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BUCKLING ANALYSIS OF THE QUADRIPOD STRUCTURE FOR THE NASA 70-METER ANTENNA

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SUMMARY

The diameter extension of the three NASA DSN (Deep Space Network) large Earth-based antennas from the existing 64 meters to 70 meters will provide a needed increase in space communication capability for the Voyager 2 - Neptune encounter in August 1989.

As part of the upgrade effort, a slim-profiled quadripod structure was designed to support the 7.7-m-diameter subreflector for the 70m antenna. The new quadripod design, which particularly emphasizes reduced radio-frequency (RF) blockage, is achieved by means of a narrow cross-sectional profile of the legs.

Buckling analysis, using NASTRAN, was conducted in this study to verify the safety margin for the quadripod structural stability.

INTRODUCTION

The upgrade of the three NASA/JPL 64m diameter antennas will provide a needed increase in Earth-based space communication capability at all three Deep Space Communications Complexes: Goldstone, California (DSS-14); Canberra, Australia (DSS-43); and Madrid, Spain (DSS-63). In addition to the increase of the antenna aperture area from 64m to 70m, a number of significant improvements in the quadripod, surface panels, subreflector positioner, and microwave aspects are included in the design. The upgrade objective is to increase the radio-frequency (RF) gain/noise temperature (G/T) by about 1.9 dB at X-band (8.45 GHz).

As part of the upgrade effort, a new, high-precision 7.7-m (25.4 ft) diameter subreflector and positioning mechanism are needed. Consequently, an entirely new quadripod structure is required to support the subreflector. The new quadripod design particularly emphasizes reduced RF blockage, which is achieved by means of a narrow cross-sectional profile of the legs. The profile adopted provides about 0.32 dB of gain improvement in comparison with the existing 64 meter design (Ref. 1). This report addresses the stability analyses performed on the new quadripod design to ensure that it has an adequate safety margin for buckling and that the minimum natural frequency is compatible with control system requirements.

QUADRIPOD DESIGN

The quadripod assembly is a tabular space-frame steel structure with four trapezoidally shaped legs connected to another large space frame at the apex, as shown in Figs. 1 and 2. The four legs are supported at the corner points of the rectangular truss system of the main reflector structure as shown in Fig. 2. The final slim profile leg cross-section envelope selected is shown in Fig. 3. Also, the quadripod will be used occasionally for hoisting the cassegrain feed cones, the subreflector, or other heavy equipment which may be removed and reinstalled.

The finite element model of the 70m quadripod truss structure is a pin-joined frame (3 translational degrees of freedom per node) comprising 156 nodes, 445 axial bars, and 28 membrane plates. The JPL/IDEAS (Iterative Design of Antenna Structures) computer program was used for analysis and design (Ref. 2). The program employs the optimality criterion to minimize the structural weight (objective function) with a constraint placed on the lowest natural frequency. A subsequent analysis of the 70m model, accounting for bending and torisonal stiffness at the joints (6 degrees of freedom per node) using NASTRAN (Ref. 3), showed only a small increase in the torsional natural frequency (Ref. 1). Outrigger braces (Fig. 2) were added thereafter to increase the lowest natural frequency.

Due to the slimness of the quadripod legs, the following requirements had to be considered:

Static buckling stability: The occasional use of the quadripod as a derrick required a check on the possibility of buckling instability. A factor of safety of at least 1.5 was recommended. The smallest eigenvalue found from a structural buckling analysis is equivalent to this factor of safety. Since the IDEAS program that was used for design and natural frequency analyses does not perform buckling analysis, the new quadripod design was optimized for the frequency requirement using IDEAS and then analyzed for buckling using NASTRAN (NASA Structural Analysis Program). NASTRAN was used to determine the buckling loads of the natural frequency-constrained quadripod design. Two versions of the NASTRAN program were used because of possible different finite element formulations: the NASTRAN-COSMIC (NASA's Computer Software Management and Information Center) (Ref. 4) and the proprietary NASTRAN-MSC version (MacNeal-Schwendler Corporation) (Ref. 3). The two versions were used both for the buckling and natural frequency analyses, and the results obtained were compared.

RESULTS OF BUCKLING ANALYSIS

The Rigid Format No. 5 of the NASTRAN program was used to perform the buckling analysis. The results of the buckling analysis for the quadripod pin-joined model are presented in Table 1. Both the COSMIC and MSC versions of the NASTRAN program were used and compared. Four antenna configurations, each subject to the maximum loads anticipated to be hoisted when employing the quadripod as a derrick, in addition to the quadripod weight, were considered in the quadripod buckling analysis:

(1) Zenith look with outriggers.

(2) Zenith look without outriggers.

(3) Horizon look with outriggers.

(4) Horizon look without outriggers.

Table 1 shows that the outriggers tend to at least double the buckling load capability.

FINITE ELEMENT PLATE STIFFNESS REPRESENTATION

Comparisons of the COSMIC-NASTRAN and MSC-NASTRAN results on the quadripod model in Table 1 show that the plate element CQDMEM2 in the COSMIC version gives a different stiffness matrix representation compared with the CQUAD4 plate element in the MSC version, or with the IDEAS plate element CQDMEM.

A parametric study was conducted to readjust the moduli of elasticity of the COSMIC CQDMEM2 plate elements to produce results similar to those of the MSC elements. Comparison of the results of the stiffness parameterization study is shown in Table 2 for the quadripod buckling analysis. The plate element used in the NASTRAN-COSMIC employs the constant stress formulation, while the elements used in the NASTRAN-MSC or IDEAS permit a stress variation. As a result, the COSMIC element generates a stiffer structure than the other elements.

CONCLUSIONS

A structural stability study was conducted for the 70m antenna quadripod. The quadripod was found to be stable in buckling when the outrigger braces were included. One computer program used in the investigation was found to give an over-estimate of the stiffness. In order to correct the excessive stiffness, a parametric study was conducted to derive empirical coefficients to adjust the plate stiffness for future use of this program.

REFERENCES

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Table 1 The quadripod buckling analysis results

Case	Antenna configuration	NASTRAN COSMIC version	NASTRAN MSC version
1	Zenith look, with outriggers	22.81	12.27
2	Zenith look, without outriggers	9.23	(not run)
3	Horizon look, with outriggers	12.87	3.77
4	Horizon look, without outriggers	4.12	1.66

Table 2 Comparison of the plate element stiffness and the smallest eigenvalues for the quadripod buckling analysis

Program	Plate element	Young's modulus, N/m^2 (psi)	Shear modulus, N/m^2 (psi)	λ_{min}
(a) Zenith Look Antenna Configuration, with Outrigger Braces:				
NASTRAN-MSC	CQUAD4	20.0×10^{10} (29.0×10^6)	8.3×10^{10} (12.0×10^6)	12.27
NASTRAN-COSMIC	CQDMEM2	10.7×10^{10} (15.5×10^6)	4.4×10^{10} (6.4×10^6)	12.30
(b) Horizon Look Antenna Configuration, with Outrigger Braces:				
NASTRAN-MSC	CQUAD4	20.0×10^{10} (29.0×10^6)	8.3×10^{10} (12.0×10^6)	3.77
NASTRAN-COSMIC	CQDMEM2	5.2×10^{10} (7.5×10^6)	2.2×10^{10} (3.2×10^6)	3.97

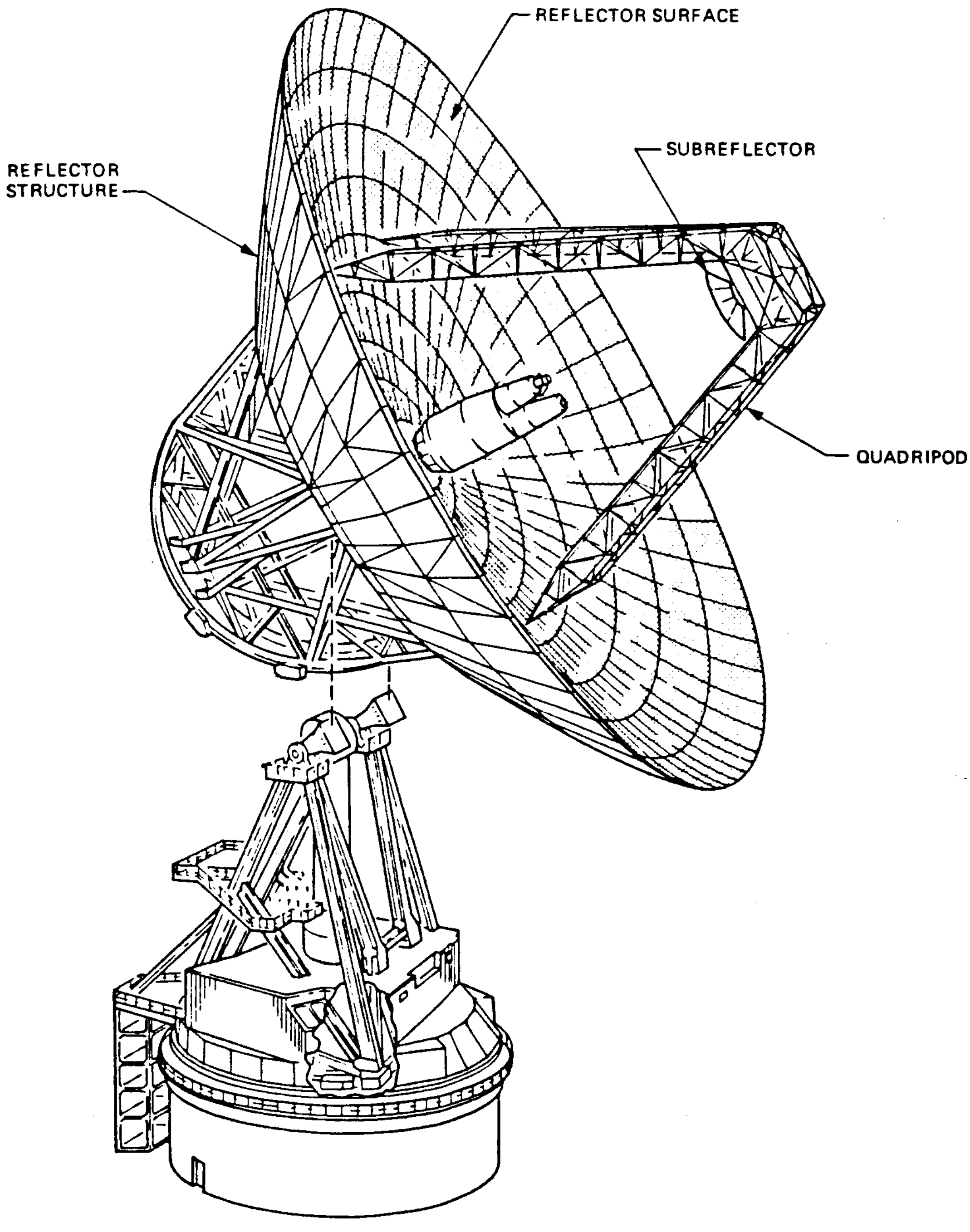

Fig. 1. Antenna quadripod and reflector system

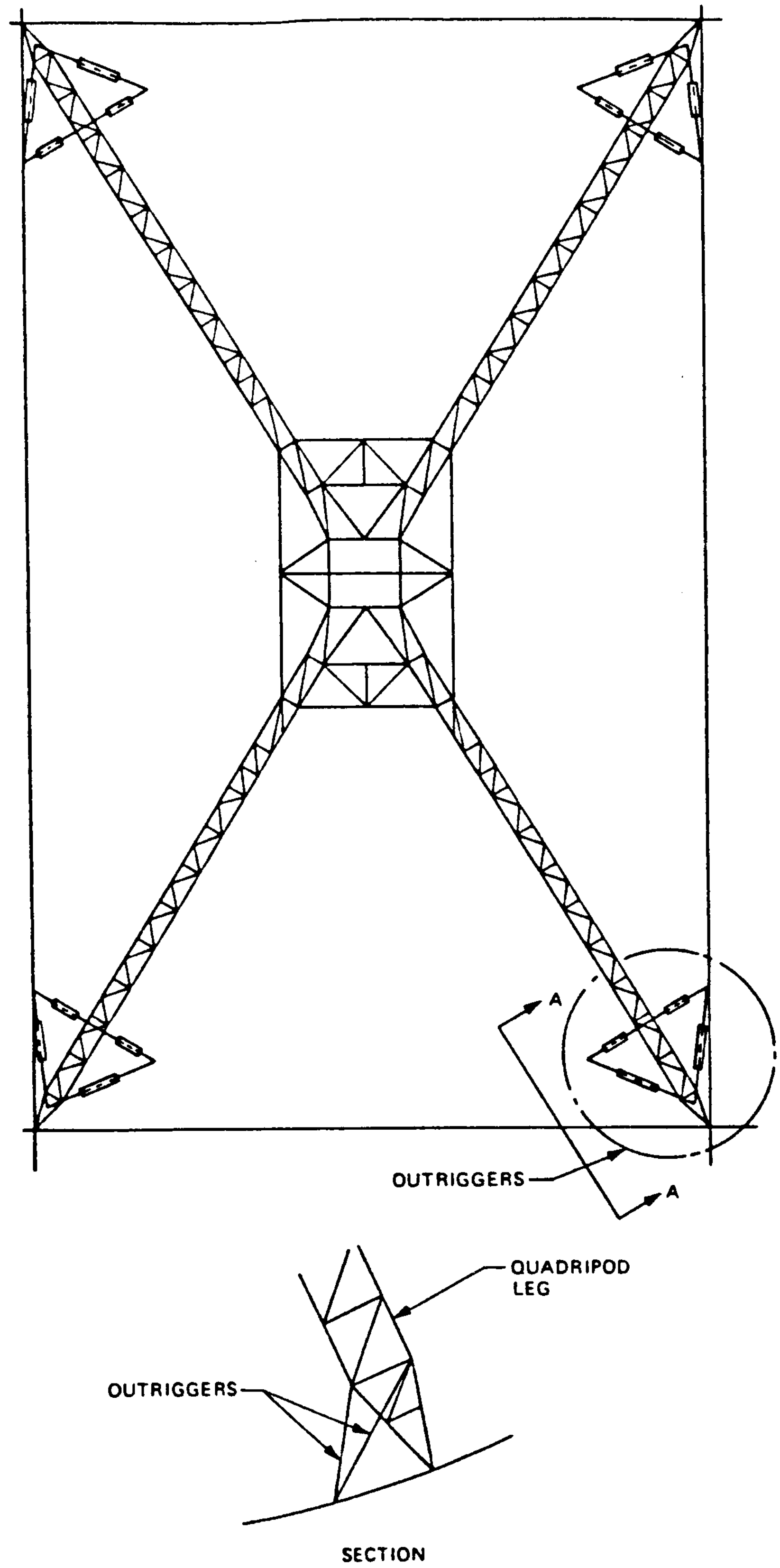

Fig. 2. Plan view of 70-m quadripod with outriggers

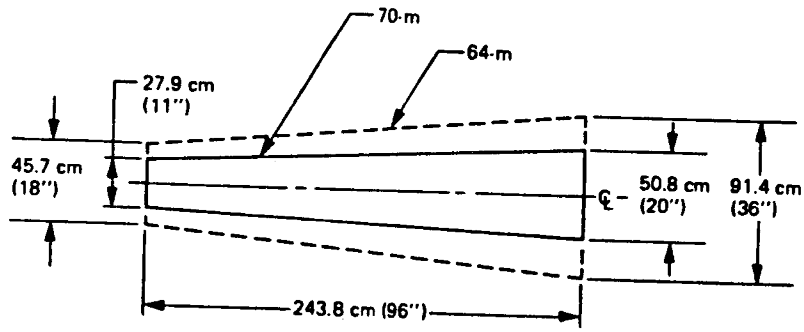

Fig. 3. Quadripod cross-sectional profile