Optical Design of a Large Segmented Space Telescope

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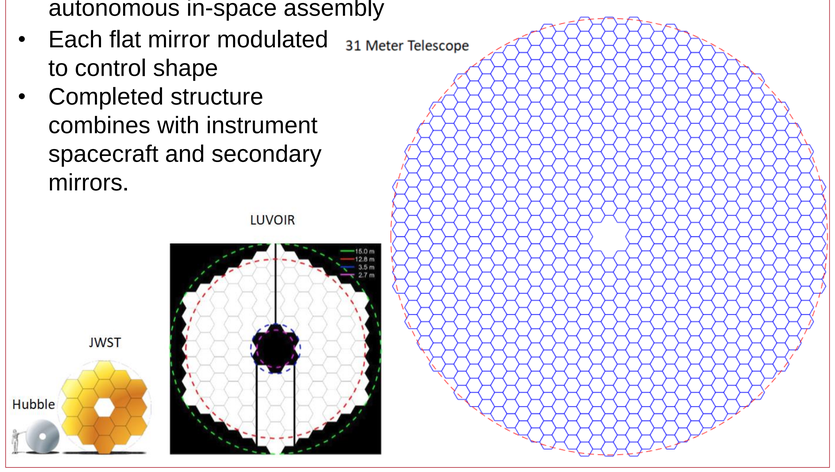
Mission Overview

- Approximately 1,000 identical, mass-produced spacecraft
- Spacecraft travel via solar sail to L2
- Each spacecraft combines to form one large telescope via autonomous in-space assembly
- Each flat mirror modulated to control shape
- Completed structure combines with instrument spacecraft and secondary mirrors.



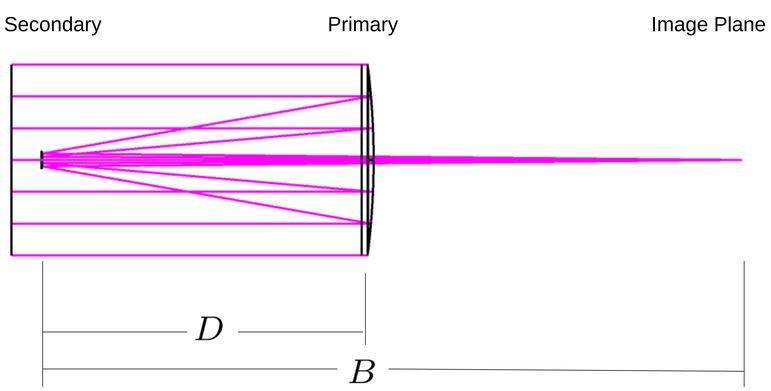
Segmentation of Primary

- Finds the correct location for each mirror
- Center mirrors removed based on geometry
- Segments excluded if >40% of the hexagonal area is outside the *31 m* diameter.
- Gaps between mirrors determined by relative angle and assumed thickness

Ideal Optical System

Ritchey-Chrétien Cassegrain Telescope

- Aperture: d = 31 m
- Primary Focal Length: $f_1 = f/2$
- Secondary Diameter: 3 m
- Effective focal length $F = f/5.6$
- Mirror Size: 1 m (flat-to-flat) ①
- Gap Size: 0.006 m



Radii of curvature

$$R_1 = \frac{-DF}{F-B}$$

$$R_2 = \frac{2DB}{F-B-D}$$

Magnification

$$M = \frac{F-B}{D}$$

Conic Constants

$$K_1 = -1 - \frac{2B}{M^3 D}$$

$$K_2 = -1 - \frac{2}{(M-1)^3}\left[M\left(2M-1\right) + \frac{B}{D}\right]$$

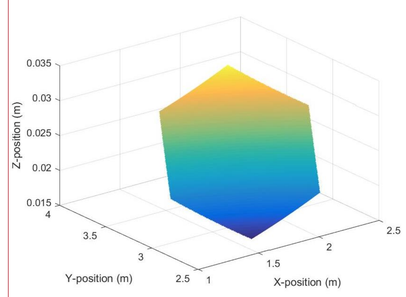
②

Parameters selected from comparisons to TMT[1], GMT[2], Hubble[3], and JWST[4]

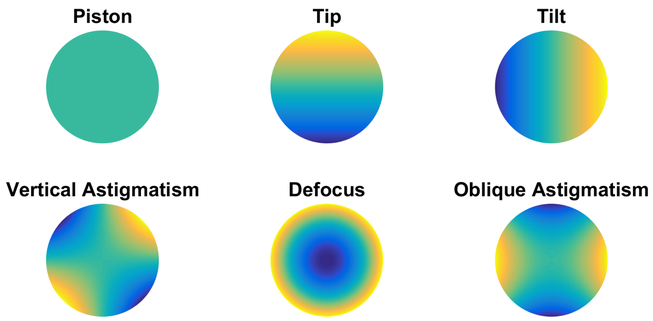
① Select Parameters → ② Design Ideal Shape → ③ Deconstruct each Segment into Zernike Modes → ④ Convert to Physical Properties (curvature, rotation angles, etc.) → ⑤ Model in Zemax OpticStudio → ⑥ Simulate PSF

Shape Reconstruction ③ ④

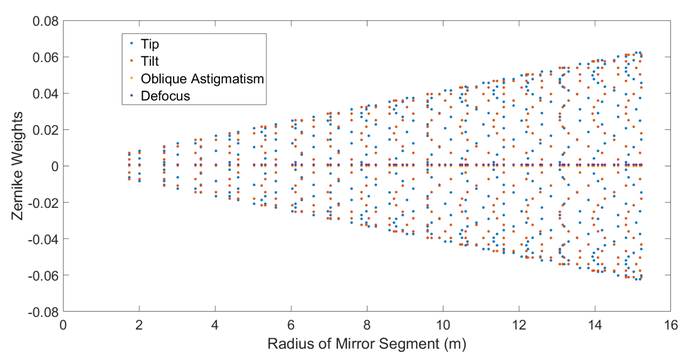
- Each mirror begins identical and flat
- Must be adjusted to the ideal shape at that location
- Least-squares fit the shape to Zernike polynomials
- Uses a hexagonal domain
- Leverage JWST technology to modulate to the first 4 modes.



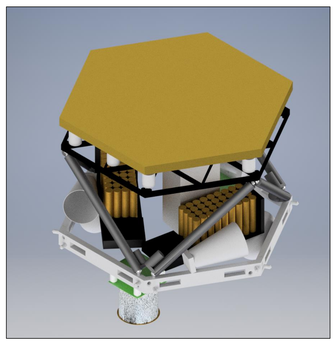
Example segment with complex shape



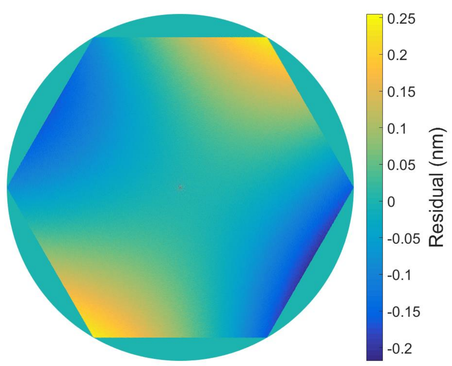
Zernike polynomials used



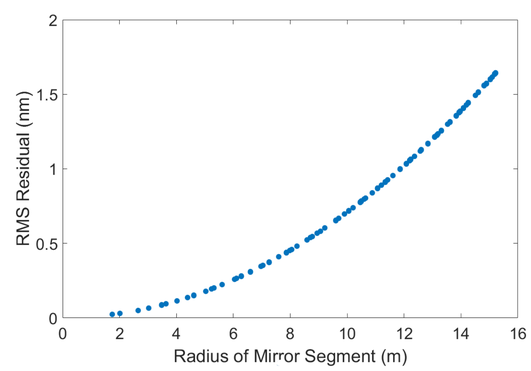
Deformation is dominated first by angular rotation, then by a curvature mode



Mirror shape modulated with curvature strut and Stewart platform

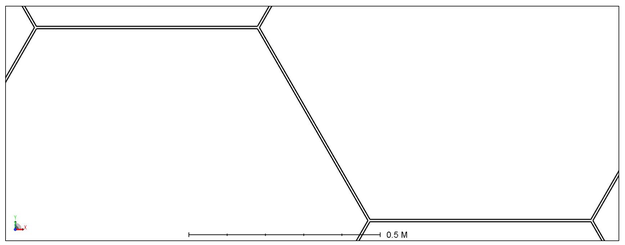


Example of residuals on a specific segment using only piston, tip, tilt and defocus modes



Root Mean Square residuals for every segment in the primary mirror

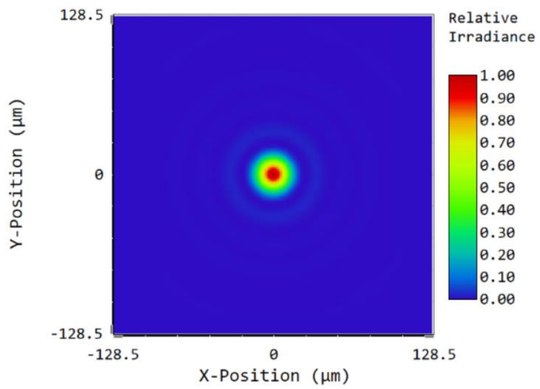
Modelling and Simulation



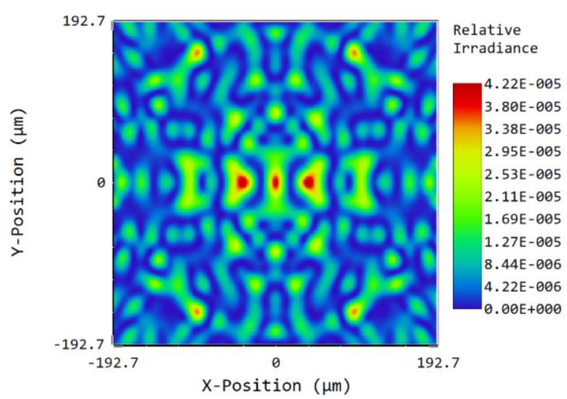
Zoomed-in view showing segment gaps in Zemax model ⑤

Point Spread Functions ⑥

Gaps, ideal shape:



Gaps, reconstructed shape:



Acknowledgements

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References

[1] Rogers, John, et. al. *Thirty Meter Telescope Observatory Architecture Document*. June 18, 2018.
[2] Johns, Matt. *The Giant Magellan Telescope*. 2007
[3] NASA, 'Hubble Space Telescope Optics System.' *nasa.gov*, 2019
[4] NASA, 'Observatory: The Optical Telescope Instrument (OTE).' *jwst.nasa.gov 2019*