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Hubble Space Telescope Secondary Mirror Vertex Radius/Conic Constant Test

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Hubble Space Telescope Secondary Mirror
Vertex Radius/Conic Constant Test
(Backup Secondary S/N 003)

Executive Summary

The Hubble Space Telescope (HST) backup secondary mirror was tested at the University of Arizona Optical Sciences Center (OSC) Large Optical Shop on December 28-29, 1990 to determine the vertex radius and conic constant. The tests were performed according to procedures submitted to and approved by MSFC and other interested NASA centers. Three completely independent tests (to the same procedure) were performed. Similar measurements in the three tests were highly consistent. The values obtained for the vertex radius and conic constant were the nominal design values within the error bars associated with the tests. Visual examination of the interferometric data did not show any measurable zonal figure error in the secondary mirror.

Introduction and Background

Although all evidence to date indicates that the imaging error in the HST is due to the incorrect conic constant on the primary mirror, it seemed prudent to perform a test on the backup HST secondary mirror to see if it was figured to the correct radius and conic constant. Because the backup secondary mirror was polished and tested concurrently with the flight secondary by the same personnel, there is good reason to believe the global characteristics (vertex radius and conic constant) of the backup mirror are within fabrication tolerances of being the same. On the other hand, because every optic is an individual work of a highly skilled craftsman, there is no reason to believe that the fine scale surface structure on the two mirrors is the same.

As a result of these considerations, it was proposed to test the backup secondary to see if the vertex radius and conic constant were the nominal design values. The test most easily performed was the traditional Hindle test using a large, fast sphere to autoreflect the test beam back to an interferometer. Although this test was easy to perform using existing test equipment at OSC, it had 2 regrets; only 85% of the on-axis aperture of the secondary could be viewed, and the long optical path required for this test meant that the interferometric data would be "noisy" due to atmospheric turbulence and vibration. These regrets are minor within the objectives of the test to determine the radius and conic constant.

The test actually performed by Perkin Elmer (now Hughes-Danbury Optical Systems) at the time of the manufacture of the secondaries was a better test than the one now being reported on in the sense that the full clear aperture of the mirror could be seen, and the unequal optical path was very short so there was little noise due to turbulence and vibration. The test performed at Optical Sciences had the advantage, however, that it was done with different test equipment and in a fundamentally different manner than the original test and thus provided a completely independent check on the original test.

In the following sections of this report, we will go over the details of the tests and the test data. We begin by describing where the test was performed and by whom it was witnessed. This is followed by a description of the principles of the test. Then the raw data from the 3 individual tests is given. An analysis is made of the systematic and statistical errors in the data and then the values are given for the vertex radius and conic constant. This is followed by an analysis of the interferometric figure error data for third order spherical aberration.

Details of the HST Secondary Mirror Tests

Comments on the test environment

The tests were conducted in the Large Optics Shop at the Optical Sciences Center, University of Arizona in Tucson. The room is about 10 × 40 meters with an 8-meter ceiling height. The room is below ground and has a laminar air flow system. These circumstances makes the room exceptionally free of vibration and the temperature is generally constant to half a degree fahrenheit over days at a time.

Overall test layout

All the test hardware was assembled on a 4 × 20 foot Newport table with the exception of the 60-in. Hindle sphere and the 6-in. fold flat (a list of test equipment used appears in Appendix A). The Newport table, Hindle sphere and fold flat stand were all grounded (not floating) to the shop floor so there would be no relative movement between parts of the test set up. A schematic layout of the test set up is shown in Fig. 1.

Temporal sequence of the tests and calibrations

The actual test was run 3 times "for real," plus once prior to this to be sure of alignment of all components and to find out if there were any hidden surprises. Then a partial test at the end was run, with the secondary rotated 90° in its cell, to see if there were any errors attributable to mounting distortion of the secondary. In the first and the subsequent "for real" tests, every piece of test equipment was moved from its position in the previous test and repositioned following the written procedures. The measuring rods used to set up the test conjugate positions were calibrated both before the tests were run and again after doing the 3 tests. The interferometer/diverger pairs and the Hindle sphere were each calibrated just once following the tests of the secondary. The calibration data in these tests was consistent with similar data taken for other previous tests in the shop.

Witnesses to the testing

The following individuals witnessed some or all of the testing reported on here. All witnessed at least one of the "for real" tests. Only Amanda Harris, Richard Sumner, and Lian Zhen Shao witnessed the interferometric test data taking in order to minimize the disturbance to the test environment.

Tom Dubos	HDOS	Henry Garrett	JPL
Howard Hall	HDOS	Lian-Zhen Shao	TORC
Amanda Harris	MSFC	Richard Sumner	OSC
Danny Johnston	MSFC	George Lawrence	OSC
Edward Motts	JPL	Robert Parks	OSC

Explanation of the principles of the test

The vertex radius and conic constant of a perfect hyperbolic secondary mirror can be calculated from the object and image conjugates as shown in Fig. 2. A perfect hyperboloid will perfectly image an on-axis object at the short conjugate into the focal plane of the long conjugate. Knowing the long and short conjugate distances from the secondary vertex allows one to calculate the vertex radius and conic constant exactly, assuming a perfect hyperbolic figure.

In general, the figure will not be perfect so we adopted the following strategy. A distance equal to the design value of the sum of the long and short conjugates was established. The secondary mirror was inserted between the two conjugates near its nominally correct position. The secondary was then adjusted along the axis defined by the conjugates until it autoreflected to the previously set long conjugate.

At this point the vertex radius and a provisional conic constant were calculated as shown below. Error bars associated with the measurements of the conjugates were also applied to the values of the radius and conic constant. Any residual third order spherical aberration found in the interferometric test data could then be added to (or subtracted from) the provisional conic constant to give the apparent conic constant. The actual test procedure followed in the tests is given in Appendix B.

Conjugate test data

Because a distance equal to the sum of the long and short conjugates was established prior to inserting the secondary mirror, this number (6687.847 mm) is constant for all three tests and has an associated error (0.628 mm) as derived in the error analysis in Appendix C. Once the secondary mirror was inserted in the test and moved axially to obtain the best visual focus at the long conjugate, a value of the short conjugate distance was obtained for each of the 3 tests. These values were:

	Short conjugate distance
Test #1	611.059 mm
Test #2	611.033 mm
Test #3	611.059 mm
Average Value	611.050 mm ± 0.015 mm

with the scatter in measured data much less than the systematic error estimated in the error analysis in Appendix C.

Using the derivation for vertex radius and conic constant given in Appendix C along with the estimated errors of the conjugate measurements, we find:

	Measured	Design
Vertex radius	1358.726 ± 0.257 mm	1358.0 mm
Conic constant	-1.49718 ± 0.00012	-1.49686

Interferometric data analysis

In this section we discuss the analysis of the interferometric data taken of the secondary mirror. This data was taken with two purposes in mind. First, if there was residual spherical aberration in the figure of the secondary, this could be scaled and added to the conic constant derived from the conjugate data. Second, if there was a significant amount of astigmatism in the test results, it might indicate that the secondary mirror was being distorted in its cell and thus the measurements of the conjugates might be affected by the distortion. We will treat each of these cases separately.

Test error sources

In trying to determine if there was any residual spherical aberration in the secondary mirror to the level of 0.01λ rms, it was necessary to be sure there was no residual spherical in any of the test optics. This made it necessary to calibrate the interferometer with each of the divergers used during the tests as well as calibrating the Hindle sphere. These wavefront errors then had to be subtracted out of the Hindle test data before making a determination of residual spherical in the secondary.

Because the errors we were looking for were quite small and the interferometric data somewhat noisy because of the long optical path of the test, we only did the analysis on the third order spherical aberration (or the 8th Zernike coefficient). For the mounting error part of the analysis, we used just the 2 Zernike astigmatism coefficients, c_4 and c_5. In all cases referred to here, we are using the full aperture Zernike coefficients (ones that do not take into account the central obscuration) because the raw data was reduced by drawing fringes right through the central obstruction.

Method of calibration — interferometer/diverger

The method of calibrating the interferometer and diverger is outlined at the beginning of the Procedure and data sheet contained in Appendix D. This calibration must be done for each of the 2 divergers used in the tests. The actual Hindle test was done with an f/15 diverger because the f/number of the long conjugate is very slow, about f/25. The Hindle sphere however is reasonably fast and was tested using an f/2.5 diverger.

Once the calibration is complete, average values for the residual astigmatism and spherical aberration Zernike coefficients of the interferometer/diverger are obtained. These errors are units of waves of surface error expressed as Zernike coefficients. Since about 25 interferograms are made during the calibration, the average values of the coefficients have associated variances that indicate the noise in the measurement.

Method of calibrating the Hindle sphere

The Hindle sphere is calibrated by making a series of interferograms of the surface error in the sphere. The residual errors in the fast interferometer/diverger are then subtracted, leaving just the errors in the Hindle sphere. Again, averaging of the interferograms gives variances for an indication of noise in the test.

Correcting the Hindle test data

A series of about 10 interferograms were taken during each of the 3 Hindle tests. The surface error Zernike coefficients of these groups of interferograms were averaged and saved in 3 separate files. First the errors in the slow interferometer/diverger and then the errors (astigmatism and spherical aberration) in the Hindle sphere were subtracted from each set of data separately to yield the error just in the Hindle test alone, that is, in the secondary. These values were then divided by 2, because the secondary surface errors affect the wavefront twice. The final value gives the secondary mirror surface error expressed in terms of Zernike coefficients.

Outline of data treatment

The procedure described above was applied to the data for each of the 3 tests as shown on the data sheets in Appendix E. To give a feel for the operation in a more concise form, we provide a line by line outline similar to a tax form.

1. Hindle sphere surface error data
2. Fast interferometer/diverger data expressed as surface error
3. Line 1) minus line 2) - Pure Hindle sphere surface error
4. Hindle test data expressed as surface error (WF divided by 2). Slow interferometer/diverger data expressed as surface error
6. Line 4) minus line 5) - Pure Hindle test surface error
7. Line 6) minus line 3) - Pure secondary mirror wavefront error
8. Line 7) divided by 2 - Secondary mirror surface error

Results of the tests

The data from the three Hindle tests were averaged to find the magnitude of the astigmatism and spherical aberration in the secondary mirror. The third-order spherical aberration amounted to 0.028λ peak-to-valley $\pm$0.026λ or 0.009λ rms at λ = 0.633 μm. This can also be expressed as a change in the conic constant of ΔK = -0.008 $\pm$ 0.008. This would make the measured value of the conic constant using the conjugate plus interferometric data to be K = -1.505 $\pm$ 0.008.

We feel the spherical aberration results are realistic because of the consistency with the astigmatism results. If the values of the astigmatism coefficients for the 3 tests are averaged, we find c_4 = 0.018 $\pm$ 0.079 and c_5 = 0.042 $\pm$ 0.084 or there was astigmatism with a magnitude of 0.092 $\pm$

0.230λ peak-to-valley with an orientation of 23.2° above the x-axis. This is the residual astigmatism in the secondary mirror after subtracting about 4 times this much astigmatism due to the Hindle sphere.

As a check on the procedure, the secondary was rotated 90° clockwise in its cell (when viewed from the mirrored surface side) and another set of interferograms were taken. When this data was reduced, the residual astigmatism in the secondary was 0.092 ± 0.252λ peak-to-valley oriented at 57.3° above the x-axis. The magnitudes of the error agree identically (as they should if the Hindle sphere astigmatism error was being subtracted correctly and the cell was not influencing the secondary mirror shape). The angle also agrees within 10° of what it should when the left-to-right image flip is taken into account when the mirror is rotated the 90°. Given the noisy nature of the data, the consistency is remarkable and gives one confidence in the data-reduction method.

Alternative method of treating the interferometric data

If one is more interested in analyzing the results of the interferometric testing in a manner that matches the drawing specification for the secondary mirror, then we can approach the data in the following way. Since the errors in the secondary mirror and the test optics are considered in an rms or lump-sum sense, we will add (or subtract) the errors quadratically and in all cases, add the variances quadratically.

The actual data are dealt with in Appendix F. Our approach was to add quadratically the interferometer calibration errors to those of the Hindle sphere and Hindle test data. We then subtracted (quadratically) the Hindle sphere from the Hindle test data for each of the 3 tests. When these data were averaged and divided by 2 to account for the double-pass nature of the Hindle test, we find our original figures for R_v and K, i.e., 1358.714 mm and -1.49716 with a residual rms surface error on the secondary of 0.043 ± 0.14λ at 633 nm.

This value of rms surface error is consistent with the astigmatism and spherical aberration values found above and is typical of the magnitude of error obtained when testing large optics over air paths of 10s of meters. This is not to say the error could not be reduced by more care and more data. Recall, hoever, that the test originally done by Perkin-Elmer was the test designed to give the least error due to the environment. Also, we do not know the definite pedigree of the back up mirror to the flight version.

Conclusion

The backup secondary mirror was tested using the traditional Hindle test and found to match the nominal design within the errors of the test. The mean value of the test data showed overcorrection by a ΔK of -0.008 $\pm$ 0.008.

The test did not turn up any surprises and leads on to conclude that the original test was correctly performed within the originally established error budget. Although this retest gave a mean value of K indicating a small overcorrection, the error bars associated with this test and the lack of a good pedigree with the flight mirror indicate that fossil data for the flight mirror should be the primary source of data used in any attempt to correct the errors in the HST.

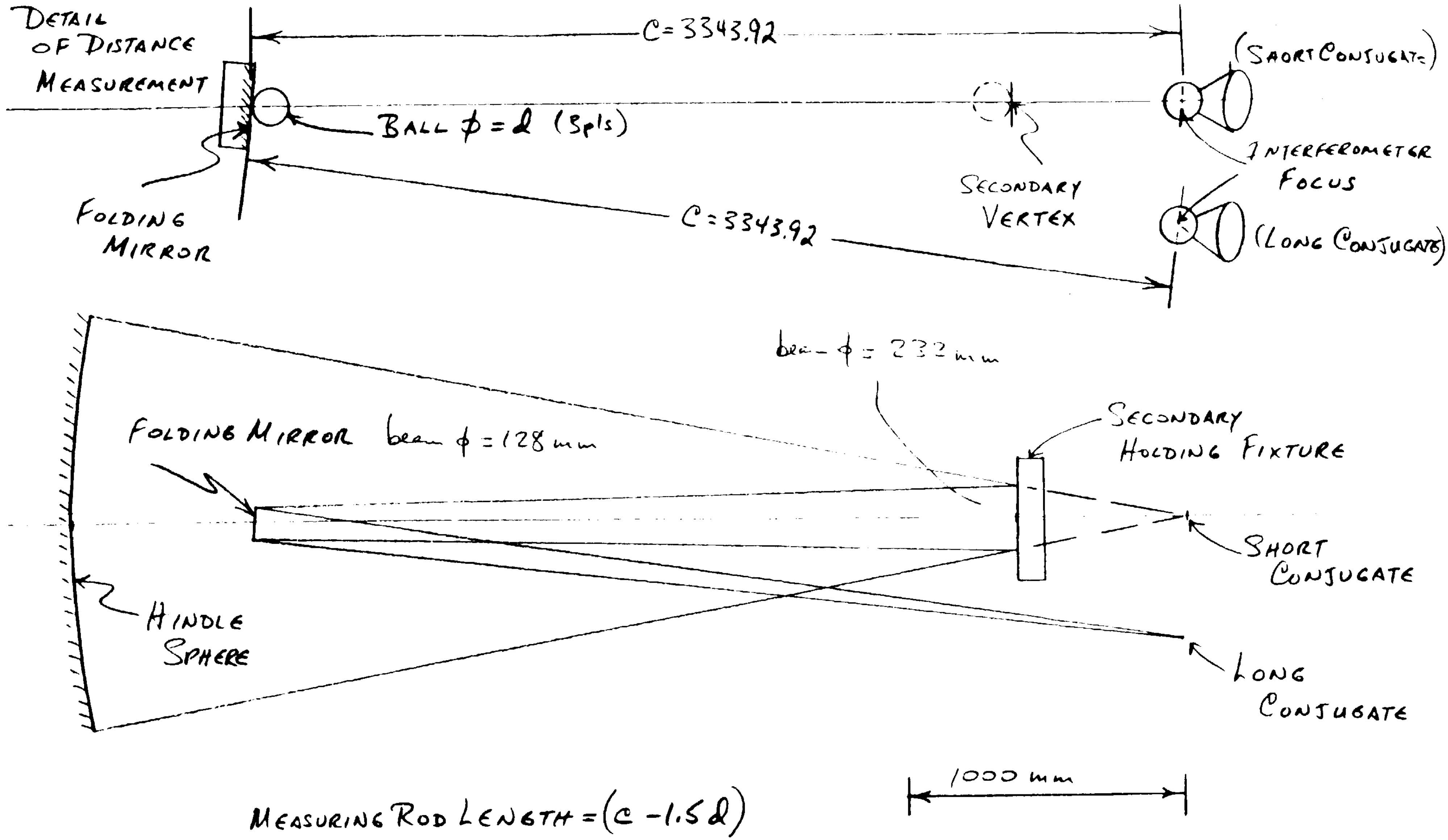
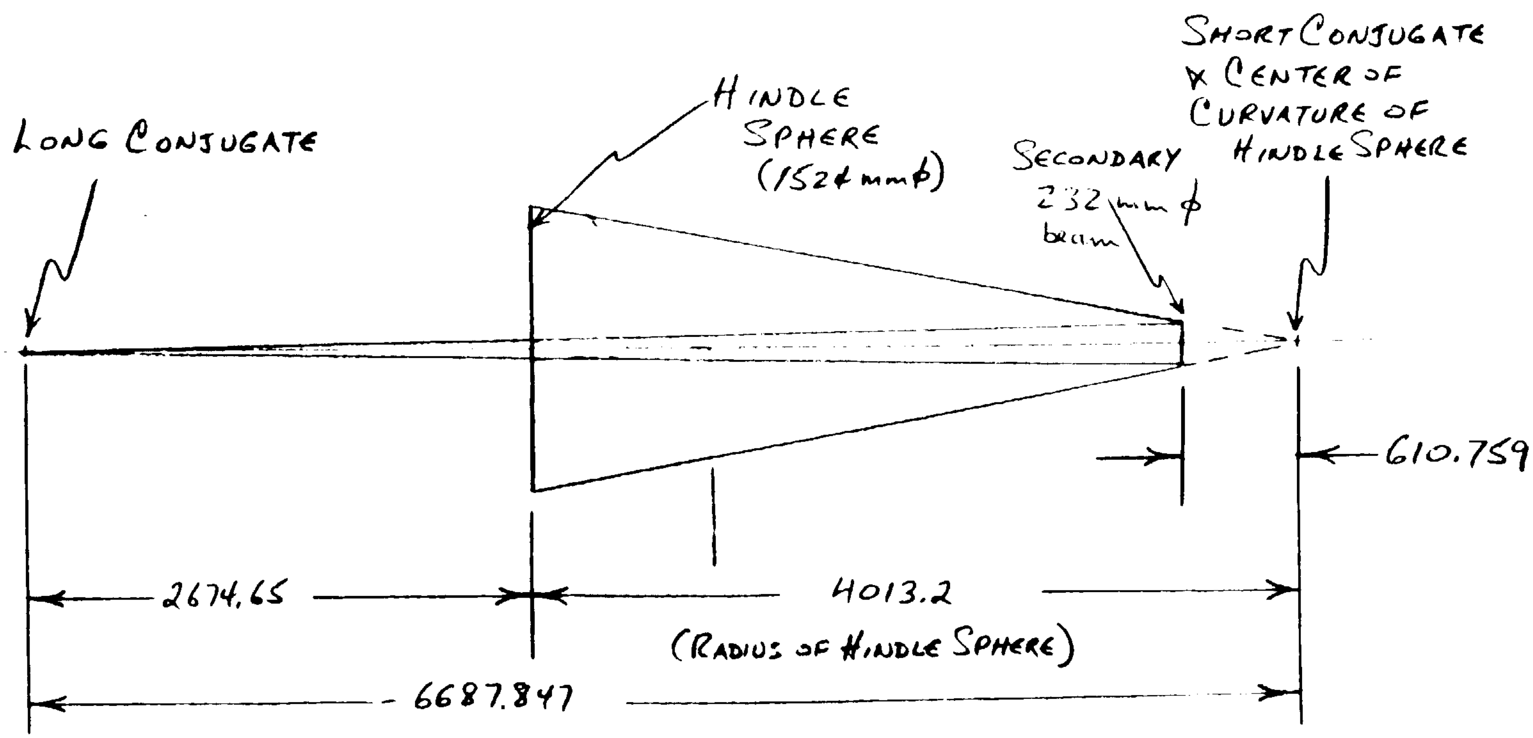


Fig. 1. Schematic layout of Hindle secondary mirror test.



SHORT CONJUGATE, $s = 610.759$

LONG CONJUGATE, $s' = 6077.088$

$s + s' = 6687.847$

$$R_s = 2\frac{ss'}{s-s'}$$

$$K = -\left(\frac{s+s'}{s-s'}\right)^2$$

Fig. 2. Parameters of HST secondary mirror Hindle test.

Appendix A

Equipment List

Steel balls, 0.5" diameter, class 25

Dummy secondary mirror made of aluminum

Point source microscope and light source (made up of Ealing and EG&G components)

Phase measuring interferometer and objectives (built at Optical Sciences)

2 - x-y-z positioning stages, not used for measuring

2 - x-y positioning stages, not used for measuring

1 - x motion stage only, not used for measuring

Mirror mount, 6" diameter with tilt adjustments

Set of measuring rods, custom made and calibrated

Pair of 72" vernier calipers, calibrated 12/90

Inside micrometer, Starrett with 26" capacity

Plano mirror, coated and certified to $\lambda/10$

2 - Stands to support measuring rods

Stand to hold 6" mirror and mount

Large mirror mount to hold secondary mirror and cell (3 translation and 2 tilt adjustments)

Cell and cover for secondary mirror

Large Newport optical table to support interferometer and secondary mirror

Hindle sphere and mount, 60" diameter $\times$ 158" radius

Appendix B

Procedure for Measuring the Vertex Radius and Conic Constant of the Backup HST Secondary Mirror

Note: Refer to the Figure for details of the test setup.

Procedure:

1. Place a point source microscope at the center of curvature of the Hindle sphere. Adjust microscope for best focus.

2. Without touching the microscope, move a 0.50" diameter steel ball in front of the microscope such that the center of the ball is coincident with the focus of the microscope.

3. Position the folding mirror longitudinally. The folding mirror is a 6" diameter flat certified to $\lambda/10$ and has a 0.50" diameter steel ball cemented to its center. Using the calibrated measuring rod of length 3324.86 mm (130.900"), move the folding mirror up to the measuring rod. This will place the surface of the mirror at 3343.92 mm from center of curvature of the Hindle sphere. (In performing this step, first bring one end of the rod up to the ball at the center of curvature of the Hindle sphere. Use a piece of thin shim stock to determine position of rod relative to the ball. Then bring the ball on the fold mirror up to other end of the rod, again using shim stock.)

4. Locate another 0.50" diameter steel ball at roughly the same height as the ball at the center of curvature of the Hindle sphere and about 400 mm to the side of it. Use the 3324.86 mm measuring rod to determine the longitudinal spacing of this ball. Use the same method as in step 3) to position this ball.

5. Adjust an interferometer with a nominally 300 mm focal length diverger that has already been calibrated per the appropriate procedure so that the focus of the diverger is coincident with the center of the ball located in step 4). The axis of the interferometer should be pointing at the center of the fold mirror. (The interferometer will now be focused at the long conjugate of the Hindle test.)

6. Offset the steel ball at the interferometer focus so the interferometer diverging beam illuminates the fold mirror.

7. Insert the secondary mirror/cell assembly into the large mirror holder that is located about 600 mm from the short test conjugate (the conjugate at the center of curvature of the Hindle sphere). Handle the mirror using the overhead crane to move the assembly from its special storage box to the mirror holder. When the mirror is in place and before removing the lifting strap, secure the mirror assembly with 2 bolts.

7a. Remove the Lexan protective cover from the secondary mirror.

8. Adjust the tilt of the secondary until the autoreflected light beam is centered on the interferometer diverger and there is an indication of fringes.

9. Continue to adjust the focus, decenter and tilt of the secondary until the fringe pattern is largely free of coma, focus and tilt. Ideally alignment would be continued until the fringes were nominally straight and about 10 fringes filled the monitor screen.

10. Record and store 5 interferograms of the Hindle test wavefront in a file named __________.

11. Position a 0.50" steel ball at the vertex of the secondary mirror. Center the ball laterally by eye. Adjust longitudinally by using a piece of shim stock to determine the proximity of the ball to the vertex.

12. Without touching the ball, move the mirror assembly back away from the ball about 2".

13. Replace the protective Lexan cover on the mirror being careful not to touch the ball.

14. Attach the crane strap and remove the 2 securing bolts holding the secondary mirror assembly.

15. Use the crane to remove the mirror assembly and replace it in its storage box. Secure the lid on the box.

16. Using a pair of inside micrometers, measure the distance between the ball at the vertex of the secondary and the ball at the short conjugate. Use shim stock to determine the fit of the micrometers.

17. Verify with the point source microscope that the ball at the short conjugate has not moved.

18. Check the inside micrometer reading with the calibrated calipers. Remember to add in half the diameter of the ball (12.7 mm) to get the short conjugate distance. Record s as __________ mm.

19. As an intermediate step, calculate $R = 2(ss')/(s' - s)$ and $k = -((s + s')/(s' - s))2$.

20. In the computer, average the 5 interferograms of the Hindle test and store in a file named ________________.

21. Subtract the Hindle sphere wavefront from the data in the file above and store in a file named ____________________.

22. Subtract the interferometer/diverger calibration wavefront from the data in the above file and store in a file named ______________________.

23. Using the residual first order (3 term fit) focus term, correct the R value found in step 19) and record R' = ______.

24. Using the residual 3rd order spherical aberration coefficient from the above file, correct the value of k found in step 19) and record as k' = ____________.

25. Repeat the above procedure 2 more times to gather a complete data package for the test of the secondary mirror.

Appendix C

Error Budget for HST Secondary Testing

The errors associated with each step of the procedure are first determined. Then these total errors are associated with the parameters used to determine the secondary vertex radius and conic constant.

1. Place microscope at center of curvature of Hindle sphere.
   - Use a 10× microscope objective.
   - Actual cone angle limited by secondary mount to f/5
   - Depth of focus is $\lambda(f/\#)^2$ or 12.5 μm for $\lambda = 0.5$ μm (white light source)
   - Error for step 1) is plus or minus 12.5 μm
2. Position center of ball at microscope focus
   - Use same 10x microscope objective.
   - Cone now governed by NA of objective at 0.2
   - Depth of focus is $\lambda/(2(NA)^2) = 6.3$ μm
   - Error for step 2) is plus or minus 6.3 μm
   - Total error in location of ball at short conjugate is ± 19 μm
3. Position fold mirror at 3343.92 mm from HS C of C
   - Calibration uncertainty for calipers = 25 μm
   - Reading error in each rod measurement = 25 μm
   - Uncompensated thermal error of 0.5° C = 18 μm
   - Positioning of fold mirror to rod = 12 μm
   - Error due to cement layer under ball = 12 μm
   - Total error in positioning mirror = 160 μm

4. Position a ball at 3343.92 mm from fold mirror

   - Same errors as in step 3) are present

   - Total error in this step = 160 μm

5. Adjust interferometer to ball set in step 4)

   - Assuming we can see 0.1 λ p-v error in focus with interferometer or delta sag of 0.03 μm

   - Interferometer objective f/# is 15

   - Detectable delta R is then 54 μm

   - (Error due to 1/10th fringe power in fold flat, i. e., an effective radius of 112,500 m, in the location of the long conjugate = 200 μm)

   - Total error in determining long conjugate position is ± 574 μm

6. Adjust the secondary mirror axially for "zero" focus error at interferometer, i. e., to less than 0.1λ p-v wavefront error in focus.

   - The shift in secondary position to produce a 0.1λ focus error is 3 μm

7. Position ball at vertex of secondary mirror

   - Error in positioning ball due to "touch" = 12 μm

   - Error in knowing height of vertex due to flat at vertex is 12 μm

8. Measure short conjugate distance with inside micrometer

   - Error in setting of micrometers due to "touch" = 12 μm

9. Calibration error of inside micrometer = 25 μm determined in cross check with calibrated calipers

   - Total error in location of secondary vertex = 64 μm

Application of errors in conjugate location to the determination of the vertex radius and conic constant of the secondary.

1. Total error in short conjugate ball location = 19 μm

2. Total error in secondary vertex location = 64 μm

3. Total error in long conjugate ball location = 574 μm so total error in short conjugate distance is 83 μm and 638 μm for the long conjugate distance.

Now from first order theory it is easy to show that

$$R = 2\,\frac{(ss')}{(s' - s)} \quad ,$$

where R = secondary mirror vertex radius;

s = the short conjugate distance; and

s' = the long conjugate distance.

Also we have

$$\kappa = -\left[\frac{s' + s}{s' - s}\right]^2 \quad .$$

Taking derivatives

$$\frac{\partial R}{\partial s} = 2\,\frac{s^2}{(s' - s)^2} = 2.47$$

$$\frac{\partial R}{\partial s'} = -2\,\frac{s^2}{(s' - s)^2} = -0.025$$

$$\frac{\partial \kappa}{\partial s} = -4\,\frac{s'(s' + s)}{(s' - s)^3} = -0.001/\text{mm}$$

$$\frac{\partial \kappa}{\partial s'} = 4\,\frac{s(s' + s)}{(s' - s)^3} = 0.0001/\text{mm}$$

The errors in the 2 conjugate measurements were

$$\Delta s' = 0.628 \text{ mm} \quad \text{and} \quad \Delta s = 0.104 \text{ mm}.$$

Thus the combined error in R is

$$\begin{aligned}\Delta R &= \pm\sqrt{\left[\frac{\partial R}{\partial s}\right]^2 (\Delta s)^2 + \left[\frac{\partial R}{\partial s'}\right]^2 (\Delta s')^2} \quad ; \\ &= \pm\sqrt{(2.47)^2(0.104)^2 + (-0.025)^2(0.628)^2} \\ &= \pm 0.257\text{mm}\end{aligned}$$

and the combined error in k is

$$\begin{aligned}\Delta \kappa &= \pm\sqrt{\left[\frac{\partial \kappa}{\partial s}\right]^2 (\Delta s)^2 + \left[\frac{\partial \kappa}{\partial s'}\right]^2 (\Delta s')^2} \quad . \\ &= \pm\sqrt{(-0.001)^2(0.104)^2 + (-0.0001)^2(0.628)^2} \\ &= \pm 0.00012\end{aligned}$$

Appendix D

Procedure for Calibrating the Interferometer/Diverger

Note: This procedure must be repeated for each diverger used (or each different f/# cone over which the same diverger is used). If divergers are changed, they do not have to be recalibrated if they are reinserted in the interferometer in the same azimuthal orientation as when they were calibrated and if they are used at the same f/# as when they were calibrated.

Principle of the calibration technique: A nominally spherical steel ball is placed so that its center is coincident with the focus of the diverger. It is assumed that both the figure of the ball and the residual error of the interferometer/diverger are small (less than $\lambda/4$) over the f/# cone of interest. Numerous interferograms are made as the ball is rotated about its center, the assumption being that the figure of the ball at each different position is uncorrelated with that at any other position.

Since the figure error due to the interferometer/diverger is common to all interferograms, when the interferograms are averaged, the result will be the signature of the interferometer/diverger plus a noise term equal to the average figure of the ball divided by the square root of the number of measurements. If the ball has an average error of less than $\lambda/4$, then there will be less than $\lambda/20$ noise in the calibration for 25 interferograms.

Procedure:

1. Insert the appropriate diverger in the interferometer for the test to be performed.

2. Rotate the diverger to a zero fiducial to locate the azimuthal position and finger tighten the lock screw.

3. After obtaining fringes off of the object under test (or a dummy object that defines the appropriate f/# cone for the test to be performed), set an aperture coincident with the edge of the object on the computer display.

4. Insert a steel ball concentric with the diverger focus. The ball should be supported in a mount such that it is easily and repeatably rotated. A hex socket wrench socket makes a good support.

5. Using either the interferometer or the ball mount, adjust tip, tilt and focus until the fringes are broken out to less than one.

6. Using the PMI option, take 25 interferograms of the ball, each in a different rotational position. Discard any data sets where the data is bad and keep taking data until there are 25 good sets. Readjust the fringes to less than one if any rotation misaligns the relative position of the ball and interferometer. Rotate the ball using something that will not contaminate the surface, a clean tissue would be good for this.

7. Average the data sets and store the average (under an appropriate file name) as the residual error for the interferometer/diverger pair at the f/# of the calibration.

8. Review the data to insure that all the interferograms going into the average were less than $\lambda/4$. This insures that the individual ball figure measurements are less than $\lambda/4$ and thus the noise will be less than $\lambda/20$.

9. Remove the ball from the diverger focus.

This completes the interferometer/diverger calibration.

Procedure for Calibrating the Figure of the Hindle Sphere

Note: This procedure need only be done once at the outset of testing as long as the sphere is not moved or readjusted in any way.

Procedure:

1. Calibrate the interferometer/diverger following the procedure for doing so.

2. Align the interferometer/diverger to the sphere using only adjustments on the interferometer.

3. Adjust the interferometer imaging focus so the CCD camera is conjugate to the Hindle sphere surface. Do this by placing an object near the sphere surface and adjusting the interferometer imaging lens until a sharp shadow is seen on the display.

4. Set the circular aperture on the display monitor to be coincident with the edge of the Hindle sphere.

5. Identify the top and left hand side of the sphere and record the locates as they appear on the monitor

6. Using the FAST option, capture and reduce 5 interferograms.

7. Average the 5 interferograms and store in a file labeled ____________.

8. Subtract the interferometer calibration wavefront from the file just saved. Store the pure Hindle sphere wavefront in a file labeled ____________.

This completes the calibration of the Hindle sphere.

Appendix E

Interferometric Data Reduction Work Sheet (First "Real" Test)

1. Hindle sphere surface error data (HSCAVE)

   C_4 -0.165 ± 0.052 C_5 0.123 ± 0.049 C_8 0.088 ± 0.009

2. Fast interferometer/diverger data (HGCAVE)

   C_4 -0.002 ± 0.038 C_5 0.030 ± 0.040 C_8 -0.010 ± 0.008

3. Line 1) minus line 2)

   C_4 -0.163 ± 0.090 C_5 0.093 ± 0.089 C_8 0.0098 ± 0.017

4. Hindle test data expressed as surface error (HTBCAVE)

   C_4 -0.192 ± 0.057 C_5 0.122 ± 0.066 C_8 0.106 ± 0.006

5. Slow interferometer/diverger data (HFCAVE)

   C_4 -0.012 ± 0.017 C_5 -0.012 ± 0.011 C_8 -0.008 ± 0.005

6. Line 4) minus line 5) - Pure Hindle test surface error

   C_4 -0.180 ± 0.074 C_5 0.134 ± 0.077 C_8 0.114 ± 0.011

7. Line 6) minus line 3) - Pure secondary wavefront error

   C_4 -0.017 ± 0.164 C_5 0.041 ± 0.166 C_8 0.016 ± 0.028

8. Line 7) divided by 2 - Secondary mirror surface error

   C_4 -0.008 ± 0.082 C_5 0.021 ± 0.083 C_8 0.008 ± 0.014

Interferometric Data Reduction Work Sheet (Second Real Test)

1. Hindle sphere surface error data (HSCAVE)

    C_4 -0.165 ± 0.052 C_5 0.123 ± 0.049 C_8 0.088 ± 0.009

2. Fast interferometer/diverger data (HGCAVE)

    C_4 -0.002 ± 0.038 C_5 0.030 ± 0.040 C_8 -0.010 ± 0.008

3. Line 1) minus line 2)

    C_4 -0.163 ± 0.090 C_5 0.093 ± 0.089 C_8 0.0098 ± 0.017

4. Hindle test data expressed as surface error (HTCCAVE)

    C_4 -0.215 ± 0.039 C_5 0.219 ± 0.056 C_8 0.0131 ± 0.020

5. Slow interferometer/diverger data (HFCAVE)

    C_4 -0.012 ± 0.017 C_5 -0.012 ± 0.011 C_8 -0.008 ± 0.005

6. Line 4) minus line 5) - Pure Hindle test surface error

    C_4 -0.203 ± 0.056 C_5 0.231 ± 0.067 C_8 0.139 ± 0.025

7. Line 6) minus line 3) - Pure secondary wavefront error

    C_4 -0.040 ± 0.146 C_5 0.138 ± 0.156 C_8 0.041 ± 0.042

8. Line 7) divided by 2 - Secondary mirror surface error

    C_4 -0.020 ± 0.073 C_5 0.069 ± 0.078 C_8 0.021 ± 0.021

Interferometric Data Reduction Work Sheet (Third Real Test)

1. Hindle sphere surface error data (HSCAVE)

   C_4 -0.165 ± 0.052 C_5 0.123 ± 0.049 C_8 0.088 ± 0.009

2. Fast interferometer/diverger data (HGCAVE)

   C_4 -0.002 ± 0.038 C_5 0.030 ± 0.040 C_8 -0.010 ± 0.008

3. Line 1) minus line 2)

   C_4 -0.163 ± 0.090 C_5 0.093 ± 0.089 C_8 0.0098 ± 0.017

4. Hindle test data expressed as surface error (HTDCAVE)

   C_4 -0.227 ± 0.054 C_5 0.154 ± 0.084 C_8 0.144 ± 0.012

5. Slow interferometer/diverger data (HFCAVE)

   C_4 -0.012 ± 0.017 C_5 -0.012 ± 0.011 C_8 -0.008 ± 0.005

6. Line 4) minus line 5) - Pure Hindle test surface error

   C_4 -0.215 ± 0.071 C_5 0.166 ± 0.095 C_8 0.152 ± 0.017

7. Line 6) minus line 3) - Pure secondary wavefront error

   C_4 -0.052 ± 0.161 C_5 0.073 ± 0.184 C_8 0.054 ± 0.034

8. Line 7) divided by 2 - Secondary mirror surface error

   C_4 -0.026 ± 0.081 C_5 0.037 ± 0.092 C_8 0.027 ± 0.017

Interferometric Data Reduction Work Sheet (Secondary Rotated 90°)

1. Hindle sphere surface error data (HSCAVE)

   C_4 -0.165 ± 0.052 C_5 0.123 ± 0.049 C_8 0.088 ± 0.009

2. Fast interferometer/diverger data (HGCAVE)

   C_4 -0.002 ± 0.038 C_5 0.030 ± 0.040 C_8 -0.010 ± 0.008

3. Line 1) minus line 2)

   C_4 -0.163 ± 0.090 C_5 0.093 ± 0.089 C_8 0.0098 ± 0.017

4. Hindle test data expressed as surface error (HTECAVE)

   C_4 -0.253 ± 0.046 C_5 0.130 ± 0.060 C_8 0.152 ± 0.028

5. Slow interferometer/diverger data (HFCAVE)

   C_4 -0.012 ± 0.017 C_5 -0.012 ± 0.011 C_8 -0.008 ± 0.005

6. Line 4) minus line 5) - Pure Hindle test surface error

   C_4 -0.241 ± 0.107 C_5 0.142 ± 0.071 C_8 0.160 ± 0.033

7. Line 6) minus line 3) - Pure secondary wavefront error

   C_4 -0.078 ± 0.197 C_5 0.049 ± 0.160 C_8 0.062 ± 0.050

8. Line 7) divided by 2 - Secondary mirror surface error

   C_4 -0.039 ± 0.098 C_5 0.025 ± 0.080 C_8 0.031 ± 0.025

Appendix F

Analysis of Interferometric Data Using rms Residual Errors

Rms error values are surface errors at λ = 633 nm after removal of tilt, focus, and coma and apply to the full circular aperture.

Hindle sphere rms surface error: 0.0998 ± 0.0189

Interferometer/fast diverger calibration error: 0.0290 ± 0.100

rss Hindle sphere error: 0.1039 ± 0.0214

Hindle test rms surface error (for each of the 3 test series)

HTBCAVE: 0.1165 ± 0.0092
HTCCAVE: 0.1472 ± 0.0156
HTDCAVE: 0.1430 ± 0.0280

Interferometer/slow diverger calibration error: 0.0110 ± 0.0048

rss Hindle test data:

HTBCAVE: 0.1170 ± 0.0104
HTCCAVE: 0.1476 ± 0.0163
HTDCAVE: 0.1434 ± 0.0284

rss Hindle test less Hindle sphere:

HTBCAVE: 0.0538 ± 0238
HTCCAVE: 0.1048 ± 0.0269
HTDCAVE: 0.0988 ± 0.0356

above divided by 2 to give rms secondary surface error

HTDCAVE: 0.0269 ± 0.0119
HTCCAVE: 0.0524 ± 0.0135
HTDCAVE: 0.0494 ± 0.0178

Average rms secondary surface error = 0.043 ± 0.014λ

HST
SECONDARY MIRROR
Vertex Radius / Conic Constant
S/N 003

DATA

Handling Procedures

Test Procedures

CERTIFICATION

Deviations

ATTENDEES

Tom Dubos	HDOS	203-797-5440
Amanda Harris	NASA/MSFC	(303) 971-6635 (205) 544-243
[illegible]	JPL	(818) 354-9573
[illegible]	JPL	(818) 354-2644
Richard E. [illegible]	U/A.	(602) 621 2341
Shao Liang	TORC	(602) - 882-0300
[illegible]	U/A	602 299 1933
[illegible]	HDOS	203 - 797 - 6695
Harry H. Johnston	MSFC	205 - 544 - 2358
[illegible]	U of A	602-795-1850

12/29/80

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° C5 = 0.019 ° C11= 0.000 ° C17= 0.000 ° C23= 0.000 ° C29= 0.000 ° C35= 0.000
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° C6 = 0.000 ° C12= 0.000 ° C18= 0.000 ° C24= 0.000 ° C30= 0.000 ° C36= 0.000
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Abort Continue

HTDCAVE.ZRN

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

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Öááááááááááááôááááááááááááôááááááááááááôááááááááááááôááááááááááááôááááááááááá
° C1 = 0.000 ° C7 = 0.000 ° C13= 0.000 ° C19= 0.000 ° C25= 0.000 ° C31= 0.000
ûááááááááááááéááááááááááááéááááááááááááéááááááááááááéááááááááááááéááááááááááá
° C2 = 0.000 ° C8 = 0.057 ° C14= 0.000 ° C20= 0.000 ° C26= 0.000 ° C32= 0.000
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° C3 = 0.000 ° C9 = 0.000 ° C15= 0.000 ° C21= 0.000 ° C27= 0.000 ° C33= 0.000
ûááááááááááááéááááááááááááéááááááááááááéááááááááááááéááááááááááááéááááááááááá
° C4 =-0.079 ° C10= 0.000 ° C16= 0.000 ° C22= 0.000 ° C28= 0.000 ° C34= 0.000
ûááááááááááááéááááááááááááéááááááááááááéááááááááááááéááááááááááááéááááááááááá
° C5 = 0.019 ° C11= 0.000 ° C17= 0.000 ° C23= 0.000 ° C29= 0.000 ° C35= 0.000
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° C6 = 0.000 ° C12= 0.000 ° C18= 0.000 ° C24= 0.000 ° C30= 0.000 ° C36= 0.000
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HTDCAVE.ZRN

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

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Öááááááááááááôááááááááááááôááááááááááááôááááááááááááôááááááááááááôááááááááááá
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° C2 = 0.000 ° C8 = 0.057 ° C14= 0.000 ° C20= 0.000 ° C26= 0.000 ° C32= 0.000
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° C3 = 0.000 ° C9 = 0.000 ° C15= 0.000 ° C21= 0.000 ° C27= 0.000 ° C33= 0.000
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° C4 =-0.079 ° C10= 0.000 ° C16= 0.000 ° C22= 0.000 ° C28= 0.000 ° C34= 0.000
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° C5 = 0.019 ° C11= 0.000 ° C17= 0.000 ° C23= 0.000 ° C29= 0.000 ° C35= 0.000
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° C6 = 0.000 ° C12= 0.000 ° C18= 0.000 ° C24= 0.000 ° C30= 0.000 ° C36= 0.000
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Abort Continue

Zernike Coefficients

HTBAAVE.ZRN

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

C1 = 0.000	C7 = 0.000	C13= 0.000	C19= 0.000	C25= 0.000	C31= 0.000
C2 = 0.000	C8 =-0.025	C14= 0.000	C20= 0.000	C26= 0.000	C32= 0.000
C3 = 0.000	C9 = 0.000	C15= 0.000	C21= 0.000	C27= 0.000	C33= 0.000
C4 = 0.004	C10= 0.000	C16= 0.000	C22= 0.000	C28= 0.000	C34= 0.000
C5 = 0.060	C11= 0.000	C17= 0.000	C23= 0.000	C29= 0.000	C35= 0.000
C6 = 0.000	C12= 0.000	C18= 0.000	C24= 0.000	C30= 0.000	C36= 0.000

Abort Continue

HTCCAVE.ZRN

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

C1 = 0.000	C7 = 0.000	C13= 0.000	C19= 0.000	C25= 0.000	C31= 0.000
C2 = 0.000	C8 =-0.104	C14= 0.000	C20= 0.000	C26= 0.000	C32= 0.000
C3 = 0.000	C9 = 0.000	C15= 0.000	C21= 0.000	C27= 0.000	C33= 0.000
C4 = 0.169	C10= 0.000	C16= 0.000	C22= 0.000	C28= 0.000	C34= 0.000
C5 =-0.170	C11= 0.000	C17= 0.000	C23= 0.000	C29= 0.000	C35= 0.000
C6 = 0.000	C12= 0.000	C18= 0.000	C24= 0.000	C30= 0.000	C36= 0.000

Abort Continue

HTDCAVE.ZRN

Zernike Coefficients

Position cursor to coefficient using mouse or arrow keys
Press mouse button or ENTER to change coefficient under cursor
Press both buttons to zero coefficient under cursor

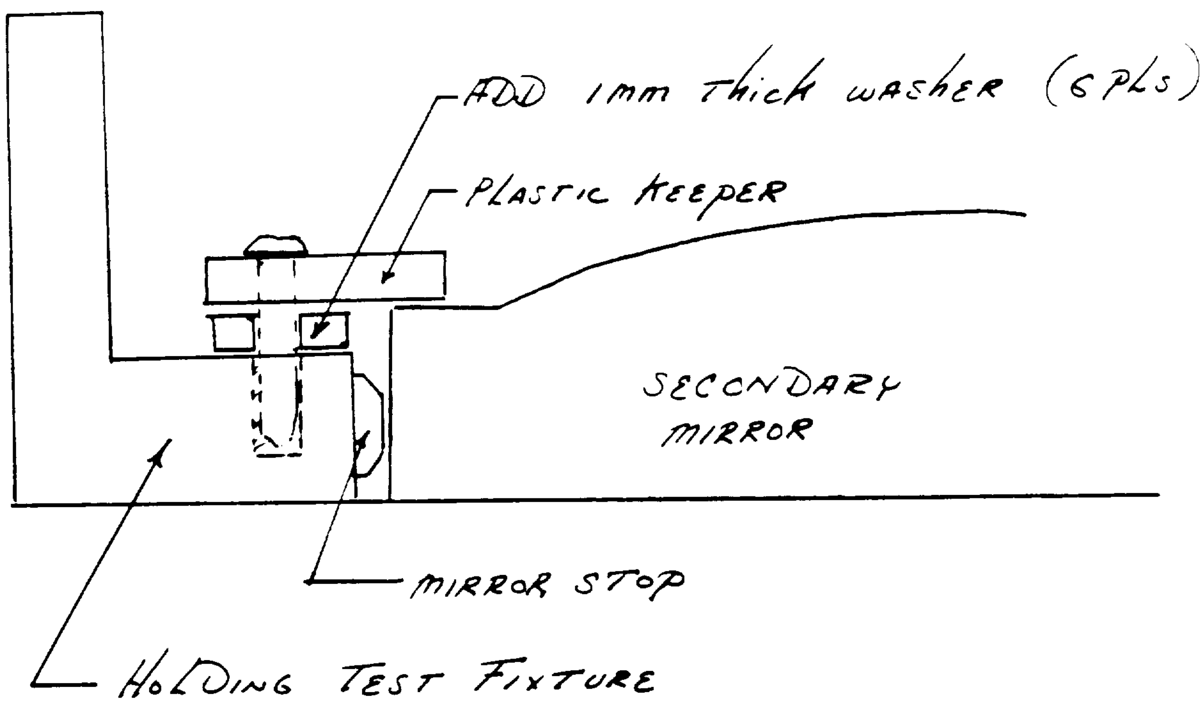
C1 = 0.000	C7 = 0.000	C13= 0.000	C19= 0.000	C25= 0.000	C31= 0.000
C2 = 0.000	C8 = 0.057	C14= 0.000	C20= 0.000	C26= 0.000	C32= 0.000
C3 = 0.000	C9 = 0.000	C15= 0.000	C21= 0.000	C27= 0.000	C33= 0.000
C4 =-0.079	C10= 0.000	C16= 0.000	C22= 0.000	C28= 0.000	C34= 0.000

12/28/98

Daily Log

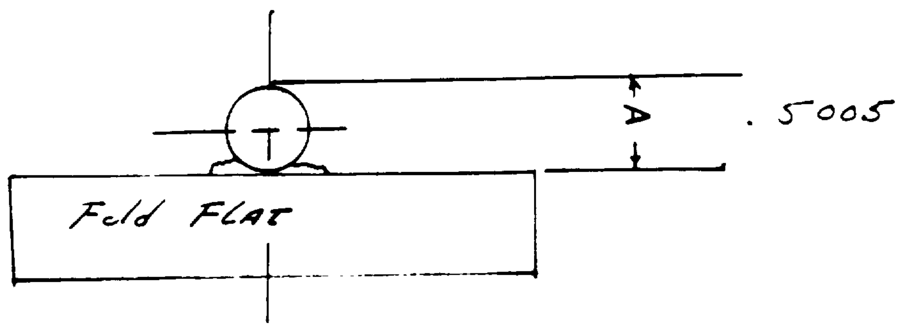
Addition / Modifications

Notes:



Hardware modification - The addition of the six washers will allow the plastic safety retainer to remain flush with the mirror edge and the holding fixture. This will relieve any unwanted bending moment applied to the plastic keeper.

T. Dubos
12/27/90



Temp. 69.3 °F

1.) Cal. micrometer to measure Ball diameter.

				uncertainty Block
.5"	Jo Block	mic reading	.5002	.000002
1.0"	Jo Block	mic reading	1.0002	.000000

Brown/sharpe Jo Block Set S/N R 4300
CAL. DATE 10/4/68

2.) Measure Ball diameter .5002
− .0002 Mic uncertainty
.5000

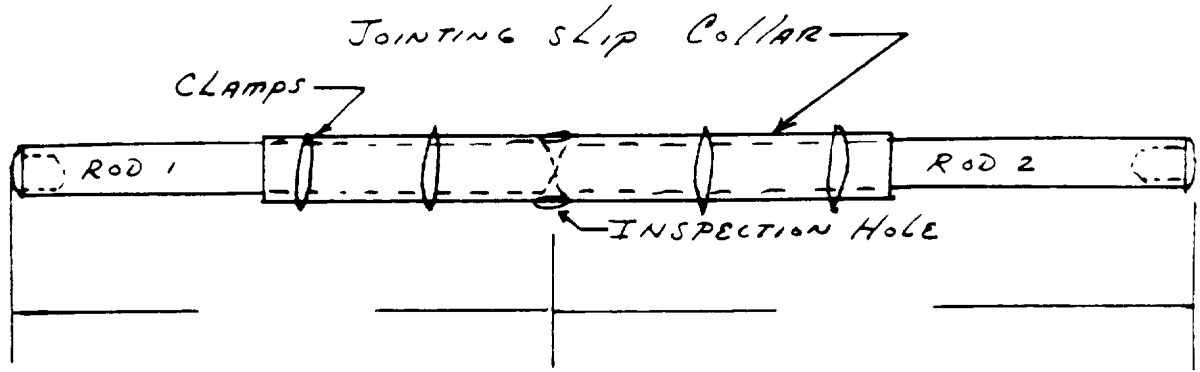
3.) Measure Dim. A using Brown/Sharp dial indicator

This value includes Ball dia + Bond line.
.5005"

4.) Measure wedge in Flat .003 inch

T. Dubos
12/27/90

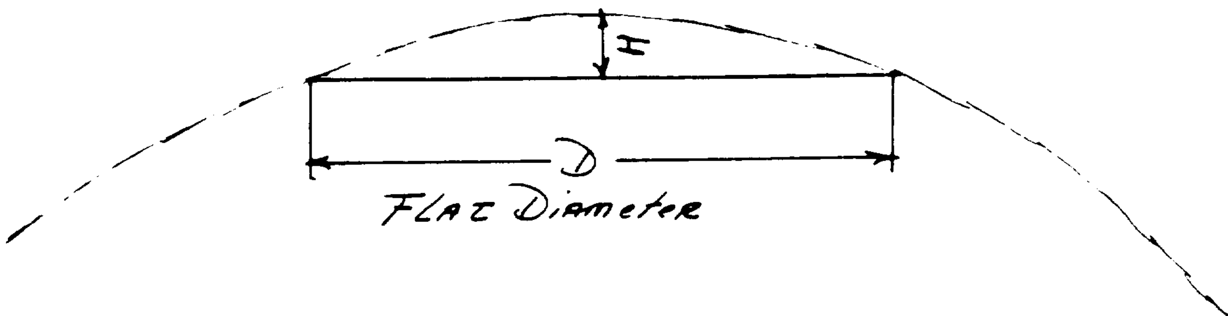
Metering Rods



All Rods will Be measured in sections using 6 Foot Calip

Certified By Washington Calibration
Cert. # 17430-Z
Date 12-19-91
S/N A-083615

T. Dubos
12/27/90



$$H = \frac{r^2}{2R} \qquad r = D/2 \qquad \frac{26\ mm}{2} \qquad 13\ mm$$

R = Vertex Radius
1358 mm

$$H = \frac{(13)^2}{2(1358)} \qquad \frac{169}{2716} \qquad .06222\ mm \qquad .002449\ \text{inch}$$

$H = 62.22\ \mu$

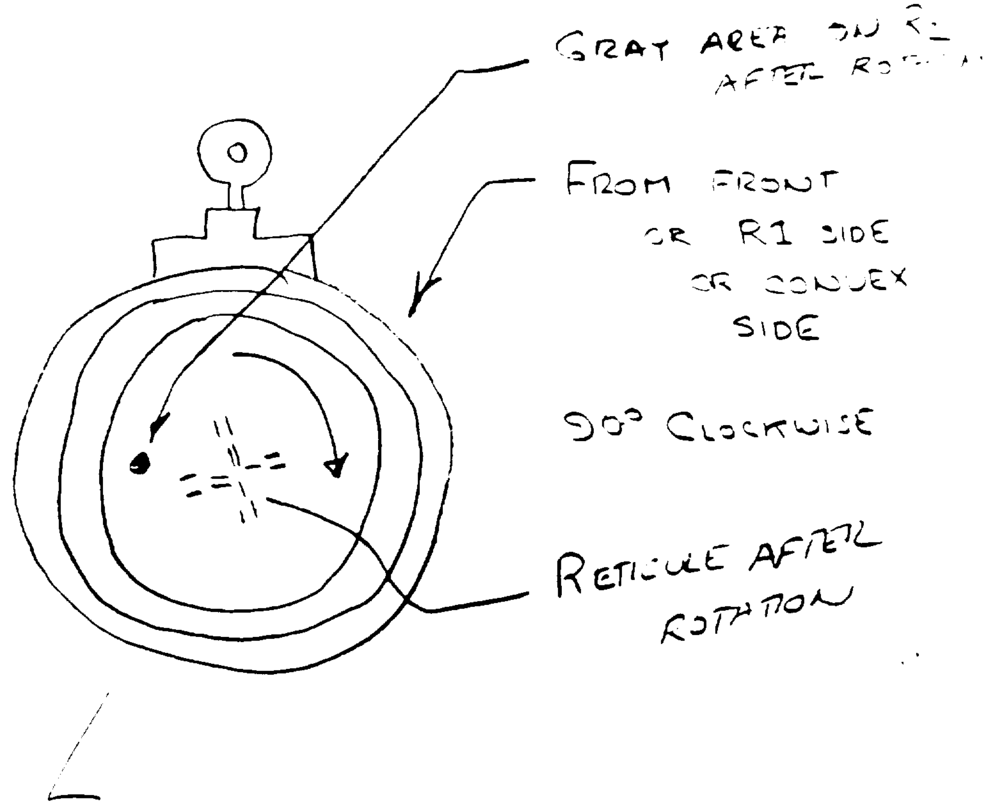
Secondary Mirror

S/N 003

T. Dubos
12/27/90

ROTATION

BEFORE



HDH
12/29/90

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Procedure for calibrating the figure of the Hindle sphere

Note: This procedure need only be done once at the outset of testing as long as the sphere is not moved or readjusted in any way.

Procedure:

1) Calibrate the interferometer/diverger following the procedure for doing so.

2) Align the interferometer/diverger to the sphere using only adjustments on the interferometer.

3) Adjust the interferometer imaging focus so the CCD camera is conjugate to the Hindle sphere surface. Do this by placing an object near the sphere surface and adjusting the interferometer imaging lens until a sharp shadow is seen on the display.

4) Set the circular aperture on the display monitor to be coincident with the edge of the Hindle sphere.

5) Identify the top and left hand side of the sphere and record the locates as they appear on the monitor

6) Using the FAST option, capture and reduce all 25 interferograms.

7) Average the all 25 interferograms and store in a file labelled ~~H005PR2~~ all

8) Subtract the interferometer calibration wavefront from the file just saved. Store the Hindle sphere wavefront in a file labelled _______________.

This completes the calibration of the Hindle sphere.

FOR MODE SHEET

Procedure for calibrating the interferometer/diverger

Note: This procedure must be repeated for each diverger used (or each different f/# cone over which the same diverger is used). If divergers are changed, they do not have to be recalibrated if they are reinserted in the interferometer in the same azimuthal orientation as when they were calibrated and if they are used at the same f/# as when they were calibrated.

Principle of the calibration technique: A nominally spherical steel ball is placed so that its center is coincident with the focus of the diverger. It is assumed that both the figure of the ball and the residual error of the interferometer/diverger are small (less than lambda/4) over the f/# cone of interest. Numerous interferograms are made as the ball is rotated about its center, the assumption being that the figure of the ball at each different position is uncorrelated with that at any other position.

Since the figure error due to the interferometer/diverger is common to all interferograms, when the interferograms are averaged, the result will be the signature of the interferometer/diverger plus a noise term equal to the average figure of the ball divided by the square root of the number of measurements. If the ball has an average error of less than lambda/4, then there will be less than lambda/20 noise in the calibration for ~~>~~25 interferograms.

Procedure:

12/29/90

1) Insert the appropriate diverger in the interferometer for the test to be performed. 77 ak

2) Rotate the diverger to a zero fiducial to locate the azimuthal position and finger tighten the lock screw. 77 ak

3) After obtaining fringes off of the object under test (or a dummy object that defines the appropriate f/# cone for the test to be performed), set an aperture coincident with the edge of the object on the computer display. 77 ak

4) Insert a steel ball concentric with the diverger focus. The ball should be supported in a mount such that it is easily and repeatably rotated. A hex socket wrench socket makes a good support. 77 ak

5) Using either the interferometer or the ball mount, adjust tip, tilt and focus until the fringes are broken out to less than one. 77 ak

6) Using the PMI option, take 25 interferograms of the ball, each in a different rotational position. Discard any data sets where the data is bad and keep taking data until there are 25 good sets. Readjust the fringes to less than one if any rotation misaligns the relative position of ball and interferometer. Rotate the ball using something that will not contaminate the surface, a clean tissue would be good for this.

7) Average the 25 sets of data and store the average (under an appropriate file name) as the residual error for the interferometer/diverger pair at the f/# of the calibration.

8) Review the data to insure that all the interferograms going into the average were less than lambda/4. This insures that the individual ball figure measurements are less than lambda/4 and thus the noise will be less than lambda/20.

9) Remove the ball from the diverger focus.

This completes the interferometer/diverger calibration.

12/29/90

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FOR HANDLE SPHERE

Procedure for calibrating the interferometer/diverger

Note: This procedure must be repeated for each diverger used (or each different f/# cone over which the same diverger is used). If divergers are changed, they do not have to be recalibrated if they are reinserted in the interferometer in the same azimuthal orientation as when they were calibrated and if they are used at the same f/# as when they were calibrated.

Principle of the calibration technique: A nominally spherical steel ball is placed so that its center is coincident with the focus of the diverger. It is assumed that both the figure of the ball and the residual error of the interferometer/diverger are small (less than lambda/4) over the f/# cone of interest. Numerous interferograms are made as the ball is rotated about its center, the assumption being that the figure of the ball at each different position is uncorrelated with that at any other position.

Since the figure error due to the interferometer/diverger is common to all interferograms, when the interferograms are averaged, the result will be the signature of the interferometer/diverger plus a noise term equal to the average figure of the ball divided by the square root of the number of measurements. If the ball has an average error of less than lambda/4, then there will be less than lambda/20 noise in the calibration for ~~25~~ 27 interferograms.

Procedure: 12/29/80

1) Insert the appropriate diverger in the interferometer for the test to be performed.

2) Rotate the diverger to a zero fiducial to locate the azimuthal position and finger tighten the lock screw.

3) After obtaining fringes off of the object under test (or a dummy object that defines the appropriate f/# cone for the test to be performed), set an aperture coincident with the edge of the object on the computer display.

4) Insert a steel ball concentric with the diverger focus. The ball should be supported in a mount such that it is easily and repeatably rotated. A hex socket wrench socket makes a good support.

5) Using either the interferometer or the ball mount, adjust tip, tilt and focus until the fringes are broken out to less than one.

6) Using the PMI option, take 25 interferograms of the ball, each in a different rotational position. Discard any data sets where the data is bad and keep taking data until there are 25 good sets. Readjust the fringes to less than one if any rotation misaligns the relative position of ball and interferometer. Rotate the ball using something that will not contaminate the surface, a clean tissue would be good for this.

7) Average the 25 sets of data and store the average (under an appropriate file name) as the residual error for the interferometer/diverger pair at the f/# of the calibration.

8) Review the data to insure that all the interferograms going into the average were less than lambda/4. This insures that the individual ball figure measurements are less than lambda/4 and thus the noise will be less than lambda/20.

9) Remove the ball from the diverger focus.

This completes the interferometer/diverger calibration.

For slow diverger

HST Backup Secondary Mirror Handling Procedures 12/27/90

1. Transfer of mirror in original shipping case

STEP	ACTION	OPTICIAN	QA
1.0	Verify the 4 latches are latched.	(P)	AH
1.1	Using 2 people, lift the shipping case onto a sturdy cart using the handles on the box.	(P)	AH
1.2	Secure the box to the cart so the box cannot slide off the cart.	(P)	AH
1.3	Q.C. verifies cart pathway is free of obstructions.	(P)	AH
1.4	Cart is guided by 2 persons to final destination.	(P)	AH
1.5	Using 2 people, lift the shipping case to a sturdy table or floor of storage room.	(P) 12/27	AH 12/27/90

HST Backup Secondary Mirror Handling Procedures

2. Removal of mirror from shipping case

STEP	ACTION	OPTICIAN	QA
2.1	Unlatch box cover, remove cover and set in clean location.	(b)	AH
2.2	Remove foam pad and tissue and set on cover	(b)	AH No tissue
2.2.1	Perform visual inspection for damage	(b)	AH
2.3	Grasp mirror through fingerholes in foam insert, lift mirror from box and set on a non-metallic stand.	(b)	AH
2.4	Replace foam pad and tissue in box and replace cover. Latch cover and remove box.	(b) 12/27/90	AH 12/27/90

visual

HST Backup Secondary Mirror Handling Procedures

3. Insertion of mirror in test fixture

STEP	ACTION	OPTICIAN	QA
3.1	Place mirror insertion fixture on a sturdy, clean work table	[illegible]	[illegible]
3.2	Place mirror mount over the insertion fixture	[illegible]	[illegible]
3.3	Place the secondary mirror on the insertion fixture while centering the mirror by eye	[illegible]	[illegible]
3.4	While one person lifts the mirror mount up around the mirror, the second person sees that the mirror is centered in the mount so that the mirror will not contact the metal portion of the mount	[illegible]	[illegible]
3.5	Continue to lift the mount clear of the insertion fixture and set the mount on the table	[illegible]	[illegible]
3.6	Secure the mirror in the mount with 3 plastic clips and bolts & washers for clearance concerns. (bolts are finger tight only)	[illegible]	[illegible]
3.7	Secure the plastic shield over the mirror with 3 bolts* (finger tight only)	[illegible]	[illegible]
		12/27/9[illegible]	12/27/9[illegible]

* Bolts

HST Backup Secondary Mirror Handling Procedures

4. Handling the mirror test fixture

STEP	ACTION	OPTICIAN	QA
4.1	Once the mirror is in the test fixture, the test fixture shall be stored in its own box until the mirror is needed for testing. Verify that the plastic cover is in place	( )	
omit ~~4.2~~	Position the storage box adjacent to where the test fixture is	( )	( )
omit ~~4.3~~	Using 2 persons, lift the test fixture into the storage box	( )	( )
4.4	The lid of the stroage box shall be secured	( )	
omit ~~4.5~~	The storage box shall be moved by 2 persons using the 2 attached handles to a safe location by means of Procedure 1	( )	( )
4.1.5	using crane, lift test fixture + position; then place ~~test~~ fixture into storage box.	( )	
4.1.6	Remove crane from fixture/storage box	( )	( )
**	Storage box is in a safe location.	( )	( )

12/27/93 12/27

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HST Back-up Secondary Mirror Handling Procedures

5. Transfer mirror/fixture to test set-up

STEP	ACTION	OPTICIAN	QA
5.1	Remove storage container cover.	( )	
5.2	Using slow speed of overhead crane, remove mirror/fixture from box via lift rings.	( )	
5.3	Transfer to test set-up and secure tow retainer bolts. For lateral stability.	( )	
5.4	Remove crane from fixture and store.	( )	

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HST Back-up Secondary Mirror Handling Procedures

4.0 Handling the mirror test fixture

STEP	ACTION	OPTICIAN	QA
4.1	Once the mirror is in the test fixture, the test fixture shall be stored in its own box until the mirror is needed for testing. Verify that the plastic cover is in place.	( )	( )
4.1.5	Using crane, lift fixture, and place into storage box	( )	( )
4.1.6	Remove crane from fixture/storage box	( )	( )
4.2	Was omitted		
4.3	Was omitted		
4.4	The lid of the storage box shall be secured	( )	( )
**	Assure storage box is in a safe location.	( )	( )

(Repeat 5.0 as necessary)

5.0 Transfer mirror/fixture to test set-up

STEP	ACTION	OPTICIAN	QA
5.1	Remove storage container cover.	( )	( )
5.2	Using slow speed of overhead crane, remove mirror/fixture from box via lift rings.	( )	( )
5.3	Transfer to test set-up and secure tow retainer bolts. For lateral stability.	( )	( )
5.4	Remove crane from fixture and store.	( )	( )

(Repeat 4.0 as necessary)

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HST Back-up Secondary Mirror Handling Procedures

4.0 Handling the mirror test fixture

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STEP	ACTION	OPTICIAN	QA
4.1	Once the mirror is in the test fixture, the test fixture shall be stored in its own box until the mirror is needed for testing. Verify that the plastic cover is in place.	( )	( )
4.1.5	Using crane, lift fixture, and place into storage box	( )	( )
4.1.6	Remove crane from fixture/storage box	( )	( )
4.2	Was omitted		
4.3	Was omitted		
4.4	The lid of the storage box shall be secured	( )	( )
	** Assure storage box is in a safe location.	( )	( )

(Repeat 5.0 as necessary)

5.0 Transfer mirror/fixture to test set-up

STEP	ACTION	OPTICIAN	QA
5.1	~~Remove storage container cover.~~	( )	( )
5.2	~~Using slow speed of overhead crane, remove mirror/fixture from box via lift rings.~~	( )	( )
5.3	~~Transfer to test set-up and secure tow retainer bolts. For lateral stability.~~	( )	( )
5.4	~~Remove crane from fixture and store.~~	( )	( )

~~(Repeat 4.0 as necessary)~~

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PROCEDURE FOR MEASURING THE VERTEX RADIUS AND CONIC CONSTANT OF THE BACK OF HST SECONDARY MIRROR.

PART NO. 679-1873-001

S/N 003

TEST CONDUCTOR U of Az

HDOS Rep. [redacted] 12/29/90

QUALITY Amanda O'Hara NASA/MSFC

TEST NO. 1

DATE OF TEST 12/28/90

ENG 12/29/90

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12/28/90

Procedure for measuring the vertex radius and conic constant of the backup HST secondary mirror

Note: Refer to the Figure for details of the test setup.

Procedure:

1) Place a point source microscope at the center of curvature of the Hindle sphere. Adjust microscope for best focus.

2) Without touching the microscope, move a 0.50" diameter steel ball in front of the microscope such that the center of the ball is coincident with the focus of the microscope.

3) Position the folding mirror longitudinally. The folding mirror is a 6" diameter flat certified to lambda/10 and has a 0.50" diameter steel ball cemented to its center. Using the calibrated measuring rod of length 3324.86 mm (130.900"), move the folding mirror up to the measuring rod. This will place the surface of the mirror at 3343.92 mm from center of curvature of the Hindle sphere. (In performing this step, first bring one end of the rod up to the ball at the center of curvature of the Hindle sphere. Use a piece of thin shim stock to determine position of rod relative to the ball. Then bring the ball on the fold mirror up to other end of the rod, again using shim stock.) (.001 shim stock on each end of rod) 65.438 65.461 130.899

4) Locate another 0.50" diameter steel ball at roughly the same height as the ball at the center of curvature of the Hindle sphere and about 400 mm to the side of it. Use the 3324.86 mm measuring rod to determine the longitudinal spacing of this ball. Use the same method as in step 3) to position this ball. 130.899

5) Adjust an interferometer with a nominally 300 mm focal length diverger that has already been calibrated per the appropriate procedure so that the focus of the diverger is coincident with the center of the ball located in step 4). The axis of the interferometer should be pointing at the center of the fold mirror. (The interferometer will now be focused at the long conjugate of the Hindle test.)

6) Offset the steel ball at the interferometer focus so the interferometer diverging beam illuminates the fold mirror.

7) Insert the secondary mirror/cell assembly into the large mirror holder that is located about 600 mm from the short test conjugate (the conjugate at the center of curvature of the Hindle sphere). Handle the mirror using the overhead crane to move the assembly from its special storage box to the mirror holder. When the mirror is in place and before removing the lifting strap, secure the mirror assembly with 2 bolts.

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TEST 1

TEMP 6808 F 335 - 41 12/23/9-

7a) Remove the Lexan protective cover from the secondary mirror.

INSTALL LEXAN COVER. TRANSFER MIRROR TO STORAGE.

8) Adjust the tilt of the secondary until the autoreflected light beam is centered on the interferometer diverger and there is an indication of fringes. ALIGNED DISTURBED. REMOVE SEC. MIRROR & REALIGN SYSTEM.

9) Continue to adjust the focus, decenter and tilt of the secondary until the fringe pattern is largely free of coma, focus and tilt. Ideally alignment would be continued until the fringes were nominally straight and about 10 fringes filled the monitor screen.

10) Record and store 5 interferograms of the Hindle test wavefront in a file named ______________________.

11) Position a 0.50" steel ball at the vertex of the secondary mirror. Center the ball laterally by eye. Adjust longitudinally by using a piece of shim stock to determine the proximity of the ball to the vertex.

12) Without touching the ball, move the mirror assembly back away from the ball about 2".

13) Replace the protective Lexan cover on the mirror being careful not to touch the ball.

14) Attach the crane strap and remove the 2 securing bolts holding the secondary mirror assembly.

15) Use the crane to remove the mirror assembly and replace it in its storage box. Secure the lid on the box.

16) Using a pair of inside micrometers, measure the distance between the ball at the vertex of the secondary and the ball at the short conjugate. Use shim stock to determine the fit of the micrometers.

17) Verify with the point source microscope that the ball at the short conjugate has not moved.

18) Check the inside micrometer reading with the calibrated calipers. Remember to add in half the diameter of the ball (12.7 mm) to get the short conjugate distance. Record s as ____________ mm.

19) As an intermediate step, calculate R = 2(s*s')/(s'-s) and k = -((s+s')/(s'-s))^2.

20) In the computer, average the 5 interferograms of the Hindle test and store in a file named ________________.

21) Subtract the Hindle sphere wavefront from the data in the file above and store in a file named ____________________.

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CHECK 12/23/9-

TEST 1

22) Subtract the interferometer/diverger calibration wavefront from the data in the above file and store in a file named ________________________.

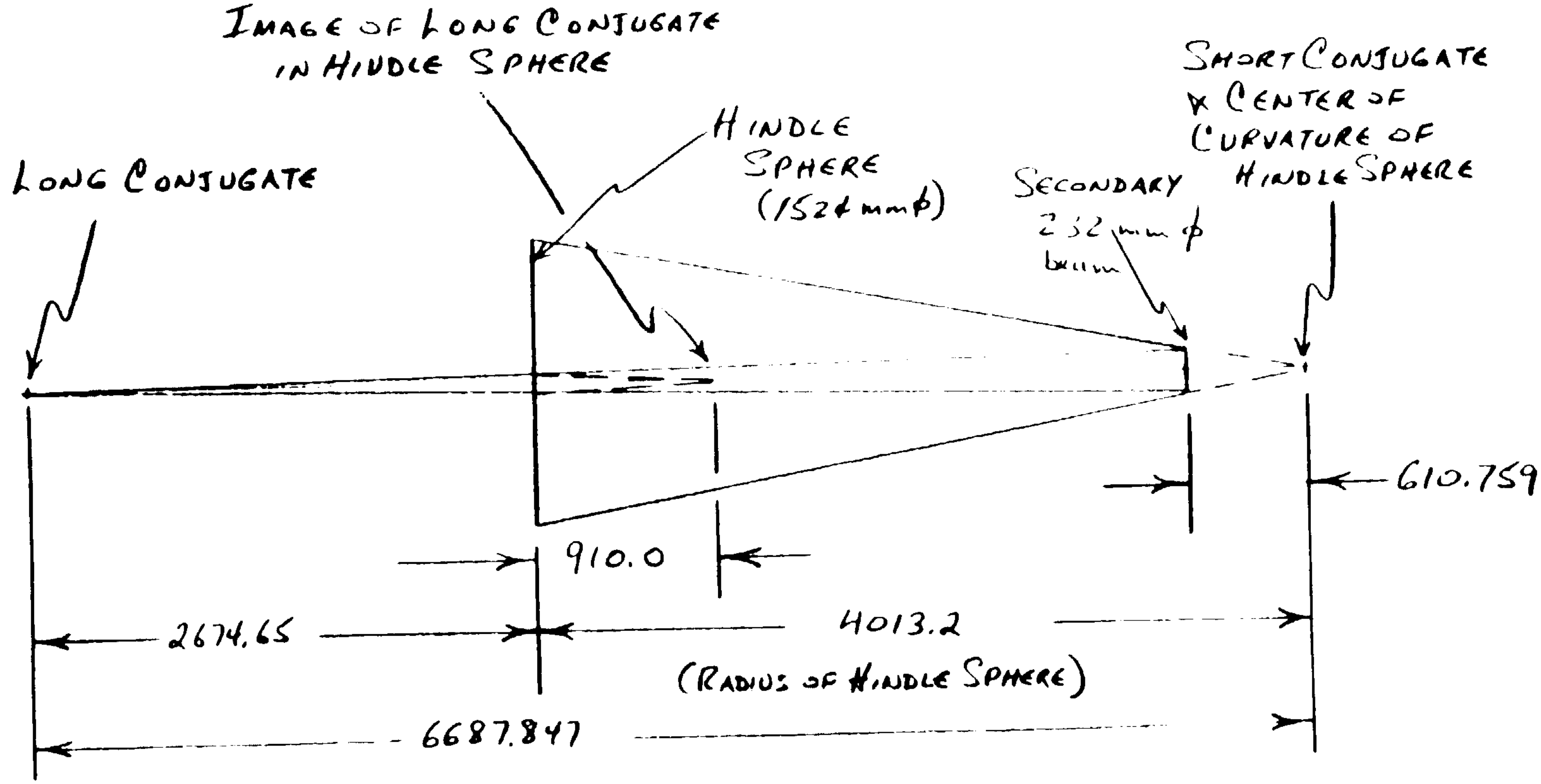
23) Using the residual first order (3 term fit) focus term, correct the R value found in step 19) and record R' = _______.

24) Using the residual 3rd order spherical aberration coefficient from the above file, correct the value of k found in step 19) and record as k' = _____________.

25) Repeat the above procedure 2 more times to gather a complete data package for the test of the secondary mirror.

JCH 12/28/90

TEST 1



SHORT CONJUGATE, $S = 610.759$

LONG CONJUGATE, $S' = 6077.088$

$$R_s = 2\frac{SS'}{S-S'}$$

$$K = -\left(\frac{S+S'}{S-S'}\right)^2$$

FIG. 1 SCHEMATIC OF SECONDARY HINDLE TEST

TEST 1

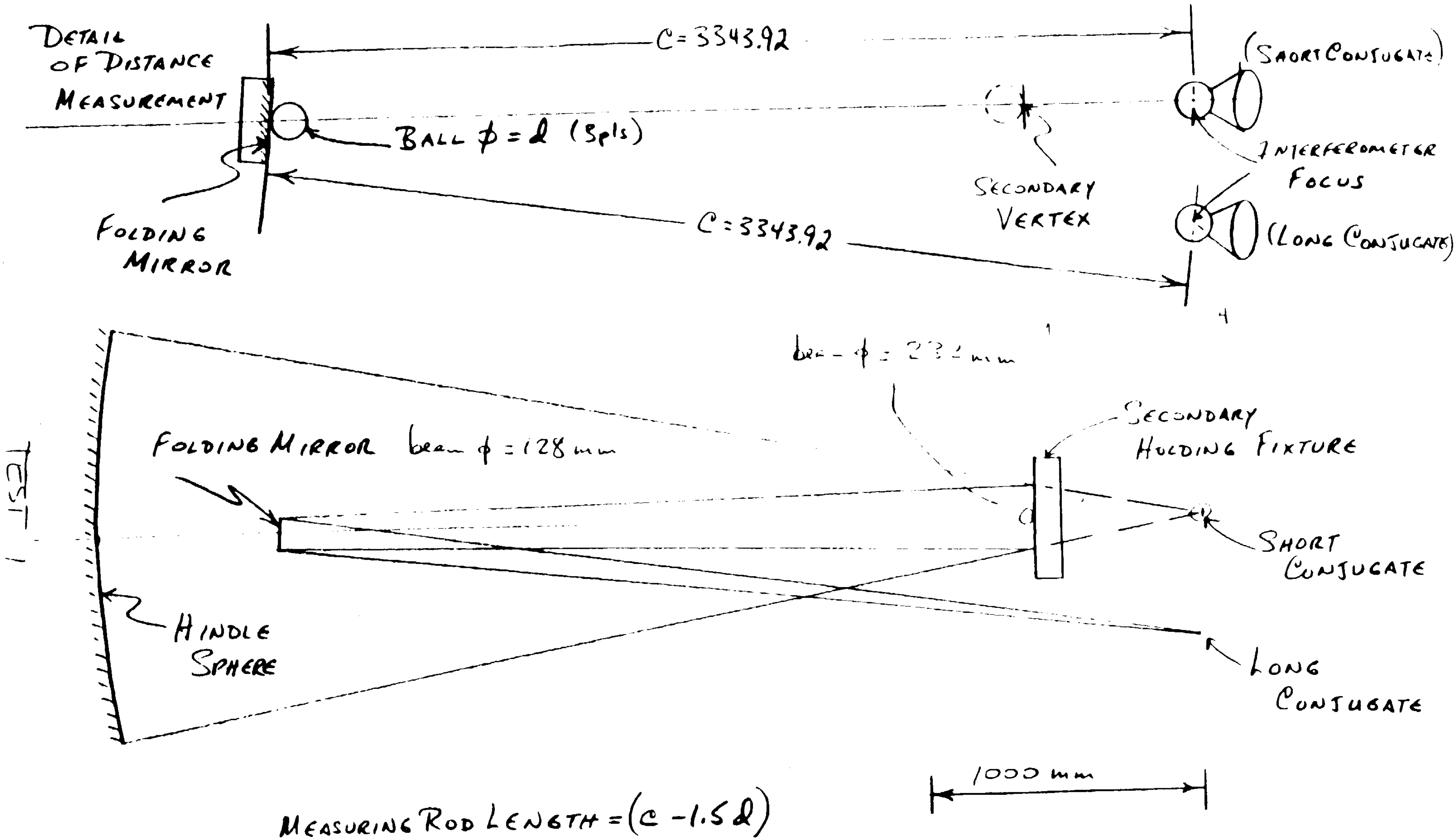


Fig. 2 Details of Secondary Hindle Tests

Test Number One

Dec 29, 1990

$\boxed{F_1 + F_2}$

$\frac{\phi B_1}{2}$ = .5000/2 = .2500

Measuring Rod #1 30.9[illegible]

$2\phi B_2$ = .5000 × 2 = 1.0000
@ 69.3°F

Measuring Rod #2 130.899

$\frac{\phi B_3}{2}$ = .5000/2 = .2500

Cement Thickness × 2 = .0005 × 2 = .0010
@ 69.3°F

Other

263.299 in
6,687.795 mm
Nom : [illegible]
Δ = [illegible]

$\boxed{F_1 + F_2}$ =

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HDH
12/29/9[illegible]

TEST #1 ...

$\boxed{F_2}$

MEASURING ROD #3 23.3015

SAG: .0024

$\frac{\varnothing\ B_1}{2}$ .2500

$\Sigma =$ 24.0539 in
(610.969 mm)
Nom = 610.759 mm
$\Delta = 210$

$$F_1 = (F_1 + F_2) - F_2 = 6687.795 - 610.9691 = 6076.836$$

TEST CALCULATIONS:

$$R_V = 2 \frac{F_1 \cdot F_2}{(F_2 - F_1)} = 1358.525$$

$$K = (-1) \cdot \left(\frac{F_1 + F_2}{F_1 - F_2} \right)^2 = -1.49686$$

$- \Delta = .000$

$$E = K + 1$$

NOMINAL E = -.49686
R_V = 1358.00mm
NOMINAL K = -1.49686

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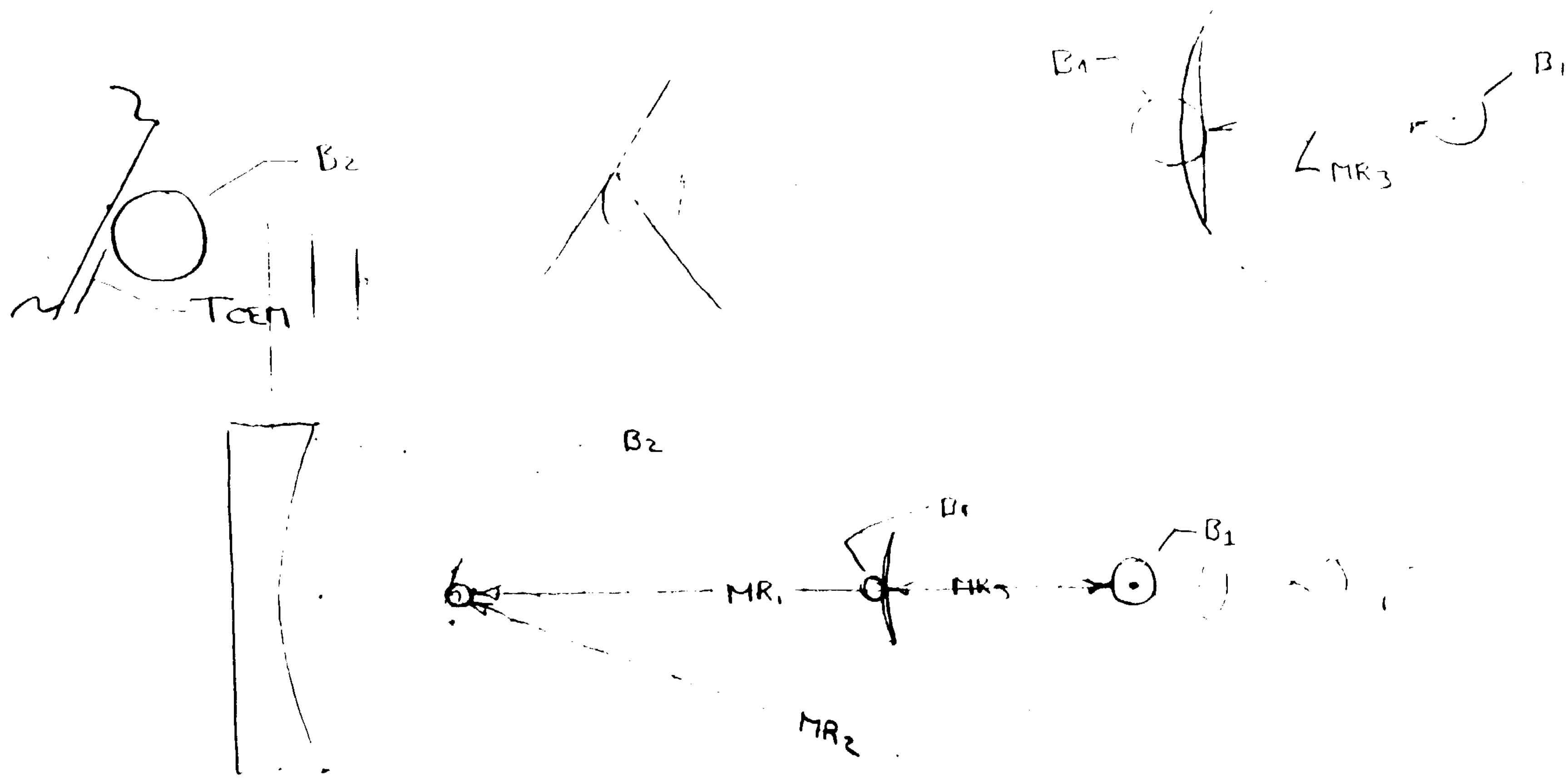

$$F_1 + F_2 = \frac{\phi B_1}{2} + \underbrace{MR_1}_{\#1+\#2} + 2\phi B_2 + \underbrace{MR_2}_{\#1+\#2+\#3} + \frac{\phi B_3}{2} + 2 \times T_{CEM}$$

$$F_2 = MR_3 + SAG + \phi \frac{B_1}{2}$$

$$F_1 = (F_1 + F_2) - F_2$$

HDHALL

PROCEDURE FOR MEASURING THE VERTEX RADIUS AND CONIC CONSTANT OF THE BACK UP HST SECONDARY MIRROR

PART NO. 679-1873-001

S/N 003

TEST CONDUCTOR [illegible]

HDOS Rep

[redacted] [illegible] 12/29/90

QUALITY Amanda O'Harris NASA/MSFC

TEST NO. 2

DATE OF TEST 12/28/90

ENG Harry J Johnston 12/29/90

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(2)

4:30 PM 12/28/90

Procedure for measuring the vertex radius and conic constant of the backup HST secondary mirror

Note: Refer to the Figure for details of the test setup.

Procedure:

1) Place a point source microscope at the center of curvature of the Hindle sphere. Adjust microscope for best focus.

2) Without touching the microscope, move a 0.50" diameter steel ball in front of the microscope such that the center of the ball is coincident with the focus of the microscope.

3) Position the folding mirror longitudinally. The folding mirror is a 6" diameter flat certified to lambda/10 and has a 0.50" diameter steel ball cemented to its center. Using the calibrated measuring rod of length 3324.86 mm (130.900"), move the folding mirror up to the measuring rod. This will place the surface of the mirror at 3343.92 mm from center of curvature of the Hindle sphere. (In performing this step, first bring one end of the rod up to the ball at the center of curvature of the Hindle sphere. Use a piece of thin shim stock to determine position of rod relative to the ball. Then bring the ball on the fold mirror up to other end of the rod, again using shim stock.) .001 shim at each end 130.899

4) Locate another 0.50" diameter steel ball at roughly the same height as the ball at the center of curvature of the Hindle sphere and about 400 mm to the side of it. Use the 3324.86 mm measuring rod to determine the longitudinal spacing of this ball. Use the same method as in step 3) to position this ball. shim .001 at each end 130.899"

5) Adjust an interferometer with a nominally 300 mm focal length diverger that has already been calibrated per the appropriate procedure so that the focus of the diverger is coincident with the center of the ball located in step 4). The axis of the interferometer should be pointing at the center of the fold mirror. (The interferometer will now be focused at the long conjugate of the Hindle test.)

6) Offset the steel ball at the interferometer focus so the interferometer diverging beam illuminates the fold mirror.

7) Insert the secondary mirror/cell assembly into the large mirror holder that is located about 600 mm from the short test conjugate (the conjugate at the center of curvature of the Hindle sphere). Handle the mirror using the overhead crane to move the assembly from its special storage box to the mirror holder. When the mirror is in place and before removing the lifting strap, secure the mirror assembly with 2 bolts.

12/28/90

TEMP 67.87 4:30PM 12/20/90

7a) Remove the Lexan protective cover from the secondary mirror. TJD

8) Adjust the tilt of the secondary until the autoreflected light beam is centered on the interferometer diverger and there is an indication of fringes. TJD

9) Continue to adjust the focus, decenter and tilt of the secondary until the fringe pattern is largely free of coma, focus and tilt. Ideally alignment would be continued until the fringes were nominally straight and about 10 fringes filled the monitor screen. TJD

10) Record and store ~~5~~ 3 OR MORE AH interferograms of the Hindle test wavefront in a file named HTB 1 → ~~5~~ 3 (OR MORE) AH. TJD

11) Position a 0.50" steel ball at the vertex of the secondary mirror. Center the ball laterally by eye. Adjust longitudinally by using a piece of shim stock to determine the proximity of the ball to the vertex. .002 Shim TJD

12) Without touching the ball, move the mirror assembly back away from the ball about 2". TJD

13) Replace the protective Lexan cover on the mirror being careful not to touch the ball. TJD AH

14) Attach the crane strap and remove the 2 securing bolts holding the secondary mirror assembly. TJD AH

15) Use the crane to remove the mirror assembly and replace it in its storage box. Secure the lid on the box. TJD AH

16) Using a pair of inside micrometers, measure the distance between the ball at the vertex of the secondary and the ball at the short conjugate. Use shim stock to determine the fit of the micrometers. .002 shim MIRROR END ⟷ .001 shim BALL END TJD

Verify on 6 Ft Caliper
23.806 - .004 = 23.802
Inside Mic Length Meas.

17) Verify with the point source microscope that the ball at the short conjugate has not moved. TJD

18) Check the inside micrometer reading with the calibrated calipers. Remember to add in half the diameter of the ball (12.7 mm) to get the short conjugate distance. Record s as 604.57 mm. 23.802 inches TJD

19) As an intermediate step, calculate R = 2(s*s')/(s'-s) and k = -((s+s')/(s'-s))^2.
Rv = 1358.74 (Nom = 1358.0 ± Δ = 740μ)
K = -1.49718 (Nom = -1.49686 ± Δ = .0003)

20) In the computer, average the ~~5~~ 3 OR MORE interferograms of the Hindle test and store in a file named ~~HTB 1-5~~ AH HTBAAVE. AH

21) Subtract the Hindle sphere wavefront from the data in the file above and store in a file named ____________________.

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TEST 2

22) Subtract the interferometer/diverger calibration wavefront from the data in the above file and store in a file named ______________________.

23) Using the residual first order (3 term fit) focus term, correct the R value found in step 19) and record R' = _______.

24) Using the residual 3rd order spherical aberration coefficient from the above file, correct the value of k found in step 19) and record as k' = _____________.

25) Repeat the above procedure 2 more times to gather a complete data package for the test of the secondary mirror.

TEST 2

FIRST "REAL TEST"

(F1 + F2)

$\phi B_1/2$	.2500
MR1	130.899
$2\phi B_2$	1.000
MR2	130.999
$\phi B_3/2$	.2500
[illegible]	.0010
SHIM 4 x .001	.004
	263.303 INCHES

$F_1 + F_2$ = 6687.896 mm (Nom = 6687.947) Δ = 49 μ

F_2 -	MR3	23.802
	SA:	.0024
	SHIM	.003
	$\phi B_1/2$	.250
	Σ =	240574 IN
		611.058 mm

(Non = 610.759 mm) Δ = 300 μ

F_1 = 6076.838

F_2 = 611.058

R_v = 1358.74 (Δ = + 740 μ

K = -1.49718 (Δ = -.0003)

Nom = -1.49686

HD HALL
12/28/9

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PROCEDURE FOR MEASURING THE VERTEX RADIUS AND CONIC CONSTANT OF THE BACK UP SECONDARY MIRROR

PART NO 679-1873-001

S/N 003

TEST CONDUCTOR

HDOS Rep
[redacted]
12/29/90

QUALITY Amanda O Harris NASA/MSFC

TEST NO 3

DATE OF TEST 12/29/90

ENG Harry W. Johnston 12/29/90

RUN #2 (3) TEMP 68.14°F 8 45 AM

12/29/90

Procedure for measuring the vertex radius and conic constant of the backup HST secondary mirror

Note: Refer to the Figure for details of the test setup.

Procedure:

✓1) Place a point source microscope at the center of curvature of the Hindle sphere. Adjust microscope for best focus. TJD

✓2) Without touching the microscope, move a 0.50" diameter steel ball in front of the microscope such that the center of the ball is coincident with the focus of the microscope. TJD

3) Position the folding mirror longitudinally. The folding mirror is a 6" diameter flat certified to lambda/10 and has a 0.50" diameter steel ball cemented to its center. Using the calibrated measuring rod of length 3324.86 mm (130.900"), move the folding mirror up to the measuring rod. This will place the surface of the mirror at 3343.92 mm from center of curvature of the Hindle sphere. (In performing this step, first bring one end of the rod up to the ball at the center of curvature of the Hindle sphere. Use a piece of thin shim stock to determine position of rod relative to the ball. Then bring the ball on the fold mirror up to other end of the rod, again using shim stock.) .001" shim on each end. 130.899 TJD

4) Locate another 0.50" diameter steel ball at roughly the same height as the ball at the center of curvature of the Hindle sphere and about 400 mm to the side of it. Use the 3324.86 mm measuring rod to determine the longitudinal spacing of this ball. Use the same method as in step 3) to position this ball. 130.899 TJD

.001" shim on each end

5) Adjust an interferometer with a nominally 300 mm focal length diverger that has already been calibrated per the appropriate procedure so that the focus of the diverger is coincident with the center of the ball located in step 4). The axis of the interferometer should be pointing at the center of the fold mirror. (The interferometer will now be focused at the long conjugate of the Hindle test.) TJD

6) Offset the steel ball at the interferometer focus so the interferometer diverging beam illuminates the fold mirror. TJD

7) Insert the secondary mirror/cell assembly into the large mirror holder that is located about 600 mm from the short test conjugate (the conjugate at the center of curvature of the Hindle sphere). Handle the mirror using the overhead crane to move the assembly from its special storage box to the mirror holder. When the mirror is in place and before removing the lifting strap, secure the mirror assembly with 2 bolts. TJD

12/29/90

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TEST 3

7a) Remove the Lexan protective cover from the secondary mirror. TJD

8) Adjust the tilt of the secondary until the autoreflected light beam is centered on the interferometer diverger and there is an indication of fringes. TJD

9) Continue to adjust the focus, decenter and tilt of the secondary until the fringe pattern is largely free of coma, focus and tilt. Ideally alignment would be continued until the fringes were nominally straight and about 10 fringes filled the monitor screen. TJD

10) Record and store ~~3~~ 5 (OR MORE AH) interferograms of the Hindle test wavefront in a file named ~~HTC1.Z5~~ (OR more) AH. TJD

11) Position a 0.50" steel ball at the vertex of the secondary mirror. Center the ball laterally by eye. Adjust longitudinally by using a piece of shim stock to determine the proximity of the ball to the vertex. .002" shim used TJD AH

12) Without touching the ball, move the mirror assembly back away from the ball about 2". TJD

13) Replace the protective Lexan cover on the mirror being careful not to touch the ball. TJD AH

14) Attach the crane strap and remove the 2 securing bolts holding the secondary mirror assembly. TJD AH

15) Use the crane to remove the mirror assembly and replace it in its storage box. Secure the lid on the box. TJD AH

16) Using a pair of inside micrometers, measure the distance between the ball at the vertex of the secondary and the ball at the short conjugate. Use shim stock to determine the fit of the micrometers. .002 shim .001 shim 23.801

17) Verify with the point source microscope that the ball at the short conjugate has not moved. TJD AH

18) Check the inside micrometer reading with the calibrated calipers. Remember to add in half the diameter of the ball (12.7 mm) to get the short conjugate distance. Record s as 604.545 mm. .002 at each end 604.570 TJD AH

23.805 - .004 = 23.801 1ST
23.806 - .004 = 23.802 2ND

19) As an intermediate step, calculate $R = 2(s*s')/(s'-s)$ and $k = -((s+s')/(s'-s))^2$.
$R_V = 1358.682$ $\Delta = .683\sim$
$K = -1.49718$ $\Delta = -.0003$ 12/22/92

20) In the computer, average the ~~3~~ 5 (OR MORE AH) interferograms of the Hindle test and store in a file named ~~HTC1.Z5~~ AH HTCCAVE AH

21) Subtract the Hindle sphere wavefront from the data in the file above and store in a file named __________________.

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TEST 3

22) Subtract the interferometer/diverger calibration wavefront from the data in the above file and store in a file named ______________________.

23) Using the residual first order (3 term fit) focus term, correct the R value found in step 19) and record R' = _______.

24) Using the residual 3rd order spherical aberration coefficient from the above file, correct the value of k found in step 19) and record as k' = _____________.

25) Repeat the above procedure 2 more times to gather a complete data package for the test of the secondary mirror.

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TEST 3

"SECOND REAL TEST"

$(F_1 + F_2)$

$\phi B_1/2$	–	.2500
MR1		130.899
$2 \times \phi B_2$		1.0000
MR2		130.399
$\phi B_3/2$		.2500
Cement		.0010
Shims		.0040
$F_1 + F_2$ Σ	=	263.303 INCHES
	=	6687.896

(F_2)

MR3	23.801
SAG	.0024
SHIM	.003
$\phi B_1/2$	.2500
Σ :	24.0564 INCH = 611.033 mm

$F_1 = (F_1 + F_2) - F_2 = 6076.863$

$R_v = 1358.682$ $\Delta = 683\mu$

$K = -1.49715$ $(\Delta = -.0003)$

Nom = -1.49686

HDHALL
12/29/90

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PROCEDURE FOR MEASURING THE VERTEX RADIUS AND CONIC CONSTANT OF THE BACK UP HST SECONDARY MIRROR

PART NO 679-1873-001

S/N 003

TEST CONDUCTOR

HDOS Rep
[redacted]

12/29/90

QUALITY Amanda OeHaus NASA/MSFC

TEST NO. 4

DATE OF TEST 12/29/90

ENG Harry H Johnston 12/29/90

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(4) Temp. 68.18 °F 11:00 AM

12/29/90

Procedure for measuring the vertex radius and conic constant of the backup HST secondary mirror

Note: Refer to the Figure for details of the test setup.

Procedure:

1) Place a point source microscope at the center of curvature of the Hindle sphere. Adjust microscope for best focus. T.J.D.

2) Without touching the microscope, move a 0.50" diameter steel ball in front of the microscope such that the center of the ball is coincident with the focus of the microscope. T.J.D.

3) Position the folding mirror longitudinally. The folding mirror is a 6" diameter flat certified to lambda/10 and has a 0.50" diameter steel ball cemented to its center. Using the calibrated measuring rod of length 3324.86 mm (130.900"), move the folding mirror up to the measuring rod. This will place the surface of the mirror at 3343.92 mm from center of curvature of the Hindle sphere. (In performing this step, first bring one end of the rod up to the ball at the center of curvature of the Hindle sphere. Use a piece of thin shim stock to determine position of rod relative to the ball. Then bring the ball on the fold mirror up to other end of the rod, again using shim stock.) .001 shim each end 130.899 T.J.D.

4) Locate another 0.50" diameter steel ball at roughly the same height as the ball at the center of curvature of the Hindle sphere and about 400 mm to the side of it. Use the 3324.86 mm measuring rod to determine the longitudinal spacing of this ball. Use the same method as in step 3) to position this ball. .001 shim at each end T.J.D. 130.899

5) Adjust an interferometer with a nominally 300 mm focal length diverger that has already been calibrated per the appropriate procedure so that the focus of the diverger is coincident with the center of the ball located in step 4). The axis of the interferometer should be pointing at the center of the fold mirror. (The interferometer will now be focused at the long conjugate of the Hindle test.) T.J.D.

6) Offset the steel ball at the interferometer focus so the interferometer diverging beam illuminates the fold mirror. T.J.D.

7) Insert the secondary mirror/cell assembly into the large mirror holder that is located about 600 mm from the short test conjugate (the conjugate at the center of curvature of the Hindle sphere). Handle the mirror using the overhead crane to move the assembly from its special storage box to the mirror holder. When the mirror is in place and before removing the lifting strap, secure the mirror assembly with 2 bolts. T.J.D.

TEST 4

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7a) Remove the Lexan protective cover from the secondary mirror.

8) Adjust the tilt of the secondary until the autoreflected light beam is centered on the interferometer diverger and there is an indication of fringes. TJD

9) Continue to adjust the focus, decenter and tilt of the secondary until the fringe pattern is largely free of coma, focus and tilt. Ideally alignment would be continued until the fringes were nominally straight and about 10 fringes filled the monitor screen. TJD

10) Record and store 5 OR MORE AH interferograms of the Hindle test wavefront in a file named HTD1 → 25 (or more) AH. TJD

11) Position a 0.50" steel ball at the vertex of the secondary mirror. Center the ball laterally by eye. Adjust longitudinally by using a piece of shim stock to determine the proximity of the ball to the vertex. .002 TJD

12) Without touching the ball, move the mirror assembly back away from the ball about 2". TJD

13) Replace the protective Lexan cover on the mirror being careful not to touch the ball.

14) Attach the crane strap and remove the 2 securing bolts holding the secondary mirror assembly. TJD

15) Use the crane to remove the mirror assembly and replace it in its storage box. ~~Secure the lid on the box.~~ Crane remained attached AH TJD

16) Using a pair of inside micrometers, measure the distance between the ball at the vertex of the secondary and the ball at the short conjugate. Use shim stock to determine the fit of the micrometers. TJD

17) Verify with the point source microscope that the ball at the short conjugate has not moved. TJD

18) Check the inside micrometer reading with the calibrated calipers. Remember to add in half the diameter of the ball (12.7 mm) to get the short conjugate distance. Record s as 604.570 mm. .001 shim on each end. 23.802 23.802 TJD

caliper 23.806 - .004

.002 shim on each end

19) As an intermediate step, calculate R = 2(s*s')/(s'-s) and k = -((s+s')/(s'-s))^2.

R_v = 1358.745mm K = -1.4718 Δ = -0.0003

20) In the computer, average the 5 OR MORE AH interferograms of the Hindle test and store in a file named HTDCAVE.

12/29/9

21) Subtract the Hindle sphere wavefront from the data in the file above and store in a file named ____________________.

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TEST 4

"THIRD REA_ TEST"

F1 + F2

ϕ B1/2 -	.2500
MR1	130.899
[illegible]	1.000
[illegible]	130.899
[illegible]	.2500
[illegible]	.[illegible]
CAP[illegible]	.0040
Σ =	263.303 INCHES
	6687.896 mm

F2

MR3	23.802
CAG	.0024
SHIM	.0030
ϕB1/2	.2500
Σ =	24.0574
=	611.058

F1 = (F1 + F2) - F2 = 6076.838 mm

R_v	1358.745 mm	Δ = + 745μ
NOMINAL =	1358 mm	
K =	-1.49718	
NOMINAL =	-1.49686	Δ = -0.0003

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Secondary Mirror

679-1873-001 S/N 003 12/29/90

6.0 TRANSFER MIRROR FROM TEST Fixture to shipping Box

6.1 TRANSFER TEST FIXTURE/MIRROR ASSEMBLY to 3 Leg platform. (+)

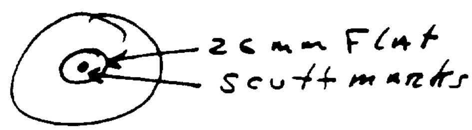
6.2 Remove LEXAN COVER. (+)

6.3 Remove 6 Bolts AND 3 plastic RETAINERS. (+)

6.4 SLIDE FIXTURE AWAY FROM MIRROR (+)

6.5 perform visual Inspection (+)

Note: spray silver scuffed AWAY FROM CENTER OF MIRROR surface



CAUSED By shim stock RUBBING on surface during measurements.

6.6 TRANSFER mirror to shipping CONTAINER. (+)

6.7 INSTALL Lexan protective COVER. (+)

6.8 INSTALL protective foam. (+)

6.9 INSTALL wooden cover and secure Latches. (+)

6.10 INSTALL SAFETY STRAPS. (+)

TRANSFER to HDOS DANBURY Ct.
T. DUBOS / H. HALL
HAND CARRY.

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Accelerators - ok.

T. Dubos
HDOS

Amanda Harris
NASA/MSFC 12/

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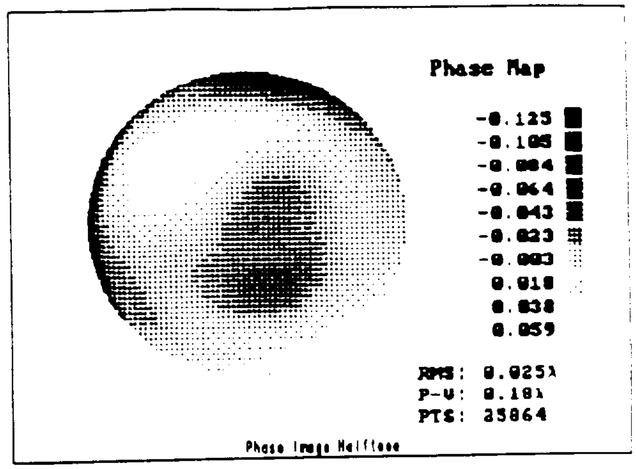
12/29

AVE OF 30 INTERFEROGRAMS OF A STEEL BALL

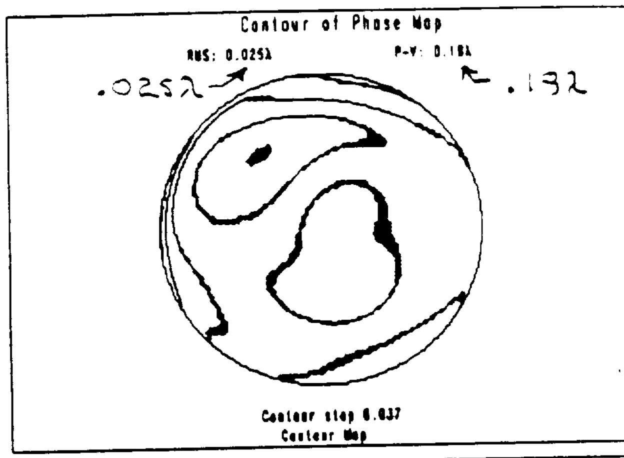
Quality of Fit for Different Polynomial Orders

Term	N	Rms fit	Zernike Polynomial Coefficients
Plane	2	0.025	0.000 0.000
Sphere	3	0.025	0.000 0.000 -0.000
4th Order	8	0.010	-0.000 -0.000 0.000 -0.006 -0.019 0.027 -0.044 -0.025
6th Order	15	0.007	0.000 -0.000 0.000 -0.006 -0.019 0.027 -0.044 -0.026 0.006 0.014 -0.006 0.005 0.002 -0.004 0.001
8th Order	24	0.006	0.000 -0.000 0.000 -0.006 -0.019 0.028 -0.044 -0.026 0.006 0.014 -0.006 0.005 0.003 -0.004 0.001 -0.010 -0.001 0.000 -0.005 -0.002 -0.001 0.007 0.011 0.003
Complete	36	0.001	-0.000 -0.000 0.000 -0.006 -0.019 0.027 -0.044 -0.026 0.006 0.013 -0.005 0.005 0.002 -0.003 0.001 -0.008 0.000 -0.000 -0.005 -0.001 -0.002 0.006 0.011 0.003 -0.002 -0.000 -0.001 0.005 0.010 -0.007 -0.010 0.007 0.006 -0.009 -0.004 -0.007

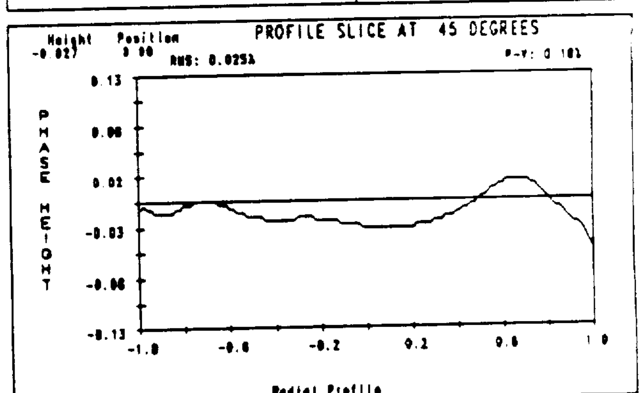
Zernike Coefficients



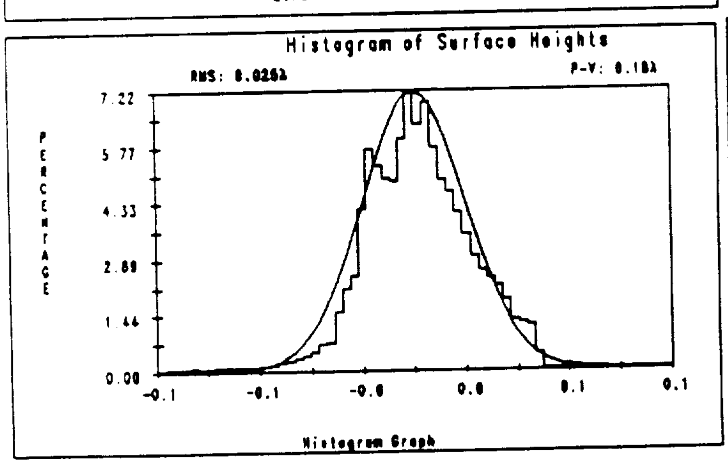
Phase Image Halftone



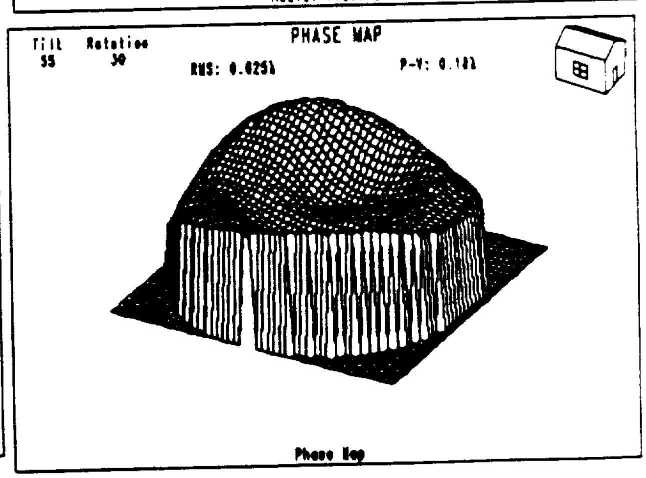
Contour step 0.037
Contour Map



Radial Profile



Histogram Graph



Phase Map

hsumave		Phase Analysis Software Tools Version 2.08
13:08:39	12-27-90	Phase Shift Tech, Inc. (c) 1986-1989

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CALIBRATION DOCUMENTATION

12/2[illegible]