Palomar Hale 200" M1 to M2 distance measurement

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1 Introduction

During the design phase of CWI there was some uncertainty as to the distance from the secondary to a datum surface on the 200" Hale Telescope. For most instruments this is not a problem as the location is sufficiently close to the nominal Cassegrain focus, that the telescope can be easily focused to where it require it. The CWI design is such that the telescope needs to focus close to the lower end of the available range. Dan McKenna, Jeff Zolkower, Shahin Rahman, and I used a laser range finder newly acquired by Palomar to measure the location of the secondary. According to the manufacturer, the range-finder measurements are accurate to within 1.5 mm, with the caveat that the instrument is typically used with a diffusing, rather than specular, surface. Data was taken on June 26, 2008, the temperature of the primary mirror cell was 20°C, the primary focus cage was at 17°C. The original version of this write-up was put together on July 1st, 2008 and updated in May 2011.

2 Configuration

This range-finder was clamped in a vice, placed on the observatory floor with the cass-cage door removed. It was aligned along the optical axis of the telescope by eye. The device was shifted so that the return beam from the secondary did not come back directly onto the sensor, otherwise the device was saturated and would not produce an output. This shift/tilt does not introduce more than 1 mm of difference into the measurement.

The telescope was fitted with the F/16 secondary and data points were taken for several primary cage encoder readings (Table 2). To provide a datum surface a 1/2" thick aluminum bar was clamped

flush against the cass rotator ring. The range-finder was then used to measure the distance to that bar. This measurement is also noted in Table 2.

Finally, a caliper and ruler were used to measure the offset of the lower surface of the aluminum bar from the lower surface of the true cass ring (this is the ring shown in the construction drawing from Hal Petrie, (4). The remaining distances used in the calculation were taken from that same drawing.

Primary Cage Encoder Reading	Distance Measurement (mm)
1.01	19263
2	19264
8	19270
15	19277
22	19284
29	19291
36	19298
43	19305
50	19312
70	19333
Bar Reading	4317

Table 1: Encoder reading for the primary focus cage and measured position of the secondary from the range-finding device resting in a vice on the observatory floor. Also included is the distance from the device at that same place to a 1/2" thick bar spanning the bottom face of the cassegrain rotator ring. The error in each measurement is no worse than 1.5mm

3 Results

The total thickness from the bottom surface of the aluminum bar to the bottom surface of the cass ring is 56.5 mm. Taking the measurement at 36mm as the "central" location of the secondary, this gives the distance from the secondary to the lower cass ring as: 14924.5 mm. The corresponding distance from the secondary to the primary vertex is: 13763.4 mm. The value used in CWI design for this distance is 13768.0 mm, which is in reasonable agreement with the measured quantity. The error in our measurement should not exceed 3mm, though this is a best-guess estimate of the error.

Distance From	Distance To	(mm)	Notes
Aluminum bar	Cass Rotator	12.7	Clamped. ($\frac{1}{2}$")
Cass Rotator	Metal Ruler	10.7	Next surface is beveled. Ruler needed to be able To use the caliper.
Metal Ruler	Second Ring	1	See above
Second Ring	Cass Ring Lower Surface	32.1	
Cass Ring	Mirror Cell	117.5	From Hale Drawing ($4\frac{5}{8}$")
Mirror Cell		612.8	Thickness. From Drawing ($24\frac{1}{8}$")
Gap		38.1	Between Mirror Cell and Mirror. From Drawing. ($1\frac{1}{2}$")
200" Mirror Rear	Mirror Vertex	498.5	From Drawing. ($19\frac{5}{8}$")

Table 2: Other distances relevant to the measurement. Some were performed at Palomar on June 26, 2008, the error on these is uncertain, but unlikely to total more than 3mm or so. Others are taken from the Palomar 200" drawing.

4 Discussion

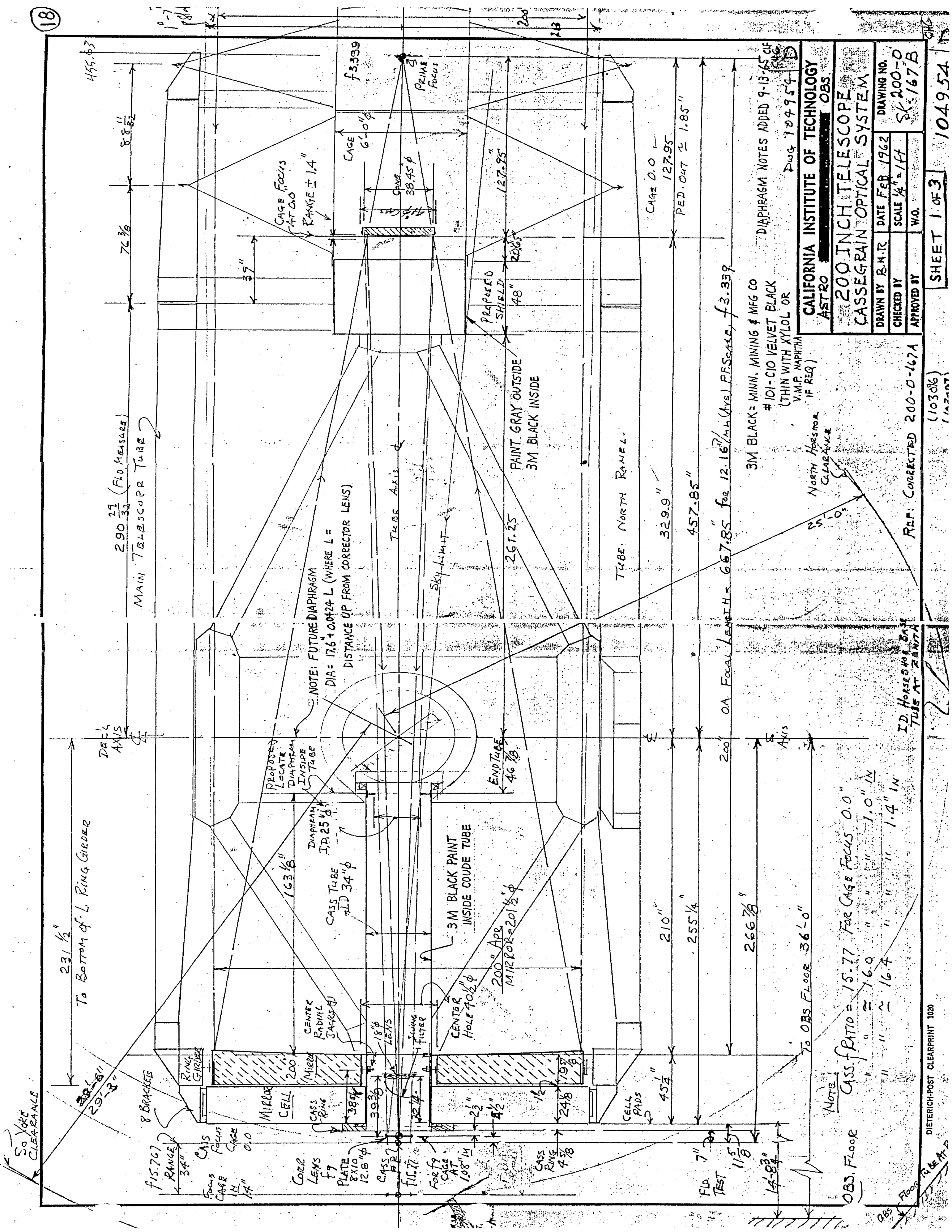
This measurement does not gives either the curvature of the secondary, nor the focus location, and as such must rely on prior data to yield a useful conclusion about the location of the nominal focus. We do have one data point to work from, which is the location of the PALM3k focus as indicated in the "as built" `ZEMAX` ray-trace of the system[1]:
`http://www.oir.caltech.edu/twiki_oir/bin/view/Palomar/HaleOptics`.
The M2 to focus distance given by the file is 14997mm. This puts the focus at ∼72.5 mm below the original cass ring, or, ∼28.5 mm below the cass rotator ring. The night before our measurement, the cass encoder reading was 55 with an AO instrument in-use. Taking the nominal values of the prime

[1]At the time when this report was originally written, in mid-2008, the ray-trace was at: `http://www.oir.caltech.edu/twiki_oir/bin/view/Palomar/Reference/OpticalModels`. That URL appears to have been lost. That was a model of the Hale telescope used for PALMAO and included several useful reference surfaces; the link in-text is a simplified version of that model. This was also the model of the telescope used in the design of CWI. A `ZEMAX` generated prescription file of this model is attached at the end of this document.

focus focal ratio and that of the Cass F/#, the shift in the position of the secondary corresponds to a factor of 22.6 larger shift in the focus position. $((\frac{F_{cass}}{F_{primary}})^2 = (\frac{15.7}{3.3})^2)$. The CWI focus is 900 mm behind the PALMAO focus, requiring the secondary be shifted downward by 39.8 mm from the PALMAO location, to an encoder reading of, roughly, 15 mm. This indicates that the Hale can be focused far enough behind the primary mirror for the purposes of CWI. These measurement givee no indication about the image quality at any point in the focus range, that measurement would likely require some on-sky engineering time.

5 Follow-up

The preceding paragraphs were written shortly after the distance measurements were made (mid 2008). At time of this update (May 2011), CWI had been built, commissioned, and seen several observing runs. The secondary-defocus surface thickness in the CWI `ZEMAX` model is -17.33 mm when the telescope is in-focus at the slicer. The instrument focuses well and close to the location found by our measurement and computed with `ZEMAX`. The secondary encoder reading for best focus has varied from 17 to 22 during our observing runs, depending on dome temperature. (There is a sign-flip between the ray-trace model and the encoder reading).


CALIFORNIA INSTITUTE OF TECHNOLOGY
ASTRO [redacted] OBS.
200 INCH TELESCOPE
CASSEGRAIN OPTICAL SYSTEM
SHEET 1 OF 3
1049.54
DIETERICH-POST CLEARPRINT 1020

```
System/Prescription Data

File : C:\Documents and Settings\Matt (Admin)\My Documents\cwi\CWI Final Raytraces\HaleTelescopeFromAO.ZMX
Title: Hale Telescope Model Used for CWI
Date : WED MAY 11 2011


LENS NOTES:

The Model of the Hale 200" telescope used for CWI.  The model was obtained from PALMAO
(Rich Dekany?)
GENERAL LENS DATA:

Surfaces               :               8
Stop                   :               2
System Aperture        : Entrance Pupil Diameter = 5105.4
Glass Catalogs         : SCHOTT
Ray Aiming             : Off
Apodization            : Uniform, factor =   0.00000E+000
Temperature (C)        :    5.00000E+000
Pressure (ATM)         :    1.00000E+000
Adjust Index Data To Environment  : On
Effective Focal Length  :        79661.94 (in air at system temperature and pressure)
Effective Focal Length  :        79661.94 (in image space)
Back Focal Length       :        14950.58
Total Track             :           14987
Image Space F/#         :        15.60347
Paraxial Working F/#    :        15.60347
Working F/#             :         15.6097
Image Space NA          :      0.03202772
Object Space NA         :     2.5527e-007
Stop Radius             :          2552.7
Paraxial Image Height   :        278.0738
Paraxial Magnification  :               0
Entrance Pupil Diameter :          5105.4
Entrance Pupil Position :               0
Exit Pupil Diameter     :        1158.564
Exit Pupil Position     :       -18079.03
Field Type              : Angle in degrees
Maximum Radial Field    :             0.2
Primary Wavelength      :            0.55 m
Lens Units              :   Millimeters
Angular Magnification   :        4.406663

Fields          : 2
Field Type: Angle in degrees
#        X-Value        Y-Value         Weight
1       0.000000       0.000000       1.000000
2       0.200000       0.000000       1.000000

Vignetting Factors
#       VDX       VDY       VCX       VCY       VAN
1  0.000000  0.000000  0.000000  0.000000  0.000000
2  0.000000  0.000000  0.000000  0.000000  0.000000

Wavelengths     : 3
Units: m
```

```
#          Value         Weight
1       0.350000       1.000000
2       0.550000       1.000000
3       0.900000       1.000000

SURFACE DATA SUMMARY:

Surf     Type         Radius      Thickness                Glass      Diameter          Conic   Comment
OBJ STANDARD       Infinity       Infinity                                 0              0   sky!
  1 STANDARD       Infinity              0                             5105.4              0   center obscuration
STO STANDARD      -33926.78      -13724.78              MIRROR      5106.071             -1   primary
  3 STANDARD       Infinity      -55.00057                          1077.405              0   secondary defocus
  4 STANDARD        -8089.9       13724.78              MIRROR        1092.2        -2.3528   secondary
  5 STANDARD       Infinity       55.00057                          596.8754              0   sec. defocus. comp.
  6 STANDARD       Infinity       1207.219                          595.0376              0   primary vertex
  7 STANDARD       Infinity            -35                          560.8434              0   bottom of cass ring
IMA STANDARD       Infinity                                         557.5221              0   ao focus

SURFACE DATA DETAIL:

Surface OBJ     : STANDARD sky!
Surface   1     : STANDARD center obscuration
Aperture       : Circular Obscuration
Minimum Radius :             0
Maximum Radius :        514.35
Surface STO     : STANDARD primary
Mirror Substrate : None
Surface   3     : STANDARD secondary defocus
Surface   4     : STANDARD secondary
Mirror Substrate : None
Aperture       : Circular Aperture
Minimum Radius :             0
Maximum Radius :         520.7
Surface   5     : STANDARD sec. defocus. comp.
Surface   6     : STANDARD primary vertex
Surface   7     : STANDARD bottom of cass ring
Surface IMA     : STANDARD ao focus

COATING DEFINITIONS:


PHYSICAL OPTICS PROPAGATION SETTINGS SUMMARY:

OBJ STANDARD                 sky!
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
  1 STANDARD   center obscuration
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
STO STANDARD              primary
   Use Rays To Propagate To Next Surface  : Off
```

```
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
  3 STANDARD    secondary defocus
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
  4 STANDARD            secondary
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
  5 STANDARD  sec. defocus. comp.
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
  6 STANDARD       primary vertex
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
  7 STANDARD  bottom of cass ring
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit
IMA STANDARD             ao focus
   Use Rays To Propagate To Next Surface  : Off
   Recompute Pilot Beam                   : Off
   Do Not Rescale Beam Size Using Ray Data: Off
   Use Angular Spectrum Propagator        : Off
   Output Pilot Radius                    : Best Fit

EDGE THICKNESS DATA:

Surf         X-Edge         Y-Edge
  1     -96.059651     -96.059651
STO  -13628.720349  -13628.720349
  3     -73.404199     -73.404199
  4   13743.183628   13743.183628
  5      55.000571      55.000571
  6    1207.219441    1207.219441
  7     -35.000000     -35.000000
IMA       0.000000       0.000000

SOLVE AND VARIABLE DATA:

Thickness of   3       : Variable
Thickness of   4       : Solve, Pickup from surface 2 scaled by -1, offset by 0
```

```
Semi Diameter   4      : Fixed
Thickness of   5       : Solve, Pickup from surface 3 scaled by -1, offset by 0

INDEX OF REFRACTION DATA:

System Temperature:    5.0000 Celsius
System Pressure   :    1.0000 Atmospheres
Absolute air index:    1.000288 at wavelength 0.550000 m
Index data is relative to air at the system temperature and pressure.

Surf                   Glass    Temp    Pres      0.350000    0.550000    0.900000
  0                             5.00    1.00    1.00000000  1.00000000  1.00000000
  1                             5.00    1.00    1.00000000  1.00000000  1.00000000
  2                  MIRROR     5.00    1.00    1.00000000  1.00000000  1.00000000
  3                             5.00    1.00    1.00000000  1.00000000  1.00000000
  4                  MIRROR     5.00    1.00    1.00000000  1.00000000  1.00000000
  5                             5.00    1.00    1.00000000  1.00000000  1.00000000
  6                             5.00    1.00    1.00000000  1.00000000  1.00000000
  7                             5.00    1.00    1.00000000  1.00000000  1.00000000
  8                             5.00    1.00    1.00000000  1.00000000  1.00000000

THERMAL COEFFICIENT OF EXPANSION DATA:

Surf                   Glass     TCE *10E-6
  0                              0.00000000
  1                              0.00000000
  2                  MIRROR      0.00000000
  3                              0.00000000
  4                  MIRROR      0.00000000
  5                              0.00000000
  6                              0.00000000
  7                              0.00000000
  8                              0.00000000

F/# DATA:

F/# calculations consider vignetting factors and ignore surface apertures.

             Wavelength:        0.350000            0.550000            0.900000
#                 Field        Tan       Sag       Tan       Sag       Tan       Sag
1   0.0000, 0.0000 deg:    15.6097   15.6097   15.6097   15.6097   15.6097   15.6097
2   0.2000, 0.0000 deg:    15.6026   15.5991   15.6026   15.5991   15.6026   15.5991

GLOBAL VERTEX COORDINATES, ORIENTATIONS, AND ROTATION/OFFSET MATRICES:

Reference Surface: 8

Surf           R11             R12             R13                 X
               R21             R22             R23                 Y
               R31             R32             R33                 Z

 1   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 center obscuration
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000 -1.172219441E+003

 2   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 primary
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
```

```
     0.0000000000   0.0000000000   1.0000000000 -1.172219441E+003

 3   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 secondary defocus
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000 -1.489699944E+004

 4   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 secondary
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000 -1.495200001E+004

 5   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 sec. defocus. comp.
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000 -1.227220012E+003

 6   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 primary vertex
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000 -1.172219441E+003

 7   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 bottom of cass ring
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000  3.500000000E+001

 8   1.0000000000   0.0000000000   0.0000000000  0.000000000E+000 ao focus
     0.0000000000   1.0000000000   0.0000000000  0.000000000E+000
     0.0000000000   0.0000000000   1.0000000000  0.000000000E+000


GLOBAL SURFACE CENTER OF CURVATURE POINTS:

Reference Surface: 8

Surf             X              Y              Z
 1               -              -              - center obscuration
 2   0.0000000000   0.0000000000 -35098.9994410056 primary
 3               -              -              - secondary defocus
 4   0.0000000000   0.0000000000 -23041.8999999093 secondary
 5               -              -              - sec. defocus. comp.
 6               -              -              - primary vertex
 7               -              -              - bottom of cass ring
 8               -              -              - ao focus

ELEMENT VOLUME DATA:

For centered elements with plane or spherical circular faces, exact
volumes are computed by assuming edges are squared up to the larger
of the front and back radial aperture.

For all other elements, approximate volumes are numerically integrated
to 0.1\% accuracy. Zero volume means the volume cannot be accurately computed.

Single elements that are duplicated in the Lens Data Editor
for ray tracing purposes may be listed more than once yielding
incorrect total mass estimates.

                           Volume cc   Density g/cc         Mass g
Total Mass:                                                0.000000
```

CARDINAL POINTS:

Object space positions are measured with respect to surface 1.
Image space positions are measured with respect to the image surface.
The index in both the object space and image space is considered.

	Object Space	Image Space
W = 0.350000		
Focal Length :	-79661.944502	79661.944502
Focal Planes :	-351043.325413	-1.420107
Principal Planes :	-271381.380911	-79663.364609
Anti-Principal Planes :	-430705.269914	79660.524395
Nodal Planes :	-271381.380911	-79663.364609
Anti-Nodal Planes :	-430705.269914	79660.524395
W = 0.550000 (Primary)		
Focal Length :	-79661.944502	79661.944502
Focal Planes :	-351043.325413	-1.420107
Principal Planes :	-271381.380911	-79663.364609
Anti-Principal Planes :	-430705.269914	79660.524395
Nodal Planes :	-271381.380911	-79663.364609
Anti-Nodal Planes :	-430705.269914	79660.524395
W = 0.900000		
Focal Length :	-79661.944502	79661.944502
Focal Planes :	-351043.325413	-1.420107
Principal Planes :	-271381.380911	-79663.364609
Anti-Principal Planes :	-430705.269914	79660.524395
Nodal Planes :	-271381.380911	-79663.364609
Anti-Nodal Planes :	-430705.269914	79660.524395