Hybrid Mirror Technology Development

Presented at

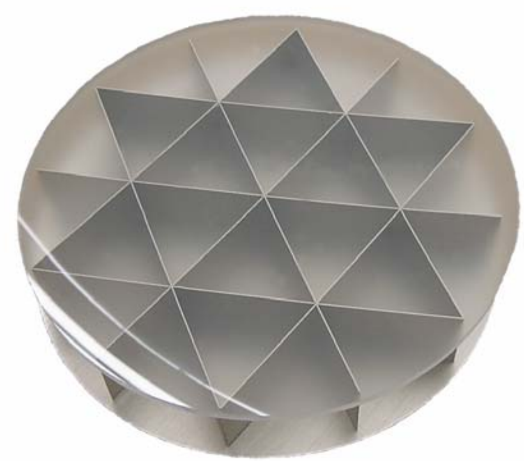
Tech Days 2003
NASA Marshall Space Flight Center

Greg Mehle

Presentation Overview

- Lightweight Hybrid Mirror Technologies Sponsored by MSFC
  - NGST Mirror System Demonstrator (NMSD)
    - Contract NAS8-97310
  - Thermally Stable Lightweight Mirrors for Earth Observing Instruments
    - P1 SBIR Contract NAS8-01032

1.6m Aperture NMSD Hybrid



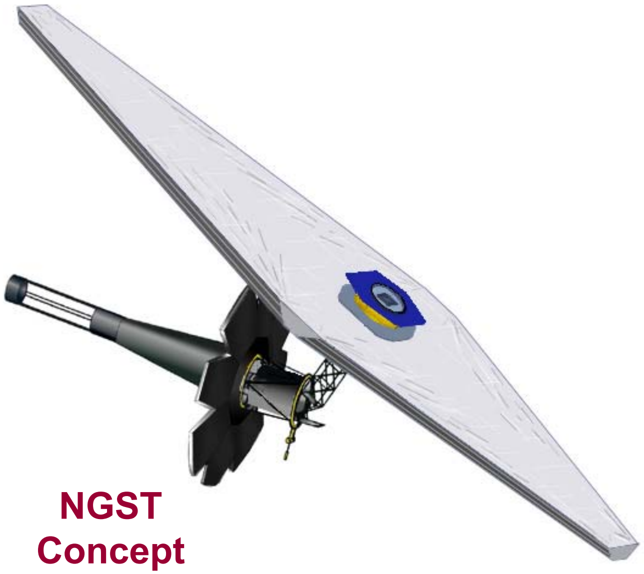
0.3m Aperture SBIR Hybrid

Hybrid Mirror Benefits
Enabling Technology for Space Missions

- **Component Level**
  - Offer a lighter weight, cheaper, faster alternative to traditional lightweight mirror technologies/materials (eg. glass, beryllium, etc) for Shorter Wavelengths
  - Large and Small Aperture Scalability
- **System Level**
  - Provides an integrated design of lightweight composite mirror in dimensional stable structure (Athermalization with Metering Structure)

NMSD Program

- Customer: NASA Marshall Space Flight Center
- Key Requirements
  - Areal Density: <15kg/m^2 for Mirror Assembly
  - Figure: λ/10 PTV at 35K in Simulated Zero Gravity



NGST Concept

Program Team

- ATK-COI: Engineering, Fabrication, and Test
- SAGEM: Optical Processing and Test Support
- NASA Marshall Space Flight Center, H. Phillip Stahl COTR
- University of Alabama, Huntsville: Optical Test

NMSD Technical Challenges

Areal Density for Mirror Assembly

- » Hubble Space Telescope Areal Density Approx 180 kg/m^2, ref
- » COI Hybrid: 11 kg/m^2 for Mirror Substrate

Optical Processing and Test

- » Conventional and Ion Figuring of Very Light Weight Hybrid Substrate
- » Subaperture (Interferometric) Figure Evaluation
- » Gravity Offloading

Thermal Extremes of (Glass and Composite) Bonded System

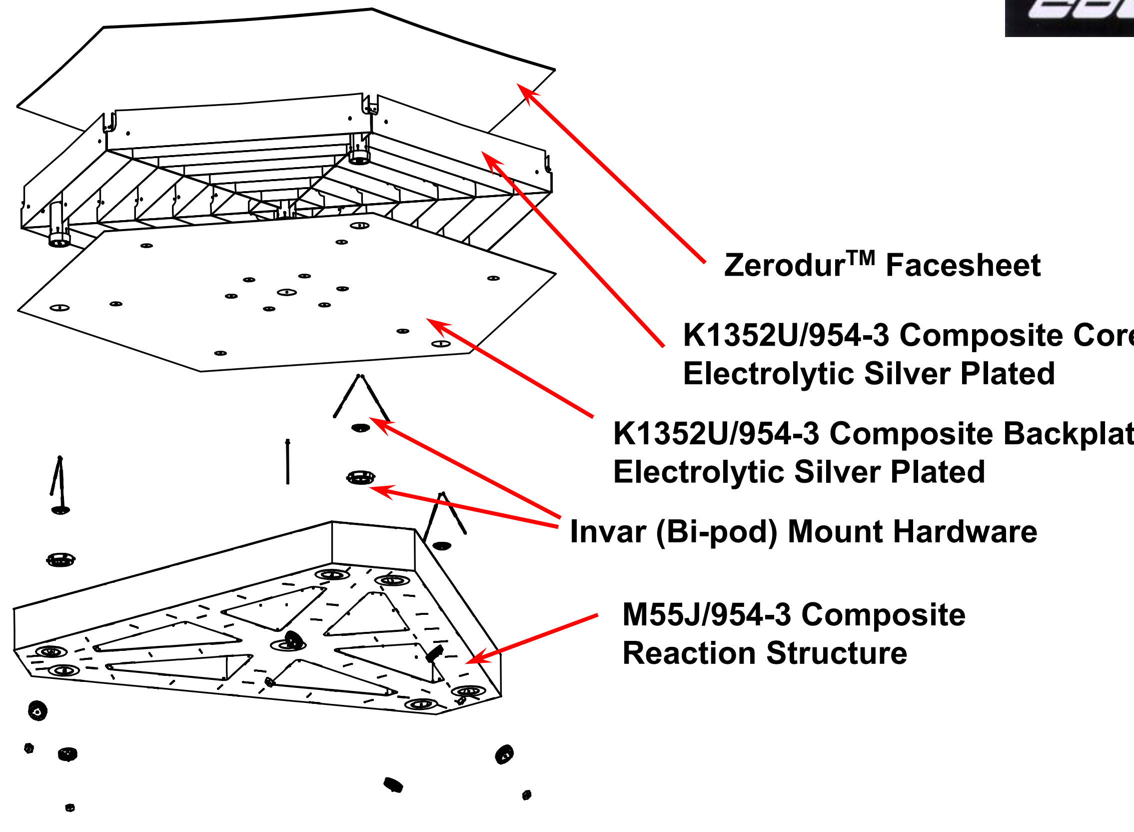
- » Ambient Fabrication and Optical Processing
- » 35K Nominal Demonstration Temperature Dimensional Stability

Dimensional Stability

- » Thermal Expansion Matching of Constituents
- » Moisture Control During Processing
- » No Hysterisis from Cryo Cycling

- ♦ **Keys to Program Success**
  - » Risk Reduction Hardware
    - › Demo Mirrors for Analytical and Materials Foundation
  - » Materials Development
    - › COI Developed Plating for Tuning Thermal Expansion Characteristics of the Composite

NGST Mirror System Demonstrator



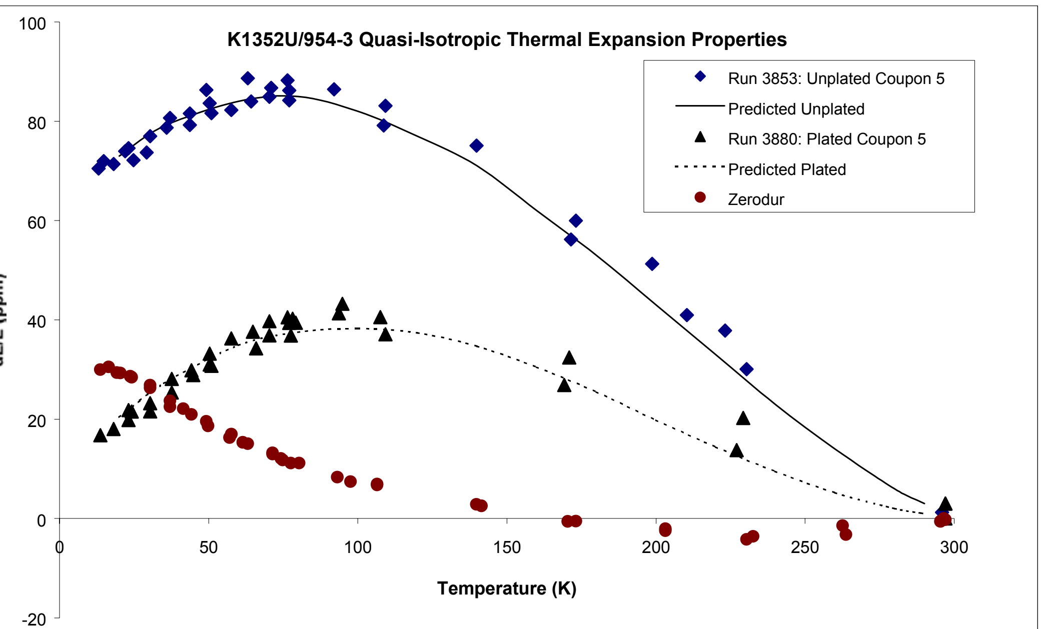
- **1.6m Aperture**
- **Primary Mirror Assembly Areal Density: 15kg/m^2**
  - **11kg/m^2 for Mirror Surface**
  - **4kg/m^2 for Reaction Structure and Invar Mounts**

NMSD Hybrid Design Approach

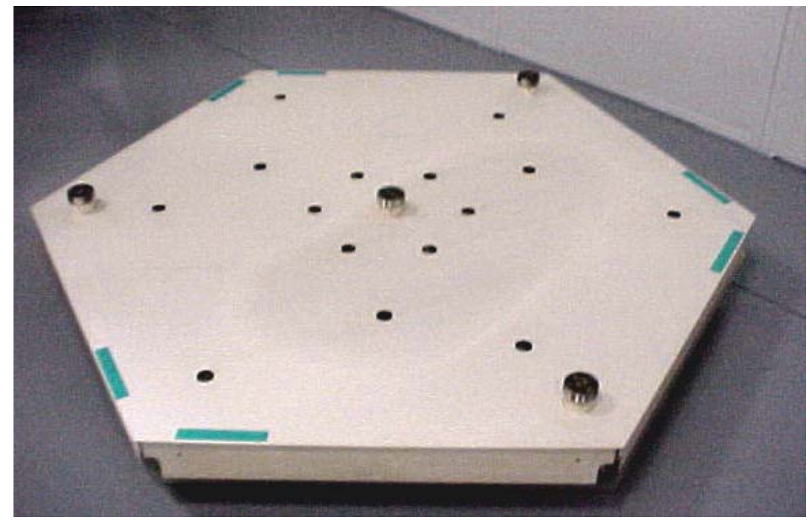
- Combine Desirable Attributes of Both Glass and Composite
- Structurally Efficient (Bonded) Sandwich Construction
  - Zerodur™ Facesheet
    - Processible Using Conventional Methods (Grinding, Polishing, Ion Figuring)
  - Composite Backface and Core
    - Low Mass, High Stiffness Support for Zerodur™ Facesheet
    - Thermal Expansion Match of Zerodur™ (Ambient to 35K)

Plating: Key Material Technology for the Hybrid Mirror

- Thermal Expansion Matching of Composite to Zerodur™
  - » Lamination and Cure Control: Tailors Fiber Volume for Targeting dL/L
  - » Plating of Cured Composite: Fine Tunes dL/L to Match Glass



Analytical Models Developed For Predicting Thermal Expansion Behavior of Laminate and Plated System Providing a Powerful Design Tool for Precision Structures

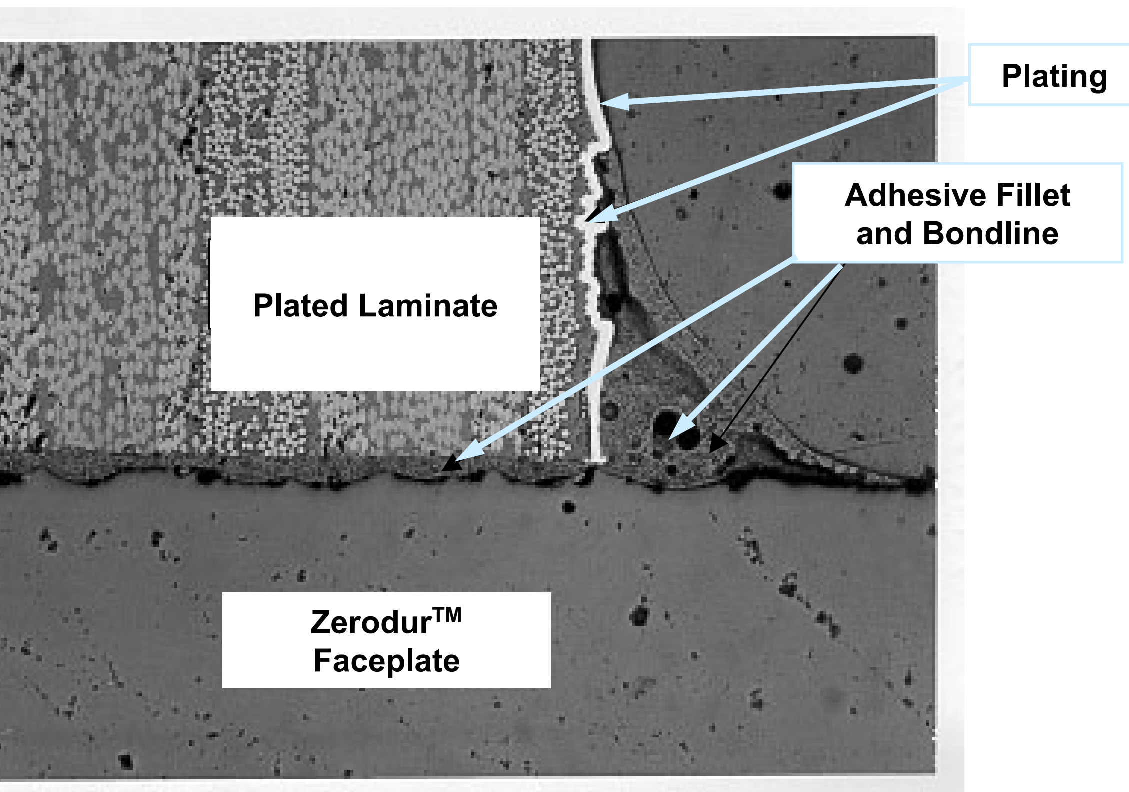


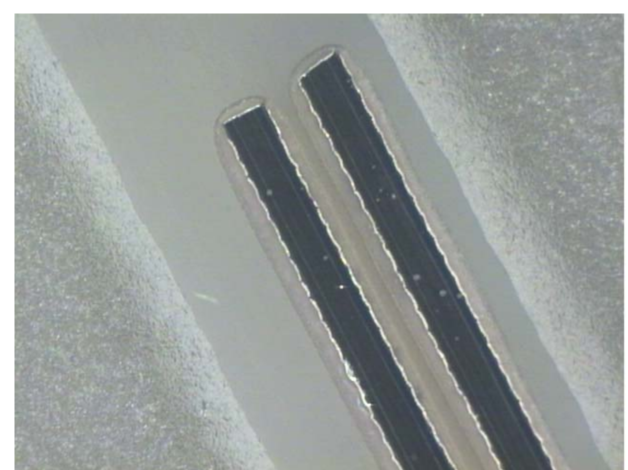
Electrolytic Silver Plating

- » Plated Hardware Cryo Demonstrated to 4K
- » Thermal Expansion Tuning of Substrate Deta
  - › Strain Matching to Facesheet
  - › Strain Matching Between Details
- » Selective Area Plating
  - › Preferential Plating Distributions Across La Components

Adhesives Technologies

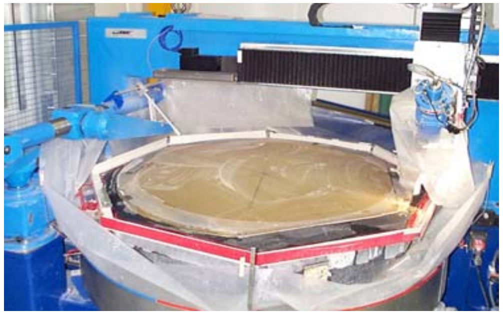
- **What Are the Real Requirements for Adhesive Selection**
  - **Bond Strength and Strain Capacity a.k.a. Cryo Survivability**
    - **Adherends: Zerodur™ to Plated Composite; Composite to Composite; Composite to Invar**
  - **Processibility**
    - **Minimized Fillet Size**
    - **Controlled and Consistent Wet-out of Adherends**

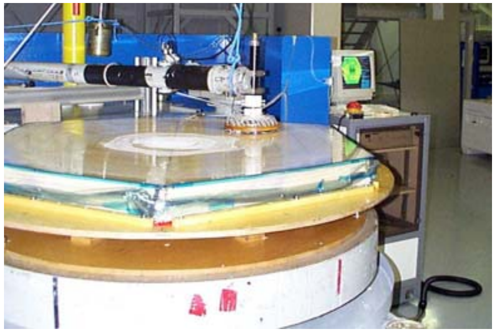


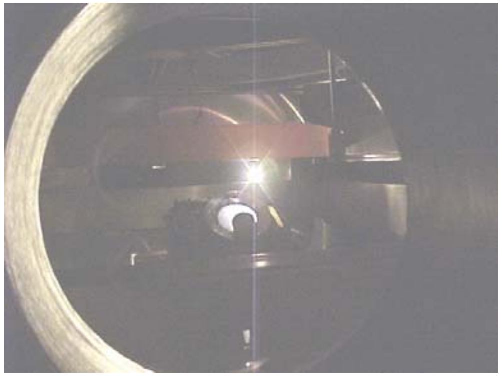


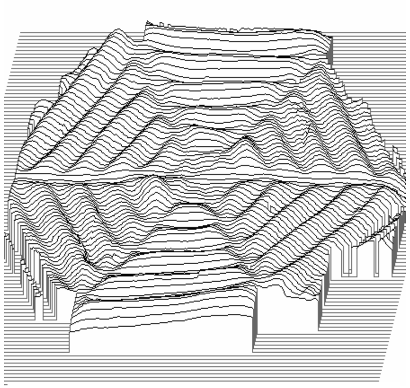
NMSD Optical Processing

- Utilize Conventional Grinding/Shaping/Polishing of the Zerodur™ Meniscus Prior to Substrate Bonded Assembly
- Low Contact Pressure Mechanical Figuring To Achieve Analytical Ambient Surface Topology
- Cryo-Test to Refine Understanding of Temperature Induced Deformation of Bonded Assembly
- Additional Low-Contact Pressure Figuring
- Final No-Contact Ion Figuring to Achieve Cryo Figure

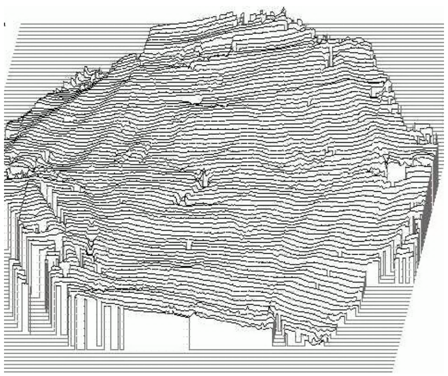






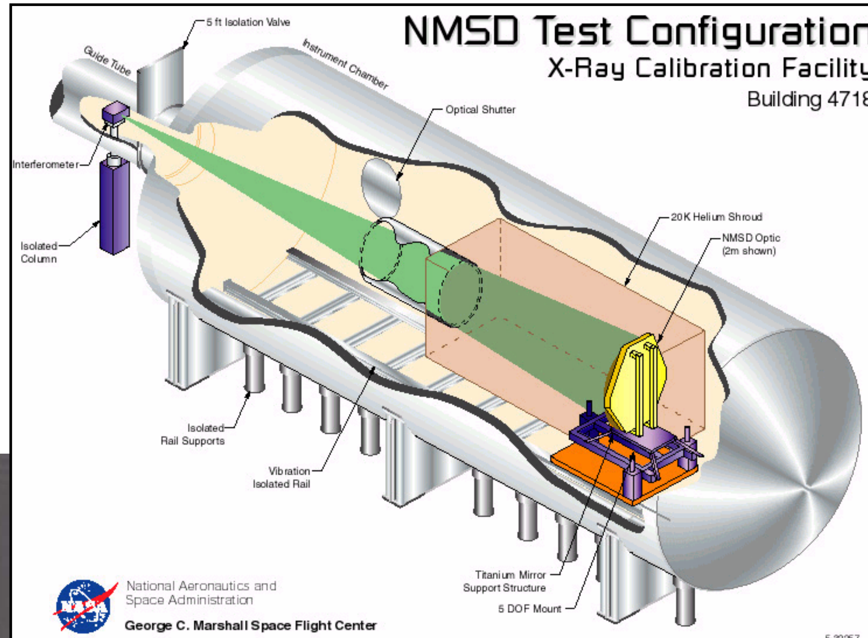


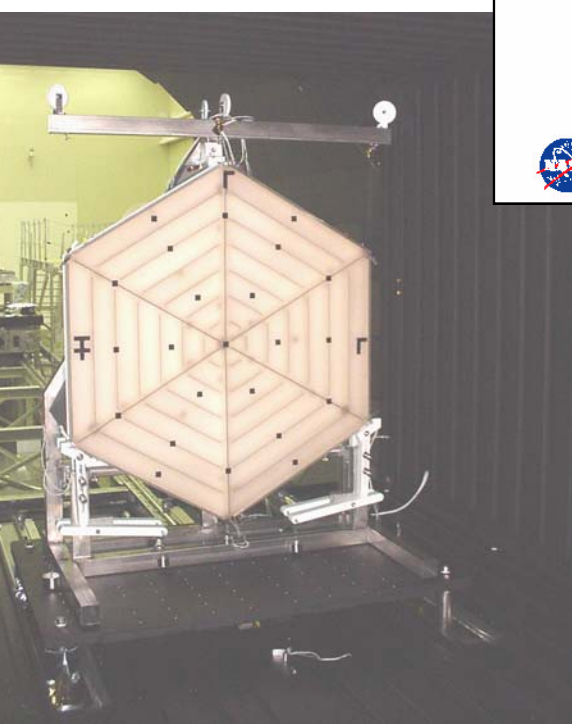
Ambient Surface

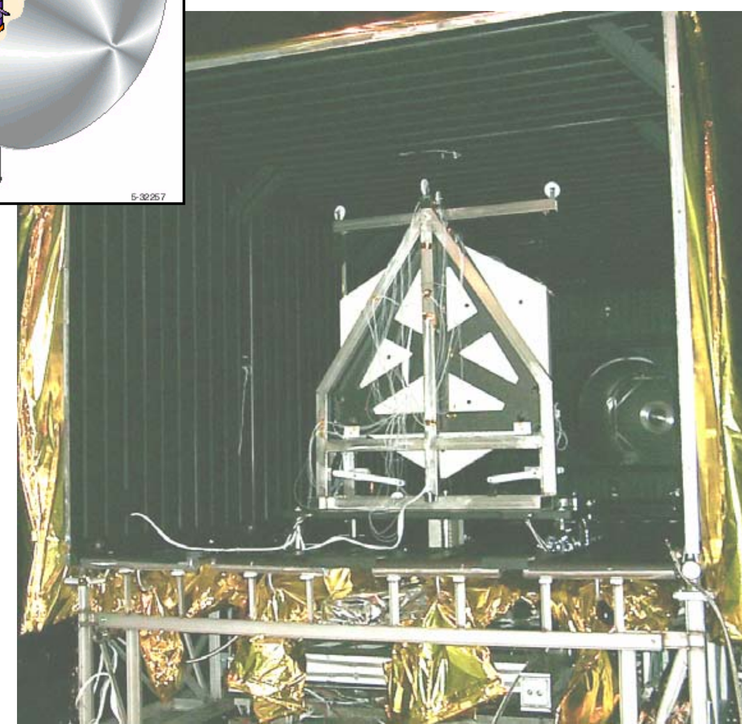


Surface at Cryo

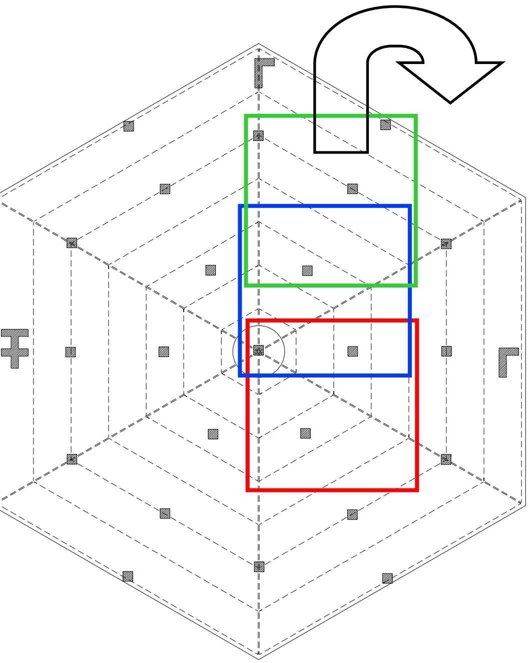
Cryo-Optical Test at MSFC
X-Ray Calibration Facility (XRCF)



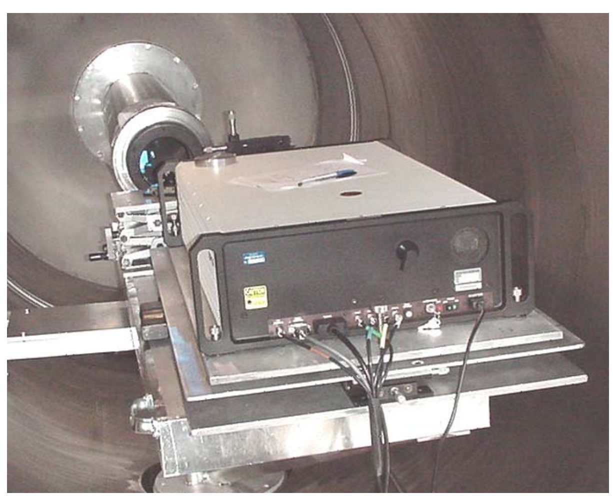


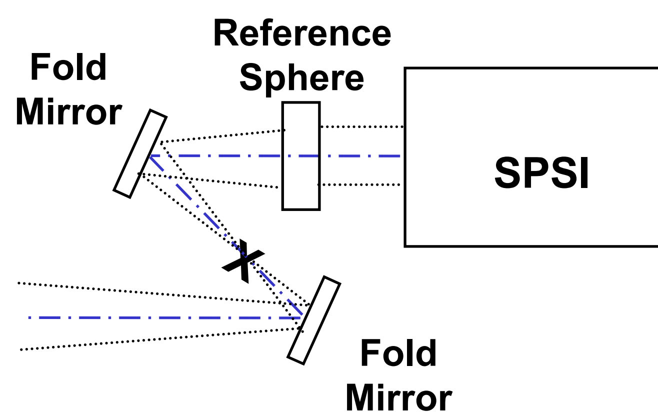


Subaperture Metrology

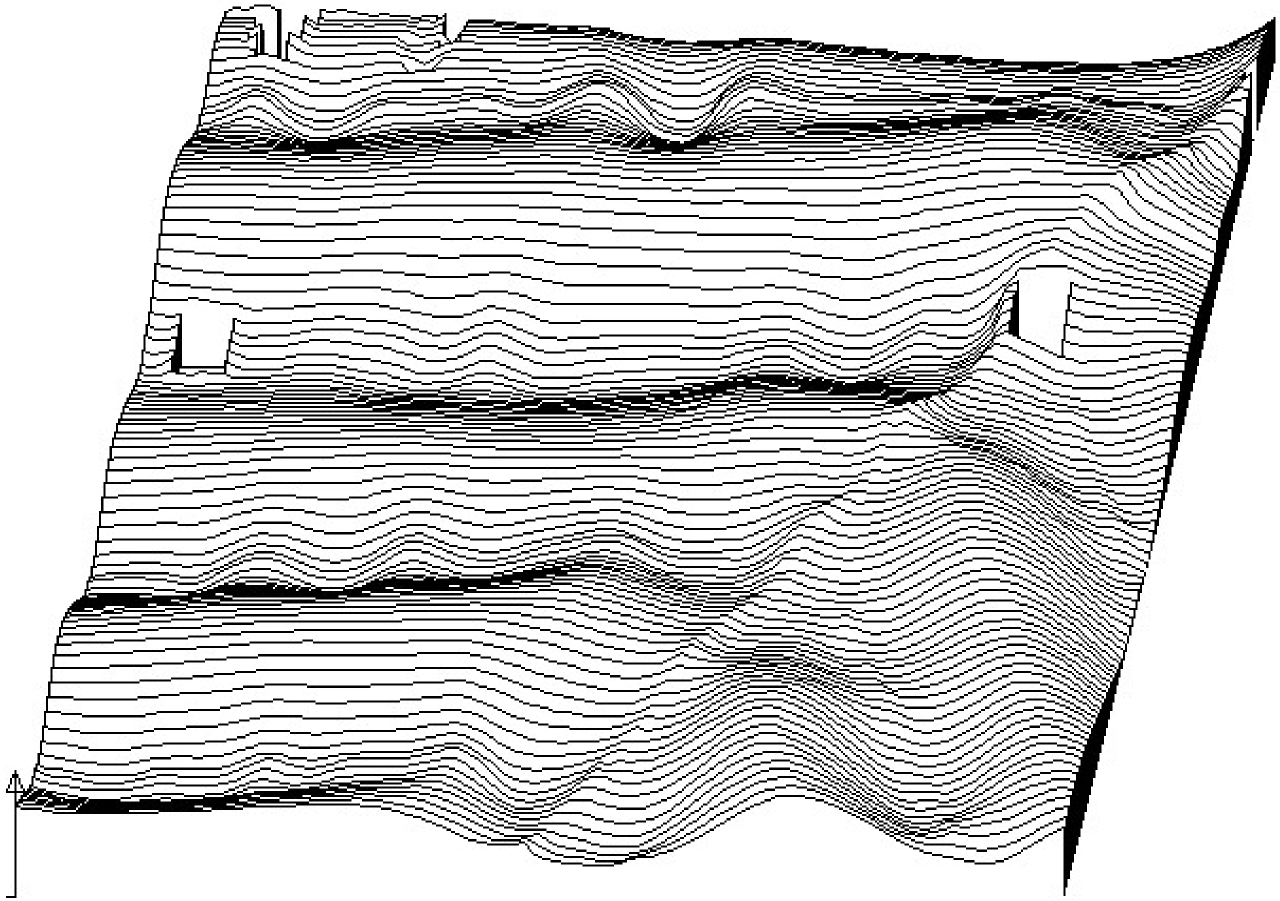


- Subaperture Interferometry Captures High Order Surface Condition (High Resolution)
  - » REOSC Simultaneously Phase Shifting Interferometer (SPSI)
- Subaperture Data is Stitched into a Contiguous Representation the Entire Aperture
  - » SAGEM Proprietary Software WARPP
  - » Low Order Behavior of the Full Aperture is Retrieved





SPSI Typical Subaperture Measurement at 25K



Cryo Test Results

Low/Mid Order Figure Repeatability (No Apparent Hysterisis)

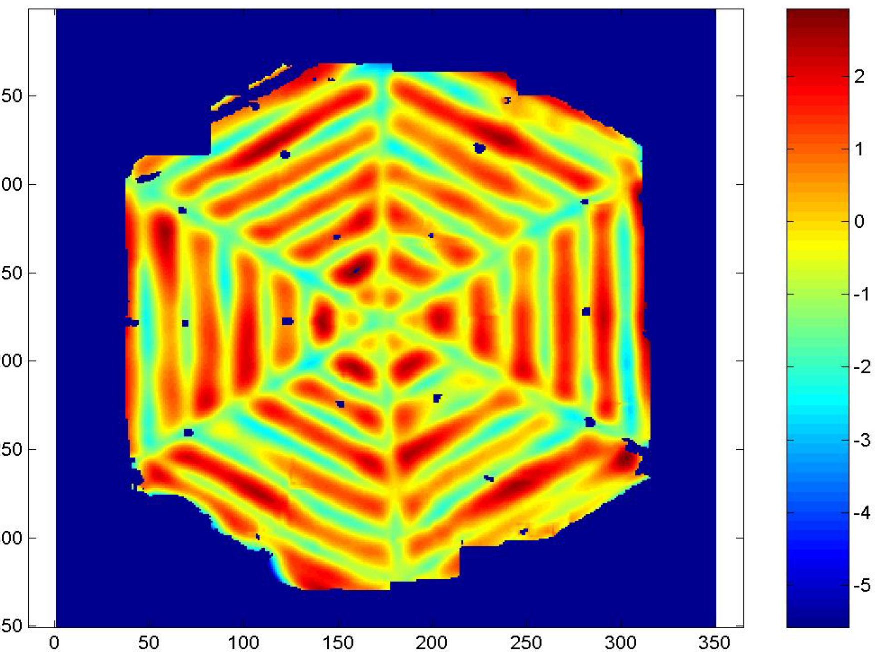
Agreement Between Test and Analytical Predictions

- **Cryo Quilting**

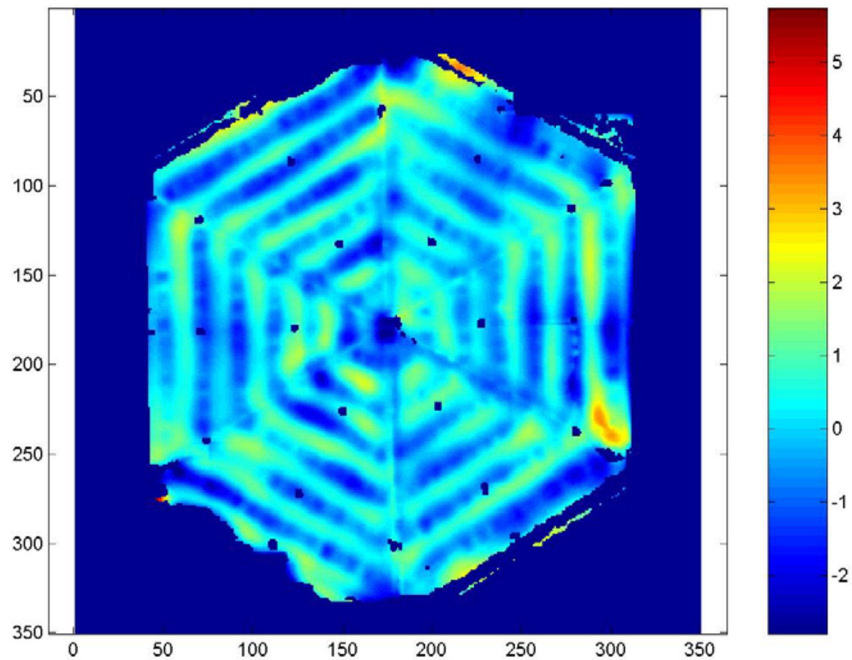
Sub Micron (RMS) Figure at Nominal Test Temperature (Low Order Aberrations Removed)

- **Low Order Dominant Behavior: Astigmatism**
- **Mid Order: Residual Quilting (Additional Optical Processing Can Correct Residual)**

Ambient Figure
(Low Order Zernikes Removed)



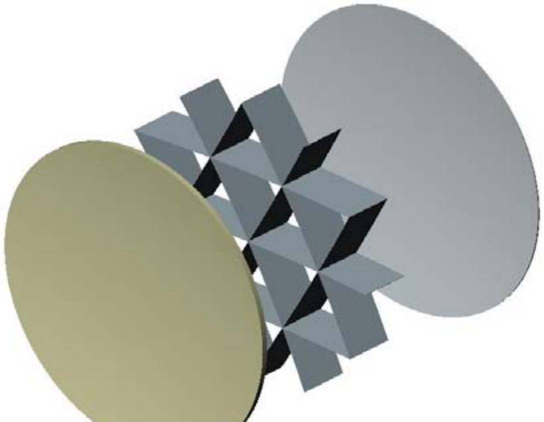
25K Figure
(Low Order Zernikes Removed)



0.8micron RMS Full Aperture
0.48micron RMS Masking Gravity Offload influences

Thermally Stable Lightweight Mirrors for Earth Observing Instruments

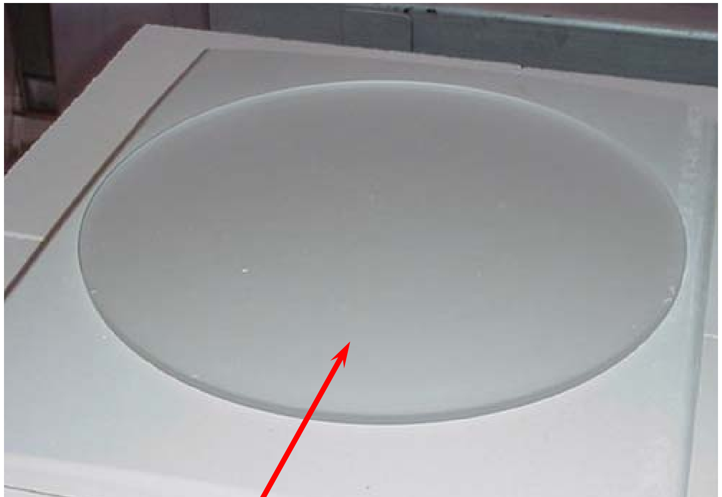
- **SBIR Sponsor: NASA Marshall Space Flight Center**
- **Program Overview**
  - » **Analytically Compare the Thermal (Distortion) Performance of Lightweight Mirrors (Beryllium, Silicon Carbide, and Composite Hybrid) for Earth-Observing Telescopes (GOES, GIFTS, SBIRS, etc.)**
  - » **Optimize the Design of a Hybrid Mirror for Thermal Stability, Mass, and Manufacturability**
  - » **Establish the Test Parameters to Demonstrate the Performance of the Hybrid Mirror Under Representative Thermal Loading**
  - » **Fabricate Substrate (No Optical Processing or Test)**

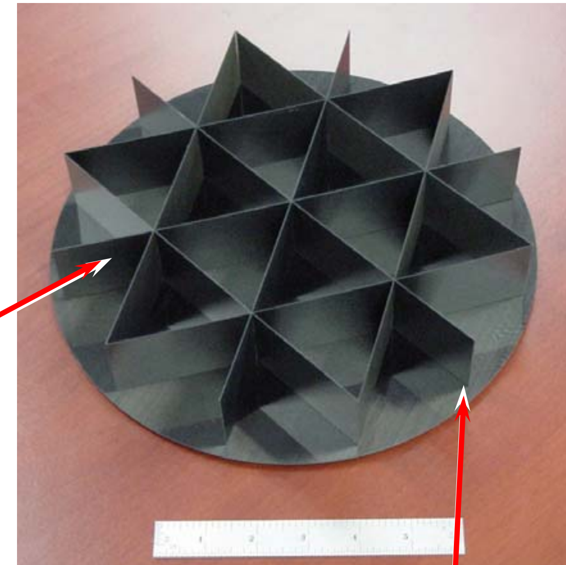


Hybrid Mirrors for Earth Observation

- Key Technologies
  - 0.3 meter Aperture at 15kg/m^2 Areal Density
    - Desired Aperture/Mass for Earth Observing Systems
    - Robust Design for Optical Processing and Operational Performance
    - Incorporate High Conductivity Composites with Matched CTE to ULE
      - K13C2U High Conductivity Core Elements; Stable M55J Backplate
  - Substrate for Powered System- Convex/Concave Sandwich
    - Doubly Curved Precision Composites
  - Reclaimed ULE Facesheet- Flowed/Fused/Slumped
    - Pre-polished Facesheet Precision Slumped on Castable Ceramic (INNOVATION)
  - Full Barrier Plating
    - Moisture Barrier and CTE Tuning (INNOVATION)
  - Near Zero CTE/CME Adhesives for Bonding Substrate (INNOVATION)

Hybrid Mirror Features

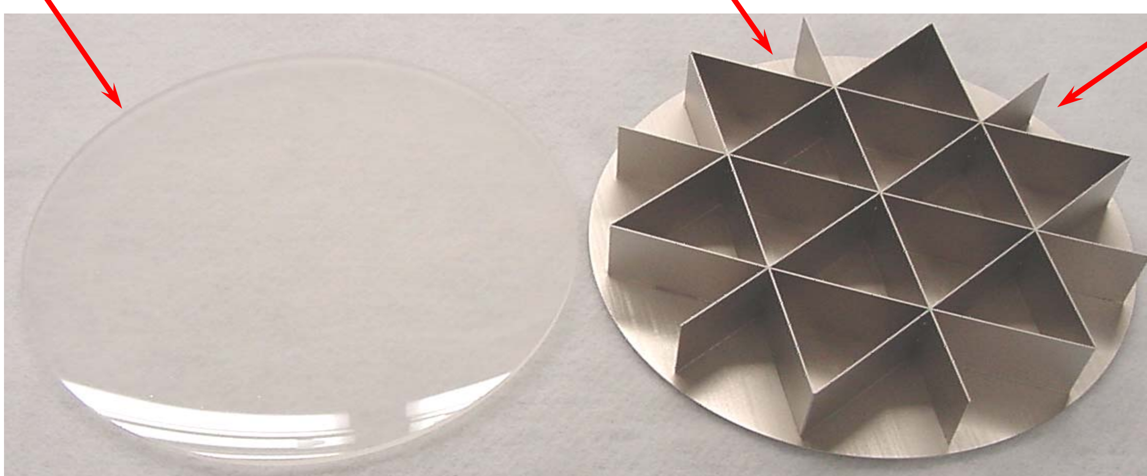




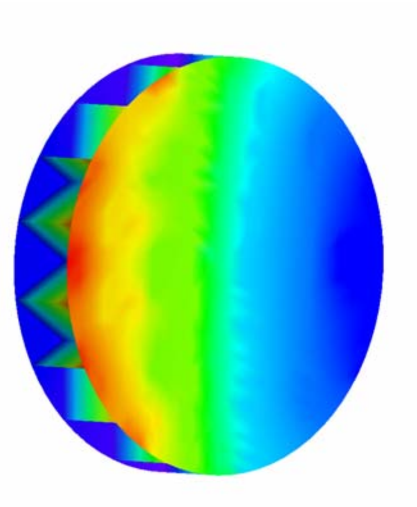
M55J (Stability Driven) Metal Plated Composite Backplate

Reclaimed ULE™ Faceplate

K13C2U (High Conductivity Metal Plated Composite Core



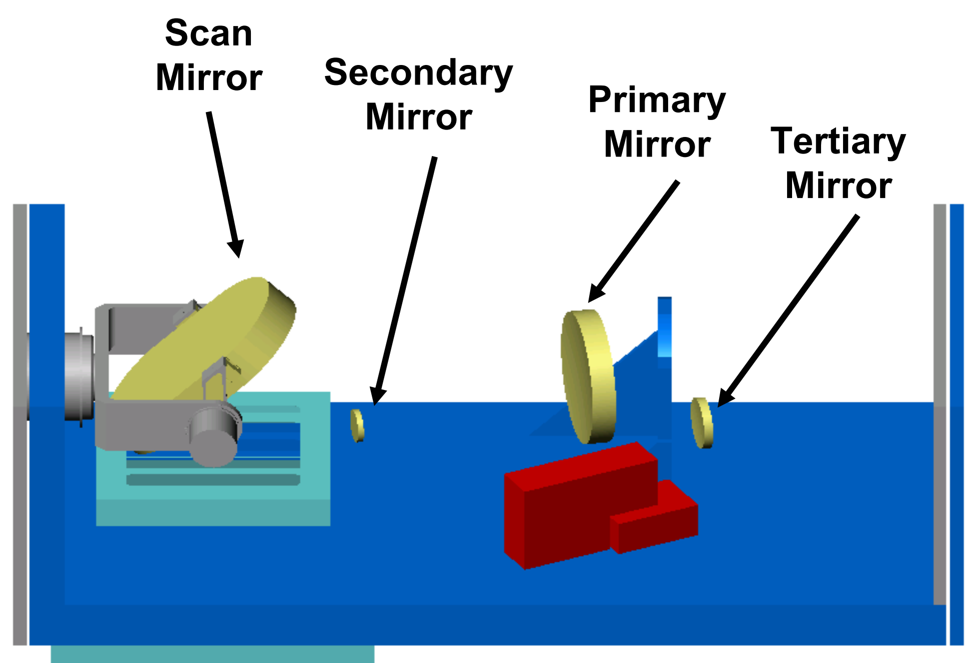
Thermal Condition of Interest
Direct Solar Load During Terrestrial Observation



Thermal Analysis to Simulate Solar Loading on Scan/Primary Mirrors

- Partial GEO (midnight +/- 30) to capture illumination of mirror
- Solar Beta angle of 0 (highest temperature) and 23 (highest gradient in mirror)
- Baffle included to provide shadowing
- EOL optical properties
- Beta 8.7 Orbit; Sun looking down the barrel (Solar Load: 11 mW/cm^2)
- Earth Heating Neglected

Analysis Assumes No Active Focus in Optical Train



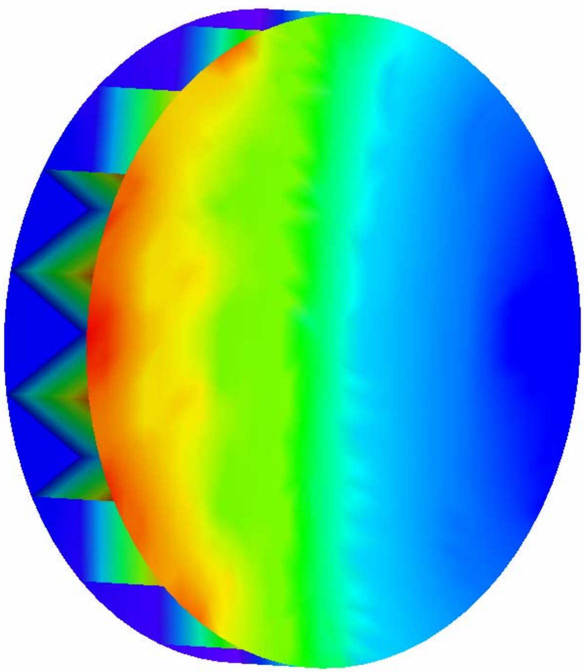
Thermal Induced Surface Errors

Mirror Type	RMS Error (microns) Initial Evaluation of Solar Loading Case	Delta ROC (microns)
Hybrid	.002	5
SiC	.001	41

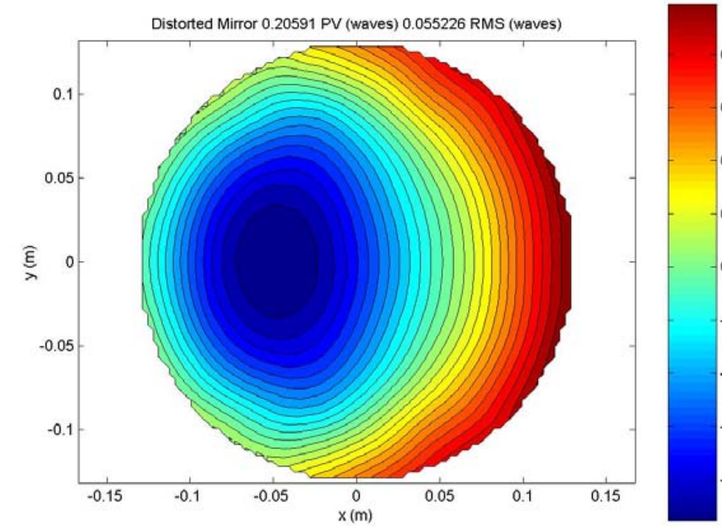
Telescope System Advantage

ybrid RoC Change is Small Compared to SiC and Be

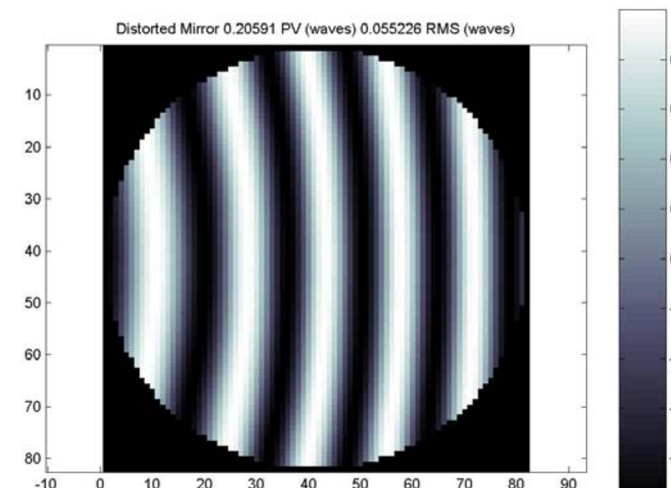
• Active Focus Correction Can Be Eliminated



Representative Solar Load Temperature Map (Range: 297K – 267K)



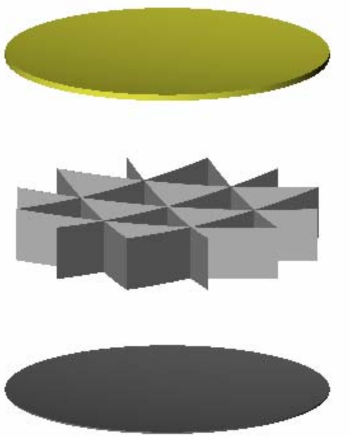
Surface Deformation for Solar Load (0.20/0.055 waves PV/RMS) No Focus Correction



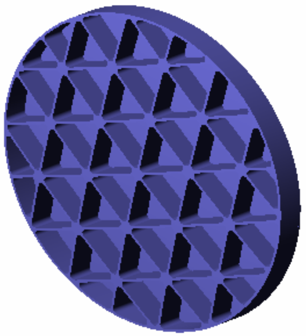
Simulated Interferogram for Solar Load

Study Trade Results

- Trade Primary Guideline: Design for Optical Processing Robustness
  - Polishing
  - Optical Test
- Hybrid Does Not Include Faceplate Lightweighting
  - Lightweighting Has Been Demonstrated on ATK-COI IRAD)



Hybrid Construction



SiC and Be Construction

Low Areal Density

Mirror Material	Mirror Type	Focal Length (cm)	Aperture (cm)	Areal Density (kg/m^2)	Mirror Depth (cm)	Facesheet Thickness (cm)	Core Thickness (cm)
Beryllium	Paraboloid	54	26	13.7	2.5	.2	0.2
Composite	Paraboloid	54	27	15.0	5.1	0.5	0.06
SiC	Paraboloid	54	26	19.9	2.5	.25	0.2

Higher Stiffness

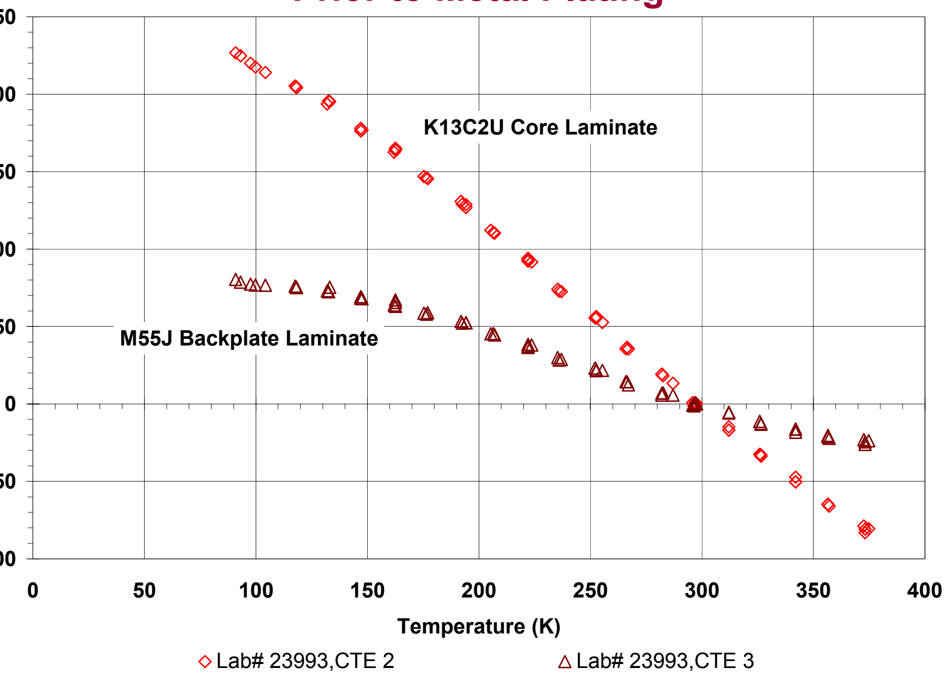
Mirror Type	1G Surface Error RMS (microns)	1G Surface Error PV (microns)	1st Fundamental Frequency (Hz)
Beryllium	.0037	.016	2017
Hybrid	.0026	.015	4213*
SiC	.0053	.023	1771

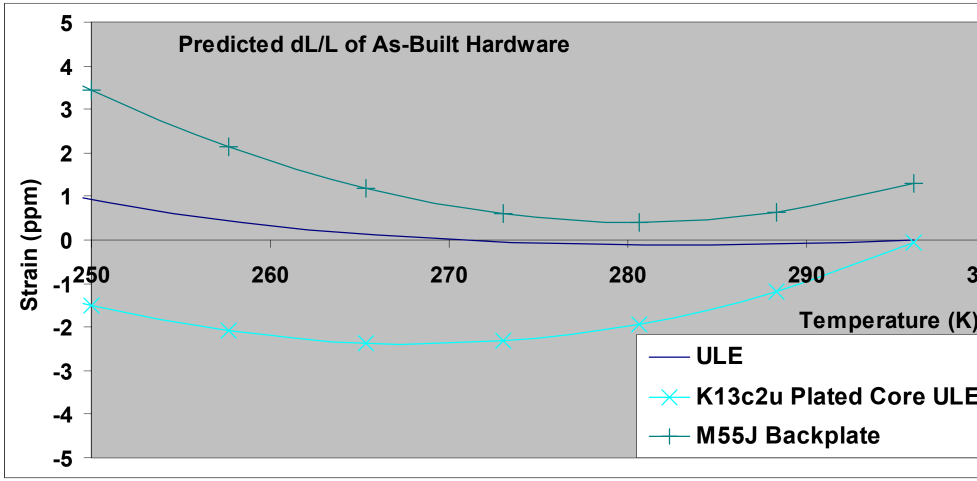
Predicted Thermal Performance

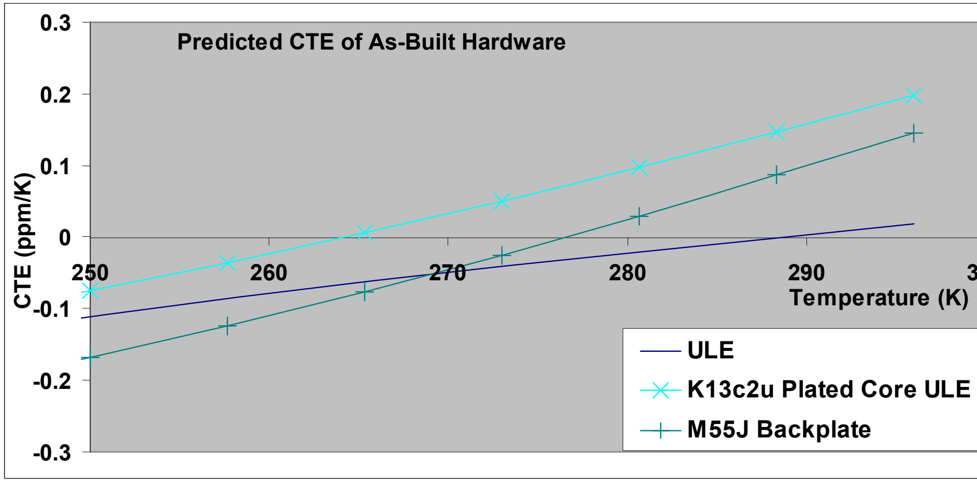
Mirror Type	Max Facesheet Temp (K)	Max In-Plane Thermal Gradient (K)	Max Out-of-Plane Thermal Gradient (K)
Hybrid	294.2	4.4	2.2
SiC	283.7	0.9	0.1

Plating Technology Tunes CTE and dL/L Behavior

Measured Thermal Strain
Core and Backplate WIP Coupons Laminate
Prior to Metal Plating







Benefits of SBIR Hybrid

- **Telescope System Level Performance**
  - Competitive Areal Density for Small Aperture
  - Temperature Tolerant Design
    - Low CTE Materials Matched to Glass ULE Facesheet
    - Passive Thermal Management Design Using High Conductivity Core Elements
  - Moisture Stability
    - Low CME Adhesive
    - Fully Plated Composite
- **Design for Producibility**
  - Scalable Laminate and Assembly Processing
  - Near-Net Shape Glass Processing
  - Final Optical Processing: Accommodates All Aspects of Conventional Optical Processing

Hybrid Technology Summary

- A Broad Range of Materials and and Fabrication Technologies Have Been Demonstrated for Low-Cost Lightweight Mirrors and Stable Structures
  - Composite Hybrids are Being Demonstrated Across Broad Temperature Ranges
- Hybrid Mirror Technology Insertion
  - Information Generated from Programs such as NMSD is Providing Valuable Knowledge of the Cryogenic Behavior of the (Bonded) Composite/Glass Hybrid System and Composite Structures in General