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LMSC/D384797
January 20, 1975

N7610379

LARGE FURLABLE ANTENNA STUDY

Contract No. 954082

Prepared For:

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LOCKHEED MISSILES & SPACE COMPANY

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FIGURES (cont'd)

FIGURES (cont'd)

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LARGE FURLABLE ANTENNA STUDY

SUMMARY

This report describes the parametric study of the performance of large furlable antennas and forecasts when various size antennas will become available.

The study considered three types of unfurlable reflector designs: The wrapped rib, the polyconic and the maypole. On the basis of these approaches, a Space Shuttle launch capability and state-of-the-art materials, it is possible in 1975 to design unfurlable reflectors as large as 130 feet (40 meters) in diameter to operate at 10 GHz and 600 feet (183 meters) in diameter at 0.5 GHz. These figures could be increased if very low thermal coefficient of expansion materials can be developed over the next 2-5 years. It is recommended that a special effort be made to develop promising light weight materials that would provide nearly zero thermal coefficient of expansion and good thermal conductivity within the next 10 years.

A conservative prediction of the kinds of unfurlable spacecraft antennas that will be available by 1985 with orbital performance predicted on the basis of test data and with developed manufacturing processes may be summarized as follows:

- Moving steerable orbiting antenna reflectors at 600 feet in diameter operating at 6 to 10 GHz.

- Stable orbiting electrically steerable antenna reflectors at 11,000 feet in diameter operating at 2 GHz and at 3000/3500 feet in diameter operating at 8 to 10 GHz. Limitation in size is controlled primarily by the Space Shuttle cargo weight launch limit of 65,000 pounds.

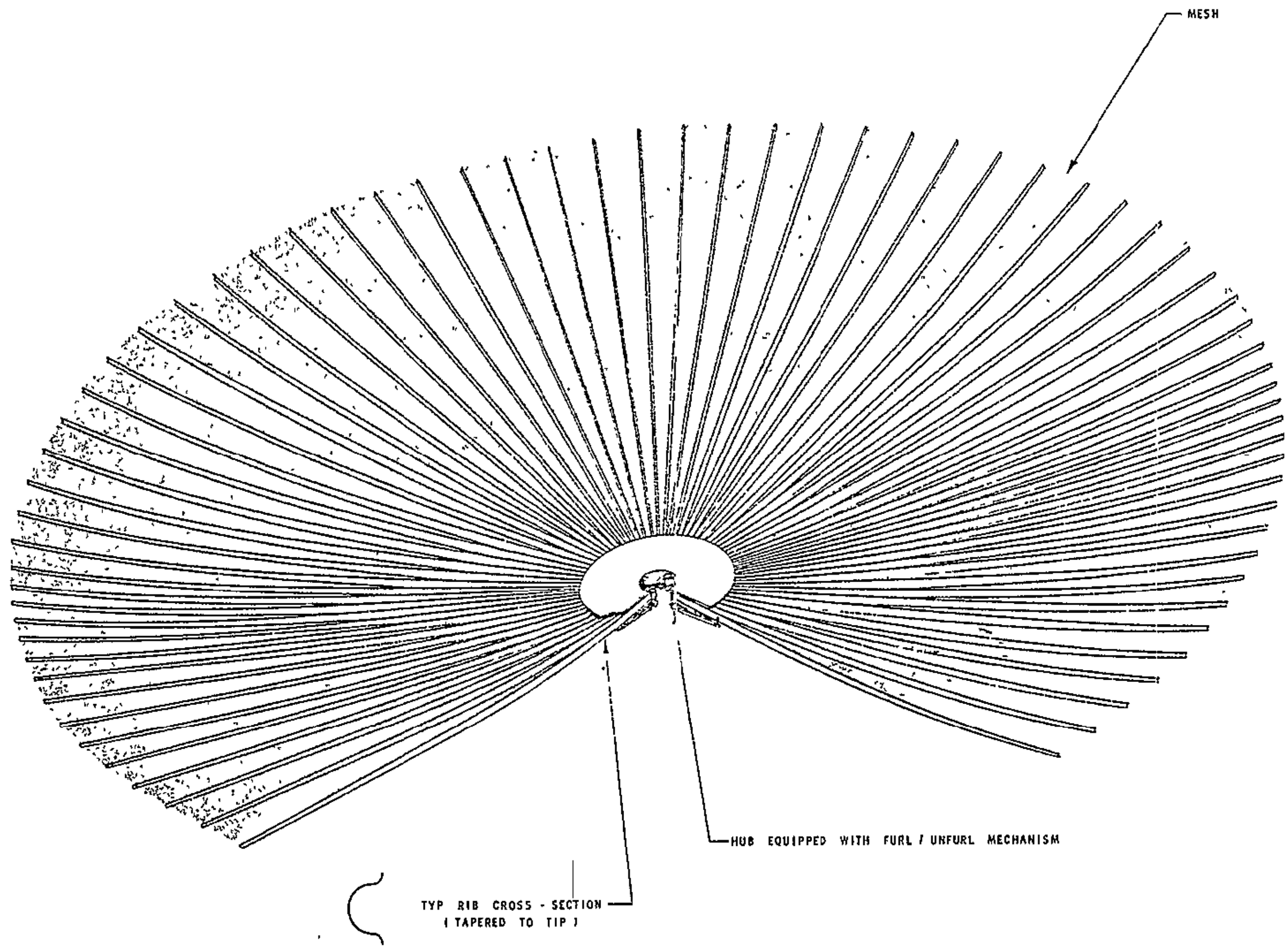
INTRODUCTION

LMSC has generated parametric technical information relative to large furlable reflector antennas under Contract No. 954082 for Jet Propulsion Laboratory-California Institute of Technology.

Parametric extrapolated data has been generated for five diameters at three r.f. frequencies of furlable/unfurlable reflector antennas of two different concept types. Isometric illustrations of these concepts are shown by Figures 1 and 2. The diameters are 30, 120, 210, 300 and 600 feet. The frequencies are 8, 2 and .5 GHz. The concept types are Wrap-Rib and Polyconic. In addition, a data section covering a reflector antenna concept type called Maypole has been added. Isometric illustrations are shown by Figures 3 and 4.

The technical information data, in general, covers the following performance or geometric areas and is indexed to cover each of the 19 items under Statement of Work, Article 1, part (b).

1. Reflector surface tolerance in rms inches versus r.f. frequency and reflector diameter.
2. Reflector surface deviation and r.f. peak gain as a function of typical thermal environment at three orbital altitudes. The best and worst performance are given with an example typical orbital time distribution position and interim variations.
3. Reflector surface tolerance versus antenna weight and antenna cost.
4. Antenna weight breakdown versus reflector diameter and r.f. frequency designated along with center of gravity locations and mass moments of inertia.
5. Geometric envelope dimensions of the furled and unfurled antennas.
6. Estimated antenna cost versus diameter, r.f. frequency and surface tolerance.
7. Estimated natural frequencies and dynamic characteristics versus diameter.
8. Reflector surface deviation as a function of rotation sweep rates with r.f. on at designated gain loss during sweeping.
9. Maximum rotational acceleration sweep rates versus antenna diameter.



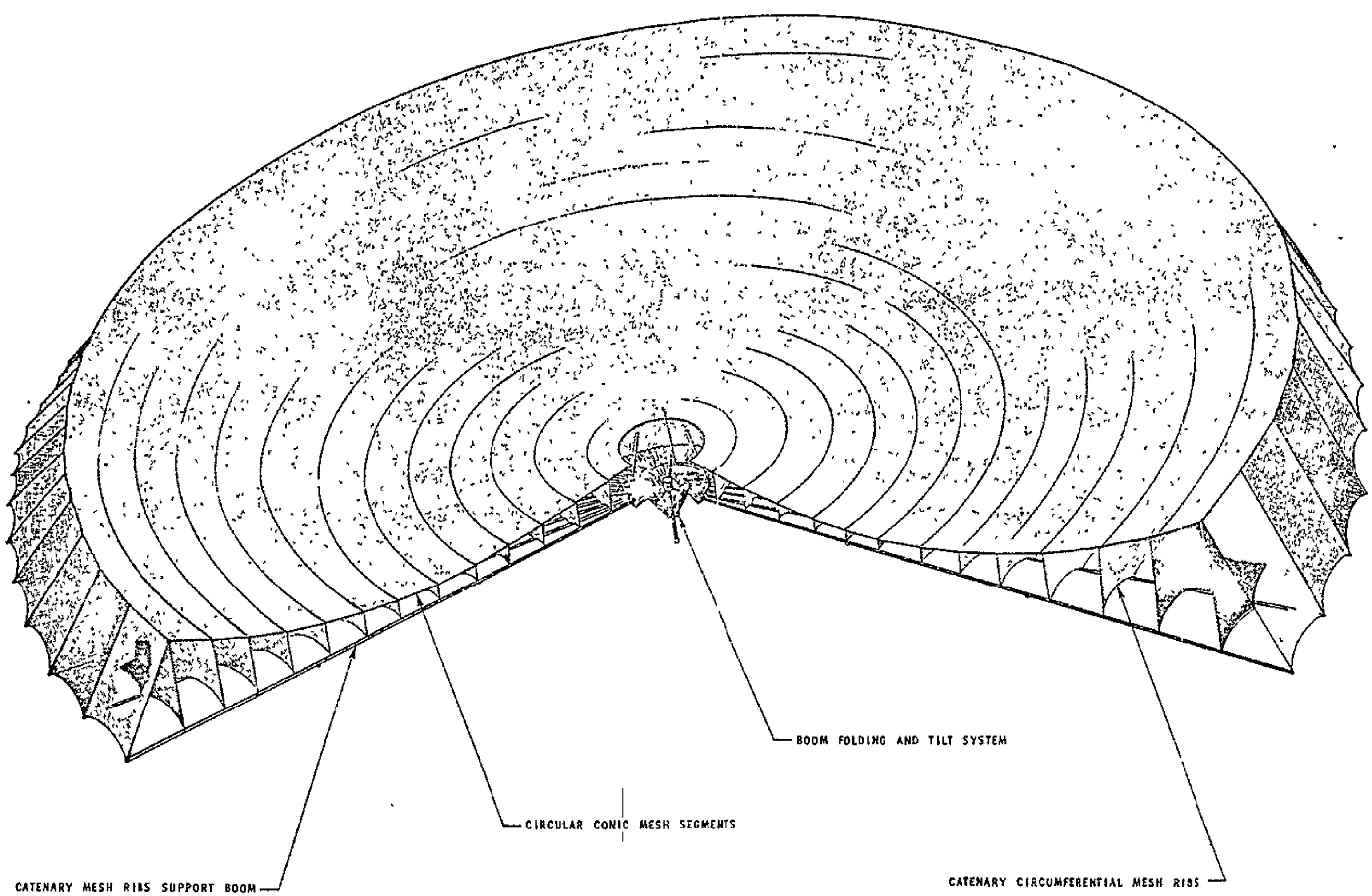
FOLDOUT FRAME 2

8 GHz

FOLDOUT FRAME 1

Figure 1

WRAP RIB REFLECTOR CANDIDATE AT 120 ft DIA

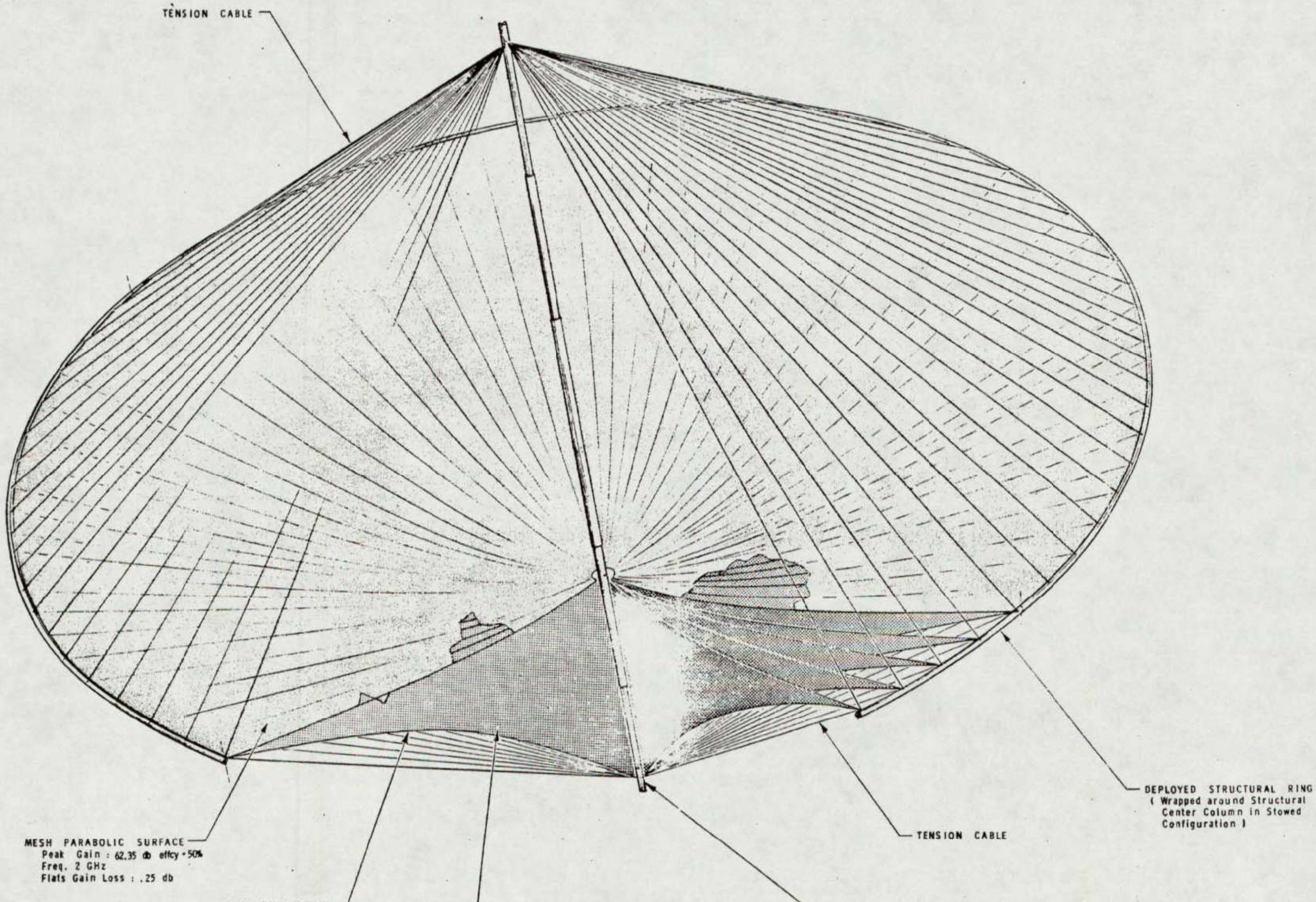


FOLDOUT FRAME

FOLDOUT FRAME

Figure 2

POLYCONIC REFLECTOR

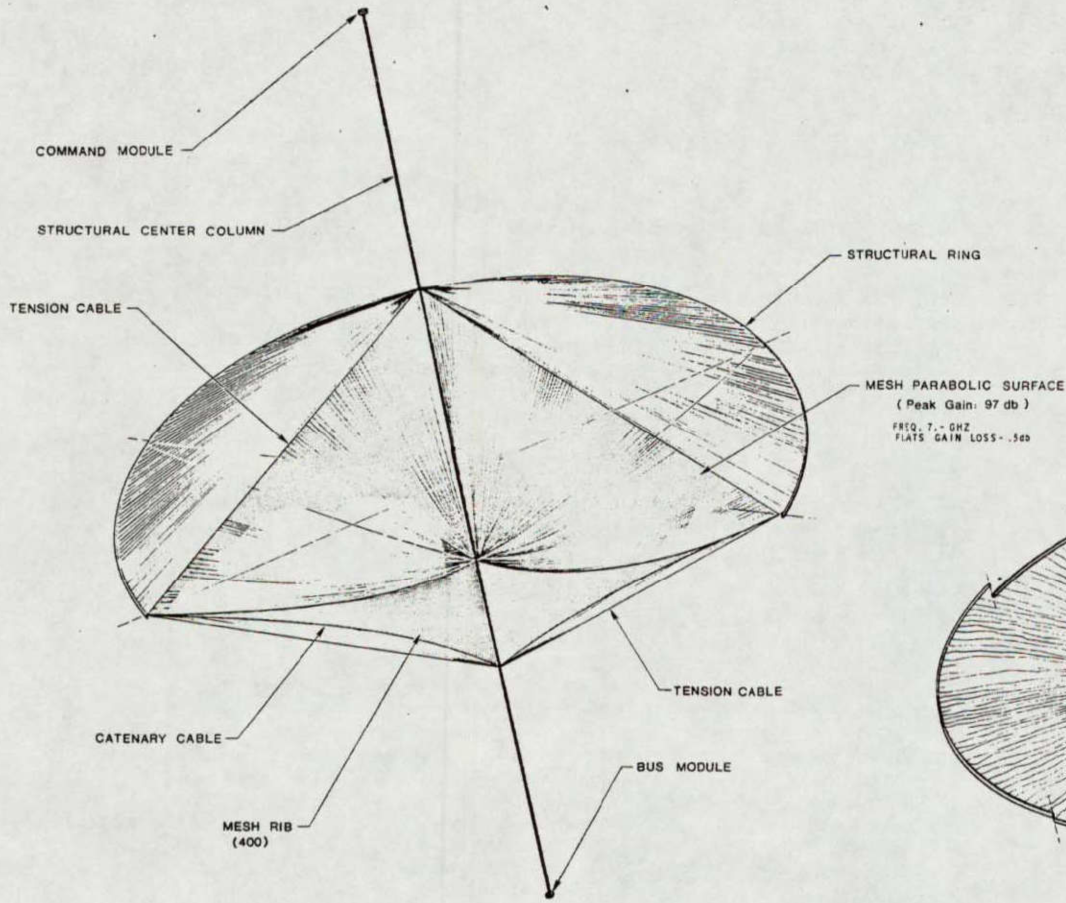


FOLDOUT FRAME 1

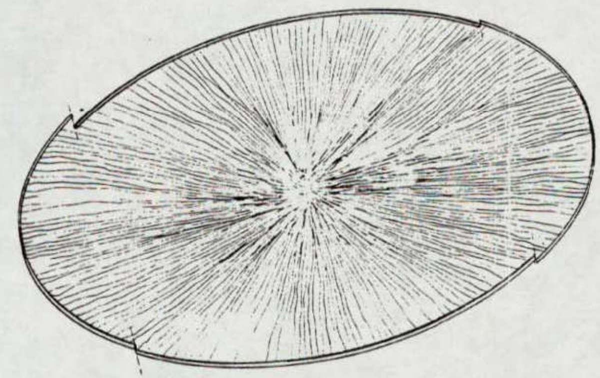
FOLDOUT FRAME 2

Figure 3

300 ft DIA MAYPOLE PARABOLIC REFLECTOR



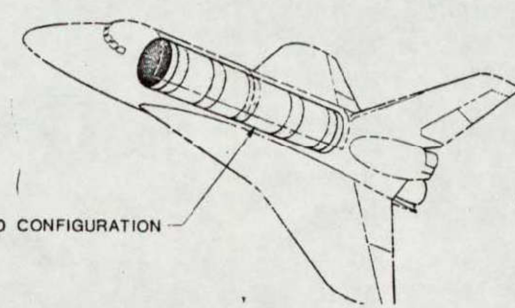
FULLY DEPLOYED CONFIGURATION



PARTIALLY DEPLOYED

SYNCHRONOUS ORBIT OPERATIONS

- O GRAVITY GRADIENT STABILIZED TO 06 DEG. POINTING ACCURACY
- O WT. OF REFLECTOR SYSTEM 46000 LBS



STOWED CONFIGURATION

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Figure 4

3100 FT DIA COMMUNICATION SYSTEM

Parametric data in sequence of Statement of Work, Article I, part (b).

Item 1. <u>List Antenna concept types covered, diameters used as data points and r.f. frequencies at which the parametric data was generated</u>.

Table I lists information desired.

Diameter	RF Frequency	Wrap-Rib	Polyconic	Maypole
30 ft/9.2 m	8 GHz	X	X	
	2 "	X	X	
	0.5 "	X	X	
120 ft/36.6 m	8 GHz	X	X	
	2 "	X	X	
	0.5 "	X	X	
210 ft/64 m	8 GHz	X	X	See Section 20
	2 "	X	X	
	0.5 "	X	X	
300 ft/91.4 m	8 GHz	X	X	
	2 "	X	X	
	0.5 "	X	X	
600 ft/182.8m	8 GHz	X	X	
	2 "	X	X	
	0.5 "	X	X	

TABLE I

Item 2. Show Reflector surface tolerance in inches rms as a function of reflector diameter for nominally manufactured hardware.

NOTE: The manufacturing process is not complete for large sizes until the contour evaluation and interconnected servo adjustment system has completed the final contour adjustment after deployment in space.

Surface accuracy deviation from a true parabola required is a function of the use r.f. frequency and the parabolic approximation geometrically built into a given concept.

Tables II, III and IV show diameters, r.f. frequencies, geometric approximation loss (nominal), number of ribs for wrap-rib concept and surface tolerance in rms inches.

Figure 5 illustrates the tabular information of Tables II, III and IV where frequency use, approximation gain loss and surface deviation allowable in rms inches are given as a function of the number of ribs used in wrap-rib concept and the reflector diameter.

Figure 6 illustrates surface deviation in rms inches versus r.f. frequency use plotted as a function of Δ G db or gain loss from geometric approximation of a true parabola.

Figures 7 and 8 are given as added information of interest. Figure 7 illustrates number of ribs N as a function of surface deviation in wavelength rms inches and diameter of reflector in wavelengths. Figure 8 illustrates geometric approximation gain loss (Δ G db) as a function of diameter of reflector in wavelengths and number of ribs used.

Figures 5, 6, 7 and 8 hold true for the geometric circular parabolic approximation used in both the Wrap-rib concept and the Maypole concept.

FLEX RIB ANTENNA

RMS REQUIRED AS MANUFACTURED

AT $\Delta G = .25$ db

Diam.	GHz	λ	D	D/λ	ΔG	No. Ribs	δ/λ	δ rms
	8	1.48	360	243	.25	48	021	.031
30'	2	5.92	360	61	.22	24	022	.130
	.5	23.70	360	15.2	.20	12	018	.427
	8	1.48	1440	972	.25	96	021	.031
120'	2	5.92	1440	244	.22	48	022	.130
	.5	23.70	1440	61	.20	26	018	.427
	8	1.48	2520	1705	.25	130	021	.031
210'	2	5.92	2520	426	.22	64	022	.130
	.5	23.70	2520	107	.20	34	018	.427
	8	1.48	3600	2435	.25	154	021	.031
300'	2	5.92	3600	608	.22	74	022	.130
	.5	23.70	3600	152	.20	42	018	.427
	8	1.48	7200	4850	.25	226	021	.031
600'	2	5.92	7200	1215	.22	112	022	.130
	.5	23.70	7200	304	.20	56	018	.427

Summary RMS shown has been modified to reflect an even number of ribs and actual ΔG value. ΔG shown as nominal .25 db.

SUMMARY

FREQ-GHZ	RMS (IN.)
8	0.031
2	0.130
.5	0.427

TABLE II

uses $$\delta_{rms} = \sqrt[1.865]{\frac{\Delta G \times \lambda^{1.865}}{346}}$$

(MODIFIED RUSE FOR SYMMETRICAL DEVIATIONS)

FLEX RIB ANTENNA

RMS REQUIRED AS MANUFACTURED

AT Δ G = .5

Diam.	GHz	λ	D	D/λ	Δ G	No. Ribs	δ/λ	δ rms
	8	1.48	360	243	.5	38	.033	.048
30'	2	5.92	360	61	.5	20	.030	.177
	.5	23.70	360	15.2	.5	10	.029	.687
	8	1.48	1440	972	.5	78	.031	.046
120'	2	5.92	1440	244	.5	38	.033	.195
	.5	23.70	1440	61	.5	20	.030	.711
	8	1.48	2520	1705	.5	104	.032	.047
210'	2	5.92	2520	426	.5	52	.031	.183
	.5	23.70	2520	107	.5	26	.033	.782
	8	1.48	3600	2435	.5	124	.033	.049
300'	2	5.92	3600	608	.5	62	.032	.189
	.5	23.70	3600	152	.5	30	.033	.782
	8	1.48	7200	4850	.5	180	.031	.046
600'	2	5.92	7200	1215	.5	88	.030	.177
	.5	23.70	7200	304	.5	44	.030	.711

Summary RMS shown has been modified to reflect an even number of ribs and actual Δ G value. Δ G shown as nominal .50 db.

SUMMARY

FREQ-GHZ	RMS (IN.)
8	.047
2	.184
.5	.734

TABLE III

FLEX RIB ANTENNA

RMS REQUIRED AS MANUFACTURED

AT Δ G = 1.0 db

Diam.	GHz	λ	D	D/λ	Δ G	No. Ribs	δ/λ	δ rms
	8	1.48	360	243	1.0	34	.042	.062
30'	2	5.92	360	61	1.0	16	.040	.236
	.5	23.70	360	15.2	1.0	8	.041	.972
	8	1.48	1440	972	1.0	66	.042	.062
120'	2	5.92	1440	244	1.0	34	.041	.243
	.5	23.70	1440	61	1.0	16	.050	1.185
	8	1.48	2520	1705	1.0	90	.040	.059
210'	2	5.92	2520	426	1.0	44	.042	.249
	.5	23.70	2520	107	1.0	22	.043	1.019
	8	1.48	3600	2435	1.0	108	.044	.065
300'	2	5.92	3600	608	1.0	52	.044	.260
	.5	23.70	3600	152	1.0	26	.049	1.161
	8	1.48	7200	4850	1.0	152	.041	.061
600'	2	5.92	7200	1215	1.0	76	.041	.243
	.5	23.70	7200	304	1.0	38	.042	.995

Summary RMS shown has been modified to reflect an even number of ribs and actual Δ G value. Δ G shown as nominal 1.00 db.

SUMMARY

FREQ-GHZ	RMS (IN.)
8	.061
2	.246
.5	1.066

TABLE IV

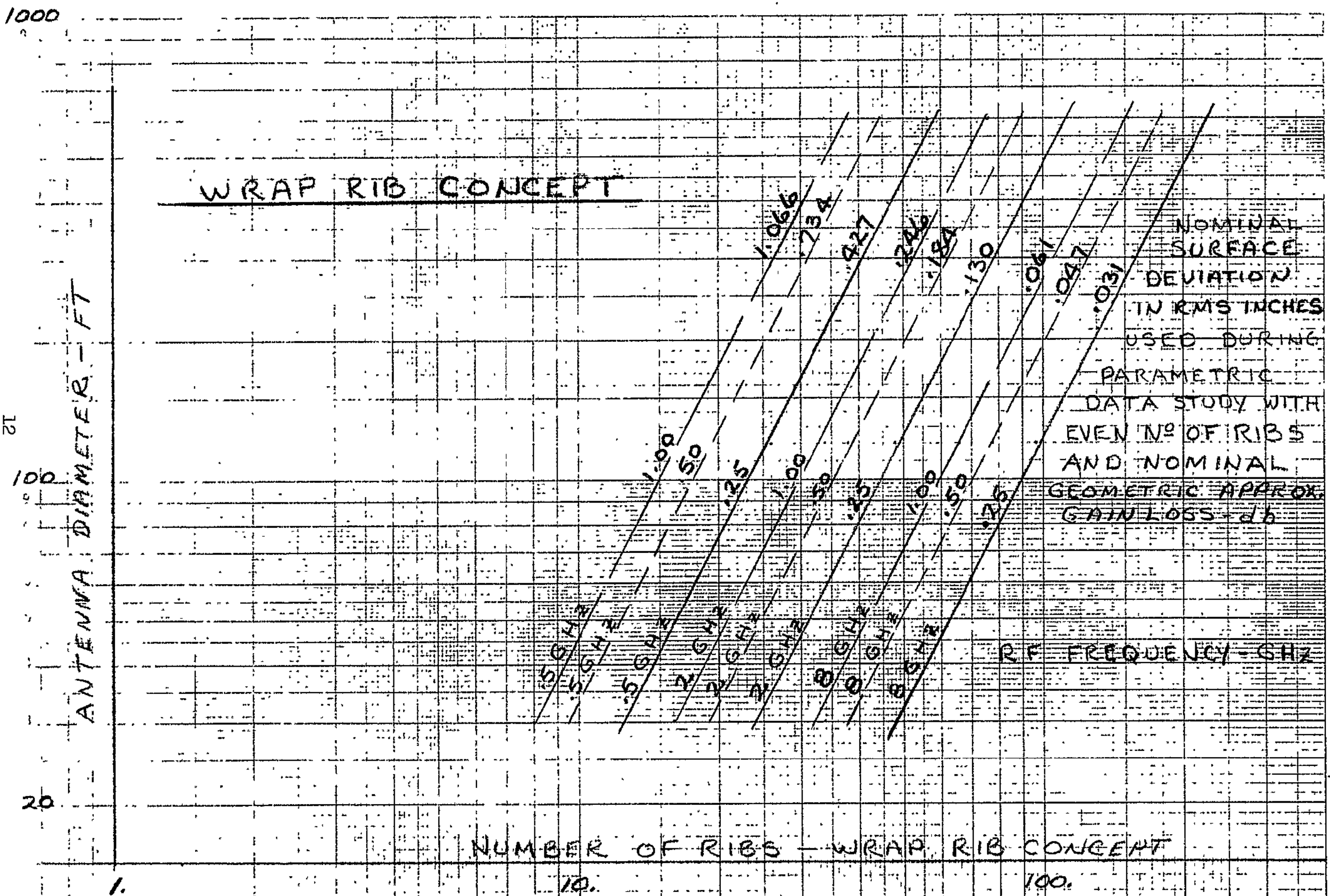


FIGURE 5.

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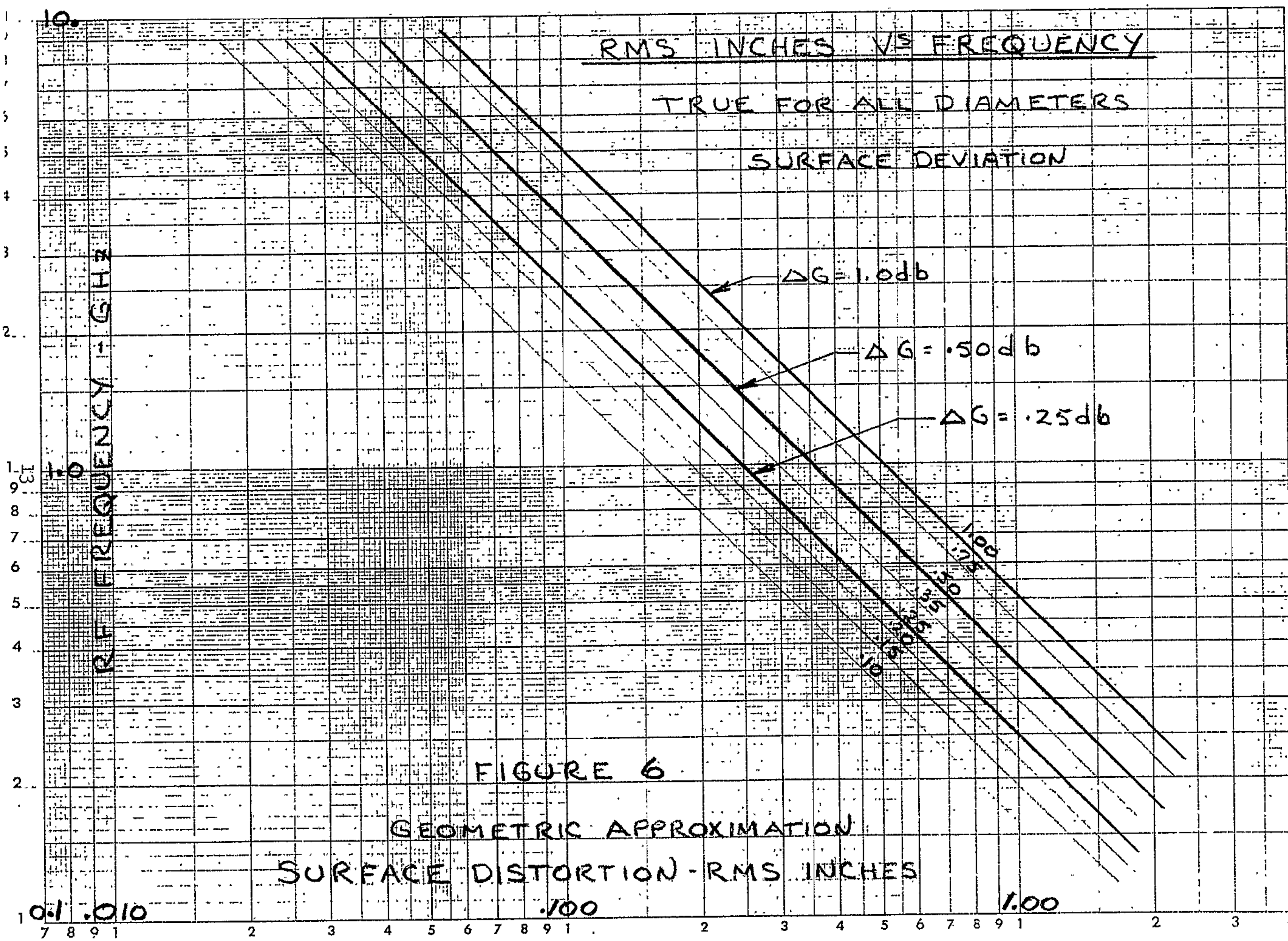

13

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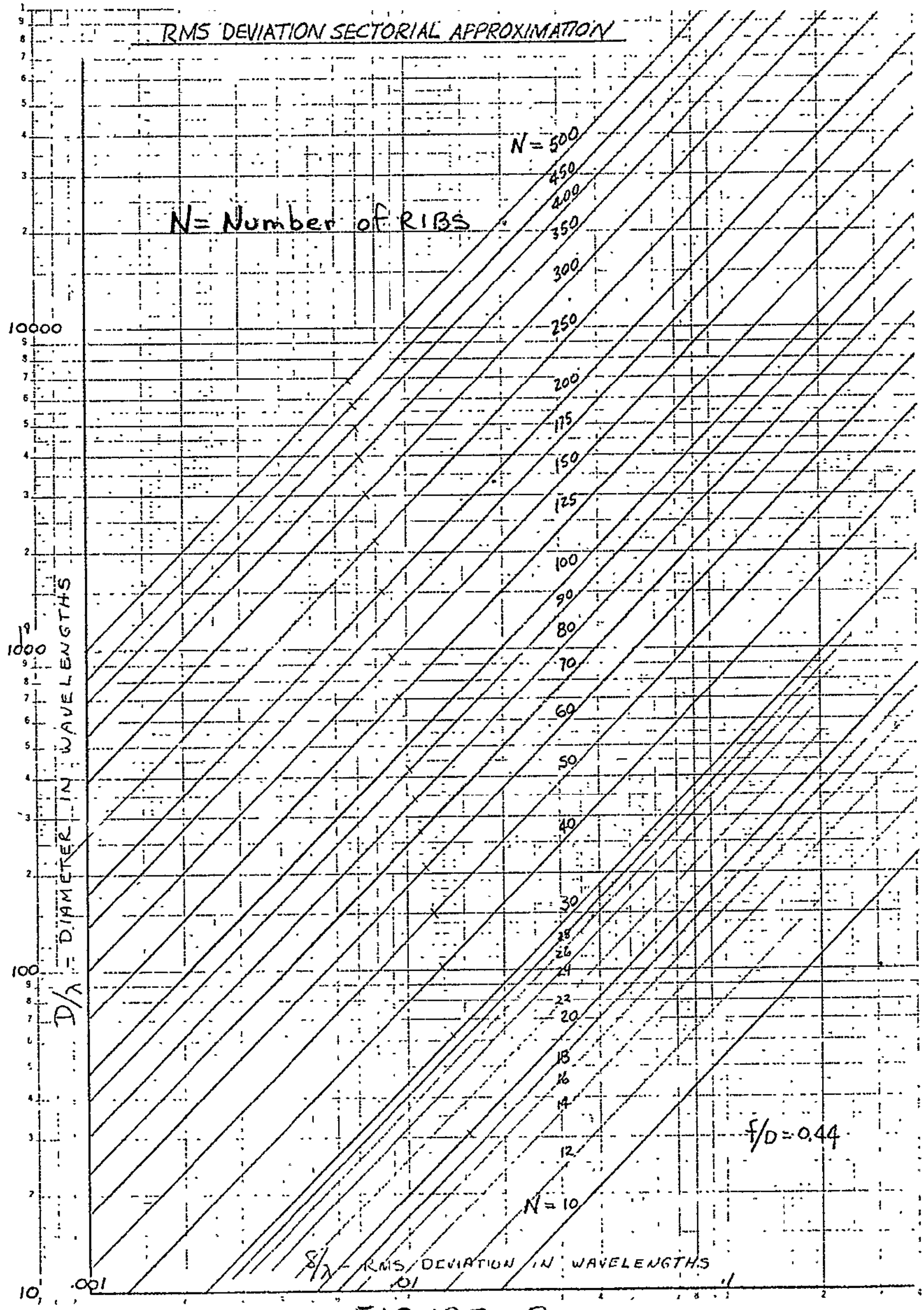
RMS DEVIATION SECTORIAL APPROXIMATION
N = Number of RIBS
N = 500
450
400
350
300
250
200
175
150
125
100
90
80
70
60
50
40
30
28
26
24
22
20
18
16
14
12
N = 10
f/D = 0.44
D/λ - DIAMETER IN WAVELENGTHS
δ/λ - RMS DEVIATION IN WAVELENGTHS
10000
1000
100
10
.001
.01
.1

FIGURE 7.

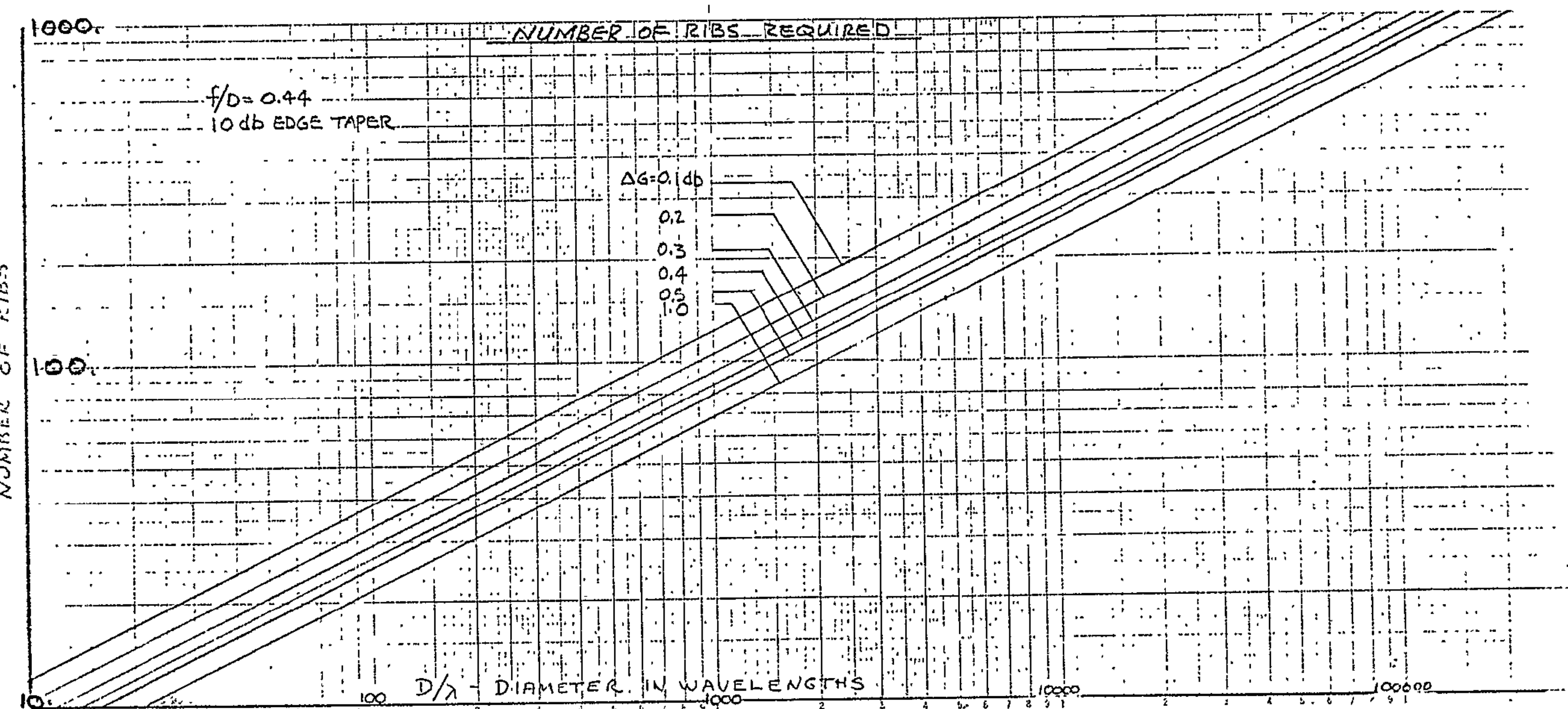
NUMBER OF RIBS REQUIRED
f/D= 0.44
10 db EDGE TAPER
ΔG=0.1db
0.2
0.3
0.4
0.5
1.0
1000.
100.
10
100
1000
10000
100000
D/λ - DIAMETER IN WAVELENGTHS
NUMBER OF RIBS

FIGURE 8.

Tables V, VI and VII illustrate similar information to that given by Tables II, III and IV but result in the number of cones used in a polyconic concept where geometric radial parabolic approximation is used.

Figure 9 illustrates tabular information of Tables V, VI and VII where frequency use, approximation gain loss and surface deviation allowable in rms inches are given as a function of the number of cones used in the Polyconic concept and the reflector diameter.

Considerable preliminary information has been presented in this Section in order to facilitate understanding of the variables used to create the parametric information in later sections. Basically, the definition required by Statement of Work question (b) 2 is answered by the data shown on Figure 6.

POLYCONIC ANTENNA

RMS REQUIRED AS MANUFACTURED

AT ΔG = NOMINAL (0.25) DB

DIAM. (FT)	GHz	λ (IN)	D (IN)	D/λ	NOMINAL ΔG (DB)	NO. OF CONES	CONE PRODUCED RMS (INS)
30	8 2 .5	1.48 5.92 23.70	360 360 360	243 61 15.2	.25	13 7 4	0.0324 0.1318 0.4296
120	8 2 .5	1.48 5.92 23.70	1440 1440 1440	972 244 61	.25	30 15 8	0.0330 0.1330 0.4315
210	8 2 .5	1.48 5.92 23.70	2520 2520 2520	1705 426 107	.25	40 20 11	0.0333 0.1337 0.4328
300	8 2 .5	1.48 5.92 23.70	3600 3600 3600	2435 608 152	.25	48 24 14	0.0335 0.1343 0.4334
600	8 2 .5	1.48 5.92 23.70	7200 7200 7200	4850 1215 304	.25	68 34 19	0.0341 0.1363 0.4346

TABLE V

POLYCONIC ANTENNA

RMS REQUIRED AS MANUFACTURED

AT ΔG = NOMINAL (0.50) DB

DIAM. (FT)	GHz	λ (IN)	D (IN)	D/λ	NOMINAL ΔG (DB)	NO. OF CONES	CONE PRODUCED RMS (INS)
30	8 2 .5	1.48 5.92 23.70	360	243 61 15.2	.50	11 6 3	0.0485 0.1861 0.7359
120	8 2 .5	1.48 5.92 23.70	1440	972 244 61	.50	24 12 6	0.0490 0.1874 0.7390
210	8 2 .5	1.48 5.92 23.70	2520	1705 426 107	.50	33 17 9	0.0497 0.1875 0.7406
300	8 2 .5	1.48 5.92 23.70	3600	2435 608 152	.50	39 20 10	0.5000 0.1889 0.7413
600	8 2 .5	1.48 5.92 23.70	7200	4850 1215 305	.50	55 29 15	0.0518 0.1905 0.7441

TABLE VI

POLYCONIC ANTENNA

RMS REQUIRED AS MANUFACTURED

AT ΔG = NOMINAL (1.00) DB

DIAM. (FT)	GHz	λ (IN)	D (IN)	D/λ	NOMINAL ΔG (DB)	NO. OF CONES	CONE PRODUCED RMS (INS)
30	8	1.48	360	243	1.00	10	0.0626
	2	5.92		61		5	0.2482
	.5	23.70		15.2		2	1.0706
120	8	1.48	1440	972	1.00	22	0.0632
	2	5.92		244		11	0.2496
	.5	23.70		61		5	1.0725
210	8	1.48	2520	1705	1.00	29	0.0638
	2	5.92		426		15	0.2508
	.5	23.70		107		7	1.0733
300	8	1.48	3600	2435	1.00	35	0.0640
	2	5.92		608		18	0.2515
	.5	23.70		152		9	1.0732
600	8	1.48	7200	4850	1.00	49	0.0651
	2	5.92		1215		24	0.2525
	.5	23.70		305		12	1.0790

TABLE VII

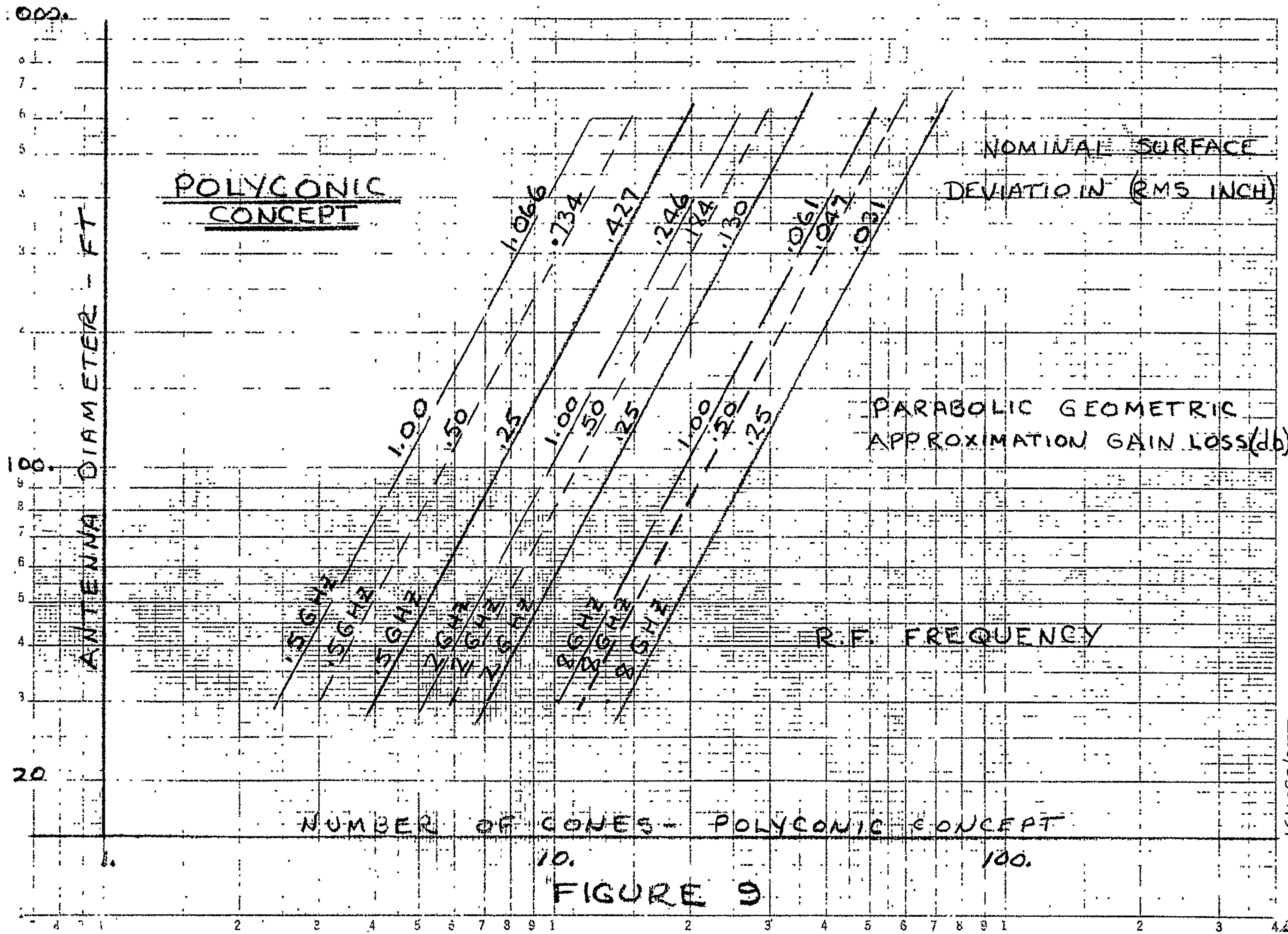

FIGURE 9

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Item 3. Show Reflector surface deviation as a function of thermal environment for a) typical near earth orbit of approximately 400 Kilometers (b) earth orbit of approximately 2000 Kilometers and c) synchronous earth orbit.

The thermally deviated surface of the reflector (at any altitude orbit) will lower the peak gain r.f. performance by means of two geometric actions or a combination of the two. The first is symmetrical opening or closing of the "perfect" parabola. This action will effectively move the focal point, on axis, either closer to the reflector vertex from a closing action or further away from the vertex from an opening action. Stated another way, the focal point of the symmetrically distorted reflector will be on axis but not at the required focal point where the feed has been set. It will be either closer or further away from the reflector. This type of action has little r.f. gain loss with small rms surface deviations but can become rather major as a r.f. gain loss with rms surface deviations that are numerically somewhat small.

The second geometric thermally induced distortion is non-symmetrical distortion. At certain side angles of sun illumination, (the worst usually falls between 40° and 80° angle of sun to vertex/focal point line) the leading edge of the reflector will be approximately parallel to sun rays while the trailing edge still receiving a substantial sun angle illumination. It will result in a relatively cold leading edge and hot trailing edge. This will cause non-symmetrical distortion that nominally may be assumed to be near a cupping inward of the heated area and an undistorted cool area. The best fit parabola within this distorted parabola will have an axis tilted away from the true focal point where the feed has been positioned. Peak gain may be nearly the same value as in an undistorted reflector but since the axis is tilted, the effective r.f. gain will be reduced. Both of these types of distortion may be approximated by Ruse formula or a modified version of the formula, but true r.f. gain performance can only be obtained by proper computation of the distorted surface using the gain integral similar to that as shown by Figure 10.

The major point intended by this discussion is that the rms value of surface distortion is not a good indicator of the gain loss by surface distortion. For this reason, this Section 3 question has been answered by parametric data, shown in the Figures, first by actual gain obtainable from the distorted surface, see Figures 11, 12 and 13, and second by presentation of surface distortion, see Figure 14. The gain obtainable includes aperture efficiency losses at 55% efficiency, mesh transmission losses at either 99 or 95% reflectivity, built in geometric approximation losses and the estimated thermally induced surface distortion gain losses.

It is germane to stress at this point that the thermally induced surface gain losses are very much dependent upon the thermal properties of the structural materials used.

When dealing with large reflectors the surface must be supported by some means. In the wrap-rib case, by the ribs which must also be capable of wrapping. In the polyconic case, by booms which need not wrap but must fold or telescope. In the maypole case, since they are mesh ribs, the surface stability will depend upon the mesh rib thermal properties.

In all concepts where a reflective mesh is used as the contoured surface, the thermal properties of the mesh material will have a considerable effect upon the distorted surface performance. To illustrate the importance of the thermal properties of the materials, the parametric data has been given, for the wrap-rib concept, with three combinations of materials.

GAIN INTEGRAL

$$G(\theta,\phi) = \eta \, \frac{\bar{I}_T \cdot \bar{I}_T^*}{\lambda^2}$$

η = RADIATION EFFICIENCY

λ = WAVELENGTH

$\bar{I}_T$ = COMPONENT OF $\bar{I}$ TRANSVERSE TO DIRECTION OF PROPAGATION

$$\bar{I} = \iint_S \frac{\sqrt{G_f(\xi,\psi)}}{\rho} \left[\bar{n} \times (\bar{i}_p \times \bar{e})\right] e^{-jk\rho(1-\bar{i}_\rho \cdot \bar{i}_R)} \, ds$$

FEED PATTERN

SPACE ATTENUATION OF FEED PATTERN

SURFACE NORMAL

RADIUS VECTOR TO REFLECTOR

POLARIZATION VECTOR

PHASE TERM

FIG. 10.

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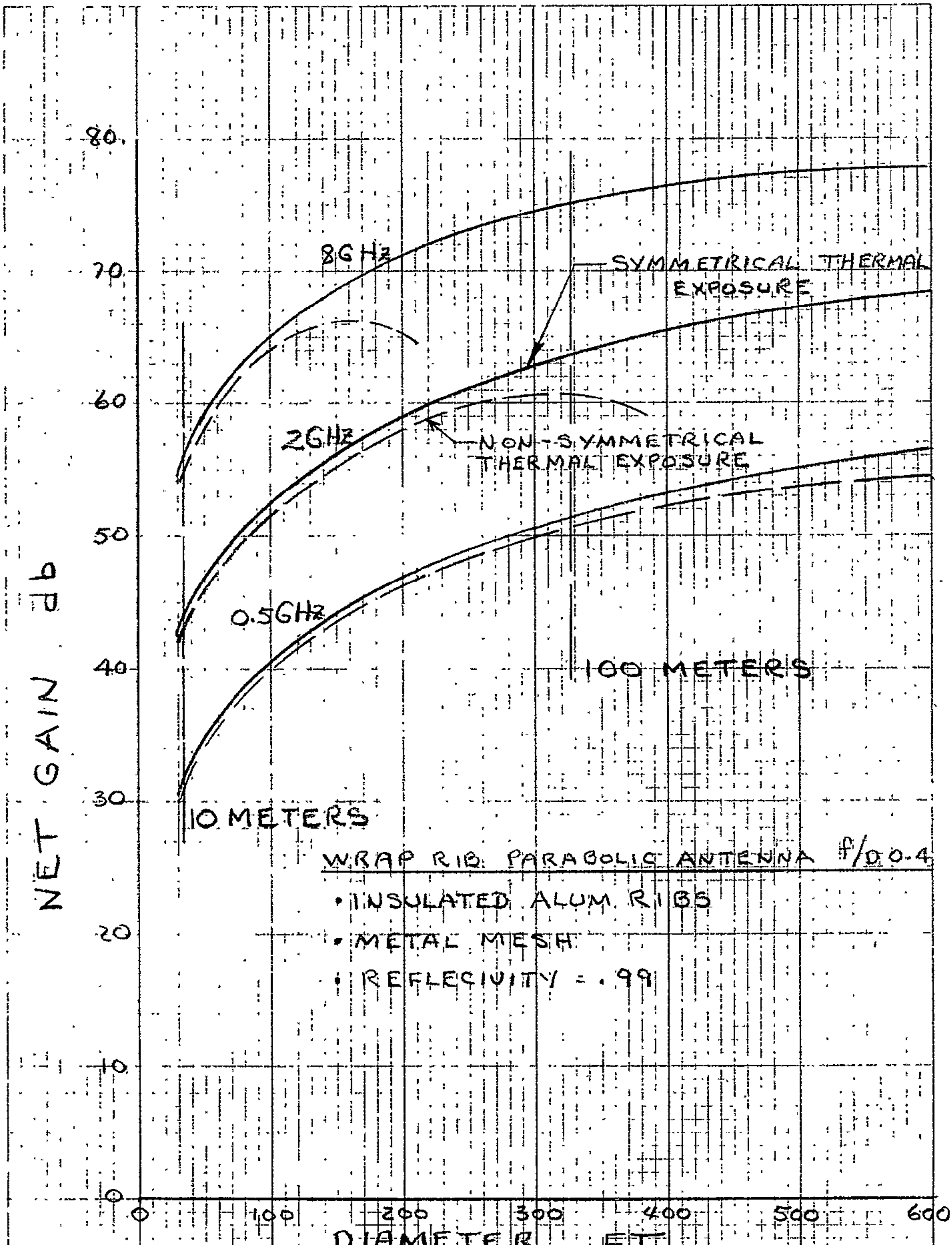

NET GAIN db
80
70
60
50
40
30
20
10
0
8GHz
2GHz
0.5GHz
SYMMETRICAL THERMAL EXPOSURE
NON-SYMMETRICAL THERMAL EXPOSURE
100 METERS
10 METERS
WRAP RIB PARABOLIC ANTENNA f/D 0.4
• INSULATED ALUM RIBS
• METAL MESH
• REFLECIVITY = .99
0
100
200
300
400
500
600
DIAMETER FT

FIGURE 11

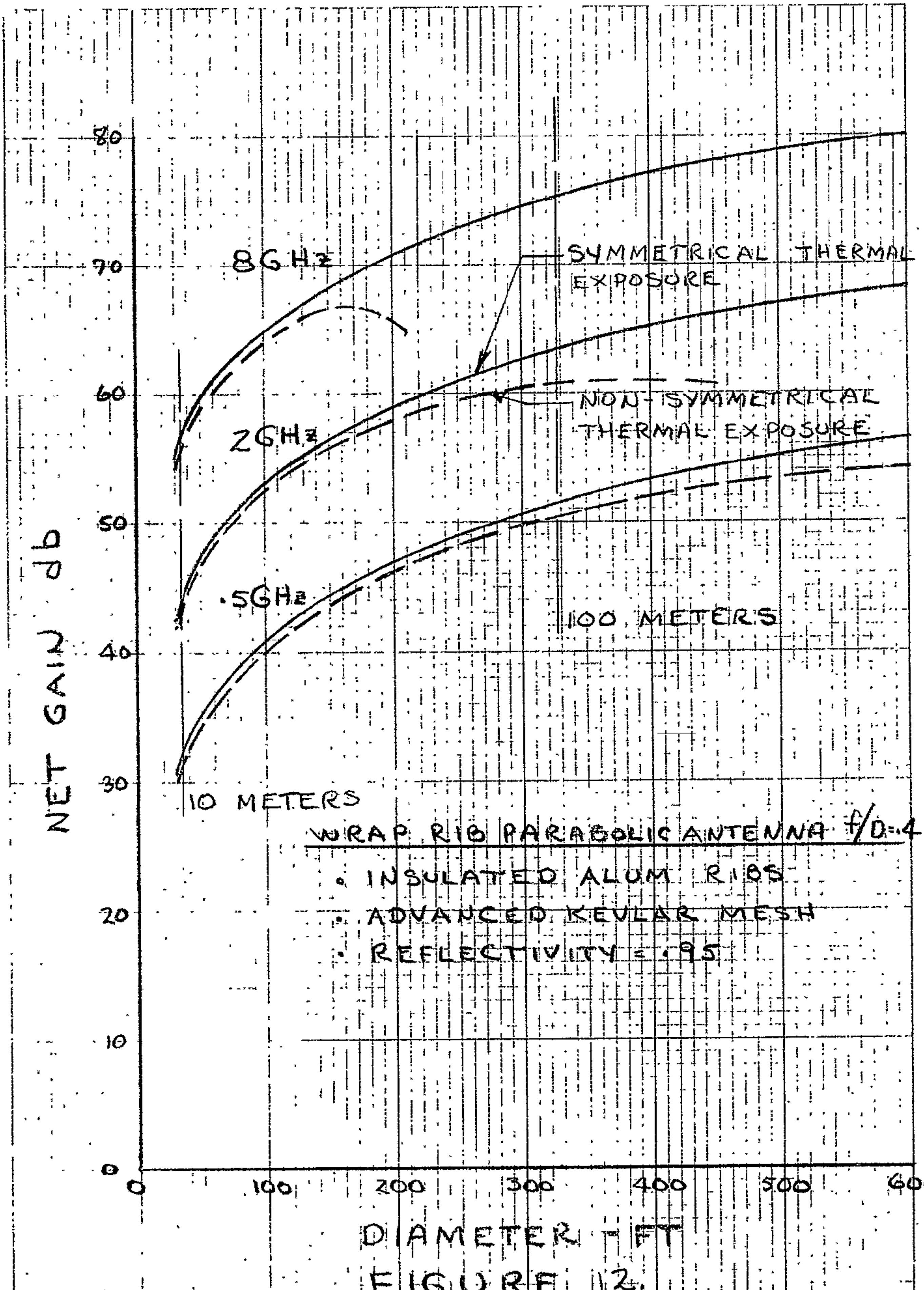
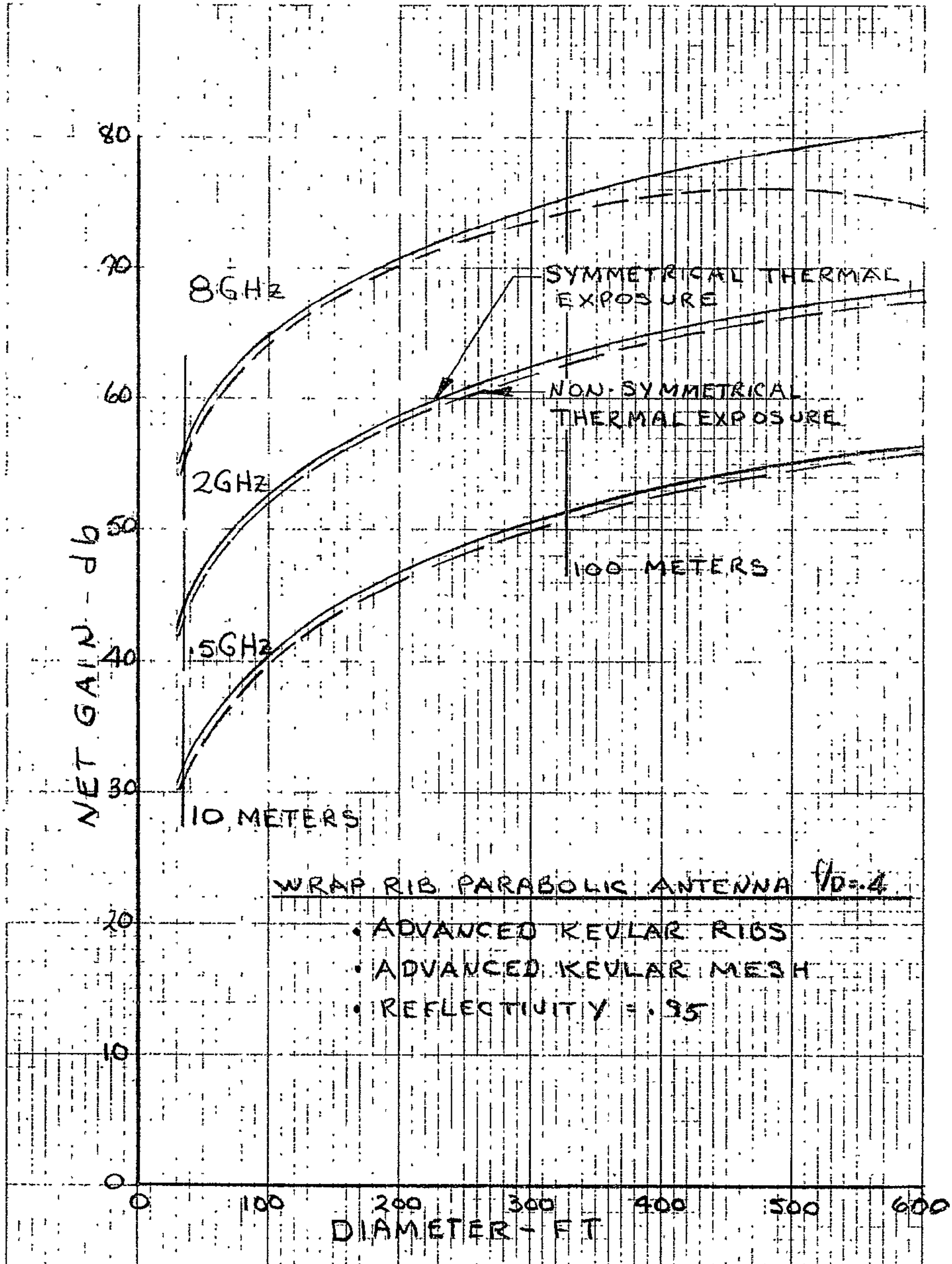

NET GAIN db
80
70
60
50
40
30
20
10
0
8GHz
2GHz
.5GHz
SYMMETRICAL THERMAL EXPOSURE
NON-SYMMETRICAL THERMAL EXPOSURE
100 METERS
10 METERS
WRAP RIB PARABOLIC ANTENNA f/D=.4
• INSULATED ALUM RIBS
• ADVANCED KEVLAR MESH
• REFLECTIVITY = .95
0
100
200
300
400
500
600
DIAMETER - FT

FIGURE 12.



80
70
60
50
40
30
20
10
0
NET GAIN - db
8GHz
2GHz
.5GHz
SYMMETRICAL THERMAL EXPOSURE
NON-SYMMETRICAL THERMAL EXPOSURE
100 METERS
10 METERS
WRAP RIB PARABOLIC ANTENNA f/D=.4
• ADVANCED KEVLAR RIBS
• ADVANCED KEVLAR MESH
• REFLECTIVITY = .95
0
100
200
300
400
500
600
DIAMETER - FT

FIGURE 13

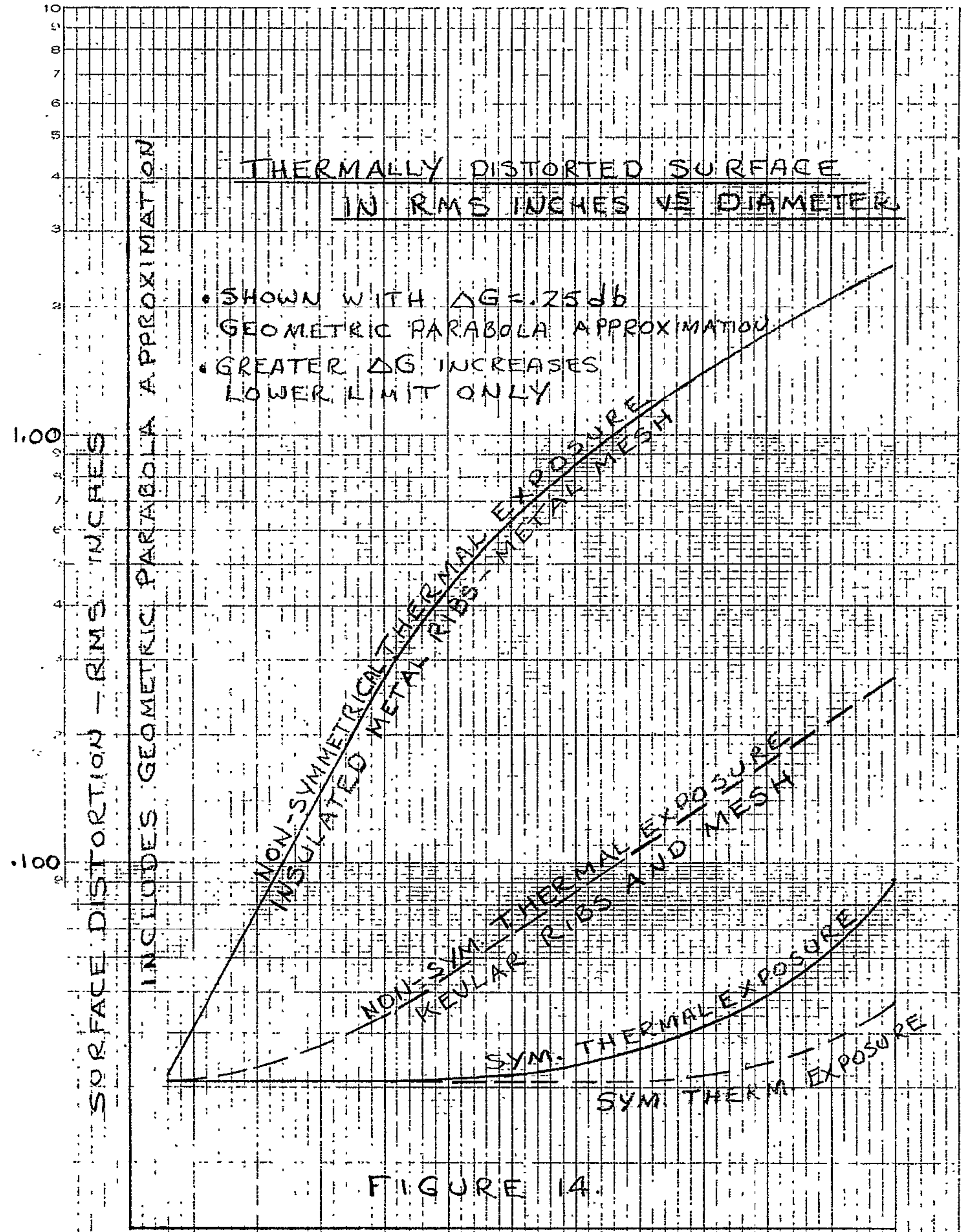

THERMALLY DISTORTED SURFACE
IN RMS INCHES VS DIAMETER
• SHOWN WITH ΔG = .25 db
GEOMETRIC PARABOLA APPROXIMATION
• GREATER ΔG INCREASES
LOWER LIMIT ONLY
INCLUDES GEOMETRIC PARABOLA APPROXIMATION
SURFACE DISTORTION – RMS INCHES
NON-SYMMETRICAL THERMAL EXPOSURE
INSULATED METAL RIBS – METAL MESH
NON-SYM THERMAL EXPOSURE
KEVLAR RIBS AND MESH
SYM. THERMAL EXPOSURE
SYM. THERM EXPOSURE
1.00
.100
.010
0
100
200
300
400
500
600
DIAMETER – FT

FIGURE 14.

a) Insulated metal ribs with metal mesh - presents a good thermally conductive structural material well insulated to produce low transverse thermal gradients and relatively low induced loads introduced into this structure by the mesh through the temperature extremes it will see.
b) Insulated metal ribs with an advanced mesh made from materials that will produce very low thermally induced mesh loads.
c) Advanced material ribs that show small thermal coefficient of expansion, insulated to reduce the effect to a minimum used with the advanced mesh of b).

The parametric data given for the polyconic concept was produced using a similar mesh to that described in a) with the advanced boom material described in c).

Figure 11A and 13A illustrate actual gain obtainable from the thermally distorted surface for the polyconic antenna concept. Useful gain at the higher rf frequencies (8 GHz) can be obtained by using a large number of support booms as shown by Figure 11A. This can be obtained at any geometric approximation loss (Δ G = .25 up to 1.00 db) because the number of surface cones used is not dependent upon the number of support booms. The use of fewer support booms has a wider spread surface distortion effect because each critically distorted boom supports greater surface area. The drop in effective use at high frequencies is shown by Figure 13A. Again the gain is independent from Δ G and the polyconic concept can be made effective by using larger number of booms at the expense of reflector weight.

The data produced for the maypole concept uses materials as described in c). Performance of these very large reflectors is only possible by the use of advanced or better than present state-of-the-art materials.

Orbital altitude influence is shown by Figure 15. Orbital period time reflector performance for each altitude as a function of the difference between symmetrical and non-symmetrical thermally induced surface distortion is given.

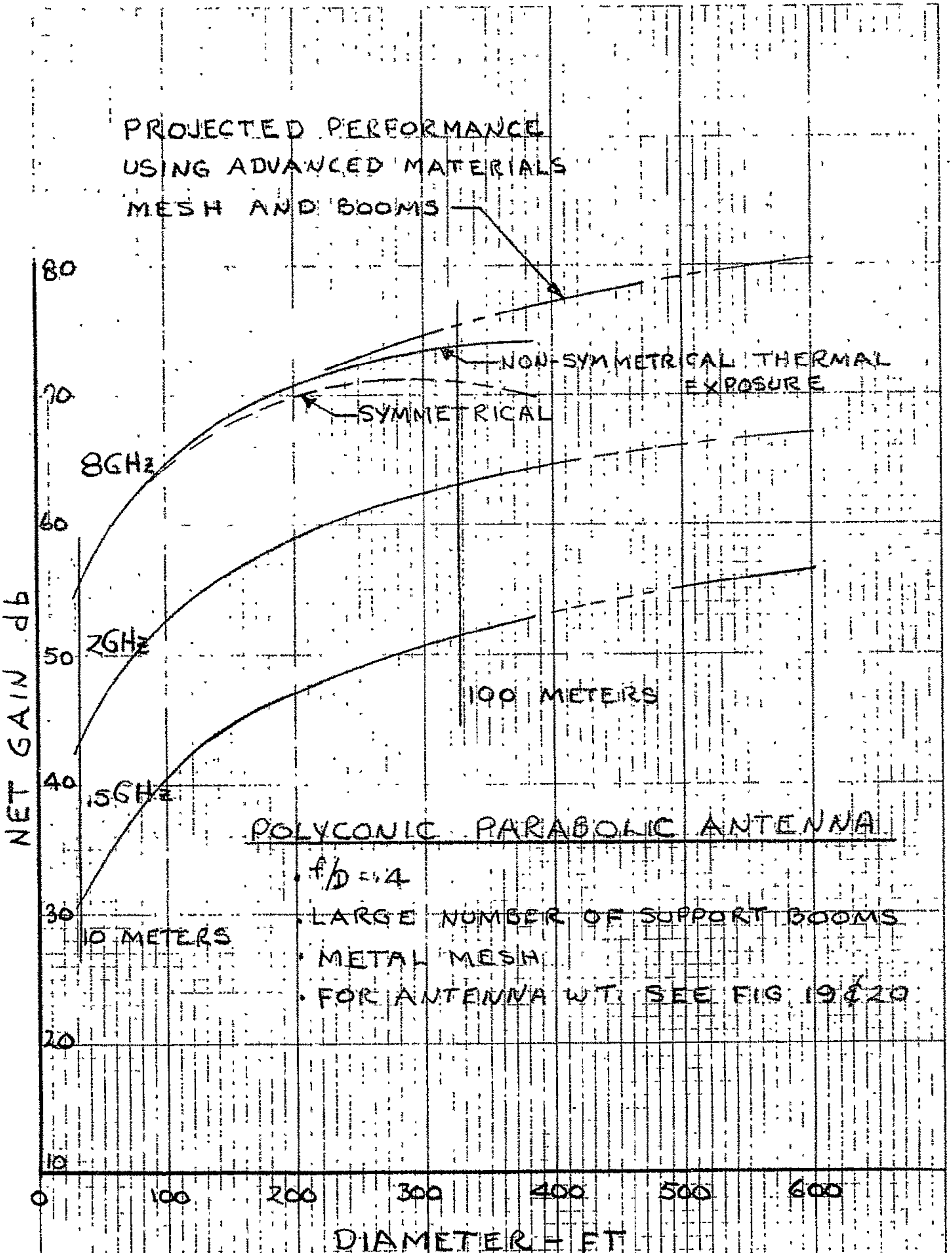
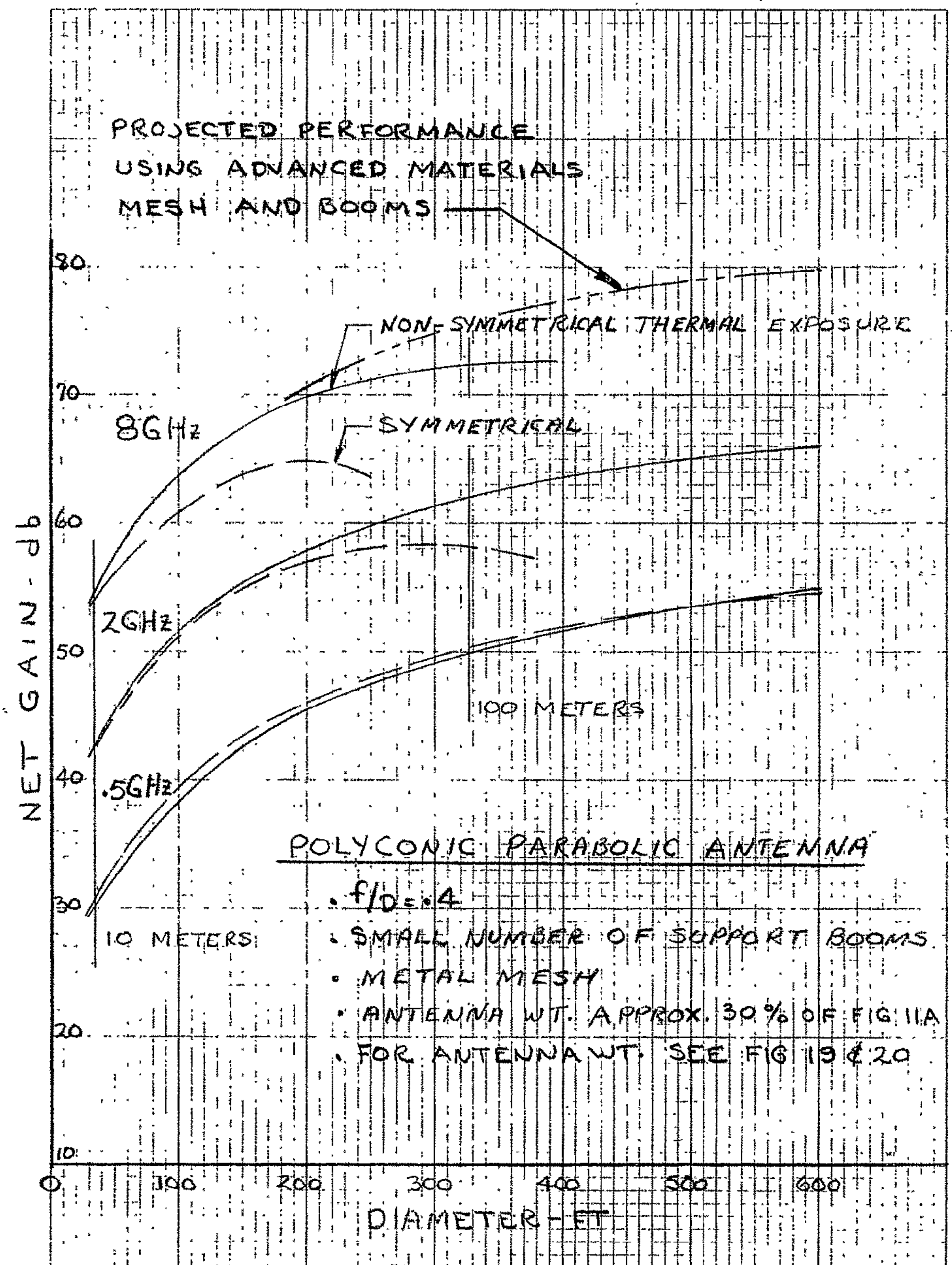

PROJECTED PERFORMANCE
USING ADVANCED MATERIALS
MESH AND BOOMS
NON-SYMMETRICAL THERMAL EXPOSURE
SYMMETRICAL
8GHz
2GHz
.5GHz
100 METERS
10 METERS
POLYCONIC PARABOLIC ANTENNA
• f/D = .4
• LARGE NUMBER OF SUPPORT BOOMS
• METAL MESH
• FOR ANTENNA WT. SEE FIG 19 & 20
NET GAIN db
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
DIAMETER – FT

FIGURE 11 A


PROJECTED PERFORMANCE
USING ADVANCED MATERIALS
MESH AND BOOMS
NON-SYMMETRICAL THERMAL EXPOSURE
SYMMETRICAL
8GHz
2GHz
.5GHz
100 METERS
10 METERS
POLYCONIC PARABOLIC ANTENNA
• f/D = .4
• SMALL NUMBER OF SUPPORT BOOMS
• METAL MESH
• ANTENNA WT. APPROX. 30% OF FIG 11A
• FOR ANTENNA WT. SEE FIG 19 & 20
NET GAIN - db
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
DIAMETER - FT
FIGURE 13A

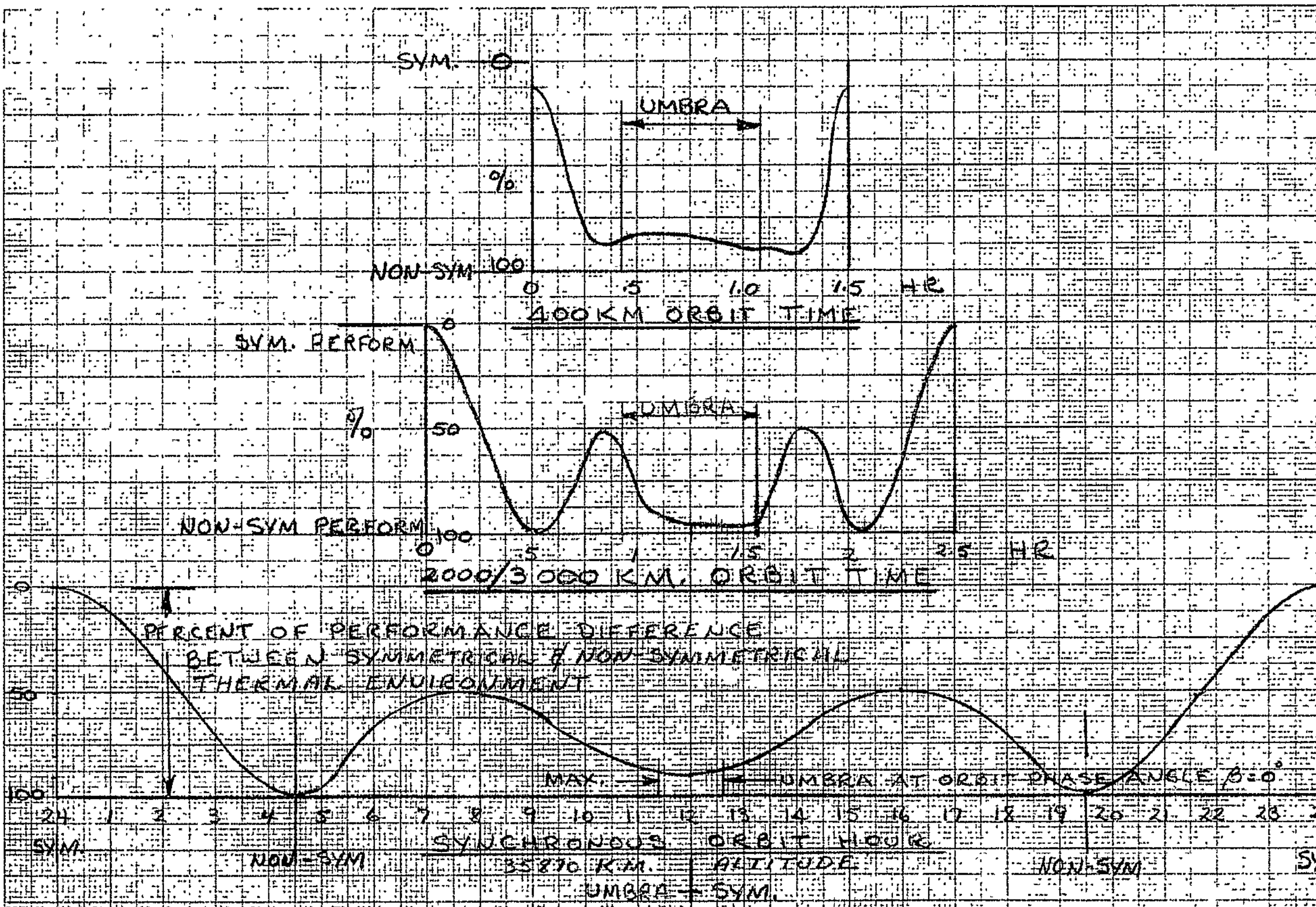


FIGURE 15

LMSC/D384797

Item 4. Show Reflector surface tolerance in inches rms of the different diameters as a function of antenna weight and cost.

The reflector surface tolerance as manufactured must be considered within its operating environment and within the performance requirements of that antenna system. If, for example, it is decided that the performance loss from parabola geometric approximation can be increased from .25 db to 1.00 db, the number of ribs used in the wrap-rib concept can be reduced and the number of cones used in the polyconic concept can be reduced. This reduction in numbers of structural components can have a major influence on both weight and cost. Increasing allowable geometric parabola approxiation will reduce both weight and cost.

There is a more detailed problem, however, that must be considered in any such trade off decision.

Meshes that are presently developed for reflector surfaces use materials that have a definitive thermal coefficient of thermal expansion. They are subjected to from 400 to 600 F degrees of temperature variation in their orbital environment. They therefore will have a varying load input to whatever structure that holds them in place, particularly since the mesh may not be allowed to go slack under zero load without destroying symmetry of surface.

Because of this situation, it may be more profitable from a performance standpoint to use a greater number of structural members but of a smaller size. The balance of the trade off conducted for any one design may not be generalized without difficulty. Improvements in mesh materials and designs in the future will reduce this factor as has been shown in Section 2.

Generalized data to this question is shown by Figure 16 with reasonable accuracy for use in general weight and cost decisions.

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OF POOR QUALITY

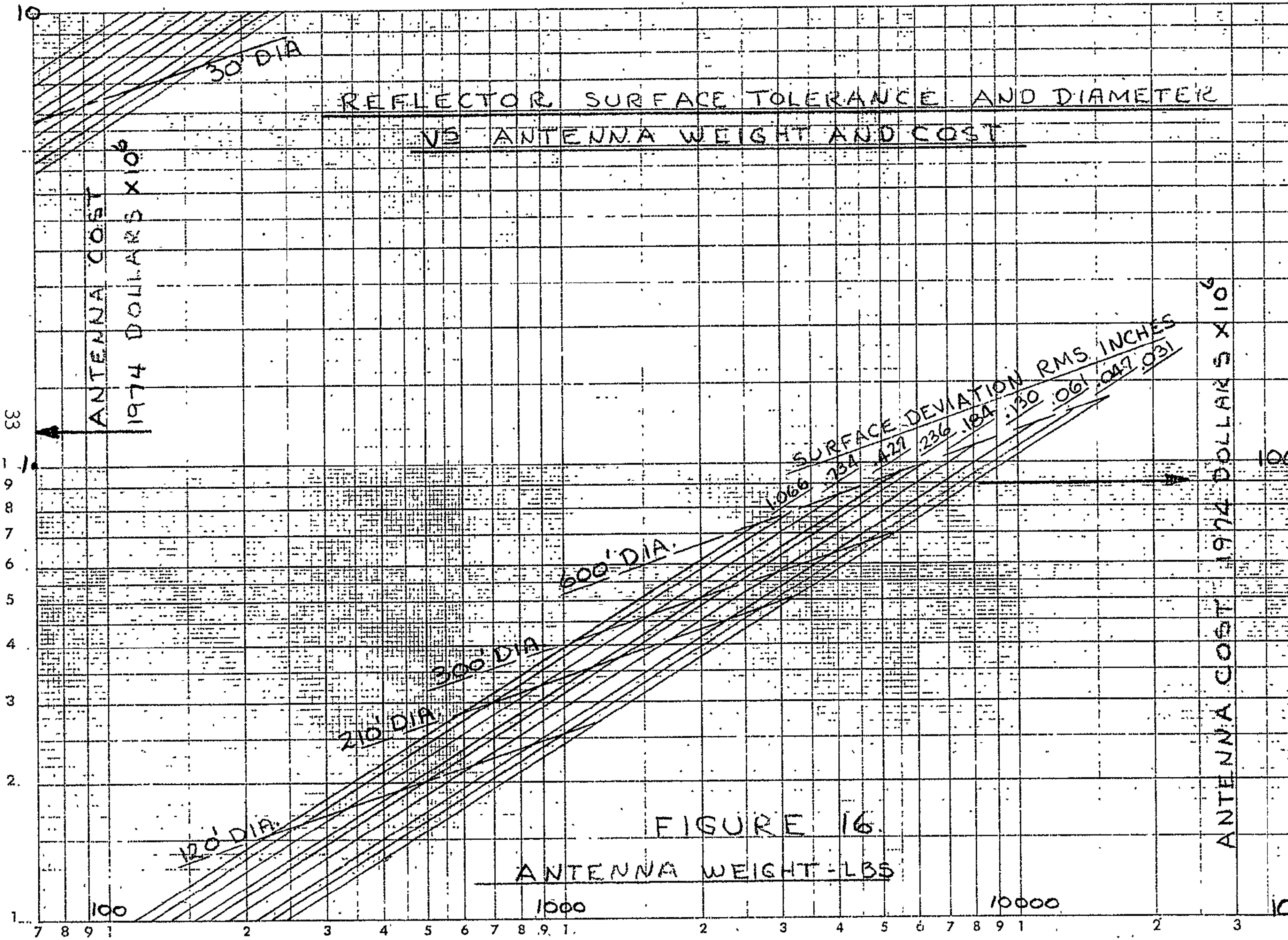


FIGURE 16

JMSC/L1304/191

Item 5. <u>Define antenna weight as a function of antenna diameter and center of gravity location.</u>

The wrap-rib concept antenna weight has been parametrically calculated for 3 different sizes of ribs for each of the 3 r.f. frequencies (8, 2 and 0.5 GHz) for each of the 5 diameters (600, 300, 210, 120 and 30 feet).

This information was also calculated using the geometric surface approximation as a variable. This variable denoted as Δ G or gain loss is related to surface tolerance as shown by Tables II III , and IV .

Figure 17 shows wrap-rib antenna weight versus reflector diameter for each size rib at each r.f. frequency at the minimum nominal geometric gain loss of .25 db. Figure 18 shows similar information at a nominal geometric gain loss of 1.00 db.

The copies of print out computer sheets that were delivered in advance of this report show approximate breakdown tables of weight for each case considered. The parametric weight data at nominal gain loss of .50 db has also been included in the delivered print out computer sheets.

The notations "max", "med" and "min rib" on Figures 17 and 18 mean the maximum sized rib, the medium sized rib and the minimum sized rib used for each diameter of antenna in the parametric data study. The details of the size dimensions of rib used in each case of the wrap-rib concept may be obtained by referring to the print out sheets of computer data.

Figure 19 presents parametric data of the polyconic antenna weight versus reflector diameter for each size structural boom at r.f. frequency design use of 8 GHz and nominal geometric design gain loss of .25 db and 1.00 db.

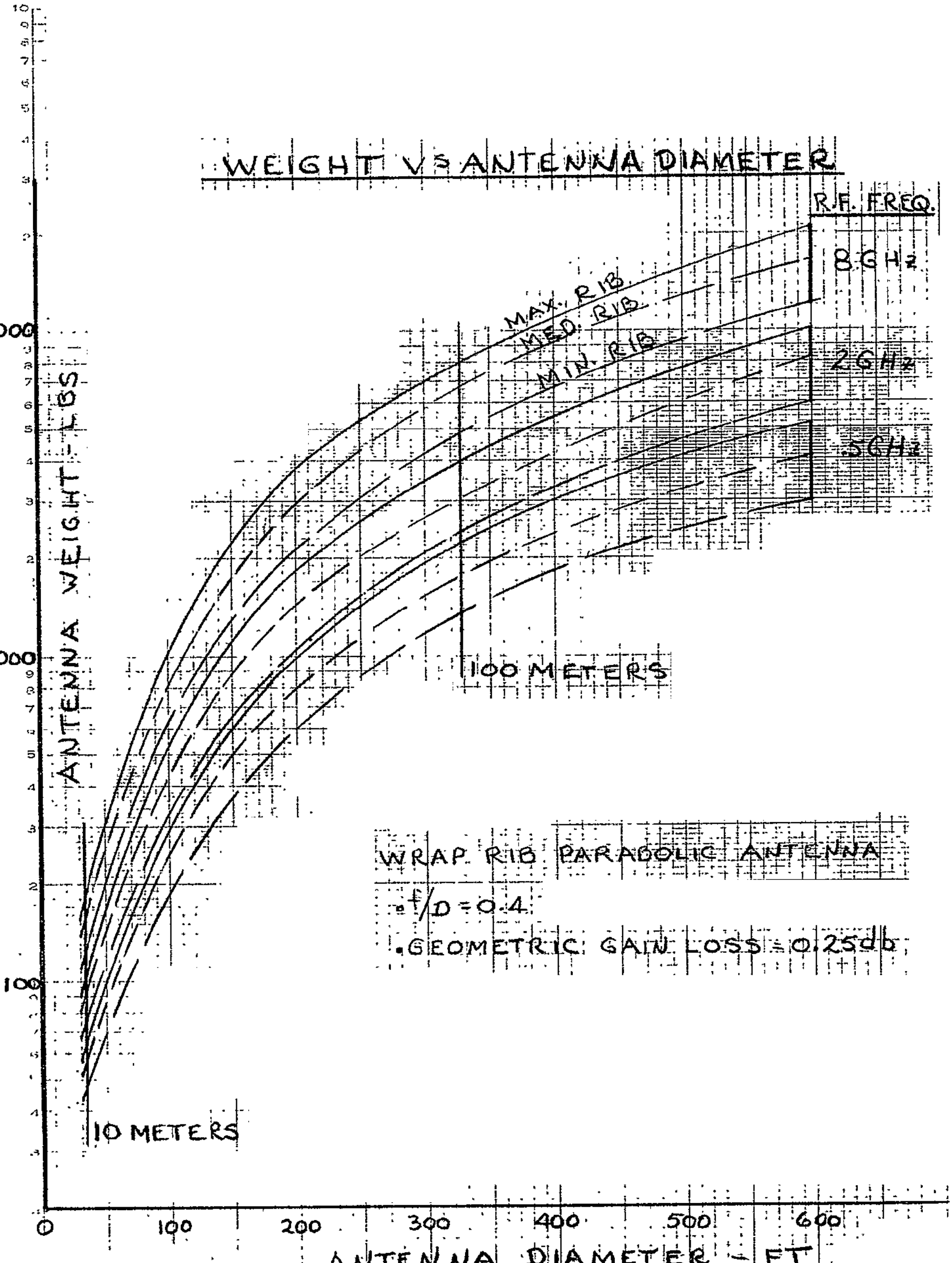

WEIGHT VS ANTENNA DIAMETER
R.F. FREQ.
8 GHz
2 GHz
.5 GHz
MAX. RIB
MED. RIB
MIN. RIB
ANTENNA WEIGHT - LBS
10,000
1000
100
100 METERS
10 METERS
WRAP RIB PARABOLIC ANTENNA
• f/D = 0.4
• GEOMETRIC GAIN LOSS = 0.25db
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 17

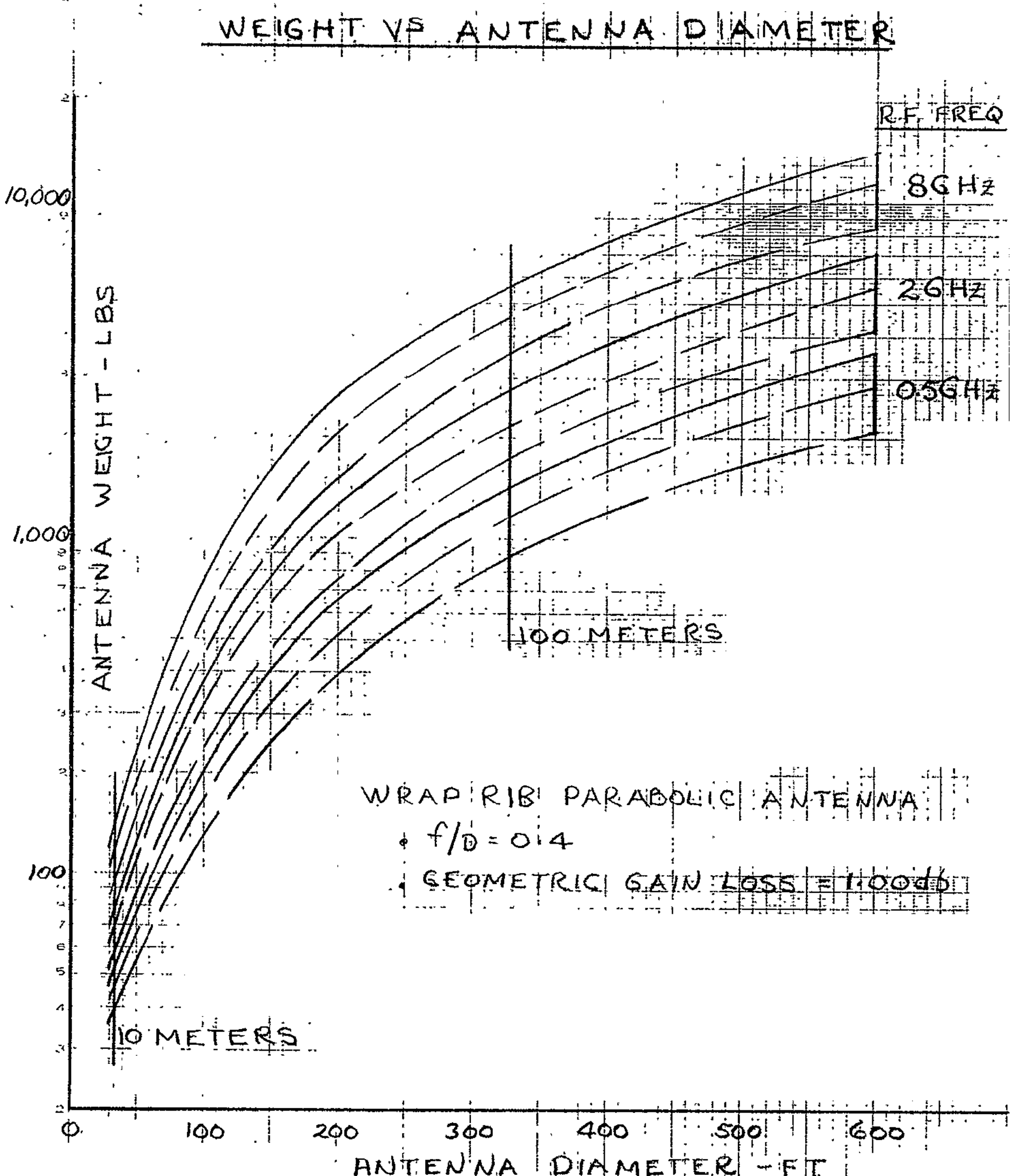

WEIGHT VS ANTENNA DIAMETER
R.F. FREQ
8GHz
2GHz
0.5GHz
10,000
1,000
100
ANTENNA WEIGHT - LBS
100 METERS
10 METERS
WRAP RIB PARABOLIC ANTENNA
f/D = 0.4
GEOMETRIC GAIN LOSS = 1.0 db
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 18

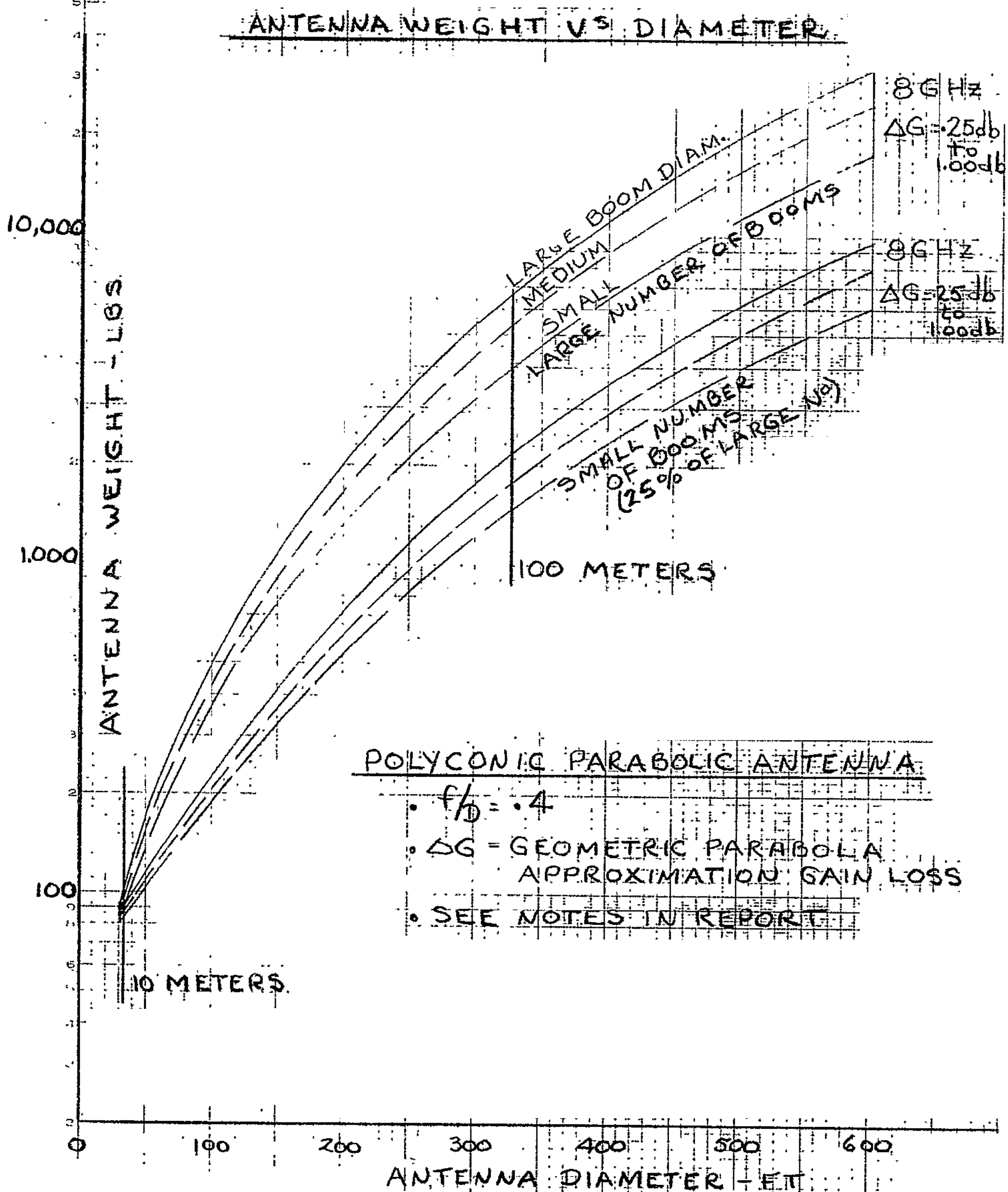

ANTENNA WEIGHT Vs DIAMETER
ANTENNA WEIGHT - LBS
10,000
1,000
100
LARGE BOOM DIAM.
MEDIUM
SMALL
LARGE NUMBER OF BOOMS
SMALL NUMBER OF BOOMS (25% OF LARGE No)
8 GHz
ΔG = .25db to 1.00db
8 GHz
ΔG = .25db to 1.00db
100 METERS
10 METERS
POLYCONIC PARABOLIC ANTENNA
• f/D = .4
• ΔG = GEOMETRIC PARABOLA APPROXIMATION GAIN LOSS
• SEE NOTES IN REPORT
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 19

Figure 20 presents similar parametric data at r.f. frequency design use of 0.5 GHz.

The polyconic concept weight, using a fewer or larger number of mesh cones to nominally approximate the parabolic reflector shape, primarily will have weight concentrated in the boom and hub support structure. The mesh cones and mesh ring catenary ribs do not make up a large percentage of total weight.

The polyconic reflector weights shown on Figures 19 and 20 show that an antenna that may allow up to 1.00 db geometric parabolic approximation loss is lighter than one that may only allow .25 db gain loss.

The reasoning behind this method of parametric design data generation is simply that it is much more likely that an antenna that may allow a greater geometric gain loss is also likely to allow a less stiff structure that will rotationally accelerate during beam pointing slewing operations at a slower rate.

This may or may not be true dependent upon the detail design requirements of any actual antenna design. It should therefore be kept in mind when using these curves that the actual weight is also dependent upon dynamic natural frequency requirements, slewing acceleration rates and time to degrade dynamic motions after slewing, perhaps more than the allowable geometric parabolic gain loss.

Detail data of weight breakdown, boom size dimensions and number of booms used is available in the print out computer sheets provided. The center of gravity position parametric data produced for both the Wrap-rib concept and the Polyconic concept is not compatible with presentation on graph plots. The Wrap-rib concept uses tapered ribs which tend to concentrate weight near the surface of the hub with heavy taper and allow major upward movement of center of gravity as the taper disappears to the minimum tapered geometric shape ribs used

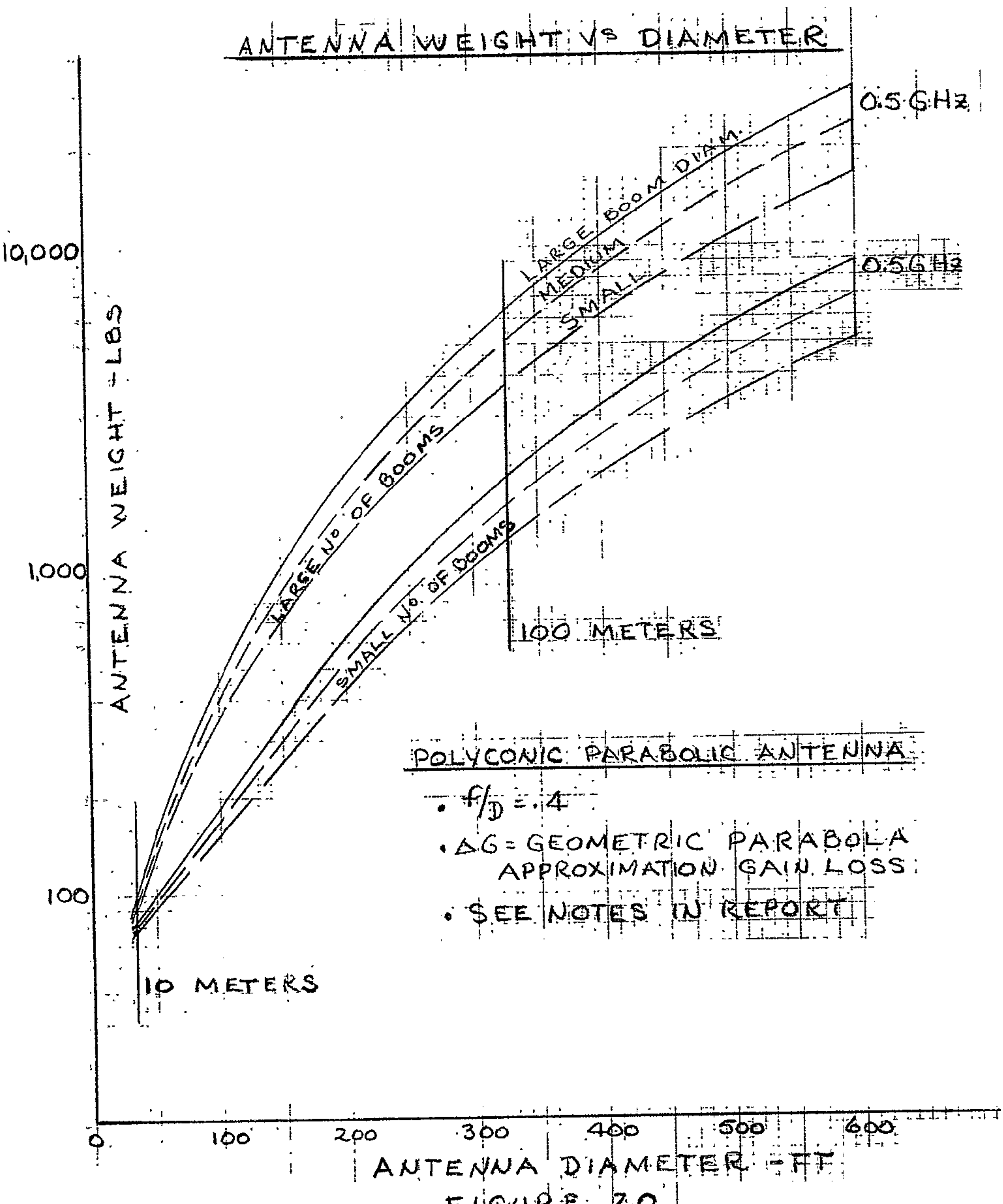

ANTENNA WEIGHT VS DIAMETER
0.5 GHz
0.5 GHz
LARGE BOOM DIAM.
MEDIUM
SMALL
LARGE No OF BOOMS
SMALL No OF BOOMS
100 METERS
10 METERS
10,000
1,000
100
ANTENNA WEIGHT - LBS
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT
POLYCONIC PARABOLIC ANTENNA
• f/D = .4
• ΔG = GEOMETRIC PARABOLA APPROXIMATION GAIN LOSS
• SEE NOTES IN REPORT

FIGURE 20

in parametric data production. The diameter size and the number of booms has a similar effect in the Polyconic concept. Therefore if center of gravity position is desired for any particular antenna diameter, geometric gain loss, r.f. frequency use or slew acceleration rate allowable it is suggested that the detail print out sheets of the computer data supplied be consulted.

Item 6. Description of the reflector antenna.

Although there are many possible types of large unfurlable antennas, only three of the most promising are included in this parametric study.

A. The wrapped rib antenna
B. The polyconic antenna
C. The maypole antenna.

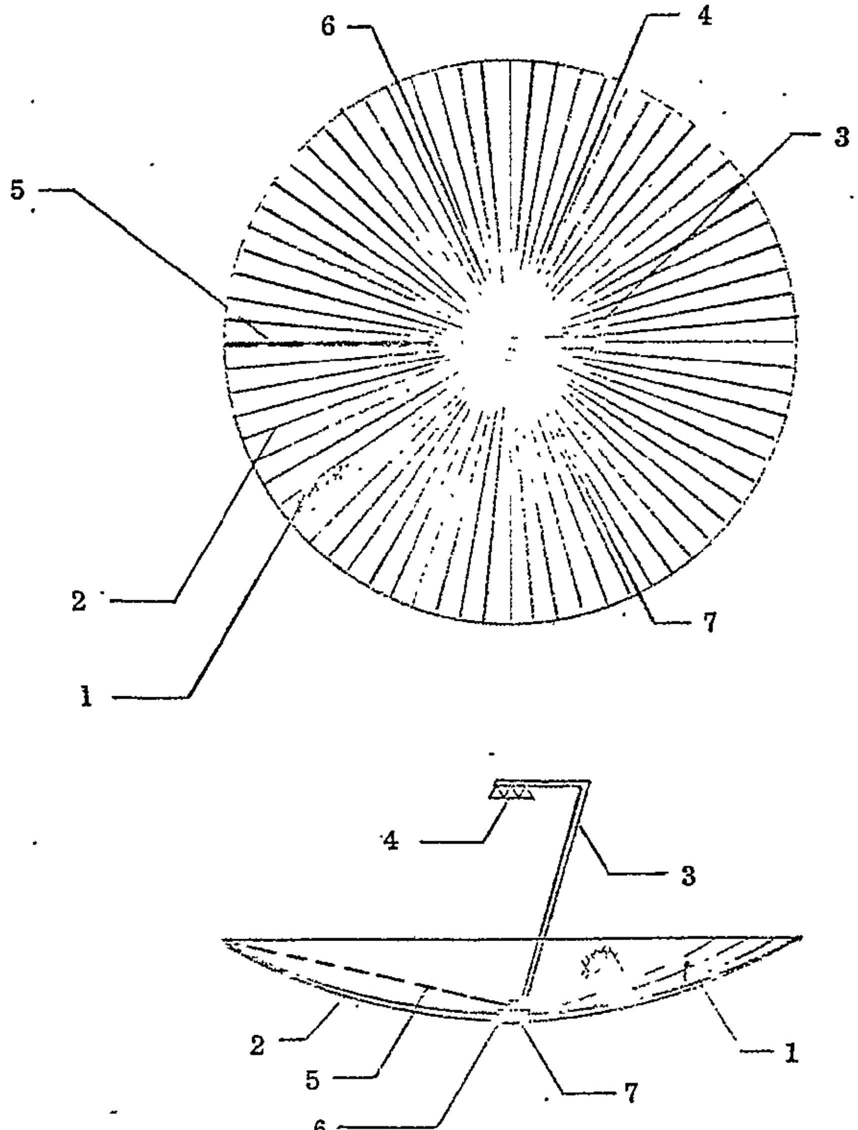
A. Wrapped Rib Antenna

The wrapped rib antenna consists of hollow doughnut shaped hub to which are attached a series of radial ribs cut to the shape of a parabola. A lightweight reflective mesh is stretched between these ribs to form the paraboloidal reflecting surface. A feed system is usually located at the prime focus of the paraboloid by a support boom. A sketch of the deployed wrapped rib antenna is shown in Figure 21. To furl the reflector, the ribs are wrapped around the hollow hub with the mesh folded between them.

The parabolic surface is formed by a lightweight reflective mesh held in place by the radial parabolic ribs. The number of ribs or mesh panels employed is dependent upon rms surface accuracy desired which in turn determines the absolute gain of the antenna. The smaller the rms surface deviation, the larger the absolute gain. Large reflectors must maintain high surface rms accuracy during varying thermal environments. They must be structurally sound during slewing operations and use a minimum of time during oscillation decay. The total structure is designed for minimum weight and to operate in zero gravity environment only. It would be assembled on the ground as a furled reflector and deployed and adjusted in space.

A hollow doughnut shaped support hub will provide mounting pads for the antenna system to the spacecraft. It will provide the

DEPLOYABLE WRAPPED RIB ANTENNA



1 MESH SURFACE-GORE APPROX.

2 WRAP RIB STRUCTURE

3 DEPLOYABLE FEED SUPPORT BOOM

4 FEEDS

5 LOS FROM SURFACE EVALUATION AND ADJUST MECHANISM

6 FURL/UNFURL DRIVE MECHANISM

7 STRUCTURAL HUB ASSEMBLY

FIGURE 21.

LOCKHEED MISSILES & SPACE COMPANY, INC.

LMSC/D384797

support points for each radial rib and stowage area for the radial ribs and the reflective mesh. It will provide the support for the "in space" deployment and refurl mechanism, as well as the support for the "in space" surface contour evaluation and adjustment system.

A power driven rotating mechanism will have the ability to contain the stored energy of the wrapped ribs and slowly deploy the reflector surface. It will also have the ability to "wipe" the ribs in a rotating manner back into their stowed configuration. The stowed configuration may be as small as 1/40 of the deployed diameter of very large antennas.

The feed or feed array is dependent upon the reflector size and intended use. It may be a single horn illuminating the total surface, it may be a cluster of horns each illuminating a portion of the reflector surface but forming one coherent beam, or it may be a cluster of feeds that form individual spot beams. The feed characteristics used in this parametric study are such that they will illuminate the reflector in such a manner as to generate a 55% aperture efficiency.

Dependent upon reflector size, the feed support boom may be a simple powered folding structural boom, it may be a structurally formed boom that is of the type power stored on rolls or it may be a modified scissors structural type boom that is powered as necessary to extend and retract. The boom will have thermal control or be built from near zero coefficient of thermal expansion materials in order to ensure precise positioning of the feeds under varying thermal environment.

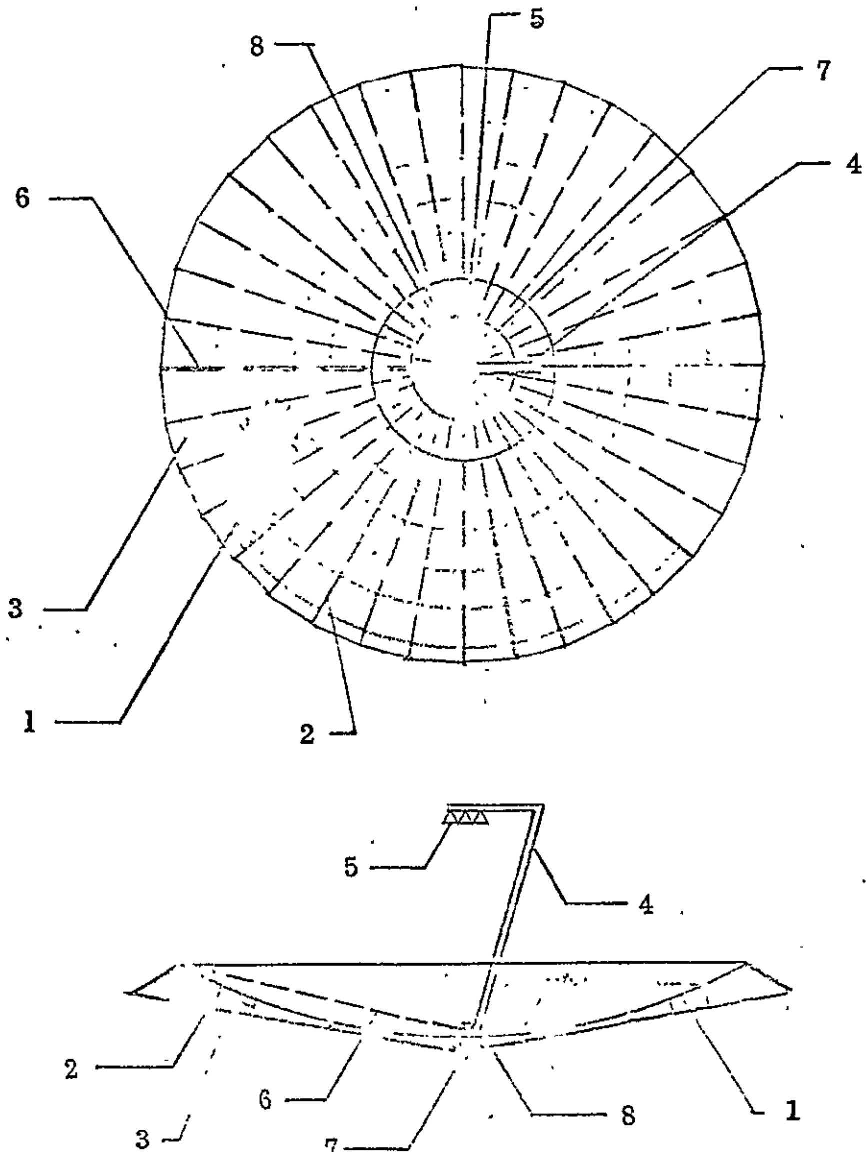
A Surface Contour Evaluation and Adjustment System is included in the antenna concept since these reflectors are built to operate in a zero gravity environment. Surface adjustment to the desired accuracy of the large sizes cannot be accomplished on ground. The system is incorporated within the antenna to adjust the surface to the desired accuracy when deployed in space. It should only be necessary to adjust the surface once, at the beginning of the mission, if the antenna is constructed from the more advanced materials described, but if less than perfect near zero coefficient of thermal expansion materials are used, the mechanism could be programmed to partially compensate for thermally induced distortions. A laser radar, mounted at the center of the hub, will rotate and measure the position of the rib tips. It will then determine and implement the necessary adjustments to minimize the rms surface deviation from an ideal paraboloid.

B. Polyconic Antenna

The parabolic surface of the polyconic reflector is formed by a series of circular conical segments of lightweight reflective mesh as shown in Figure 22. These conical segments are positioned by mesh ribs and a series of radial booms mounted to a central hub. The radial structural booms and polyconic reflective mesh surfaces are folded in a vertical direction like an umbrella. The length of booms will determine the necessity of intermediate folds of each boom.

The parabolic surface is formed by a lightweight reflective mesh held in place by circular mesh ribs which are anchored to radial stiff booms. The desired surface accuracy is obtained by the use of many circular conic sections joined, one to the other, in the circumferential direction. Each junction of one conic segment to the next is held by circular mesh ribs, the top edge of which forms the circular conic junction desired. The bottom edge is terminated in a catenary member which can be adjusted in length to produce desired reflective surface accuracy. The higher the surface accuracy desired, the larger the number of conical sections required. Like the wrapped rib reflector, the polyconic reflector must be designed to be sufficiently rigid to permit slewing without excessive weight or oscillation decay time.

DEPLOYABLE POLYCONIC ANTENNA



1 MESH SURFACE - CONIC APPROX.

2 SURFACE SUPPORT BOOMS

3 CIRCULAR MESH RIBS

4 DEPLOYABLE FEED SUPPORT BOOM

5 FEEDS

6 LOS FROM SURFACE EVALUATION AND ADJUST MECHANISM

7 BOOM FOLDING & TILT MECHANISM

8 STRUCTURAL HUB ASSEMBLY

FIGURE 22.

The hub construction must provide support for the boom deploy and retract mechanism. It must provide the structural base for the hinged booms, it must provide the structural base for the feed mounting central boom and it must provide mounting positions for the automated "in space" surface contour evaluation and adjustment system.

Each radial boom is deployed from a vertical position. If the reflector surface is very large, each boom must be folded onto itself some number of times in order to fit the folded booms into the Space Shuttle cargo bay length. Screw jack controlled leverage will deploy the booms with articulation extension of the booms.

The feed is similar to that described for wrapped rib concept.

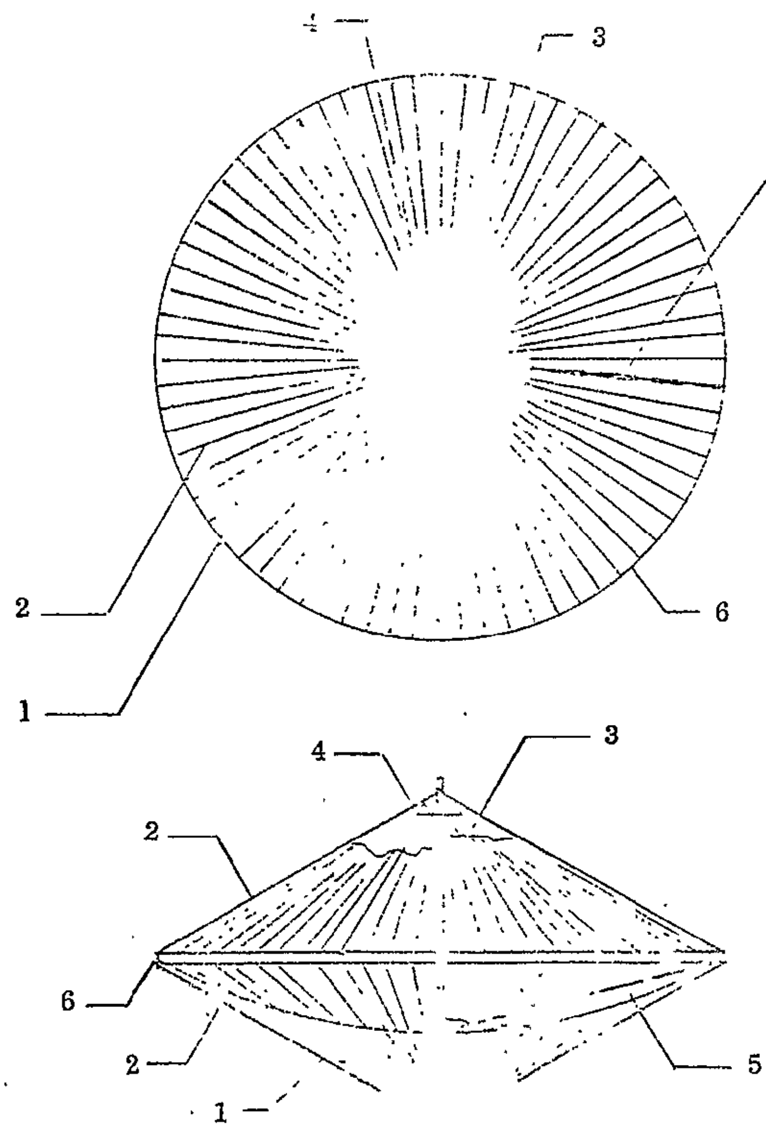
Since the radial booms that support the reflective surface do not wrap around the hub, as in the wrapped rib reflector, but fold into a vertical stowed position, the stowed configuration is limited only by the length of the cargo compartment. Dependent upon antenna diameter some or all of the feed support boom may be of a fixed construction. The necessary extension beyond the approximate 60 foot fixed boom may be of similar construction to that described for the wrapped rib antenna.

A system similar to that described for the wrapped rib antenna must be provided. It will have the additional task of scanning each conic surface junction and determining the required adjustments to the catenary controlled circular mesh ribs. Basic position adjustment will be controlled by vertical movement of the booms. Fine surface adjustments will be made by catenary member control on the circular mesh ribs.

C. Maypole Antenna

The maypole antenna resembles a maypole or bicycle wheel. It consists of a long central column hub, a rigid outer rim and a system of cables (spokes) that tie the hub and rim together. A reflective, paraboloidal mesh cup is suspended at the center of the "wheel" to form the reflector. A sketch of the maypole antenna is shown in Figure 23.

DEPLOYABLE MAYPOLE ANTENNA



1 MESH SURFACE — GORE APPROX.

2 TENSION CABLE

3 DEPLOYABLE CENTER COLUMN

4 FEEDS

5 LOS FROM SURFACE EVALUATION AND ADJUST MECHANISM

6 STRUCTURAL RING

FIGURE 23.

The design is based upon a sufficiently rigid outer rim member to withstand the tension loads of the "spoke" tension ties to the central column "hub". Large and very large reflectors may be designed that will use very low tension loads in the spoke ties. These loads are held at a stable low value by use of "load maintainer" mechanisms in each spoke. The "sufficiently rigid" outer rim and the center column become feasible because of the low load values in the spokes.

The central column may be extended to carry spacecraft control modules which will also gravity gradient stabilize the antenna system against solar winds to the degree desired dependent upon the mass moment of inertia ratios. The maypole concept will become feasible when near zero thermal coefficient of expansion materials become available for the mesh, the structural rim, the central column and the tension tie spokes.

Initial investigation shows that an antenna in the 1 to 2 GHz frequency range up to 11,000 foot diameter can be stowed within the cargo volume and weight limits of one Space Shuttle flight. Further development of materials will allow the use of frequencies up to 10 GHz.

Item 7. Indicate RF Gain Orbital Performance and Test Versus Prediction RF Performance Data.

Figures 11, 11A, 12, 13 and 13A in Section 3 show symmetrical and non-symmetrical solar thermally heated r.f. performance of the antennas as a function of reflector diameters. The reasoning behind presentation of gain performance as a measure of surface deviation has been included in prior sections.

As indicated, the thermally influenced r.f. performance was extrapolated from detailed thermal analyses that LMSC has carried out in the past on similar reflectors ranging from 30 feet to near 70 feet in diameter. The surface distortion induced by solar heating is independent from the antenna operating r.f. frequency; in other words, it is structures dependent, but the same measure of surface distortion will result in a greater gain loss for higher operating r.f. frequencies than for lower. This effect is clearly indicated by Figures 11, 12 and 13A.

Figure 24 is presented to illustrate predicted performance at an overall feed and aperture efficiency of 55% versus that actually tested at the Santa Cruz Test Range for the 30 foot diameter ATS Wrap Rib Parabolic Antenna. The circled points shown at 200 MHz, 850 MHz, 2.7 GHz, 6.1 GHz and 8.25 GHz show quite uniform conformity to r.f. performance predictions.

Tests shown were made for the "best" contour which conforms to a symmetrical thermal exposure solar heating. Similar tests with as good conformity between tests and predictions were made for the non-symmetrical thermal exposure thermal heating case.

30 Ft. REFLECTOR – MEASURED GAIN

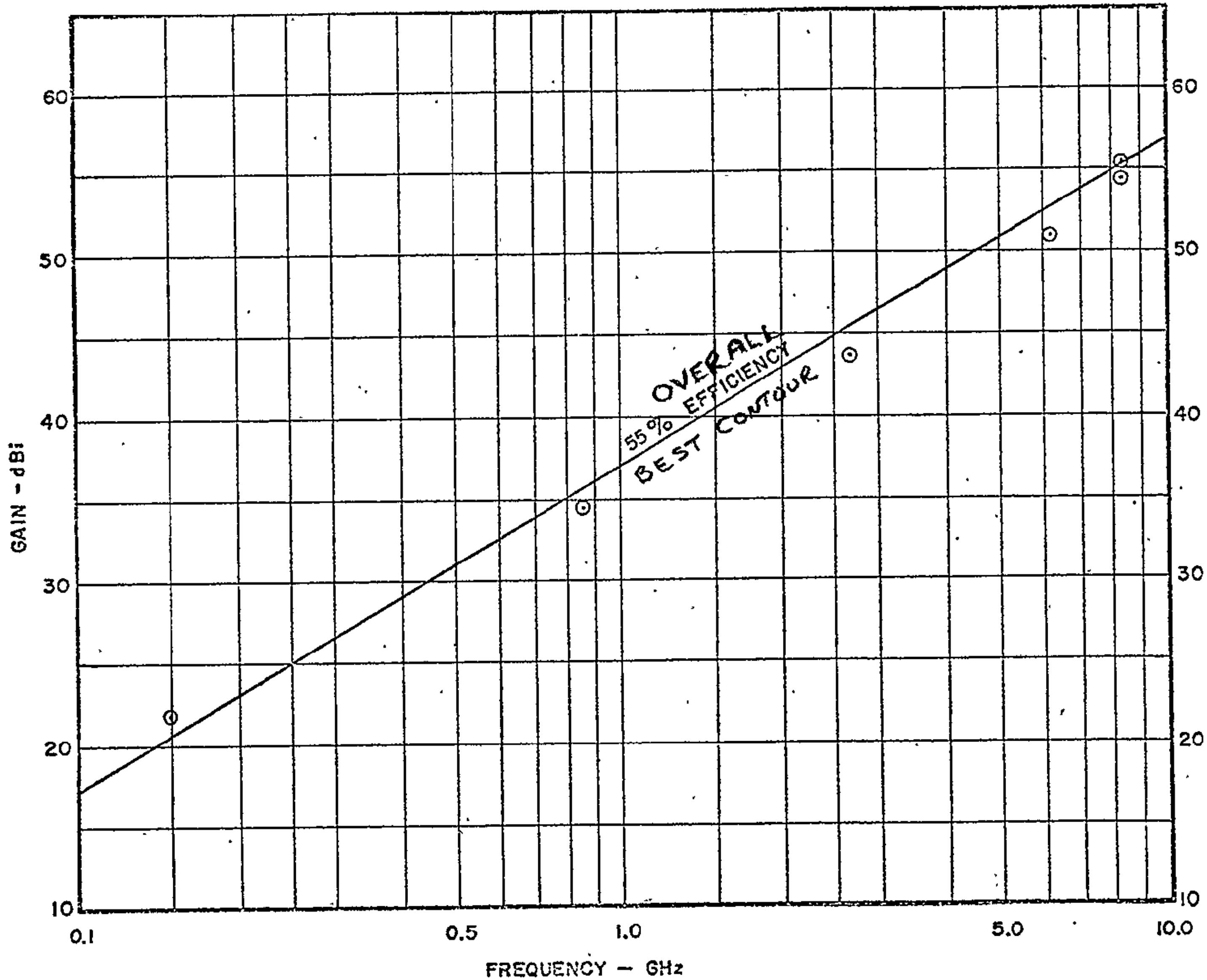


FIGURE 24.

Item 8. Estimate Antenna System Costs.

Estimated antenna costs for the Wrap Rib antenna concept are presented by Figure 25. The antenna costs are shown versus number of ribs used. The number of ribs used is a function of the design r.f. frequency in GHz, antenna diameter and the excellence of manufactured surface tolerance desired. All values are shown on Figure 25.

The basis for these estimates are projected 1974 dollar value of actuals for the 30 foot diameter reflector and detailed estimates previously made for 60 to 70 foot diameter antennas in 1974 dollars. The method used to extrapolate these actuals or detailed estimates into costs of larger sizes with varying surface accuracy requirements is presented by Tables VIII and IX.

Sufficient information is presented in Tables VIII and IX to estimate the cost per square foot at 8, 2 and .5 GHz with contour approximation losses of .25, .50 and 1.00 db. Figure 26 presents some of this information.

Estimated costs for the Polyconic antenna concept are presented by Figure 27 which has similar to Figure 25 data display.

Tables X and XI present the method used to estimate the costs of the Polyconic antennas. Sufficient data is available on Table XI to create data presentation display of cost per square foot similar to Figure 26 if desired.

Figure 25A presents estimated costs for a refurbishable test antenna reflector system that includes such mechanically testable subsystems as: furl/unfurl mechanism; deploy/retract feed support boom; surface contour adjustment servo mechanism, and reflector mounted gimbal.

ESTIMATED TOTAL COST OF OPERATIONAL WRAP-RIB ANTENNA SYSTEM

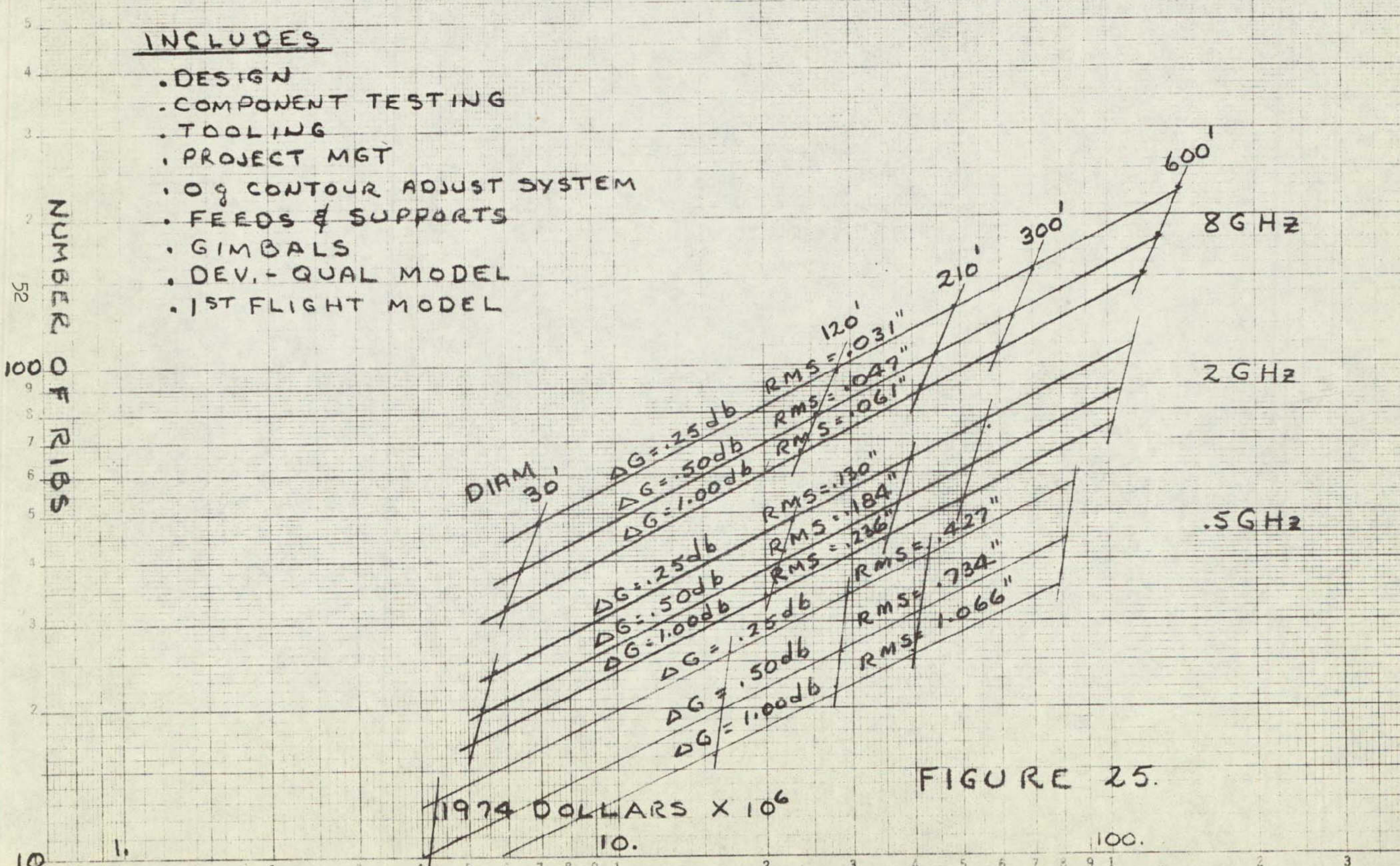


FIGURE 25.

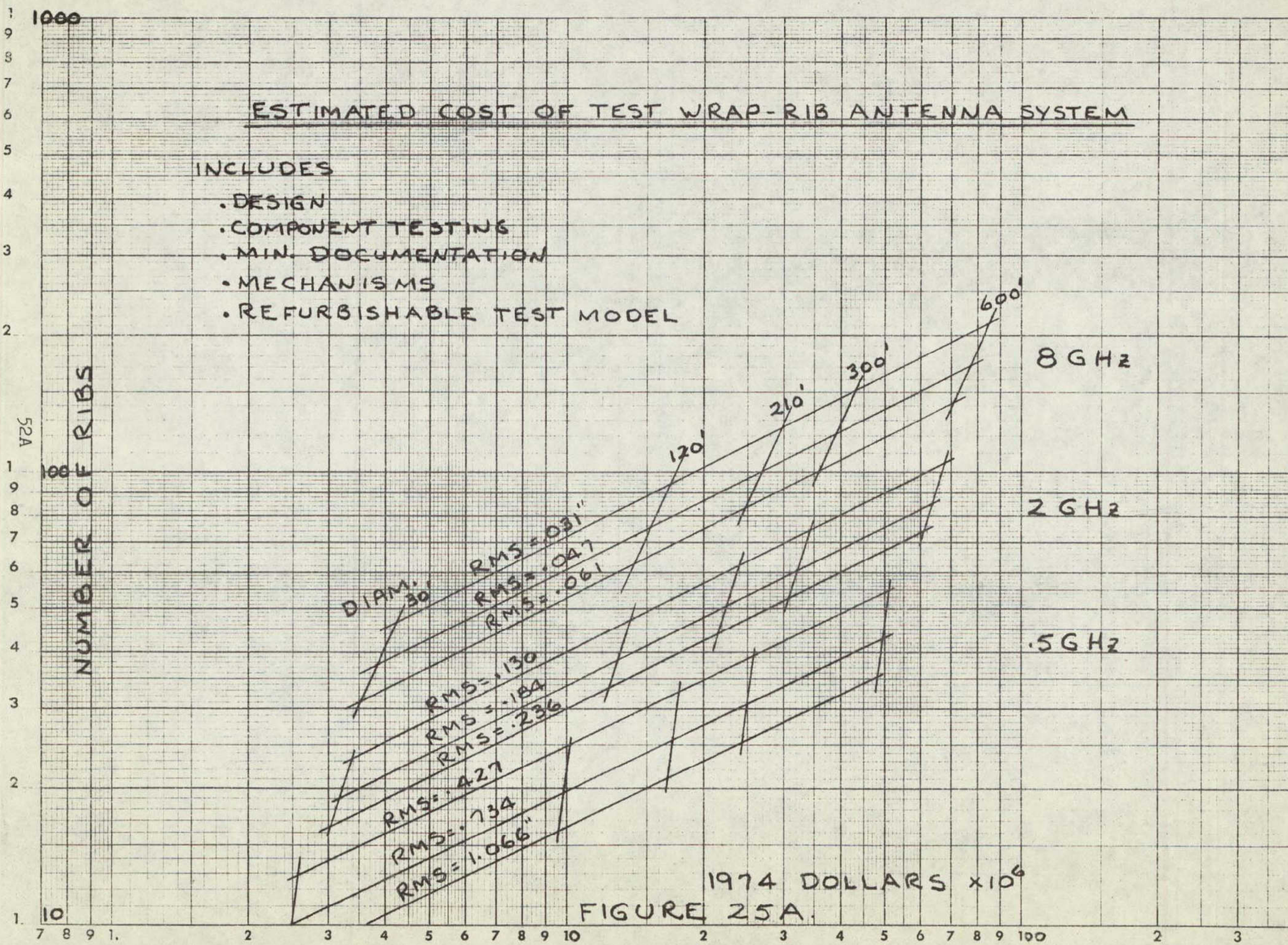


FIGURE 25A.

52A

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	ANTENNA DIAM.			30 FT.	120'	210'	300'	600'
	ANTENNA AREA FT^2			707	11300	34700	70700	283000
	Freq.	G Nominal	Cost/Ft. Diam.					
TOTAL COST SYSTEM	8	.25 .50 1.00	\$233K \$213K \$198K	\$7.M 6.40 5.95	28.M 25.6 23.8	49.M 44.8 41.6	70.M 64.0 59.5	140.M 128.0 118.5
COST PER SQ. FT.	8	.25 .50 1.00		\$9900. 9050. 8400.	2480. 2260. 2110.	1410. 1290. 1200.	990. 905. 840.	495. 453. 420.
NO. OF RIBS	8	.25 .50 1.00		48 38 34	96 78 66	130 104 90	154 124 108	226 180 152
TOTAL COST SYSTEM	2	.25 .50 1.00	\$190K 176.5K 166.5K	5.7M 5.3 5.0	22.8M 21.2 20.0	39.8M 37.1 34.9	57M 53. 50.	114M 106. 100.
COST PER SQ. FT.	2	.25 .50 1.00		\$8060. 7500. 7070.	2020. 1875. 1770.	1145. 1065. 1005.	806. 750. 707.	403. 375. 353.
NO. OF RIBS	2	.25 .50 1.00		24 20 16	48 38 34	64 52 44	74 62 52	112 88 76
TOTAL COST SYSTEM	.5	.25 .50 1.00	\$141.5K 135.2K 130.6K	\$4.25M 4.05 3.92	17.0M 16.2 15.6	29.7M 28.4 27.4	42.5M 40.5 39.2	85.M 81. 78.4
COST PER SQ. FT.	.5	.25 .50 1.00		\$6000. 5720. 5550.	1505. 1435. 1380.	853. 816. 787.	600. 572. 555.	300. 286. 278.
NO. OF RIBS	.5	.25 .50 1.00		12 10 8	26 20 16	34 26 22	42 30 26	56 44 38

TABLE IX

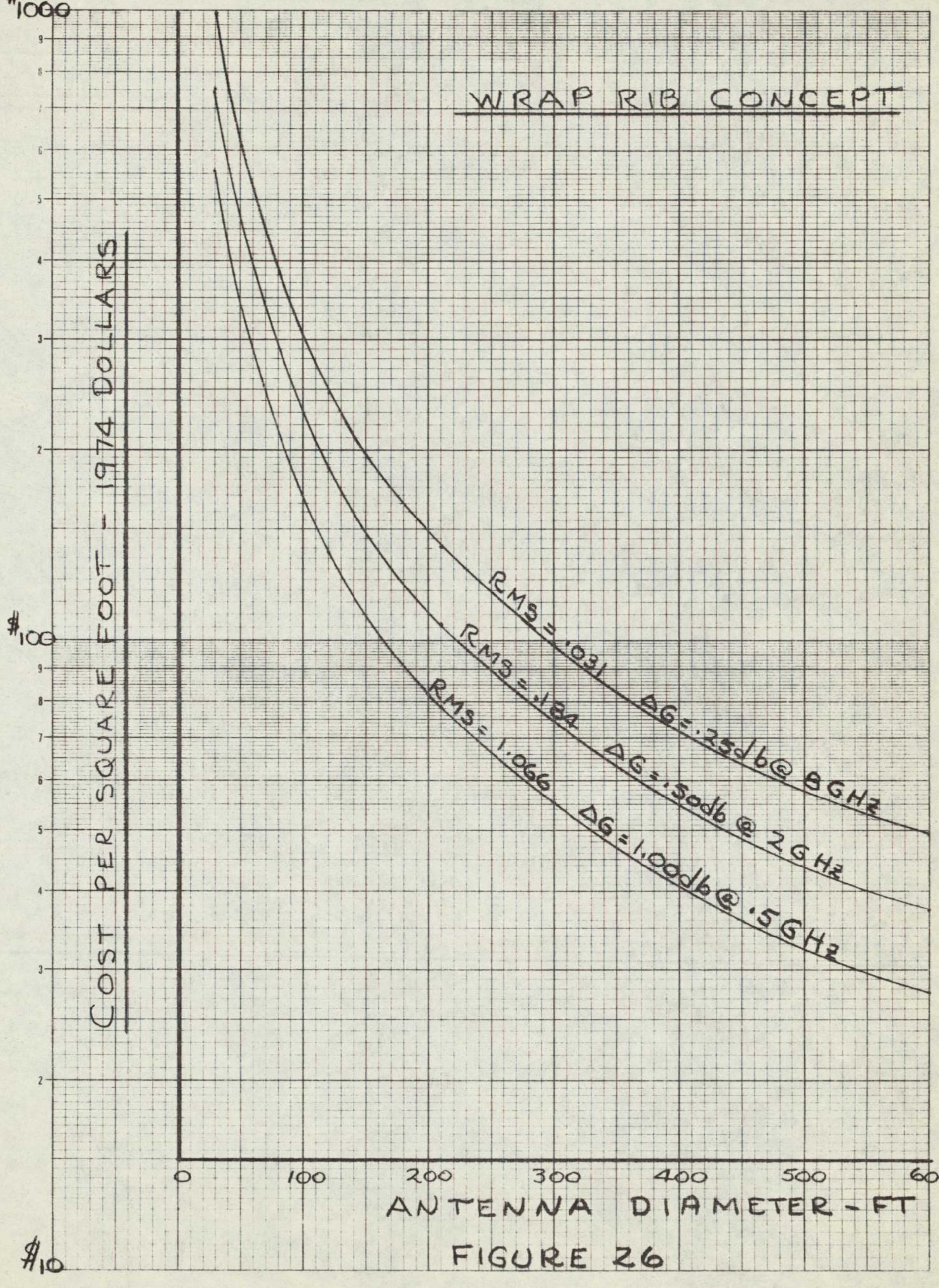

WRAP RIB CONCEPT
$1000
$100
$10
COST PER SQUARE FOOT - 1974 DOLLARS
RMS = .031 ΔG = .25db @ 8GHz
RMS = .184 ΔG = .50db @ 2GHz
RMS = 1.066 ΔG = 1.00db @ .5GHz
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 26

POLYCONIC ANTENNA
FREQ = 8 GHz

K$

Area Sq. Ft.	Dia. Ft.	Nominal ΔG(db)	Nominal RMS(in)	Number of Booms	Number of Cones	No. of Intersection	Surface Variable	Hub Variable	Constant	Total per ft.d
		.25	.031	160	68	10880	180	33	100	313
283000	600	.50	.047	80	55	4400	150	25	100	275
		1.00	.061	40	49	1960	120	17	100	237
		.25	.031	80	48	3840	150	33	100	283
70700	300	.50	.047	40	39	1560	130	25	100	255
		1.00	.061	20	35	700	120	17	100	237
		.25	.031	56	40	2240	150	33	100	283
34600	210	.50	.047	28	33	924	130	25	100	255
		1.00	.061	14	29	406	120	17	100	237
		.25	.031	32	30	960	150	33	100	283
11300	120	.50	.047	16	24	394	130	25	100	255
		1.00	.061	8	22	176	120	17	100	237
		.25	.031	8	13	104	130	33	100	266
707	30	.50	.047	8	11	88	130	25	100	255
		1.00	.061	8	10	80	130	17	100	247

TABLE X

ia. Ft)	Area (Ft^2)	Nom. G (db)	FREQ = 8. GHz Nom. RMS (in)	No. of Boom/Cone Intersection	Total Cost (M$)	Cost per ft^2 (($)	FREQ = 2. GHz Nom. RMS (in)	No. of Boom/Cone Intersection	Total Cost (M$)	Cost per ft^2 ($)	FREQ = .5 GHz Nom. RMS (in)	No. of Boom/Cone Intersection	Total Cost (M$)	Cost per ft ($)
		.25	.031	10880	187.	660.	.130	5440	152.	536.	.427	3040	141.	497.
00	283,000	.50	.047	4400	165.	582.	.184	2320	132.	466.	.734	1200	120.	424.
		1.00	.061	1960	142.	500.	.246	960	112.	395.	1.066	480	103.	364
		.25	.031	3840	85.	1200.	.130	1920	68.	960.	.427	1120	62.	875
00	70,700	.50	.047	1560	76.	1072.	.184	800	62.	875.	.734	400	53.	750
		1.00	.061	700	71.	1002.	.246	360	56.	792.	1.066	180	47.	665
		.25	.031	2240	59.	1705.	.130	1120	48.	1390.	.427	616	40.	1158
10	34,600	.50	.047	924	53.	1535.	.184	476	43.	1245.	.734	252	35.	1012
		1.00	.061	406	50.	1445.	.246	210	39.	1130.	1.066	98	30.	866
		.25	.031	960	34.	3020.	.130	480	27.	2390.	.427	256	21.4	1895
20	11,300	.50	.047	394	31.	2740.	.184	192	25.	2210.	.734	96	18.8	1665
		1.00	.061	176	28.	2480.	.246	88	22.	1945.	1.066	40	16.9	1495
		.25	.031	104	8.0	11300.	.130	56	6.2	8760.	.427	32	4.6	6500
30	707	.50	.047	88	7.7	10900.	.184	48	6.0	8480.	.734	24	4.3	6080
		1.00	.061	80	7.4	10450.	.246	40	5.8	8200.	1.066	16	4.0	5660

TABLE XI

Item 9. Define Envelope of furled and unfurled antenna hardware and geometry of structural support points.

Figure 28 presents furled dimensions of the Wrap-Rib antenna concept versus the unfurled diameter of the parabolic contour. Similar information for the Polyconic antenna concept is printed out in tabular form on the supplied computer sheets. This furled dimensional information may be summarized for the Polyconic antenna concept in a more valid form by statements rather than plotted graph illustration.

The length of the furled concept will use the full length of Space Shuttle cargo bay available - or approximately 60 feet, unless the reflector unfurled diameter is less than 120 feet. If it is less, then the furled length will be close to one half of unfurled diameter.

The furled outside diameter will depend upon the number of booms chosen, the diameter of booms chosen, each of which depends upon the chosen manufacturing material for boom construction. Reference to tables on the computer printout sheets is desirable while keeping in mind the statements made in Section 3 on the peak gain characteristics of the Polyconic antenna concept. There will be no inside diameter hole through the hub of this concept.

Information on the stowed, furled dimensions relating to the Maypole concept may be obtained in Section 20 wherein all Maypole information data is given.

It is usual to provide four structural support mounting brackets attached to the inside diameter of the Wrap-Rib concept. Lack of central hole through the hub of the Polyconic antenna concept requires that structural support mounting point fittings be attached at the lower end of the hub structure near the diameter of the boom pivot points. Refer to Figures 1 and 2 for further clarification of positions noted. Nominal unfurled dimensions of the antennas may be calculated from $(D/2)^2 = 4\,fx$ and f/D is a given ratio. D = diameter, height = 5 to 10% greater than f.

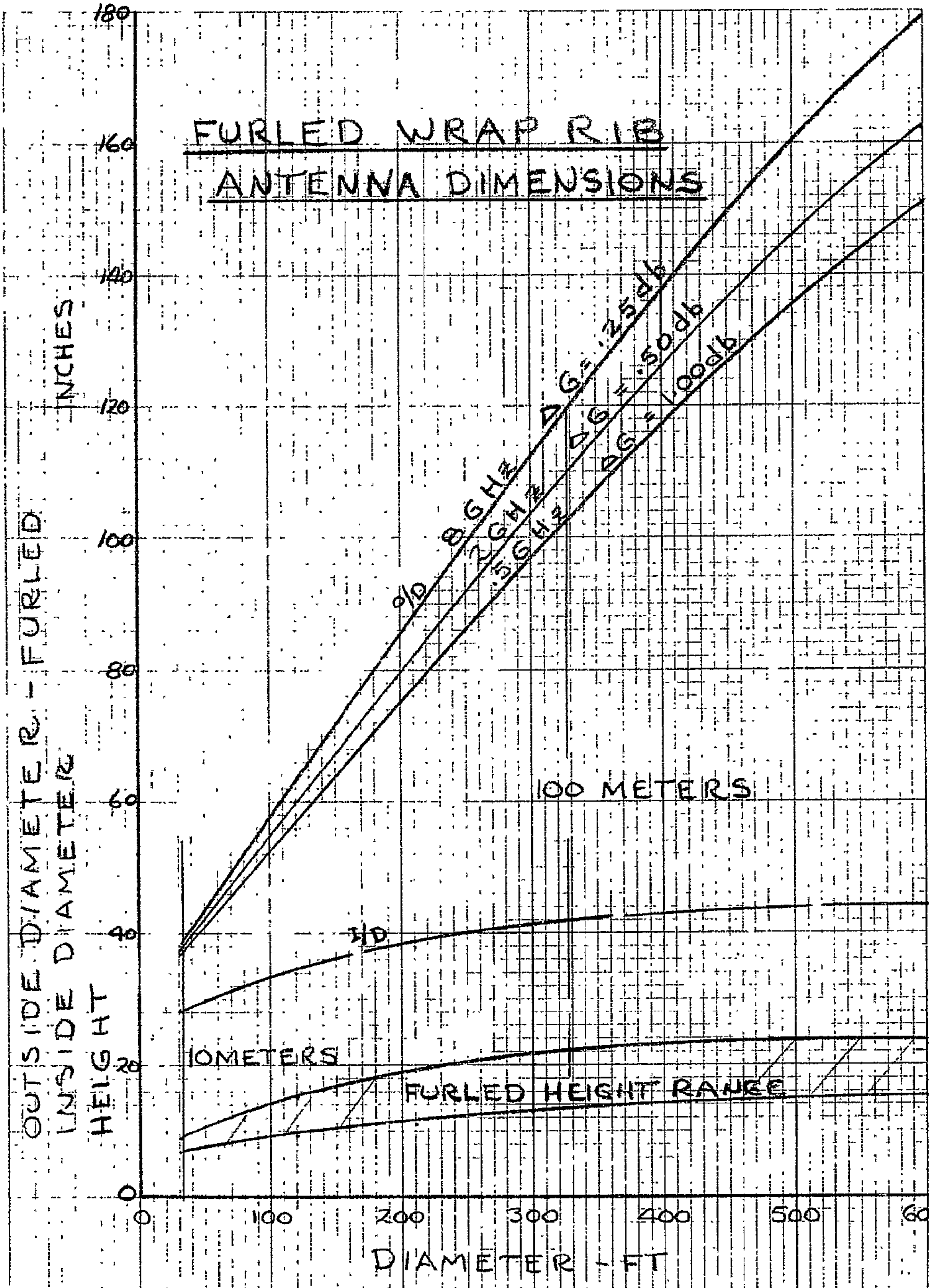

FURLED WRAP RIB
ANTENNA DIMENSIONS
OUTSIDE DIAMETER - FURLED
INSIDE DIAMETER
HEIGHT
INCHES
O/D 8 GHz ΔG = .25db
2 GHz ΔG = .50db
.5 GHz ΔG = 1.00db
100 METERS
I/D
10 METERS
FURLED HEIGHT RANGE
0
20
40
60
80
100
120
140
160
180
0
100
200
300
400
500
600
DIAMETER - FT

FIGURE 28

Item 10. Discuss Development stage of antenna concepts considered.

Wrap-Rib Antenna Concept.

A 30 foot diameter, stored energy unfurling model has been built, tested and flown successfully.

Larger models are being built that include mechanical unfurling mechanisms. These larger models are being built in a flight type testable design with the end objective of being used in space.

Polyconic Antenna Concept.

Up to 20 foot diameter polyconic conceptual models have been made primarily to represent and solve the problems of conic surface parabolic approximation. Design studies have been conducted on a preliminary basis to solve the problems of support structure and boom deployment. Flight type hardware has not been built for test or flight.

Maypole Antenna Concept.

The desire to build very large diameter reflectors of up to 11,000 feet led to the conceptual design of the Maypole Antenna Concept. Compressive structural members have been replaced in as many places as possible by tension cables or tensioned mesh. The development of the ability to build models of this concept over 100 meters in diameter depends to a great extent on the practical ability to develop mesh, tension and structural materials that have very low coefficient of thermal expansion.

Item 11. <u>Define mechanical and/or electrical pointing capability of proposed antenna concepts with tolerances</u>.

Directing the manufactured mechanical axis within close tolerances of any of the concepts under consideration will depend upon the sensing and actuating tolerance ability of the contour evaluation and servo adjustment system developed for use in space. The ability to provide good rf gain performance depends directly upon the ability to produce low surface deviation parabolic approximations regardless of the reflector diameter. This means that the mechanical and electrical axis will become more closely aligned to theoretical center line axis as the reflector goes up in diameter. Concepts considered for the "contour evaluation and surface adjustment servo mechanism" may become very accurate dependent upon the number of operating iterations allowed. There is no technical breakthrough required to design such a system that would be capable of handling up to 8 GHz frequency and 600 feet in diameter. The major problem in achieving the larger diameters at the higher frequencies will be the development of sufficiently thermal stable construction materials.

Figure 29 illustrates the electrical axis beam pointing accuracy obtained from reflectors built from sufficiently thermal stable materials to produce reasonable rf gain performance.

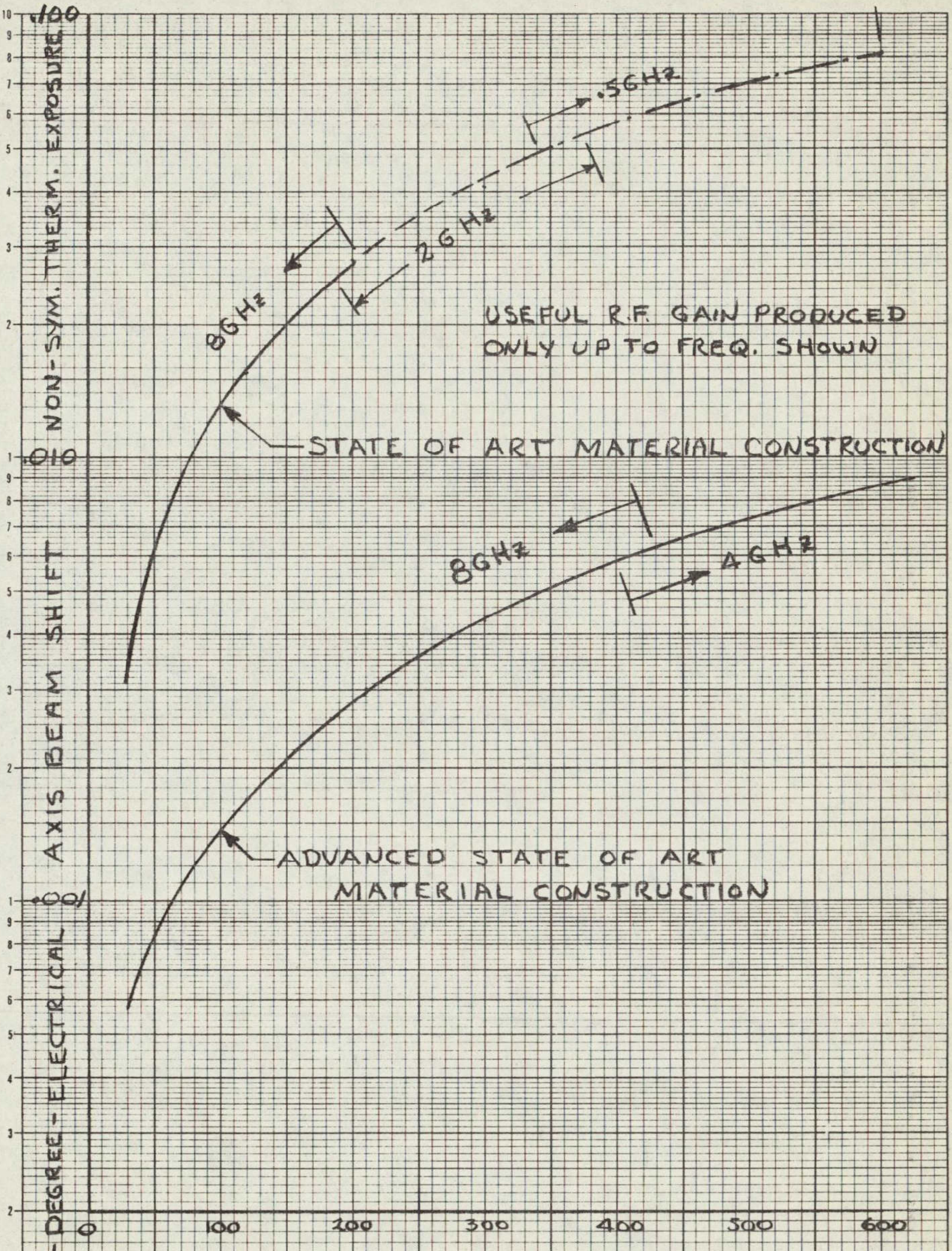

.100
.010
.001
DEGREE - ELECTRICAL AXIS BEAM SHIFT NON-SYM. THERM. EXPOSURE
.5GHz
2GHz
8GHz
USEFUL R.F. GAIN PRODUCED
ONLY UP TO FREQ. SHOWN
STATE OF ART MATERIAL CONSTRUCTION
8GHz
4GHz
ADVANCED STATE OF ART
MATERIAL CONSTRUCTION
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 29.

Item 12. Identification of structural design loads and criteria for new and existing designs.

The following list identifies design loads and criteria that may be considered critical for successful development and tested performance of the Wrap Rib and Polyconic antenna concepts.

Wrap Rib Antenna Concept

- Ribs - be sufficiently structurally stiff to resist a deflection, under mesh induced loads, that will not allow surface contour deviation greater than r.f. performance degradation allowable. The design loading criteria developed for a particular diameter reflector used at a particular r.f. frequency is therefore an integral portion of the surface contour deviation allowable, the structural properties of the rib and mesh used, the thermal stability of the mesh and rib materials and the optimized mesh tension developed during design analyses.

- Hub - be sufficiently structurally stiff to not materially contribute to the mesh tension induced surface contour distortion by holding the attachment of the rib in a stable manner. This design load criteria applies to all members and components of the hub that by load induced deflection can allow excessive rotation of the ribs. Dependent upon required rotational acceleration slewing rates required by design concept criteria, the critical vertical stiffness loading may result from bending buckling resistance to bending moments induced by the rotational acceleration slewing rates.

- Surface mesh - be made from materials and/or constructic methods that will minimize surface mesh induced loading in the ribs. For example, knit meshes have a lower modulus of elasticity than woven construction. Mesh construction materials with very low thermal coefficient of expansion will induce lesser loads into ribs under changing thermal environment. The critical loading criteria is therefore that combination of structural design and thermally induced loading that will produce more than acceptable surface deviation in orbital operation.

- Existing design additional critical loading criteria - In the past where smaller reflectors were designed and tested, two more loading criteria were important. They disappear when mechanically induced space only unfurling concepts are used. They are demonstration of deployment capability in 1g environment without the use of aids. This requirement added torsional rigidity to the ribs unnecessary for any other load criteria. The second loading criteria was the ability to unfurl using stored energy only. The stored energy so released at unfurling implementation, resulted in stop loading into the hub that no other load criteria produced.

Polyconic Antenna Concept

- Booms - be sufficiently stiff to resist excessive deflection induced by mesh loads. The weight of the booms is load dependent as usual but in the case of large reflectors that are deployable in space only, i.e., they do not need to resist 1g environment deployment loading, the critical loading on the booms is an optimized combination of factors. They include minimizing mesh loading induced by solar thermal heating and minimizing loading induced into the boom by thermally induced boom deflection against the mesh loading. Dependent upon design concept required rotational acceleration slewing rates, the critical stiffness of the booms may result from bending moments induced by the slew rate.

- Hub - be sufficiently structurally stiff to not materially contribute to the mesh tension induced surface contour distortion by holding the attachment points of the booms in a structurally stable manner.

- Surface mesh - The same criteria as outlined under the Wrap Rib Concept affect the design of the Polyconic surface mesh. In addition, this surface mesh is directly held in place by circular mesh ribs which are attached to the booms. These mesh circular ribs must be made from a mesh material that is not only stable in the vertical loading direction under low loading, i.e., it must have a relatively high modulus of elasticity but must be relatively thermally stable in order to reduce loads transferred from the mesh surface to the boom structure.

Item 13. Evaluation of dynamic characteristics of antenna concepts. Evaluation of surface deviation as a function of sweep rates.

The natural frequencies of the Wrap Rib concept reflector antennas evaluated are shown by Figure 30. The rocking mode antenna natural frequency shown is about the sweeping axis of rotation. The values shown under nominal maximum rib are those calculated for the maximum sized rib used in this parametric evaluation. The geometric shape and dimensional range used for ribs evaluated is shown by Figure 31.

The natural frequencies of the Polyconic concept reflector antennas evaluated are shown by Figure 32. The nominal maximum to minimum boom sizes are shown by Figure 31

The furled Wrap Rib antenna concept will have a lowest resonant natural frequency of approximately 20 Hertz. This estimated value is based upon the tested similar construction, used in the ATS stowed wrap rib reflector, that showed lowest resonant fn equal to 22 Hz.

The mass moments of inertia of interest in this parametric study are shown by Figures 33 and 34 for the Wrap Rib concept and by Figure 35 for the Polyconic antenna concept. The mass moments of inertia shown by these figures are those about the rotational axis used during rotational rf sweeping operations. Figure 33 illustrates mass moments of inertia for Wrap Rib construction using the number of ribs indicated on Table II with Figure 34 representing the number of ribs used on Table IV . If intermediate values of mass moment of inertia for the Wrap Rib reflector antenna concept are desired for all parametric sizes and number of ribs evaluated, reference should be made to the computed summary print-out sheets provided. For similar intermediate value information

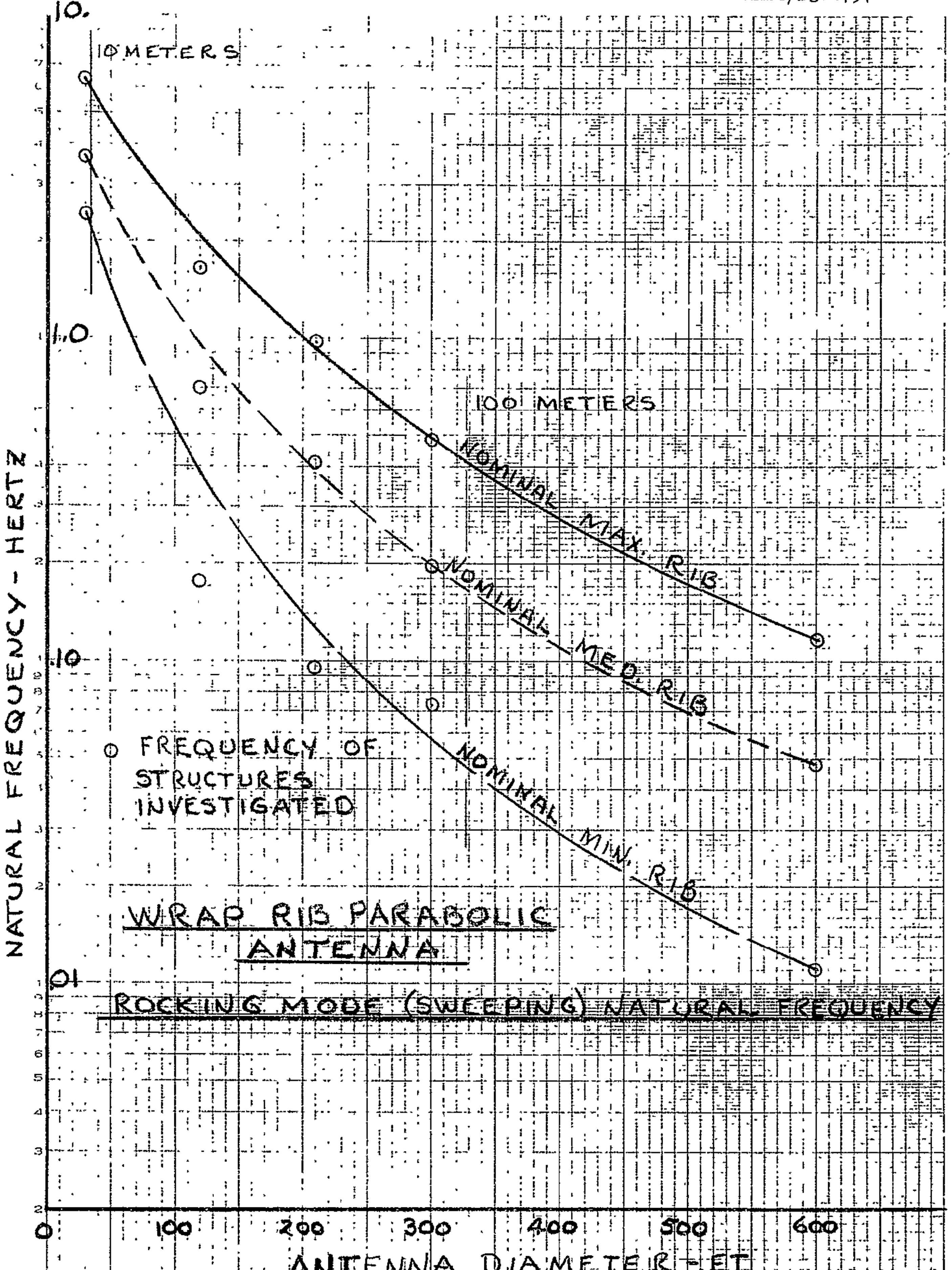
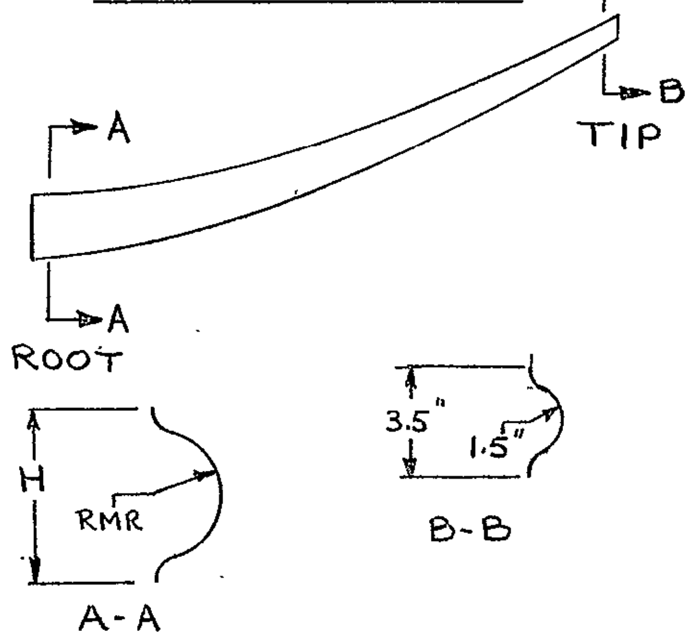

10.
10 METERS
1.0
100 METERS
NOMINAL MAX. RIB
NOMINAL MED. RIB
NOMINAL MIN. RIB
.10
FREQUENCY OF STRUCTURES INVESTIGATED
WRAP RIB PARABOLIC ANTENNA
.01
ROCKING MODE (SWEEPING) NATURAL FREQUENCY
NATURAL FREQUENCY - HERTZ
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

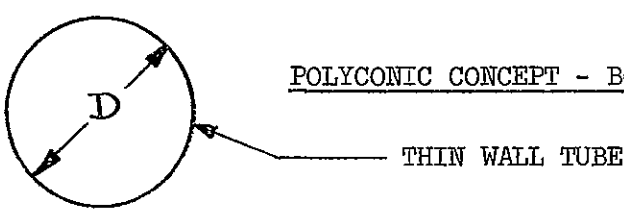
FIGURE 30

WRAP RIB CONCEPT - RIB SIZE



Antenna Diam.		600'	300'	210'	120'	30'
RMR	MAX	6.0"	6.0	6.0	4.5	2.0
	MED	4.0	4.0	4.0	3.0	1.5
	MIN	2.0	2.5	2.0	1.5	1.0
H	MAX	14."	14."	14.	11.	6.
	MED	10.	10.	10.	8.	5.
	MIN	6.	7.	6.	5.	4.

POLYCONIC CONCEPT - BOOM SIZE



Antenna Diam.		600'	300'	210'	120'	30'
D	MAX	8."	5.	4.	3.	2.0
	MED	6."	3.75	3.	2.5	1.5
	MIN	4."	2.5	2.	2.	1.0

FIGURE 31

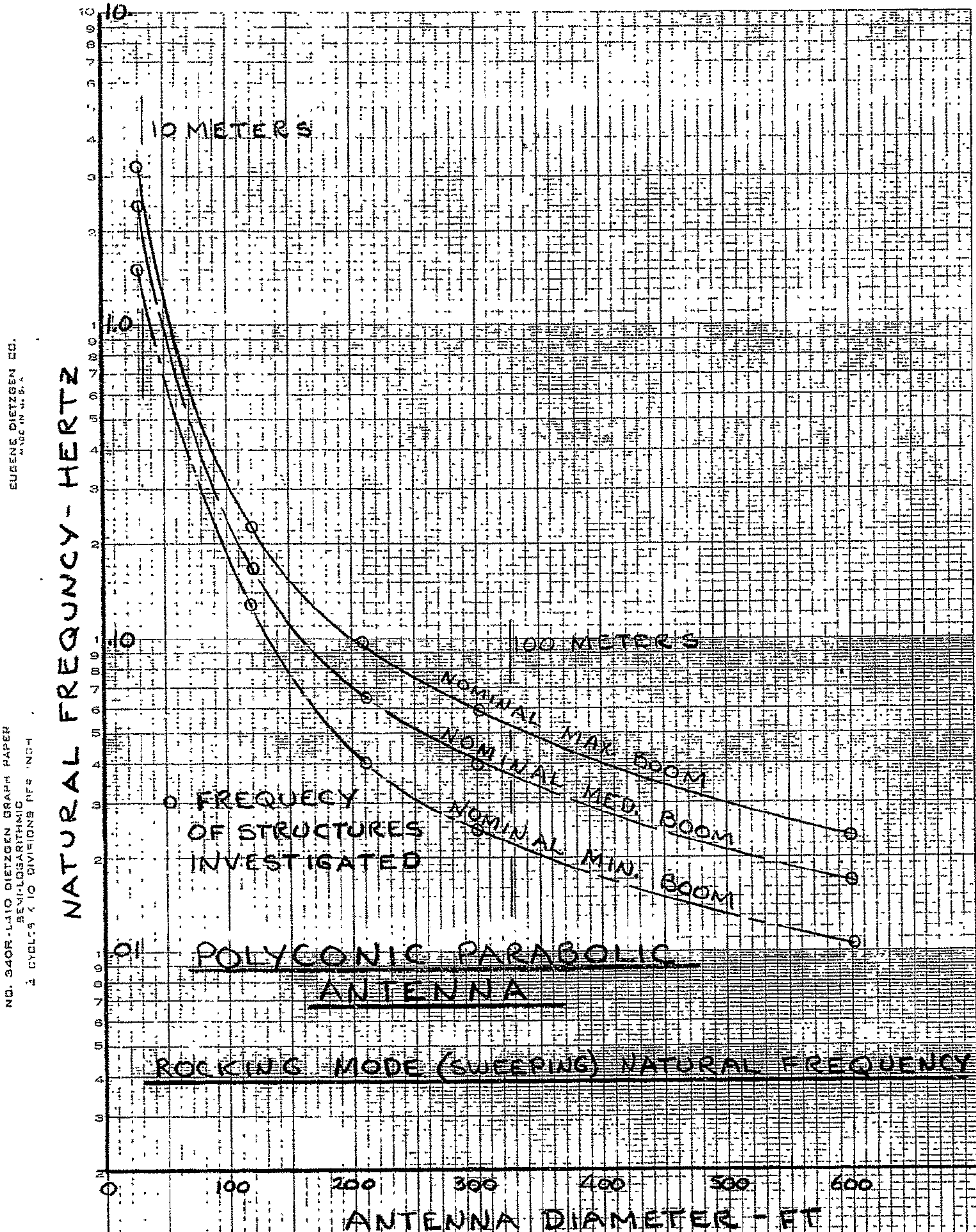

NATURAL FREQUNCY - HERTZ
10
1.0
.10
.01
10 METERS
100 METERS
NOMINAL MAX. BOOM
NOMINAL MED. BOOM
NOMINAL MIN. BOOM
FREQUECY OF STRUCTURES INVESTIGATED
POLYCONIC PARABOLIC ANTENNA
ROCKING MODE (SWEEPING) NATURAL FREQUENCY
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 32

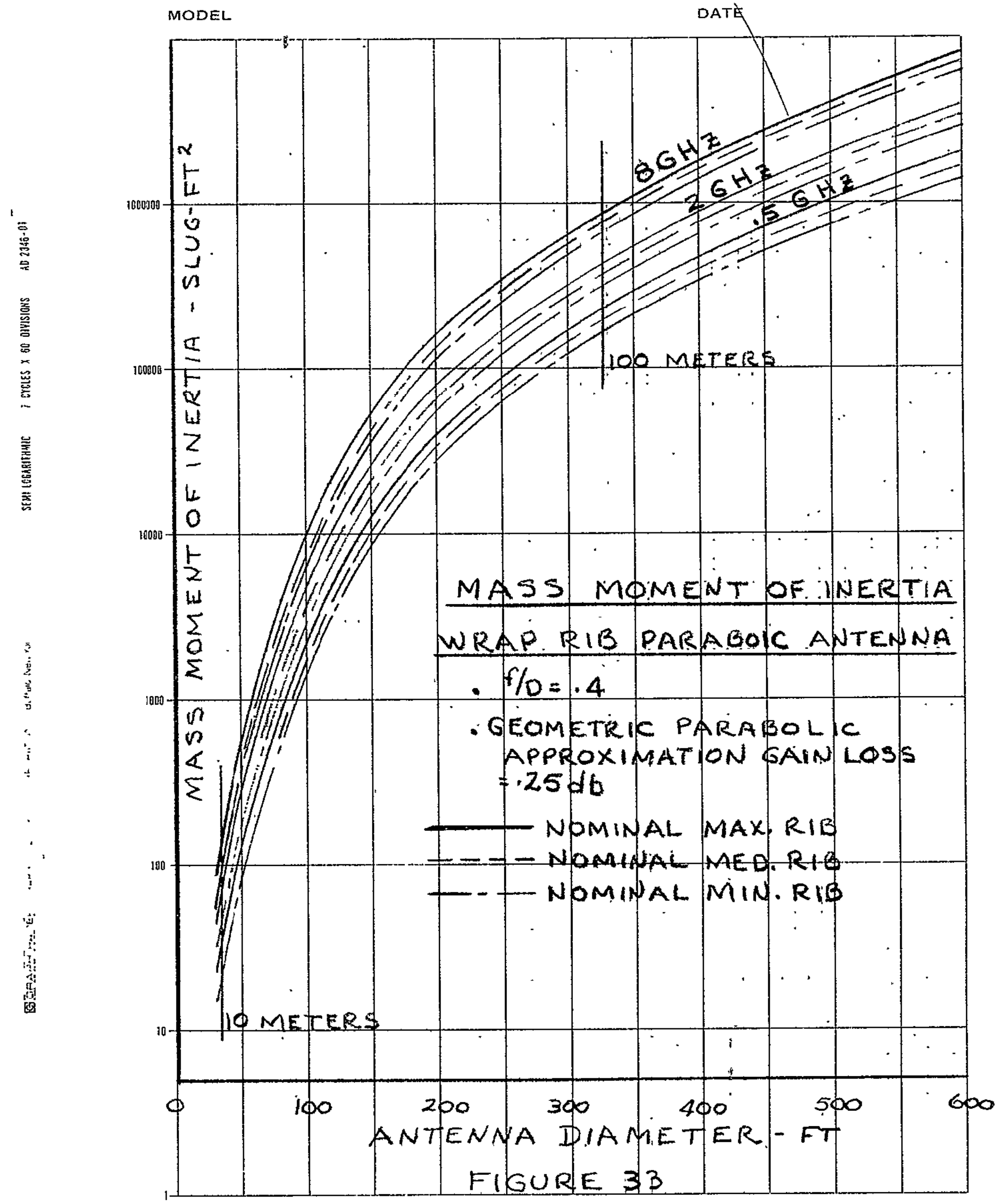

MODEL
DATE
MASS MOMENT OF INERTIA - SLUG-FT²
1000000
100000
10000
1000
100
10
1
8GHz
2GHz
.5GHz
100 METERS
10 METERS
MASS MOMENT OF INERTIA
WRAP RIB PARABOIC ANTENNA
• f/D = .4
• GEOMETRIC PARABOLIC APPROXIMATION GAIN LOSS = .25db
NOMINAL MAX. RIB
NOMINAL MED. RIB
NOMINAL MIN. RIB
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT
SEMI LOGARITHMIC 7 CYCLES X 60 DIVISIONS AD 2346-07

FIGURE 33

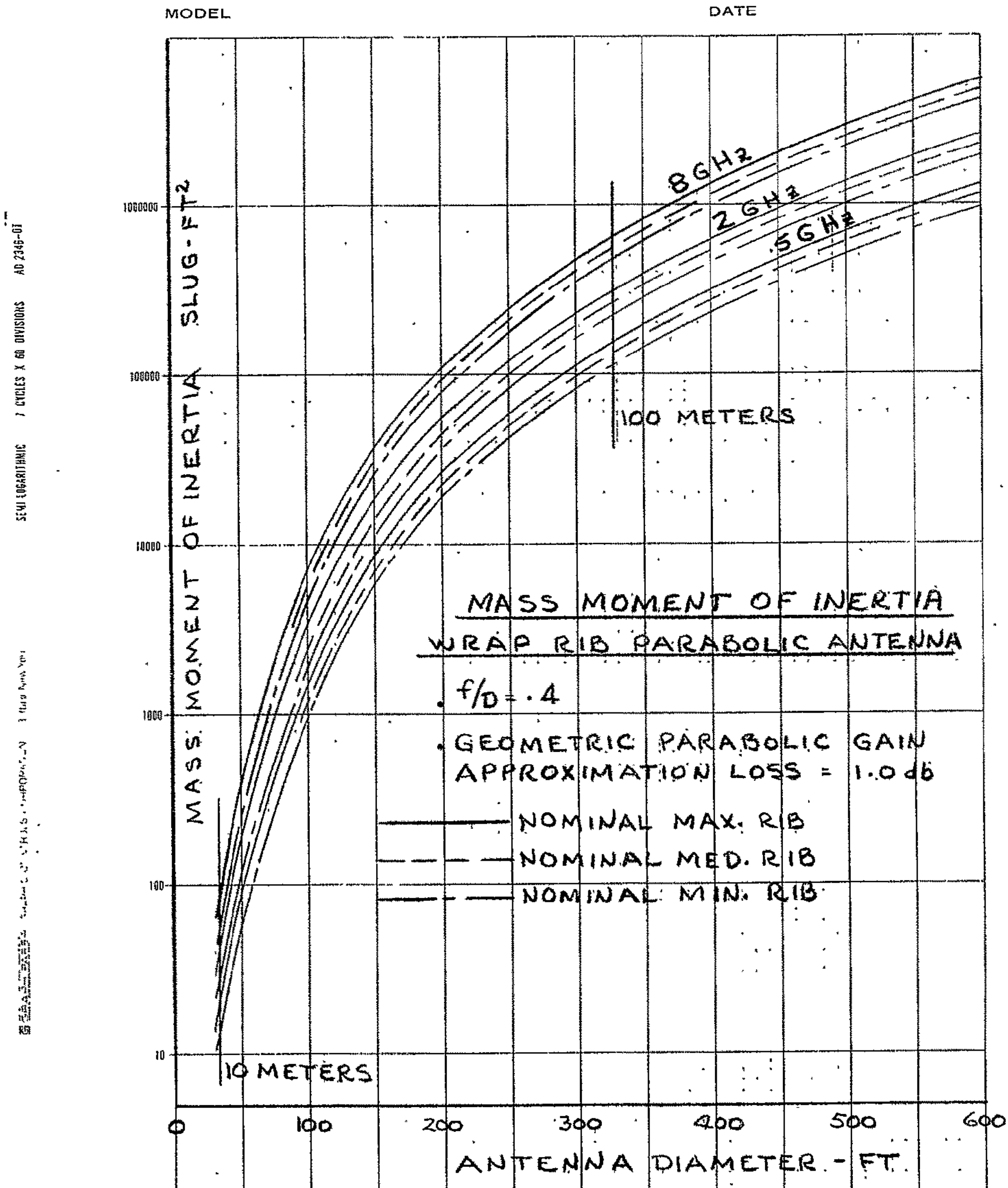

MODEL
DATE
MASS MOMENT OF INERTIA SLUG-FT²
8GHz
2GHz
5GHz
100 METERS
10 METERS
MASS MOMENT OF INERTIA
WRAP RIB PARABOLIC ANTENNA
f/D = .4
GEOMETRIC PARABOLIC GAIN
APPROXIMATION LOSS = 1.0 db
NOMINAL MAX. RIB
NOMINAL MED. RIB
NOMINAL MIN. RIB
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT.
SEMI LOGARITHMIC 7 CYCLES X 60 DIVISIONS AD 2346-07

FIGURE 34

MODEL DATE

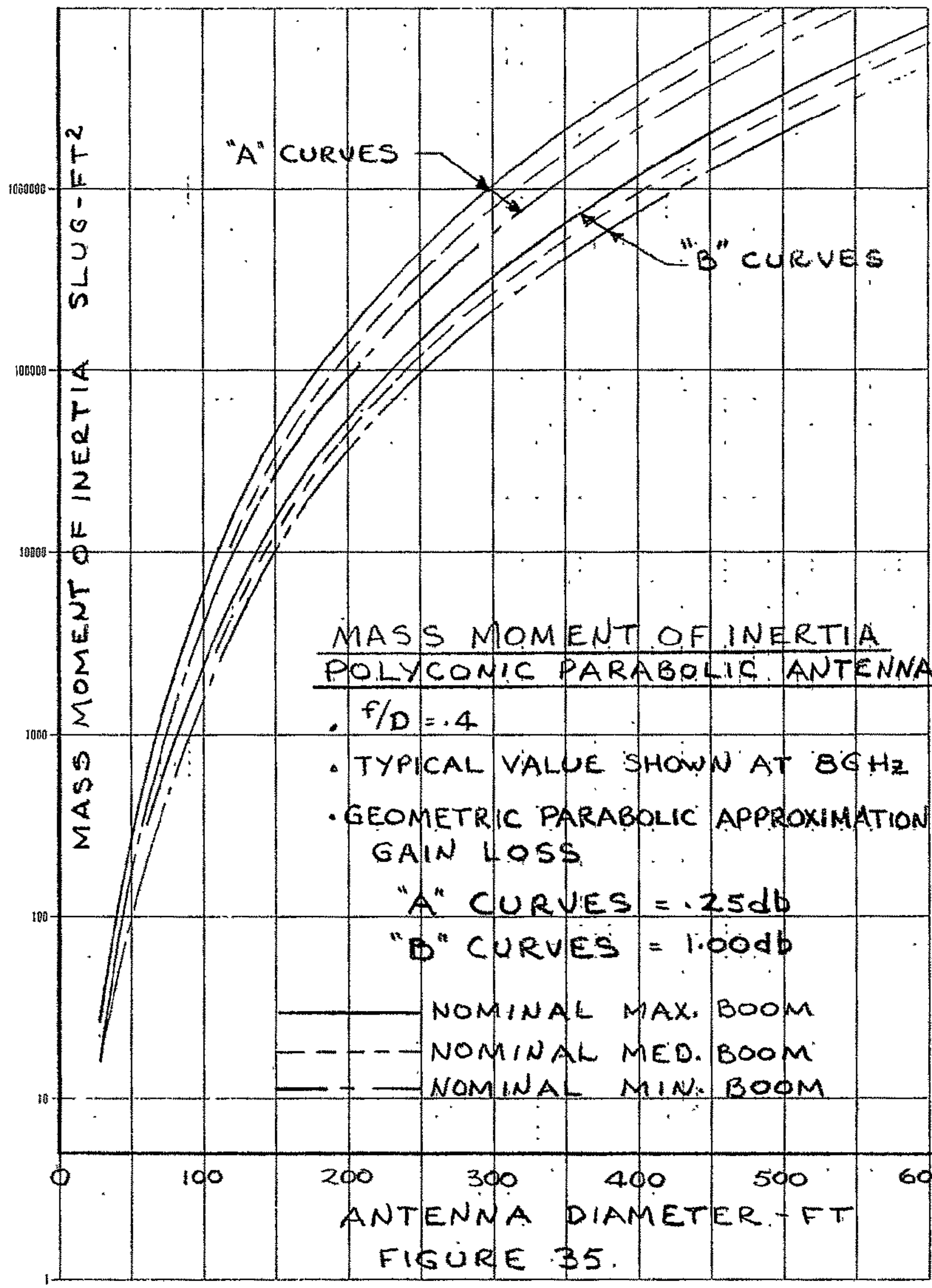


FIGURE 35.

with reference to the Polyconic concept, reference should be made to the Polyconic computed summary print-out sheets.

The surface deviation as a function of rotational sweep rates is illustrated by predicting the maximum rotational acceleration rate allowable that will produce surface distortions of one and two db down rf gain over nominal undistorted surface contour gain. Since gain degradation is a function of rf wavelength (frequency) and contour distortion, where contour distortion is a function of rotational loading and reflector structural stiffness, the maximum allowable rotational acceleration rates for any structural stiffness and gain degradation may be calculated.

Figure 36 shows allowable acceleration rotational rates at 1 db down from nominal rf gain plus 0.25 db geometric contour approximation gain loss for Wrap Rib reflector antenna concept. Figure 37 shows similar information at 2 db down plus 0.50 db geometric contour loss. The summary print-out computer sheets provided cover the following combinations at all three parametric rf frequencies.

Gain loss from rotational loaded structure contour distortion	Gain loss from geometric parabolic contour approximation (nominal)		
1.0 db down	.25 db	.50 db	1.00 db
2.0 db down	.25 db	.50 db	1.00 db

Figure 38 presents surface contour deviation data versus rf frequency that may be referred to in conjunction with Figures 36, 37, 39 and 40 in order to directly read the estimated surface deviation at the rotational acceleration allowable. The allowable rotational acceleration is a function of the stiffness of the structure used in the parametric data study.

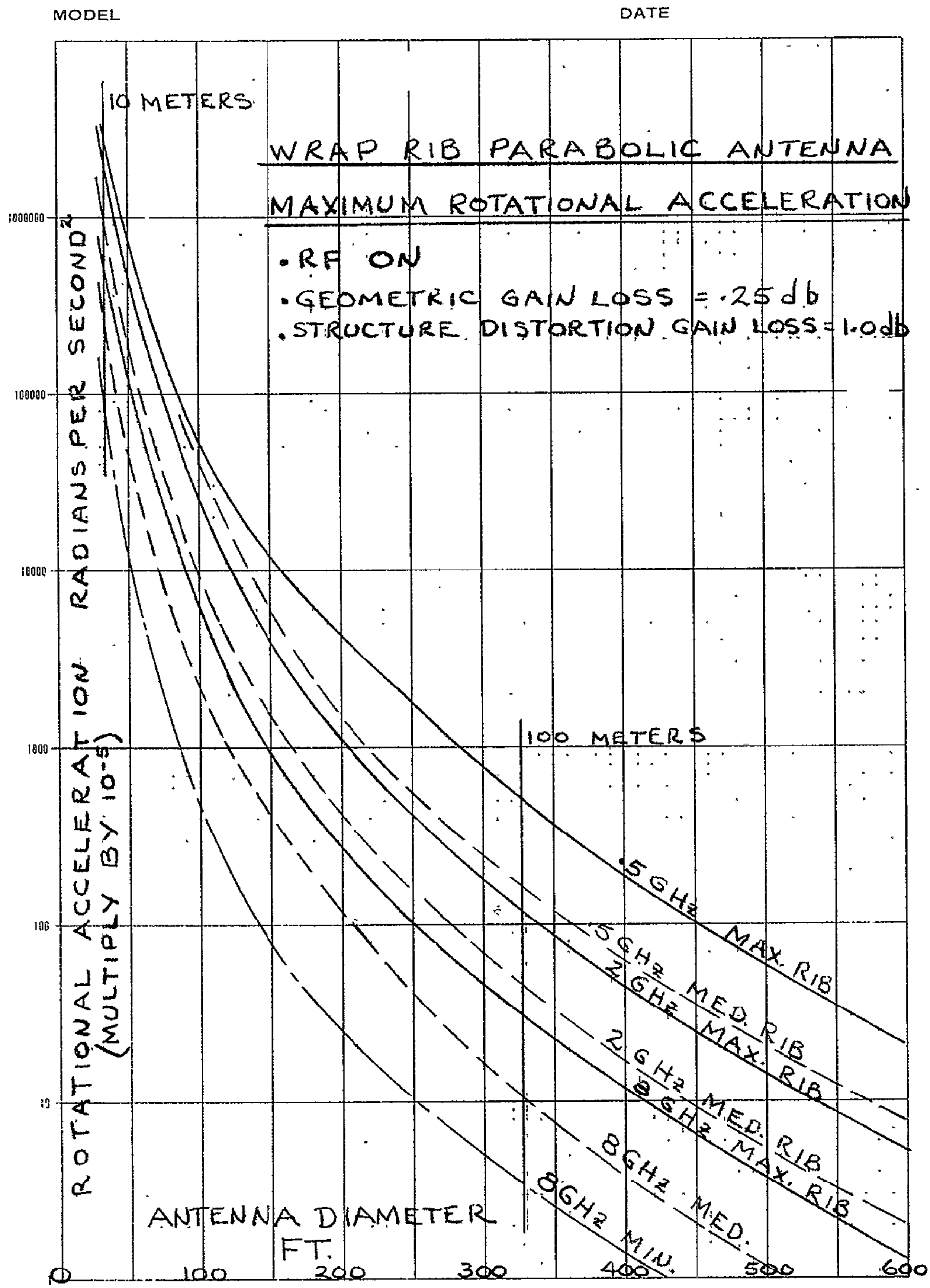
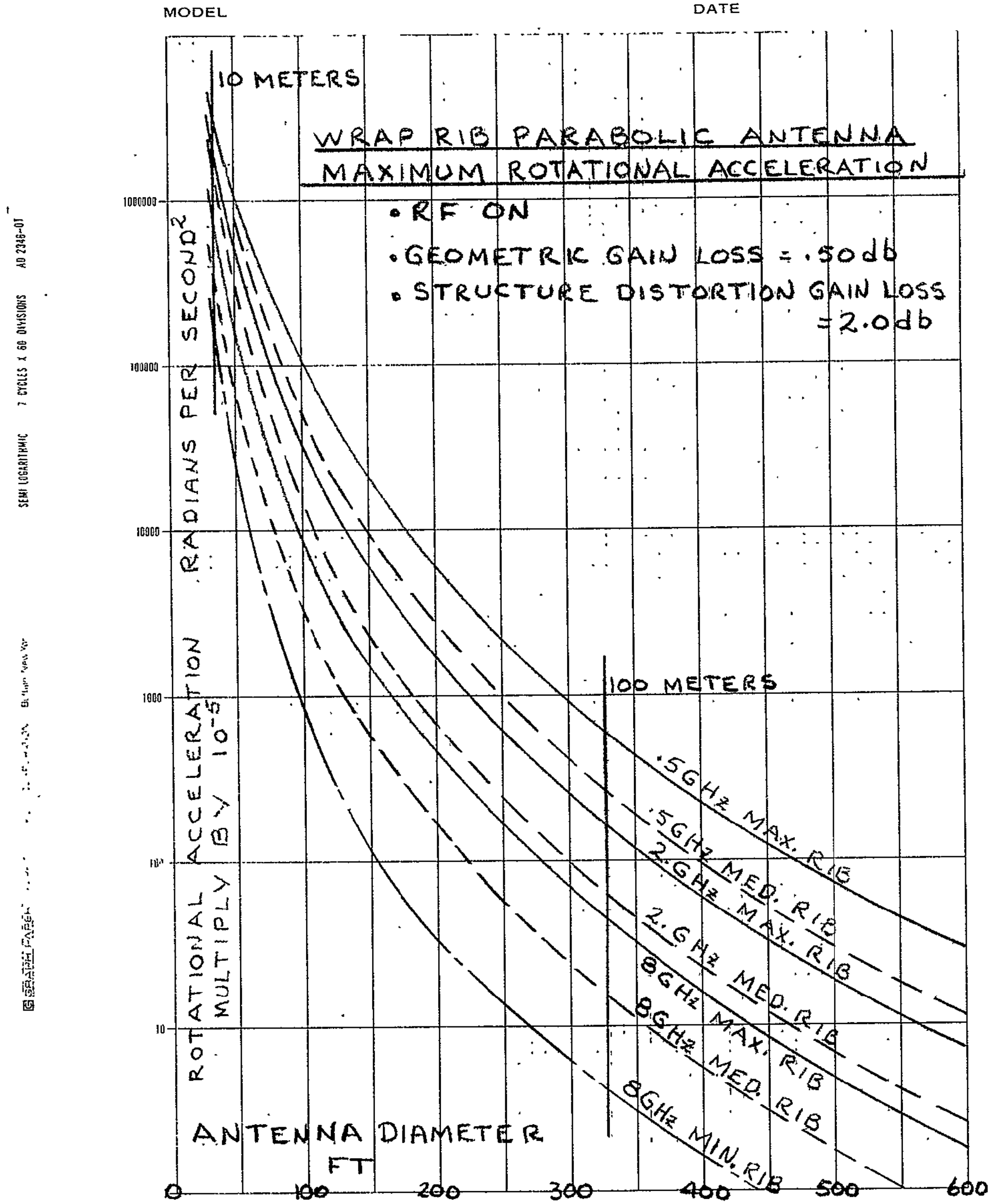

MODEL
DATE
10 METERS
WRAP RIB PARABOLIC ANTENNA
MAXIMUM ROTATIONAL ACCELERATION
• RF ON
• GEOMETRIC GAIN LOSS = .25 db
• STRUCTURE DISTORTION GAIN LOSS = 1.0 db
ROTATIONAL ACCELERATION RADIANS PER SECOND²
(MULTIPLY BY 10⁻⁵)
1000000
100000
10000
1000
100
10
100 METERS
.5 GHz MAX. RIB
.5 GHz MED. RIB
2 GHz MAX. RIB
2 GHz MED. RIB
8 GHz MAX. RIB
8 GHz MED.
8 GHz MIN.
ANTENNA DIAMETER FT.
0
100
200
300
400
500
600
SEMI LOGARITHMIC 7 CYCLES X 60 DIVISIONS AD 2346-0T

FIGURE 36



MODEL
DATE
10 METERS
WRAP RIB PARABOLIC ANTENNA
MAXIMUM ROTATIONAL ACCELERATION
• RF ON
• GEOMETRIC GAIN LOSS = .50db
• STRUCTURE DISTORTION GAIN LOSS =2.0db
1000000
100000
10000
1000
100
10
ROTATIONAL ACCELERATION RADIANS PER SECOND²
MULTIPLY BY 10⁻⁵
100 METERS
.5GHz MAX. RIB
.5GHz MED. RIB
2.GHz MAX. RIB
2.GHz MED. RIB
8GHz MAX. RIB
8GHz MED. RIB
8GHz MIN. RIB
ANTENNA DIAMETER FT
0
100
200
300
400
500
600
SEMI LOGARITHMIC 7 CYCLES X 60 DIVISIONS AD 2346-0T
GRAPH PAPER

FIGURE 37.

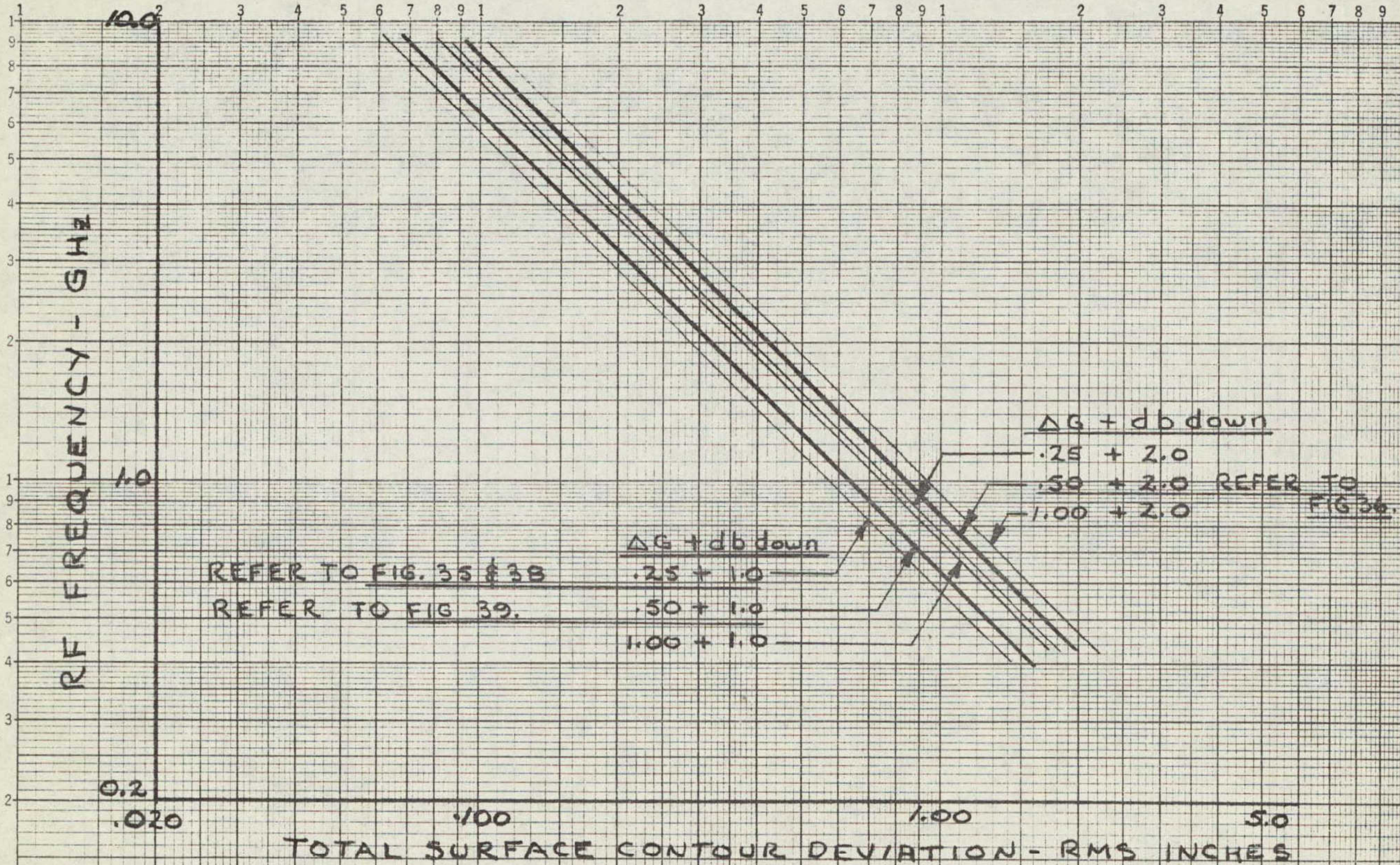

RF FREQUENCY - GHz
10.0
1.0
0.2
.020
.100
1.00
5.0
TOTAL SURFACE CONTOUR DEVIATION - RMS INCHES
ΔG + db down
.25 + 2.0
.50 + 2.0 REFER TO FIG 36.
1.00 + 2.0
ΔG + db down
REFER TO FIG. 35 & 38 .25 + 1.0
REFER TO FIG 39. .50 + 1.0
1.00 + 1.0

FIGURE 38

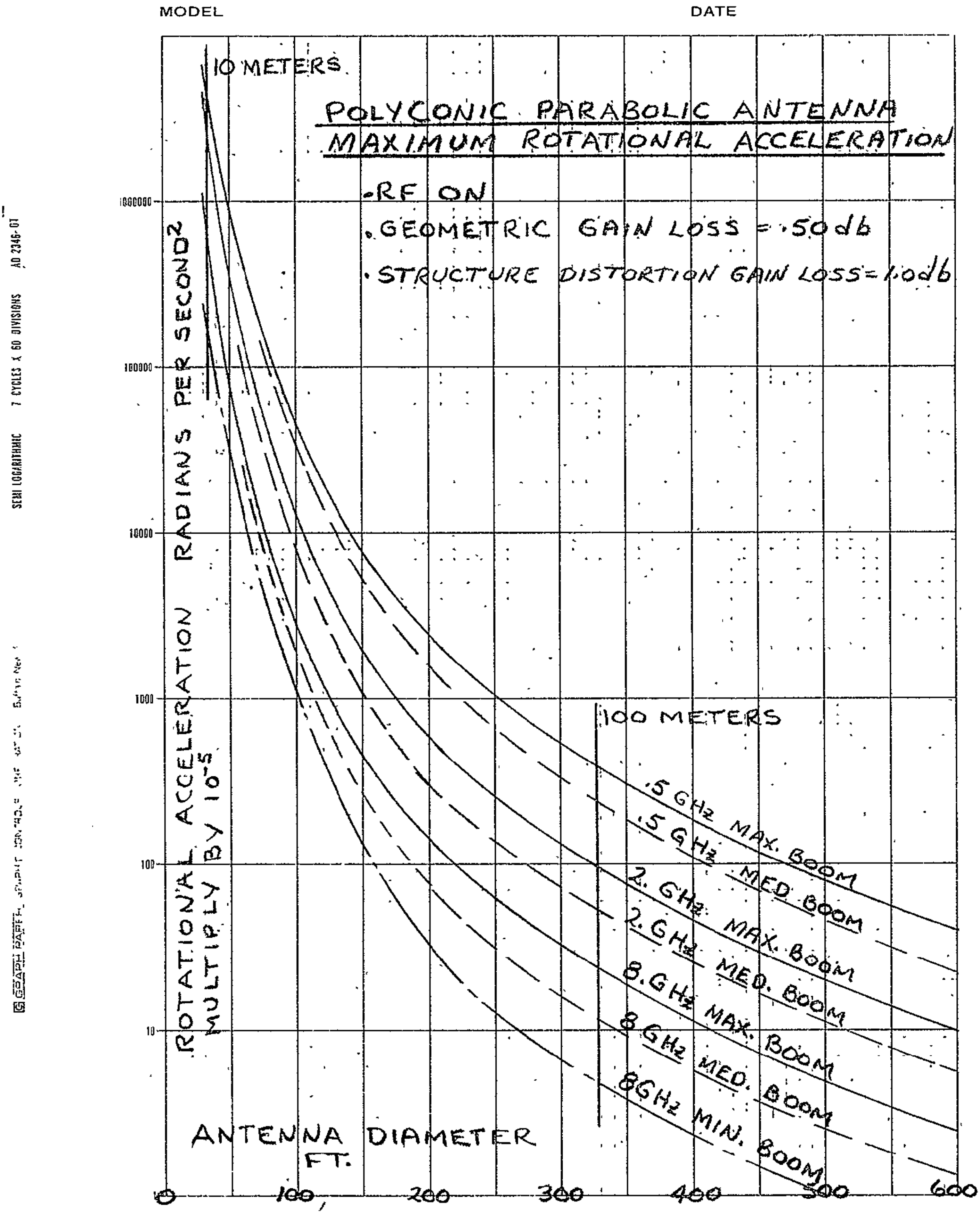

MODEL
DATE
10 METERS
POLYCONIC PARABOLIC ANTENNA
MAXIMUM ROTATIONAL ACCELERATION
•RF ON
•GEOMETRIC GAIN LOSS = .50 db
•STRUCTURE DISTORTION GAIN LOSS = 1.0 db
ROTATIONAL ACCELERATION RADIANS PER SECOND²
MULTIPLY BY 10⁻⁵
1000000
100000
10000
1000
100
10
100 METERS
.5 GHz MAX. BOOM
.5 GHz MED. BOOM
2. GHz MAX. BOOM
2. GHz MED. BOOM
8. GHz MAX. BOOM
8 GHz MED. BOOM
8 GHz MIN. BOOM
ANTENNA DIAMETER FT.
0
100
200
300
400
500
600
SEMI LOGARITHMIC 7 CYCLES X 60 DIVISIONS AD 2346-01

FIGURE 40

The function of this system of curves is to present sufficient data so that maximum allowable acceleration rates may be estimated with the rf communication system operating with no more than geometric parabolic approximation gain loss plus a given additional gain loss from acceleration loading. Points chosen for the acceleration loading gain loss were 1 db and 2 db down from nominal undistorted peak gain.

Item 14. Evaluate the maximum allowable rotational acceleration of unfurled antenna while not in r.f. operation.

Figure 41 illustrates maximum rotational acceleration rates, limited by rib loading buckling, for the Wrap Rib antenna concept. Since the mesh between ribs does little to support the rib loading, the rotational rate is relatively insensitive to the number of ribs used in reflector construction and therefore to the design r.f. frequency.

Figure 42 illustrates maximum rotational acceleration rates, limited by boom loading bucking for the Polyconic antenna concept.

The maximum elastic distortion of either concept structures was calculated in the computational programs. The natural frequency in the rotational acceleration loaded mode was calculated. Figures 43 and 44 present the time required after acceleration loading and resultant structural deflection to degrade structural vibratory movement to a useful surface contour distortion. The useful surface contour distortion is measured in db gain down from peak gain producible from the geometric approximation of a perfect parabola surface.

R.F. operation may be turned back on, after illustrated time lags with no more than 5% extra added for mesh r.f. operation.

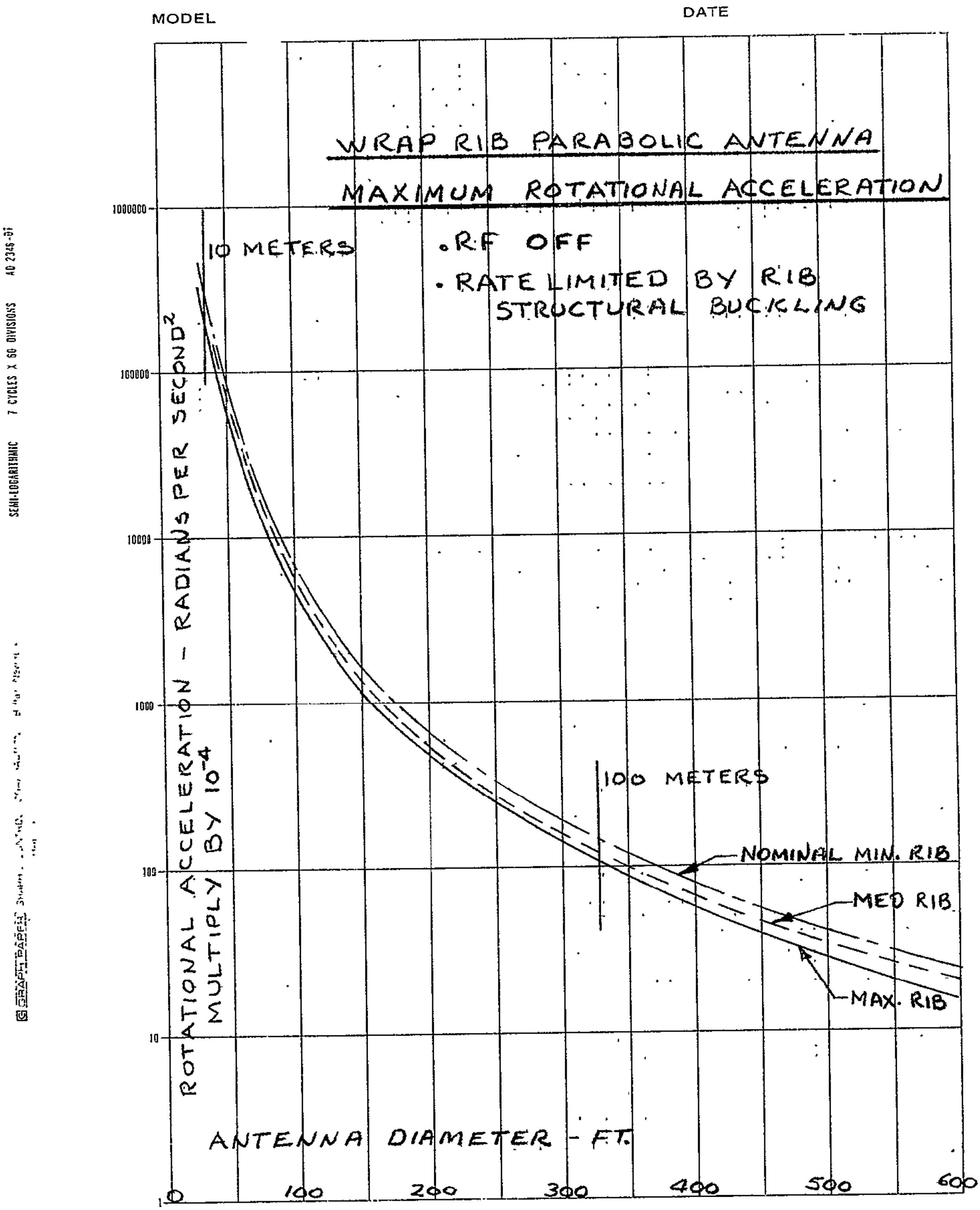

MODEL
DATE
WRAP RIB PARABOLIC ANTENNA
MAXIMUM ROTATIONAL ACCELERATION
• RF OFF
• RATE LIMITED BY RIB STRUCTURAL BUCKLING
10 METERS
100 METERS
NOMINAL MIN. RIB
MED RIB
MAX. RIB
ROTATIONAL ACCELERATION - RADIANS PER SECOND^2
MULTIPLY BY 10^{-4}
ANTENNA DIAMETER - FT.
1000000
100000
10000
1000
100
10
1
0
100
200
300
400
500
600

FIGURE 41.

MODEL DATE

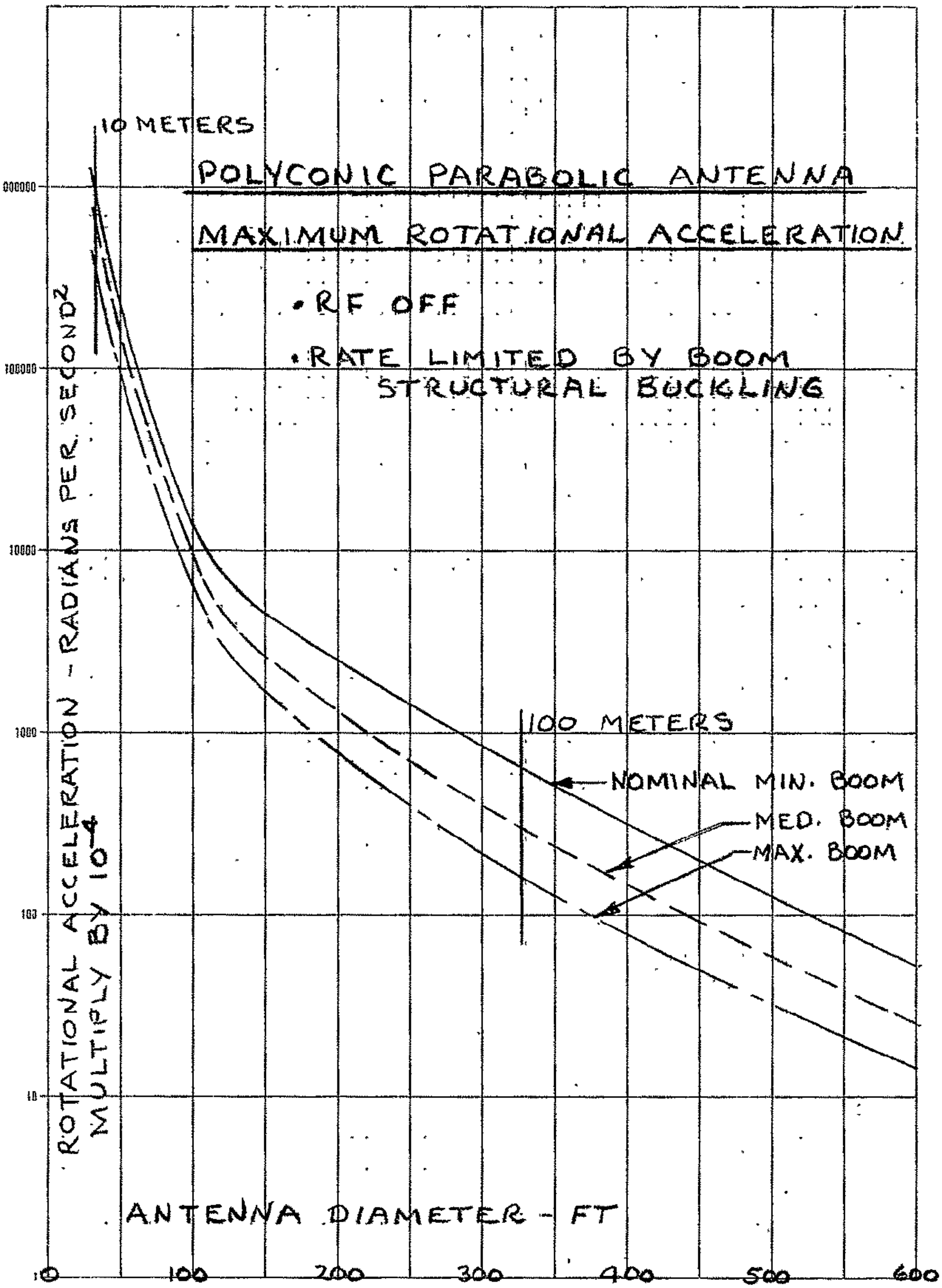


FIGURE 42.

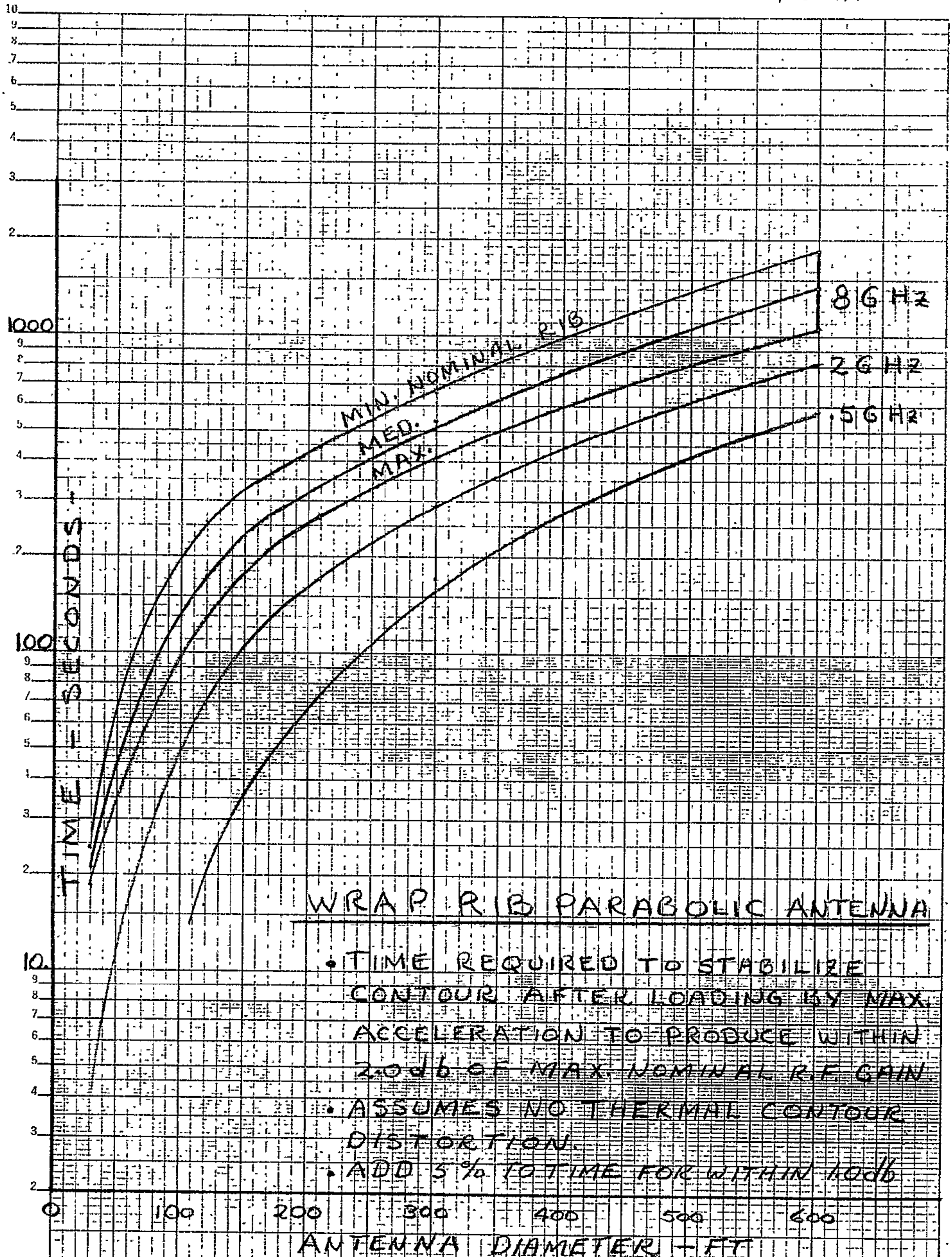
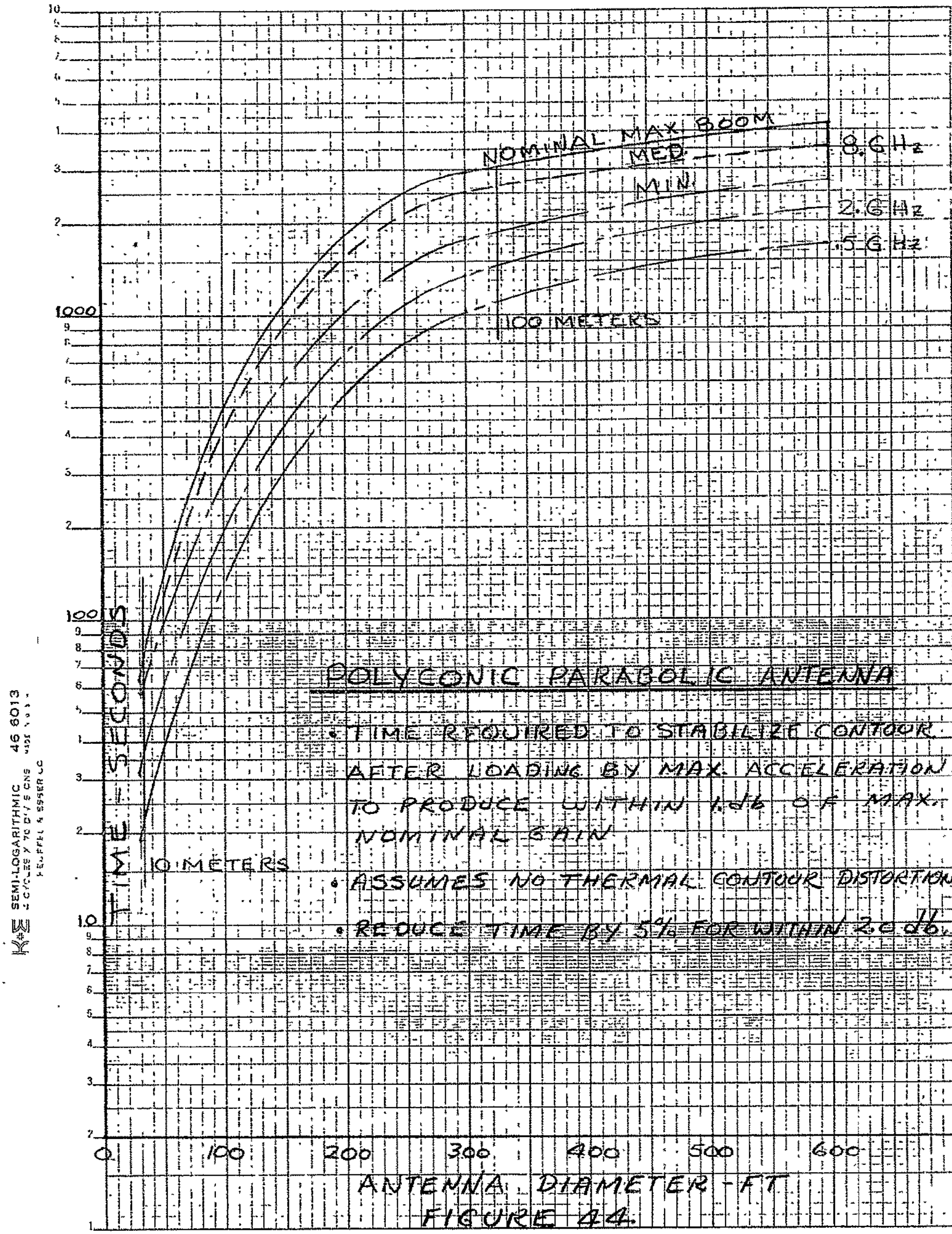

TIME - SECONDS
1000
100
10
1.
MIN. NOMINAL RIB
MED.
MAX.
8 GHz
2 GHz
.5 GHz
WRAP RIB PARABOLIC ANTENNA
• TIME REQUIRED TO STABILIZE CONTOUR AFTER LOADING BY MAX. ACCELERATION TO PRODUCE WITHIN 2.0 db OF MAX. NOMINAL R.F. GAIN
• ASSUMES NO THERMAL CONTOUR DISTORTION.
• ADD 5% TO TIME FOR WITHIN 1.0 db
0
100
200
300
400
500
600
ANTENNA DIAMETER - FT

FIGURE 43.



NOMINAL MAX BOOM
MED
MIN
8 GHz
2 GHz
.5 GHz
100 METERS
10 METERS
TIME SECONDS
1000
100
10
0
100
200
300
400
500
600
POLYCONIC PARABOLIC ANTENNA
• TIME REQUIRED TO STABILIZE CONTOUR AFTER LOADING BY MAX ACCELERATION TO PRODUCE WITHIN 1 db OF MAX. NOMINAL GAIN
• ASSUMES NO THERMAL CONTOUR DISTORTION
• REDUCE TIME BY 5% FOR WITHIN 2.0 db.
ANTENNA DIAMETER - FT
K&E SEMI-LOGARITHMIC 46 6013

FIGURE 44.

Item 15. Mechanical techniques used for furling and unfurling the antenna.

Wrap Rib Antenna Concept

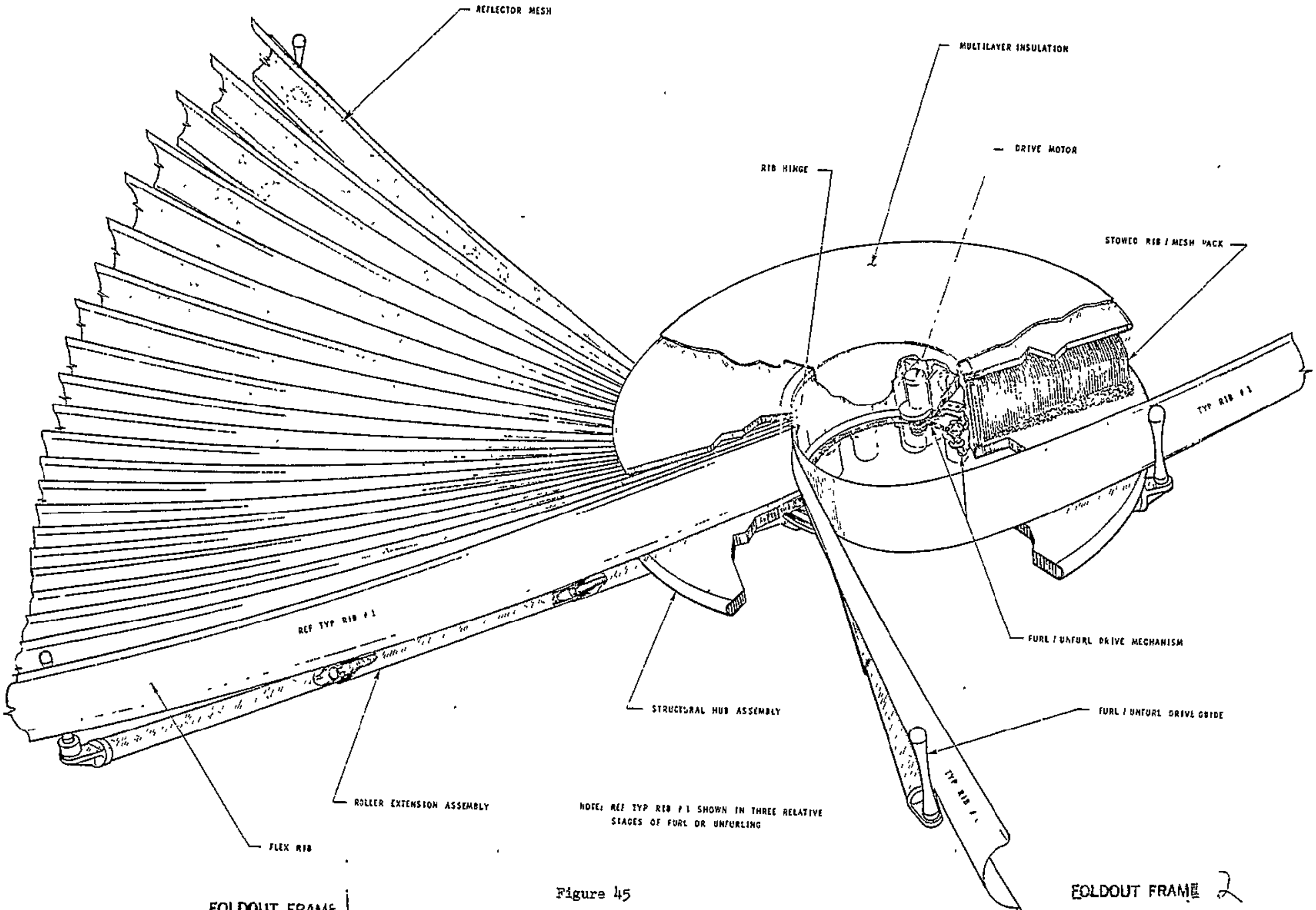
Figure 45 illustrates the furl/unfurl driving mechanism proposed for use on the very large diameter wrap rib reflectors that also use large numbers of ribs.

Figure 46 shows a cross section of the working mechanism including a legend of operating parts. The basic operating mode is as follows: The rib furl/unfurl drive guides, Item 9, are rotated by the driven ring gear, Item 3. They either wipe the hinged ribs into a stowed wrapped condition or restrain the stored energy in the stowed ribs into a controlled rate deployment. The rib design, Item 10, is either lenticular or semi-lenticular in cross section in order that the ribs may be flattened for wrapping around the hub with material elastic limits.

The extension arm, Item 8, may be a solid member when used on smaller reflector diameters where a relatively few ribs are used for geometric parabolic contour approximation. These guides, Item 8, must be extendible as illustrated when the system is used in conjunction with very large diameter reflectors using large numbers of ribs. The cross over point wherein the driven extension ability is required is likely to be approximately 150 feet in diameter with 80 to 90 or more ribs.

Polyconic Antenna Concept

Figure 47 shows a cross section of the Polyconic antenna concept shown on Figure 2. The legend attached to Figure 47 represents an operating description of the furl/unfurl mechanism. The booms or segments of booms, Items 7, 8 and 9, may be one piece provided the folded antenna does not exceed 60 feet in length. The polyconic surface mesh and its supporting circular mesh ribs that are attached to the supporting booms will fold and compact itself in between and around the folded booms in the stowed configuration.



FOLDOUT FRAME 1

Figure 45

WRAP RIB FURL/UNFURLING SYSTEM

FOLDOUT FRAME 2

WRAP-RIB FURL/UNFURLING SYSTEM

ITEMS
(1) Drive Motor Assy.
(2) Rotation Gear
(3) Rotation Ring Gear (Turn-Table)
(4) Planet Roller Extension Gear
(5) Station Ring Gear
(6) Vertical Bevel Gear Drive
(7) Horiz. Bevel Gear Drive
(8) Roller Extension Assy. (Extend Position)
(9) Furl/Unfurl Drive Guide
(10) Wrap-Rib
(11) Mesh
(12) Flex Rib Hinge
(13) Structural Hub Assy.
(14) Thermal Control Insulation
(15) Drive Motor Support Structure

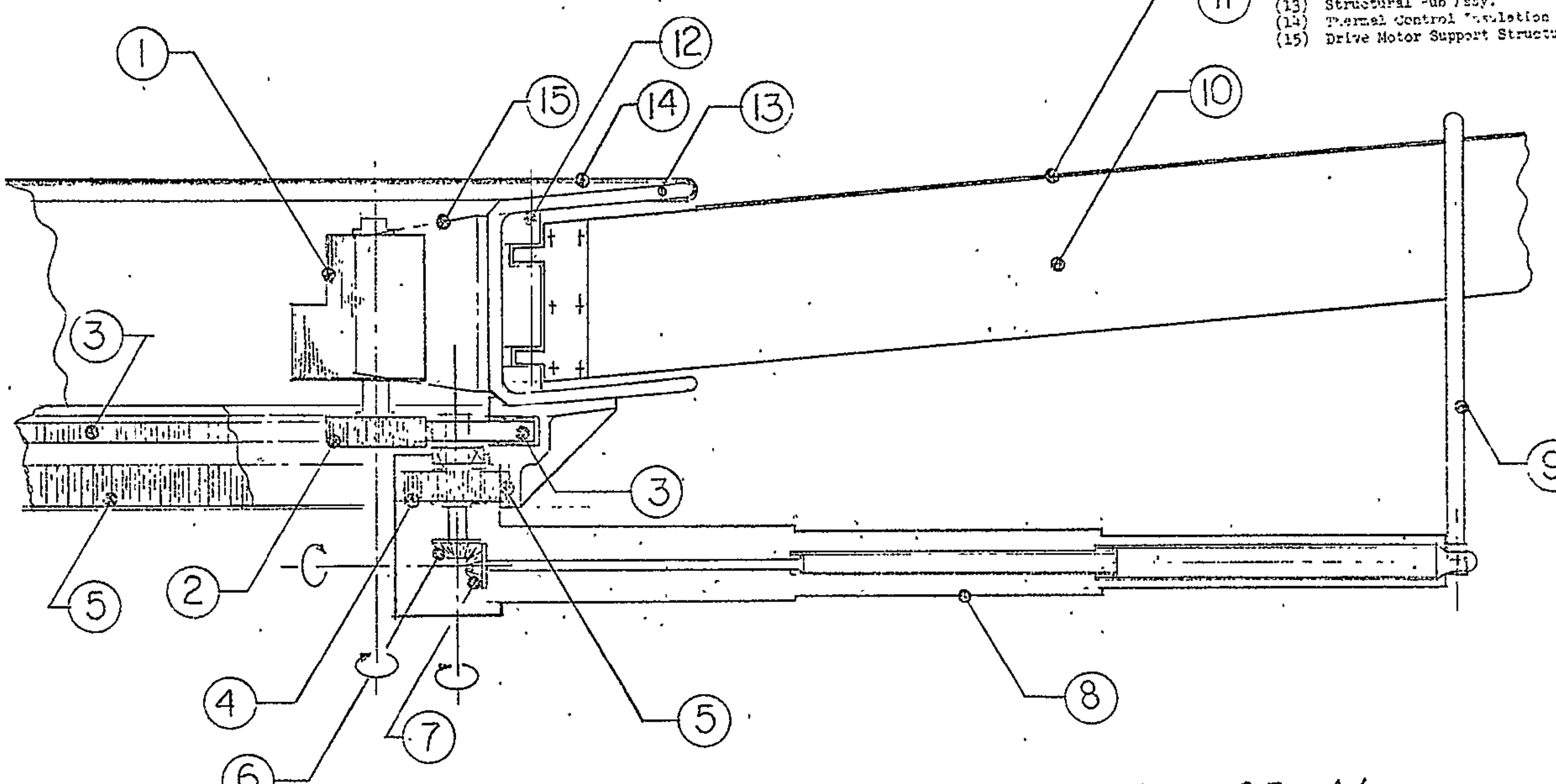
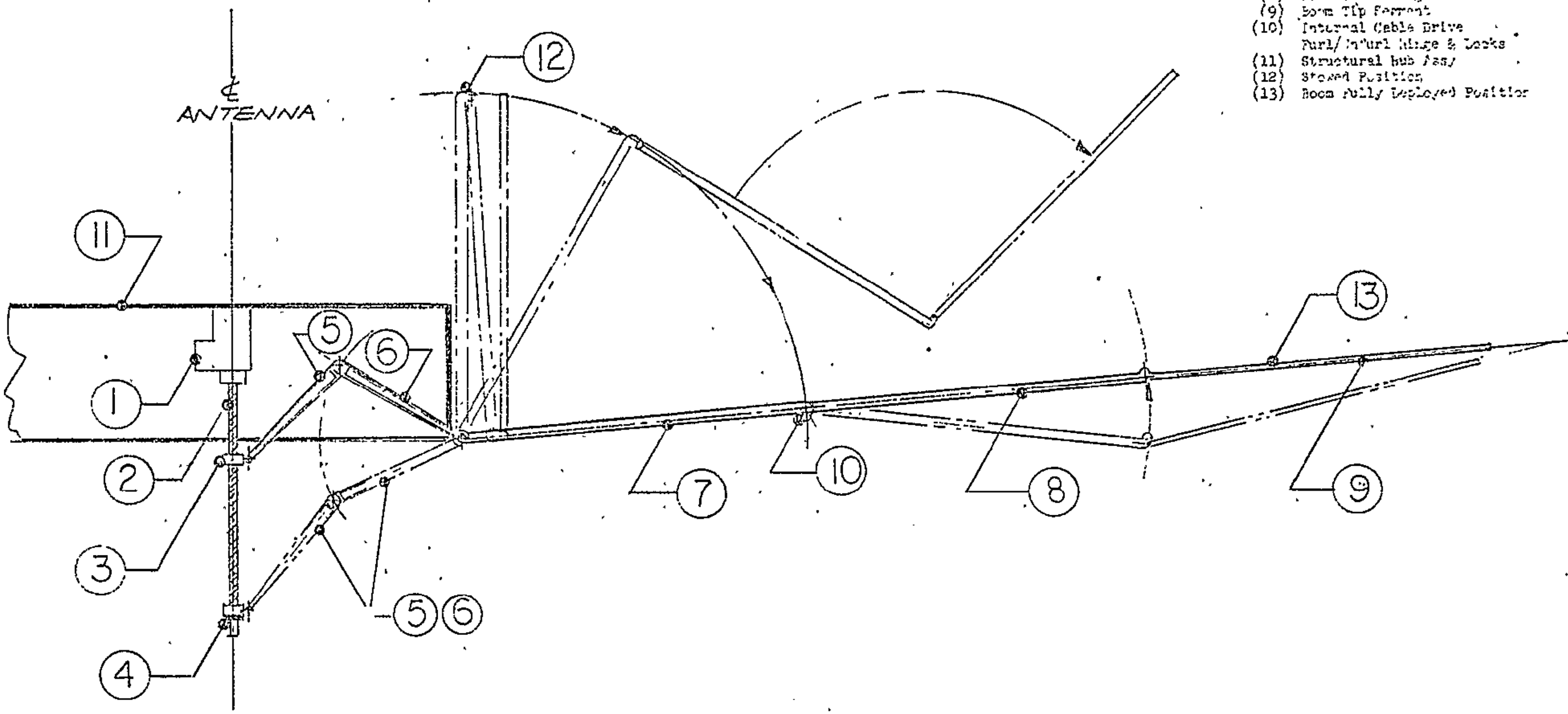


FIGURE 46

LMSC/D384797

ITEMS
(1) Drive Motor
(2) Screw Jack
(3) Moving Collar
(4) Stop
(5) Lever Arm Inner
(6) Lever Arm Outer
(7) Boom Root Segment
(8) Boom Center Segment
(9) Boom Tip Segment
(10) Internal Cable Drive Furl/Unfurl Hinge & Locks
(11) Structural Hub Assy
(12) Stowed Position
(13) Boom Fully Deployed Position



POLYCONIC BOOM FOLDING AND TILT SYSTEM
FIGURE 47.

Item 16. Mechanical and electrical interfaces of the antenna concepts.

Mechanical interfaces of the antenna concepts may be restricted to two structural points. The first is antenna hub support, the antenna support point structure that attaches directly to either the spacecraft body, an extension boom or a gimbal mechanism attached to either boom or spacecraft body. The second is the feed support structure or a Cassegrain reflector support structure which may be tied directly to the central hub structure of either wrap rib or polyconic concepts. Each of these concepts has a structurally sound hub framework as illustrated by Figures 1, 2, 46 and 47. Detail design of mechanical interface support point structure has not been attempted within the scope of this study.

The electrical interfaces of the antenna concepts may be divided into two classes. Electrical power line interfaces used to motivate such electrical devices as drive motors, locks and indicator instrumentation, etc. Electrical power used to drive gimbal servo mechanisms and contour evaluation systems. These electrical power interfaces may be any standard pin type disconnects that are space qualified. The second class of electrical interface relates to transfer of microwave power from transponder outlet/input to the antenna feeds. Dependent upon length of lines and rf frequency used, these transfer lines may be waveguide or coaxial cable. The antenna system interface to the spacecraft receiver/transmitter housing may be relatively simple, aligned bolt-together choke joints as waveguide interfaces or standard disconnect coaxial cable joints. However, the necessary mechanical movement imposed on either waveguide or coaxial cable from gimbal action or feed boom extensions may and probably will require either considerable flexural movement or rotary joint movement at some point within the rf line connections.

The design problems that large angular or universal joint movement impose on the rf connections will be of greater importance to reduce resultant gain loss than the actual spacecrafts antenna system interface joints. Design details of these potential problems are closely aligned to the antenna concept chosen and its operational specifications.

Item 17. Potential applications of subject antenna concepts.

A wrap rib reflector antenna, 30 feet in diameter, was built by LMSC under subcontract to Fairchild Industries for the NASA-Goddard sponsored ATS-6 communications satellite. This reflector differed from Figure 1 pictured concept in that it used the release of the stored energy in the wrapped ribs for deployment operation. It did not have a mechanized furling and unfurling system incorporated in the design. The ATS spacecraft vehicle, with solar arrays in deployed condition, was designed to withstand the loads imparted by the deploying antenna at 2800 foot pounds of torque. In addition to the subsequent mechanized furl/unfurl system, LMSC has developed multi layer insulation systems for use on the wrap ribs. This insulation reduces the rib distorting transverse thermal gradient by up to a factor of 10. Further design work is proceeding wherein the development of ribs made from materials that hold the transverse thermal gradient to a low value is used but in addition the material properties will have a greatly reduced thermal coefficient of expansion. Thermally induced rib deflections which cause surface distortion and consequent loss in rf gain are a function of

$$\text{deflection} = f\,(\Delta T \alpha L^2) \text{ where}$$

ΔT = transverse thermal gradient

α = thermal coefficient of expansion

L = length of rib

It can readily be seen that as the diameters of the reflector antenna systems go up, the importance of improvement of the construction material thermal properties (Δ T and α) become greater. This statement holds true for any reflector concept that uses structural materials for surface mesh support. Designs of the wrap rib concept have been developed in some detail up to well over double the diameter of the ATS reflector. Performance analysis for these designs have been carried out.

The Polyconic antenna concept has been built as a mechanical demonstration model only.

When considering the objective of this parametric study, i.e., to produce sufficient data to determine an antenna reflector concept that may be built to very large diameters, maintain useful surface contour, be weight competitive by being deployable only in a zero gravity environment, and as a consequence be surface contour adjustable to surface design rms requirements after deployment in space, the number of contour adjustment mechanisms becomes important. Graded under this ground rule it becomes apparent that the fewer required contour adjustment mechanisms required by the antenna reflector concept, the more feasible, reliable, less costly and lower weight the system will become.

Item 18. <u>Unique features of the antennas under consideration</u>.

The unique features of each antenna concept are as listed.

<u>Wrap-rib antenna concept</u>

- Uses a given number of pie shaped segments of parabolic cylindrical surfaces to approximate the perfect parabola.
- May be stowed in a circular shaped package that is between 1/10th and 1/30th the deployed diameter. The stowed package of the reflector will normally not exceed 2 feet.

- At 8 GHz frequency use and up to 600 feet in deployed diameter, the maximum number of contour adjusting servo mechanisms necessary for contour adjustment in space zero gravity environment is 224. This number adjusts to a lower value only as reflector diameter and rf use frequency is reduced.

Polyconic antenna concept

- Uses a given number of circular cone segments to approximate the perfect parabola.
- Uses catenary supported mesh ribs to hold the rf reflective surface mesh in place above structural booms or ribs.
- Allows use of non-wrappable booms or ribs at the expense of much greater stowage volume than the wrap rib concept.

Maypole antenna concept

- Uses two compression resistant structural members only, the center column and the outer rim.
- Uses light weight mesh ribs to create the contoured surface approximation of the perfect parabola.
- Since the major construction material is light weight mesh, feasible reflector diameters given relatively thermally stable materials are very large. Estimates show that an 11,000 feet in diameter reflector usable to 2 GHz may be made within the weight lift limits of one Space Shuttle cargo compartment at 65,000 pounds.

Item 19. Largest practical reflector diameters of antenna concepts.

Wrap Rib antenna concept.

Figures 11, 12 and 13 show net gain achievable using the Wrap Rib reflector concept under three sets of construction material properties. The largest diameter practical is very much dependent upon the maximum rf frequency use.

1) Present day state-of-the-art materials, such as multi layer insulated aluminum ribs and silicone coated knit Copper/Beryllium/Silver metal mesh is practical without severe gain loss up to 600 feet in diameter when used at frequencies no higher than 500 MHz. Figure 11 shows that this diameter reduces to 120 to 150 feet in diameter when used at 8 GHz rf frequency.

2) Figure 12 indicates useful rf performance of Wrap Rib reflectors near 250 feet in diameter at 2 GHz and quite useful rf performance at 150 feet in diameter at 8 GHz when the present state-of-the-art metal mesh is replaced with an improved material property mesh with a lower coefficient of thermal expansion. Non-symmetrical thermal exposure rf performance has not radically improved. Thermal distortions of ribs still predominate over mesh induced loads. Insulated aluminum ribs are used.

3) Figure 13 shows good rf performance at up to 8 GHz when the rib construction methods have been improved to the point where the multiple $\Delta T \alpha$ is considerably lower than that available with insulated aluminum ribs. State-of-the-art improvements that may be accomplished within a 2 to 3 year period will make this rf performance feasible and therefore

reflectors between 400 and 500 feet in diameter usefully feasible at 8 GHz rf frequency.

Polyconic antenna concept.

Figures 11A and 13A illustrate the same type of rf frequency use, reflector diameter, and construction materials used interrelationship shown for the Wrap Rib concept.

Since the booms do not wrap to a small furled package in this concept, present state-of-the-art materials may be used for boom construction. The feasible diameter reflectors used at 8 GHz are dependent upon improvements in the state-of-the-art of mesh construction materials. In general, feasible diameters with useful rf performance are the same as in the Wrap Rib concept, but at the penalty of considerable increase in weight, furled packaging dimensions and number of servo mechanisms necessary for contour adjustment after deployment in space.

Maypole antenna concept.

Section 20 of this report will go into considerable more detail in the reasons why this concept, with development, is considered feasible up to very large diameters. The necessary improvements in the state-of-the-art of construction materials must be accomplished first. Rim or hoop and center column materials must be improved to reduce thermal coefficient of expansion properties while not radically increasing thermal conductivity. Mesh with low thermal coefficient of expansion and low modulus of elasticity must be available. These materials could be produced within a 2 to 5 year well organized development program at a relatively low cost.

If such is the case, useful maypole concepts may be extrapolated as a practical design up to 3000 feet in diameter at 8 GHz, and 11,000 feet in diameter at 2 GHz.

Item 20. Maypole Antenna Concept

Figure 3 illustrates a 300 foot diameter Maypole Antenna. Figure 4 illustrates a 3100 foot diameter Maypole Antenna. Generalized construction description has been given in Item 6.

LMSC is in the process of evaluating this antenna concept by an "in-house" effort. As further information is developed with regard to weight versus rf frequency, gain, cost and thermal stability, it will be made available to JPL.