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Astro2020 APC White Paper

ULTRA Segment Stability for Space Telescope Coronagraphy

PI: Conrad Wells PhD.
Co-PI: Robert Egerman

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Call for APC White Papers

From:
L3Harris Technologies, Inc.
400 Initiative Drive
Rochester, NY 14606

Project Lead:
Lynn Allen
New Business Manager
585-269-6222
Lynn.Allen@L3Harris.com

1.0 Executive Summary

L3Harris Corp (Rochester, NY) is well positioned to continue its long-standing history of supporting prominent NASA astronomical missions by providing this white paper on the state of the technology required to grind, polish and optically test the HabEx primary mirror. The HabEx Primary Mirror is a 4 meter off-axis monolith with state-of-the-art surface figure requirements (Table 1). The process steps required to achieve the HabEx surface figure smoothness are the current state-of-the-art. L3Harris has produced smaller mirrors of this quality before but meeting all requirements on a mirror of this size requires further engineering development of existing technologies. L3Harris is confident that with our current technologies and advancements in some key areas, the HabEx mirror requirements are achievable. This paper outlines the technologies required and L3Harris' role in developing them.

Table 1: HabEx Primary Mirror Prescription and Preliminary Surface Figure Error Requirements

Primary Mirror Prescription	
Optical Clear Aperture:	4.0 meter (circular off-axis)
Off-Axis Distance:	2.5 meter
Radius of Curvature:	19.8 meter (concave)
Conic Constant:	-1.0
Primary Mirror Surface Figure Error Specification	
Specification	Required
Low-Order <30 cycles	< 5 nm RMS
Mid-Spatial 30 to 90 cycles	< 3.5 nm RMS
High-Spatial > 90 cycles	< 3.4 nm RMS
Roughness	<1 nm RMS

L3Harris has supported studies and hardware designs for coronographic missions in the past and currently supports the study efforts for both the LUVOIR and HabEx missions. During the Terrestrial Planet Finder-Coronagraph (TPF-C) program, L3Harris designed and developed technology for the Technology Demonstration Mirror (TDM) which had very similar requirements. The 1.8 m off-axis asphere extended L3Harris' metrology expertise to ultra-low SFE telescope optics for coronagraphy.

There are engineering development challenges to achieving the surface figure error (SFE) requirements for the HabEx mirror. Smoothing processes, mirror metrology absolute accuracy, and the analysis of the 1-G to 0-G shift can limit the ability to figure telescope mirrors. From a mirror polishing standpoint, L3Harris utilizes the technologies required to meet the SFE requirements, but facility updates will be required to accommodate the 4m size of the HabEx PM. The appropriate balance of smoothing processes must be developed further, but experience dictates that the metrology absolute accuracy and 1-G to 0-G shift prediction may limit the ability to converge to the proper surface figure. Technology advancement in calibration holograms underway at L3Harris will advance the state-of-the-art to HabEx levels. Multiple programs are also advancing the ability to predict the surface figure shift from 1-G to 0-G.

The sections that follow discuss:

1. Facilitation to support a mirror 4m in size.
2. Smoothing processes to achieve HabEx requirements.
3. Mirror metrology
4. 1-G release.

2.0 Facility Updates

L3Harris Technologies has extensive heritage of fabrication of large space telescope mirrors. From the Hubble space telescope backup mirror, the development of the JWST glass mirror demonstrator (Advanced Mirror System Demonstrator - AMSD), to the WFIRST 2.4 m primary mirror, dozens of mirrors fabricated by L3Harris have flight heritage. More recently, L3Harris was chosen by the Large Synoptic Survey Telescope (LSST) to figure the 3.5 m LSST secondary mirror and completed it in 2018. The same fabrication technologies used by L3Harris to grind, polish and final figure these challenging optics are directly applicable to a 4 m HabEx mirror. While no new fabrication technologies are required, the development of the appropriate balance of existing processes and tooling investment to handle a 4m class optic are needed.

2.1 OptiFlex Mirror Fabrication Facility

L3Harris proposes the use of the internally designed OptiFlex fabrication facility, a new state-of-the-art grinding, polishing and metrology center. The OptiFlex system concept, Figure 1, is a larger and more capable version of the existing L3Harris Large Machining Center (LMC). The computer-controlled gantry and configurable machine tool heads can generate, probe, grind, and polish large telescope mirrors.

Computer controlled small tool polishing and magnetorheological (MRF) process are utilized for highly deterministic finishing. The co-location of these capabilities in a single facility location, integrated with in-situ interferometric metrology equipment reduces process cycle time and risk by limiting the amount of the optic handling.

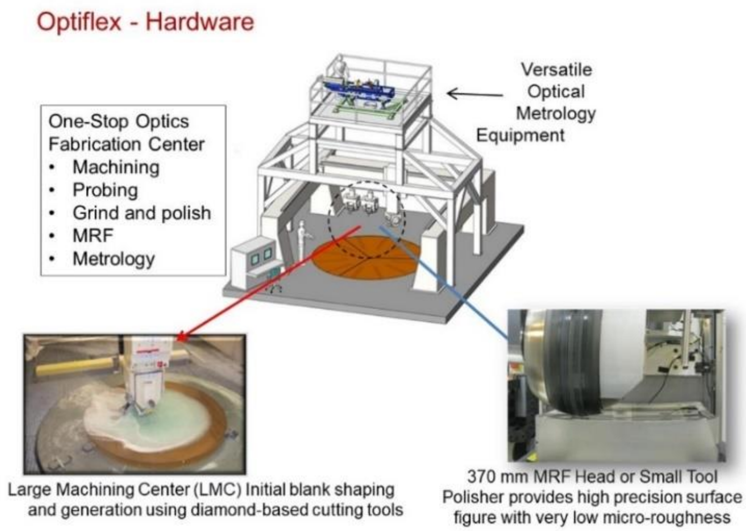

Figure 1 Opto-Flex Optics Fabrication Facility

The OptiFlex utilizes technologies in use at L3Harris on optics up to 3.5 meters in size and presents a straight forward incremental step required to process a HabEx mirror.

2.2 Ion Beam Figuring Chambers

The largest L3Harris ion beam figuring (IBF) chamber can accommodate optics up to 3.5m in diameter. This facility was used to deterministically finish the LSST 3.5m M2. A new IBF facility is needed for final IBF correction of the HabEx PM. L3Harris developed the IBF capability and has employed this capability for over 30 years. This is a core capability for L3Harris and can be utilized to finish a large mirror like the HabEx PM.

3.0 Smoothing Processes

The talented L3Harris process team has multiple processes and metrology tools available to address the full range of surface figure errors of interest for HabEx (see Figure 2.) The mirror processing and metrology requirements are broken up by spatial frequency.

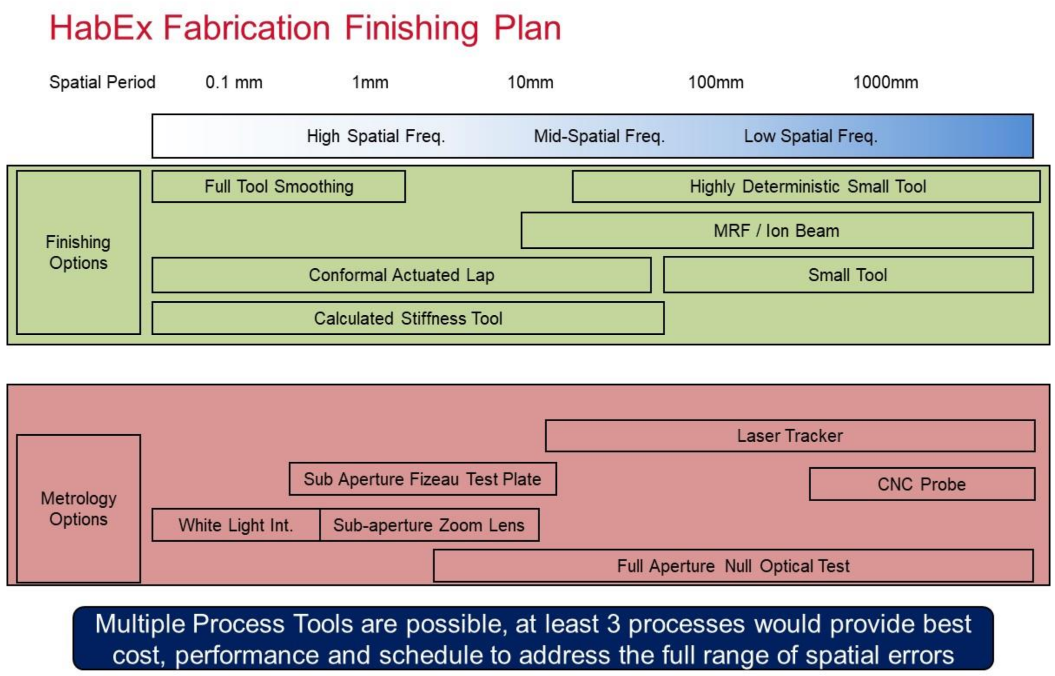

Figure 2 Fabrication finishing plan

The low spatial frequency errors are characterized by full aperture interferometric testing and are removed via deterministic small tool, MRF finishing, and eventually Ion Beam Figuring (IBF) to the limits of metrology system repeatability. The deterministic finishing process ensures rapid figure convergence and L3Harris has produced meter class mirrors with performance that meet HabEx requirements. Both the 0.5 m Advanced Mirror Technology Demonstrator (AMTD, 0.5 m circular) and the Multiple Mirror System Demonstrator (MMSD, 1.35 m hexagon) mirrors achieved ~5nm 1-G RMS SFE when smoothed to 50 mm with a low pass filter, demonstrating that existing process steps achieve HabEx low spatial frequency requirements.

The mid and high spatial frequency SFE requirements present L3Harris with an engineering challenge to advance existing technologies to meet HabEx requirements. The size of the Ion beam, MRF head or small tool leave behind a set of higher frequency errors that are smoothed out near the end of the polishing process. Removal of these spatial frequencies requires a larger tool and L3Harris believes that the proper use of a calculated stiffness tool (State of practice) and a Conformal Actuated Lap (CAL, state of the art) needs to be evaluated. During the TDM/TPF program L3Harris developed a Conformal Actuated Lap (CAL) to achieve mid and high spatial figure requirements. L3Harris has design concepts to improve the engineering design and performance of a CAL and further engineering and process development is required for HabEx. The CAL is envisioned to be a relatively large sub-aperture tool with capabilities similar to the sub-aperture active tool developed by the University of Arizona, but with improved capabilities.

Traditional micro-roughness requirements for visible imaging applications are ~2 nm RMS over spatial periods from ~100 um – 1 um. The polishing process for ULE® and Zerodur® can be optimized to meet the tighter HabEx requirements and L3Harris has produced optics to the required levels in the past.

4.0 Mirror metrology

Absolute calibration of the null test optics to the levels required for HabEx is state-of-the-art and is under development at L3Harris. Decades of experience dictate that with modern interferometers and calibration holograms, test noise and repeatability do not limit the absolute accuracy of a mirror surface. Knowledge of null calibration hologram imperfections typically dominant surface figure uncertainties in the metrology error budget. A practical example on JWST is illustrative: during JWST primary mirror testing at Johnson Space Center, the calibration of the null was repeatable to levels approaching 0.7 nm SFE, while the absolute uncertainty of the calibration hologram itself was 2.5 nm SFE. Achieving HabEx level performance requires calibration hologram absolute accuracies approaching 1nm RMS.

Under IRAD, L3Harris has developed a process for qualifying calibration holograms and we have proposed further testing under the LUVOIR ULTRA follow-on program. The successful demonstration of this technology under the ULTRA program will raise the TRL level of these holograms from TRL 2 to TRL 3.

5.0 Mirror Gravity Sag Uncertainty

L3Harris has had success backing out the impacts of gravity release to the levels required for visible telescopes, but HabEx requires significantly lower uncertainties that are state of the art. L3Harris has a multi-step approach to reducing the impacts of 1-G release and engineering development is underway on the WFIRST and LUVOIR ULTRA programs.

To reduce the uncertainty of the analytical backout, precision measurements of the faceplate and core thicknesses are performed during fabrication to develop an as-built analytical model of the mirror. Airbags and multi-point support mechanical systems are used to limit the magnitude of the gravity sag. Finally, optical testing is performed optical axis vertical to reduce the model uncertainties of the mirror on an airbag and/or multi-point offloader

To further reduce uncertainties (and risk), L3Harris recently performed a multiple orientation optical test on the WFIRST spare PM to empirically crosscheck the 1-G models. The recent testing on WFIRST was highly successful and indicated the gravity modeling was accurate to ~3% which is on the levels required for HabEx. Under the LUVOIR Ultra Program, L3Harris proposed further engineering analysis to understand the impacts of model fidelity and off loader design to bring the analysis for a coronagraph mirror to a TRL 3 level. The advances made under these programs will further demonstrate that existing technologies can meet HabEx requirements.

6.0 Conclusion

L3Harris strongly believes that the proper combination of infrastructure investment and technology development will enable the successful fabrication of the HabEx mirror. Technology developments in mirror smoothing technology, mirror metrology and 1-G modeling required for HabEx are under way at L3Harris.