The Shape of the Acrylic Vessel

R.J. Komar
February 15, 1998

SNO-STR-98-003

1 Summary

This report presents the results of the surveys of the acrylic vessel. The results for the upper half are only summarized here, as the details were previously reported in SNO-STR-97-053. The results for the lower half of the vessel are reported in detail here. As a whole, the vessel was found to be spherical within the design tolerance of $\pm 0.5''$, with an inner radius of $236.38''$.

2 The Upper Half of the Vessel

The results of the survey of the upper half of the acrylic vessel are presented in detail in the SNO internal report SNO-STR-97-053 ("The Shape of the Upper Half of the Acrylic Vessel Prior to Hanging it on Ropes"). As such, only a summary of the results are presented here, and the reader is referred to the above document for more details.

2.1 Description of the Surveying

After the upper half of the acrylic vessel was completed, but prior to its being lifted off the platform and suspended freely on the ropes, targets were placed on the inside surface of all of the panels, and the dome was surveyed. There were generally three targets placed on each panel (at the lower left, middle and upper right areas), with two extra targets placed on the rope groove panels (at the upper left and lower right areas). In addition to these, a target was also placed on the bottom edge of every 102 panel. A total of 231 targets were used to survey the shape of the dome.

The surveying was done in two parts: the 101-106 panels were shot on Nov 28, and the 108-110 and 102 bottoms were shot on Dec 16. A common reference frame was used when comparing and combining the two datasets. The reference frame had its origin at the center of the construction platform, and defined the nominal axis of symmetry of the vessel and PSUP. As a consistency check, the best-fit sphere to each dataset was calculated separately, and compared. The centers differed by $0.048''$, and the spherical radii by $0.015''$, showing that the results were consistent. The two datasets were then combined, and fit as a whole.

2.2 Results of the Surveys

The results of the spherical fit to the whole upper half of the acrylic vessel are shown below:

$$\text{vessel center (x,y,z)} = (0.042, 0.020, 91.550)$$
$$\text{radius} = 236.383$$
$$\text{maximum deviations} = +0.200, -0.233$$

The nominal values are:

$$\text{vessel center (x,y,z)} = (0.0, 0.0, 91.591)$$
$$\text{radius} = 236.43$$

Hence, the best-fit sphere center was found to deviate from the nominal value by $0.06''$, and the spherical radius deviated from the nominal value by $-0.05''$. As the acrylic panels in the upper half of the vessel are slightly thicker than the nominal thickness of $2.17''$, the reduced spherical radius is not undesirable. The variation in the spherical radius of $\pm 0.23''$ was well within the design tolerance of $\pm 0.5''$.

The bottom edge of the upper half of the vessel showed a slight elliptical distortion. The spherical radius varied by $\pm 0.17''$, and the height by $\pm 0.023''$. The major axis of the ellipse was approximately aligned in the East-West direction, and the minor axis in the North-South direction.

3 The Lower Half of the Vessel

The results of the surveys of the lower half of the acrylic vessel are presented here in detail. Unlike the upper half, the lower half of the vessel could not be surveyed in its entirety upon completion. Instead, we have had to rely on the results of partial surveys done after each row of panels was completed. Some details of the construction and surveying work on the lower half are given here as they are relevant for estimating the accuracy of the presented results.

3.1 Construction

After the upper half of the vessel was lifted and hung freely on the ropes, the bottom of the equator was surveyed and the ropes adjusted until the vessel was level to within $\pm 0.020''$. The vessel was built downwards row-by-row, with the panels in each row being aligned, bonded to each other into a ring, and then bonded to the rest of the vessel at each stage. Before setting and aligning each row of panels, the platform was lowered about $10'$ below the bottom edge of the vessel and supported on scaffolding. The panels were supported on a steel jig on the platform during the aligning and bonding processes. The presence of the jig and the upward curvature of the lower part of the vessel made it difficult to access (and thus clean) the inside of the acrylic above the bottom two rows of panels. Hence, it was decided that a final cleaning of the row next to the bottom would be done prior to lowering the platform at the end of each stage, and that the cleaned panels would be protected by a tarp during the construction of the rest of the vessel below.

For quality bonds, the gaps between the panels into which the bonding syrup was poured had to be a width of $0.125'' \pm 0.063''$. This, in effect, constrained the panels to be positioned within $\sim 0.15''$ of the nominal spherical radius and to within $\sim 0.10''$ of the nominal height.

The variation in height and radius between adjacent panels was usually much less than this ($\leq 0.08''$), to ensure that the panels overlapped well. Thus, the bonding process forced the alignment of the panels to be well within the $\pm 0.5''$ tolerance specified by considerations of the overall vessel strength.

The final shape of the vessel is determined, not only by the original alignment of the panels prior to bonding, but also by deformation caused by mild internal stresses set up during the bonding process. Such a deformation was noticed when the upper half of the vessel was lifted off the supporting jig and hung freely on the ropes. The elliptical deformation of the equator had increased such that the spherical radius varied by $\pm 0.54''$, and the height by $\pm 0.09''$. The major axis of the ellipse was still in the East-West direction. As it was impossible to keep the bond gaps and overlaps between panels on the lower half within the tolerances with such a large distortion, the vessel was brought back into round during the aligning and bonding processes. This was accomplished during alignment with two sets of ropes and suction cups along the major axis of the vessel, each pulling with a force of less than 300 lbs (the force required to pop the suction cup free). During bonding, the extension arms on the jig that held the panels were used to make the vessel rounder.

3.2 Surveying

The method of construction of the lower half of the vessel introduced the following constraints for the surveying:

i) because of the problem of accessibility, surveying targets were only placed on the two bottom rows of panels, and the ones on the higher of the two rows were removed when the panels were cleaned prior to lowering the platform. To make cleaning easier, only one target was placed on the face of each accessible panel (although many were placed temporarily on the dirty bottom edge of the vessel during surveying, as described below). This meant that a complete survey of the bottom half of the vessel could not be done as for the upper half (there would also be a problem with setting up the theodolites within the vessel for such a job).

ii) when the ropes or extension arms that were used to make the vessel rounder were removed, the elliptical distortion would return to some lesser degree (as shown below). The final survey of each row was done with the ropes and extension arms removed, so the elliptical distortion is visible in the results. However, as the bonding of subsequent rows probably further reduced the distortion of the vessel, the results of the final survey for each row can't be said to represent the positions of those panels on vessel completion. Rather, it is more likely that the survey results provide upper estimates of the deviation of the final radius from the nominal value at each target location.

iii) when the platform was lowered at the end of each stage, its new absolute position was only known to an accuracy of a few inches. Thus, the center of the platform could no longer be used to define the nominal center of the vessel as it was for the upper half. Instead, the nominal sphere center had to be defined at each stage using the accessible portion of the vessel, itself. This was done by surveying the bottom edge of the vessel, fitting those points with a circle, and translating upward from the circle center the nominal distance to the sphere center. As a check, an alternate method was used to estimate the sphere center in two of the jobs. The coordinates of the 103 targets were determined in the sphere center

Table 1: Average Spherical Radius and Maximum Deviations

Row	Avg. Rad. (in)	Max. Pos. Dev. (in)	Max. Neg. Dev (in)
101	235.063	0.361	-0.432
103	236.367	0.265	-0.292
105	236.310	0.188	-0.216
107	236.318	0.169	-0.144
103-107	236.331	0.301	-0.256

frame of the 101/103 survey job (Mar 23, 1997). The coordinate frame that best reproduced these old target coordinates in the new 103/105 job was used to estimate the position of the sphere center in the latter job. The two sphere centers got with the different methods differed by only 0.063″. Likewise, using the old coordinates of the 105 targets to estimate the alternate sphere center in the 105/107 job produced a difference of 0.056″ between the two sphere centers. Thus, the method used to estimate the sphere center is accurate enough for the present measurements.

iv) the 107 row was the last to be surveyed using the theodolites. Once the 109 panels were in position, there wasn't enough room to set up the theodolites in the hole in the vessel left for the bottom plug. Instead, the bond gaps, overlaps and circularity of the hole for the bottom plug were used to determine when the panels were in position. As a final check, the distance from the top of the chimney to the vessel bottom was measured and compared to the nominal distance to deduce the spherical radius at which the plug was set.

3.3 Surveying Results for the 101, 103, 105 and 107 Rows

Figure 1 shows the spherical radius of the 101 panels after the 103 panels were bonded beneath them. The spherical radius of the target near the middle of each panel in the 103 and the 105 rows is also shown in Figures 2 and 3, respectively. In the latter two cases, the results before and after the subsequent row was added are shown, indicating how the vessel improved its shape between each set of readings. Figure 4 only shows the spherical radius of the 107 row before the 109 panels were added, since there are no survey results following that job.

Table 1 shows the average spherical radius and the maximum deviations based on the last survey for each row, as well as the results for the combined 103-107 rows. The average radius for the 101 panels is smaller than for the other panels because the targets were placed on the thick portions of the rope groove panels. The numbers indicate that the deviations from sphericity decreased with each new row. What is not known is whether the deviations for the higher rows decreased later as the lower rows were added. The before and after data for the 103 and 105 rows indicate that this is likely, but to an unknown degree. So, it seems best to treat the last surveyed positions as maximum deviations from sphericity rather than the final coordinates for the panels.

For reference, the target coordinates given in the sphere center frame for all three survey jobs are tabulated in the Appendices to this report.

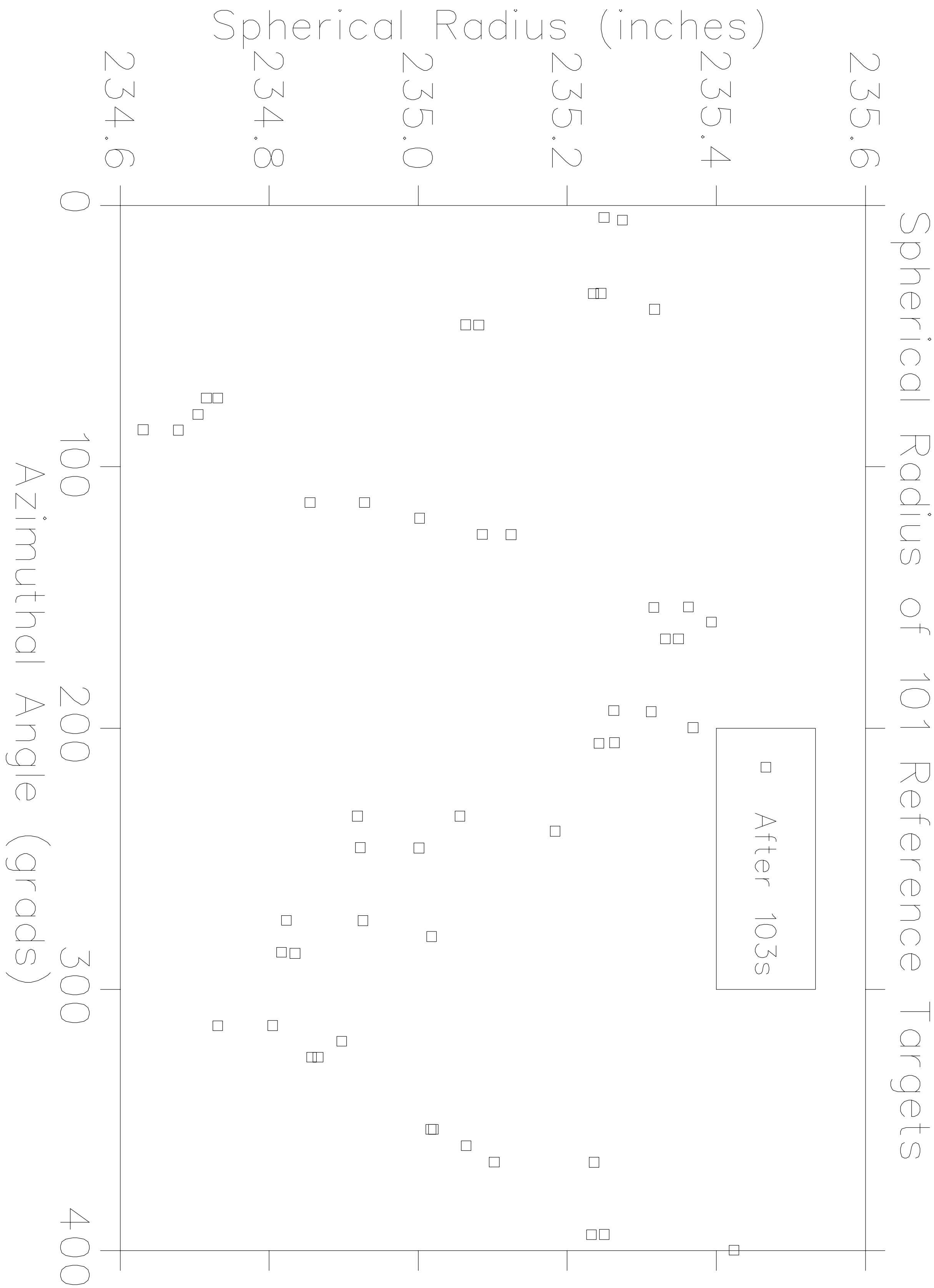

Figure 1: Spherical Radius of the 101 Panels.

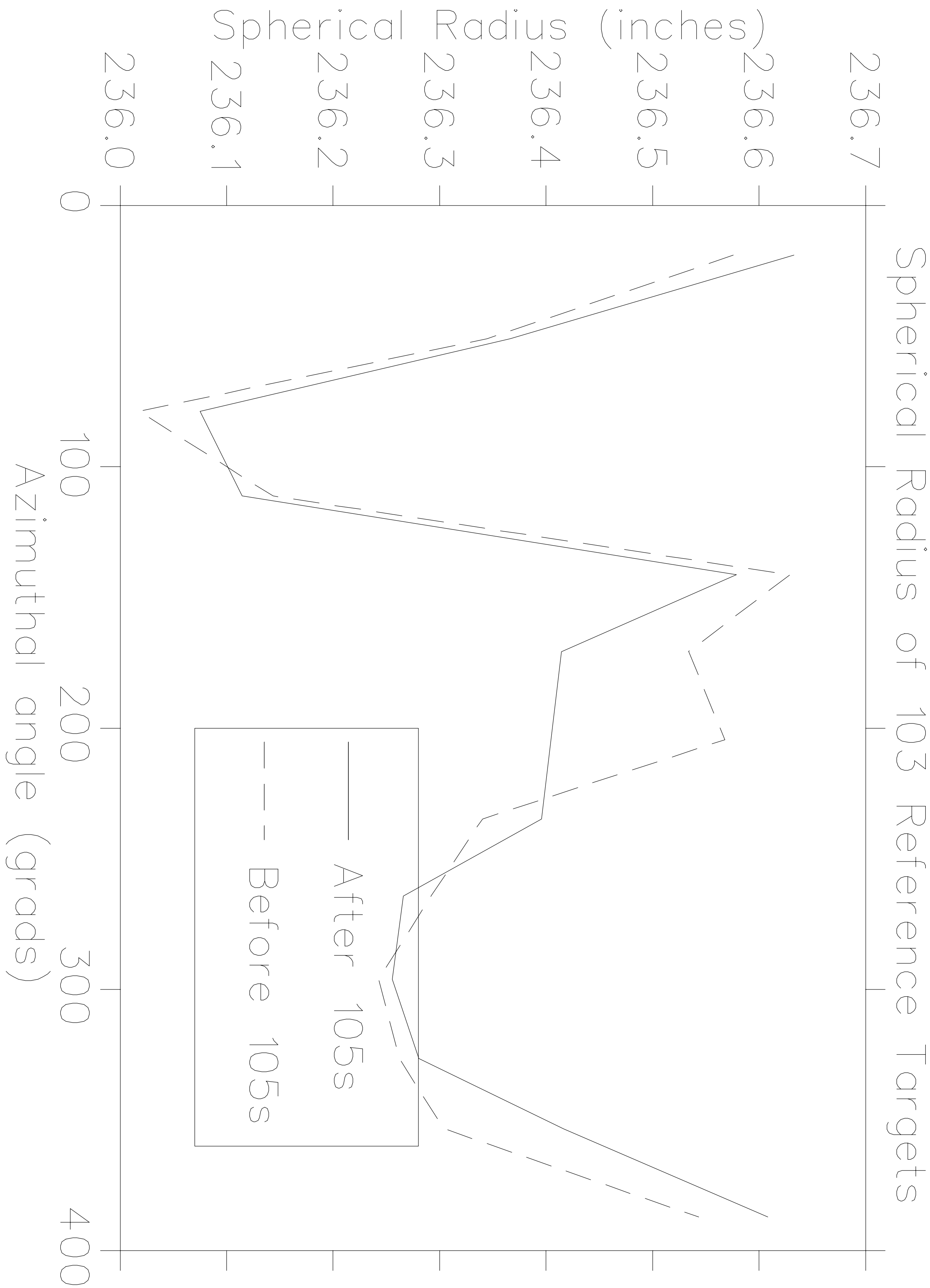

Figure 2: Spherical Radius of the 103 Panels.

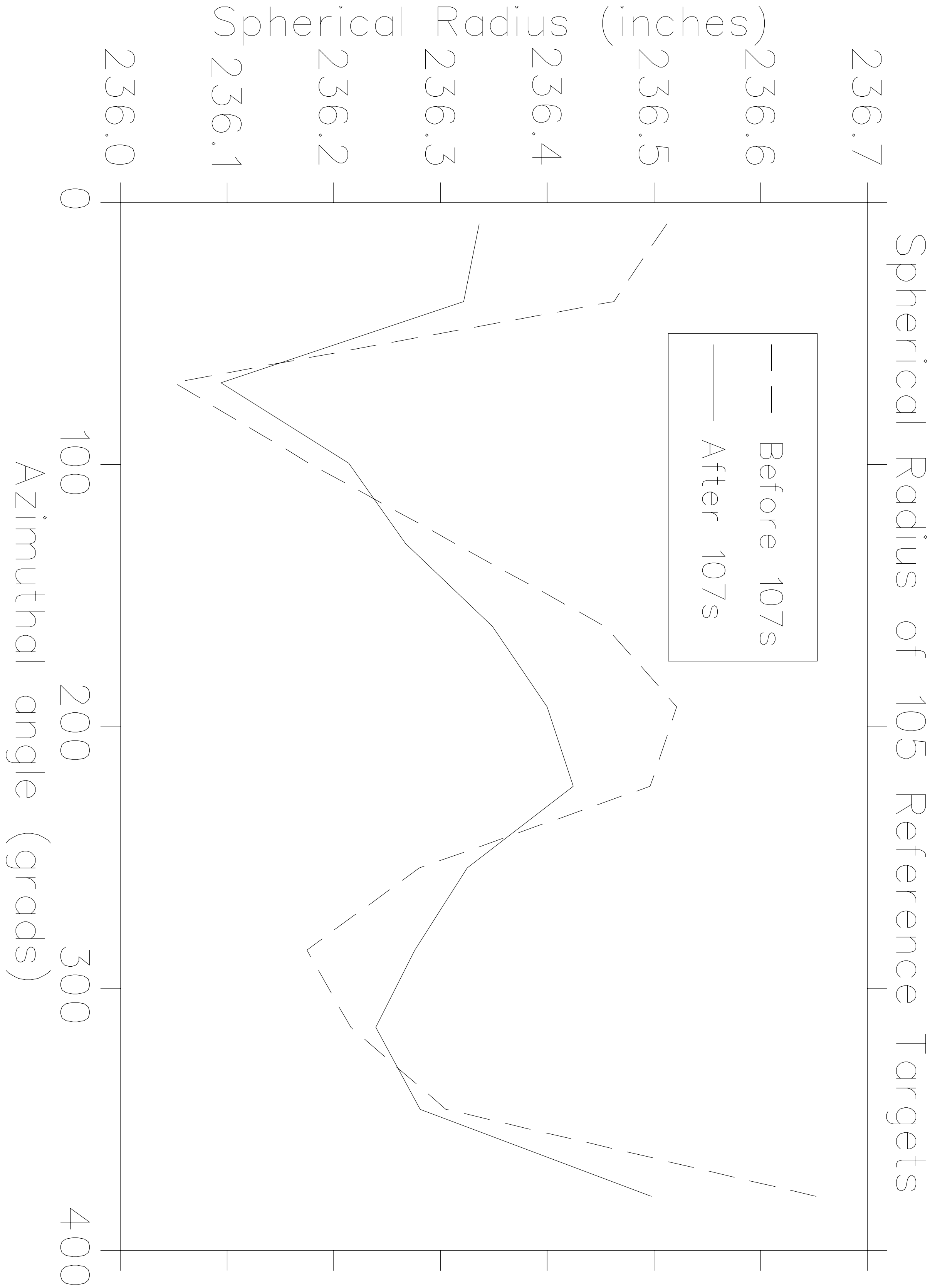

Figure 3: Spherical Radius of the 105 Panels.

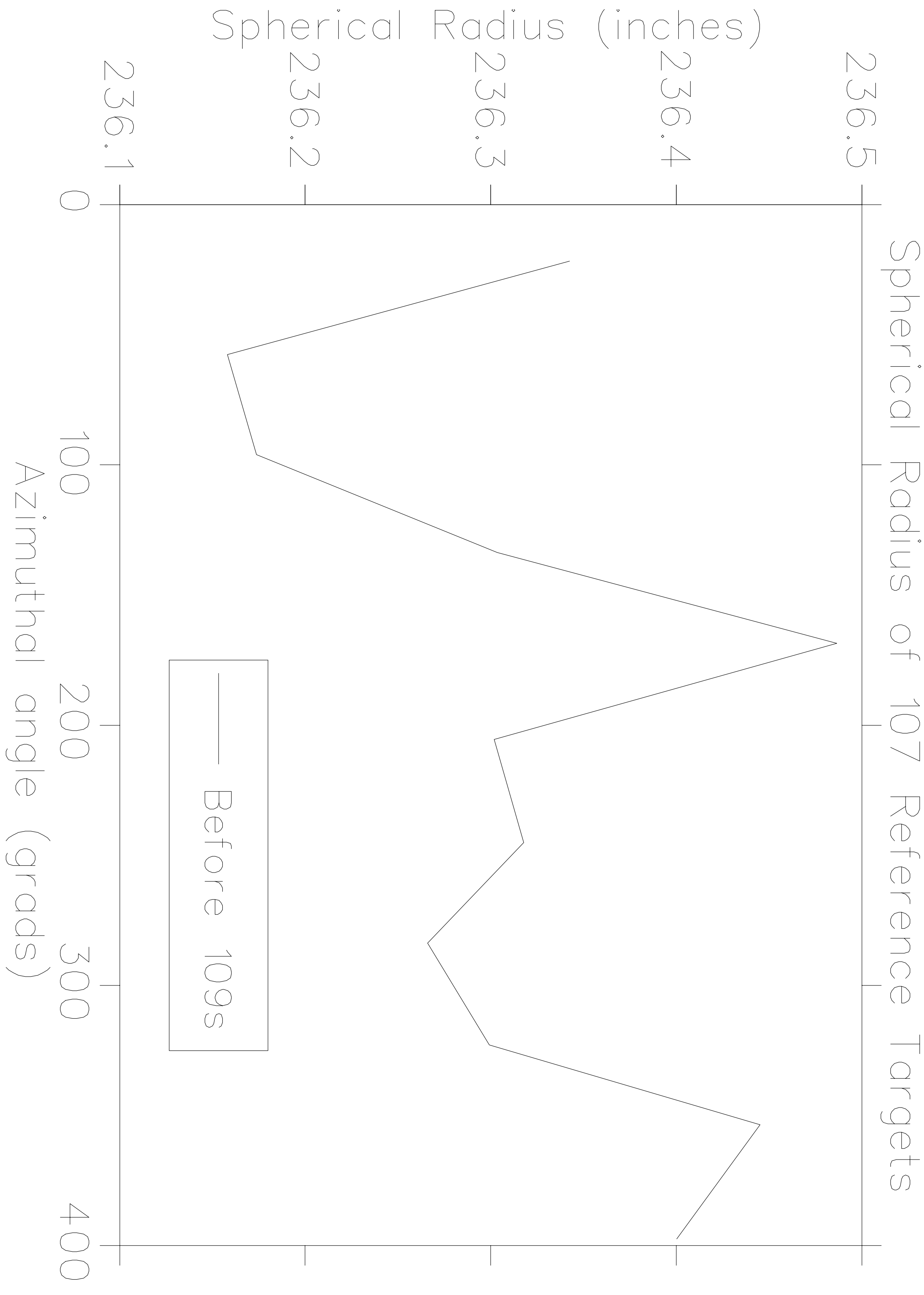

Figure 4: Spherical Radius of the 107 Panels.

3.4 Spherical Radius of the Bottom Plug

On Jan 12, 1998, the distance from the top of the chimney to the bottom of the vessel was measured with a steel tape to be $742.59'' \pm 0.05''$. The nominal distance can be calculated based on previous measurements of the distance from the top of the chimney to the center of the vessel. On Mar 23, 1997, when the 101/103 final survey was shot, a steel tape was lowered from the top of the chimney into the vessel. A point on the steel tape inside the vessel was shot using the calibrated surveying system, thus determining its height relative to the bottom of the 103 panels as $26.253''$. That point on the tape was $574.173''$ below the top of the chimney. Given that the nominal distance from the bottom of the 103 panels to the center of the vessel is $94.3''$, that put the center of the vessel a distance of $506.126''$ below the top of the chimney. A pair of similar measurements relative to the bottom of the 107 panels (taken on Aug 8 and Aug 17, 1997) yielded distances of $506.285''$ and $506.059''$, respectively. Based on these three sets of measurements, the center of the vessel is estimated to be $506.16'' \pm 0.12''$ below the top of the chimney. Adding the nominal inside radius of the vessel ($236.43''$) to the distance from the top of the chimney to the center of the vessel yields an expected distance of $742.59'' \pm 0.12''$ from the top of the chimney to the bottom of the vessel. That is exactly equal to the result measured on Jan 12, 1998, indicating that the 109 panels and bottom plug are in the correct position relative to the rest of the bottom of the vessel.

4 Conclusions

Prior to hanging it on ropes, the upper half of the acrylic vessel was seen to be spherical, with a radius of $236.38 \pm 0.23''$. When hung freely on the ropes, an elliptical distortion of $\pm 0.54''$ in the spherical radius became apparent in the equatorial region of the vessel. As it was impossible to keep the bond gaps and overlaps between panels on the lower half within the tolerances with such a large distortion, the vessel was brought back into round during the aligning and bonding processes. When allowed to hang free after each new row was added, the distortion would reappear, but to a lesser extent each time. Since the higher rows could not be re-surveyed after the lower rows were added, the final shape of the vessel is not precisely known. However, the results of the last survey for each row probably provide upper extimates of the deviation from sphericity. Combining the results for the lower half of the vessel (including the 109 panels and the bottom plug), the average spherical radius was seen to be close to the value of $236.38''$ obtained for the upper half of the vessel. The deviations from sphericity in the lower half were at most $\pm 0.30''$, and were likely to be less at the completion of the vessel. For the upper half of the vessel, only the 101 panels were surveyed after the 103 row was bonded on. At that time, the largest deviation from sphericity was $0.43''$. It is likely that the deviations are smaller with the completion of the lower half of the vessel, and will certainly be less than the design tolerance of $\pm 0.5''$.

5 Appendix A

Measure
EVENT SUMMARY

Job Name: 970323-2 101/103 ROW
Date: 98/02/15
Operator: robk

Job Comments:
Survey of the 101/103 panels taken on Mar 23, 1997.
The sphere center was got by fitting a circle to the bottom of the
103 panels, and translating upwards the nominal distance from the
circle center.

JOB SUMMARY

VALUES SHOWN IN: R Hand Inch Grads

Event No.	CS No.	X	Y	Z	POINTING ERROR	APEX ANGLE	EVENT NAME
Polar		234.9279	86.3514	106.0827			
22	3	228.5025	-49.7535	-22.4125	0.0025	0.00	101-04-LL
Polar		235.1247	74.0690	106.0820			
23	3	214.9034	-92.7206	-22.4286	0.0011		101-04-LR
Polar		235.0018	80.2698	98.7665			
24	3	223.7637	-71.6583	4.5532	0.0003	0.00	101-04-M
Polar		234.8548	86.2912	94.0001			
25	3	228.4125	-49.9602	22.1013	0.0012	0.00	101-04-UL
Polar		235.0859	74.1555	94.0263			
26	3	215.0285	-92.4281	22.0269	0.0015		101-04-UR
Polar		235.3161	46.1608	105.8860			
27	3	155.3963	-175.3673	-21.7256	0.0006		101-02-LL
Polar		235.3491	34.1107	106.1523			
28	3	119.5938	-201.4220	-22.7088	0.0004		101-02-LR
Polar		235.3935	40.5695	98.8868			

29	3	140.0375	-189.1631	4.1158	0.0007	101-02-M
	Polar	235.3627	46.3193	93.9084		
30	3	155.8157	-174.9612	22.4868	0.0004	101-02-UL
	Polar	235.3318	34.1484	93.9965		
31	3	119.7312	-201.3814	22.1594	0.0007	101-02-UR
	Polar	235.2625	6.6787	106.3510		
32	3	24.5133	-232.8057	-23.4313	0.0007	101-05-LL
	Polar	235.2426	-5.7895	105.9111		
33	3	-21.2719	-233.2614	-21.8114	0.0009	101-05-LR
	Polar	235.3688	0.1780	99.7851		
34	3	0.6582	-235.3665	0.7947	0.0015	101-05-M
	Polar	235.3126	6.2988	93.9757		
35	3	23.1400	-233.1141	22.2342	0.0011	101-05-UL
	Polar	235.2633	-5.5373	93.9353		
36	3	-20.3447	-233.3112	22.3783	0.0013	101-05-UR
	Polar	234.9184	-33.6647	106.0945		
37	3	-117.9738	-201.9026	-22.4548	0.0011	101-09-LL
	Polar	234.9221	-45.7502	106.1282		
38	3	-153.9482	-176.0073	-22.5790	0.0014	101-09-LR
	Polar	235.1837	-39.4318	98.8217		
39	3	-136.5105	-191.4610	4.3526	0.0012	101-09-M
	Polar	235.0560	-33.6946	93.8485		
40	3	-118.1276	-201.9478	22.6777	0.0017	101-09-UL
	Polar	235.0011	-45.9061	94.0087		
41	3	-154.4623	-175.7249	22.0837	0.0019	101-09-UR
	Polar	234.8229	-73.5349	106.1549		
42	3	-213.8195	-94.3886	-22.6676	0.0019	101-08-LL
	Polar	234.8164	-85.7693	106.1058		
43	3	-227.9218	-51.8146	-22.4866	0.0019	101-08-LR
	Polar	235.0178	-79.7238	99.2145		

44	3	-223.1810	-73.5881	2.8997	0.0022		101-08-M
Polar		234.9259	-73.6444	93.9625			
45	3	-214.1134	-94.0784	22.2463	0.0024		101-08-UL
Polar		234.8347	-86.1877	93.6633			
46	3	-228.1940	-50.3015	23.3361	0.0026		101-08-UR
Polar		234.7310	-113.8989	105.9914			
47	3	-228.1448	50.6162	-22.0586	0.0018	0.00	101-01-LL
Polar		234.8568	-125.8931	106.0758			
48	3	-214.7157	92.4879	-22.3803	0.0012		101-01-LR
Polar		234.8973	-119.7737	98.5884			
49	3	-223.6022	71.7750	5.2081	0.0016		101-01-M
Polar		234.8045	-113.7996	93.9020			
50	3	-228.2586	50.2679	22.4568	0.0025	0.00	101-01-UL
Polar		234.8656	-125.8837	93.9685			
51	3	-214.7516	92.4658	22.2183	0.0023		101-01-UR
Polar		235.0203	-153.5051	106.2169			
52	3	-156.0405	174.2436	-22.9146	0.0014		101-03-LL
Polar		235.2359	-166.1730	106.2323			
53	3	-118.6233	201.8311	-22.9922	0.0004		101-03-LR
Polar		235.0642	-159.7805	98.7759			
54	3	-138.7966	189.6583	4.5197	0.0005		101-03-M
Polar		235.0171	-153.5500	93.7739			
55	3	-155.9131	174.3488	22.9477	0.0010		101-03-UL
Polar		235.1021	-166.0652	93.7855			
56	3	-118.9007	201.5206	22.9136	0.0001	81.12	101-03-UR
Polar		235.2497	-193.7612	105.9312			
57	3	-22.9175	233.1056	-21.8858	0.0008		101-10-LL
Polar		235.2741	194.3347	105.9485			
58	3	20.8181	233.3208	-21.9519	0.0013		101-10-LR
Polar		235.4237	-199.7361	98.9655			

59	3	-0.9758	235.3906	3.8254	0.0015		101-10-M
Polar		235.2323	-193.8527	94.0999			
60	3	-22.5818	233.1317	21.7699	0.0006		101-10-UL
Polar		235.2493	195.3670	94.0575			
61	3	17.0307	233.6052	21.9273	0.0006		101-10-UR
Polar		235.2453	166.3163	105.9500			
62	3	118.2240	202.1916	-21.9545	0.0014		101-07-LL
Polar		235.0637	154.3030	105.9409			
63	3	153.9368	176.2914	-21.9043	0.0009		101-07-LR
Polar		235.3173	160.2564	98.6434			
64	3	137.5171	190.8877	5.0140	0.0010		101-07-M
Polar		235.2351	166.2536	93.9888			
65	3	118.4071	202.0480	22.1787	0.0007		101-07-UL
Polar		235.0814	154.2653	94.0258			
66	3	154.0450	176.2048	22.0283	0.0009		101-07-UR
Polar		234.7311	126.3335	106.2736			
67	3	213.8915	93.8923	-23.0942	0.0014		101-06-LL
Polar		234.6309	114.1441	106.1531			
68	3	227.7956	51.4600	-22.6424	0.0013		101-06-LR
Polar		234.7047	120.0094	99.1246			
69	3	223.1856	72.5537	3.2273	0.0006		101-06-M
Polar		234.7157	126.2829	93.9163			
70	3	214.0140	93.7436	22.3961	0.0020		101-06-UL
Polar		234.6782	113.9852	93.7104			
71	3	227.9214	50.8908	23.1478	0.0016		101-06-UR
Polar		236.1436	88.8155	123.1473			
72	3	217.3080	-38.5758	-83.9818	0.0012	0.00	103-12-BM
Polar		236.6288	58.6639	111.5386			
73	3	185.3885	-140.7300	-42.6539	0.0008		103-04-TM
Polar		236.5340	29.3336	117.1576			

74	3	101.3757	-204.2177	-62.9796	0.0022		103-08-M
Polar		236.5676	-4.4287	123.1385			
75	3	-15.3696	-220.5785	-84.1021	0.0012		103-02-BM
Polar		236.3402	-34.7559	112.0152			
76	3	-120.5348	-198.3984	-44.3412	0.0008		103-05-TM
Polar		236.2922	-64.1656	122.8036			
77	3	-187.1532	-118.0893	-82.8409	0.0016	99.09	103-10-BM
Polar		236.2426	-96.1456	111.5393			
78	3	-231.9466	-14.0602	-42.5869	0.0026		103-13A-TM
Polar		236.2621	-126.4453	123.3518			
79	3	-201.7887	89.0025	-84.7328	0.0026		103-11-BM
Polar		236.3041	-153.2887	111.1422			
80	3	-155.8239	172.8161	-41.1475	0.0016		103-07-TM
Polar		236.5436	-187.1078	122.7141			
81	3	-44.5796	217.1171	-82.6176	0.0013		103-01-BM
Polar		236.5760	180.9556	111.8271			
82	3	68.5209	222.1790	-43.6985	0.0015		103-09-TM
Polar		236.3447	149.0145	123.1349			
83	3	158.6060	153.7700	-84.0103	0.0010		103-03-BM
Polar		236.0177	121.2223	112.1187			
84	3	218.9959	75.8344	-44.6575	0.0010		103-06-TM
Polar		236.0282	101.5456	126.1856			
85	3	216.2780	5.2517	-94.3692	0.0015		103-12-BL
Polar		236.3620	74.3597	126.1563			
86	3	199.3523	-84.9335	-94.4031	0.0013		103-12-BR
Polar		236.4406	70.7671	126.1395			
87	3	194.3316	-96.0850	-94.3771	0.0014		103-04-BL
Polar		236.6675	43.4039	126.0864			
88	3	136.7967	-168.5473	-94.2868	0.0011		103-04-BR
Polar		236.7008	39.7101	126.0808			

89	3	126.8152	-176.2281	-94.2807	0.0006		103-08-BL
	Polar	236.5956	12.6453	126.0711			
90	3	42.8266	-212.7642	-94.2058	0.0015		103-08-BR
	Polar	236.5585	8.9059	126.0750			
91	3	30.2568	-214.8721	-94.2044	0.0013	65.36	103-02-BL
	Polar	236.3872	-18.0718	126.1052			
92	3	-60.7174	-208.1137	-94.2391	0.0013		103-02-BR
	Polar	236.3978	-21.3828	126.1031			
93	3	-71.4581	-204.6880	-94.2362	0.0014		103-05-BL
	Polar	236.3208	-48.1729	126.1429			
94	3	-148.7514	-157.5447	-94.3408	0.0010		103-05-BR
	Polar	236.3500	-52.8331	126.1364			
95	3	-159.9022	-146.2680	-94.3306	0.0005		103-10-BL
	Polar	236.3504	-79.0777	126.1733			
96	3	-205.0599	-69.9282	-94.4563	0.0010		103-10-BR
	Polar	236.3370	-83.5278	126.1583			
97	3	-209.4529	-55.4374	-94.3998	0.0020		103-13A-BL
	Polar	236.2500	-110.5427	126.1525			
98	3	-213.6310	35.7051	-94.3451	0.0021	0.00	103-13A-BR
	Polar	236.2248	-114.4475	126.1528			
99	3	-211.0176	48.7278	-94.3364	0.0023	0.00	103-11-BL
	Polar	236.2857	-140.7745	126.1259			
100	3	-173.7243	129.4763	-94.2692	0.0022		103-11-BR
	Polar	236.3106	-145.0842	126.1275			
101	3	-164.5837	140.9446	-94.2844	0.0020		103-07-BL
	Polar	236.5107	-171.9030	126.0890			
102	3	-92.6622	196.1407	-94.2330	0.0028	96.72	103-07-BR
	Polar	236.4963	-176.0371	126.0813			
103	3	-79.7380	201.7388	-94.2010	0.0015	96.78	103-01-BL
	Polar	236.6531	197.5640	126.0600			

104	3	8.3052	216.9419	-94.1910	0.0015	103-01-BR
	Polar	236.6555	194.0186	126.0621		
105	3	20.3676	216.1425	-94.1989	0.0011	103-09-BL
	Polar	236.6755	167.6112	126.0770		
106	3	105.7467	189.6006	-94.2579	0.0009	103-09-BR
	Polar	236.5873	161.9710	126.0832		
107	3	122.0572	179.4260	-94.2439	0.0009	103-03-BL
	Polar	236.1211	135.6967	126.1627		
108	3	183.3144	115.1136	-94.3285	0.0021	103-03-BR
	Polar	236.0673	132.3806	126.1778		
109	3	188.9966	105.3781	-94.3585	0.0011	103-06-BL
	Polar	236.0459	104.9025	126.1992		
110	3	215.6967	16.6435	-94.4224	0.0015	103-06-BR

6 Appendix B

Measure
EVENT SUMMARY

Job Name: 970706 103/105
Date: 98/02/15
Operator: robk

Job Comments:
Survey of the 103/105 panels taken on Jul 6, 1997.
The sphere center was got by fitting a circle to the bottom of the 105 panels, and translating upwards the nominal distance from the circle center.

JOB SUMMARY

VALUES SHOWN IN: R Hand Inch Grads

Event No.	CS No.	X (COORDINATES)	Y	Z	POINTING ERROR	APEX ANGLE	EVENT NAME
	Polar	236.1144	88.8163	123.1438			
10	3	217.2862	-38.5689	-83.9593	0.0012		103-12-BM
	Polar	236.5788	58.6579	111.5418			
11	3	185.3341	-140.7167	-42.6568	0.0008		103-04=TM
	Polar	236.4144	29.3140	117.1654			
12	3	101.2582	-204.1387	-62.9756	0.0015		103-08-M
	Polar	236.3956	-34.7839	112.0055			
13	3	-120.6537	-198.3977	-44.3160	0.0012		103-05-TM
	Polar	236.2659	-64.1909	122.8016			
14	3	-187.1814	-118.0031	-82.8249	0.0000	51.46	103-10-BM
	Polar	236.2557	-96.1802	111.5375			
15	3	-231.9683	-13.9351	-42.5827	0.0015		103-13-TM
	Polar	236.2805	-126.4787	123.3475			
16	3	-201.7629	89.1178	-84.7243	0.0021		103-11-BM
	Polar	236.4167	-153.3141	111.1385			

17	3	-155.8308	172.9625	-41.1535	0.0019	21.97	103-07-TM
Polar		236.6081	-187.1185	122.7091			
18	3	-44.5564	217.1902	-82.6229	0.0003	30.16	103-01-BM
Polar		236.6328	180.9471	111.8241			
19	3	68.5675	222.2252	-43.6982	0.0004		103-09-TM
Polar		236.3660	149.0034	123.1302			
20	3	158.6516	153.7605	-84.0015	0.0008		103-03-BM
Polar		236.0752	121.2195	112.1109			
21	3	219.0577	75.8451	-44.6401	0.0009		103-06-TM
Polar		236.1764	100.6175	137.2631			
22	3	196.8512	1.9094	-130.4809	0.0021	49.37	105-02-M
Polar		236.3133	69.9412	134.1376			
23	3	180.9178	-92.3927	-120.7325	0.0006		105-05-M
Polar		236.4545	38.1894	136.7591			
24	3	111.8471	-163.5294	-129.0701	0.0016		105-09-M
Polar		236.5214	7.6308	138.8722			
25	3	23.1721	-192.3921	-135.6124	0.0006		105-04-M
Polar		236.4965	-22.7430	135.0908			
26	3	-70.4532	-188.7499	-123.8564	0.0002		105-07-M
Polar		236.2800	-53.9495	138.2490			
27	3	-146.0955	-129.0068	-133.5723	0.0015	50.14	105-12-M
Polar		236.1749	-85.2501	134.6260			
28	3	-196.6937	-46.4054	-122.2157	0.0007		105-01-M
Polar		236.2160	-114.8096	137.2308			
29	3	-191.6542	45.4062	-130.4030	0.0019		105-08-M
Polar		236.3051	-146.0476	134.2182			
30	3	-152.1603	134.3499	-120.9854	0.0008		105-10-M
Polar		236.6528	-179.3432	137.3464			
31	3	-62.8335	186.8019	-131.0020	0.0010	32.50	105-06-M
Polar		236.5120	191.8277	133.9805			

32	3	26.0662	201.9373	-120.3320	0.0007		105-03-M
Polar		236.4627	162.2421	136.2643			
33	3	111.2973	165.1162	-127.5309	0.0013		105-13-M
Polar		236.0503	131.2854	135.2483			
34	3	177.0225	94.7470	-124.1200	0.0016		105-11-M
Polar		236.2127	98.0670	143.4195			
35	3	183.2858	-5.5669	-148.9019	0.0016	49.87	105-02-LM
Polar		236.4383	67.1622	143.3695			
36	3	159.7664	-90.5903	-148.8999	0.0009		105-05-LM
Polar		236.5787	36.7302	143.3253			
37	3	100.2994	-154.1105	-148.8605	0.0019		105-09-LM
Polar		236.6290	9.8508	143.3144			
38	3	28.3485	-181.7420	-148.8607	0.0009		105-04-LM
Polar		236.4884	-23.7683	143.3309			
39	3	-67.0359	-171.1302	-148.8201	0.0015		105-07-LM
Polar		236.3696	-52.0661	143.3773			
40	3	-133.9624	-125.5377	-148.8790	0.0002	49.28	105-12-LM
Polar		236.2677	-85.7790	143.4119			
41	3	-178.8733	-40.6355	-148.9144	0.0008	37.56	105-01-LM
Polar		236.2992	-115.5967	143.4003			
42	3	-178.0034	44.5034	-148.9011	0.0004	3.58	105-08-LM
Polar		236.4353	-145.7185	143.3624			
43	3	-138.3138	120.8574	-148.8774	0.0012		105-10-LM
Polar		236.5560	-176.2543	143.3090			
44	3	-67.0130	171.2508	-148.7991	0.0024	34.05	105-06-LM
Polar		236.6348	190.6378	143.2909			
45	3	26.9617	182.0130	-148.7965	0.0018		105-03-LM
Polar		236.4720	160.2105	143.3303			
46	3	107.5312	149.0377	-148.8080	0.0008	39.08	105-13-LM
Polar		236.1404	130.0174	143.4123			

47	3	163.3265	83.2752	-148.8355	0.0013	105-11-LM

7 Appendix C

Measure
EVENT SUMMARY

Job Name: 970817 107-1C
Date: 98/02/15
Operator: robk

Job Comments:
Survey of the 105/107 panels taken on Aug 17, 1997.

The results are presented in the sphere center coordinate frame.
The sphere center was got by fitting a circle to the bottom of the
107 panels, and translating upwards the nominal distance from the
circle center.

JOB SUMMARY

VALUES SHOWN IN: R Hand Inch Grads

Event No.	CS No.	X	Y	Z	POINTING ERROR	APEX ANGLE	EVENT NAME
	Polar	236.2140	100.6237	137.2516			
8	3	196.9058	1.9293	-130.4663	0.0021	66.17	105-02-M
	Polar	236.2672	69.9540	134.1366			
9	3	180.9026	-92.3394	-120.7058	0.0013		105-05-M
	Polar	236.3489	38.1934	136.7720			
10	3	111.7926	-163.4279	-129.0525	0.0007		105-09-M
	Polar	236.3998	7.6206	138.8887			
11	3	23.1250	-192.2619	-135.5929	0.0014		105-04-M
	Polar	236.4243	-22.7641	135.1010			
12	3	-70.4873	-188.6502	-123.8510	0.0051		105-07-M
	Polar	236.3250	-53.9683	138.2412			
13	3	-146.1740	-128.9989	-133.5739	0.0031	34.12	105-12-M
	Polar	236.2761	-85.2413	134.6082			
14	3	-196.8048	-46.4605	-122.2116	0.0025		105-01-M

Polar		236.2393	-114.7789	137.2331			
15	3	-191.6905	45.3172	-130.4229	0.0049		105-08-M
Polar		236.2810	-146.0114	134.2218			
16	3	-152.2161	134.2448	-120.9846	0.0004		105-10-M
Polar		236.4976	-179.3097	137.3700			
17	3	-62.8751	186.6004	-130.9891	0.0001	61.08	105-06-M
Polar		236.3363	191.8377	134.0045			
18	3	26.0093	201.7464	-120.3194	0.0011		105-03-M
Polar		236.3217	162.2273	136.2762			
19	3	111.2559	164.9723	-127.4920	0.0021		105-13-M
Polar		236.0940	131.2720	135.2378			
20	3	177.0933	94.7370	-124.1097	0.0016		105-11-M
Polar		236.1738	103.9083	157.1311			
21	3	147.0086	9.0365	-184.6208	0.0012	64.01	107-04-M
Polar		236.3036	66.3061	150.4911			
22	3	143.1134	-83.7109	-168.3759	0.0010		107-06-M
Polar		236.3020	-5.4153	151.8416			
23	3	-13.7797	-161.6016	-171.8537	0.0014		107-05-M
Polar		236.4866	31.4125	157.0163			
24	3	70.0117	-130.1821	-184.5992	0.0008	62.04	107-01-M
Polar		236.3177	-45.1571	156.9019			
25	3	-96.4216	-112.3329	-184.2017	0.0014		107-03-M
Polar		236.2660	-83.8100	153.8526			
26	3	-151.6170	-39.4113	-176.8634	0.0021		107-02-M
Polar		236.2995	-122.8970	151.7525			
27	3	-152.0336	57.1679	-171.6247	0.0007		107-10-M
Polar		236.4452	-153.6032	157.2765			
28	3	-97.9202	109.6827	-185.1693	0.0007		107-09-M
Polar		236.4003	-197.4132	149.9591			
29	3	-6.7947	167.1296	-167.0527	0.0021	61.65	107-07-M

Polar		236.3424	178.2761	156.5007			
30	3	49.9350	140.6101	-183.2841	0.0013		107-08-M
Polar		236.1581	142.3027	151.6207			
31	3	128.0702	100.3203	-171.1857	0.0033	18.59	107-11-M
Polar		236.2257	114.7281	160.1605			
32	3	134.6812	31.7263	-191.4601	0.0028	57.51	107-04-LL
Polar		236.3128	88.5526	160.1559			
33	3	136.2007	-24.7584	-191.5206	0.0014		107-04-LR
Polar		236.3873	78.4341	160.1320			
34	3	130.6742	-46.0415	-191.5291	0.0019		107-06-LL
Polar		236.4965	52.1692	160.1094			
35	3	101.3454	-94.6641	-191.5682	0.0027		107-06-LR
Polar		236.4919	4.1655	160.0827			
36	3	9.0726	-138.4610	-191.5063	0.0019		107-05-LL
Polar		236.4486	-20.9300	160.0879			
37	3	-44.7885	-131.2873	-191.4826	0.0010		107-05-LR
Polar		236.5610	43.1438	160.0887			
38	3	87.0157	-108.1120	-191.5755	0.0023		107-01-LL
Polar		236.5449	16.6109	160.0913			
39	3	35.7972	-134.0662	-191.5680	0.0005	62.73	107-01-LR
Polar		236.4360	-31.3291	160.0971			
40	3	-65.5260	-122.2249	-191.4926	0.0017		107-03-LL
Polar		236.3778	-60.2895	160.1290			
41	3	-112.4599	-80.9281	-191.5148	0.0039	49.32	107-03-LR
Polar		236.3644	-65.0066	160.1311			
42	3	-118.1301	-72.3732	-191.5085	0.0038	45.61	107-02-LL
Polar		236.2890	-97.3267	160.1455			
43	3	-138.3278	-5.8122	-191.4787	0.0037		107-02-LR
Polar		236.2277	-106.2055	160.1546			
44	3	-137.7297	13.4680	-191.4489	0.0006		107-10-LL

Polar		236.3547	-132.7167	160.1275			
45	3	-120.6467	68.1059	-191.4928	0.0009		107-10-LR
Polar		236.4777	-139.2297	160.1233			
46	3	-113.1296	80.1201	-191.5833	0.0025		107-09-LL
Polar		236.5048	-166.9786	160.0914			
47	3	-68.7801	120.4900	-191.5359	0.0008	64.43	107-09-LR
Polar		236.4973	-177.9348	160.0883			
48	3	-47.1317	130.4936	-191.5229	0.0020	65.78	107-07-LL
Polar		236.5588	195.9645	160.0757			
49	3	8.7936	138.5393	-191.5453	0.0000	66.20	107-07-LR
Polar		236.5130	187.9075	160.0778			
50	3	26.2038	136.2889	-191.5127	0.0023		107-08-LL
Polar		236.4394	160.1504	160.1018			
51	3	81.2426	112.3782	-191.5056	0.0021		107-08-LR
Polar		236.4212	152.3846	160.1097			
52	3	94.2900	101.6321	-191.5079	0.0056		107-11-LL
Polar		236.2175	123.1192	160.1477			
53	3	129.3750	49.1637	-191.4256	0.0018		107-11-LR