NASTRAN Structural Model for the Large 64-Meter Antenna Pedestal, Part I

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Static analysis and a computer structural model for the large 64-m antenna pedestal are developed using the MSC version of the NASTRAN program. This model was necessary to conduct a variety of hydrostatic bearing rehabilitation studies. The results obtained from the model show that the top surface deflections due to pad loads are in good agreement with the results previously obtained from a simplified "shortcut" analytical model, and also in agreement with field measurements. In addition, the displacement and force distributions as well as the state of stress and strain are obtained.

I. Introduction

The hydrostatic bearing of the large 64-m antenna of the NASA Mars Deep Space Station (DSS 14) at Goldstone has experienced some oil leakage problems. A computer structural model, using the MSC version of NASTRAN, has been developed in order to support the current rehabilitation efforts of the hydrostatic bearing.

This article is the first in a series of reports on the static analysis performed for the pedestal under pressure loadings at the three hydrostatic bearing pads. The displacement and force distribution throughout the model as well as the state of stress and strain are obtained.

A separate model for the hydrostatic bearing runner is also being developed. The two models will be combined to form a runner-pedestal system for further hydrostatic bearing studies.

II. Pedestal Description

A general arrangement of the hydrostatic bearing system for the 64-m antenna is shown in Fig. 1. The azimuth hydrostatic bearing, set on the pedestal top, supports the full weight of the moving parts of the antenna and permits a very low friction azimuth rotation on a pressurized oil film (Ref. 1). Three movable pad-and-socket assemblies float on the oil film over a stationary runner and support the three corners of the alidade base triangle as shown in Fig. 2. The stationary runner for the bearing and the three bearing pads are completely enclosed in an oil reservoir. The three hydrostatic bearing pads are equidistant from the central axis of the pedestal as shown in Fig. 3.

The pedestal is a two-story, reinforced concrete building 25.3 m (83 ft) in diameter, with a diaphragm top which has a concrete collar in the center; the pedestal supports the movable structure of the antenna. The wall thickness is 1.1 m (3.5 ft).

The three principal forces from the antenna alidade which act on the pedestal are: (1) vertical forces from the azimuth hydrostatic bearing pads, (2) rotational forces from the azimuth drives, and (3) horizontal forces on the azimuth radial bearing.

The three hydrostatic bearing pads, made of carbon steel, are 1.016 m (40 in.) wide, 1.524 m (60 in.) long, and 0.508 m

(20 in.) deep. There are six recesses in the bottom of each pad as indicated in Fig. 4, with the two center recesses being larger than the corner recesses. According to the original design specification, the pedestal concrete is required to have a Young's modulus of elasticity E of 3.5×10^{10} N/m^2 (5.0×10^6 psi). However, it is believed that the current Young's modulus of elasticity for the pedestal concrete is less than this value, and a reduced value, consistent with current core-sample measurements, is assumed for this report.

III. Model Description

All three pads are assumed to support the same amount of loads. Therefore, the pedestal is divided into three identical segments. Moreover, due to the symmetry with respect to the center line of the pad, each segment can be further divided into two segments.

As a consequence, a one-sixth segment of the pedestal, with angular span of 60°, is being developed in the present structural model as shown in Fig. 5. Appropriate boundary conditions are being applied to reflect the aforementioned symmetry.

The computer model comprises 630 six-sided solid elements with a total of 880 grid points as shown in Fig. 6.

It is pointed out in Appendix A that one of the three bearing pads (Pad No. 3) does support more load than the other two. The actual ratios of the loads in the three pads are approximately 9:9:11. However, in our modeling, the three pads are assumed to carry equal amounts of loading. A FORTRAN program was used to generate the grid. The model can be further modified to obtain a finer grid, if necessary.

The pedestal concrete is assumed to be homogeneous, with a reduced Young's modulus of elasticity E of 2.8×10^{10} N/m^2 (4.0×10^6 psi). The hydrostatic pressure in the pad is exerted on the first three rows of the top pedestal surface, with an angular span of 3.75° as shown in Fig. 6. A uniform pressure of 6.9×10^6 N/m^2 (1000 psi) is assumed under the pad. The MSC (Macneal Schwendler Corp.) version of NASTRAN is used in the present static analysis of the pedestal model.

IV. Comparison with Previous Work

Three approaches were followed to determine the pedestal surface deflection: a detailed NASTRAN computer model, an independent shortcut model, and field measurements.

First, the deflection map of the pedestal top surface, using NASTRAN for a uniform pad pressure of 6.9×10^6 N/m^2 (1000 psi), is shown in Figs. 7 and 8. The negative sign indicates a downward deflection (compressive) which is in the same direction as the applied pressure, while the positive sign indicates an upward deflection (tensile). The average deflection distribution for the top surface, as a function of the angular increment, is given in Fig. 9. The maximum deflection occurs at the outer edge. It has a relative deflection of 1.064 mm (0.0419 in.). If the average deflections are considered, the maximum deflection becomes 0.917 mm (0.0361 in.).

Second, a simplified shortcut analytical model was used which considered the pedestal as a semi-infinite plate (Appendix B and Fig. 10). The deflection at the pad center, for a pad pressure of 6.9×10^6 N/m^2 (1000 psi), was found to be 0.914 mm (0.036 in.). The pad center deflection derived from the present NASTRAN model is 0.935 mm (0.0368 in.). Third, a level measurement was conducted at the DSS 14 pedestal in which the maximum deflection was found to be 1.067 mm (0.042 in.). Hence, the comparison shows a good agreement among results obtained from the three different methods.

In addition to the top surface deflection, the present NASTRAN model gives additional information about the deflection and force distribution, as well as the state of stress and strain throughout the pedestal.

V. Conclusions

The good correlation of the top pedestal surface deflection among the NASTRAN computer model, the independent shortcut analytical model, and the field measurement assures the validity of the present pedestal NASTRAN computer model. This detailed pedestal structural model will be useful to the current rehabilitation studies of the large antenna pedestal.

Additional work is planned to improve the present pedestal NASTRAN computer model by including the haunch areas in the new pedestal model and the actual pressure pattern of the oil under the pad.

The top surface deflection of the pedestal obtained from the newly proposed NASTRAN model will then be used as an input to an in-house computer program to determine the minimum oil film height under the pad.

Acknowledgement

The authors acknowledge the assistance given by H. Phillips, F. Lansing, S. Rocci, V. Lobb, A. Riewe, D. McClure, F. McLaughlin, D. Wells, and J. Dyson during the various execution steps of this work.

References

1. *The NASA/JPL 64-Meter-Diameter Antenna at Goldstone, California: Project Report*, Technical Memorandum 33-671, Jet Propulsion Laboratory, Pasadena, Calif., July 15, 1974.

2. Timoshenko, S., *Theory of Elasticity*, 1st ed., p. 92, McGraw-Hill, New York, 1934.

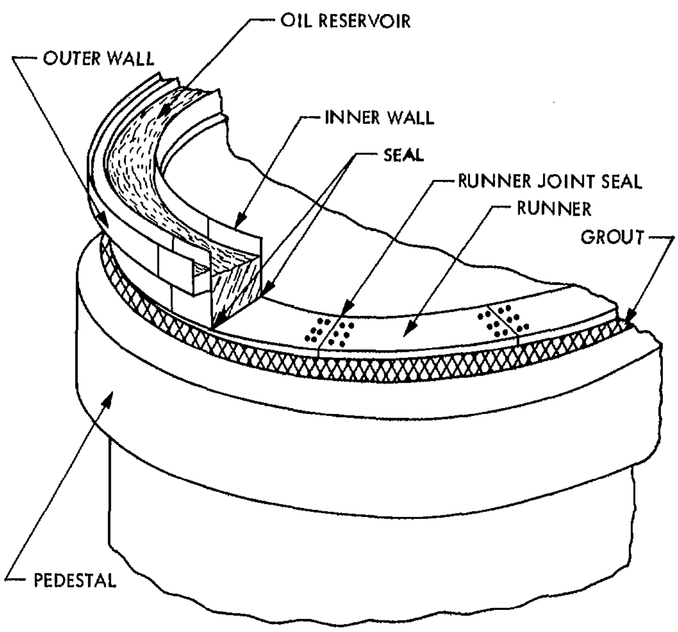


Fig. 1. General arrangement of 64-m antenna hydrostatic bearing

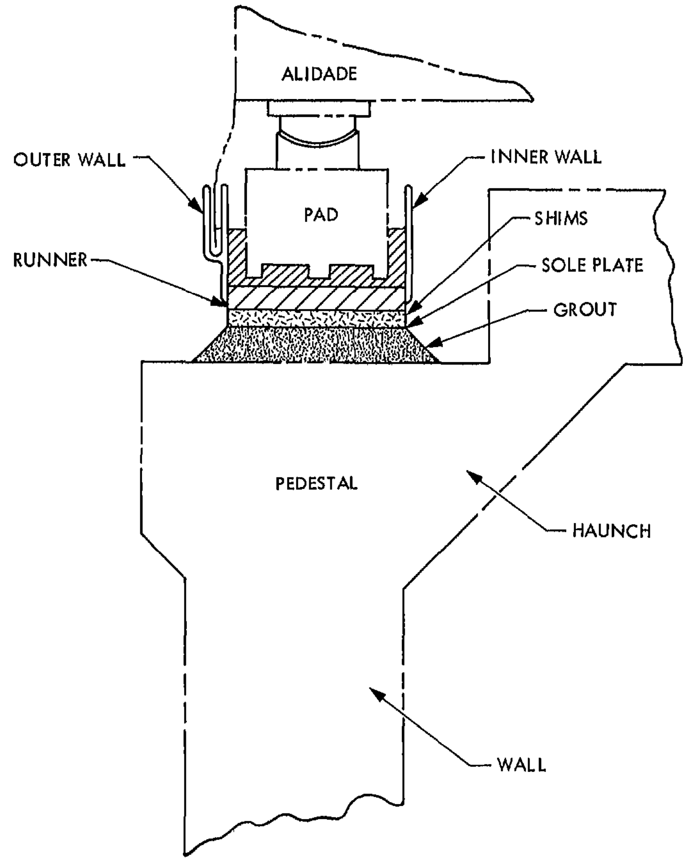


Fig. 2. Cross section of hydrostatic bearing system

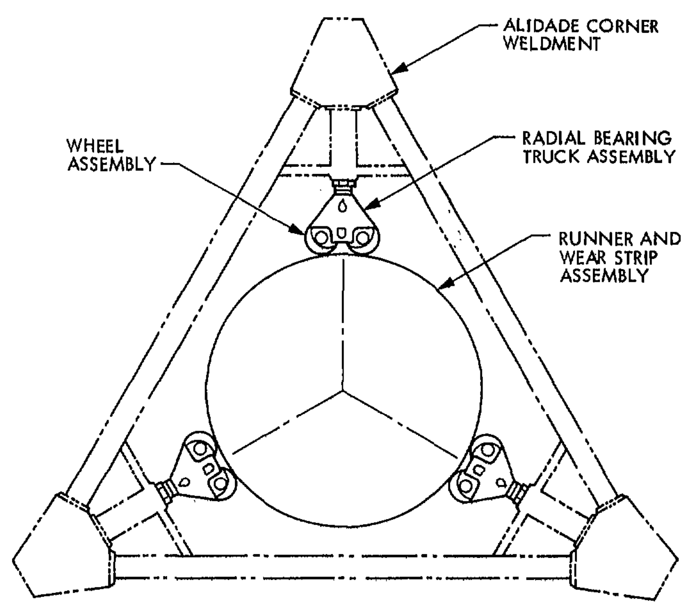
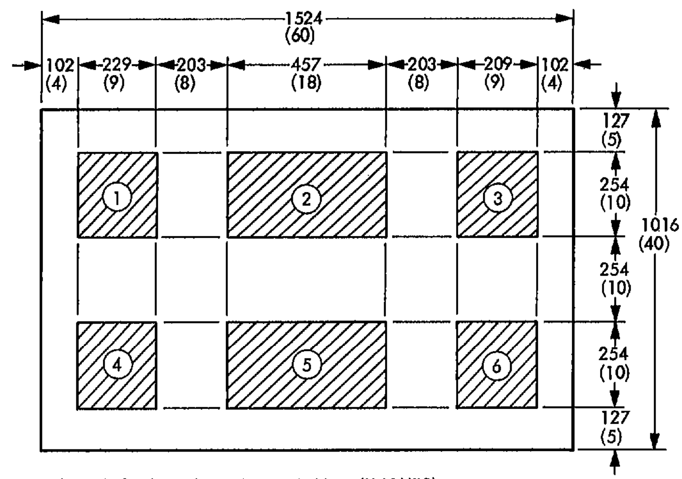


Fig. 3. Alidade base triangle and radial bearing assembly



DIMENSIONS IN MILLIMETERS AND (INCHES)

Fig. 4. Recess pattern of hydrostatic bearing pad

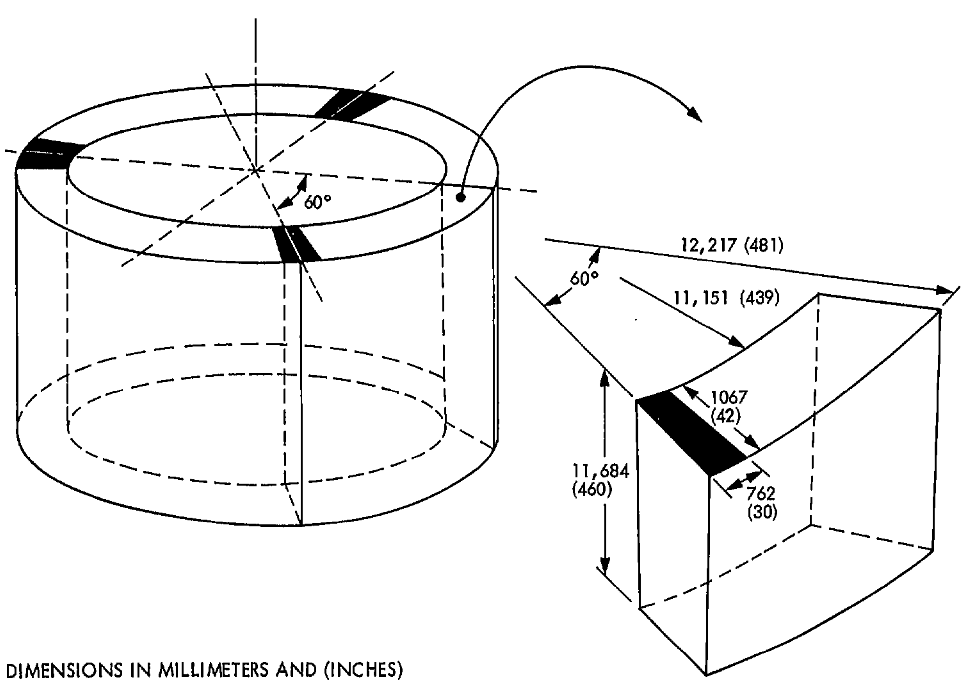


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Fig. 5. One-sixth segment of the pedestal mode

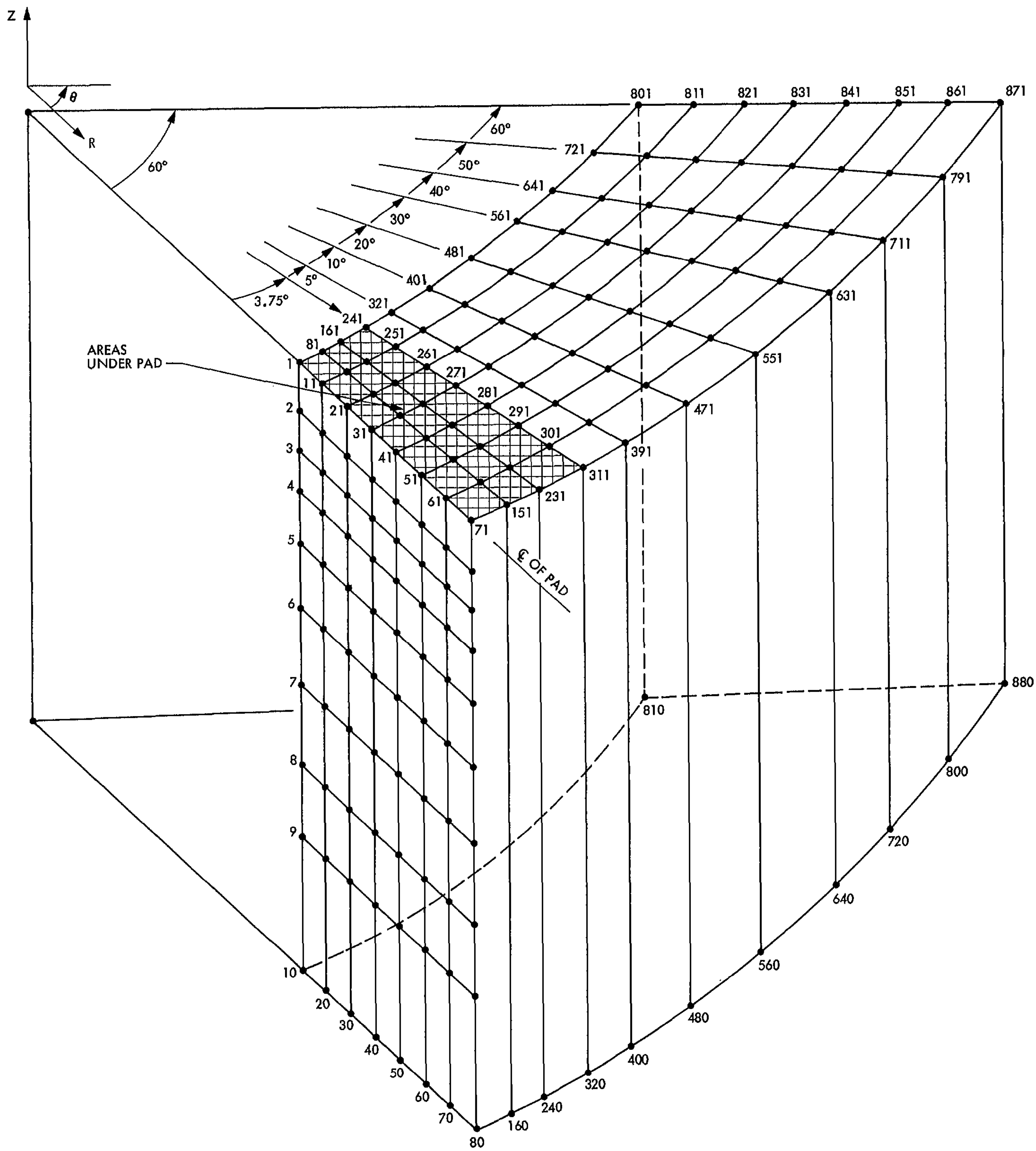

Fig. 6. NASTRAN pedestal model and nodal points

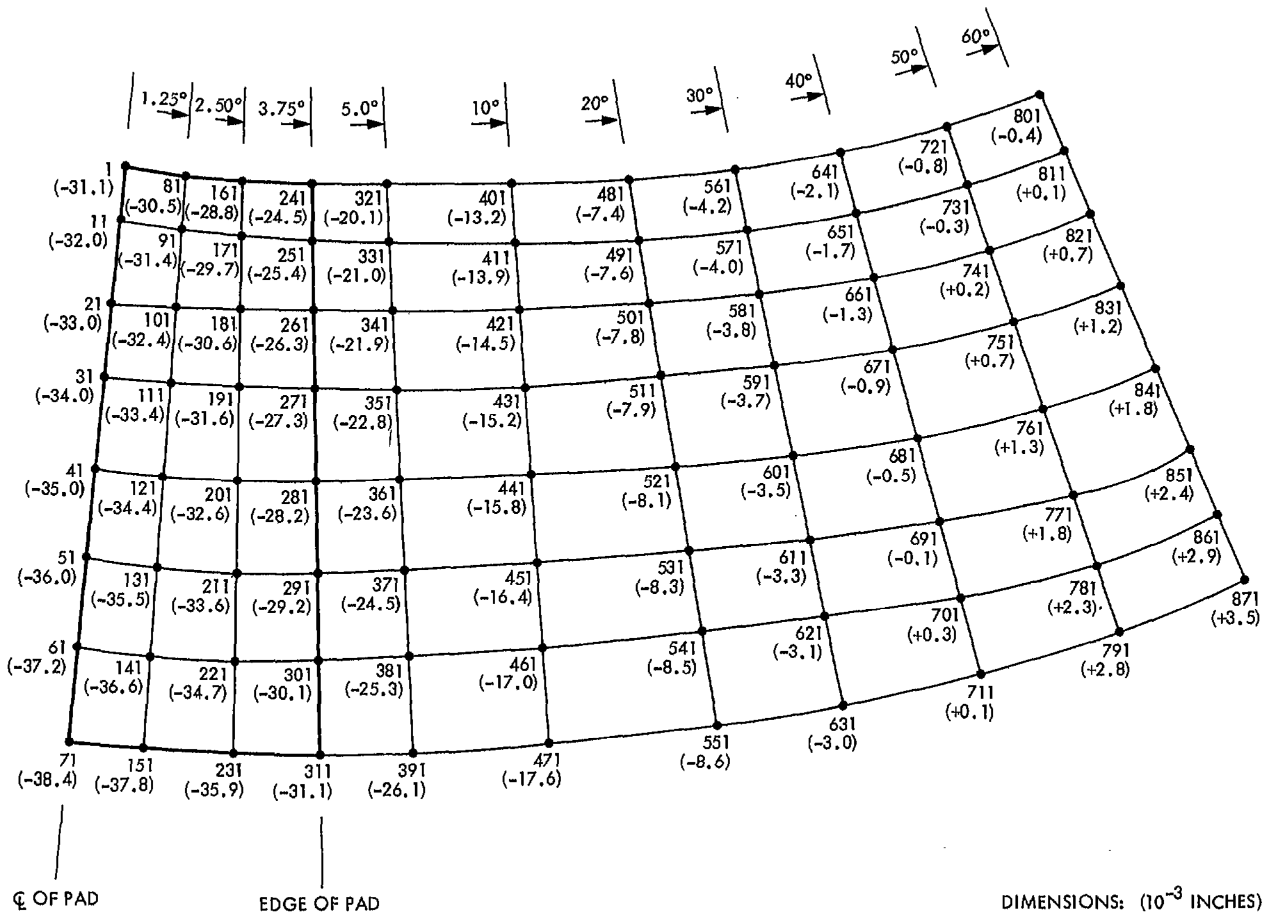

Fig. 7. Deflection map of pedestal top surface

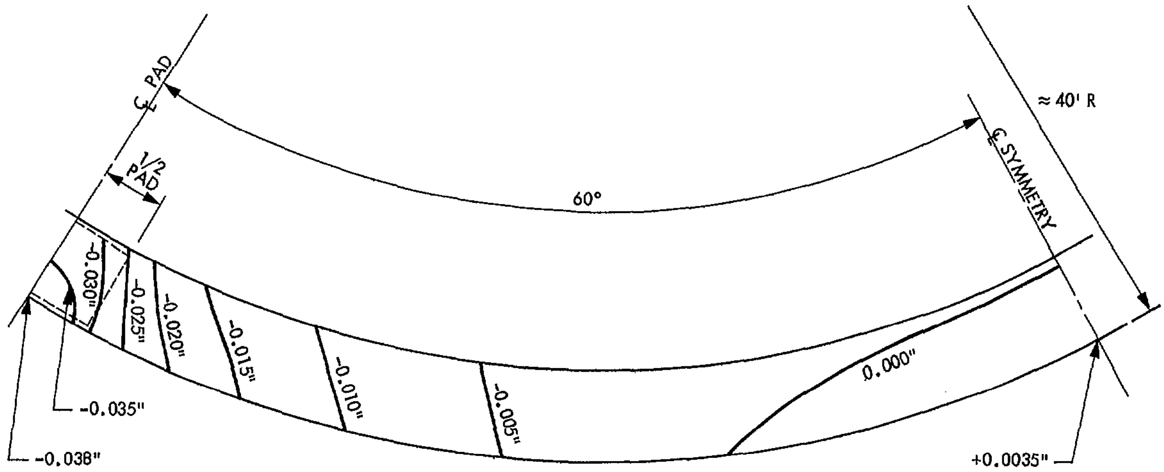

Fig. 8. Pedestal deflection under hydrostatic bearing runner

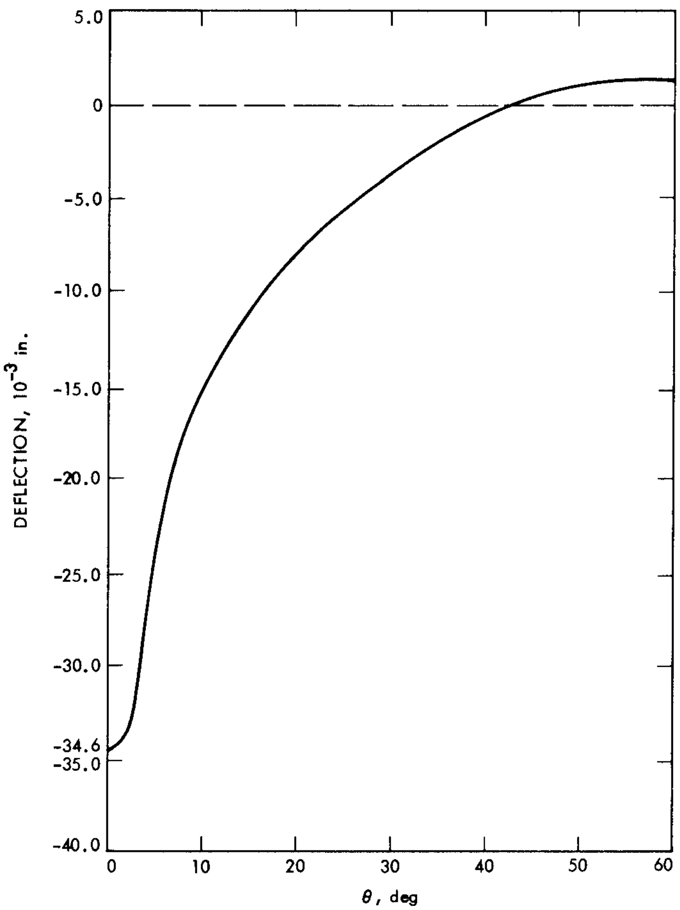

Fig. 9. Average top surface deflection

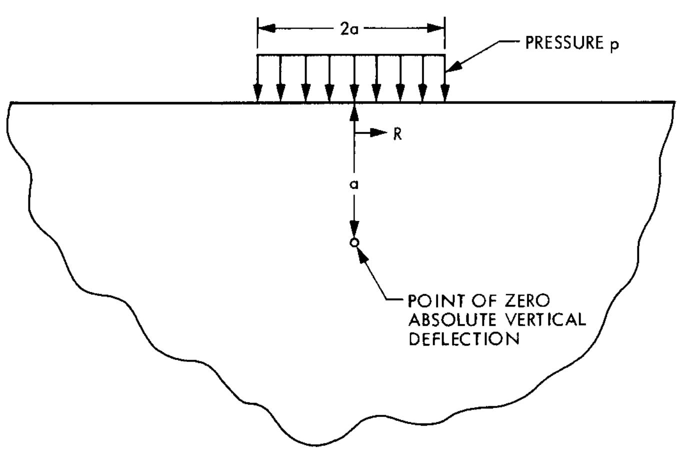

Fig. 10. Semi-infinite plate under pressure

Appendix A

Field Measurements of Pad Pressure

The three hydrostatic bearing pads, made of carbon steel, are 1.016 m (40 in.) wide, 1.524 m (60 in.) long, and 0.508 m (20 in.) deep. There are six recesses in the bottom of each pad as indicated in Fig. 4, with the two center recesses being larger than the corner recesses. Two sets of recess pressure field measurements were obtained at DSS 14, (Tables A-1 and A-2).

Based on the geometric configuration of the recess areas, a simple equation is derived to relate the load (in lb) on each of the three pads as a function of the six recess pressures (in psi);

$$L_i = 264\,(p_1 + p_3 + p_4 + p_6) + 455\,(p_2 + p_5) \qquad \text{(A-1)}$$

where

$$i = 1, 2, 3.$$

The load L_i and the average pressure $\langle P_i \rangle$ on each pad, calculated from the pad recess pressures, are given in Tables A-3 and A-4. The total load of the three pads is also obtained.

It is noted that the ratios of the pressures among the three pads are about

$$\langle P_1 \rangle : \langle P_2 \rangle : \langle P_3 \rangle = 9:\ 9:\ 11$$

Table A-1. First set of pad recess pressures[a]

Recess pressure	Pad No. 1	Pad No. 2	Pad No. 3
p_1	9,135,000 (1325)	8,101,000 (1175)	10,859,000 (1575)
p_2	6,722,000 (975)	7,067,000 (1025)	7,757,000 (1125)
p_3	8,101,000 (1175)	8,446,000 (1225)	11,894,000 (1725)
p_4	7,757,000 (1125)	6,722,000 (975)	11,894,000 (1725)
p_5	6,378,000 (925)	6,722,000 (975)	9,480,000 (1375)
p_6	7,412,000 (1075)	7,412,000 (1075)	9,825,000 (1425)

Dimensions: N/m^2 (psi).

[a]Data taken in 1966.

Table A-2. Second set of pad recess pressures[a]

Recess pressure	Pad No. 1	Pad No. 2	Pad No. 3
p_1	9,997,000 (1450)	8,791,000 (1275)	9,997,000 (1450)
p_2	6,378,000 (925)	8,446,000 (1225)	7,067,000 (1025)
p_3	8,446,000 (1225)	8,274,000 (1200)	11,721,000 (1700)
p_4	8,791,000 (1275)	6,550,000 (950)	12,066,000 (1750)
p_5	6,205,000 (900)	6,205,000 (900)	7,757,000 (1125)
p_6	8,963,000 (1300)	7,757,000 (1125)	8,791,000 (1275)

Dimensions: N/m^2 (psi).

[a]Data taken in Jan. 1982. Wind speed about 25 mph, control room azimuth 180°, oil temperature 84°F.

Table A-3. First set of pad loads and average pressures[a]

Load and ave pressure	Pad No. 1	Pad No. 2	Pad No. 3
Load, N (lb)	9,373,000 (2,106,240)	9,281,000 (2,085,690)	12,645,000 (2,841,590)
Total load, N (lb)	31,300,000 (7,033,520)		
Ave pressure N/m^2 (psi)	6,054,000 (878)	6,000,000 (869)	8,164,000 (1184)

[a]Corresponds to pad recess pressures in Table A-1.

Table A-4. Second set of pad loads and average pressures[a]

Load and ave pressure	Pad No. 1	Pad No. 2	Pad No. 3
Load, N (lb)	9,868,000 (2,217,425)	9,652,000 (2,168,985)	11,613,000 (2,609,685)
Total load, N (lb)	31,133,000 (6,996,095)		
Ave pressure, N/m^2 (psi)	6,371,000 (924)	6,233,000 (904)	7,495,000 (1087)

[a]Corresponds to pad recess pressures in Table A-2.

Appendix B

"Shortcut" Analytical Pedestal Model

The deflection of the grout beneath the runner will be estimated based upon the following assumptions.

The runner has a negligible bending stiffness in comparison to the foundation beneath it. Thus, ignore the runner and assume the pad load is applied directly to the foundation which is composed of concrete and grout, each having the same elastic modulus of $E = 2.8 \times 10^{10}$ N/m^2 (4,000,000 psi). It will be assumed that at ground level, 11.68 m (460 in.) below the top of the foundation, the absolute vertical deflection is zero.

The pedestal or foundation will be considered as a semi-infinite plate with a uniformly distributed load applied to the top surface. By superposing various uniform loads, any loading normal to the surface can be simulated.

From Ref. 2, the following expressions for deflection will be employed:

$$V_c = \frac{2aP}{\pi E}\left[(1-\nu) + 2\ln\frac{d}{a} - (1-\lambda)\ln(1-\lambda) - (1+\lambda)\ln(1+\lambda)\right], \lambda < 1 \qquad \text{(B-1)}$$

$$V_0 = \frac{2aP}{\pi E}\left[(1-\nu) + 2\ln\frac{d}{a} + (\lambda-1)\ln(\lambda-1) - (\lambda+1)\ln(\lambda+1)\right], \lambda > 1 \qquad \text{(B-2)}$$

where V_c and V_0 are the vertical deflections at the surface within the loaded area and outside the loaded area respectively, and $\lambda = R/a$.

The deflection at the pad center, for a pad pressure of 6.9×10^6 N/m^2 (1000 psi), was found to be 0.914 mm (0.036 in.).