Roman Optical Telescope Assembly (OTA) Build and Integration Progress

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ABSTRACT

The Nancy Grace Roman Space Telescope (RST) is a Hubble-class telescope with a large field of view for large surveys of the sky, cold temperatures for enabling near infrared imaging, and controlled temperature stability for long exposures and coronagraphy. The OTA includes the primary mirror, secondary mirror, and aft optics for guiding light into the Wide Field Instrument and the Coronagraph Instrument. The testing of the optical assemblies and structures are nearly complete in preparation for telescope integration. Pictures and descriptions of the assemblies are provided, followed by performance results measured at these level of assemblies.

The assemblies are nearly complete as they are tested through thermal cycling to cold temperatures for infrared operation, mechanical strength and vibration, and optically testing. Optical surface figure error results are shown for all the optical surfaces..

Keywords: RST, Roman, Infrared, telescope, optical test, vibration test, load test

1. INTRODUCTION

At our last conference report[1], the inherited hardware was tested for the RST environment and the requirements were established to design the optical telescope for RST. Much has been accomplished in the meantime along with name changes, the pandemic, and the development of launch vehicle parameters. The critical telescope design review was completed remotely in December 2020. The inherited hardware was dismantled, re-shaped, and re-built. All mirrors, structural components, and electronics have been completed by early 2021. Now most optical and electrical assemblies are complete. Strength testing and environmental testing is nearly complete at the assembly level. Integration planning is in progress. After summarizing the design, the current status of hardware will be shown along with testing status and results to date.

2. OPTICAL TELESCOPE DESIGN OVERVIEW

The telescope illustrated in Figure **1** uses an inherited 2.4-meter primary mirror that was re-figured for a diffraction-limited ~ 0.8° x 0.5° sky field of view in a three-mirror anastigmat design for the Wide Field Instrument (WFI). A portion of the field is picked off with a fold mirror to a design with three powered mirrors to provide a collimated pupil to the Coronagraph Instrument (CGI). Both sets of aft optics are compactly packaged to leave room for the instruments and the Instrument Carrier (IC). The secondary mirror is supported by an actuated hexapod and contains redundant fine focus drives for on-orbit adjustments. The aft optics contain two actuated flats to adjust differences in the two (WFI and CGI) channels using a shared primary and secondary mirror configuration. Three bi-pod struts support the telescope over the Instrument Carrier. The full telescope is managed thermally using a proportional-integral control loop to maintain the tight optical stability requirements for RST. The actuator drive electronics and the thermal management electronics are within a box mounted with the other electronics on the Spacecraft Element.

3. PRIMARY MIRROR ASSEMBLY (PMA) IN ENVIRONMENTAL TESTING

The Primary Mirror is an inherited lightweighted optic using a honeycomb core with facesheets made with Ultra Low Expansion glass for a mass density of 40 kg / m^2. The coating on the mirror was stripped and the optical surface was re-figured to the RST prescription. The mirror sits on 3 bi-pod struts with the mounts and struts re-designed to be optimized for the RST operating temperature. The struts attach to the inherited 0.28-meter-thick ribbed composite box-paneled Aft Metering Structure (AMS). A composite stray light primary mirror baffle extends from the center of the AMS up through the center of the PM.

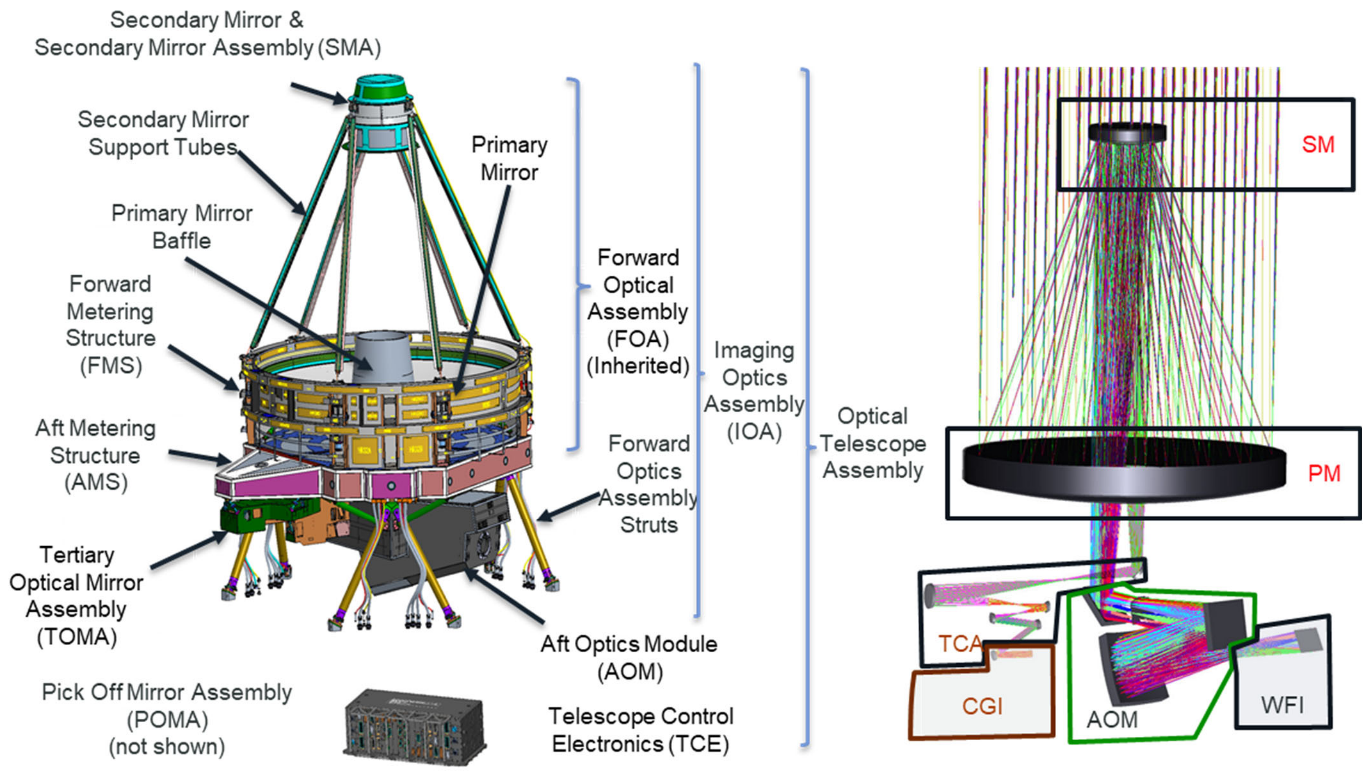


Figure 1. Design overview of the optical telescope shows (a) the schematic overview (left) and (b) the ray trace (right).

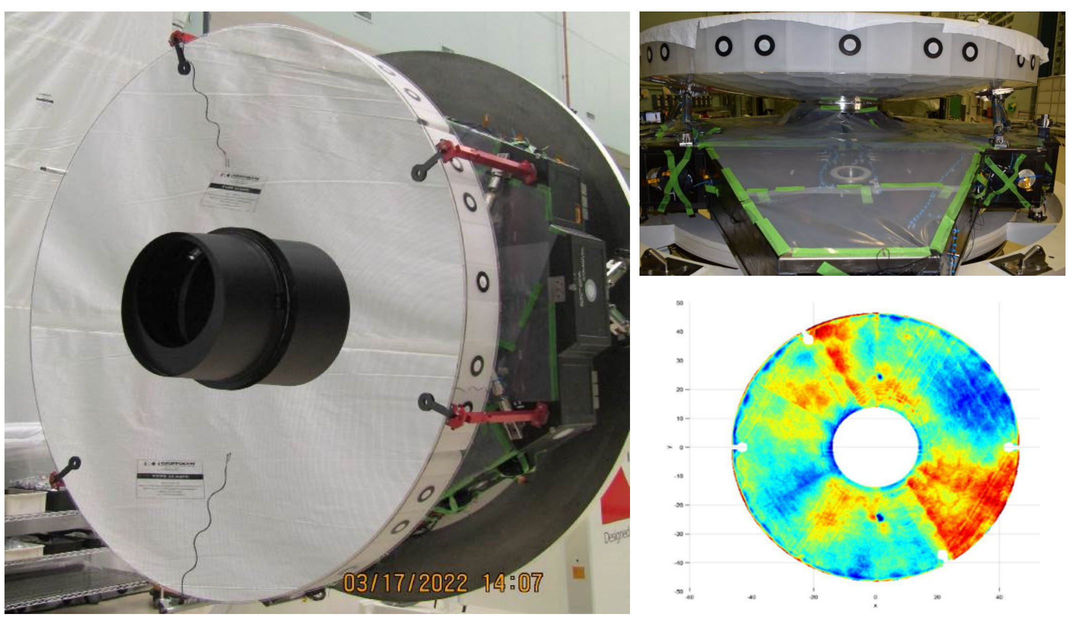


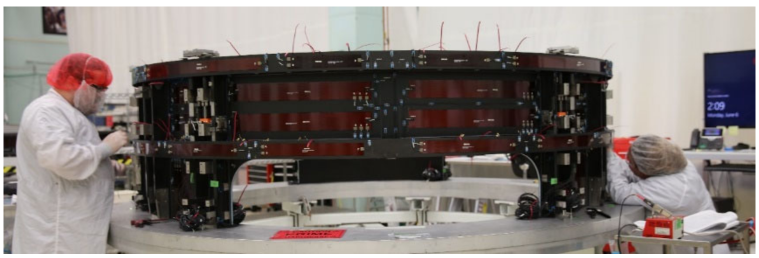
Figure 2. Primary Mirror Assembly during (a) the horizontal optical test (left) and (b) after the test (top right). (c) Surface figure error map extrapolated to zero gravity and operating temperature.

The PMA has completed a vertical optical test at the cold operating temperatures, and a multi-orientation horizontal test confirmed the gravity signature within the test uncertainties. The predicted surface figure error (SFE) with zero gravity at operating temperature is 16 nm RMS with 13 nm of uncertainty for a total of 21 nm RMS. The PMA will be tested again at operating temperature as part of the wavefront measurement through the full integrated telescope.

The AMS has been load tested up to 61 kN in 32 unique configurations and will undergo one more load test configuration. The PMA is currently in preparation for a modal survey and a sine burst vibration test.

4. FORWARD STRUCTURE ASSEMBLY (FSA) IN ENVIRONMENTAL TESTING

The FSA consists of a Forward Metering Structure (FMS), a composite hoop that attaches onto the top of the AMS. The FMS contains six actuators (Alignment Drives) that drive six struts in a hexapod configuration to position the secondary mirror assembly over the PMA. The FMS also provides heaters around the perimeter of the Primary Mirror.



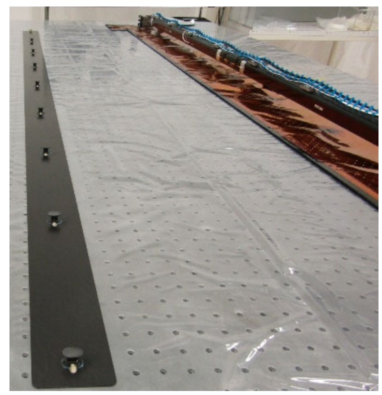


Figure 3. (a) Installation of thermal hardware and wiring on the Forward Metering Structure (left). (b) The right image shows a stray light scraper on the left prior to bonding under the thermal blanket on the right under a secondary mirror strut.

The inherited FMS structure was stripped and re-built with flexures, thermal control hardware and wiring. The assembly is complete and fully strength tested. The strength test alerted the need for tighter assembly tolerances on flexure assemblies used between the alignment drives and the struts. The flexures were re-assembled and the strength test through the flexures completed. The alignment drives completed all testing including strength, vibration, cold performance, and life testing. They are ready for integration with the FMS and secondary mirror struts.

The ~2.4-meter-length secondary mirror struts have been strength tested. Thermal blankets have been integrated, and scrapers for blocking light from striking the blanket have been integrated. The strength testing for the integrated scraper bonds are in process.

The Secondary Mirror Assembly (SMA) mounts at the top of six struts. This inherited assembly was dismantled and stripped of hardware with expired life or incompatible with the RST application. The glass was re-figured to the RST prescription. This assembly was re-built with new thermal hardware, wiring, and flexures. The assembly includes new redundant actuators for fine focus adjustment of the mirror. The focus drives have completed strength testing, vibration testing, cold performance testing, and life testing. They are now integrated in the SMA. The SMA has completed thermal cycling, optical testing, and vibration testing. The predicted surface figure error (SFE) with zero gravity at operating temperature is 12 nm RMS with 5 nm RMS of uncertainty included.

On top of the six struts lies the Secondary Mirror Assembly (SMA). This inherited assembly was dismantled and stripped of hardware with expired life or incompatible with the RST application. The glass was re-figured to the RST prescription. This assembly was re-built with new thermal hardware, wiring, and flexures. The assembly includes new redundant actuators for fine focus adjustment of the mirror. The focus drives have completed strength testing, vibration testing, cold performance testing, and life testing. They are now integrated in the SMA. The SMA has completed thermal cycling, optical testing, and is currently undergoing vibration testing. The predicted surface figure error (SFE) with zero gravity at operating temperature is 12 nm RMS with 5 nm RMS of uncertainty included.

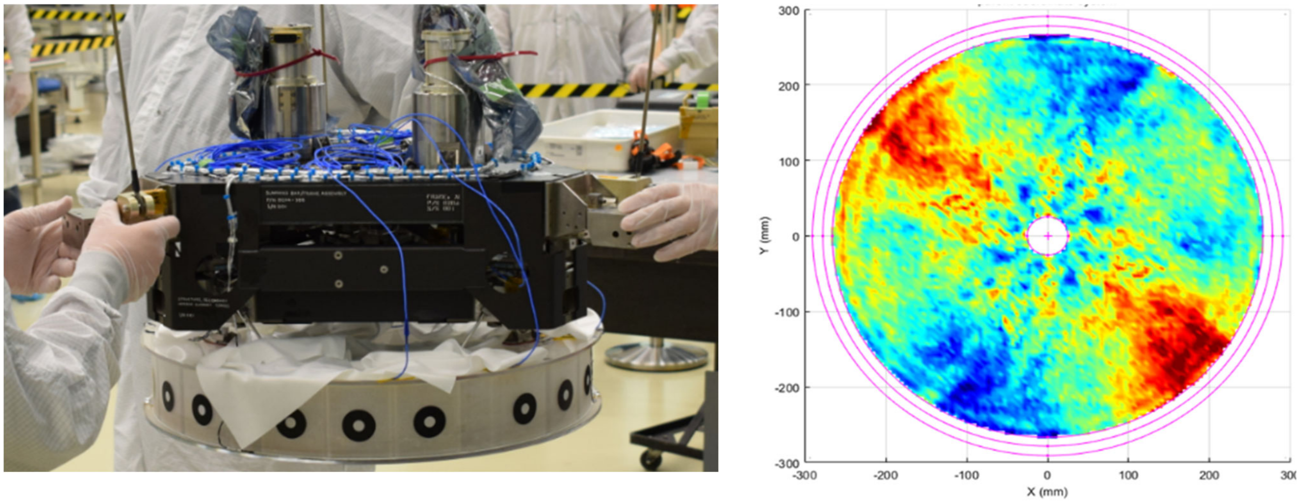


Figure 4. (a) Preparation of Secondary Mirror Assembly for vibration testing (left). (b) Surface figure error map of Secondary Mirror including extrapolation to zero gravity and operating temperature.

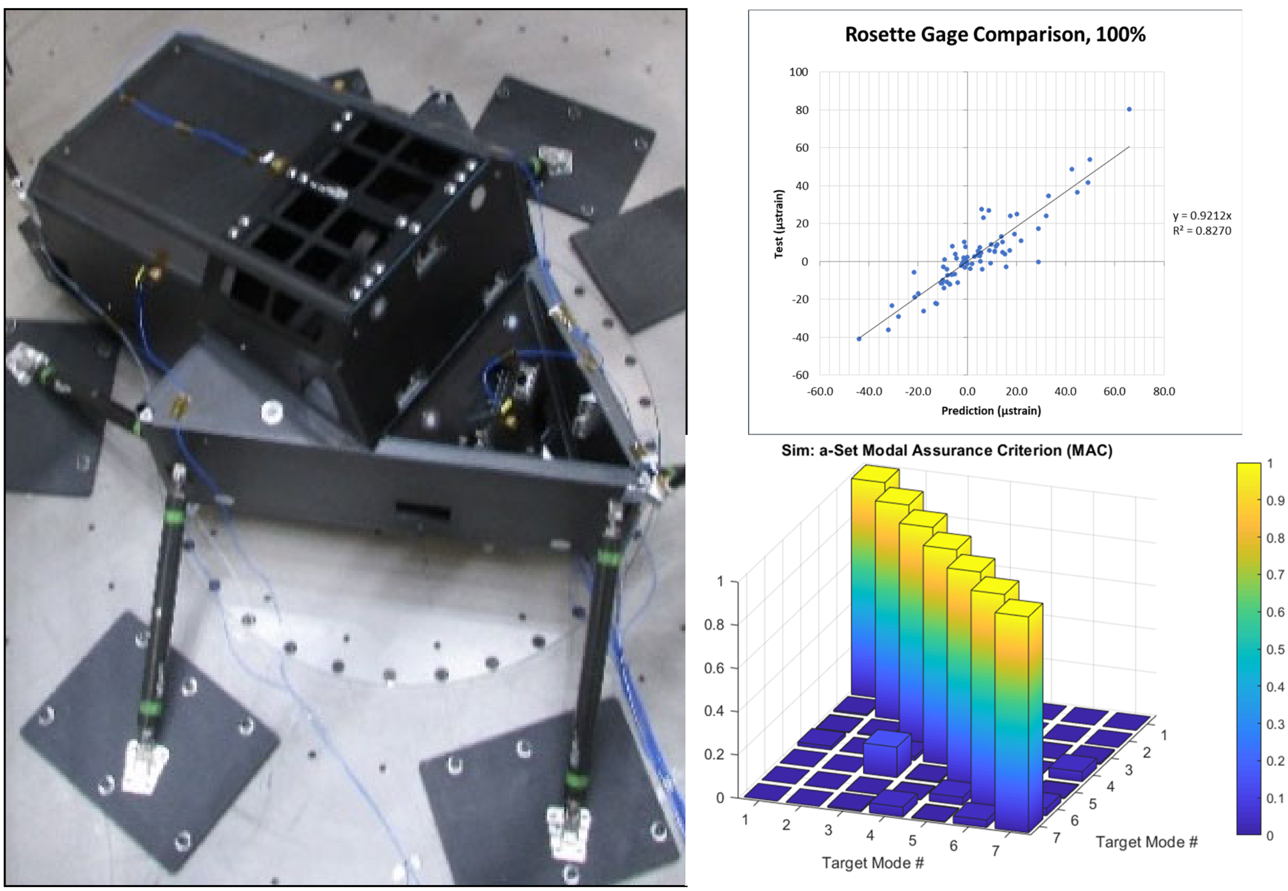


Figure 5. (a) Upside down Aft Optics Structure in the modal survey configuration (left). (b) Typical load case correlation between test and prediction for static load testing (upper right). (c) Modal survey MAC with off-diagonal values under 0.2 indicating good data quality (lower right).

5. AFT OPTICS MODULE

The Aft Optics Module (AOM) met the challenge of compressing the design into a small enough package to fit within the space inside the instrument carrier and give more room for the Wide Field Instrument (WFI). To fit within the constrained space, the second fold mirror was designed with a bite removed from the bottom of the mirror to allow clearance for the beam from the tertiary mirror to the WFI. The first fold mirror includes three actuators to compensate for telescope tolerances and compromises with the SM alignment for both the WFI channel and the Coronagraph channel, as well as compensate for tolerances in the WFI alignment.

The three bi-pod struts between the AMS and the Aft Optics Structure are complete with strength testing. They were designed to withstand a 47 K thermal gradient between the two structures. The structure has also been strength tested with 18 unique load cases, completed a modal survey, and is set up to start adding the thermal hardware and wiring.

The three light-weighted mirrors that will be installed in the Aft Optics Module are complete and mounted on their reaction structures. The second fold mirror (FM2) and the Tertiary Mirror assemblies are in preparation for thermal cycling and vibration testing. The first fold mirror assembly will be completed when the actuators are available. The actuators are currently under development for cold operation with ample cold torque margin. Current surface figure error maps are shown below.

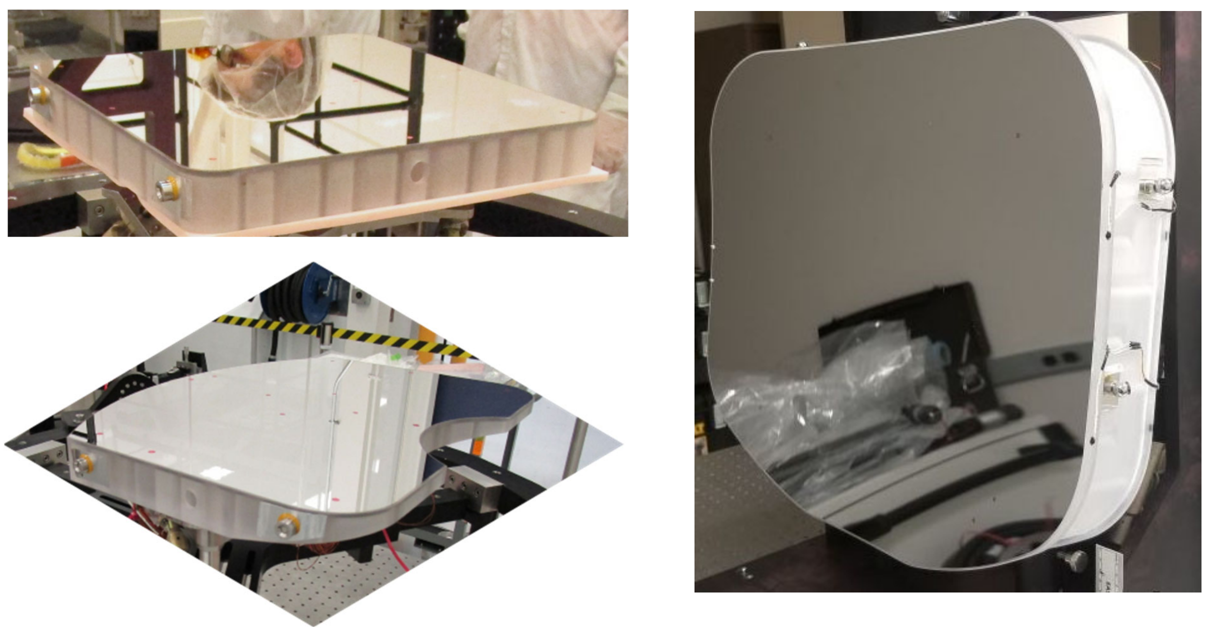


Figure 6. (a) FM1 assembly, upper left, awaiting actuators integration. (b) FM2 assembly, lower left, and (c) Tertiary Mirror, right, ready for thermal cycling and vibration testing. (d) Note the bite and wedge on right side of FM2 to provide space for the Wide Field Instrument.

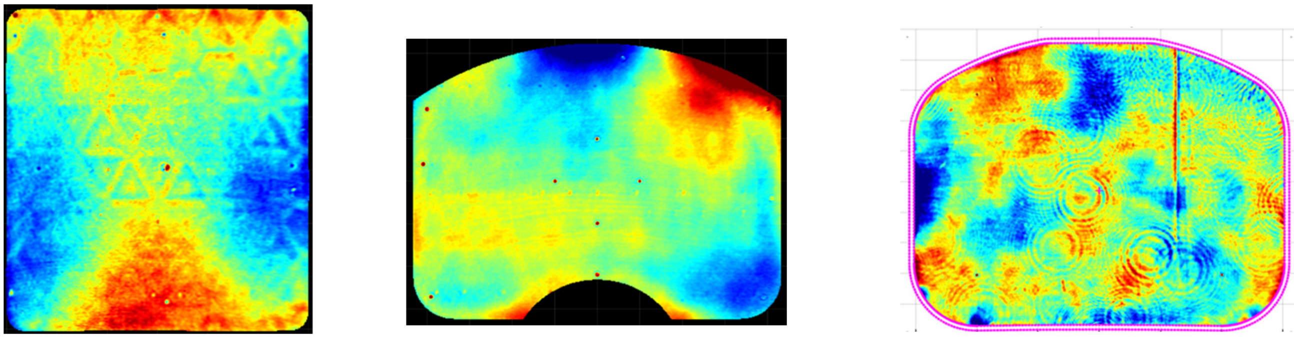


Figure 7. (a) Surface figure error maps of FM1A, FM2A, and TMA, left to right respectively, at this stage of assembly and testing.

Table 1. Aft Optics Module optical assembly surface figure errors.

Mirror Assembly	Beam Footprint Diameter (mm)	Predicted Surface Figure Error over Footprint (nm RMS)	Included Uncertainty (nm RMS)
Fold Mirror 1	35	5.4	3.3
Fold Mirror 2	100	4.4	2.6
Tertiary Mirror	211	9.2	5.8

6. TERTIARY COLLIMATOR ASSEMBLY

The Tertiary Collimator Assembly shapes a section of the light from the secondary mirror into a collimated beam for the Coronagraph Instrument (CGI). The aft optics for this light path are split into two assemblies -- the Pick-Off Mirror Assembly (POMA) and the Tertiary Optics Module Assembly (TOMA). The POMA is a composite structure that attaches to the AMS with a flat oval-shaped mirror to fold the beam from the Secondary Mirror underneath the AMS to the TOMA. The TOMA consists of a composite structure attached to 3 bi-pod strut pairs connected to the bottom of the AMS. Inside the TOMA are three powered mirrors (M3, M4, M5) and a flat mirror at the end of the optical path to fold into the CGI. This last flat mirror as two actuators to tip/tilt the collimated beam for pupil shear alignment into the CGI. The TOMA operates at room temperature with a 28 K gradient to its mount on the AMS.

The POMA structure and optical assembly are complete including thermal cycling, strength testing, and optical testing. The structure is ready for integration to the PMA. The TOMA structure is complete including strength testing with 7 load configurations and is ready for integration with the mirror assemblies. The powered mirror assemblies are complete, have undergone all testing, and are ready for integration. The actuated fold mirror assembly has completed thermal cycling and is preparing for vibration testing. The remaining 4 optical assemblies are complete with strength testing and ready for integration.

All of the TOMA optical assemblies will be integrated into the TOMA structure. The TOMA will be tested optically as a complete assembly, and tested mechanically as a complete assembly prior to integration to the PMA.

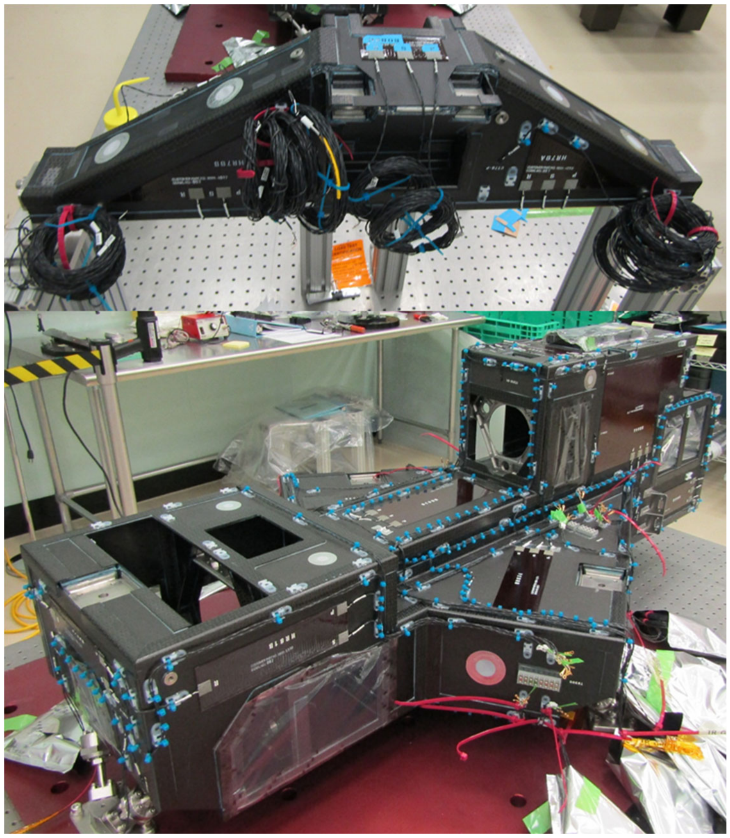


Figure 8. (a) POMA structure, top, and (b) TOMA structure, bottom, ready for integration.

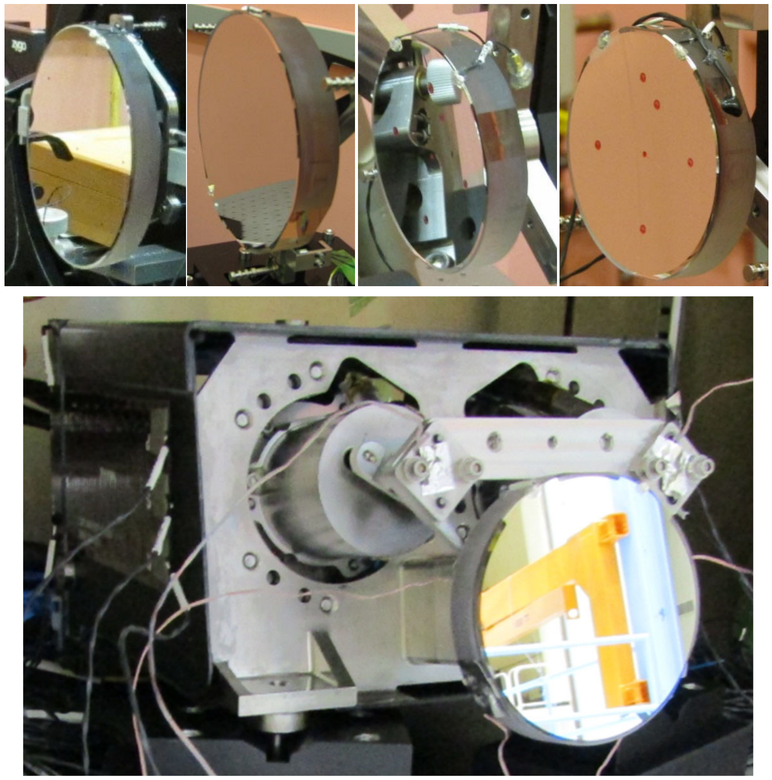


Figure 9. (a) POMA flat mirror, M3, M4, M5 (with temporary fiducial marks), top left to right, ready for integration. (b) TOMA fold mirror with actuators, bottom, after thermal cycling.

Table 2. Surface figure errors of TCA optics.

Mirror Assembly	**Predicted Surface Figure Error over Footprint (nm RMS)**	**Including Uncertainty (nm RMS)**
POMA F1	15 (including power)	4.3
M3	12	4
M4	5.4	2.5
TTF	17 (including power)	3.6

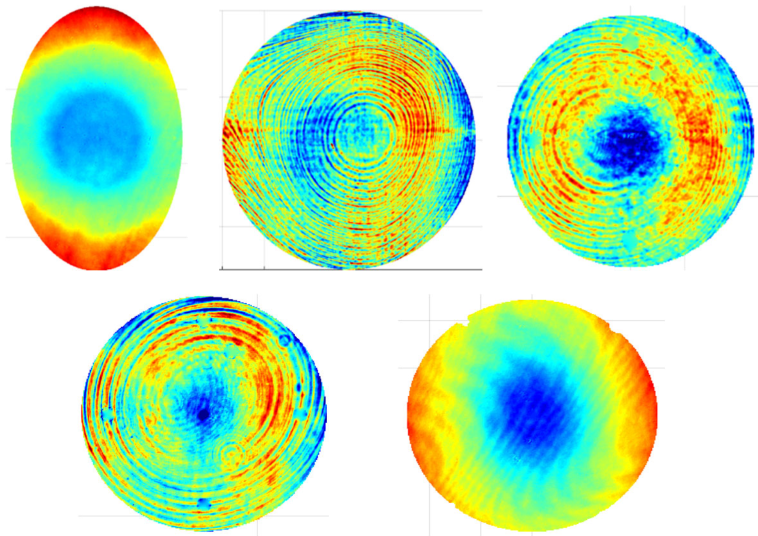
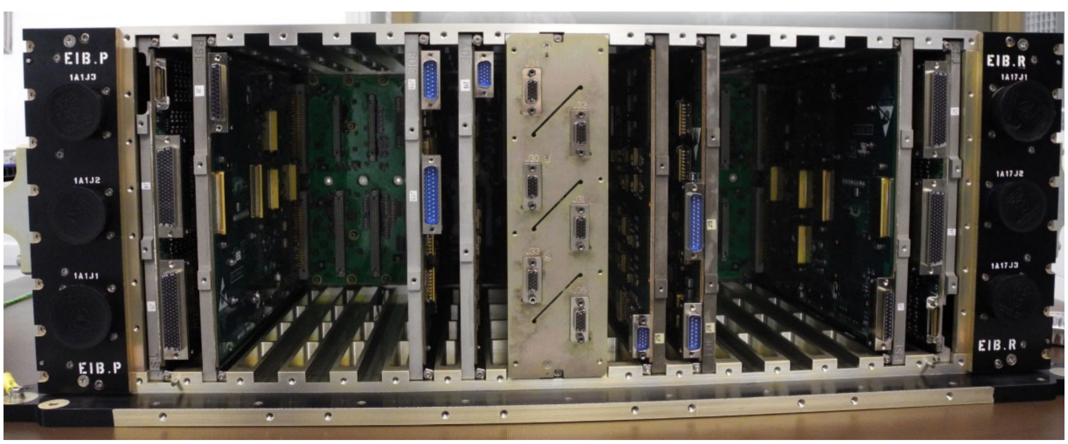


Figure 10. (a) Surface figure maps of POMA F1, M3, M4, top, left to right. (b) M5 and TTF, bottom, left to right.

7. TELESCOPE CONTROL ELECTRONICS (TCE)

The TCE consists of 17 circuit board assemblies in a chassis including primary and redundant assemblies. The electronics manage up to 96 heater zones per side with pulse-width modulation control and thermal calibration sensing to support the stringent optical stability requirements of the Roman Space Telescope. The electronics also supply motor drive and telemetry circuits for 13 actuators described above, and SpaceWire communication to the spacecraft. A brassboard TCE tested the electrical and firmware design including stable thermal control using thermal load simulators inside a vacuum chamber at RST temperatures, reaching ~ 1 mK stability[2].



Fifteen (15) of the seventeen (17) board assemblies have been completed electrical functional testing. A 16[th] board assembly has completed a power up test. A voltage regulator failed while testing a board assembly and a replacement board assembly is underway. Five other board assemblies are in re-work to assure reliable voltage regulator operation. Therefore, 11 boards are currently assembled in the chassis as shown in Figure **11**.

Figure 11. Eleven (11) out of seventeen (17) circuit board assemblies tested and installed in chassis in preparation for testing at the box level of assembly.

8. INTEGRATION AND TEST

The Primary Mirror Assembly is the cornerstone of the integration. Upon completion of the PMA mechanical testing, the rest of the assemblies (except the TCE) integrate to the PMA. The full telescope is aligned optically prior to locking in the Secondary Mirror position, the TOMA position, the position of the second fold mirror in the AOM, and the Tertiary Mirror position. The optical alignment includes meeting wavefront error requirements, pupil alignment requirements, and image surface position requirements. After alignment the telescope is tested optically at RST operating temperatures and undergoes thermal balance testing in a thermal vacuum chamber as shown in Figure **13**. The telescope is also vibration tested and acoustically tested.

Upon completion of the telescope testing, the instrument carrier is integrated to the telescope using the six (6) Forward Optical Assembly struts, shown in Figure 1 and Figure **12**, with bearings at each strut end. These struts have completed load testing and are preparing for thermal and electrical hardware installation. Then the optical and thermal testing in cold vacuum is repeated to check alignment and interfaces between the two systems.

New test equipment for the telescope testing is currently in design and procurement. The telescope will be tested in a hanging configuration with a full aperture flat mirror for double-pass interferometer testing. The mirror has been coated, optically tested, and is ready for integration into the rest of the test assembly.

Figure 12. (a) FOA struts during thermal cycling (left) have also completed load testing. (b) Coated flat mirror for double-pass optical test of the telescope ready for final optical test before assembly for the thermal vacuum chamber.

9. SUMMARY

All mirrors and structures are complete. Nearly all the assemblies are complete or in testing. The TOMA integration will be starting soon. The rest of the telescope integration will commence at the completion of the strength testing and modal survey of the primary mirror assembly.

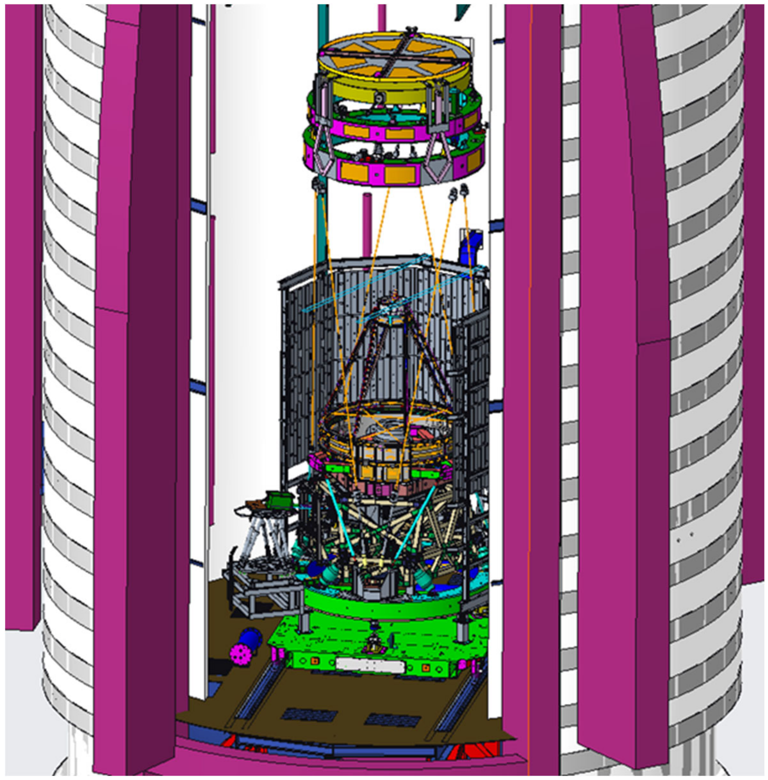


Figure 13. Thermal vacuum test configuration of telescope with instrument carrier. A full aperture flat at the top. Thermal shroud partially hidden.

ACKNOWLEDGEMENT

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REFERENCES

[1] Smith, J. S., Bartusek, L., Casey, T., Content, D., et.al., "Wide-Field Infrared Survey Telescope: Optical Telescope Assembly Status," Proc. SPIE 10698 (2018).

[2] Miller, P., Ferry, N., Martens, B., et.al., "Nancy Grace Roman Space Telescope (RST) – Demonstration of integrated thermal control system test for the optical telescope assembly," Proc. SPIE 12188 (2022).