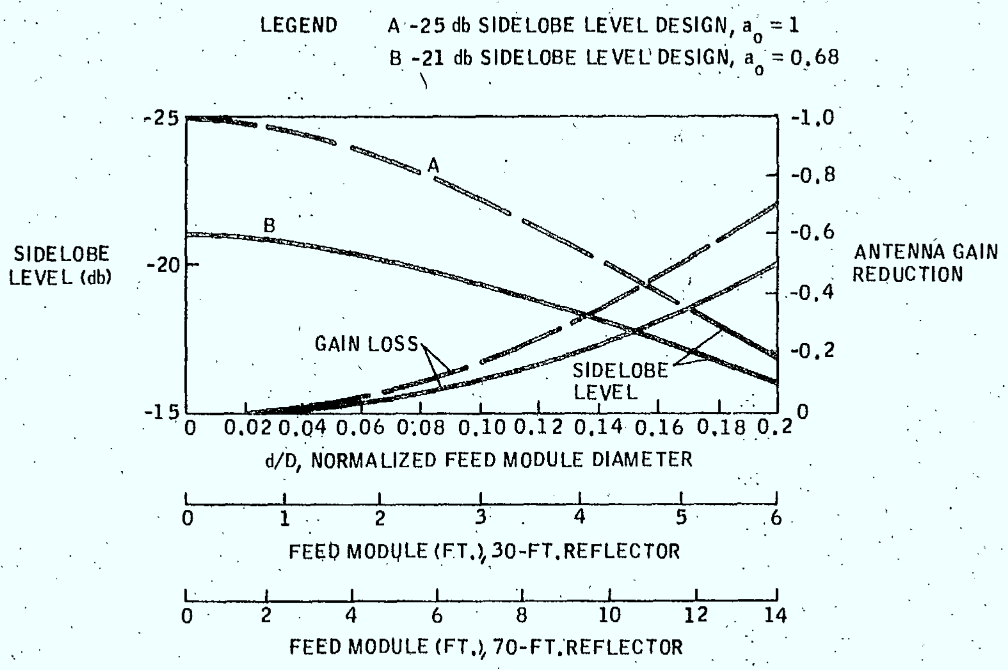
*J. H. Wested, "Shadow and Diffraction Effect of Spars in a Cassegrain System," IEE Conference Publication 21, pp. 110-115, London, 1966.

RF BLOCKAGE EFFECTS



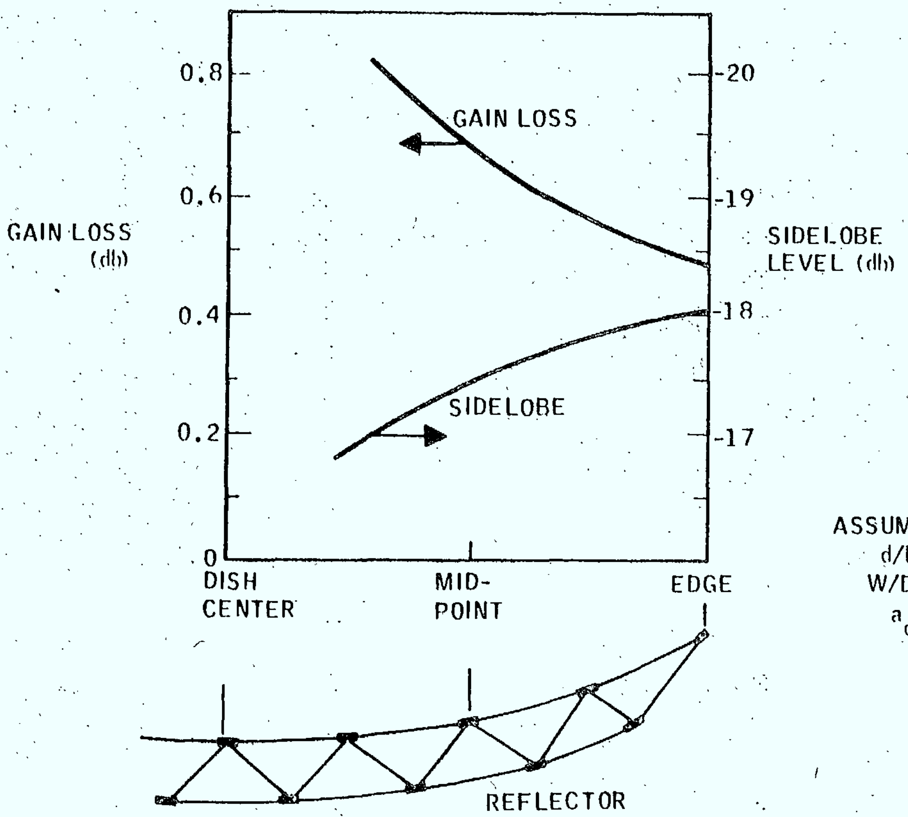
SYMBOL	PARAMETER	VALUE
f/D	FOCAL-LENGTH/DIAMETER	0.4
d	FEED MODULE SIZE	d/D = 0-0.2
W	FEED STRUT WIDTH	W/D = 0-0.04
h	REFLECTOR ATTACH POINT	h/D = 0.25, 0.38, 0.50
a_0	ILLUMINATION TAPER $(1-a_0\gamma^2)$	$a_0 = 0.68, 1.0$
D	ANTENNA DIAMETER	30 & 70 FT.

EFFECT OF INCREASING FEED MODULE SIZE ON ANTENNA GAIN AND SIDELOBE LEVEL



EFFECT OF REFLECTOR ATTACH POINT

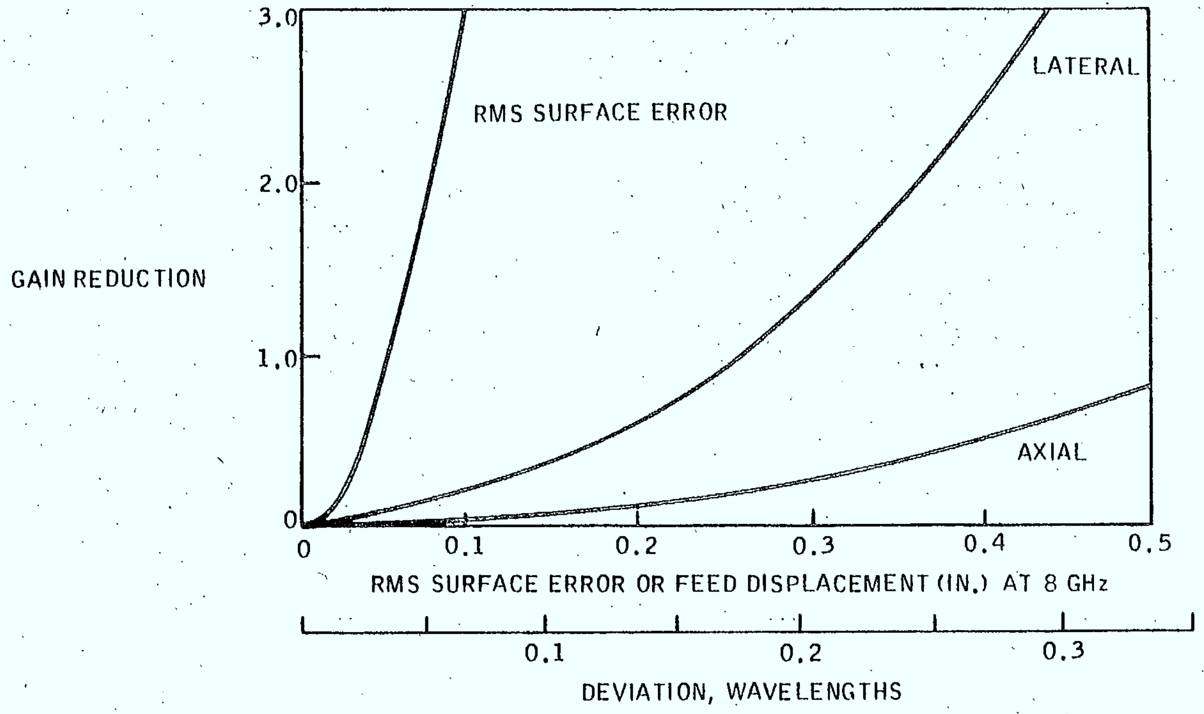
An eight-bay truss antenna provides four alternate tripod attach points. Points nearer the center of the antenna increase the preshaped shadow area (Area No. 3). The optimum attach point is at the edge. An advantage of approximately 0.6 db in sidelobe level and 0.4 db in gain is obtained by attaching at the reflector edge rather than midpoint, as shown below.



ASSUMPTIONS:
$d/D = 0.1$
$W/D = 0.02$
$a_o = 0.684$ (-21 db S.L.)

GAIN REDUCTION FOR FEED DISPLACEMENTS

Feed positioning errors and associated gain losses are illustrated in the chart below for an eight-GHz operating frequency. RF gain is more sensitive to lateral than axial positioning — approximately 0.06 inch (lateral) and 0.20 inch (axial) for a 0.1 db gain loss. Rms surface loss is also shown from the Ruze equation.

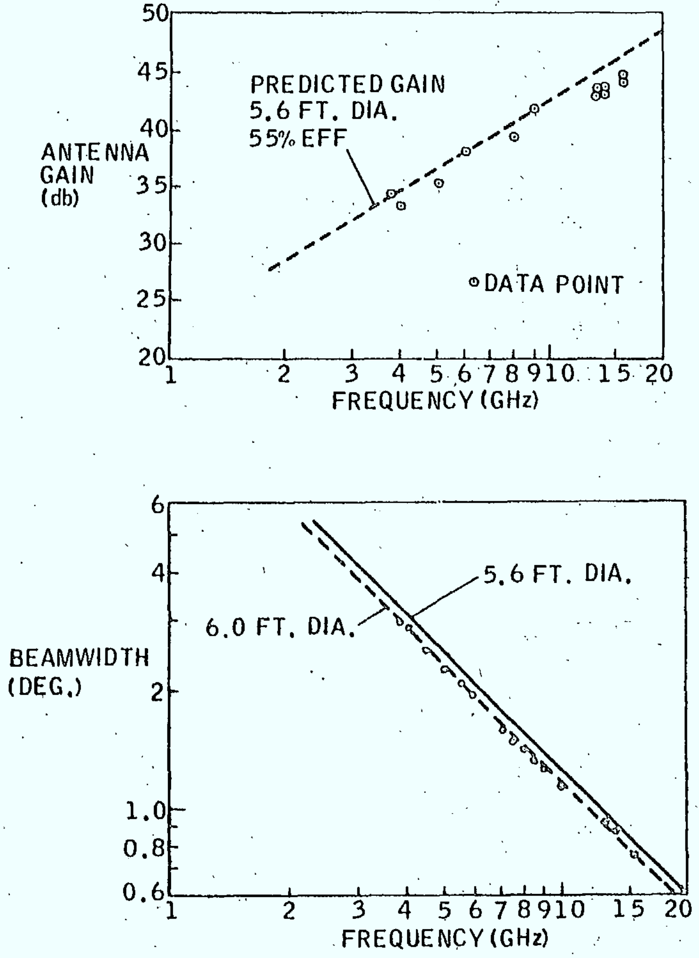


ANTENNA PATTERN FOR SIX-FOOT MODEL

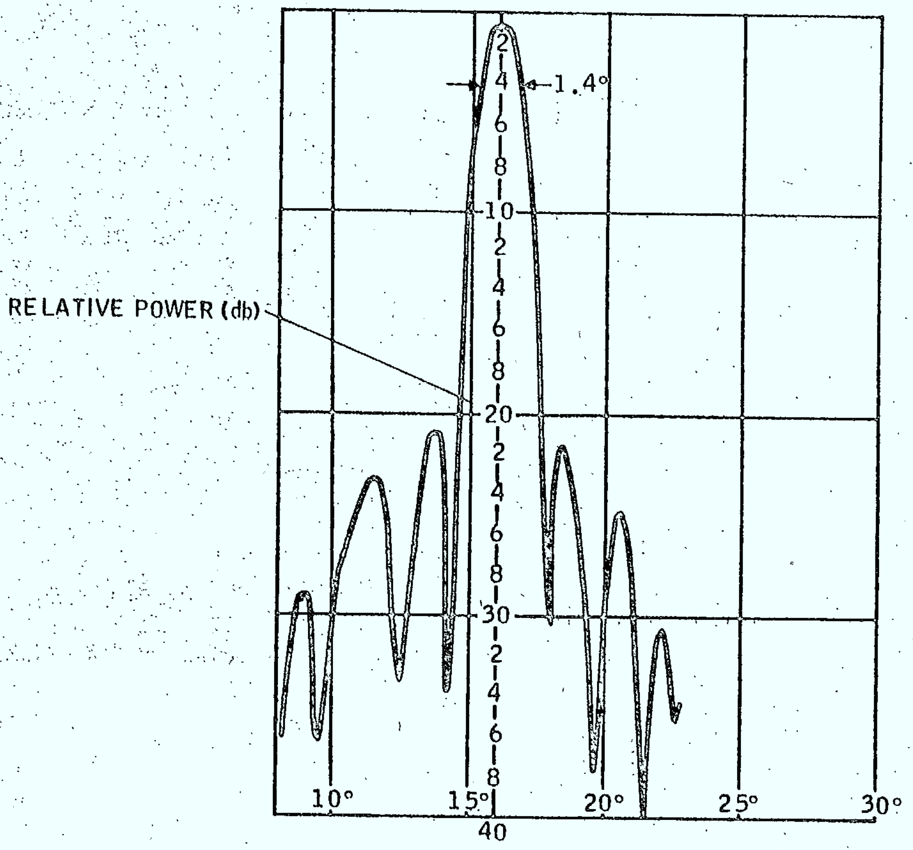
RF measurements have been taken on a simplified antenna model (six-foot diameter) of the expandable truss antenna. The model incorporates no provisions for fine mesh contour control. The pattern at right is typical of those taken at eight GHZ.

The six-foot diameter antenna model was tested to approximately 60% of its maximum gain frequency, achieving a gain of 44 db and 0.75-degree half-power beamwidth at 15.5 GHz. RF measurements are lower-limit performance values because of the economical mesh installation.

GAIN & BEAMWIDTH - SIX-FOOT MODEL



ANTENNA PATTERN OF SIX-FOOT MODEL AT 8 GHz



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5. ATS-F&G Parabolic Truss Antenna (PETA) Applications Study, Final Report, No. GDC DCL 68-005, 7 December 1968.

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