National Aeronautics and
Space Administration

AI1-SYS-LLD
BASELINE
RELEASE DATE: OCTOBER 28, 2010

ARES I-X

LESSONS LEARNED

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REVISION AND HISTORY PAGE

Status	Revision No.	Change No.	Description	Release Date
Draft	-	-	First written draft for peer review	2/24/2010
Draft	-	-	Incorporation of IPT comments	5/17/2010
Draft	-	-	Edits and reconciliation of differences	8/17/2010
Draft	-	-	Incorporation of mission manager comments	9/15/2010
Released	-	-	Baselined version	10/28/2010

NOTE: Updates to this document, as released by numbered changes (Change XXX), are identified by a black bar on the right margin.

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1.0 INTRODUCTION

1.1 PURPOSE

This document provides lessons learned to benefit future NASA projects, including flight tests, vehicle development programs, missions, and other related work. These lessons are based on activities accomplished by the Ares I-X development flight test team from May 2007 to October 2009. The lessons address tasks that were performed very well and tasks that were not conducted as efficiently. This exercise of documenting challenges and pitfalls is also a means for Ares I-X team members to reflect upon the accomplishments and to prepare for future challenges.

1.2 SCOPE

This document draws upon discussions within and among the Ares I-X Integrated Product Teams (IPTs), the Ares I-X Systems Engineering and Integration (SE&I) organization, the Ares I-X Project Integration organization, the Ares I-X Technical Authority, and the Mission Management Office (MMO). Lessons learned address vehicle- and system-level activities or activities involving at least two IPTs.

This report focuses on data collected since the establishment of the MMO in May 2007. This document does not address individual or discrete organization concerns unless the implied lesson affected the overall mission. Note: for readers not familiar with the Ares I-X mission, the mission was to collect data that could be used to support the Ares I crew launch vehicle design. The mission was accomplished by setting objectives, developing a test system, launching a rocket, and assessing the data.

Authors of these lessons learned agreed to filter suggestions from this document that fell into the following criteria:

- Solutions or things not-to-do or things to do better without a problem or root benefit (i.e., lessons must be linked to an underlying behavior that was either beneficial to the test or could have been done more efficiently or effectively) – e.g., An example of a positive lesson learned with a root benefit is “given that loads were updated late in the mission’s life cycle, the impacts could have been less if the threat/risk of late loads was documented at critical design review (CDR)” as opposed to a weak lesson learned such as “Don’t have late loads updates.”
- Opinions from one group on what would be “better” for them – e.g., “An example of a positive lesson learned that is not an opinion is, “a plan to provide XYZ and obtain concurrence of all affected parties would improve visibility and downstream integration allowing work arounds to be developed in advance” as opposed to the weaker lesson learned of “provide XYZ product earlier.”

- A change that makes people comfortable; or able to stay in their paradigms; or better follow an established process, document – e.g., An example of a positive lesson learned is “the CM Process worked as defined, but could have been more effective if the following step was added or deleted”, as opposed to the weaker lessons learned of, “the Ares I-X CM process did not adequately provide for ABC, resulting in delays in decisions or h/w delivery or extra cost to FTRR…”
- A statement of the obvious – e.g., “An example of a positive lesson learned is “given that requirements may change after CDR, the systems engineering management plan (SEMP) should address a process to assess and report impacts” as opposed to a weaker lesson learned such as “baseline all requirements early per the NASA Systems Engineering Handbook.”

These ground rules helped to keep the discussions and final lessons learned constructive and forward thinking, with an emphasis on providing useful advice in the context of the overall mission and flight test.

The left frame shows a photo of the Ares I-X rocket shortly after it was rolled out to Launch Pad 39B at Kennedy Space Center (KSC). The center photo captures the flight test vehicle going into the clouds. The right frame highlights a halo effect that formed around the vehicle in-flight. The halo is a physical indicator of a stable flight. The left figure also shows one of three lightning protection towers that were erected for this flight and future flights.

2.0 DOCUMENTS

2.1 APPLICABLE DOCUMENTS

The following documents include specifications, models, standards, guidelines, handbooks, and other special publications. The documents listed in this paragraph are applicable to the extent specified herein.

AI1-SYS-MIP Ares I-X Mission Implementation Plan

2.2 REFERENCE DOCUMENTS

The following documents contain supplemental information to guide the user in the application of this document.

CxP 70127 Ares I-X Flight Test Plan

These pictures capture the assembly of the rocket in the Vehicle Assembly Building at KSC.

3.0 EXECUTIVE SUMMARY

3.1 BACKGROUND

Concepts for the first Ares I suborbital development flight tests were initially documented in 2005. Concepts emphasized obtaining early dynamic, environmental, and controllability data for the Ares I crew launch vehicle during the liftoff, ascent, separation, and first stage recovery portions of flight. The test was initially named Ares I-1 then renamed Ares I-X in 2006 after official authority to proceed. Ares I-X also provided an opportunity to develop, build, and test new ground systems and demonstrate operations. Over the course of nearly four years, a multi-center, multi-contractor effort was mounted to design, develop, and build the team, hardware, processes, and procedures necessary to make the test possible.

The team included individuals from Glenn Research Center (GRC), Johnson Space Center (JSC), Kennedy Space Center (KSC), Langley Research Center (LaRC), and Marshall Space Flight Center (MSFC), as well as prime contractors ATK Space Systems, Jacobs Engineering, Teledyne Brown Engineering (TBE), United Space Alliance (USA), and Lockheed Martin (subcontractor to Jacobs).

3.2 FLIGHT TEST OVERVIEW AND RESULTS

The Ares I-X development flight test vehicle (FTV) incorporated a mix of existing/heritage and new hardware to compose a configuration to simulate specific operational vehicle characteristics. Propulsion/liftoff power was generated by a four-segment reusable solid rocket motor (RSRM) from the Shuttle inventory. The RSRM/booster was joined with a simulated (mass and outer mold line) fifth motor segment and a forward section for housing auxiliary components to create the first stage of the Ares I-X rocket. The addition of the simulated fifth segment made the stage approximately the same size as the five-segment Ares I motor under development.

The Ares I-X flight profile closely approximated the flight conditions of Ares I by traveling at a speed of Mach 4.5 to a flight altitude of approximately 120,000 feet and through maximum dynamic pressure (“Max Q”) of approximately 900 pounds per square foot.

The flight and ground elements were developed, built, and integrated at multiple NASA centers, with the first stage (FS) managed at MSFC in Alabama in cooperation with ATK where the FS was built and tested in Utah; the avionics systems managed by MSFC and built and tested by a combined Jacobs Engineering/Lockheed Martin team in Alabama and Colorado, respectively; the roll control system, known as RoCS, managed at MSFC. Primary RoCS components were obtained from decommissioned U.S. Air Force Peacekeeper missiles and reconfigured in a new system built and tested for Ares I-X by Teledyne Brown Engineering in Huntsville, AL. The upper stage simulator (USS) was designed and built at GRC in Ohio; the crew module/launch abort system (CM/LAS) simulator was developed and built at LaRC in Virginia; systems engineering and integration for Ares I-X was also performed by LaRC; project integration for Ares I-X

was performed by MSFC; ground systems such as the launch pad, mobile launcher platform (MLP) and ground and launch operations were prepared by KSC personnel in Florida in cooperation with USA.

On October 23, 2009, the Ares I-X FTV rolled out of KSC's Vehicle Assembly Building (VAB) atop a Shuttle MLP and crawler-transporter to Launch Complex 39 Pad B. After completing a series of countdown simulations and flight test readiness reviews, the Ares I-X team made its first launch attempt during a four-hour launch window on October 27. The first attempt was scrubbed due to weather-related launch commit criteria constraints and one intrusion into the restricted range by a boat. On the second launch attempt at 11:30 a.m. Eastern Time on October 28, the 327-foot-tall rocket lifted off from KSC (the largest rocket in the world at the time and the first test flight in 30 years from KSC), executed a fly-away maneuver and a planned roll maneuver, ascended to an altitude of approximately 150,000 feet, performed staging/separation between first stage and its upper body, deployed its first stage parachutes after a prescribed set of tumble motor burns, then splashed down into the Atlantic Ocean approximately 150 miles from KSC, where the first stage was recovered. Ares I-X successfully satisfied all of its primary flight test objectives, a nearly unprecedented achievement for the first flight test of a new launch vehicle.

Depicted left is the FTV/MLP rolling out of the VAB on the NASA Crawler Transporter. Shown right is the Ares I-X rocket at lift-off on October 28, 2009.

The only major anomaly during flight was the failure of a first stage main parachute and the partial failure of a second first stage main parachute. This resulted in damage to the first stage motor segments upon splashdown due to the segments striking the water at a higher velocity because of the parachute problems. As expected, the upper body of the rocket tumbled after separation and landed in the water sinking as planned.

Flight data was telemetered to the ground during the flight and also collected and stored on the on-board flight data recorder in the first stage. The recorded was successfully recovered from the first stage fifth segment simulator after the flight. All data is being reviewed and analyzed by NASA engineers to correlate and reconstruct the engineering models used to design the Ares vehicle and to inform designers of future launch vehicles.

3.3 LESSONS LEARNED

Most of the technical lessons learned from Ares I-X relate to early planning. For example, performing additional work earlier in the life cycle of Ares I-X to prevent problems later in the flight test; applying technical expertise from other centers or agency-related organizations (e.g., NASA Engineering and Safety Center (NESC)); identifying developmental flight instrumentation (DFI) requirements from the top down; using a common computer-aided design (CAD) system; and establishing technical practices earlier in the life cycle,.

The primary lesson learned was to finalize requirements of all types—as well as roles, responsibilities, processes, and expectations—as early as possible in the life cycle.

Management lessons learned included using a “flat” organizational structure; centralizing the scheduling process; establishing and tracking project milestones; and educating team members on different centers’ operational practices (especially at KSC).

Shown above are representatives of the incredible Ares I-X team two days prior to the launch of the rocket. The rocket is shown in the background at KSC Launch Complex 39 Pad B.

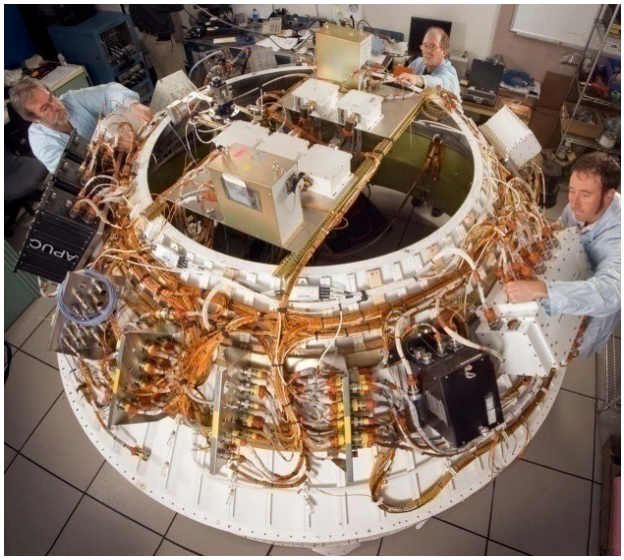
4.0 TECHNICAL LESSONS LEARNED

4.1 AVIONICS

4.1.1 Single Systems Integration Laboratory (SIL)

4.1.1.1 Lesson Learned: Avionics Systems Integration and Testing

The Ares I-X MMO used a reconfigured Atlas rocket avionics SIL furnished by the Lockheed Martin (LM) facility in Denver, Colorado (pictured below). The lesson learned is that the extensive testing performed using the SIL was a major enabling asset of the Ares I-X system. The SIL enabled the Ares I-X team to retire common vehicle development risks because control software and hardware could be extensively tested before the actual flight. The SIL was also beneficial because it was a tool that enhanced the ability to provide on-time deliveries of the avionics boxes, thereby also saving cost and leading to a safe launch. This represents the 'Test Like You Fly" philosophy The LM Avionics SIL was used to simulate the form, fit, and functions with flight software interactions of the FTV.



The SIL, shown left, included both ground test hardware and actual flight hardware boxes with full-length control cables. This combination of hardware was used to simulate interactions between the first stage and other hardware with very high fidelity to the flight system. In addition to running nominal and off-nominal flight simulations, the SIL was a long distance stand-in for the actual flight vehicle during countdown simulations conducted at KSC's Launch Control Center with the Ares I-X launch team. These exercises included simulated hardware activations, malfunctions, and anomalies.

Rationale:

The success of the mission can be directly linked to having a dedicated SIL facility for early integrated testing of hardware and software.

Detailed Recommendation(s):

- The SIL should consist of flight-like (form, fit, and function) hardware.
- All SIL components that simulate flight functions should be models of the actual hardware. Note: Where actual functionality cannot be provided, deviations

should be identified, analyzed, documented to the greatest extent possible. . Use of flight components is preferred.

- Special attention should be given to the newest and least understood parts of the system and their interaction with the established system (e.g. commercial-off-the-shelf (COTS) and new designs).
- Project personnel should complete comprehensive nominal and off-nominal testing.
- Systems and interfaces that can best be modeled in the SIL should be defined early so that required on-site testing (e.g. hot fire and radio frequency) can be identified and accomplished.
- Running simulations with parameters extracted directly from the mission parameter database is highly recommended.
  - Note: using these parameters and associated processes identified flight control parameter errors that initially escaped visual inspection by both LM and NASA and would have compromised stability margins if not identified.
- Regression testing should be performed for each hardware and software change.
- All differences between the SIL and flight vehicle should be precisely defined and maintained.

4.1.2 Signature Authority on Drawings and Procedures

4.1.2.1 Lesson Learned: IPT Signature Authority

The Avionics IPT should be included in the review and/or concurrence/approval of all drawings and related installation documentation (e.g., Work Authorization Documents (WADs)) for avionics components. This will help mitigate the possibility of installation risks. The level of review, concurrence, or approval must be negotiated and documented in an element-to-element working agreement.

Rationale:

Avionics components including boxes, harnesses, and sensors were installed in all of the FTV elements. When installing some of these components, numerous non-conformances occurred for many different reasons. This resulted in costly rework. Additional collaboration by both sides of the interface, prior to installation of the components, may have reduced the number of non-conformances.

Detailed Recommendation(s):

- Clearly establish division of responsibility in the interface agreements.

- Conduct more robust Interface Readiness Reviews (IRR) as defined in the Mission Implementation Plan (MIP) by discussing division of responsibilities. Note: the sole intent of the Ares I-X IRRs per the MIP was to ensure work being transferred was clearly understood by both delivering and receiving parties.

4.1.3 Electromagnetic Environmental Effects (E3) Working Group

4.1.3.1 Lesson Learned: E3 Working Group

Establish an Electromagnetic Environmental Effects (E3) Working Group during the design phase and continue the working group throughout the project's life cycle.

Rationale:

E3 engineering efforts should begin prior to CDR to reconcile the qualification status of each component. This enables the Avionics IPT to better focus any required delta qualification efforts at the component level or to design system-level testing aimed at augmenting any component test "holes." E3 qualification programs at the component level are generally tailored to the unique threats associated with the full system.

Detailed Recommendation(s):

- Begin a dialogue with the team that is responsible for the installation of the avionics into the FTV early in the design flow, but no later than 60 days prior to CDR.
- Involve E3 Engineering in the component selection and requirements definition process.
- Ensure that E3 expertise is available at the vehicle integration level; this is particularly important when integrating heritage hardware and personnel with significantly different backgrounds.

4.1.4 Environmental Control System (ECS) for Avionics Boxes

4.1.4.1 Lesson Learned: Environmental Control for Ground Processing

When use of a ground ECS is a critical factor in meeting the technical and programmatic requirements, detailed procedures and backup systems should be developed to mitigate the possibility of loss of the primary ECS.

Rationale:

A loss of ECS can lead to added work such as testing and waivers. It also can lead to a loss of hardware or the mission.

Detailed Recommendation(s):

- ECS must be available from manufacturing through the umbilical eject at launch, except for necessary and planned disconnects and other exceptions clearly annotated in the requirements.
- The benefits of near-continuous ECS operations are well-controlled temperatures throughout numerous scenarios, including fine-tuning environmental control and controlling air quality from foreign object debris (FOD)/salt/debris/etc. Note: lack of environmental control can cause hardware to lose qualification status and result in costly problem reporting and failure investigation efforts.

4.1.5 Lightning Recovery Approach

4.1.5.1 Lesson Learned: Canary Circuits for Lighting Detection

Design or identify one or more canary circuits into the vehicle for lightning detection and retest. Canary circuits are used to indicate that a lightning event has exceeded minimum safety requirements for the avionics. This provides information as to whether or not damage is likely to have occurred and indicates a definite need for avionics system retest and/or roll back. Ares I-X made a conscious decision not to build-in a canary circuit, but there was a near lightning strike the night before launch day and the hardware was not damaged. Note: Ares I-X took the risk not to employ a canary circuit based on a planned launch in April. In retrospect, the mission would most likely not change this decision due to cost and schedule impacts. A project team must review the cost/benefit trade to see if the extra expense and schedule of designing in such a circuit offsets the potential launch day slips.

Rationale:

Lightning strikes can delay launch operations if hardware and procedures are not in place to recover from the strikes. There was not a canary circuit on Ares I-X; therefore the team had to work lightning retest on the day of launch. A large group effort was required for the Ares I-X team to get waivers in place for launch.

Detailed Recommendation(s):

- For a one-time flight, not using canary circuits might be considered an acceptable risk; however, to avoid costly launch delays, a stand-alone canary circuit(s) would be useful in resolving lightning issues at pad quickly.

4.1.6 Management of Developmental Flight Instrumentation (DFI)

4.1.6.1 Lesson Learned: DFI Requirements

Identification and development of DFI systems can be optimized by employing a top-down systems engineering approach.

Rationale:

On Ares I-X, the first set of DFI requirements was based on requests from cognizant engineers as opposed to deriving requirements from the flight test objectives. Although the top-down approach was discussed during Phase A development activities, the tendency was to select a large set of DFI sensors then narrow it down based on priority. Both approaches are acceptable, but going top down ensures methodical buy-in from stakeholders. Note: more time was consumed discussing which sensor to remove or not install than actual time installing the sensors.

Detailed Recommendation(s):

- Generate a system DFI requirements document for review at the system requirements review (SRR).
- Map all DFI requirements to the flight test objectives.
- Obtain stakeholder buy-in at SRR, preliminary design review (PDR), CDR, and anytime changes are made after CDR.
- Define post installation calibration requirements.
- Develop a DFI Implementation Plan that includes a clear division of responsibility.
- Ensure that the development of the DFI requirement is independent of the vehicle development, although vehicle development is dependent on the DFI selected. Note: some exceptions may exist, especially for existing hardware, where the DFI requirement may have to be modified to accommodate vehicle design, but that scenario should be an exception.
- Create a DFI owner under Avionics that has authority under SE&I to integrate the DFI as a system. As noted above, there must be clear division of responsibility.
- Create and follow a DFI development process and/or model to follow.
- DFI quantity discussions should not focus entirely on power and bandwidth capability. Lead time for procurement, cost, calibration, installation, and testing should also be factored into the decision process.

4.1.7 Other Avionics Lessons Learned

4.1.7.1 Shipping Plans

4.1.7.1.1 Lesson Learned: Shipping Strategy

Formulate a detailed mission level strategy for shipping hardware between NASA centers and contractors and define applicable system requirements based on this strategy. Obtain buy-in from NASA Center Institutional logistics groups, because these groups are not part of Programs/projects and won't follow a Program document if it is different than established local Center procedures.

Rationale:

Each NASA center and contractor has different requirements for receiving hardware that can result in delays for operations personnel being able to use shipped/received hardware and can also increase costs for paperwork reconciliation.

The above figure provides a snap shot of the delivery process for several major structures. From left to right, a USS segment being loaded onto the Delta Mariner, the CM Simulator rolling into the C-5 aircraft, and the First Stage Forward Skirt being trucked down a street in Florida in route to KSC.

4.1.8 Property Manager

4.1.8.1.1 Lesson Learned: Property Management

Assign a property manager for each IPT and establish working groups, as required, to help ensure accounting of property.

Rationale:

Having an IPT point of contact (POC) for property exchange will ease the burden of keeping track of hardware during all phases of the project, ensuring efficient processing and final closeout.

4.1.9 Computer-Aided Design

4.1.9.1.1 Lesson Learned: CAD Tools

Identify computer-aided design (CAD) tool alternatives, to be used by all IPTs and contractors, and select a preferred common tool to be used by all, to the extent practical. Selection of this tool should be based on a cost-benefit-risk assessment.

Rationale:

A common CAD tool ensures that common file types and design conventions are used, therefore mitigating the risk of design errors and properties on the parts will stay defined as files are shared.

4.1.10 Requirements Formulation

4.1.10.1.1 Lesson Learned: Requirements Development Strategy

Fully define *all* element requirements, no later than an element/IPT-level preliminary design review (PDR), in accordance with the guidelines per the NASA Systems Engineering Handbook.

Rationale:

Early and firm definition of requirements prevents design conflicts or delays at CDR. The late development of Ares I-X DFI requirements resulted in a system re-design post-CDR.

4.1.11 Loads and Environments

4.1.11.1.1 Lesson Learned: Communication of Loads and Environments

Quantify and clearly communicate the confidence and the associated risk level of loads and environments [requirements] at design milestones (e.g., PDR and CDR) and via a well documented peer review process (i.e., as defined in the Systems Engineering and Management Plan (SEMP)). The confidence and risk level must be communicated after every release of the applicable requirements levied on the hardware. The formal risk management system should be used to characterize and document risk levels of loads and environments.

Rationale:

Early definition of loads and environments, including confidence level, allows hardware designers to build-in margin and/or allow management to set the risk level. On Ares I-X, erroneous loads were released that may have been corrected sooner if the review process was structured differently. Also, robust/conservative loads were released early in the design cycle of Ares I-X and a vast majority of the hardware was built to withstand these loads. Very few hardware modifications had to be made based on the final loads for flight. The approval of robust environments and loads requirements, as early as possible in the life cycle of the mission, also helps mitigate the possibility of requalification of hardware leading to other consequences such as mission delays, cost growth, cancellation or loss of mission.

4.2 MISSED OPPORTUNITIES

4.2.1 Agency Expertise

4.2.1.1 Lesson Learned: Use of Available Resources

Use capabilities and expertise within NASA and program contractors at all centers and across all programs. Specifically, engage independent subject matter experts as early as possible, but no later than system requirements development.

Rationale:

NASA has a diverse set of skill sets and expertise at each of its centers and associated contractors that help perform independent reviews, fill gaps, and add expertise to tiger teams. Ares I-X leveraged external mission resources for PDR, CDR, verification product reviews, technical reviews of select problems, and other situations; however, using additional resources during the early phase of the mission (i.e., up to and including SRR) could have reduced risks and identified problem areas earlier, thereby maintaining schedule and reducing overall life cycle cost. Note: the Ares I-X systems requirements development process may have been shorter if a larger team was put in place to derive and validate the requirements. Based on the large number of RIDs written at the SRR, the requirements were not robust and a pre-screen team staffed by independent SMEs would have helped with the requirements analysis process. Adding resources and time to perform pre-screen reviews also needs to be traded on a project by project basis. Ares I-X being largely based on heritage hardware was able to conduct its SRR as scheduled while concurrently working on the preliminary design of its system.

4.2.2 NASA Engineering and Safety Center (NESC)

4.2.2.1 Lesson Learned: Role of NESC

Use NESC expertise on specific, exact, and acceptable technical methodologies, not just large integrated system issues.

Rationale:

NESC experts were asked to help investigate specific questions during Ares I-X development, including wind-induced oscillations during rollout and dielectric withstanding voltage (DWV) testing; their input and participation proved invaluable in subsequent technical discussions.

4.2.3 Expendable Launch Vehicles (ELV) Subject Matter Experts

4.2.3.1 Lesson Learned: Role of ELV SMEs

Apply expertise from all ELV programs in specific technical and verification issues (e.g., overview of ELV processes and consultation on major issues).

Rationale:

At present (March 2010), there are three different launch vehicle contracts at NASA supporting five different launch vehicles. While the design certification work completed on several of these vehicles is more than 30 years in the past (many in the past seven years, one ongoing), the development timelines are similar to that desired by the Ares test vehicle project. Note: the Avionics IPT employed expertise from EELV SMEs to support development and launch activities and KSC CE office used EELV SME that made a large contribution to vehicle loads.

4.2.4 COTS Hardware

4.2.4.1 Lesson Learned: COTS Qualification Planning

Provide a qualification plan for all COTS hardware by PDR.

Rationale:

Developing a COTS qualification plan as soon as possible after SRR ensures that design options using COTS hardware consider the requirements in the COTS qualification plan. This also provides an opportunity to identify risks and associated risk mitigation plans. For example, Ares I-X used COTS air duct hangers, but did not develop a qualification plan. The lack of a plan resulted in analysis and testing that was unexpected and costly. For Ares I-X, heritage hardware was also treated similar to COTS, for example; Avionics, First Stage, and RoCS did not initially have qualification plans, although each of these IPTs understood during the system requirements timeframe that heritage hardware ratings had to be within the Ares I-X environments and loads envelops otherwise additional qualification steps would have to be implemented. For some heritage components, such as the First Stage Linear Shaped Charge, additional testing was performed. Some Avionics components also had to be re-qualified.

The generation of a Qualification Plan for COTS is generally a good practice to identify the qualification requirements and then ensure that the necessary qualification activities are within the scope of the project.

4.3 VERIFICATIONS

Multiple NASA Centers successfully implemented a common verification process. System requirement owners worked with element requirement document (ERD) owners to ensure that lower-level verifications met system-level verifications and that the team had complete traceability between verification products and requirements. Individuals performing Ares I-X verifications were able to track and close associated waivers. Independent reviews also contributed extensively to the success of verification closeouts. All requirements were appropriately verified per the planned and approved processes, though Ares I-X team members did experience some challenges with verifications, citing the following lessons learned:

4.3.1 Link SE&I to Lower Level Organizations

4.3.1.1 Lesson Learned: SE&I Link to IPT Verification Compliance

Project and SE&I processes, procedures, requirements, etc. as defined formally in the SEMP, Master Verification Plan, SRD, and other system/project governing documents, need to be impressed upon the prime contractors, through normal and special negotiations (e.g., Lean Events). To ensure that all the prime contractors' work is in phase with the established project/SE&I approach, SE&I should be included in the review, tailoring and/or revising of contractual Data Requirements (DR), to the extent practical (negotiated from project to project), as well as the review of DR products. For

example, SE&I should review both the IPT SEMP DR Document (DRD) and the IPT SEMP deliverable and then make recommendations if an inconsistency is identified. In some cases the SE&I approach may need to be modified to find the optimum overall IPT/SE&I working relationship. The key to this approach is that SE&I personnel must be matched/integrated well with IPT leads and/or IPT counterparts, as early as possible in the acquisition process / project life cycle, all the way through the product delivery/acceptance process, albeit the IPT COTR has 'actual authority' to facilitate communications and compliance with the prime contractor.

Rationale:

Common processes were not established until late in the mission; therefore, all responsible parties were not fully trained on the system formulation before they started the process. This happened, in part, because the IPTs were in place and setting up contracts before SE&I was fully staffed. As a result, SE&I did not have the initial resources to be involved in IPT start-ups and IPT procurements, resulting in disconnects between top level processes and existing contracts.

4.3.2 System Engineering Processes

4.3.2.1 Lesson Learned: Design Certification Reviews for Test Flights

Perform a system-level design verification review at some point prior to completing final verifications by holding a design certification review (DCR), systems acceptance review (SAR), or equivalent review to assure that there are no gaps. Also, communicate the verification closeout schedule. Even in a fast-paced program, it is important to use the standard system engineering process.

Rationale:

Although the mission had planned to conduct DCRs to establish verification accountability, system verification was behind schedule due to resources being committed to working hardware and software issues instead of completing the verification paperwork. At a minimum, IPTs and SE&I should have completed the verification products that had sufficient data to close some verifications, especially qualifications. The recommendation is to add hardware milestones into the schedule for verification reporting, thereby conducting incremental DCRs (i.e., milestones on the schedule to address verification status). Note: Given that Ares I-X was a one-time flight, DCR was by definition per the Flight Test Plan a function of verification review and closeout.

4.3.3 Product vs. Design Verification

4.3.3.1 Lesson Learned: Rules for Product and Design Verification

Projects need to identify whether product or design verification standards apply in a particular verification situation. Note: Product verification is a verification that depends

on data from hardware/software inspections, demonstrations, and test. Design verification is verification that depends on analysis. The specific lesson learned is to select detail verification methods (i.e., what types of analysis and testing) early in the life cycle of a project with a draft at SRR and final at PDR to have needed deliverables for verification indentified. See also the 4.3.4 Lesson Learned entitled "System-Level Verification Implementation Plan by PDR." Effective verification is enhanced by the following:

- Tailoring verification processes between design and product verification based on new development or successful production processes.
- Writing a feasible verification plan and ensuring feasibility by flowing down plan requirements to the contracts before they are fully negotiated. The key is to confirm that verification products can be obtained within cost and schedule.
- Reviewing and closing the design verification at CDR, if practically possible. At a minimum, a draft of the analysis products should be available at the CDR.

Rationale:

Classifying design vs. product verification will allow for better management and more accurate status accounting. This accounting will mitigate the possibility of not completing verification in a timely manner. Completed verifications also will help identify potential issues early in the life cycle, therefore making problem solving more effective. Verifications associated with qualification activities also can be tracked as such, ensuring the qualification is tracked and completed before building flight hardware.

4.3.3.2 Lesson Learned: Verification Product Review

Projects need to clearly define who is going to review and approve verification. For example, a prime contractor develops a verification product (VP) (e.g., analysis or test report) to satisfy a verification requirement and submits the VP to the government for review and concurrence that a specific requirement was properly realized effectively in the design solution.

Rationale:

Ares I-X adopted the method that it's VPs had to be approved one level higher than the requirements owner. For example, a verification of a system requirement was presented to an independent body for review. Ares I-X did struggle with SE&I's expectations of what it needed to review as compared to what the IPTs believed was the responsibility of SE&I. For example, the USS IPT submitted its VPs to SE&I for review and concurrence that USS element requirements were met, whereas the First Stage collected most of its element VPs from its prime contractor then used the Ares First Stage Office to review and confirm verification. The First Stage Office approach reduced the need for SE&I to perform a redundant inspection of the verification product, but SE&I was still responsible for developing its system verification products using First

Stage products. This approach added concern for SE&I as they were responsible for overall verification. In summary, establishment of very detail verification closeout processes and, roles and responsibilities, as early as possible in the life cycle of a project, will facilitate smooth closeout of verification.

4.3.4 System-Level Verification Implementation Plan by PDR

4.3.4.1 Lesson Learned: System Level Verification Plan

Projects should baseline a system-level verification plan including verification requirements by PDR.

Rationale:

The verification plan should include the processes normally documented in a Master Verification Plan (MVP) and a Test and Evaluation Master Plan (TEMP). The combination of the MVP and the TEMP will allow the project to predict schedule and cost more accurately and to secure resources and facilities. The basic verification requirements, such as how a requirement will be verified (i.e., analysis, test, demonstration, and/or inspection), should be approved at SRR. The detailed verification requirements also should be at a draft level at SRR and 90 percent final at PDR. Detailed verification requirements imply that when a test is listed as the verification solution, the verification requirement will outline the type and levels of the test, anticipating test procedures being written and baselined by CDR.

4.3.5 Resource Loading for System Requirement Owners (SROs)

4.3.5.1 Lesson Learned: SRO Assignments

SROs need to be assigned when the System Requirements Document (SRD) and Element Requirements Document (ERD) are written. SROs need to participate in verification product reviews and associated DCRs.

Rationale:

Some Ares I-X element verifications were not completed in a timely manner because SROs were not available; key personnel were fully engaged with other duties and could not focus on SRO verification responsibilities. The surge team, meant to help SROs, did not always meet the technical level needs, as they required a learning curve, and their services came at a premium to the IPTs. Note: The lack of an SRO Working Group also limited visibility into progress and potential problems that otherwise might have been detected and reported. The surge team was a practical solution to alleviate compressed schedule conditions.

4.3.6 Waiver Traceability

4.3.6.1 Lesson Learned: Waiver Association to the Requirements

Requirements databases must identify associated waivers so that a database search will be able to identify all waivers being tracked for a particular requirement. In addition, projects must ensure that every waiver traces back to a requirement number. The entire set of waivers should be searchable by keyword, and a specific field needs to be set up in both verification and waiver databases to link waivers and requirements.

Rationale:

Ares I-X did not have a system that easily linked requirements and waivers. As a result, Ares I-X team members could not readily call up a requirement and all of the associated waivers for verification compliance statements easily, which caused delays in closing requirements compliance statements. For Ares I-X, approved waivers were documented via the waiver number with the associated requirement imbedded in the decision package. Although the data was well documented and archived, there was not an automated way to search for waivers by requirement number making the SRO's job more manual to trace between waivers and requirements.

4.3.7 Requirements Tracking and Document Repository

4.3.7.1 Lesson Learned: Requirements Management Tool

NASA's SE&I groups should employ a computerized application/tool for requirements management and a document repository that is quickly accessible, easily searchable, and optimum for the project. If a requirements management tool such as Cradle (http://www.threesl.com/) is not the most efficient tool for a particular project, another tool should be used instead. Ares I-X SE&I used a Microsoft Access Requirements and Verification Engineering database (RAVEN) because the learning curve associated with Cradle was not feasible for Ares I-X. No matter what tool is used, SE&I should validate requirement traces when requirements documents are approved.

Rationale:

NASA's Cradle tool was not optimum for Ares I-X systems requirements management. Ares I-X team members could not find broken links easily, and remote access to the tool was not practical for one test flight.

The Windchill document repository system was slow, and the directory structure did not allow team members to make quick searches for documents if they were not familiar with the structure.

4.3.8 Other Verification Lessons Learned

4.3.8.1 ERD Control Perspectives

The Ares I-X mission maintained baseline control the Ares I-X system requirements, element requirement documents (ERDs), and associated verification requirement

documents (VRDs). There exists multiple perspectives on the method of decomposition and ownership of requirements. The following Ares I-X lesson learned draws upon different points-of-view to guide future missions and projects.

4.3.8.1.1 Lesson Learned: Requirements Ownership from Multiple Perspectives

An IPT Perspective: IPTs should own ERDs and VRDs as long as the element is defined sufficiently at the system level and SE&I is a formal reviewer of the ERDs and VRDs.

A Mission Management Office Perspective: The requirements (e.g., an ERD) in which an IPT develops a product from should be owned by the mission/project. The IPTs are responsible for decomposing the ERDs into subsystem specifications. They are also responsible for implementing a bottom's up verification process where element requirement verification is conducted to the satisfaction of the mission/project and SE&I.

A System Perspective: The SRD should allocate system requirements to the elements and contain verifiable element requirements as 3.7 requirements or equivalent in the SRD.

A General/Best Practice Perspective: Projects should clearly define customer and product provider responsibilities including the ownership of requirements.

Rationale:

An IPT Perspective: An Ares I-X IPT suggested that IPTs should develop and baseline an ERD based on approved XCB allocated requirements from the SRD. The IPT would be responsible for delivering the IPT approved ERD to the Mission Manager. The Mission Manager would be responsible for reviewing the ERDs via SE&I to ensure the ERDs meet the intent of the mission. This suggested alternative allows the Mission Manager to approve the ERDs without engaging the XCB.

Mission Management Office Perspective: The review process and control authority for a requirements document will depend on the size and scope of the project. Regardless of what approach is utilized, system requirements must be approved by the project control board and the next lower specification must also be approved by the project control board. This approach ensures that the products delivered by the Elements to the Mission/Project are verified to the requirements approved by mission/project/SE&I.

A System Perspective: If an ERD is controlled at the element level then the SRD must contain element requirements in a SRD 3.7 section or equivalent. This approach provides a SE&I/project/mission level decomposition and allocation of the system requirements to the elements and ensures that element verification also satisfies system verification.

A General/Best Practice Perspective: The requirements in which a product is produced must be owned by the customer and not the product provider. Each project must ensure

that the allocation and decomposition of requirements is properly controlled by a stakeholder/customer and each product provider must be accountable to a stakeholder. The level of control will vary from mission to mission depending on scope, size, and structure of the project, and the customer to product provider responsibilities must be clearly defined.

4.3.8.2 Requirements and Verification Training

4.3.8.2.1 Lesson Learned: IPT Leads Requirements and Verification Training

Conduct requirements/verification training for IPT leads at the beginning of a project.

Rationale:

A project led systems level class on how requirements verification will be performed and rolled up would help ensure that responsible parties agree and understand the approved processes, procedures requirements, and reporting criteria. This will assure more effective requirements reviews and preparation for DCRs.

4.4 INTERFACES

4.4.1 Interface Definition Process

4.4.1.1 Lesson Learned: IRD Ownership

All interface requirements documents (IRDs) between the IPTs should have an SE&I owner. The roles and responsibilities for interface design and documentation personnel should be defined in the SEMP.

Rationale:

SE&I was responsible for the integrated product; therefore, it is in the best interest of the integrated system to include a stakeholder from SE&I to ensure that all interface requirements are mutually agreed to by all interface parties. SE&I should serve as the mediator in the event of a dispute. The SE&I team is also is responsible for ensuring that the interface is robust from a system perspective.

4.4.2 Interface Requirements Definition Should Be Tightly Linked to Verification

4.4.2.1 Lesson Learned: Verification of Interface Requirements

Definitions of interface requirements should be tightly linked to verification requirements. Requirement documents should call out interfaces.

Rationale:

Although the Ares I-X SE&I team was responsible for vehicle interfaces, the interface details were delegated to the IPTs, which required the IPTs to work out the differences. The proposed solution would be for SE&I to be a knowledgeable stakeholder of the interfaces and take the lead in developing the interface requirements and the ICDs.

Because SE&I is responsible for vehicle integration and the IPTs cannot see the whole integrated scenario, SE&I must also be responsible for the credibility of the vehicle interfaces. For example, an IPT may believe a certain size of wire or bolt is reasonable for an interface; however, SE&I, being knowledgeable of the integrated vehicle dynamics, may have a different design solution based on dynamics not known or understood by the IPT.

4.4.3 Interface Definition Working Groups

4.4.3.1 Lesson Learned: Interface Definition

Interface definition working groups should be established by SE&I to improve the effectiveness of interface definition.

Rationale:

Interface definition working groups will enhance the allocation of system requirements and ensure division of responsibility. Ares I-X established interface control working groups (ICWGs) that worked well to identify gaps and address issues quickly. Prior to the establishment of working groups and prior to the discussion of interface requirements at the XCB, development of ICDs did not progress as quickly as needed. In summary, SE&I should establish ICWGs as early as practically possible in a projects life cycle.

4.4.4 ICD Content and Definition

4.4.4.1 Lesson Learned: Interface Control Documents

ICD content and definition should be defined and controlled at the project level via SE&I IPTs should also take definite steps to assure that the other side of their interface matches well. A cooperative effort between SE&I and the IPTs will help mitigate the possibility of interface mismatches.

Rationale:

The definition and utility of an ICD is different between NASA centers. Standardization of IRD/ICD content for a project will ensure that content is not missed or misunderstood by the integrator. Exceptions can apply if well understood by implementing parties. SE&I must know, agree, and ensure that both sides of an interface can and are properly verified in cooperation with the IPTs.

4.4.5 Control of Models and Drawings

4.4.5.1 Lesson Learned: Use of ICDs for Models

There should be clear definition and direction on how the various types of computer models and drawings of a vehicle system are used in the ICDs. This must be established early in a project's life cycle via the SEMP and then levied on existing and

new contracts. For example, a process must be established at the system level to help ensure model and drawing databases are current, and all contracts and IPTs should have drawings and models delivered through a standardized change process.

Rationale:

Using computer models rather than pre-CAD generations is a general standard practice. To this end, a model not controlled produces the same effect as an uncontrolled ICD.

4.4.6 A Single System Integration Lab (SIL) Should be Assembled as Early as Possible

See Section 4.1.1 for more details.

4.4.7 Closure of One Side of an Interface

4.4.7.1 Lesson Learned: Interface Verification

Given that there are multiple sides to an interface, closing the interface verification of one side of the interface is acceptable as long as requirements are clearly delineated for each interface and the interface manager sees the interface and agrees it meets the interface requirements. The system level verification should be held open until the interface manager sees both sides and verifies it will work or meet the requirements of the interface from a system perspective.

Rationale:

In the event of a problem with one side of an interface, the problem report will drive re-verification of the mating interface, if precipitated by an agreed to interface requirement or ICD change. Interface manager must own the interface for the system.

4.5 LOADS

Background

Ares I-X initially released very conservative environments and vehicle loads assumptions. The remaining work pointed toward validating these assumptions and refining the models and loads. The predictions were good, and the vehicle's performance was as expected. As the launch date drew closer, late test results (some planned and some surprises) were incorporated; late models were integrated, independent validation and verification (IV&V) was completed, and the loads were updated. This process was very challenging, but was not unusual compared to other one-of-a-kind complex systems.

The SE&I Integrated Design and Analysis (ID&A) group was molded to form a close-knit, disciplined team structure to facilitate a fast timeline for the flight test (i.e., a "skunk works" mindset). For example, the Hyper X (X-43A) project followed this approach. The Hyper X structure was a fundamental factor for selecting the original vehicle integration

management and ID&A teams in that such a team formulation requires the following to be successful:

- An extremely disciplined team that works very well together and that understands cross-discipline feeds (i.e., not stovepiped; individuals able to see beyond their own responsibilities).
- Element modeling inputs and reviews such that vehicle integration is closely involved in element design, making integration a natural process.
- Design cycle rigor such that perfection is expected therefore decreasing the possibility of extra design cycles.
- Meticulous model/analysis management and configuration control.
- Strong leadership and sufficient resources.

4.5.1 Loads Staffing

4.5.1.1 Lesson Learned: Loads Definition Team

Loads and environments are fundamentally requirements. Critical staffing must be addressed during the formulation phase of the project, not the design phase. Projects need to identify and staff critical ID&A disciplines immediately and clearly communicate shortfalls and related expertise needs. The ID&A discipline must develop a clear path and control metrics. A dedicated ID&A loads staff is needed to ensure resource availability.

Rationale:

Staffing for the complete ID&A team was limited when the group was managed out of the original vehicle integration office known as the Ares I-X Vehicle Integration Office (AVIO). After the SE&I team was formed to replace AVIO, it took three to six months following the mission reorganization before a fully effective team was in place. Staffing of lead and supporting analysts for the unique vibroacoustics discipline proved difficult, leading to pocketed expertise on the subject and a tendency to rely on committee rulings for explaining/accepting methods or results. This lack of expertise led to delays and “conservative” vibroacoustics loads.

4.5.2 Cross-Discipline Training

4.5.2.1 Lesson Learned: Skills Mix

An analyst’s experience level must be matched against the project pace and schedule in the formulation phase of a project. Experience must include cross-discipline understanding through past experience and/or training.

Rationale:

Fast-paced projects require key, highly experienced leads in many areas. Tools and methods for each discipline must be clearly understood. However, key leads also need to have an understanding of what other disciplines will need to do their jobs. For example, the Ares I-X trajectory lead had a strong structures background and had developed methods for mapping distributed aerodynamic loads onto structures to define ascent structural loads. This characteristic of the analysts allowed Ares I-X to complete PDR and CDR sufficiently to proceed with development.

4.5.3 Configuration Control (CM) of SE&I Technical Data

4.5.3.1 Lesson Learned: CM Control of Models and Analyses

Configuration management (CM) of models and analyses must be maintained within the SE&I organization. SE&I must identify internally controlled items, such as trajectory data, and formally capture changes from the beginning to the end of the project. SE&I staffing must be able to facilitate critical model/data capture to feed the design cycle process. See also 5.2.8, Model Formats.

Rationale:

Ares I-X experienced a lack of SE&I configuration control resources to maintain lock and capture of models. The Systems Configuration and Integration (SC&I) function within SE&I was dismantled after MMO was established due to the lack of resources and schedule constraints.

The typical tendency of the SE&I analytical team was to pass along information informally within the group. The intent of this practice was to facilitate quick analytical turnaround with the latest information, which is typical of the LaRC concept study process. Passing along the latest occasionally gave way to instances where team members lost their lock on design cycle synchronization. For example, trajectory updates, due to time-of-year changes, were passed along informally, creating baseline control issues and requiring additional time to sort out and justify the differences in the baseline and other related updates to associated documentation. An ordered SE&I CM system would have established a clear history of changes, therefore minimizing the challenge of interpreting and implementing complex technical changes.

4.5.4 Timing of Analytical Model Reviews and Approvals

4.5.4.1 Lesson Learned: Schedules for Reviews of Models

Reviews of analytical models (e.g., a forcing functions model) and approvals must occur before they are used for system-level integration. IPT models and analyses should have schedule-defined review milestones prior to delivery milestones to mitigate the risk of delaying major milestones such as the PDR, CDR, and/or Mate Review. Additional

reviews will help identify shortfalls, offering an opportunity for corrective action. SE&I should develop delivery checklists at the beginning of each design cycle to ensure ground rules and assumptions are maintained, thereby also facilitating model expectations and integrity.

A unique aspect of the 3D modeling approach was that it evolved over time and was not a baseline requirement. Ares I-X increasingly used models as more design detail was available. Ares I-X used the CM process for drawings well, but the process did not work as well for the models. This did contribute to the lack of formality with the models and analysis at times.

Rationale:

Ares I-X experienced a lack of related IPT and system level defined model reviews and deliverable schedule milestones (see also the lesson learned entitled, Loads Dependency) resulting in cases of incompatibility, validation concerns, and schedule delays. SE&I assembled IPT provided models into system level models. IPTs were responsible for ensuring these models were valid and had appropriate technical review. Due to the rapid nature of the Ares I-X development process, only a limited review of these models occurred by SE&I and the systems engineering level. SE&I trusted that the delivered models were approved, however, late in the verification process, questions arose as to the validity of IPT model inputs, leading to further in-depth reviews and analysis. This also could have been resolved if SE&I had resources to dedicate to each IPT from the start that knew the IPTs model process.

4.5.5 Loads Dependency

4.5.5.1 Lesson Learned: Design Cycle Timeline

Structural and thermal loads are subject to change as a design develops. The change timeline within the design cycle process should be established up front to ensure design expectations and margins are managed and communicated. SE&I and the IPTs need to work together to develop an integrated design cycle schedule with agreed-upon long-lead supporting tests, required IPT deliverables, and entry/exit products/checklists. Project management needs to provide supporting resources (i.e., infrastructure and personnel) to maintain supporting data configurations, independent reviews, a de-scoping and processing plan, and constant communication.

Rationale:

Finalizing environments and loads was a vexing problem for SE&I and the element IPTs because loads compliance issues was a constant burden up until the day-of-launch. Original ID&A planning was formulated around multiple design cycles, but the rigor of maintaining synchronization during and between design cycles was exacerbated by:

- Loss of consistency during the transition of three different ID&A managers.

- Lack of integrated schedule communication. For example, the supporting deliverables between IPTs and SE&I were not well documented.
- Late support/data from wind tunnel tests.
- Elimination of SE&I CM staffing for critical models data capture and configuration.

4.5.6 Co-location of Design Leaders and Managers

4.5.6.1 Lesson Learned: Loads and Environments Collaboration

Dramatic improvement can be achieved in all areas of loads and environments analysis by co-locating design leaders and managers for a short period (approximately 3 to 4 months) early in the definition process. Ares I-X did not do this, but strongly recommends, after reflecting on past events, that this approach of co-location will help any mission/test/flight.

Rationale:

Co-location assures that highly qualified resources will be assigned and integrated into the project very quickly. It also allows the team to develop a detailed design analysis cycle (DAC) plan so that all team members understand the fidelity and schedule of the products required.

4.5.7 Late Loads

4.5.7.1 Lesson Learned: Late Loads Contingency Plan

Project leaders need to anticipate changes in environments and/or loads late in the project development cycle and beyond the last planned DAC. The project should have a contingency action plan for resolution of ‘unknown-unknown’ issues. Note: Late loads issues are not rare for a technically complex, one-of-a-kind system. Typically margins and/or conservative loads factors are applied during design; that way, if an error is discovered in a model or an analysis, and/or hardware fails in test, the contingency action plan can be executed to mitigate the issue.

Rationale:

Load changes occurred late in the life cycle for Ares I-X. The estimated aerodynamic, thermal, acoustic, and other loads and environments affecting the FTV were analyzed up until the day of launch, as the computer models and loads cases evolved. This was very late in the process but this was a flight test. The models evolved as they were discovered to be either too conservative or not conservative enough. These loads analysis cycles did cause a strain on the team, including additional schedule pressure as the launch date approached.

4.5.8 Fly-Away Maneuver (FAM)

For the Ares I-X flight, the FTV was programmed to tilt 3 degrees in the +Y axis immediately after first stage ignition, enabling the rocket to lift off at an angle from the launch pad (image at left). This FAM was designed to reduce the likelihood of the FTV striking the launch pad's fixed service structure (FSS) in the event of unfavorable winds, as well as reduce the potential for damage to the FSS due to the solid rocket's plume impingement.

4.5.8.1 Lesson Learned: FAM Induced Loads

A special study should be conducted to assess the coupled loads of FAM for Ares I.

Rationale:

The FAM exerted additional and significant loads on the rocket/vehicle. Assessment of these additional loads took months to resolve. An even more aggressive FAM is planned for Ares I; therefore special consideration should be applied given the potential negative consequences of severe loading on a vehicle carrying astronauts into orbit.

Ares I-X used the Ares load approach, but the Ares load approach did not include the impact of maneuvering loads. Note: The FAM exerts a large maneuvering load. Also note, the Ares I vehicle is more flexible than the Ares I-X, so it could have very severe bending moments because of a very aggressive FAM.

4.6 TRIBOELECTRIFICATION

4.6.1 Triboelectrification Requirements

4.6.1.1 Lesson Learned: Tribo What (Triboelectrification)

Triboelectrification requirements should be documented at the system level during the project's requirement development phase as opposed to being addressed in an applicable document (i.e., Range Safety document) . The solution as noted is for projects to include a system-level triboelectrification requirement in the SRD. SE&I also should allocate and verify individual Range Safety Requirements relating to triboelectrification.

Rationale:

Ares I-X launch availability was severely reduced due to the triboelectrification weather Launch Commit Criteria (LCC). Triboelectrification can be generated by high-level clouds as the rocket flies through them, which can create a corona of static around the rocket that interferes with radio signals transmitted or received by the vehicle. This can create problems when a rocket tries to transmit data down to the ground or if the Range Safety Officer at Cape Canaveral Air Force Station needs to send a signal to the flight termination system (FTS). The impact of this LCC on Ares I-X launch operations was not realized until the pre-flight test readiness preparation timeframe. The Ares I-X first stage external coating did not meet the criteria to satisfy an "exception-by-test", even though Shuttle flies with a waiver on this paint. A late attempt at exception-by-analysis was not completed in time to obtain a waiver for this requirement.

The relevant document/requirement addressing triboelectrification was AIX-SYS-LCC v.13, 6.5.9 (AFSPCMAN 91-710, v6, A7.2.5.4.10), which stated:

- Triboelectrification. Do not launch if a vehicle has not been treated for surface electrification and the flight path will go through any clouds above the –10°C level up to the altitude at which the vehicle's velocity exceeds 3,000ft/sec. A vehicle is considered "treated" for surface electrification if:
    - All surfaces of the vehicle susceptible to precipitation particle impact have been treated to assure that the surface resistivity is less than 10^9 ohms/square;

      and
    - That all conductors on surface (including dielectric surfaces that have been treated with conductive coatings) are bonded to the vehicle by a resistance that is less than 10^5 ohms;

      or

- It has been shown by test or analysis that electrostatic discharges (ESDs) on the surface of the vehicle caused by triboelectrification by ice particle impact will not be hazardous to the launch vehicle or the mission. In A7.2.5.4.10.1.1 above, the correct unit for surface resistivity is ohms/square. This means that any square area of any size measured in any units has the same resistance in ohms when the measurement is made from an electrode extending the length of one side of the square to an electrode extending the length of the opposite side of the square. The area-independence is literally valid only for squares; it is not true for other shapes such as rectangles and circles.

Since Ares I-X used heritage Shuttle assets, AFSPCMAN 91-710 Volume 6 was NOT tailored to Ares I-X needs. Volume 6 addresses Ground and Launch Personnel, Equipment, Systems and Material Operations Safety. Per Joint Operating Procedure, 45SW 15E-3-14 (NASA-KSC KCA 1308), operations occurring on KSC to include Ground and Launch Pad Safety, excluding operations specific to Vehicle Flight Safety, are the responsibility of NASA-KSC. The Range LCCs were included in this volume.

Range Weather LCC's were not addressed until February 2009. The Ares I-X Range LCCs were derived from Shuttle LCCs. Triboelectrification LCC is not applicable to Shuttle, using its extensive flight history as justification. However, Ares I-X was a new vehicle, so the LCC applied, in that Ares I-X was the first flight of new design and the first flight subject to AFSPCMAN 91-710. The Natural Environments Group felt that triboelectrification was not a significant concern based on the launch date, which was targeted for the morning of July 11. However, weather LCCs were not adequately evaluated against each IPT or SE&I, and this particular LCC not re-addressed until October 2009, the month of the new launch date.

4.6.2 Triboelectrification Document Review Process

4.6.2.1 Lesson Learned: Triboelectrification Requirements

Projects need more insight into range requirements. A large document such as the Range Safety Requirements Manual contains a significant number of requirements that need to be verified. Review and verification of these requirements should contain the same rigor and control as the technical systems requirements and the SR&QA requirements. All requirements should be tracked line by line by SE&I or as delegated in the project plan or the SEMP.

Rationale:

Information contained within the weather section of the LCC document was available early enough to accommodate an analysis that supported an exception to the triboelectrification LCC. Ares I-X had insufficient staffing to handle the workload; as a result, some LCCs were not reviewed or understood as well as they could have given a more robust verification process for range requirements. Although all of the IPTs, SE&I, and S&MA were required to review the LCC document, because it was a CoFTR

product, inadequate early review still resulted in late notification of the triboelectrification requirement.

4.7 ELECTRONIC DEVELOPMENT FIXTURE (EDF)

The EDF was a computer-aided database where all of the Ares I-X 3D CAD models/drawings were assembled into a common database. EDF is a state-of-the-art replacement for physical development fixtures that typically used wooden parts (i.e., models) to verify the fit and interfaces. The EDF collected the three-dimensional CAD models from the NASA and contractor systems and assembled them into a virtual vehicle using the ProE CAD tool. The common database allowed designers at MSFC to virtually assemble the vehicle and check that interfaces were correct and identify where interferences occurred. The team using the EDF identified several interferences and corrected them during the process, which allowed the team to successfully assemble the vehicle in the VAB the first time it was attempted. This task was done as a Project Integration function.

4.7.1 Lesson Learned: EDF Approach

Define the EDF approach in the Systems Engineering and Management Plan (SEMP) and have all IPTs and SE&I flow this down to their contractors in the contracts.

Rationale:

The efficiency of EDF was reduced because a written plan was not well documented, communicated, or implemented. Although the EDF approach was understood by key players, implementation was impaired because it required integrated support by all IPTs and SE&I. Also, IPTs did not put it in contracts to support the EDF so it was supported as the right thing to do by the working level.

The EDF effort for Ares I-X was officially authorized on November 8, 2006, and included the following:

- CAD 3-D models to support vehicle design and integration rather than the physical models and mockups.
- Drawings were specified as the controlling contractual deliverables, but CAD models were used to share information during the design and integration effort.

EDF products included the following:

- Performed real time “fly-throughs”. This was done to provide engineering data and overviews to reviewers of the full rocket as a system.
- Created ProE reference drawings of the integrated CAD FTV.
- Created a virtual DFI sensor map for the EDF’s CAD FTV. CAD models were developed to represent various sensors throughout the vehicle to provide a

spatial representation of their locations and serve as a tool to check for sensor location discrepancies.

  - A sensor model integrated with the EDF is more useful than just X, Y, and Z coordinates.

- Performed Crew Module (CM) and Service Module (SM) match drill interference fit checks (IFCs) as well as Interstage (IS) and First Stage (FS) Drill Mount Bracket IFCs.
- Created a ProE model of the Ares I-X outer mold line (OML) with logos and z-stripe for imagery analysis.
- Provided “Lightweight” EDF for non-CAD users to better understand the rocket.

4.8 DESIGN REVIEWS

4.8.1 Lesson Learned: Design Review Options

Fast paced projects or flight test such as Ares I-X should consider implementing unique and innovative design reviews.

Shown above is the Ares I-X team at the System CDR in LaRC.

Rationale:

The First Stage project recognized the need to reconcile the Ares I-X Level III SRR, PDR, and CDR milestone activities with the scope of First Stage work that needed completion to meet the launch date. Traditional data drops and design cycles would not support the desired project timelines or the flight date. As a result, a First Stage Major Design Review (FSMDR) process was developed to bridge the need for disciplined design review rigor with incremental sub-element reviews tied to release items. The FSMDR’s were a comprehensive and systematic assessment of the Ares I-X sub-element designs that covered all aspects of the design, architecture, requirements, verification methods, interfaces, hardware, software (as applicable), and plans. The FSMDR’s demonstrated that the designs were of sufficient detail to establish preliminary design baselines and detailed designs (as applicable for the particular review) were of sufficient completion to grant manufacturing release for flight hardware.

5.0 MISSION MANAGEMENT LESSONS LEARNED

5.1 MISSION MANAGEMENT APPROACH

5.1.1 Mission Objectives

5.1.1.1 Lesson Learned: Flight Test Objectives

The flight test evolved from well established objectives that were formulated via a methodical process of obtaining inputs from potential stakeholders. Having clear objectives gave the mission team a framework to build from, validate against, and assess post flight results. The positive lesson learned from Ares I-X is to establish clear mission objectives before starting the mission. Also, do not let the objectives change without sound justification and replanning.

Rationale:

By establishing and maintaining objectives at the outset of the flight test campaign, the flight test team was able to quickly define flight and ground configurations, formulate an effective organizational structure, promote a rapid development timeline, and enable systems requirements development.

5.1.1.2 Lesson Learned: Flight Test Planning

The flight test plan (FTP) was prepared at the outset of the mission. The plan provided a strong foundation for the development of the system requirements and a basis for initial cost estimates and good forward plan. The FTP also provided the requirements for flight test readiness and the certification process. A strong working relationship between Level 2/Cx Operations and Test Integration (OT&I), and MMO is critical to the planning of the test and implementation of the flight test readiness process.

Rationale:

The FTP was used as the driving document for the test. The FTP comprised the flight test objectives, constraints, organizational responsibilities, a top level schedule, a top level CONOPS, descriptions, definitions, and certification of flight test readiness (CoFTR) reviews and instructions. The FTP was used to derive the system requirements, the functional organization, and the CoFTR certification forms. The document was prepared cooperatively between Cx OT&I and MMO. The document was also vetted through ESMD. The flight test readiness process was summarized and presented to the centers. An overall process flow figure was added by ESMD to provide linkage to all the reviews and responsible parties. Overall, Ares I-X was very successfully in planning from the outset and conducting a strong flight test readiness review process that started with the Mate Review.

5.1.1.3 Lesson Learned: Open Work

Identification of all open work prior to major reviews, such as the pre- Flight Test Readiness Review, was helpful in assessing the risk to proceeding. Listing all open work on the CoFTR Endorsement Forms creates extra work and should be tracked at the project level.

Rationale:

Tracking all open work is a major, but critical task in determining readiness of a flight. This can be accomplished as the project function and listed as a one liner on the CoFTR endorsement forms except in the case where an open work item is cause for identifying an exception to flight.

5.1.2 Flat Organization

5.1.2.1 Lesson Learned: Decision Layers

Mission objectives can be achieved safely and successfully by reducing the number of review boards and by reducing the organizational layers between the technical decision makers and the programmatic decision makers. See also 5.2.1.1, Review Boards, and 5.6.5, Number of Decision Boards.

Rationale:

A flatter organization (i.e., only one level between the project/mission manager and the key technical recommendation and/or decisions) minimized decision times for Ares I-X and encouraged communication up and down. For example, this type of organization resulted in more openness because the manager was in daily close communication with the leads who were facilitating the processes; this enhanced the “sense of team” via a unified team approach as opposed to a group approach. This approach also occasionally caused work overloading for particular individuals due to having to assure the time necessary to promote effective communications.

A flatter organization as compared to Shuttle or other CxP organizations minimized decision times for Ares I-X and encouraged communication among the various players. The small team provided a “skunk works”-like approach, where the MMO was able to leverage talented people and dedicated people from across NASA. One thing that could have been done earlier and better was to place key personnel in one location, but that option could not be practically implemented. Instead, the team communicated well via teleconferences, hand-held devices, email, Windchill, and purpose-driven face-to-face meetings. However, there were times when the smaller staff resulted in work overload on particular individuals. The end result was that the flat team worked well for Ares I-X, but may not work in other situations. Efforts will need to be made in the future to ensure that similar “lean” teams have contingency plans and backup resources to call upon to reduce workload on key personnel.

5.2 BOARDS AND PANELS

5.2.1 Number and Types of Control Boards

5.2.1.1 Lesson Learned: Review Boards

Ensure that the mission has the correct number and type of boards to facilitate decision making. The number of boards must be optimized to minimize the processing time of a change request. If only one board is needed, then multiple boards should not be used to accommodate a specific organization. For example, an IPT or SE&I may prefer to work a decision at their level, but if the issue needs to go to the next level anyway, then submitting a topic to two different boards is not recommended. Note: a clear division of responsibility and proper allocation of requirements will minimize the need for multiple board decisions on the same topic. See also 5.2.1, Decision Layers, and 5.6.5, Number of Decision Boards.

Rationale:

One of the reasons that MMO was formed was to reduce the number of review boards in order to process request more quickly and help ensure that the flight test occurred on schedule, which it did.

The MMO managed its milestones with the following boards:

The *Ares I-X Control Board (XCB)* was responsible for mission- and system-level issues. The XCB was used to make technical decisions once a technical board, panel, working group, or tiger team performed a systems analysis (i.e., defined the problem, identified alternative solutions, assessed the problem, and prepared recommendations). If an XCB decision was appealed via the Technical Authority (TA), the Constellation Control Board (CxCB) acted as the arbiter.

The *Systems Engineering Review Forum (SERF) and Engineering Review Board (ERB)* were venues for detailed technical discussions and were responsible for making technical decisions for the technical team. If decisions could not be made at this level because they affected cost and schedule, changed a requirement, or required a disposition from a designated officer (i.e., mission manager), they were referred or appealed to the XCB with a technical recommendation. A few months before the mate review, the ERB was charged with reviewing and approving technical waivers. The Mission Manager was still responsible for approving decisions with cost and schedule impacts.

The *Developmental Flight Instrumentation Control Board (DXCB)* was responsible for addressing specific concerns with the mission's DFI. This board was formed when DFI was being physically integrated with the vehicle to ensure that flight test stakeholders (i.e., Ares Projects Office) were in the loop on decisions concerning individual sensor

repair, replacement, or removal. On at least one occasion a discrepancy between the Ares I-X MMO and a stakeholder was raised to the CxCB on DFI removal.

The *Technical Review Board (TxRB)* was responsible for addressing technical issues related to Ground Operations processing at KSC. The Mission Manager was still responsible for approving decisions with cost and schedule impacts over a threshold.

The *IPT boards* conducted programmatic and technical matters that affected only IPT-specific products.

Lead Systems Engineer's Working Group conducted the primary technical work of evaluating system-level technical matters and vehicle interfaces. This working group's decisions affected SE&I documentation such as data books (e.g., thermal, structural, etc.), processes (e.g., SEMP), and guidance memos.

A Systems Engineering and Integration Board (SEIB) was not formally used, but if it had been, it might have included the Technical Authority and had the following responsibilities:

- Interface between vehicle and ground elements.
- Maintain the technical baseline and communicate changes.
- Maintain the Design Definition Document (DDD) and design cycles.
- Schedule SE&I activities.
- Assess system-level risks.
- Prepare technical recommendations to the XCB.
- Develop DFI requirements.
- Maintain configuration management (CM) for technical documents

Ares I-X Senior Material Review Boards (MRBs) were established by the First Stage and GO IPTs. The Senior MRBs were used when elevation criteria caused reassignment from the local MRBs to the Senior MRB for disposition. In summary, elevation criteria needs to be aligned with risk based criteria. This approach will help mitigate the possibility of increasing work scope and schedule impacts.

5.3 SCHEDULE

5.3.1 Identification of Key Milestones at ATP

5.3.1.1 Lesson Learned: Schedule Detail

Ares I-X established and documented key milestones at authority to proceed (ATP), including all CoFTR Reviews, SRR, PDR, and CDR. A more detailed schedule with IPT-level reviews might have helped highlight potential conflicts with overlapping reviews.

Rationale:

At ATP the elements of the flight test, later known as IPTs, did not have project plans; however, the Mission Implementation Plan (MIP) was baselined to provide overall mission direction. The MIP did not specify how the IPTs would manage their organizations because each IPT was unique. The IPTs did provide detailed schedules, although there were some gaps and disagreements with content that provided a good framework for management to engage. The main lesson learned was to bring all schedule conflicts to the XCB as soon as possible to minimize the impact of integration issues.

5.3.2 Schedule Structure

5.3.2.1 Lesson Learned: Level of Schedules

Define a schedule structure at ATP that defines the level of schedules required by each IPT and SE&I. Also, define common tools to be used for scheduling and clearly document the plan for management of the schedule.

Rationale:

A standard scheduling approach, approved at the XCB, would have minimized conflicts between what MMO needed and what was provided by the IPTs. The basis of the disconnect between MMO and the IPTs was that due to schedule constraints, what MMO wanted and what MMO needed was verbally communicated but not clearly documented as a baselined mission requirement. A hard requirement or written guideline would have given MMO some additional leverage to obtain the data needed and the IPTs would have had official instructions to work and abide by.

5.3.3 Schedule Variance Reviews

5.3.3.1 Lesson Learned: Manager Reviews

Hold mission manager variance reviews periodically. Depending on the project phase, this may be weekly, bi-monthly, or monthly.

Rationale:

MMO reviewed the schedule weekly, but the rationales for variances, including recovery plans, were not always addressed. Workaround plans could have been prepared and implemented more effectively if variances had been documented. Given effective workaround plans, the launch of Ares I-X might have been sooner.

5.3.4 Automated IMS

5.3.4.1 Lesson Learned: Schedule Automation

The Integrated Master Schedule (IMS) should be automated based on lower-level schedules.

Rationale:

Ares I-X schedule data was pulled manually from each of IPT's and SE&I's schedules to generate and maintain the Ares I-X IMS. This manual step created extra work for the scheduling team, but it reduced the amount of time the schedule team had to review the new schedule data. Schedule automation will require the IPTs and their prime contractors to use the same scheduling tools (Primavera, Project, or other). The use of common tools will ultimately depend on a cost-to-benefit analysis, in terms of the cost of the tools and the cost of training, as compared to potential savings in scheduling time and management.

5.3.5 Centralized Schedule Control

5.3.5.1 Lesson Learned: Schedule Visibility

Mission Management Office (MMO) representatives should have greater visibility into the development of lower-level IPT and SE&I schedules, in order to have a better understanding of the challenges and risks.

Rationale:

For Ares I-X, the Mission Manager relied on the IPT/SE&I Leads to manage their schedules and report variances. The MMO had minimal visibility into the IPTs' working schedules until the IPTs delivered them. This resulted in MMO having to act in a reactive mode as compared to a proactive role. A more centralized/proactive approach (i.e., more insight in lower level schedule variances) would have allowed conflicts to be identified and mitigated earlier.

5.3.6 Setting Schedule Expectations

5.3.6.1 Lesson Learned: Schedule Reporting

A project should prepare a written set of schedule reporting requirements and guidelines at the beginning of the project. This will ensure that all elements are working in a synergistic manner. Using the same schedule tools also will enable a seamless linkage and optimum visibility.

Rationale:

Ares I-X did not set schedule expectations because they did not document schedule structure, communication processes, consequences, review processes, and other tools for enhancing the schedule development process, maintenance, and reporting process.

5.3.7 The Power of Milestones

5.3.7.1 Lesson Learned: Milestone Tracking and Status

Develop multiple top- and lower-level milestones at the beginning of the project. Manage to the milestones and provide statuses of the supporting tasks with "stop lights"

(i.e. red/yellow/green status indicators) to depict the degree to which a milestone is being achieved.

Rationale:

Ares I-X did not use rigorous multiple milestone tracking at the inception of the mission, although other methods were used to track progress. Strict tracking of each milestone's status could have triggered corrective action before a milestone or the associated tasks were impacted. When MMO did not allow milestones to slip without high-level approval, there was a drop in actual slipped activities because corrective action was practically demanded. This was one way MMO helped to push the schedule.

5.3.8 Open Dialogue

5.3.8.1 Lesson Learned: Schedule Pressure

Maintain continuous and open dialogue on the schedule between MMO and the schedule developers at the element levels. The Mission Manager should maintain pressure on the IPTs to ensure there is not a break in momentum and progress.

Rationale:

The pressure exerted by Ares I-X Mission management was consistently strong, though positive; the focus was always on meeting the requirements while not letting the launch date move outside the margin.

5.3.9 Establish Proper Test Flight Rigor "Good Enough"

5.3.9.1 Lesson Learned: Requirements Creep I

For a test, understand what is "Good Enough" and carefully assess the addition of requirements that are qualitatively more than good enough. This simply means do not permit requirements creep to make the project more sophisticated than it has to be. For example, Ares I-X was not human rated, therefore adding requirements to make it human rated would have been superfluous. See also 5.3.15, Scope Creep.

Rationale:

To some this is a cultural change because developers tend to overdesign to increase reliability, quality, and other safety factors. Overdesign can cause a project to prematurely exhaust its budget by trying to make something better than required. Ares I-X was a test, albeit with significant ramifications, so the project had to maintain a critical balance between objectives and a reasonable approach in order to adhere to NASA policy and requirements.

5.3.10 Forecasting Critical Path

5.3.10.1 Lesson Learned: Establishment of the Critical Path

A forecast of critical path items needs to be well documented and communicated at the beginning of a project's life cycle.

Rationale:

Several Ares I-X IPT level deliverables were not identified in the overall mission's critical path. This resulted in schedule slips and special measures that had to be taken to reclaim schedule margin.

5.3.11 Loads Products Tracking

5.3.11.1 Lesson Learned: Analysis Accountability

Analysis products that could have a significant impact on the product should be tracked aggressively as any deliverable. This includes associated requirements verification activities.

Rationale:

An analysis can affect the design of a product; therefore, the date on which critical analysis data will be available is important to risk assessment. For example, baselining a product's design when environments are still under review is a risk. The magnitude of the risk is partially dependent on when the data will be available.

5.3.12 Schedule Management Delegation

5.3.12.1 Lesson Learned: Empowerment to Manage the Schedule

The project manager should delegate a limited amount of schedule authority to a deputy manager to assist with management of the schedule for specific items.

Rationale:

A deputy that is empowered to manage the schedule on a daily basis will ensure a continuous monitoring of activities. The deputy needs to be fully empowered to authorize contingency planning including adding resources as required. Ares I-X used the Project Integration Office to manage the schedule and a deputy to track progress, but neither had the authority to enforce preventive changes. The decision to delegate or not needs to be done on a project by project basis, but the PM should trade the different options of schedule management.

5.3.13 Schedule Margin

5.3.13.1 Lesson Learned: Margin Management

Allow MMO and the project elements/IPTs to manage a reasonable amount of schedule margin. MMO should build margin into the major milestones and need dates. This will allow SE&I and the IPTs to carry some margin. The amount of margin depends on the

point of the project's life cycle. The IPT margin and risks should be disclosed to the Mission Manager in order for the Mission Manager to assess the overall schedule risk.

Rationale:

As designs are being formulated, elements are still assessing alternative ways to develop their products; therefore, the schedule and associated margins are highly uncertain up to PDR. As the design matures, the elements should establish detailed schedules with hard milestones set by the project. The IPTs should also manage their schedules and rely on the project to grant relief or reduce margin if justified. This centralized approach of tracking progress and managing margin permits the overall management of the end products, yet allows the flexibility for the elements to adjust their schedules within the established milestones.

5.3.14 Schedule Detail

5.3.14.1 Lesson Learned: Schedule Line Items

The level of detail for a schedule should be consistent with the phase of the mission. For example, during the design phase the focus needs to be on design and analysis products while during the production phase the focus needs to be on hardware fabrication, assembly, verification and integration. The amount of schedule line items depends on the resolution necessary to inform and adjust without impacting the critical path. The decision maker needs to be clear on what resolution (i.e., level of detail) is reasonable for reporting or how early they want to know of a threat to a milestone.

Rationale:

The decision maker needs to be supplied with an amount of data that is adequate for assessing the state of the project. The data provided should be tailored to the phase of the project, though data also must be available to assure the decision maker that future tasks are well planned.

5.3.15 Scope Creep

5.3.15.1 Lesson Learned: Requirements Creep II

Do not increase scope during the execution of the project unless additional requirements are flowed down through the approved top-down process. See also 5.3.9, Establish Proper Test Flight Rigor "Good Enough".

Rationale:

Ares I-X added scope changes (e.g., 90-degree roll maneuver, fly-away-maneuver (FAM), SR&QA requirements, etc.) in response to interpretations of its mission and technical analysis results. Although some changes were difficult to implement, following the CM change process was important because changes may have associated impacts that could jeopardize the mission. For example, if a scope change is not complemented

by an assessment of its cost or schedule impact, then one change (e.g., SR&QA requirements were not baselined until after SRR) could have cancelled the flight test if relief was not given. Ares I-X was allowed to tailor, with approval, some of the CxP processes to accommodate the uniqueness of the flight test. The FAM, although needed for technical reasons, resulted in impacts to the launch pad, albeit within scope. The most important lesson learned was that for every scope change, an associated cost, schedule, and technical impact should be documented, as Ares I-X did in all cases.

5.3.16 Contractor Schedules

5.3.16.1 Lesson Learned: Schedule Reporting

Require the contractors to formally agree to the schedule reporting requirements as part of their contract.

Rationale:

Requirements for schedule reporting should be flowed down to the prime contractors. This will ensure that schedule data reported is not delayed due to incompatibilities (e.g., different schedule tools or different reporting cycles) between the project's approach and the contractor's approach. This may be a cost impact, but the benefits must be traded from project to project.

5.3.17 Schedule Meetings

5.3.17.1 Lesson Learned: Schedule Updates

Schedule meetings should match the phase of the project (e.g., approximately every two weeks up through SRR, weekly from PDR until after CDR, then twice-a-week status meetings after that), with periodic updates given directly to the Mission Manager, as needed.

Rationale:

The reporting of schedule progress should vary depending on the phase of the project. A detailed approach for reporting schedule progress should be in the project plan because the project plan is the tool used to ensure agreement and participation of affected parties.

5.3.18 Schedule Tracking Tools

5.3.18.1 Lesson Learned: Rainbow Chart

In addition to the IMS, Projects should use special tracking tools such as colored coded charts to highlight issues and risks.

Rationale:

An example of a special tool used was a “rainbow chart” provided by Lockheed Martin to track harness development progress for Ares I-X. This tool provided a means for the Avionics IPT to provide status and communicate needs to the stakeholders. For example, the cable harness deliveries were often a threat to the critical path, but the rainbow chart helped highlight and communicate the magnitude of the issues and the risks. This data was used by decision makers to either replan or accept the risk.

5.3.19 Lean Event Requirements

5.3.19.1 Lesson Learned: Schedule Lean Event

A good schedule should be a candidate for a lean event when faced with a program management challenge (e.g., new scope, risk mitigation, and issue resolution). A lean event should only be a tool used by the project manager to assess a change or a problem.

Rationale:

When a schedule is well developed, normal tracking and reporting should be sufficient to raise alerts and corrective action. In the event that corrective action is needed a possible solution is to conduct a lean event. A lean event also can be used to accelerate a project, but it should be used to keep the project team on pace with the project requirements.

Lean Six Sigma is a combination of two well-known business improvement disciplines: Lean Manufacturing and Six Sigma. Lean processes emphasize reducing the overall cost of doing business and improving the value stream. Six Sigma is a quality improvement process, designed to reduce defects in manufacturing processes. Lean Six Sigma, then, seeks to reduce waste in business processes while improving technical quality.

To facilitate better understanding between CxP and Ares, a Lean Six Sigma summit was established to clarify safety requirements and approval processes for COFRs. An integrated team of individuals from Safety and Mission Assurance (S&MA), FITO, Ground Operations (GO), Ares Projects management, and the Ares I-X Vehicle Integration Office (AVIO) met at LaRC in April and May 2007 to conduct a comprehensive value stream mapping that would address three primary topics:

1. Risk acceptance philosophy
2. Decision and approval authority
3. Systems engineering processes

The meeting began by recapping initial work to date, identifying decision and approval flows, developing time and location maps, and ensuring that products and people were optimally deployed and synchronized to execute lean flight test readiness approval process ahead of schedule. The scope ended with Flight Test Readiness approval.

Team members from each IPT participated in their own Lean events as well as other IPT lean events.

Through these events, Ares I-X management gained an understanding of the “true” schedule drivers and developed a working core team trust that minimized risk and obtained insight into potential issues.

5.3.20 Monte Carlo Analysis

5.3.20.1 Lesson Learned: Schedule Monte Carlo

Consider using Monte Carlo techniques for scheduling, after CDR, assuming that designs, plans, and deliverables are well established. Use Monte Carlo to understand the pitfalls associated with schedule risk in which some activities that have more sensitivity to change than others.

Rationale:

A Monte Carlo analysis helps highlight sensitivities/pitfalls. Ares I-X applied Monte Carlo analysis with success about a year before flight. Using this tool earlier in the life cycle of the mission could have helped quantify schedule risks and mitigation approaches.

Note: The Monte Carlo process can reach the point of diminishing returns – sometimes it is better to apply the K.I.S.S. (Keep It Simple, Silly) principle. It is often better to use other approaches for schedule assessment (e.g., critical path method) when a small team of dedicated analysts can provide a good prediction of the end date. Ultimately, the key to good schedule analysis is validated data, therefore the team should be charged with ensuring assumptions are checked and robust.

Monte Carlo is a tool and not an exact science. If an organization is going to apply a Monte Carlo analysis to a schedule, then it needs to plan for that analysis as part of its scheduling process. It is very easy to fall into a situation where you get “Garbage In, Garbage Out” on analysis results. That said, the tool still can help a project drive out uncertainty in their scheduling projections.

5.3.21 Critical and Near Critical Path Assessment of Risk

5.3.21.1 Lesson Learned: Schedule Analysis

The scheduling team should focus on the critical path and the near-critical paths to identify schedule risk.

Rationale:

The most effective use of a scheduler’s time is to focus on activities that can have the most negative impact to the schedule such as the critical path or near-critical paths. A schedule analysis of the whole schedule is necessary, but is not a substitute for a stand-alone assessment of the critical path.

5.4 VEHICLE INTEGRATION ROLES AND RESPONSIBILITIES

5.4.1 Assembly, Integration, and Test Plan (AITP)

5.4.1.1 Lesson Learned: Success of the AITP

Develop a more complete AITP, early in the life cycle of a project, that clearly defines all requirements and IPTs' roles and responsibilities throughout the entire lifecycle of project (design through launch), with an emphasis on product deliverables and processes (e.g., hardware, software, requirements, etc.).

Rationale:

The AITP was developed late in the mission life cycle and included a requirement for IPT reporting that was not in the IPT implementation plans or in the prime contractor's contracts. The AITP also included sub-tier Avionics Integrated Test Plans, but only after some of the avionics hardware was already complete. The AITP should be baselined by CDR with an understanding that it is a living document, therefore there exists the possibility of cost and schedule impacts with all changes after CDR. The AITP will build in provisions for adding and modifying activities, which are to be expected, but baselining the document early will provide the impetus for early detail planning. Updates should be made via official change request (CR). The result is a *current* document throughout the *entire* lifecycle of the project.

The AITP written for Ares I-X attempted to document the processing flow as a concept of operations during Ground Operations (GO) at KSC. This approach worked well and yielded an accurate product that conveyed the concept of operations (CONOPS). However, the AITP did not fully document the associated detailed products and processes that would be utilized during assembly, integration, and testing; specifically, the owner of a particular product or process and the required support of a product or process was not documented. As a result, some IPTs assumed differing levels of roles and responsibility during the assembly, integration and testing phases that did not always agree. This varying level of assumptions among the IPTs created differing positions on level of responsibility and ownership of their role during processing. The assumption differences were eventually overcome through a steep learning curve, but in most cases could have been avoided entirely. Many assumptions could have been avoided by establishing and communicating a more detailed AITP that is process and product centric, and defines who owns the process or product as well as who is to support the product or process during a particular phase of the project.

Success of the AITP development and execution would be heavily dependent upon the appointment of a very knowledgeable, high/manager level, book manager that is intimately familiar with KSC processes and products required to execute all phases of assembly, integration, and testing. This book manager also would need to ensure that clear communication of expectations of all IPTs were understood and agreed upon during the development phase of the document. In order to define roles and

responsibilities as early as possible and ensure minimal downstream impacts, it is strongly recommended that the project commit to the development of the AITP after ATP.

5.4.2 Ground Operations 101

5.4.2.1 Lesson Learned: KSC 101

Adopt and implement a “KSC 101” course that is tailored to the work content of the project. This will be instrumental in educating team members on processes, practices, roles, and responsibilities during assembly, integration, and test.

Rationale:

The learning curve encountered by all IPT personnel supporting processing at KSC was very difficult to overcome. In the initial planning phases prior to hardware delivery to KSC, the GO IPT hosted a “KSC 101” course to educate the Ares I-X team on day to day processing activities at KSC. However, the course was more Shuttle Program- centric and not specifically tailored to all of the Ares I-X activities; therefore, much of the information was unclear to the non-KSC participants. A “KSC 101” course that is specific to the mission or vehicle would capture and communicate all processes and practices to key team members months prior to the actual assembly, integration, and testing efforts at KSC. This course would explain in specific detail GO’s processing contractors’ business practices including but not limited to: the Integrated Work Control System, scheduling system, constraints management process, information technology access, badging area access requirements, training requirements, configuration management process, requirements management process, non conformance process, logistics process, DD250 & DD1149 processes, facility-specific CONOPS, launch team plans, and local safety requirements. Having intimate knowledge of these processes and practices utilized at KSC beforehand would facilitate and assist to answer questions and eliminate assumptions regarding roles and responsibilities amongst IPT personnel during actual flight hardware assembly, integration, and test.

5.4.3 Concurrent Engineering

5.4.3.1 Lesson Learned: Concurrent Engineering Process

Implement the concurrent engineering process before CDR.

Rationale:

As a mitigation of the risk of late requirements delivery, the project implemented a concurrent engineering (CE) process to expedite the delivery of all products (e.g., Operational Test Requirements (OTRs and assembly drawings) needed to support vehicle assembly, integration, and test.

The CE process was implemented for SE&I, CM/LAS, USS, and AVI. The FS IPT had implemented their specific version of the CE process known as the Integrated Product & Process Development (IPPD) prior to the project implementation. Also, the RoCS IPT had developed and baselined their requirements in advance of the CE process.

Overall, the CE process was a very successful effort that provided a streamlined approach for concurrently releasing assembly drawings, OTRs, inspection plans, hazard analyses, and Work Authorization Documents (WADs). All impacted IPTs worked together throughout the process resulting in reduced design and process iteration for these products. The CE process helped to establish key relationships between IPT personnel. Once these relationships were established, it created a mechanism to communicate and understand the flight hardware requirements and roles and responsibilities during the assembly, integration, and testing of the vehicle. Lastly, the CE process allowed for an informal technical forum to work requirements and or issues with all the necessary stakeholders present.

The success of the CE process implementation and execution is heavily dependent upon the appointment of very strong leadership that is intimately familiar with KSC processes and products required to execute all phases of assembly, integration, and testing and the many design processes and analyses utilized by the IPTs. These leaders need to act as facilitators, integrators, and outstanding communicators and must truly possess systems engineering skills. Adopting and implementing the CE process before CDR is strongly recommended.

5.4.4 Technical Review Board (TxRB)

5.4.4.1 Lesson Learned: Review of GO Technical Issues

Use a TxRB during processing to support project-defined processes is encouraged. As noted in 5.2.1, Number and Types of Control Boards, the Ares I-X TxRB was responsible for addressing technical issues related to Ground Operations processing at KSC. The Mission Manager was still responsible for approving decisions with cost and schedule impacts over a threshold.

Rationale:

All IPTs assumed differing levels of involvement during integration and testing. Varying assumptions did not always agree between IPTs, thus creating differing positions on the appropriate level of involvement and roles & responsibilities during processing. The AITP attempted to document IPT roles and responsibilities throughout the entire lifecycle of the project, specifically design through launch, but did not fully document detailed processes that would be used during integration and testing (e.g., OTR Waiver/Exception). To better facilitate processing at KSC, a TxRB should be authorized after CDR to make decisions concerning integration ground processing. Additional options include using other boards such as the SERF to handle this responsibility. Note: First Stage rarely utilized the TxRB, but it had the resources and processes of the Ares I

First Stage Office and Shuttle heritage tools. Additionally, the MM and the TxRB chair had offices next to each other so coordination on resolution paths occurred multiple times per day allowing the TxRB chair to make efficient decisions that maintained the processing flow.

5.5 MMO-CENTER INTERACTIONS

5.5.1 Institutional Practices

5.5.1.1 Lesson Learned: Overlapping Reviews

Very strong institutional and programmatic ways of doing business are difficult to change; therefore, establish an agreed upon early review process, with institutional involvement, to eliminate conflicting or overlapping reviews.

Rationale:

NASA centers each have their own special history, institutional culture, and unique practices that affect how business is done. Technical and procedural terminology is different between or among centers, and there are variations in practices and procedures for verification, integrated testing, engineering file formats, and review processes which can impact the program. These inter-center differences mean that future mission teams will need to establish review processes early to eliminate conflicting or overlapping engineering reviews. Another lesson learned while developing the avionics for Ares I-X was that contractor processes are different from, and in some cases more applicable to, the project at hand.

5.5.2 Center Buy-off

5.5.2.1 Lesson Learned: Resources

NASA centers' management must allocate resources required to perform a project, both personnel and facilities. Centers are also partners with the projects on risk management.

Rationale:

Ares I-X was not a project per the requirements in NPR 7120.5D because it was a flight test defined by a Flight Test Plan (FTP) prepared by the program. Although Ares I-X was not a project, it followed the applicable project requirements in NPR 7120.5D such that the FTP and Mission Implementation Plan (MIP) were reviewed by NASA HQ. The FTP clearly defined responsibilities including center allocations. The centers respectfully acknowledged the flow-down of responsibilities and conducted Center Management Council (CMC) meetings and iCMCs at the appropriate levels to ensure smooth integration across centers. The centers also leveraged the reporting process of the IPTs' managers, SE&I Chief, deputy mission managers, and the Technical Authority representatives. Center representatives were also invited to participate in planning

sessions such as the Lean Event in July 2008 that streamlined the acceptance review process.

5.5.3 Dual Roles of Mission and Center Management

5.5.3.1 Lesson Learned: Governance

Mission deputies, IPT leads, TAs, SE&I chief and Project Integration (PI) managers should have dual-role accountability to the Mission Manager and Center Management. This dual accountability ensures the mission can be implemented as planned and centers can be engaged/informed of mission status/needs.

Rationale:

The dual role of Ares I-X Deputy Mission Managers, PI Manager, SE&I Chief, Chief Safety Officer (CSO), and Chief Engineer facilitated communication therefore ensuring preparedness for flight readiness.

5.5.4 External Communications

The Ares I-X MMO relied on both traditional and new communication methods to share its message with important stakeholders, including elected officials, the public, news media, employees, and industry. These methods included the following:

- Press conferences
- Technical papers
- A dedicated NASA web site (http://www.nasa.gov/mission_pages/constellation/ares/flighttests/aresIx/index.html)
- A NASA blog site (http://blogs.nasa.gov/cm/blog/Ares%20I-X/)
- A Facebook page (http://www.facebook.com/group.php?gid=77195835389)
- A Twitter account (http://twitter.com/nasa_ares_i_x)

Methods also included exhibits and informational collateral, which appeared at technical and non-technical conferences across the country before and after the flight test. The content was developed by NASA Public Affairs Office (PAO) personnel at the mission centers (i.e., GRC, JSC, KSC, LaRC, and MSFC) and NASA Headquarters, as well as technical writers and exhibits personnel at those centers.

5.5.4.1 Lesson Learned: Graphic Artists Training

Mission graphic designers/artists should be familiar and trained in NASA standards, practices, and approval processes regarding the appearance of public outreach materials.

Rationale:

There were several occasions when MMO managers agreed to a set of graphics that were prepared by Ares I-X graphic designers/artists, only to have those graphics

rejected by the NASA Communication Materials Review (CMR) process. If the graphic designers/artists had been more familiar with the CMR standards and processes, they would have gotten that approval before presenting graphics to the MMO.

5.5.4.2 Lesson Learned: Outreach Material

Needs and lead times for outreach materials should be determined in advance to ensure that they will be available when needed based on production lead times.

Rationale:

A set of “baseball cards” (i.e., facts sheets) was developed for Ares I-X, but they were not printed in time to be distributed on the day of the launch. As a result, only team members at LaRC received them.

5.5.4.3 Lesson Learned: Coordinated Support

Having the support of program, project, directorate managers, and Center management is very important as well as the backing of the Agency when organizing and implementing a highly visible event such as Ares I-X).

Rationale:

Obtaining resources, such as funding, people, and event support for Ares I-X was a challenge, because event planners were awaiting direction on how to proceed and to what extent the milestone should be recognized.

5.5.4.4 Lesson Learned: Funding for Special Events

Obtain funding for guest operations, animation videos, education, public outreach, and internal and external communications activities early in the project and continue with funding throughout the planning, implementation, and wrap up of the event.

Rationale:

External communications efforts for Ares I-X did not receive early funding and it was a challenge to find funding once the project was under way since it all was external to Ares I-X.

5.5.4.5 Lesson Learned: Funding Conflicts

Funding by codes for media events and special operations does not necessarily fund support on media events and special operations for all projects.

Rationale:

Ares I-X events occasionally did not or could not receive the assistance or resources needed from other NASA projects or parts of the Constellation Program because of funding codes. For example, the space shuttle funds imagery during the launch of a shuttle but that does not cover the launch of other vehicles. Note: arrangements were

made to obtain the imagery for Ares I-X. Also, travel expenses for MSFC external communicators such as event planners, speech writers, etc. had to be paid out of institutional funds because there was no Ares I-X money available.

5.5.4.6 Lesson Learned: Facebook

Social media sites (e.g. Facebook, NASA.gov dedicated site/page) should become a normal and early part of a mission's public outreach and education plan.

Rationale:

The Internet has become the default location for private citizens to access information and get involved in causes and activities they enjoy. Individuals interested in space exploration are particularly likely to use the internet to obtain information. Dedicated Facebook, NASA.gov, and other sites are excellent channels for keeping the public informed, assuming they do not consume too much of the communications team's time to maintain. The Ares I-X Facebook page acquired 1,300 "fans" by launch day, another 300 on the day of launch, and as of March 11, 2010, had 2,115 fans, despite the communications team no longer posting after the day of launch.

5.5.4.7 Lesson Learned: Technical Writer

Programs/projects need to request a dedicated PAO, media writer, and/or technical writer from the outset. These individuals, embedded within the organization, need access to information about project progress, mission objectives, and hardware descriptions.

Rationale:

External communications professionals can help ensure early and regular communication with the public via technical papers, press releases, presentations, and outreach collateral. This regular public outreach is especially important for large projects with a lot of visibility. The earlier professional communicators are brought into a project, the more familiar they will be with the content and the less need they will have to ask subject matter experts for inputs during real-time information requests from the media or other stakeholders.

5.5.4.8 Lesson Learned: Setting Expectations

Mission managers and external communicators need to set expectations up-front regarding the possible outcomes of the test.

Rationale:

Obtaining information for-public-use to describe mission success in layman's terms was a challenge because of the complex nature rocket design.. The purpose would be to explain to the public how the engineering process works and why failures or anomalies are useful for the long-term development process from a test. This work also would

include the need for candor and clear communication if a mission had a failure. Expectation setting is especially important for agency messaging—the public needs regular reminders of what might or might not happen so that unnecessary “surprises” can be avoided; for example, the perceived near miss between the USS and the First Stage after separation was not anticipated by the media. Ares I-X started conducting discussions with the media over a year prior to launch and increased the level and volume of communications with the media as the launch date approached. In summary, the discussion with the media should include a continuous focus on the success criteria as well as other possible scenarios.

5.5.4.9 Lesson Learned: Technical Support for Writing

External communicators need designated points of contact for answering questions about specific aspects of the mission (e.g. propulsion, avionics, and GO) prior to and during the mission.

Rationale:

PAOs and technical writers often depend on subject matter experts (SMEs) to provide technical content for specific deliverables such as papers, press releases, fact sheets, etc. or to fact check content developed by the communicator. While public outreach is not a primary function of anyone working a technical project, NASA is still expected to inform the public about its missions. Media outlets expect information quickly, and typically get their information from the PAO, which depends on SMEs if the content is not already available. PAOs and other technical communicators need to know whom to tap for quick, easy access to mission information in real time.

5.6 TECHNICAL AUTHORITY (TA)

5.6.1 TA Chain of Command

5.6.1.1 Lesson Learned: TA Path

The TA path should be consistent and established at ATP.

Rationale:

The Ares I-X Chief Engineer’s chain of command went through LaRC while the CSO’s chain of command went through the CxP CSO. This was not consistent, resulting in uncertainty in the chain of command leading up to CDR.

5.6.2 Multiple Chief Engineers

5.6.2.1 Lesson Learned: Chief Engineer

A project should have a lead Chief Engineer.

Rationale:

If a project has more than one Chief Engineer, it can result in decision conflicts. The original plan for the flight test was to use two equal Chief Engineers: one with responsibilities for the flight vehicle and the other for ground operations. This changed to a lead Chief Engineer for the entire mission/system because the mission/system, when integrated, consisted of both vehicle and operations.

5.6.3 Role of the Lead Engineer (LE) vs. the LSE

5.6.3.1 Lesson Learned: IPT Lead Engineer

The Lead Systems Engineer (LSE) should not be the Technical Authority Lead Engineer's (LE) representative at the IPT or SE&I level.

Rationale:

The IPTs and SE&I were arguably complex enough to separate the role of LSE from LE. This is the case at the mission level where there is a dedicated LSE for the mission and a dedicated Chief Engineer, but at the lower/IPT level, there exists the option of combining the LSE/LE role. Separating the two functions depends largely on the complexity of the responsibilities. For Ares I-X, the choice was to have both a LE and a LSE at the IPT level.

Per NPR 7120.5D, Lead Discipline Engineers (LDE) [known as LEs for Ares I-X], are extensions of the Chief Engineer at lower levels of the system, project, or mission. For complex missions and systems such as a rocket development, the LSE has enormous responsibilities; therefore, giving the LDE assignment to a separate individual will be more effective. Each level in the system must decide if the LSE can handle the role of the LE simultaneously.

5.6.4 SERF/ERB

5.6.4.1 Lesson Learned: Combining Boards

Combining the Ares I-X SERF and ERB was very efficient and effective.

Rationale:

The combination SERF/ERB resulted in timely decision making because this forum assured that key participants (e.g., Chief Engineer and the LSE) were represented.

5.6.5 Number of Decision Boards

5.6.5.1 Lesson Learned: Number of Boards

The level/number of subordinate boards should be well defined at the beginning of the project. See also 5.1.2.1, Decision Layers, and 5.2.1.1, Review Boards.

Rationale:

Defining the functions or activities required by a board can help determine how many boards and types of boards are required. This can be a continuous process that changes the number of boards as the project progresses.

5.7 GENERAL PROJECT INTEGRATION / CONFIGURATION AND DATA MANAGEMENT (CDM) LESSONS LEARNED

5.7.1 Lesson Learned: Timeframe for Implementing CDM

Implement CDM practices before defining the system requirements and its design.

Rationale:

Start early; don't wait until the project is well underway to establish CDM requirements. CDM requirements should be endorsed early by the Project Manager and specified in the project's high-level documentation (e.g., the System Requirements Document's "shall" statements are corroborated in the Project Plan). Programmatic CDM requirements should carry no less weight than technical requirements. The project is dependent on both technical and programmatic disciplines to accomplish its objectives.

5.7.2 Lesson Learned: CDM Accountability

Effective CDM implementation, whether distributed or not, calls for direct accountability to the highest project authority to provide visibility into CDM activities, succinct lines of communication, and an unambiguous reporting structure for CDM team members.

Rationale:

As the development approach matures, clear lines of organizational responsibility begin to emerge. Accountability is defined, and a reporting structure is put into place. Once this is done, authorizing documentation (e.g., Project Plan, Systems Engineering Management Plan, CDM Plan, and SRD) is generated as a basis for project management decision making.

5.7.3 Lesson Learned: CDM Life Cycle Process

Implementing a mature life cycle CDM process model provides both technical and programmatic insight into a project.

Rationale:

For CDM this means timely identification and control of products instead of after-the-fact capture of artifacts. For the project it means an opportunity to identify risks and to establish appropriate processes to mitigate risks.

5.7.4 Lesson Learned: CDM Distributed Environment

Implementing CDM in a distributed project environment requires a disciplined approach.

Rationale:

Project implementation in a distributed environment must consider culture and geographical differences, in addition to the diversity of business goals for a particular site or center. What is important for one may not be important for another. The actual implementation should reflect a consensus between centers that is supported by all.

5.7.5 Lesson Learned: Team Member Awareness

After identification of the team members, develop mechanisms to keep all team members aware of what is happening across the team.

Rationale:

The distributed project environment lends itself to miscommunication and a feeling of isolation by team members. The Ares I-X Newsletter was prepared and distributed, approximately once a week, starting at CDR.

5.7.6 Lesson Learned: CDM Training

The CDM Plan should reflect a common understanding of all team members not just those that wrote it. Training on this is important for the team.

Rationale:

The Project Manager should approve the CDM Plan before implementation activities begin. This approach authorizes the CDM activities at the proper level and prevents misconceptions and false starts in the CDM process. Once the CDM team reaches a common understanding of the approach, the CDM Plan is drafted and then communicated to management for buy-in and approval. Following an approved CDM Plan provides a credible, best-practices approach to the CDM planning activities.

Many questions are answered and decisions made during the course of CDM Plan development. Questions such as, what are the system components to be controlled? How will each of the components be controlled? At which project milestones will control begin? And how will the components be verified prior to delivery? The CDM Plan should include decisions on what tools are used to facilitate the CDM activities, change authorities for proposed changes to baseline products, and how CDM procedures are documented and approved.

5.7.7 Lesson Learned: Project Integration Requirements

Establish project integration requirements for CDM that meet the needs of a distributed work environment without compromising the intent of the CDM objectives.

Rationale:

Establishing PI requirements provides an opportunity to consider usability issues and buy-in from users, thus reducing risk during implementation. An added benefit is an increased likelihood of user acceptance of the CDM procedures.

5.8 CM/DM DETAILED LESSONS LEARNED

5.8.1 Lesson Learned: CDM Responsibilities

Define CM/DM functions/responsibilities as early in the flow as possible. Try and use the same processes as much as possible. Define all these in the plan and use the same for the different elements. Understand how other elements make changes and how they are recorded.

Rationale:

Ares I-X comprised team members from different centers and cultures. To this end, it was very advantageous to get different centers to establish clear management and processes as early as possible in the life cycle of the mission by agreeing to and working to common practices. The longer the common processes take to become established, the greater possibility of two or more processes having to be merged into one. Starting with a common process is easier than merging existing processes.

5.8.2 Lesson Learned: Model Formats

Require contract deliverables to be in the same format (e.g. models, drawings, etc.), using common applications. See also 4.5.3.1, CM Control of Models and Analyses.

Rationale:

Any time products have to be integrated, the best practice is to have the products adhere to a common format. A common format will reduce the risk of interpretation and reformatting errors. A cost-benefit analysis should be performed because each project is different.

5.8.3 Lesson Learned: Records Management

Start out with CM/DM Records (i.e., Change Requests [CRs], Data Requirements [DRs], Problem Reports [PRs], Waivers, etc.) in a database (DB) like Microsoft Access to help ensure that all records are in one place/one DB).

a) Enforce Checkout/Check-in rules immediately for DB repository (i.e., Windchill).

b) Anyplace a Microsoft Excel Spreadsheet is used, a DB can be used instead. A DB helps enforce standardization: e.g., one “Field” with a pick list can replace several columns.

Rationale:

A DB is a tool which, when applied effectively, can help manage data more efficiently. Ares I-X had a lot of data, but was also a one-time mission; therefore there were pros and cons to developing a database structure. Ares I-X did use DBs for managing requirements, risks, and issues. Excel was used to manage other data, but one should note that Excel is also a simple form of a DB.

5.8.4 Lesson Learned: Archive Plan

Start out with an Archive Plan and begin archiving early so it is only a matter of updating data when the Project is completed.

Rationale:

A project life cycle also includes the closeout and disposal phase. Various names are used to plan for this phase. Development of an archive plan is one approach, although this type of planning can be documented in the CM/DM plan. The bottom line is that awareness of archiving should start on day one of the mission.

5.8.5 Lesson Learned: Technical Sub-boards

Start technical sub-boards earlier rather than when the need becomes critical. Each board's duties need to be defined in very specific detail.

Rationale:

There was some confusion in Ares I-X, at times, regarding which board handled what responsibilities.

5.8.6 Lesson Learned: Information Technology Access

Early in the project, apply for personnel access to locations, applications and systems (HOSC, Solumina, KSC data/computer sites, Windchill, KSC access badging, etc.).

a.) Obtain a non-disclosure agreement (NDA) for subcontractors early in the project, if required.
b.) Obtain whatever clearances may be needed early in the project. Assign points-of-contact for each resource to get the access done as fast and efficient as possible.

Rationale:

Ares I-X employed a PI office to facilitate personnel access needs. Larger organizations with more resources typically have more defined roles to administer resources. This is a trade that every project must make.

5.8.7 Lesson Learned: Email Addresses

Make sure the project has all contractor personnel email addresses in a central address book or provide the contractor personnel with a NASA email address.

Rationale:

On occasion, some contractors were not invited to board meetings because email addresses were not available.

5.8.8 Lesson Learned: Standardized CDM Instructions

No CM work instructions existed for Ares I-X. There were no standardized instructions (Organizational Work Instructions [OWIs] and Modification Work Instructions [MWIs]) available for processing of engineering change request, engineering orders, waivers/deviations, and other specific IPT/SE&I change processes.

Rationale:

Although this may seem to be a disadvantage, the lack of standardized instructions allowed for flexibility and adjustment in a fast-paced environment like Ares I-X. The processes in the CM Plan evolved along with the program and were adjusted to minimize work stoppages.

5.8.9 Lesson Learned: Document Storage

Utilize one document storage system and a seamless transfer of data. Projects need to take advantage of Windchill's capabilities.

Rationale:

Ares I-X was supported by several IPTs that built the different elements that were integrated into the Ares I-X flight test vehicle. The IPTs had different data applications, and the integration process involved transfer of data (e.g., drawings, models, etc.) across several databases. It ended up being a manual process because the databases were not linked automatically.

5.8.10 Lesson Learned: CM Tools

A tool for CM processes (e.g., changes, accounting, approvals, closures, etc.) would be beneficial by adding efficiency.

Rationale:

Most of the CM processes were manual. The baselining of integrated drawings was the only process that incorporated approval signatures in Windchill. Teams need to take advantage of Windchill's capabilities such as searches. Training is required to understand the embedded capabilities of complex databases such as the ICE Windchill application.

Also, as the launch day got closer, the closure of XCB related artifacts depended upon minutes being approved. This process was not as expedient as desired. An automated system with signatures and comments might help alleviate this problem.

CLOSING:

Ares I-X worked well together as a tight team that functioned across both Center and contractor boundaries. The team thanks you for your interest in Ares I-X and if you ever need any additional information please let any of the Ares I-X managers listed below know how they might help.

- Ares I-X Mission Flight Test Team Points of Contact:
- Bob Ess, JSC, Mission Manager
- Ed Mango, KSC, Launch Director
- Steve Davis, MSFC, Deputy Mission Manager
- Jon Cowart, KSC, Deputy Mission Manager
- Bruce Askins, MSFC, Project Integration Manager
- Marshall Smith, LaRC, SE&I Chief
- Jonathan Cruz, LaRC, CM/LAS IPT Manager
- Vince Bilardo, GRC, USS IPT Manager
- Ron Unger, MSFC, RoCS IPT Manager
- Chris Calfee, MSFC, First Stage IPT Manager
- Kevin Flynn, MSFC, Avionics IPT Manager
- Mike Stelzer, KSC, GS IPT Manager
- Tassos Abadiotakis, KSC, GO IPT Manager
- Joe Brunty, MSFC, Chief Engineer
- Shaun Green, KSC, Chief Engineer
- Dawn Stanley, MSFC, Assistant Chief Engineer
- Dan Mullane, MSFC, Chief Safety Mission Assurance Officer

Shown above is the Ares I-X team at one of the designated Launch Control Center sites

APPENDIX A – ACRONYMS AND ABBREVIATIONS

ADP	Acceptance Data Package
AITP	Assembly, Integration, and Test Plan
AIX	Ares I-X
ATP	Authority to Proceed
AVI	Avionics
AVIO	Ares I-X Vehicle Integration Office
CAD	Computer Aided Design
CDR	Critical Design Review
CE	Chief Engineer
CE	Concurrent Engineering
CM	Configuration Management
CM	Crew Module
COFTR	Certification of Flight Test Readiness
CONOPS	Concept of Operations
COTS	Commercial Off the Shelf
CR	Change Request
CSO	Chief Safety Officer
CxCB	Constellation Control Board
CxP	Constellation Program
DDD	Design Definition Document
DFI	Developmental Flight Instrumentation
DR	Data Requirement
DRD	Data Requirement Document
DXCB	Development Flight Instrumentation Control Board for Ares I-X
EDF	Electronic Development Fixture
ERB	Engineering Review Board
ERO	Element Requirement Owner
FEC	Field Engineering Change
FITO	Flight and Integrated Test Office
FOD	Foreign Object Debris
FS	First Stage
FTP	Flight Test Plan
FTRR	Flight Test Readiness Review
FTV	Flight Test Vehicle

GO	Ground Operations
GRC	Glenn Research Center
HQ	Headquarters
HW	Hardware
ICD	Interface Control Document
ID&A	Integrated Design and Analysis
IPPD	Integrated Product & Process Development
IRD	Interface Requirements Document
JSC	Johnson Space Center
KSC	Kennedy Space Center
IPT	Integrated Product Team
ISS	International Space Station
LaRC	Langley Research Center
LAS	Launch Abort System
LCC	Launch Commit Criteria
LM	Lockheed Martin
MLP	Mobile Launcher Platform
MMO	Mission Management Office
MRB	Material Review Board
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NDA	Non Disclosure Agreement
NESC	NASA Engineering and Safety Center
OT&I	Operations and Test Integration
OTR	Operational Test Requirements
PDR	Preliminary Design Review
POC	Point of Contact
R&R	Role and Responsibilities
RoCS	Roll Control System
RSRM	Reusable Solid Rocket Motor
S&MA	Safety and Mission Assurance
SE	System Engineer
SE&I	Systems Engineering and Integration
SEIB	Systems Engineering and Integration Board
SERF	Systems Engineering Review Forum
SIL	Systems Integration Laboratory

SRB	Solid Rocket Booster
SRD	System Requirements Document
SRO	System Requirement Owner
SW	Software
TA	Technical Authority (CE and/or CSO)
TBE	Teledyne Brown Engineering
TIM	Technical Interchange Meeting
TxRB	Technical Review Board for Ares I-X
ULA	United Launch Alliance
USA	United Space Alliance
USS	Upper Stage Simulator
VAB	Vehicle Assembly Building
VP	Verification Product
VRDS	Verification Definition Requirement Sheet
WAD	Work Authorization Document
XCB	Ares I-X Control Board