DESIGN OF A LOW-FREQUENCY (5-20 GHz), 15-METER-DIAMETER PASSIVE RADIOMETER FOR GEOSTATIONARY EARTH SCIENCE PLATFORMS*

A. K. Sinha
Lockheed Missiles and Space Company, Inc.
Sunnyvale, California

*Some original figures not available at time of publication.

83

WHAT IS A WRAP-RIB REFLECTOR?

The Wrap-Rib Antenna is a deployable lightweight shaped reflector as shown in Fig. 1. It consists of a central hub, parabolic ribs, and an rf reflective mesh. The wrap-rib reflector approximates the desired surface by means of pie-shaped segments of parablic cylinders.

The wrap-rib concept has the advantage of a compact stowage container when the reflector is fully furled. The reflector will completely unfurl on command using the stored energy of the wrapped ribs when the peripheral cable securing the stowage doors is cut by a pyrotechnic operated cable cutter.
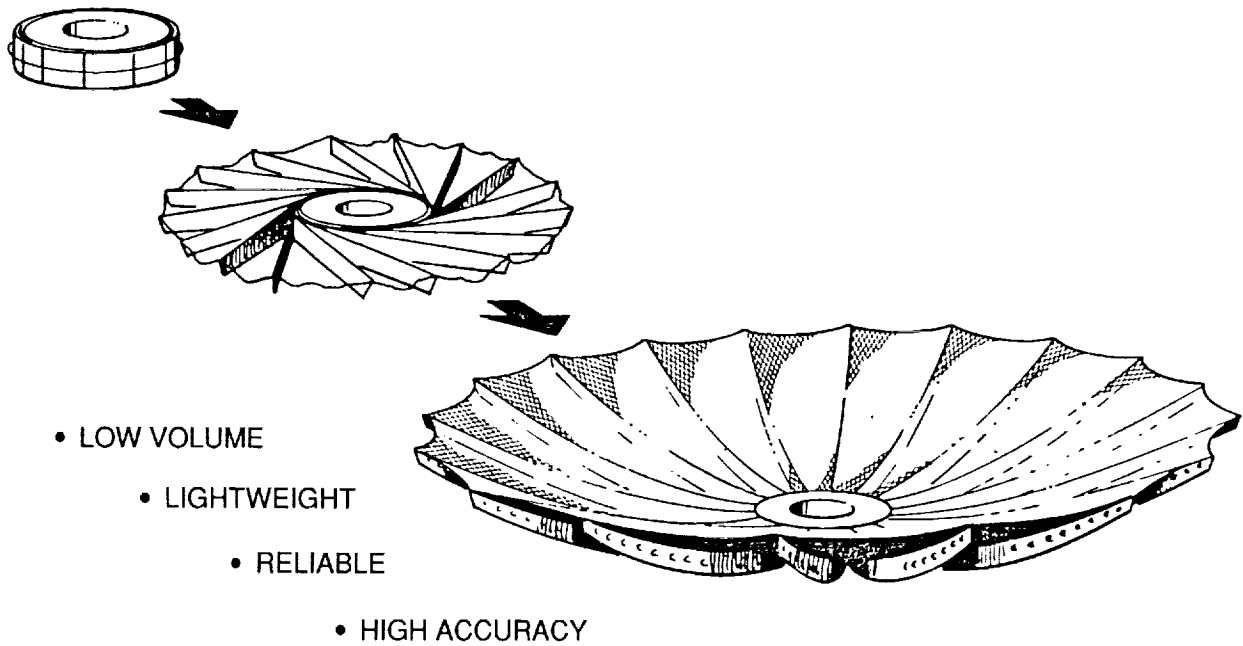
• LOW VOLUME

• LIGHTWEIGHT

• RELIABLE

• HIGH ACCURACY

Figure 1

Figure 2 shows a system-level overview of the reflector design parameters. The number of ribs employed is determined by the antenna operating frequency and the reflector size. The hub diameter is also dependent on the number of ribs needed for proper rf operation. The reflector container height can be held to approximately 3 percent of reflector diameter. The rib and mesh materials are selected to suit specific applications, e.g., at higher rf frequencies, ribs made of graphite/epoxy, and low CTE* mesh materials are needed to reduce the deleterious effects of thermal distortion.

*Coefficient of thermal expansion (CTE).

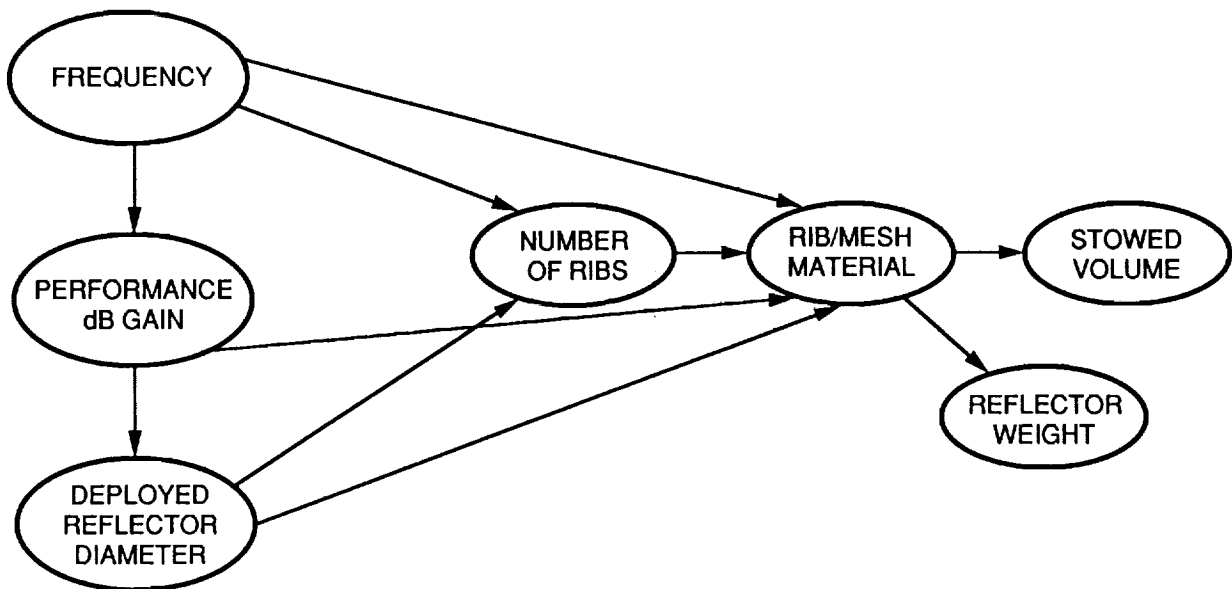SYSTEM PARAMETERS   REFLECTOR DESIGN PARAMETERS

Figure 2

As shown in Fig. 3, LMSC Antenna Laboratory has been involved in the development of the wrap-rib reflector technology for the past 20 years. To date, the designs of 3-, 6-, 10-, 20-, and 30-ft-diameter reflectors have been manufactured and qualified for space application. The largest feasible diameter depends on the frequency of operation, but the designs for antennas as large as 150 ft in diameter have been studied. One of these studies led to a partial build of a 55-m-diameter antenna for a NASA contract during 1983-84.

*Lockheed Missiles and Space Company (LMSC).
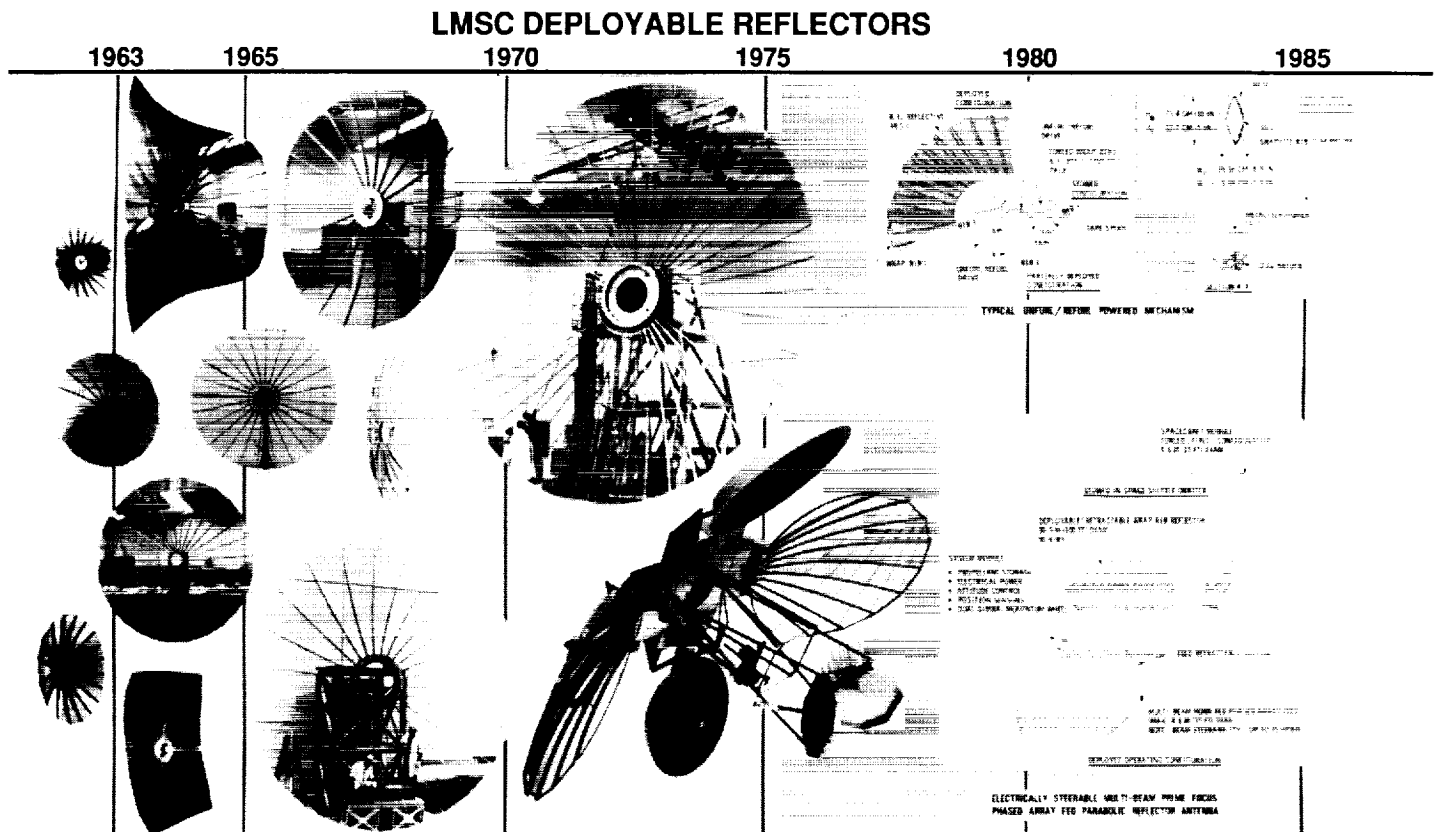
LMSC DEPLOYABLE REFLECTORS

Figure 3

Over the past several years, Lockheed has studied several controlled deployment concepts. The controlled deployment concept will reduce the impact of a sudden release of stored strain energy in the ribs. This will also reduce the effect of sudden reaction force on the spacecraft.

Two main concepts are shown in Figs. 4 and 5. The first is based on a gear and motor system where the hub is turned by the motor, and the ribs are guided through a set of candles. The second deployment is based on power-driven tape. The tape is attached to the central hub and wrapped circumferentially along every third rib. The tape travels over a set of idlers and then a slack take-up mechanics terminates at a spool that is part of the central hub.

The addition of these mechanism makes the design a lot more complicated and adds substantially to the system weight. The controlled deployment system is not recommended until the ground test or other system constraints prove that it is required.
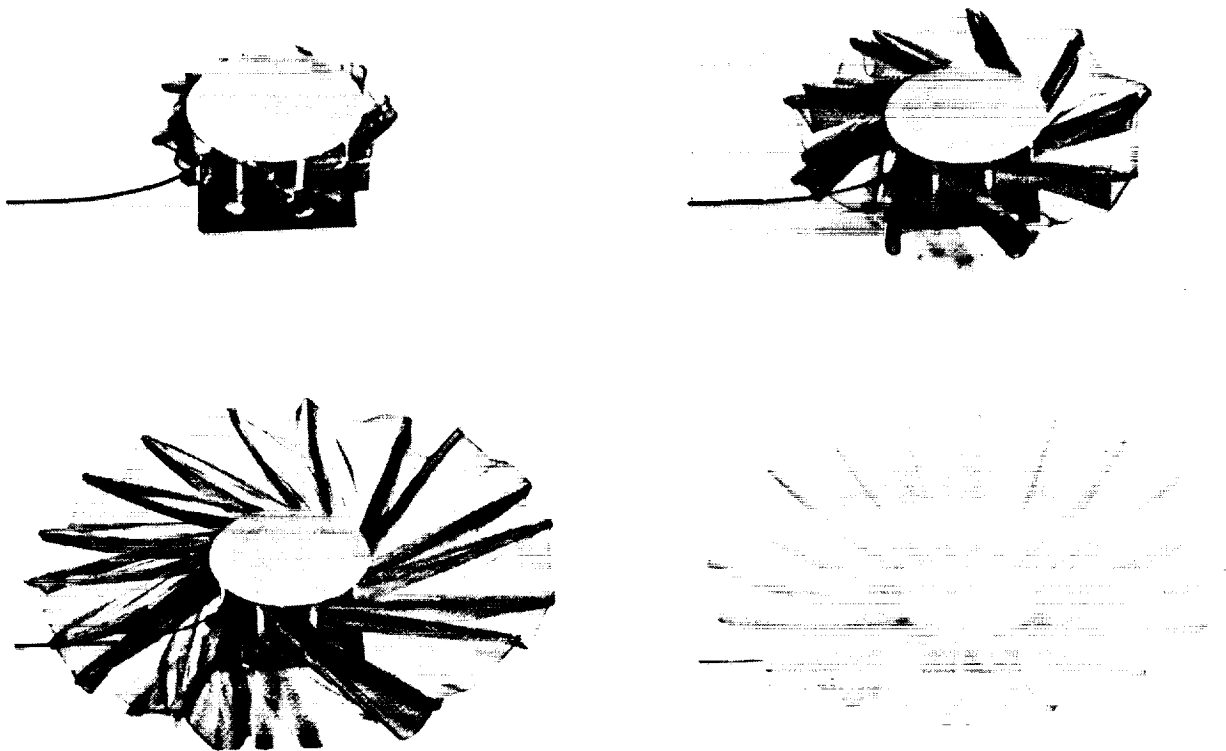

Figure 4

C-2

Figure 5

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

The ATS-6 spacecraft, shown in Fig. 6, carried a 30-ft-diameter wrap-rib antenna made of aluminum ribs and Dacron mesh. It was designed to operate up to an 8 GHz frequency. The deleterious effect of thermal distortion in space limits the use of such a system to relatively low frequencies. To overcome this limitation, LMSC has worked extensively on the development of thermally stable materials for ribs and mesh. These advances have made it possible to design an antenna system operable at 25 GHz with only a very low-gain degradation of 0.75 dB.

ATS-6 SPACECRAFT

66 dB GAIN
● 25 GHz
(0.016" RMS)
▲G= -0.75 dB

θ deg

30-ft DIA
WORST CASE PERFORMANCE
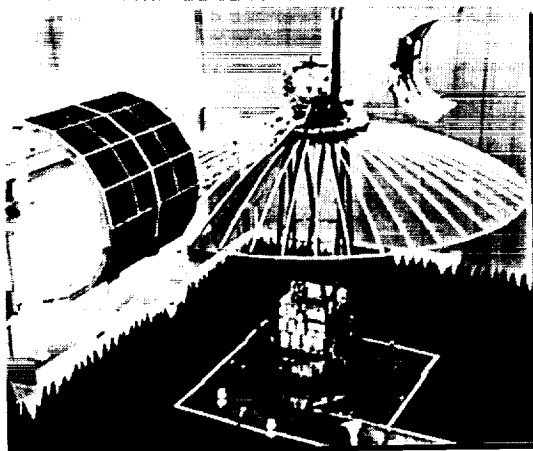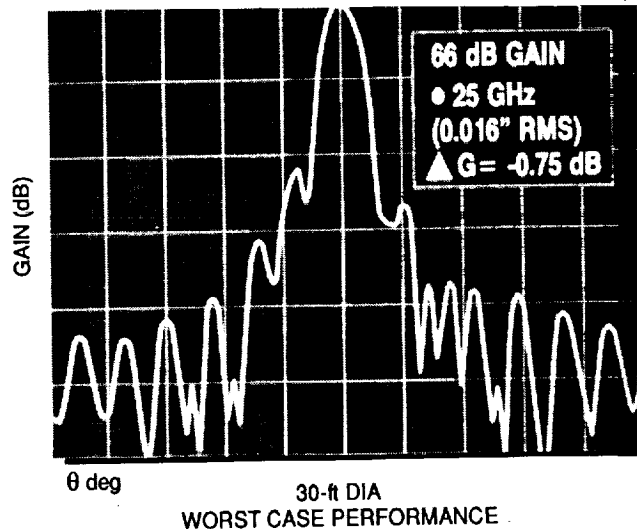
MODERN WRAP RIB KEY FEATURES

- ❏ GRAPHITE-EPOXY RIBS
- ❏ PROPRIETARY KEVLAR/BeCu MESH
- ❏ PASSIVE DEPLOYMENT

- ❏ PROVEN TECHNOLOGIES
- ❏ VERIFIED ANALYSIS
- ❏ PASSIVE INTERMOD PRODUCTS < -150 dB

Figure 6

The wrap-rib technology development matrix, shown in Fig. 7, lists the various areas in which the technology development is taking place to meet the future application needs for higher frequencies and larger diameters. Advances in materials and design methodology have resulted in thermally and visco-elastically stable structure for the ribs. The same type of effort is focused in the area of developing thermally stable mesh designs. These activities in the rib and mesh materials are extensively supported by hardware tests. Some work has been done in the controlled deployment concept development, but it has not attracted concentrated attention. One of the major focuses has been to develop analytical methods to accurately predict the antenna far-field in an integrated way. The approach has been to integrate the various softwares in the rf and structural analysis areas.
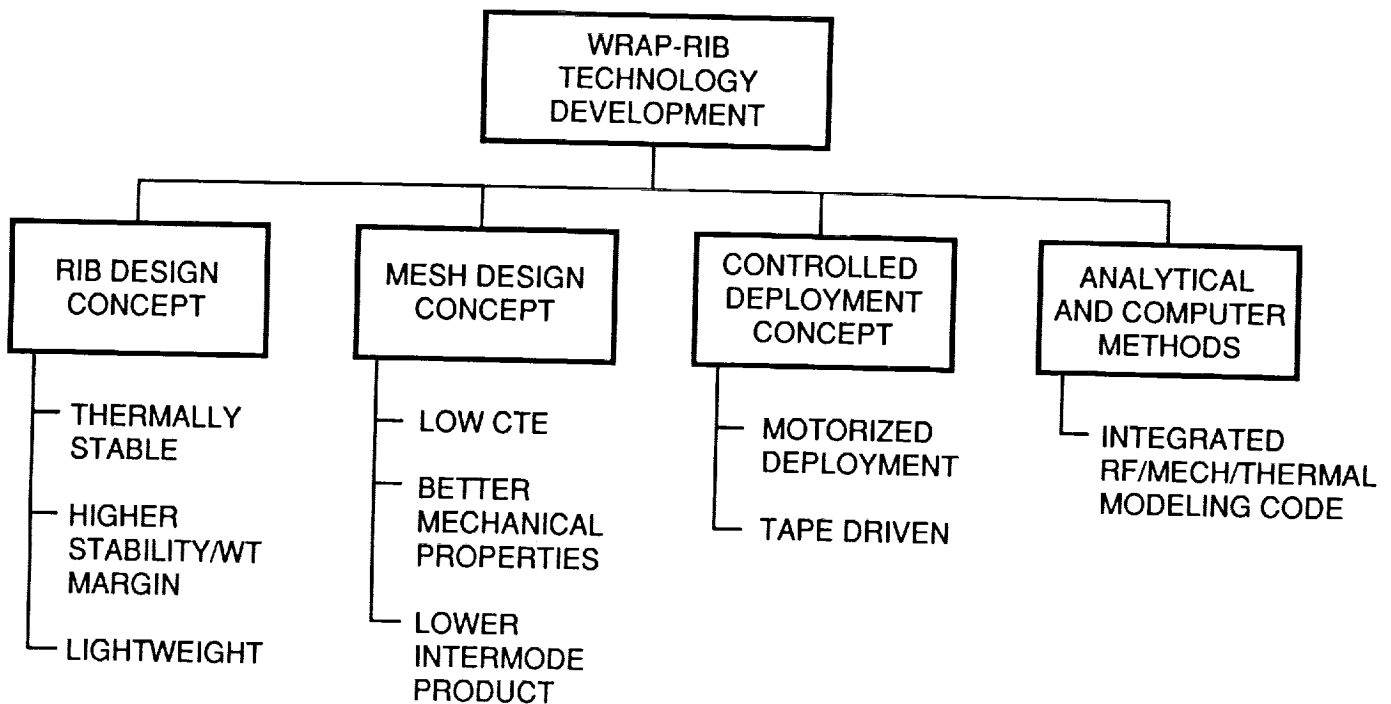
Figure 7

Figure 8 shows the tested visco-elastic behavior of the newly designed C-section rib made of graphite-expoxy. In this test the long-term, visco-elastic behavior was simulated by submerging the specimen in hot water for 28 days and then recording its recovery over the next 14 days. As shown in the figure, the visco-elastic creep recovered to well within the 0.03 dB performance loss target that was set as our design requirement. This result is of great significance due to the fact that when a rib gets wrapped around the hub, it is subjected to stress levels very close to its yield limit and this had a tendency to produce appreciable creep deformation in the rib.
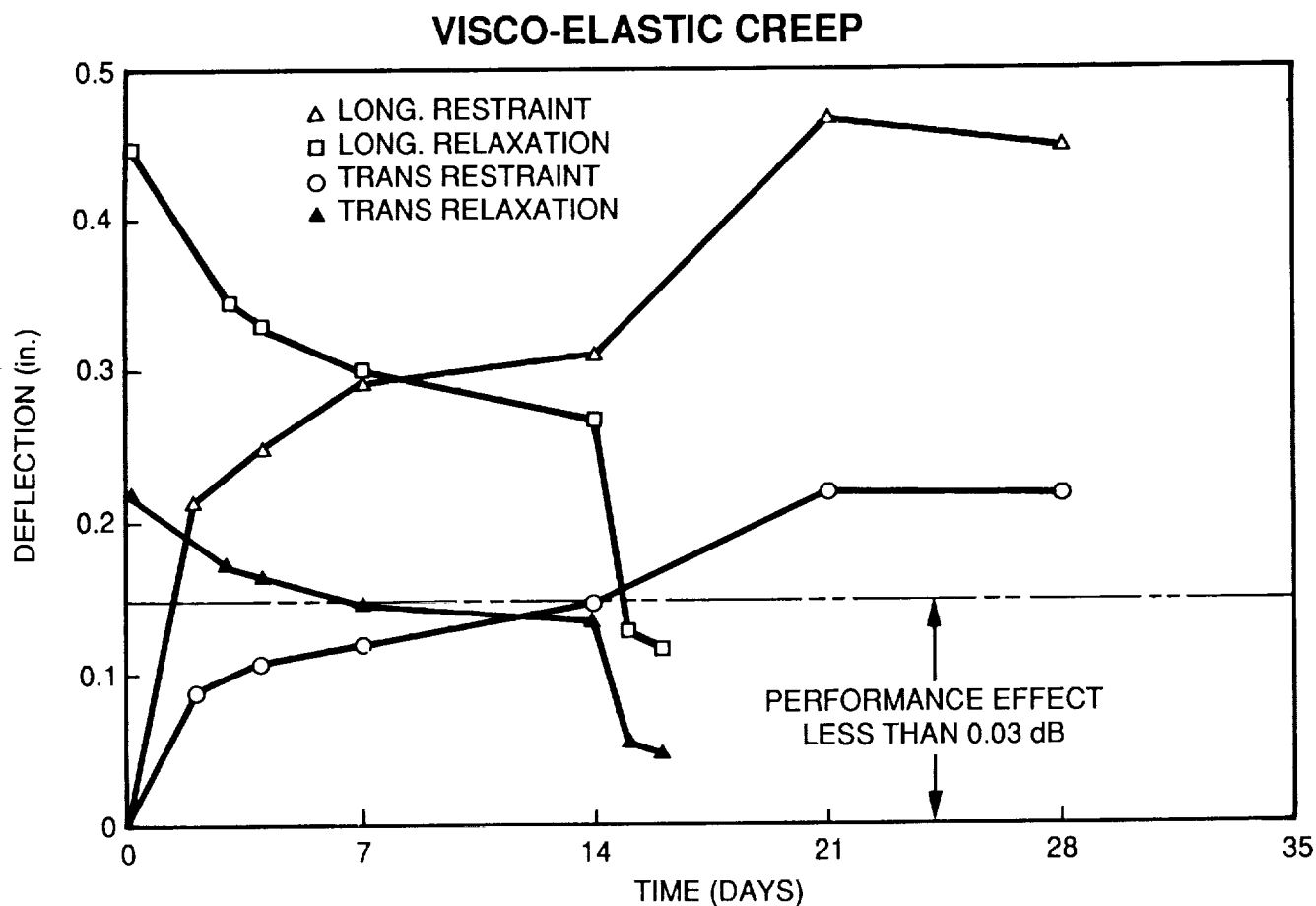
VISCO-ELASTIC CREEP

Figure 8

CTE STABILIZATION DATA

Figure 9 shows the results of CTE tests on the recently developed antenna mesh. As mentioned earlier, wrap-rib antenna design is a mesh-dominated design and any distortion of the mesh directly translates into the antenna performance degradation. Therefore, the goal was to design a zero CTE mesh, and from the test data one can determine that the new mesh CTE varies between -0.2×10^{-6} to 0.4×15^{-6} in./in/°F.
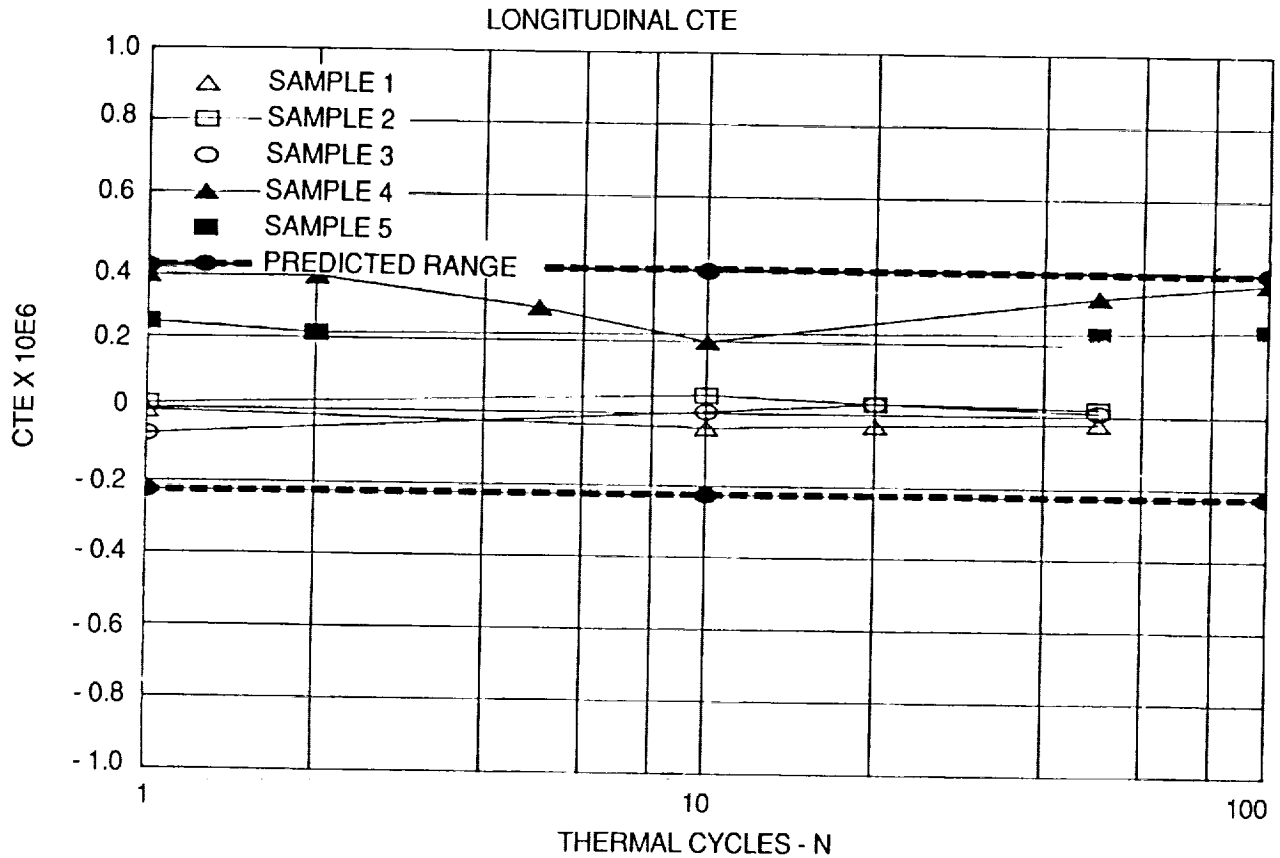

Figure 9

92

The material property table in Fig. 10 compares the data on the new mesh to the other types of mesh. It is obvious that the new mesh outperforms the moly/gold and Dacron in almost all the categories. For comparison, CTE improvement over the Dacron mesh which was used on the ATS-6 spacecraft is remarkable.

PROPERTY	BeCu - KEVLAR WEAVE	MoAu 2310/1012 KNIT	ATS DACRON WEAVE
ABSORPTIVITY/EMISSIVITY	0.289, 0.651 ①	0.480	0.167
CREEP RATE ② (in./in./day)			
WOOF/WALE	0	9.1×10^{-5}	- - -
WARP/COARSE	0	6.5×10^{-5}	- - -
COEFFICIENT OF THERMAL EXPANSION $(10^{-6}$ /°F)	- 0.16	2.8	0.5 - 12.0 ③
RF REFLECTIVITY (%)	92.9 AT 25 GHz	99+ AT 25 GHz	99+ AT 8 GHz
SHEAR STIFFNESS (lb/in.)	(SEE NOTE 4)	1.9	- - -
SHEAR OVERSTRAIN	PASS	FAIL	PASS
TENSILE MODULUS (lb/in.)			
WOOF/WALE	45.9	5.3	(SEE NOTE 5)
WARP/COARSE	19.3	20.4	(SEE NOTE 5)

NOTES:

1. HIGHER α/ε VALUE IS FOR BeCu-KEVLAR WEAVE WITH A FLAT BLACK SILICONE OVERCOAT.
2. DUE TO THE SCOPE OF THE TESTING PROGRAM, CREEP RATES LISTED ARE GENERAL TENDENCIES DERIVED FROM THE DATA, NOT ABSOLUTE VALUES.
3. THE CTE FOR THE ATS DACRON MESH VARIES WITH TEMPERATURE FROM 12×10^{-6} /°F AT -280°F TO 0.5×10^{-6}/°F AT 80°F, WITH A TRANSITION DROP OF 8×10^{-6}/°F OCCURRING AT -80°F.
4. SHEAR STIFFNESS TESTING SUSPENDED DUE TO BUDGETARY CONSTRAINTS.
5. FOR ATS DACRON MESH, ONLY MODULUS OF A SINGLE STRAND IS AVAILABLE. ESTRAND = 3.6×10^5 PSI.

Figure 10

Figure 11 shows the CTE stability of the new mesh over the temperature excursions to which antenna systems are subjected to while in an orbital environment. Again, the average values of CTE printed on the charge proves the thermal stability the new mesh.

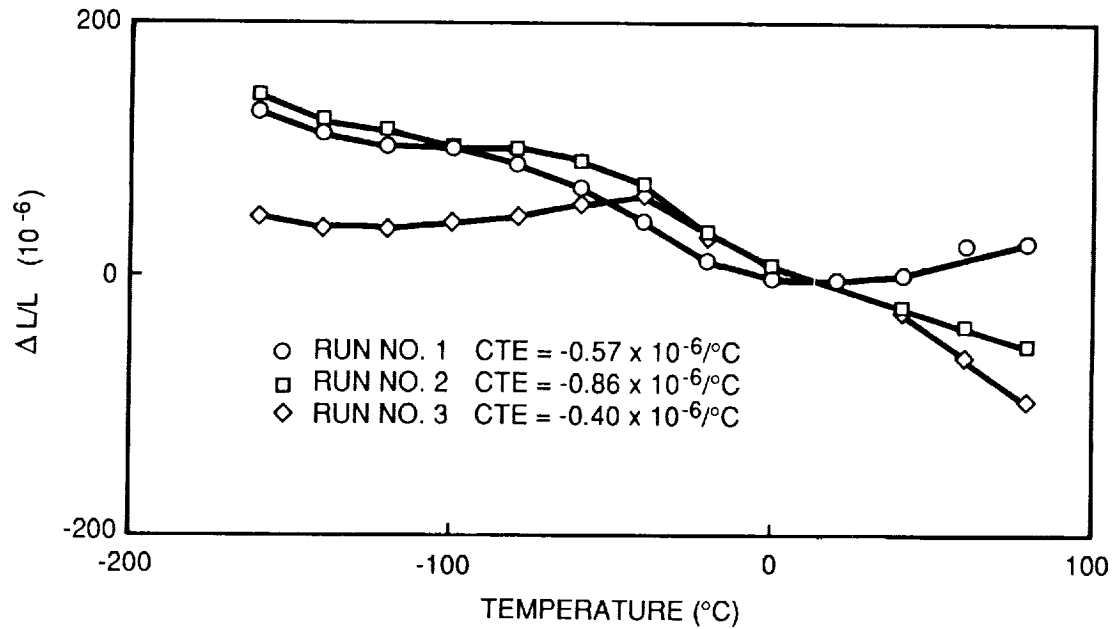## FIRST THREE RUNS ON SINGLE SPECIMEN

Figure 11

The flow chart in Fig. 12 shows the schematic of the integrated software analysis capability for antenna performance prediction. This spatial modeling of the antenna surface due to any perturbation mechanism includes the spacecraft dynamics and momentous transfer effect as a result of mechanical scanning. The analysis software can account for detailed thermal distortion as function of time and the orbital location. The rf prediction is based on physical optics formulation which is being updated to include the edge diffraction time using GTD technique.
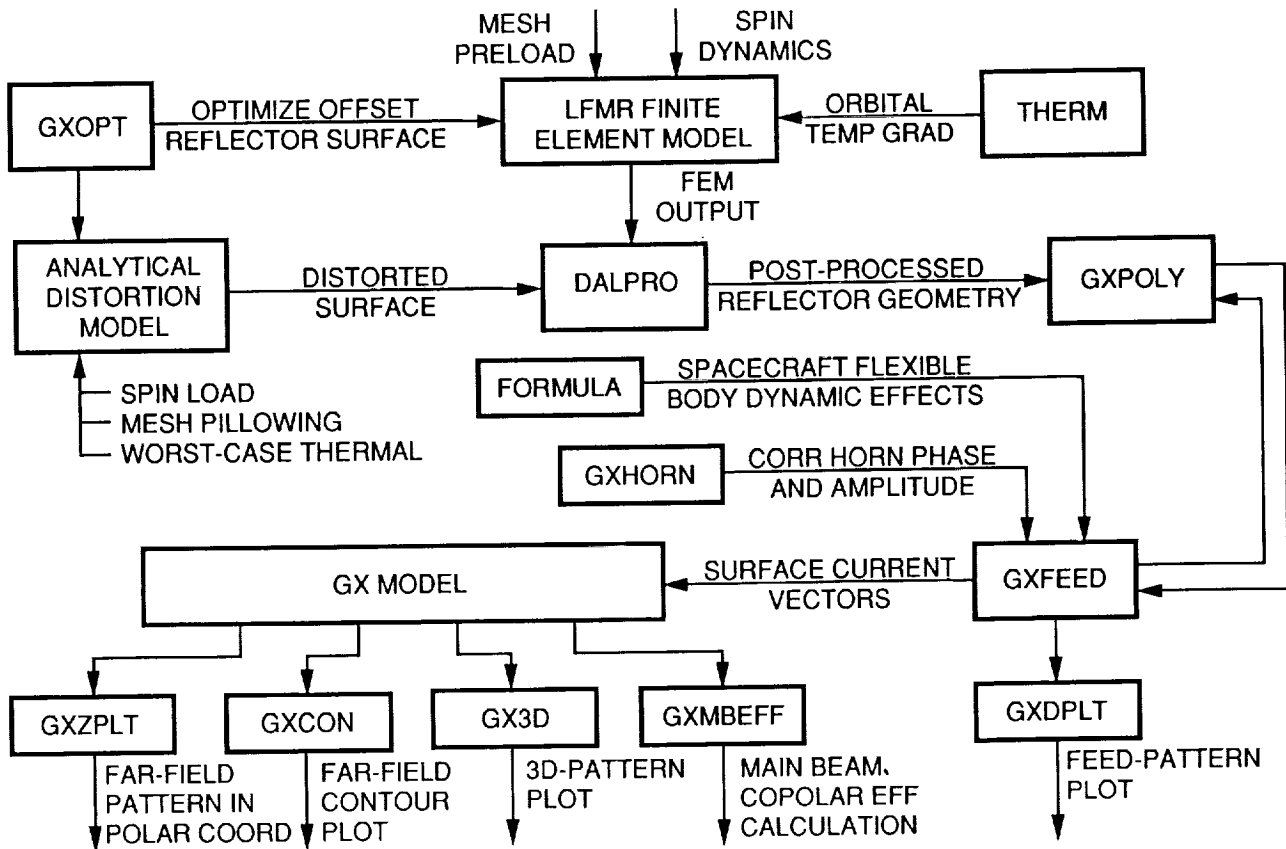

Figure 12

Figure 13 shows an example of the application of integrated software in solving the antenna far field. Segment (D) shows a finite-element model of 30-ft-diameter wrap-rib antenna. Segments (A) and (C) show the spatial temperature distribution on a typical rib and mesh respectively. And finally, segment (B) gives the antenna far field for the side-sun case. The asymmetrical distortion of the reflector surface for this side-sun case is graphically evident by the shift of the peak of the main beam.
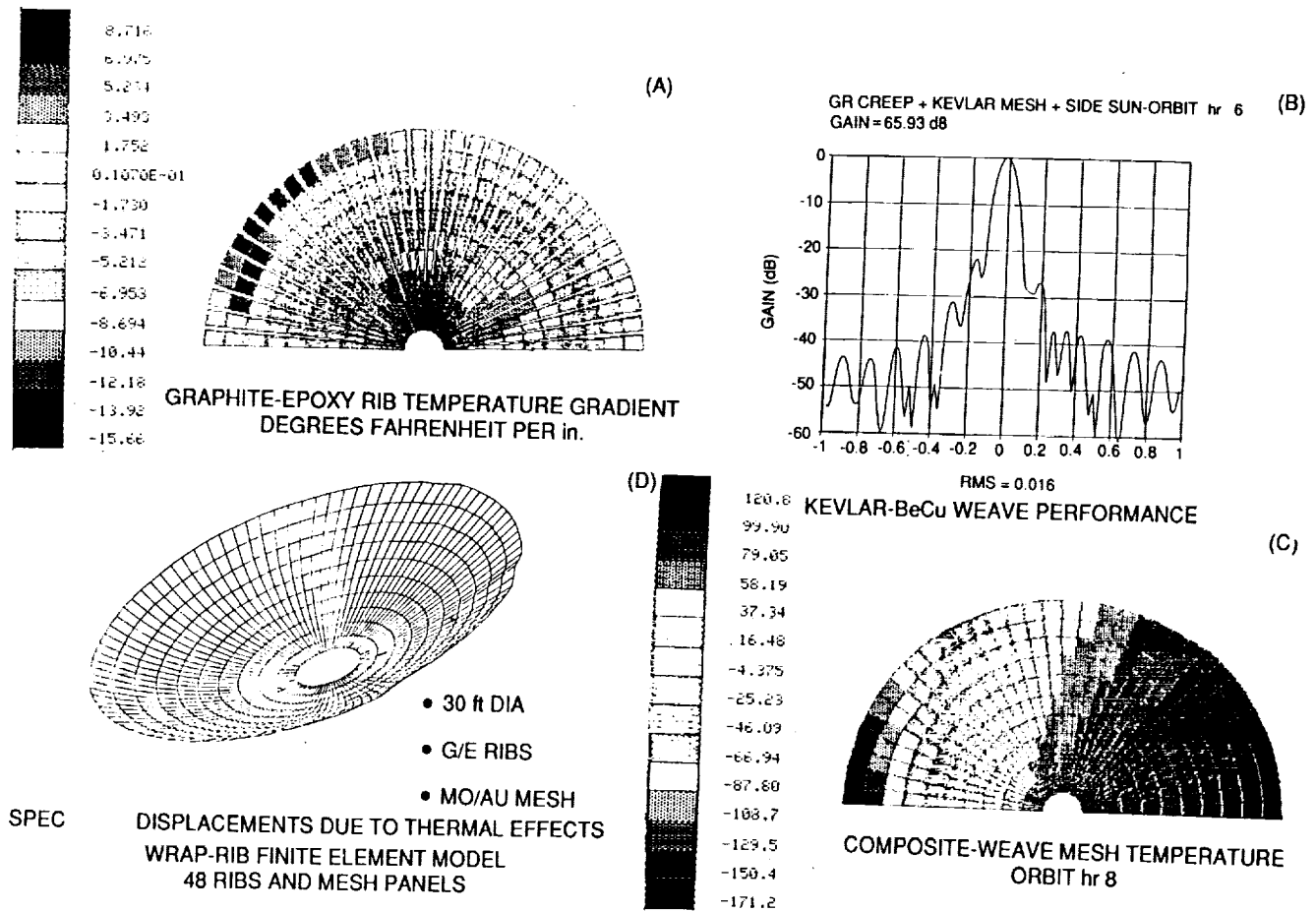
(A)

GRAPHITE-EPOXY RIB TEMPERATURE GRADIENT
DEGREES FAHRENHEIT PER in.

GR CREEP + KEVLAR MESH + SIDE SUN-ORBIT hr 6   (B)
GAIN = 65.93 d8

RMS = 0.016
KEVLAR-BeCu WEAVE PERFORMANCE

(D)

• 30 ft DIA

• G/E RIBS

• MO/AU MESH

SPEC   DISPLACEMENTS DUE TO THERMAL EFFECTS
WRAP-RIB FINITE ELEMENT MODEL
48 RIBS AND MESH PANELS

(C)

COMPOSITE-WEAVE MESH TEMPERATURE
ORBIT hr 8

Figure 13

Figures 14, 15, and 16 compare the results of new technology over the old technology vis-a-vis a baseline performance of 30-ft-diameter wrap rib with 68 ribs for a 25 GHz application. Under the old technology, an aluminum rib and Dacron mesh are used for the two worst orbital thermal conditions. As can be easily seen, the far-field pattern is badly degraded. There is approximately a 9 dB loss at 25 GHz. The same antenna made of composite mesh material and graphite-expoxy rib has only 0.3 dB loss for the worst thermal distortion case.
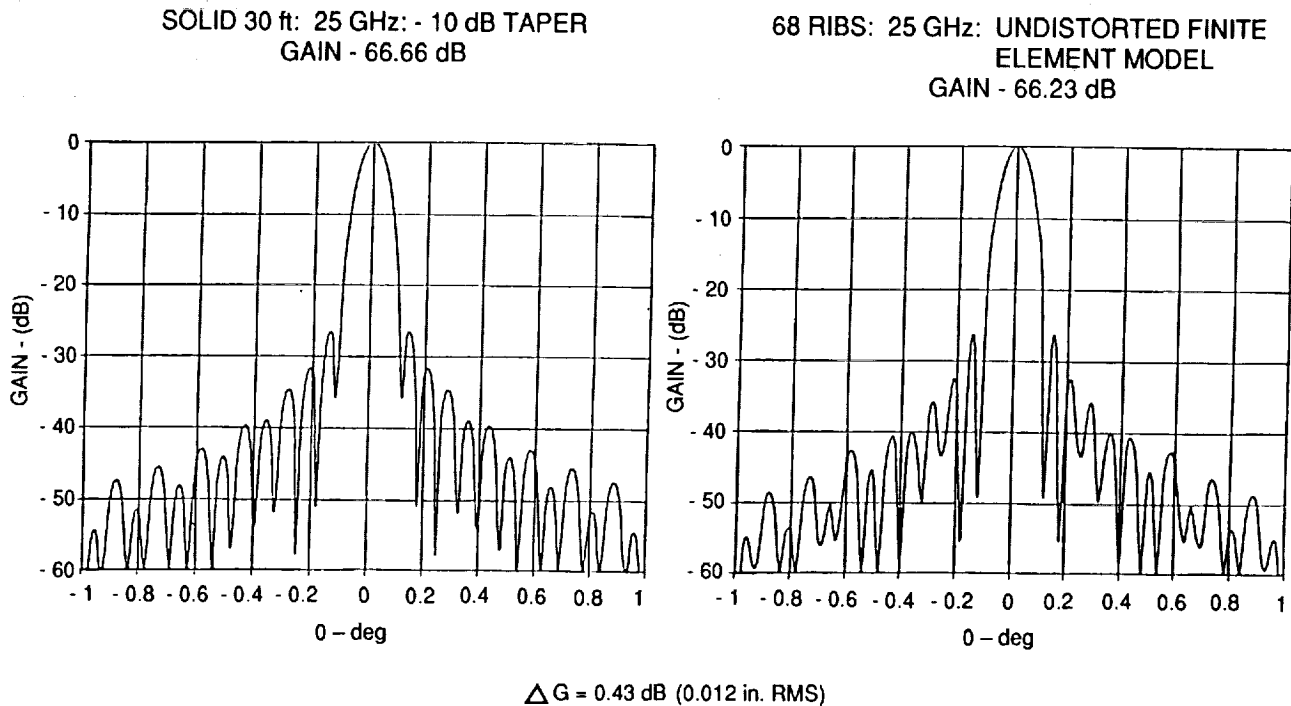
SOLID 30 ft: 25 GHz: - 10 dB TAPER
GAIN - 66.66 dB

68 RIBS: 25 GHz: UNDISTORTED FINITE ELEMENT MODEL
GAIN - 66.23 dB

$\triangle$G = 0.43 dB (0.012 in. RMS)

Figure 14

97

OLD TECHNOLOGY
WILL NOT MEET REQUIREMENTS

AL RIBS: DACRON MESH: ORBIT hr 12
GAIN - 57.07 dB

AL RIBS: DACRON MESH: ORBIT hr 6
GAIN - 58.28 dB

RMS = 0.056

RMS = 0.052
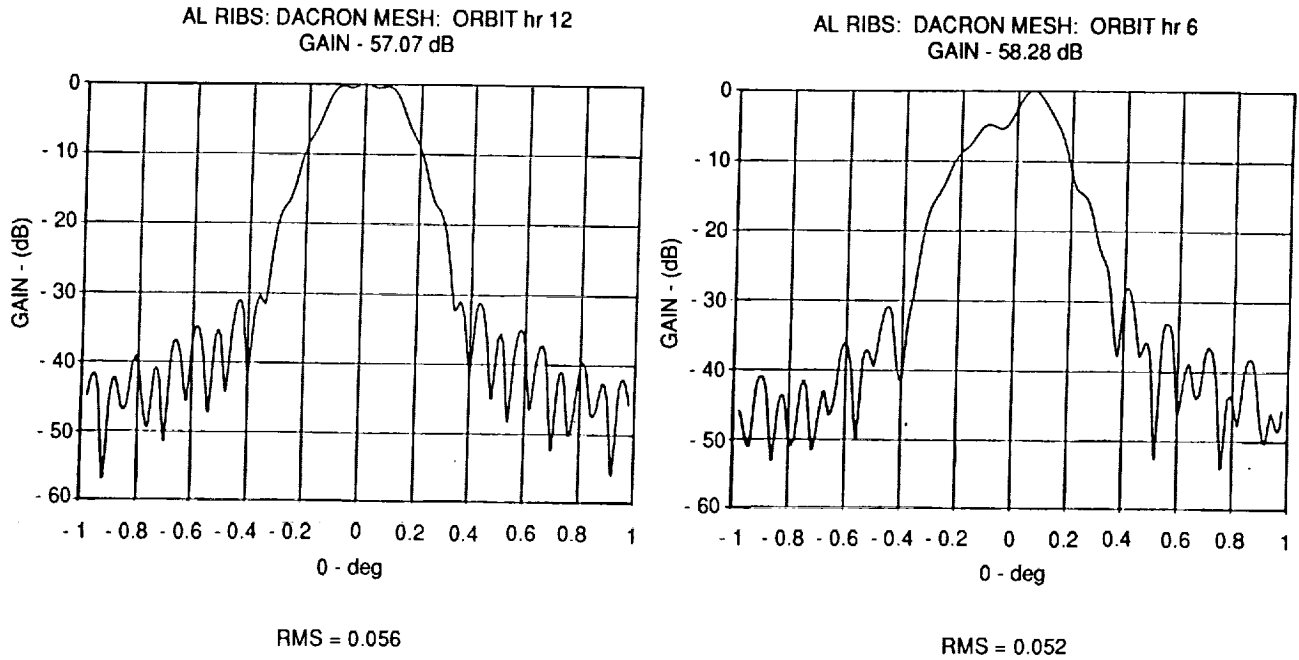
Figure 15

(U) KEVLAR-BeCu
WEAVE PERFORMANCE

GR CREEP + KEVLAR MESH + ECLIPSE – ORBIT hr 12
GAIN = 66.11 dB

GR CREEP + KEVLAR MESH + SIDE SUN – ORBIT hr 6
GAIN = 65.93 dB

RMS = 0.013

RMS = 0.016
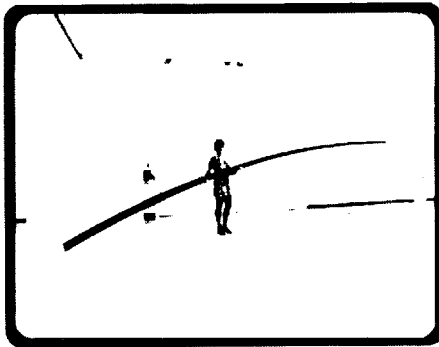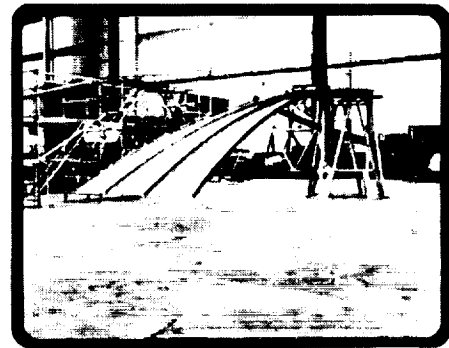
Figure 16

98
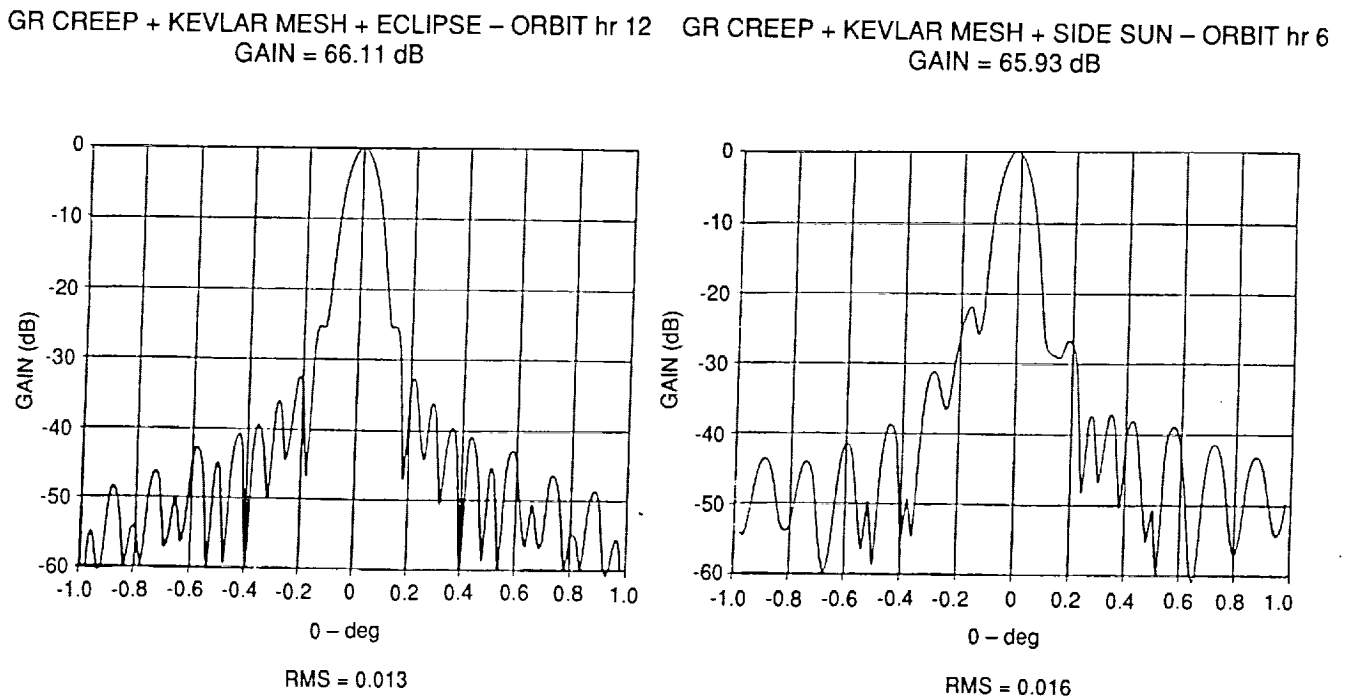
The LMSC Antenna Laboratory (Fig. 17) has been involved in the development of 50-ft-diameter wrap-rib antennas for some time. Some of the early work in this area could not design and build thermally and disco-elastically stable ribs using a C-section for the rib. Then the effort was directed toward a closed-section design called lenticular-section rib. This presented problems with the free deployment characteristic of the wrap-rib antenna. The collapsed cross section of the lenticular rib could not recover fast enough to provide proper margin of stability. This meant that a controlled deployment device was needed.

Some of the most recent technology development effort has resulted in the design of a stable C-section rib which can be freely deployed.
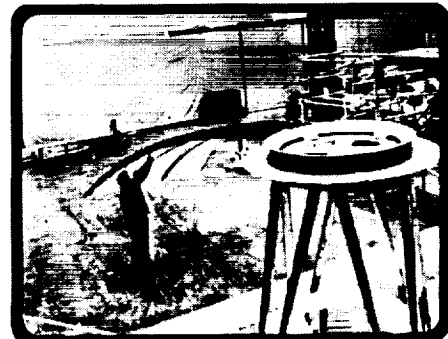

GRAPHITE EPOXY RIB

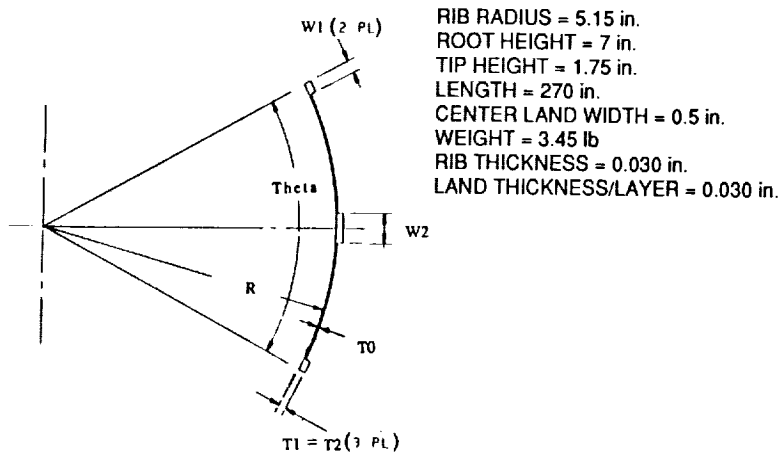| KEY REFLECTOR REATURES |
|---|
| MAX RMS ERROR_____0.040 |
| WEIGHT_____280 lb |
| STOWED DIAMETER____76 in. |

4-RIB – 3-GORE
REFLECTOR SEGMENT

VIEW OF REFLECTOR HUB

Figure 17

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE IS
OF POOR QUALITY

99

The proposed 50-ft-diameter reflector rib is shown in Fig. 18. The unique feature of this rib is the continuously staggered layers of center and edge lands as a function of rib length. Various other section properties are also listed.

RIB RADIUS = 5.15 in.
ROOT HEIGHT = 7 in.
TIP HEIGHT = 1.75 in.
LENGTH = 270 in.
CENTER LAND WIDTH = 0.5 in.
WEIGHT = 3.45 lb
RIB THICKNESS = 0.030 in.
LAND THICKNESS/LAYER = 0.030 in.

EDGE LANDS		CENTER LANDS	
XN (in.)	FN NO. OF LAYERS	XN (in.)	FN
0	10	0	10
7	9	15	9
23	2	32	8
40	7	50	7
59	6	70	6
79	5	91	5
101	4	114	4
125	3	141	2
153	2	189	1
222	1		

Figure 18

Figures 19 through 22 show the design factors of safety for parameters such as torsional stability, bending stability, yeild stress, and charcteristic radius. As illustrated in the figures, these factors of safety have met or exceeded the design margins for 1-g deployment and safe wrapping and unwrapping of the rib around the hub.
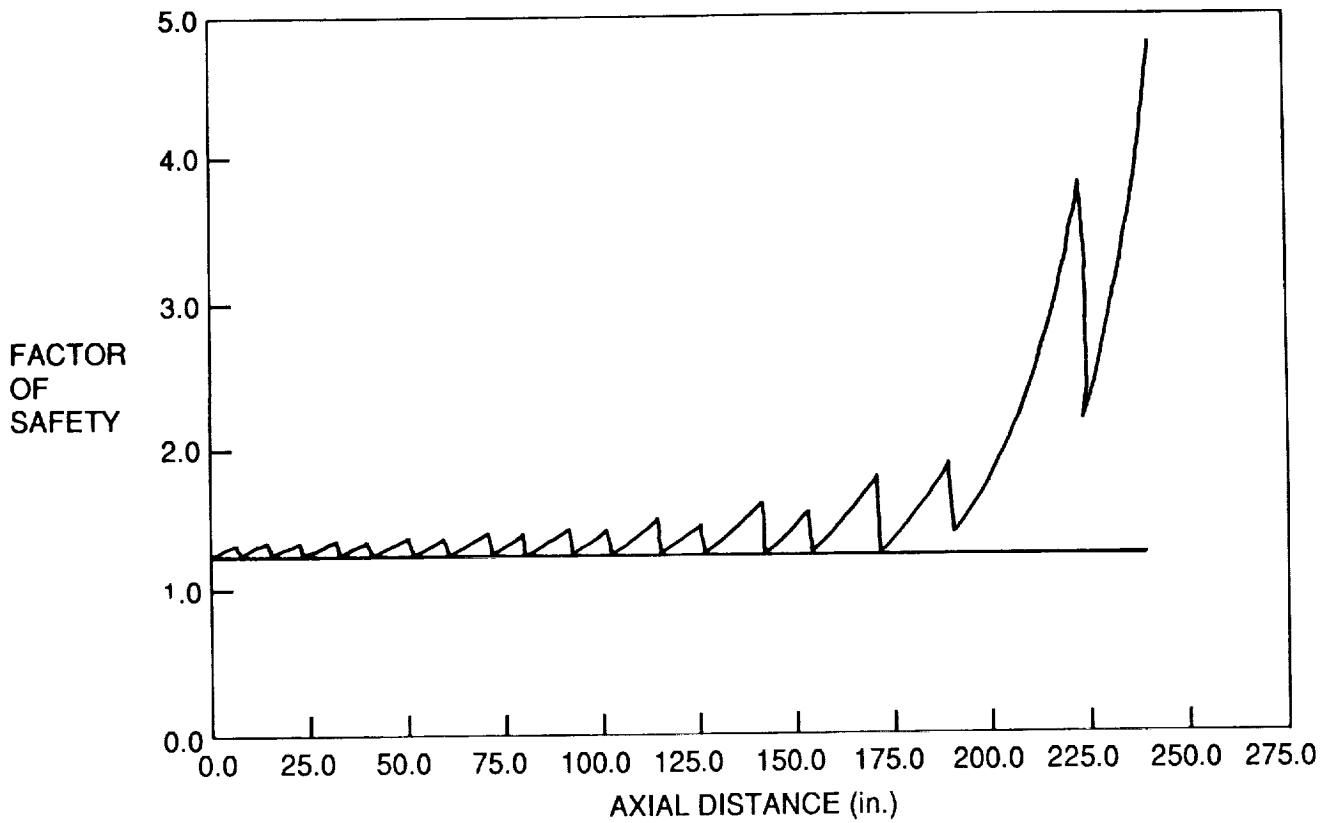
TRIAL RIB FOR 50-ft ANTENNA

Figure 19

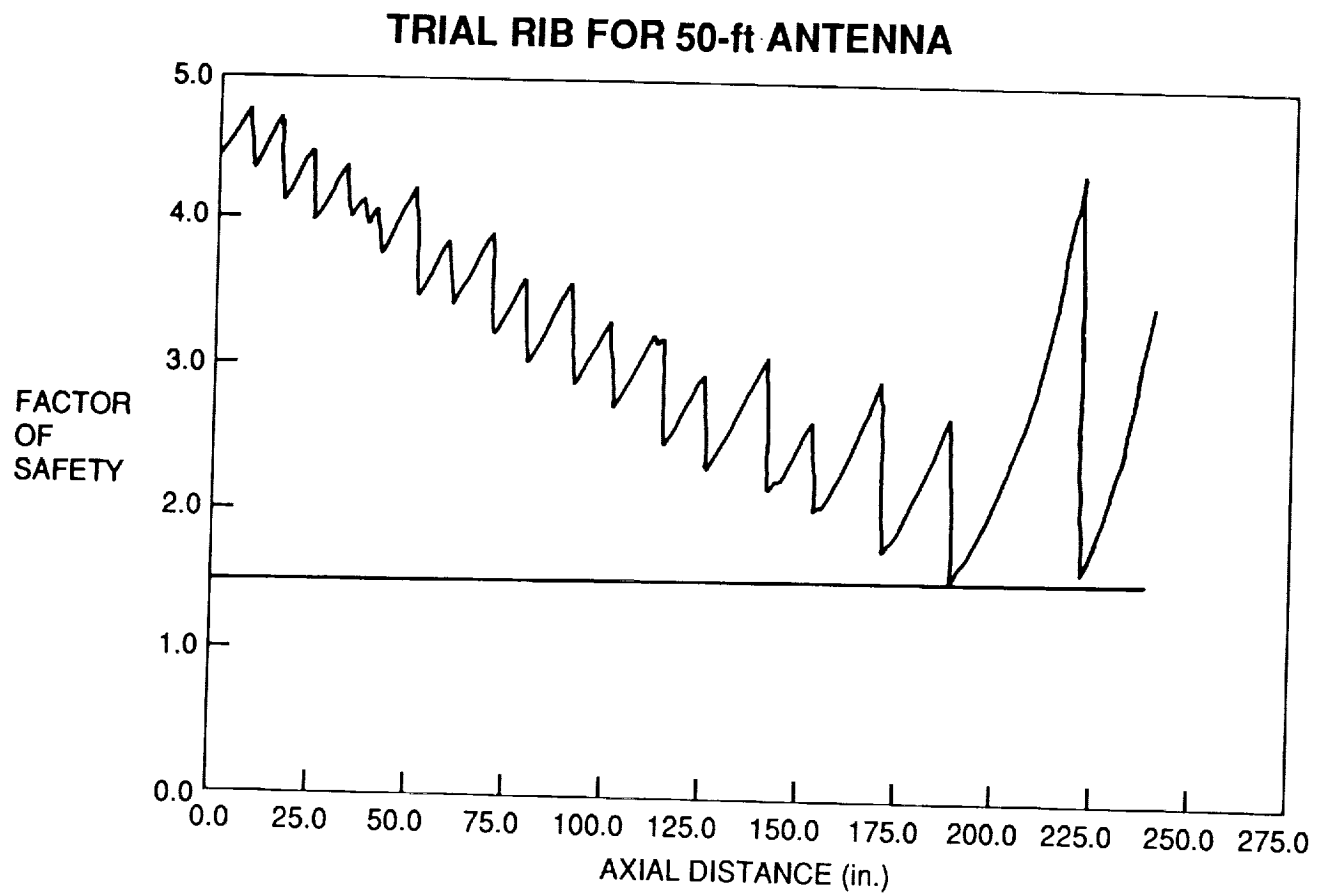# FACTOR OF SAFETY (TORSIONAL) vs. AXIAL DISTANCE

TRIAL RIB FOR 50-ft ANTENNA

Figure 20

FACTOR OF SAFETY (STRESS) vs. AXIAL DISTANCE

TRIAL RIB FOR 50-ft ANTENNA

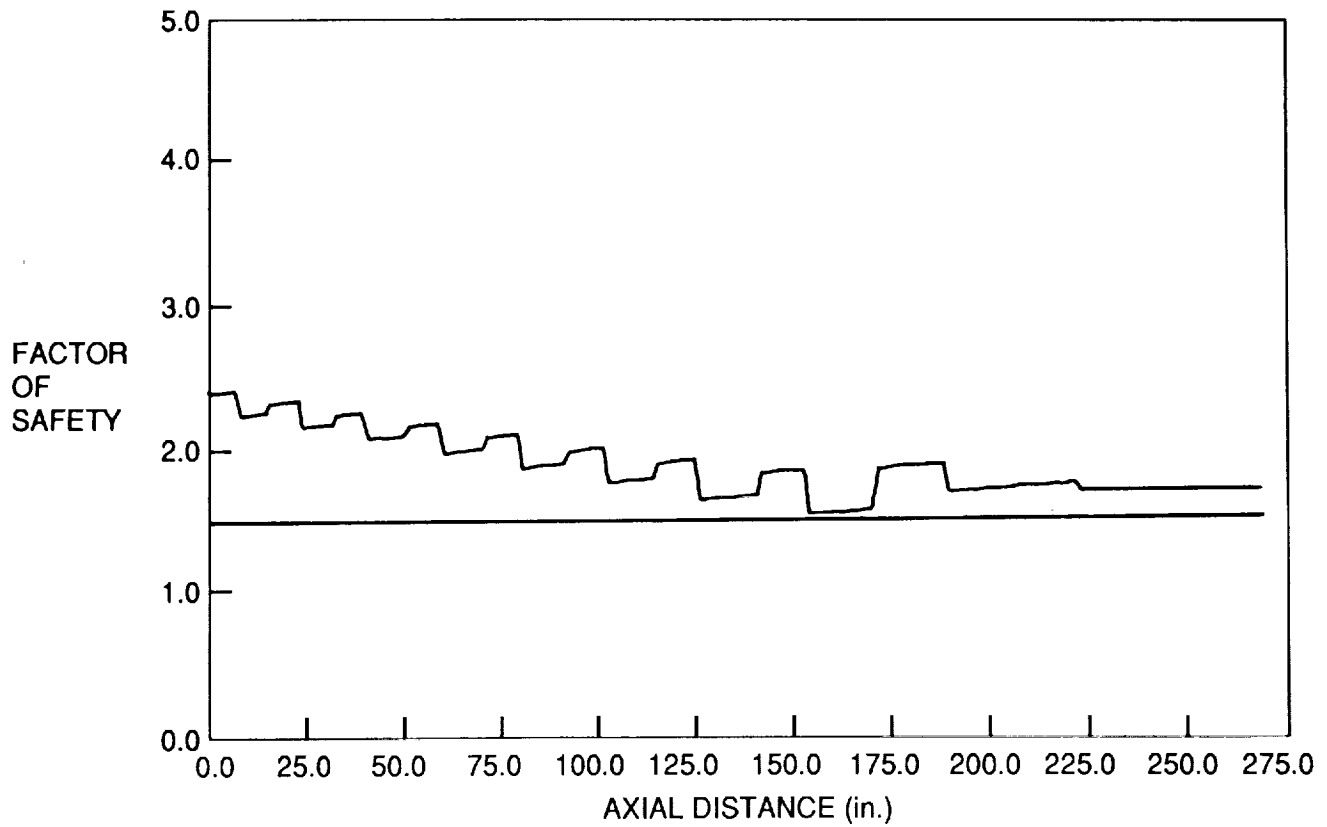
Figure 21

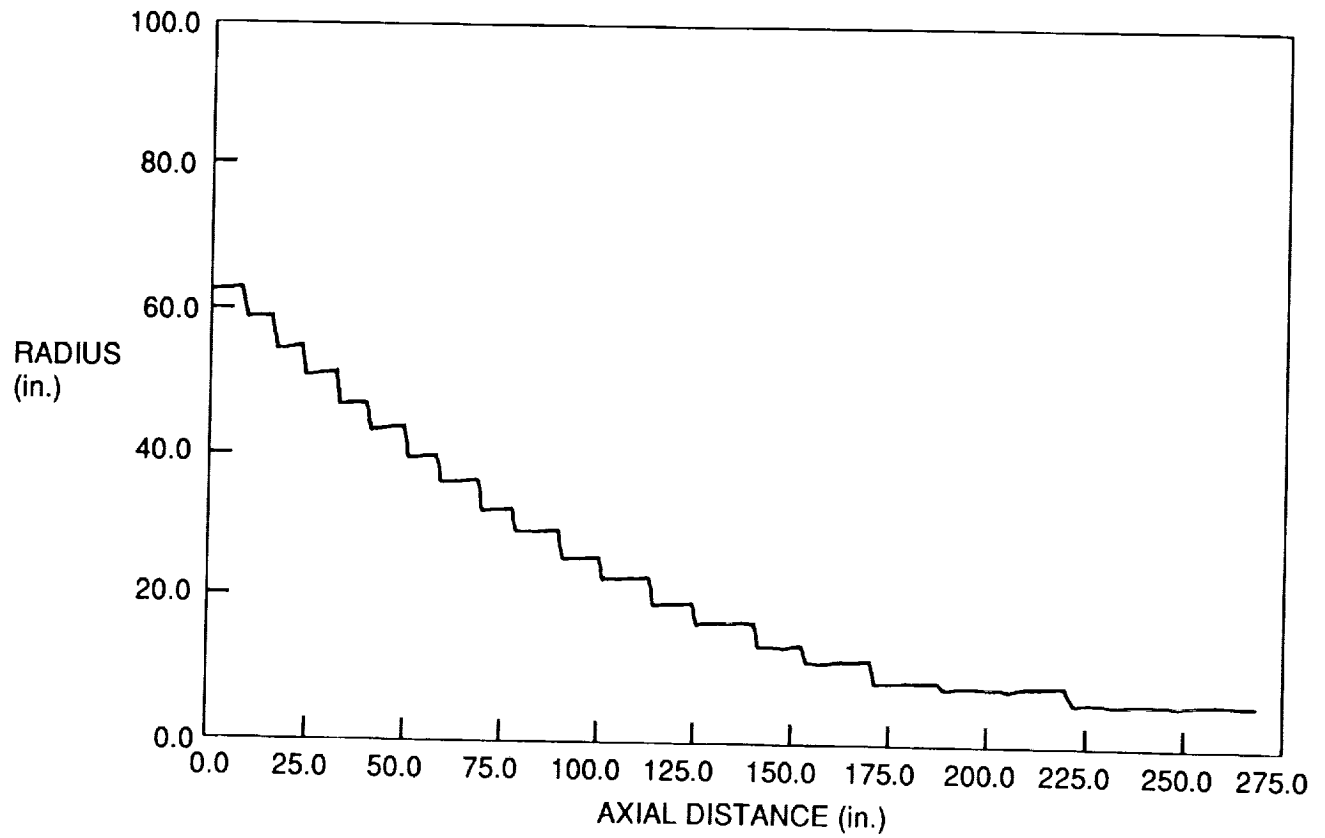# CHARACTERISTIC RADIUS vs. AXIAL DISTANCE

TRIAL RIB FOR 50-ft ANTENNA

Figure 22

Figure 23 shows the structural characteristics of the 50-ft-diameter rib. Its lowest structural frequency is 0.62 Hz, which is the pin-wheel mode. Cup-up and cup-down stability numbers give the margins of the reflector's stability in a 1-G loading environment.
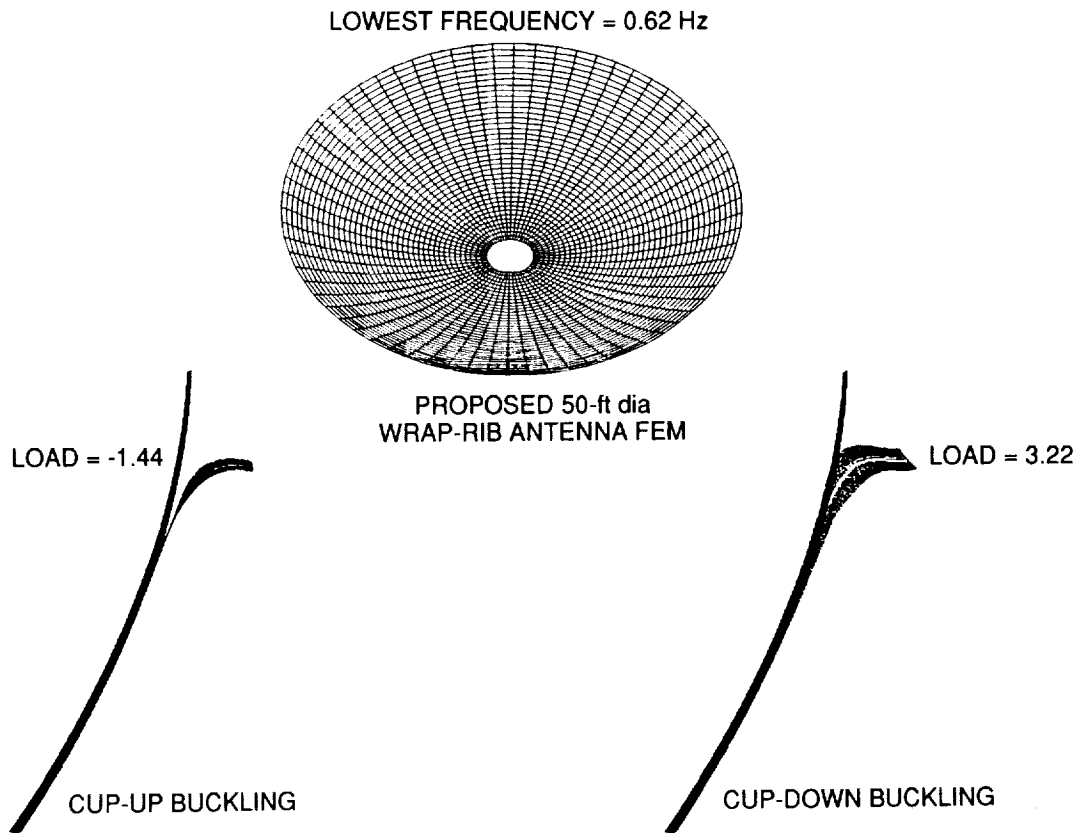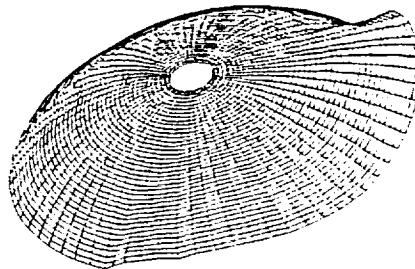
LOWEST FREQUENCY = 0.62 Hz

PROPOSED 50-ft dia
WRAP-RIB ANTENNA FEM

LOAD = -1.44

LOAD = 3.22

CUP-UP BUCKLING

CUP-DOWN BUCKLING

Figure 23

Figure 24 shonws the far-field performance of the 50-ft-diameter antenna for the worst distortion case. This was generated using the integrated rf/mechanical analysis code. This shows that far-field gain is quite respectable even for the worst case.
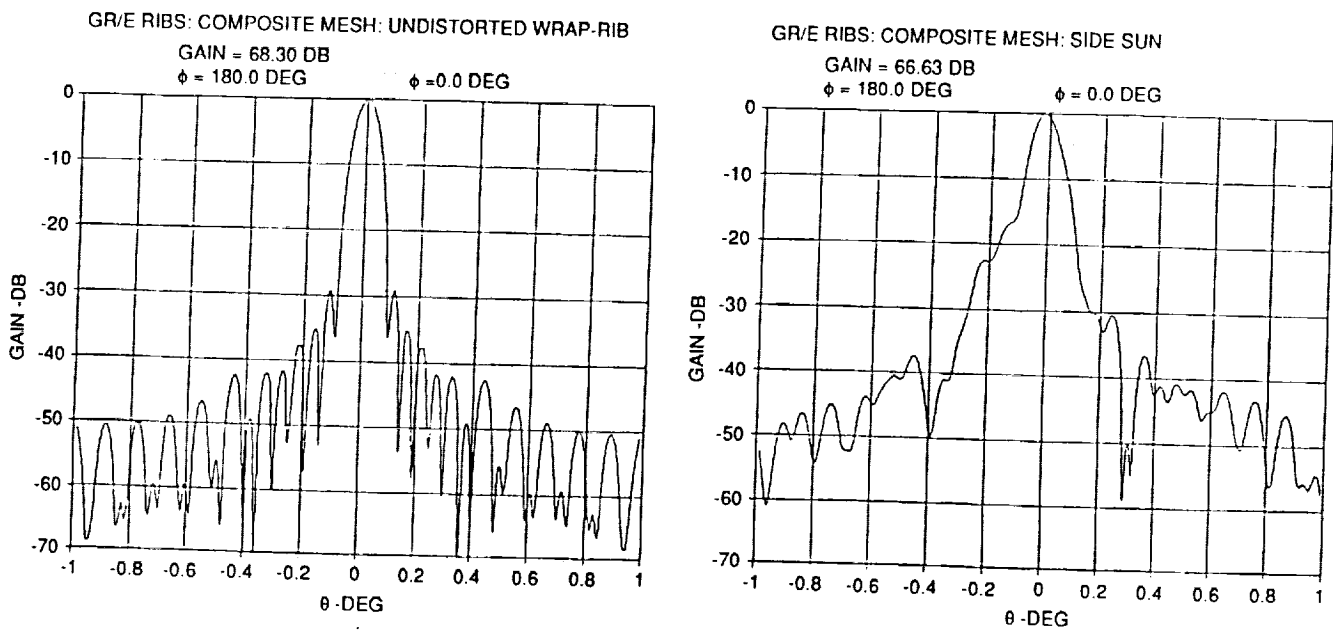
50 ft. DISH DISTORTED FOR SIDE SUN

GR/E RIBS: COMPOSITE MESH: UNDISTORTED WRAP-RIB

GAIN = 68.30 DB

φ = 180.0 DEG   φ =0.0 DEG

GR/E RIBS: COMPOSITE MESH: SIDE SUN

GAIN = 66.63 DB

φ = 180.0 DEG   φ = 0.0 DEG

Figure 24

BASELINE 50-FT-DIAMETER WRAP-RIB DESIGN DATA

Figure 25 list an approximate system weight of a typical 50-ft-diameter wrap-rib antenna to be operable up to 20 GHz. The total weight of 522 lb assumes the hub structure is made of aluminum. This can be easily replaced by a graphite-epoxy material which will result in substantial weight saving.

HUB OUTER DIA	97 in.
HUB INNER DIA	72 in.
HUB WEIGHT	124 lb (ALUMINUM)
HUB HEIGHT	12 in.
TOTAL RIB WEIGHT	238 lb (FOR 68 RIBS)
TOTAL MESH WEIGHT	10 lb
APPROXIMATE FEED SUPPORT STRUCTURE WEIGHT	150 lb
TOTAL APPROXIMATE WEIGHT	522 lb

Figure 25

CONCLUSIONS

The technology for a 50-ft-diameter wrap-rib reflector for radiometric application for frequencies up to 20 GHz is near term. The elements of the total system can be designed to meet the specification. A full-up system build and contour verification must be accomplished before this size reflector can be declared space qualified.