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SPECIAL DESIGN CONSIDERATIONS FOR WIND INDUCED POINTING ERRORS IN LARGE UNBLOCKED APERTURE RADIO REFLECTORS

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PURPOSE:

Much analytical work has been done regarding wind induced pointing error on large radio reflectors. Recently a new breed of large Radio Reflectors with unblocked apertures has been proposed. These offset feed arm reflectors introduce more complicated mechanisms with regards to wind induced pointing error. The purpose of this paper is to show trends in the behavior of one such reflector, the NRAO 100m Green Bank Telescope (GBT), through pressure loadings applied to the NRAO NASTRAN model of the proof of concept elevation structure.

DESCRIPTION:

The model tested is the NRAO proof of concept model presented on February 7, 1991 to the prime contractor of the GBT, Radiation Systems Incorporated. The prime, through its subcontractor, Loral Western Development Laboratories, is independently designing a structure whose performance will be different from that of this model. The model tested was jointly proposed by NRAO and JPL and preliminary optimization of the model was made by JPL using the JPL-Ideas Reflector Optimization Code. The model was adopted by NRAO and modified to improve performance of the arm and the box/el bearing/el wheel structure. Further optimization was performed by NRAO using JPL-Ideas. The final model consisted of 7100 members with 40 different cross sections that fulfilled gravity induced surface error budgets, natural frequency constraints, and wind induced pointing error budgets for wind loading of the primary reflector. These pressure loadings were generated using JPL document CP-4 and were applied as point force loadings in the optimization phase and pressure loadings in the analysis phase.

The analysis phase pursued questions pertaining to pointing error components that were not applied during the optimization process, as well as to generate procedures that would allow NRAO to evaluate the contractor model. The final set of environmental loadings provided for eight wind load sets, gravity induced surface deformation constraints, and natural frequency constraints. The latter two were found to be consistent with the optimization and are discussed no further. The eight wind load sets are shown in Figure 1.

They consist of six wind loads where the wind vector lies in the plane of symmetry (three with the arm on the windward side, and three with arm on the leeward side), and two where the wind vector is normal to the plane of symmetry of the primary. The loadings are applied at the operating environment wind velocity of 7 m/s. The loading sets are: pressure loading applied to the primary reflector (using JPL CP4), line loads applied to arm members generated by multiplying member width by dynamic pressure, point loads applied to nodes surrounding sail areas on the arm (i.e. feed rooms, etc.), and force and moment loads caused by wind effects on the secondary reflector. All but the first load set were scaled using the one-eighth power rule of aerodynamics (with reference height as height of el axis).

Eleven components are included in the pointing error calculations. Basic procedure indicates loading the model with a particular wind load, using the generated deformations from the finite element results to calculate a Best Fit Parabola (BFP) for the primary reflector, and then writing all subreflector motions with respect to the BFP coordinate frame. These calculations determine the eleven components:

- Rotation of the BFP in the plane of symmetry
- Translation of the BFP in the plane of symmetry (2 components)
- Rotation of the Secondary in the plane of symmetry
- Translation of the Secondary in the plane of symmetry (2 components)

- Change in Focal Length
- Rotation of the BFP about the axis that is the cross product of the axis of the parent paraboloid and the elevation axis
- Translation of the BFP along the vector normal to the plane of symmetry
- Rotation of the Secondary about the axis that is the cross product of the axis of the parent paraboloid and the elevation axis
- Translation of the Secondary along the vector normal to the plane of symmetry

Pointing error scalars generated by the NRAO RF optics group were applied to these terms and resulting pointing errors calculated. Note that the six wind directions whose vector lies in the plane of symmetry cause errors of the type described in the first five entries above. Transverse wind loads cause errors of the type described in the last five entries (change in focal length is inherent to both).

Note that close comparisons were made between these wind loading studies, JPL's CP4 and 7816 documents, and the NRAO wind tunnel model. The results indicate that model behavior correlates well with these other references.

RESULTS:

Table 1 shows the overall elevation pointing error broken down by orientation. Table 2 shows the component breakdown of the three major error components and their superposition (which should equal that shown in Table 1) for the Symmetric Plane Wind Loads. Both are normalized to maximum error found. Sign of pointing error is rotation with respect to reference coordinate system using right hand rule. The reference coordinate system is the elevation structure coordinate frame, not the global coordinate frame.

TABLE 1: OVERALL POINTING ERROR

Load Case	Pitch Angle	Elevation Angle	Normalized Pointing Error
Wind Vector In Plane of Symmetry: Arm on Windward Side*			
1060	60°	96°	.13
1090	90°	66°	.20
1120	120°	36°	.15
Wind Vector in Plane of Symmetry: Arm on Leeward Side*			
2060	60°	36°	-1.00
2090	90°	66°	-.40
2120	120°	96°	-.09
Wind Vector Normal to Plane of Symmetry**			
3065	65°	91°	-.67
3155	155°	1°	-.65

ALL POINTING ERRORS NORMALIZED TO WORST CASE POINTING ERROR

* indicates pointing error as rotation about el axis

** indicates pointing error about axis normal to axis of parent paraboloid in plane of symmetry

TABLE 2: COMPONENT BREAKDOWN OF POINTING ERROR FOR SYMMETRIC PLANE LOADS				
Load Case	Primary Induced Normalized Pointing Error	Arm Induced Normalized Pointing Error	Feed/Sub Induced Normalized Pointing Error	Superposition Normalized Pointing Error
Wind Vector in Plane of Symmetry: Arm on Windward Side*				
1060	-.424	.185	.374	.135
1090	-.397	.327	.266	.196
1120	-.444	.393	.205	.154
Wind Vector In Plane of Symmetry: Arm on Leeward Side*				
2060	-.518	-.276	-.205	-1.000
2090	.172	-.303	-.269	-.400
2120	.283	0	-.377	-.091

CONCLUSIONS:

The pointing error is largest In load case 2060. The major contributor to this mechanism is the fact that in this load case the arm motion Is opposite that requlred by the optics so that the feed illuminates the proper portion of the sky as the BFP rotates underneath it. This implies the errors are additive Instead of cancellative, and hence the largest error. This is a major design consideration since this asymmetric behavior is caused by attaching two different substructures (arm and primary reflector backup structure) to one support structure (box/el bearing/el wheel) at two different points. This does not happen In blocked aperture designs since the feed support attach points and primary reflector backup structure Integration Insure that the two substructures behave monolithically. The unblocked aperture design type is also highly dependent upon the positioning of the elevation axis with respect to the box/arm and box/primary reflector integration points, since this directly affects the magnitudes of the force and moment loads applied to the box.

An equally Important design consideratlon Is the fact that thls error occurs at a point in the orientation of the reflector where small changes in the orientation of the reflector cause large scale changes in the loadings. This perturbation Is caused by the fact that the primary is in the region where it ceases to act like a plate normal to the airstream and begins to behave as an airfoil. Evidence indicates that the error increases as one decreases between thirty six and thirty degrees elevation with the arm on the leeward side. A pyramid with vertex height angle of approximately six degrees (elevation 30 through 36 degree) and vertex width angle of approximately ninety degrees (45 degrees on either side of current azimuth) defines the problem area.

In any design where high degrees of Pointing accuracy are required, the design engineer should be aware of these error mechanisms and investigate whether the chosen design exhibits weaknesses to these loadings. They do not directly affect safety of the design, but they have a great Impact on performance.

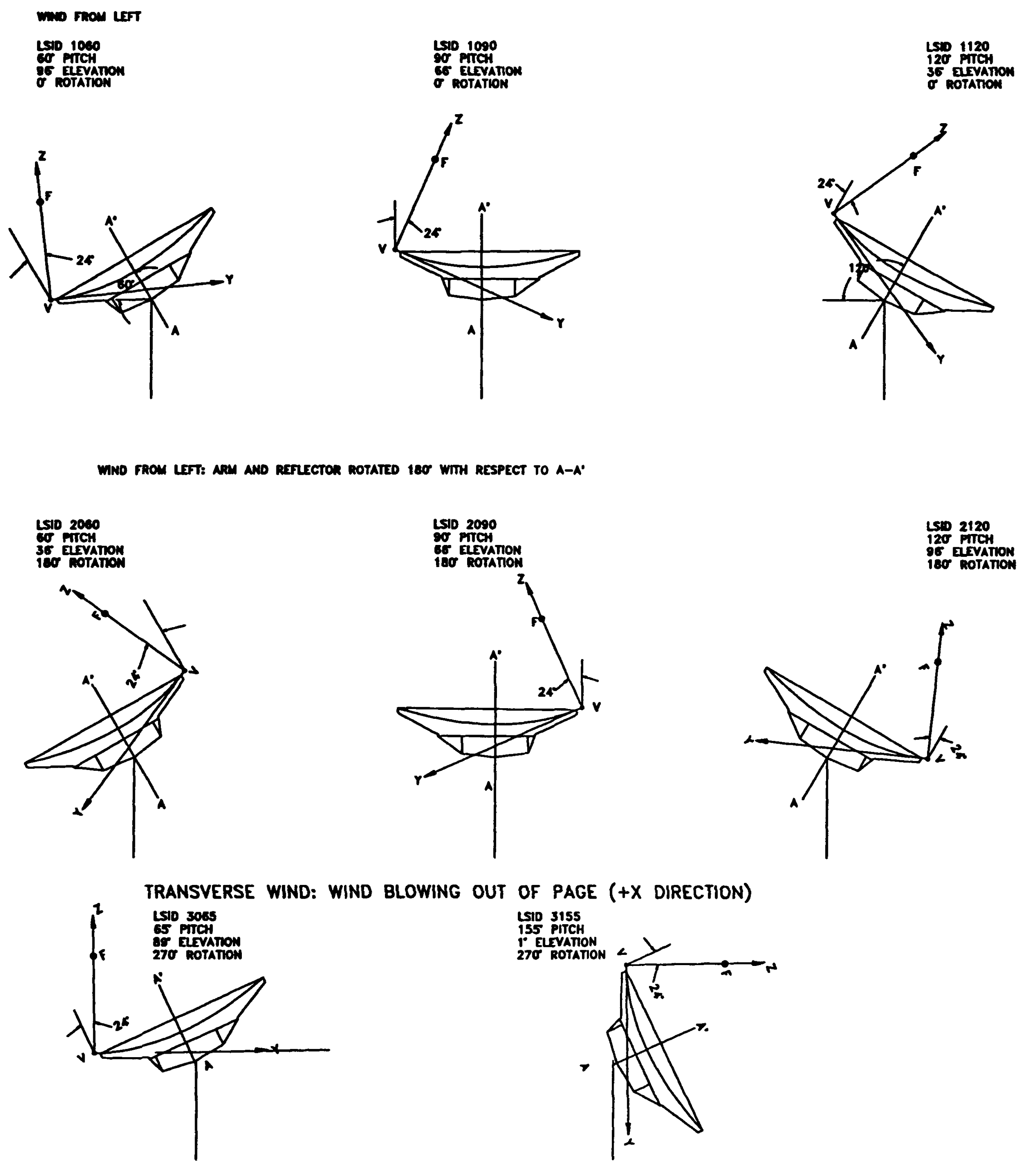
WIND FROM LEFT
LSID 1060
60° PITCH
96° ELEVATION
0° ROTATION
LSID 1090
90° PITCH
66° ELEVATION
0° ROTATION
LSID 1120
120° PITCH
36° ELEVATION
0° ROTATION
WIND FROM LEFT: ARM AND REFLECTOR ROTATED 180° WITH RESPECT TO A–A'
LSID 2060
60° PITCH
36° ELEVATION
180° ROTATION
LSID 2090
90° PITCH
66° ELEVATION
180° ROTATION
LSID 2120
120° PITCH
96° ELEVATION
180° ROTATION
TRANSVERSE WIND: WIND BLOWING OUT OF PAGE (+X DIRECTION)
LSID 3065
65° PITCH
89° ELEVATION
270° ROTATION
LSID 3155
155° PITCH
1° ELEVATION
270° ROTATION
Z
F
V
Y
A
A'
24°
60°
120°

FIG. 1