Radio-Frequency Boresight Analysis of the Low-Cost 64-Meter Antenna

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Two configurations of the reflector-only assemblies, using different width backup cones, are analyzed for RF boresight direction changes and wind distortions. The wider backup cone is best for minimum weight; however, there is an optimum weight which minimizes the RF boresight errors for a wind load that produces the maximum pitching moment of both configurations.

I. Introduction

One of the important performance characteristics of a large ground antenna is the pointing accuracy of its RF boresight with respect to the indicated positions on the axes angle measuring devices. As the beamwidth of the RF pattern decreases with increases in operating frequency and antenna diameter, the pointing changes due to the environmental (gravity, wind, temperature) load changes must be limited to a fraction of the beamwidth to prevent excessive gain loss.

The DSN ground antenna must operate continuously through day and night and, on occasions, in wind gusts up to 84 km/h (55 mi/h) on S-band frequency. Operation under a limited environment is considered to be satisfactory for X-band as a balanced requirement to the frequent occurrences of large gain loss of X-band through a moisture-laden atmosphere.

The use of the conical scan pointing system relieves the pointing requirements but "blind" pointing again becomes important when very-long baseline interferometry (VLBI) is activated.

Radio-frequency boresight errors due to gravity loading can be calibrated and compensation applied by many means, such as the future minicomputer in the pointing equipment, so these errors will not be considered here. Errors from wind loads will be difficult to model and calibrate; hence, minimizing by design would probably be the best solution.

Since the connections between the symmetric reflector structure and the alidade under consideration are at only two points with the forces or reactions determinant, the reflector can be analyzed by itself and its reactions applied to the alidade. By this method, the complete antenna can be analyzed.

This reporting will be on the analysis of the wind load resulting in the maximum pitch or yaw moments on the reflector-only configuration. The follow-on reporting will describe the overall effects of the selected wind load on the complete antenna.

The asymmetry of the maximum pitching moment wind load, 60-deg elevation angle with wind from the back, results in the maximum distortion of the reflector as well as the RF boresight deflection. A design that can minimize and compensate for the RF boresight error may be adequate to cover other operating conditions where the gain loss is less and accurate boresight compensations are thus not as critical.

It should be noted here that large gain losses can occur at high RF frequency use with symmetric winds, winds directly into or back of the reflector, as a result of axial RF phase center offsets to the best-fit paraboloid.

The reflector structural configuration and its backup structure is a follow-on of that described in Ref. 1.

The JPL-IDEAS (Ref. 2) computer programs and special programs, as described in Ref. 1, were used to generate most of the computer data which saved both generation and verification time.

II. Antenna Description

A. Reflector Structure

As shown in Fig. 1, the radial distances to the hoops were made up of four increments of 3.05 m (120 in.), one of 3.56 m (140 in.) and four of 4.06 m (160 in.). These spacings can be changed slightly and not affect the distortion characteristics of the reflector. Equal distances along the parabolic arc might be in order to reduce tooling costs of the surface panels.

Two alternate backup cones were used. The standard configuration attached to the fourth hoop and the wider cone attached to the fifth hoop.

A diaphragm or plate flexture-type structural member covers only the bottom of the center bay, and, with the center connection to the backup structure, only lateral reflector support is provided at the center. The axial as well as the second lateral support point is provided by the apex of the backup cone assembly. A torsion constraint link would be required for the actual antenna, but for the one-half symmetrical computer model, constraints on the symmetry plane prevent this torsional motion. Diagonals in at least one bay or space between two ribs would also be required in the actual antenna or constraints would have to be provided by the surface panels.

The center bay is hollow to provide for easy access to the cassegrain cone mounted on hoop 1. Face diagonals are used between hoop 1 and hoop 2 on both top and bottom surfaces to essentially form a torus structure. Otherwise, no other face diagonals are used except between hoops 5 and 6 to tie the intermediate ribs to the main ribs.

As stated previously, the reflector-only configuration is analyzed in this reporting with two different backup cones. Other configuration changes, such as a deeper reflector and thicker outer edges, have been computed, but not completely analyzed at this point.

Since this reflector-cone assembly is connected to the backup structure with the statically determinable two points, the reflector-only configuration can be analyzed by itself, and the reaction loads can then be applied to the backup structure and alidade assembly in order to obtain the total system deflections.

B. Backup Structure and Alidade

The backup structure and alidade is shown in isometric view as Fig. 2. The four-point azimuth wheel supports at ⑤⑥⑦ and ⑧ provide a wide support base which insures stability against overturning from the survival wind loads. At the same time, the four wheel loads are about equal for gravity load because the alidade lacks torsional rigidity about the elevation axis. The rigidity is supplied by the wheels. Loads in the elevation axis direction on elevation bearings ③ and ④ are transmitted to the center radial bearing by diagonal bars ③-⑨ and ④-⑨.

The reflector is attached at points ① and ②.

III. Analysis Description

As stated previously, the wind direction producing the maximum pitching moment occurs with the antenna at 60-deg elevation and the wind from the back. Since the quadripod is protected by the reflector, no wind loads will be assumed on it. The reflector surface is 50-percent porous in the outer 50-percent radius, the same configuration as the present Mars 64-m antenna.

The pressure difference coefficients were developed by the method described in Ref. 2.

The JPL-IDEAS program first minimized the gravity distortions, maintaining the structural integrity for the stow wind loads of 44.70 m/s (100 mi/h). By multiplying the resulting bar areas by 2 and again input to the JPL-IDEAS program using a ratio of 0.2, the output resulted in weight reduction steps with the gravity distortion figures remaining substantially the same, just slightly above the minimums resulting from the first computations. In this way, the data for structural weight vs. the distortion rms for the 31.29-m/s (70-mi/h) wind velocity were developed as well as parameters of the best-fit paraboloid.

The above follows from the theory that, if the surface panels and the cassegrain cone loads are not considered, fixed percentage changes of all of the bars of the reflector structures result in no change in the gravity distortion rms.

IV. Analysis Results

The outputs from the JPL-IDEAS programs related to the 60-deg elevation back-wind load input are detailed in Tables 1 and 2 for the standard and the wider backup cones, respectively.

Offset F figures were calculated from the lateral motion required of the RF phase center in order to maintain the original undeflected RF boresight direction. Radio-frequency ray tracing was used with a reflection factor of 0.85 applicable for a uniformly illuminated reflector as illustrated in Fig. 3.

Figure 4 shows the results of Tables 1 and 2 plotted with respect to the reflector structural weight variations. The rms and offset F curves are almost identical by chance.

V. Conclusions

It must be concluded that the RF boresight direction error for a particular wind load is a function of the structural weight of the reflector.

The wider backup cone decreases both the offset F and the distortion rms for the maximum pitching moment wind load.

The other factors that must be taken into account are: (a) displacement of the RF phase center at the paraboloid's focus, and (b) the deflection characteristics of the reflector's backup wheel and alidade that affect the differences between the indicated positions of the axes angle transducers and the true pointing directions. These factors will be discussed in follow-on reporting.

References

1. Levy, R., "Conceptual Studies for New Low-Cost 64-m Antennas," in *The Deep Space Network Progress Report 42-33*, Jet Propulsion Laboratory, Pasadena, Calif., pp. 55–61, June 15, 1976.
2. Katow, M. S., "Aerodynamic Static Differential Pressure Values for the 50 Percent Porous Reflector Dish," in *The Deep Space Network Progress Report 42-29*, Jet Propulsion Laboratory, Pasadena, Calif., pp. 60–65, Oct. 15, 1975.

Table 1. Parameters of the best-fit paraboloid (Fig. 3) reflector only with standard backup cone

Sequence	Structural weight, kg (kips)	Rms, mm (in.)	Focal length, m (in.)	A Y-coord, cm (in.)	B Z-coord, cm (in.)	C X-rotation, rad	D Offset, cm (in.)	E Offset, cm (in.)	F Offset, cm (in.)
1	482,100 (1063)	2.21 (0.087)	27.1041 (1067.089)	9.972 (3.926)	0.053 (0.021)	0.002061	5.585 (2.199)	4.387 (1.727)	2.184 (0.860)
2	386,900 (853)	2.74 (0.108)	27.1018 (1067.0)	12.466 (4.908)	0.066 (0.026)	0.002576	6.983 (2.749)	5.484 (2.159)	2.731 (1.075)
3	310,700 (685)	3.40 (0.134)	27.1011 (1066.974)	15.583 (6.135)	0.084 (0.033)	0.003220	8.730 (3.437)	6.853 (2.698)	3.419 (1.346)
4	260,800 (575)	4.01 (0.158)	27.1000 (1066.927)	15.583 (6.887)	0.109 (0.043)	0.003661	9.921 (3.906)	7.572 (2.981)	4.100 (1.614)
5	241,300 (532)	4.39 (0.173)	27.0989 (1066.884)	19.944 (7.852)	0.107 (0.042)	0.004122	11.171 (4.398)	8.773 (3.454)	4.369 (1.720)

Wind load = 60° elevation back wind

Dynamic pressure = 84.9 kN/m^2 (12.3 psi)

Wind velocity = 31.3 m/s (70 mi/h)

F = (D/0.85) − E

Rms = distortion in one-half pathlength errors

A, B, C, D, E, F = Fig. 3

Table 2. Parameters of the best-fit paraboloid (Fig. 3) reflector only with wider backup cone

Sequence	Structural weight, kg (kips)	Rms, mm (in.)	Focal length, m (in.)	A Y-coord, cm (in.)	B Z-coord, cm (in.)	C X-rotation, rad	D Offset, cm (in.)	E Offset, cm (in.)	F Offset, cm (in.)
1	525,500 (1160)	1.37 (0.054)	27.1063 (1067.175)	4.702 (1.851)	0.061 (0.024)	0.001031	2.794 (1.100)	1.908 (0.751)	1.379 (0.543)
2	423,600 (935)	1.70 (0.067)	27.1055 (1067.146)	5.873 (2.312)	0.076 (0.030)	0.001288	3.493 (1.375)	2.380 (0.937)	1.730 (0.681)
3	338,400 (747)	2.11 (0.083)	27.1046 (1067.109)	7.338 (2.889)	0.097 (0.038)	0.001610	4.364 (1.718)	2.974 (1.171)	2.159 (0.850)
4	271,800 (600)	2.77 (0.109)	27.1031 (1067.051)	8.649 (3.405)	0.127 (0.050)	0.001941	5.260 (2.071)	3.388 (1.334)	2.799 (1.102)

Wind load = 60° elevation back wind
Dynamic pressure = 84.9 kN/m^2 (12.3 psi)
Wind velocity = 31.3 m/s (70 mi/h)
F = (D/0.85) − E
Rms = distortion in one-half pathlength errors
A, B, C, D, E, F = Fig. 3

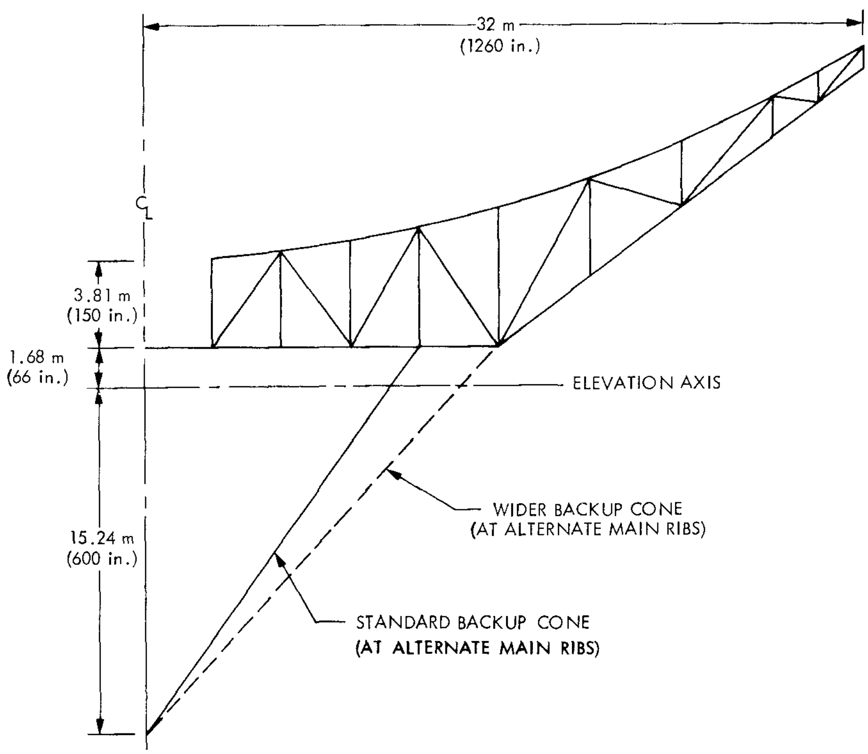

Fig. 1. Reflector structure with backup cone

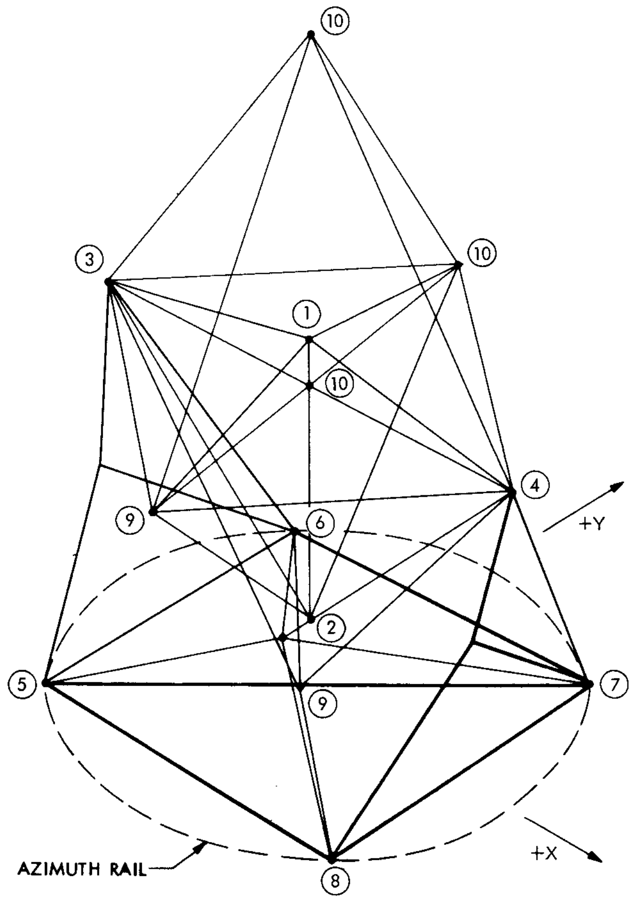

Fig. 2. Reflector backup structure with alidade

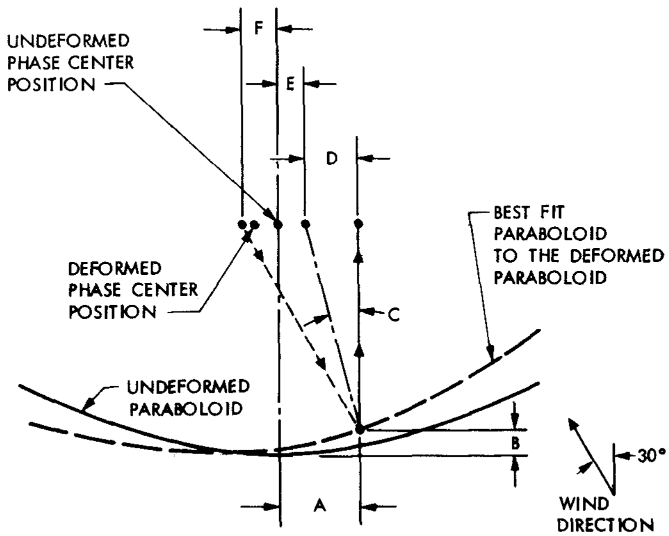

Fig. 3. Best-fit paraboloid parameters

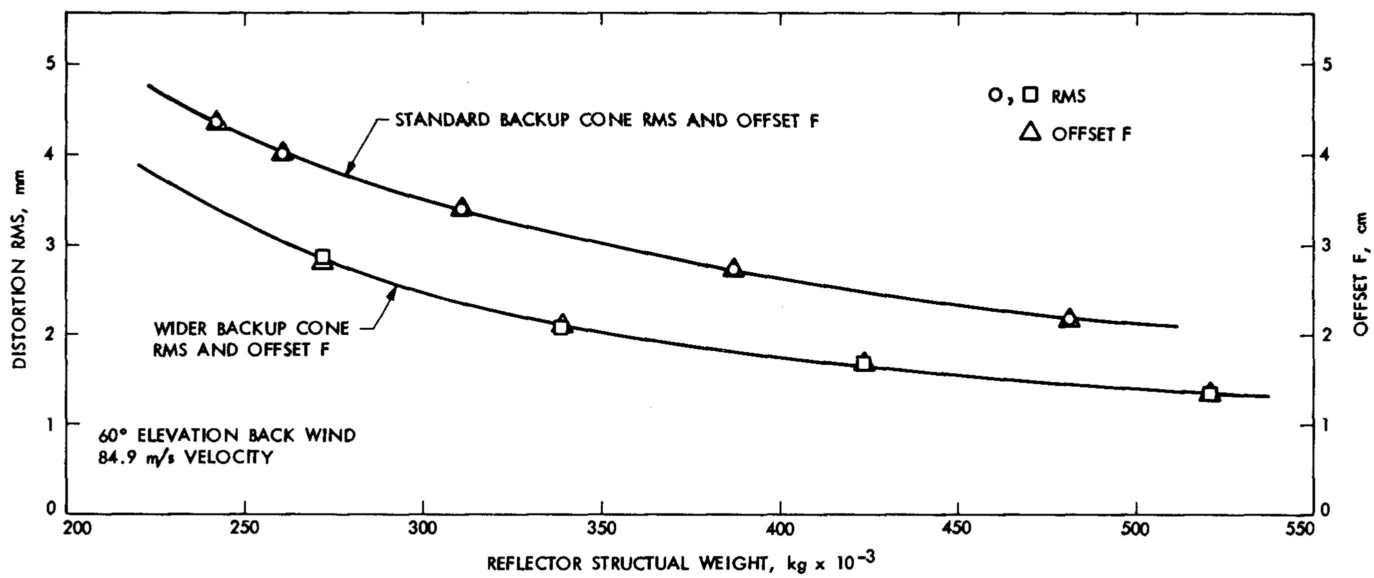

Fig. 4. Reflector distortion rms and offset F vs structural weight