ADVANCED LIGHTWEIGHT MIRRORS FOR SPACE-BASED MISSIONS

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HARRIS® TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

Outline

- Harris Optical Components Capability Overview
- Advanced Mirror Construction (AMC) Strategy
- Capture Range Replication (CRR) Overview
- ULE CRR Development
- Other AMC Advancements
- Summary

Harris optics capability overview

Assured optical performance with challenging mission requirements

- Over **130 missions** with Harris optical components placed in orbit—more than any other provider
- **50+ years** of operational excellence on the most stringent optic requirements
- Industry **leaders** in vertically integrated, optics design, deterministic processing, manufacturing, assembly and testing infrastructure

Optimized solutions: schedule, cost, performance

- The best materials for the application - demonstrated experience processing materials including ULE®, fused silica, composite, Zerodur®, SiC, spinel, sapphire, silicon, and more
- Deliver best-value flat, spherical, aspheric, and freeform optics from 0.2 to 3.5 meters in size

Meeting customers' current and future needs through innovation

- Advanced mirror replication, construction, and additive manufacturing strategy
- Insertion of enabling materials

ULE® is a registered trademark of Corning Corp.
Zerodur® is a registered trademark of Schott

Space-based Imaging Optics

Ground-based Telescope Optics

- **Keck**
- **HET**
- **SALT**
- **TMT**
- **LSST**

High-energy Optics

- **LLNL**
- **LLE**
- **PNNL**

Innovation in large optics by Harris

For more than 50 years, Harris has specialized in large precision optics, integration, and testing for the world's most sophisticated earth and space observing systems.

Harris' innovative manufacturing technologies meet demanding quality requirements and offer faster production of lighter weight optics to meet our customers' most pressing schedules.

Key market trends

Space-based optical components are going...

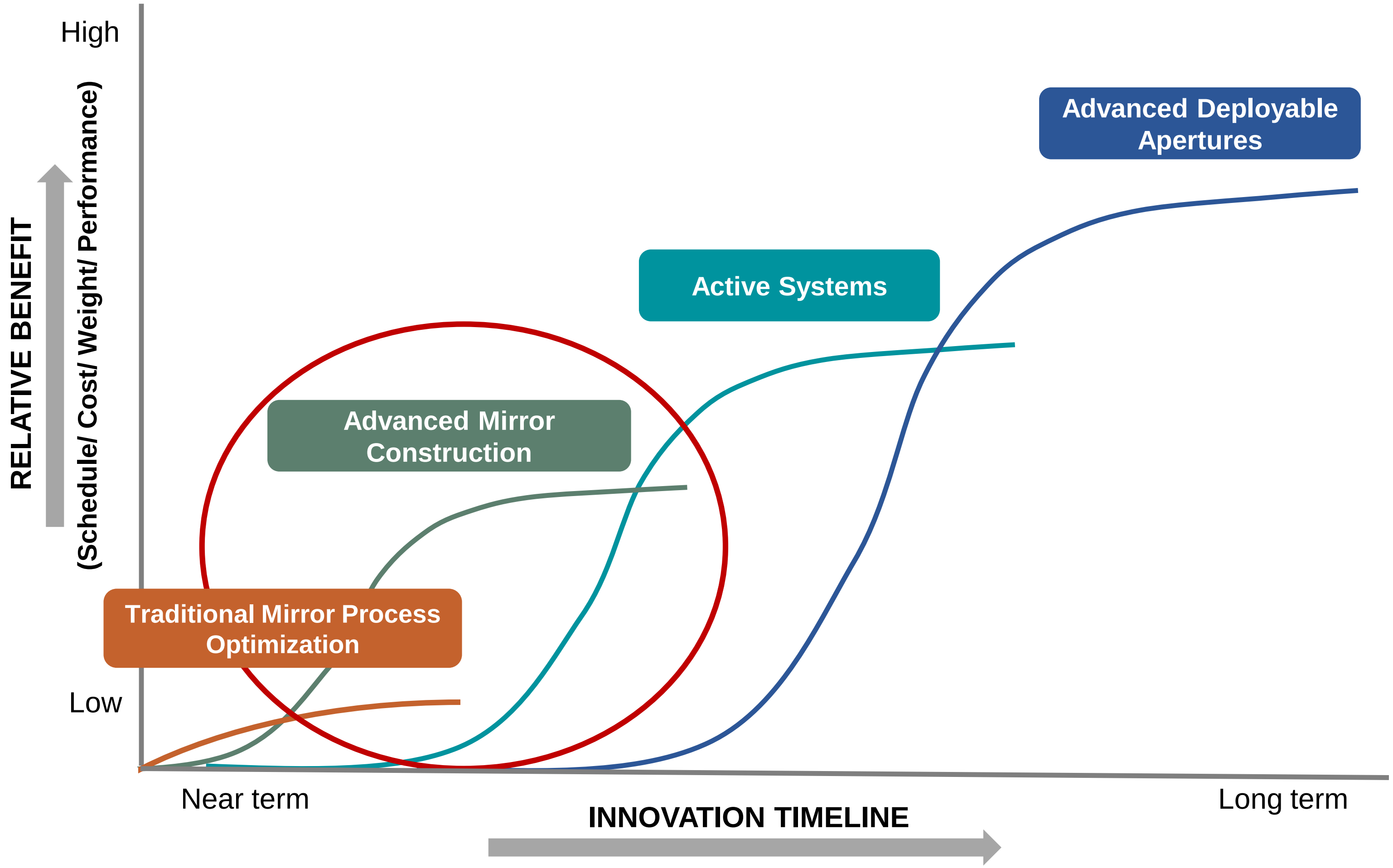
*Credit: SpaceX public domain**

- Disrupter: Affordable access to space for large and small systems…and cars
- Need affordable, rapid optical solutions that meet mission performance requirements

**These official SpaceX public domain images are being made available to the public and news media with no restrictions.*

Continuous innovation

Innovation in large aperture, space-based optical components



Harris is leveraging an Advanced Mirror Construction strategy to break the current cost and schedule constraints for large precision mirrors while continuing to pursue future leapfrog technologies

Advanced mirror construction strategy

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Need

Resiliency: Shorter cycle time/higher production rate
Persistence: Higher quantity or larger apertures at higher production rate, lower cost, lower mass
Flexible Mission Architecture: Lower mass
Relieve Acquisition Constraints: Material diversity, shorter mirror development timeline

Strategy

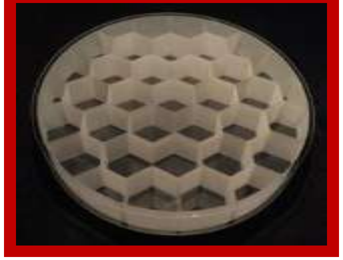
Capture Range Replication (CRR): Replication to within capture range of final finishing

Mirror Structure: Advanced materials; simple components; fast, rapid construction

Advanced Bonding: Stable, versatile

Solution Space

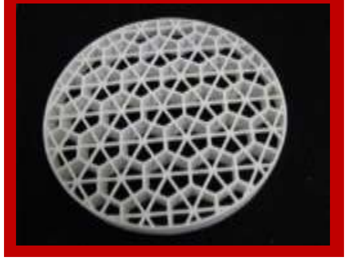
ULE® CRR Mirror



Composite CRR Mirror

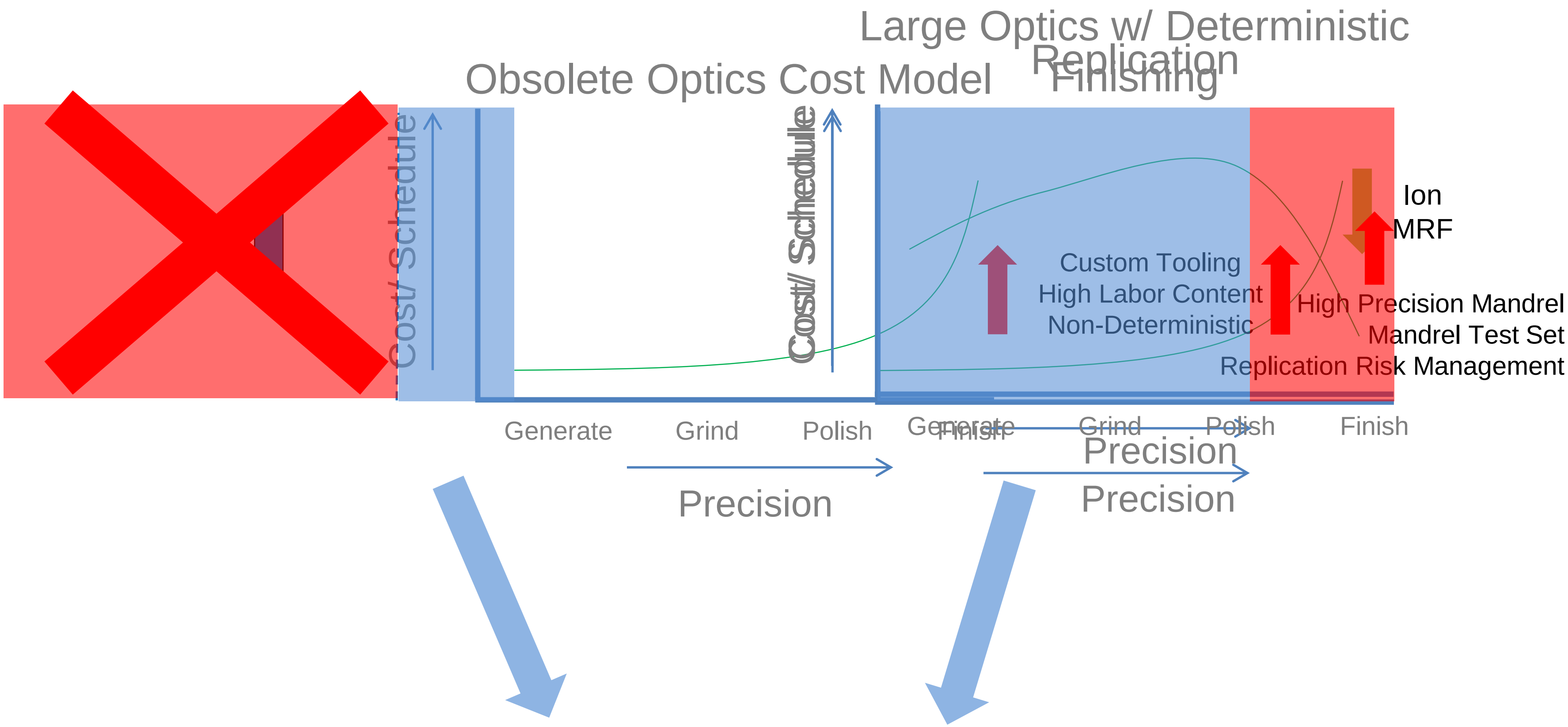
Constructed Core Mirror

3D Printed Architecture for Lightweight Mirrors



Harris is working multiple solutions under a common strategy to provide significant cost and schedule reduction for high precision mirrors for near and long term applications.

Capture Range Replication (CRR) overview



CRR leverages the strengths of replication to eliminate the high cost/ schedule processes in optical fabrication to provide an optimized solution

Large mirror finishing, traditional

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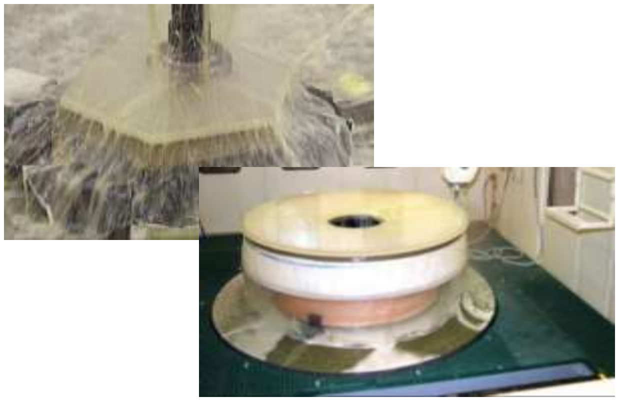
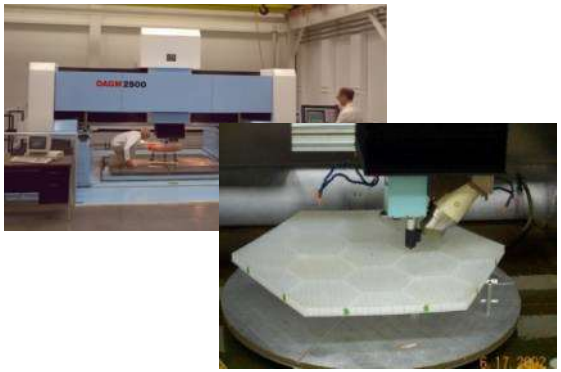
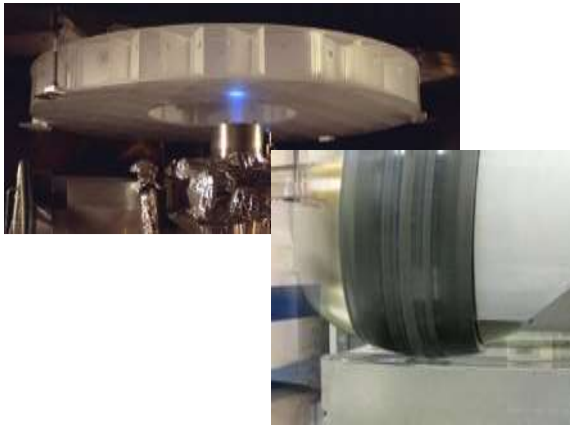
Plate Thinning	Surface Generation	Asphierization





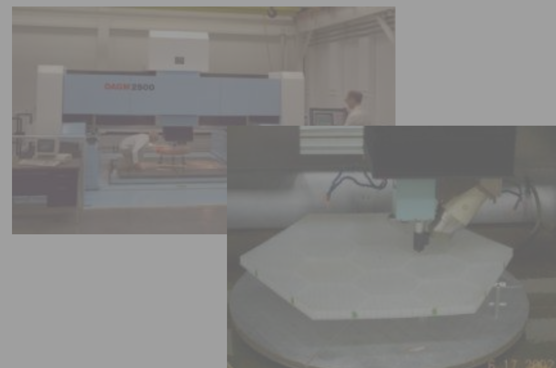
Precision Metrology	Small Tool/Ion Beam Figuring/MRF	Precision Metrology



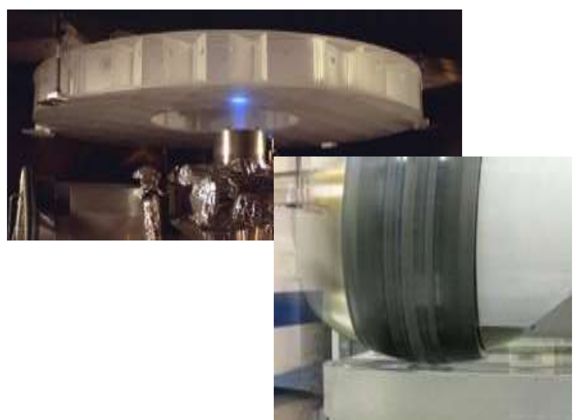
Traditional Mirror Finishing

Large mirror finishing with CRR

Plate Thinning	Surface Generation	Asphērization


Precision Metrology	Small Tool/Ion Beam Figuring/MRF	Precision Metrology

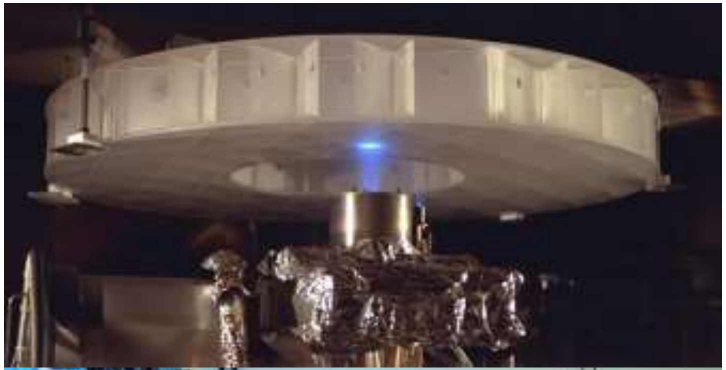




Mirror Finishing with CRR: ~50% Cycle Time reduction

CRR facilities: Deterministic finishing

Ion Beam Figuring (IBF)

- Superior deterministic finishing capability uses neutral ion beam processing of optical surfaces
- Sub-aperture process provides excellent figure control to edge
- Long-term stability for large optical surfaces
- Capability up to 3.5 meters



Sub-aperture Computer Controlled Surfacing (CCS)

- Sub-aperture tools for deterministic grinding and polishing processes
- Dwell time-based figure correction capability
- Achieves surface micro-roughness requirements
- Capability up to 2.5 meters

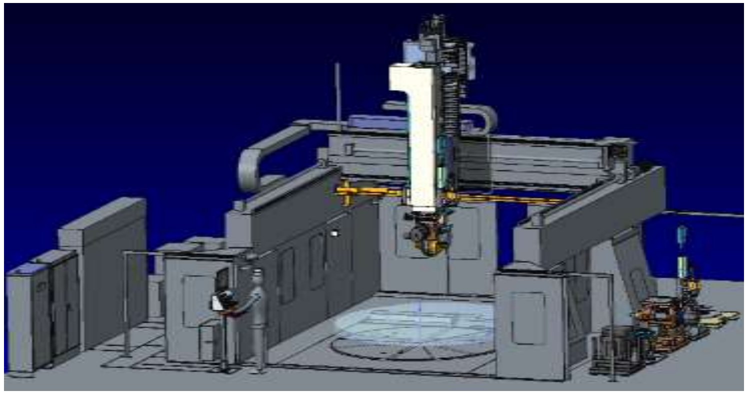
Magneto-Rheological Finishing (MRF™)

- Extensive large-optic capability and process knowledge
- High-precision surface figure with very low micro-roughness
- Rapid convergence to desired figure or features
- Current capability up to 3.5 meter

MRF™ is a trademark of QED

CRR facilities: New large MRF capabilities

- Harris partnered with QED Technologies to implement a 3.5 meter MRF system on an existing CNC machining platform within Harris' precision optics manufacturing facility while maintaining CNC machining capability.
- System is capable of MRF polishing flat, spherical, aspherical, and freeform surfaces.
- The MRF system went through qualification in Dec, 2017 and is now on-line.



Harris has the largest MRF platform in the world

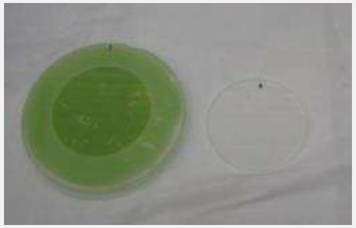
MRF™ is a trademark of QED

CRR development

Mandrel Release Study

Several parameters were investigated including mandrel material, replication pressure and temperature, coatings, and mandrel surface condition

DOE Configuration

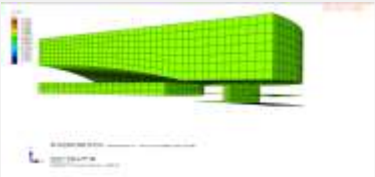


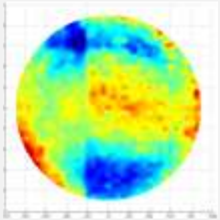
Coating Study

Techniques for achieving release were established and demonstrated

Faceplate Replication

- Replicated a flat faceplate a spherical SiC mandrel
- Utilized a load body to accelerate the slumping process



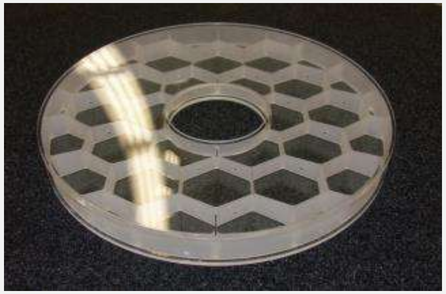


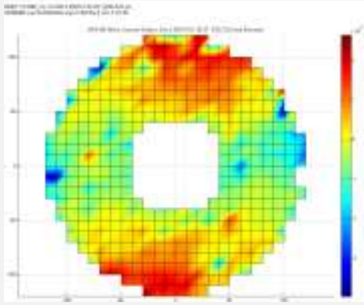
Replicated faceplate to ~1um departure from mandrel shape

Successful capture range replication of a 200mm ULE® faceplate

ULE® CRR Mirror

- Replicated a 250mm spherical mirror with a center hole
- Successfully replicated with a resulting figure error of <3µm P-V from mandrel shape

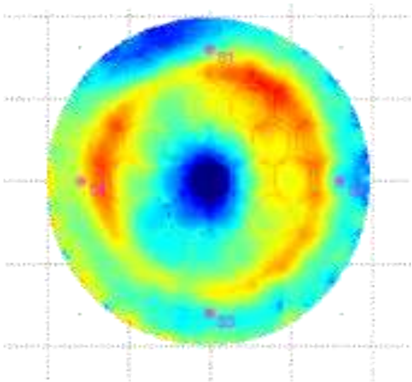




Successful construction of a CRR ULE® Mirror has been demonstrated

Successful ULE® CRR mirrors

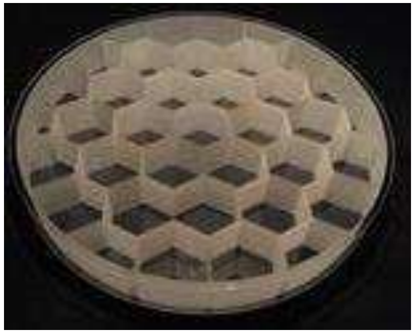
Mirror 1
LTF-> Slumped-> CRR

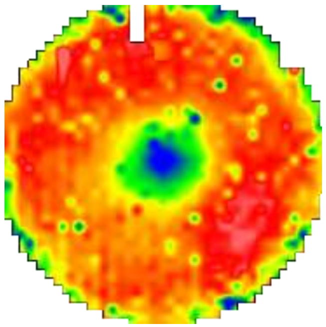


P-V: 3.2 um
over 400 mm

Post LTF/CRR Optical Data (power removed/center feature masked)

Mirror 2
Slumped-> LTF-> CRR





P-V: 6.1 um
over 400 mm

Post LTF/CRR CMM Data (power removed)

Harris has demonstrated successful CRR at 0.5 meter class mirrors.

AMC strategy: Constructed Core mirror

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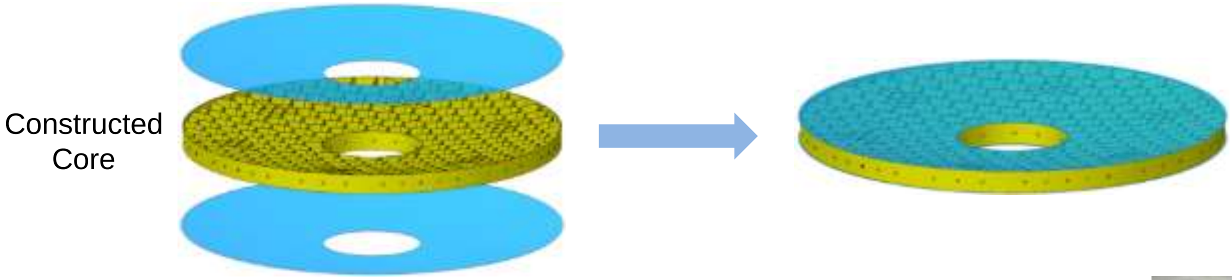
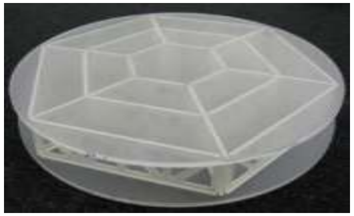
Replicated ULE® plates bonded to an optimized, constructed core



Composite Core Mirror

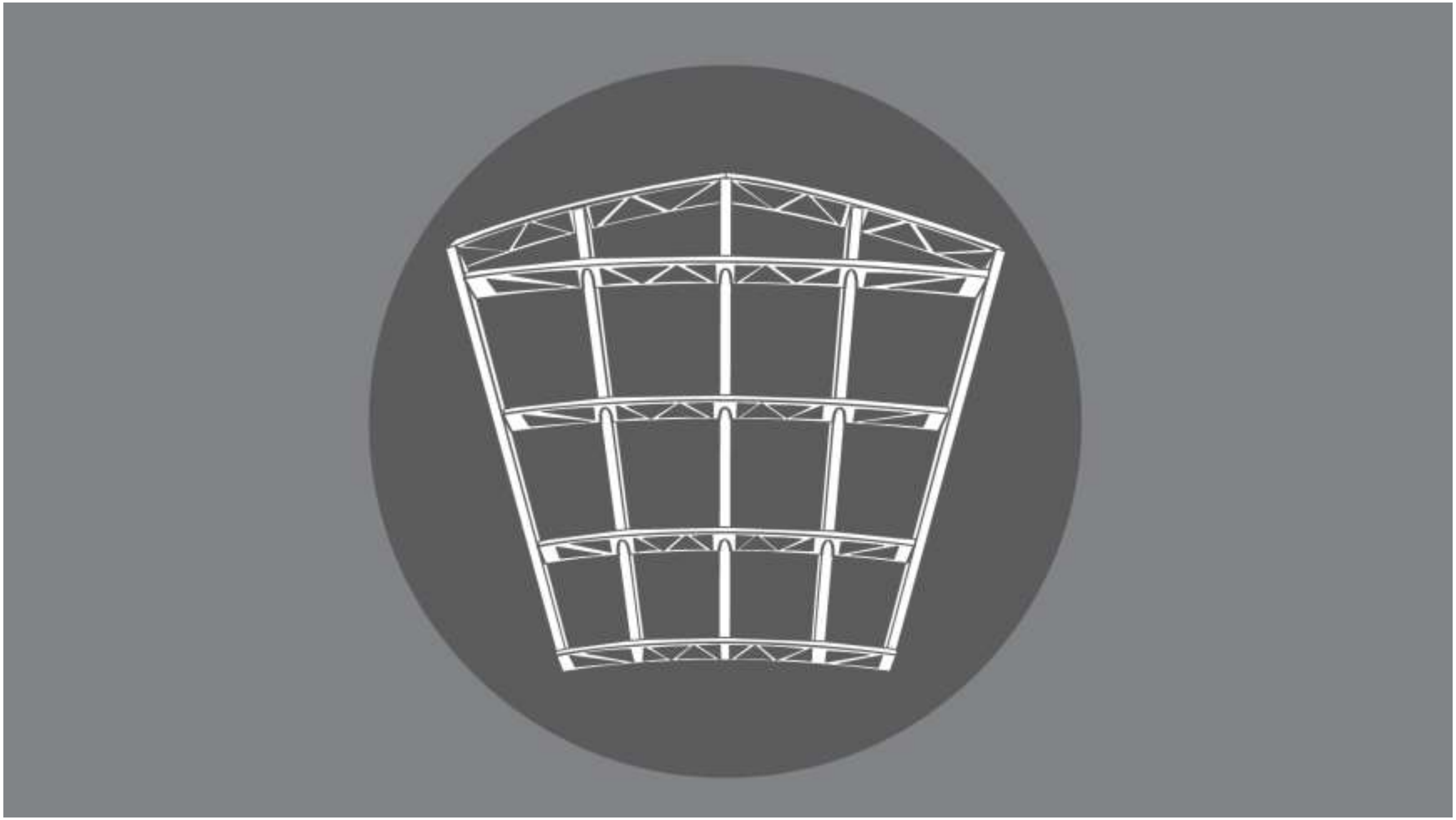


Constructed Core Mirror

- Leverage simple, commoditized components to construct the mirror core
- Utilizes replicated faceplates bonded to constructed core to minimize mirror processing

Constructed Core technology leverages commoditized core components combined with faceplate replication to provide rapid, affordable mirror solutions

AMC strategy: Constructed Core mirror

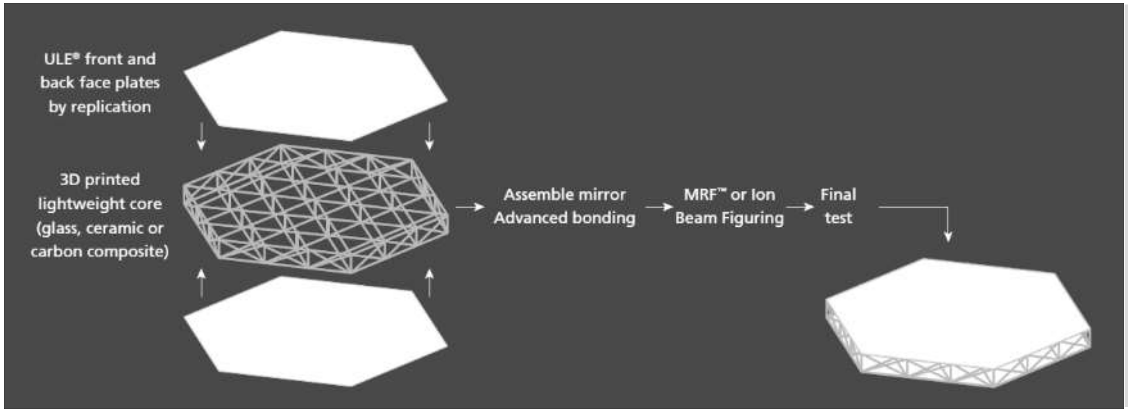


Constructed Core technology leverages commoditized core components combined with faceplate replication to provide rapid, affordable mirror solutions

AMC strategy: 3D Printed Architecture

Harris employs additive manufacturing combined with demonstrated replication and advanced bonding to optimize mirror production for schedule, weight, affordability, and performance.

Process Description



- Order of magnitude reductions in primary mirror schedule and cost.
- Maximizes mirror stiffness and stability while minimizing mirror weight.
- Low risk, short duration development path

3D Printed fused silica core

Mirror constructed with 3D Printed fused silica core

Innovative mirror designs enabled by 3D printing

In addition to significant schedule and cost advantages, 3D printing enables volume optimization of mirror cores for ultra-lightweight designs

Summary

- Harris has a long history of successfully providing enabling space-based optical components.
- Harris is leveraging an Advanced Mirror Construction strategy to break the current cost and schedule constraints for large precision mirrors while continuing to pursue future leapfrog technologies.
- Harris has demonstrated successful replication of ULE mirrors.
- The initial stages of the AMC strategy are demonstrating the key capabilities needed to enable future technologies such as composite mirrors, constructed core mirrors, and 3D printed mirrors.