Artemis Innovative Assembly and Integration Operations of the Launch Abort System at KSC

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Abstract--- This paper describes the Artemis program assembly and integration approach that enables affordable and low risk processing operations for the Launch Abort System at KSC. NASA is currently developing the Artemis 1 spacecraft to meet the test objectives of an uncrewed orbital mission to the moon and return to earth in 2021. The Artemis Orion spacecraft consists of a Crew Module (CM), a Service Module (SM), and a Launch Abort System (LAS) to safely transport a crew of 4 to the moon and return to earth. The LAS enables the CM to have an abort capability for the crew during the launch phase of the mission from the launch pad throughout the ascent phase. The LAS includes motor elements for abort, attitude control, and stage separation is assembled at the Launch Abort System Facility (LASF) adjacent to the CM/SM (CSM) assembly operations in the Neil Armstrong Operations and Checkout Building (O&C) at KSC. The LAS integration to the CSM is completed in the LASF and the completed Artemis spacecraft is integrated to the Space Launch System (SLS) in the Vehicle Assembly Building (VAB) at KSC. A significant LAS development flight test milestone was recently completed in 2019 for the Ascent Abort (AA-2) flight test at Cape Canaveral Air Force Station where a high-altitude abort test was successfully achieved using a Peacekeeper booster stage exercising all of the LAS systems including propulsion, avionics, and pyrotechnics demonstrating the LAS readiness for crewed flight. The first operational flight of the LAS will be for the Artemis 2 mission which is the first crewed mission for the Orion program planned in 2023.

The LAS assembly and integration is performed at the launch site at KSC to enable seamless operations for the integration to the Artemis spacecraft and the SLS launch vehicle. The LAS abort, jettison, and attitude control motor assemblies are processed in a hazard operations environment in the LASF separate from the Artemis CSM spacecraft operations. Common use of CSM O&C assembly processes, equipment, and technician workforce are deployed to the LASF avoiding the need for stand-alone and dedicated operations reducing LAS processing costs and risks. The LAS assembly operations support systems reside in a contemporary digital environment documenting and managing the requirements, engineering drawings, production plans, and vehicle as-built configurations and are compatible with the NASA KSC integration environment. The LAS integration by the NASA Exploration Ground Systems (EGS) operations completes the integration to the SLS launch vehicle. Any LAS anomalous conditions are rapidly addressed using onsite EGS and Artemis technical support as required. The LAS processing at KSC enables a low risk and affordable assembly and integration approach for the Artemis program to support NASA Gateway missions of the future.

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1. INTRODUCTION

The Artemis program is developing a human rated spacecraft design, manufacturing and test capability to support the NASA exploration missions using an incremental approach with multiple flight test articles to retire program risk with qualification and flight tests. The Artemis program's objective is to provide a crew transportation vehicle for the NASA Exploration Systems Development (ESD) program to support missions beyond Low Earth Orbit (LEO). This paper describes how the Artemis program is implementing innovations in the Launch Abort System (LAS) assembly and integration operations reducing programmatic cost and risk while ensuring crew safety in support of NASA's Exploration Missions. The Artemis 1 spacecraft will meet the test objectives of an uncrewed orbital mission to the moon and return to earth in 2021. Lessons learned from earlier flight test articles including the Pad Abort (PA-1 in 2010), Exploration Flight Test (EFT-1 in 2014) and the Ascent Abort (AA-2 in 2019) are being incorporated into the spacecraft vehicle design and assembly and integration processes to continue to reduce risk and cost to the Artemis missions.

A key contributor to a low risk assembly and integration capability on the Artemis program is the decision to locate the vehicle assembly operations adjacent to the launch site at the Kennedy Space Center (KSC). The Neil Armstrong Operations and Checkout Facility (O&C) with the Launch Abort System Facility (LASF) are located at KSC where the spacecraft assembly and integration operations are performed. In 2006 NASA initiated the refurbishment of the O&C facility for the spacecraft assembly and test operations and renovated the Canister Rotation Facility (CRF) from the Space Shuttle program for LAS assembly and integration operations. The LASF was selected enabling segregated hazardous operations of the LAS solid motors from the CM & SM (CSM) spacecraft operations in the O&C. The O&C and the LASF were selected because, as existing facilities, they provided a lower cost and more affordable approach versus having to build new facilities. Additionally, their location at KSC eliminated the transportation and checkout risks that would be realized if the spacecraft were assembled at other locations across the country.

The LAS objective is to provide launch abort capability for the Orion spacecraft and crew during the ascent phase of the mission from the launch pad to orbit. Risk reduction flight tests for the LAS have been successfully completed and the first LAS production vehicle was completed in November of 2019 supporting the Artemis 1 mission. Assembly innovations have been incorporated in the LAS production operations and validated for the Artemis 1 mission. The necessity for affordability on the Artemis program stems from the funding levels being significantly lower than previously experienced on programs such as Apollo or the Space Shuttle. Cost projections for future manned missions are considerable for Lunar Gateway and Mars exploration missions. Their affordability is enhanced if Artemis cost can be kept to a minimum. The LAS assembly and integration innovations summarized in this paper contribute to Artemis affordability.

2. ARTEMIS 1 MISSION OVERVIEW

The Artemis 1 flight test is an all systems risk reduction milestone and will be the first mission with flight configuration hardware for the spacecraft and the launch vehicle. This mission will be unmanned and will demonstrate the spacecraft systems supporting a lunar transit and return to earth as shown in Figure 1. This mission will utilize the ground processing infrastructure at KSC for the CSM servicing, the LAS integration to the CSM, and the integration of the Artemis spacecraft to Space Launch System (SLS) launch vehicle including the Mobile Launch (ML) platform as shown in Figure 2. Artemis 1 will fly with a fully qualified LAS and will only fly a nominal ascent mission without an abort event.

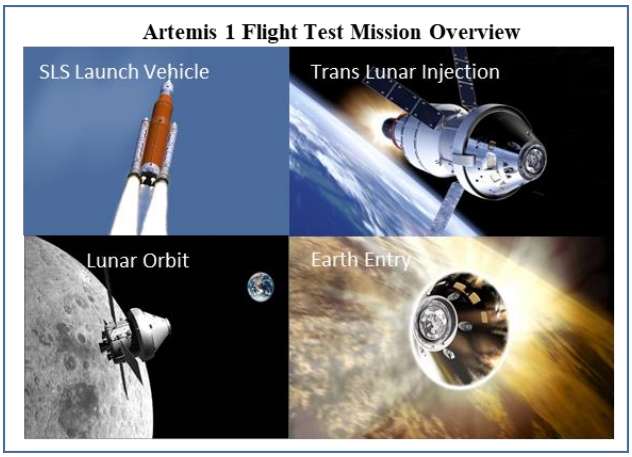

Figure 1 Artemis 1 Flight Test Mission to the Moon and Return

The LAS propulsion system will jettison the LAS from the CSM as a nominal mission to complete the ascent trajectory to LEO. LAS abort risk reduction tests have already been completed using two dedicated abort tests. Completion of the Artemis 1 flight test will complete the risk reduction and qualification of the LAS providing crew abort capability for the first crewed mission on Artemis 2.

Figure 2 Artemis 1 Launch Configuration Identifying the LAS on the Orion Spacecraf

3. LAUNCH ABORT SYSTEM OVERVIEW

The LAS is a propulsion system located above the CSM and rapidly separates the CM from SM and the SLS launch vehicle during an abort condition to enable a safe crew return to earth. Figure 3 shows the abort maneuvers that the LAS performs to safely separate and orient the CM to deploy the landing parachutes for recovery. Three solid rocket motors are located in the LAS which include the abort motor which pulls the CM from the launch vehicle, the attitude control motor which rotates the CM heat shield first, and the jettison motor which separates the LAS from the CM enabling the reentry and the parachutes to deploy for a safe landing. The jettison motor is also used to separate the LAS from the CSM during a nominal mission.

Figure 3 LAS Abort Events Summary

The LAS qualification program is comprised of component and individual solid rocket motor testing, abort system level risk reduction testing, and the final Artemis 1 flight test. The abort system level risk reduction testing was performed for two flight cases 1) abort from the launch pad (PA-1) conducted at WSMR and 2) ascent abort at altitude (AA-2) at KSC as shown in Figure 4.

LAS pathfinder assembly operations were performed on the AA-2 LAS test article in early 2019 in the LASF and validated the processes and procedures for the flight LAS assembly for the Artemis 1 configuration.

LAS Pad Abort Flight Test WSMR (2010)

LAS Ascent Abort Flight Test KSC (2019)

Figure 4 LAS Abort Events Summary

The Artemis spacecraft configuration is comprised of three major elements including the LAS, CM, and the SM as shown in Figure 5. The CM is mated to the SM (CSM) throughout a nominal mission until separation for earth re-entry. During an ascent abort condition, the LAS separates the CM from the SM to enable an abort landing. The LAS configuration includes three motor assemblies and a fairing cover called an Ogive to protect the CM during ascent and abort environments.

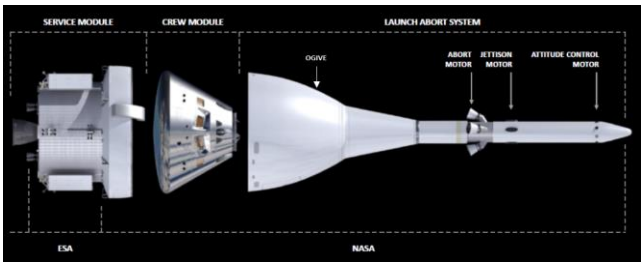

Figure 5 Artemis Configuration Overview

4. LAS ASSEMBLY & INTEGRATION OPERATIONS

The Orion spacecraft assembly and integration operations are located at KSC where the CM and SM are assembled and become the CSM in the O&C building, the LAS is assembled in the LASF, and the LAS is integrated to the CSM in the LASF. LAS assembly operations are segregated from the O&C assembly and test operations in the LASF due to the explosive hazards of the solid rocket motors. A key feature to the Artemis ground operations at KSC is the deployment of Artemis and the Exploration Ground Systems (EGS) teams working together to ensure that assembly and integration handoffs are well defined and coordinated. This approach provides a seamless integration spacecraft elements and integration to the SLS launch vehicle.

The LAS assembly configuration is described in Figure 6 where the three solid motors; abort, ascent control, and jettison are shown. The LAS motor assembly includes the Nose Cone, Forward and Aft Inter-stages, the Truss Assembly, Fillet Panels, and the Ogive Assembly. The LAS configuration includes electrical harnesses and raceway covers to complete the assembly.

The LAS assembly approach has the individual motor assemblies delivered from various suppliers to the LASF where the final installations and checkouts are performed. The orientation of the motor assembly operations is configured horizontally to accommodate adequate hardware access for assembly installations and inspections. The final integration and mate to the CSM is facilitated vertically in the LASF.

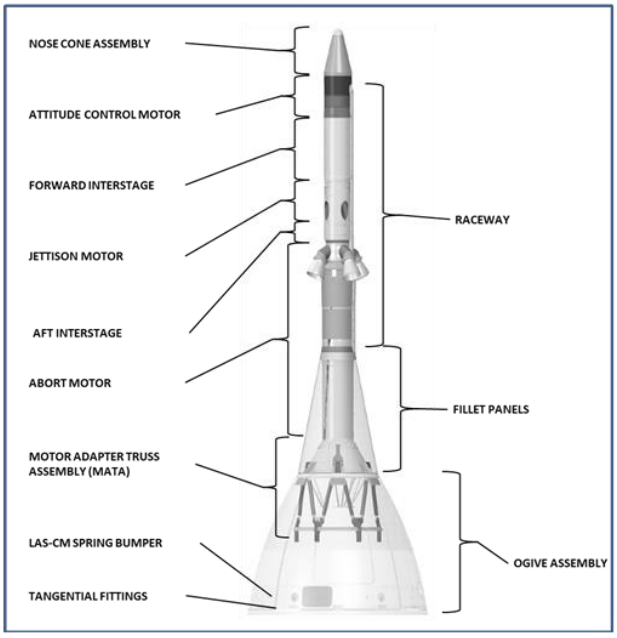

Figure 6 LAS Assembly Configuration Summary

The LAS motor assembly flow of operations in the LASF is summarized in Figure 7 where an Assembly Integration Tool (AIT) is utilized to facilitate element assembly horizontally. Each assembly is transported to the LASF from the suppliers where roll-transfer and crane lift operations are used to install the LAS elements onto the AIT. The completed LAS Motor assembly is completed in the AIT and ready for vertical integration to the Orion spacecraft.

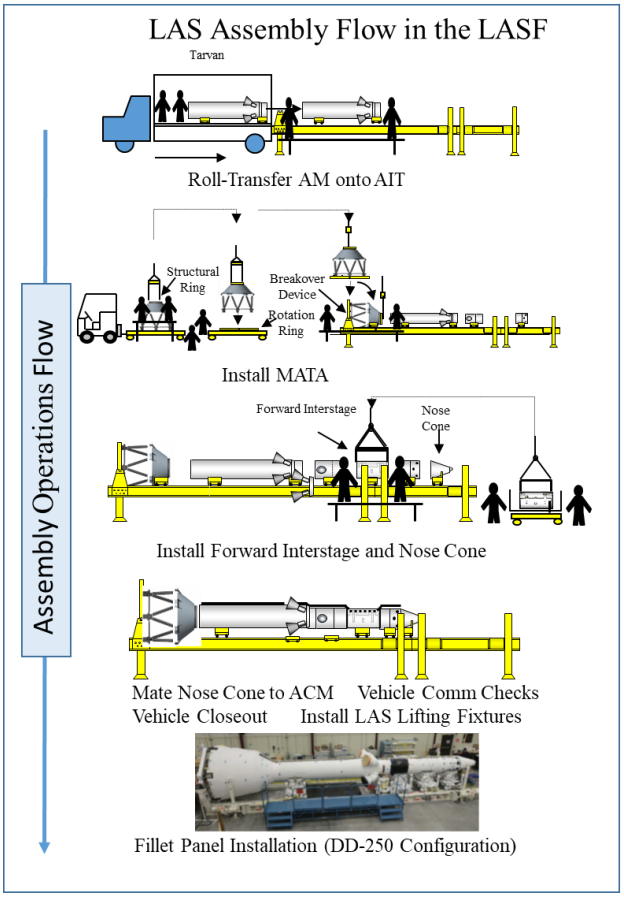

Figure 7 LAS Assembly Flow Overview

The LAS integration approach to complete the Orion spacecraft at KSC utilizes a seamless concept of ground operations between the spacecraft and the ground operations teams. At completion of assembly operations in the O&C, the CSM vehicle shown in Figure 8 is delivered to EGS ground operations where hardware transfer is accomplished from NASA JSC to NASA EGS using the DD250 process. The CSM is transported to the KSC Multi-Purpose Processing Facility (MPPF) for fuel and commodities services for propellants, liquids and gasses. The serviced CSM is transported to the LASF where the LAS is installed to complete the final assembly of the Artemis spacecraft shown in Figure 9.

Figure 8 Artemis CSM Complete in the O&C

Figure 9 LAS Vertical Mate to the CSM

The integration of the completed Artemis spacecraft to the SLS launch vehicle is completed in the VAB as shown in Figure 10.

Figure 10 LAS / CSM Vertical Mate to the SLS

The Artemis assembly and integration flow process at KSC is summarized in Figure 11 showing the location and operations performed to complete the assembly, servicing, and integration of the Artemis spacecraft and the integration to the SLS launch vehicle. As the Artemis spacecraft processing operations are managed by the EGS ground team, on-site technical support is also available to provide support by the Artemis spacecraft team to ensure successful integration throughout the flow process. Any anomalous conditions with the Artemis spacecraft can be rapidly addressed using the onsite capabilities of parts inventory, assembly processes and certified technicians.

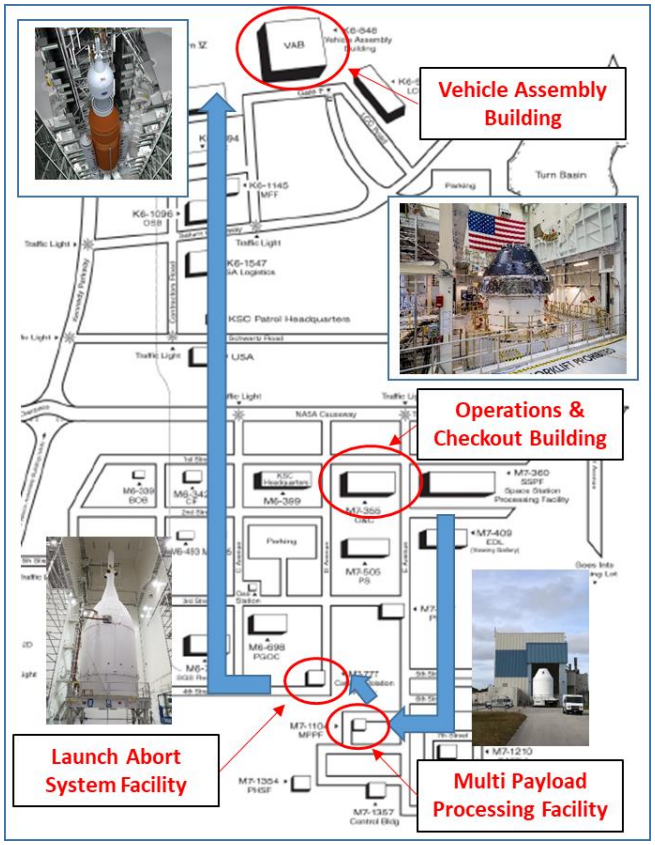

Figure 11 Orion Assembly & Integration Flow at KSC

5. LAS AFFORDABILITY

Artemis affordability has been a priority for hardware assembly and integration operations on the program and is supported by engineering design producibility initiatives, incorporating lean and six sigma principles in the manufacturing and production operations and collocating the assembly and integrating operations at the launch site at KSC. The LAS assembly and integration operations benefits from these affordability initiatives providing a low cost and low risk approach to delivery and integration of the hardware all the way to the SLS launch vehicle. Six significant LAS assembly and integration operations initiatives are described in Table 1 that contribute to a low risk and affordable LAS operations on the Artemis program at KSC.

In addition to the previously discussed innovations of co-location, segregation of hazard operations, and coordinated EGS operations at KSC, supplier delivery strategy and the DD250 delivery innovations contribute to LAS success. Delivery of the LAS motor assemblies are coordinated with the assembly schedules to minimize storage time and reducing storage space requirements in the LASF. The processing time to complete the LAS assembly in the LASF is approximately six months which establishes the motor delivery for "just in time" arrival dates to support the LAS integration flows. Innovations using the Artemis digital assembly "paperless" environment documents and manages the requirements, engineering drawings, production plans, and vehicle as-built configurations and are compatible with the NASA KSC integration environment. This system develops the Acceptance Data Packages (ADP) that provide rapid and automated "as-built" configuration reports to support timely delivery of data supporting the DD250 process.

Item No.	LAS Assembly & Integration Operations Innovations	Benefits
1	Co-located the LAS assembly operations at the KSC launch site	Reduces LAS transportation cost, schedule, and risk. Seamless operations with KSC Integration teams provded onsite and timely anomaly resolution during processing Operations.
2	Isolate Hazardous Large Scale Ordnance of Motor Assemblies	Solid rocket motors pose a hazard to personnel and must be isolated from office space and critical operations facilities. The LASF is close to the O&C, but is physcally separate to provide a safe distance in the event of a mishap.
3	LAS Engineering and touch-labor co-located with CSM Operations in the O&C	Reduced Labor cost of a "Standing Army" for LAS Processing using "Pay by the Drink" labor
4	"Just in time" deliveries of assembly hardware from suppliers	Reduce storage space required for flight hardware and minimizes risk and cost.
5	LAS and CSM DD250 Deliveries Coordinated with EGS	Acceptance Data Package (ADP) As-design to As-Built Reporting in digital format compatible to EGS Configuration Management Environment reducing cost and technical risk
6	LAS and CSM Integration operations coordinated with Orion and EGS teams using seamless team environment	Enables successful integration of Orion hardware to the SLS launch vehicle.

Table 1 LAS Assembly and Integration Innovations

A significant affordability approach is the LASF assembly operation approach of utilizing the O&C operations and resources to support the LASF operations as shown in Table 2. The timeline to complete a LAS assembly is significantly less than the time to complete the Artemis CSM and requires a strategy of utilizing common LAS and CSM resources to avoid a dormant dedicated "standing army" for the LAS assembly operations. Common operations and processes for floor operations, manpower and support services enables the LAS assembly operations to complete a LAS assembly in a "pay by the drink" approach minimizing labor cost by utilizing the adjacent O&C resources. LAS assembly and integration innovations enable affordable operations for Artemis spacecraft processing at KSC.

LASF Assembly Ops/Processes	LAS Unique	LAS/CSM Common
Design Engineering Lead	X	
Assembling Engineering Lead	X	
Assy Integration Trailer (AIT)	X	
Hazardous Ops (Solid Motors)	X	
Crane Operations		X
Design Engineering Support		X
Assembly Technicians		X
Receiving / Inspection		X
Inventory Storage	"Pay	X
Assembly Processes	by the	X
Scheduling/Planning	Drink"	X
Facilities Engineering		X
Quality Assurance		X
Safety		X

Table 2 LAS Affordable Concept of Operations

6. SUMMARY

This paper describes how the Artemis program is implementing innovations achieving improved affordability goals in the Launch Abort System (LAS) assembly and integration operations. Six major innovations have been summarized to complete the LAS assembly and support integration of the Artemis spacecraft processing into the SLS launch vehicle. The LAS processing at KSC enables a low risk and affordable assembly and integration approach for the Artemis program to support NASA Gateway missions (Figure 12) for the future.

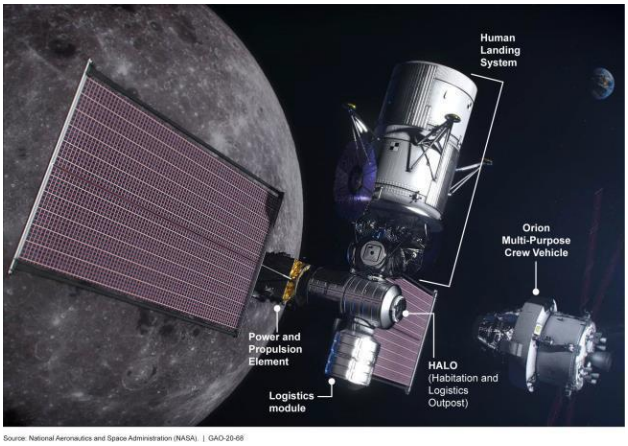

Figure 12 Artemis Spacecraft and the Lunar Gateway

BIOGRAPHY

William Koenig *received a B.S. in Marine Transportation from the United States Merchant Marine Academy in 1979 and a M.S. in Industrial Engineering from the University of Central Florida in 1996. He worked 20 years with United Space Alliance supporting the Space Shuttle Program in numerous managerial positions. For the last 10 years he has been working for NASA as the Orion Program lead for Production Operations. He is responsible for the fabrication, assembly, test and checkout of the Orion spacecraft at Kennedy Space Center. From the NASA standpoint, he was responsible for the successful renovation and modernization of the KSC Operations and Checkout Building for the Orion program.*

Richard Harris *received an M.S. in Aeronautics and Astronautics from Massachusetts Institute of Technology in 1975 and completed 35 years with Lockheed Martin Space System Company. He was the Orion Deputy Program Manager for Production Operations and was responsible for the fabrication, assembly, test and checkout of the Orion spacecraft at Kennedy Space Center. He was responsible for Lockheed Martin's renovation and modernization of the KSC Operations and Checkout Building for the Orion program.*

Carlos A. Garcia *received a BS in Mechanical Engineering from Texas A&M University, Kingsville in 1987 and an MBA From Florida Institute of Technology in 1993. He has worked over 32 years for NASA at the Kennedy Space center with various positions within the Shuttle, Space Station and Orion Programs. For the last 7 years he has worked for the Orion Program as Lead for Production Operations of the Launch Abort System. He is responsible for the assembly, test and checkout of the Orion Spacecraft at the Kennedy Space Center. He also was responsible for the renovation and modernization of the KSC's Launch Abort System Facility as a dual use facility to accommodate both the Orion and EGS (Exploration Ground Systems) Programs.*

Lisa Akers *received a B.S. from the United States Air Force Academy in 1992 and a M.E. in Space Operations from the University of Colorado in 1996. Her work experience spans military, civil, and commercial space operations, space environment forecasting, and for the last ten years, leading the Launch Abort System assembly operations for Orion. She was responsible for developing the plans, processes, and equipment used in the LAS assembly. As the Lockheed Martin Orion manufacturing lead, she directed the daily activities, managed hardware deliveries, and coordinated the external support needed to complete LAS assembly in support of the PA-1, EFT-1, AA-2, and Artemis I flight vehicles and the GTA, STA, and ETA test articles. Lisa now serves as the Chief Engineer representative for the Orion Production and Operations Contract.*