DEPLOYABLE TRUSS STRUCTURE
ADVANCED TECHNOLOGY

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FUTURE SPACE ANTENNA REQUIREMENTS DRIVE DEPLOYABLE STRUCTURE TECHNOLOGY

Deployable space structures can be divided into three classes: linear support members, platforms, and antennas. Although each class has unique technology issues, future large, space antenna systems, with severe stiffness, stability, weight, and packaging requirements, are the major drivers of deployable structures technology (Figure 1).

Commercial and military communication, radiometric, and surveillance satellites increasingly require reflector antennas with RF apertures 5 meters or larger to satisfy future mission requirements. Due to launch vehicle payload envelope constraints, reflectors that can be deployed in space are required for the 5-meter or larger aperture antenna.

Typically, deployable reflectors use a flexible RF reflective surface supported by a deployable back structure. Deviation of a reflector surface from that of an ideal paraboloid results in degradation of its radiation pattern. Several factors contribute to on-orbit surface error, including surface geometry approximations, fabrication and adjustment tolerances, thermal and dynamic distortion due to the orbital environment, gravity effects, and deployment repeatability.

Current large, deployable RF reflectors are typically designed to operate at low frequencies where large surface errors can be tolerated without significant performance loss. However, the trend of future advanced space applications is toward the utilization of frequencies above 14 GHz where sidelobe degradation and gain loss due to surface error can severely penalize antenna performance. To meet future requirements, the large deployable reflector will be required to achieve on-orbit surface error approaching that of a solid-surface reflector (3-10 mils rms).

In addition, requirements to maximize gain performance and radiation pattern purity are dictating the use of offset reflector geometry to eliminate blockage by the feed array and support structure. Collectively, these requirements drive future antenna systems toward high stiffness and thermal stability. These characteristics are best provided by deployable composite truss structures.

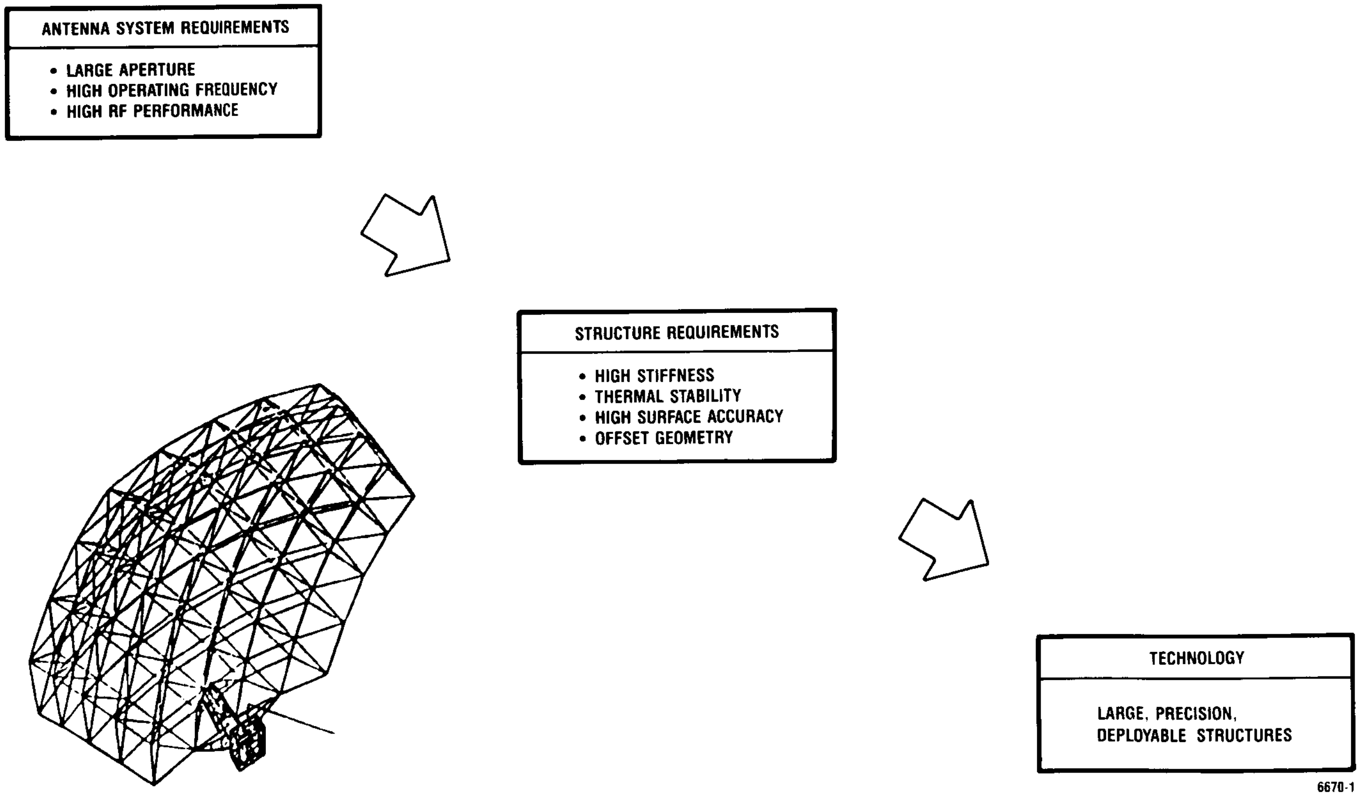


Figure 1.

DEPLOYABLE TRUSS STRUCTURES FOR FUTURE SPACE ANTENNAS

The deployable truss structure, when integrated with a precisely contoured mesh reflective surface, possesses the features needed to meet future space antenna requirements. Truss characteristics shown in Figure 2 that provide enhanced performance capabilities include:

- High Specific Stiffness — High inherent truss stiffness permits structure and control system frequency separation and minimizes active control needed to suppress structural vibrations excited by slewing torques and other dynamic disturbances. High stiffness also reduces deflections and reflector surface contour errors due to gravity effects during manufacture, adjustment, and ground test.
- Low Thermal Deformations — Low thermal deformations result from the use of simple axial truss structural members in an array manufactured from low-expansion, advanced composite materials.
- Good Packaging Efficiency — Folding tetrahedral building blocks provide an efficient structural package. This repeating modular truss design provides versatility by permitting simple scaling to accommodate varying geometric requirements.
- Edge-Mount Capability — For offset reflector applications, the tetrahedral truss reflector and feed structure are both deployed from one, simple edge mount thereby simplifying deployment, reducing weight, and improving system stiffness.

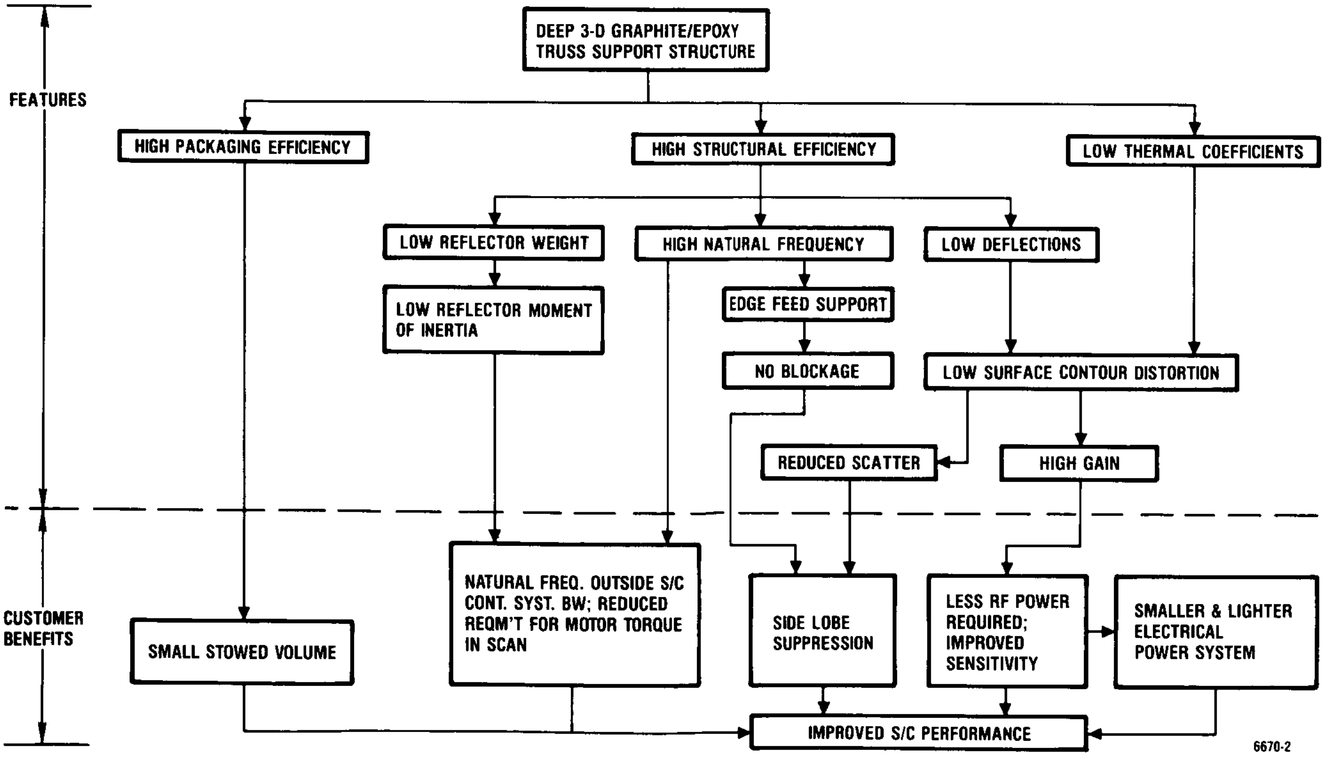


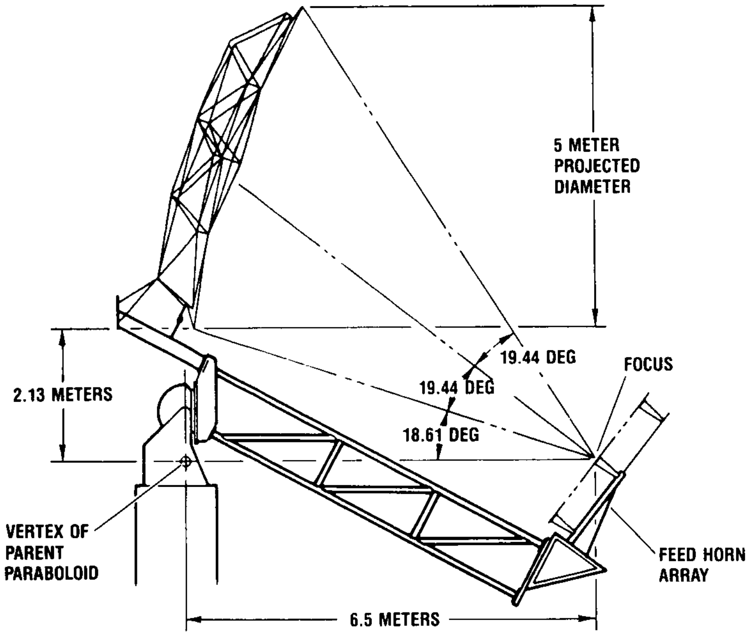
Figure 2.

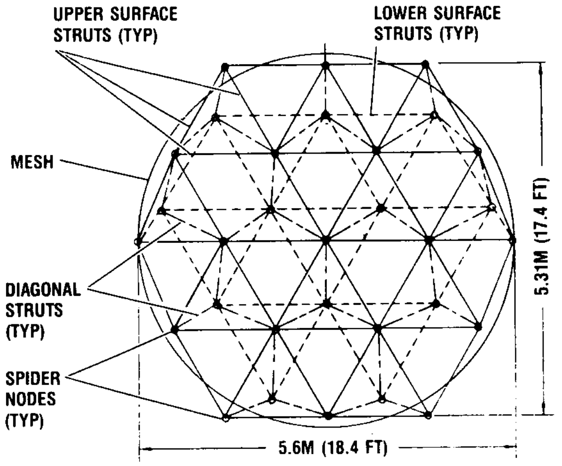
TECHNOLOGY DEMONSTRATION ANTENNA

A 5-meter antenna (Figure 3) was recently fabricated by General Dynamics Space Systems to demonstrate precision deployable, tetrahedral truss reflector technology. Design requirements representative of a space-borne communications antenna operating over a frequency range up to 30 GHz included a 5-meter projected aperture with an F/D ratio of 1.3, an offset of 2.13 meters and manufacturing rss surface tolerance of 7.7 mils, and total on-orbit rss surface tolerance of 11 mils.

On-orbit errors are created by thermal, dynamic hygroscopic, and visco-elastic effects. Thermal distortion is minimized by setting an overall thermal expansion coefficient goal (near zero), and then designing the individual structural elements to meet this overall goal.

The deployable truss was fabricated from graphite/epoxy composites for high stiffness and low thermal expansion. The reflective surface was fabricated from gold-plated molybdenum wire knit into a tight mesh for low transmission losses.





- DEPLOYABLE GRAPHITE/EPOXY TRUSS STRUCTURE
- PRECISION MESH SURFACE
- EDGE MOUNT

ERROR BUDGET FOR 5M DEPLOYABLE REFLECTOR

ERROR SOURCE	RMS SURFACE (MM)	ERROR MIL
FABRICATION SOURCES		
PROBE POSITION	0.054	(2.10)
PROBE GEOMETRY	0.064	(2.50)
MESH MEASUREMENT	0.051	(2.00)
MESH ADJUSTMENT	0.064	(2.50)
GRAVITY PREDICTION	0.051	(2.00)
DEPLOYMENT REPEATABILITY	0.076	(3.00)
SURFACE APPROXIMATIONS	0.114	(4.50)
ALIGNMENT	0.051	(2.00)
RSS TOTAL	0.194	(7.63)
ON-ORBIT SOURCES		
THERMAL DISTORTION	0.0787	(3.10)
DYNAMIC DISTORTION	0.0025	(0.10)
HYGROSCOPIC EFFECTS	0.0051	(0.20)
VISCOELASTIC CREEP	0.0127	(0.50)
RSS TOTAL	0.0800	(3.15)
TOTAL	0.255	(10.87)

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Figure 3.

TRUSS STRUCTURE DESIGN

The truss structure design was based on the deployable tetrahedral truss configuration with geometry and members selected to meet stiffness and surface precision requirements. A computerized tetrahedral truss analysis program (Figure 4) was used to generate the complete three-dimensional truss geometry and define the required truss element properties.

All structural elements, including tubular truss members and node fittings, used graphite/epoxy laminates designed to have an overall coefficient of thermal expansion (CTE) near zero. Zero tolerance titanium carpenter tape hinges were used to fold the truss members for packaging and to provide stored spring energy for deployment. The large, positive CTE of the titanium hinges was considered in the strut design so that when combined with the negative CTE graphite/epoxy tubes, the overall CTE of the member was near zero.

TRUSS PARAMETER: 4 BAY 30.00 DEG AN 5M (16.0 FT) RF DIAMETER
0.00 EF 283 L-RHO ROUND .400 F/D 20.0% CONTINGENCY

COMPONENTS	UNIT WEIGHT KILOGRAMS	UNIT WEIGHT (POUNDS)	NUMBER REQUIRED	WEIGHT KILOGRAMS	WEIGHT (POUNDS)
STRUTS	0.138	(0.305)	102	14.1	(31.1)
UPPER SURFACE	0.167	(0.369)	42	7.0	(15.5)
TUBES	0.099	(0.218)	42	4.1	(9.1)
HINGE	0.015	(0.032)	42	0.6	(1.4)
END FITTING + PINS	0.027	(0.060)	84	2.3	(5.0)
DIAGONALS	0.076	(0.167)	36	2.7	(6.0)
TUBES	0.073	(0.161)	36	2.6	(5.0)
END FITTING + PINS	0.001	(0.003)	72	0.1	(0.2)
LOWER SURFACE	0.182	(0.402)	24	4.4	(9.6)
TUBES	0.112	(0.247)	24	2.7	(5.9)
HINGE	0.015	(0.032)	24	0.4	(0.8)
END FITTINGS + PINS	0.028	(0.061)	48	1.3	(2.9)
SPIDER ASSEMBLY	0.125	(0.275)	31	3.9	(8.5)
MESH INSTALLATION	2.241	(4.941)	1	2.2	(4.9)
CONTINGENCY				4.0	(8.9)
REFLECTOR WEIGHT				24.3	(53.5)

X-C.G. CENTIMETERS (INCHES)	0.00000	(0.00000)
Y-C.G. CENTIMETERS (INCHES)	0.00000	(0.00000)
Z-C.G. CENTIMETERS (INCHES)	17.60790	(6.93223)
Ixx KILOGRAM METER SQ. (SLUG FT2)	56.98889	(42.00081)
Iyy KILOGRAM METER SQ. (SLUG FT2)	56.98889	(42.00081)
Izz KILOGRAM METER SQ. (SLUG FT2)	105.50880	(77.75999)
Ixy KILOGRAM METER SQ. (SLUG FT2)	0.00000	(0.00000)
Ixz KILOGRAM METER SQ. (SLUG FT2)	0.00000	(0.00000)
Iyz KILOGRAM METER SQ. (SLUG FT2)	0.00000	(0.00000)

NOTE - MOI ABOUT CENTER OF GRAVITY

MISCELLANEOUS GEOMETRY DATA	UPPER SUR		DIAGONAL		LOWER SUR	
LOAD (PCR) NEWTONS (LB)	896.0	(200.0)	1013.0	(226.0)	784.0	(175.0)
DIAMETER CM (IN.) STRUT	1.69	(0.67)	1.27	(0.50)	1.72	(0.68)
THICKNESS CM (IN.) STRUT	0.051	(0.020)	0.051	(0.020)	0.051	(0.020)
DES STRUT LENGTH CM (IN.)	154.4	(60.8)	102.3	(40.3)	169.3	(66.7)
HINGE LENGTH CM (IN.)	12.8	(5.0)	0.0	(0.0)	12.8	(5.0)

STANDOFF LH CM (IN.)	20.2	(8.0)	SPIDER DIA CM (IN.)	13.1	(5.2)
MESH AREA M2 (FT2)	22.5	(242.2)	TRUSS DEPTH M (FT)	0.2	(0.8)
PACKAGE DIA CM (IN.)	61.2	(24.1)	HEIGHT CM (IN.)	170.2	(67.0)

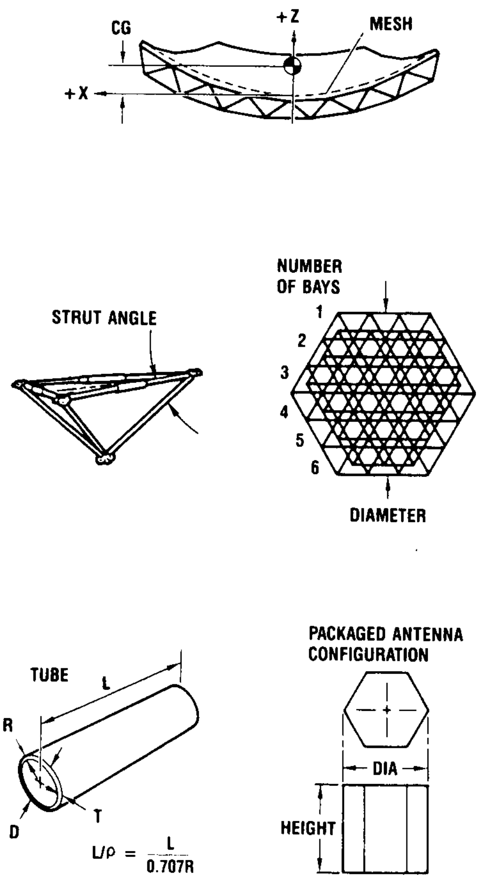

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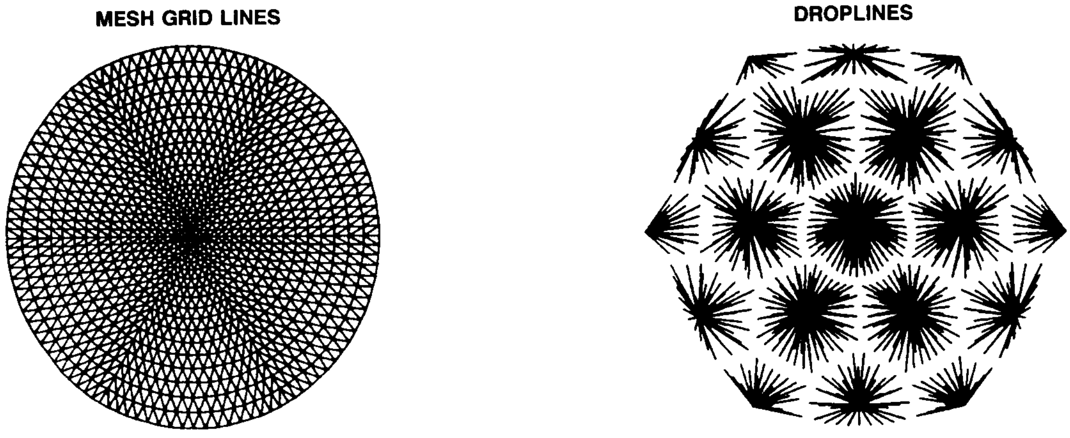
Figure 4.

MESH REFLECTOR DESIGN

Mesh system design used a computerized geometry analysis that optimally subdivided the mesh surface into small, triangular facets whose positions are controlled by lines attached to the truss structure node fitting (Figure 5). Consideration of illumination taper permits facet geometry to be varied so that the facet sizes progressively increase from the center to the periphery. This non-periodic geometry reduces grating lobes that may result from an equally subdivided surface. To meet the high precision required, the 5-meter diameter surface was divided into 1,944 facets varying in size from three to six inches on a side.


MESH GRID LINES

DROPLINES

MESH SYSTEM WEIGHT SUMMARY

ITEM	NO. REQ	WEIGHT
MESH TRIANGLES	1944	2.975
GRID LINE SEGMENTS	2970	1.194
DROP LINES	1027	1.369
BUTTONS	1027	1.046
CLIPS	1027	0.136
MESH SYSTEM TOTAL		6.719
MESH AREA (SQ YDS)		25.1
TOTAL LINE LENGTH (FT)		3749.0

MESH DIA (FT)	16.404
NO. OF BAYS	4
F/D	1.300000
NO. OF DIV./BAY	9
X OFF SET - % DIA.	0.000000
Y OFFSET - % DIA.	0.426000
HOLE RADIUS (IN.)	0.0000
DB TAPER	10.00000
WEIGHTING 0-NONE, 1-AR, 2-ILL, 3-BOTH	3
MESH LOAD LB/IN.	0.06000
GRID LINE LOAD LB	1.50000
GROSS WEIGHT LB	6.719
X-ARM	−0.022
Y-ARM	183.383
Z-ARM	36.337
I_{XX}-SLUG FT2	3.763
I_{YY}-SLUG FT2	3.768
I_{ZZ}-SLUG FT2	4.006
I_{XZ}-SLUG FT2	0.000
I_{XY}-SLUG FT2	0.000
I_{ZY}-SLUG FT2	1.183

NUMBER OF POINTS	65124
NORMAL RMS	0.00451
HALF PATH L RMS	0.00453
X DEFLECTION	−0.16197
Y DEFLECTION	−0.07396
Z DEFLECTION	0.04038
DELTA FOCAL LENGTH	0.33303
ROTATION ABOUT X-X	−0.00063
ROTATION ABOUT Y-Y	0.00031

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Figure 5.

TRUSS STRUCTURE FABRICATION

A simple but highly precise modular approach was used to fabricate the truss structure. Assembly was accomplished with the aid of 19 tooling stanchions (Figure 6) that precisely located the truss node fittings. Individual truss members and fittings were assembled on this tool so that any tolerances were removed by simple, on-assembly length adjustments.

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Figure 6.

MESH SURFACE FABRICATION

The mesh surface was fabricated using 20-gauge, two-bar tricot knit fabric. The pattern results in a 0.045-inch maximum dimension hole size, which extends RF performance into K-band and reduces cross-polarization response significantly. The fabric is knit from 1.2-mil, gold-plated molybdenum monofilament wire.

The mesh assembly is formed to the parabolic contour of a precision plaster mold (Figure 7). The initial contour of the mesh is maintained by a system of grid lines interconnected to buttons located at each apex of the triangular facets subdividing the mesh. The buttons, which are attached and bonded to the mesh, also provide the attach points for the 1,027 mesh control lines. These lines run from the truss node fittings to the mesh and are used to adjust the mesh surface.

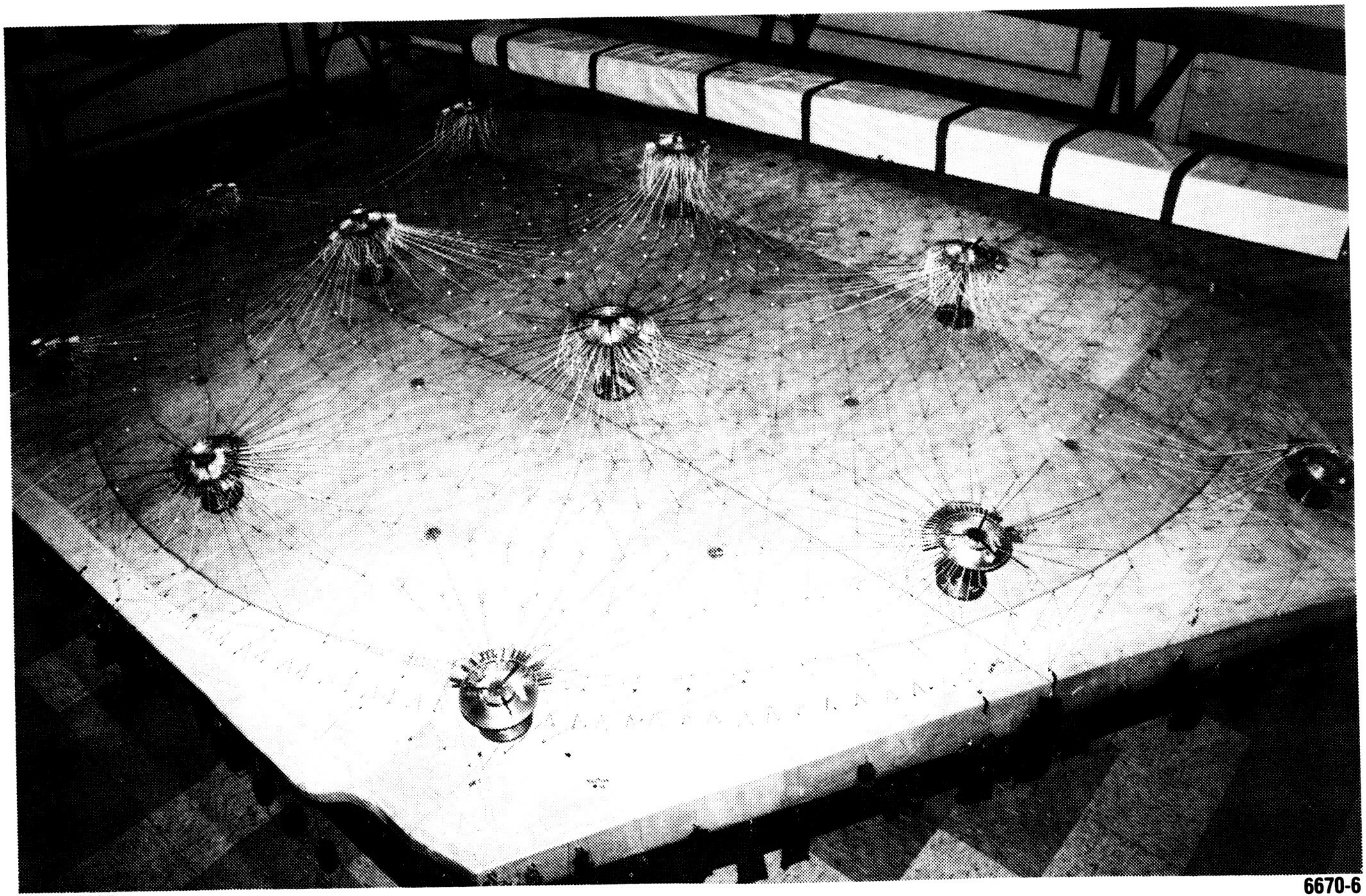

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Figure 7.

CONTOUR MEASUREMENT AND ADJUSTMENT

A computer-controlled profilometer contour measurement system incorporating a non-contact sensing probe (Figure 8) was used for measurement and adjustment of the reflective, mesh surface. The probe uses a digitally driven, capacitive transducer accurate to ±$1/2$ mil for proximity detection of the mesh surface. The 1,027 control lines between the mesh surface and the truss structure were loosened or tightened to adjust the mesh surface. Four iterations were required to complete adjustment of the mesh surface to the required accuracy. After the surface was set, the mesh control lines were locked out and the adjustment devices removed.

Photogrammetric measurements of 315 random targets on the surface were used to independently verify contour accuracy. After four adjustment cycles, the measured normal surface error was 8.3 mils rms using the profilometer and 8.6 mils using photogrammetric results.

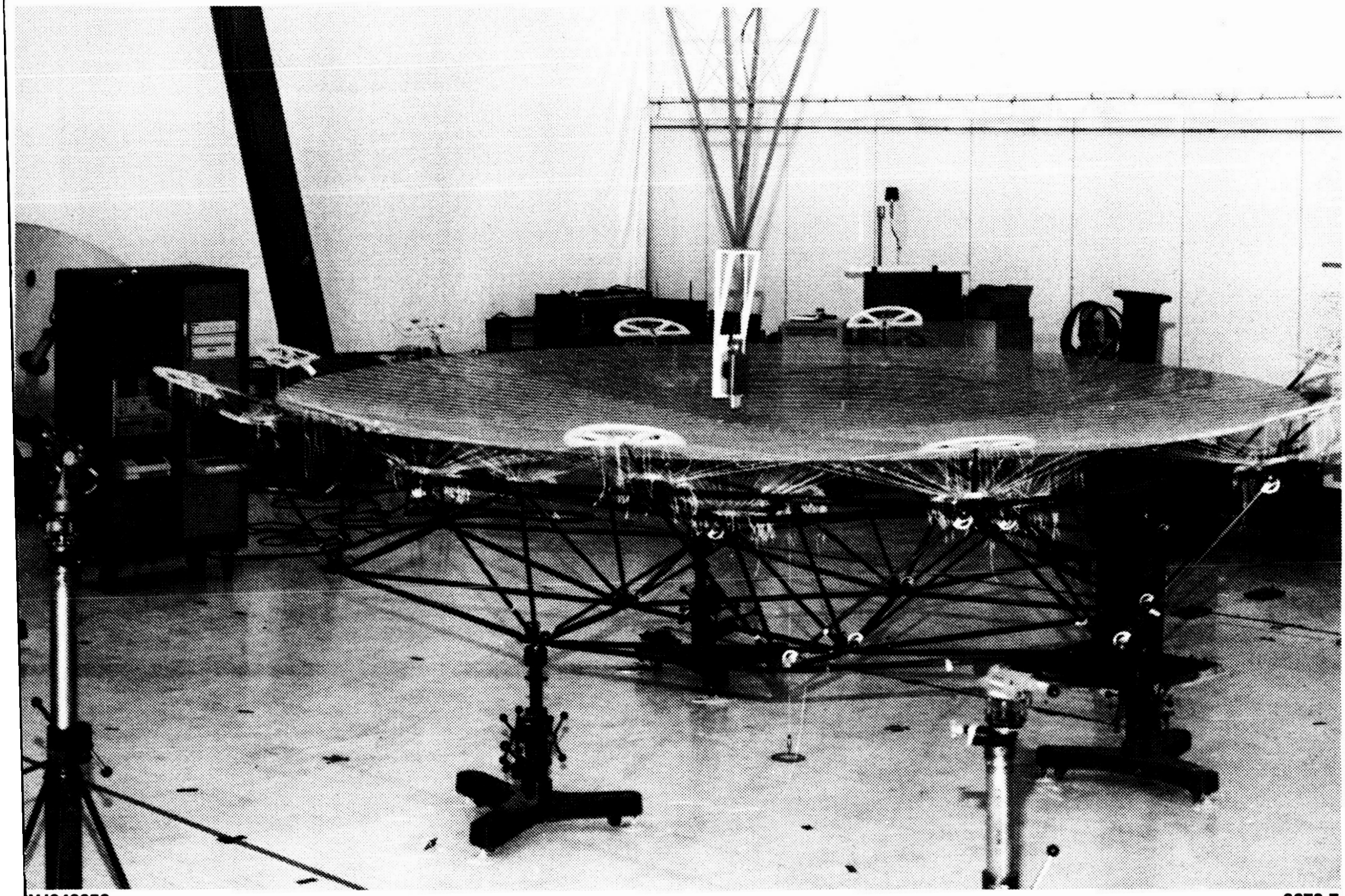

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Figure 8.

PACKAGED REFLECTOR

When folded, the truss reflector forms a compact package whose dimensions are overall height - 1.8 meter, truss height - 1.1 meters, mesh diameter - 1.4 meters, and truss diameter - 0.9 meter. Packaged diameter is set by the number and size of node fittings used, and height is set by the length of the truss diagonal struts. The packaged reflector shown in Figure 9 shows one of three alternate packaging approaches, i.e., with all surface struts folded in. The other two approaches are with top struts folded out and with both top and bottom struts folded outward, which produces a longer, smaller-diameter package.

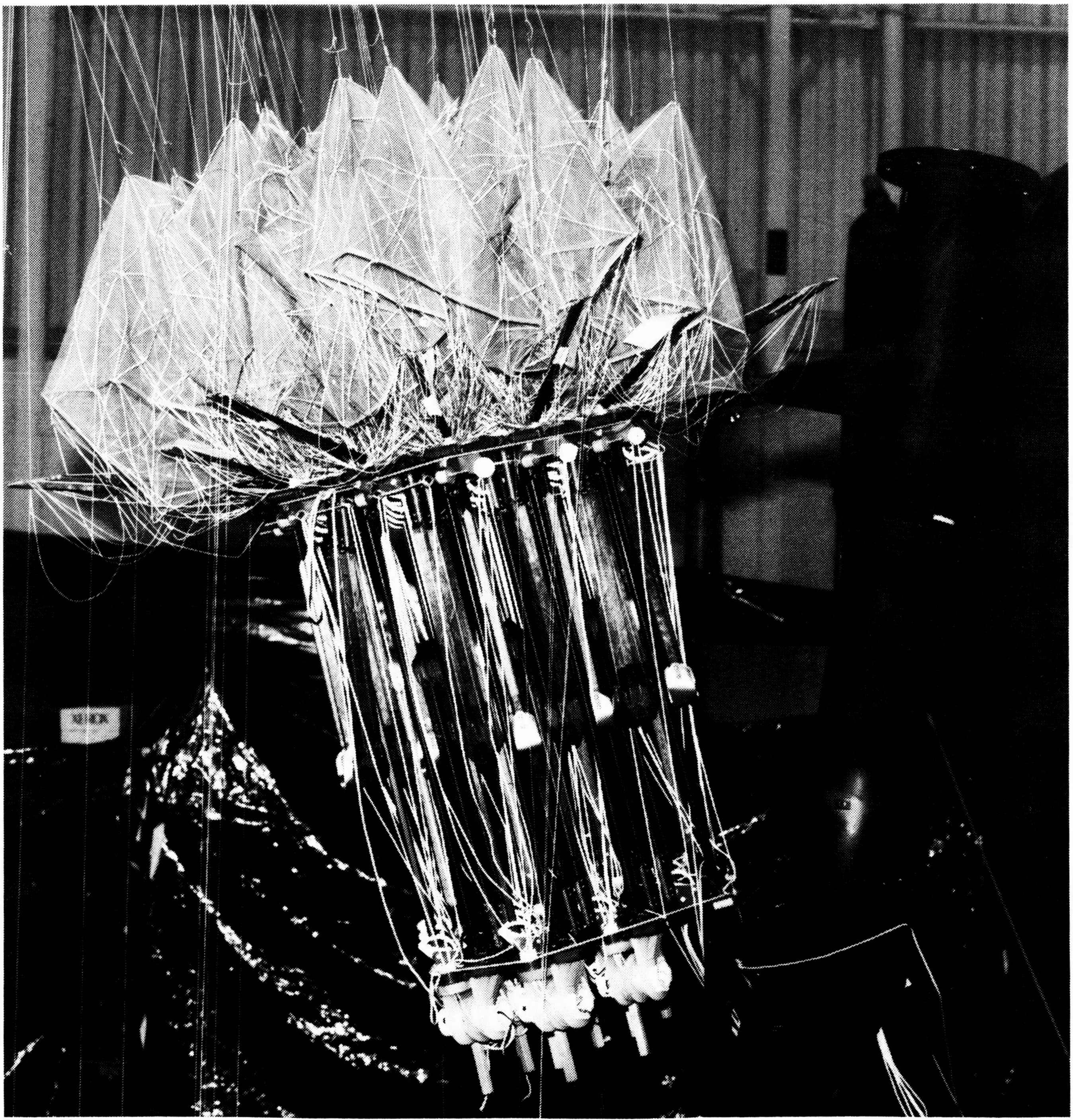

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Figure 9.

REFLECTOR DEPLOYMENT

Three deployments of the reflector were performed as shown in Figure 10. The truss reflector is normally a freely deploying system employing stored energy in folded spring hinges (carpenter tape hinges). These hinges are incorporated in all truss strut members of the geotruss structure supporting the reflector surface. When the package restraints are released, each strut begins to unfold. This action automatically drives the node fittings apart until the surface struts lock in their deployed position. The hinge provides a nearly constant deployment force until just before lock-up. At that point, the hinge force increases sharply to lock the truss member into its final position. This final lock-up force also ensures that the antenna surface mesh is stretched into its desired configuration.

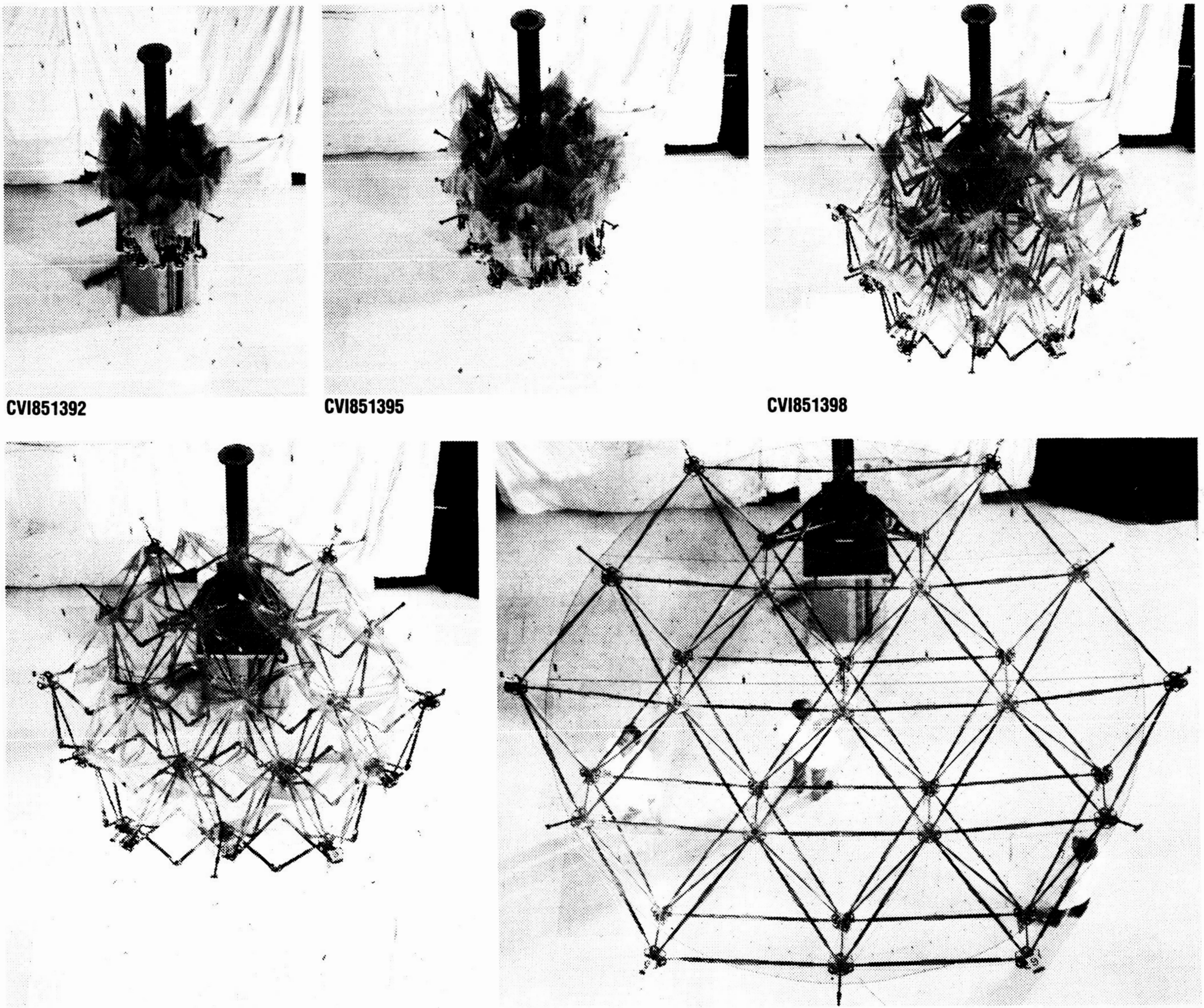

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Figure 10.

ELECTROMAGNETIC (RF) TESTING

RF performance tests of the 5-meter tetrahedral truss reflector were performed at the Martin Marrietta Near Field Measurement Laboratory in Denver, Colorado. Linearly polarized on-focus feeds supplied by NASA LaRC were used to measure gain, far field patterns and cross-polarization at 2.27, 4.26, 7.73, and 11.6 GHz. Installation of the reflector on a 20-foot tower in the near field facility is shown in Figure 11. Results of these tests are being evaluated at NASA LaRC and General Dynamics Space Systems. Preliminary results indicate good RF performance that correlated well with analytical predictions. Typical results at 4.26 GHz are shown in the plot in Figure 11.

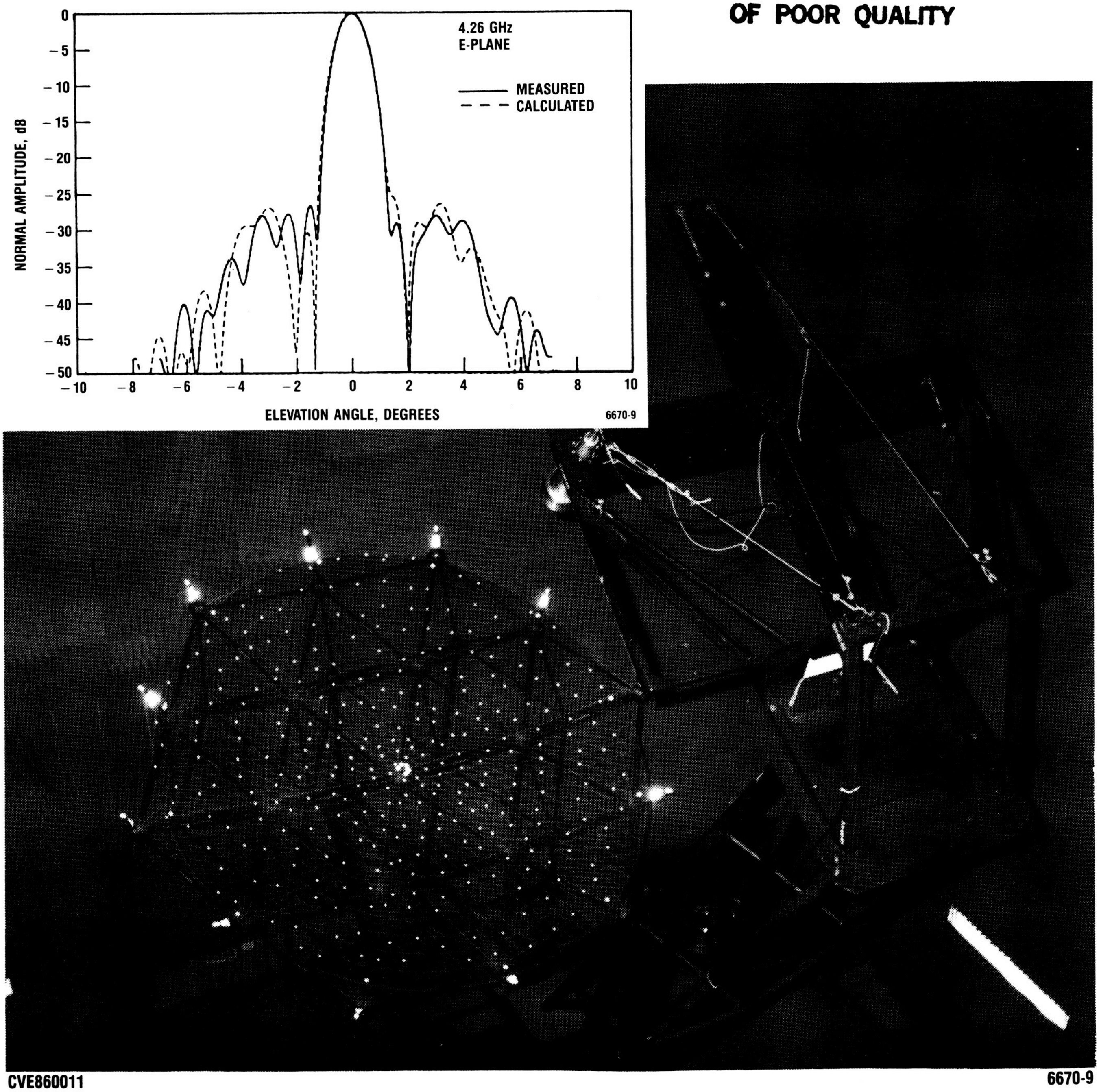

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Figure 11.

DEPLOYABLE TRUSS TECHNOLOGY VERIFICATION PROGRAM

The 5-meter technology antenna program demonstrated the capability to successfully fabricate and test a precision deployable truss antenna. Deployable truss structure technology issues associated with on-orbit performance requirements need to be verified next by an integrated program of analysis and ground and flight testing. These technologies can be divided into five general categories: structural dynamics, active control, thermodynamics, electromagnetics, and structure/mechanisms design.

A 5-meter deployable truss reflector integrated with a deployable truss beam (Figure 12) can serve as a low-cost testbed for initial technology verification testing. Subsequent testing of a larger 15- to 20-meter article could be used to verify scaling-sensitive technology issues.

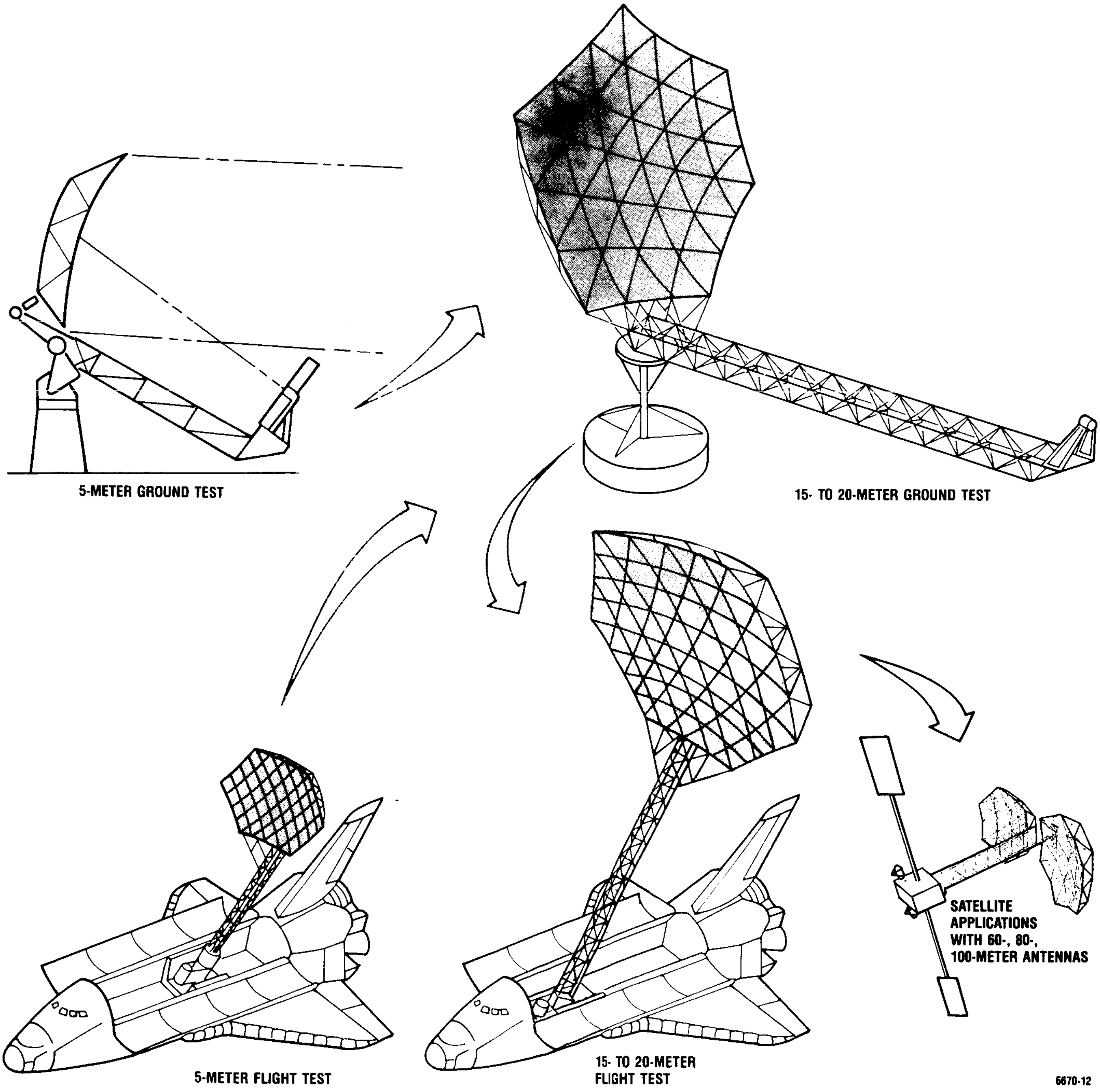

Figure 12.

CONCLUSIONS

The 5-meter technology antenna program demonstrated the overall feasibility of integrating a mesh reflector surface with a deployable truss structure to achieve a precision surface contour compatible with future, high-performance antenna requirements. Specifically, the program demonstrated:

- The feasibility of fabricating a precision, edge-mounted, deployable, tetrahedral truss structure.
- The feasibility of adjusting a truss-supported mesh reflector contour to a surface error less than 10 mils rms.
- Good RF test performance, which correlated well with analytical predictions.

Further analysis and testing (including flight testing) programs are needed to fully verify all the technology issues, including structural dynamics, thermodynamics, control, and on-orbit RF performance, which are associated with large, deployable, truss antenna structures.