NATIONAL RADIO ASTRONOMY OBSERVATORY

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ENGINEERING MEMO #124

Stepping Bar Results for the 140-foot Telescope

John W. Findlay

1. Introduction

This note is intended to give the results of the measurements made on June 7 and June 8 and to draw conclusions from them. The way the measures were made is covered in J. Ralston's Memo. #123. The details of the lengthy data reduction will not be given; the methods were straightforward.

2. Edge and center ring measures

On May 3 and again on June 1 the elevations of the outer ring of targets were measured using the Wild level on top of the Cassegrain house. The results are given in Table 1. To remove the unknown tilt of the telescope, a best-fit plane surface was passed through the measured points; the numbers in Table 1 are the elevations with respect to this plane. The agreement between the two sets of measurements is good. We propose to use such measurements, taken again when the dish is finally measured, to fix the end-point values for each of the stepping runs. In presenting the results of the June 7 & 8 runs, we have adjusted the unknown "zero-point angle" of the bar and inclinometer to give the end-point values for the four radii the same as those found from Table 1.

Table 2 gives a similar set of measures (see Memo #123) for the center ring of targets. We have not troubled to adjust the present results to include these elevations; this must, of course be done in the final measurements.

3. The raw data and its reduction to angles and lengths.

Table 3 shows the raw data in volts from the tilt and length sensors. Each tilt value is the mean of 10, and each length the mean of 5 readings. The RMS of the tilt voltage was also read and stored.

The following relations were used to get the tilt angle A and the step length L from the corresponding sensor voltages:-

$$\sin A = (.0071 - V) \times 5.01036 \times 10^{-2} \qquad \text{..... (1)}$$

$$L = 0.508\ (V - 3.3127) \qquad \text{............... (2)}$$

Table 4 gives all the angle and length data which result from these conversions.

4. <u>The computed profiles for the four radii</u>.

The profiles were computed from the data of Table 4 in the following way. A single value (X= 1575.77 mms, Y = 33.94 mms) was used for the start points for each radius. The first runs on all radii on June 8 (called June 8.1 throughout) were inadvertently taken with the DVM set on the 100-volt scale instead of the 10-volt scale. The error due to digitising is 1 millivolt (10.8 arc seconds) and this is not serious. However, inspection of the results shows that the meter calibration differs by about 0.16 % on the two ranges. This was allowed for in reducing the data. Each run over a radius was forced to give the end value found from the optical level measures.

The 9825A print-out gives the X and Y values for each of the 33 points along a radius. To show the departures from the parabolic shape, the quantity D was computed for each point.

$$D = {}^{X^2}/_{73152} - Y \qquad \text{................ (3)}$$

where X and Y are the measured co-ordinates of the point in mms. Table 6 gives the values for D for each of the three runs along the four radii. The mean D is also given, and the final column is the RMS value of the departures of D from this mean. The D values are also plotted in Figures 1.1 through 1.4.

5. <u>Discussion of the results</u>

In studying the data, it became apparent that the step-length measures were not as consistent as they should be. This can be seen by looking at the numbers in Table 5, where, for example, Step # 19 shows a range of L of half a millimeter. We believe this can easily be improved, and so to minimise the effects of the L differences from run to run we have used the mean L values in deriving the D values.

Figures 2.1 through 2.4 are interesting. They show the measured RMS values for the angles. We have plotted all three runs on a given radius on the same graph. (The value of zero at maximum X is a plotting error). High values of the RMS seem to cluster at 8-10 meters and at about 20 meters. There was a fair amount of machinery running during the measurements, and this amy be the source of the vibration. Nevertheless, the noisy values of angle on Radius # 1 at 8 - 10 meters do not seem to cause errors in the profile - in fact the agreement in D is best for Radius # 1.

Finally, in the following Table 7, we summarize the results.

Table 7 The Results for the 4 radii .

Radius #	Date measured	Zero-point angle	RMS of D	Edge value of Y
1	June 7	16.9782°	0.973 mm	-.53 mm
	June 8.1	16.9727°	0.912 mm	
	June 8.2	16.9770°	0.885 mm	
2	June 7	16.9722°	1.476 mm	+1.71 mm
	June 8.1	16.9646°	1.528 mm	
	June 8.2	16.9727°	1.297 mm	
3	June 7	16.9813°	1.709 mm	-.71 mm
	June 8.1	16.9757°	1.608 mm	
	June 8.2	16.9806°	1.804 mm	
4	June 7	16.9905°	1.036 mm	+.92 mm
	June 8.1	16.9843°	1.099 mm	
	June 8.2	16.9893°	1.118 mm	

The values of the zero-point angle do not tell much, since they include the unknown tilt of the telescope. The values for June 8.1 are all lower;

this may well be due to the DVM having a slightly different zero on its 10 and 100 volt scales, as well as the calibration slope difference already noted.

If we accept as a rough measure of the accuracy of the stepping method the average of all the RMS values of D in Table 6, we arrive at:-

Mean RMS = 112 microns

However, this does not include errors due to our reliance on the optical level edge measures, but it does seem safe to go ahead with the whole dish measurement, with a good chance of getting a measuring accuracy of about 200 microns. This would be quite good enough.

6. Some practical points

(a) Why are the L measures not more consistent ?

(b) We should now calibrate the inclinometer. I favor doing this by mounting it on the 140-foot and tilting it with the elevation drive. A calibration to a few arc seconds is fine, and the inductosyns will do this.

(c) If we do (b), we should check for long-term calibration changes.

(d) We might train two two-person crews to do the bar setting. I would prefer to have JR and SS supervising - and I hope one could do the optical edge measures while the stepping is being done.

(e) I would try to do 24 radii a night (6 hours, 24x33 = 792 points) and then interleaf the other 24 radii the following night. The excellent June 7 to June 8 agreement makes this look good.

(f) Can the targets be fixed ahead of time? Ask Rick Fisher' opinion. If not, it can be done just before the measurements.

Table 1

The elevations of the outer ring of telescope targets measured on May 3rd. and June 1st 1978 by Wild level.

The elevations are in millimeters above or below the plane which best fits the results. Positive values mean that the point lies below the best-fit plane.

May 3	June 1	May 3 - June 1
2.1705	1.4881	0.6824
1.0767	1.0214	0.0553
2.2503	2.0858	0.1645
1.4956	1.0766	0.4190
2.4972	2.5000	-0.0029
-2.2699	-2.2967	0.0268
-1.9301	-1.7654	-0.1647
-1.6274	-1.2967	-0.3307
-0.1951	0.0497	-0.2449
-2.5458	-2.1247	-0.4211
-0.3614	0.0725	-0.4339
-0.7830	-0.6352	-0.1478
3.1492	3.2666	-0.1174
0.9755	0.7532	0.2223
4.3773	4.2906	0.0867
-1.8035	-2.1544	0.3510
-0.4940	-0.9947	0.5007
-1.6409	-1.7324	0.0915
1.4500	1.5604	-0.1105
-3.7069	-3.3181	-0.3888
-1.0763	-1.0897	0.0133
-1.9330	-1.7563	-0.1766
1.1890	0.6397	0.5493
0.7456	1.0960	-0.3504
1.1528	0.8894	0.2635
0.8666	1.1461	-0.2794
0.8331	1.2917	-0.4586
-1.0922	-1.0491	-0.0431
1.4062	1.5875	-0.1813
-0.4768	-0.9458	0.4690
0.7234	0.5129	0.2105
-0.9593	-1.4658	0.5066
2.0785	2.1278	-0.0493
-1.3608	-1.6478	0.2870
1.8048	1.2250	0.5798
-0.4137	-0.6473	0.2336
-0.3058	0.2809	-0.5867
-0.4322	0.0943	-0.5265
0.4660	1.2269	-0.7608
-0.8132	-1.1881	0.3749
-0.8127	-0.1378	-0.6749
-0.9758	-0.8901	-0.0857
-0.5166	-0.2629	-0.2537
-0.2898	-0.0544	-0.2353
-0.8703	-0.7828	-0.0875
-2.1937	-2.8362	0.6424
-0.5357	-0.9222	0.3865
1.7077	1.7115	-0.0038

The elevations in millimeters of the starting circle of targets. The plane of reference is the best-fit to the points

Points 1 to 24	Points 25 to 48
-0.076	-0.088
-0.087	-0.090
-0.019	-0.026
-0.010	0.001
-0.083	-0.066
-0.053	0.026
-0.055	0.104
0.007	0.035
-0.021	0.017
0.048	0.105
0.050	0.127
0.118	0.041
-0.072	-0.133
0.092	-0.119
0.163	-0.057
-0.048	-0.035
-0.080	-0.069
-0.036	-0.044
-0.037	0.002
0.001	0.120
-0.020	0.067
0.015	0.109
0.044	0.092
0.020	0.016

Table 2

RADIUS #1

THE RAW DATA AS TILT VOLTS AND LENGTH VOLTS ARE GIVEN BELOW

JUNE 7		JUNE 8.1		JUNE 8.2	
-4.84875	3.4957	-4.83860	3.4118	-4.84426	3.4093
-4.47785	4.0267	-4.46870	3.4220	-4.47551	3.4149
-4.15974	3.7708	-4.15240	3.3824	-4.15865	3.4818
-3.77054	3.2662	-3.76290	2.6338	-3.76931	3.3538
-3.45072	3.4170	-3.44300	3.4394	-3.45099	3.4588
-3.14335	3.5174	-3.13710	3.5920	-3.14444	3.4986
-2.75979	3.4274	-2.75310	3.4946	-2.75920	3.4973
-2.38337	3.6676	-2.37700	3.3484	-2.38123	2.9967
-2.12295	3.2577	-2.11660	3.2744	-2.12113	3.1588
-1.73983	3.3505	-1.73260	3.4472	-1.73702	3.4609
-1.44174	3.5472	-1.43880	3.6116	-1.44171	3.5256
-1.11453	3.4462	-1.10840	3.4560	-1.10516	3.5685
-0.77097	3.4116	-0.76680	3.3592	-0.76935	3.5696
-0.50906	3.2947	-0.50390	3.3376	-0.50520	3.5794
-0.13835	3.3787	-0.13330	3.3602	-0.13688	3.5922
0.16321	3.3984	0.16310	3.3342	0.16199	3.6166
0.44155	3.3136	0.44030	3.2382	0.43912	3.6967
0.74635	3.4639	0.74440	3.4942	0.74467	3.7487
1.06592	3.5928	1.06520	2.8302	1.06574	3.7938
1.35180	3.7638	1.35300	3.2190	1.35323	3.7995
1.63099	3.4838	1.63170	3.3080	1.63269	3.8172
1.90766	2.6195	1.90600	2.9720	1.90580	2.7079
2.20916	3.0496	2.20750	3.1792	2.20788	3.4505
2.46798	3.2174	2.46510	3.2782	2.46641	3.5296
2.73520	3.6090	2.73060	3.3078	2.73398	3.2612
3.00501	3.3201	3.00300	3.2890	3.00375	3.4643
3.22216	3.2521	3.21740	3.2790	3.21849	3.5117
3.52890	3.5031	3.52560	3.4280	3.52830	3.5579
3.74839	3.1956	3.74170	3.0694	3.74522	3.5471
3.98483	3.3982	3.97980	3.0950	3.98251	3.5952
4.19823	3.4398	4.19270	3.1190	4.19713	3.7325
4.45314	3.5101	4.44980	3.2260	4.45447	3.4070

Table 3

Note: The rightmost column was reproduced for the scanning process. The original data were obscured by a piece of scotch tape and unscanable.

RADIUS #2

THE RAW DATA AS TILT VOLTS AND LENGTH VOLTS ARE GIVEN BELOW

JUNE 7		JUNE 8.1		JUNE 8.2	
-4.83536	3.4729	-4.82320	3.4460	-4.83315	3.5809
-4.48717	3.2277	-4.47650	3.4190	-4.48540	4.5938
-4.12979	3.3843	-4.12090	3.5360	-4.12915	4.6416
-3.78967	3.2314	-3.78110	3.4472	-3.78845	4.6423
-3.42561	2.8628	-3.41900	3.0910	-3.42731	4.4582
-3.14646	3.5749	-3.14050	3.3720	-3.14867	4.4392
-2.79027	3.3455	-2.78370	3.3840	-2.79039	4.4508
-2.34356	3.5013	-2.33660	2.9790	-2.33821	4.4560
-2.10680	3.3960	-2.10060	3.3426	-2.10619	4.7001
-1.76375	3.1870	-1.75640	3.4310	-1.76277	4.6930
-1.42741	2.8755	-1.42060	2.9350	-1.42526	3.4430
-1.08993	3.3932	-1.08810	3.3390	-1.09111	3.4959
-0.79362	3.5016	-0.79100	3.4024	-0.79817	3.5266
-0.50441	3.8605	-0.50310	3.1788	-0.50690	3.4865
-0.15873	3.3691	-0.15540	3.2992	-0.14949	3.5599
0.17138	3.2407	0.17070	3.2946	0.16870	3.5920
0.42129	3.2416	0.42010	3.2500	0.41972	3.5673
0.71486	3.0844	0.71370	3.1252	0.71049	3.5974
1.16186	2.8547	1.16370	2.3378	1.16365	3.6741
1.30246	3.2953	1.30410	3.1744	1.30935	3.6781
1.63718	3.7164	1.64550	3.1540	1.64788	3.6596
1.89532	3.3829	1.89520	3.2654	1.89703	3.6425
2.22237	3.1798	2.22140	3.0690	2.22251	3.6757
2.46954	3.3278	2.46790	3.4198	2.46864	3.7340
2.71053	3.3943	2.70810	3.3310	2.70893	3.7106
3.00813	1.8898	3.00630	1.8670	3.00449	3.7264
3.25596	3.3909	3.25280	3.0898	3.25262	3.7152
3.51569	3.0738	3.51170	3.1160	3.51229	3.0836
3.74458	3.0007	3.73930	2.9660	3.73883	3.1649
3.93214	3.6448	3.93380	3.0602	3.93282	3.2224
4.21953	1.6475	4.21510	1.8210	4.21292	3.3006
4.45940	2.9294	4.45390	2.8474	4.45273	3.3507

Table 3

RADIUS #3

THE RAW DATA AS TILT VOLTS AND LENGTH VOLTS ARE GIVEN BELOW

JUNE 7		JUNE 8.1		JUNE 8.2	
-4.82337	3.0813	-4.81180	3.0560	-4.82005	3.5462
-4.49006	3.0868	-4.48000	3.1468	-4.48757	3.5685
-4.14783	1.3336	-4.13960	1.1570	-4.14720	3.5489
-3.80214	3.2541	-3.79440	2.9500	-3.80175	3.5079
-3.46735	3.2266	-3.46040	3.0830	-3.46730	3.5004
-3.12001	3.5947	-3.11410	3.2510	-3.12081	3.5353
-2.79339	3.3381	-2.78740	3.3034	-2.79265	3.5585
-2.41962	3.3773	-2.41250	3.5872	-2.41671	3.6145
-2.10902	3.1874	-2.10320	3.3710	-2.10905	3.5848
-1.81045	3.1141	-1.80600	3.2230	-1.81050	3.5323
-1.43407	3.1981	-1.42770	3.3816	-1.43283	4.1966
-1.08804	2.2814	-1.08260	2.3898	-1.08644	4.2162
-0.78374	2.5991	-0.77940	2.6372	-0.78578	4.2274
-0.45636	2.7804	-0.45220	2.7410	-0.45559	4.2857
-0.18588	2.9569	-0.18140	3.2560	-0.18335	3.9307
0.16951	3.1540	0.16970	3.2100	0.16878	3.9074
0.47016	3.0237	0.46970	3.1770	0.46960	3.8993
0.74165	3.1578	0.74010	3.1650	0.73990	3.9976
1.11645	3.2052	1.11780	2.3728	1.11916	3.9896
1.33419	3.0348	1.33720	3.0990	1.33658	4.0107
1.64455	3.1684	1.64460	3.1860	1.64592	4.0761
1.89658	2.5819	1.89580	2.6572	1.89689	4.1010
2.22350	4.9685	2.22140	3.3830	2.22290	4.0839
2.46299	3.1300	2.45960	3.2478	2.46243	4.2412
2.71815	3.0510	2.71490	3.2190	2.71705	4.2210
3.02094	2.5713	3.01680	2.4780	3.02072	4.2078
3.24651	2.3762	3.25380	1.7502	3.25642	2.1148
3.49831	2.6641	3.49130	2.4260	3.49596	2.7975
3.74156	2.7135	3.73510	2.5460	3.73669	2.9191
3.98511	2.9685	3.97830	2.9930	3.98379	3.1926
4.19198	2.9814	4.18260	3.0490	4.18724	3.1187
4.44564	3.3838	4.43720	3.1838	4.44037	3.3853

Table 3

RADIUS #4

THE RAW DATA AS TILT VOLTS AND LENGTH VOLTS ARE GIVEN BELOW

JUNE 7		JUNE 8.1		JUNE 8.2	
-4.85614	2.10640	-4.84590	2.14580	-4.85262	3.47110
-4.47940	3.05240	-4.46910	3.19300	-4.47525	3.56900
-4.18725	2.92220	-4.17820	3.13800	-4.18593	3.85430
-3.77340	2.34310	-3.76570	2.56740	-3.77164	3.89810
-3.45519	3.12490	-3.44730	3.11800	-3.45529	3.94250
-3.13858	0.16680	-3.13020	0.32000	-3.13878	0.59200
-2.77729	3.31120	-2.77080	3.24900	-2.77707	3.41090
-2.36773	2.97970	-2.36340	3.08800	-2.36682	2.47990
-2.09892	2.68350	-2.09360	2.87480	-2.09764	3.12720
-1.78162	3.22910	-1.77620	3.23200	-1.78004	3.47570
-1.44988	1.91120	-1.44680	2.08160	-1.44940	3.43280
-1.14063	3.13570	-1.13560	3.14540	-1.14243	3.49500
-0.76228	2.88770	-0.75980	2.82840	-0.76205	3.57680
-0.50870	3.05330	-0.50930	3.04300	-0.51173	3.39910
-0.15983	3.17810	-0.15990	3.17300	-0.16044	3.47510
0.15260	2.53060	0.15270	3.23660	0.15042	3.72090
0.46996	3.68440	0.47060	2.76700	0.46941	3.75740
0.72930	4.22180	0.72910	3.79800	0.72838	4.04080
1.11029	2.80920	1.10910	3.50520	1.10971	4.04970
1.33722	3.24850	1.33470	3.53480	1.33563	4.02930
1.61828	3.96650	1.61650	2.87680	1.61848	4.10570
1.92583	2.32910	1.92390	3.01600	1.92494	4.19490
2.17951	2.32560	2.17680	3.00580	2.17792	3.52390
2.45517	1.75960	2.45550	0.36740	2.45770	1.50600
2.74198	3.17010	2.73830	3.31780	2.74146	3.69080
2.97576	6.22430	2.97190	3.19100	2.97458	3.60940
3.24049	3.21820	3.23500	3.33380	3.23845	3.63800
3.48183	1.11740	3.49950	2.67800	3.50301	2.73150
3.72427	3.13670	3.72030	3.09000	3.72415	3.41490
3.96202	3.12210	3.95760	3.28800	3.96019	3.43550
4.20160	3.05530	4.19610	3.22400	4.19932	3.42170
4.43830	2.92560	4.43320	3.04840	4.43192	3.40490

Table 3

CONVERSION OF RADIUS #1

JUNE 7		JUNE 8.1		JUNE 8.2	
14.08113	650.0930	14.07385	650.0503	14.07276	650.0491
12.98595	650.3627	12.97999	650.0555	12.98360	650.0519
12.05050	650.2327	12.04844	650.0354	12.05151	650.0859
10.91038	649.9764	10.90568	649.6551	10.91060	650.0209
9.97679	650.0530	9.97041	650.0644	9.98107	650.0742
9.08206	650.1040	9.07857	650.1419	9.08841	650.0944
7.96864	650.0583	7.96213	650.0924	7.96972	650.0938
6.87890	650.1803	6.87159	650.0181	6.87511	649.8395
6.12646	649.9721	6.11802	649.9805	6.12334	649.9218
5.02138	650.0192	5.00865	650.0683	5.01504	650.0753
4.16288	650.1191	4.16115	650.1518	4.16425	650.1082
3.22159	650.0678	3.20915	650.0728	3.19577	650.1299
2.23419	650.0502	2.22581	650.0236	2.23032	650.1305
1.48192	649.9909	1.46948	650.0126	1.47135	650.1355
0.41755	650.0335	0.40371	650.0241	0.41348	650.1420
-0.44815	650.0435	-0.44856	650.0109	-0.44481	650.1544
-1.24728	650.0005	-1.24571	649.9622	-1.24074	650.1951
-2.12267	650.0768	-2.12050	650.0922	-2:11858	650.2215
-3.04101	650.1423	-3.04386	649.7549	-3.04156	650.2393
-3.86319	650.2292	-3.87291	649.9524	-3.86866	650.2473
-4.66690	650.0869	-4.67651	649.9976	-4.67343	650.2563
-5.46426	649.6479	-5.46832	649.8269	-5.46081	649.6928
-6.33440	649.8663	-6.33986	649.9322	-6.33292	650.0700
-7.08253	649.9516	-7.08566	649.9825	-7.08047	650.1102
-7.85622	650.1505	-7.85559	649.9975	-7.85543	649.9738
-8.63887	650.0038	-8.64702	649.9880	-8.63823	650.0770
-9.26994	649.9692	-9.27109	649.9829	-9.26251	650.1011
-10.16333	650.0967	-10.17016	650.0586	-10.16514	650.1246
-10.80413	649.9405	-10.80205	649.8764	-10.79864	650.1191
-11.49595	650.0434	-11.49981	649.8894	-11.49317	650.1435
-12.12181	650.0646	-12.12518	649.9016	-12.12282	650.2133
-12.87135	650.1003	-12.88235	649.9560	-12.87977	650.0479

<u>Table 4</u>

The data of Table 3 converted to angles in degrees and lengths in millimeters.

CONVERSION OF RADIUS #2

JUNE 7		JUNE 8.1		JUNE 8.2	
14.04150	650.0814	14.02821	650.0677	14.03988	650.1362
13.01341	649.9568	13.00301	650.0540	13.01275	650.6508
11.96260	650.0364	11.95585	650.1134	11.96490	650.6751
10.96631	649.9587	10.95898	650.0683	10.96658	650.6754
9.90361	649.7715	9.90036	649.8874	9.91203	650.5819
9.09110	650.1332	9.08847	650.0301	9.10071	650.5723
8.05701	650.0167	8.05098	650.0362	8.06017	650.5782
6.76380	650.0958	6.75460	649.8305	6.75069	650.5808
6.07983	650.0423	6.07175	650.0152	6.08019	650.7048
5.09032	649.9361	5.07735	650.0601	5.08927	650.7012
4.12164	649.7779	4.10868	649.8081	4.11689	650.0662
3.15086	650.0409	3.15069	650.0134	3.15536	650.0931
2.29926	650.0960	2.29545	650.0456	2.31315	650.1087
1.46857	650.2783	1.46718	649.9320	1.47623	650.0883
0.47606	650.0287	0.46725	649.9931	0.44969	650.1256
-0.47161	649.9634	-0.47042	649.9908	-0.46408	650.1419
-1.18911	649.9639	-1.18761	649.9681	-1.18502	650.1293
-2.03221	649.8840	-2.03216	649.9048	-2.02036	650.1446
-3.31685	649.7673	-3.32752	649.5048	-3.32316	650.1836
-3.72124	649.9912	-3.73199	649.9297	-3.74237	650.1856
-4.68473	650.2051	-4.71632	649.9194	-4.71720	650.1762
-5.42868	650.0357	-5.43713	649.9760	-5.43551	650.1675
-6.37256	649.9325	-6.38008	649.8762	-6.37520	650.1844
-7.08705	650.0077	-7.09377	650.0544	-7.08692	650.2140
-7.78473	650.0415	-7.79029	650.0093	-7.78282	650.2021
-8.64793	649.2772	-8.65662	649.2656	-8.64038	650.2102
-9.36827	650.0397	-9.37424	649.8868	-9.36183	650.2045
-10.12481	649.8786	-10.12956	649.9001	-10.11843	649.8836
-10.79299	649.8415	-10.79502	649.8239	-10.77996	649.9249
-11.34163	650.1687	-11.36487	649.8717	-11.34759	649.9541
-12.18436	649.1541	-12.19106	649.2422	-12.16920	649.9939
-12.88978	649.8053	-12.89444	649.7636	-12.87464	650.0193

Table 4

The data of Table 3 converted to angles in degrees and lengths in millimeters.

CONVERSION OF RADIUS #3

JUNE 7		JUNE 8.1		JUNE 8.2	
14.00603	649.8824	13.99443	649.8696	14.00110	650.1186
13.02193	649.8852	13.01333	649.9157	13.01914	650.1299
12.01554	648.9946	12.01081	648.9049	12.01789	650.1200
11.00278	649.9702	10.99793	649.8157	11.00549	650.0992
10.02527	649.9563	10.02121	649.8833	10.02863	650.0954
9.01421	650.1433	9.01161	649.9687	9.01969	650.1131
8.06605	650.0129	8.06172	649.9953	8.06673	650.1249
6.98373	650.0328	6.97441	650.1394	6.97775	650.1533
6.08624	649.9363	6.07927	650.0296	6.08845	650.1382
5.22492	649.8991	5.22054	649.9544	5.22690	650.1116
4.14081	649.9418	4.12915	650.0350	4.13869	650.4490
3.14543	649.4761	3.13486	649.5312	3.14192	650.4590
2.27088	649.6375	2.26207	649.6568	2.27754	650.4647
1.33059	649.7296	1.32078	649.7096	1.32884	650.4943
0.55400	649.8193	0.54202	649.9712	0.54693	650.3139
-0.46624	649.9194	-0.46754	649.9478	-0.46431	650.3021
-1.32944	649.8532	-1.33027	649.9311	-1.32829	650.2980
-2.10917	649.9213	-2.10812	649.9250	-2.10488	650.3479
-3.18628	649.9454	-3.19533	649.5225	-3.19519	650.3439
-3.81252	649.8588	-3.82737	649.8914	-3.82074	650.3546
-4.70596	649.9267	-4.71373	649.9356	-4.71155	650.3878
-5.43231	649.6288	-5.43886	649.6670	-5.43511	650.4005
-6.37583	650.8411	-6.38008	650.0357	-6.37632	650.3918
-7.06810	649.9072	-7.06973	649.9670	-7.06895	650.4717
-7.80681	649.8671	-7.81003	649.9524	-7.80636	650.4614
-8.68513	649.6234	-8.68716	649.5760	-8.68753	650.4547
-9.34078	649.5243	-9.37715	649.2063	-9.37289	649.3915
-10.07413	649.6705	-10.06998	649.5496	-10.07080	649.7383
-10.78417	649.6956	-10.78273	649.6105	-10.77371	649.8001
-11.49677	649.8251	-11.49541	649.8376	-11.49692	649.9390
-12.10346	649.8317	-12.09548	649.8660	-12.09377	649.9014
-12.84926	650.0361	-12.84519	649.9345	-12.83824	650.0369

Table 4

the data of Table 3 converted to angles in degrees and lengths in millimeters.

CONVERSION OF RADIUS #4

JUNE 7		JUNE 8.1		JUNE 8.2	
14.10300	649.3872	14.09549	649.4072	14.09752	650.0805
12.99052	649.8678	12.98117	649.9392	12.98283	650.1302
12.13126	649.8016	12.12430	649.9113	12.13163	650.2751
10.91874	649.5074	10.91388	649.6214	10.91742	650.2974
9.98982	649.9046	9.98297	649.9011	9.99361	650.3199
9.06819	648.4019	9.05848	648.4797	9.07195	648.6179
8.01938	649.9992	8.01352	649.9676	8.02154	650.0499
6.83367	649.8308	6.83221	649.8859	6.83343	649.5769
6.05708	649.6804	6.05151	649.7775	6.05550	649.9058
5.14182	649.9575	5.13450	649.9590	5.13907	650.0828
4.18631	649.2880	4.18421	649.3746	4.18640	650.0610
3.29664	649.9101	3.28749	649.9150	3.30297	650.0926
2.20923	649.7841	2.20567	649.7540	2.20934	650.1342
1.48088	649.8682	1.48501	649.8630	1.49011	650.0439
0.47922	649.9316	0.48019	649.9290	0.48114	650.0825
-0.41769	649.6027	-0.41866	649.9613	-0.41158	650.2074
-1.32886	650.1888	-1.33286	649.7228	-1.32775	650.2259
-2.07369	650.4618	-2.07647	650.2465	-2.07177	650.3699
-3.16857	649.7442	-3.17028	650.0978	-3.16801	650.3744
-3.82124	649.9674	-3.82017	650.1128	-3.81800	650.3640
-4.63029	650.3321	-4.63266	649.7786	-4.63249	650.4028
-5.51667	649.5003	-5.52003	649.8493	-5.51603	650.4482
-6.24877	649.4986	-6.25106	649.8441	-6.24637	650.1073
-7.04548	649.2110	-7.05785	648.5038	-7.05526	649.0822
-7.87587	649.9276	-7.87794	650.0026	-7.87712	650.1921
-8.55395	651.4791	-8.55658	649.9382	-8.55351	650.1507
-9.32326	649.9520	-9.32237	650.0107	-9.32059	650.1653
-10.02608	648.8848	-10.09393	649.6776	-10.09136	649.7048
-10.73365	649.9106	-10.73942	649.8869	-10.73705	650.0519
-11.42913	649.9032	-11.43468	649.9875	-11.42777	650.0624
-12.13170	649.8692	-12.13518	649.9549	-12.12925	650.0554
-12.82765	649.8034	-12.83339	649.8657	-12.81335	650.0468

<u>Table 4</u>

The data of Table 3 converted to angles in degrees and lengths in millimeters.

The measured step lengths in millimeters.

Radius # 1

Step #	June 7	June 8.1	June 8.2	RMS
1	650.093	650.050	650.049	0.020
2	650.363	650.056	650.052	0.146
3	650.233	650.035	650.086	0.084
4	649.976	649.655	650.021	0.163
5	650.053	650.064	650.074	0.008
6	650.104	650.142	650.094	0.020
7	650.058	650.092	650.094	0.016
8	650.180	650.018	649.839	0.139
9	649.972	649.981	649.922	0.026
10	650.019	650.068	650.075	0.025
11	650.119	650.152	650.108	0.019
12	650.068	650.073	650.130	0.028
13	650.050	650.024	650.131	0.045
14	649.991	650.013	650.135	0.064
15	650.034	650.024	650.142	0.053
16	650.044	650.011	650.154	0.061
17	650.000	649.962	650.195	0.102
18	650.077	650.092	650.221	0.065
19	650.142	649.755	650.239	0.209
20	650.229	649.952	650.247	0.135
21	650.087	649.998	650.256	0.107
22	649.648	649.827	649.693	0.076
23	649.866	649.932	650.070	0.085
24	649.952	649.982	650.110	0.069
25	650.151	649.998	649.974	0.078
26	650.004	649.988	650.077	0.039
27	649.969	649.983	650.101	0.059
28	650.097	650.059	650.125	0.027
29	649.941	649.876	650.119	0.103
30	650.043	649.889	650.144	0.105
31	650.065	649.902	650.213	0.127
32	650.100	649.956	650.048	0.060

THE MEAN VALUE OF THE RMS IN MMS IS 0.073869945

Table 5

The measured step lengths in millimeters.

Radius # 2

Step #	June 7	June 8.1	June 8.2	RMS
1	650.081	650.068	650.136	0.030
2	649.957	650.054	650.651	0.307
3	650.036	650.113	650.675	0.285
4	649.959	650.068	650.675	0.315
5	649.771	649.887	650.582	0.358
6	650.133	650.030	650.572	0.235
7	650.017	650.036	650.578	0.260
8	650.096	649.830	650.581	0.311
9	650.042	650.015	650.705	0.319
10	649.936	650.060	650.701	0.335
11	649.778	649.808	650.066	0.129
12	650.041	650.013	650.093	0.033
13	650.096	650.046	650.109	0.027
14	650.278	649.932	650.088	0.142
15	650.029	649.993	650.126	0.056
16	649.963	649.991	650.142	0.078
17	649.964	649.968	650.129	0.077
18	649.884	649.905	650.145	0.118
19	649.767	649.505	650.184	0.279
20	649.991	649.930	650.186	0.109
21	650.205	649.919	650.176	0.128
22	650.036	649.976	650.168	0.080
23	649.932	649.876	650.184	0.134
24	650.008	650.054	650.214	0.088
25	650.041	650.009	650.202	0.084
26	649.277	649.266	650.210	0.443
27	650.040	649.887	650.204	0.130
28	649.879	649.900	649.884	0.009
29	649.842	649.824	649.925	0.044
30	650.169	649.872	649.954	0.125
31	649.154	649.242	649.994	0.377
32	649.805	649.764	650.019	0.112

THE MEAN VALUE OF THE RMS IN MMS IS 0.173693348

Table 5

The measured lengths in millimeters.

Radius # 3

Step #	June 7	June 8.1	June 8.2	RMS
1	649.882	649.870	650.119	0.114
2	649.885	649.916	650.130	0.109
3	648.995	648.905	650.120	0.553
4	649.970	649.816	650.099	0.116
5	649.956	649.883	650.095	0.088
6	650.143	649.969	650.113	0.076
7	650.013	649.995	650.125	0.057
8	650.033	650.139	650.153	0.054
9	649.936	650.030	650.138	0.082
10	649.899	649.954	650.112	0.090
11	649.942	650.035	650.449	0.220
12	649.476	649.531	650.459	0.451
13	649.637	649.657	650.465	0.385
14	649.730	649.710	650.494	0.365
15	649.819	649.971	650.314	0.207
16	649.919	649.948	650.302	0.174
17	649.853	649.931	650.298	0.194
18	649.921	649.925	650.348	0.200
19	649.945	649.523	650.344	0.335
20	649.859	649.891	650.355	0.226
21	649.927	649.936	650.388	0.215
22	649.629	649.667	650.400	0.355
23	650.841	650.036	650.392	0.330
24	649.907	649.967	650.472	0.253
25	649.867	649.952	650.461	0.262
26	649.623	649.576	650.455	0.404
27	649.524	649.206	649.391	0.130
28	649.671	649.550	649.738	0.078
29	649.696	649.611	649.800	0.078
30	649.825	649.838	649.939	0.051
31	649.832	649.866	649.901	0.028
32	650.036	649.935	650.037	0.048

THE MEAN VALUE OF THE RMS IN MMS IS 0.197858429

Table 5

The measured step lengths in millimeters

Radius # 4

Step #	June 7	June 8.1	June 8.2	RMS
1	649.387	649.407	650.080	0.322
2	649.868	649.939	650.130	0.111
3	649.802	649.911	650.275	0.202
4	649.507	649.621	650.297	0.349
5	649.905	649.901	650.320	0.197
6	648.402	648.480	648.618	0.089
7	649.999	649.968	650.050	0.034
8	649.831	649.886	649.577	0.135
9	649.680	649.778	649.906	0.092
10	649.958	649.959	650.083	0.059
11	649.288	649.375	650.061	0.346
12	649.910	649.915	650.093	0.085
13	649.784	649.754	650.134	0.173
14	649.868	649.863	650.044	0.084
15	649.932	649.929	650.082	0.072
16	649.603	649.961	650.207	0.248
17	650.189	649.723	650.226	0.229
18	650.462	650.247	650.370	0.088
19	649.744	650.098	650.374	0.258
20	649.967	650.113	650.364	0.164
21	650.332	649.779	650.403	0.279
22	649.500	649.849	650.448	0.391
23	649.499	649.844	650.107	0.249
24	649.211	648.504	649.082	0.308
25	649.928	650.003	650.192	0.111
26	651.479	649.938	650.151	0.682
27	649.952	650.011	650.165	0.090
28	648.885	649.678	649.705	0.380
29	649.911	649.887	650.052	0.073
30	649.903	649.987	650.062	0.065
31	649.869	649.955	650.055	0.076
32	649.803	649.866	650.047	0.103

THE MEAN VALUE OF THE RMS IN MMS IS 0.191980703

Table 5

Estimating the Measuring Error

THE MEAN VALUE OF D AND ITS RMS ALONG RADIUS # 1

	June 7	June 8.1	June 8.2	Mean	RMS
1	0.000	0.000	0.000	0.000	0.000
2	0.881	0.861	0.800	0.847	0.035
3	0.821	0.796	0.727	0.781	0.040
4	1.600	1.614	1.531	1.582	0.036
5	0.829	0.852	0.777	0.819	0.032
6	0.799	0.812	0.809	0.807	0.006
7	1.889	1.926	1.986	1.934	0.040
8	1.511	1.535	1.634	1.560	0.053
9	-0.168	-0.164	-0.074	-0.136	0.044
10	0.642	0.612	0.714	0.656	0.043
11	-0.239	-0.353	-0.225	-0.272	0.057
12	-0.068	-0.139	-0.025	-0.077	0.047
13	0.072	-0.080	-0.173	-0.060	0.101
14	-0.493	-0.679	-0.770	-0.647	0.115
15	0.867	0.598	0.479	0.648	0.162
16	0.332	-0.037	-0.092	0.068	0.188
17	0.094	-0.215	-0.277	-0.133	0.162
18	0.802	0.576	0.522	0.633	0.121
19	1.393	1.259	1.176	1.276	0.089
20	1.184	1.082	0.975	1.080	0.086
21	1.168	1.014	0.906	1.029	0.108
22	1.404	1.199	1.076	1.226	0.135
23	1.802	1.614	1.530	1.649	0.114
24	1.288	1.101	1.049	1.146	0.103
25	1.195	1.036	0.995	1.075	0.086
26	1.033	0.951	0.858	0.948	0.071
27	0.512	0.397	0.360	0.423	0.065
28	1.371	1.311	1.329	1.337	0.025
29	0.108	0.031	0.059	0.066	0.032
30	-0.248	-0.228	-0.211	-0.229	0.015
31	-0.519	-0.476	-0.429	-0.474	0.037
32	-0.018	0.053	0.076	0.037	0.040
33	-0.530	-0.530	-0.530	-0.530	0.000

THE MEAN VALUE OF THE RMS IN MMS IS 0.071497815

Table 6

Estimating the Measuring Error

THE MEAN VALUE OF D AND ITS RMS ALONG RADIUS # 2

	June 7	June 8.1	June 8.2	Mean	RMS
1	0.000	0.000	0.000	0.000	0.000
2	0.499	0.434	0.475	0.469	0.027
3	0.821	0.724	0.784	0.776	0.040
4	0.670	0.581	0.653	0.635	0.038
5	0.612	0.526	0.592	0.577	0.037
6	-0.176	-0.213	-0.105	-0.165	0.044
7	1.098	1.117	1.273	1.163	0.078
8	1.818	1.855	2.024	1.899	0.090
9	-1.102	-1.083	-1.053	-1.079	0.020
10	-0.743	-0.731	-0.696	-0.723	0.020
11	-0.732	-0.782	-0.703	-0.739	0.033
12	-0.949	-1.062	-0.981	-0.997	0.048
13	-1.548	-1.574	-1.533	-1.552	0.017
14	-1.261	-1.243	-1.089	-1.198	0.077
15	0.033	0.123	0.289	0.148	0.106
16	0.283	0.358	0.221	0.287	0.056
17	-0.140	0.040	-0.118	-0.073	0.081
18	1.357	1.647	1.422	1.475	0.124
19	3.134	3.517	3.335	3.328	0.156
20	-0.314	0.033	-0.195	-0.159	0.144
21	1.476	1.786	1.332	1.531	0.189
22	1.583	1.600	1.034	1.405	0.263
23	2.509	2.515	1.866	2.297	0.304
24	1.620	1.626	0.934	1.393	0.325
25	1.565	1.582	0.871	1.339	0.331
26	2.397	2.438	1.716	2.184	0.331
27	1.862	1.889	1.266	1.672	0.288
28	1.570	1.617	1.046	1.411	0.259
29	0.888	0.971	0.436	0.765	0.235
30	0.766	0.920	0.472	0.720	0.186
31	2.585	2.537	2.206	2.443	0.169
32	2.372	2.334	2.182	2.296	0.082
33	1.710	1.710	1.711	1.710	0.000

THE MEAN VALUE OF THE RMS IN MMS IS 0.131264433

Table 6

Estimating the Measuring Error

THE MEAN VALUE OF D AND ITS RMS ALONG RADIUS # 3

	June 7	June 8.1	June 8.2	Mean	RMS
1	0.000	0.000	0.000	0.000	0.000
2	-0.010	-0.077	-0.058	-0.048	0.028
3	0.300	0.199	0.228	0.242	0.043
4	0.632	0.541	0.594	0.589	0.037
5	0.860	0.778	0.862	0.834	0.039
6	1.331	1.268	1.380	1.326	0.046
7	1.590	1.561	1.709	1.620	0.064
8	2.275	2.262	2.411	2.316	0.067
9	1.753	1.697	1.828	1.759	0.054
10	2.050	1.979	2.158	2.062	0.074
11	3.484	3.427	3.624	3.512	0.083
12	3.355	3.228	3.479	3.354	0.102
13	2.559	2.374	2.650	2.528	0.115
14	2.373	2.151	2.551	2.358	0.164
15	1.893	1.621	2.060	1.858	0.181
16	2.915	2.567	3.006	2.829	0.189
17	2.407	2.109	2.530	2.349	0.176
18	2.074	1.833	2.219	2.042	0.159
19	2.766	2.605	2.971	2.780	0.150
20	0.735	0.533	0.842	0.704	0.128
21	1.261	0.946	1.276	1.161	0.152
22	0.947	0.605	0.902	0.818	0.152
23	1.664	1.309	1.592	1.522	0.153
24	0.569	0.230	0.499	0.433	0.146
25	0.589	0.299	0.516	0.468	0.123
26	0.982	0.722	0.923	0.876	0.111
27	-0.184	-0.399	-0.265	-0.283	0.089
28	-0.295	-0.901	-0.776	-0.657	0.261
29	-0.504	-0.987	-0.936	-0.809	0.217
30	-0.686	-1.080	-0.978	-0.915	0.167
31	-1.052	-1.356	-1.338	-1.249	0.140
32	-0.399	-0.528	-0.553	-0.493	0.067
33	-0.709	-0.710	-0.710	-0.710	0.000

THE MEAN VALUE OF THE RMS IN MMS IS 0.114930267

Table 6

Estimating the Measuring Error

THE MEAN VALUE OF D AND ITS RMS ALONG RADIUS # 4

	June 7	June 8.1	June 8.2	Mean	RMS
1	0.000	0.000	0.000	0.000	0.000
2	0.985	0.970	0.936	0.964	0.021
3	0.829	0.777	0.705	0.770	0.051
4	2.375	2.314	2.269	2.320	0.044
5	1.547	1.500	1.439	1.496	0.044
6	1.512	1.457	1.460	1.476	0.025
7	2.273	2.177	2.277	2.242	0.046
8	2.293	2.201	2.336	2.276	0.056
9	-0.093	-0.132	-0.039	-0.088	0.038
10	-0.278	-0.310	-0.229	-0.272	0.033
11	0.043	-0.002	0.074	0.038	0.031
12	0.288	0.289	0.333	0.304	0.021
13	1.102	1.069	1.235	1.135	0.072
14	0.040	0.037	0.189	0.089	0.071
15	1.179	1.297	1.451	1.309	0.111
16	1.164	1.367	1.473	1.335	0.128
17	1.078	1.344	1.476	1.299	0.165
18	0.597	0.890	1.023	0.837	0.178
19	1.563	1.898	2.028	1.830	0.196
20	-0.402	-0.012	0.086	-0.109	0.211
21	-0.130	0.351	0.414	0.212	0.243
22	0.336	0.865	0.869	0.690	0.250
23	-0.128	0.438	0.430	0.247	0.265
24	0.199	0.815	0.803	0.606	0.288
25	0.342	0.884	0.842	0.689	0.246
26	-0.298	0.298	0.203	0.068	0.261
27	0.022	0.665	0.545	0.411	0.279
28	-0.018	0.718	0.556	0.419	0.316
29	0.240	0.192	-0.002	0.143	0.105
30	0.563	0.518	0.289	0.457	0.120
31	0.934	0.895	0.689	0.839	0.107
32	1.084	1.080	0.884	1.016	0.093
33	0.921	0.920	0.921	0.921	0.000

HE MEAN VALUE OF THE RMS IN MMS IS 0.128682189

Table 6

Figure 1.1

THE 140 FOOT SURFACE

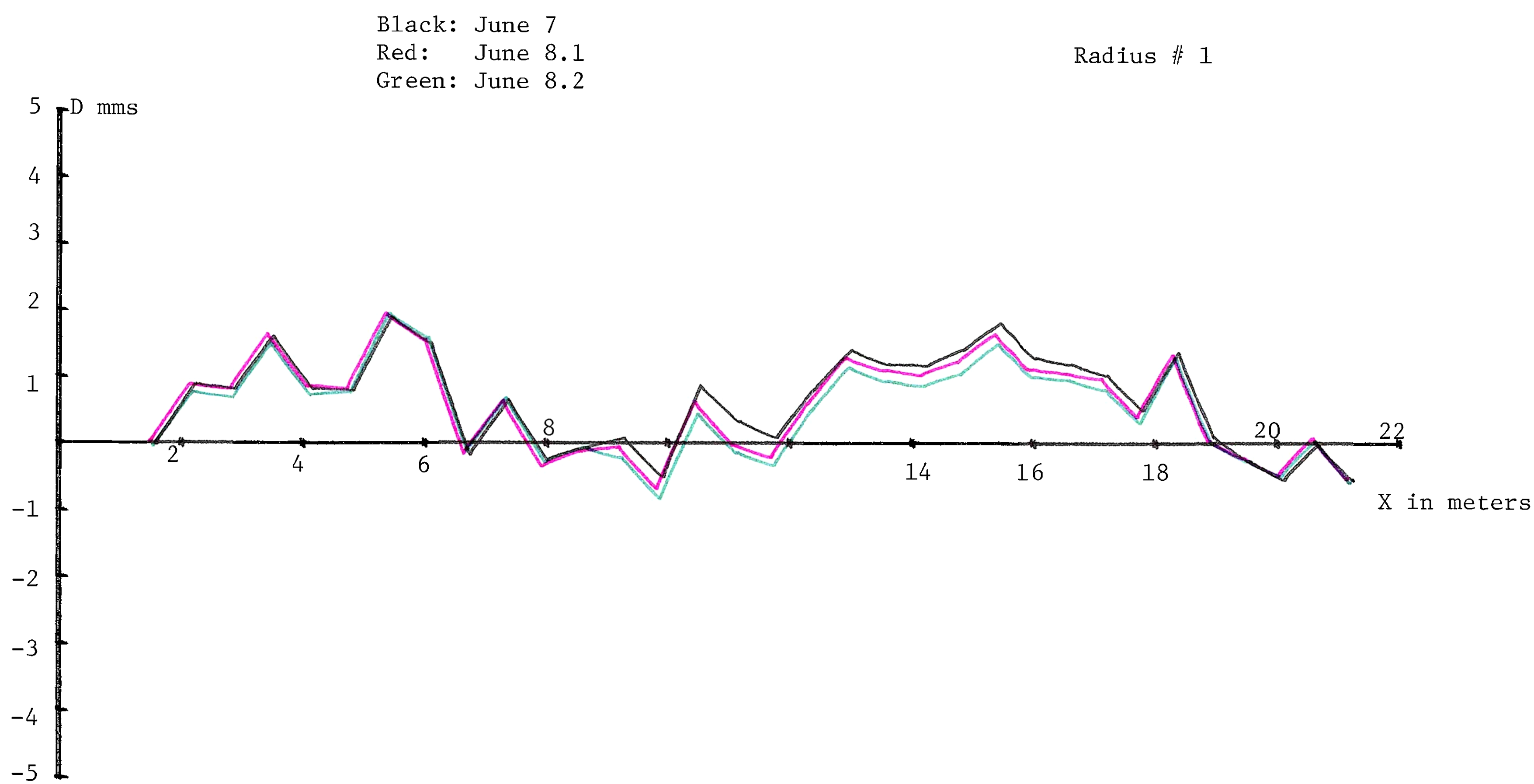


Figure 1.2

THE 140 FOOT TELESCOPE SURFACE

Black: June 7
Red: June 8.1
Blue: June 8.2

Radius # 2

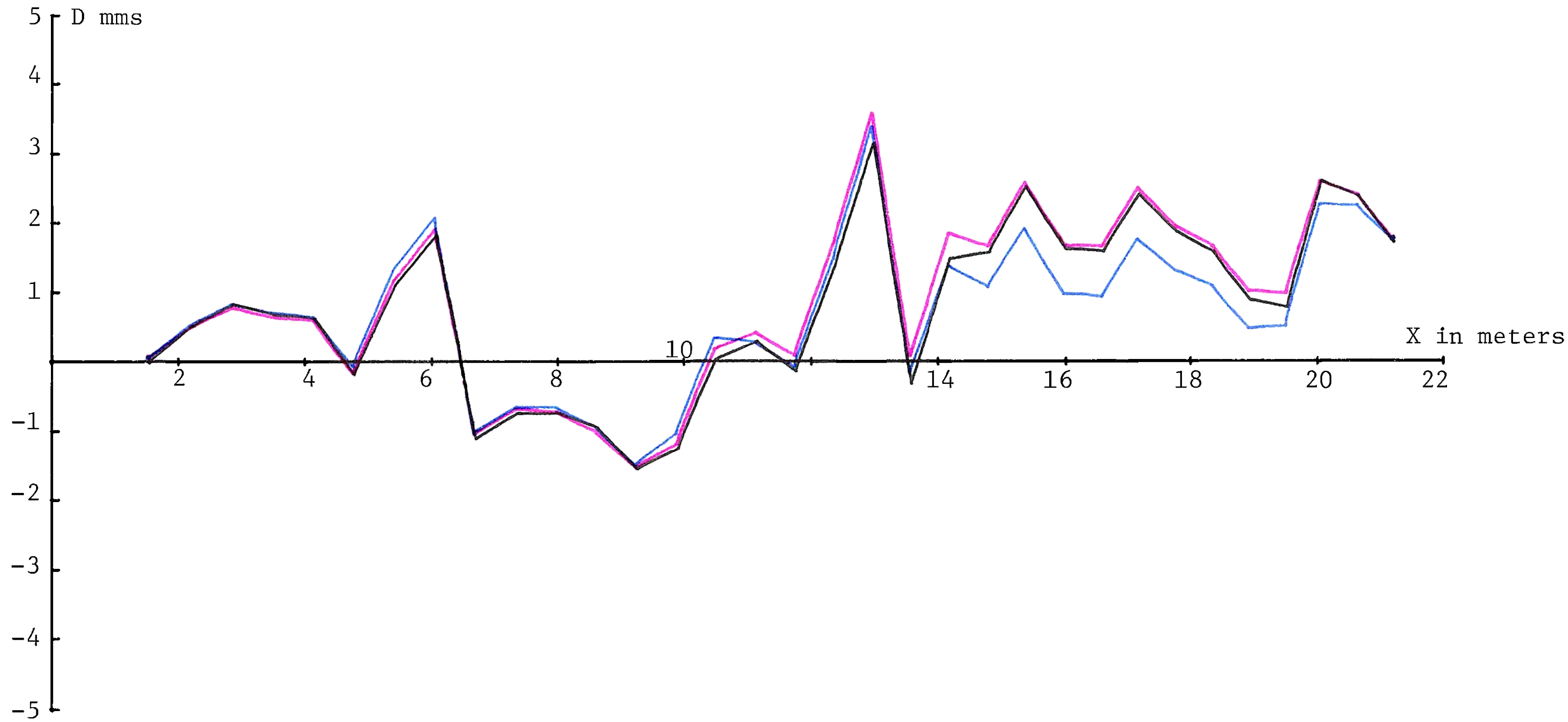


Figure 1.3

THE 140 FOOT SURFACE

Black: June 7
Red: June 8.1
Blue: June 8.2

Radius # 3

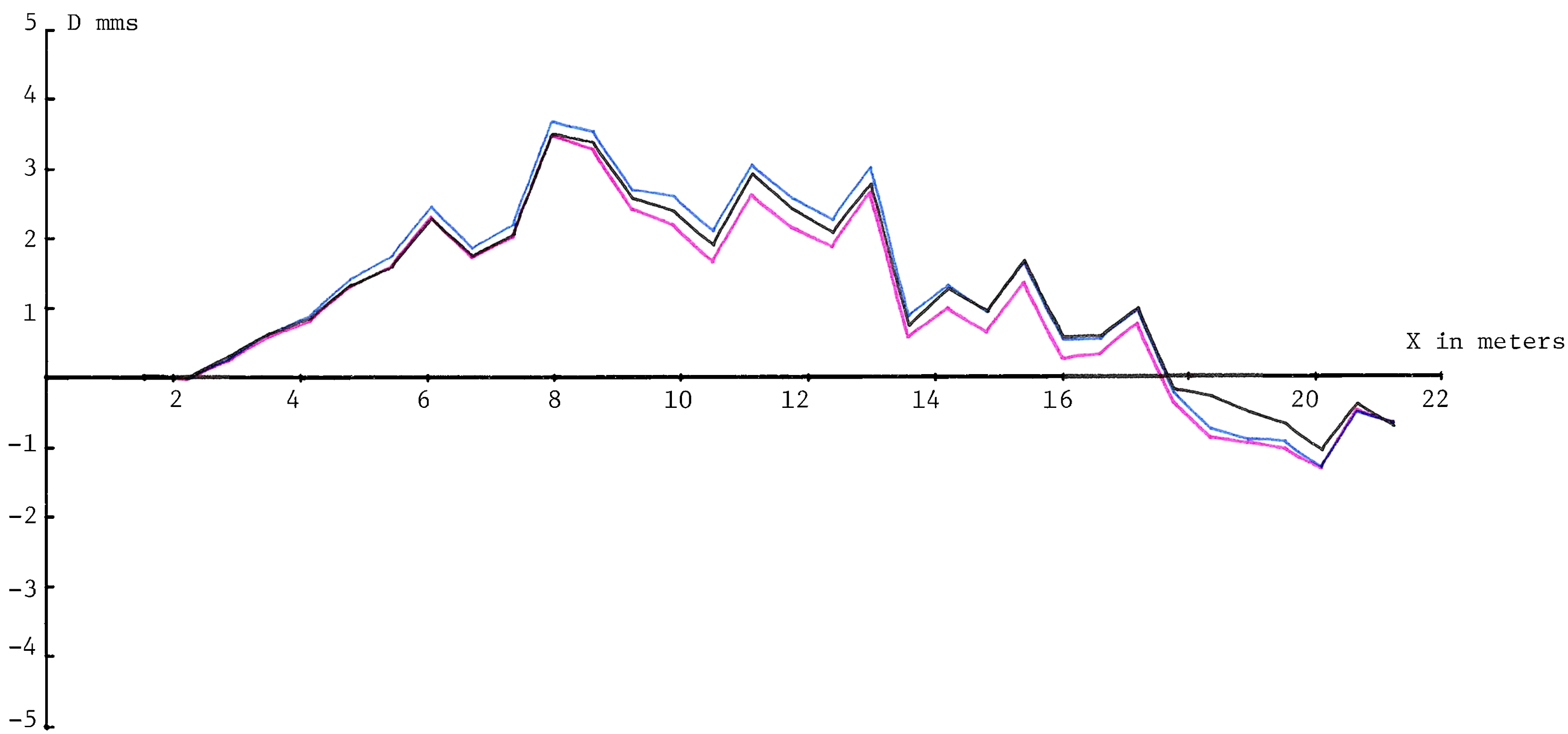


Figure 1.4

THE 140 FOOT SURFACE

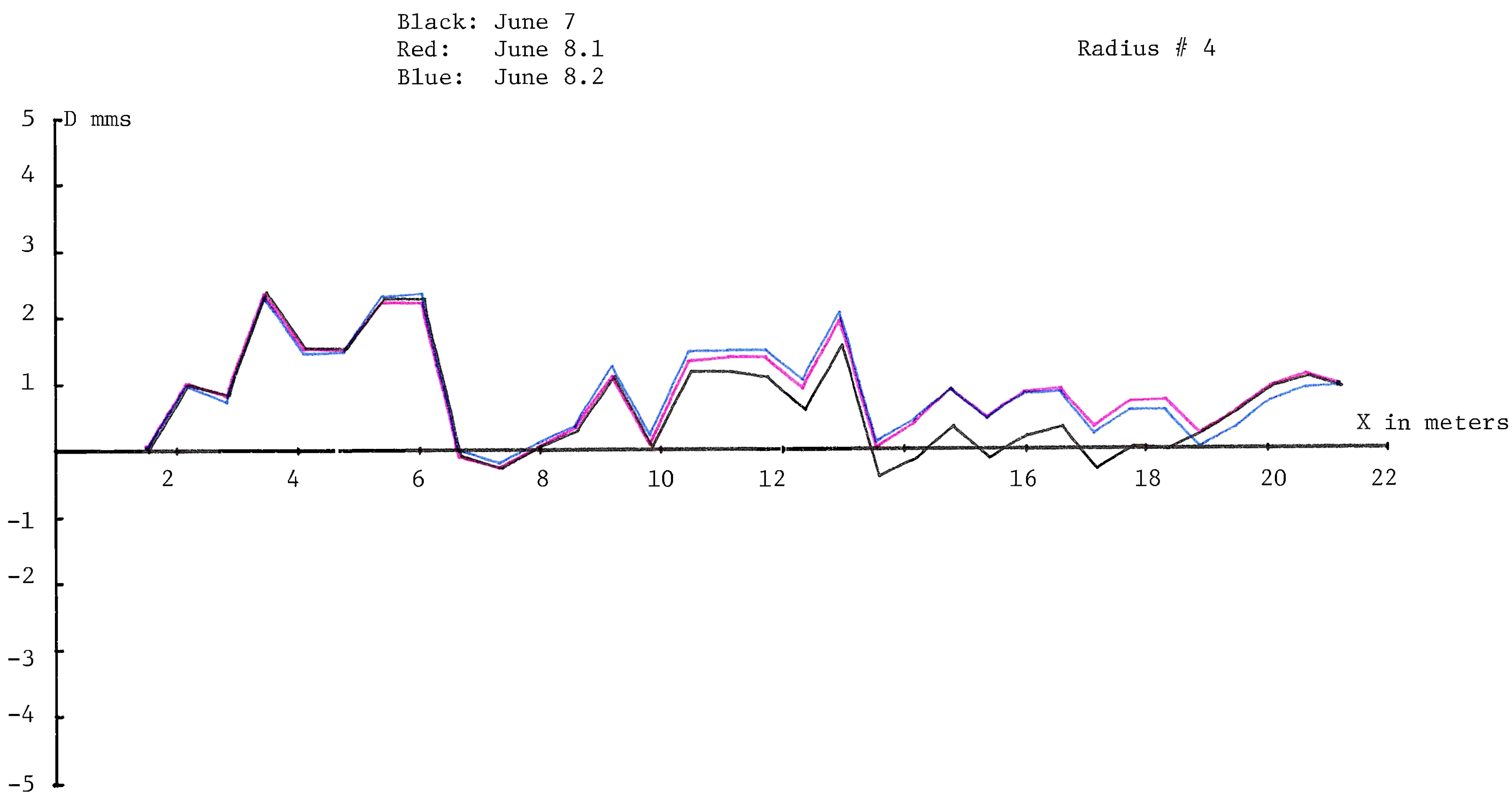


Figure 2.1

THE 140 FOOT SURFACE

The RMS of the angle readings

Radius # 1

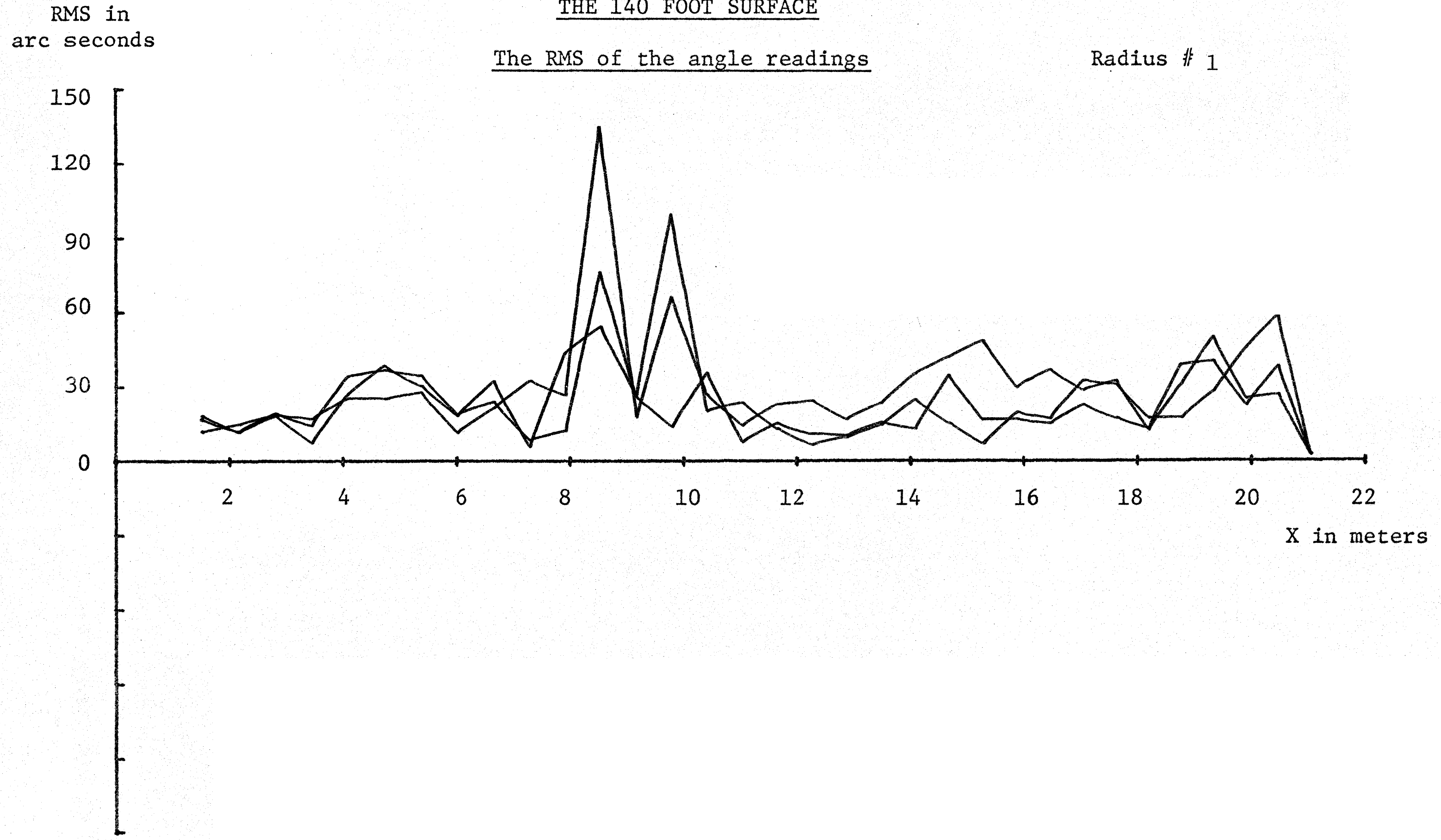


Figure 2.2

THE 140 FOOT SURFACE

The RMS of the angle readings

Radius # 2

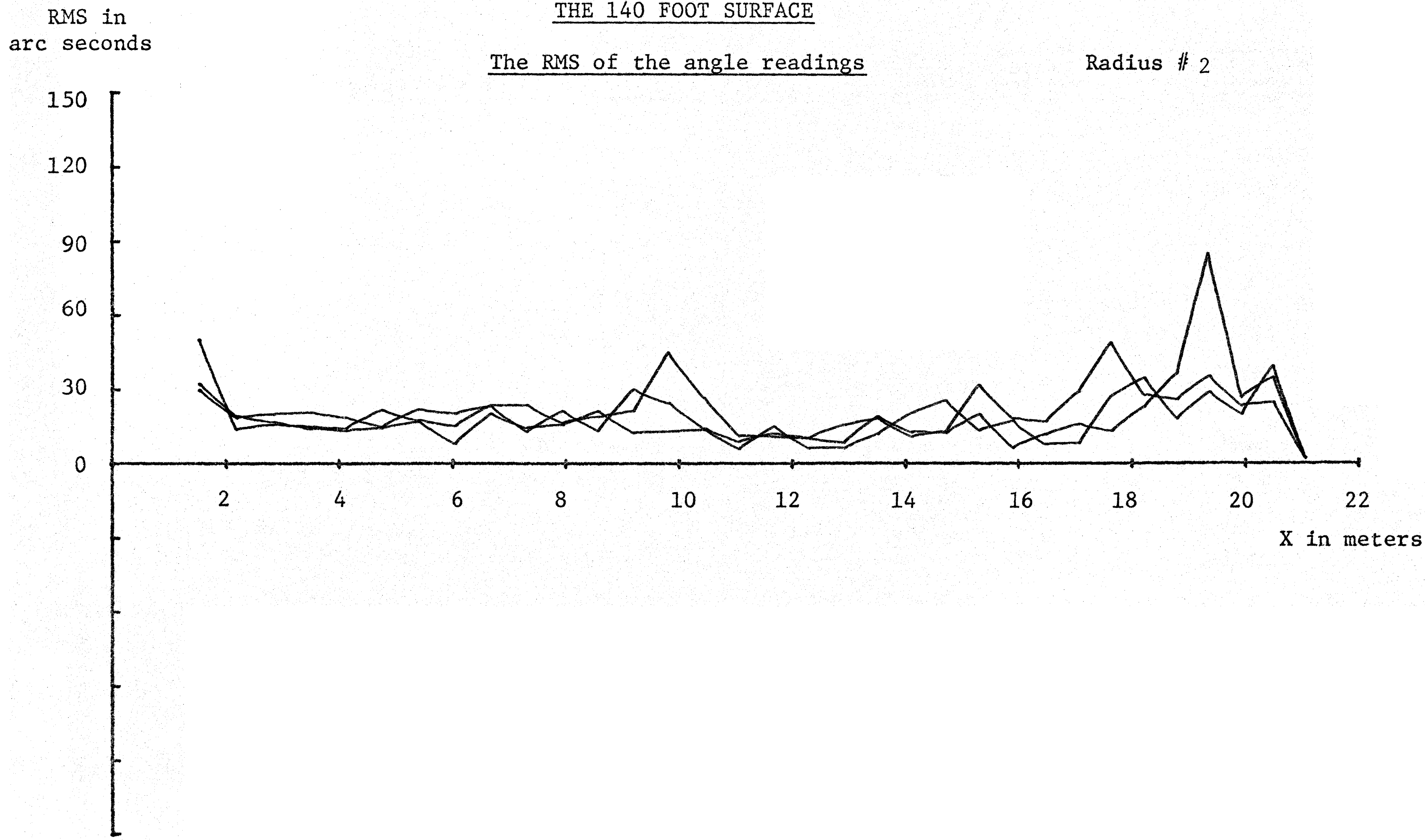


Figure 2.3

THE 140 FOOT SURFACE

The RMS of the angle readings

Radius # 3

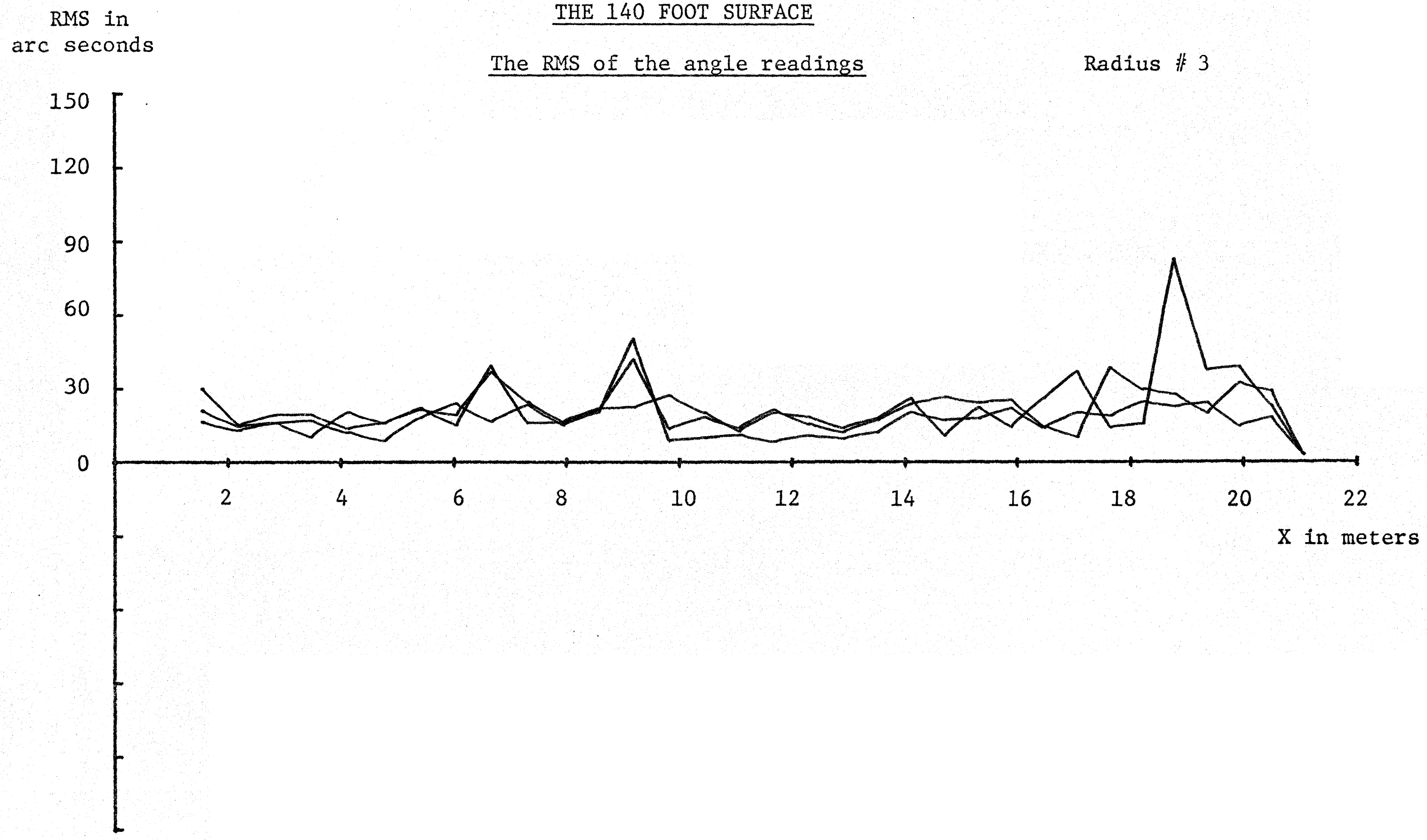
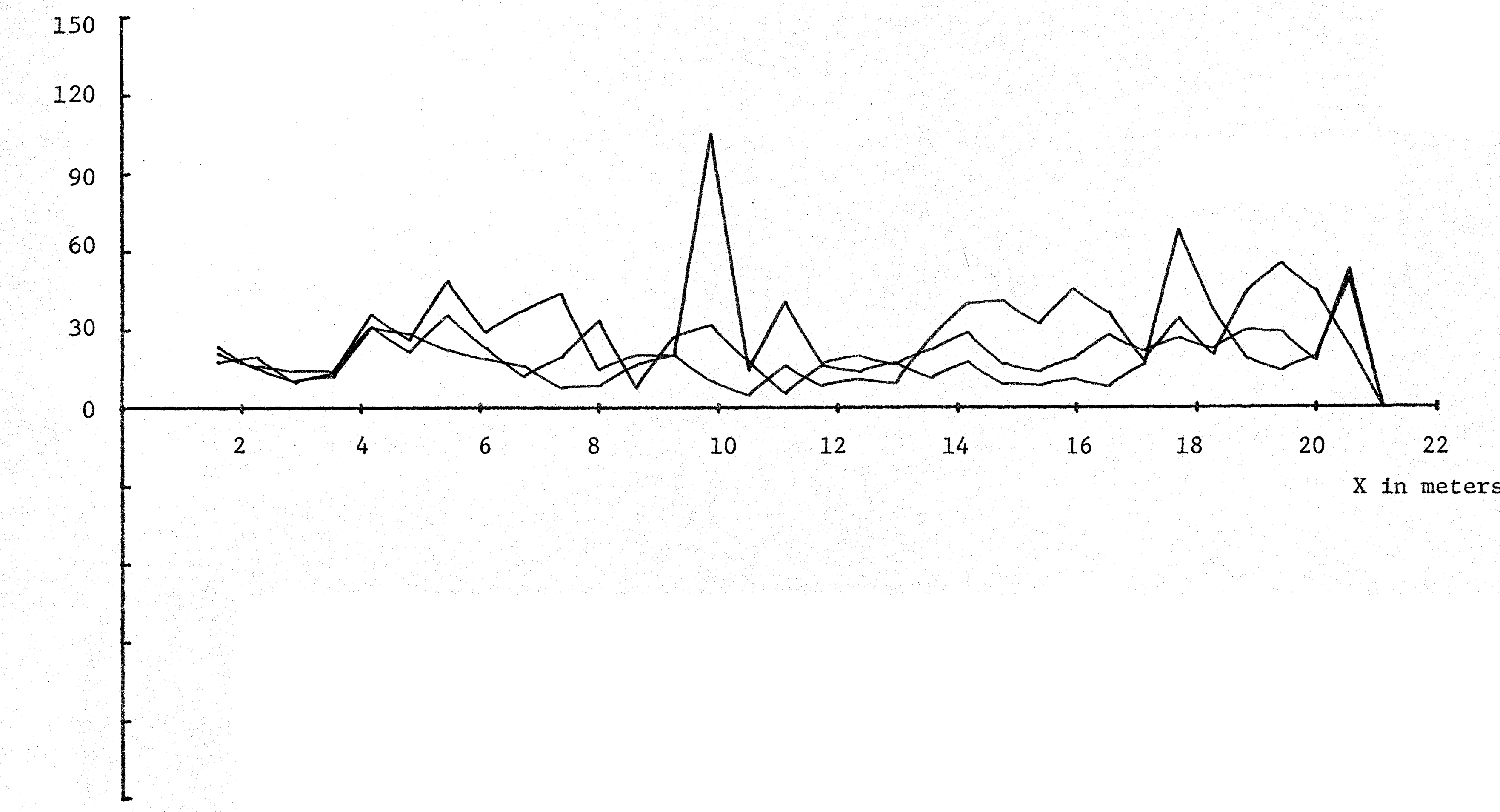


Figure 2.4

THE 140 FOOT SURFACE

The RMS of the angle readings

Radius # 4



NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

June 28, 1978

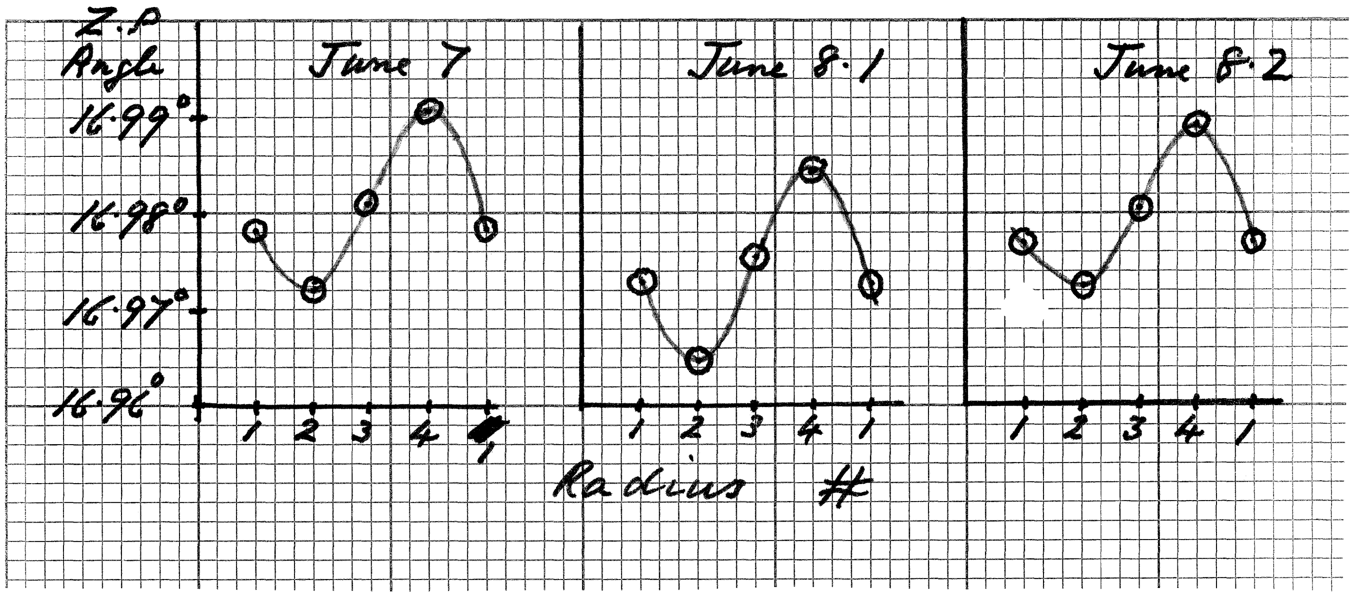
M E M O R A N D U M

To: Those Receiving Engineering Memo No. 124

From: John W. Findlay

Subj: Additional Analysis

1. I left the discussion of the results given in Table 7 of Memo No. 124 with a less-than-complete look at the zero-point angles (see the end of page 3). However, if one plots these angles against the radii for the three runs, one gets:



These results clearly support the suggestion that the dish was set each day at the same tilt. The way of stowing the dish now does this.

2. The best-fit curves to the points are:

June 7 $A = 16.98053+9.285\times10^{-3}\ (\sin\frac{n\pi}{2} + 100°)$

June 8.1 $A = 16.97432+9.975\times10^{-3}\ (\sin\frac{n\pi}{2} + 99°)$

June 8.2 $A = 16.97989+8.520\times10^{-3}\ (\sin\frac{n\pi}{2} + 102°)$

The agreement of amplitude and phase of the tilt is excellent, and says that the mean dish surface was 33 $\pm$ 2 arc seconds away from the local gravity horizontal.

If we leave out June 8.1 (DVM zero errors is possible), we find the mean A for the measuring bar was:

$$A_o = 16.9802° \pm 1 \text{ arc second.}$$

If all this is true, it seems as if our measuring system does have excellent day-to-day stability.

JWF/pj