In-Space Assembled Telescope Production

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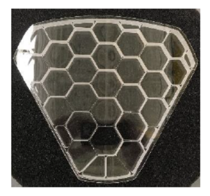
ngvla
Next Generation Very Large Array

Introduction and Background

- Emerging concepts for large, segmented space-based telescopes require production of large numbers of highly-stable 1-meter-class primary mirror (PM) segments
  - LUVOIR 15m or 8m telescope concept
  - iSAT 20m telescope concept

- Timelines require cost-effective, high mirror production and verification rates over short durations
- Mirror segments require lightweight, high-stability structures with tight surface figure error (SFE) requirements over low-, mid- and high-spatial frequencies and micro-roughness
- Approaches in development / demonstration include
  - Capture Range Replication (CRR)
  - Advanced smoothing
  - Additive manufacturing
  - Optical metrology concepts for large ground-based segmented mirrors



L3Harris Technologies Innovation in Large Optics

For more than 50 years, L3Harris has specialized in large precision optics, integration, and testing for the world's most sophisticated earth and space observing systems.

L3Harris' innovative technologies meet demanding quality requirements and offer faster production of light weight optics to meet the most pressing schedules

Mirror Segment Manufacturing Challenges

Production rates

- LUVOIR 15m PM – requires 120 segments over ~5 year period
- iSAT PM concept – requires ~230 segments over ~7 to 8 year period

Manufacturing challenges

- Off-axis aspheric forms
- Lightweight mirror construction
- Many segments
- Segment-to-segment radius matching
- Measurement and verification of 1.5 to 5nm rms SFE for mid/high spatial frequency errors with little edge relief
- <0.5 nm rms surface micro-roughness (μR)
- Radius and SFE metrology

Key technologies to meet mirror segment requirements

- Replication and additive manufacturing processes
- Deterministic figuring processes
- Controlled smoothing / polishing processes
- Optimized polishing for low micro-roughness
- Precision metrology for radius matching and surface figure error (SFE) for multiple off-axis segment types

Existing capabilities can be optimized to meet mirror segment requirements

L3Harris Advanced Mirror Construction (AMC) Strategy

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 development timeline

Strategy

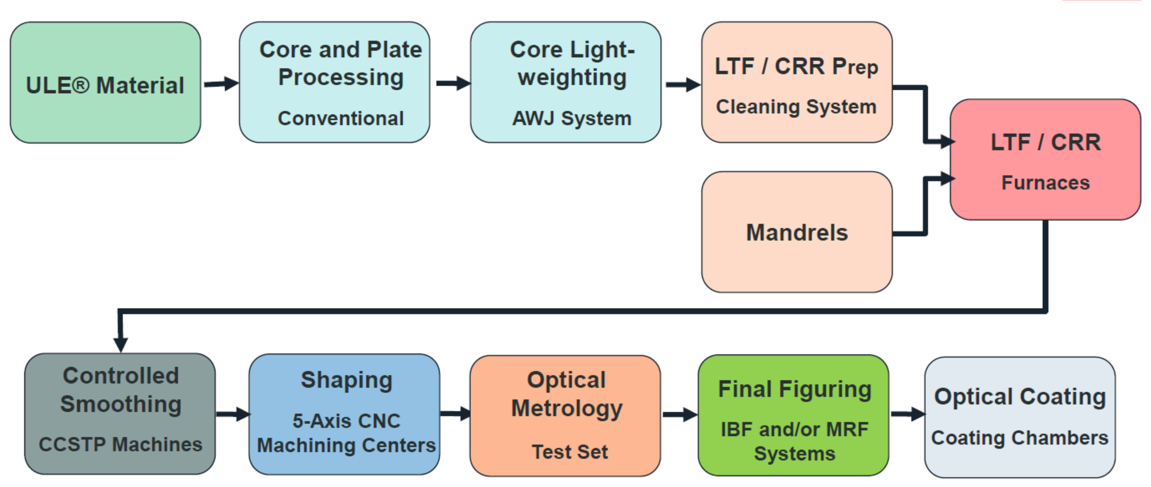
Capture Range Replication (CRR™): Replication to within capture range of final finishing
Mirror Structure: Advanced materials; simple components; fast, rapid construction
Advanced Bonding: Stable, versatile

Solution Space

L3Harris is implementing solutions under a common strategy to provide significant cost and schedule reduction for high precision mirror applications

CRR™ is a trademark of Harris Corp
ULE® is a registered trademark of Corning

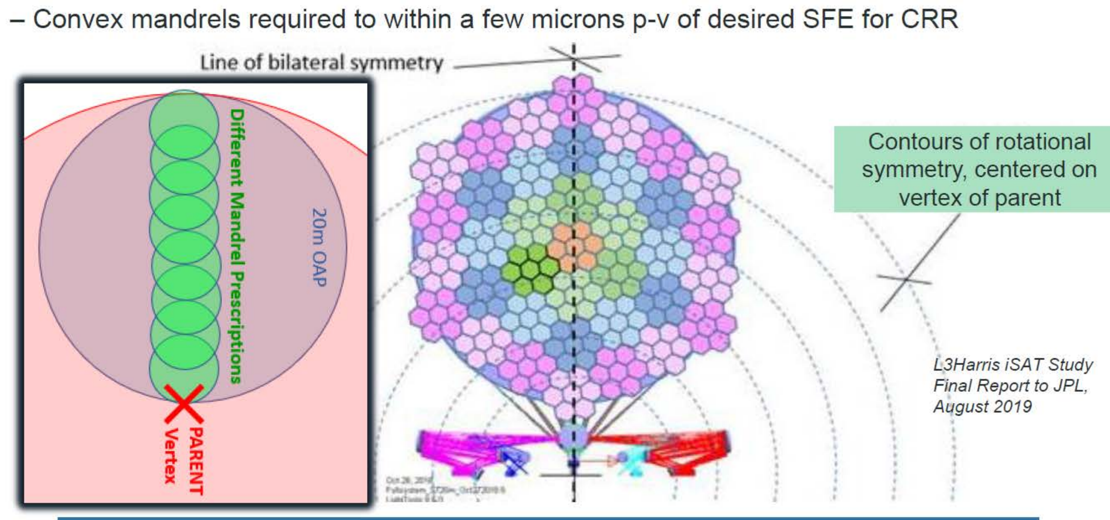
Notional Mirror Segment Process Flow



- Goal is PM segment production on 10 day centers once in full production
- Production rate can be met by scaling to multiple production lines

Mirror Manufacturing Assumptions

- For on- or off-axis PM designs with many segments, multiple mandrels for replication are required
  - Estimated between ~8 to ~20 mandrel substrates required; refigured for form changes driven by segment position relative to parent
  - Drives schedule but not a large cost driver
  - Convex mandrels required to within a few microns p-v of desired SFE for CRR

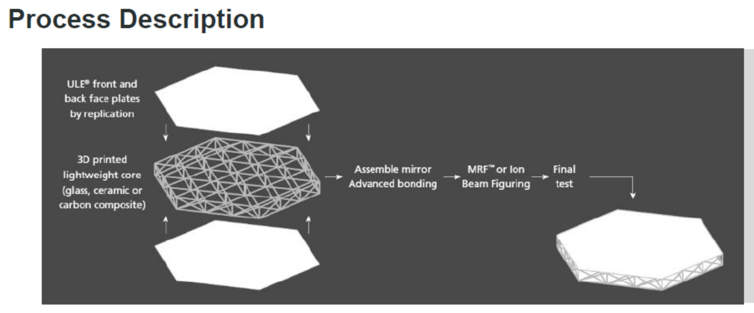


Mirror optical surfaces are replicated on mandrels using L3Harris CRR

Future Development and Demonstration 3-D Printed Architecture

L3Harris 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

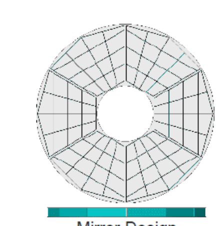
Mirror constructed with 3D Printed fused silica core

Innovative mirror designs enabled by 3D printing

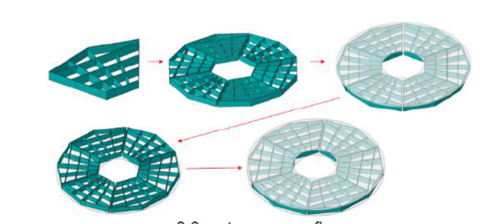
3D printing enables volume optimization of mirror cores for ultra-lightweight designs

Future Development and Demonstration Additively Manufactured Mirrors Using Constructed Core

Demonstrated constructed core concept on 0.6 meter flat mirror with epoxy bond

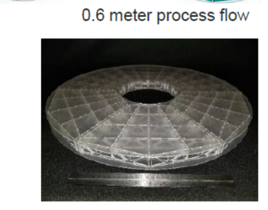


Mirror Design



0.6 meter process flow

0.6 meter core assembly



0.6 meter mirror

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

CRR Capabilities: 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 3.5m

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 2.5m

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
- Capability up to 3.5m

MRF™ is a trademark of QED

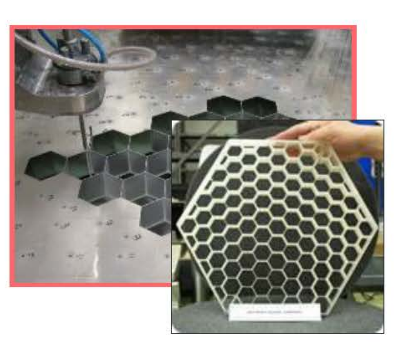
LTF / CRR Capabilities: Furnaces and AWJ

Facilities and equipment exist to perform abrasive waterjet light-weighting and furnace operations (LTF / CRR)

- **Furnace and Cleaning Capability**
  - 1.5m capacity ultrasonic cleaning line
  - 3m capacity furnace
  - Multiple >1.5m capacity furnace
- **Abrasive Water Jet - 2m class CNC**

Ultrasonic Cleaning Line

>1.5m furnace

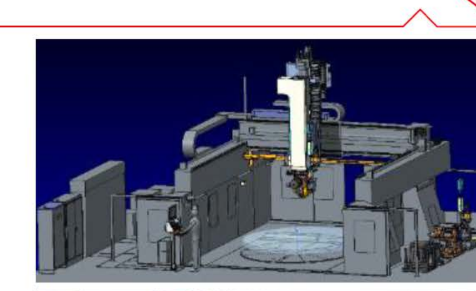


>2m AWJ

3m furnace

CRR Capabilities: Large MRF

- L3Harris partnered with QED Technologies to implement a 3.5m MRF system on an existing CNC machining platform while maintaining CNC machining capability.
- System is capable of MRF polishing flat, spherical, aspherical, and freeform surfaces.
- The MRF system completed qualification in December 2017 and is operational



L3Harris has the largest MRF platform in the world

Conclusions

- AMC strategy is being executed to meet high volume precision mirror segment fabrication and testing for emerging large, space-based optical telescopes
- CRR provides the ability to produce highly-stable precision ULE® mirrors rapidly and at reduced cost, potentially meeting the needs of the large space-based segmented primary mirrors
- Additional demonstration needed for advanced smoothing to meet all mirror surface requirements
- Emerging additive manufacturing technologies including 3-D printing of low CTE materials and advanced adhesives are in development and may provide capabilities for consideration in the future
- Metrology approaches in development by current large ground-based telescopes may offer lower-cost advantages

AMC strategy implementation enables high-volume precision mirror segment production for large space-based telescopes

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The Next Generation Very Large Array is a design and development project of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.