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OFFSET WRAP RIB CONCEPT AND DEVELOPMENT

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## BACKGROUND AND STUDY OBJECTIVES

A ten month contract for "Study of Wrap Rib Antenna Design" was undertaken by Lockheed Missiles and Space Company, Inc. in January 1979. This contract was originated by Jet Propulsion Laboratory in direct support of the Large Space Structures Technology Program.

The objectives of the contract are summarized in Figure 1. LMSC was to perform a study of the Wrap Rib Antenna Design and determine the applicability of the design for offset feed configurations for antennas up to 300 meters in diameter. In addition, a technical approach was to be developed and costed which would provide a high degree of confidence for the space flight application of a large Wrap Rib Antenna.

- CHARACTERIZE OFFSET AND SYMMETRIC WRAP RIB REFLECTORS
- IDENTIFY AND QUANTIFY CRITICAL DEVELOPMENT TECHNOLOGIES
- IDENTIFY ROM COST AND SCHEDULES FOR DEVELOPMENT
- DEVELOP A TECHNOLOGY PLAN FOR LOW RISK DEMONSTRATION

Figure 1.- Study objectives.

## STUDY TASKS

The specific technical tasks performed in support of this contract were to (a) define the wrap rib antenna design for both symmetric and offset configurations in terms of surface quality, cost, weight and mechanical complexity, (b) develop a supporting deployable feed support structure and characterize it in terms of performance impact, cost, weight and mechanical complexity, and (c) develop a technical approach for implementation consisting of a combination of analysis and component test, model testing, and possibly space flight hardware demonstrations.

These tasks are summarized in Figure 2.

- **1.0 TRADE ANALYSIS - 6 MONTHS**
  - DEFINE SURFACE QUALITY VS DIAMETER
  - DEFINE WEIGHT VS DIAMETER/SURFACE QUALITY
  - DEFINE MECHANICAL DIFFERENCES BETWEEN OFFSET AND AXI-SYMMETRIC CONFIGURATIONS
  - DEVELOP FEED SUPPORT STRUCTURE CONFIGURATIONS
  - DEFINE ROM ANTENNA COST DATA
  - IDENTIFY AND QUANTIFY CRITICAL TECHNOLOGIES

- **2.0 PROGRAM PLAN - 9.5 MONTHS**
  - DEVELOP TECHNICAL PROGRAM APPROACH FOR UP TO 300 M
  - IDENTIFY ANTENNA ANALYSIS/TESTING/VERIFICATION OBJECTIVES
  - IDENTIFY COMPONENT/MODEL LEVEL OBJECTIVES
  - IDENTIFY FULL UNIT 1-G AND FLIGHT LEVEL OBJECTIVES
  - IDENTIFY AND QUANTIFY TECHNOLOGY ITEMS
  - IDENTIFY FACILITY REQUIREMENTS

- **FINAL REPORT - 10 MONTHS**

Figure 2.- Study tasks/schedule.

## ANTENNA GEOMETRY

To date the large antenna systems are most commonly constructed as symmetric reflector systems. This geometry is shown in the left of Figure 3. Concerns with efficiency and side lobe levels have recently placed emphasis on the offset feed configuration shown in the right of the figure.

Geometrically an offset reflector is described by a parabolid where the geometric centerline is not coincident with the parabolic axis of symmetry. In order to gain the electrical advantages of reduced blockage, the parabolic axis and, therefore, the focal point must in fact be located external to the section aperture. This section can most easily be visualized by forming a large paraboloid of diameter D and then passing a cylinder, with a parallel axis of symmetry, through the paraboloid. If the cylinder has a diameter (d) less than D/2 and its radius is common with the radius of the parabola, the section of the paraboloid bounded by the cylinder is representative of the desired offset reflector surface. Further, if D/2-d is larger than the radius of the feed and the feed support structure is attached external to the radius of the offset section, there is no blockage of the electrical field of view.

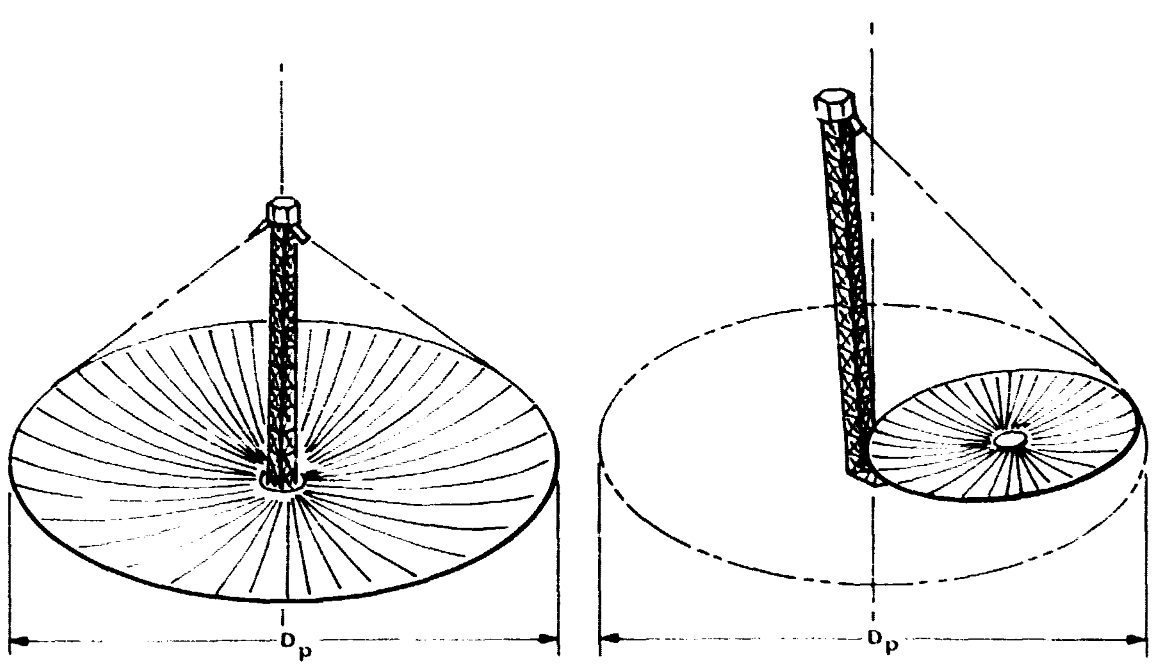


Figure 3.- Symmetric and offset antenna configuration comparison.

## ASCENT AND DEPLOYMENT CONFIGURATIONS

Figure 4 presents an overview of the ascent sequence through the operational state of the vehicle. The STS stack shows an IUS attached to a vehicle from which the stowed feed support tower and reflector are attached. After achieving the desired operational orbit the deployment sequence begins with the tower extending, separating the vehicle from the reflector. The final event is the reflector deployment which occurs after the feed support tower has been completely deployed. The operational vehicle configuration was chosen to place the feeds, electronics and electrical power system components together for maximum efficiency since for the offset configuration this package does not block the antenna aperture.

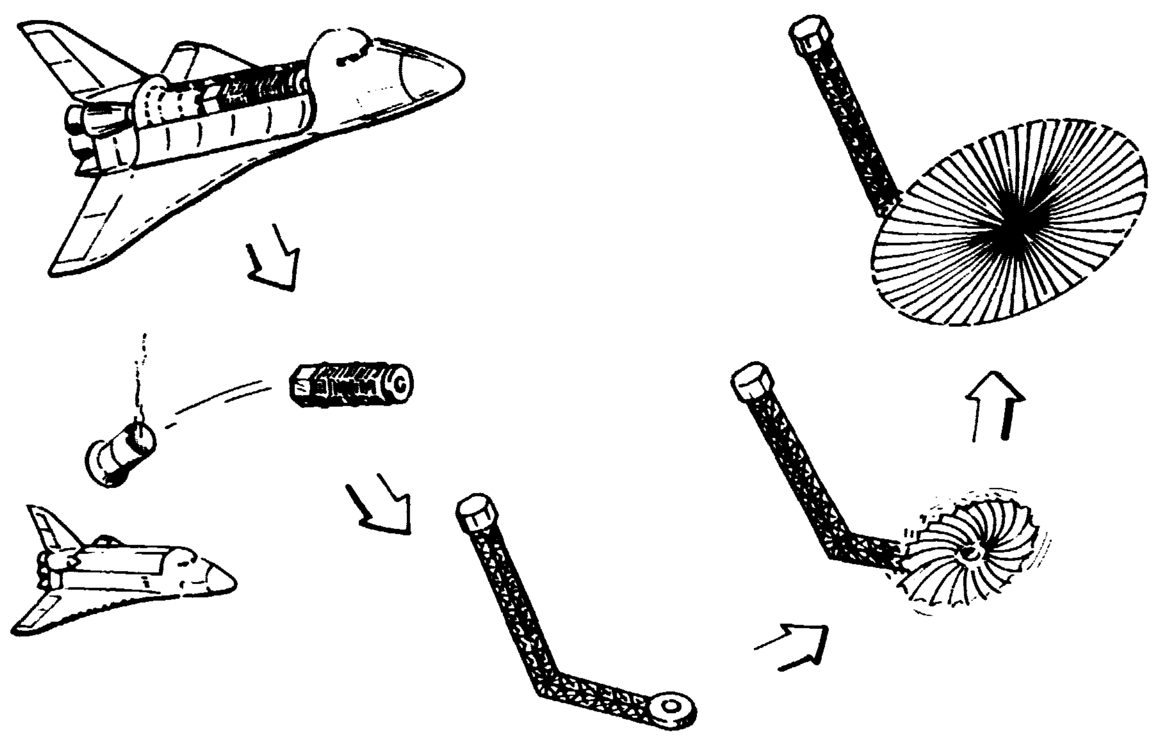

Figure 4.- Ascent configuration and deployment sequence.

## WRAP RIB REFLECTOR DESIGN

The wrap-rib parabolic reflector is based on an approximation to a paraboloid of revolution. The wrap-rib antenna is comprised of radially emmanating gores between the ribs which take the form of parabolic cylinders. The parabolic cylinders more closely approximate a true paraboloid of revolution as the number of gores is increased. The point of diminishing returns for this reflector in terms of antenna performance is a function of both the radio frequency wavelength of interest and the reflector diameter. Figure 5 illustrates the physical appearance of the resulting reflector.

The gores are fabricated from a flexible membrane material which is usually a knitted or woven fabric of electrically conductive material. The gores are sewn to parabolically curved cantilevered ribs terminated at the central hub structure in a hinge fitting. For launch the antenna must be folded into a package size which will fit into the shuttle transportation system. For stowage the ribs are rotated on the hinge pin, then elastically buckled and wrapped around the hub. Once in space, the reflector is deployed by a deployment restraint mechanism which simply controls the rate of energy release and therefore the deployment rate.

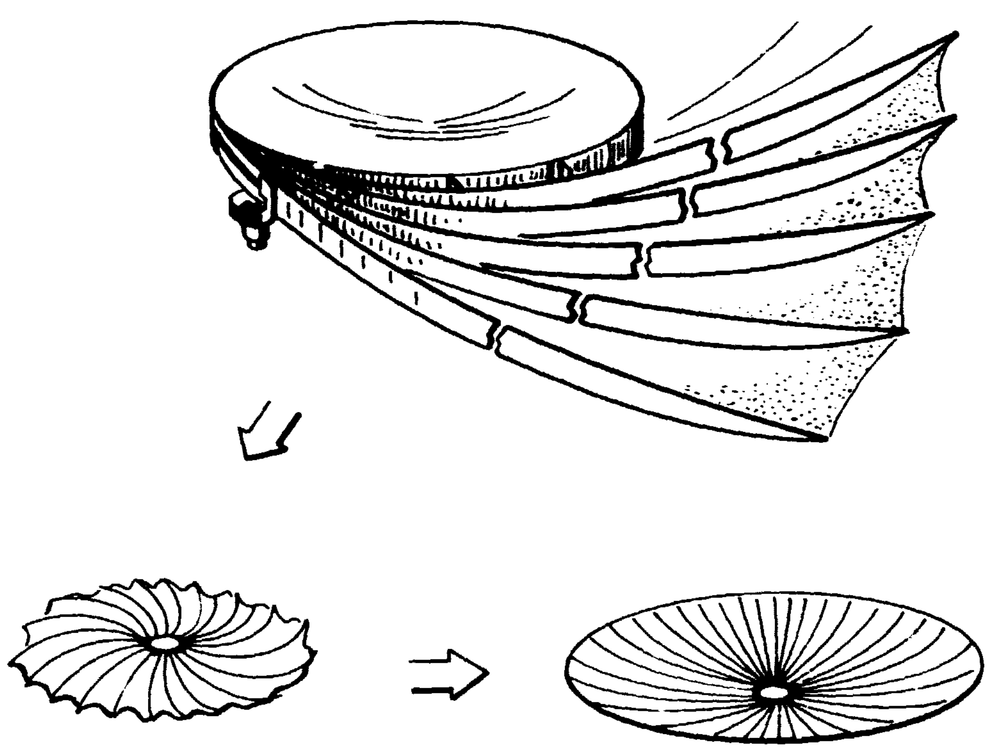

Figure 5.- Wrap rib reflector overview.

## REDEPLOYABLE MAST

The key elements in the Redeployable Mast are the three lenticular shaped longitudinal members which can support an appreciable load when erect, but which can be folded upon themselves through the application of lateral and axial forces. For resisting torsional and lateral shear forces, wire tension cables are provided. The battens are necessary for supporting section hinges and for resisting the lateral, destablilizing cable reactions.

Figure 6 shows the overall mast system and emphasizes the stowage and deployment systems. The inner system performs the actual, section-by-section deployment and retraction of the mast through the use of three syncronous motor, sprocket, chain and development cog systems. It also serves as the bottom mast section until that section, itself, is fully erect. The guide rails in which these devices operate, are also provided with ramp cams which actuate the strikers for collapsing the lenticulars during retraction. The outer base system acts as the stowage bay for both the mast sections and the inner base system which must be extended during mast extension or retraction, but to minimize stowed length is retracted into the outer base system during full stowage. A chain drive system is also provided for the latter purpose.

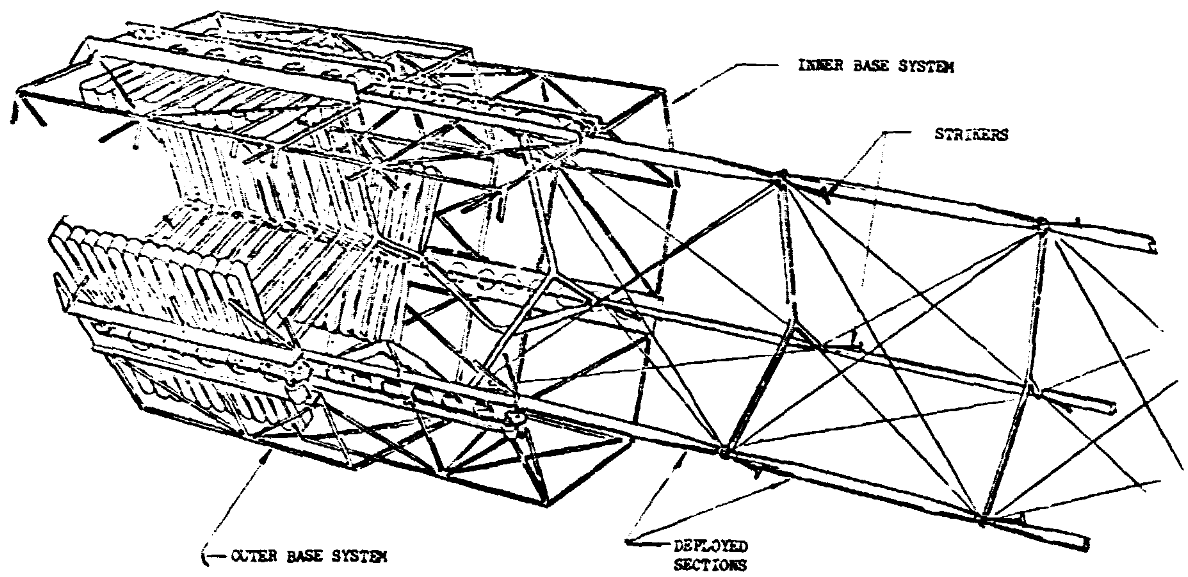


Figure 6.- Redeployable mast.

## STUDY APPROACH

The approach taken to develop the parametric design and performance data focussed on the construction of a computer aided reflector and mast design packages. The reflector design package was constructed to accept basic material and structural element characteristics and develop design solutions which satisfied these inputs and the mission constraints of weight, stowed diameter and antenna system geometry. The developed designs were then analyzed to determine the extent of orbital and assembly surface errors, deployment integrity, and development costs.

Having defined the reflector size and operational frequency, a mast design could be developed with a design constraint that the pointing error be held to less then 0.05 beam widths. The mast design package approach was similiar to the reflector package.

This developed program is overviewed in Figure 7.

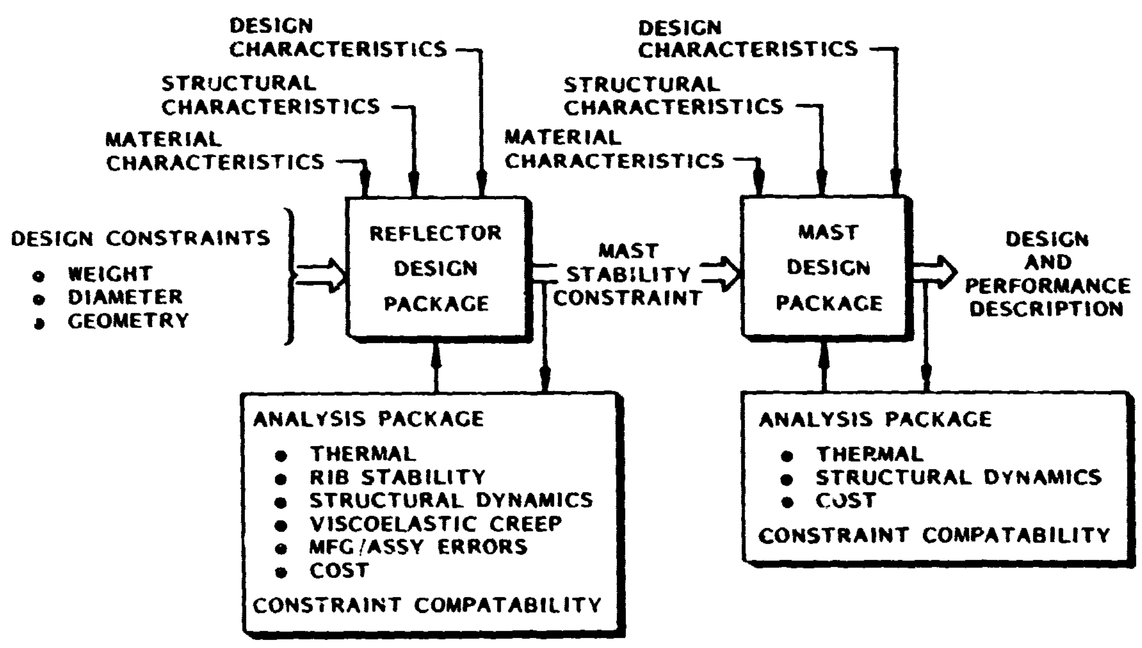


Figure 7.- Modeling approach.

## COMPUTER PROGRAM OVERVIEW

The computer program assembled for this study of necessity provided more capability than a simple parametric study tool. In fact it is required to generate a complete preliminary design and performance analysis. This resulted in a flow chart and data output which, although meaningful, requires extensive discussion to make the reviewer comfortable. The final study report will contain this information, and for this overview Figure 8 was selected to introduce the operation.

This figure contains a flow chart developed from study case input data, computer programs, and output data. There are thirty-six input values, two of which describe mission constraints (weight and stowed diameter). The remaining variables are design and material characteristics. The main computer program develops the required compatible antenna designs and directly outputs a summary of the key output parameters while writing all of the detailed information to a file. Any or all of the design cases can be recovered in a readable form at a time selected by the user. This detailed information contains complete element design descriptions, weight breakdown and performance budget and can be used as a baseline preliminary design.

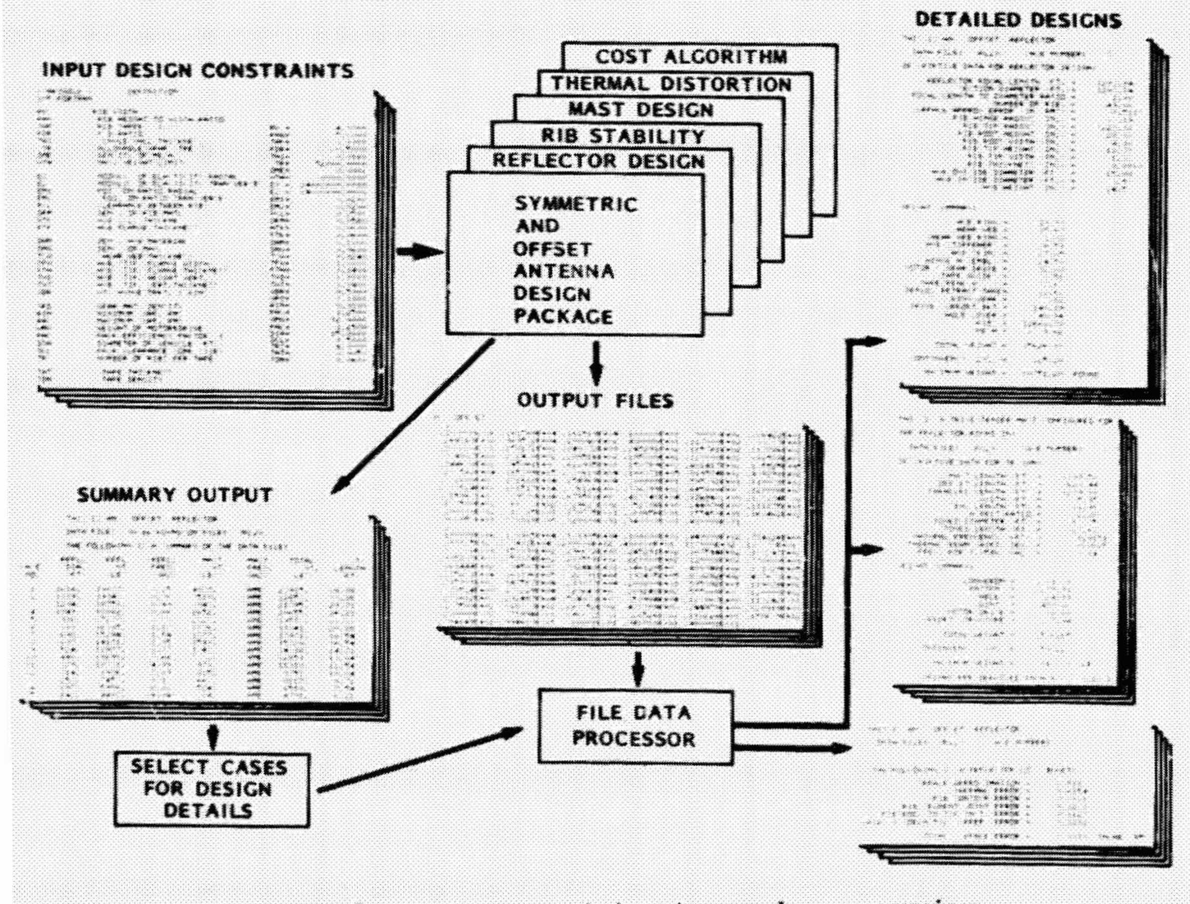


Figure 8.- Antenna optimization package overview.

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Figure 9 illustrates the effect that limiting the antenna weight has on the resulting system capability. With allowable antenna weights greater than approximately 4500 Kg (≈ 10,000 lb.), the maximum aperture diameter at a given operating frequency is limited by the STS diameter. As the weight limit is reduced, a corresponding reduction in the maximum aperture at a frequency can also be anticipated. The performance advantage the offset antenna configuration has over the symmetric system is also evident in that for any aperture diameter, the offset system will operate at a higher frequency, and at any frequency a larger offset reflector is possible than for the symmetric case.

STS DIAMETER CONTRAINED

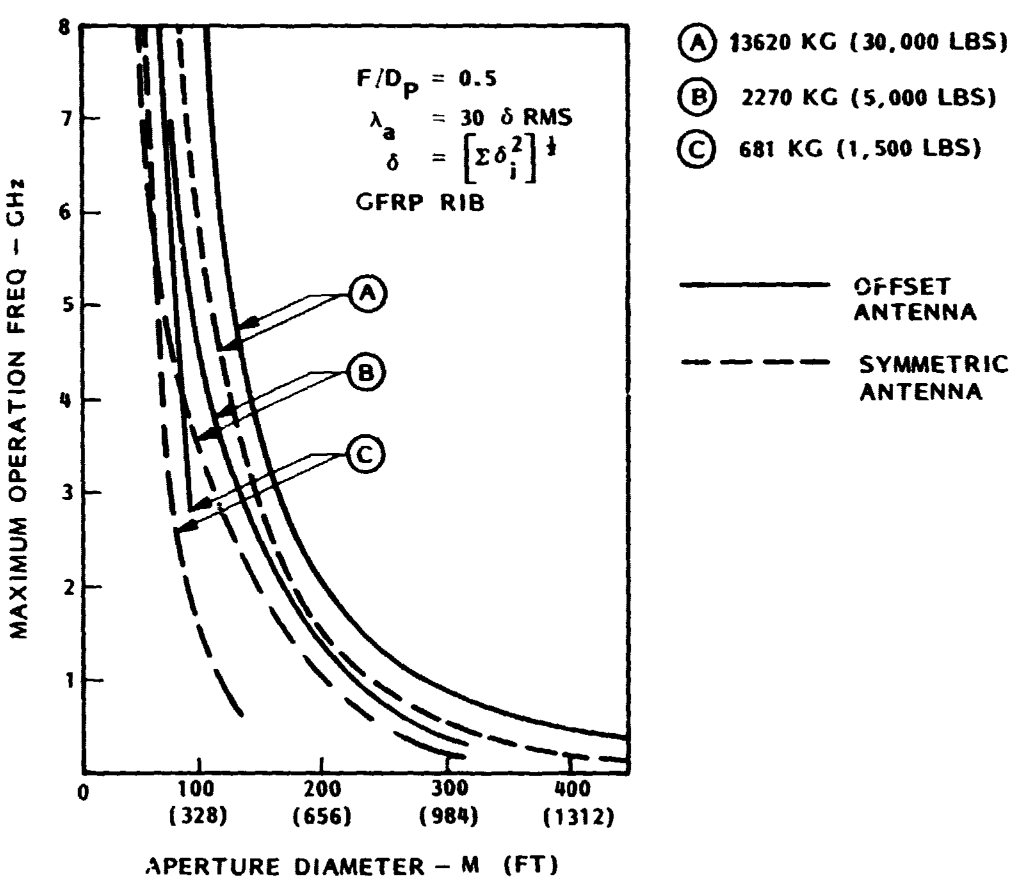


Figure 9.- Antenna aperture limits.

The analysis performed included calculations of the resulting system stowed length. As could be anticipated, the offset system exhibits a longer package than the symmetric counterpart as shown in Figure 10. This is due to the additional feed support tower length required.

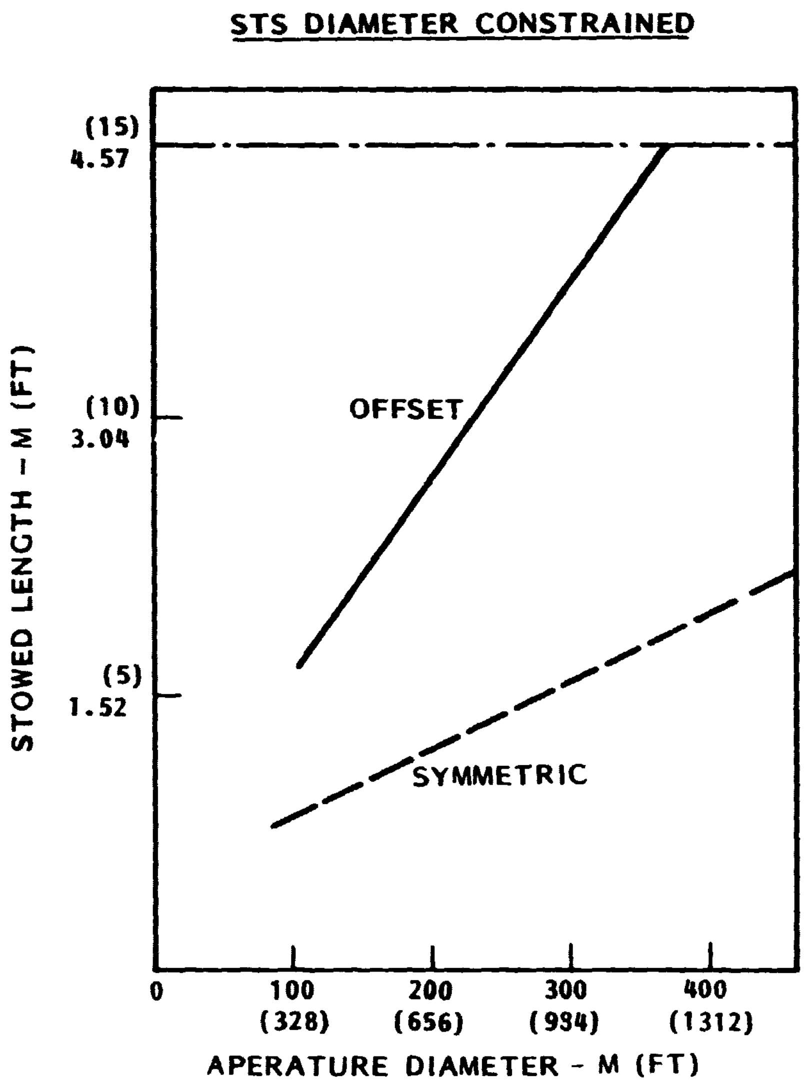


Figure 10.- Stowed diameter characteristics.

Using essentially no bounds on the allowable antenna weight (≈ 5000 Kg), the maximum reflector aperture is limited by the STS diameter and, as will be shown later, the allowable surface figure. The STS diameter limit causes the number of ribs to reduce as the aperture diameter increases. These results shown in Figure 11 indicate an increased surface error and a corresponding reduction in operating frequency.

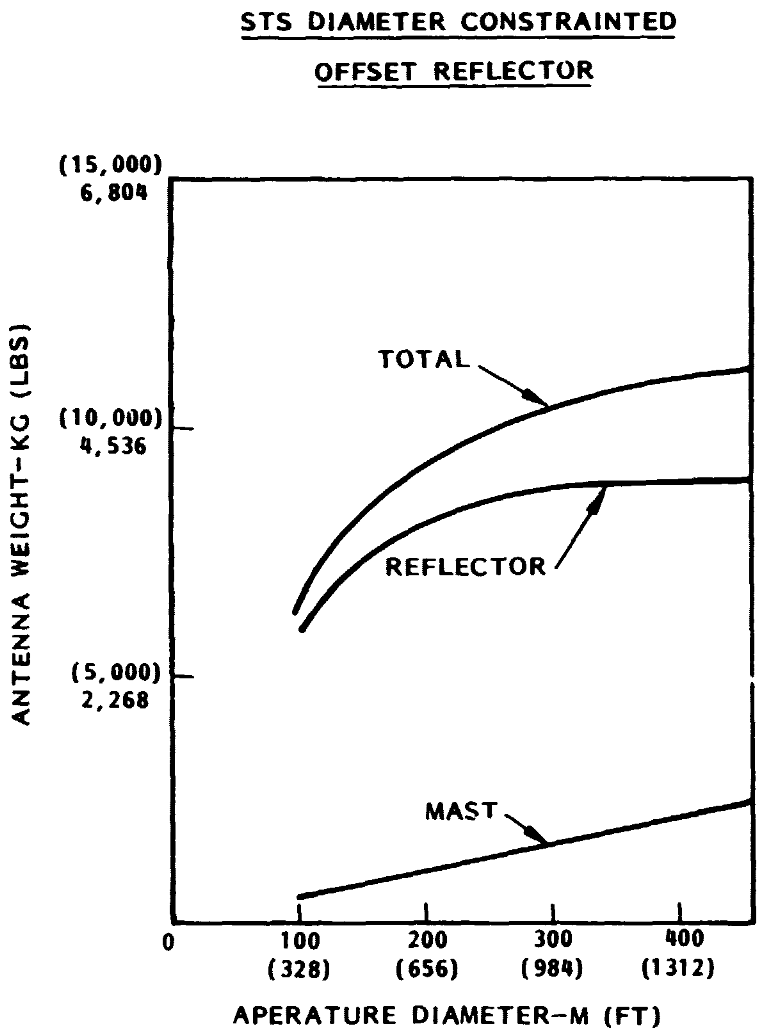


Figure 11.- Antenna weight characteristics.

The surface figure of a graphite epoxy reflector structure is a function of six seperate causes; rib segment fab-ication, rib assembly, reflector assembly, viscoelastic creep, thermal distortion, and designed surface approximation.

The total effect of these errors was taken as the root-sum-squared (RSS) of the individual error components.

The surface approximation and the thermal distortion are the dominant error contributors for the cases performed. It is interesting to note from Figure 12 that, for the smaller (less than 300 meters) symmetric apertures and correspondingly higher frequencies, the thermal distortion is the larger of the two while at larger apertures and lower frequencies, the surface approximation dominates. This is due to the limiting effect of the STS diameter constraint which takes over at about that point.

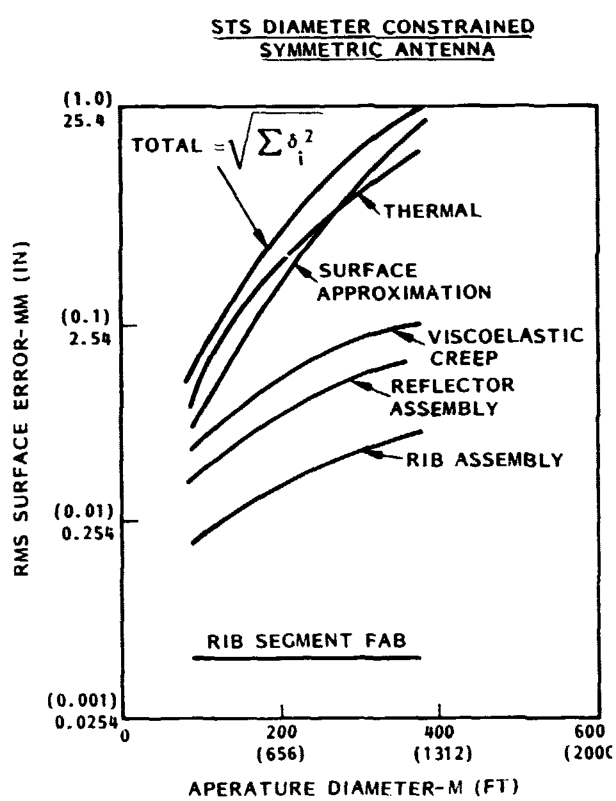


Figure 12.- Surface figure characteristics.

The longer f/D ratio for the offset antenna causes the surface approximation errors to be less than for the symmetric system. As a result, the thermal distortion error for the offset reflector, Figure 13, is the dominant factor thoughout the area of interest.

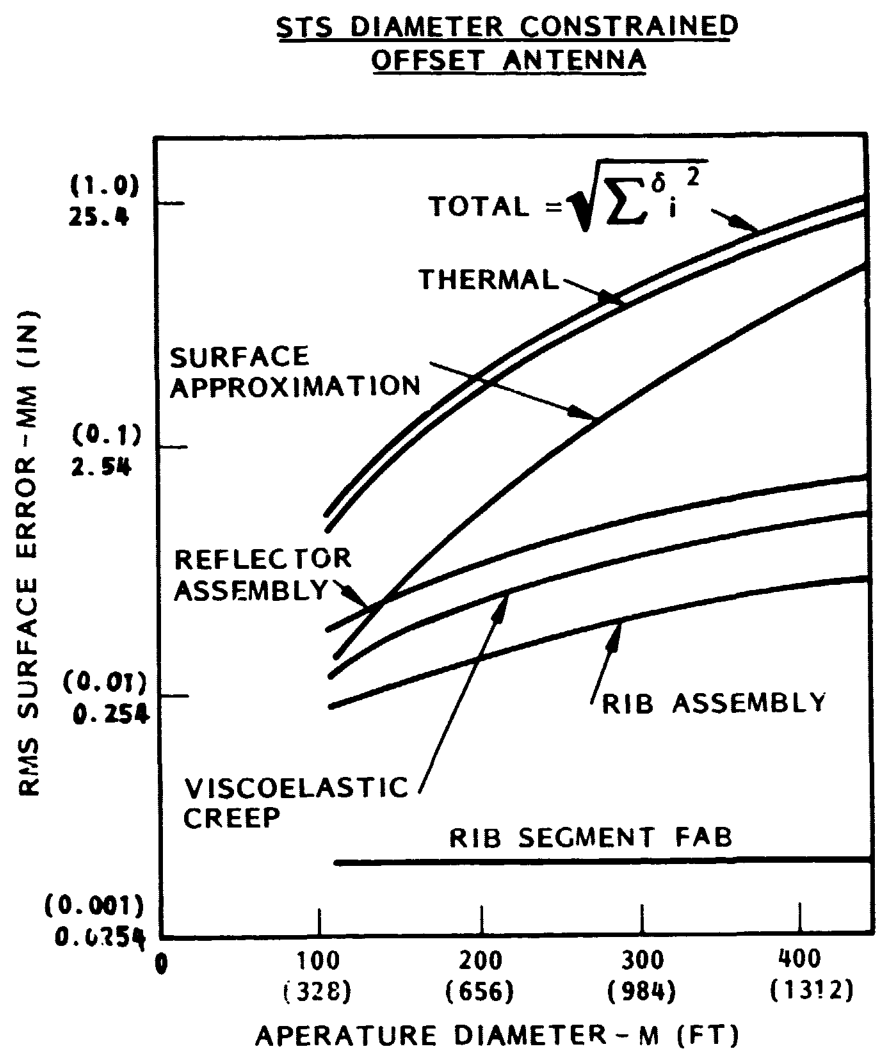


Figure 13.- Surface figure characteristics.

When the weight limit of 2300 Kg is applied, the surface approximation error for the symmetric case was found to become dominant at a much smaller aperture. This occurs due to the decrease in the number of ribs that must occur at a given diameter in order to meet the weight constraint. Th. effect can be seen by comparing Figures 12 and 14.

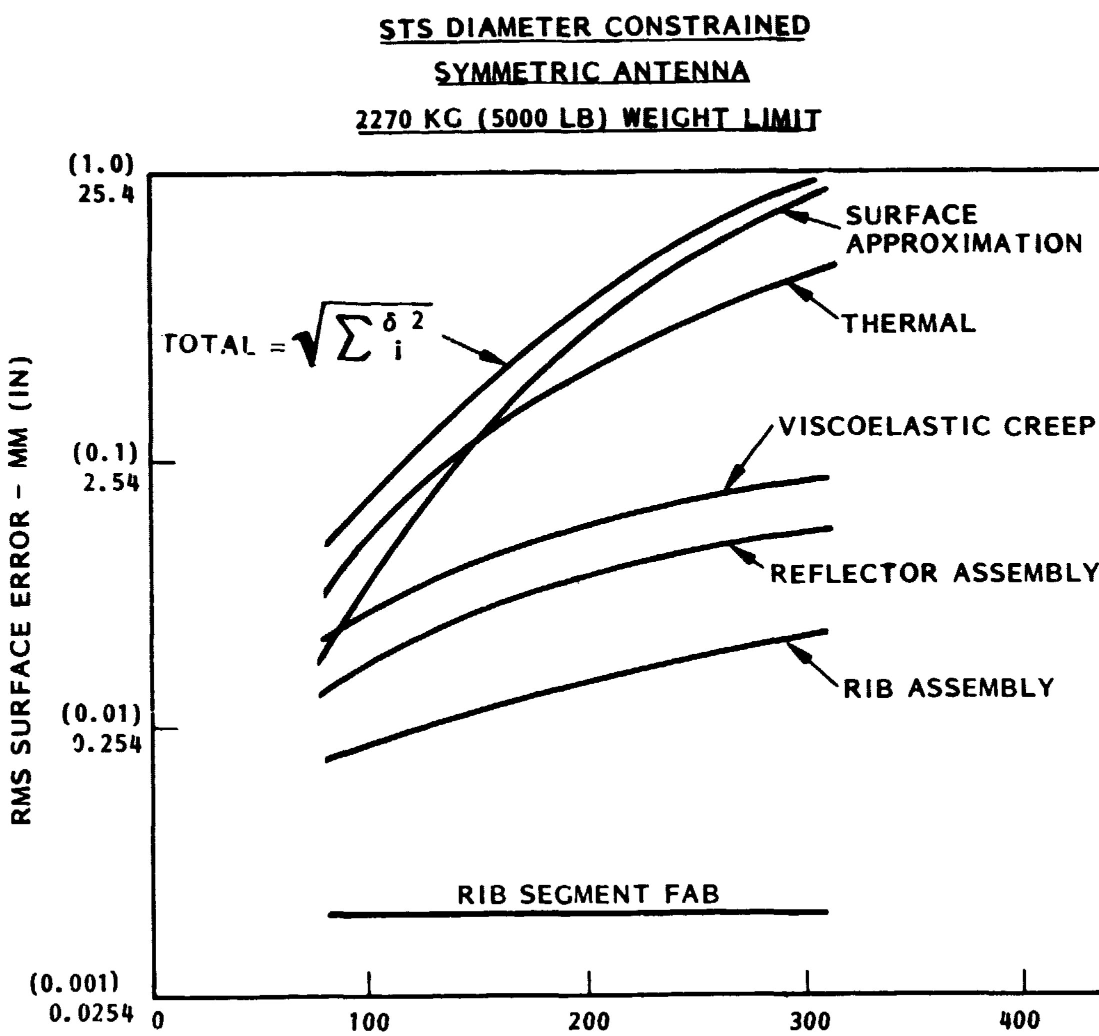


Figure 14.- Synchronous P/L surface characteristics.

When the 2300 Kg weight constraint is applied to the offset antenna, the surface approximation error more closely matches the thermal distortion contribution. Comparison of Figures 13 and 15 illustrate this effect.

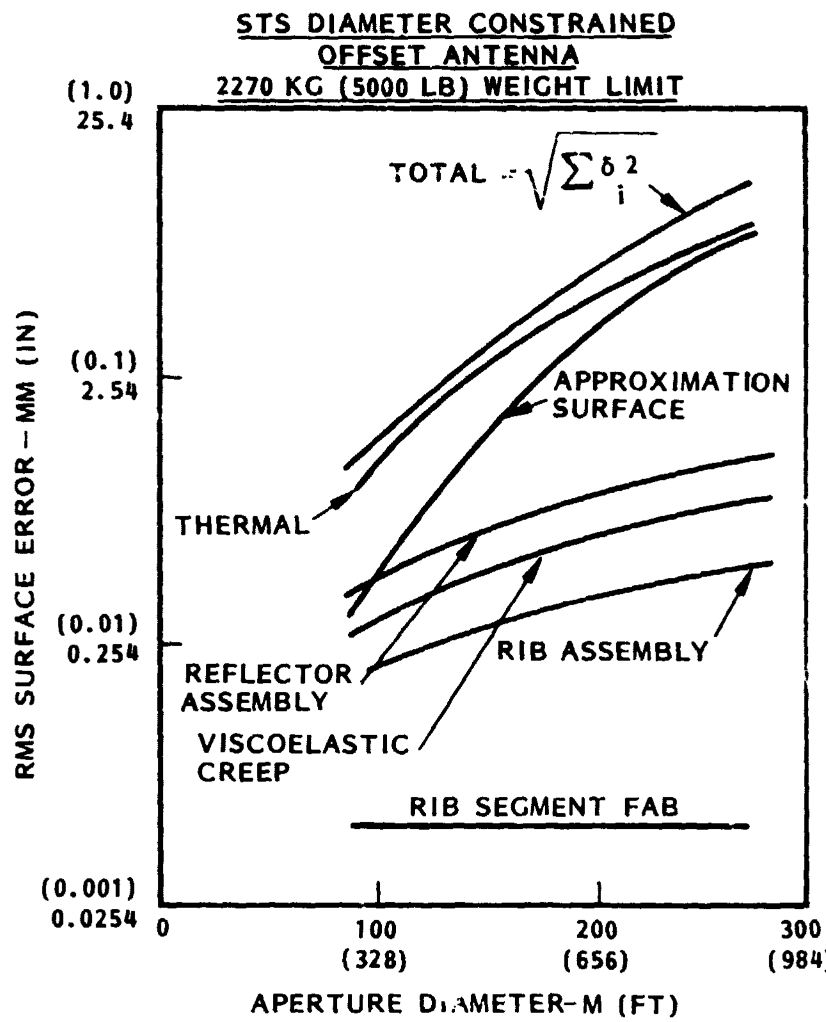


Figure 15.- Synchronous P/L surface characteristics.

Limiting the allowable reflector weight to 680 Kg results in a surface figure that is almost totally driven by the surface approximation contribution and in fact, the thermal errors become comparable to those associated with material properties and fabrication capabilities. This, shown in Figure 16, is due to the greatly reduced aperture associated with the lighter system.

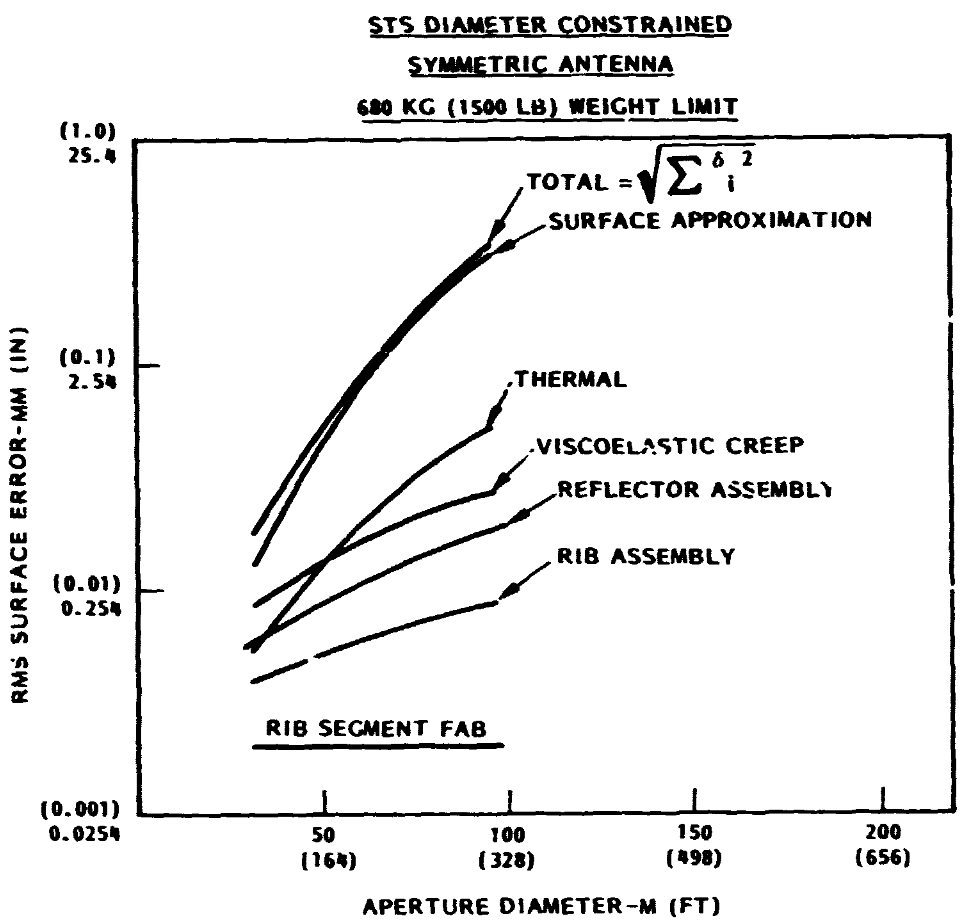


Figure 16.- Synchronous component surface characteristics.

Applying the 680 Kg limit to the offset reflector, Figure 17, has the same effect on the error distribution as for the symmetric antenna. The effect of the higher f/D ratio can be readily seen in comparing this and the previous chart.

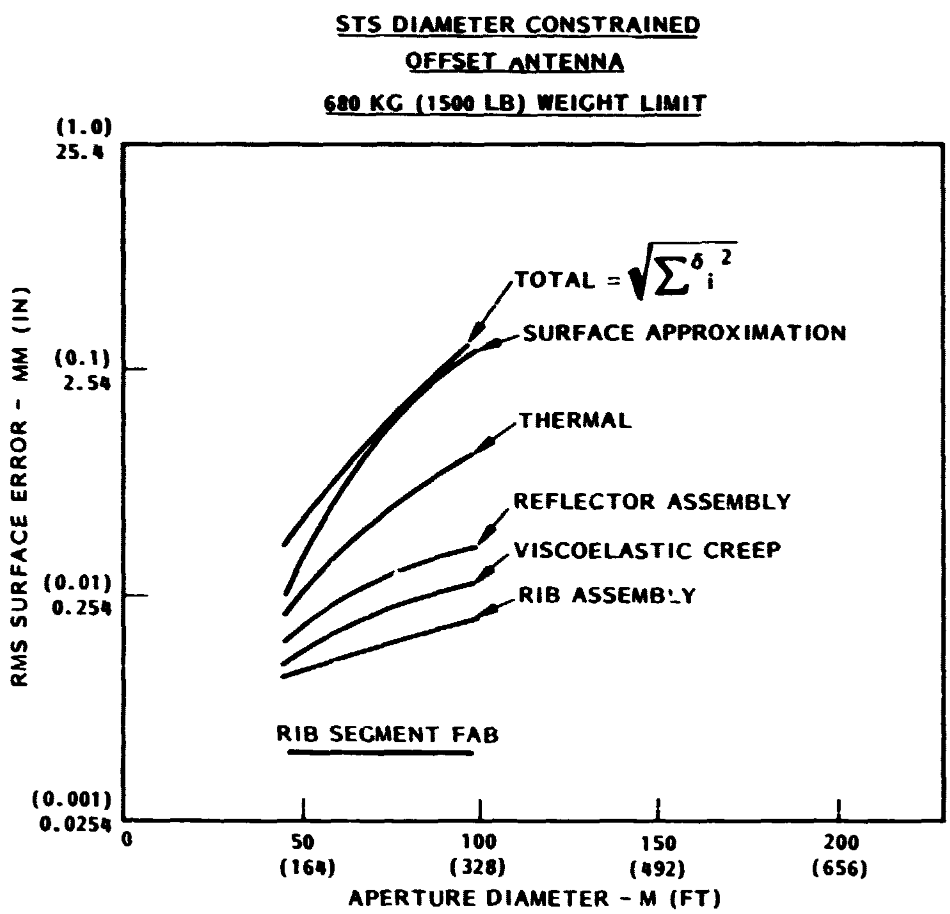


Figure 17.- Synchronous component surface characteristics.

The relationship the f/D ratio has on the frequency and aperture are illustrated in Figure 18. A given offset reflector with a parent f/D ratio of 0.25 will not perform at the same frequency as the same reflector configured with an f/D ratio of 0.50. Conversely, at a given frequency, a larger aperture can be made to work at an f/D ratio of 0.50 than at 0.25. This effect is present up to an f/D ratio of approximately 0.75. Beyond that, the curvature effect is not discernable.

The reason for this effect is due to the segmented reflector geometry. As the reflector curvature becomes less (higher f/D and flatter reflector) the effect of the flat panel approximation becomes less significant. In the limit, with an f/D of infinity, the reflector would be a flat plate and the segmented reflector would exactly approximate the surface.

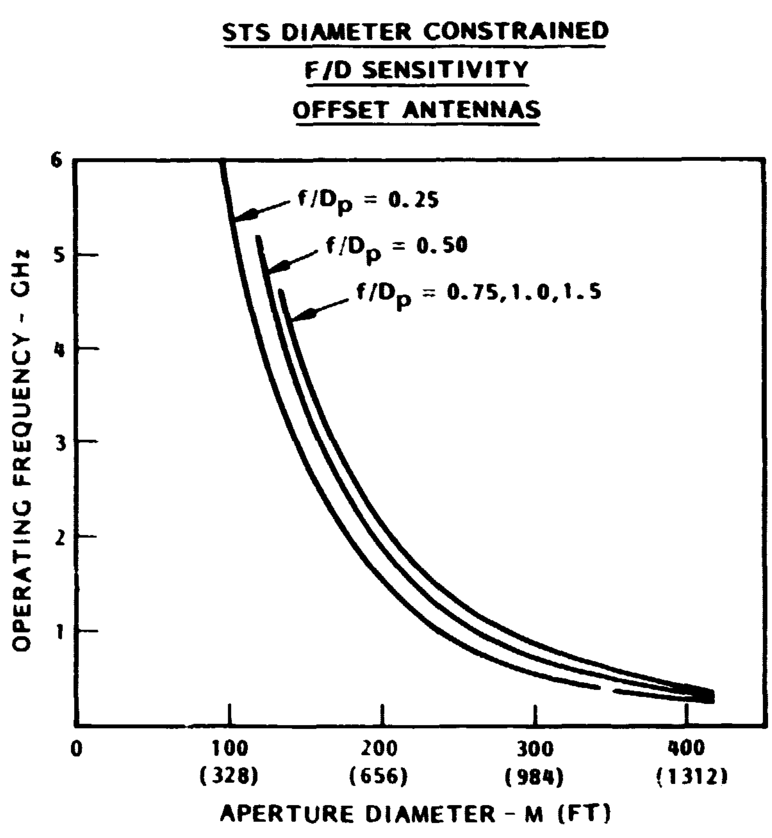


Figure 18.- Antenna system sensitivity to F/D.

Because of the impact of thermal distortion on the antenna performance, it is important to understand the causal parameters. One of the major contributors is the coefficient of thermal expansion (CTE). For the majority of the analyses performed on this study, a CTE of $1 \times 10^{-7}/^{o}F$ was chosen to reflect a graphite epoxy reference structure. The performance sensitivity to this property can be seen in Figure 19.

Another property of the structure materials that has a significant effect on performance is the thermal conductivity. The advent of metal matrix composites (MMC), which combine the distortion coefficient of the graphite fibers with the thermal conductivity of metals, has had a significant effect on the projection of antenna performance.

The top curve on this chart was prepared using the properties typical of graphite magnesium MMC. The CTE used is $1 \times 10^{-7}/^{o}F$ and the thermal conductivity is 18 BTU/HR-°F-FT. The corresponding K for the graphite epoxy structure is 13.5 BTU/HR-°F-FT.

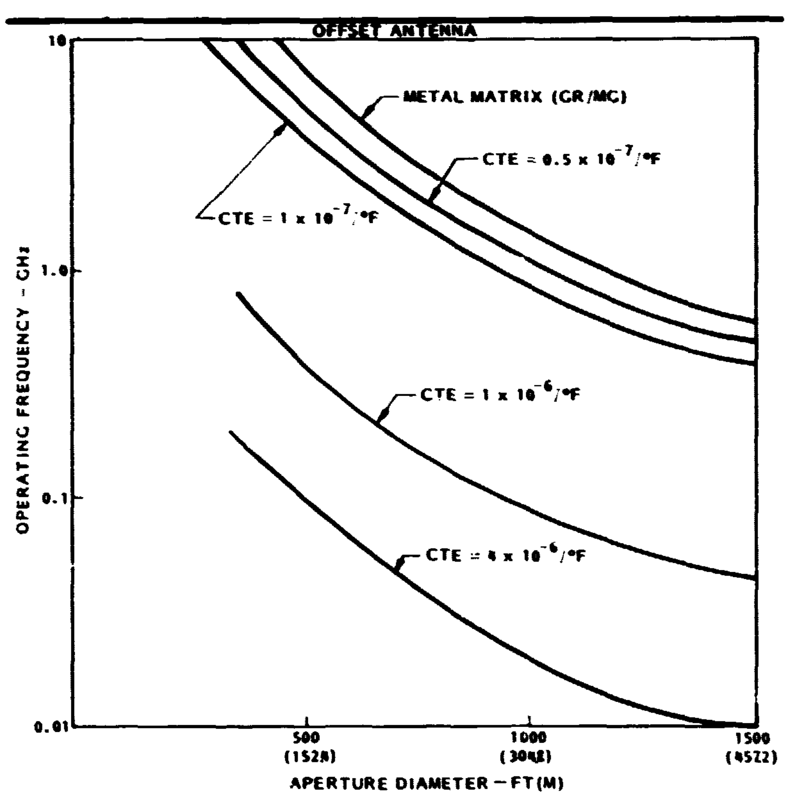


Figure 19.- Antenna sensitivity to material characteristics.

Application of the MMC properties to the analysis of the offset reflector results in reduced surface figure errors due to the lower thermal distortion and thereby increases the useable aperture diameter at a given frequency. Note also, on Figure 20, the MMC materials will not exhibit the viscoelastic creep error associated with graphite resin composites.

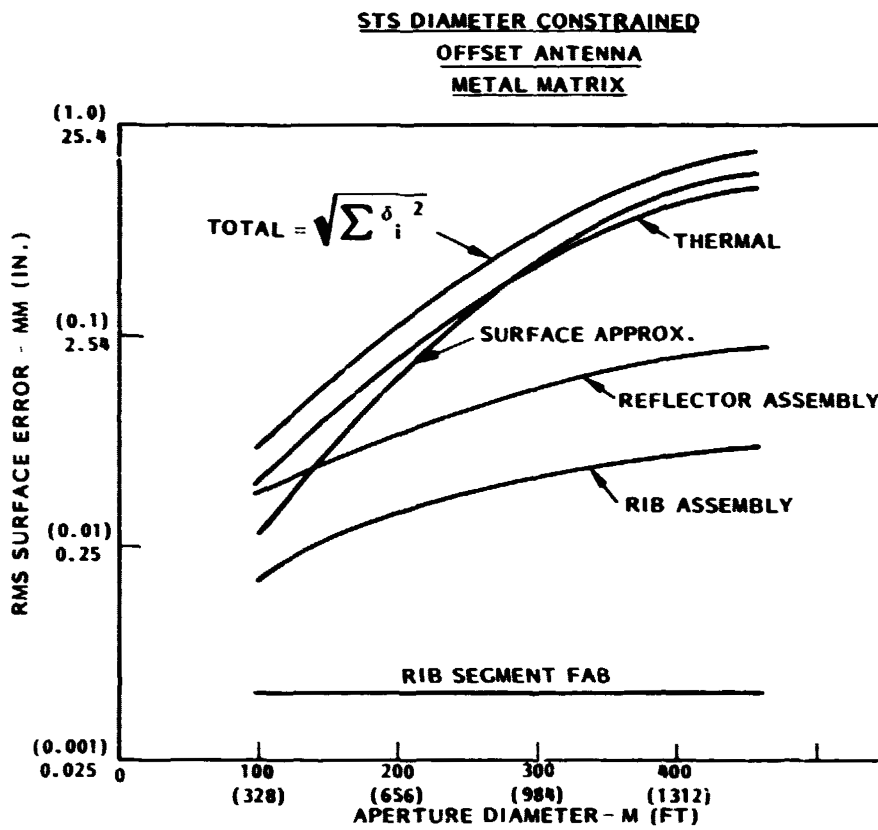


Figure 20.- Surface figure characteristics with metal matrix ribs.

Throughout the analyses thus far presented, the rib configuration has been held as a constant varying only in length and parabolic shape. This lenticular rib has a hub attachment cross section (rib root) of one inch wide, 4 inches high and a width taper of 2:1. The effect of changing the rib root geometry to 5 inch wide, 20 inches high can be seen in Figure 21. Increasing the rib width and height of the rib has the effect of reducing the number of ribs that can be attached to the hub. This in turn, reduces the useable operating frequency at a given diameter.

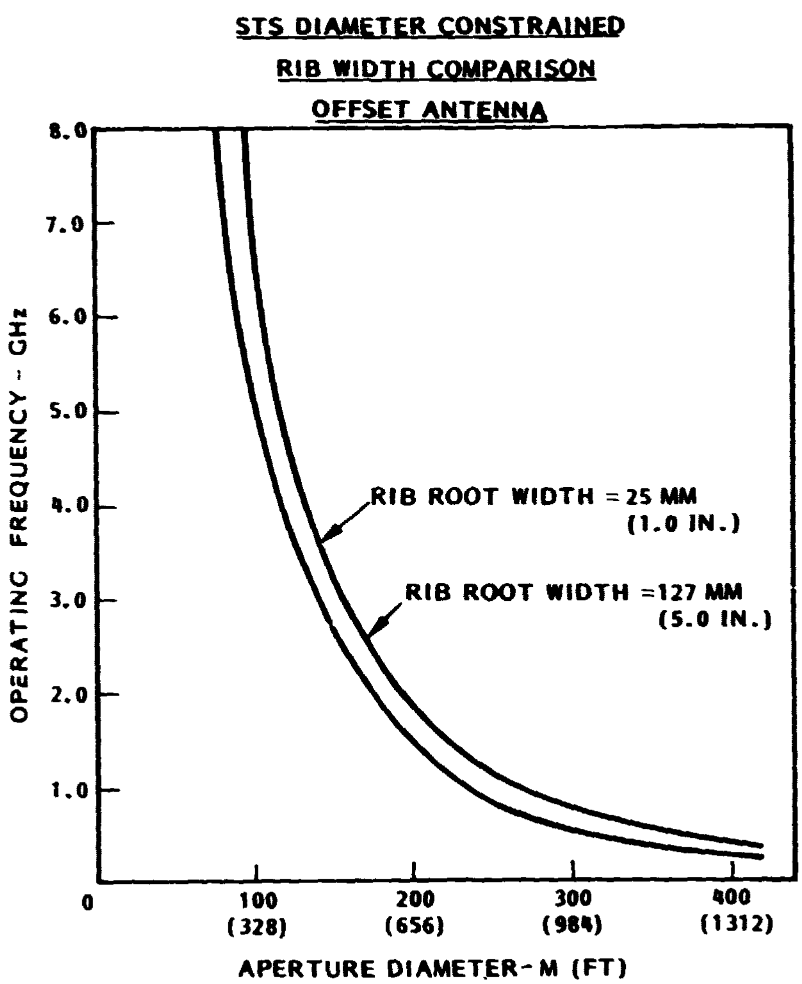


Figure 21.- Antenna system sensitivity to rib design.

## PROJECTED ANTENNA COSTS

Figure 22 presents the projected cost for an offset antenna as a function of aperture size, weight and operating frequency. The data show that for low frequency apertures the cost is reasonably proportional to weight or diameter. As operating frequency limits are pushed the costs start to rise rapidly. This seems to occur in the 50 to 100 million dollar range for frequencies greater than 2 GHz.

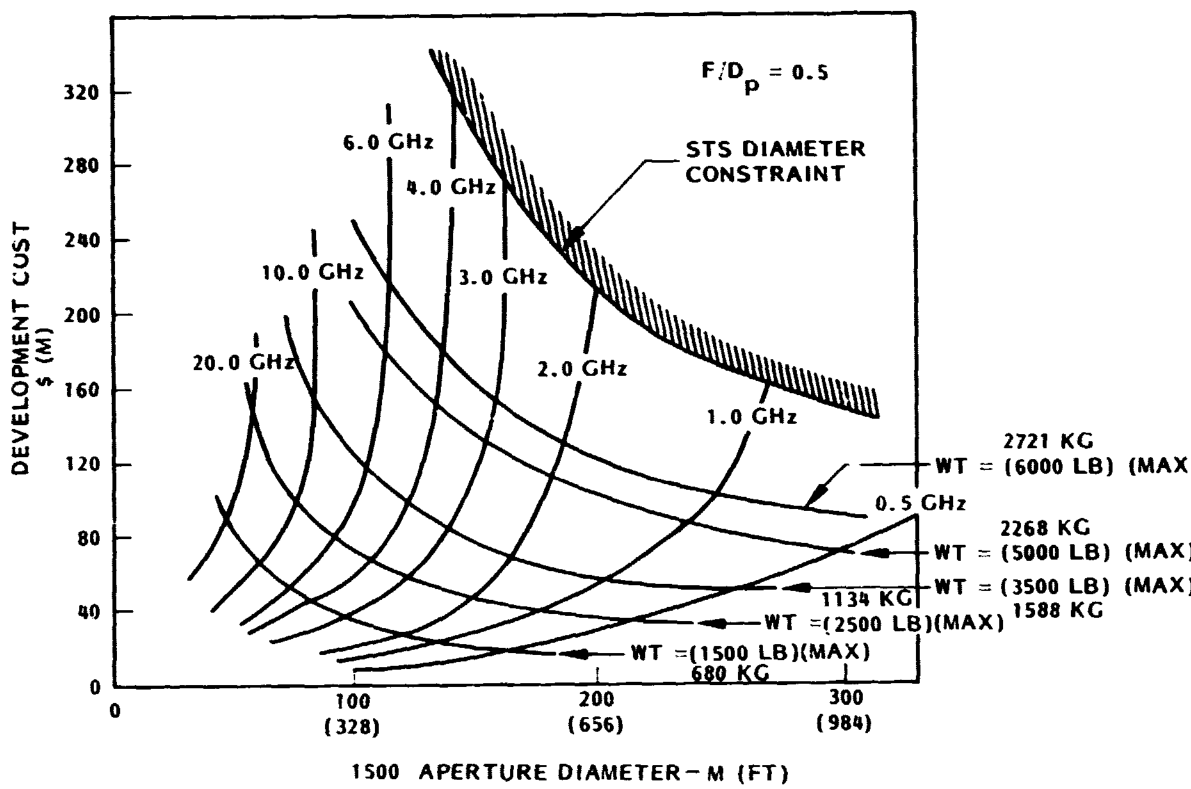


Figure 22.- Offset antenna cost projections.

## OFFSET VS SYMMETRIC COST COMPARISON

The data presented in Figure 23 present the cost factor for an offset antenna. This increase is between 15 and 30%. The 30% factor is dominated by size and extra mast length costs, while at the higher frequencies the costs for maintaining a highly accurate reflector surface dominate.

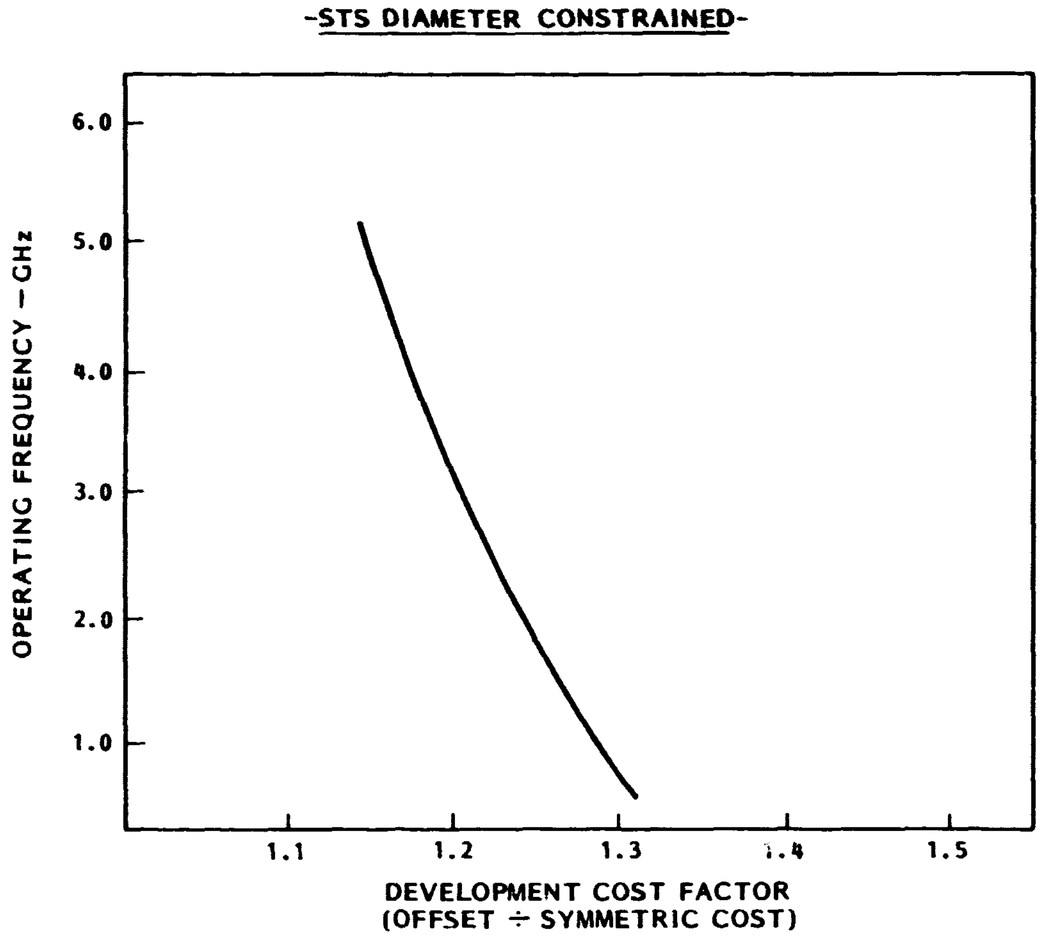


Figure 23.- Offset vs. symmetric antenna cost comparison.

## TECHNICAL CONCERNS

The results of the investigation were surprising and satisfying. Earlier projections indicated the appropriateness of the Wrap Rib for large diameter antennas, and these projections have been reinforced. Technically, however, these are some concerns which must be addressed prior to a program undertaking. Figure 24 summarizes these concerns. The first four items can only be satisfactorily addressed through a hardware program. Further studies will resolve the latter three.

- ACCURACY OF ANALYSIS OVER 1-1/2 ORDERS OF MAGNITUDE
- MANUFACTURABILITY OF LARGE COMPONENTS
- ASSEMBLY ALIGNMENT FACILITY REQUIREMENTS
- MESH MANAGEMENT DURING DEPLOY/RETRACT
- VEHICLE STABILITY REQUIREMENTS DURING DEPLOYMENT
- LACK OF 1-G TESTABILITY (CONTOUR AND STRENGTH)
- OPERATIONAL CONTROL SYSTEM INTERACTION/STABILITY

Figure 24.- Performance projection technical concerns.

## PROGRAM PLAN

The final study activity was expended reviewing the concerns with undertaking a space flight program demonstration of a large diameter Wrap Rib antenna. The projected costs and technical risks identified the necessity of developing an early data base at a size which could comfortably be analytically scaled and which would reduce risk through demonstration. This program, identified in Figure 25, would involve developing a testable segment of a 50 M aperture. This would be used to validate the design and provide a scaling factor of 2 or 3 for the 100 to 150 M missions. The dominant effects of thermal distortions in the performance projections indicate orbital surface adjustment may prove cost effective and should be investigated. Finally, since the design is being defined, the stability and control system interactions and limitations should be identified.

ESTABLISH A COST EFFECTIVE 50 M DATA BASE

- MANUFACTURE AND TEST COMPONENTS/PROCESSES
- ASSEMBLE 1-G TESTABLE SEGMENT
- DEMONSTRATE DEPLOYMENT AND RETRACTION
- MEASURE DEPLOYED CONTOUR WITH OFFLOADING TEST AID
- UPDATE DESIGN AND DESIGN ALGORITHM

EVALUATE BENEFITS OF INCORPORATING ACTIVE FIGURE CONTROL

- ONE TIME ADJUSTMENT
- CONTINUOUS ADJUSTMENT
- DEGREES OF FREEDOM REQUIRED
- COSTS

INVESTIGATE CONTROL SYSTEM INTERACTION

- DEFINE PRELIMINARY REQUIREMENTS
- INVESTIGATE ACTIVE DAMPING AND DISTRIBUTED CONTROL SYSTEM

Figure 25.- Risk resolution/development plan.

## STUDY CONCLUSIONS

As with any study one must be conservative when drawing conclusions. In this case we can conservatively draw those indicated in Figure 26. It is hoped that further activity will defend the reasonableness of designs which are at the limits indicated by the technical work performed.

- OFFSET WRAP RIB ANTENNAS UP TO 150 M DIAMETER ARE FEASIBLE FOR OPERATION AT 2 TO 3 GHz
- STS COMPATABILITY IS NOT A DESIGN DRIVER
- COST AND TECHNICAL RISKS INDICATE A NEW DATA BASE REQUIRED PRIOR TO UNDERTAKING 100 TO 150 M DESIGNS
- FURTHER ACTIVITY SHOULD INCLUDE ACTIVE SURFACE CONTROL AND CONTROL SYSTEMS INTERACTION STUDIES

Figure 26.- Study conclusions.