12-m Memorandum No. 11

# THE 11-METER TELESCOPE STABILITY TESTS

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## 1. Introduction

The general behaviour of the 11-meter (36-foot) telescope when exposed to different thermal environments has long been suspect. Evidence has accumulated from the radio performance of the telescope and from surface shape measurements. The history extends backwards in time for more than 8 years. We decided to investigate in a simple way whether the telescope was truly ill-behaved when exposed to fairly steady, but different, ambient temperatures. We did not plan to study effects of large temperature differences across the structure, but we realized that we might not be able to find conditions where all the telescope was truly isothermal. We were scheduled for somewhat less than 72 hours of telescope time on February 18, 19 and 20; as it turned out we had enough measurements in hand to return the telescope almost a day early.

## 2. The Measurement Plan

We decided to carry out two simple but different types of measurement on the telescope reflector. We refer to these as "edge measures" and "stepping measures".

### (a) Edge measures.

The Wild N-III level was mounted* in the dish center so that it could measure the elevations of 12 targets mounted near the edge of the dish.

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* In this and several other practical matters our work was much helped by Paul Rhodes and his staff at Tucson.

** replaces memo #11 dated 3/6/81.

Three-dot targets were used. They were set at approximately equal radial distances from the dish vertex. Figure 1 shows the layout of the 12 targets at the ends of radii No. 1 to No. 12. We tried to avoid the areas of the dish which suffered most damage years ago when the feed legs fell onto the reflector, but, as we shall see, radius No. 11 had a severely damaged shape.

Our intent was to measure the elevation of the 12 edge targets; then to best-fit a tilted plane through the targets and finally to see to what extent the differences of the target positions from this plane remained stable. We could assume that the N-III would stay (to perhaps 50 microns or so) stable in elevation above the dish vertex, so we would also watch how the average elevation of the telescope edge moved as the temperature changed.

(b) Stepping measures

We decided to use the stepping method to measure the profile of 4 of the 12 radii, and we chose those 4 to be fairly close to being parallel and perpendicular to the elevation axis. Our intent here was to look for the (expected) spherical aberration of the telescope and perhaps to find whether the reflector changed shape in such a way as to produce astigmatism.

(c) Our general intent

We were looking for thermally induced effects showing up as changes in our observations. We therefore did not spend much time on ensuring the absolute nature of our metrology. For example, we only determined to about a millimeter or so that the inner 4 stepping targets were equidistant from the nominal dish vertex.

## 3. Preparation and Measurements

The tasks of mounting the N-III, determing the angular and radial distances of the edge and stepping targets and setting up and testing the stepping system all took some time. In order to get a quick look at the telescope we did the edge runs first and then took the time needed to install the stepping targets.

The measurement program is described in Table I. We observed the temperature of the telescope at 6 points, using the available sensors. In Table I we show only the mean of these readings--we have, of course, a record of the individual values.

## Table I

## Log of Measurements

1. 12-point edge runs

| Run No. | Date (1981) | MST Start | MST End | Observer | Mean Temp. °C | Mean Elevation mm | RMS microns |
|---|---|---|---|---|---|---|---|
| 1 | Feb 17 | 1555 | 1615 | JWF | 15.3° | 5.543 | 334 |
| 2 | Feb 17 | 1620 | 1640 | JR | 15.2° | 5.481 | 323 |
| 3 | Feb 17 | 2205 | 2225 | JWF | 9.1° | 4.550 | 322 |
| 4 | Feb 17 | 2240 | 2255 | JR | 8.9° | 4.595 | 304 |
| 5 | Feb 18 | 0650 | 0710 | JR | 6.8° | 4.640 | 309 |
| 6 | Feb 18 | 0710 | 0730 | JR | 6.8° | 4.711 | 315 |

2. Stepping runs on 4 radii

| Run No. | Date | MST Start | MST End | Stepper/ Recorder | Mean Temp. °C | Mean Focal Length mm |
|---|---|---|---|---|---|---|
| 1 | Feb 18 | 1300 | 1327 | JR/JWF | 13.9° | 8793.0 |
| 2 | Feb 18 | 1341 | 1410 | JR/JWF | 14.5° | 8793.0 |
| 3 | Feb 18 | 2022 | 2104 | JR/JWF | 10.7° | 8781.3 |
| 4 | Feb 19 | 0635 | 0717 | JR/JWF | 8.3° | 8782.1 |

All the measurements were recorded, by hand for the edge runs and automatically for the stepping runs, on a 9825A tape. All data reduction was done on a 9825A or on the HP computer at Ivy Road. The stepping data has been entered by hand into the Ivy Road Computer.

## 4. Discussion of Results

### (a) Edge measurements

Table II

Summary of 12-point Edge Runs

| Runs No. | Mean Elevation mm | RMS microns | Fitted Sine Curve | | Mean Temperature |
|---|---|---|---|---|---|
| | | | Amplitude microns | Phase degrees | |
| 1 & 2 | 5.512 | 38 | 361 | 46.3° | 15.3° |
| 3 & 4 | 4.573 | 39 | 244 | 44.5° | 9.0° |
| 5 & 6 | 4.676 | 50 | 208 | 189.7° | 6.8° |

See Table I,1 and Table II, and note that the 6 runs fall into 3 pairs. Each pair is typical of a fairly uniform ambient temperature. To illustrate the repeatability of the NIII readings, we have computed what we call the RMS of the differences of the observed elevations of the 12 targets in run No. 1 and Run No. 2, and so on.

$$\mathrm{RMS} = \left\{ \sum_{1}^{12} \frac{\left[ Z_n(1) - Z_n(2) \right]^2}{12} \right\}^{1/2} \qquad (1)$$

Column 3 of Table II shows these values. $Z_n$ is the elevation of the observed target above or below the best-fit plane through the targets. Table

II, columns 4 and 5, shows the phase and amplitude of the sine curve which, for each pair of runs, best fits their tilted plane.

We conclude from the results in Table II that:

(i) The mean elevation of the edge of the dish rose by about 900 microns as the temperature fell. (Note--a higher N-III reading is a lower target.)

(ii) The agreement between the pairs of runs is good enough for us to continue to treat them in pairs.

(iii) The mean edge of the telescope was always close to the gravity horizon. (A sine wave amplitude of 300 microns is a tilt of about 11 arcseconds.)

(iv) As the temperature changed, however, this tilt direction altered in azimuth by about 145°.

We note that for all our measurements the azimuth brakes were set and the elevation stow pin was in place. The dome was closed for all measurements, but was opened between 1700 and 2100 MST on February 17 to help in lowering the ambient temperature.

Figures 2(a) and 2(b) also show the edge measures. In 2(a) we see how the edge shape changed--and in 2(b) we show this more clearly. We conclude from these results:

(i) The shape of the telescope at the edge varied significantly with temperature. We note that the Onsala 20-meter telescope showed no such changes greater than about 40 microns when subjected to a $\Delta T$ of about 8°C.

(ii) The edge went through an astigmatic phase (Runs 1,2 - Runs 3,4 in Figure 2(b)). It then developed a different tilt. Such shape changes are large enough to give both gain and pointing changes at short millimeter wavelengths.

(b) Stepping measurements

With these not very happy indications of shape changes, we turned to the stepping runs. We used the 650 mm bar made for the 140-foot measurements, but with a zero-point angle of about 7.2°. Data taking was identical to our 140-foot work. Table I.2 shows our log of measurements.

The first two runs were made close together to check how good our stepping results might be. All results were reduced in the standard way, using a single value for the zero-point angle and the inclinometer calibration made for the 140-foot measurements.

In Table I.2 we have given the mean focal lengths derived from our runs over radii Nos. 2, 5 and 8. Radius No. 11 was so bad that we will discuss it separately.

In Table III we show the comparison between the data for radii 2, 5, and 8 taken on runs Nos. 1 and 2. Each radius was best-fitted to a parabola. Then for Table III we computed an RMS just as in equation (1), except that we had only 7 independent pairs of points to compare for each radius.

Table III

A Comparison between the $\Delta z$ Values Found in Stepping Run Nos. 1 and 2

| Radius No. | RMS of differences between Run Nos. 1 and 2 |
|---|---|
| 2 | 25 microns |
| 5 | 13 microns |
| 8 | 14 microns |

The results of the stepping runs are shown in Figures 3 and 4 and in Tables IV and V.

Table IV

The Best-Fit for the Focal Length from the Stepping Runs

| Run No. | Radius No. | Focal Length mm | RMS microns | Inner Dish Focal Length mm |
|---|---|---|---|---|
| 1 | 2 | 8792.7 | 111 | 8784.0 |
| | 5 | 8795.5 | 112 | 8786.4 |
| | 8 | 8790.8 | 125 | 8780.2 |
| | 11* | 8793.0 | 873 | -- |
| 2 | 2 | 8792.9 | 114 | 8785.3 |
| | 5 | 8796.0 | 105 | 8787.9 |
| | 8 | 8790.1 | 119 | 8780.9 |
| | 11* | 8793.0 | 859 | -- |
| 3 | 2 | 8781.7 | 121 | 8778.1 |
| | 5 | 8782.4 | 91 | 8776.7 |
| | 8 | 8779.8 | 64 | 8775.2 |
| | 11* | 8781.3 | 718 | -- |
| 4 | 2 | 8781.6 | 116 | 8773.8 |
| | 5 | 8783.7 | 103 | 8775.8 |
| | 8 | 8781.0 | 88 | 8773.8 |
| | 11* | 8782.1 | 830 | -- |

*For radius No. 11 we used the mean of the values for the other 3 radii as the focal length.

We can draw the following conclusions from the results of the stepping measurements:

(i) The method gave satisfactory reproducibility as shown in Table III.

(ii) The reflector changed its focal length as the temperature changed (Table IV, column 3). The sense of this change--as the dish gets warmer it gets flatter--has long been known and is allowed for empirically in the telescope control. The magnitude of the change is about that shown by the edge measures in Table II.

(iii) In Figure 3 we have plotted radius No. 11 using as focal length the mean of the values for the other 3 radii. It was clearly of no interest to fit a parabola to radius No. 11.

(iv) In Table IV, column 5 we have found the best-fit focal length for the inner half of each radius 2, 5, and 8. We see that the half-dish has a focal length about 7.5 mm less than the whole dish. This has been strongly suspected from the focus curve and from JMP's surface measurements made in 1974 and 1975.

(v) In Figures 4(a) and 4(b) we have looked for the changes of shape of the dish at different temperatures. Figure 4(a) shows the shape changes which occurred between runs No. 1 and 2 taken together, and run No. 3. There shape changes show astigmatic behaviour--the best fit parabolic shape has been removed.

(vi) Figure 4(b), however, shows that by run No. 4 the dish has resumed a "good" shape, but with a changed focal length. We note that it has taken 17 hours to go from runs No. 1 and No. 2 to run No. 4.

(vii) To show this same result in a different way, Table V is the RMS differences taken point by point between runs Nos. (1,2) and run 3 and runs Nos. (1,2) and run 4.

Table V

The Differences Between the Best-Fitted Stepping Runs

| Runs Differenced | RMS of difference for radii: | | | |
|---|---|---|---|---|
| | No. 2 | No. 5 | No. 8 | No. 11 |
| Mean of Runs No. 1 and No. 2<br><br>And Run No. 3 | 73 microns | 40 microns | 78 microns | 155 microns |
| Mean of Runs No. 1 and No. 2<br><br>And Run No. 4 | 25 microns | 12 microns | 40 microns | 42 microns |

## 5. Conclusion

It is not possible to give a full picture of the thermal behaviour of the 11-meter telescope in so short a time. These results must be considered as a sample--drawn from what may be a wide range of behaviour.

However, they do confirm in a semi-quantitative way what has long been known:

(a) The gain, focal length and pointing of the 11-meter telescope depend on temperature, in a way still not fully explained.

(b) The reflector has a gross error in shape; this is essentially spherical aberration.

(c) In detail the reflector surface is rough, with an RMS in the 300-400 micron range. The damage to the reflector shape extends over significantly large areas of the telescope aperture.

## 6. References

There are many reports on the 11-meter telescope. Payne, Hollis and Findlay published shape measurements in the Review of Scientific Intruments, 47, pp. 50-55, 1976. Payne and Ulich have studied the gain, astigmatism and focal length effects in many internal reports. Findlay has described measurements similar to these made on the 140-foot and on the Onsala 20-meter telescopes.

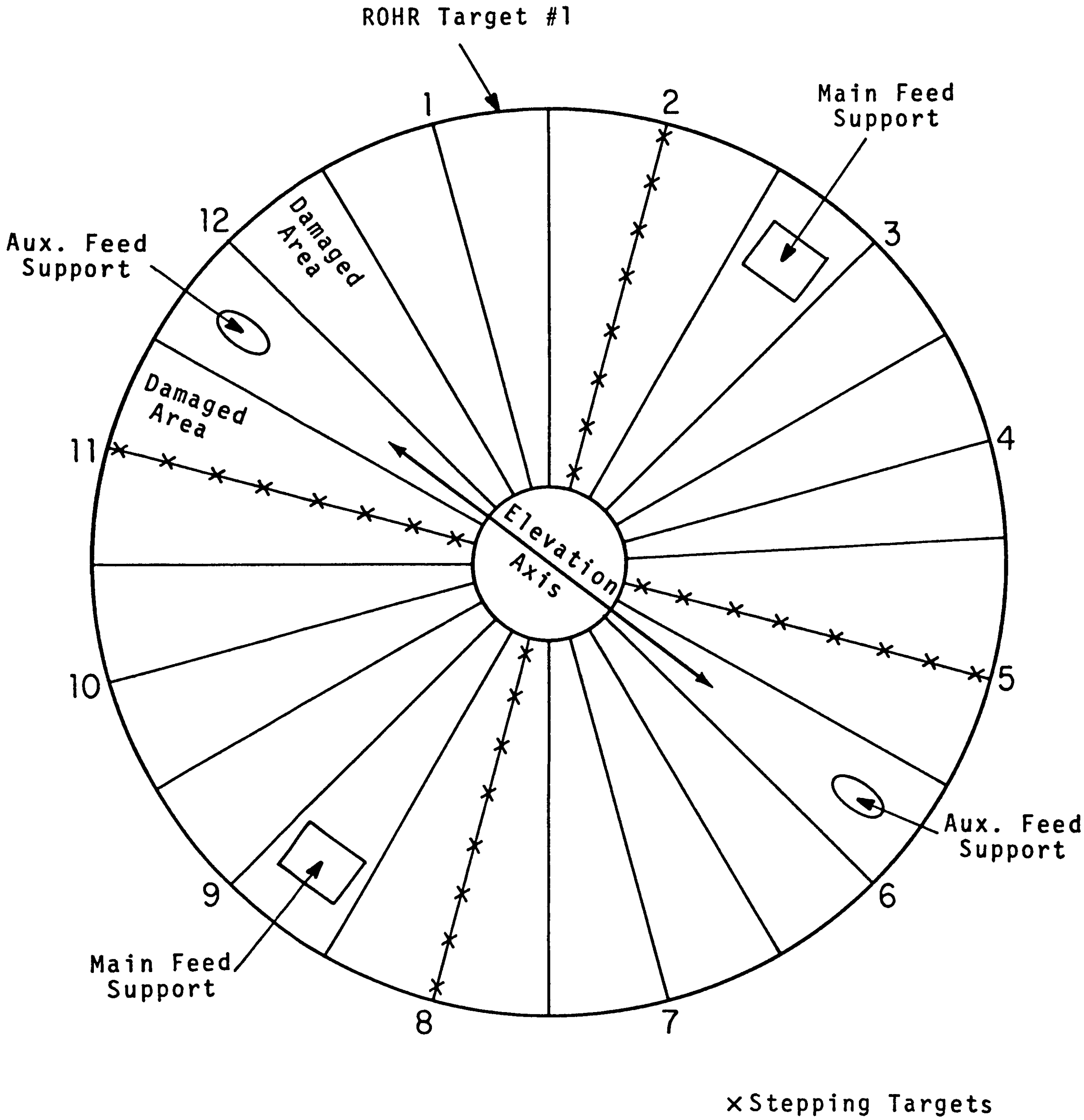


Figure 1. The targets and radii measured.

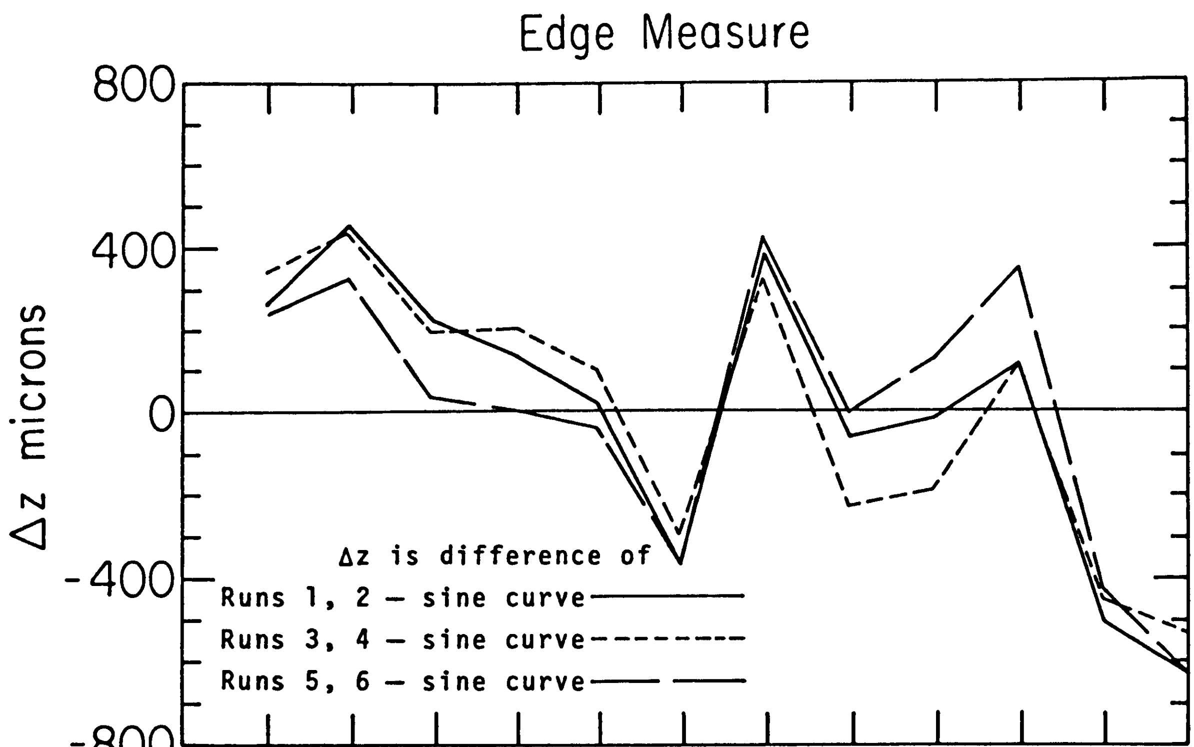


Figure 2(a)

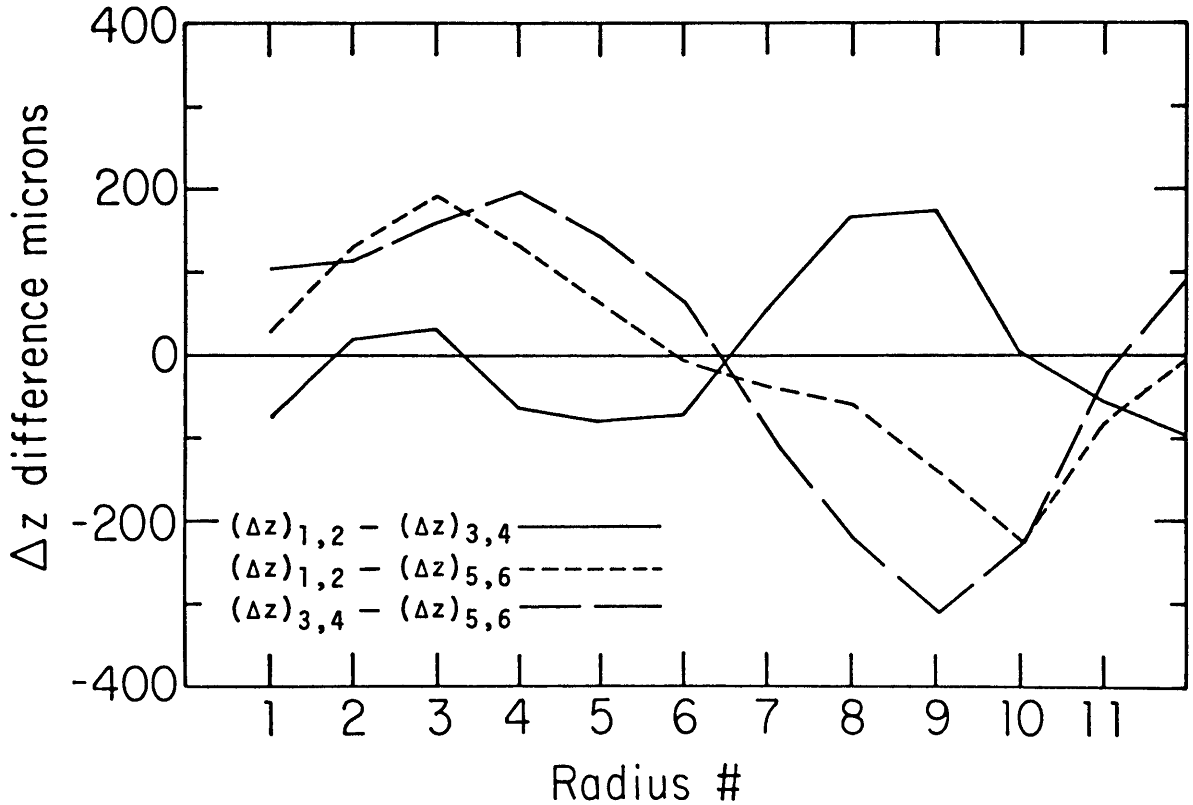


Figure 2(b)

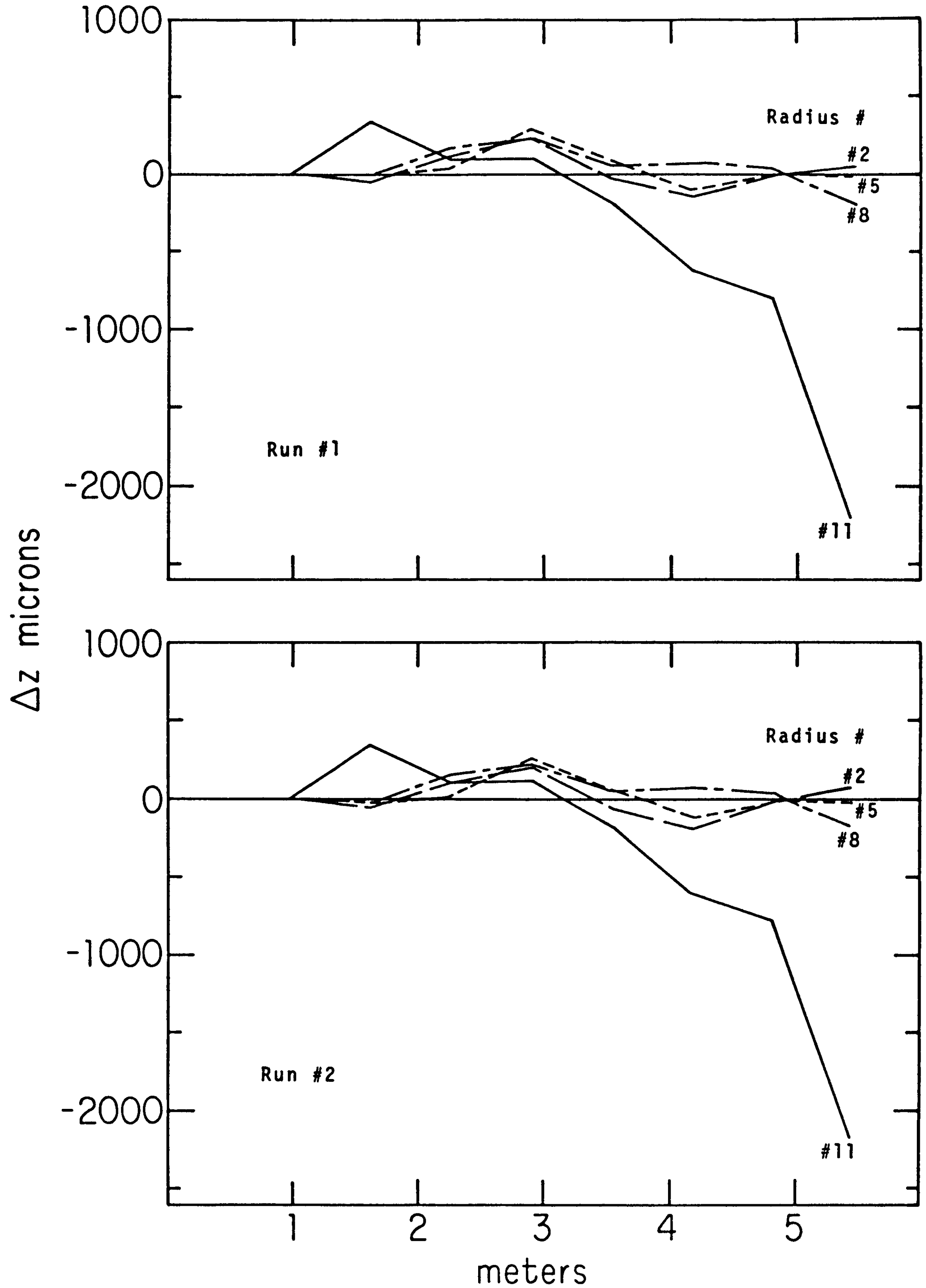


Figure 3(a) The departures of the stepping runs from the best-fit parabolic shape.

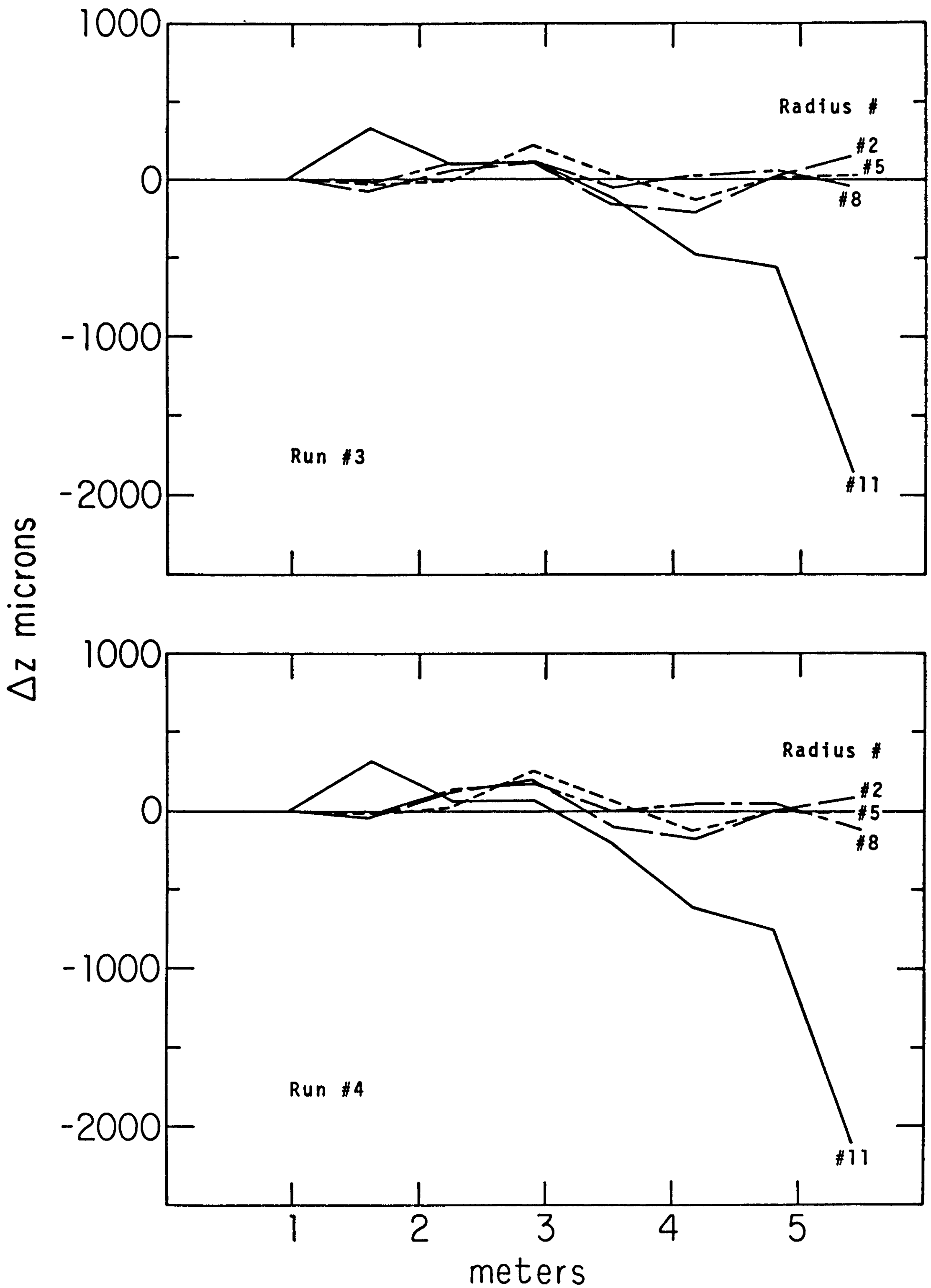


Figure 3(b) The departures of the stepping runs from the best-fit parabolic shape.

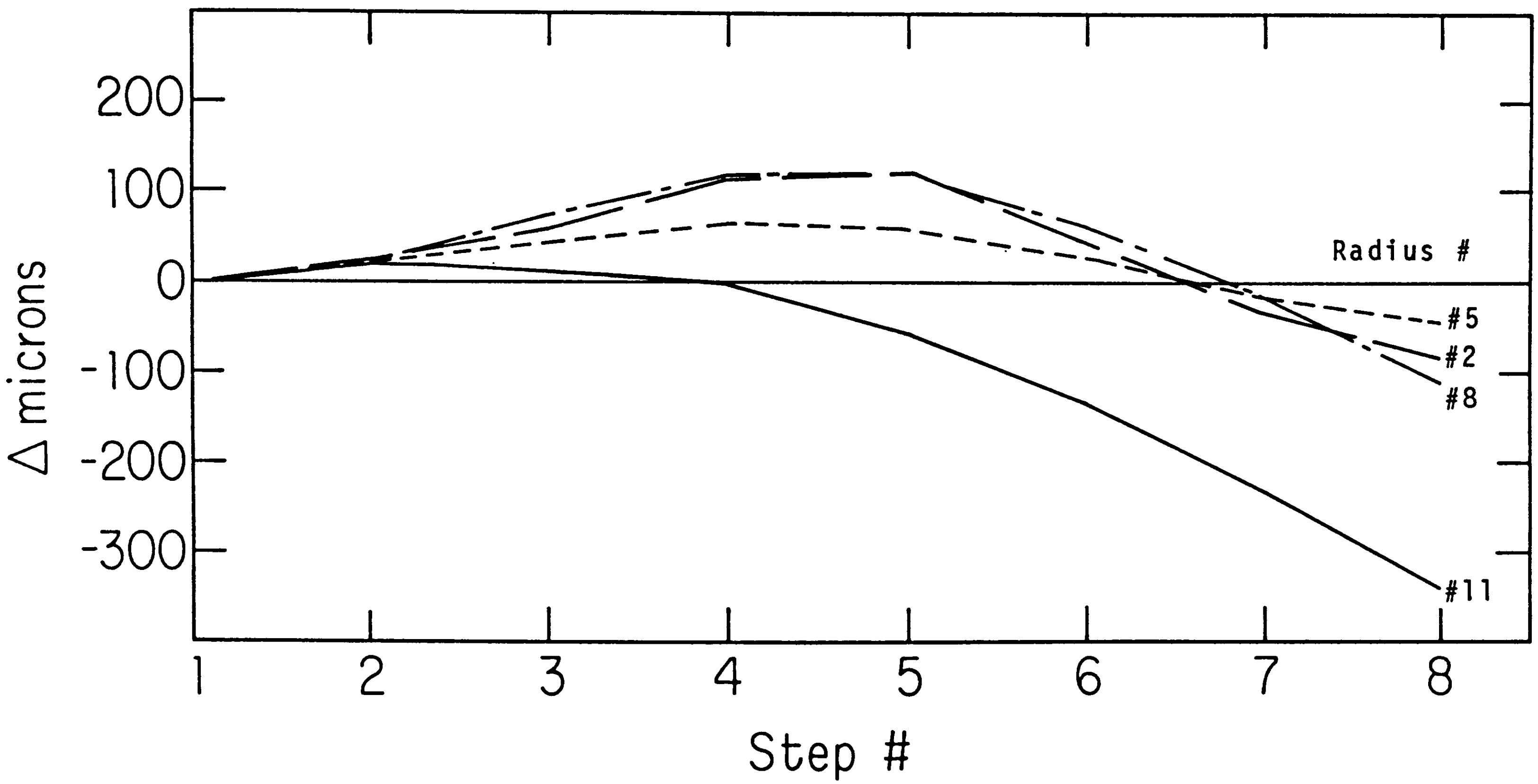


Figure 4(a) Differences between the best-fit stepping runs #(1,2) and run #3.

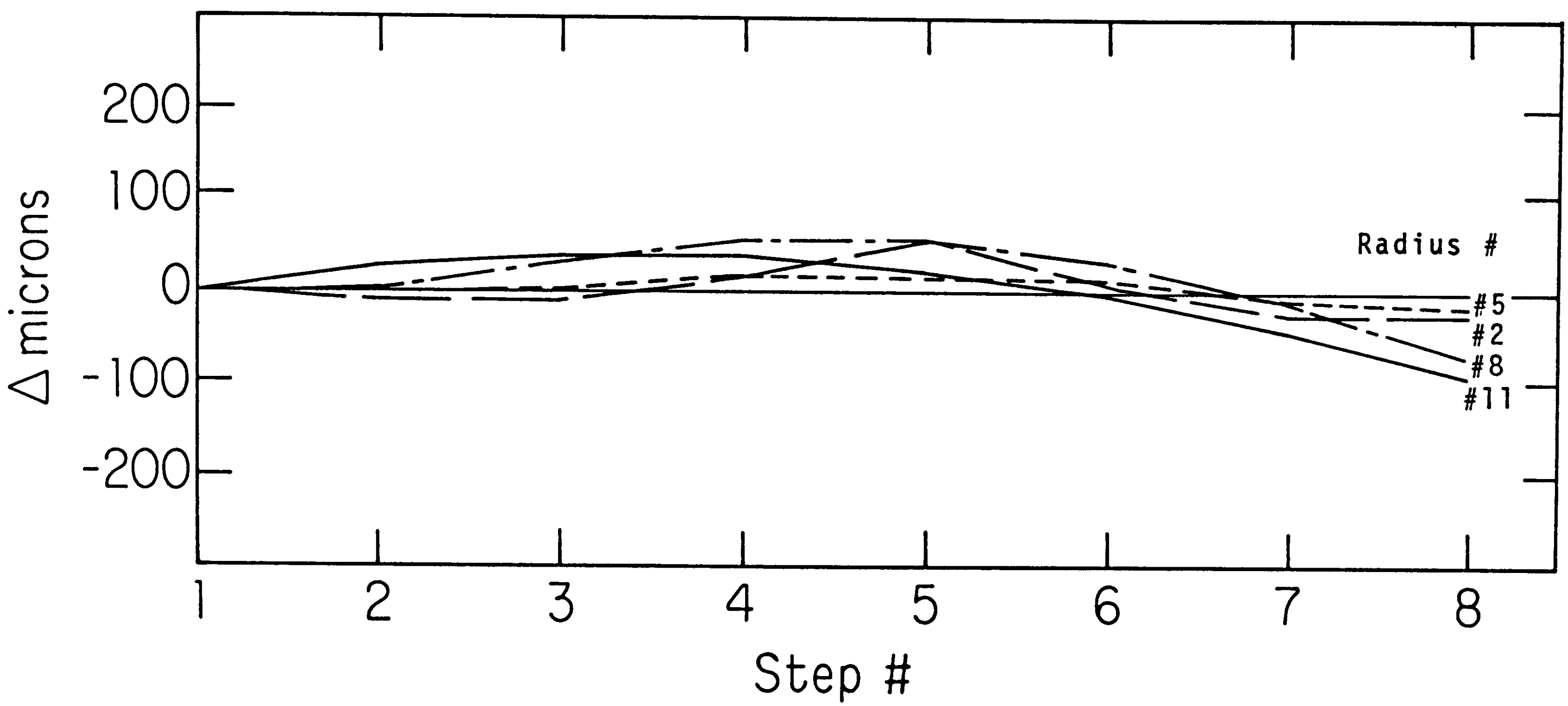


Figure 4(b) Differences between the best-fit stepping runs #(1,2) and run #4.