AVIATION WEEK NETWORK

2020 Program Excellence Awards

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Gregory Hamilton
President
Aviation Week Network

Acknowledged, agreed, and submitted by

Roger McNamara [signature] 6/11/2020

Nominee's Signature Date

Nominee's Name (please print): Roger McNamara

Title (please print): Director - Launch Abort System, Orion

Company (please print): Lockheed Martin

AVIATION WEEK NETWORK

2020 Program Excellence Awards

NOMINATION FORM

Name of Program: Orion Ascent Abort-2 (AA-2) Launch Abort System

Name of Program Leader: Roger McNamara, Lockheed Martin Launch Abort System & AA-2 Director

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- [ ] Customer Approved
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- [ ] Supplier Approved (if named in this nomination form)
  - Date: June 18, 2020 ____
  - Contact (name/title/organization/phone): Cheryl Rehm/Program Mgr/Aerojet Rocketdyne/916-355-5496
  - Date: June 18, 2020 ____
  - Contact (name/title/organization/phone): Patricia Hamilton-Bouknight/Program Mgr/Northrop Grumman/410-392-1111 ____

CATEGORY ENTERED

Refer to definitions in the document "2020 Program Excellence Directions." You must choose one category that most accurately reflects the work described in this application**. The Evaluation Team reserves the right to move this program to a different category if your program better fits a different category.**

Check one

- [x] Special Projects
- [ ] OEM/Prime Contractor Systems Design and Development
- [ ] OEM/Prime Contractor Production
- [ ] OEM/Prime Contractor Sustainment
- [ ] Supplier System Design and Development
- [ ] Supplier System Production
- [ ] Supplier System Sustainment

Point Distribution

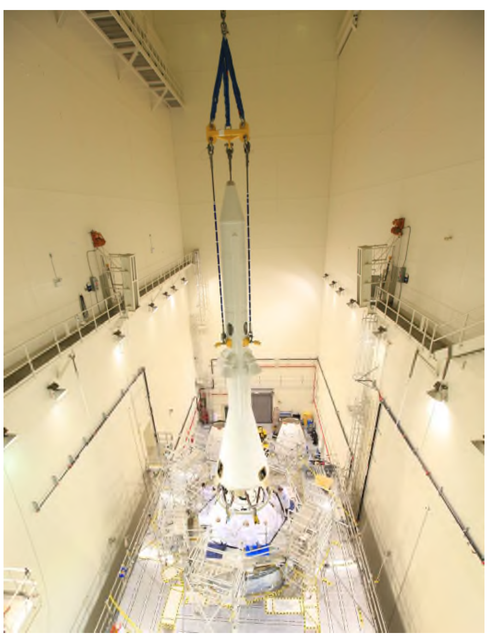
Executive Summary: Make the Case for Excellence (15 pts)		
Metrics **10 pts** Predictive Metrics (10)	**Program Volatility/ Uncertainty/Complexity/ Ambiguity** **25 pts** Describe overall VUCA (10) Cite examples of team response (15)	**Organizational Best Practices & Team Leadership** **40 pts** Innovative Tools and Systems (15) Unique Innovative Processes for People Development/Knowledge Transfer (15) Unique Practice es for Customer Engagement (10)
Value Creation (10 pts)		

Abstract

The Lockheed Martin Orion AA-2 Launch Abort System (LAS) team manufactured, delivered, tested, and verified the LAS in support of the highly visible NASA Ascent Abort-2 Mission. This flawless test flight, completed July 2, 2019, proved that the LAS would successfully rescue the crew capsule and astronauts in an abort situation during ascent. The diverse, multi-organization AA-2 team came together to form a “close knit badgeless” team to test and deliver all hardware on an accelerated timeline, delivering seven months in advance of the contract date and launching six months in advance of the baseline launch date. The successful integration of the LAS to the boost vehicle became the basis for future Orion vehicle integration processes, both for the development and production programs. The strong technical background and collaborative approach of the LAS team ensured efficient resolution of schedule and technical critical issues during final assembly, resulting in 100% mission success of the AA-2 flight test. This test, combined with subsystem qualification and the Pad Abort-1 flight test, results in a LAS that is now certified to fly on the Artemis missions with astronauts on board.

Purpose

The goal of the Ascent Abort-2 (AA-2) flight test was to prove that the LAS would successfully rescue the crew capsule and astronauts, without harm, in the most extreme abort situation conditions during the ascent from liftoff to 350,000 feet. The successful flight test would achieve the next major milestone for the NASA Artemis Program to return crew to the Moon and then to Mars. AA-2 concluded the third flight in the abort flight test series consisting of Pad Abort, Nominal Flight, and Ascent Abort situations. The key flight objectives were to demonstrate the abort capability at maximum aerodynamic pressure; the stability characteristics and reorientation dynamics of the Launch Abort Vehicle; obtain structural loads data; demonstrate LAS structural integrity; and to obtain interface data for the LAS and crew module, separation mechanisms, external environments including acoustic, aerodynamic, thermal and acceleration.



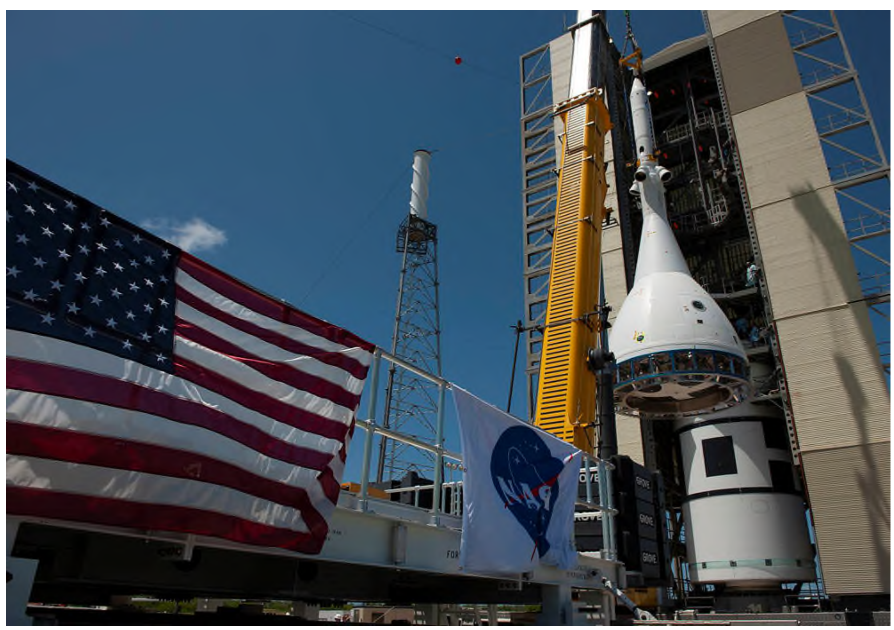


Photo Credit: NASA

Executive Summary: Make the Case for Excellence *(Value: 15 pts)*

What is the vision for this program/project? What unique characteristics and properties qualify this program for consideration?

The Orion program is NASA's next generation spacecraft to carry humans to deep space, further than they have ever gone before, and then return them safely back to Earth. Proposed destinations include to the Moon, Mars, asteroids, and beyond. Lockheed Martin is the prime contractor for the Orion program, responsible for leading and integrating the contractor team comprised of partners and teammates from all 50 states and several European countries. Orion is the safest spacecraft designed for humans ever built, due in part to its state-of-the art Launch Abort System (LAS). The LAS sits atop the crew module and includes three solid rocket motors designed to work together to pull the crew module safely away from an emergency on the pad, or during the climb to orbit. The Ascent Abort-2 (AA-2) test flight was the final demonstration of the LAS, subjecting it to in-flight maximum dynamic pressure conditions, before certifying the LAS's acceptability for use on the Artemis I and II flights in 2021 and 2022. Artemis II will be the first flight to carry humans on board.

On July 2, 2019, the NASA Orion Ascent Abort-2 Test flight performed the next major Artemis Program milestone, flawlessly launching from Cape Canaveral's Launch Complex 46 at 7 am EST. The test was the culmination of a successful design, development, integration, and test of the Lockheed Martin Launch Abort System (LAS), the Northrop Grumman booster, the NASA Langley simulated crew module, and the NASA Johnson avionics/software. The flight test was accelerated seven months ahead of the originally baselined schedule. All the predetermined 38 Flight Test Objectives (FTO's) were achieved, the planned abort occurred at the designated extreme flight test conditions, and all ground and flight data were successfully collected. The collected data immediately provided engineers and technicians with critical abort information used in the design, manufacture, and validation of systems needed for the Artemis I, Artemis II, and subsequent crewed, deep-space missions.

The Lockheed Martin Orion Launch Abort System team manufactured, delivered, tested, and verified the vehicle for the highly visible NASA Ascent Abort-2 Mission. The flawless test flight demonstrated that the LAS would successfully rescue the crew capsule and astronauts in the most serious abort situation during ascent. The AA-2 team was spread across the nation from coast to coast, with components developed from major and minor suppliers including Northrop Grumman, Aerojet Rocketdyne, Applied Composites, Moog, FMI, Taylor Devices, and Lockheed Martin's Denver, Sunnyvale and Michoud facilities The diverse, multi-organization AA-2 team came together to form a "close knit badgeless" team to test and deliver all hardware on an accelerated timeline, delivering seven months in advance of the contract date and launching six months in advance of the baseline launch date. In addition, during the LAS integration with the boost vehicle, LAS team members were instrumental in helping to define the future Orion vehicle integration process. The strong technical background of the integrated team allowed for efficient resolution of technical and schedule critical issues during final assembly, resulting in 100% mission success.

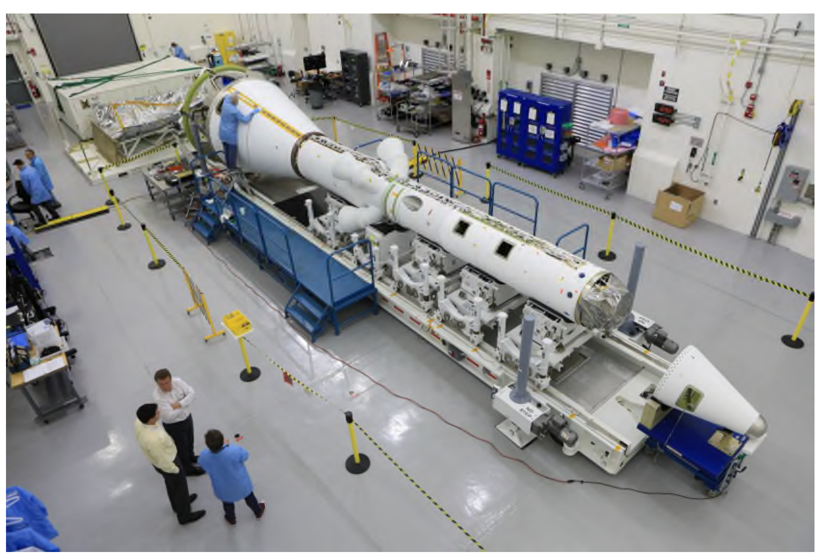


Photo Credit: NASA

The Launch Abort System is a critical component of the Orion spacecraft which consists of the Crew Module (CM), the living and working area for the astronauts, the Service Module (SM) that provides power and Environmental, Crew, and Life Support Systems (ECLSS) to the CM, and the LAS which provides emergency abort capability to protect astronauts in the event of a launch failure on the pad or during ascent. On May 6, 2010, the LAS demonstrated pad abort (PA-1) capability; on December 5, 2014 Exploration Flight Test -1 (EFT-1) demonstrated the LAS nominal flight; and on July 2, 2019, the third flight phase of the LAS capability qualification, abort during ascent, was demonstrated. The LAS successfully aborted from the test booster at ~40,000 ft during maximum dynamic pressure and carried the Crew Module to safety. The Ascent Abort-2 flight test is another major milestone in the agency's preparation for Artemis missions that will return crew to the Moon and that will eventually lead to astronaut missions to Mars.

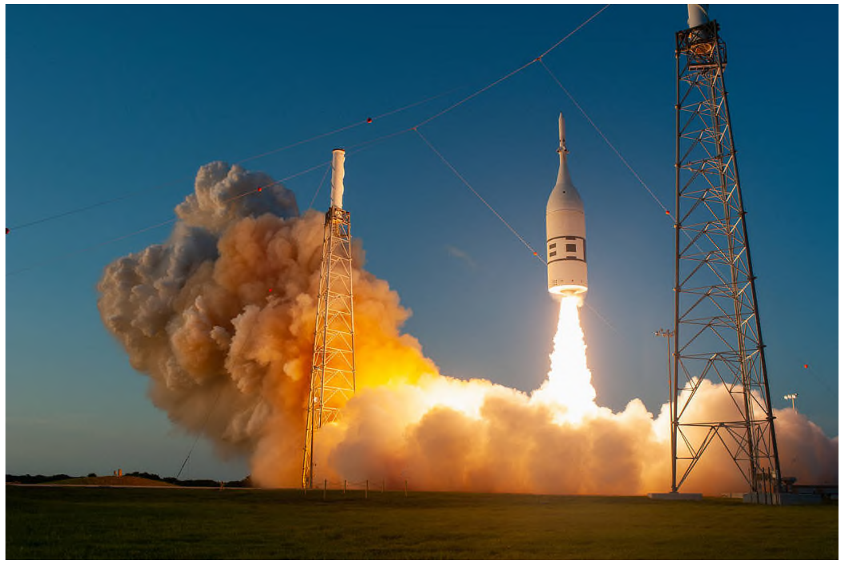


Photo Credit: NASA

VALUE CREATION *(Value: 10 pts)*
Please respond to the following prompt:

- **Clearly define the value of this program/project for the corporation beyond profit and revenue**
  - The Orion program is an opportunity for the Lockheed Martin team to contribute to the nation's human spaceflight program and to do something that has never been done before, developing a spacecraft that will carry humans to explore deep space and the cosmos.
  - Orion is the spacecraft that will carry humans further into the solar system than ever before and return them safely back to Earth. Destinations include returning to the Moon, eventually Mars, and beyond. The Launch Abort System provides a unique capability in that it contributes to making Orion the safest spacecraft ever built for humans to fly in, with the ability to abort from the pad and throughout the entire climb to orbit.

- **Clearly define the value of this program/project to your customer**
  - The AA-2 flight test was a demonstration of the Launch Abort System capability to perform within max dynamic pressure flight environments. This test, combined with subsystem qualification and the PA-1 flight test, results in a LAS that is now certified to fly on the Artemis missions with astronauts on board.
  - AA-2 was the first-time pathfinder for NASA-led integration operations of the LAS, Crew Module, and Northrop Grumman booster, resulting in significant collaboration and knowledge transfer between the Lockheed Martin and NASA teams in order to be successful and meet the compressed schedule.
  - With continuous hardware challenges on both the Orion and Space Launch System (SLS) programs that resulted in delays to the Artemis I and II launches, acceleration of the AA-2 flight test ahead of Artemis I resulted in an opportunity to help "keep the program sold" to the NASA administration and Congress, while the Artemis I hardware was completed. The last flight test prior to AA-2 was Exploration Flight Test -1 (EFT-1) in December 2014.
  - AA-2 provided an opportunity to gather a significant amount of flight test data from the vehicle during worst-case abort conditions. This data will be used by the NASA and Lockheed Martin teams to anchor and validate system level loads and environments models, that will verify and influence the spacecraft design moving forward.
  - Given the scale of the Orion program, the AA-2 mission provided the opportunity to test the verification and validation methods of the LAS. Lessons learned during the review and approval of formal deliverables during this phase will be applied to the entire Orion program.
  - NASA built the Crew Module mass simulator for the AA-2 test flight and procured the booster, demonstrating their commitment to the success of this mission.

- **Clearly define the value of this program/project to members of your team**
  - The AA-2 flight test campaign represented an opportunity for the Lockheed Martin Orion LAS team to contribute to and achieve something that has never been done before, including:
    - Development and qualification of the world's first human-rated controllable solid rocket motor including a high-power, redundant battery-controller-actuator valve control system.
    - Qualification of the world's first human-rated li-ion battery and Controller FPGA.
    - Development of a reverse-flow manifold for use in a solid rocket motor application.
    - Development and manufacture of human-rated, light-weight composite structures.
    - Demonstration of several complex LAS mechanisms while subjected to flight environments, a test which could not be completed while on the ground.

  - The design, development, test, and execution of the AA-2 flight created many experts across the program who now have experience in flight and all the associated difficulties. The benefit and lessons learned of these experts will now be distributed across the program to expedite completion of the first Artemis mission.

- The LAS team accepted the challenge of accelerating the original launch campaign by seven months and was very successful. They led the program to manufacture, integrate, test, verify, and certify the AA-2 launch abort system for flight.

➢ **Clearly define the contribution of this program/project to the greater good (society, security, etc.)**

- In addition to development of NASA's next generation spacecraft to carry humans to explore deep space, and completion of the AA-2 flight test to support certification of the LAS for flight with humans, the Orion program has resulted in numerous spinoff technologies that have enabled technological advancements for other commercial space companies as well as for humans in everyday life. Specifically, the LAS included:
    - The world's first human-rated li-ion battery and controller field-programmable gate array (FPGA);
    - Developed and qualified several new composite materials and CC-SiC components (used in the attitude control motor);
    - Several unique thermal and structural modeling techniques were developed and validated, due to the AA-2 flight tests data.

- The Orion spacecraft program has utilized more than 2800 suppliers in all 50 states, Washington D.C. and Puerto Rico since its inception. A significant portion of the supply chain comes from small and disadvantaged businesses which provide high tech jobs distributed to communities across the nation. In addition, NASA's partnership with ESA has employed subcontractor companies across 10 European countries internationally.

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- Similar to the Space Shuttle and the Apollo Program, Orion inspires the current and next generation of STEM learners to pursue difficult challenges, solve problems, and dream about what lies beyond what eyes can see in the sky.

METRICS *(Value: 10 pts)*

Please respond to the following prompt:

➢ **How do your predictive metrics drive action toward program excellence?**

Hardware challenges on both the Orion and SLS programs resulted in delays to the Artemis I and II launches. A program decision was made to accelerate the AA-2 flight test ahead of Artemis I, compressing the LAS schedule by seven months compared with the baseline. The LAS team had to closely manage drawing release, procurement, hardware manufacture and delivery, and paperwork completion in order to successfully deliver to the accelerated schedule. Metrics were developed in each of these areas, and closely monitored, as progress left unmeasured is bound to degrade. Because of these metrics, any trouble areas quickly became apparent, allowing the team to focus on resolving those issues. This approach allowed the team to deliver 100% mission success.

- **Schedule Margin:** When the decision was made to accelerate the AA-2 mission, the LAS schedule included 12 months of margin. Seven months were used with the acceleration, leaving five months (15% of total schedule) left to work technical and programmatic issues that might arise during the flight-test campaign. The remaining schedule margin was minimal given the significant challenges remaining to complete development, first-time acceptance and qualification testing of complex electronic components, as well as first-time integration operations. The LAS management team moved the schedule margin to the end of the schedule and held the Lockheed Martin and subcontractor team to earlier dates. In some cases, this required a re-negotiation of subcontractor contracts, and a collaborative effort to determine how to achieve these dates using multiple shifts, additional resources, and additional risks. Daily status meetings were held to track critical milestones and elevate and work issues as soon as they came up. Monthly schedule deep dives were also held with the MAF manufacturing center, KSC ATLO team, and each of the subcontractors to review critical paths, discuss any remaining technical debt or risks, and create action plans that were statused weekly, if not daily. The entire team was made aware of critical schedule milestones and progress toward them (all components delivered, integration complete, DD-250 etc.) and held accountable to achieving the dates. All in all, this approach worked well, as issues and mitigation plans could be worked as soon as they started to appear. The schedule margin was used only when agreed to by management for significant, unforeseen challenges (flooding of the first completed electronics controller, loads increases that drove late-breaking ogive composite panel design modifications, acceptance test anomalies).

- **Drawing Release:** With more than 1100+ initial release drawings, plus revisions, for the AA-2 Launch Abort System, the team developed a detailed drawing release plan and statused daily progress against that plan throughout the flight test campaign. Drawings were scheduled weekly by the structural design team, in collaboration with stress analysts and other program stakeholders. Drawing metrics were reported daily to the LAS team and to program management, which emphasized the great importance of and urgency to all team members. Meetings were held as needed, multiple times per week, to work critical technical issues between designers and stakeholders and to ensure signatures were received and drawings released to support the needs of the procurement and manufacturing teams. Overall, the proactive approach worked extremely well, with only a handful of the 1100+ drawings or revisions late to next user need. The success of the mission allowed for a major drawing reuse effort between the AA-2 flight test campaign and the Artemis I flights.

- **Procurement:** Procurement management represented one of the major successes of the program. AA-2 procurement metrics were tracked and statused weekly for the hundreds of parts on order to complete the vehicle. Procurement buyers, engineers, and management worked to prioritize key procurements at risk of jeopardizing the critical path with suppliers across the nation and across dozens of companies. When needed, daily meetings and onsite visits at vendors were completed to work critical delivery schedules. In addition, an engineer on the design team worked as an independent procurement tracker to ensure all parts were on order with adequate delivery dates. Procurement metrics, along with strong working relationships between departments and with vendors, allowed for early identification and mitigation of technical issues that could jeopardize hardware delivery dates, including changes to manufacturing requirements, support for mandatory inspections, and work arounds at the next higher level of assembly. This approach worked to deliver all procured components on the critical path either on time or ahead of schedule.

- **Verification Burn Down:** A detailed verification burn down plan was created for the 1000+ component and subsystem verifications required to be completed in support of AA-2 LAS DD-250. The burn down plan was statused on a weekly basis, aiding in the coordination of resources to complete analyses, and write and approve verifications. Any change in metrics to the original baseline would provide headlights to the LAS management on emerging paperwork issues that could also impact hardware, such as late breaking loads changes, or design non-compliances that could result in waivers. These issues were elevated and resolved quickly so as not to impact hardware delivery, certification, or DD-250 milestones. The LAS team was also quick to highlight differences between the test environment and flight, streamlining the delivery of verifications that were relevant but highlighting paths to full verification for the Artemis flight program. The Artemis human spaceflight program has been able to re-use verifications of design for most of the parts used in AA-2 for the LAS reducing overall cost and schedule of the effort.

- **Certification Boards:** An incremental certification approach was developed early in the flight test campaign with each component and subsystem coming to the chief engineer's certification board as early as possible. These dates served as milestones for when all tests, analysis and verification paperwork needed to be closed for each component. Dates and progress were statused weekly with the LAS team and NASA customer. Certification boards were held on the original dates whenever possible, even if all paperwork was not completed. This approach allowed for an honest risk assessment to be completed for the work left to go, and for the program and customer to help determine the best path forward for any remaining risks or open items. The incremental approach and weekly status were very useful in completing paperwork and reducing technical debt as early as possible in the flight test campaign. By the time DD-250 came around, it was mostly a formality, as paperwork had been closed and reviewed by the program and customer all along as part of the incremental certification boards.

DEALING WITH PROGRAM CHALLENGES (VOLATILITY, UNCERTAINTY, COMPLEXITY, AMBIGUITY, OR VUCA)

(Value: 25 pts)

Please respond to the following prompts:

➢ *10 pts:* **Describe overall VUCA faced by your project/program.**

The Orion program is part of a new generation of space exploration targeted on transition to deep space, human-led activity. With any new generation of spacecraft development, there are significant challenges which relate to VUCA during the development and implementation of new technologies. The challenges and uncertainties of new technology and implementation can only fundamentally be solved through the pursuit of "test like you fly" campaigns of which AA-2 represents the pinnacle.

- **Organizational Complexity:** AA-2 was a complex program management and team integration problem. The AA-2 team was spread across the nation from coast to coast, with components developed from major and minor suppliers including Northrop Grumman, Aerojet Rocketdyne, San Diego Composites, Moog Inc., Fiber Materials Inc., Taylor Devices, and Lockheed Martin in Denver, Sunnyvale and Michoud. The Launch Abort System was designed and managed by Lockheed Martin in Denver and delivered component by component to Kennedy Space Center for integration. Late deliveries of components and late design modifications added further complexity to the integration effort and drove preplanning activities to meet the agreed upon completed LAS delivery dates.

- The primary LAS to Crew Module interfaces are well designed for the Orion program and the Orion capsule, but needed to be modified for the specific AA-2 mission. The Orion Crew Module was replaced with a simulated CM for this flight in order to attach to the LAS and contain the flight command and data handling. The crew module simulator teams were based at both NASA Langley (simulated crew module) and NASA Houston (adapting new electronics to work both with the boost vehicle the CM). The boost vehicle was selected from a refurbished Peacekeeper booster by Northrop Grumman Innovation Systems based in Arizona. The flight software, trajectory, and even mass of the boost vehicle needed to be modified to meet the mission requirements. This effort was coordinated with the Air Force and NASA KSC Flight Test Management Office, as the flight test was to launch from the Cape Canaveral Air Station. All these complex interactions and interfaces provided significant challenges to overcome due to development of a specific test interface to meet mission requirements in a different product developed, by separate suppliers across the country.

- **Design Development on an Accelerated Schedule:** One of the major accomplishments of the AA-2 team was to deliver all components and complete integration activities early, in support of a seven-month acceleration of the baseline test campaign. The Orion program accelerated the launch of AA-2 flight test in order to support data acquisition, validation of the LAS vehicle, anchor modeling and conduct technical analyses early. It also allowed a manifest switch due to delays in the Artemis 1 Crew Module and Space Launch System. In order to successfully achieve the accelerated schedule, first-time component build, acceptance testing, and qualification had to be completed for the LAS components and system. Changes were driven into the LAS design compared with PA-1 in order to meet NASA human-rated requirements and to reduce mass. These changes included: A modified ACM valve control system (controller, battery, actuators), redesign motor adapter truss assembly from composite to metallic, the addition of a fairing assembly including composite fillet and ogive panels and associated mechanism systems, and a reduced thrust abort motor. Each of these activities came with additional program technical risks that had to be watched and mitigated to maintain the accelerated schedule. The team diligently managed each of these activities and immediately elevated any risks or problem areas so they could be worked. Whether it be major program review boards or minor engineering changes, AA-2 topics were made priority around the program. This allowed for decision velocity acceleration and a rapid result from elevation of program issues and technical challenges.

- **Verification Complexity:** Verification of the vehicle design was a major hurdle for the program. AA-2 was the first major verification of the Launch Abort System design requirements, which included many unique human-rated, NASA standard, and reliability and redundancy requirements. There was uncertainty in how much effort it would take to verify the interconnecting requirements (>600 LAS component requirements in total). As the verification process began, it was clear that there was a large amount of effort to be completed to address the requirements in an accelerated time window. The program was able to implement, with the assistance of the customer, an expedited review and approval process. All stakeholders, regardless of organization, were put on notice for the combined initial and final review of the Verification Closure Notice (VCN). This action provided focus on a thorough but rapid turnaround of a single verification due to the opportunity to collect all comments at once. Lastly, Systems Engineering review forums were held frequently, as necessary, to realign and modify any requirements to meet the overall flight test objectives while considering the compressed schedule.

- *15 pts:* **Cite specific example(s) and how your team responded.**

Although the Launch Abort System only represents a third of the overall Orion vehicle, the entire program was focused on the successful execution leading up to the Ascent Abort-2 flight test. Several programmatic and technical challenges along the development path drove exceptional teamwork among the integrated team led by Lockheed Martin. Specific examples provided below emphasize the complexity and uncertainty of the flight test environment and rapid change necessary to execute on an aggressive program schedule.

- **Developmental Flight Instrumentation (DFI) Collaboration:** An important success criterion of the flight was to gather flight data and environments to aid in Orion development, testing, and model validation. In order to gather the flight test data, an extensive flight instrumentation system needed to be developed and installed. The design of most of the LAS had been completed when instrumentation requirements started to be defined. Lockheed Martin led meetings between analysts and hardware owners via a forum where prioritization discussions would be held balancing the necessity of collecting data versus the difficulty of routing instrumentation to the location desired. Due to the late nature of assigning development flight instrumentation to the vehicle, parts procurement often happened after the motor vendor need dates. To ensure that late DFI could still be installed on the vehicle, new technical communication channels were established with suppliers to facilitate incorporation of design modifications. To expedite delivery of instrumentation, daily contact with the instrumentation vendors and NASA was set up. 'Swapping' among vendors based on need date was also used when DFI delivery could not expedited. By fully utilizing the true needs across the LAS vendors, a successful data system was realized helping to verify the Orion flight vehicle for years to come.

- One additional example of reactivity and uncertainty comes from integration of the sensor system upon delivery. It was discovered at KSC that two sensors had been damaged during build up and integration of the component. This discovery occurred on a Friday afternoon. By Saturday, the team had developed an executable plan to quickly troubleshoot the hardware to determine if it was salvageable. This test plan was executed and presented to NASA and Lockheed Martin program management on Sunday where a decision was made with the owner of the sensors and hardware to use the hardware as-is and scrap one of the test items. The paperwork for that fix was completed Sunday evening and the floor was back to nominal schedule by Monday morning, mitigating any potential schedule impact.

- Ultimately, the DFI used on the test flight led to the anchoring of critical modelling to verify LAS components for their first human rated flight on the Orion Artemis I mission, scheduled for 2021, and provided confidence in the predicted levels from this new abort system for dynamically sensitive crew module electrical and propulsion components. Furthermore, the AA-2 test data and model anchoring effort were used to reduce overall dynamic environments for crew module components by >3 dB.

- **The Battle Against Nature:** One of the most challenging moments of the Ascent Abort-2 test campaign came less than one year before the flight. During a critical stage of integration for the delivery and test of the first fully attitude controllable solid rocket motor for human application, the Attitude Control Motor, a natural disaster flooded the flight electronic controller. After three years of development, manufacturing, and test, the deliverable was submerged in flood waters four days after delivery for integration. In response to this tragedy, a rapid response team was put in place to accelerate additional units to ready another controller for flight. This was nuanced in that there were a limited number of uses allowed on these controllers and a path needed to be determined which allowed for electronic box qualification, three qualification hot fire tests, and the first launch with humans aboard Orion with only three controllers remaining. In less than three weeks, a path was determined that addressed all these concerns, allowing for acceleration and delivery of a controller for integration and test, at the prime subcontractor for the Attitude Control Motor, as well as the reuse of the remaining assets for both qualification and the Artemis II launch.

- **Motor Qualification Activities:** As part of the push for flight test, the three solid rockets (with three separate functions) that make up the LAS needed to undergo a qualification test for model validation and mission assurance. All three tests occurred within 12 months of the scheduled flight with no runway left to produce and test additional qualification motors if something went awry. These tests were led by three different subcontractors (Northrop Grumman Utah, Northrop Grumman Elkton, and Aerojet Rocketdyne) all of whom were required to produce both an AA-2 flight motor and qualification motor in an accelerated timespan. After the testing was successfully completed, the data was distilled and delivered to the customer before the flight could proceed. An additional difficulty was that some of the hardware used in the qualification hot fire testing was bound for additional tests before the flight test was conducted. Lockheed Martin spearheaded the difficult role of managing both the required testing and analysis before flight in addition to the juggling schedules of prioritizing a limited set of test hardware.

- **New Attitude Control Motor Technology:** On top of the listed challenges with reacting to a last-minute natural disaster associated with the Attitude Control Motor (ACM), several other challenges existed due to the complexity of the relationships and network of dependencies. The ACM solid rocket motor being developed was the first human rated thrust vectorable solid rocket motor. The ACM had a full additional layer of complexity over a traditional solid rocket motor because the control system includes a controller, batteries, and mechanisms to control the thrust of the motor through eight valves and steer the launch abort system during an abort. The ACM also had to meet stringent NASA human spaceflight and redundancy requirements, which added complexity to the design. This subsystem was led and managed by Lockheed Martin and the customer maintained the item as the highest risk item to successful flight test due to the complex nature of the system. A new field-programmable array (FPGA) was used on the controller which was brought from low TRL to flightworthy through this flight and made acceptable for human spaceflight. The ACM valves included composite CC-SiC materials that were qualified for high strength and temperature applications in support of AA-2, And the ACM also included the world's first human-rated lithium ion battery that was developed and qualified for the first time in support of AA-2.

- The "badgeless team" environment between Lockheed Martin, NASA, and the ACM suppliers allowed the team to address integration and testing challenges quickly and efficiently with a team driven by necessity to develop and build a quality product and fly in successfully. This effort became most evident when a last-minute FPGA issue was found just weeks before delivery. A failure review team was assembled and condensed months of testing down to weeks. Only necessary data was collected to characterize the anomaly and mitigate any impact during a flight. A workaround was put in place to assure to the customer that no risk was brought onto the flight vehicle and the team was able to deliver and integrate the controller on time in support of the AA-2 flight test.

- **Structural Design Changes:** Following the LAS PA-1 flight test, a program decision was made to add a Fairing Assembly to the Launch Abort System to reduce acoustic environments from the Abort Motor on dynamically sensitive crew module components. AA-2 represented the first time the fairing assembly would be exposed to abort flight environments. The LAS team worked diligently with the procurement team to bird dog metallic forging and machining operations on the motor adapter truss assembly, and complete forging qualification in parallel with the AA-2 build. There fairing assembly also included some new mechanisms components including a bumper design that required close collaboration between the Lockheed Martin, NASA, and supplier team to develop a tip material and design that could withstand the long-life requirements necessitated by the mission. The LAS team also worked with the composites supplier and Michoud Assembly Facility team to build and integrate fillet and ogive panels including composite layup, acceptance testing, match drilling operations, and thermal protection systems installation. When late-breaking loads changes came in, the team also worked to add design modifications (stiffeners and high strength fasteners) to the already built ogive panels to reinforce them structurally, and they worked with NASA to reduce analysis conservatism and factors of safety required to fly the AA-2 mission. Due to procurement delays, some of these design modifications were required to be installed at KSC using non-standard procedures, yet with the same rigor to ensure mission success.

ORGANIZATIONAL BEST PRACTICES AND TEAM LEADERSHIP *(Value: 40 pts)*
Please respond to the following prompts:

➢ *15 pts:* **In executing the program, what unique and innovative practices, tools and systems frame your program and help you achieve program excellence**?

- **Small Team:** One best practice that allowed for a successful AA-2 flight test was the use of a small, concise team that was dedicated to making AA-2 successful. This team had several dozen people on it, carved out from the larger 1000+ person Orion program team, and represented the LAS and mechanisms components and subsystems. This dedicated team had only a few POCs with NASA which allowed the rest of the team to focus on building the components needed for AA-2. The POCs were responsible for the successful integration of the LAS and were the Lockheed Martin points for problem resolutions. Having a small, concise team, with upper management and NASA support, allowed for swift problem resolution and decisions.

- **Program Decision Process:** Another practice used during the AA-2 flight test campaign involved streamlining of the program decision making processes. Typically, on Orion there are several Lockheed Martin and NASA review boards needed each with a pre-meeting that has both NASA and Lockheed Martin attendance. The final decision board is the NASA MPCB (Orion Multipurpose Crew Vehicle Program Control Board), chaired by NASA program management. The process can take weeks to get buy-in from all stakeholders before a final decision is approved. On AA-2, several boards were combined, and attendance streamlined, such that a final decision could be made quickly. Issues were elevated quickly up the program management chain so a decision could be made expediently. Often the boards would be stood up overnight and on weekends. The boards were also chaired by both Lockheed Martin and NASA leaders empowered and dedicated to making a decision that held the launch date. This streamlined decision-making process, combined with cultural and a paradigm shift, greatly increased decision velocity and helped enable the accelerated AA-2 launch to occur, while still maintaining necessary rigor behind those decisions to ensure mission success.

➢ *15 pts:* **What unique and innovative processes and practices are you using to develop people and transfer knowledge and how do you know they are working?**

- **Orion Program Organization Structure:** With the Orion program transitioning to the production phase, personnel from the small AA-2 LAS team have been strategically embedded in key roles throughout the Orion program moving forward into the new production organization. This has allowed the AA-2 team members to share their technical knowledge, programmatic know-how, and efficient best practices with others on the Orion program. The LAS Manager was also selected for a strategic integration leadership role at the enterprise level, tasked with documenting and sharing integration best practices, tools, and training with other programs throughout Lockheed Martin Space. The AA-2 fight test effort was a huge success for Orion, NASA, and Lockheed Martin, and through these efforts, the rest of the Orion program, and the Lockheed Martin Space company, has been able to leverage AA-2 best practices to improve program performance.

- **Lockheed Martin SMEs for first-time NASA integration:** While Lockheed Martin built and integrated the Launch Abort System, NASA was responsible for the integration of the LAS to the Crew Module. AA-2 represented the first time NASA integrated the Launch Abort Systems with the Crew Module and Booster, as Lockheed Martin had performed this role for the PA-1 and EFT-1 flight tests. During the integration operations, Lockheed Martin provided key manufacturing and integration engineers and technicians that served as subject matter experts to aid in knowledge transfer of integration operations and to expedite resolution of technical issues and parts shortages as they arose. This effort was very successful in that the ATLO and NASA personnel operated as a badgeless team and were able to complete flight stack integration operations ahead of schedule.

- **Lessons Learned Summary:** Additionally, a comprehensive lesson learned effort was completed following the successful AA-2 flight test to document best practices during all phases of the flight test life cycle. A summary was documented and presented at an Orion program-level ERB meeting. Many of the best practices were adopted by the program moving forward into the Artemis I and II launch campaigns including streamlined processes for verification creation and approval, tailored fracture control approaches, and innovative ways to document requirements deviations and risk assessments.

➢ *10 pts:* **What unique practices are you using to engage customers and how do you know?**

- **Orion Lockheed Martin/NASA Program Structure:** The Orion program, including the AA-2 flight test effort, operates in a unique manner from a customer engagement standpoint in that the program is organized by integrated product team (IPT) with a point of contact in each IPT that aligns with a customer at a NASA facility. The Lockheed Martin IPT organization and NASA center organizations mirror each other at every level of the team and are in daily communication with each other. This organizational approach means there is nearly constant communication with the customer regarding status on technical issues and brainstorming/feedback regarding critical decisions.

- **Badgeless Team:** The AA-2 team truly operated as a badgeless team between the NASA Flight Test Management Office (FTMO), Langley Research Center, Marshall Space Flight Center, Johnson Space Center, Air Force (Range), Lockheed Martin and subcontractors. For example, NASA Langley provided the crew module, NASA JSC provided the booster, and NASA Armstrong provided developmental flight test instrumentation, and finally Lockheed Martin was responsible for integrating all hardware together and assuring functionality once delivered back to the customer. Without the close working relationship and culture of trust and accountability with each of the NASA partners, the flight test would have had little chance of success. The combined team shared a common goal to complete the AA-2 mission successfully and on-time to the accelerated schedule.

- **Decision Process:** The combined team changed the cadence of decisional meetings to be on demand, holding meetings at any time including over the weekend, if needed. Attendance from all stakeholders, including the highest levels of Lockheed Martin and NASA program management, was required so that decisions could be made quickly and keep the hardware and integration efforts moving. Using the normal program channels which would have been schedule prohibitive.

- **Continuous Onsite Support:** Lockheed Martin and NASA also worked together to ensure there was always someone from the Orion program office and a technical lead present onsite when integration operations were performed. This provided appropriate oversight as well as decision velocity should an issue occur. Communication and delivery of accurate up-to-date schedules allowed for Lockheed Martin and NASA to assure the appropriate component representative could be made available and onsite to oversee and mitigate any issues that come from integration activities.