STUDY OF ADVANCED SUNFLOWER PRECISION DEPLOYABLE ANTENNA

FINAL REPORT

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REPORT NO. MEL-79-B-126

JPL CONTRACT NO. 955340

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ONE SPACE PARK · REDONDO BEACH · CALIFORNIA 90278

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ABSTRACT

TRW has been contracted by JPL to conduct a study of the solid deployable antenna reflector which has been developed at TRW. The maximum deployed diameter stowable in shuttle has been determined for the original concept and for new more efficient concepts developed as part of this study. Estimates of weight, surface accuracy and cost have been made for the various configurations. Five critical technologies have been identified which would be required to manufacture large solid deployable reflectors. These technologies are concerned with surface accuracy improvement and verification.

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1.0 INTRODUCTION

This report is a summary of the results of a study performed at TRW to determine the feasibility of stowing large solid antenna reflectors in the shuttle using the Advanced Sunflower Concept developed at TRW. This work was sponsored by JPL as part of its study of precision self-deployable antenna systems, which in turn is part of the NASA Large Space Systems Technology (LSST) program.

The deployment concept was originally developed at TRW to meet the new requirement for large diameter, high accuracy reflectors to be used in the 6 to 100 GHz range or higher, within the size limitations of the launch vehicle.

The contract outlined two major tasks. The first was to conduct an investigation of the original deployment concept, including the following:

(1) Determine the largest antenna of this design stowable in the shuttle payload compartment.
(2) Determine the upper boundary for surface quality versus antenna diameter.
(3) Determine packing efficiency and weight versus diameter.
(4) Develop ROM cost estimate versus diameter and surface quality.
(5) Perform the above tasks for offset fed antennae.
(6) Identify critical technologies required for construction of these antennae.

The second task involved the development of advanced designs which would allow antennae up to 100 feet in diameter to be accommodated by the shuttle. The same information as in the first task was to be obtained for the most promising of these designs. The original concept of a 6 Main Panel, 33.2 foot reflector deployed on shuttle, is illustrated in Figure 1. An 80 foot reflector of the preferred advanced design is shown in Figure 2.

To satisfy these requirements, the following studies have been performed. The original design was optimized to achieve the most efficient packaging. Estimates were made of antenna weight and surface accuracy. Critical technologies were identified which would be required to manufacture large antennae. These estimates and technologies apply to both the original and advanced designs.

Several concepts were identified for increasing the diameter stowed in shuttle, and the advantages and disadvantages of each are disucssed.

A detailed study of offset reflectors was not performed due to time limitations and since it was given the lowest priority by JPL. Preliminary investigation, however, indicates that these would stow more compactly than axial-feed antennas of the same diameter, due to the reduced panel curvature. Manufacture would be more difficult, however, due to the fact that some symmetry is lost, and more, different shaped, panels must be built.

2.0 TECHNICAL DISCUSSION

2.1 Optimization of the Original Concept

The 6, 12 and 18 main panel configurations of the original design were optimized with an f/D of .4; these configurations are shown in Figures 3 through 8. The optimization was accomplished by adjustment of the hinge locations to allow a more efficient packing of the panels and subsequent trimline adjustment to avoid interference between panels when stowed. The procedure is illustrated for a 12-panel design in Figure 9 which shows the affect of adjustment in one direction for the five degrees of freedom available. Figure 10 shows the results of optimization of the 6-panel configuration compared to the original design of the 11-inch model (Figure 11). It was determined that for antennas of this f/D, more than 18 main panels would not improve the stowing ratio. As shown in Figures 6, 7, 8, and 9, each triangular panel must remain within an angle determined by the number of panels. A larger number of panels results in smaller angles. However, since the curvature of the triangular panels remains the same, they cannot be stowed as close to the center resulting in a larger stowed diameter.

The results of this study are summarized in Figure 12. The largest antenna possible in the shuttle with an f/D of .4 as predicted by this graph would be 42 feet with the 18 panel configuration. An increase in the f/D ratio to .62 for the 18 panel configuration would allow an antenna of about 50 feet to be stowed. Such an increase may also allow the use of more panels, to reduce the stowed diameter still more, at the cost of increased complexity. A similar f/D increase would not result in significant improvement for the 6-panel configuration; however, since the panel width is the governing factor of the stowing ratio rather than the curvature. Figure 13 illustrates the effect of an increase in f/D for the 6 and 18 main panel configurations.

Figures 14, 15 and 16 show the three configurations as they might appear in the shuttle payload compartment. Figures 17 and 18 show an isometric view of the 18 Main Panel configuration deployed and stowed.

2.2 Weight Estimate

The weight of antenna reflectors has been estimated for diameters of 16 to 100 feet. The results are plotted in Figure 19. The weight of feeds and sub-reflectors are not included. Since the weight of the reflector sandwich structure predominates (90-98%), the data is approximately valid for advanced configurations described in later sections which may require additional hinges or other hardware. The following assumptions were made for the calculations:

(1) Reflector

(a) The 24 foot antenna reflector has the following properties:

face sheet density (graphite-epoxy):	.06	lb/in^3
core density (aluminum honeycomb):	1.6	lb/ft^3
face sheet thickness:	.009	in
core thickness:	.5	in

(b) The 100 foot antenna reflector has the following properties:

face sheet density:	.06	lb/in^3
core density:	3.2	lb/ft^3
face sheet thickness:	.018	in
core thickness:	2.0	in

(c) The area density is linear between the 24 and 100 foot diameters.

(d) Adhesive weight for all antennas: .012 lb/ft^3/side.

(e) White paint .004 in. thick at .05 lb/in^3.

(2) Support Ring

(a) The 24 foot reflector support ring weighs 8.81 lbs. based on a previously designed computer model.

(b) The ring for the 100 foot reflector weighs 10 times the ring for the 24 foot reflector or 88.1 lb.

(c) The weight of the rings for intermediate sizes varies linearly between the above values.

(3) Other hardware, including hinges, drive shafts, tiedowns, deployment springs and dampers

(a) The weight of the hardware for the 24 foot reflector shall be determined by the ratio:

$$\frac{\text{Weight of Hardware (24 foot)}}{\text{Weight of Hardware (16 foot)}} = \frac{\text{Weight of Ring (24 foot)}}{\text{Weight of Ring (16 foot)}}$$

where the 16 foot component weights are obtained from a previously designed antenna and the ring for the 24 foot weighs 8.81 lb.

(b) The weight of the hardware for the 100 foot reflector is ten times that for the 24 foot.

(c) The weight of the hardware varies linearly between the 24 and 100 foot antennae.

(4) The weight of the 16 foot antenna is calculated from the above-mentioned model and does not follow the calculation for the 24 to 100 foot antennae.

2.3 Surface Accuracy

An attempt has been made to estimate the surface quality obtainable for the large aperture antenna reflectors of both the original and advanced designs. Four separate estimates have been made. The first three are based on presently available fabrication technology, improved fabrication technology and post-fabrication adjustment of the panels, respectively. The fourth estimate is for a system with on-orbit active control of panel contour. Details of the improved technology, post-fabrication adjustment and active control are discussed in Section 2.4.

The estimates of error without active controls are based upon the following assumptions. Where δ is the RMS panel deviation, L is the panel true length, and t is the panel thickness, all in inches.

(1) Errors in the panels as fabricated

A. Existing technology

$\delta = 2.0 \times 10^{-4} L$

B. Improved technology

$\delta = .7 \times 10^{-4} L$

C. Post-Fabrication Adjustment

δ = .0005" for all lengths.

(2) Assembly errors

A. For the largest antenna in the one, two and three ring configurations (40, 80 and 120 feet respectively).

- o Error due to inspection system tolerance: δ = .0005 per 20 ft
- o Error due to positioning of panels: δ = .001" per row of panels
- o Error due to 1G deflections: δ = .001" per row of panels.

B. For the smaller antennae in each configuration, the total error due to assembly is .001" less than that of the largest, per 10 feet diameter reduction.

(3) Deployment Errors

A. for the single ring configuration: δ = .001" per 40 ft diameter

B. for the 2 ring configuration: δ = .00[illegible]5" per 40 ft diameter

C. for the 3 ring configuration: δ = .0015" per 40 ft diameter + .0015".

(4) Errors due to thermal effects

A. $\delta = \frac{KL}{t}$

where $K = 1.185 \times 10^{-5}$ based on the previously analyzed 16 foot diameter reflector whose panel length and thickness were 54" and .32" respectively and whose maximum RMS error due to thermal effects was .002".

B. For the 100 foot reflector, disregarding the fact that there may be three separate rings, L = 570", t = 2" and δ = .0034".

C. δ varies linearly between these values for all reflectors (Figure 20).

D. The panel thickness varies linearly from .32" for a 16 foot diameter to 2" for a 100 foot diameter reflector (Figure 20).

These errors are summarized in Tables 1, 2 and 3.

For the fourth estimate, the active control compensates for the errors due to assembly, deployment, and thermal effects. The fabrication errors with improved technology (Table 2) are assumed to apply with a factor of four improvement. All four error estimates are plotted versus antenna diameter in Figure 21. Also included in Figure 21 is the acceptable RMS error for various antenna frequencies. These values are based on the equation:

$$\text{Antenna Efficiency} = \eta_s = e^{-\left(4\pi \frac{\varepsilon}{\lambda}\right)^2}$$

where λ is the wavelength of the antenna frequency, and:

$$\varepsilon = \frac{\Delta Z}{1+\left(\frac{r}{2f}\right)^2}$$

In this equation, if the focal length (f) is equal to .8 times the radius (r) that is, the f/D ratio is .4, then:

$$\varepsilon = .719\ \Delta Z$$

where ΔZ is the RMS error of the reflecting surface.

If $\frac{\varepsilon}{\lambda}$ = .02 is an acceptable ratio, resulting in a gain/loss of 10 log η_s = .274 db,

then $$\Delta Z = \frac{\varepsilon}{.719} = \frac{.02\lambda}{.719} = .0278\lambda$$

2.4 Critical Technologies

Several critical new technologies judged necessary for the construction of successful large diameter antennae have been identified. These technologies mainly concern the advanced fabrication and adjustment techniques mentioned in Section 2.3, and related problems. In addition, they apply equally to both the original design and the advanced concepts, and therefore, no additional technologies have been defined for the advanced concepts.

The five proposed studies are outlined in Tables 4 through 8. Table 4 describes a program to investigate ways to improve manufacturing and reduce the as-fabricated errors discussed in Section 2.3. The second study (Table 5 and

Figure 22) would determine the design of back-up structure and adjustment joints of panels for post-fabrication adjustment of contours. The active control concept is described in Table 6, and Figures 23 and 24 illustrate two possible systems. A study of layup molds for large reflectors is described in Table 7, and a contour measuring device for assembly and testing complete reflectors is proposed in Table 7, and a contour measuring device for assembly and testing complete reflectors is proposed in Table 8 and illustrated in Figure 25.

2.5 Alternate Designs For Improved Packing Density

Several designs have been considered as possible alternatives to improve the stowed to deployed diameter ratio, and thereby increase the size of the antenna stowable in the shuttle. Of the six designs examined, one, the sunflower concept, is an existing and successful design, one is a modification of the original design, and the other four involve the addition of a second and possibly a third ring of panels to the original configuration.

2.5.1 Sunflower

This design, illustrated in Figure 26 has been previously developed for space applications and is capable of providing a 100 foot antenna stowable in the shuttle. The major drawback, however, is that upon deployment, the panels are not connected together and would require either complicated latching mechanisms or considerable EVA to achieve a sufficiently accurate reflector.

2.5.2 Main Panel Hinges Removed

In an attempt to allow greater flexibility in the geometry, the hinges between the main panels and support ring were removed and arms were added to control deployment. These control arms extend from the torque tube at the support ring to the outboard hinge between the triangular panels. In this configuration the main panels are supported and driven by the triangular panels. The concept is illustrated in Figure 27. A new set of possible hinge point adjustments were generated for optimization, similar to that for the original optimization (Figure 9), with ten degrees of freedom. The optimization study, however, indicated that no significant improvement in stowed diameter was to be gained by this approach, since the curvature of the panels or the outside length of the triangular panels still governs the ratio. The loss of stiffness with the removal of the hinges also makes it undesirable. This method may be useful, however, for stowing antennae into non-cylindrical compartments.

2.5.3 Double Ring Configurations

The most successful approach, so far discovered to improve packing, has been to break the antenna into two rings of panels rather than one. By this method, the effect of the panel curvature is reduced and the panels may be folded closer to the axis of the reflector. Several ways of attaching and controlling this second ring have been examined. With the possible exception of the last, all of the concepts have the potential of being extended to a three-ring configuration, perhaps using different concepts for each ring.

2.5.3.1 Equal Numbers of Panels in Each Ring

The simplest double ring configuration consists of converting a single ring of panels by splitting each panel approximately mid length. The hinges of the single ring are repeated in each new ring. The main panels of the outer ring are hinged to the outboard end of the main panels of the inner ring, while the triangular panels of the two rings are not connected. By utilizing this new degree of freedom and by manipulation of the outer ring hinges, the second ring can be optimized independently, taking advantage of the reduced curvature of the shorter panels. This approach is illustrated in Figure 28.

2.5.3.2 Half as Many Panels in the Inner Ring

To reduce the number of panels required for the system described above, the inner ring may be comprised of half as many panels as the outer, taking advantage of the reduced packing density required in the lower part of the stowed antenna. Since alternate outer ring main panels are then unsupported, additional mechanisms must be added to completely control deployment. A configuration with 6 main panels in the inner ring and 12 in the outer is illustrated in Figures 29 through 32, and a 18-36 configuration is shown in Figures 33 through 36.

2.5.3.2.1 Long Arms as Dummy Main Panels

To substitute for the inner ring main panels, control arms could be substituted. These arms are connected to the support ring and are driven by the same drive shaft as for the original panels. This configuration is alternate B in Figure 37 which shows a six panel inner ring and a twelve panel outer ring. A major drawback of this configuration is that the arms are not connected to the inner ring of panels as were the main panels which results in a less stiff reflector. The control arms may also add significant weight and complexity to the structure.

2.5.3.2.2 Pin and Slot Between Inner and Outer Triangular Panels

An alternate control device concept, which eliminates the need for the long control arms, consists of a pin and slot joint between the inner and outer ring triangular panels. This concept is alternate A in Figure 37. The exact location on the back of the panels and the shape of the slot have not been determined, although preliminary studies indicate that the design is feasible. While this device would reduce weight compared to the control arms, the reflector would be more unstable during deployment since the position of the three panels between the two controlled outer ring panels is not completely defined, throughout deployment. This lack of definition would be acceptable, however, since it does not allow panel interference or jamming, and upon deployment, the outer ring of panels is supported more rigidly at the outer edge of the inner panels, rather than by the support ring through the control arm.

2.5.3.2.3 Outer Ring Main Panels Pinned to Inner Ring Hinge Line

In this version, illustrated in Figure 38, alternate outer ring main panels are made very narrow, and the inboard end is attached to the hinge line between the triangular panels of the inner ring. The principle advantage is that the control arms are eliminated, while still providing a unique position for all panels throughout deployment. This concept has not been fully developed, due to time limitations, and there remain interference problems between certain panels in the fully stowed position. A third ring would be more difficult to design for this configuration than the others, although it may be useful as a third ring added to a second ring of another design.

3.0 COST ESTIMATES

ROM cost estimates have been made for four reflector configurations, all with a stowed diameter of 14.5 feet to fit in the shuttle orbiter bay.

The cost breakdown and configuration description are presented in Table 9 and the cost is plotted versus diameter in Figure 39. The estimates were based on 1980 rates.

4.0 CONCLUSIONS

It has been determined that for the original single ring concept, an 18 main panel configuration would provide the most efficient stowed package, allowing a 42 foot diameter reflector to be accommodated by the shuttle payload bay. With a constant f/D ratio, fewer panels would result in less complexity at the cost of stowable diameter. More panels would both increase complexity and reduce stowable diameter.

Reflector weight has been estimated to range from 68 lb for a 16 foot antenna to 7800 lb for a 100 foot antenna.

Contour errors have been estimated for various manufacturing techniques, and it has been concluded that on-orbit active control would be required for antenna frequencies greater than 100 GHz. However, 20 GHz is achievable for most sizes without adjustment, if improved fabrication technology is implemented.

A double ring configuration has been chosen as the most promising to increase the deployed diameter. Up to 80 foot diameter reflectors could be stowed with an 18 main panel inner ring and a 36 main panel outer ring. Six and 12 main panels in the inner and outer rings respectively would allow a 49 foot reflector, compared to 42 feet for an 18 main panel single ring, which has the same number of panels.

Reflector cost has been estimated between $1.4 million and $4.6 million, depending on size and configuration.

5.0 RECOMMENDATIONS

Several critical technologies have been identified, all of which are concerned with the contour accuracy of reflectors. It is recommended that a study be conducted for each. The first choice for a single study which would improve contour the most would be the development of a post-fabrication adjustment technique. This technique would compensate for systematic errors due to the mold and due to fabrication of individual panels. It also would bias the contour to minimize thermal distortions. Existing molds can be used for panel fabrication and improvement in the accuracy of individual panels can be evaluated by measuring the contour before and after adjustment with existing inspection equipment. The main disadvantage of this system is that it requires a dual structure which represents a significant increase in cost and weight.

An additional or alternate study would be to improve contour accuracy by increasing mold accuracy and panel fabrication procedures without adding structure behind the reflector surface.

To achieve the highest degree of accuracy, an active control system should be studied. Two concepts are illustrated in Figures 23 and 24. The concept of Figure 23 in conjunction with post fabrication adjustment would compensate for many of the errors but with the additional adjustment capability of the concept shown in Figure 24, or new concepts, the accuracy could be further improved. It is recommended that a study of active control systems be conducted in conjunction with the post-fabrication adjustment system. After completing development of an actuating system for individual panels this system would be combined with a contour sensing system for verification on a single panel, then multiple panels and finally a complete reflector. The accuracy predictions for each of the contour improvement techniques are illustrated on the plot of Figure 21. An additional recommendation is to build a scale model of a dual ring reflector to verify the kinematics of this new concept and to further evaluate the results of the critical technology studies.

6.0 NEW TECHNOLOGY

The following is a list of items considered new technologies reportable to NASA. In all cases the innovators are the authors of this report (William B. Palmer, Staff Engineer, TRW; and Martin M. Giebler, Member of the Technical Staff; TRW), and the technologies are presented only in this report.

- Post fabrication adjustment techniques for solid deployable reflector panels, pages 37, 38
- On-orbit active control of panel contour, pages 39, 40, 41
- Contour measuring and assembly device for large reflectors, pages 43, 44
- Double ring deployable reflector configuration, pages 47-50

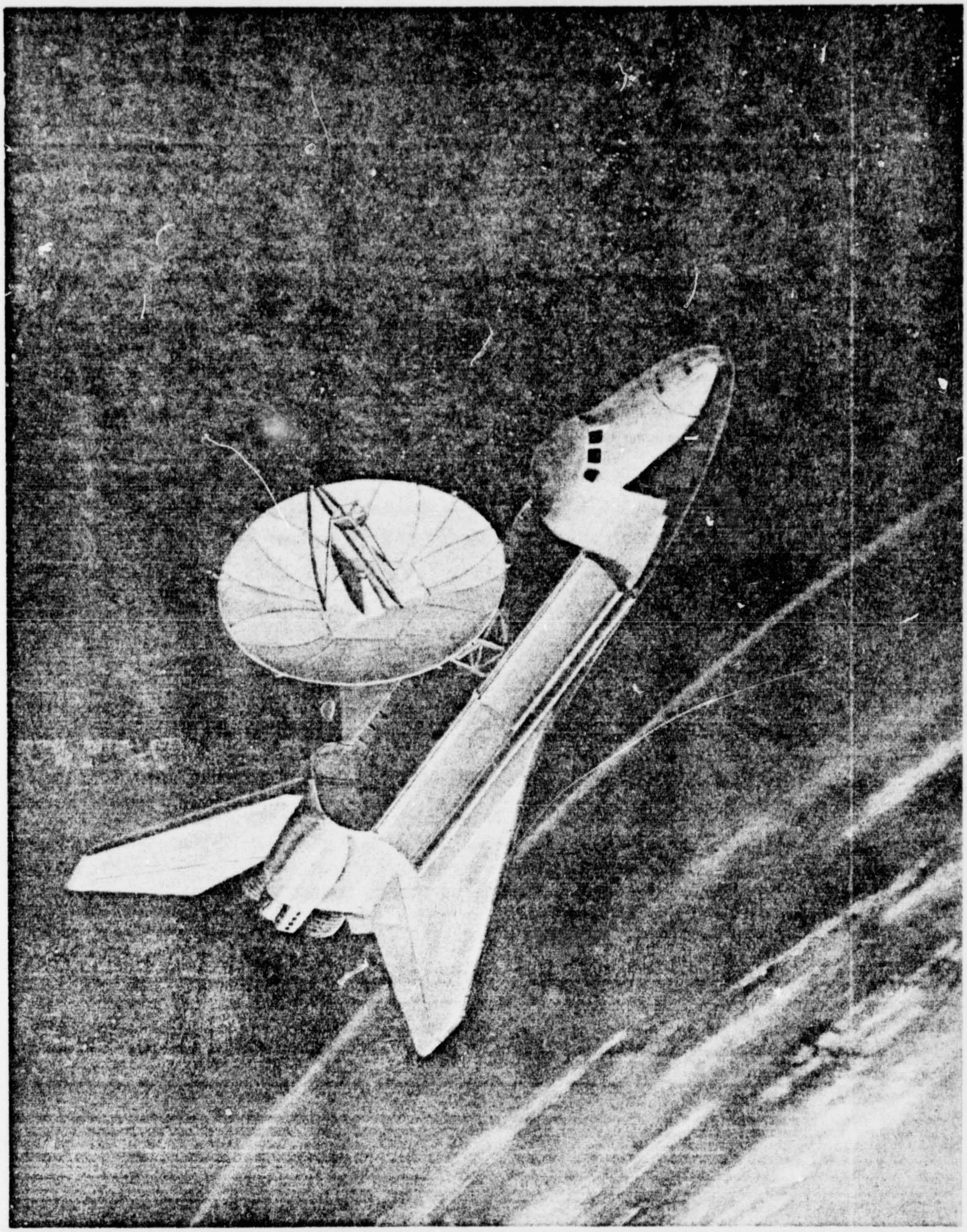

FIGURE 1 6 MAIN PANEL, 33.2 FT. REFLECTOR ON SHUTTLE

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OF POOR QUALITY

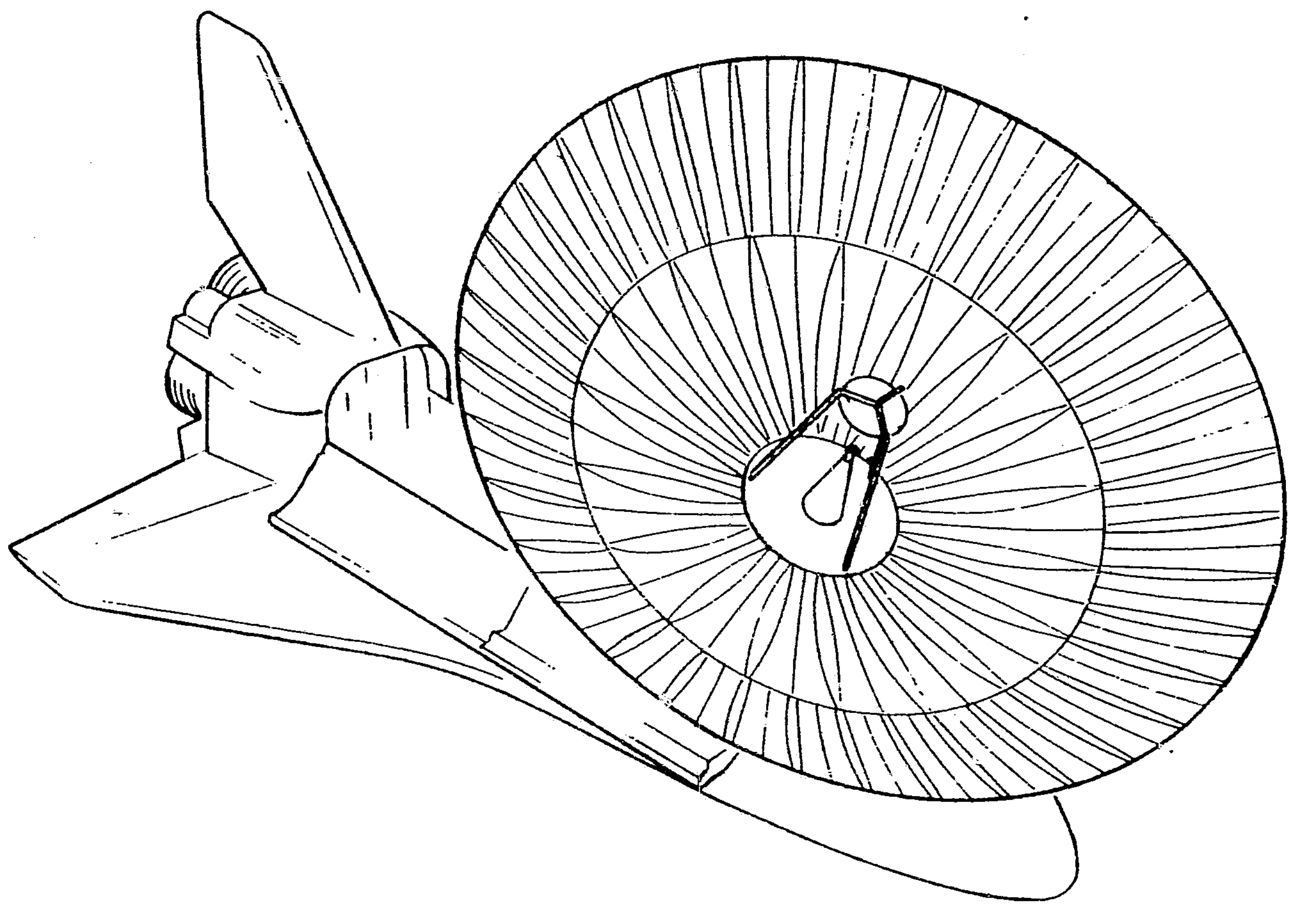


FIGURE 2 80 FT., 24.4 METER PRECISION DEPLOYABLE REFLECTOR ON SHUTTLE

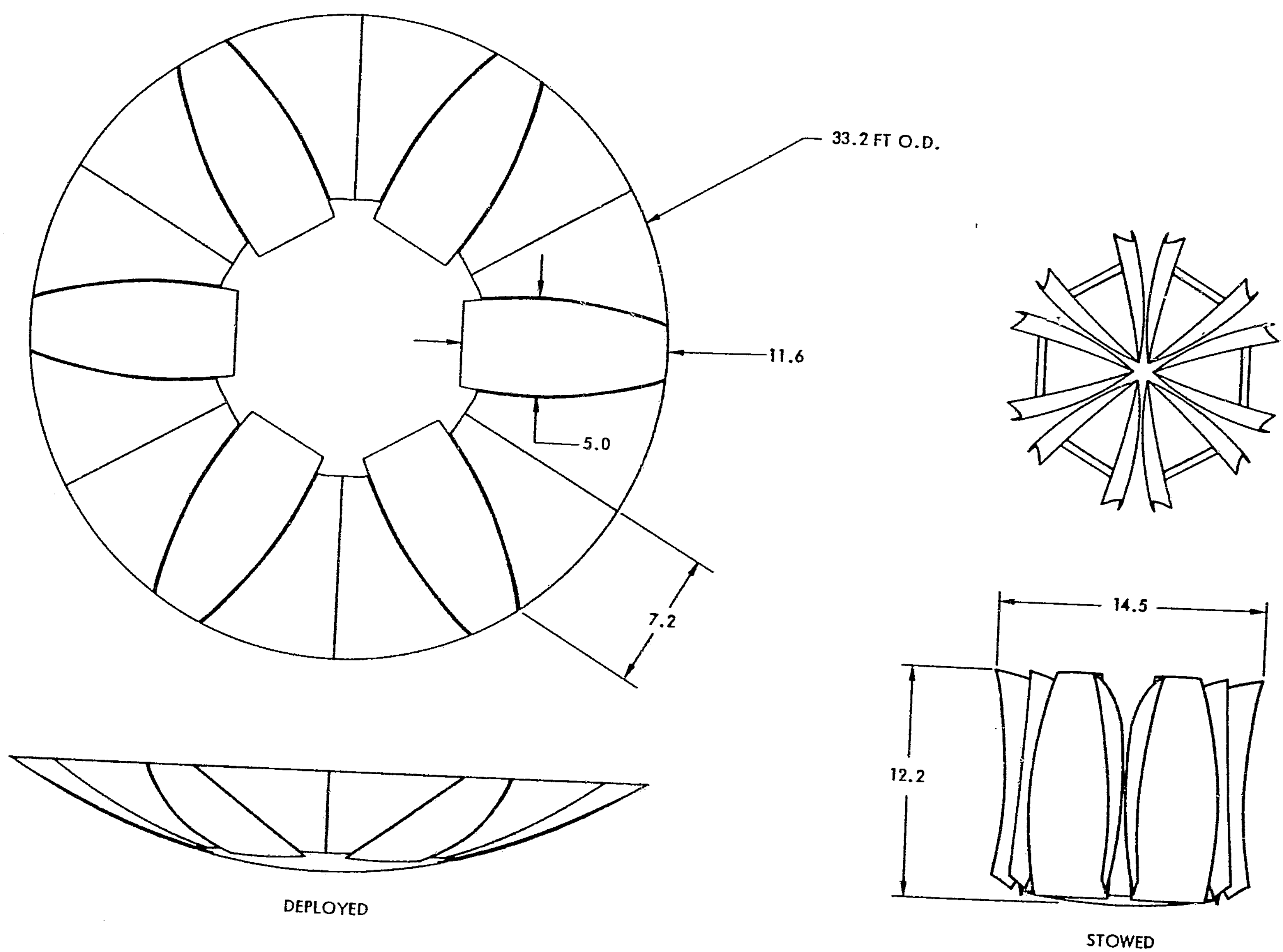


FIGURE 3 6 MAIN PANEL CONFIGURATION

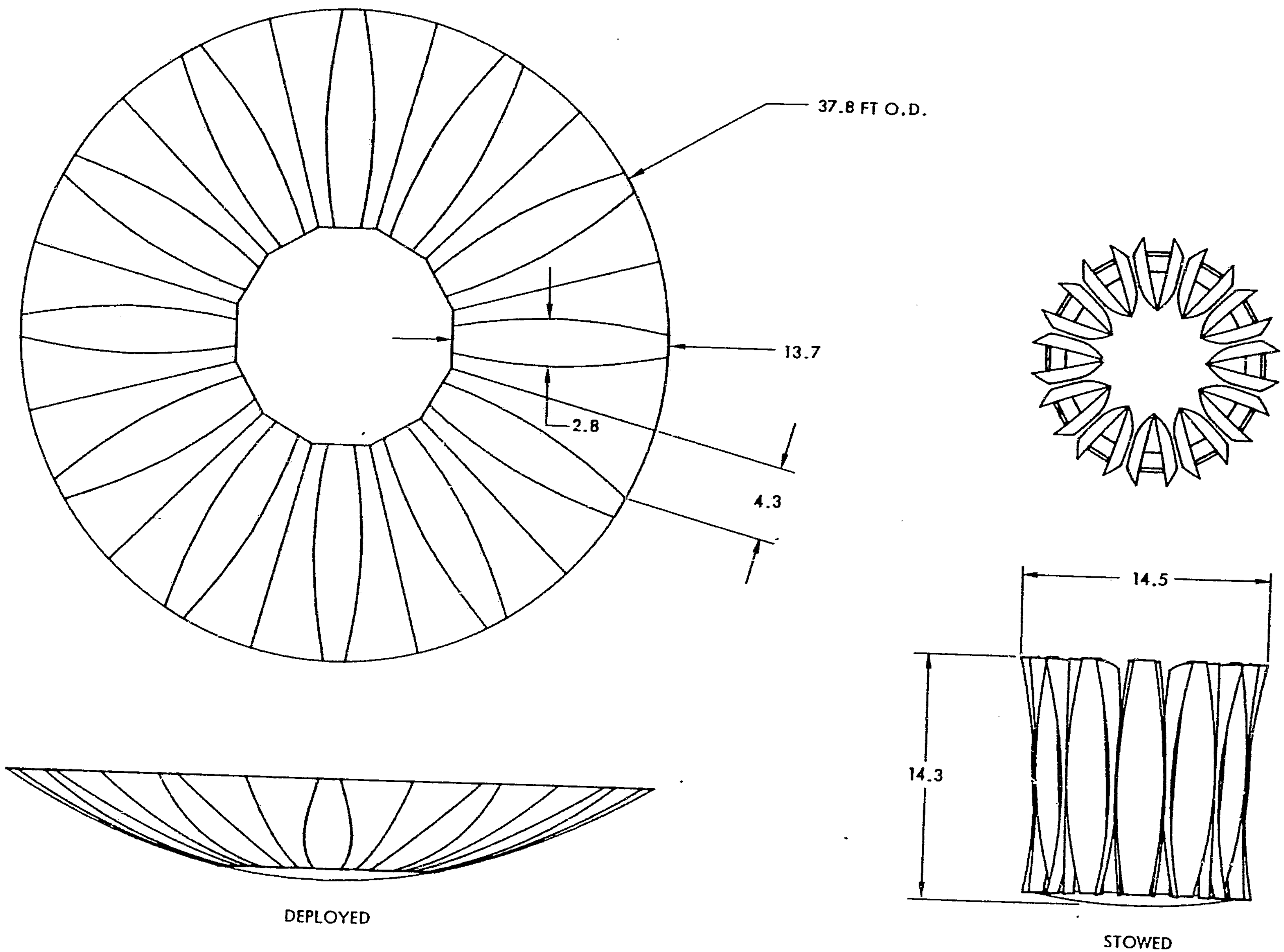


FIGURE 4 12 MAIN PANEL CONFIGURATION

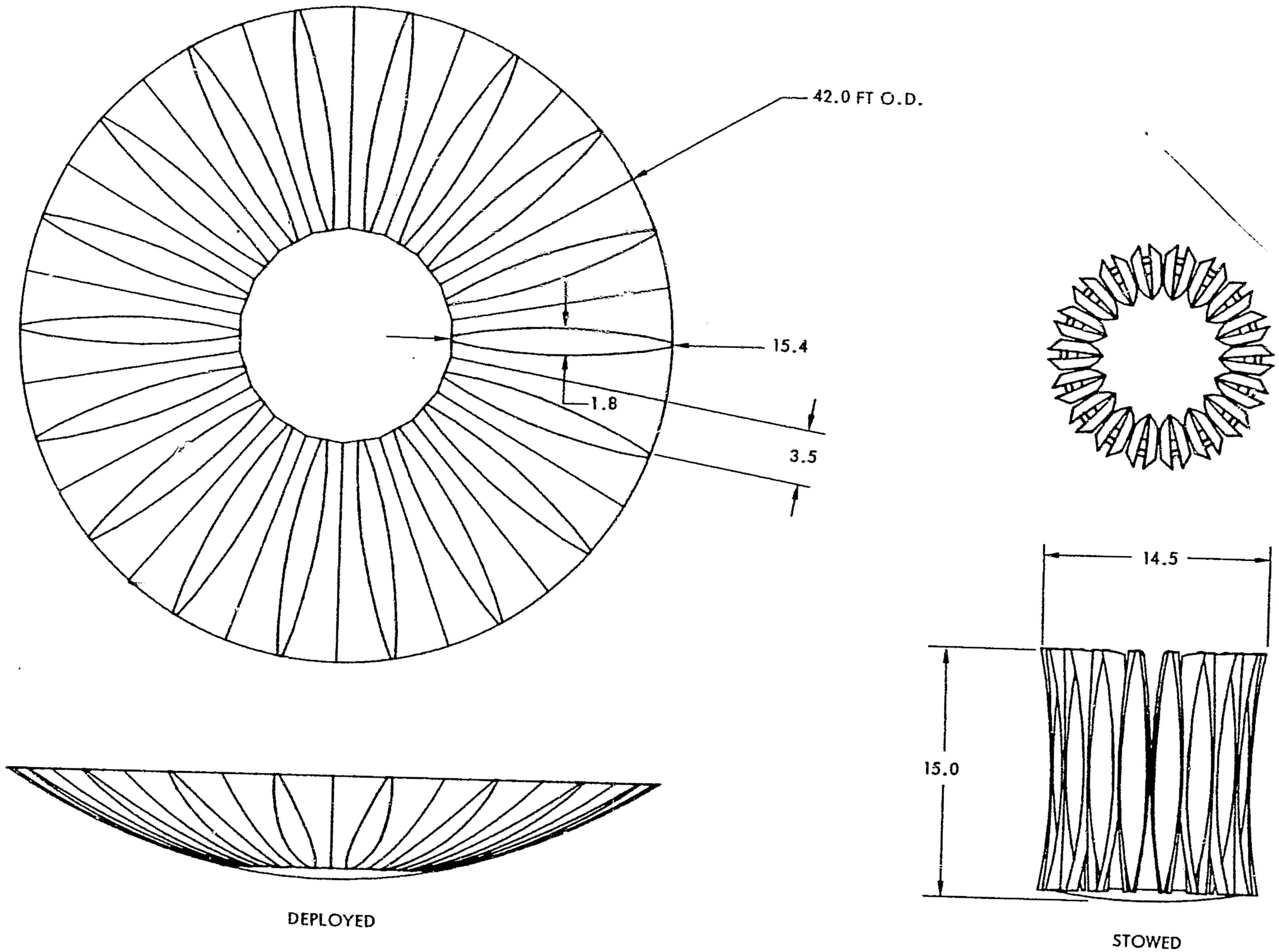


FIGURE 5 18 MAIN PANEL CONFIGURATION

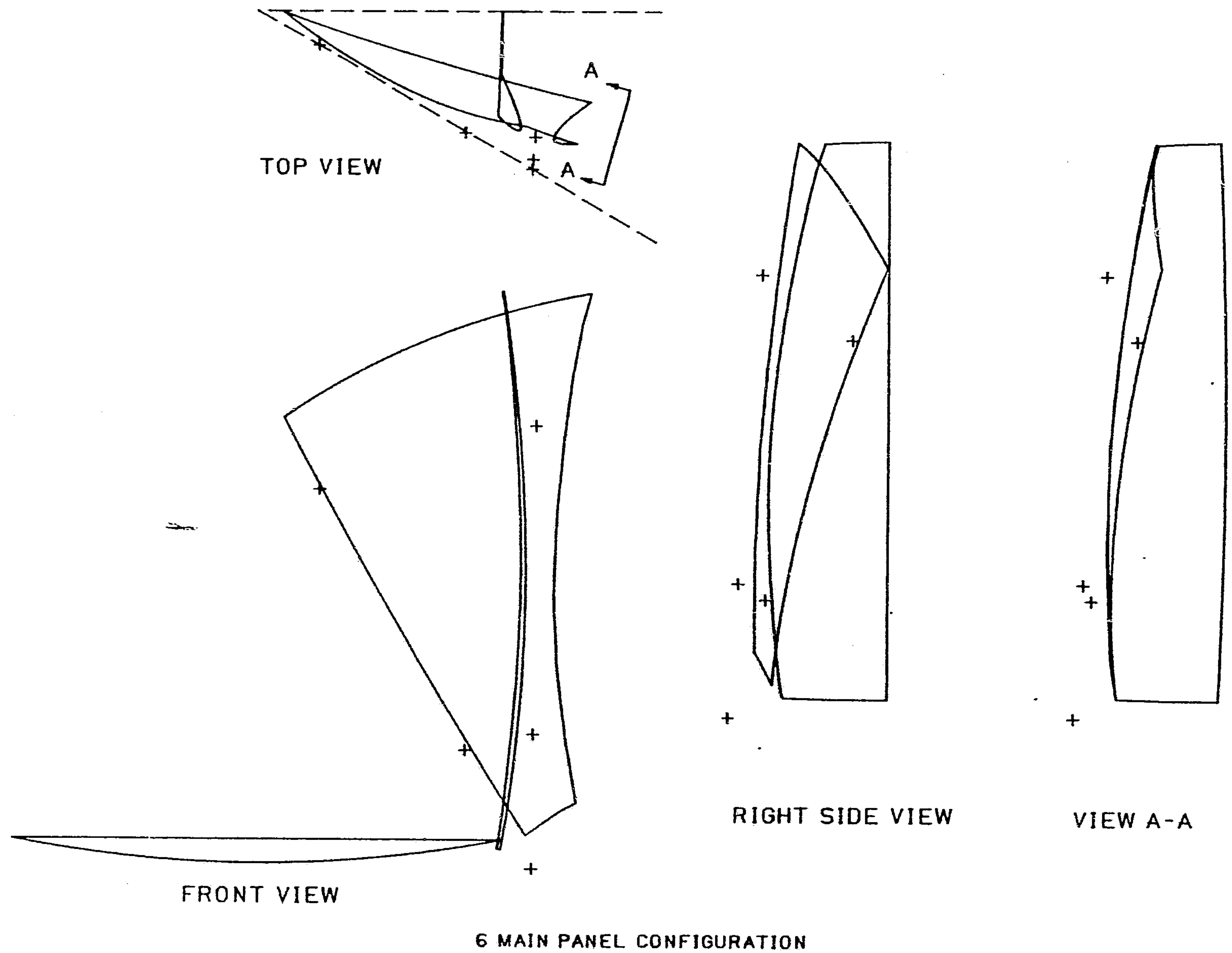


FIGURE 6 6 MAIN PANEL CONFIGURATION

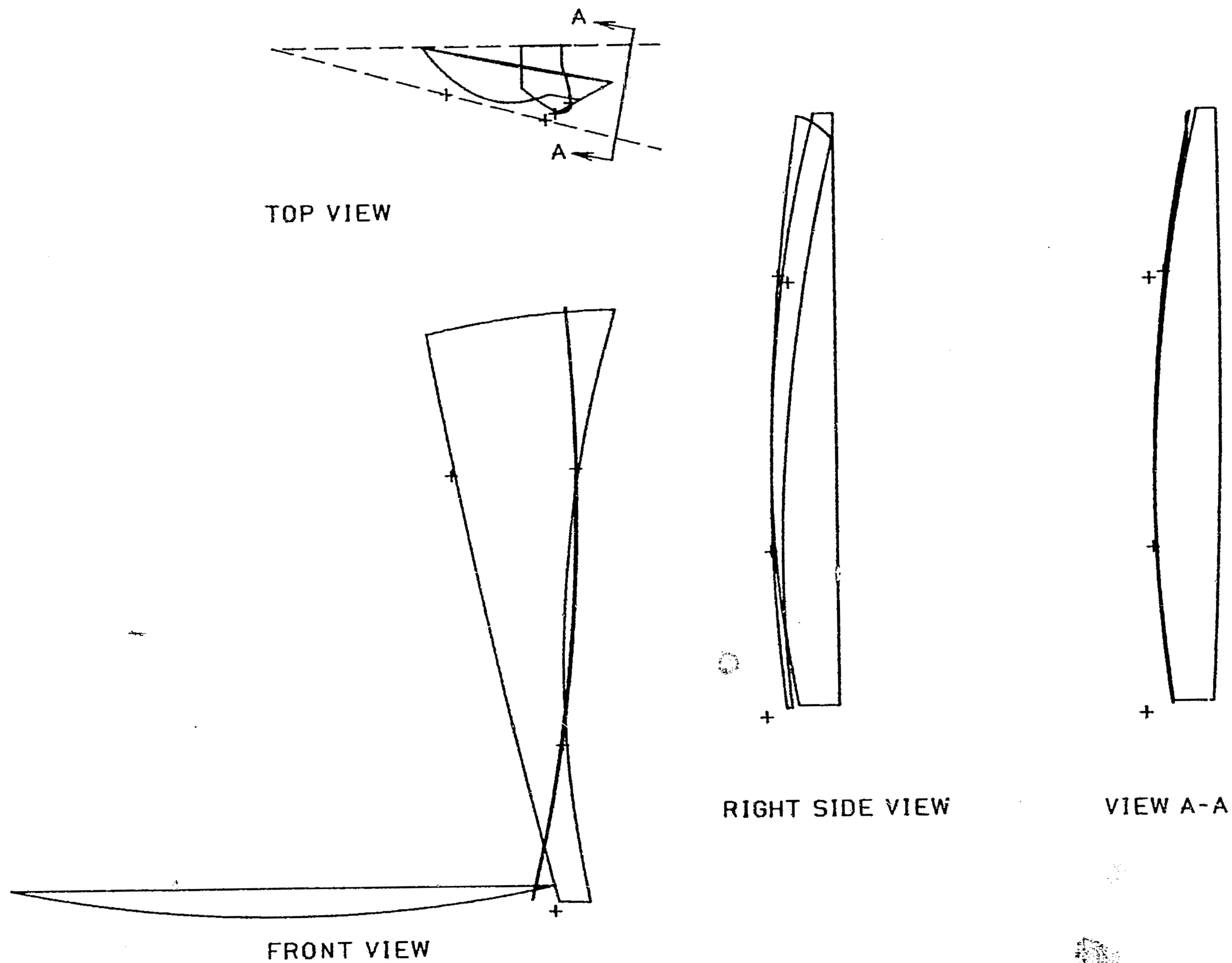


FIGURE 7   12 MAIN PANEL CONFIGURATION

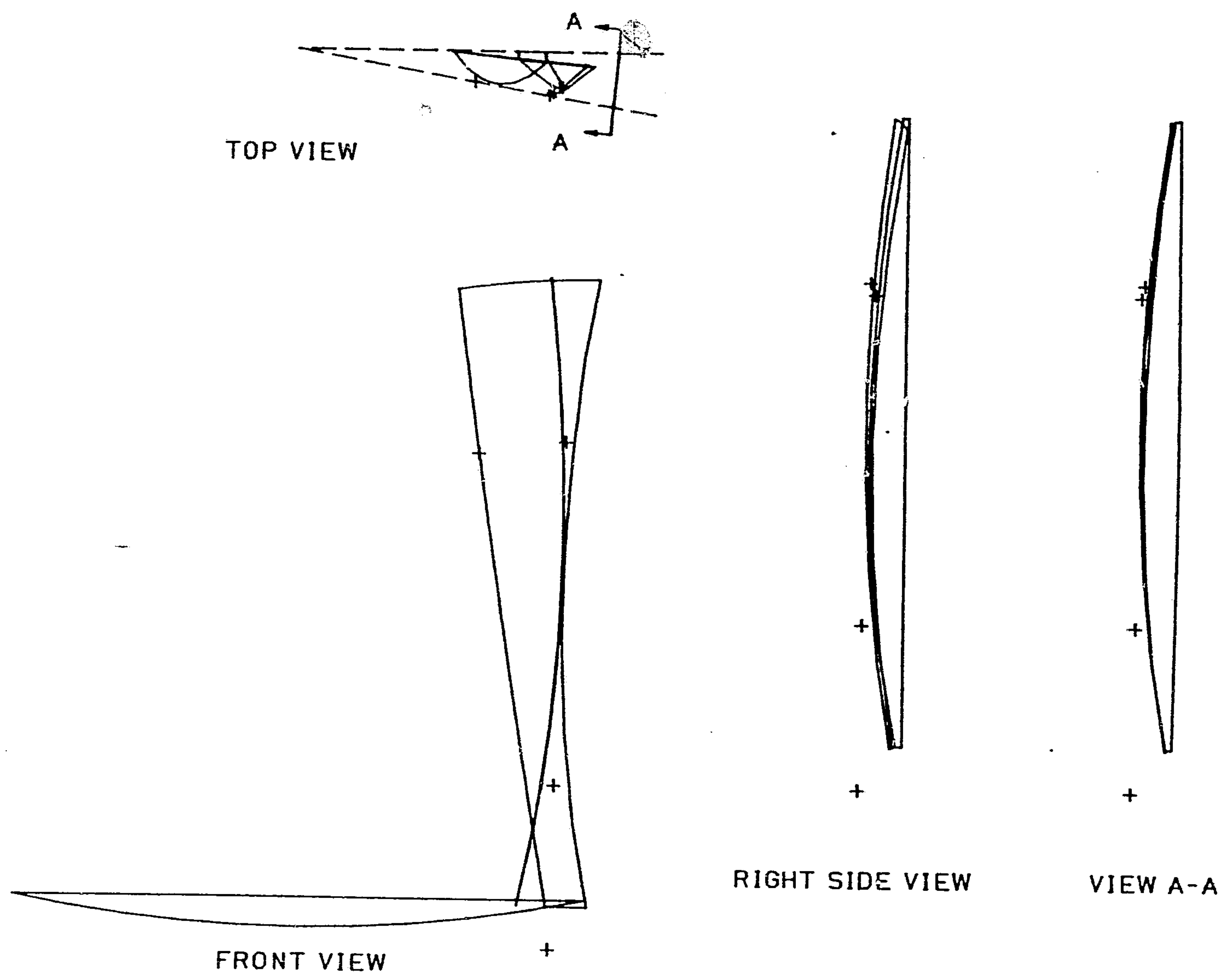


FIGURE 8 18 MAIN PANEL CONFIGURATION

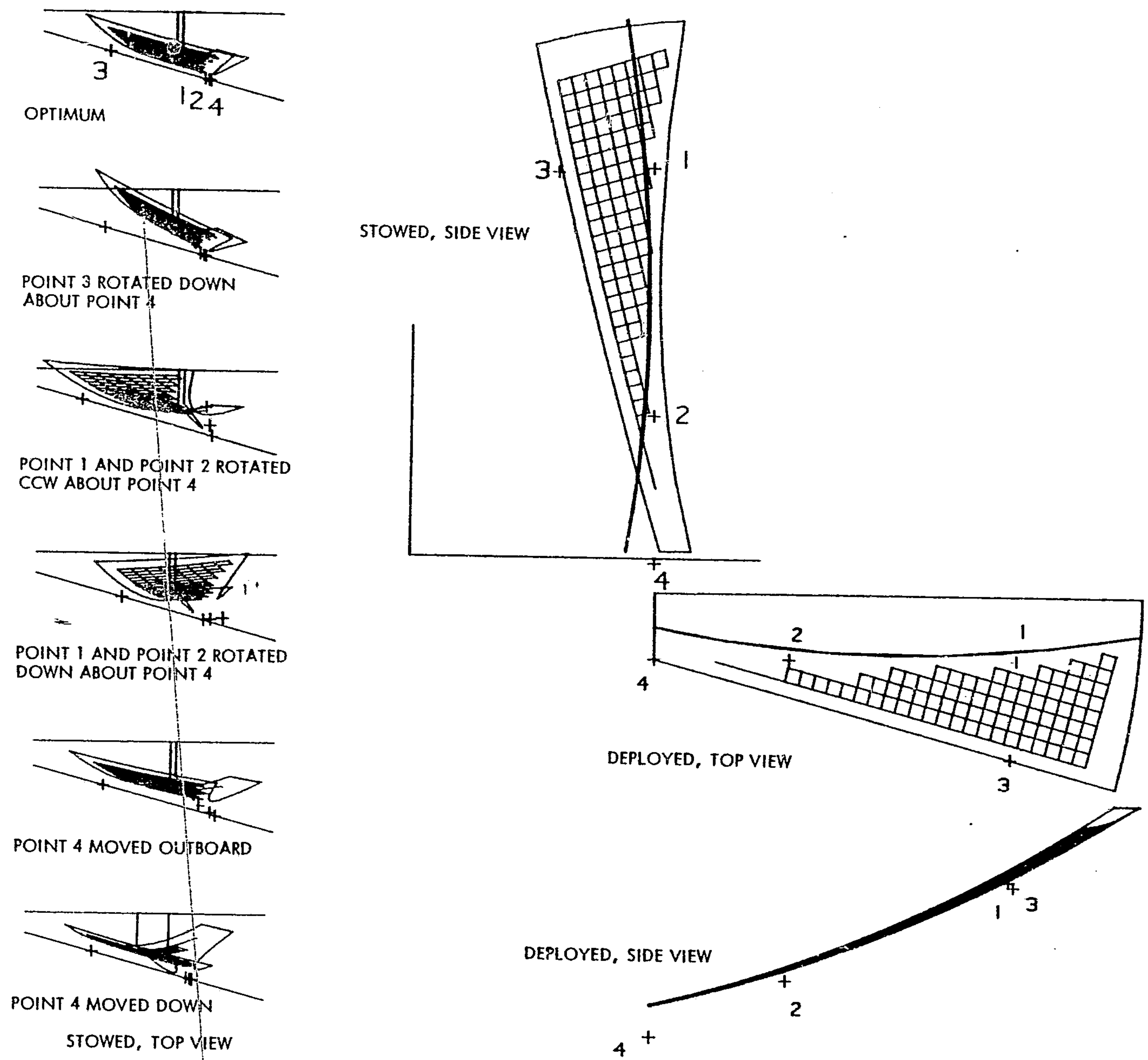
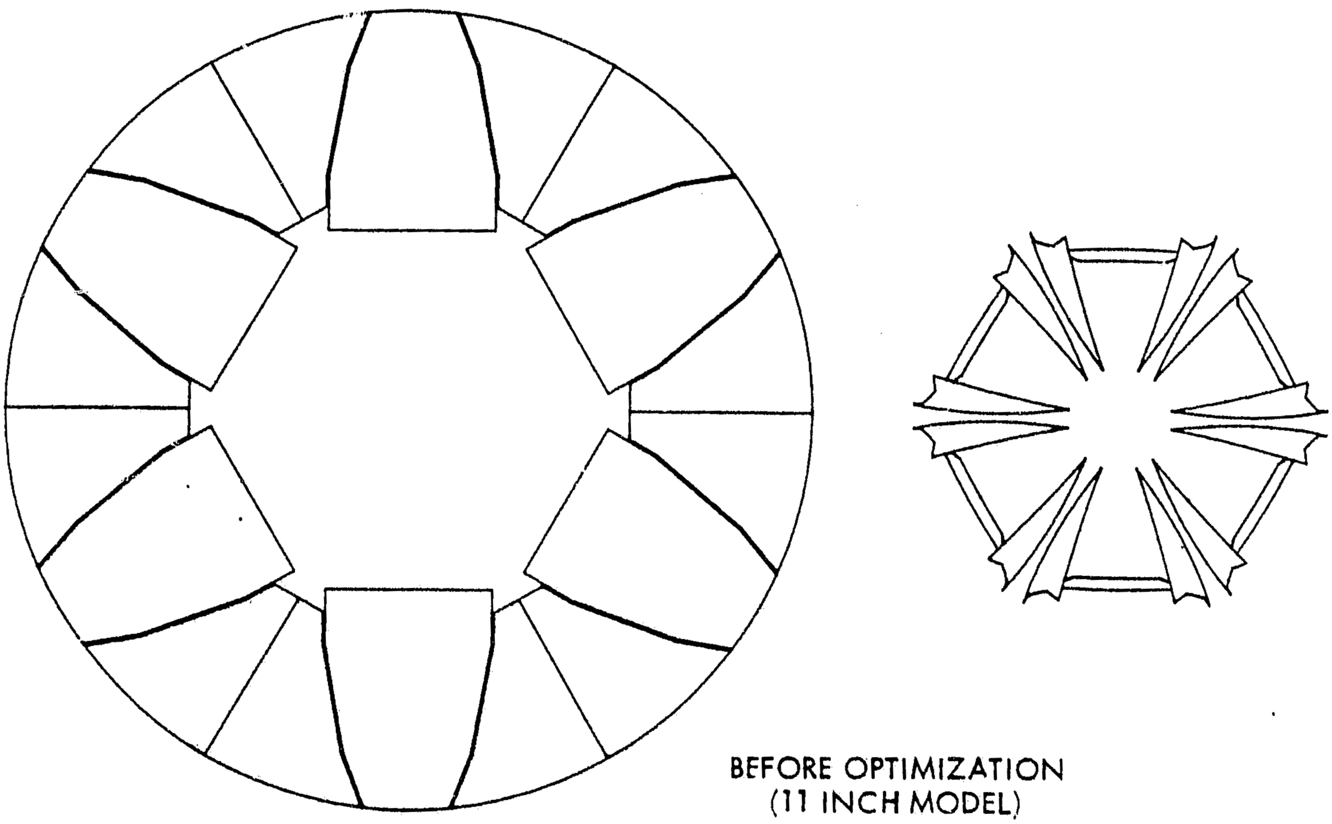
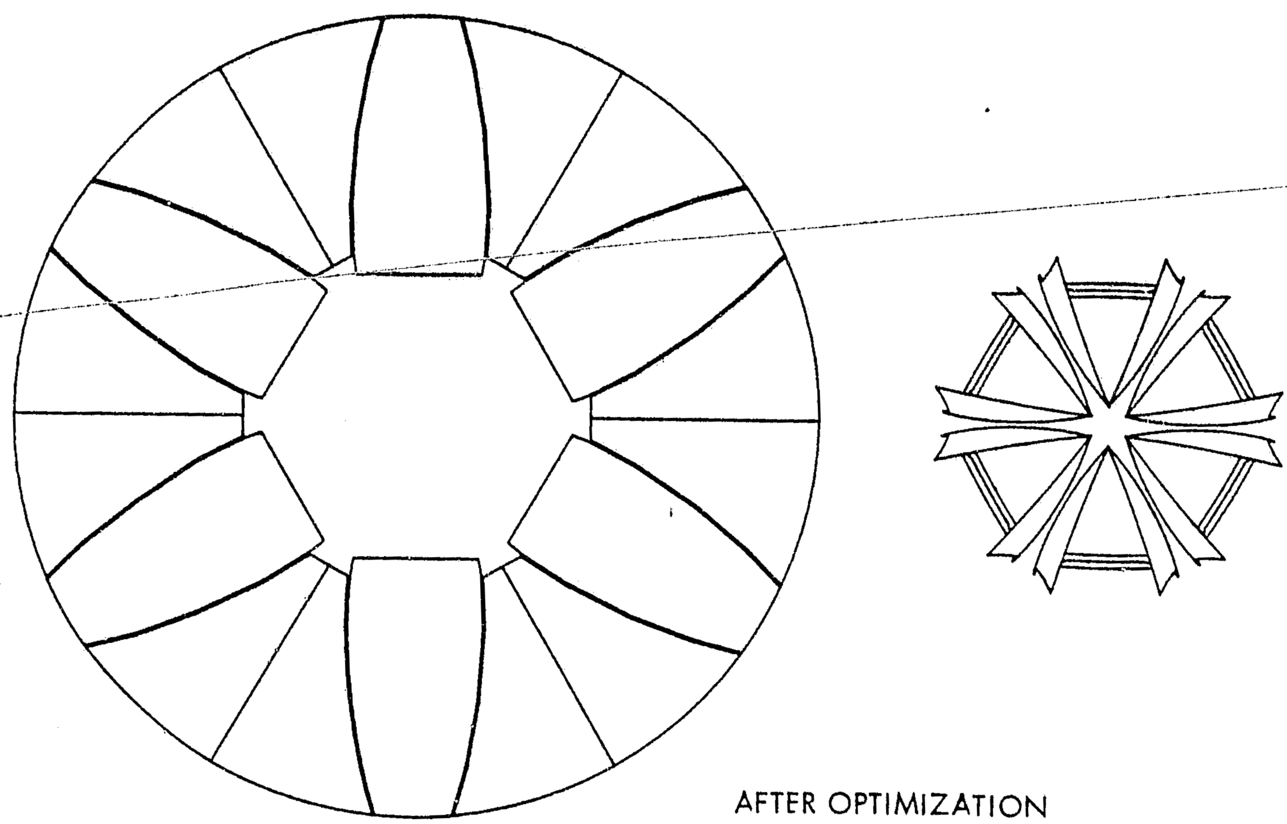


FIGURE 9 OPTIMIZATION PROCEDURE (12 MAIN PANEL CONFIGURATION SHOWN)

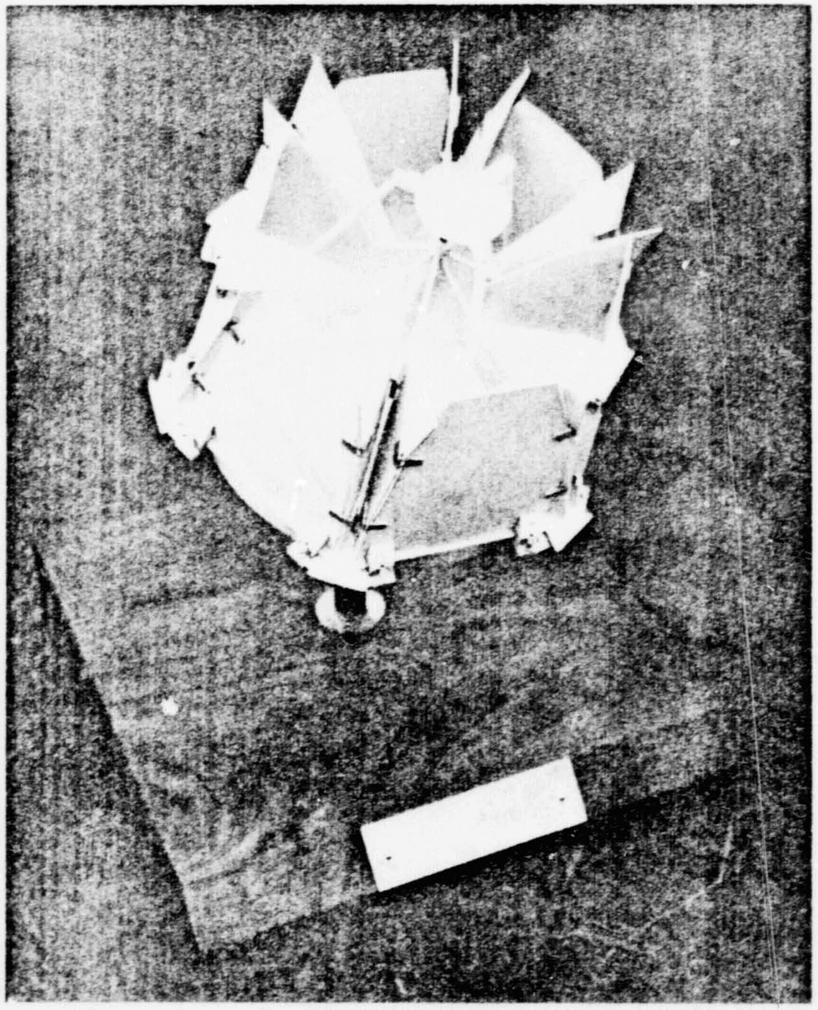


BEFORE OPTIMIZATION
(11 INCH MODEL)

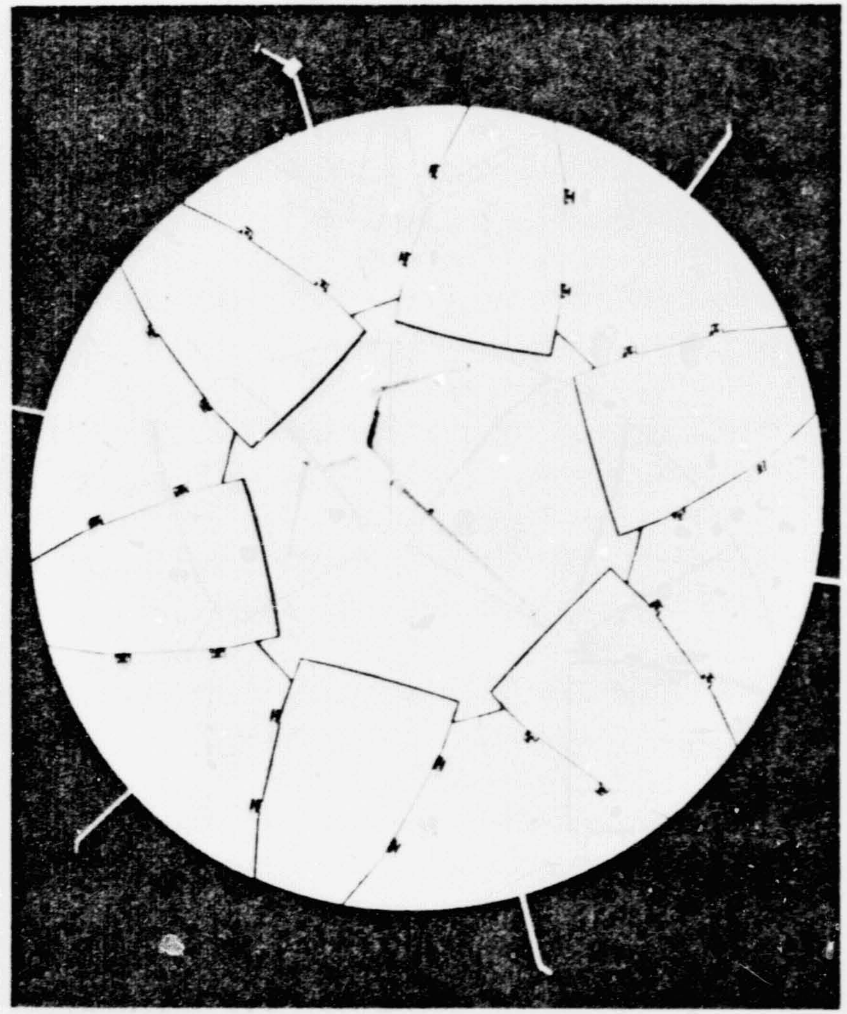


AFTER OPTIMIZATION

FIGURE 10 6 MAIN PANEL CONFIGURATION BEFORE AND AFTER OPTIMIZATION



STOWED



DEPLOYED

FIGURE 11 11 INCH MODEL

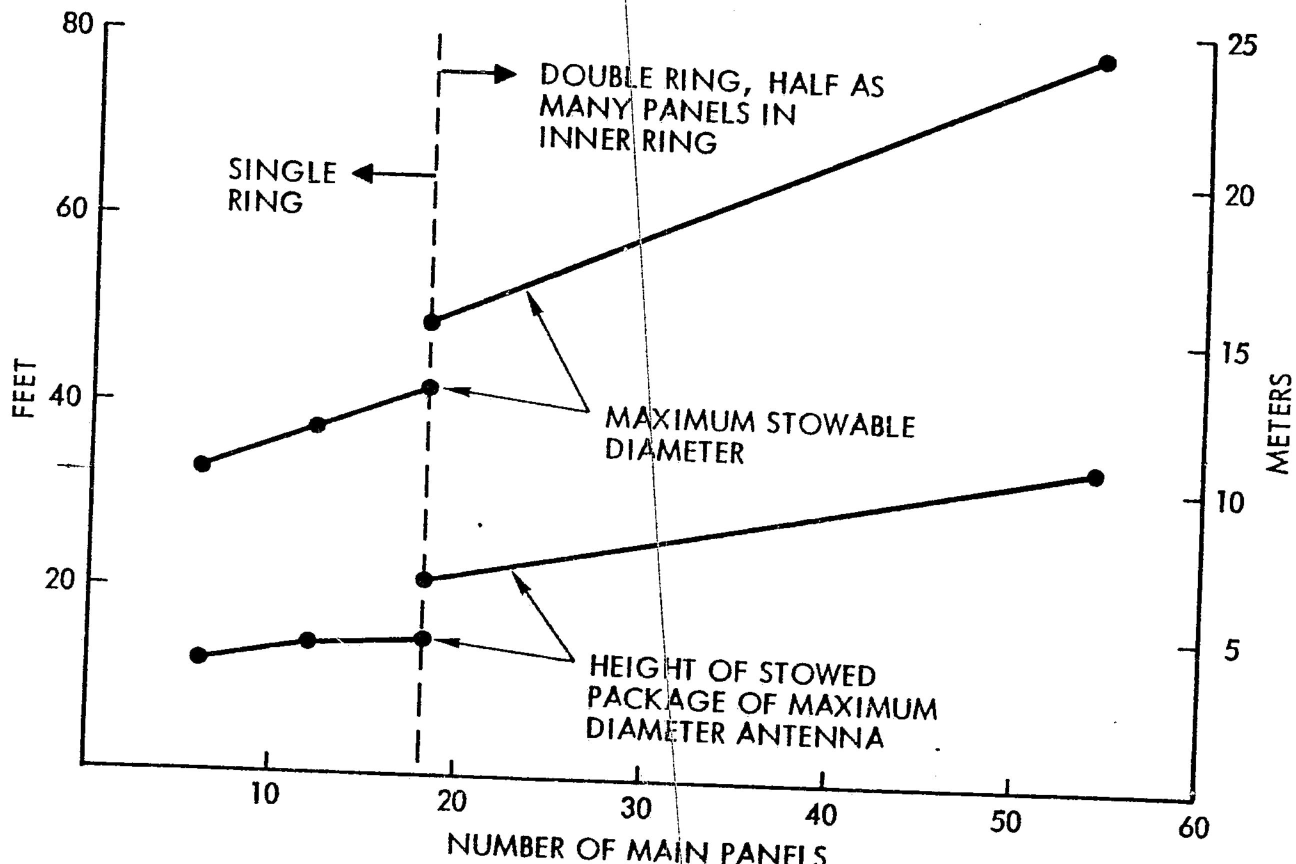


FIGURE 12 DIMENSIONS OF THE LARGEST ANTENNA STOWABLE IN SHUTTLE FOR VARIOUS CONFIGURATIONS

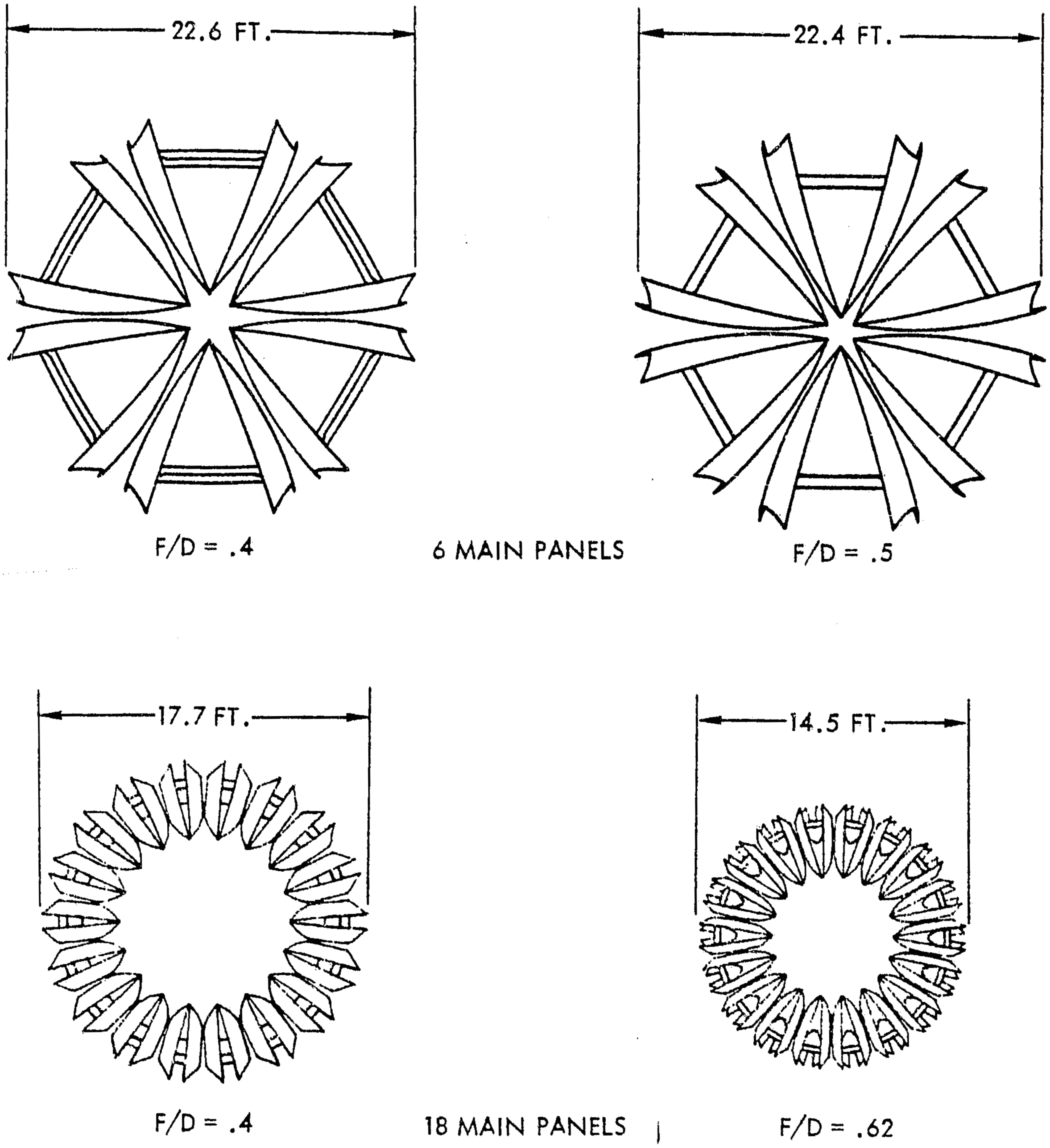


FIGURE 13 EFFECT OF INCREASED F/D. (ALL ANTENNAS 51 FT. DIAMETER DEPLOYED)

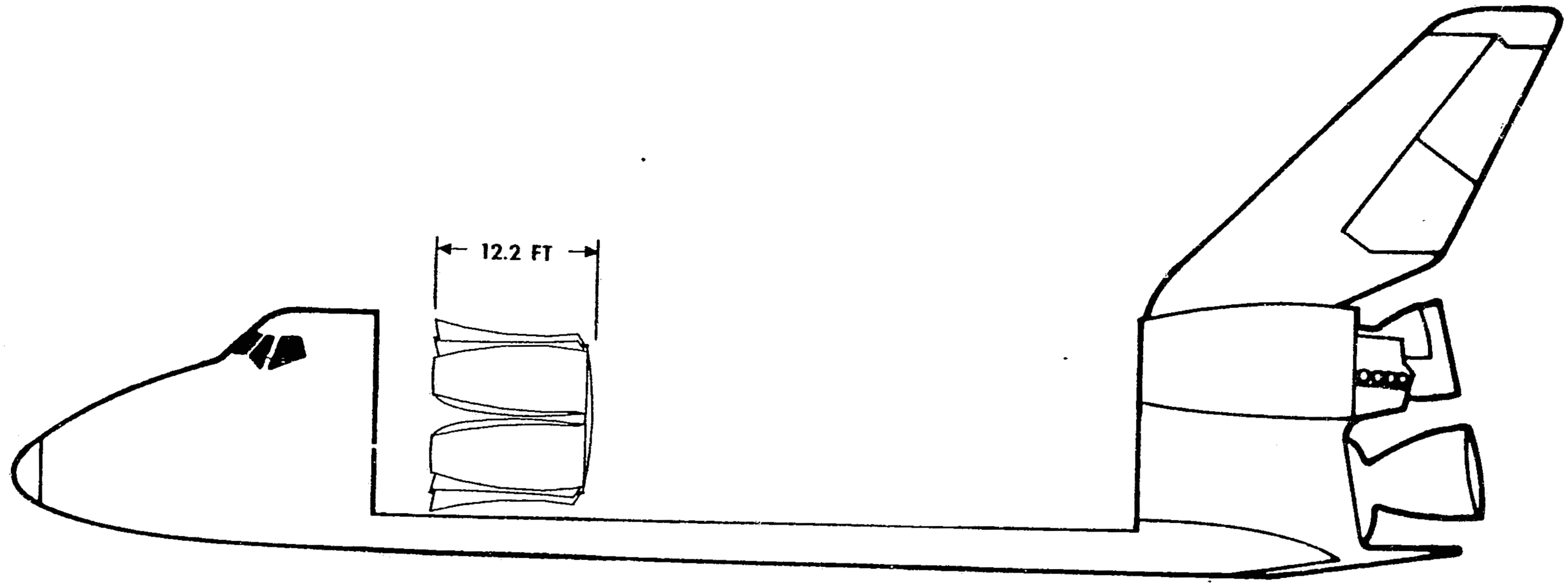


FIGURE 14 6 MAIN PANEL CONFIGURATION IN SHUTTLE

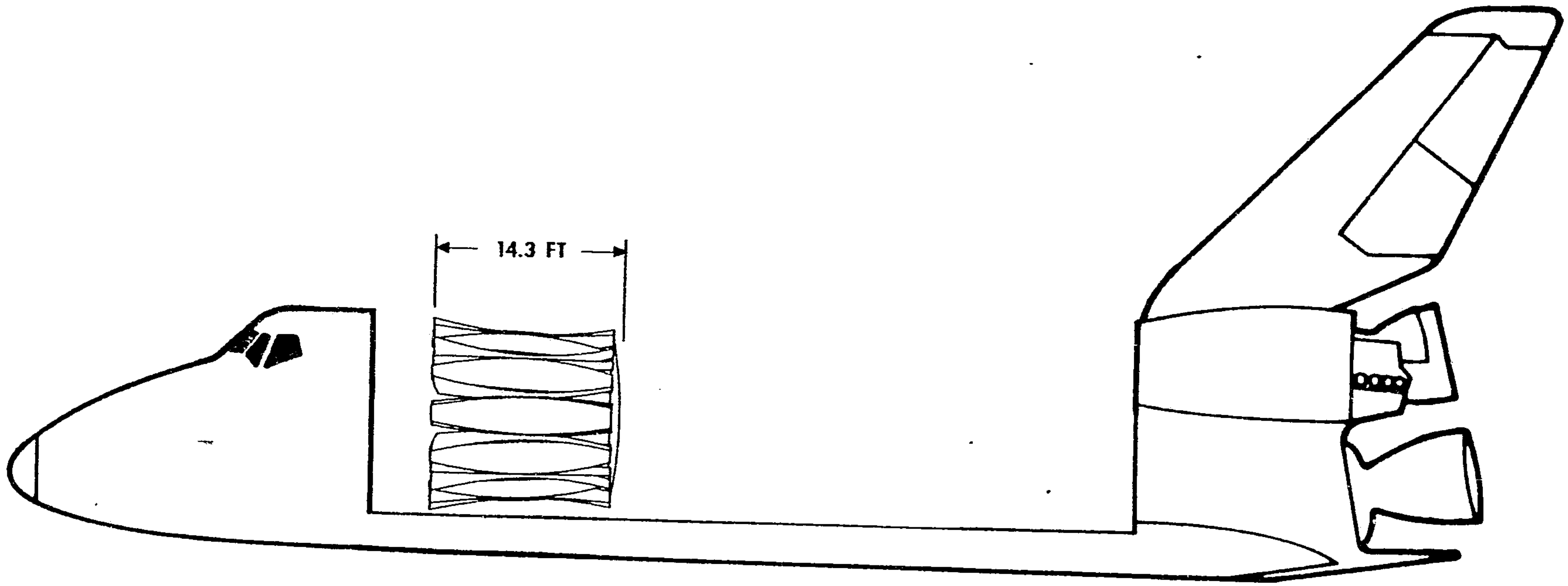


FIGURE 15 12 MAIN PANEL CONFIGURATION IN SHUTTLE

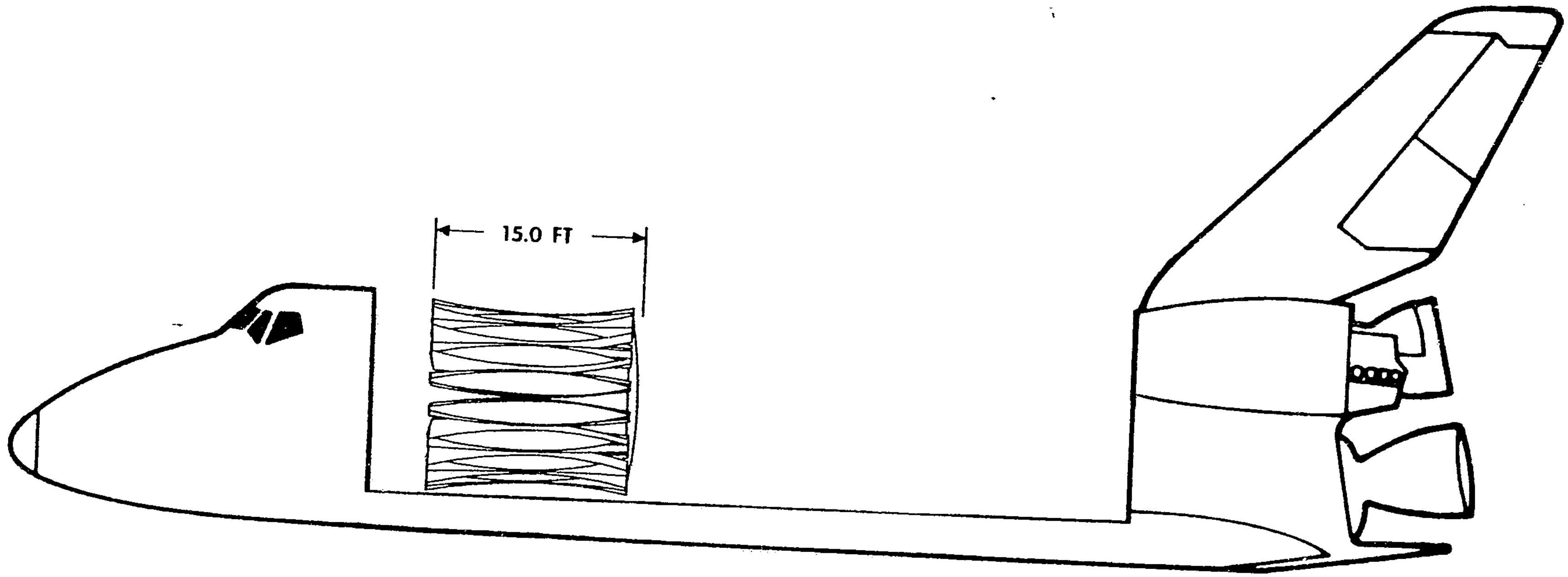


FIGURE 16 18 MAIN PANEL CONFIGURATION IN SHUTTLE

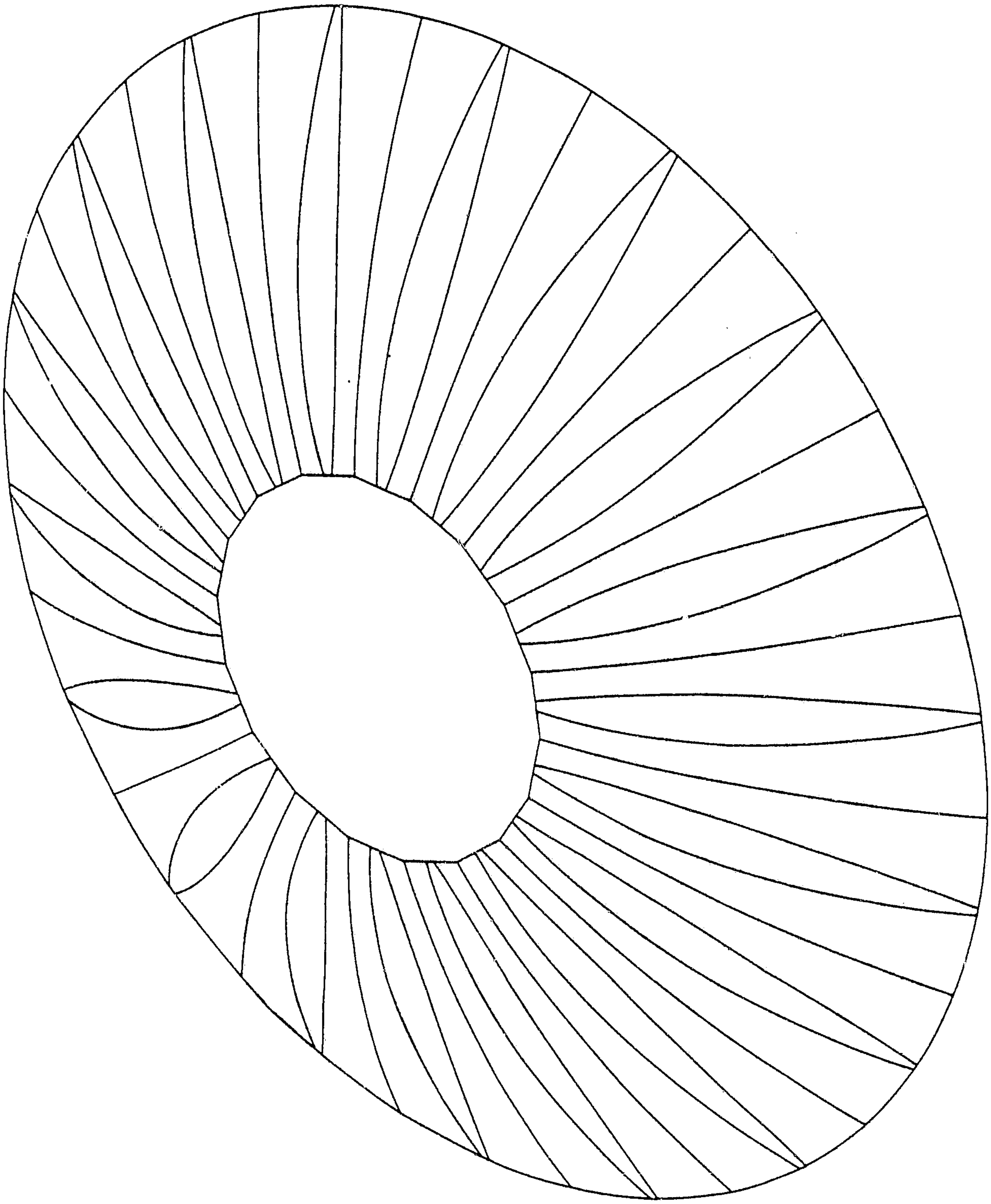


FIGURE 17 18 MAIN PANEL CONFIGURATION, DEPLOYED

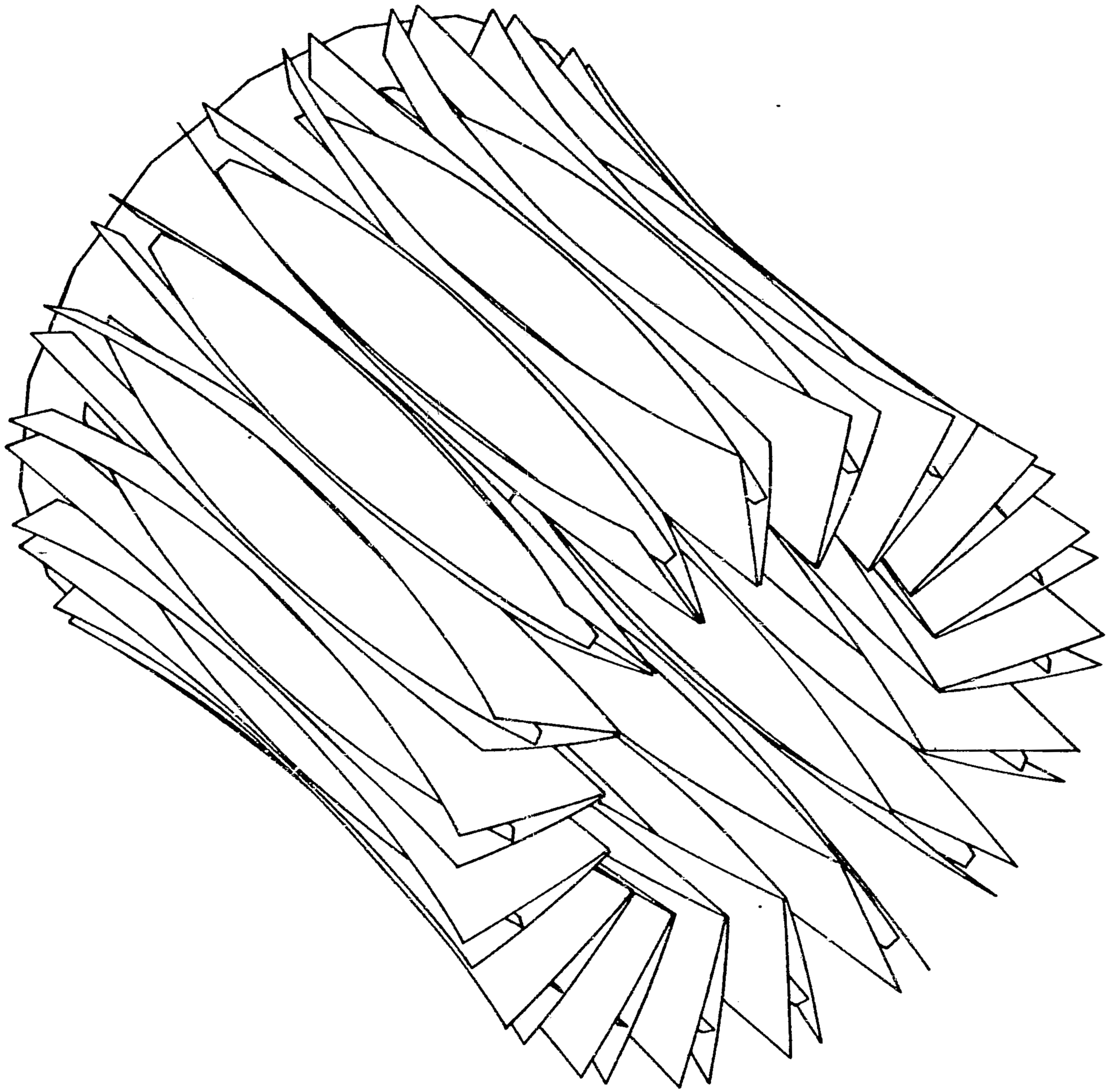


FIGURE 18 18 MAIN PANEL CONFIGURATION, STOWED

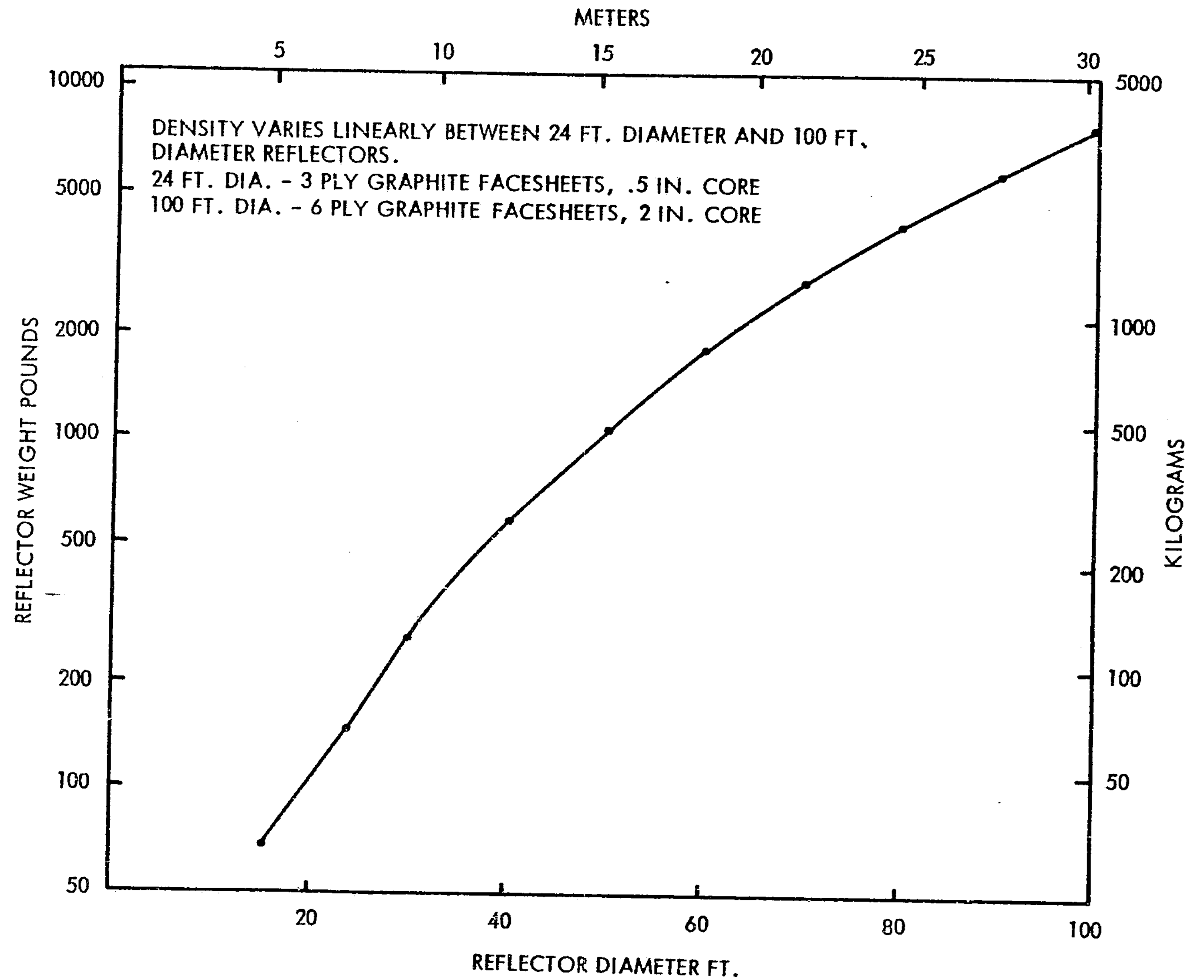


FIGURE 19 ANTENNA REFLECTOR WEIGHT VS. DIAMETER

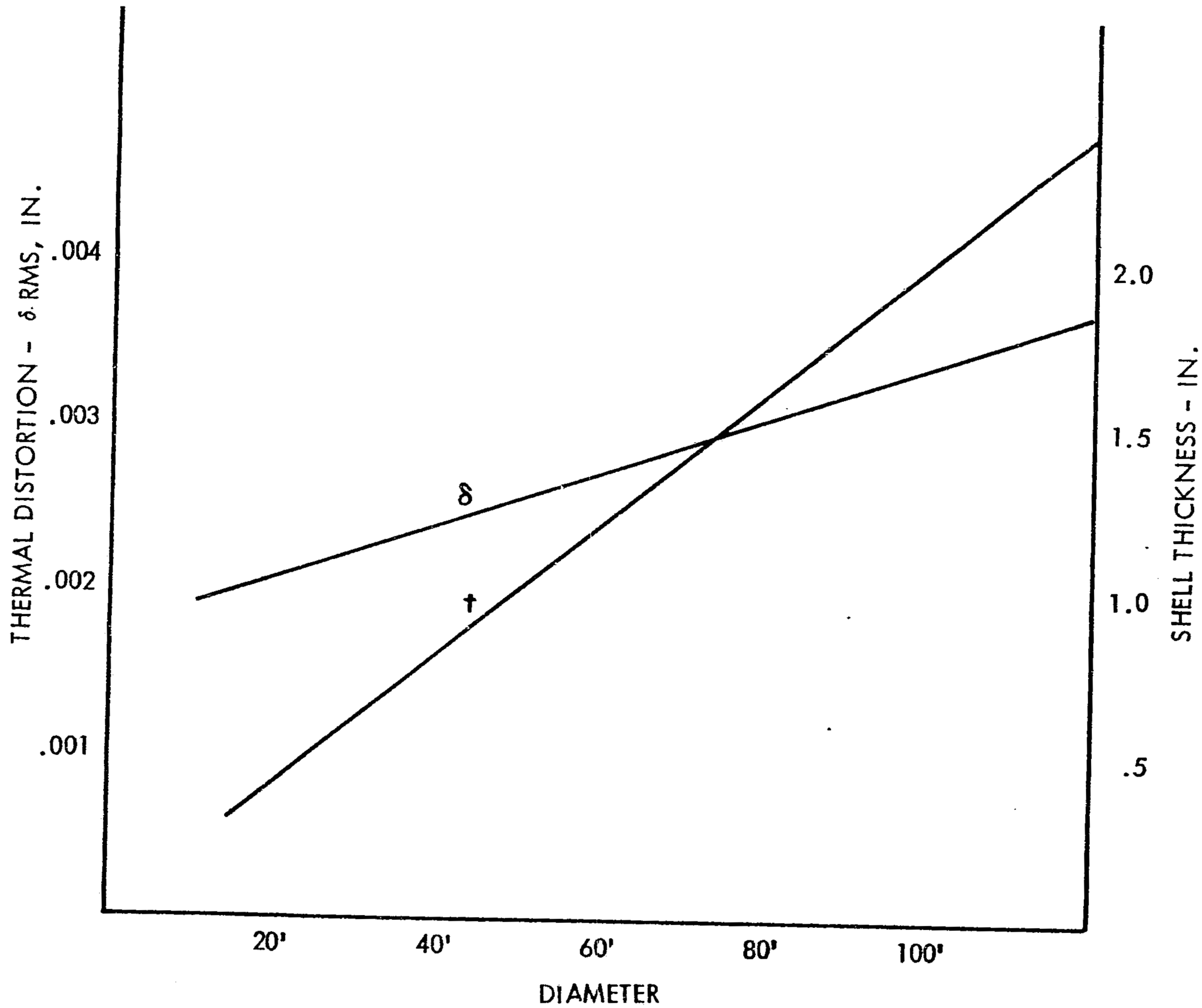


FIGURE 20 THERMAL DISTORTION AND SHELL THICKNESS VS. REFLECTOR DIAMETER

TABLE 1 ESTIMATE OF RMS ERROR, EXISTING TECHNOLOGY

ERROR CONTRIBUTOR	1 RING			2 RINGS			3 RINGS		
	20'	30'	40'	40'	60'	80'	80'	100'	120'
AS FABRICATED	.017	.020	.031	.0154	.0294	.043	.029	.038	.047
ASSEMBLY	.001	.002	.003	.004	.005	.006	.007	.008	.009
DEPLOYMENT	.0005	.0008	.001	.0015	.002	.003	.0035	.004	.0045
THERMAL	.002	.0022	.0024	.0024	.0027	.003	.003	.0034	.0037
TOTAL	.0205	.0250	.0374	.0233	.0391	.0540	.0425	.0534	.0642

TABLE 2 ESTIMATE OF RMS ERROR, NEW FABRICATION TECHNOLOGY OF PANELS

ERROR CONTRIBUTOR	1 RING			2 RINGS			3 RINGS		
	20'	30'	40'	40'	60'	80'	80'	100'	120'
AS FABRICATED	.0057	.0067	.0103	.0051	.0093	.0143	.0097	.0127	.0157
ASSEMBLY	.0010	.0020	.0030	.0040	.0050	.0060	.0070	.0080	.0090
DEPLOYMENT	.0005	.0008	.0010	.0015	.0020	.0030	.0035	.0040	.0045
THERMAL	.002	.0022	.0024	.0024	.0027	.0030	.0030	.0034	.0037
TOTAL	.0092	.0117	.0167	.0130	.0195	.0263	.0232	.0281	.0329

TABLE 3 ESTIMATE OF RMS ERROR, POST FABRICATION PANEL ADJUSTMENT

ERROR CONTRIBUTOR	1 RING			2 RINGS			3 RINGS		
	20'	30'	40'	40'	60'	80'	80'	100'	120'
POST FAB ADJUSTMENT	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005
ASSEMBLY	.0010	.0020	.0030	.0040	.0050	.0060	.0070	.0080	.0090
DEPLOYMENT	.0005	.0008	.001	.0015	.0020	.0030	.0035	.0040	.0045
THERMAL	.0020	.0022	.0024	.0024	.0027	.0030	.0030	.0034	.0037
TOTAL	.0040	.0055	.0069	.0084	.0102	.0125	.0140	.0159	.0177

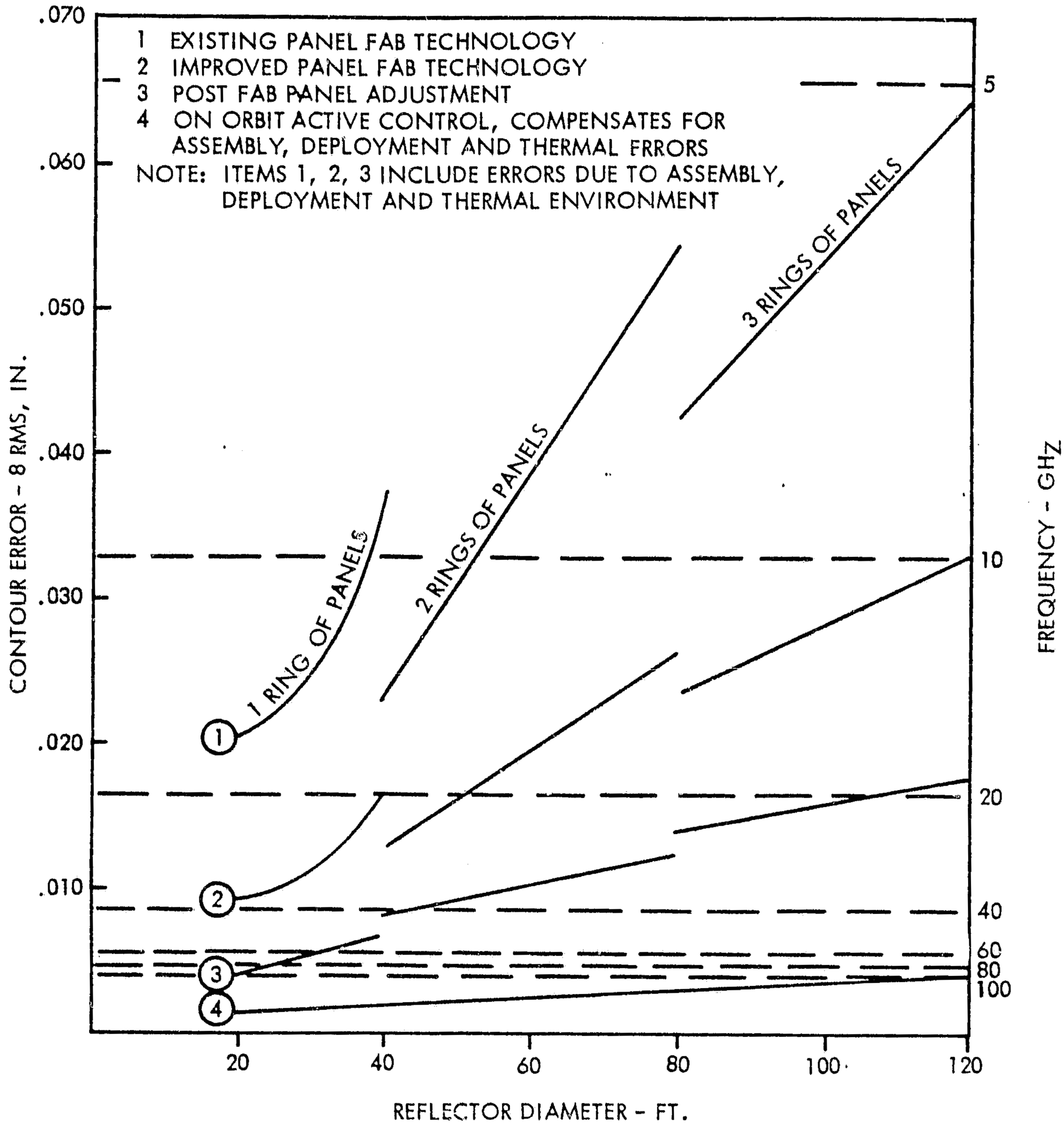


FIGURE 21 PREDICTED CONTOUR ACCURACY OF LARGE DEPLOYABLE REFLECTORS LAUNCHED ON SHUTTLE

TABLE 4 CRITICAL TECHNOLOGY STUDY 1

TITLE: CONTOUR ACCURACY CONTROL FOR PRECISION DEPLOYABLE REFLECTORS.

OBJECTIVE: IMPROVE ACCURACY OF FABRICATING INDIVIDUAL PANELS.

APPROACH: DESIGN, FABRICATE AND MEASURE PANELS TO DEMONSTRATE THE ADVANTAGE OF ONE CONFIGURATION OVER ANOTHER. ANALYTICAL MODELING WILL BE UTILIZED WHERE FEASIBLE TO PREDICT THE EFFECT OF THE VARIOUS PARAMETERS.

TASKS:

- IDENTIFY PARAMETERS THAT COULD CONTRIBUTE TO DISTORTION
- MODEL PANEL AND VARY PARAMETERS TO ASCERTAIN CONTRIBUTION OF EACH
- DESIGN TEST PANELS TO ISOLATE EACH PARAMETER TO DETERMINE ITS CONTRIBUTION
- FABRICATE BOTH FLAT AND CURVED PANELS TO ISOLATE THE PARAMETERS AND PROVIDE CONTROL AND REPEATABILITY OF THE FABRICATION PROCESSES
- MEASURE CONTOUR ACCURACY
- OPTIMIZE THE CONFIGURATION

TABLE 5 CRITICAL TECHNOLOGY STUDY 2

TITLE:	CONTOUR ACCURACY IMPROVEMENT BY POST-FABRICATION ADJUSTMENT OF PRECISION DEPLOYABLE REFLECTORS.
OBJECTIVE:	DEVELOP CONCEPT FOR IMPROVING ACCURACY OF INDIVIDUAL PANELS BY POST FABRICATION ADJUSTMENT.
APPROACH:	ONE OR MORE CONFIGURATIONS WILL BE CHOSEN FROM TRADE-OFF STUDIES OF VARIOUS CONCEPTS. THE ACCURACY OF THE CONCEPTS WILL BE DEMONSTRATED BY DESIGNING, FABRICATING AND MEASURING THE CONTOUR OF PANELS REPRESENTATIVE OF A DESIRED LARGE DIAMETER REFLECTOR.

TASKS:

- CONCEPTUAL DESIGN OF ALTERNATE CONFIGURATIONS
- USE ANALYTICAL MODEL TO DETERMINE OPTIMUM NUMBER AND LOCATION OF ADJUSTMENT POINTS
- CHOOSE PRIME CONFIGURATION AND DESIGN SHELL, AND BACK-UP STRUCTURE
- FABRICATE SHELL ON EXISTING MOLD OF 98 IN. FOCAL LENGTH IF DEEMED ADEQUATE
- FABRICATE BACK-UP STRUCTURE
- MEASURE CONTOUR
- ADJUST TO OPTIMIZE CONTOUR

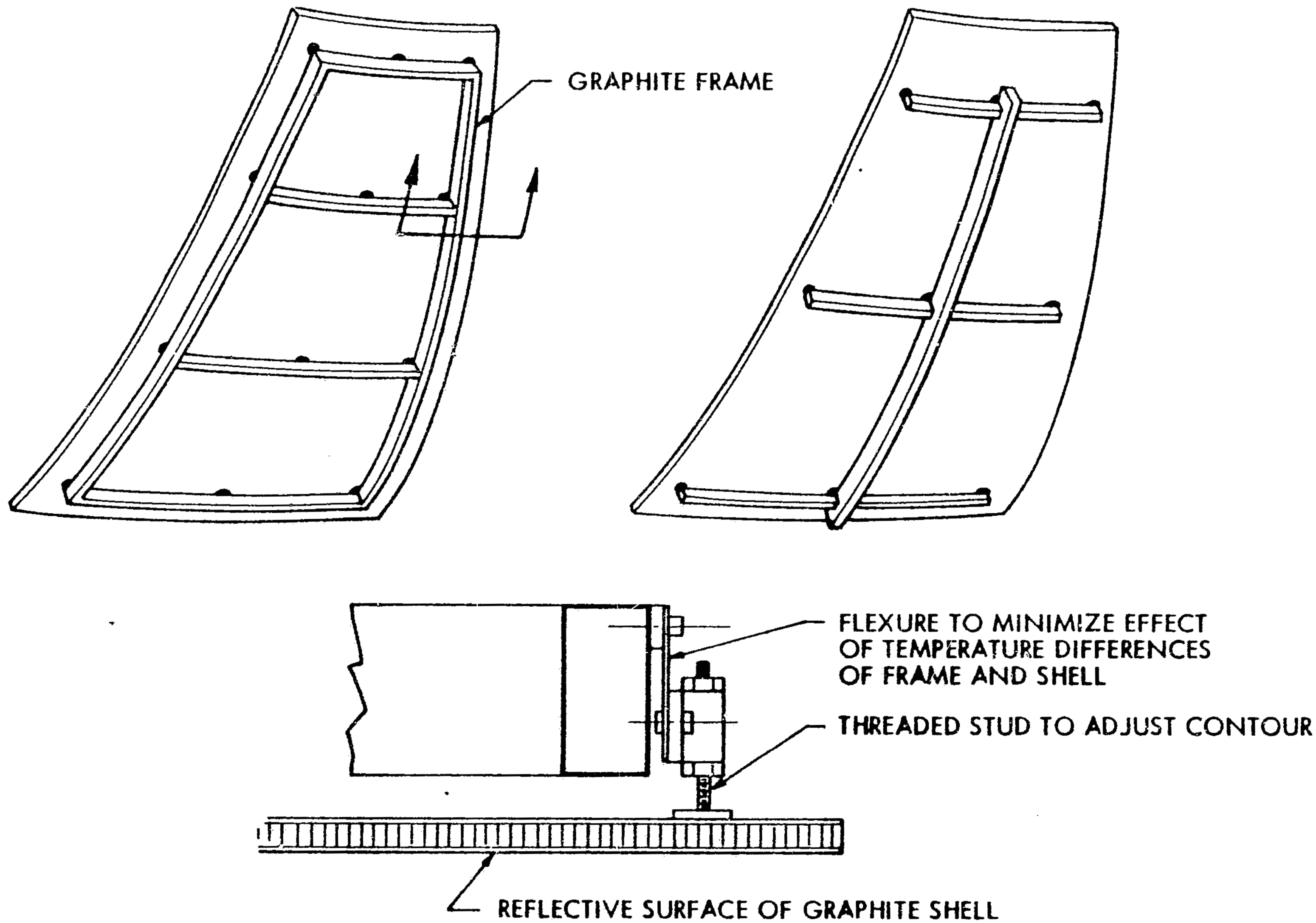


FIGURE 22 CONTOUR ADJUSTMENT CONCEPTS

TABLE 6 CRITICAL TECHNOLOGY STUDY 3

TITLE:	A STUDY OF ACTIVE CONTOUR CONTROL OF LARGE PRECISION DEPLOYABLE REFLECTORS.
OBJECTIVE:	DEVELOP CONCEPT FOR IMPROVING ACCURACY OF COMPLETE REFLECTOR IN SPACE WITH ACTIVE ADJUSTMENT.
APPROACH:	AN ANALYTICAL MODEL WILL BE USED TO PERFORM THE TRADE-OFFS OF THE CONCEPTUAL DESIGNS. AFTER THE ADJUSTMENT LOCATIONS AND THE REQUIRED FORCE/MOTION IS DETERMINED THE ACTUATING SYSTEM WILL BE DESIGNED. ONE OR MORE TYPICAL JOINTS WILL BE DESIGNED, FABRICATED AND TESTED TO VERIFY ITS CAPABILITY. A BREADBOARD OF THE SENSOR SYSTEM AND CONTROL ELECTRONICS WILL BE DESIGNED AND BUILT TO DEMONSTRATE THE COMPLETE SYSTEM ON A REPRESENTATIVE PANEL.

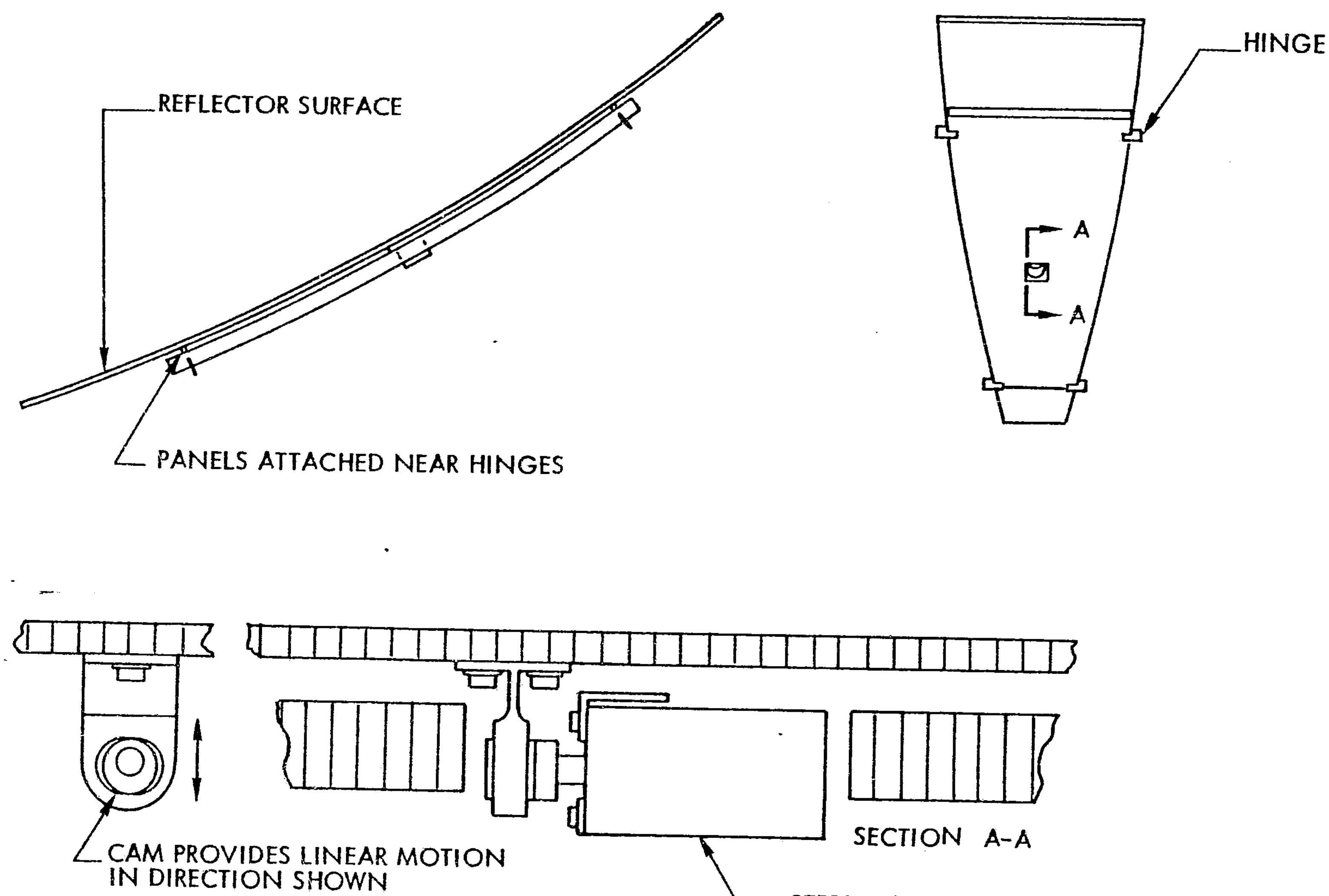


FIGURE 23 ANTENNA REFLECTOR ON-ORBIT ACTIVE ADJUSTMENT

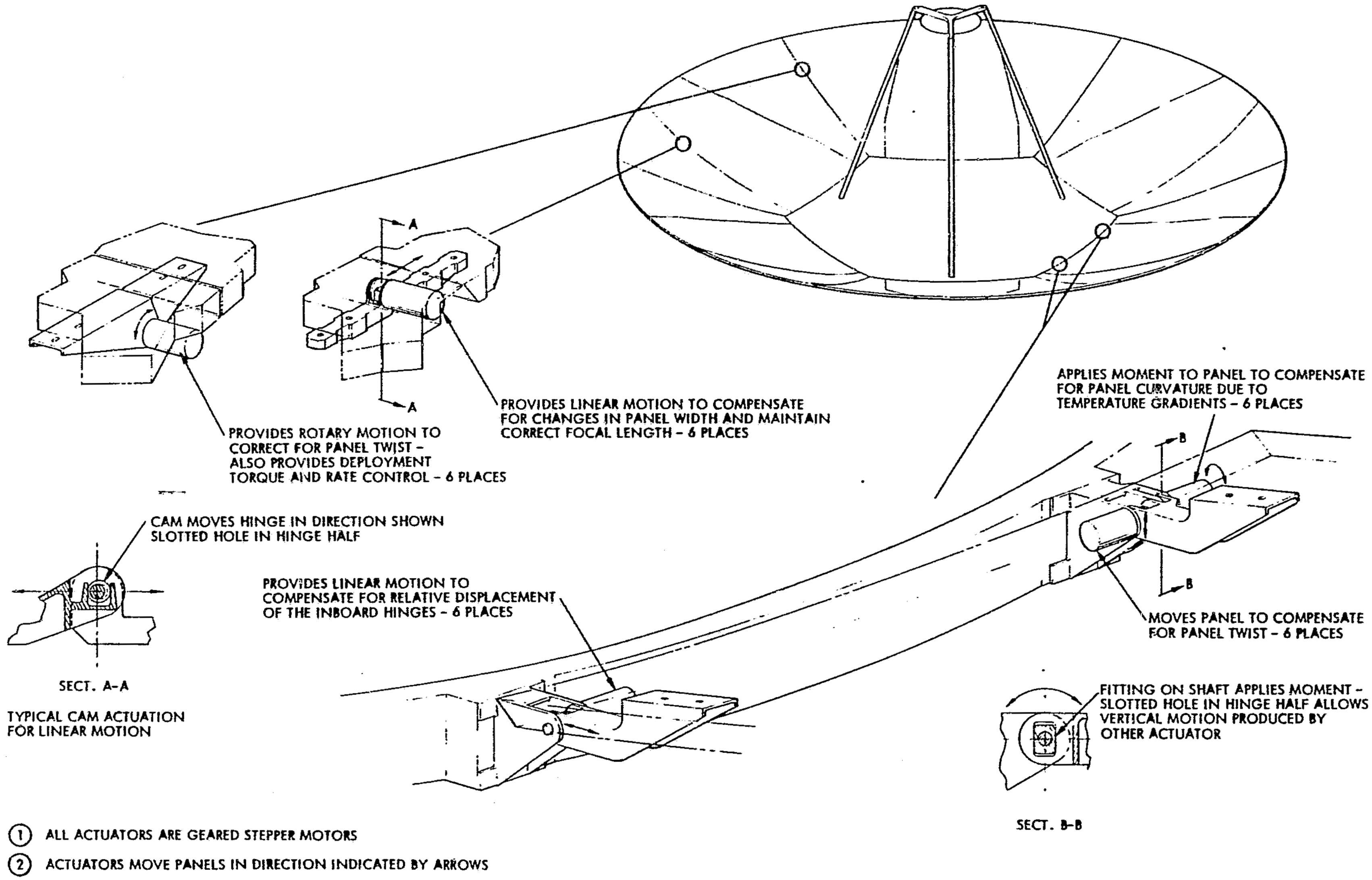


FIGURE 24 SHAPE CONTROL ACTUATION SYSTEM FOR LARGE PRECISION DEPLOYABLE REFLECTORS

TABLE 7 CRITICAL TECHNOLOGY STUDY 4

TITLE:	A STUDY OF LAYUP MOLDS FOR LARGE PRECISION DEPLOYABLE ANTENNA REFLECTORS.
OBJECTIVE:	TO DEFINE A MOLD CONFIGURATION THAT WILL PROVIDE THE NECESSARY ACCURACY WITH MINIMUM PRODUCIBLITY COSTS.
APPROACH:	DESIGN REQUIREMENTS WILL BE DEFINED. METHODS FOR FABRICATING THE MOLD WILL BE COMPARED AND SIZE CONSTRAINTS ESTABLISHED. A PRELIMINARY DESIGN WILL INCORPORATE THE REQUIRED FEATURES FOR THE MOST COST EFFECTIVE CONFIGURATION.

TASKS:

- DEFINE ACCURACY AND SIZE REQUIREMENTS
- CONSIDER FABRICATION METHODS TO PROVIDE THE DESIRED ACCURACY
- DETERMINE SIZE LIMITATIONS OF MOLD FOR INDIVIDUAL REFLECTOR PANELS
- DETERMINE OPTIMUM MATERIAL FOR MOLD
- DEFINE TEMPERATURE CONTROL SYSTEM FOR CURING REFLECTOR PANELS
- PRELIMINARY DESIGN OF MOLD
- PROVIDE COST ESTIMATES FOR VARIOUS SIZE AND ACCURACY REQUIREMENTS

TABLE 8 CRITICAL TECHNOLOGY STUDY 5

TITLE:	CONTOUR MEASUREMENT SYSTEM FOR LARGE, SOLID SURFACE, ANTENNA REFLECTORS.
OBJECTIVE:	DEVELOP CRITICAL COMPONENTS OF THE MEASUREMENT SYSTEM.
APPROACH:	A CONFIGURATION WILL BE CHOSEN FROM ALTERNATE CONCEPTS. CRITICAL COMPONENTS WILL BE DESIGNED AND FABRICATED TO VERIFY THE OPERATION AND ACCURACY OF THE SYSTEM.
TASKS:	• PERFORM CONCEPTUAL DESIGN OF ALTERNATE CONFIGURATIONS • MAKE TRADE OFF STUDIES OF CONFIGURATIONS • CHOOSE PRIME CONFIGURATION • DESIGN CRITICAL COMPONENTS FOR DEMONSTRATION • FABRICATE AND ASSEMBLE SYSTEM • MEASURE A PANEL TO DEMONSTRATE THE ACCURACY OF THE SYSTEM

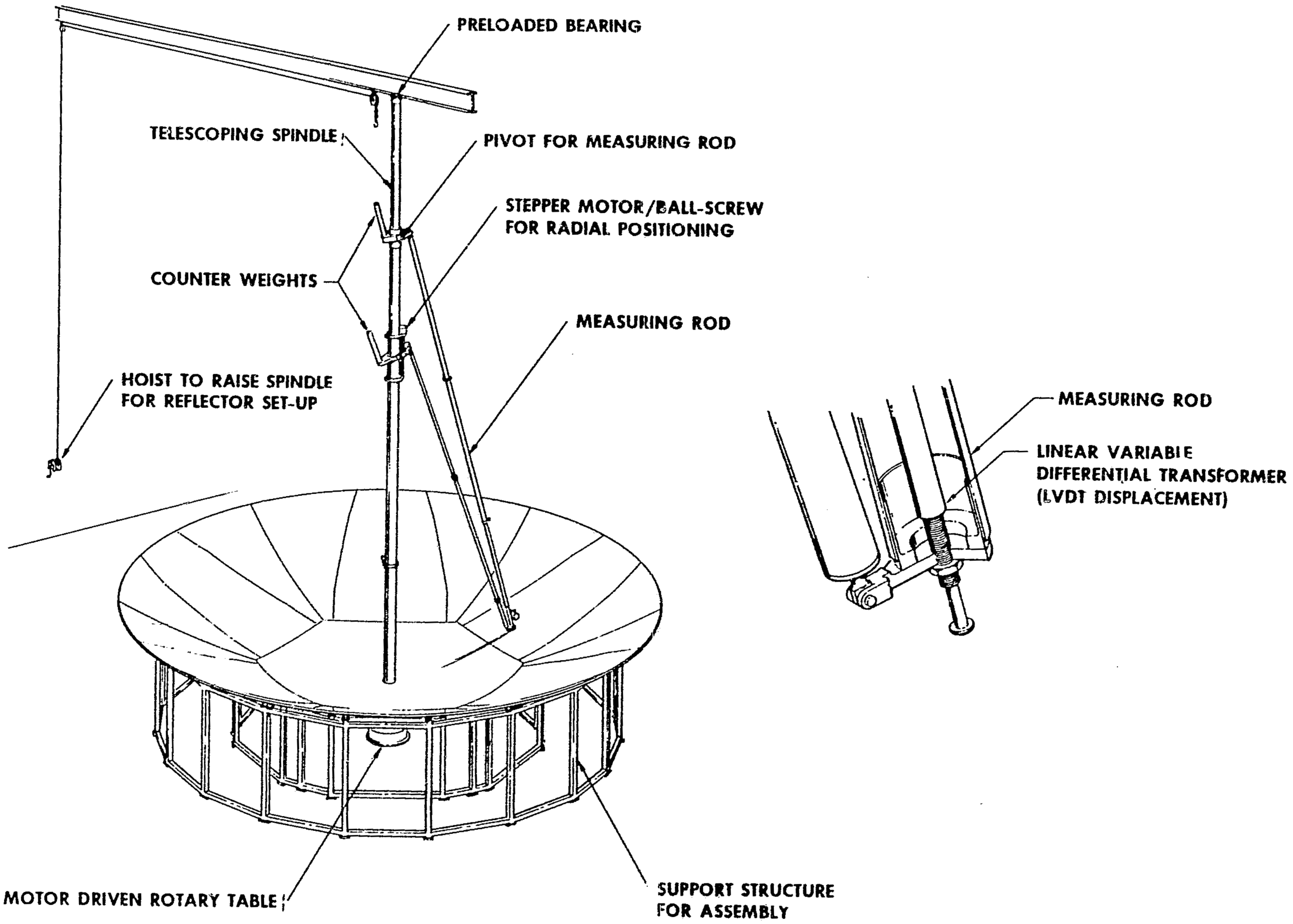
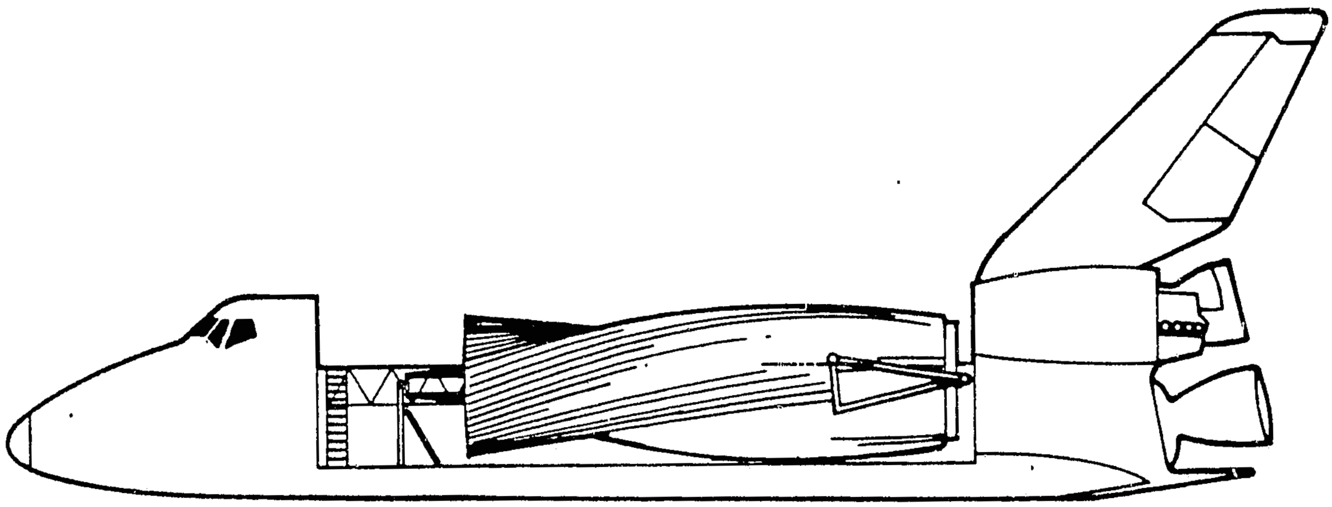
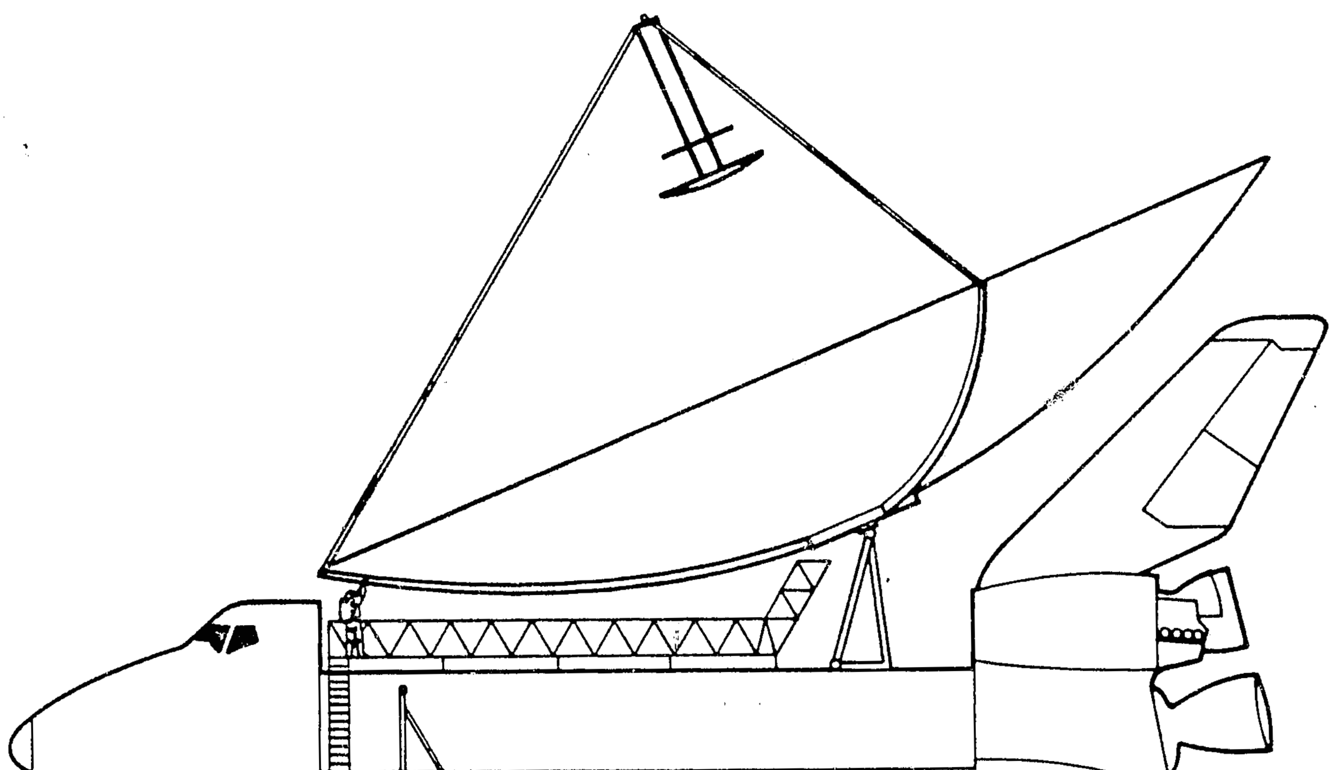


FIGURE 25 REFLECTOR ASSEMBLY AND INSPECTION TOOL



STOWED



DEPLOYED

FIGURE 26   100 FOOT DIAMETER SUNFLOWER REFLECTOR

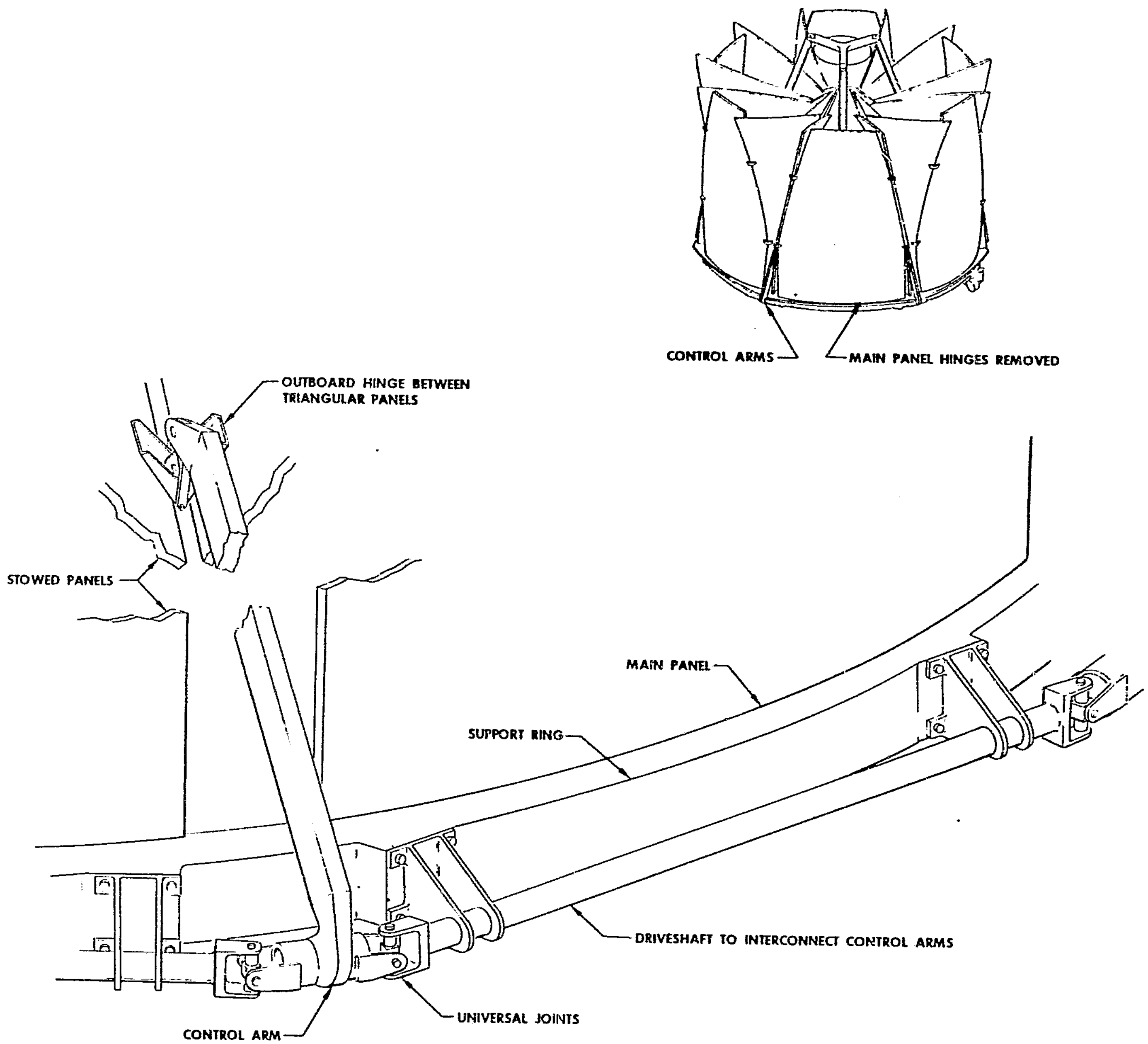


FIGURE 27 ORIGIONAL DESIGN WITHOUT MAIN PANEL HINGES

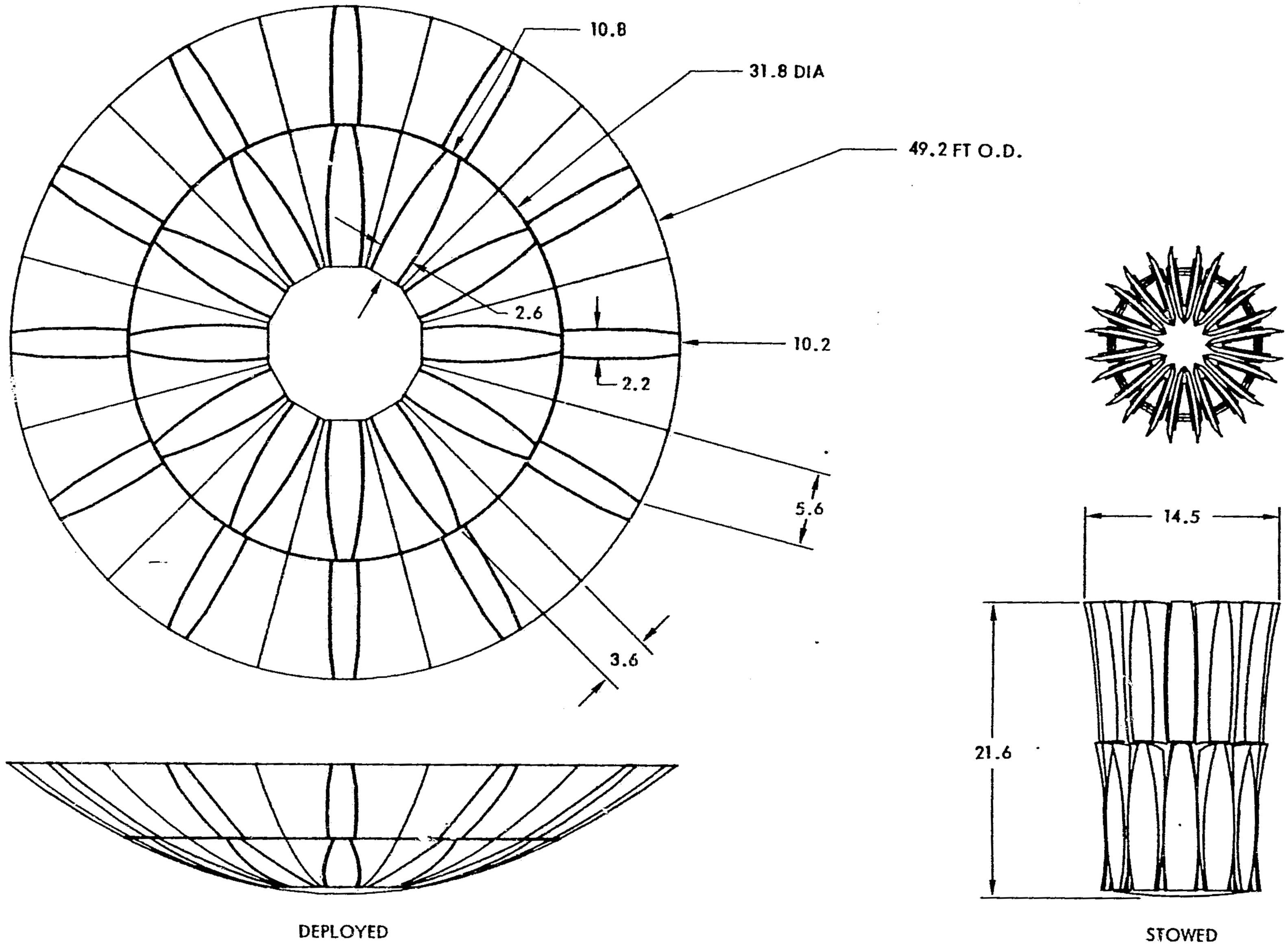


FIGURE 28 DOUBLE RING CONFIGURATION WITH EQUAL NUMBERS OF PANELS IN EACH RING (12 MAIN PANELS PER RING SHOWN)

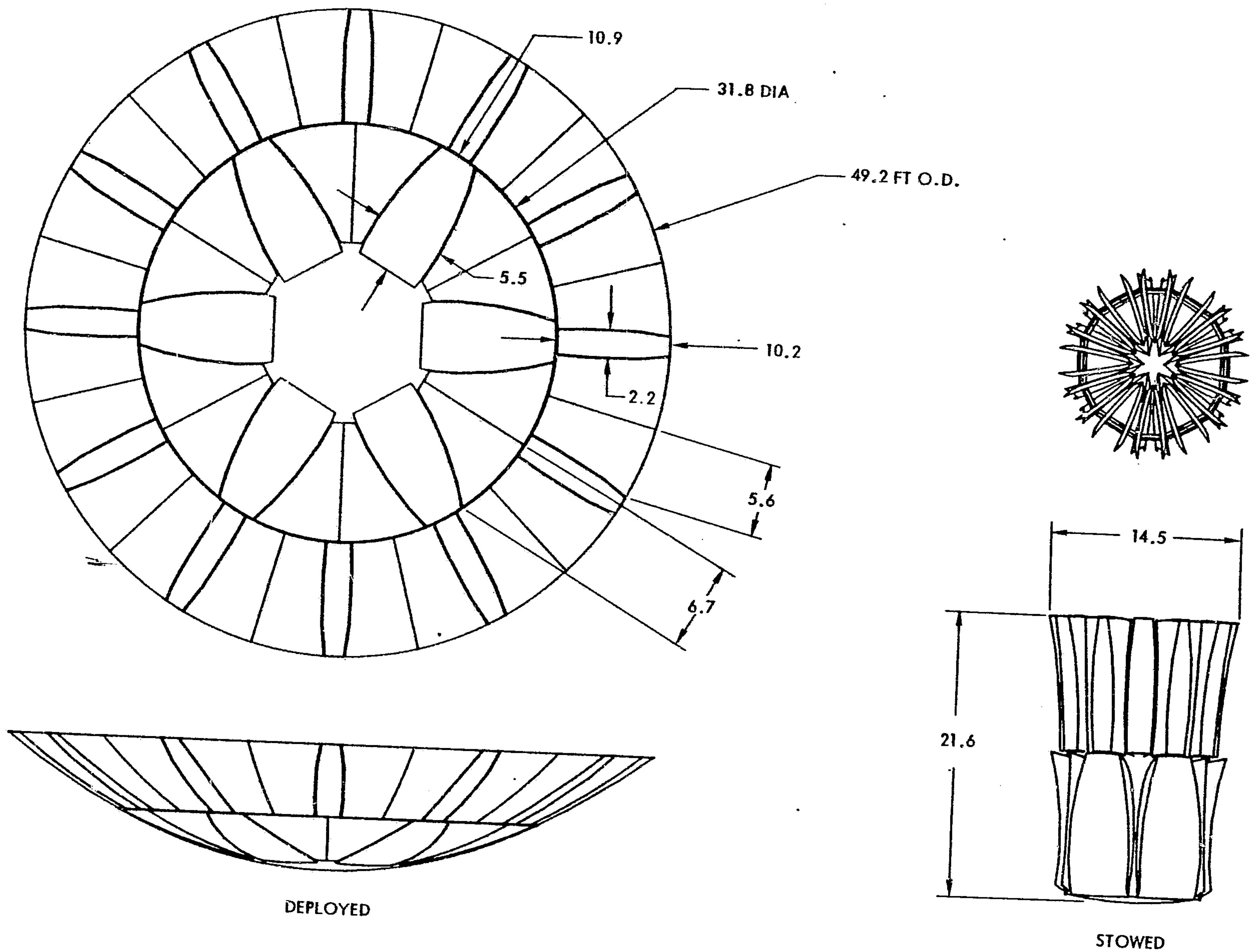


FIGURE 29 6-12 MAIN PANEL DOUBLE RING CONFIGURATION

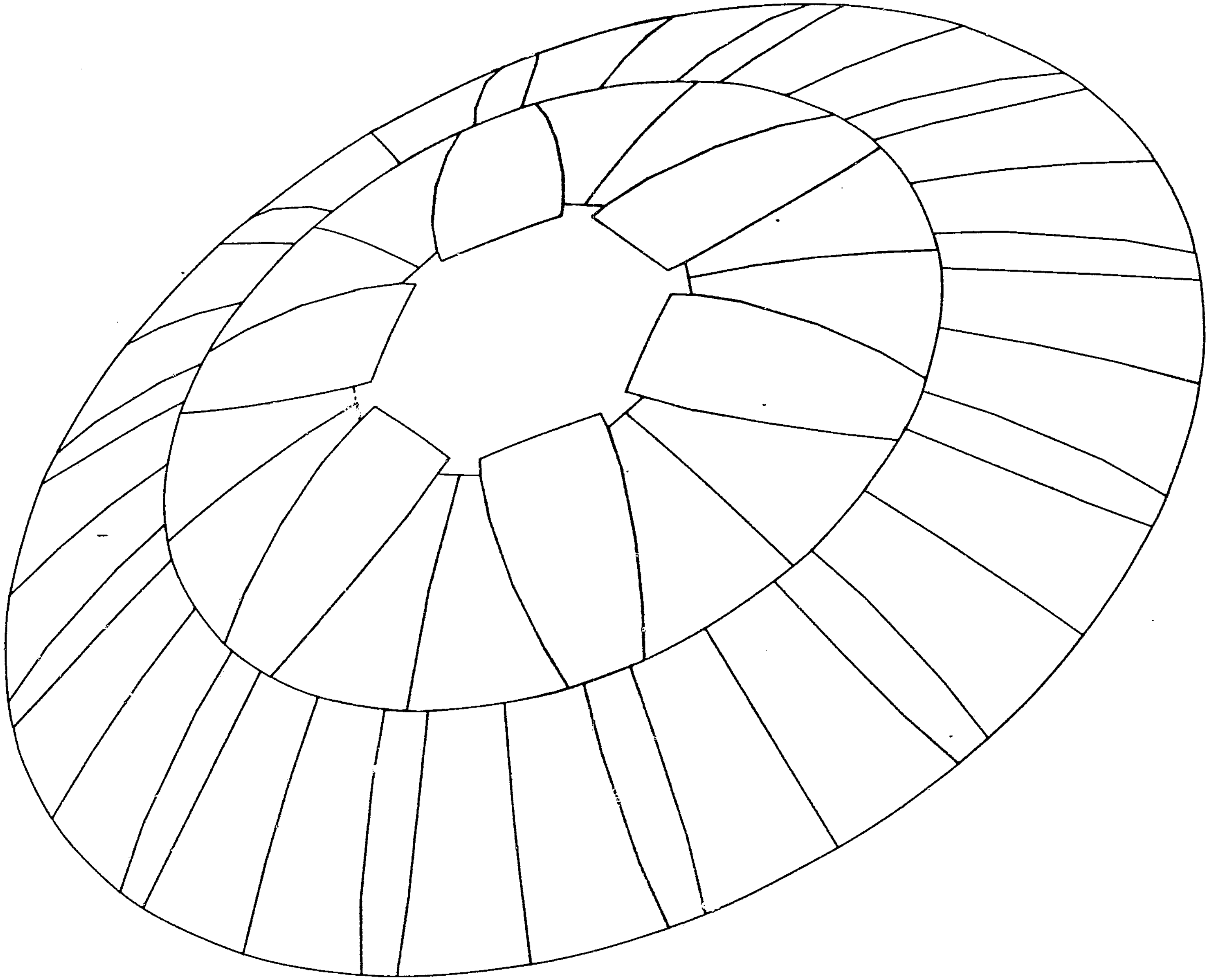


FIGURE 30 6-12 MAIN PANEL DOUBLE RING CONFIGURATION, DEPLOYED

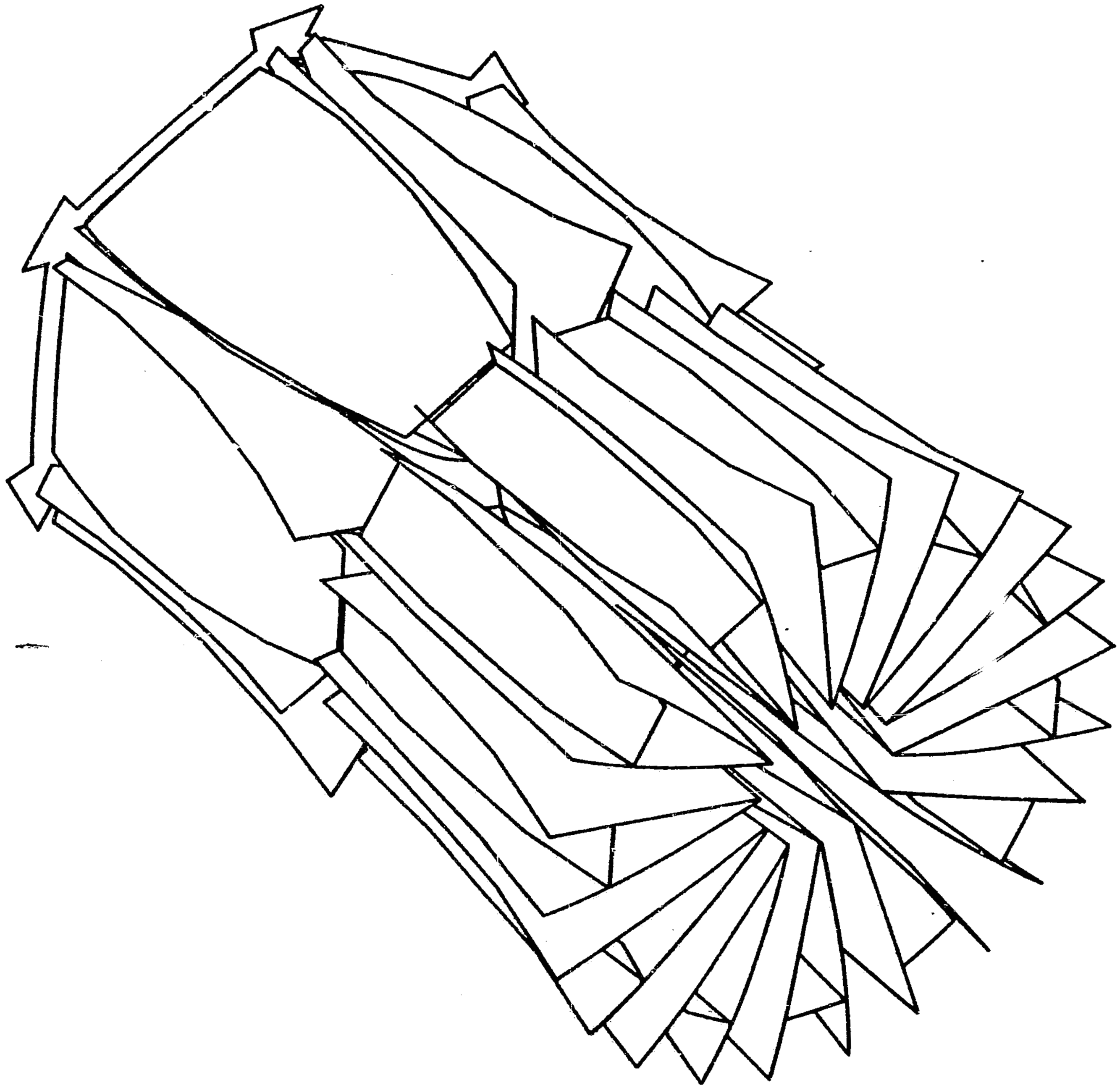


FIGURE 31   6-12 MAIN PANEL DOUBLE RING CONFIGURATION, STOWED

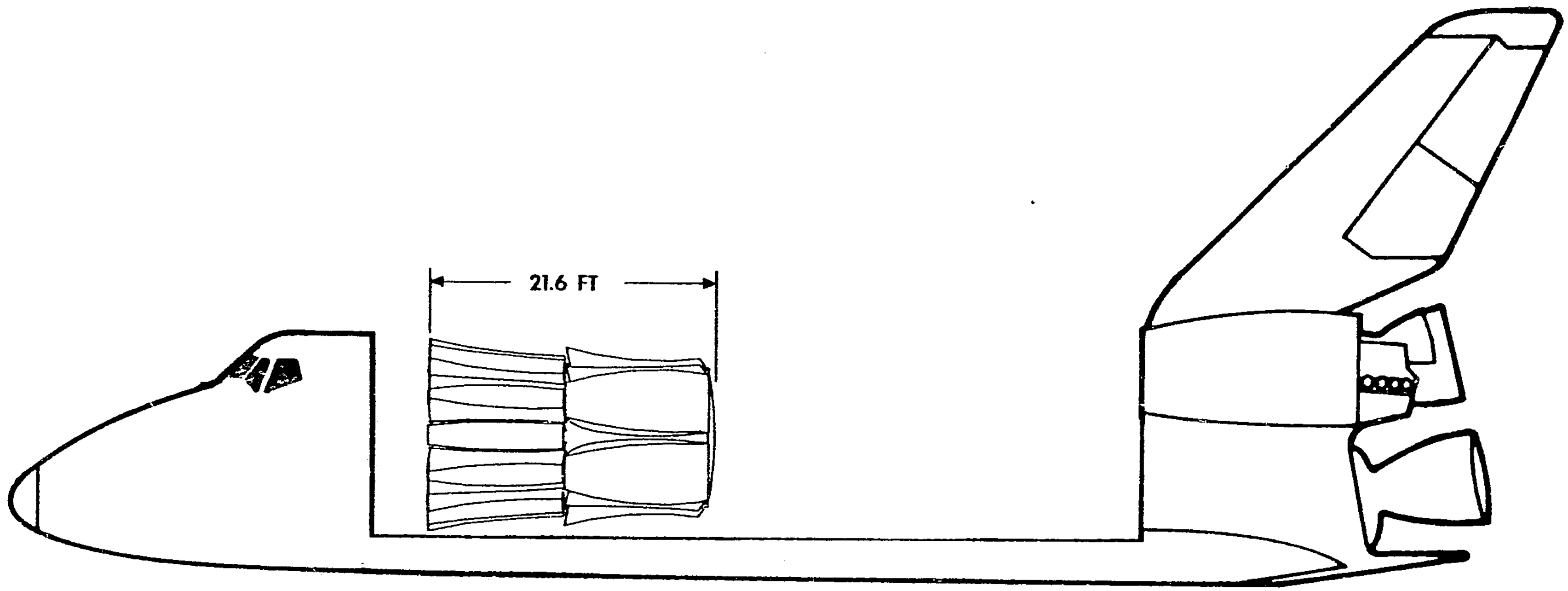


FIGURE 32 6-12 MAIN PANEL DOUBLE RING CONFIGURATION IN SHUTTLE

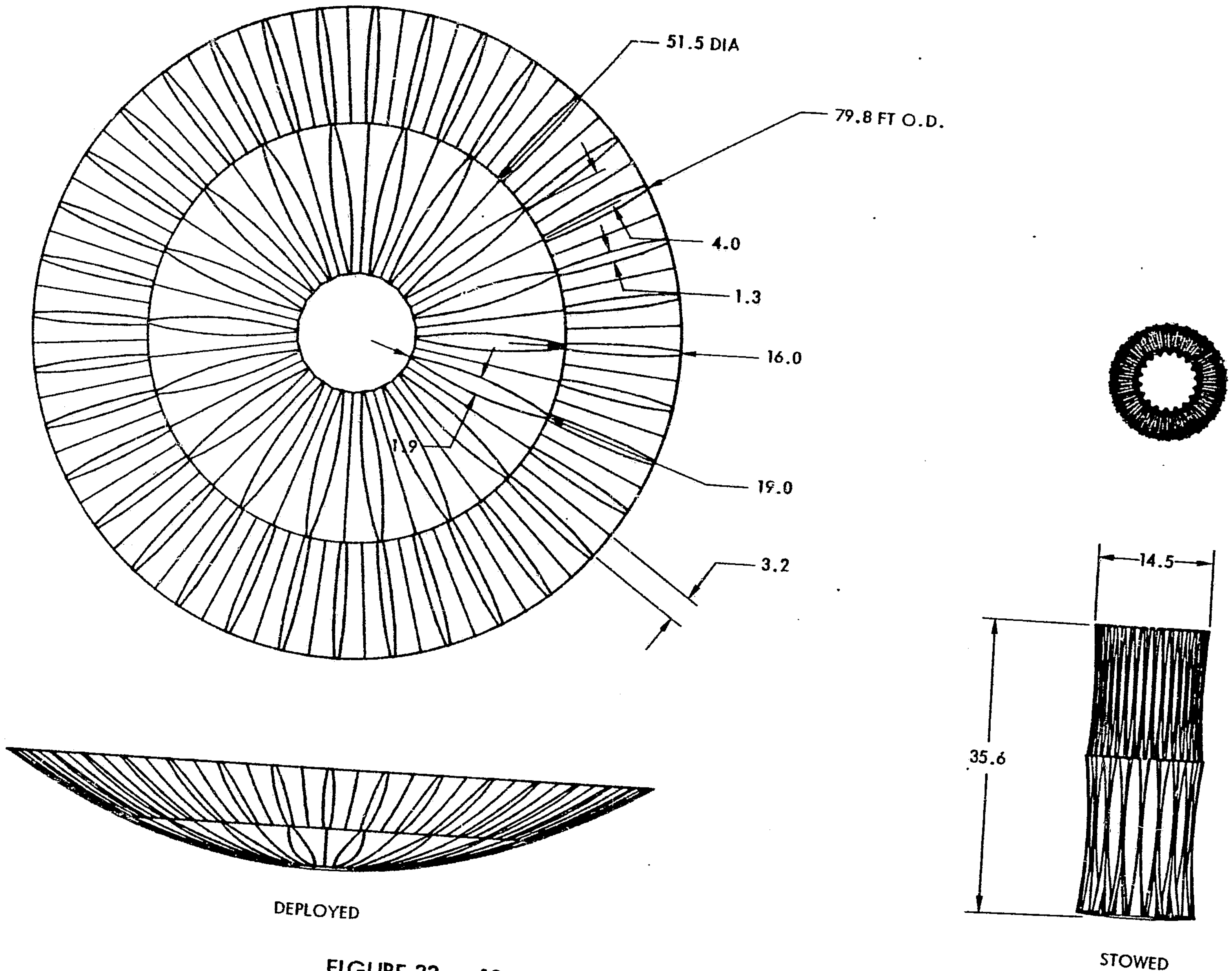


FIGURE 33 18-36 MAIN PANEL DOUBLE RING CONFIGURATION

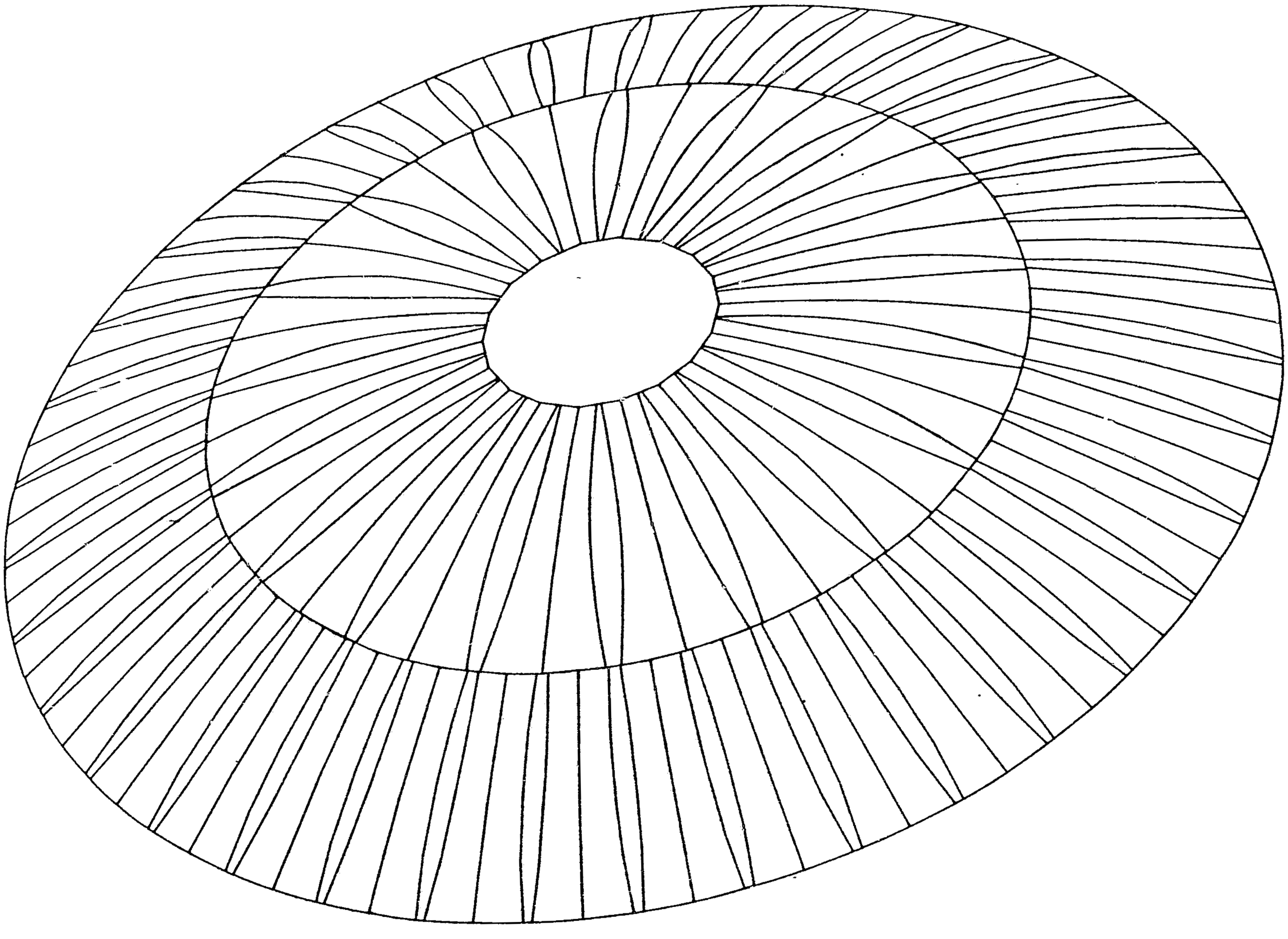


FIGURE 34 18-36 MAIN PANEL DOUBLE RING CONFIGURATION, DEPLOYED

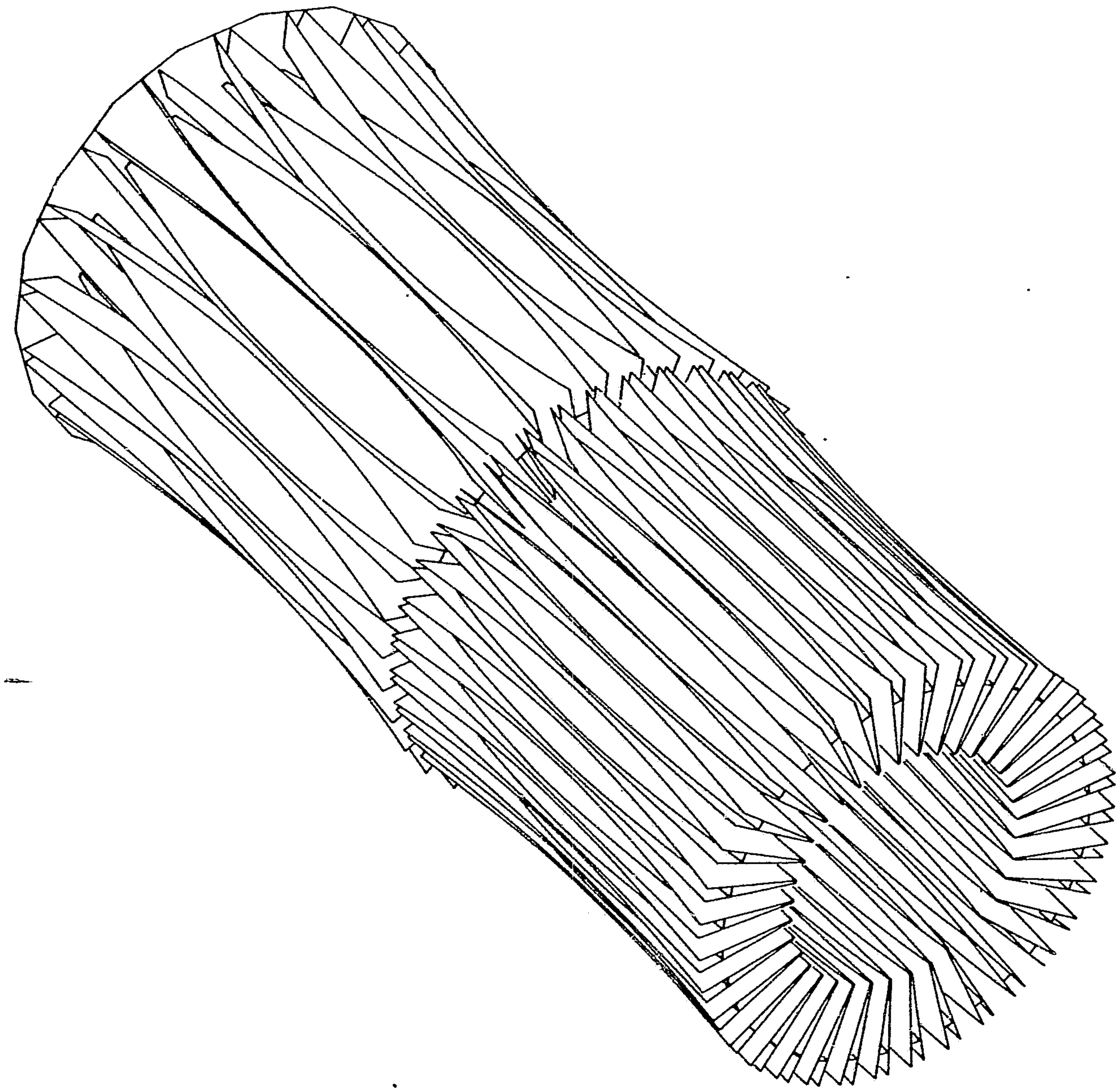


FIGURE 35 18-36 MAIN PANEL DOUBLE RING CONFIGURATION, STOWED

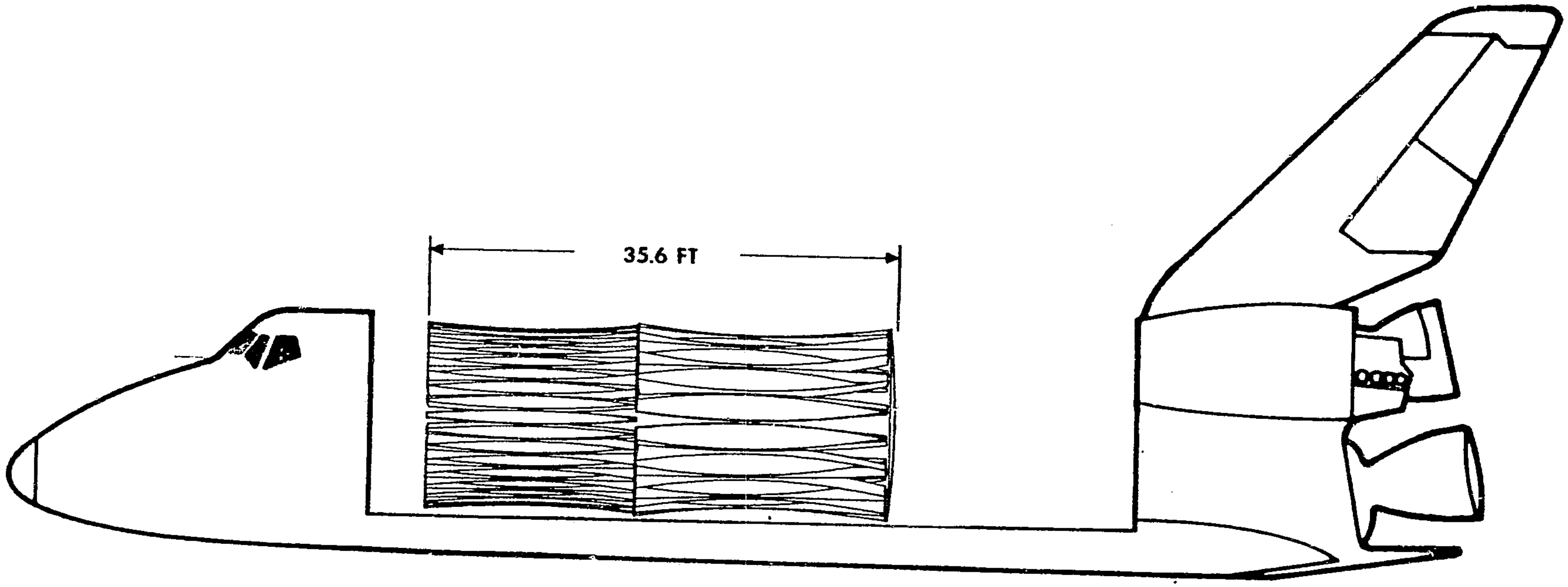


FIGURE 36 18-36 MAIN PANEL DOUBLE RING CONFIGURATION IN SHUTTLE

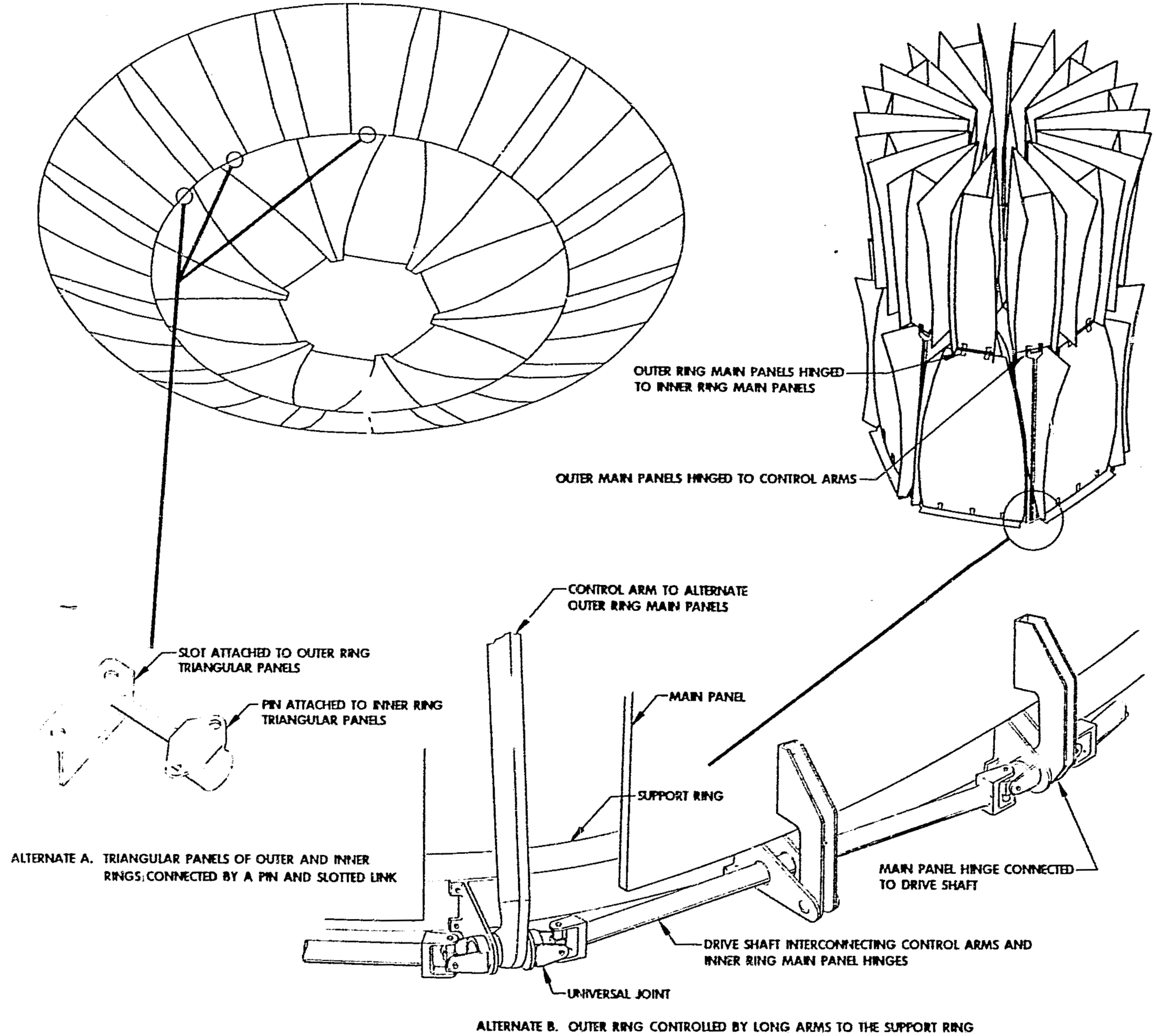


FIGURE 37 DOUBLE RING CONFIGURATION MECHANISM ALTERNATES (6-12 MAIN PANELS SHOWN)

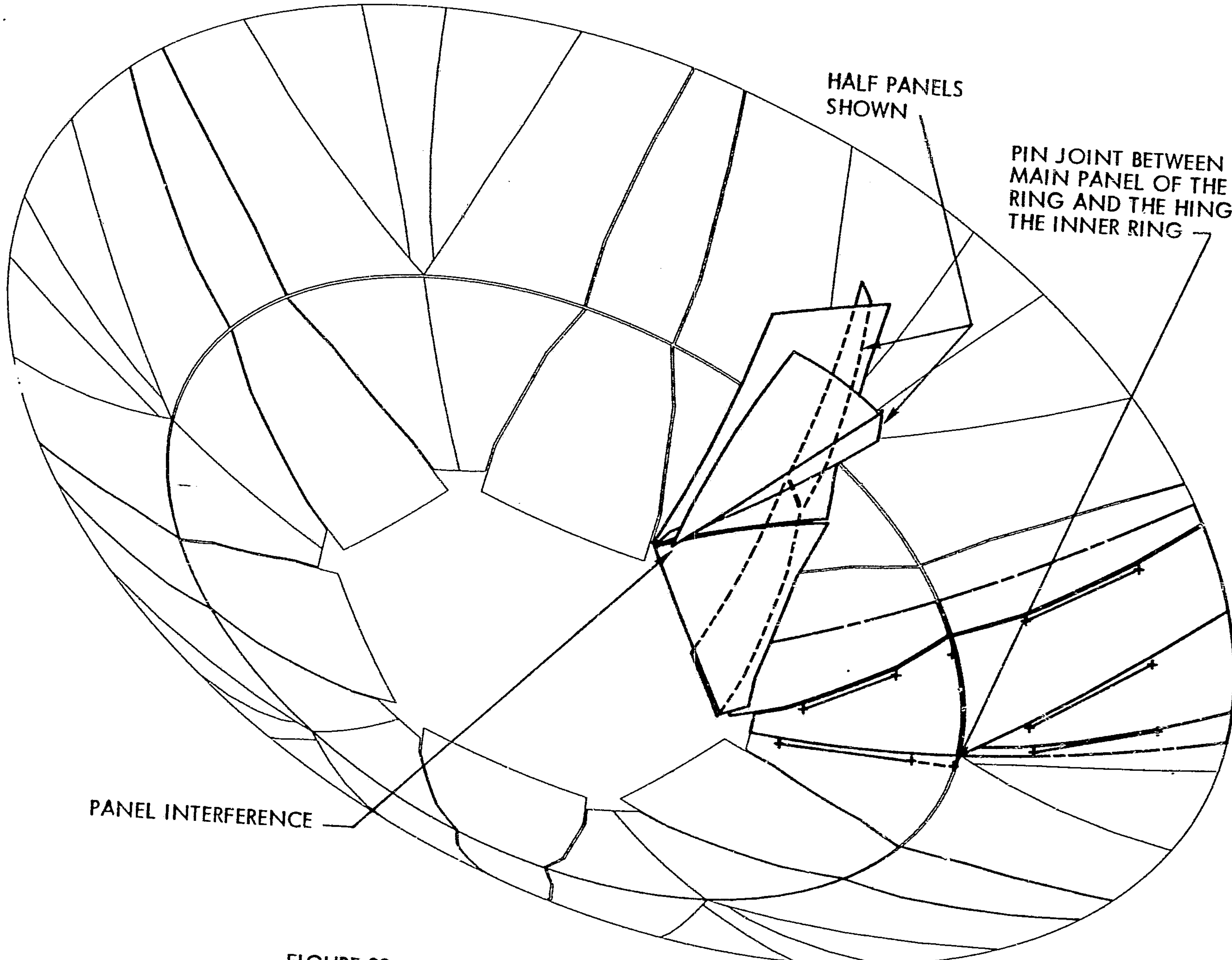


FIGURE 38 DOUBLE RING CONFIGURATION, OUTER RING PINNED TO INNER RING

TABLE 9 ROM COST ESTIMATE BREAKDOWN

CONFIGURATION	A	B	C	D
NO. MAIN PANELS, INNER RING	6	18	6	18
NO. MAIN PANELS, OUTER RING	0	0	12	36
DEPLOYED DIA, FT (METERS)	33 (10)	42 (13)	49 (15)	80 (24)
ENGINEERING	$ 615,107	$ 696,712	$ 971,213	$ 1,111,098
MANUFACTURING				
RECURRING	386,977	801,433	741,515	2,004,045
NONRECURRING	185,000	195,104	352,261	501,239
PRODUCT ASSURANCE	37,145	81,844	75,392	203,710
MATERIAL	204,093	266,213	396,357	905,030
TOTAL	$1,428,322	$2,041,306	$2,536,738	$4,725,122

ASSUMPTIONS:

- MATERIAL CHARACTERIZATION COMPLETED

DOES NOT INCLUDE THE FOLLOWING:

- ANY ENVIRONMENTAL TESTS
- GROUND HANDLING EQUIPMENT
- SHIPPING CONTAINER

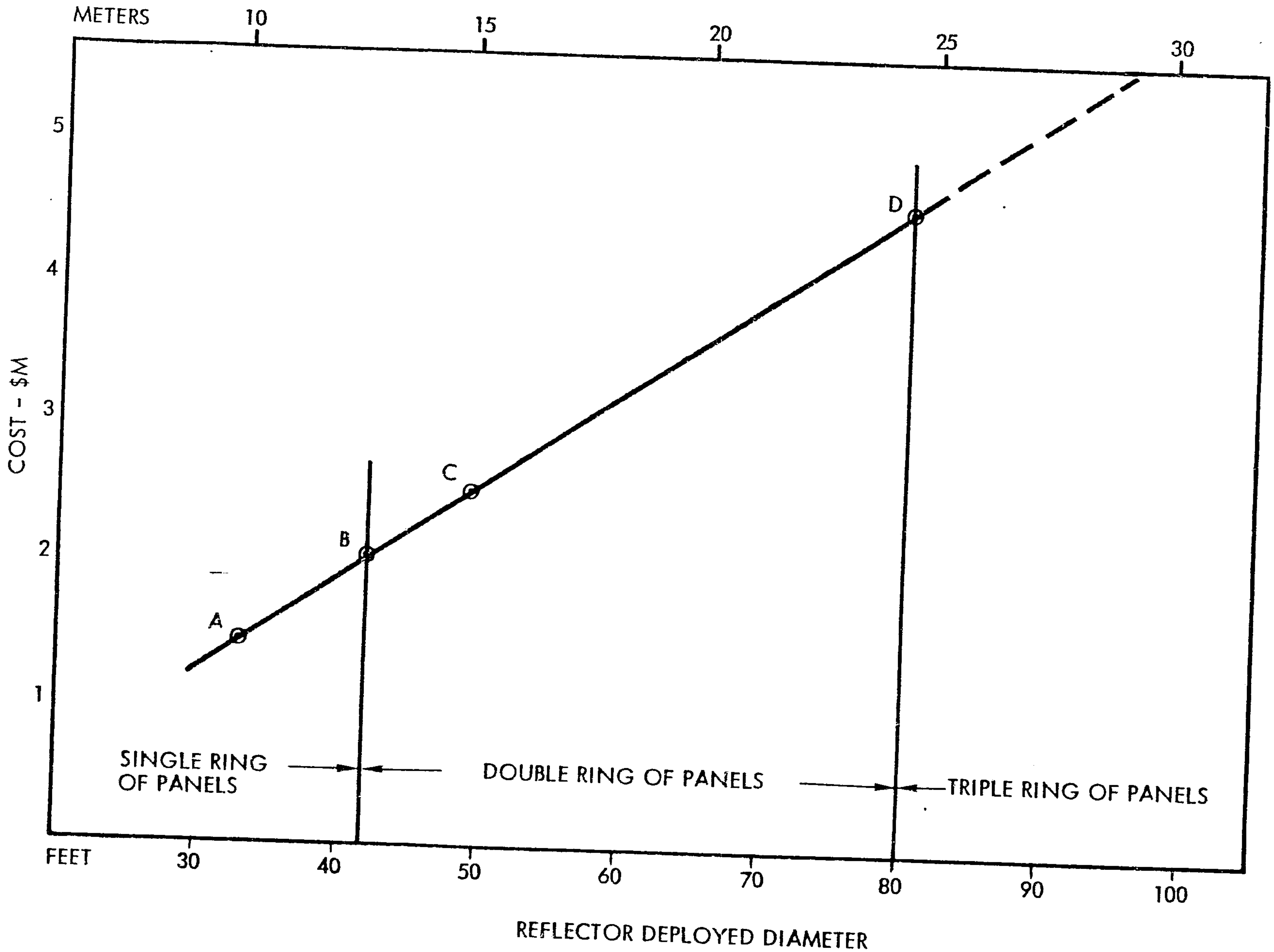


FIGURE 39 ROM COST VS. ANTENNA DIAMETER