Interoffice

National Radio Astronomy Observatory

Charlottesville, Virginia

May 26, 1981

To: Bill Horn

12 METER MILLIMETER WAVE TELESCOPE
MEMO No. 39

From: W-Y. Wong

Subject: A competing proposal for one 12-m reflector structure

Enclosed please find a proposal for the 12-m reflector design. I trust by the 29th of this month (last date for the concept design, see H. Hvatum's memo no. 34), you will have all three proposals - Horn's, King's and Wong's - in front of you to review. I hope you will exercise your most unbiased judgement and select a good one.

INTRODUCTION

To build a larger, deeper and better telescope without weight increase is a non-trivial engineering problem. Also, the 12-m replacement must provide enough tie-down points to fit a given geometry of surface panels. The structure itself must fit into the existing yoke. It should be so designed that it can be taken apart into modules of manageable size and weight for shipment, and can be assembled without the need for field weldings. The proposed design, shown in Figures 1(a) and 1(b), fulfills all these requirements.

This antenna design calls for the replacement of the entire existing elevation structure. The removal of the existing structure entails the loosening and disconnection of 20 bolts and one elevation bearing. The installation of the new structure requires a reversal of the process. This approach will shorten the telescope's down time.

This design has a strong central hub, supporting the cross-beams and the reflector on one end, the counterweight and the auxilliary elevation wheel on the other. Four receiver mounting spaces are available on the outside wall of the hub. The alignment of the receivers is 90° to the telescope's optical axis (J. Payne: 12-m memo 19, 4/16/81). This externally-mounted concept provides a very direct reach to the receivers. It is a departure from the conventional frontal vertex-mounted concept, which requires a considerable amount of walking over the surface.

A rigid reference floor of 1.4 m in diameter behind the vertex is available for the path length modulator mount during normal operation, and for the measuring jig support during the measurement/setting period. A circular track will also be available along the outer rim of the backup structure for reference targets (J. Findlay: 12-m memo 36, 5/14/81).

As for telescope performance, it can be summarized as follows:

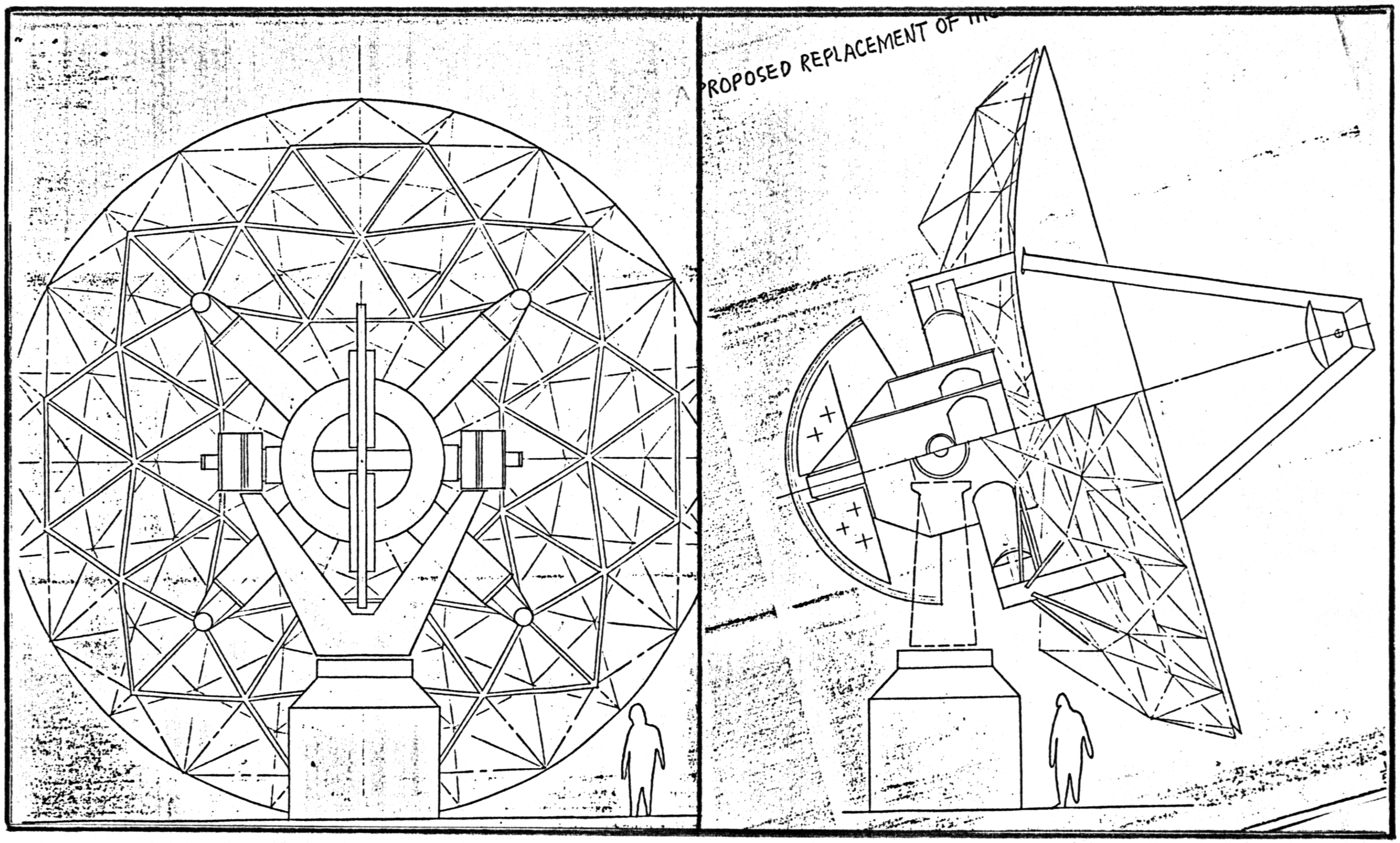
a) Gravity effects: 1σ error from the backup structure alone is estimated to be 0.025 mm rms, with a peak value of 0.031 mm.

b) Change of ambient temperature would cause the surface degradation of 0.015 mm at the worst situation, around noon time when the rate is estimated to be 5° C/hr., the 1σ value is about 0.009 mm rms.

c) A temperature gradient across the telescope structure would degrade the surface by the amount of 0.020 mm peak, 0.012 mm rms.

d) Thermal pointing caused by the reflector structure alone is estimated to be 2.7 arc-sec peak, 1.6 arc-sec rms.

e) Estimated fundamental frequency of the structure is 11 Hz, and the vibration mode is rocking about the elevation axis.



(a) (b)

Fig. 1 Two views of the proposed 12-m reflector: (a) view from the rear, and (b) view from the side. The compactness of this design, i.e., keeping the reflector structure close to the elevation shaft, enables a smaller counterweight and maintains a constant total weight.

THE BASIC DESIGN CONCEPT

The problem facing this new 12-m design is clearly stated in the previous section. The smaller f/D ratio produces a deeper structure, causing a shift of the center of gravity further away from the elevation axis (the shortening of the feed leg structure compensates some). Hence the emphasis of the structural design is not on achieving a true homologous solution, but on keeping the counter balance small.

The solution is to use a combination of a space frame and a cantilever cross-beams system. The space frame forms the reflector part, while the cross-beams provide the supports. Since the deepest section of the frame is at r = 0.5·R, R being the radius of the telescope, the profile is lower by an amount of D (see Figure 2) compared with a cantilever system with the deepest section at r = 0.

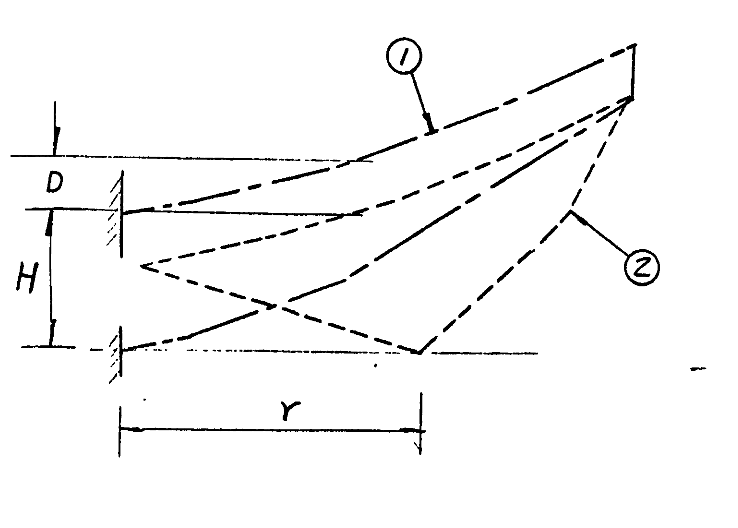


Fig. 2 Two cantilever structures with the same depth H: (1) E-system concept, with the deepest section at the supporting end, and (2) NRAO concept, with the deepest section at the middle. Profile of (1) is higher than (2) by the amount of D. The center of gravity of (2) is lower.

The space frame is a design (W. Wong: A 25-m Radio Telescope Design for the VLB Array Project; 7/7/80) providing a large number of points on the surface, and requires 4 supporting points on the back. It consists of a relatively small number of members, with two different sizes.

The 4 cantilever cross-beams are 90° apart, clear entirely the existing elevation bearings, motors and encoder packages on the top of the yoke. This means one can locate the 4 beams as close as possible to the elevation axis, limited only by the physical contact between the two lower beams and the yoke arm as the telescope tilts to its lowest elevation position. Due to the symmetry of the design, the stiffness of these 4 beams is equal.

This concept also provides an uncloistered space around the hub area, rendering it possible to install receivers on the wall of the central hub.

SURFACE PANELS

Figure 3 illustrates the surface panels used for the new reflector. The geometry of the panels is based on the best information available, but certainly will be subjected to some adjustment once the information is verified with ESSCO. The thin tick marks in (a) denote the location of the adjustment screws, with the corresponding radius in inches given in (b). The cut-off surface forms a 12-m diameter reflector, and with the original focal length of 5.08 m, the new surface has a f/D = 0.42.

There are 48 outer panels, and 24 inner panels. Each outer panel has 6 adjustment screws, and each inner panel has 7 adjustment screws, and a total of 456 screws.

The outer panel measures approximately 94 inches, with one end measuring 31" wide and the other end 20" wide.

The inner panel measures approximately 134 inches, with one end measuring 40" wide, and the other end 6" wide.

The total surface area is estimated to be 1,307.5 square feet. The total weight is estimated to be 2,900 lbs.

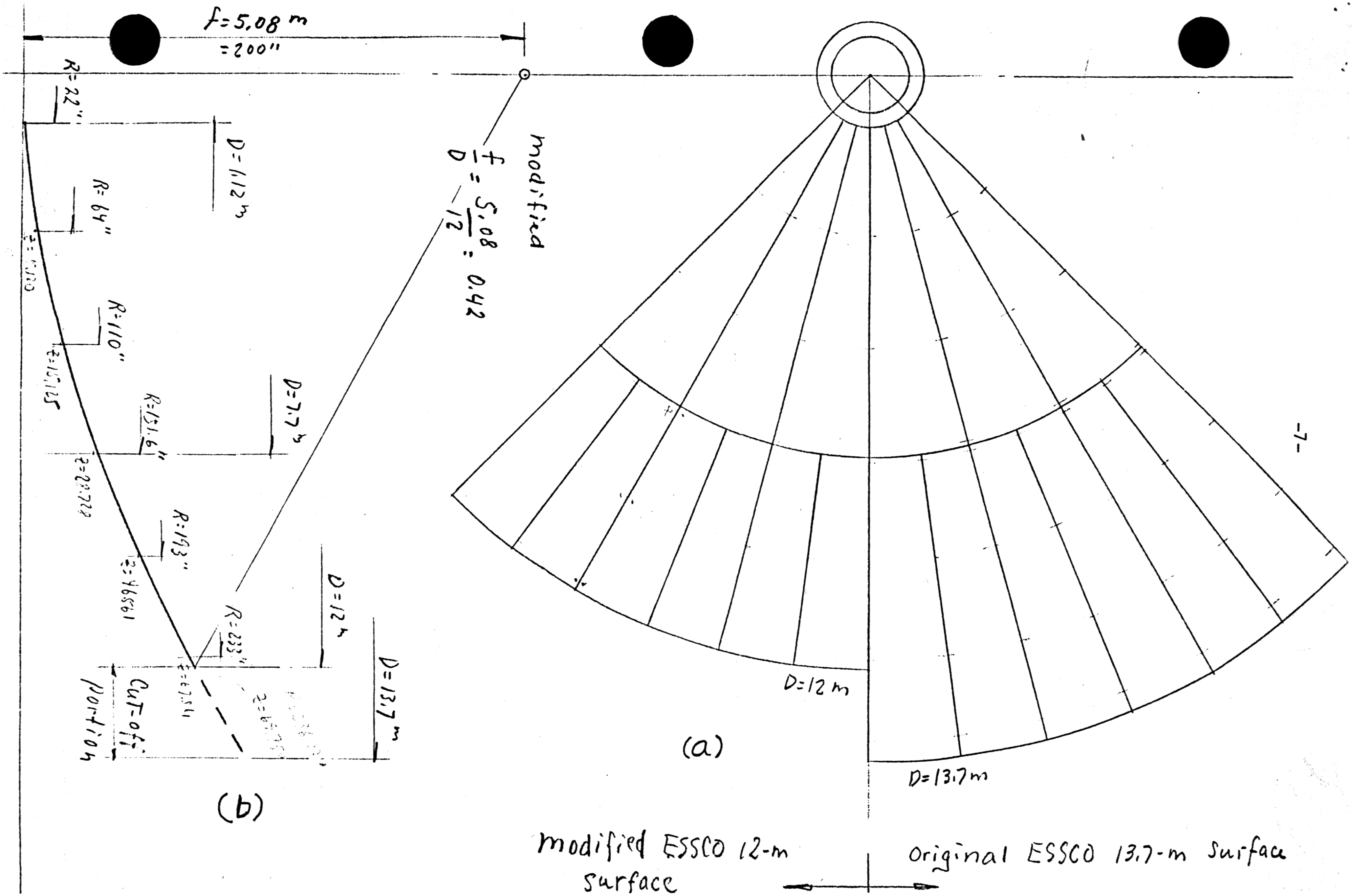


Fig. 3 ESSCO's 13.7-m surface panel arrangement and its modification to a 12-m surface. (a) Top view showing a 22.5° section of the original 13.7-m and a section for its modified outer panels. The faint tick marks denote the locations of adjustment screws. (b) A radii of the parabolic section showing the locations of adjustment screws. All dimensions are to be verified with ESSCO.

THE CONSTRUCTION, ASSEMBLY AND DISASSEMBLY OF THE REFLECTOR

Considering that most of the construction will take place in Green Bank, plus the subsequent test assembly, measurements, disassembly, and shipment, the reflector should be built by modules. Figure 4 illustrates the assembled end-product of the structure. And figures 5 and 6 depict the bird's eye view of the modules laid out on the ground unassembled (with some miscellaneous items not shown).

A list of the modules and their relevant information are given as follows:

Subpart	Module Name	No. Needed	App. Size	Wt./Module	Total Wt.
Reflector	Type A	4	19'x 9'x4'	788 lbs.	3152 lbs.
	Type B	4	20'x11'x5'	1132 lbs.	4527 lbs.
	Type C	4	11'x 7'x4'	269 lbs.	1075 lbs.
	Misc. Connection	16	7'x 5'x½'	84 lbs.	1346 lbs.
Interface	Feed leg apex	1	6'x 6'x3'	300 lbs.	300 lbs.
	Support leg	4	20'x 2'x1'	208 lbs.	832 lbs.
	Elbow	4	9'x 7'x4'	1054 lbs.	4216 lbs.
	Hub	1	12'x12'x6'	4350 lbs.	4350 lbs.
	Hub ext.	1	5'x 5'x4'	434 lbs.	434 lbs.
	Aux. elev. whl.	2	11'x 5'x½'	470 lbs.	945 lbs.
				GRAND TOTAL	21,177 lbs.

Due to the large equipment required for the manufacture of the hub and its extension, it is suggested that these items be done by an outside contractor.

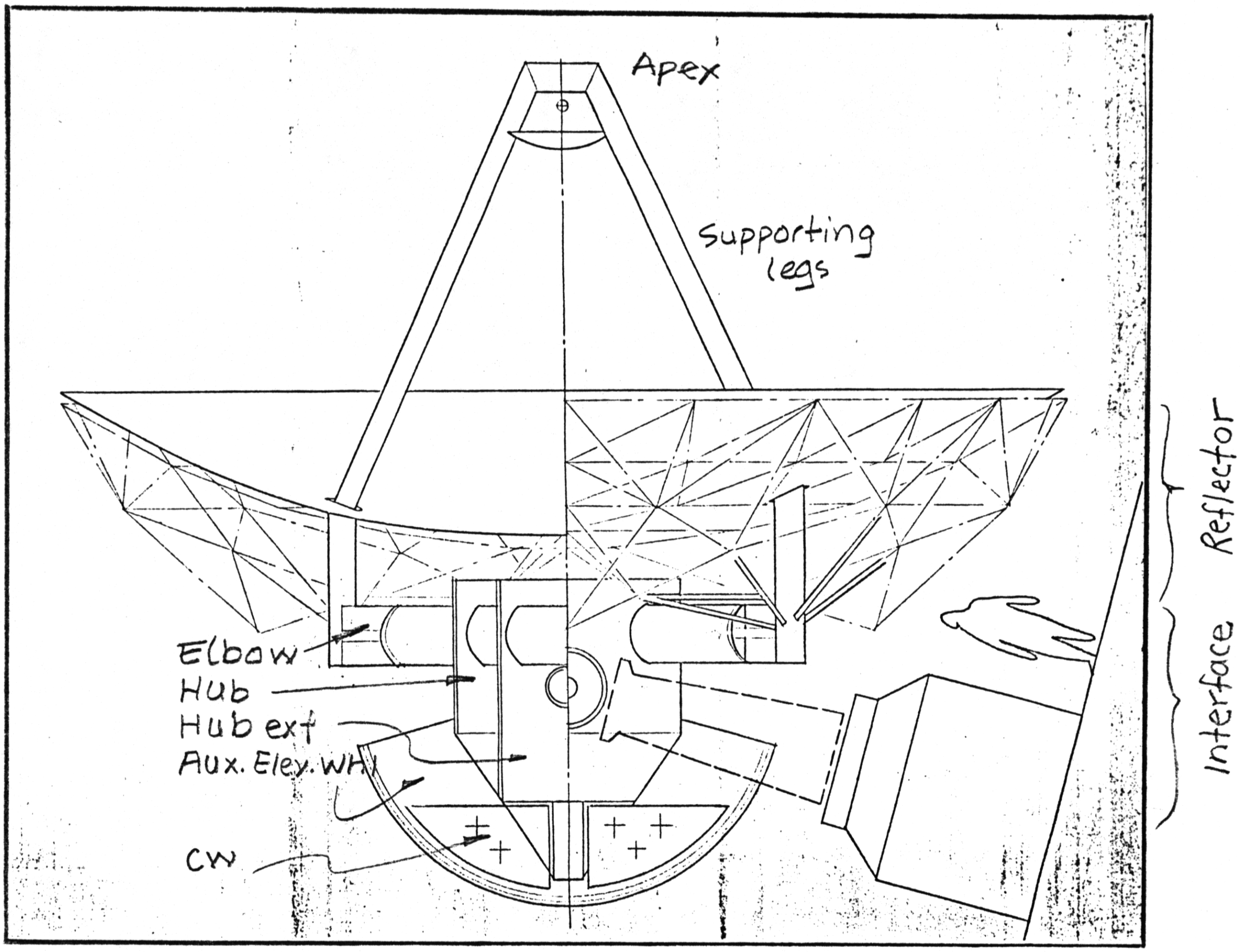


Fig. 4 Assembly of the 12-m reflector consists of numerous structural modules. All modules are bolted together. The reflector part consists of three typical modules of 4 each, plus some miscellaneous connections. The interface part consists of the quadripod, 4 elbows, 1 hub, 1 hub ext., and 2 auxilliary elevation wheel sections. The hub and its ext. are to be done by an outside contractor.

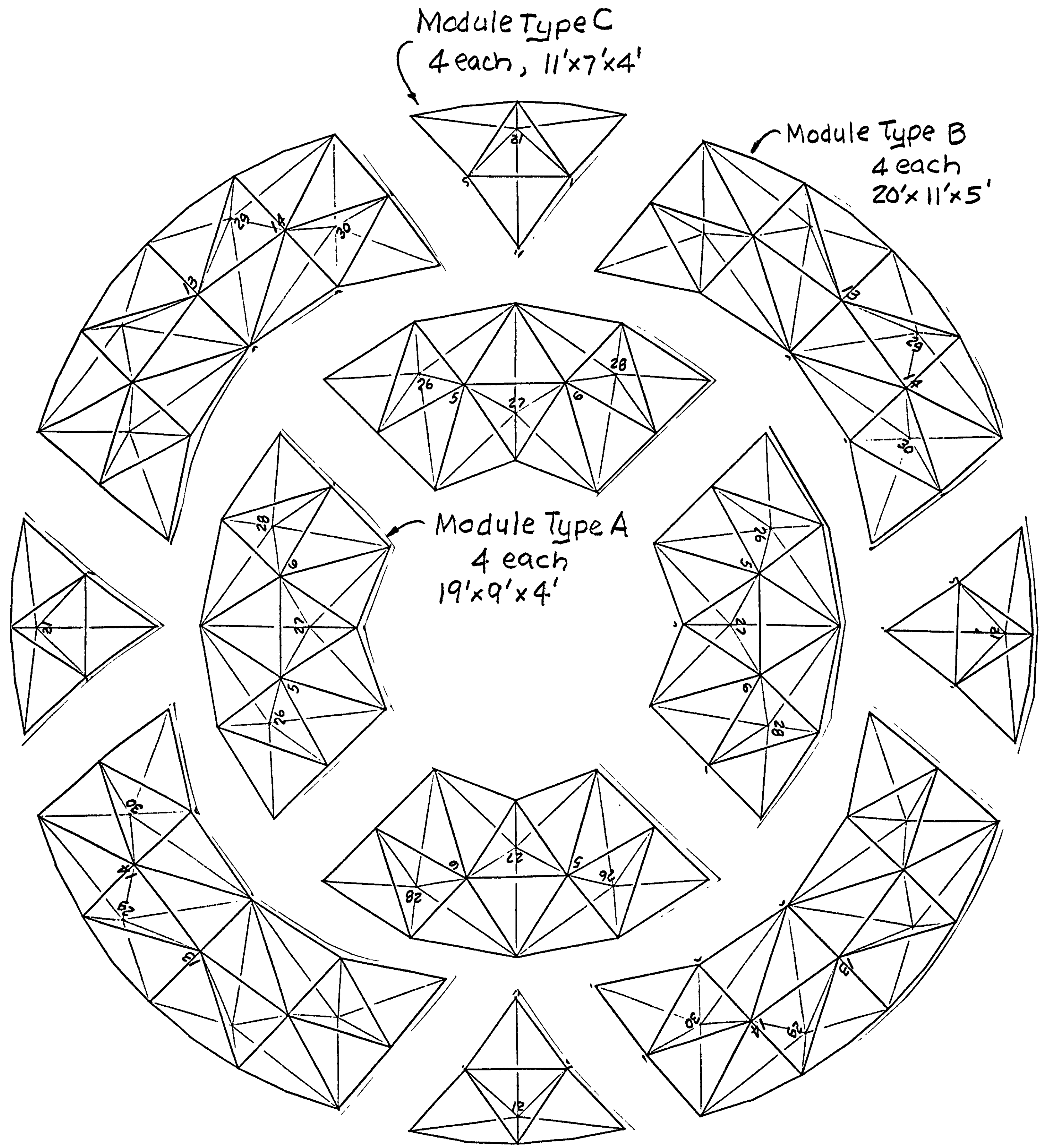
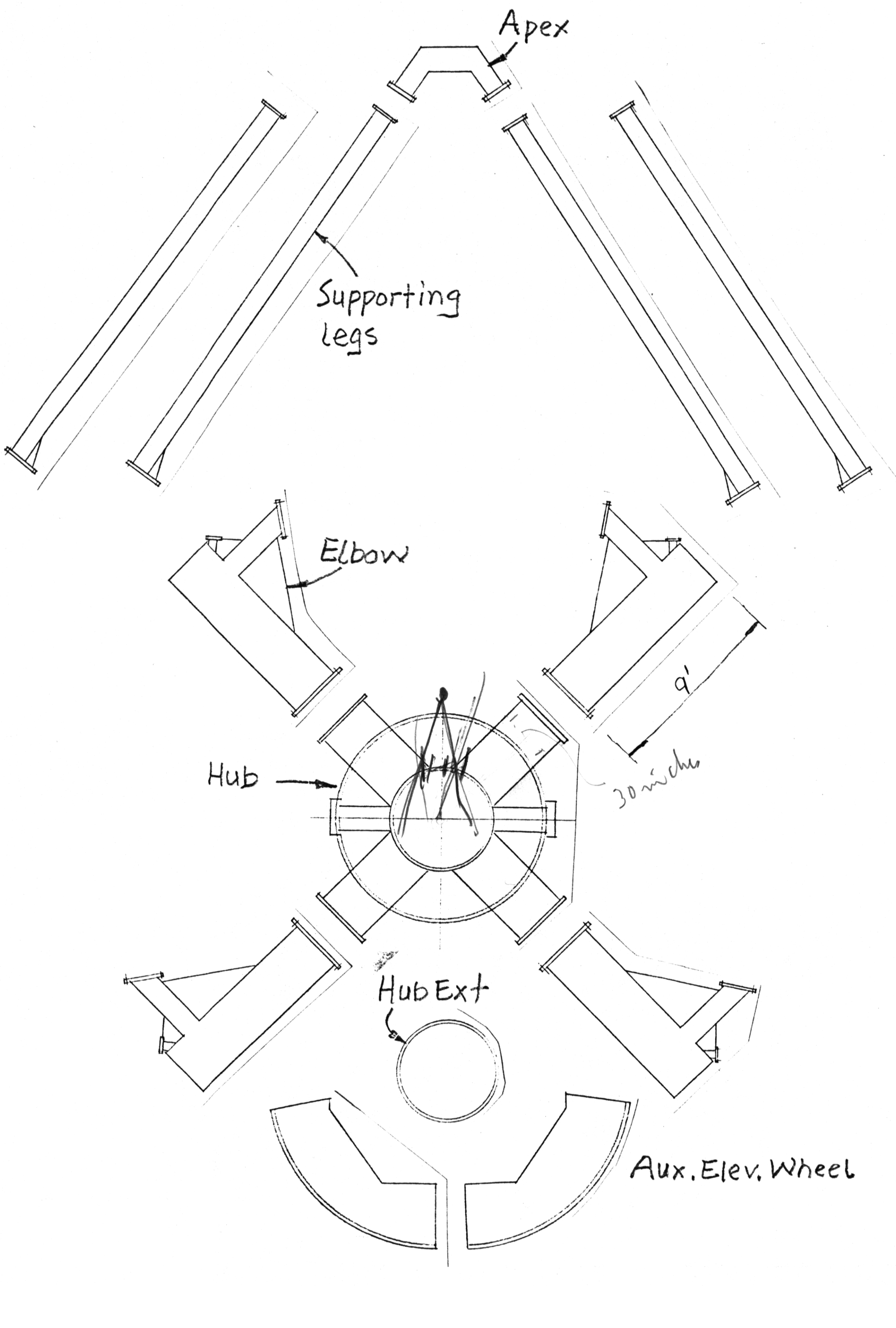


Fig. 5 A bird's eye view of the reflector modules laid on the ground before assembly. Three major types of modules are needed. The largest module (Type B) measures 20'x11'x5' and weighs 1132 lbs. By placing it in tilt position, two modules can fit into a truck.

Fig. 6 A bird's eye view of the interface parts laid on the ground before assembly.



WEIGHT AND INERTIA

The existing reflector, including all moving parts in elevation, has the following data:

Structure wt. (incl. the surface, the back-up structure and the feed supports)		= 20,200 lbs.
Counter balance wt.		= 23,720 lbs.
	TOTAL	= 43,920 lbs.
Moment of inertia about the elevation axis		= 44,000 slug-ft. sq.

The new reflector has the following data:

Surface plates		= 2,900 lbs.
Reflector & interface structure		= 21,177 lbs.
Counter balance wt.		= 20,000 lbs.
	TOTAL	= 44,077 lbs.
Estimated moment of inertia		= 45,045 slug-ft. sq.

The new structure is overweight by < 1%, the moment of inertia is larger by 2%.

THE SURFACE ERROR

Gravitational Distortion

Based on the surface error budget discussion at meeting no. 2 on 4/14/81, the gravity effect is to be less than 30 microns. The two-step analysis, with the structure in zenith position (g = -x) and horizontal position (g = -y) showed the following results:

position	surface error
g = -Z	30 microns
g = -y	64 microns

Calibration

Based on the above analytical results, together with selecting a surface panel adjustment position, the surface error caused by gravity effects at any given telescope position can be resolved. The following list illustrates the surface error at various zenith angles after the surface is adjusted to a "perfect" paraboloid at 40°.

zenith angle (deg.)	gravity effects (microns)
10	31
20	20
30	10
40	0
50	9
60	16
70	23
80	28
rms	25

Note that with the range from 10° to 80° zenith positions, the mean error caused by gravity effects is 25 micron rms, and the peak value at 10° is 31 microns.

<u>Surface Error Caused by a Change of Ambient Air Temperature</u>

Based on the 25-m studies, the thermal time constant of steel pipe painted white is $\tau = 68.9 \times 10^{-3}\ {}^{hr}/mm$. Together with the given wall thickness on each member, the analytical results show that this structure's surface degrades by the following amount:

Error due to ambient temp. change = 3 micron/C°/hr.

On a typical day, the steepest temperature change around noon time is about 5°C/hr. Hence the error due to $\dot{T}$ effect is:

$\dot{T}$ effect: 15 microns peak; 9 microns rms

<u>Surface Error Caused by an Idealized Gradient Across the Structure</u>

The surface errors caused by this idealized thermal gradient of 1°C across the structure are:

Surface error due to ΔT effect in ~~x~~ z direction = 8 microns/°C
Surface error due to ΔT effect in y direction = 0 microns/°C
Average ΔT effect = 4 microns/°C

The gradient measured on various telescopes showed a peak value of 5°C. Hence the error due to ΔT effects on a typical day is

ΔT effect: 20 microns peak; 12 microns rms

THERMAL POINTING

A temperature difference across the telescope structure also causes a slight rotation of the best fit paraboloid. This rotation is a combination of various mechanical deflections, together with the optical characteristics of the telescope. From the analyses, the beam tilt due to 1°C across the structure is computed and described as follows:

$\theta\ (\Delta m)$ = Beam tilt due to the lateral motion of the main reflector
$= +2.8 \times 10^{-6}$ rad

$\theta\ (\alpha m)$ = Beam tilt due to the rotation of the main reflector
$= -1.0 \times 10^{-6}$ rad

$\theta\ (\Delta s)$ = Beam tilt due to the lateral motion of the subreflector
$= -4.0 \times 10^{-6}$ rad

$\theta\ (\alpha s)$ = Beam tilt due to the rotation of the subreflector
$= -0.4 \times 10^{-6}$ rad

$\theta\ (\Delta P)$ = Beam tilt due to the lateral motion of the phase center
$= 0$

The combined beam tilt due to 1°C temperature difference is the sum of these contributions, or:

$$\theta = -2.6 \times 10^{-6}\ \text{rad/C}^\circ = -0.54\ \text{sec/C}^\circ$$

The mean temperature difference on a typical day is 2.9° C, and the peak value is 5.0° C. The corresponding thermal pointing is estimated to be:

Thermal pointing < 2.7 sec peak / 1.6 sec avg.