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Adaptive Imaging for ISR Applications

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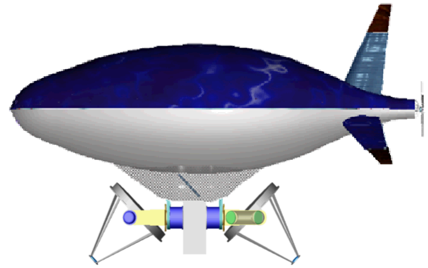
Foveated Optical Adaptive Zoom (FOcAZ)
Variable Field-of-View Imaging Sensor



10X Optical Zoom → 10X increase resolution

Provide Wide FOV surveillance

Send relevant information to ground

Characterize and track multiple objects with High Resolution

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Airship ISR requirements

The parameters required to drive subsequent R&D efforts will include:

- **Wavelength - day/night coverage requirements**
- **Area coverage -** adjudicate between wide area exploration and dynamic region of interest (ROI) exploitation
- **Desired ground resolution**
- **Imagery update rates**
- **Sensitivity/Signal-to-Noise Ratio**
- **Instrument platform details**
  - **Altitude, speed, endurance, view angles**
  - **Size, weight, and power limitations**
  - **Platform jitter/PSD**
  - **Data storage/downlink requirements**
- **Ground station details**
- **Downlink data interface**

Current or Alternative Approaches

- Gimbals/Pods (WESCAM MX-20, MTS-B, Litening, ATFLIR, WAPPS (AngelFire/BlueDevil) etc.)
  - Often weigh > 200 pounds or more for 12”apertures

- Multiple staring systems
  - ARGUS-IS (1.8 GPixel with a 500 pound pod)
  - Gorgon Stare (1100 pounds - 12 separate cameras)
- Computational Approaches
  - Coded Apertures (LACOSTE is predicted to have 10X lower resolution than the proposed Sandia system)
  - Compressive Imaging (MOSAIC and similar) attempts to increase the space bandwidth product (SBP) – unproven technology that requires extremely complex processing. If successful, this approach is complementary and could be used WITH the Sandia technique

Adaptive Imaging

- **Adaptive zoom uses adaptive optical elements (Deformable Mirrors, Spatial Light Modulators, or Adaptive Lenses, etc.) to change the magnification of the system. (Patent #6,977,777)**

- **Optical (Foveated) scanning uses active optics to steer the high resolution area over a wide area without slewing the entire system (e.g. gimbals, reducing reduce weight and power requirements) (Patents # 6,473,241 and 6,421,185)**

Foveated Imaging + Optically Adaptive Zoom

=

FOcAZ

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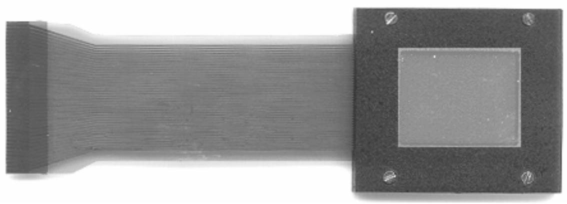
FOcAZ
Concept of Operations

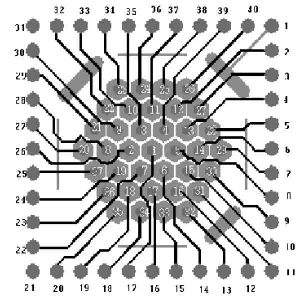
- Sensor collects WFOV (±10°) imagery, to survey and coarsely track objects
  - Significantly lighter than conventional wide-field telescope (e.g. Schmidt) by replacing glass mirrors with composites and removing the need for a corrector plate
  - NO gimbals
  - All Reflective Zoom systems DO NOT currently exist
    - 3X reflective zoom has been demonstrated, but no systems have been deployed due to their complexity and weight.
- Sensor changes magnification to precisely track objects at coarse resolution or provide high resolution imagery on zoomed-in areas or targets of interest
  - 1/3 meter system would provide 36mm ground sampling distance from 65K feet altitude
  - Goal of 20X zoom that can be redirected ANYWHERE within the FOV in milliseconds
  - Co-boresited wavefront sensor to insure repeatability over time
- Format a compact data packet with minimal but sufficient information for downlink

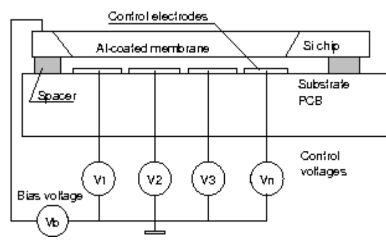
Adaptive Optics

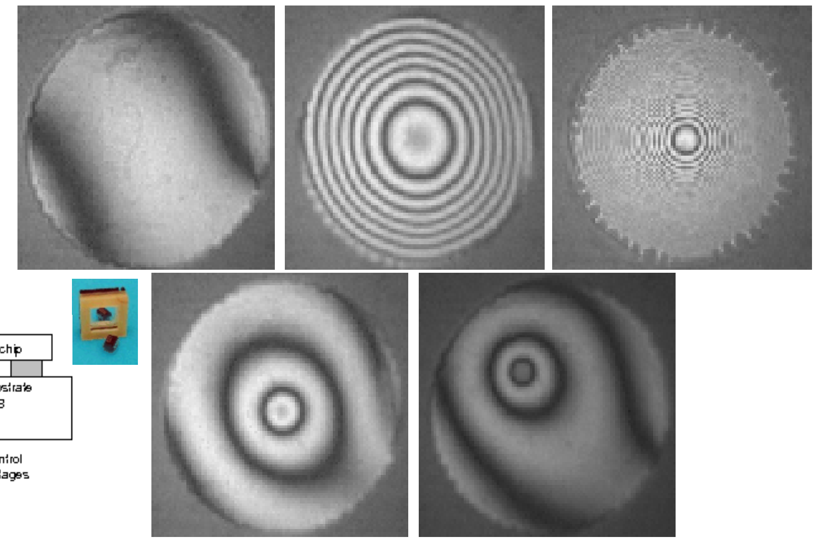
Liquid Crystal Spatial Light Modulators



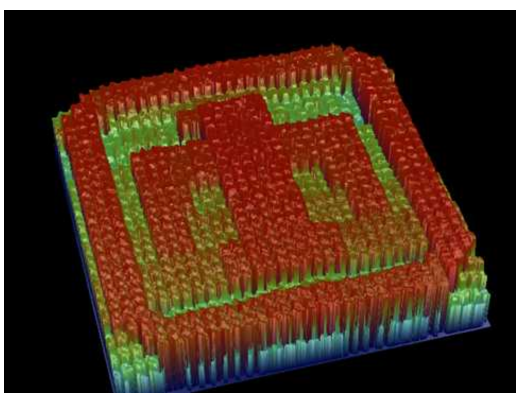
Continuous Electrostatic DMs



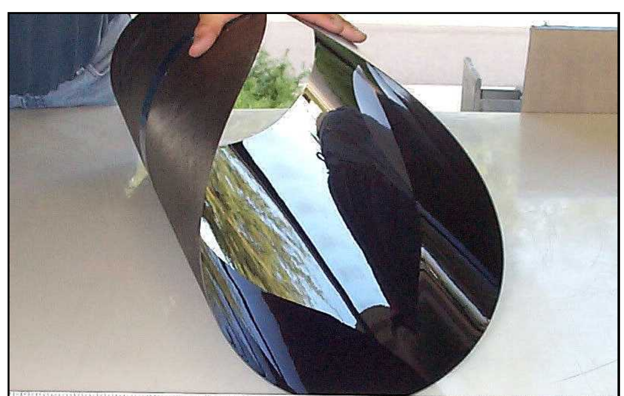




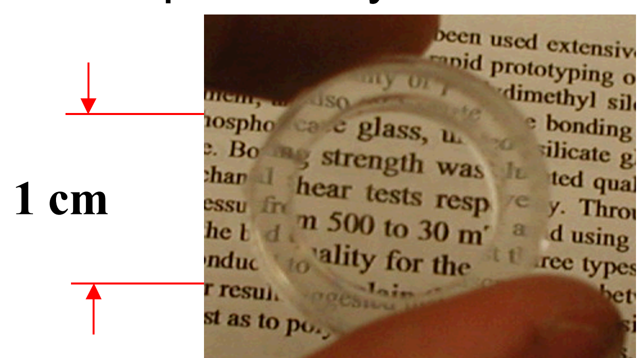
MEMS Deformable Mirrors



Composite –
Variable Radius Mirror



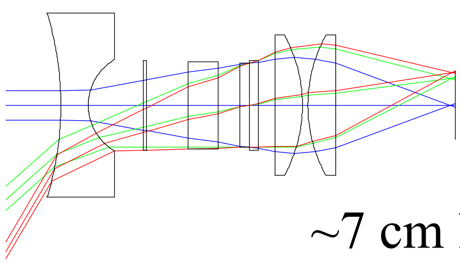
Adaptive Polymer Lens



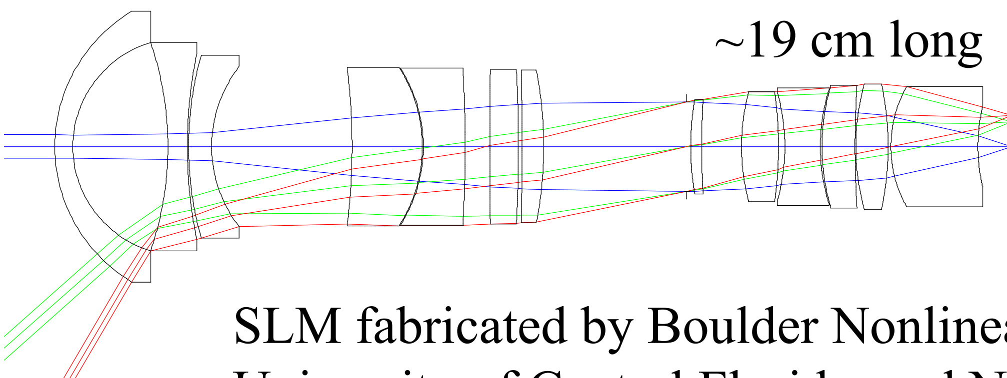
Benefits of Foveated System vs. Conventional

BNS
BOULDER NONLINEAR SYSTEMS

Full Field of View = 120^{o}
Effective focal length ~ 8 mm
Working f-number ~ 1.4



~7 cm long



~19 cm long

Patents: US 6,421,185
US 6,473,241

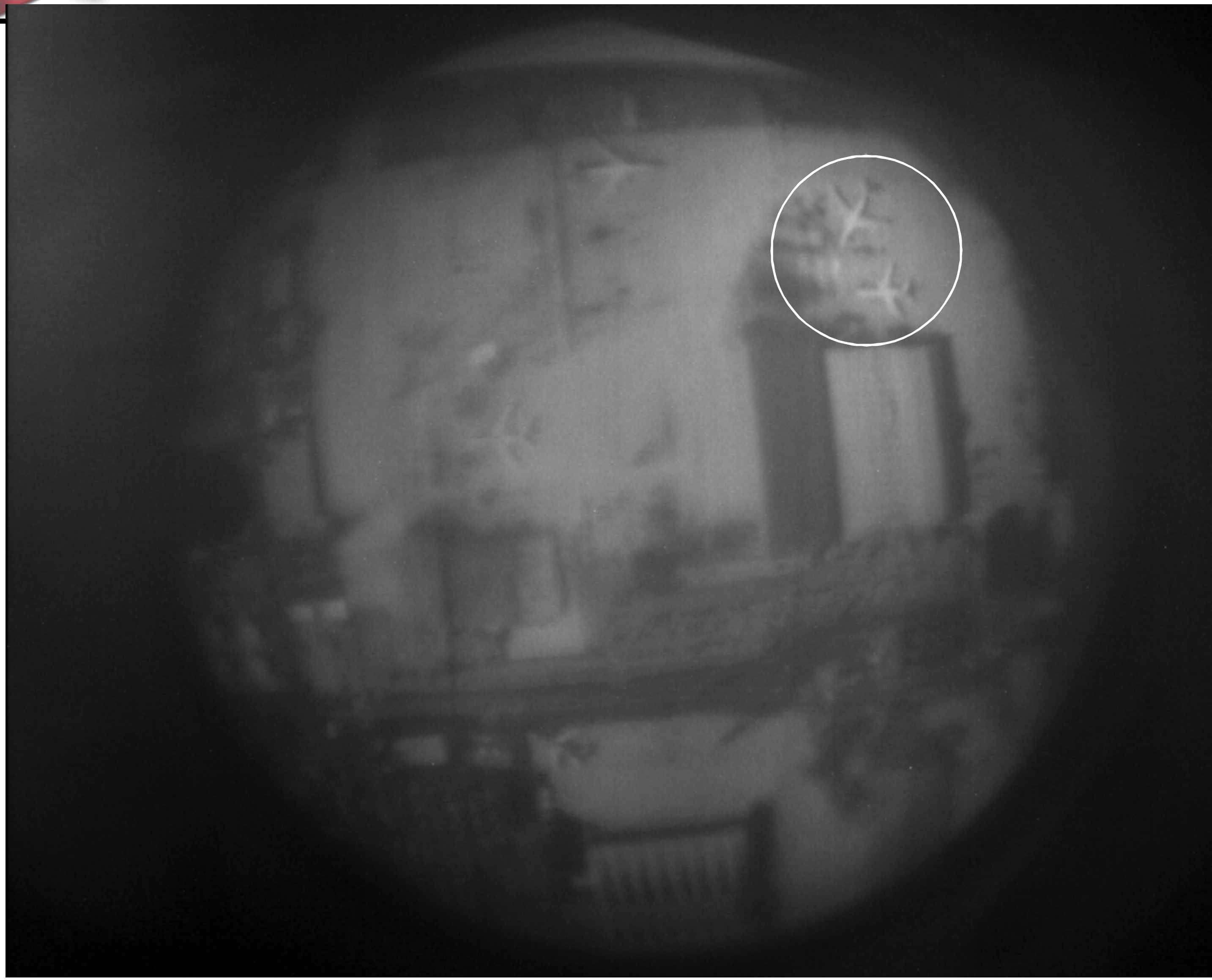
SLM fabricated by Boulder Nonlinear Systems, Inc, the University of Central Florida, and Narrascape.

Bio-Optic Synthetic Systems

Foveated Demonstration

Foveated Demonstration

Foveated Demonstration



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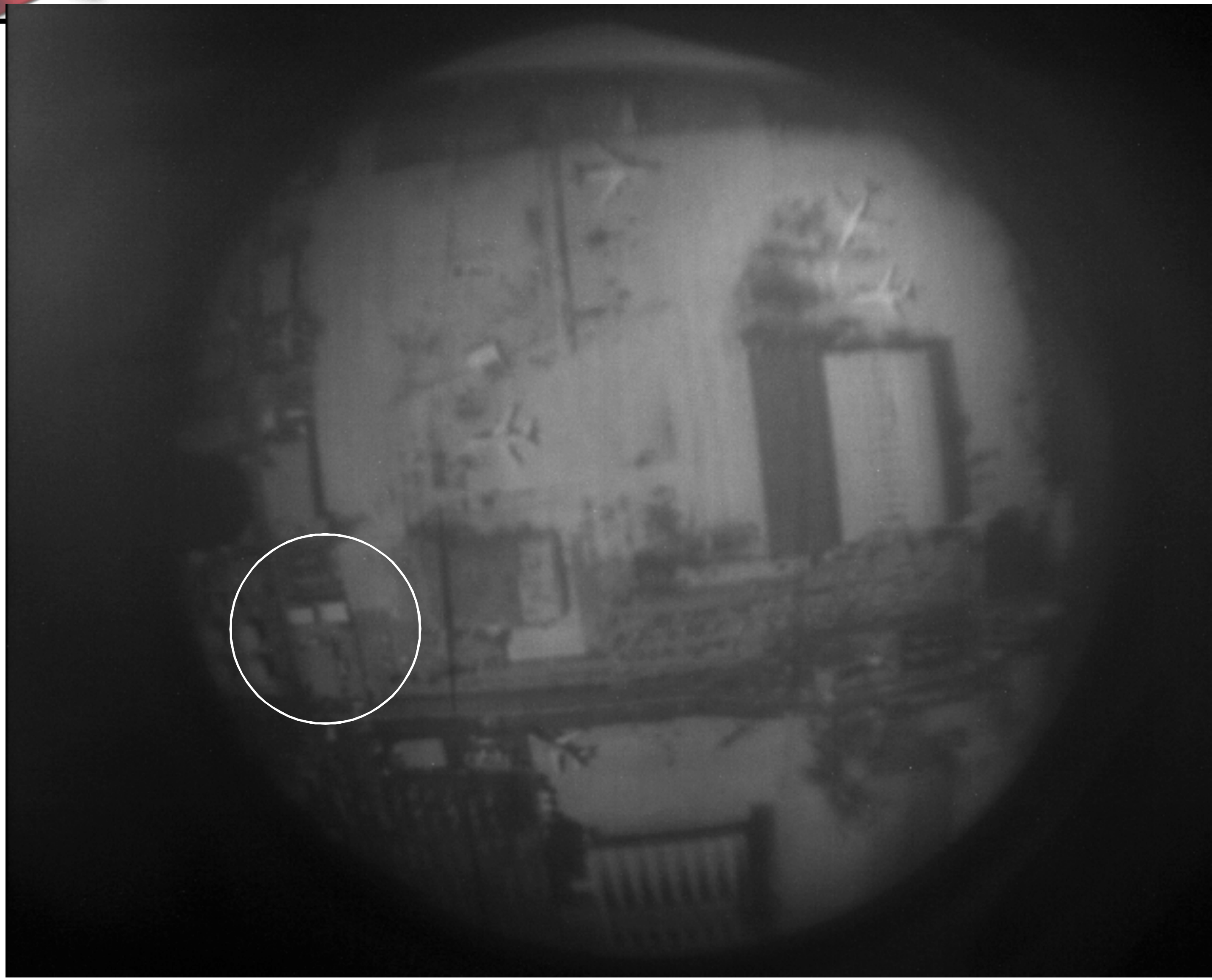
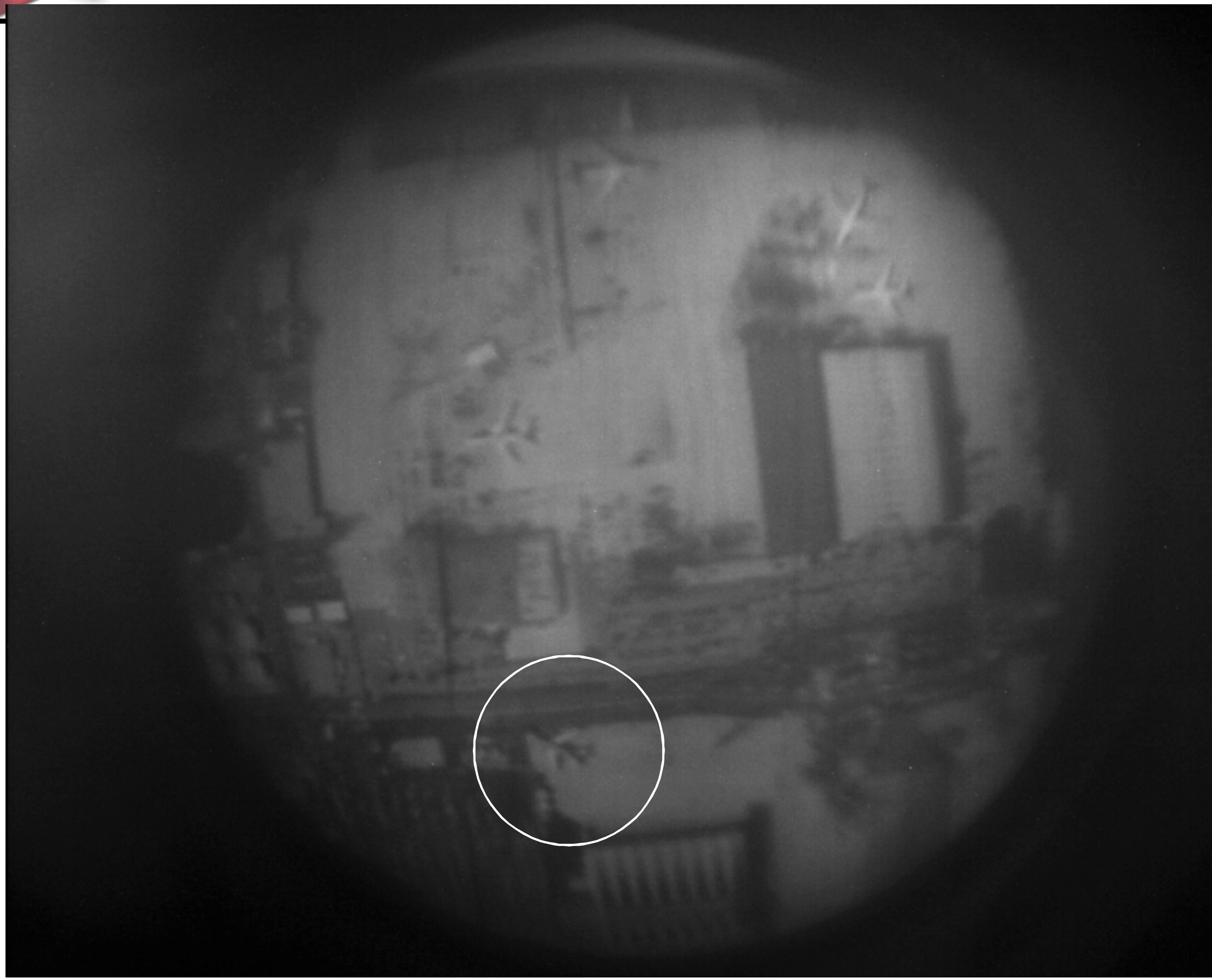
Foveated Demonstration



Foveated Demonstration



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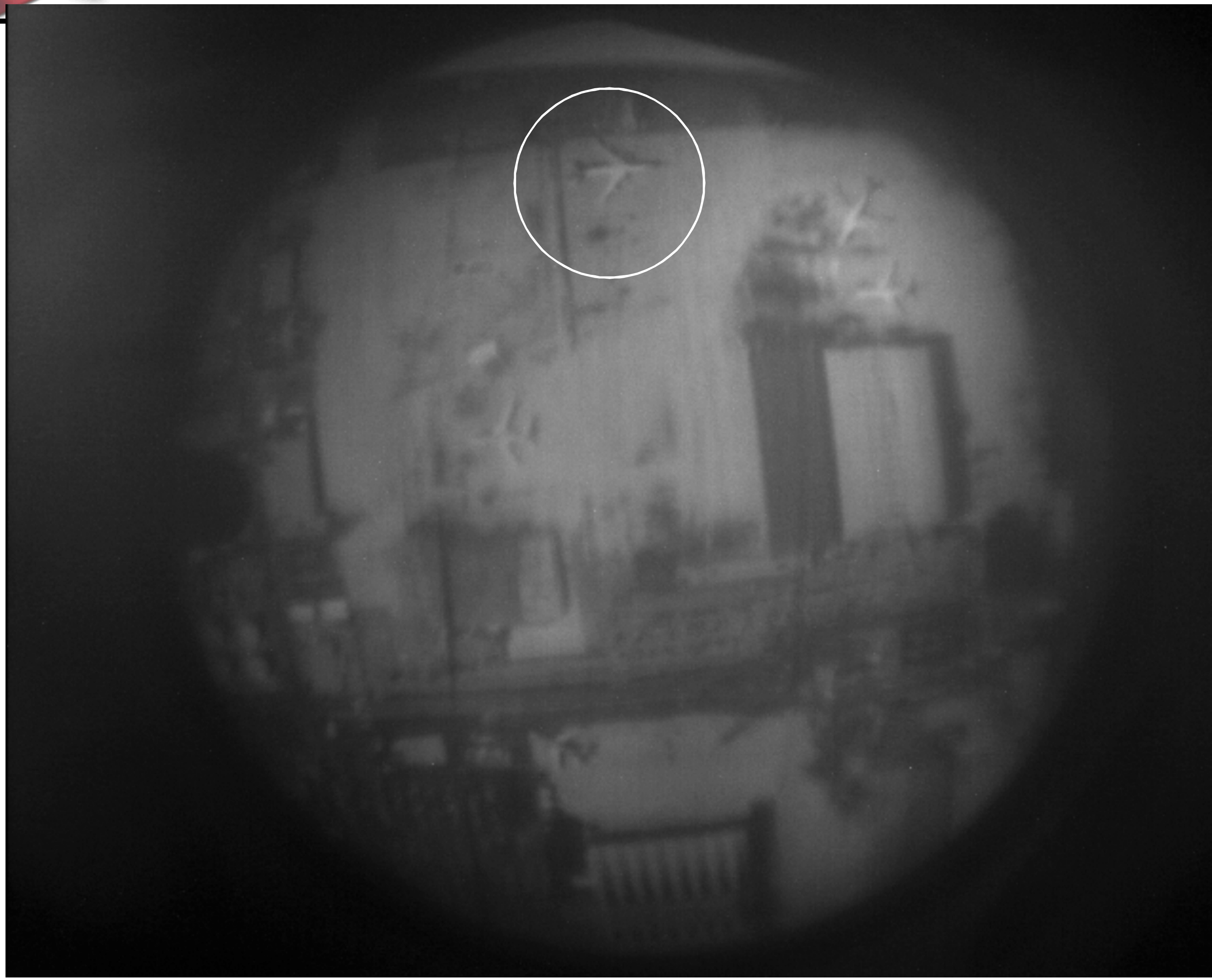
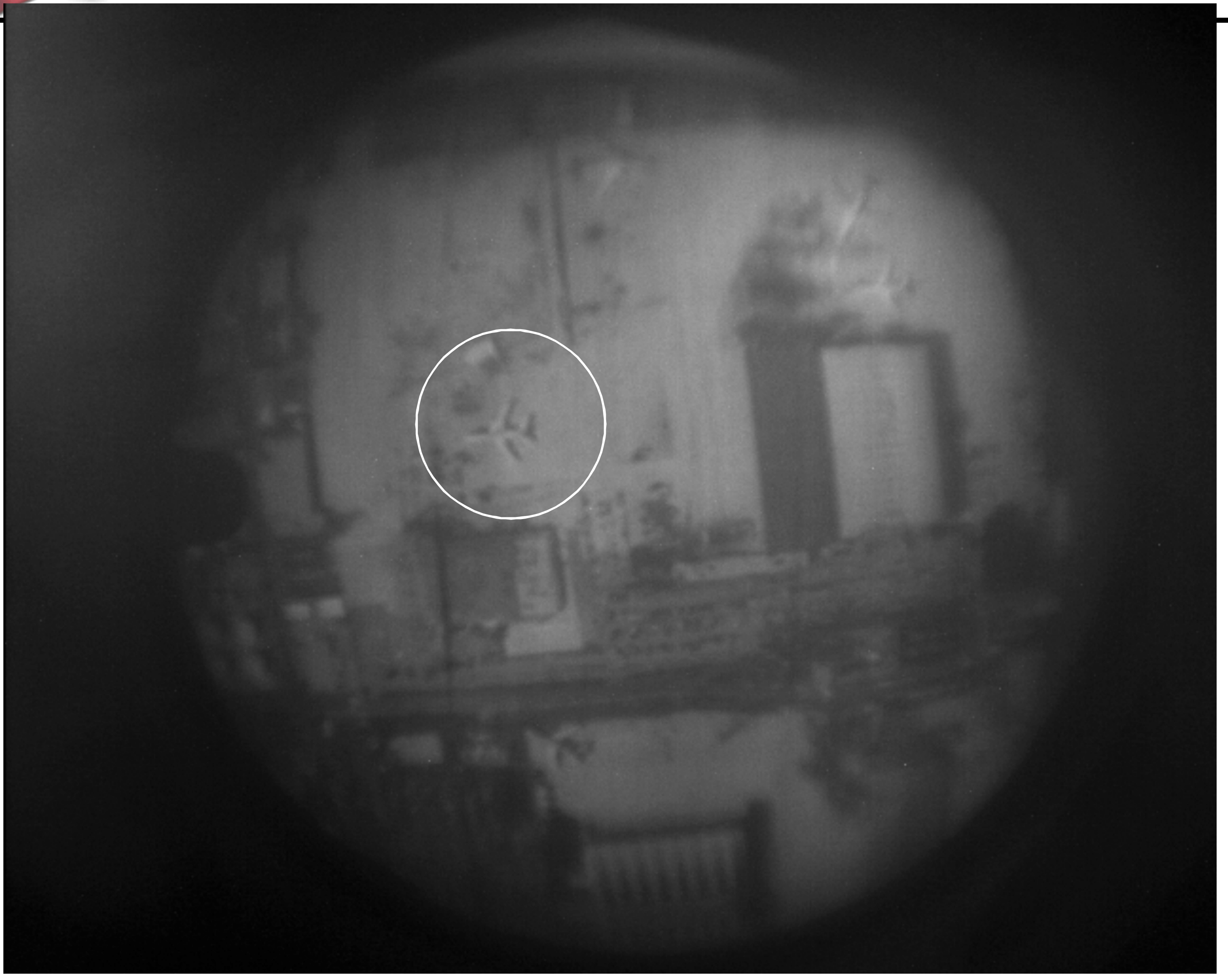
Foveated Demonstration



Foveated Demonstration



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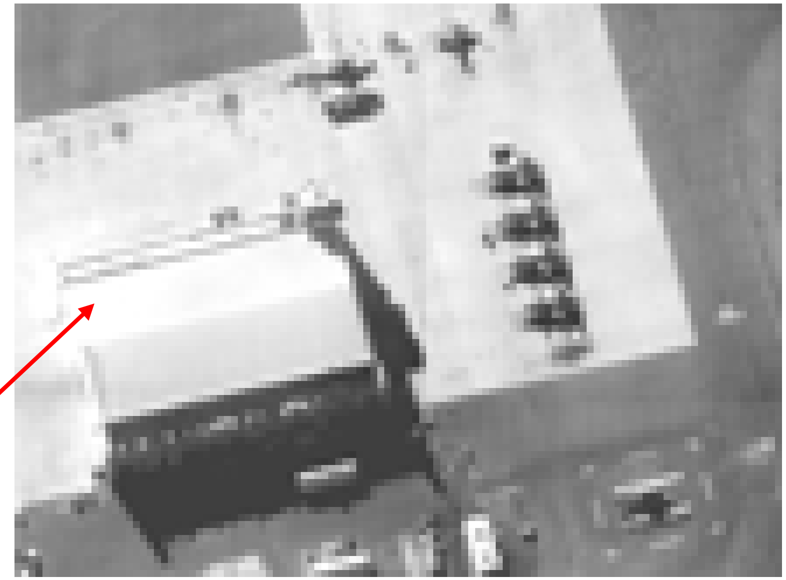
Optical Zoom vs. Electronic (Digital) Zoom

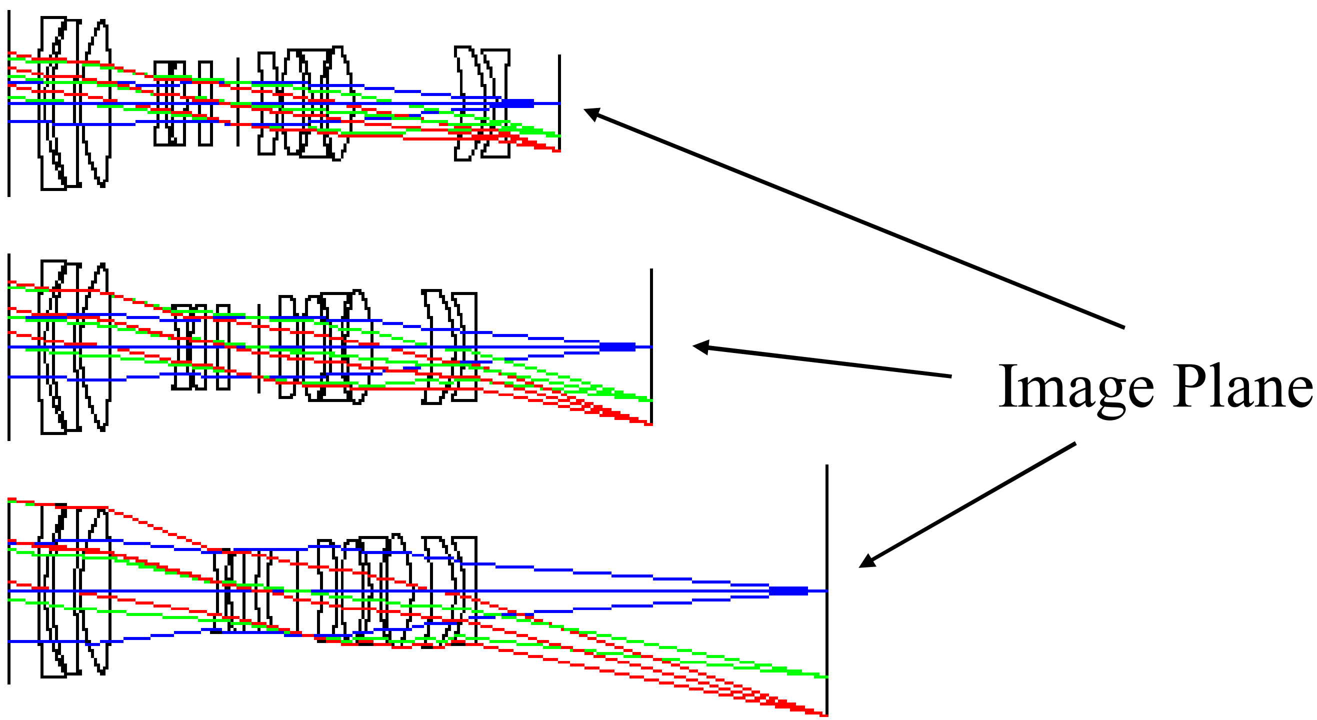
Electronic (Digital) Zoom



4X Optical Zoom

ZEMAX Layout
Conventional 2.5X Zoom

Wide field-of-view

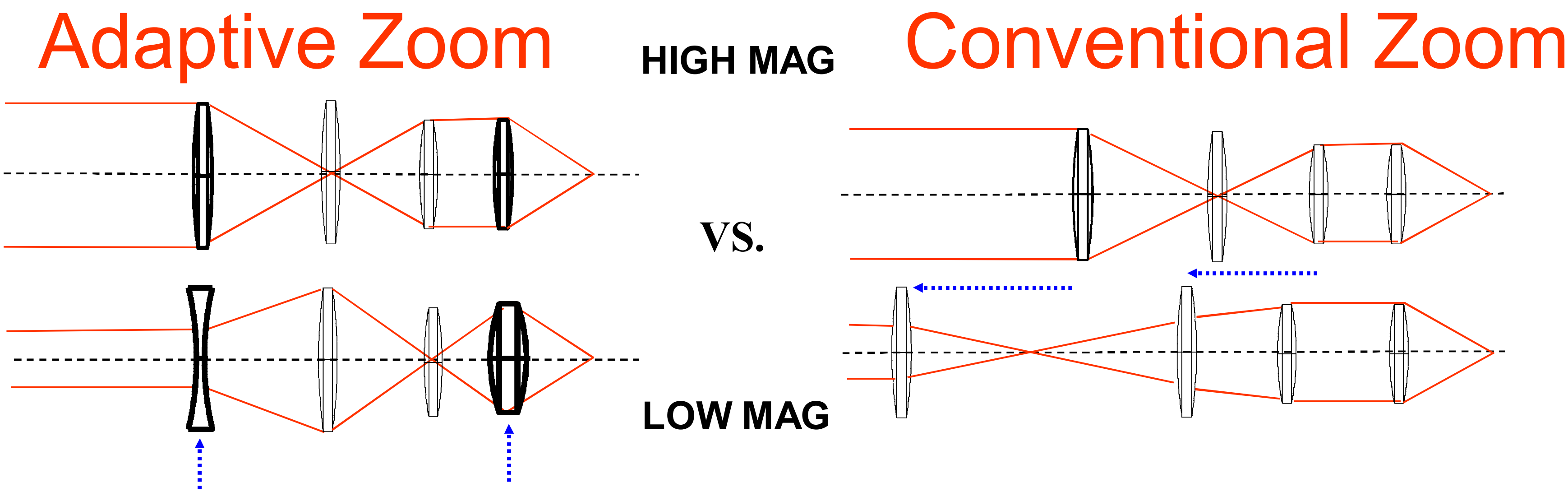


Narrow field-of-view – ON AXIS

Adaptive Zoom
How does it work?

Small changes in the individual <u>focal lengths</u> of elements

<u>Large changes in magnification</u> of the system.

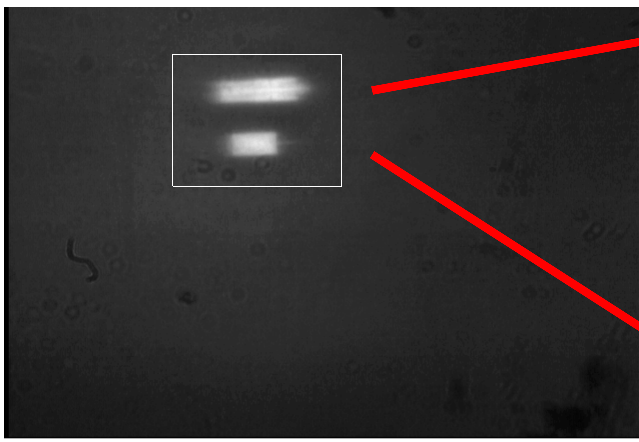


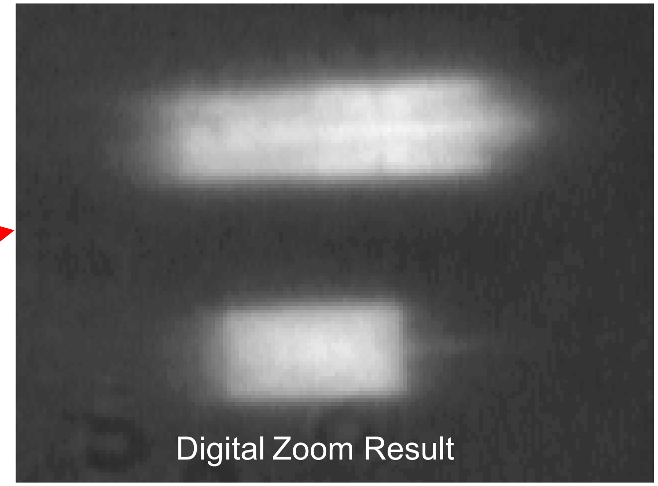
- **Power consumption can be greatly REDUCED**

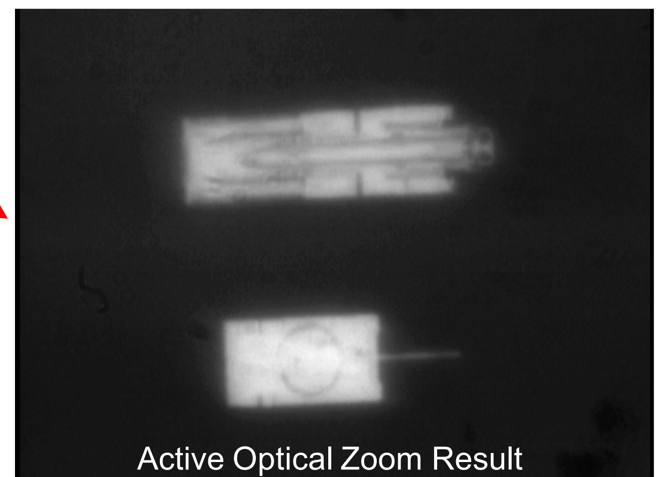
U.S. Patent #6,977,777

Active Optical Zoom vs Digital (Electronic) Zoom

Digital Zoom is simply larger: no increase in resolution.



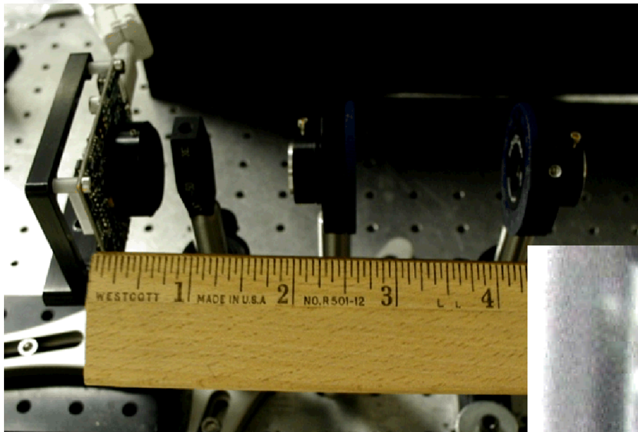


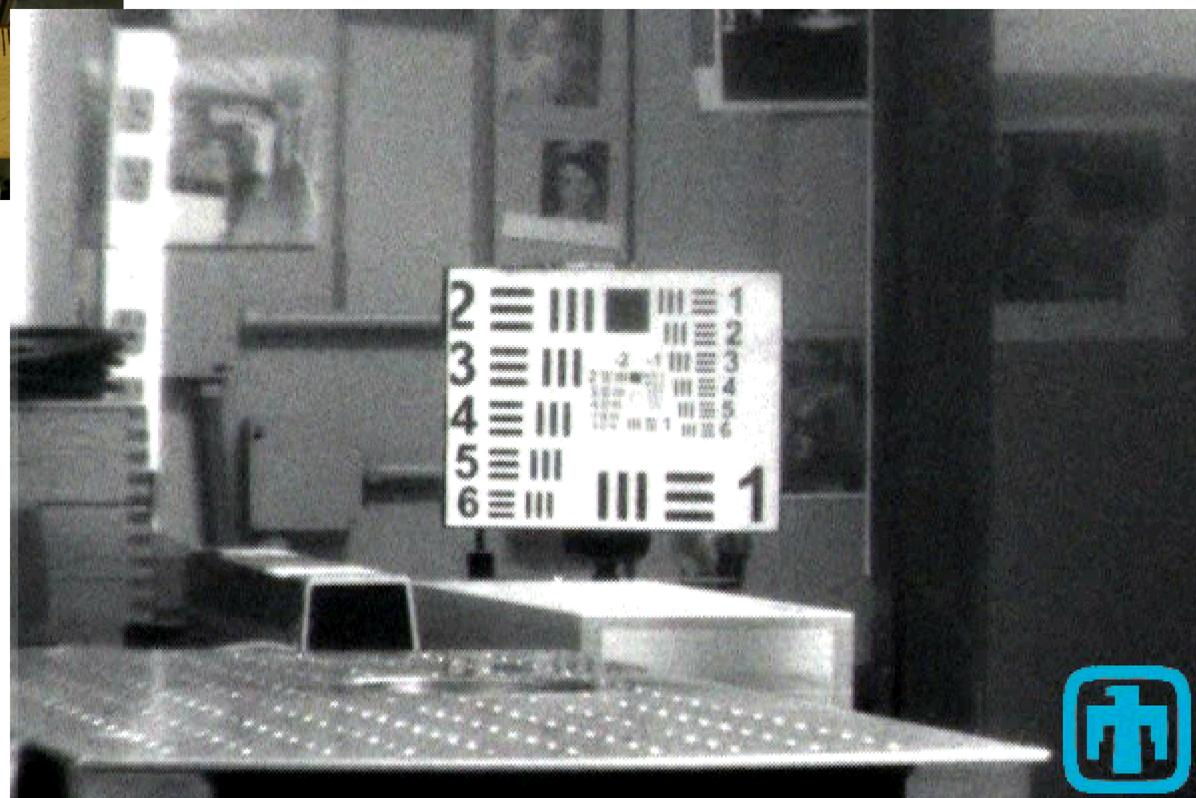


Active Optical Zoom accomplished by changing the voltages that were applied to the two SLMs.

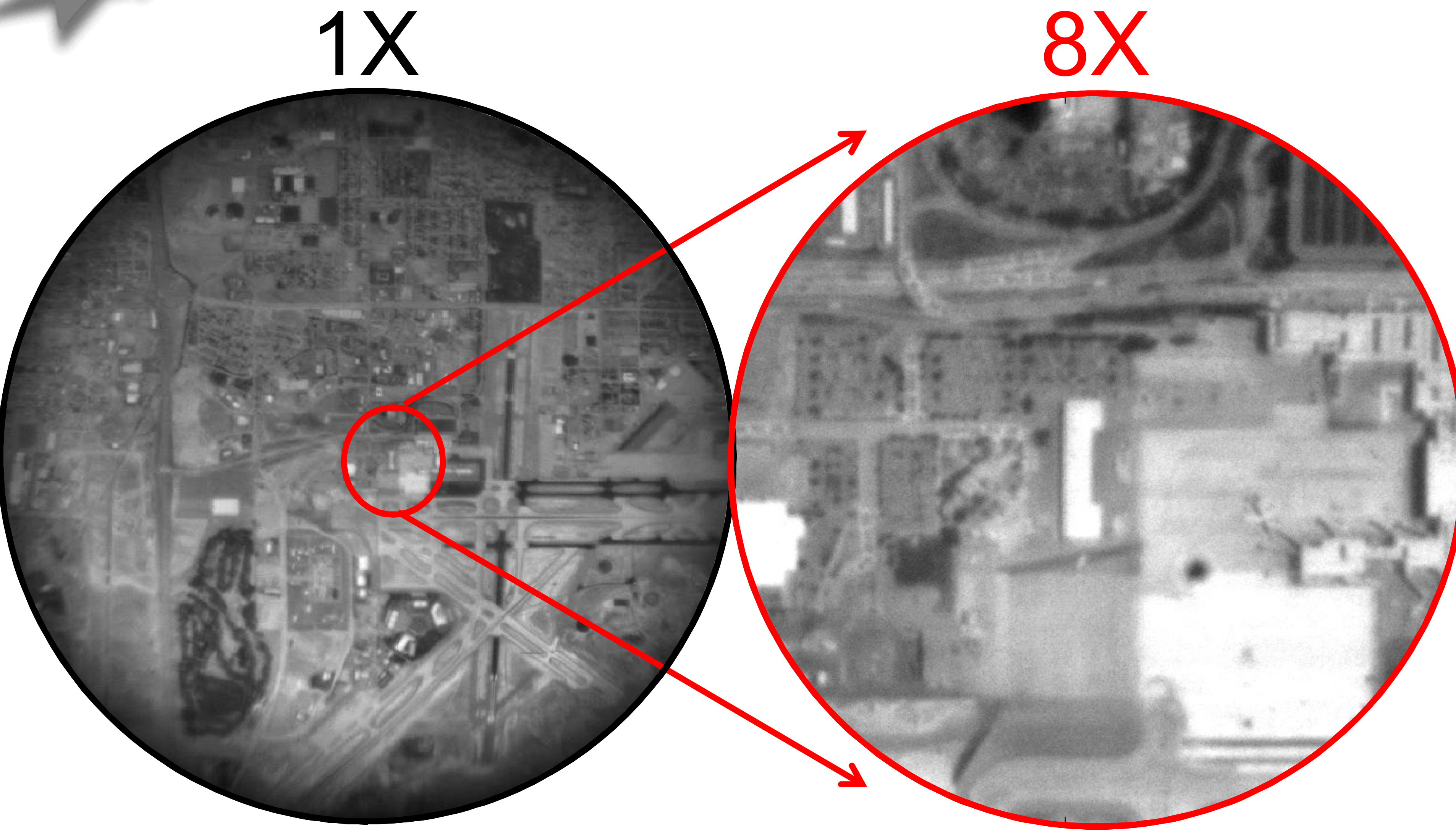
NO MOVING PARTS

4x Zoom using Adaptive Polymer Lenses



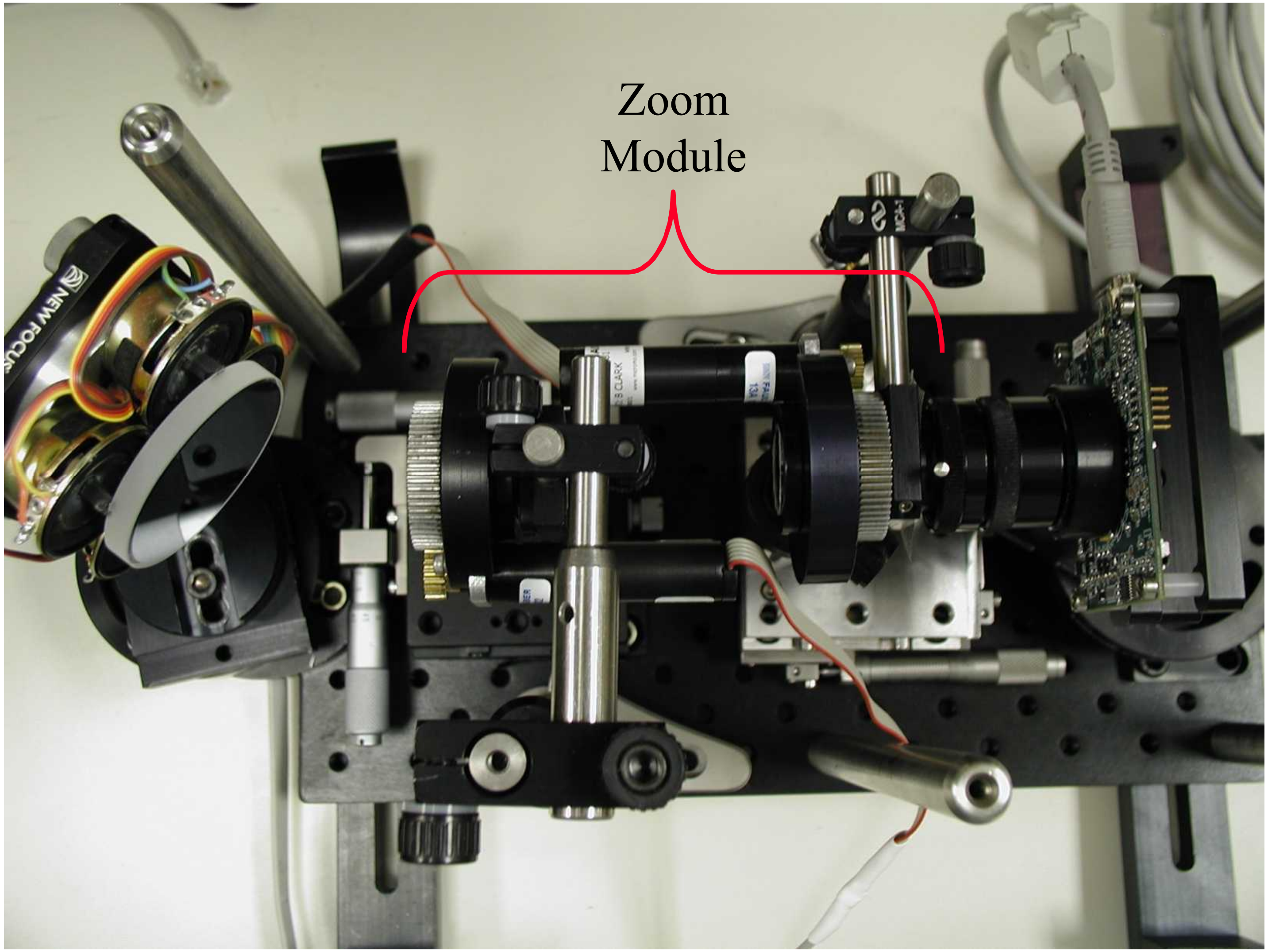


First Demonstration Adaptive Lenses



Scanning with zoom

Fast
Steering
Mirror
+/-7 deg



Off-axis Zoom using optical tilt in place of gimbal

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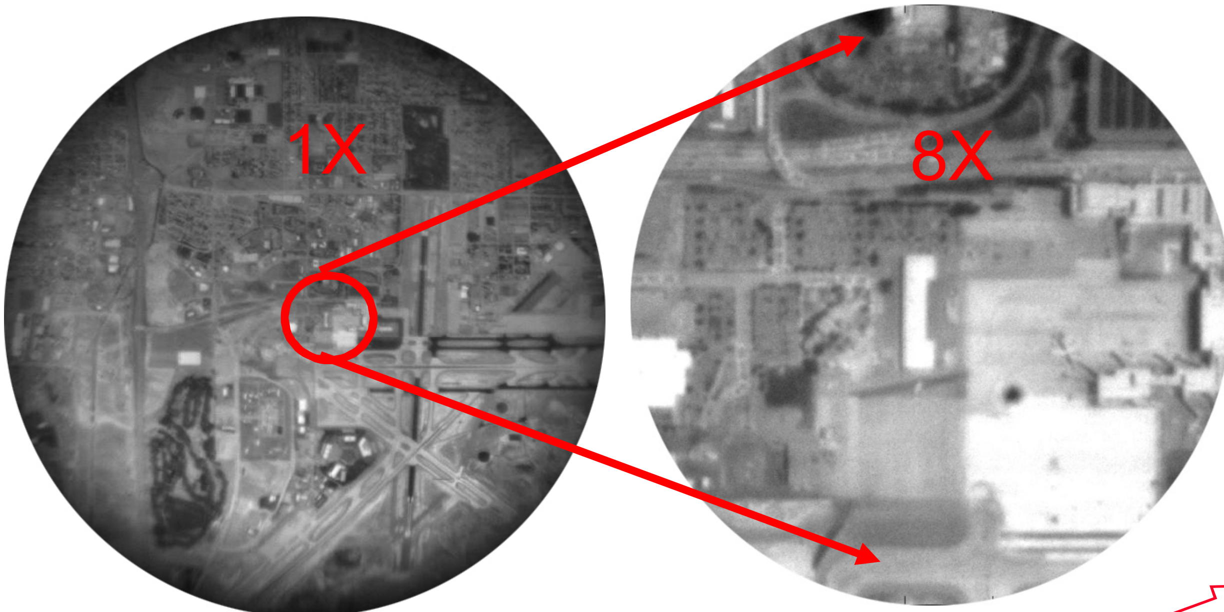
Why Composite Mirrors

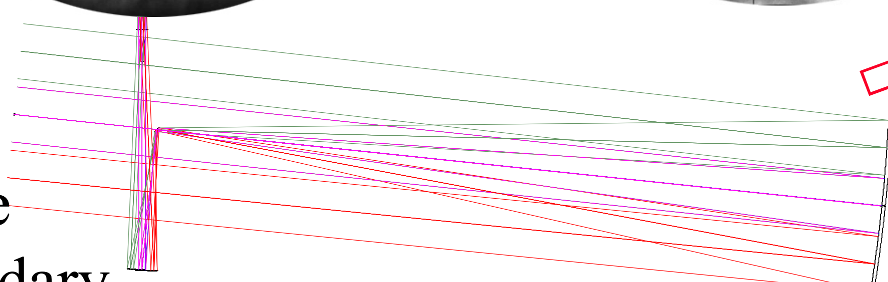
Large aperture Carbon Fiber Reinforced Polymer (CFRP) mirrors are thin-shelled and lightweight yet significantly more rugged than other flexible materials (e.g. membranes) but not as brittle as SiC or thin glass.

- Larger apertures allow larger zoom ratios
- Size, Weight, Power a bigger issue as you move to larger apertures. Conventional approach: separate acquisition and tracking (Gimbaled).
- High resolution, reflective zoom does not exist – “Shadows” or off-axis tolerances
- Leveraging previous work from NRL

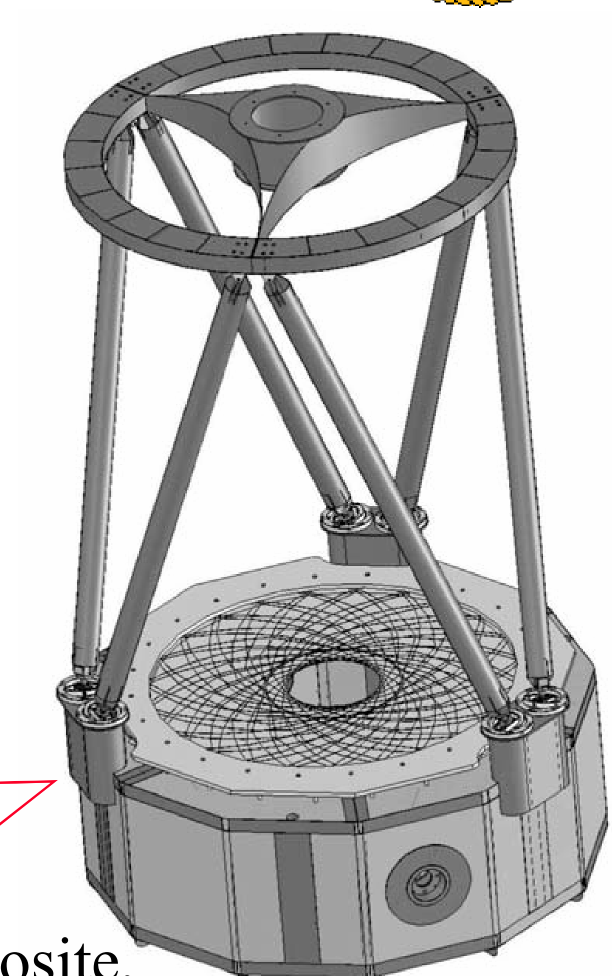
System Concept

Actual images taken from an 1-8X REFRACTIVE, small aperture adaptive zoom system (in the lab with a poster - not at altitude).





Active Secondary



Composite, variable radius mirror

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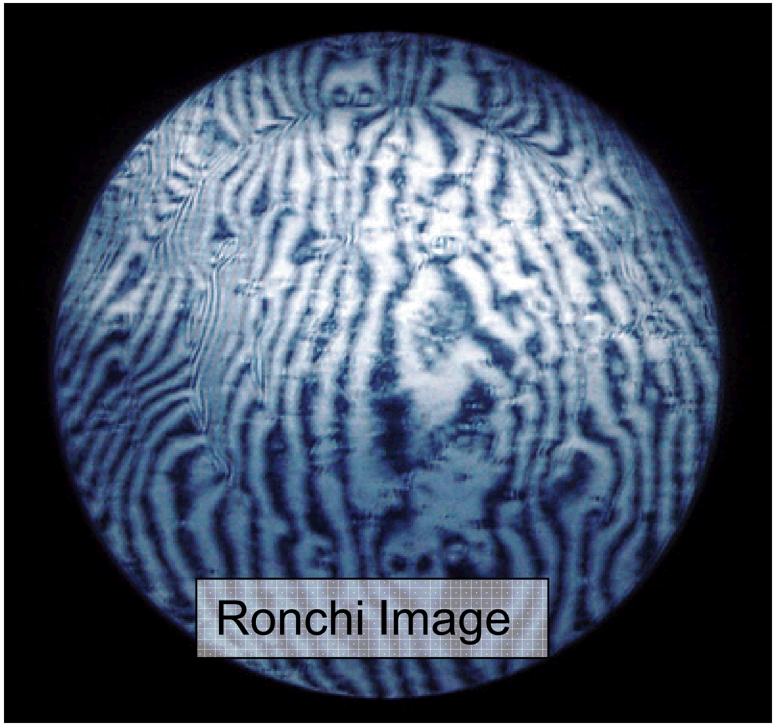
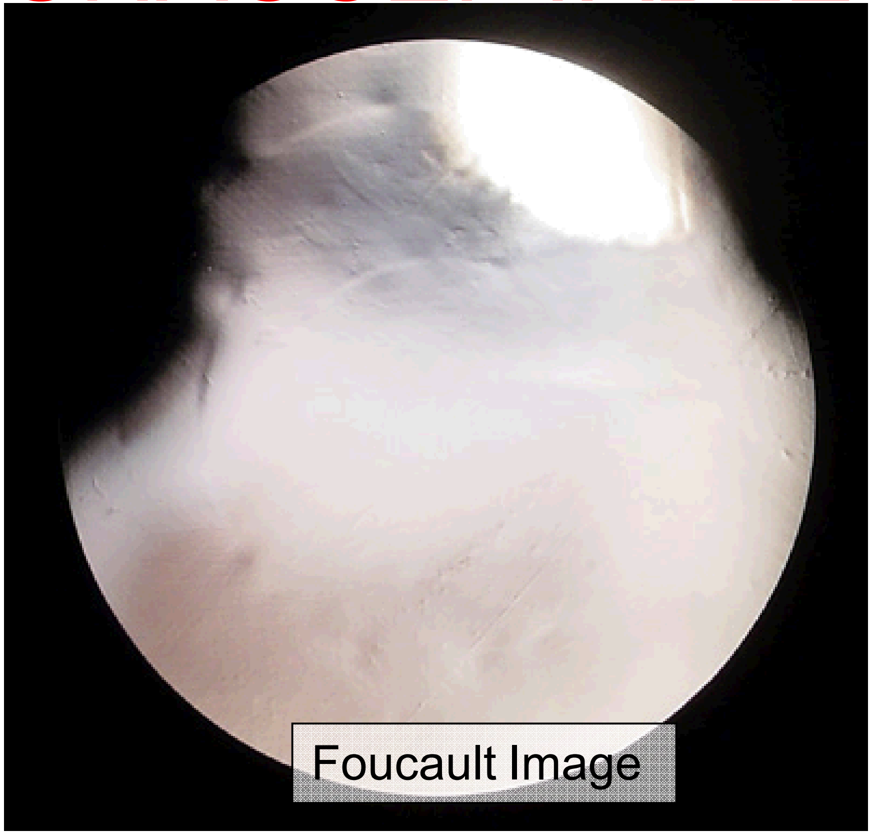
16-ply CFRP
Variable Radius Mirror



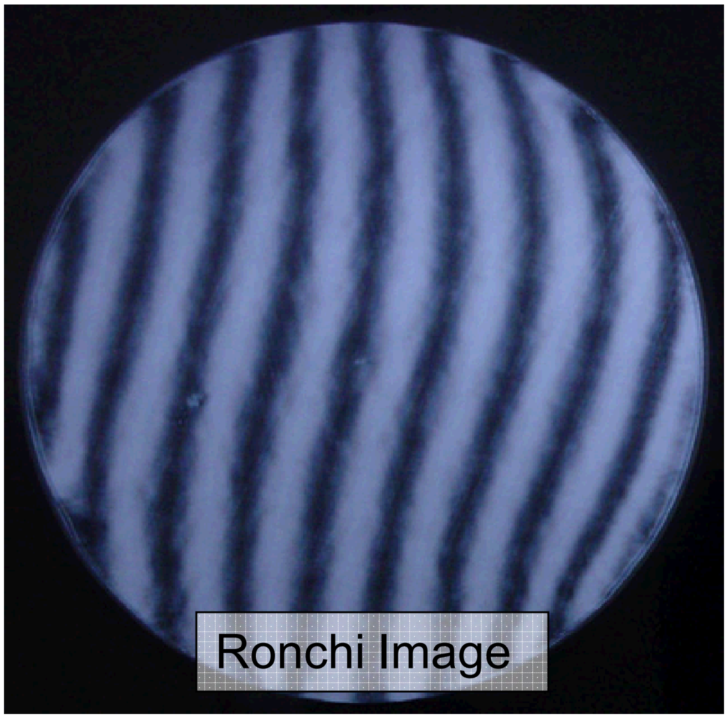
CFRP VRM
400 mm diameter X 1.75 mm thick
Standard orientation 16-plies
Coating: aluminum + SiO
Measured with Ronchi, 50 lines/in.

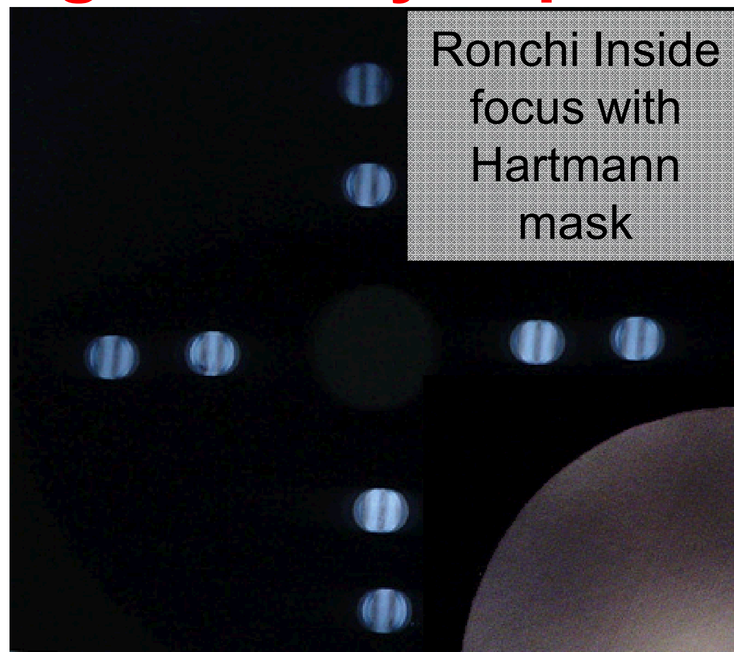
UNACCEPTABLE

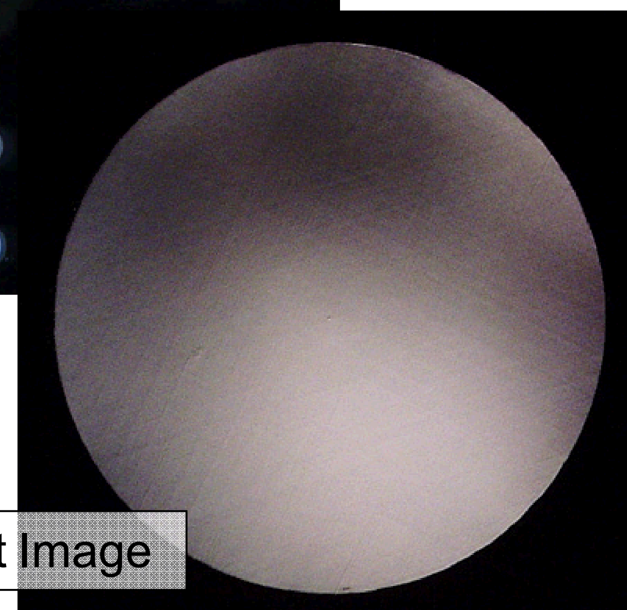


Parallel mirror development
24-ply CFRP VRM

Thicker mirror – Significantly improved



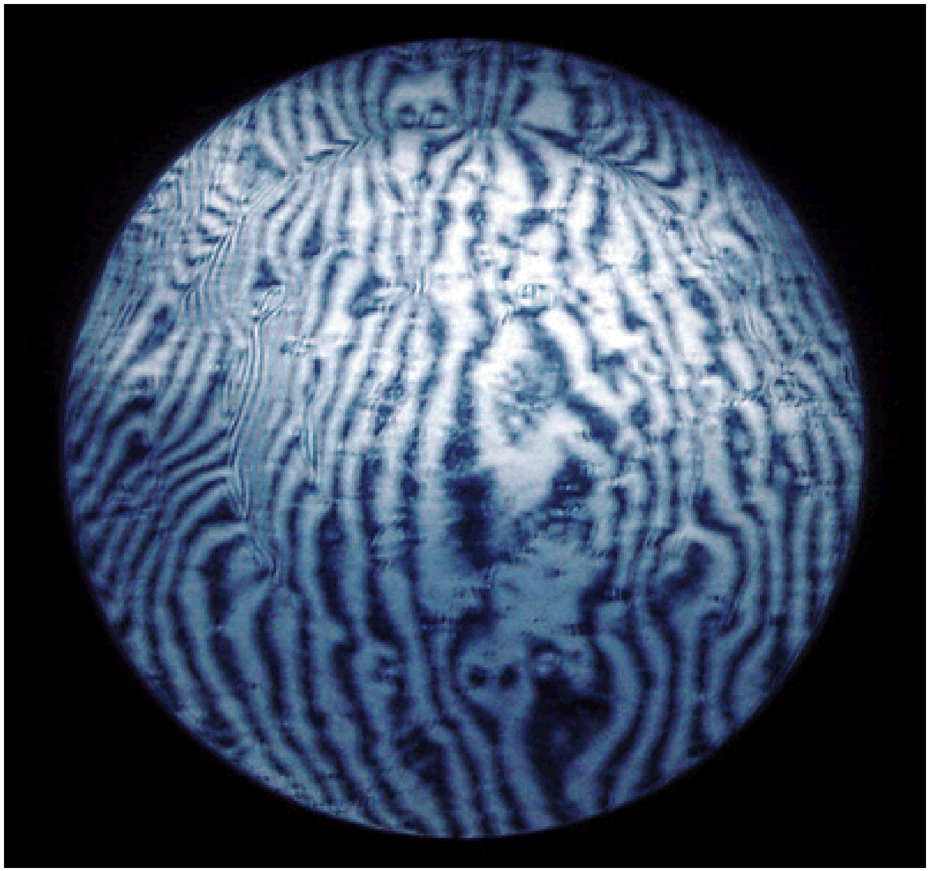




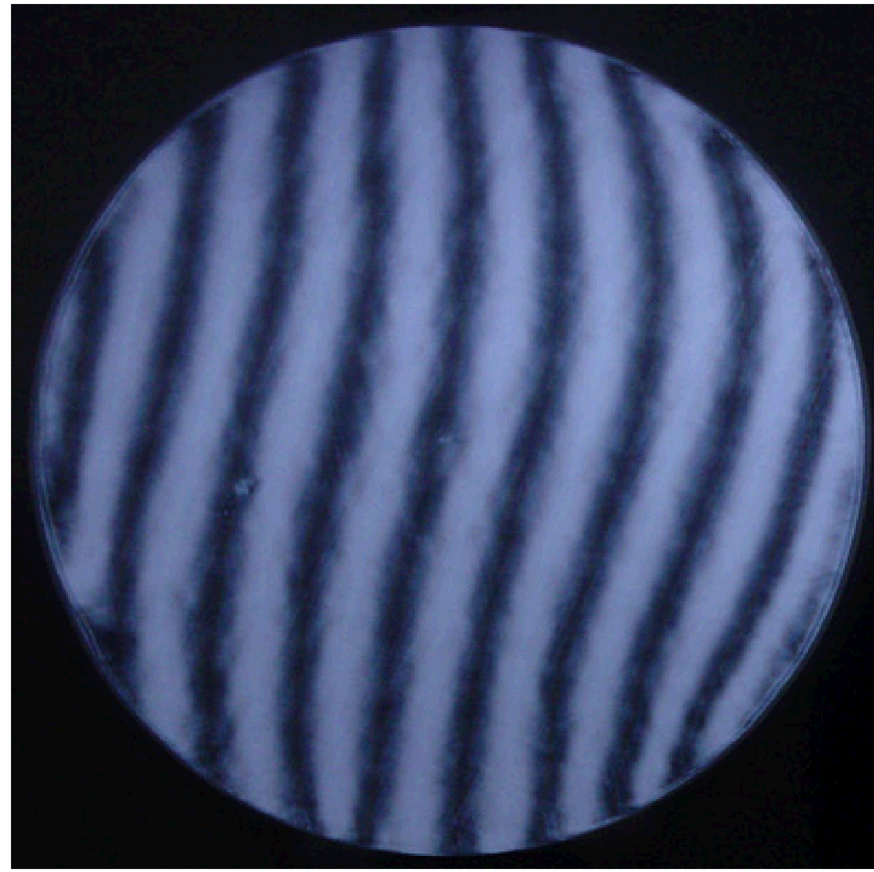
CFRP VRM
400 mm diameter X 2.5 mm thick
Standard orientation 24-plies
Coating: aluminum + SiO
Measured with Ronchi, 50 lines/in.

Comparison 16- vs 24-ply CFRP mirrors

Ronchi Image comparison between 16 and 24-ply mirrors



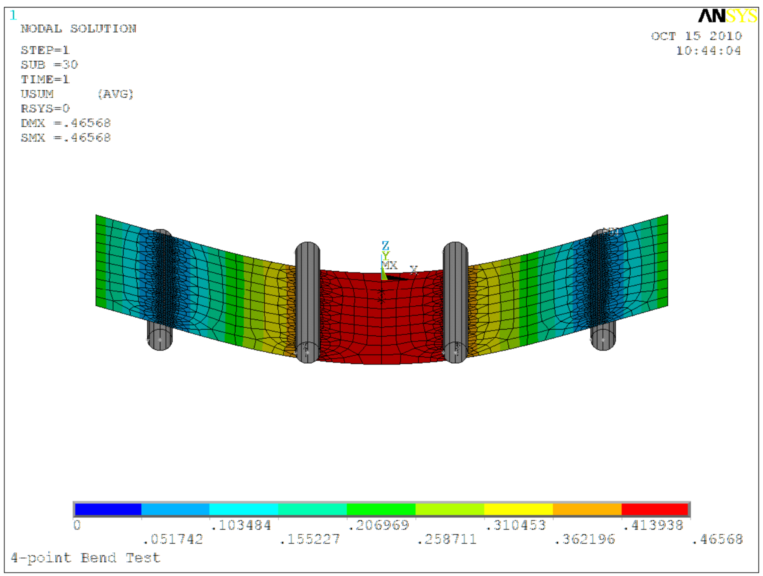
16-ply

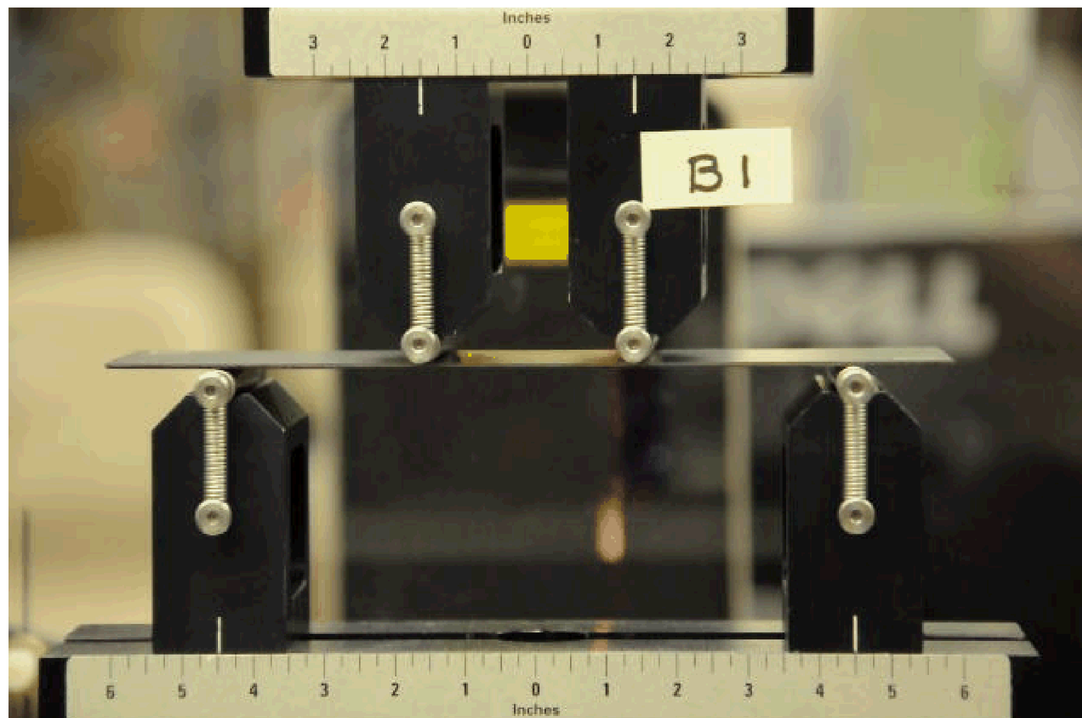


24-ply

4-pt bending test completed

- **25 composite coupons were fabricated (16-ply and 24-ply with standard layups and 0° and 12° orientations, along with 5 uniaxial samples).**
- **Coupons tested by Brad Boyce (1831) to ascertain Young's modulus in each direction (x, y, and z), Poisson ratios, and shear modulus. These 9 values are then used in ANSYS to describe each layer.**





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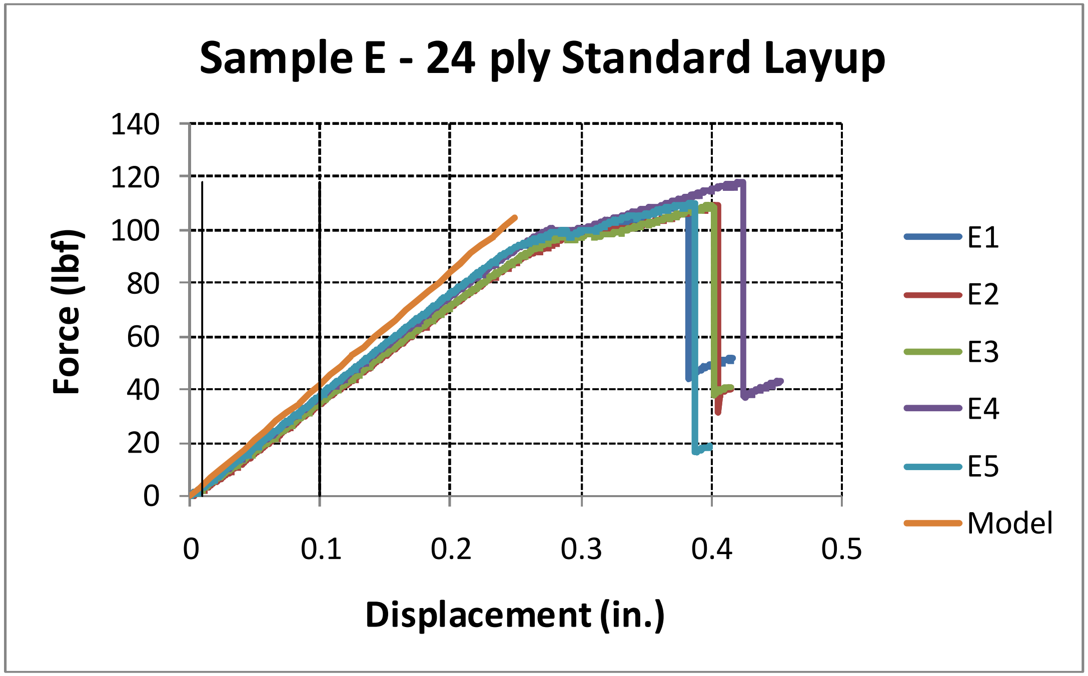
4-pt bend test results

Property	Published (psi)
E_1	46.2×10^6
E_2	1.07×10^6
E_3	1.02×10^6
v_{12}	0.30
v_{13}	0.30
v_{23}	0.49
G_{12}	0.7×10^6
G_{13}	0.7×10^6
G_{23}	0.63×10^6



Composite (Young's) modulus in fiber direction (E_1), matrix modulus, and shear modulus (G_{12}) adjusted based on measurements. Poisson's ratios (v) were estimated based on literature values, and we used volume fraction of fiber as quoted by the vendor.

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Zygo wavefront measurements

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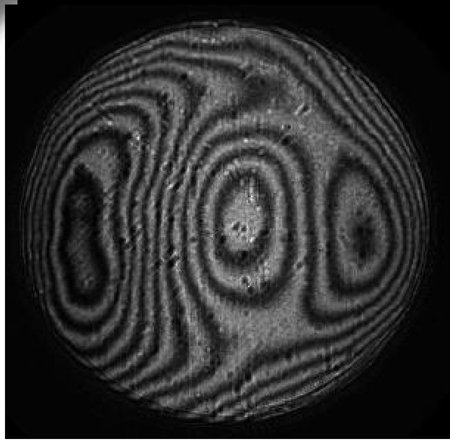
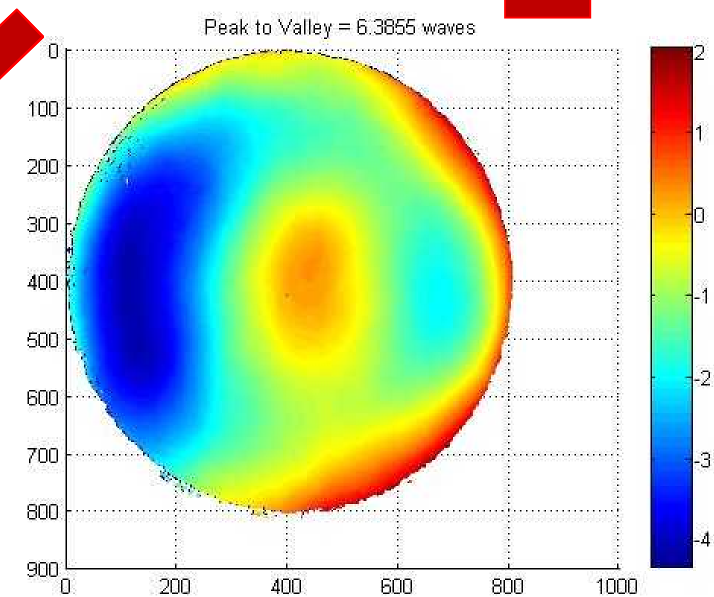


CFRP Mirror



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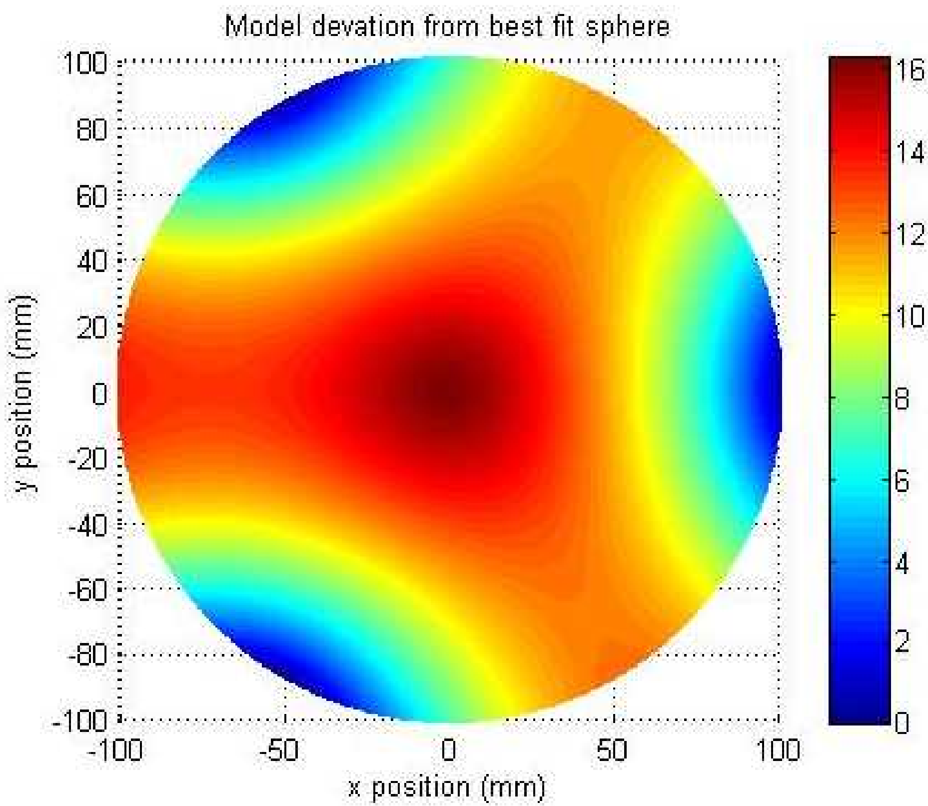
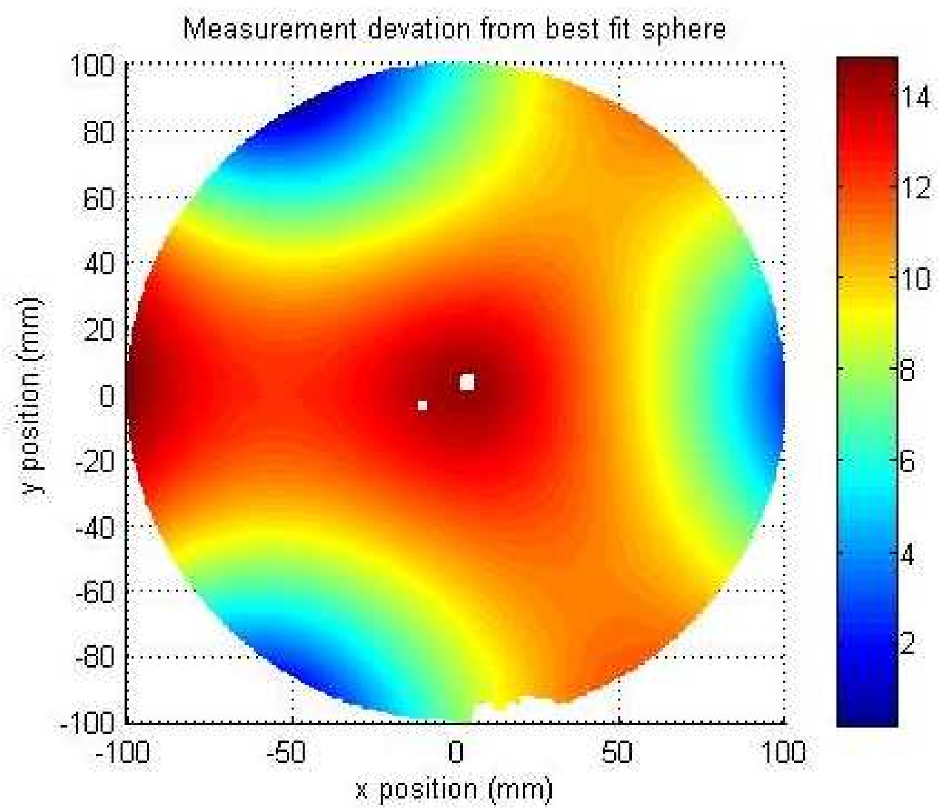
Wavefront with three point contact and point load in center

FEM with 0.86 N of force at Center



Measured 0.86 N of force at Center



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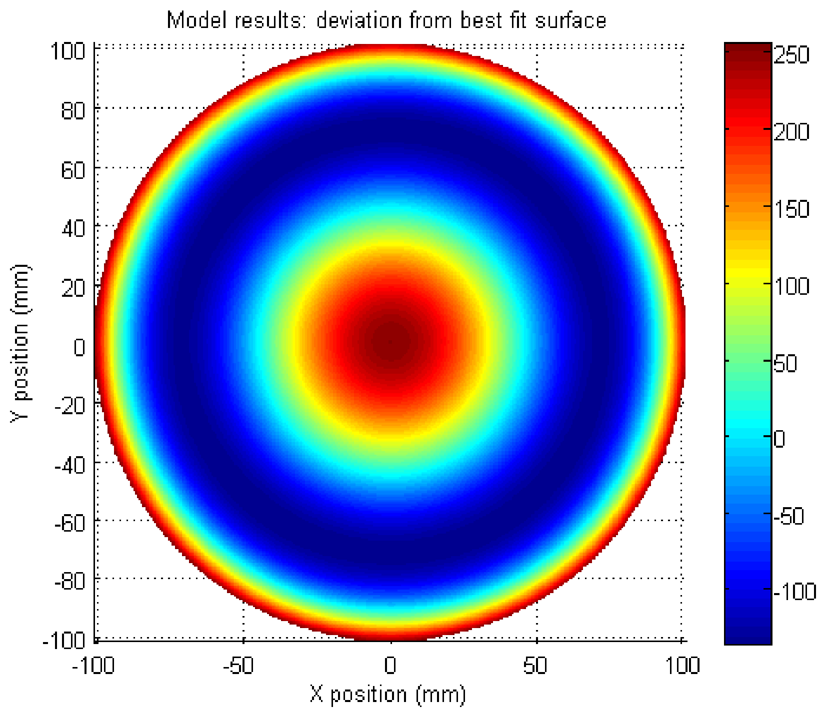
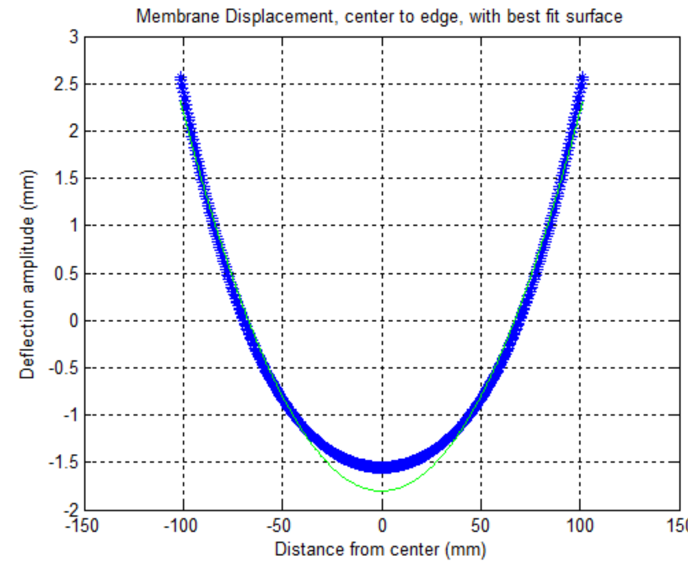
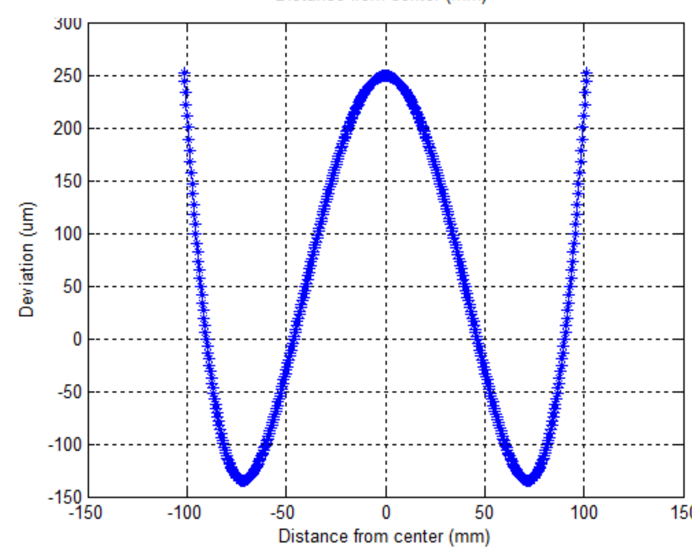
Change in Radius of Curvature Predicted Wavefront Error

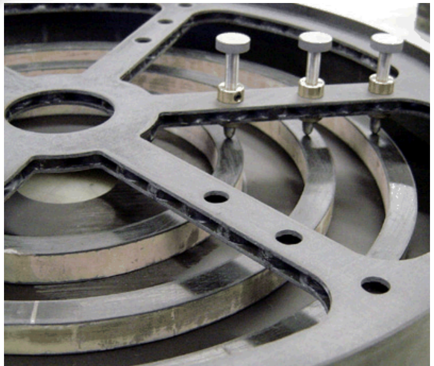






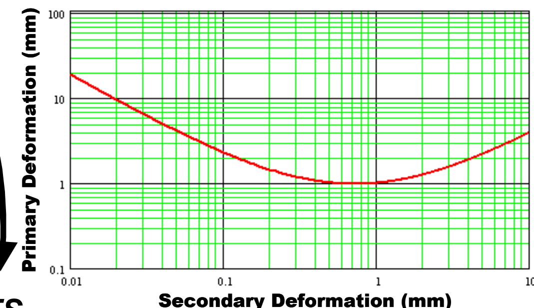
Results in varying the radius from 2m to 1.25 m via tangential displacement (uniformly around circumference). Top shows wavefront compared to 1.25 m ROC sphere and the bottom is the difference (in microns).

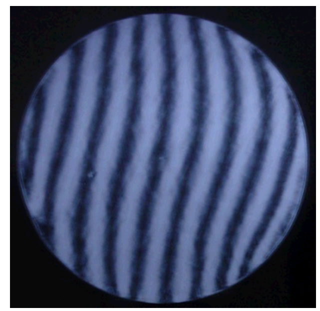
Proposed Development of Composite Mirrors



MATERIALS

MATERIAL REQUIREMENTS





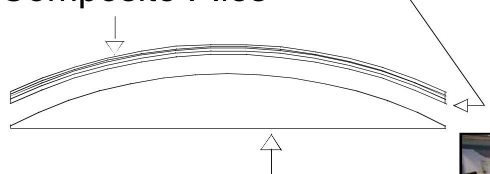
ACTUATION

SYSTEM REQUIREMENTS

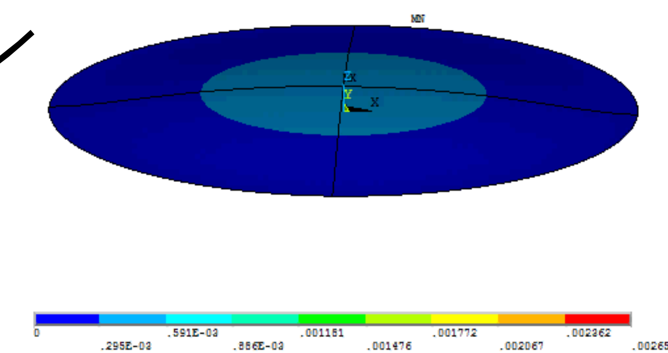
FABRICATION

MODELING

MEASURED PERFORMANCE

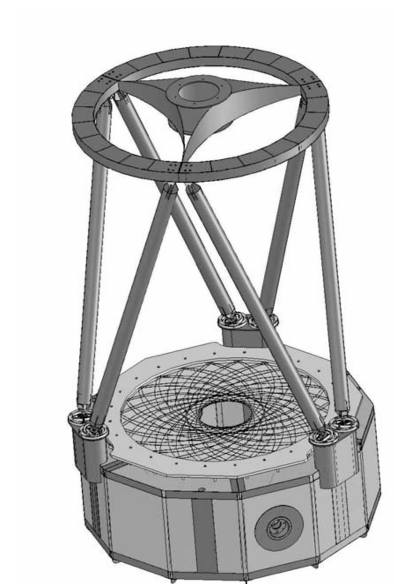


PREDICTED PERFORMANCE



CFRP potential capabilities

- **Variable Radius of Curvature** – Pan, Tilt, and >10X Optical Zoom without macroscopic motion. These thin shelled mirrors can vary their Radius-of-Curvature (ROC) with minimal mechanical motion and little power. Actuation will also allow aberration correction (dynamic aberrations (jitter/thermal) or due to variations over time).
- **Multispectral** – Reflective system not limited to single wavelength band (e.g. visible or SWIR).
- **Larger Apertures** – Higher resolution and greater light gathering capability (i.e. higher S/N)
- **Lightweight** →



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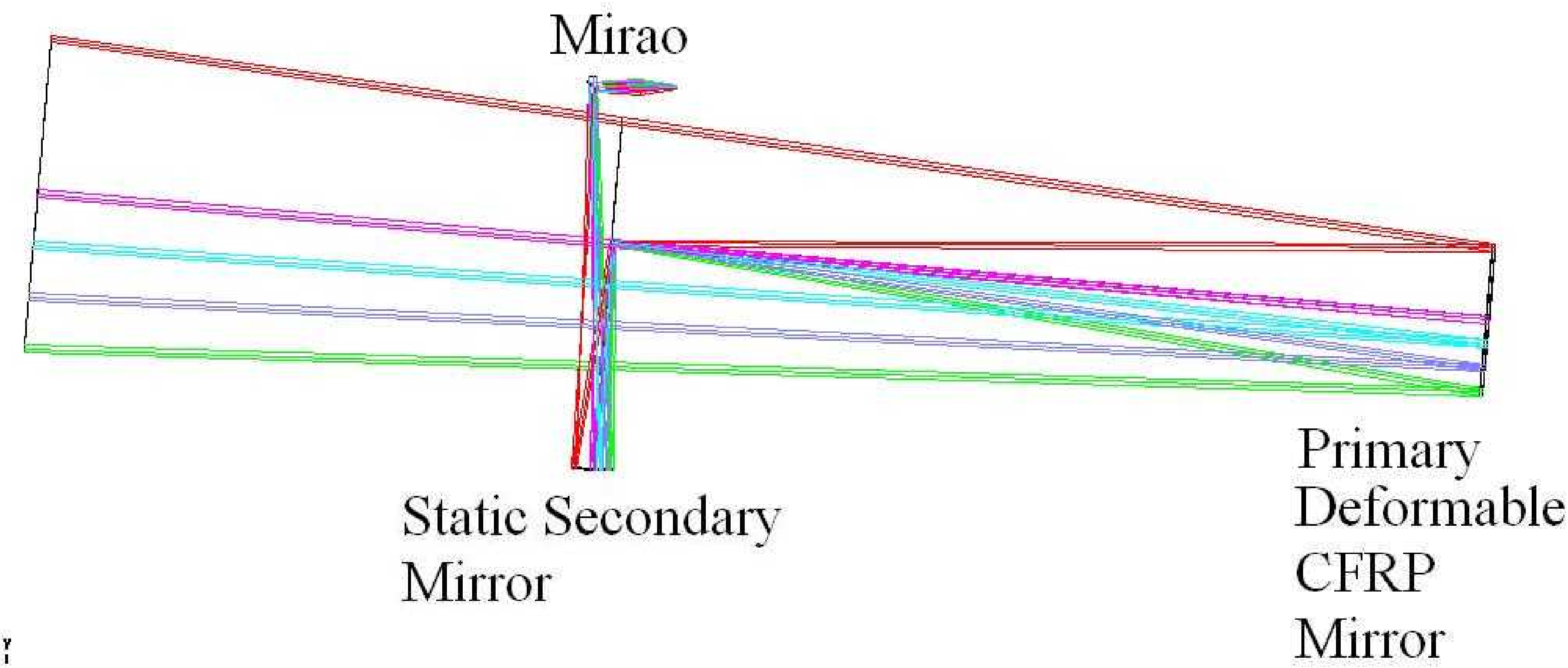
Example:12X Zoom CFRP Design for 16” Primary Mirror

ONLY 4mm Deformation on the Primary



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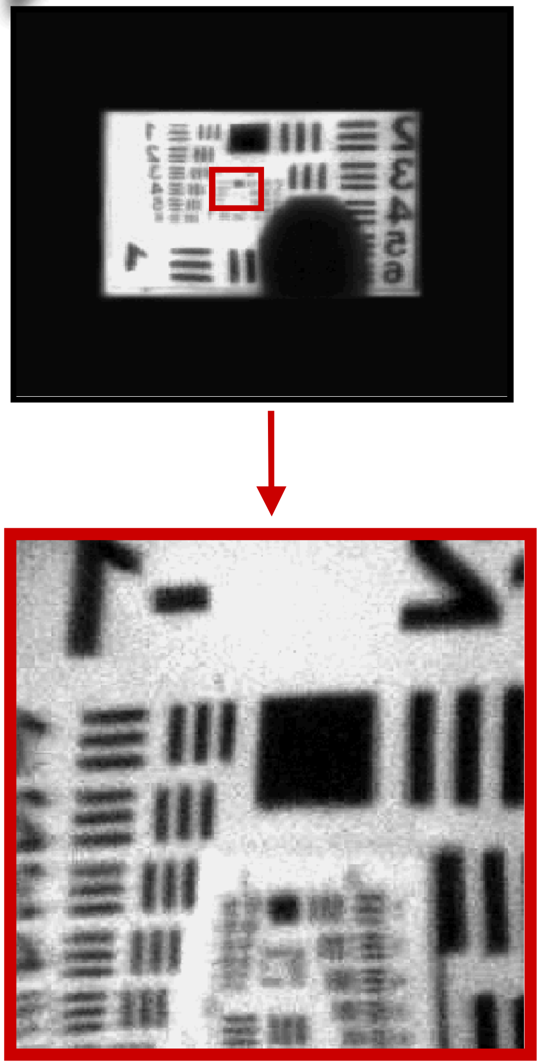
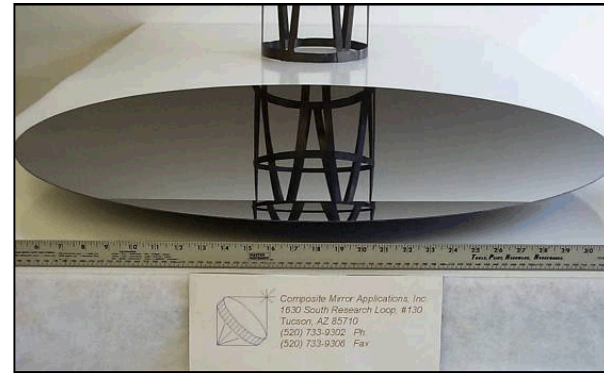
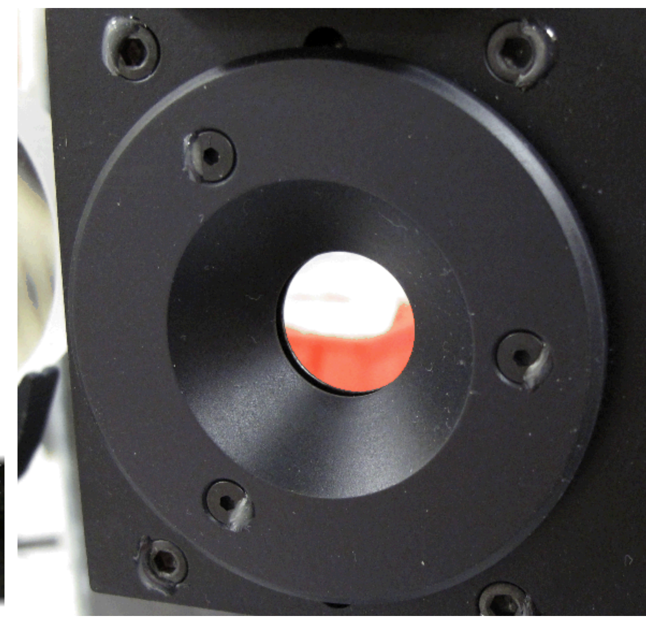
10X Zoom using a composite mirror



10X Zoom with an Uncoated 16-inch diameter CFRP shell
and a MiroAO electrostatically addressed membrane mirror





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Acknowledgements and Questions

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