A Deterministic Method for Aligning Multiple Optical Waveguides to a Paraboloidal Collector

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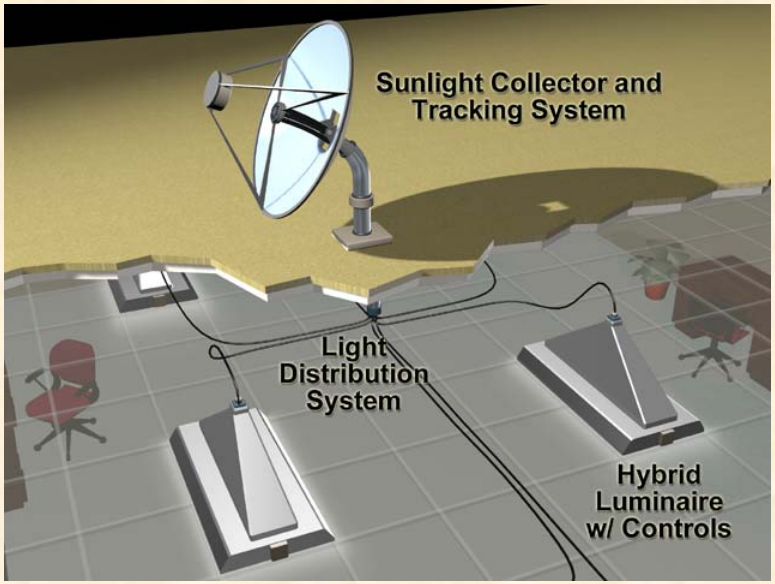
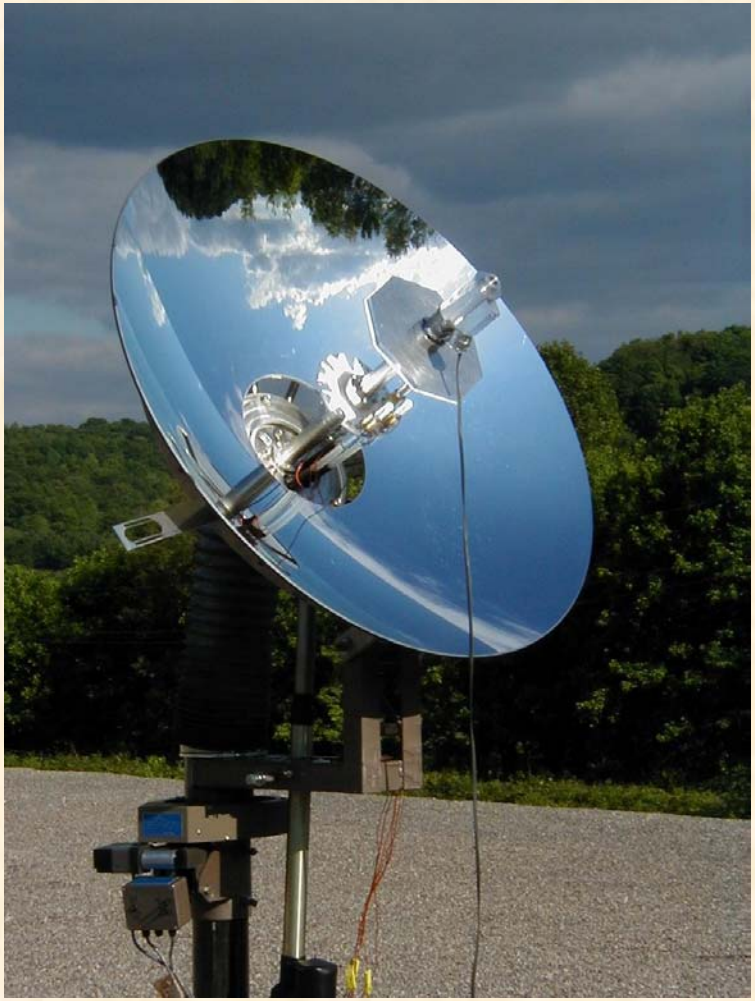
Hybrid Solar Lighting provides natural daylighting in an implementation compatible with existing infrastructure

- Sunlight concentrated 200x
- Transmitted through small roof penetration via optical waveguides
- Combined with artificial light in hybrid luminaires of conventional troffer design



Solar concentrators for waveguide distributed lighting systems must balance three interdependent parameters

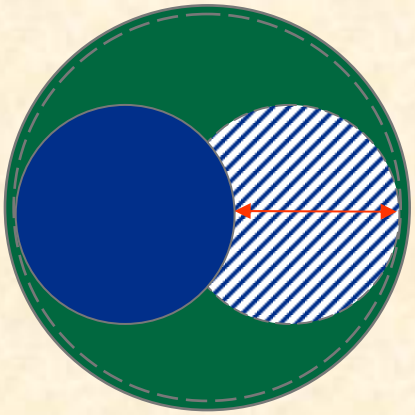


- **Primary mirror quality**
- **Waveguide input aperture**
- **Tracking system resolution**

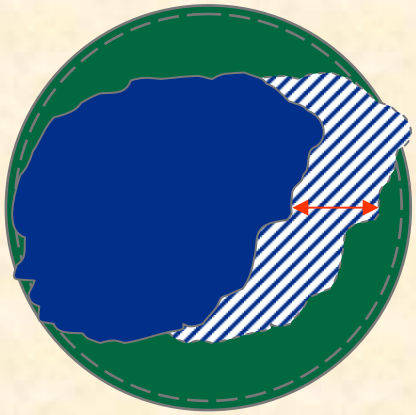
Fixing any two of these component parameters will define the requirements of the third

For a given aperture size, the size and quality of the focused spot directly determines the required level of tracker performance

An un-aberrated focused spot remains within the aperture over a wide range

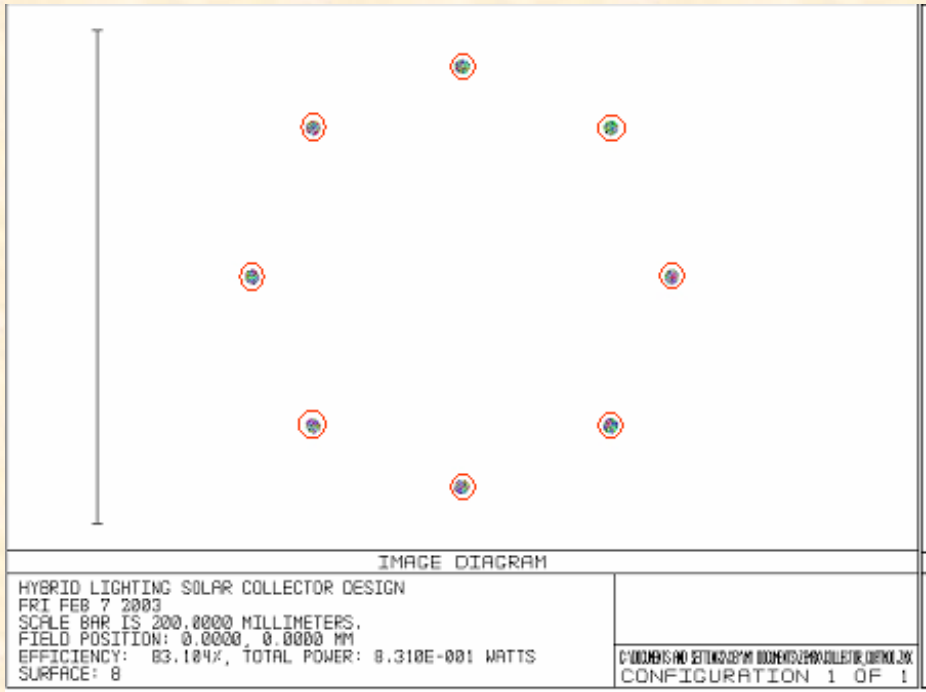


A larger, distorted spot requires a higher level of tracker performance

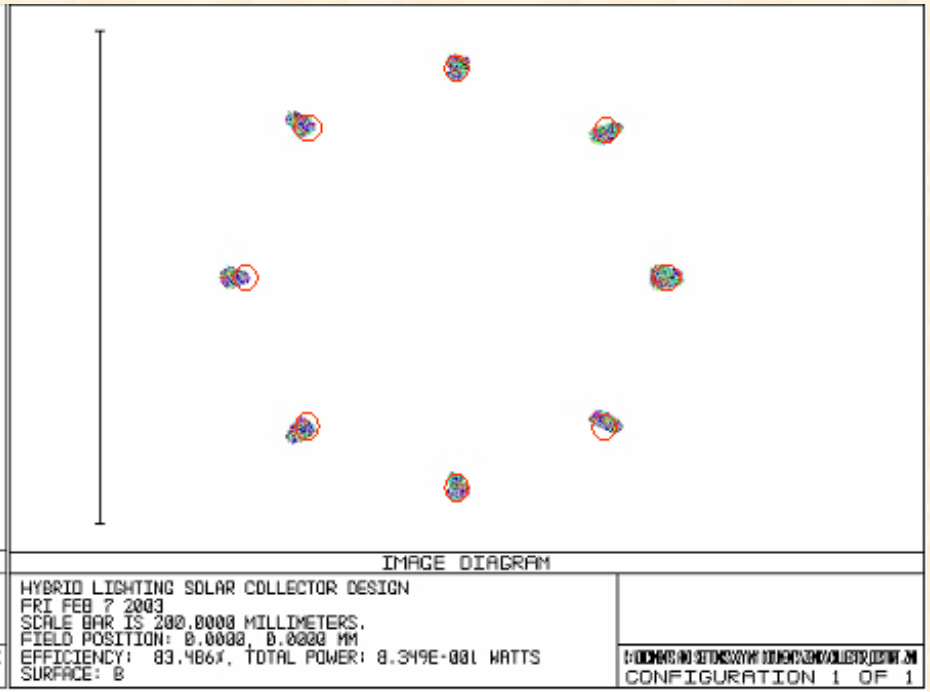


Optical aberrations due to mis-alignment are indistinguishable from those that arise from primary mirror distortions

Accurate optical alignment is essential to achieve the optimum performance possible with a given primary mirror



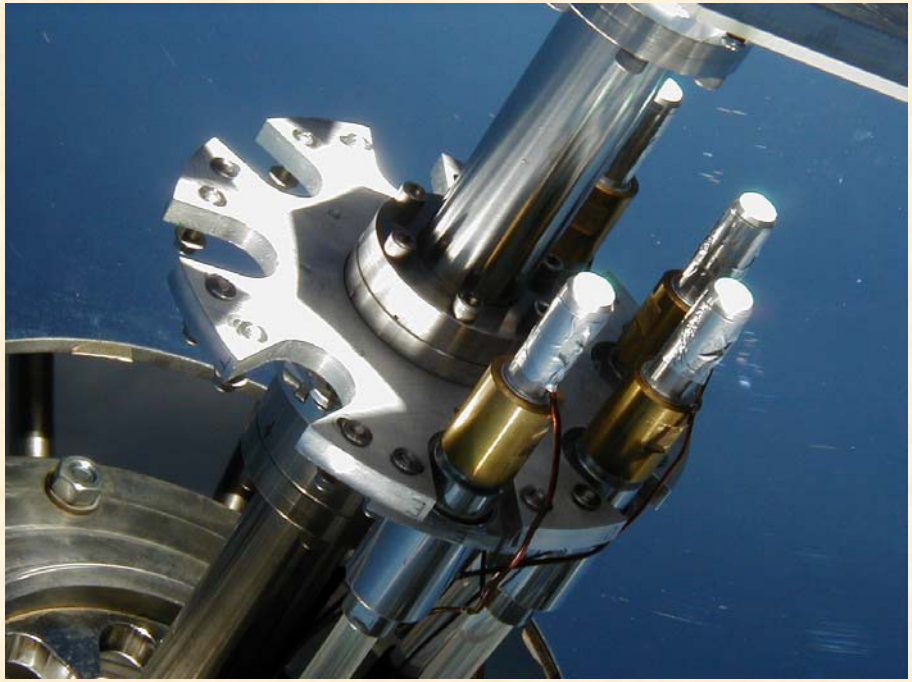
"Perfect" system with round spots centered in individual apertures



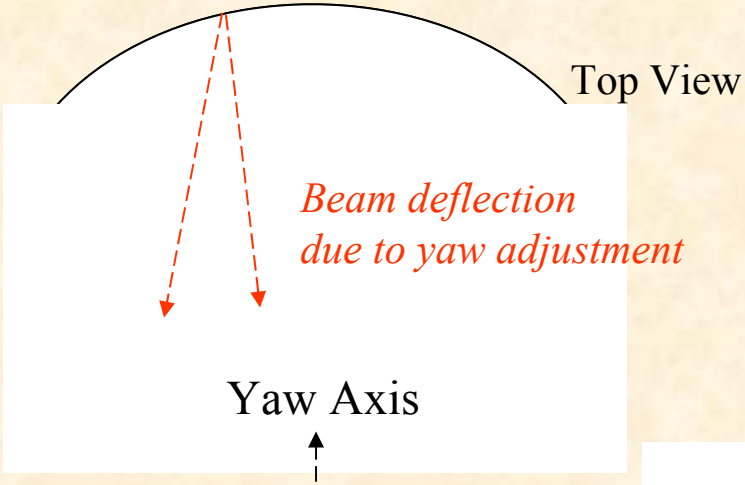
Distorted and mis-aligned primary affects spot size, shape and centroid

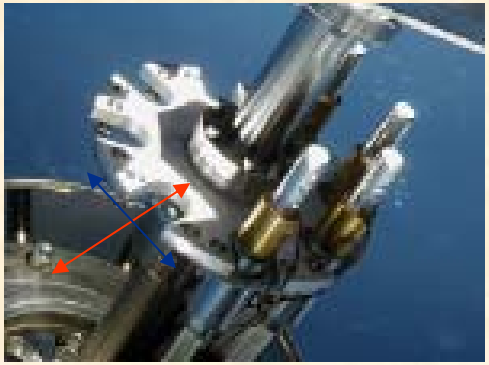
To optimize performance of the prototype system, a systematic alignment strategy was developed to work within the adjustment capabilities of the system

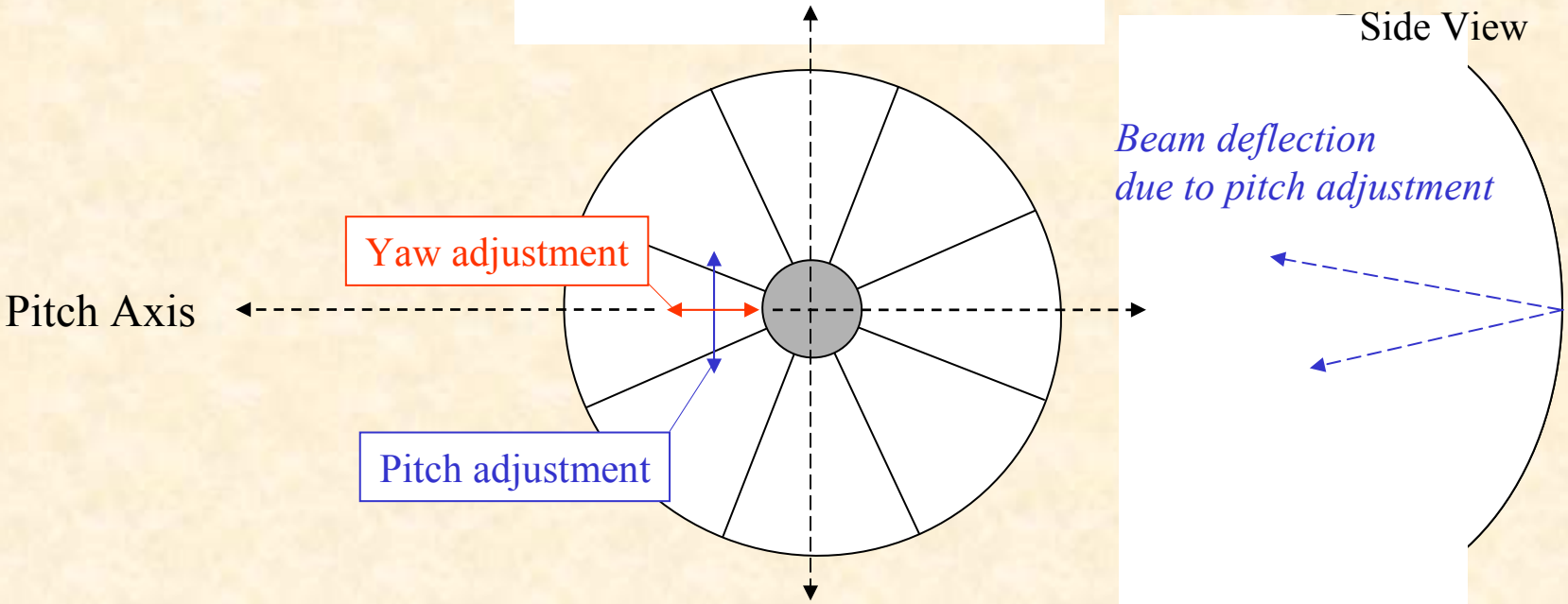
- Dimensionally align the paraboloid within the mount using mechanical references
- Optically align each waveguide holder to the best-fit paraboloid associated with it
- Perform final on-sun alignment to accommodate minor variations in the axes of individual best-fit segments



Definitions of alignment axes and adjustments

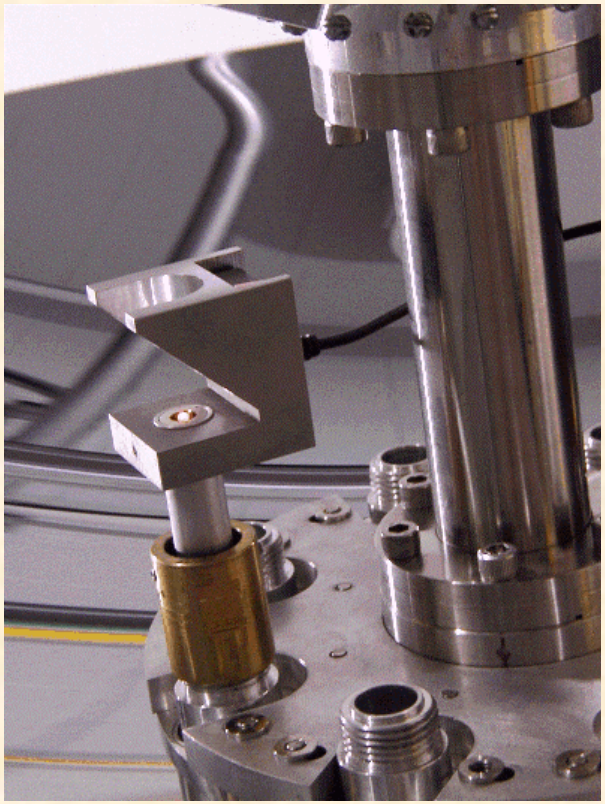






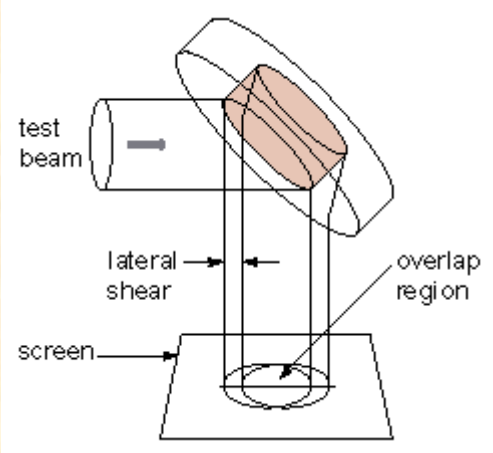
A point source (single mode optical fiber) was positioned in the waveguide mount and adjusted until it was at the optimum focus of the best-fit paraboloid

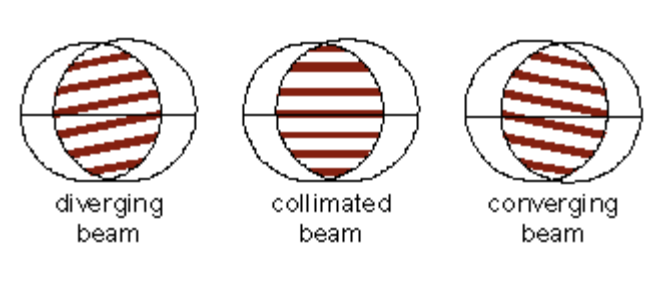
- Light from point source diverges to fill center of paraboloid segment
- Collimated light is analyzed directly with shear plate to identify and eliminate astigmatism
- Cornercube retroreflector returns light to parablolid where beamsplitter diverts a fraction onto CCD array



The shear plate interferometer reveals beam aberrations as well as focus errors

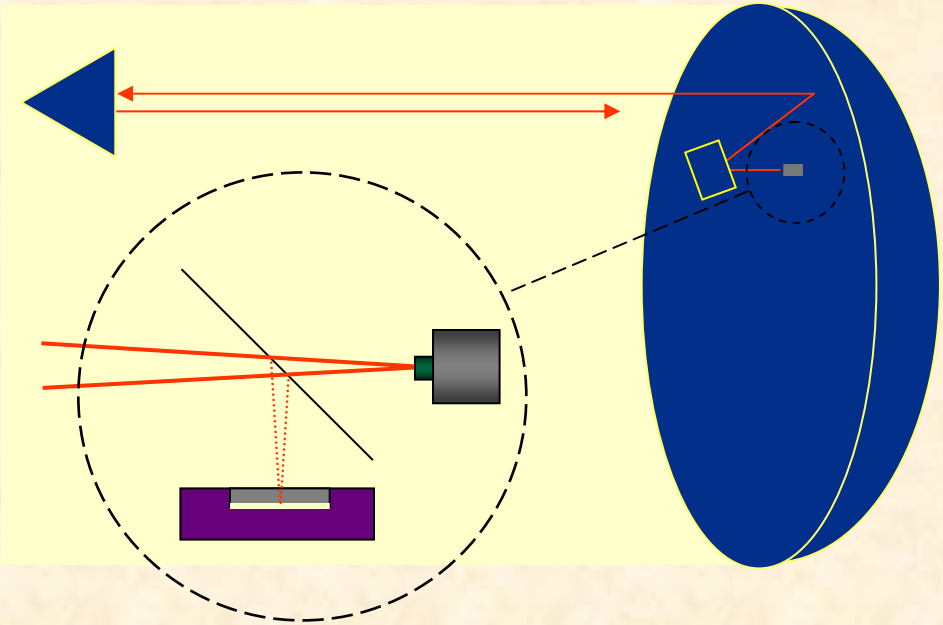
Shear axis is repeatedly aligned parallel to the pitch and yaw axes. Pitch, yaw and focus are iteratively adjusted until the focus error between the two axes is minimized (i.e. astigmatism removed)





The cornercube retroreflector returns the light to the parboloid, where a portion of it is sampled by the imaging beamsplitter and diverted to the CCD array

Hollow cornercube retroreflector



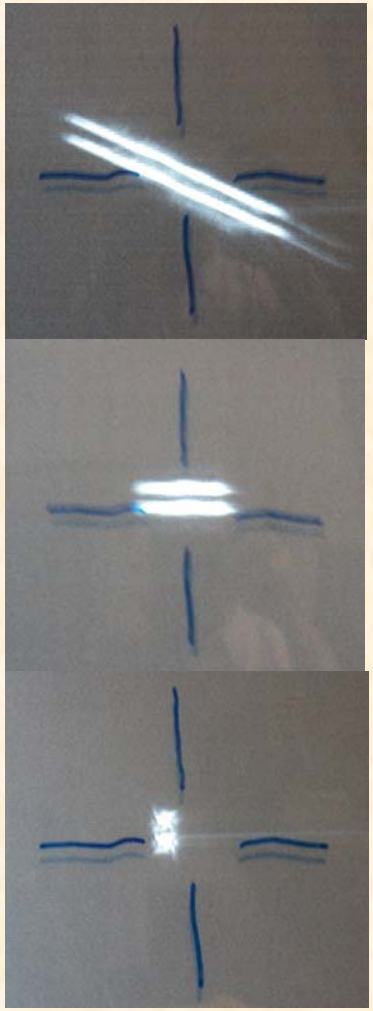
Schematic representation of imaging test with detail inset of imaging beamsplitter

With the beamsplitter parallel to the pitch axis, the light returned from a cornercube produces easily interpreted alignment images on the CCD array

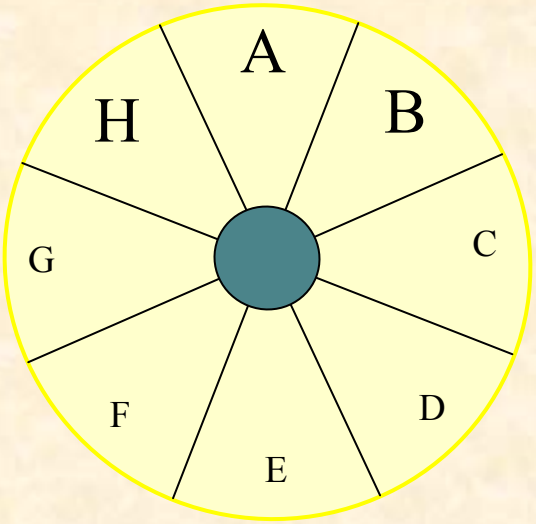
With pitch, yaw and focus errors present, the focused image is elongated and rotated with respect to the axis of the CCD array

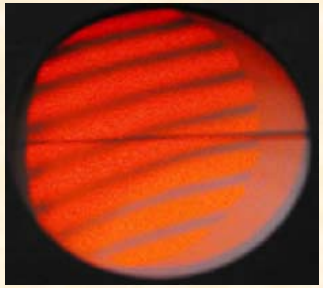
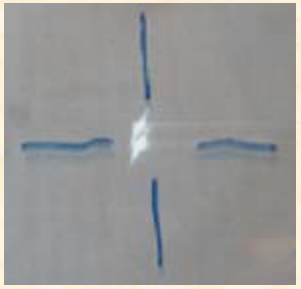
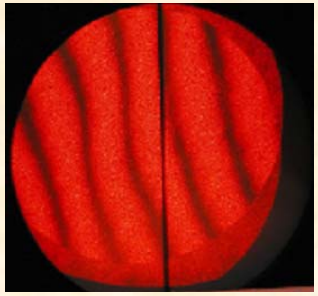
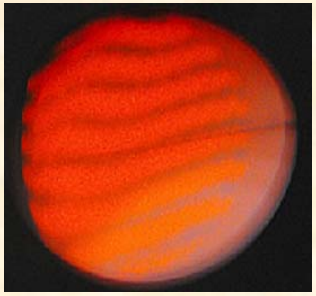
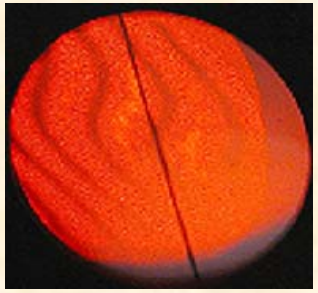
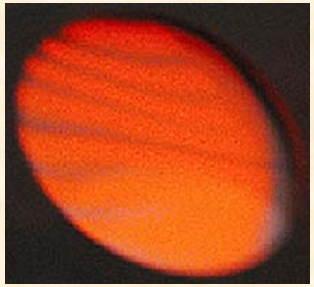
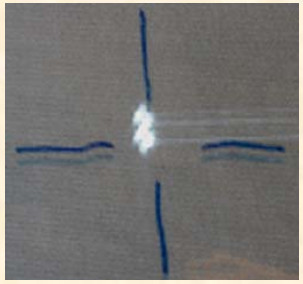
Pitch is adjusted to eliminate the rotation component so that the remaining elongated spots are parallel to the reference axis

Finally, yaw is adjusted to eliminate any remaining elongation of the spots



Test results from three mirror segments show good correlation of results



Segment	pitch shear	yaw shear	image
A			
B			
H			

Observations and Recommendations

- Optical alignment to an arbitrary paraboloid is possible using relatively simple apparatus
- Imaging techniques combined with an understanding of the information in the focused spot provide a rapid deterministic method for achieving the optical alignment
- Shear plate techniques require iterative interpretation but will eventually yield comparable results
- Maximize use of mechanical references wherever possible
- Work with mirror manufacturer to optimize references at the earliest design stage possible