29. THE REQUIREMENT FOR DESIGNING ANALYZABLE SPACE DEPLOYABLE STRUCTURES

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SUMMARY

The Applied Technology Satellite Parabolic Reflector Subsystem is one of the first systems designed for space environment with limited terrestrial environmental ability. As a result, the complete performance of the system could not be demonstrated in a terrestrial environment without unacceptable design compromises. This problem was circumvented by developing a test philosophy which relied heavily on analysis to qualify and accept the flight hardware. Such a solution avoids the design compromises and costly test aids that are required for full terrestrial demonstration. The test program was successfully concluded and an optimized, low cost structure resulted. It is felt that this test and analysis philosophy can be applied to future space systems, resulting in substantial cost and schedule savings and a mission optimized system.

INTRODUCTION

Designs for large, space deployable, high positional accuracy structures have evolved over the last decade. A primary area of implementation of these structures is the area of communications. With the desire for large aperture reflectors comes the problem of launch constraints, both size and weight. Since the subject structures are intended for functional use only in space and are designed to maximize booster payload effectiveness while maintaining minimum weight, the optimum design is one which will not perform in the terrestrial environment. In order to achieve this optimum design some of the normal ground test requirements must be deleted from the test program and heavy reliance on analysis must be substituted. This places new requirements on the design: that the analysis must be qualified, or verified, and that the structure itself must be as simple and straightforward to analyze as is possible, to provide additional confidence in analytical assumptions.

In a space deployable antenna system the reflector surface distortions and alignments are as critical to the system as ascent and deployment integrity. As a result the Applied Technology Satellite (ATS) test program was provided with the additional problem of qualifying orbital radio frequency performance which encompassed thermal, structural and electrical analyses.

This paper presents the ATS test program which evolved to qualify the paraboli reflector subsystem hardware and analyses. The significant test and analysis results are presented and the design simplifications for analytical modeling are also discussed.

DESIGN DESCRIPTION

The ATS parabolic reflector design (Figure 1) approximates a parabolic reflector by providing a reflective surface of forty-eight parabolic cylinders or gores of a woven dacron substrate, coated with copper and overcoated with silicone. These gores are sewn to forty-eight semi-lenticular, chem-etched sculptured and contoured ribs. The ribs are attached through hinges to a central hub weldment which in turn is attached to the spacecraft. The deployed reflector diameter is 9.144 meters; the focal length to diameter ratio is 0.44. The reflector weighs 83.9 kg and stows in a 1.47 m inside diameter by 1.98 m outside diameter by 20.32 cm thick torus.

To stow the reflector for ascent the ribs are rotated about their hinges until they are tangent to the hub. After this rotation the ribs are elastically buckled or collapsed and the ribs and mesh are then wrapped around the hub between the upper and lower hub covers. While the ribs and mesh are held in the hub structure, twenty-four doors are closed and a restraining cable is placed around the periphery. When the reflector is deployed, redundant pyrotechnic cable cutters are used to sever the cable; the stored energy in the ribs causes a reversal of the above process and the ribs and mesh deploy to form the parabolic surface.

DESIGN SIMPLIFICATIONS

The most critical requirements for a space deployable reflector are that it deploy reliably and maintain the desired surface contour. The deployment of the ATS reflector is accomplished with only one active element, a pyrotechnic cable cutter. There are redundant cutters. The remainder of the mechanisms are passive and consist of rib stored energy, rib hinge springs and door springs. Rib hinge springs were necessitated by a requirement to achieve a full deployment in a reflector cup up orientation in air. For a vacuum deployment the rib stored energy is more than sufficient to achieve a full deployment. The door springs were required to meet spacecraft stability requirements. The rib hinges rotate on spherical bearings which can rotate in their outer race or about the hinge pin. The door hinge has a large clearance hole through which the hinge pin is placed.

The reflector contour is dictated mainly by the rib/mesh interaction which essentially is a membrane loading of a cantilever beam. The mesh can be modeled structurally as a membrane with thermal and edge loads; the rib, by a standard beam with offset shear center finite elements. Thermally the mesh can be modeled as semi-transparent cylindrical section elements. The ribs employ only thermal surface coatings as opposed to multi-layer insulation to avoid dependence on reliable, repeatable shape for insulation effectiveness and to avoid concerns associated with identifying and eliminating or attempting to model joints and leaks.

A further source of contour error is associated with hub top to bottom differential expansion. This type of distortion causes a rotation of the rib in a direction normal to the reflector surface. The hub consists of two rings welded together with spacers. A fixed thermal blanket is used for insulation purposes. This provides a relatively simple design for thermal and structural analyses.

Contour repeatability is also of concern since the contour to which all performance is relative is of significance. To provide a reliable, repeatable deployed contour, rib rotation normal to the reflector surface is eliminated since this direction is perpendicular to the hinge axis. Rib position is set by a stop at the hinge and position is maintained by a tapered plunger which is released by a cam on the hinge when the rib has rotated to the radial position. The only repeatability error is then in the rib radial angular position which produces negligible surface errors.

TEST PROGRAM

Even though the reflector itself was inherently simple in design and simple to analyze, a test program demonstrating performance was necessary. The qualification test program for the ATS reflector is shown in Figure 2. It represents a normal test program with the exception that final acceptance of the test article was contingent on analyses since it was required to demonstrate conformance of the deployment envelope, contour repeatability and radio frequency performance with analytical requirements to obtain qualification certification.

The reflector can be and was designed to deploy to a stable contour under gravity loading; however, the weight impact associated with making that contour the ideal orbital contour was unacceptable. As a result it was decided to measure the deployment envelopes and reflector contours at each of the deployments, both in the cup up and cup down attitude, and then analytically to calculate zero gravity contour. This calculated contour was then compared to the desired zero "g" manufacturing contour. The measured distortions were also used to compare to the structural model analysis results for analytical correlation and verification of the structural model. The analytical one "g" distortion correlation with the measured data is presented in Figure 3. In a similar manner the zero gravity deployment envelope was determined and the resulting analytical envelope was used to show compliance with the requirements. A total of ten deployments was used to provide demonstrations of compliance in these areas.

The final requirement on a reflector is to show compliance with the r.f. performance specification for the entire orbit. The reflector contour in one "g" could not, however, be achieved without a test aid to hold the contour. Since this contour was being artifically induced it was extremely important that the information used to derive the contour be shown to be accurate. It was decided that two contours would be used to demonstrate compliance, the orbital predicted "best" and "worst" contours. These contours are dependent on the proper prediction of the thermal loadings and their resulting structural surface distortions. If these analyses are correct, then the complete orbital radio frequency analyses would be correct; this was verified by correlation of the test predictions with the test measurements from the two test contours.

The verification of the thermal analysis predictions necessitated an additional test on a reflector model in a solar simulator. This model consisted of a full scale 5-rib sector of the reflector with the flight thermal control system.

Three positions of the test model were investigated during the test so that the full effects of mesh transparency and rib/mesh shading were experienced. The data obtained from these tests were then compared to the analytical predictions for the test model. This provided verification of thermal analysis modeling assumptions and temperature predictions. Figure 4 presents the analysis predictions and the test results obtained for the absolute temperatures occurring on the center rib at test position one. The data presented in Figure 5 present the analysis/test prediction comparison for the rib top to bottom gradients for test position number 3. These results were typical of those obtained and show excellent correlation of absolute temperature predictions with the test results. The correlation of predicted rib depthwise gradient with test results was also excellent since the gradients predicted were always larger than the measured data. For this type of reflector design, this leads to conservative surface distortion predictions.

The thermal distortion, or structural, model was, in addition to the aforementioned gravity loading certification, verified by an isothermal test of the full reflector. The contour change from 20°C to 110°C was measured during a thermal test in the NASA/MSC test chamber and this measurement compared to predictions to achieve correlation.

GENERAL TEST RESULTS

The ATS test program was extremely successful considering the developmental nature of the hardware program. There was however, one major failure that occurred and this resulted from overconfidence in expected performance stemming from the simplistic design. As stated earlier, if the cable cutter cuts the cable, there is nothing that can stop the reflector from opening since the ribs seek their original shape and a considerable amount of force is required to hold them closed. There was apparently no mechanism in or on the reflector which could generate the required force. This was not true and a failure occurred during a low temperature (-110°C) vacuum deployment test.

The failure mode appeared just after the cable was cut. Sections of ribs started to peel off the wrap (Figures 6, 7 and 8) and tear the mesh as they were opening. The result was a deployed reflector with two torn mesh panels. This was an unacceptable condition. A failure investigation was started immediately to determine the cause of and corrective action for the failure. The failure mechanism discovered was the mesh overcoat of silicone.

The silicone (CVM DC 6-1104) is applied to the mesh as a protective coating for the copper and as a thermal surface coating. Silicones have a characteristic phenomenon in that they stick together. It was determined during the failure mode testing that the silicone blocking force is highly dependent on temperature. At temperatures above -45°C there is relatively little force required to unstick the surfaces; however, at temperatures below - 73°C there is an increase in blocking force by several orders of magnitude. This force at -110°C was proven to be sufficient to hold the ribs within the hub structure so that when a rib started to unfurl, the rib adjacent to it was held sufficiently within the hub by the silicone that forces in the mesh were developed to the point that the mesh failed in tension.

Since the reflector was deployed at -110°C for reasons of test convenience rather than as a result of pre-deployment thermal analysis predictions, the test temperature was changed to a deployment temperature consistent with predictions of -18°C. However, since the failure did occur, a solution to the problem uncovered no aging or curing of the silicone coating which would reduce the low temperature blocking forces to acceptable levels. As a result a strip was added to carry the load which the blocking could produce. In addition, the strip had to be designed so that it would be ineffective once the deployment was achieved so that it would not cause surface distortions due to orbit thermal loading. The design solution was to install the strip so as to be always slack during the orbit conditions and to use a material with a high modulus of elasticity relative to the mesh so that it would unload the mesh and carry the blocking loads if the situation reoccurred.

The modifications were implemented and the test re-run. The coldest temperature at time of deployment was recorded as $-50^{o}C$ occurring on the reflector doors. The reflector deployed successfully with no sticking due to silicone blocking apparent.

CONCLUDING REMARKS

The Applied Technology Satellite Parabolic Reflector Subsystem development program was faced with a unique problem. That was: How do you space qualify a reflector system that is designed optimized for operation in the orbital environment? The solution to the problem was to derive a test program which eliminated terrestrial test conditions that would cause design compromises. This required the qualification of analyses used in conjunction with the derived test program. This resulted in a qualification of the reflector based on the combined analysis/test program. The solution led to a very satisfactory design with a minimum of ground test compromises and provided the necessary confidence to certify the flight worthiness of the reflector. It is felt that this is a valuable approach for future programs where a mission optimized design is desired.

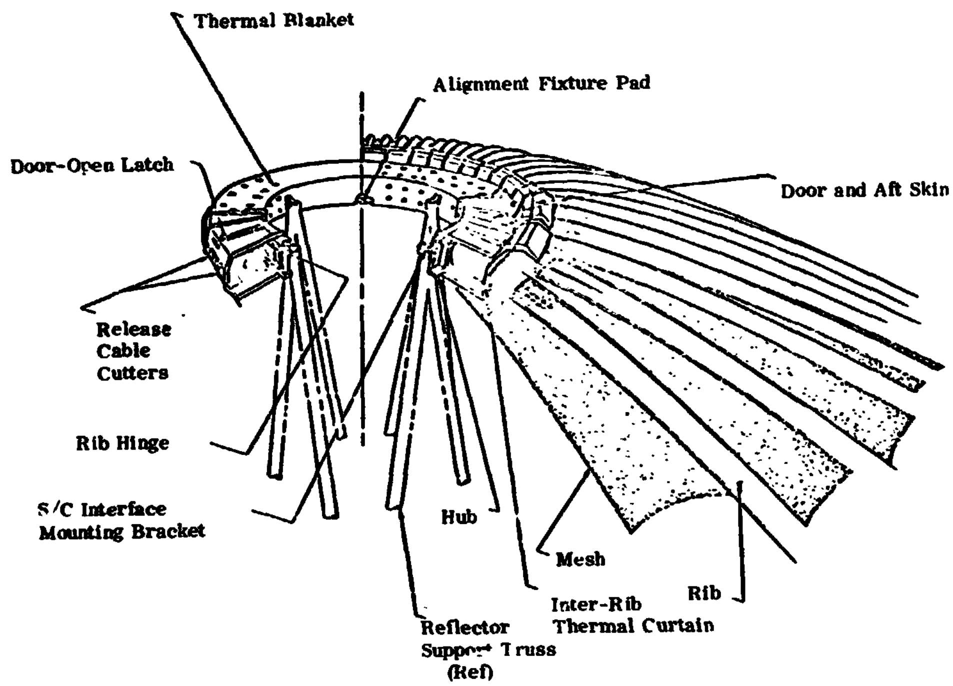

Figure 1.- Applied Technology Satellite parabolic reflector subsystem.

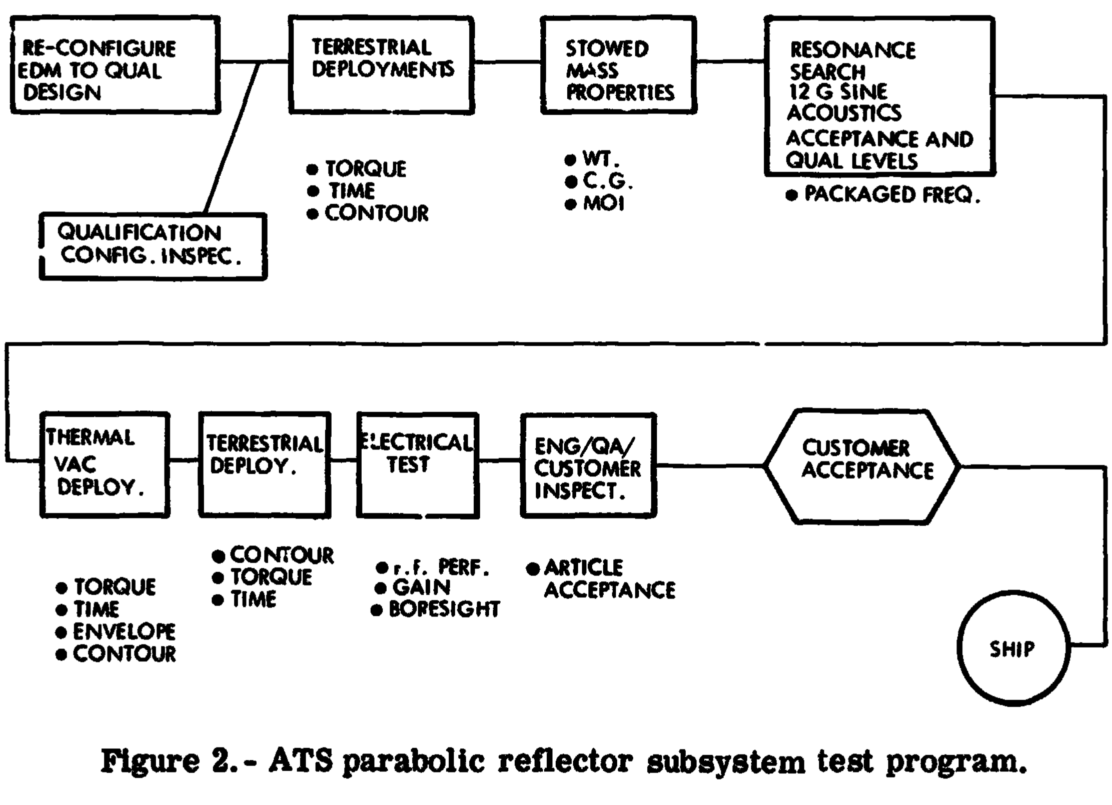

Figure 2.- ATS parabolic reflector subsystem test program.

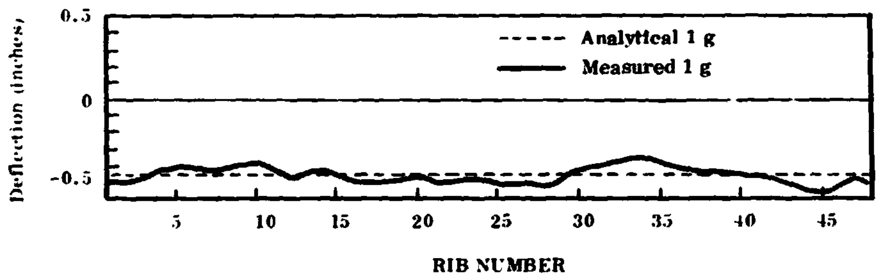

Figure 3.- One g analysis/test results.

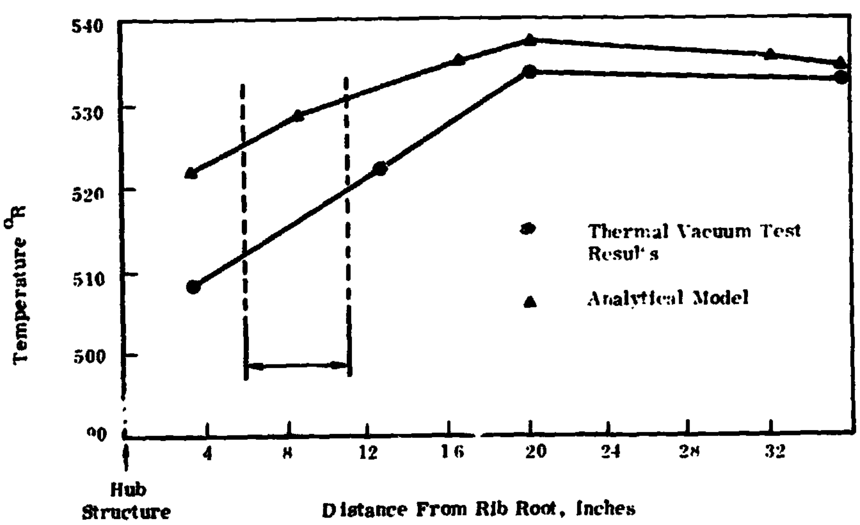

Figure 4.- Average temperature analysis/test results, position 1.

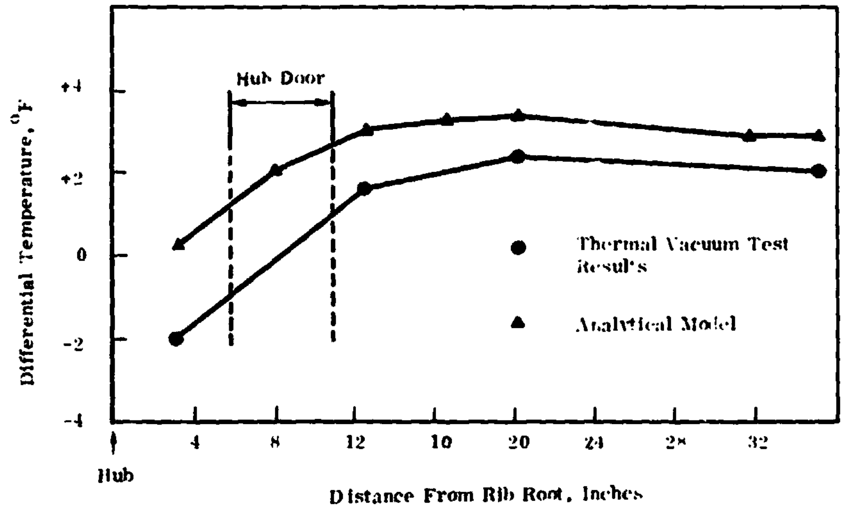

Figure 5.- Depthwise temperature gradient analysis/test results, position 3.

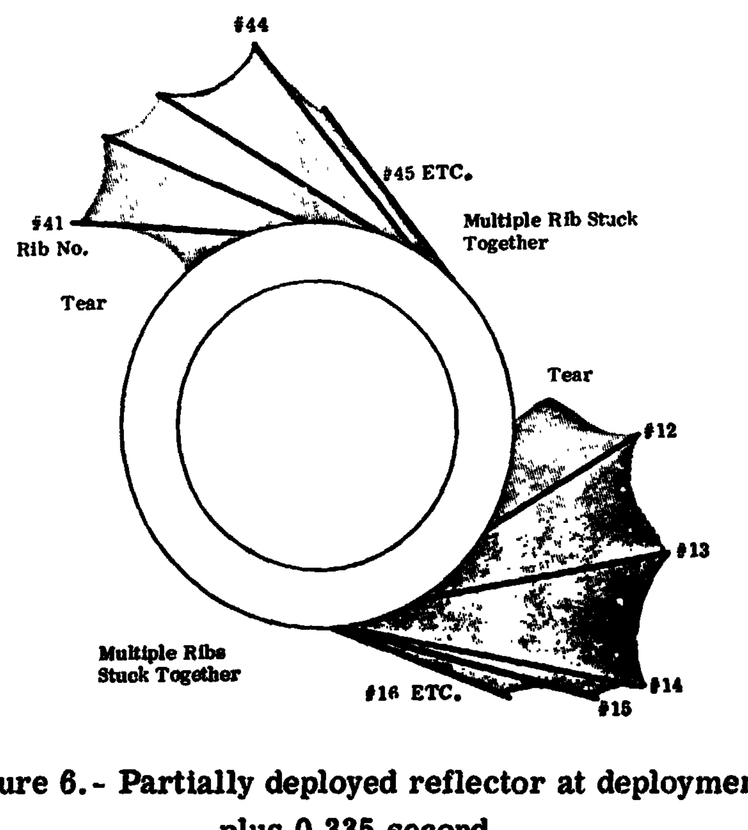

Figure 6.- Partially deployed reflector at deployment plus 0.335 second.

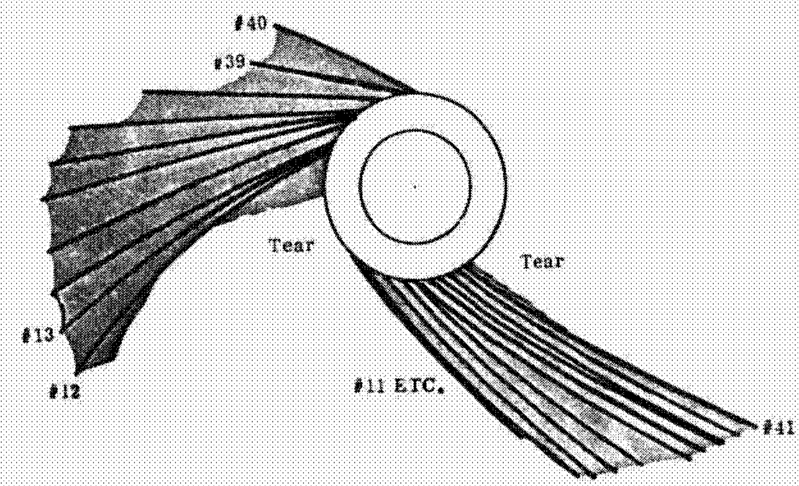

Figure 7.- Partially deployed reflector at deployment plus 1.36 seconds.

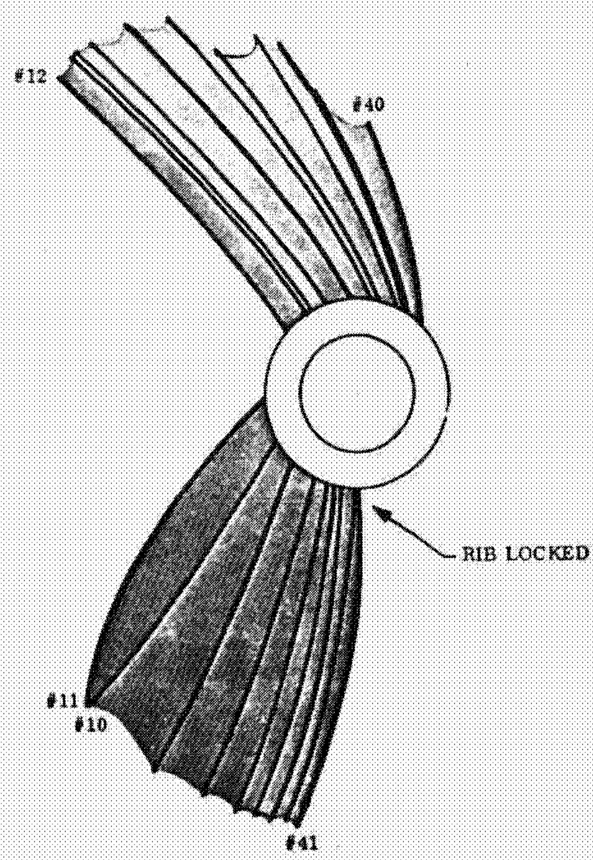

Figure 8.- Reflector at time of full deployment plus 1.9 seconds.

NASA-Langley, 1973 —— 31 L-9262