NASA
Exploration Systems Mission Directorate
Ares I-X Knowledge Capture

Volume II: IPT ThinkTank Session Results









Ares I-X Project Management and Integrated Product Teams

ESMD Risk & Knowledge Management Office

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1.0 Introduction

Volume II of the ARES I-X Knowledge Capture Report encapsulates the results (i.e., the raw *lessons learned* input) from the ThinkTank Sessions conducted with each Integrated Product Team (IPT) after the successful test flight on October 28, 2009. Following a brief overview of the knowledge capture (KC) methodology, KC process, and KC transfer and communication, the detailed session reports from each IPT are presented in Section 2.0, followed by key lessons learned on Engineering Technical Authority and Configuration & Data Management.

KC Methodology

The KC activity was designed as a story telling-based, “high yield – low impact” effort that imposes minimal impact on busy program/project teams. KC process features included:

- Structured engineering management thematic framework for knowledge capture
- Rigorous time-management
- Storytelling interview format
- Telephone – one hour interviews with IPT Leads
- On-site, face-to-face, 3-Hour IPT Knowledge Capture process with 5-15 IPT members

The thematic framework used in the knowledge capture process included:

- Engineering Management
- Systems Engineering
- Requirements Management
- Organization
- Test and Verification
- Resources
- Technical Authority (S&MA and Engineering)
- Schedule
- Design
- Manufacturing
- Communication

The KC process focused on eliciting mini-stories or vignettes from integrated product team (IPT) members relevant to each of the thematic areas. To initiate the thought process, each participant was asked to consider three questions:

1. Up front, early on we should have ______________________________.

2. Our team really did well with ____________ because of ____________.

3. If I were” King/Queen,” the top 3 things I would change are _____________________.

Each lesson learned (ideally) can be considered to incorporate a challenge, a management response and/or outcome combined in a contextual short story. The Ares I-X KC process has pulled together nearly one thousand individual "issues."

Knowledge Capture Process

The ESMD KC process begins with a series of "kickoff" activities, including coordination with project management, identification of key contacts, and preliminary schedule planning. The second step "discovery," is when the KC-team comes up to speed on the project background, including the Design Reference Mission (DRM), success criteria, Centers, contractors, and existing ESMD risk records or other documented issues. At this step, a wiki-space will typically be established to assist in document management and planning. The discovery process also provides the necessary background to initiate the Knowledge Based Risk (KBR) process that may be conducted in parallel with the KC process.

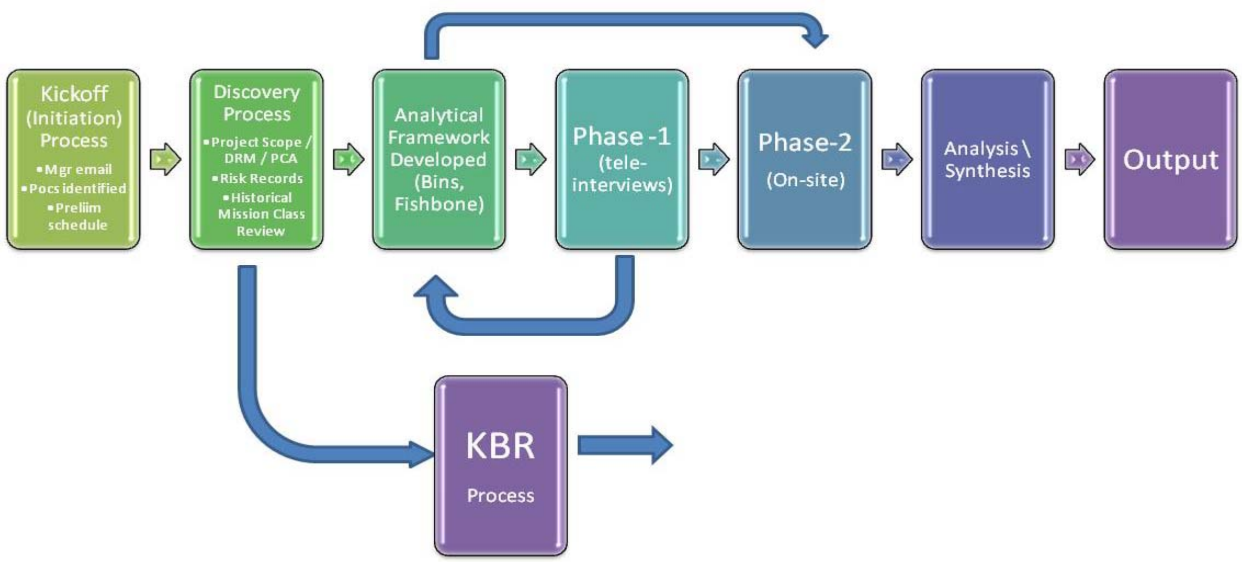

Figure 1: KC Process Flow

Step 3 involves development of the analytical framework for the analysis. This framework can be considered a taxonomy used to stimulate and guide knowledge capture discussions (telephone interviews). The framework may be represented as a fishbone diagram and/or "bins or buckets" within the ThinkTank tool used in the on-site interviews. Step 4 involves one-hour telephone interviews with IPT-leads, or equivalent subsystem-managers.

Feedback from telephone interviews is used to refine the analytical framework in preparation for on-site activity. The on-site team interviews will typically involve 7-10 members of the IPT or equivalent subsystem team. Following the field work is a period of analysis and integration followed by a report and a series of knowledge transfer products (see Knowledge Transfer & Communication section below).

A powerful laptop-brainstorming tool, ThinkTank, is typically employed to assist in gathering issues and opportunities for improvement. ThinkTank provides a web-based solution for gathering ideas simultaneously from multiple participants, and it allows the session leader to quickly organize inputs into logical bins (figure 2) so that information can be voted on by the group to establish a rank-ordered, prioritized list of ideas (figure 3) that represent the best path forward as determined by the "wisdom of the group." The results of a ThinkTank session are then easily exported to a text-based document for further use outside the software.

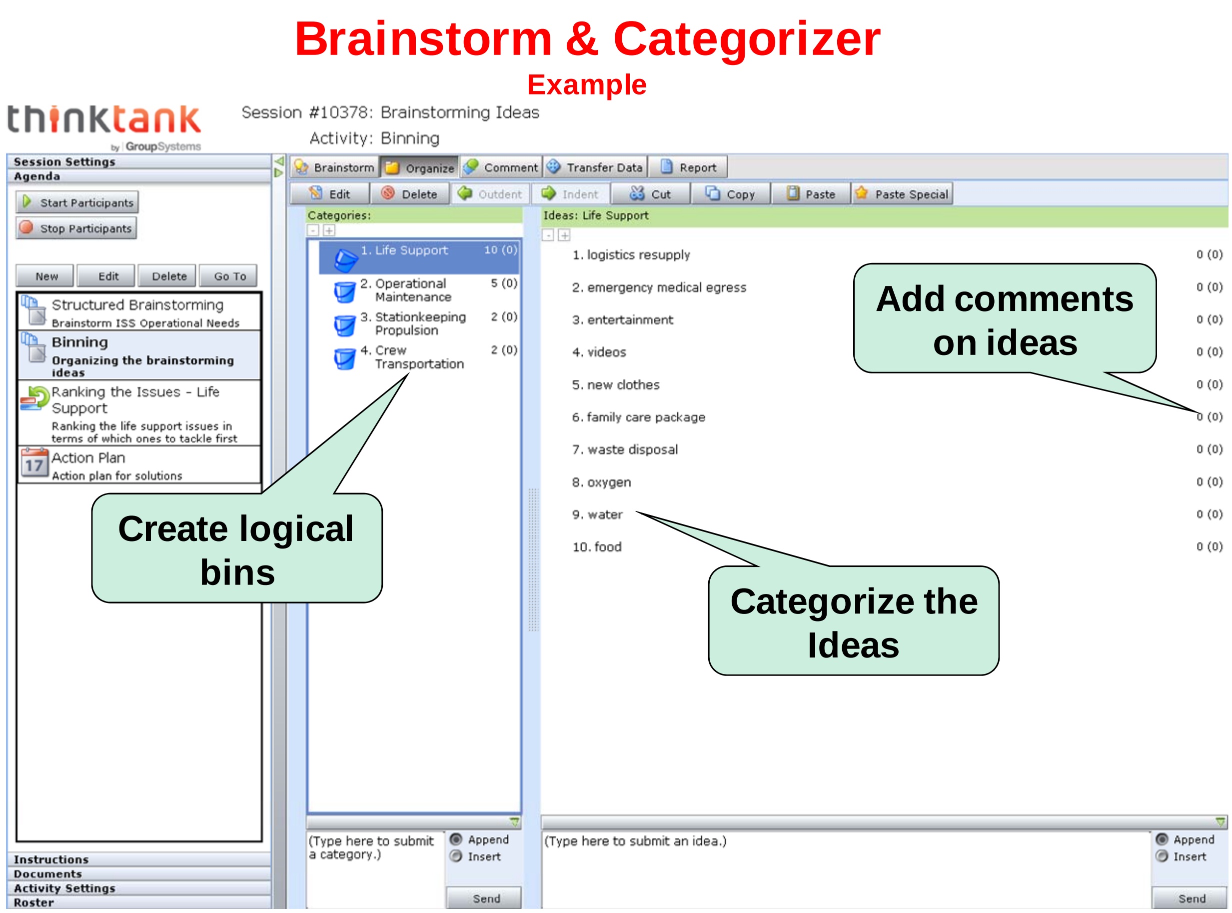

Figure 2: ThinkTank Brainstorming and Categorization

Rank Order Vote

Example

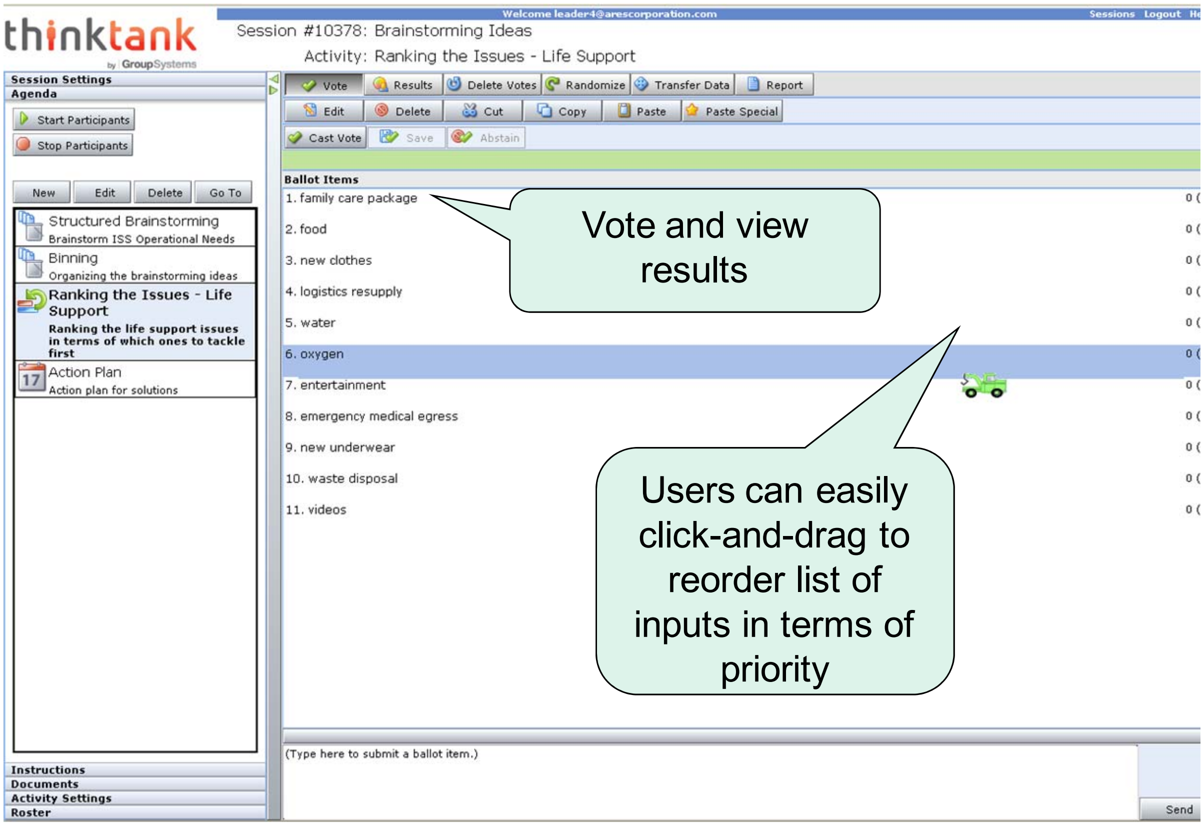

Figure 3: ThinkTank Rank Order Voting

Knowledge Transfer & Communication

Delivery and communication of Ares I-X knowledge capture content will employ multiple modalities including:

Ares I-X Briefings: This methodology involves briefing chart presentations to ESMD Level I / II / III management (HQ, Constellation, Ares, Orion, Ground Ops, etc.) and Mission Support Offices (Office of Chief Engineer (OCE), Office of Safety & Mission Assurance (OSMA). Further partnering with OCE and OSMA will involve providing links to the OCE, Lessons Learned Information System (LLIS) and the NASA Safety Center PBMA-Knowledge Management System (PBMA-KMS).

Ares-I Critical Design Review: Some Ares I-X lessons may be deemed critical enough to be used as part of the Ares-I Critical Design Review (CDR). These lessons will be provided to the Ares-I Project as a checklist to be considered as part of the CDR entry/exit criteria.

Peer Assists: This methodology involves making available specific Ares I-X team members to Constellation or Level II projects upon request for the purpose of a very specific knowledge exchange between peers. These problem-solving sessions can last between ½ to 2 days.

Interactive Cafés: This methodology leverages small group brainstorming and problem solving and is normally a facilitated event. Multiple topics may be addressed by Ares I-X personnel with Constellation or Level II projects with participants rotating among topics after short (usually 30-40 min) focused discussions. Topics are aligned with the knowledge capture themes.

ICE Wiki implementation (multi-media): This methodology involves a long-term, passive delivery process of Ares I-X knowledge captured and codified in the ICE wiki environment. It would preferably be accompanied by video interviews and other Ares I-X artifacts (e.g., documents, reports, etc.).

Knowledge-Based Risks: This methodology also provides a long-term preservation of Ares I-X knowledge in the form of a risk record and storytelling narrative which includes how the risk was mitigated—what worked or didn't work.

Ares I-X IPT Lead Briefings: This methodology calls upon Ares I-X Managers and IPT Leads to "hit the road" with storytelling/conversation briefings for program and project teams within ESMD and across the Agency sharing those lessons with broad, crosscutting applicability.

Ares Projects Assessment: Because of the difficulty in getting already busy project teams reading lessons learned and figuring out how to incorporate them, an assessment may prove a more effective approach at actually transferring lessons learned. For example, the lessons learned from Ares I-X could be turned into an assessment guide, and knowledgeable Ares I-X personnel could "audit" the Ares-I program to identify where the lessons learn best fit and identify the specific activities that need to happen to effectively incorporate the lessons.

Multimedia Case Study: There is a great opportunity to create a multi-media based case study similar to other successful ESMD case studies (e.g., the Super Lightweight Tank Case Study). This would feature lessons learned across several engineering disciplines, and incorporate video of the Ares I-X key participants to emphasize these lessons. The course is designed as a half-day classroom course where project teams identify their approach, which is then compared to that of the "experts" via video. Conducting these sessions throughout the Ares Project would enable the lessons to be tailored to the needs of each particular group.

2.0 Laptop Brainstorming (ThinkTank) Session Results

ARES I-X Knowledge Capture (KC) activities were conducted in two phases: 1) telephone interviews with IPT Leads, and 2) on-site KC activities with IPTs (6-15 people).

Ares I-X IPT Lead Telephone Interviews

For Phase 1, IPT Leads were interviewed using a risk-informed question set in a one-hour timeframe. Results of these interviews were used to build the IPT "story," and they were also used to frame the discussion at the IPT "Team-Level".

Team / Interviewee	Interview Date
CM/LAS IPT – Jonathan Cruz/LaRC	May 27, 2009
Roll Control Systems IPT - Ron Unger /MSFC	May 29, 2009
Upper Stage Simulator IPT – Vince Bilardo//GRC	June 25, 2009
Avionics IPT – Kevin Flynn/MSFC	July 24, 2009
Ground Systems IPT - Mike Stelzer/KSC	July 24, 2009
First Stage IPT - Chris Calfee/MSFC	August 5, 2009
Grounds Operations IPT - Tassos Abadiotakis	August 6, 2009
SE&I IPT - Marshall Smith	September 23, 2009
Technical Authority – Glen Jones	September 25, 2009
Project Integration Manager – Bruce Askins	September 29, 2009
Mission Management Team - Jon Cowart / Steve Davis	September 30, 2009
Mission Manager – Bob Ess	October 6, 2009

IPT On-site KC Sessions

Phase 2 involved structured interviews of 6-15 IPT team members at their Center.

Team / Interviewee	Date
Ground Operations (KSC)	November 4, 2009
Ground Systems (KSC)	November 4, 2009
S&MA (MSFC)	November 9, 2009
Rocs (MSFC)	November 9, 2009
1st Stage morning (MSFC)	November 10, 2009
Avionics (MSFC)	November 10, 2009
Upper Stage Simulator (GRC)	November 13, 2009
CM/LAS (LaRC)	November 16, 2009
SE&I (LaRC)	November 16, 2009
Engineering - Technical Authority (MSFC)	February 16-18, 2010

The following sections (2.1-2.9) summarize the results of the Phase 2 KC ThinkTank Session Results for each IPT. Sections 2.10 and 3.0 provide insights gained from Engineering Technical Authority and Configuration & Data Management, respectively.

2.1 Ground Operations IPT Knowledge Capture

1. Engineering Management / Systems Engineering and Integration

1.1. Lack of Detailed Assembly Drawings - Design IPTs (and SE&I) did not provide assembly drawings / GO spent enormous time and money "putting all the requirements together" - LaRC (SE&I) should have developed the detailed operational test requirements and IPTs should have developed detailed assembly drawings—this did not happen. Timely delivery of complete requirement set is the number one concern. Need design IPTs to consider, define, and document integration and assembly integration, and test requirements.

1.1.1. Including the Launch/Integration site personnel with appropriate identified roles and responsibilities as well as funding is a positive outcome. The late requirements forced this to occur and were difficult due to lack of the previous items.

1.1.2. Drawings were delivered after drawings and resulted in weeks of delay in hardware processing.

1.1.3. This should focus more on the fact that the I-X Project did not clearly define IPTs roles and responsibility associated with engineering ad releasing detailed assembly drawings that KSC required to assemble and test H/W at KSC. As in all projects I've been involved with, the last thing the project and design IPTs think about is how and all that is required to assemble and test H/W at KSC. This caused tremendous efforts and monies to overcome the delays in getting drawing and test requirements very late at KSC. The USS and CM-LAS H/W actually "sat" weeks due to late drawings and OTRs.

1.1.4. Therefore, KSC GO led the SE&I integration effort to flush out all the requirements from IPTs for assembling and testing the H/W. This is actually a very good positive the fact that "SE&I" turned to KSC GO to lead the integration of the drawing and testing requirements that GO would need to author detailed procedures. There is something to be said about KSC having major inputs through the concurrent engineering process thus ensuring minimal work stoppage trying to make engineering right during the assembly and testing.

1.2. For whatever reason, part of SE&I's role did not include an integration role to integrate across IPTs to flush out requirements for assembling and testing H/W at KSC. Again, the positive was that KSC GO led this effort.

1.3. Lack of common Engineering standards across IPTs

1.3.1. SE&I needs to ensure that all IPTs use a consistent set of drawing and requirements ground rules and practices.

1.4. Challenges in Detailed Integration at Design Level - Detailed integration at design level was less than adequate Examples Include: - ATK uses metal tape for TPS shielding of wiring. LM (Orion) never uses metal tape for shielding - Welded joints (GRC) verses bolted joints (LM)

1.5. Clearly Defined Test & Verification Roles and Responsibilities - Need more clear roles and responsibilities for Test and Verification - Zero system level verification completed with only 3 months prior to flight. No clear path to completion available.

1.6. Ground Ops Process Orientation - different approaches existed between GRC Upper Stage Simulator project team and KSC GO concerning work discipline and control processes. It took a period of time before the GRC team and KSC GO "got on the same sheet of music." They eventually worked it out.

1.7. Impact of late design engineering and Acceptance Data Packages of hardware transfer

1.7.1. ADPs were homegrown by each IPT. Consistent ground rules defined very early in the project and communicated to all IPTs would have resulted in less diverse products.

1.7.2. Schedule pressures drove transfer of hardware before engineering and ADPs were ready

1.7.3. Late delivery of engineering and ADP material caused significant impacts to turnover processes (DD1149) and tracking of hardware configuration at KSC

1.8. Lack of standard processes across the Project - drawings, requirements, acceptance data products, design reviews, etc.

1.9. SE&I failed to coordinate with Range. As a result KSC had to step in and do this coordination which was too late and led to issues like tribo-electrification.

1.9.1. SE&I did coordinate with the range. The tribo-electrification LCC was baselined for months before launch. The problem was that the XCB did not understand the impacts until late.

1.10. Future project should be using 3D modeling to resolve interference and conflicts. Example, EDF out of MSFC helped with interface compliance on the launch vehicle. This helped the Avionic and GO IPTs see the routing of cables and found several cases where it was not possible to physical installed cables in USS. This saved time for ground operation for the filed installation.

1.11. Complexity of contract structure led to miscommunication between IPTs regarding roles and responsibilities. As a result hardware and material flow between centers was complex.

1.12. NASA should learn to pass lessons learned to new projects, Ares I-X repeated many mistakes from previous projects.

1.13. NASA should use experienced project managers for project manager roles. Technically smart folks do not necessarily make good project managers

1.14. Don't set up a project within a project, having a separate control board created a huge amount of overhead that was specific to the project

1.15. Property management and DD1149 process requirements not understood by all centers. Center property managers and contracting officers were not always engaged in the hardware transfer process.

1.16. The end process owner should have earlier input into the design and fabrication of the final hardware. For example, the USS IPT allowed the GO IPT access and inputs on handrails, battery hoisting, and ECS ducting which paid dividends later in the processing flow.

1.17. Integration responsibility should reside at the center doing the work. SE&I did not have the knowledge to develop test requirements and had no understanding of how to integrate ground processing. Only KSC GO had that knowledge and wound up doing the integration but should have been tasked with that role from the beginning.

1.18. Launch Commit Criteria need to include rationale for the basis of the requirement to assist real-time decision-making on launch processing anomalies

1.19. Excessive and duplicate documentation across the Project.

1.19.1. Separate SQ&MA documents - plan, requirements etc.

1.20. SE&I did not provide full Integration across the IPTs

1.21. Early in the project it was difficult to get anything approved through XCB. This sometimes held up work. It got better late in the project due to the urgency. This may not have been so much the leadership as the disparate perspectives from various centers resulting in issues continuously. No one could agree.

2. Requirements Management

2.1. Definition of Avionics Requirements - GS avionics requirements were not fully articulated to GO - Make-shift environmental conditioning systems had to be created in High-Bay 4 to support avionics requirements

2.2. Requirements Ownership and Resource Conflicts - A disconnect exists between requirements ownership and funding – Bob Ess (Mission Manager) has requirement but must go to Pepper Phillips (KSC Ground Ops) for funding - The requirement owner needs to also own budget

2.3. Design “Plus” Requirements Definition Essential - Facility requirements need better definition. - Interfaces requirements need better definition - Manufacturing and assembly requirements need more focus and attention by SE&I folks

2.4. Lack of CM and Requirements Management rules at the very beginning of the Project.

2.4.1. An example is the initial CM plan only identified how to fill out a CR and not the CM process associated with things like how to get a drawing change approved.

2.5. Lack of a Project wide CM tool.

2.5.1. FSAM configuration was unknown to GO until well after hardware transfer.

2.5.2. IPTs have individual CM process and they are not integrated into the GO/Integrated CM tool.

2.6. Design requirements information was not provided in a consistent electronic format (PDF does not count)

2.7. Lack of consistent electronic format for work instructions across IPTs

2.8. The requirements closure method used at the project level was cumbersome and low using paper forms for closure with long complex review process. GO, on the other hand, verified their requirements in Work Instructions and closed-loop closed them real time as testing was completed. This also implies that system level requirements may not have been cleanly verifiable.

2.9. Generic operational logistics requirements were not adequately captured during the requirements review process. Requirements to provide "logistics" support were not able to be quantified.

2.10. Launch Site Support Plan process was cumbersome and the time required to capture the required IPT requirements was not adequate.

2.11. Poor written requirements made hard for implementation and verifications for final assembly at the test site.

2.12. Test requirements were often added, change or deleted very late, sometimes after the fact. An example is DFI testing and the late addition of RoCS DFI.

2.13. There was no thought given upfront to the requirements, configuration management processes, board approvals, change management system, tools, etc... That KSC would need to assemble and test H/W at KSC. KSC GO had to define processes, build its own configuration management system and tool for drawings and OTRs and KSC GO had to lead the integration effort with all design flight IPTs to eventually get all requirements on drawings and OTRs.

2.14. Although for the most part the concurrent engineering process did a good job of baselining good enough drawing and testing requirements for KSC to assemble and test H/W at KSC, the schedule pressure became such that the teams shifted the focus from writing good requirements to getting WADs ready to work and accepting "TBDs" as part of the baseline requirement. This caused some heroic opportunities on the floor by the KSC and flight IPT engineering teams but some very difficult times during configuration management requirements reconciliation. We would absolutely minimize baselining requirements with TBD for a future program.

2.15. 4. Constellation requirements and documentation need to flow down from the prime contractor and all sub tier vendors to the prime contractor. Several waivers were required to the Avionic requirements, as Jacob Engineering (Avionics Prim Contractor) did not impose Constellation documentation of its subcontractor (Lockheed Martin).

2.16. Separating ground and flight data on different ground control systems is not an acceptable long-term solution. This led to confusion on console as well as driving operators to look at 3 or more screens (GSE, Flight, and test procedure), often more (Business Systems for references).

2.17. Make decisions early the formation of a project if Agency requirements are imposed on the project. For example, the Agency workmanship requirements for DWP (i.e. NASA-STD-8739) for cable hardness fabrication and testing were not imposed at the start of the Ares I-X. Later, it was decided to impose the Agency’s requirement for DWP testing. This decision later in processing flight hardware caused confusion and delays in processing hardware.

2.18. The DD 1149 and DD 250 process is completely misunderstood by multiple NASA Centers. The Constellation Program needs to document the DD 1149 and DD 250 Process.

2.19. The project, SE&I and flight IPTs could not understand that they should not set themselves up to have VRDS "complete" based on having a KSC assembly drawing and/or OTR "complete" at KSC.

2.20. The requirement for Flight Commentary needs to be considered for future flights. The Ares I-X Flight Commentary was an afterthought or a nice to have. However, the flight commentary is the public face of NASA and it should be considered in future launches. Things to consider: who will giving the commentary, all flight data shall be available for the person to assess and display, where will the data be displayed, training provided or a knowledge personnel in all systems on the launch vehicle is required, public affairs training provided for the individual supporting flight commentary, and provide simulated flight data in a plus count for the flight commenter to practice.

2.21. First Stage Parts Transfer – Transfer of FS parts to an AG account from an AT required additional time before the parts could be delivered to the VAB for support. All FS parts needed to be sent directly to the VAB for the FS IPT. For Ares I-X, some of the parts were sent to the VAB and others were sent to the ARF first and then were kitted and sent to the VAB to be merged with the remaining parts.

3. Organization and Culture

3.1. The Agency has standards for quality; however, each center has different interpretation and ways of implementing the Agency's standards. There are culture differences of how the quality function is performed at each center.

3.2. The matrixed organization challenged MMO authority constantly. The various centers answered to their own management and sometimes rebelled against project management.

3.2.1. This also implied lack of adherence to schedules.

3.3. IPTs were requested to send liaison personnel to KSC early to understand the culture and practices of the Integration and Launch site - this was ignored and caused a steep learning curve and many misunderstandings when hardware arrived

3.3.1. This needs to be both ways. GO IPTs needs to have reps at the design/fabrication facilities.

3.3.2. KSC 101 and scheduling practices were not understood ahead of time - the IPTs learned these in a real-time basis as their hardware arrived and was processed at KSC. Previous exposure would have improved this process.

3.4. If you are going to work at KSC you are going to have to work by the KSC rules

3.5. IPTs held on to their Design Center culture and rejected the experience base established over years of Shuttle processing at KSC

3.5.1. Shuttle processing has both good and not so good process - the good process were not given adequate acknowledgment by individual IPTs.

3.6. Concurrent engineering was not fully utilized

3.6.1. The AIX Concurrent Engineering was much closer to real-time engineering. True Concurrent Engineering involves the end user at the start of the design process.

3.7. The cultures of R&D facilities and Operations facilities (KSC) were very far removed. KSC is accustomed to extreme discipline in issues like work on flight hardware, configuration management, etc. The R&D centers were accustomed to working without detailed procedures and not tracking flight hardware configuration. This led to issues at times.

3.8. No integration or definition of roles and responsibilities. The center strengths should have been utilized versus having the design centers trying to learn how to process in a new environment.

3.9. The Federal Acquisition Regulation has requirements for property management, however, each center interprets the FAR requirements differently and has center property processes based upon their interpretation. Center property practices differ between design centers and operational centers. Delays occurred when property processes conflicted.

3.9.1. We had issues accepting property from other centers if it was not marked properly. CM/LAS didn't put part numbers on their hardware. Quality couldn't accept the hardware at KSC without part numbers.

3.10. GO should have had a larger leadership, project mgmt role once all the hardware was delivered to KSC.

3.11. Design centers should have sent or utilized a resident office at KSC to take care of IT, security, logistics, etc....

3.12. PRACA was not integrated among the IPT's. CxPRACA is not a real time tool for hardware processing.

3.13. Design IPTs generally did not have a strong sense of urgency on schedule. They would get behind but continue business as usual (single shift operations, weekends off, etc). KSC is used accustomed to delivering to a schedule and had a different sense of urgency.

3.14. Czar's for processing due not work.

3.15. When the Project manager was not available the decision making process was at a standstill.

3.16. Like all projects, the focus upfront of each center and organization was on what they know how to do from a design, research stand point. It took a very long time to convince the different centers to shift the focus on how their hardware was going to be assembled and tested at KSC (e.g. assembling drawings, OTRs, Solumina, WADs, etc...) That said, I really believe that this project started to turn the corner when all of us finally realized that the onus and the responsibility was on each of us to clearly communicate in a common language what each of us needed to do to reach a common goal. As an example, we went up to Marshall Space Flight Center to talk to all the IPTs on how we were going to do business at KSC and we mentioned "WADs" ... everybody looked at me like I had two heads ... we quickly realized that the onus was going to be on KSC to educate the flight IPTs very clearly on how we were going to assemble and test H/W at KSC.

3.16.1. Having this all worked out upfront in the future will avoid major conflicts, wasted time and energy.

3.17. Communication was very stove-piped. If GO had an issue with Avionics, Bob would address it with Avionics but not GO in the room. No accountability.

3.18. All IPTs needed to have dedicated resources to support operations. Each had to approve procedures. SE&I for example had 2 engineers here and only one of those had full authority. We needed them on at least 2 shifts per day including weekends.

3.19. Design IPTs doing work at KSC did not work well. It resulted in documentation issues, configuration management issues, and hardware deficiencies.

3.20. The I-X project MMO made a conscious decision to shift some of the roles and responsibilities from SE&I to the Project Integration office and by doing this, it caused some holes and oversights that had to be plugged by folks/organizations at KSC.

3.21. I think the real key to the success of I-X was when they reorganized the project into IPTs and gave them budget and schedule authority. Bringing KSC on board to lead the efforts for developing the OTR plan, the LCC, and the drawings was huge. CxP really needs to consider doing this. It was different than just having an MK type organization. MK represents the design side and they do not always understand the GO side. Having key GO people lead these items allowed us to communicate our needs to SE&I and the IPTs in a way that an MK group could not.

3.22. It seemed that the project struggled getting the IPTs to live to a MMO schedule until the hardware got to KSC. Prior to that, there were times that it seemed IPTs would just ignore the schedule.

3.23. Having a lean OTR/LCC process helped a lot. The SOWG/LCCWG had key design people who owned the hardware. There was not a lot of people grandstanding and justifying their existence. Shuttle has too many of those.

3.24. It was important to have a consistent LPE type person from cradle to grave. It helped focus the team on proper integration issues, provided leadership from KSC to the project, and built MMO trust in LPE so when we had issues during the count they could be worked easier.

4. Communications

4.1. Common IT was a real issues since the different business systems between centers, contractors, IPT's was not compatible

4.1.1. email address were difficult to locate - contractor emails not in the NASA global.

4.1.2. distribution lists were not consistent

4.2. Lack of sufficient face-to-face communication early in the Project

4.3. WindChill access privileges were difficult to obtain

4.4. Individual IPTs developed expectations of what, how, where and when they were going to operate at the Integration/Launch site without coordinating through the GO IPT - MMO made commitments that GO could not satisfy

4.5. Windchill was very difficult to use

4.5.1. Cut and paste the document in the WindChill search and it would not find the document

4.5.2. Windchill was poorly structured and managed. Products could not be easily identified and found. Without the exact link, you could not find the document by name or document number.

4.6. On site visits are essential to understanding how each IPT works

4.6.1. IPTs were requested to send liaison personnel to KSC early to understand the culture and practices of the Integration and Launch site - this was ignored and caused a steep learning curve and many misunderstandings when hardware arrived

4.7. training requirements among IPT's was not existent

4.8. Searching for items in Windchill was impossible.

4.8.1. Typing an actual document name in the search engine failed to locate it.

4.9. Never knew if you had the latest revision of the document in Windchill. Document managers had to manually link reference documents to parent documents. Had to obtain latest copy of reference document from document owners outside of Windchill because we didn't have access to the reference documents.

4.10. KSC was required to train the IPT's with respect to Launch site processes; safety, facility access, IT, tool control, etc......the IPT's did not make the time for this upfront and significant time was lost while the IPT's learned to work at KSC

4.11. As the S&MA Team approached the launch of Ares I-X, there were excessive meetings between the GO/GS S&MA IPT and the Ares I-X CSO/Flight S&MA IPTs on how KSC approached quality. Multiple meetings were held to rehash the same arguments and explaining the GO processing over and over. After the second or third meetings on this same topic, it became inefficient use of personnel time and resources.

4.12. GO personnel had significant issues with using Primavera for scheduling. It was difficult to provide a schedule that clearly identified the work actually scheduled for today. GO works to very detailed schedules which go down to the hour.

4.12.1. Real-time changes and quick turnaround on schedule changes were not easy.

4.13. Communication of transferred work was not clean. A crime scene investigation was needed every time hardware arrived to understand open PRACA, transferred work, etc. CM/LAS DFI, USS harness, and DFI rework, etc.

4.14. Words/definition of words like waivers, deviations, Field Engineering Changes (FEC), EOs meant different things to different folks. This caused many hours of discussions in telecons and boards trying to get folks to agree on the definition associated with a specific requirement. Recommend a standardized, clearly understood vocabulary for future program.

4.15. There was a lot of documents and project "requirements" (e.g. CoFTRs) that were agreed to months, years before the implementation that when the time came, didn't make much sense relative to how the project was really doing business. Recommend ensuring documents/project requirements are applicable to how the project evolves.

4.16. there was a lot of miscommunication with IRMA. Risks that were transferred to another IPT or MMO where not closed or mitigated to the originators satisfaction

4.17. Proprietary drawings/ procedures made getting information required to process the vehicle difficult.

4.18. Avionic needed to have a better communication path with GO. Issues that LM generated Q-Notes for were never relayed to the proper GO representative.

5. Resources

5.1. Contractor support defined in the contract did not clearly establish the personnel required. Specifically, the ULA personnel supporting Ares I-X heavily limited team to support Atlas V and Ares I-X. Ares I-X had limited support from two individuals prior to vehicle stacking was complete in VAB High Bay 3. Once Integrated testing started, Ares I-X had dedicated support from one individual, and limited support from another. This limited support caused delays in procedure development, simulation support, and testing. In addition, the one dedicated individual was required to work at the limits of the worktime rules for several weeks.

5.2. Each element IPT was responsible for providing most of the flight material required to process the flight vehicle at KSC. GO ended up procuring flight material during vehicle integration when operations required more material than design estimated or when rework had to be done to resolve issues. GO had no budget for flight material.

5.3. Flight spares and Flight material were the first cuts made to the budget.

5.4. Lack of clarity regarding contractual responsibilities of who was providing what material resulted in confusion and hardware processing delays. Case in point - Frothpack and RT-455 used for processing the First Stage element.

5.5. Logistics support for Ares I-X was significantly underestimated. Shipping and handling costs were constant and could not be adequately estimated. The IPTs were constantly shipping additional items to and from their center.

5.6. The Software Integration Lab (SIL) in Denver was a very valuable resource for the Ares I-X Integrated Test Team. The SIL availability was very limited due to the dual support for Ares I-X and Altas V. The SIL had enough personnel to support one or the other, and the commercial Atlas V program was always priority. This resource should have been located at the Launch site, and should have been dedicated to the Ares I-X procedure development, software development and Integrated Test team training.

5.7. Personnel changes were too frequent prior to having established processes- affected all IPTs

5.7.1. Agreements were made between IPT representatives prior to establishing processes- those reps were reassigned and all agreements were null and void or had to be renegotiated

5.8. Lack of dedicated I-X resources at KSC proved to be a tremendous challenge. KSC engineering constantly battled priorities between supporting shuttle processing, launches and landing with I-X very tight schedule. Although the accomplishments were heroic, we should never set ourselves up for failure for a future program by not having the majority of the team be dedicated to the project/mission.

5.9. The individual flight IPTs and SE&I did not have the resources, time and priorities up front to really understand the KSC processes, safety, scheduling, tools, etc... to make work more efficient when their H/W and people arrived at KSC. This caused conflicts and wasted time and energy that we overcame with time.

5.10. Transferred work was a significant impact to resources and were not accounted for from a budget and personnel perspective

5.11. The MMO drove requirements but did not have budget control

5.12. All personnel assigned to perform a function should have the ability/responsibility to perform all functions associated with that function regardless of who they work for, i.e. NASA, Contractor. Due to a contract requirement, NASA System Engineers and Test Management were not authorized to author procedures. This limitation reduced the number of personnel available for procedure authoring and led to delays.

5.13. GRC and Langley should have set up a S&MAll dedicated team to support KSC operations up front.

5.13.1. This should have taken place at KSC to understand the work site rules and environment

5.14. Design IPT's kept trying to re-invent the wheel from well established process that work well

5.15. All Prime contractors and their associated sub tier vendors shall use the Constellation Problem Reporting and Corrective Action (CxPRACA) System. For Ares I-X, CxPRACA was an option for the design/fabrication centers to use. However, CxPRACA was imposed by Ares I-X on all users once their hardware arrived at KSC. The Design IPTs waited too late to receive training on CxPRACA. The various design/fabrications problems reporting systems did or could not interface with CxPRACA. The lack of a centralized problem reporting system made it difficult to determine if all non-conformances were closed and resolved. The lessons learned from using a single database could be used to help mitigate Risk #9287 “GO Cost Impact driven by CxP Acceptance Data Package (ADP) data format requirements.”

5.16. Scarcity of support resources shared across multiple programs led to scheduling challenges for personnel and tasks. This included cranes, access construction, and other configuration support personnel.

5.17. Write contracts for the future that allow flexibility on how to manage multiple contractors working on the project. For example, we were unable to fully manage the critical ULA engineers required for all integrated procedure development, integrated test and launch. This led to rescheduling of numerous tasks to account for lack of personnel availability.

6. Safety & Mission Assurance / Technical Authority

6.1. Hazards Analysis Success Factors - KSC TS&MA Team has done an outstanding job of conducting System Safety Hazards Analysis and addressing integrated hazards and implementing control and mitigation in processes and procedures

6.2. Project documentation and requirements developed and approved should not be used a guideline. For example, the Hardware Acceptance Review and Acceptance Data Packages were well defined in the Mission Implementation Plan (AI1-SYS-MIP). However, when it can time to accept hardware, the MIP was disregard or tossed aside in favor is making schedule.

6.3. The AFSOP did not address specific Ares I-X processing environment with respect to SSP. Not sure why work environments were treated differently with the same personnel and similar hardware in the same facility.

6.3.1. Odd, the Ares I-X Florida Safety Operating Plan (AFSOP) was developed from the Florida Safety Operating Plan (FSOP). The FSOP is used for SSP. The difference in AFSOP and FSOP accounted for the different hazards associated with processing Ares I-X hardware.

6.4. Using a single lead for all DD250 and DD1149 reviews was outstanding. This insured that all hardware was treated in a similar manner with respect to receiving inspections.

6.4.1. Property personnel and contracts needed to be tied into this process.

6.5. Existing contractor Safety organization was underutilized during the Ares I-X Integrated Testing in the VAB and at the Launch PAD. USA Safety personnel with extensive Shuttle experience could have provided insight, and could have further demonstrated the "badge-less" environment that is planned for CxP.

6.5.1. True. When the Safety organization was invited and allowed to participate, there was great benefit and cooperation. Operations and Engineering should always engaged and seek input from their Safety counterparts.

6.6. There was a negative perception from S&MA project lead no matter how many times we explained it of not trusting how the processes at KSC worked to ensure all safety and hazard requirements were captured in KSC drawing and OTR

6.6.1. KSC Safety had already verified implementation of those requirements.

6.7. Hardware and processes that were GFE did not consistently adhere to approved rules/guidelines. There are fewer incentives for the Government to adhere to requirements as compared to contractors (e.g. Award Fee issues).

6.8. Transferred/Deferred worked performed by the Avionics IPT needed to be monitor by GO QC. During some instance issues where worked without GO been notify immediately. GO found out days later or even at all.

7. Schedule

7.1. IPTs worked to their own internal schedules that were not accounted for in the Integrated Master Schedule leading to planning issues, budget issues and personnel issues that were not adequately accounted for.

7.2. The IMS never had the same level of detail for all the different IPT's.

7.2.1. Recommend conducting a survey and finding a better tool. KSC uses AMS, which is far better for planning down to the hour for floor schedules. There may be others, but planning personnel at KSC should be involved in any such decision. The tool for a 3 year project might not be the same tool as a daily floor schedule.

7.3. Primavera did not accurately define or communicate the work or risk associated with the design or assembly and integration across the project.

7.4. Schedule and deliverable accountability was not enforced by MMO.

7.4.1. Major program review conducted one day and the following day an IPT changes delivery date by 90 plus days - there is a disconnect between what is said and agreed to and what is worked to.

7.5. Compressed manufacturing timeline resulted in lack of attention to integrated processing planning.

7.6. Product deliverable need dates were missed in every case - was this due to lack of communication and understanding or lack of enforcement?

7.7. The assembly drawings and OTRs required at KSC to assemble and test I-X H/W was not part of the I-X project schedule. As an example, at CDR, the project and flight IPTs were advertising on schedules that drawings were 90 - 100 % complete when in fact they hadn't even started working on the assembly drawings and OTRs. In the future and in past projects I've been involved with, we made sure the KSC GO requirements to assemble and test H/W were part of the CDR or we had a "delta" CDR for KSC drawings, GSE, test requirements, etc... thus, these drawings and OTRs did not show up on the I-X integrated schedule till very late in the project and unfortunately, never really got the attention it required from the project. In other words, delivery dates of drawings and OTRs came and went on a regular basis with the consequences of late engineering impacting the KSC processing and launch site schedule.

7.7.1. Late assembly drawings and OTRs along with late H/W delivery led to KSC having to work 6-7 days a week to author WADs to implement requirements (assemble and test H/W).

7.8. During the hardware acceptance review a significant amount of transferred work was not accounted for or reflected in the schedule. Also project milestones were not adjusted to reflect this transferred work which affected launch date and budget

7.8.1. This could have been avoided if the MMO had followed the requirements for hardware acceptance reviews documented in AI1-SYS-MIP. Hardware was shipped to KSC knowing that there were significant amount of open work and this was an accepted risk by the MMO. Deferring the work to KSC only increased cost to the overall bottom line and compressed the processing timeline.

7.9. Late requirements, late hardware, drove missed milestones, budget overruns and a delayed launch date. This information was available along the way, but not accepted by MMO.

7.10. CIPS Integrated system is a great idea, but the implementation of the several products involved, Attentus, Solumina, Peoplesoft, Primavera was very challenging. Multiple system training, multiple system passwords, etc. The idea that all the data is automatically populated into the right databases is great in theory, but did not work in the real world.

7.11. Schedule must allow for fit check of GSE months prior to first us to allow for rework.

8. Design

8.1. Fasteners: The IPT's used non-aerospace fasteners that later drove significant design certification issues at the flight readiness review. This was carried throughout the entire process because design margins were very conservative and a real assessment of loads and environments hard to assess.

8.2. ECS Flight doors had multiple fasteners with nut plates and required running torque verification prior to installation. The first fit check was performed at the Launch Pad. The door was only installed one additional time for the first launch attempt. After the first launch attempt was scrubbed, the door was removed to establish ECS to the vehicle. The door was installed for the 3rd and final time, but failed running torque on 80% of the fasteners.

8.3. Some of the design decisions made by flight IPTs forced GO operations/processing engineering to provide design support that typically is done by the design agency. As an example, GO had issues with achieving a torque value on CM-LAS close out panels. This forced GO to modify tools, build shop aids and impacted GO schedule for a least a week to other work due to design deficiency. Some of the avionics requirements for wire protection and bend radius and 16" support seemed to be over kill in some instances.

8.4. There was a requirement to protect critical H/W in I-X (e.g. avionics boxes, 5-hole probe) at KSC in the VAB environment without any design solutions. KSC GO had to come up with design solutions that typically should be supplied by the design IPT/owner of the H/W.

8.5. NASA bought an avionics architecture from the Atlas project that is processed in an air conditioned environment without an understanding of the consequences that I-X was going to be assembled and tested in the VAB. Need to learn from this for future program.

8.6. Design a vehicle that accounts for tribo-electrification effects and documents them to maximize ability to launch.

8.6.1. All design requirements internal (Agency or Constellation) and external (i.e. Range Safety, Avionic Vendor requirements for ESD, etc.) need to be captured and well understood by the Technical Authorities.

8.7. Little effort was given to human factors which caused significant amount of rework and special tooling and caused tasks to significantly increase in duration affecting cost and schedule.

8.8. Each Element used non- common and non-common materials. This made supplying parts and materials difficult. Hardware had different pedigree requirements. Some had a flight pedigree, some did not. Material had different pedigree requirements at different stages of vehicle processing. Case in point, RT-455 is procured under one spec at the vendor, and under a Marshall spec at the vehicle integration site.

8.9. Lift requirements on USS Stack 1 lifting lugs had three different standards which applied. Each analysis had different margins of safety and factors of safety. The technical authorities (CSO and CE) at the various centers imposed the Agency lifting standard completely different.

8.10. Design standards were relaxed or not adhered to in order to accommodate an aggressive design and manufacturing schedule.

8.10.1. Established processes in place early on would prevent this issue.

8.10.2. Not all hardware had part numbers.

8.11. Avionics ECS requirements were not communicated through the OTRs properly.

9. Manufacturing

9.1. Many Avionics cable assemblies required re-work and this was identified at the time of use - very late.

9.2. The lack of configuration mgmt between IPT's forced significant rework at KSC with respect to harnesses, connectors, routing, etc.

9.3. Avionics cables had to be sent back multiple times to correct manufacturing defects.

9.4. Proprietary issues prevented huge issues at KSC because special training was required to work on connectors and other hardware but LM never committed the resources to support the project milestones. Technicians were trained but not accepted by LM.

9.5. ESD standards seemed to evolve rather than be established prior to active integration activities.

10. Test & Verification

10.1. While the SIL provided very good preparation for the Flight Avionics, the DFI suffered significant setbacks in testing due to assembly and test being the first time the system was assembled.

10.2. Integrated Testing procedures development could have been faster and more efficient if more personnel were able to author procedures. In addition, the procedure development tool, Solumina, has a large learning curve to become proficient. The limited time frame made this learning curve very steep, and only allowed for a very limited number of personnel to become experts.

10.3. Flight IPTs and SE&I insisted on holding their VRDS's captive pending completion/closure of KSC GO drawing and/or OTRs. They should have verified design requirement was in baselined drawing and OTR and understand that KSC has a CM tool to close verify baselined requirements to close VRDS.

10.4. KSC Quality needs to staff up to comply with the Constellation Program requirement for 100% verification of GMIPs.

10.5. The Solumina interface is not like Windows, Mac, or Unix so it takes some getting used to. You really need about 3 months of use before you are proficient. The integrated testing team got really good at this, but the INS team struggled early on.

10.6. The hold/constraints inside Solumina work great, but engineers are not the most disciplined bunch of folks. The CIPS ICM portal was a little cumbersome when engineers had to move from a Primavera (Cat 1) to Solumina (Cat 2) constraint. You might need to think about having an organization similar to CMQC police this. Once the work order is issued, it is easy to manage. It is just the Cat 1 to Cat 2 process that needs work. It also was not apparent to me if a Cat 2 Solumina constraint was due to a predecessor book, who closed the Solumina hold?

10.7. In Solumina, there is no way to compare operations within a work order when an alteration is made. You have to compare the entire work order which takes a long time. The engineers got good at putting info into the communication but that is not the same as looking at the actual words. You need a tool that allows this compare.

10.8. The Discrepancy Workbench was a huge improvement. I could see all the data from Solumina. It was huge. The only problem I had was finding closed discrepancies. I did not realize you needed to use the Find Discrepancy Item function and not the workbench.

10.9. The closure of discrepancies need a little more discipline and probably business processes. In some cases it appeared the engineer would close and SA work order but not close the discrepancy item.

10.10. The ability to produce a readable pdf from Solumina would have been great. We could produce a pdf if the machine you were on had Adobe. This needs to be added.

10.11. We need a better way to close loop account for drawing type requirements in Solumina. Apparently the RPE guys cannot get their as built until the WO closes. This is good, but sometimes our engineering folks did not send a review communication to the RPEs.

10.12. We should really force each design element to have the DFI installed at the vendor and we only test the integrated portion at KSC. HB4 was a nightmare not only because of late drawings/requirements/hardware, but because installing and channelizing all DFI at KSC was a lot more work than we expected.

10.13. The SIL was a huge part of our success in Integrated Testing. The impact cannot be underestimated. It allowed us to validate our procedures and software against real hardware. Training was also so realistic that you could not tell the difference between a simulation and real test.

10.14. The GCS model was also huge. The model was actual GCS I/O modules and control net busses so it was just like the real thing. Again, it was huge in developing our procedures and training the team. Tying the GCS and SIL through an internet connection from KSC to Denver saved our butts many times during training and software validation.

10.15. For the most part the LTDT concept worked, but we underestimated the numbers for the front of FR1. The ULA method of launch should be considered. They only have a few operators in the front and the back room has all the technical personnel for both Denver and Florida. I know we have already “built” the next firing room but it appears we could learn some valuable lessons here. In reality only a few people send commands from each console. The rest are there for technical support. In Atlas the back room personnel can log in as an operator monitor and they see every command send from the front. The console layout was not good. Since we had Solumina, 1 display had to be dedicated to it most of the time. While you could toggle between Solumina and IRIS it was not optimal during critical ops. If you take the Shuttle model, you really need a display for the procedure, a data retrieval display, a display for command/control, and one for business applications. If you took the ULA approach you may be able to reduce the displays in the front and the back. CCLS/ADMS allows one operator to send commands via a command window while also plotting data on the same display or on another display. The command/control window is only available to certified operators and is based on user permissions. We did supplement the ULA position with a BASIS machine for Solumina and he had a laptop for access to ULA resources via VPN. Bottom line is with the command/control window, you could reduce the displays from 4 to 3. I think putting Solumina and business apps on the same display is OK. You still need to plan for some laptops.

10.16. Having the design center reps in the prime firing room during testing was critical. There were several times when we had a hardware or procedural problem that needed to be discussed. Having them present allowed us to quickly disposition problems and/or change the procedure. This should be considered mandatory for the next test flight.

10.17. Having a lean test team that got along was critical. Many of us spent hundreds if not thousands of hours together in design reviews, SIL testing, FR1 procedure validations and testing, and most importantly in non work settings. Going to dinner or out on the town built a trust with us all so that on launch day it was easy to execute problem resolution.

11. Operations

11.1. Contingency Planning and Mishap Investigation process could be improved. Fortunately, there was no major mishap or investigation required for Ares I-X. There are pros and cons with having a single individual developing and executing the mishap plan. KSC needs to develop a training plan for new personnel on data impoundment process and roles for the Shuttle and Constellation Program. Shuttle and Constellation Programs need to clearly define and document when and what data on electronic medium (jump drives, laptops, serves, blackberries, etc) are secured under the data impoundment process.

12. Top Lessons

12.1. Better contracts structure and contracts integration
12.2. Vehicle integration needs to procure hardware for GO integration
12.3. Impose accountability of centers (and IPTs) to project manager

2.2 Ground Systems IPT Knowledge Capture

1. Engineering Management / Systems Engineering and Integration

1.1. CxP Verification Complexity Adds Time - "Most of our testing and verification validation has gone real well. The only thing……. I noticed was that Constellation is so much more cumbersome (than Shuttle). As a matter of fact, we tried to leverage the Shuttle process to address the verification process to Constellation. With the Shuttle process, the folks involved in the verification validation, they are watching the testing, they are looking at the reports that they develop so it is really is easy for them to sign off at our verification reviews and our operational readiness reviews that these systems are ready to go. What we are doing here with I-X we are able to sign off internally at KSC within days or weeks and say that this modification is ready to go. Then the verification enters the Constellation cycle and they go off to a wide audience including SE&IE at Langley and different IPTs at their centers and now we start working with a group of people who have not been down here not watching the testing, not reviewing the reports and they have to go and try to get the equivalent level of familiarity that the folks down here have and it is hard to do that over the internet. It is hard to go into Windchill and look through some documentation and it takes a lot of time where we are able to do this stuff in a week down here. When we went to the Constellation process, the first set of verifications we put through took two months to process to get everybody so that they were looking at the right stuff, that they understood what they were looking at. We got just a ton of questions that would have been answered if they were down here. We went ahead and addressed their comments or questions and finally got their verifications closed out. We have been able to cut that in half. We can now get a set of verifications closed in within a month maybe a little more than a month but we are still no where we were on shuttle where we have the right folks right there." - If you have to do it over again, what would you do differently? There has got to be a simpler way. It should not take even a month to close a verification. I had fifteen years in Shuttle and I have spent 10 years in launch services and in both of those areas in closing requirements the verifications took days and weeks, not months. Probably what Constellation is doing is a lot more thorough and maybe that is needed for some requirements but not for all requirements.

1.2. SE&I boundaries and responsibilities need to be established and agreed upon at the beginning of a project/program

1.2.1. SE&I took the position that they were responsible for everything. Everything was part of the system. Every requirement had to have their approval. They got way too deep into the weeds and IPT technical issues.

1.3. Engineering management that is not directly tied or associated to the active project needs to follow that projects communication and process paths

1.3.1. MSFC Chief engineering office started issuing direction to First Stage IPT contrary to direction First Stage IPT was getting from MMO. This conflict in direction cost project time and schedule.

1.4. We used 7120 and 7123 partly as guidelines and in most part made up what seemed to make sense. In some cases we over emphasized certain aspects of 7120 (use of NAR) and in others missed key milestones or decision points(CDR, DCR, and SAR). Same applies for 7123 as it compliments those key milestones or decision points to make sure the right reviews and data is available to determine continuance.

1.4.1. The NAR (Non Advocate Review) is needed and necessary. AIX struggled with what this meant and so the NAR became this independent group of people who had enormous influence over the project and the use of its resources. The same could be said about NESC. During Ares I-X at one time we had 4 different independent reviews on the same topic. This in itself created confusion. Both NPR 7120 and 7123 have undergone extensive review and re-write and for a project approaching the size of Ares I-X tailoring these guidelines should be done very carefully and agreed upon by all project managers up front. Also all the project managers need to understand and agree what milestones and key decision points they will meet and what those actually mean. Specifically the term “Design Certification Review” is no longer listed or identified as a KDP in either 7120 or 7123. It appears based on my experience and understanding of what a DCR was its content has been split between the CDR and SAR. It has been my experience that CDRs (Critical Design Reviews) were formal (attended by engineering management) 90% or better design reviews that focused on the technical accuracy and correctness of the design.

1.5. SE&I should pay equal attention to Ground Systems and Flight systems. Both are equal in importance for a successful program. Operations is a significant recurring cost in any space program and those operations are significantly impacted by ground system design. Complex GS can be avoided if flight systems could be curbed based on GS/GO requirements.

1.6. Some confusion at the ERB level and during verification process resulting from waivers that were really documentation clarification, cleanup, and correction of errors. In other words, there was no true violation of the real technical requirement. However, the term “waiver” was still used.

1.6.1. Don’t use waivers for documentation cleanup. This amounts to generating a separate document to explain what is wrong with the original document instead of just updating the original document. Multiple “waivers” to the same original document without that document being updated makes it confusing for anyone trying to understand the original documentation and the actual final configuration. By using the term “waiver” for documentation cleanup, it may be confusing at FTRR to try to sort out which waivers are for actual technical requirements violations, and which waivers are being used to clean up/fix paper issues. This obscures the real technical /safety risks since they are mixed in with multiple other non-critical documentation cleanup waivers. It doesn’t appear that overhead is saved since the team is still reviewing CRs and paperwork, whether it is an update to a document or a waiver to a document. A streamlined review process is helpful. If for some reason documents cannot be updated, then refer to the documentation updates/cleanup something other than a waiver.

1.7. Complexity and late definition of predicted launch induced vibro-acoustic environments /plume impingement led to challenges with VSS design. Working with LaRC GN&C to define Pad keep out zones was extremely helpful in finalizing VSS design and areas on the Pad that needed additional structural reinforcement prior to flight. This coordination with vehicle worked out well, as the fly-away maneuver successfully protected the Pad FSS and VSS structures.

1.7.1. For launch induced environments, flight and ground environments should be considered together. Launch environments should be treated as an interface since the vehicle flight path can induce adverse environments on the ground structures and ground structures need to survive the induced environments from the agreed-upon flight path. This was not documented as an interface for Ares I-X. Pad liftoff clearance should also have been documented as an interface; instead it was listed as a ground requirement. GS spent months defining launch induced environments for the VSS. LaRC provided great support in working with GS to ensure appropriate liftoff clearances and protect the Pad/VSS from major primary structural damage such as buckling and associated hazards to personnel trying to decommission Pad B. Future work with GS and vehicle should focus on how to protect the MLP and lower levels of Pad structure to avoid extensive repair work in between flights. GS should probably have more strongly communicated expected damage given the different trajectory from Shuttle and the nozzle deflection required to perform the fly-away maneuver (to avoid major structural damage to the VSS and FSS). This would have probably lessened the “surprise” with regard to the MLP damage. The MLP damage could possibly have been avoided with the appropriate use of flame deflectors, cover plates, etc., however GS had already decided not to modify the MLP to protect it since it was designated to become scrap metal following the Ares I-X flight. Perhaps another lesson learned is to go ahead and attempt to protect assets anyway to accommodate the ever-changing directions given to NASA.

1.8. "Heritage” interfaces may not have been truly heritage and could have been better defined. GN2 purge had higher flow rates for “low flow” than shuttle, though considered a heritage interface, and also was being used for an additional non-heritage purpose, thermal conditioning of the aft RRGU. Heritage facility configurations/capabilities were not defined within requirements documentation – this information would have been helpful to other IPTs and also helped to define early on our final “heritage” systems configuration for rollout/launch. i.e. what position should we place platform A1-R in for rollout for Ares I-X vs. what we normally do for Shuttle, etc..

1.8.1. In this case an AI1-IRD-F2G Appendix III was used to document differences with heritage interfaces for flight to ground. A full review was conducted, but an actual FS-GS ICD would have probably been better and less confusing. It would also be helpful to state a requirement not as “provide a VAB” but to actually document the VAB commodities, capabilities, configuration, etc.

somewhere and have the requirement point to this information. This might have made things easier for GO in trying to help flight IPTs understand what would be available at KSC. Also, in terms of configuration of the VAB, MLP and Pad for rollout/launch, the product requirements could have pointed to this document or included this information.

1.9. SE&I should be there to help resolve issues that impact several IPTs. They should not be a body that micromanage each individual IPT.

2. Requirements Management

2.1. Project Plan Versus Resource Disconnects - The MLP vertical stabilization system (VSS) was in the project plan but had no funding in the resource plan. The requirement firmed up only after CDR. The analysis conducted by LaRC was the basis for the decision and late requirement. - "One of the lessons learned is when you add a big requirement like with the VSS, everyone just needs to understand that there is a huge schedule risk"

2.2. Requirement identification and definition was too specific at the system level. Requirements were created that in the end became ridiculous to close.

2.2.1. We continued to create requirements that were actually the design solution.

2.3. The current thoughts and processes in CxP are too focused on product and therefore don't address design requirements.

2.4. Systems requirement verification artifacts were not always clearly identified. When it came time to close these requirements, there was a significant amount of discussion across the SE&I verification team as to what artifact should be used to close the requirement.

2.5. There is questionable value in tracking a systems requirement for an existing heritage facility such as the LCC, VAB, Pad-B, MLP-1 or RPSF.

2.6. Requirements maturity is essential prior to design start. Cost impacts are inevitable with insufficient requirements.

2.7. Individual ground system timeline goals were tracked as requirements. There is questionable value in doing that, especially since the requirements could be met and the real need (for example, total time off of purge) would still not be met.

2.8. The system requirements closure process can overwhelm the team if too many requirements are trying to be closed at the same time.

2.9. Verification artifacts should not have to be identified up front. That should wait until the time verification occurs. Artifacts can change over the course of the project.

2.9.1. This is the current method being used by CxP. Section 4.X of all the requirement documents does exactly this. How is CxP going to handle changes in the future (several years down the road) on these thousands of requirements?

2.10. It took several months to perform the verification activities and close some Ares I-X ground systems requirements following work complete. Other programs provide closure in under 1-2 weeks.

2.11. Late development of CoFTR documentation and products required for FTRR resulted in some level of confusion within the verification process. There was also ongoing confusion with requirements scope and areas of responsibility (i.e. what is meant by ground system – with Ares I-X, ground hardware owned by flight IPTs was considered part of flight). Some documents considered Hangar AF part of GS, instead of FS.

2.11.1. Development of a CoFTR document early on (as was done with Shuttle) would help to drive what IPT/project products are needed to support Flight Readiness Reviews and other milestone reviews. By understanding what products are needed for FTRR, required verification processes/products can be derived and agreed upon by all parties at an early stage. Have philosophical/scope discussions with all stakeholders at the beginning with regard to appropriate requirements verification to avoid debate while going through the verification closure process. Recommend that ground systems refer to everything used on the ground and flight systems refer to only hardware that actually flies to avoid confusion

2.12. With rapidly evolving requirements and concepts of operation (i.e. ASOC vs. LCC, rollout stabilization vs. Pad-only VSS, communication/data paths, HB-4 ECS, lightning towers vs. lightning mast, etc.), there was some difficulty with keeping various IPT and system level requirements in sync. Changing requirements also drove up costs.

2.12.1. Develop a Concept of Operations document as part of requirements development. This should include approximate sequence of events and estimated timelines. This will facilitate easier development of design requirements, operational requirements, and corresponding support requirements all at the same time by "walking through" all aspects of integrated operations. Without this "road map" requirements development is excessively challenging and full system impacts of changes to the concept of operations may not be fully understood in time to avoid schedule, cost, and technical impacts. The ConOps should be one document, not a group of unofficial ConOps splintered into multiple documents as is the case with Ares I-X. This can lead to inconsistency and confusion. Ideally a ConOps would be updated as program/project baselines change to provide latest information on "the baseline." This could also clarify requirement "ownership" and roles and responsibilities.

2.13. Requirements should state simply that. Requirements should be reviewed to be verifiable. Methods and artifacts should be IPT level determined at time of PDR. They should be able to be changed at CDR. CDR should be where requirement methods and artifacts are finalized, but can be different for each IPT with respect to the same requirement.

2.14. Poorly defined requirements in some cases led to difficulty and complexity in the verification process. Also, in some cases there were hidden ground requirements within flight ICDs. An example is the "no more than 48 hours without ECS purge" requirement for avionics. The word "cumulative" was added later to the Avionics ICD. There is a big difference between allowing 48 hours at a time without purge and allowing only 48 hours cumulative for an entire flow. The Avionics ICD included ground design and operational requirements, but because it was an ICD between avionics and flight vehicle, this created confusion as to what requirements applied to KSC operations.

2.14.1. Develop corresponding verification requirement (which can change later) at same time as developing design requirements to ensure only valid, verifiable requirements are written and to obtain baseline approval of all verification methods/products. Make sure all stakeholders agree on scope and intent of requirement, especially interfaces. Make sure design documentation (ERD, SRD, IRD) points to ground design requirements that may exist within other flight documentation, or have it listed directly within the flight to ground IRD. Ground operations was relying on the IRDs and SRDs to help flag potential OTRs.

2.15. Ongoing confusion about what requirements belonged in the AI1-SYS-GSRD, AI1-SYS-PRD, and AI1-SYS-LSSP.

2.15.1. Do not place operational / PRD-type requirements in a design document (ERD/SRD/IRD). These include items like weather, imagery, communications, ground power supplies, etc.

2.16. Overall timeline requirements within GSRD created confusion between what timelines design could meet and what would actually occur operationally

2.16.1. Avoid timeline requirements in a design document, except for design requirements such as ability to mechanically deploy a platform within 15 minutes, etc.. Use integrated ConOps to assist design in developing systems that will not violate overall desired Pad timelines, etc.. Example: Launch sequencing documentation was developed too late to assist VSS /ECS design decisions in helping to meet overall Pad desired timelines. There is a big discrepancy between the design ‘timelines” and the operational timelines as a result, with avionics potentially having to power down sooner than expected following a scrub due to these operational limitations. If the integrated Pad operations had been understood at a higher level earlier in design development, avionics and ground may have had different design solutions. Keep ground operational requirements in OTRs, PRD, etc., not within the GSRD.

2.17. Requirements for CoFTR buy-off changed very late in the process. The basics of CoFTR buy-off don't change. These requirements should have been defined early in the life cycle instead of being "refined" during a time crunch immediately prior to the FTRR. In addition, CoFTR requirements for Technical Authority were modified by the Mission Manager, violating precepts of Technical Authority.

2.18. Launch environments should be determined for both flight and ground systems. Both can have significant program impacts in cost and schedule, both during the design phase and as the program is matured an operational.

3. Organization and Culture

3.1. Kennedy Space Center went to great efforts to design the nature of the Prime Launch Team. As we moved towards launch, the Design IPTs and other outside entities pushed to be more and more involved in the launch decision. The evolution to the final format the week of launch was very difficult for the team to go through. The Con-Ops of the entire launch team should be defined early in the project, communicated to the entire team and all higher chains of management, and maintained through launch once defined.

3.1.1. Any future launch team needs to listen to the Ares I-X launch attempt and launch day tapes. There are very valuable lessons to be learned. Simple yes no questions seem to constantly require dissertations before delivering a yes or no. Several launch opportunities were lost because of lack of time management.

3.1.2. When working with a very new program, like Ares I-X, with very little time for operations to gain experience with hardware, sometimes the Design IPT has the most experience with hardware with testing and their expertise should be utilized by the launch team.

3.2. Design IPTs did not worry about learning tools, processes, or procedures used at KSC until their hardware was delivered, resulting in significant inefficiencies and delays in processing the hardware at KSC until the Design IPTs had arrived at KSC and completed their training.

3.3. Langley utilized KSC resources to fabricate and deliver their "Birdcage" GSE that they had designed. Langley assumed that certain KSC resources would support the effort without prior coordination. The full scope of resources necessary to deliver a product should be scoped out and coordinated vs. assuming how skills would be used and that they would be made available.

3.3.1. Specific areas of concern were S&MA support at KSC and certification of the equipment.

3.4. As an agency we are still struggling between design and operations (ability vs. trust).

3.4.1. Trust is not necessarily the most accurate term. There seems to be a perception that the designer is best suited to see the actual full scale assembly all the way through. Unfortunately once into an operational situation there are many requirements that they are not cognizant on just like operations are not fully cognizant of all their design limitations. Again not best word but we need to develop better trust between groups and appreciate more each other’s talents and abilities.

3.5. In an agency where technical prowess is highly regarded it is interesting that each center has a different engineering process for developing technical products. Also this applied to the language and different definitions of like terms.

3.6. Still too much "my way is better than your way" among NASA Centers. This affected teamwork, although this did improve with time as we learned to understand WHY certain processes, engineering practices, etc. are used and appreciate each other's strengths and differences.

3.6.1. Emphasize more team building early on with Inter-Center projects to help people get comfortable with communicating and trusting one another. Emphasize to different organizations to focus on understanding a process that is new or different to them vs. immediately criticizing or judging it. If folks are willing to openly communicate (without being overly critical) ideas, hopefully the best solutions will result. In some cases if a person had simply said "Hey, have you ever thought of doing it this way!" vs. "You guys are doing this all wrong", communications would have gone much more smoothly... There were many examples where all the Centers pulled together through excellent communication and teamwork and this showed NASA at its best!

3.7. Equal consideration should be given to both Ground Systems IPT and Flight Systems IPT. Several instances occurred where the impact to GS was dismissed due to flight system concerns.

3.8. Design should be considered part of the operations team until operations has gained appropriate experience with the hardware. That typically can be accomplished in a few flows. Ares I-X was unique with only one flow, so it appeared GS was interfering with GO, but the main experience with the hardware was within GS. It takes a few flows to transfer that understanding of the system.

4. Communication

4.1. During the course of this project there were several key personnel who were changed/moved onto other things

4.1.1. The transition and communication of these changes were not done very well. The team did not easily change or adapt to new personnel and their way of operating very well.

4.1.2. It seemed that though everyone said they were working towards one goal/objective everyone seemed to have a different path and idea of what that meant and how to get there. Example is until L-1 we still did not as a team have a good definition/agreement what success really was or meant.

4.2. Need stream lined organization focused on one common and well defined goal

4.3. Terminology across the multiple organizations, IPTs, and Centers caused a lot of miscommunication and re-work

4.3.1. A common language (i.e.- definition of critical terms - CDR, DCR, etc...) and clear understanding and agreement on interpretation and more importantly implementation of NASA documents (i.e. 7120 and 7123) is paramount.

4.4. Technology is a wonderful tool but it should never replace or be a substitute for the face to face gatherings.

4.4.1. Periodic face-to-face gatherings of the core management team is imperative.

4.5. Engineering communications were critical especially for interfaces. In some cases assumptions were made without communicating with all stakeholders. Certain IPTs assumed other IPTs knew something that was "common knowledge" within their own IPT. The result was different IPTs and SE&I at times working to different sets of assumptions.

4.5.1. Encourage greater frequency/open communications at the technical engineering levels, especially for interfaces or when an issue affecting one IPT may be a common issue for everyone. There is no such thing as too much communication, especially in a fast-paced project.

4.6. Face-to-face meetings can be helpful to mend differences. At times team communications were a bit disrespectful.

4.6.1. Teams need to be cognizant of the value of treating each other with courtesy and respect, despite any technical differences. In other words, attack the problem, not each other!!!!

4.7. Wireless communications should not be the primary path to close operations paper in the field. Paperless process are a great path, but hardline connections are needed. VSS and ECS connects at the Pad were hampered due to dropped wireless communications in Solumina.

4.8. Delivery delays happening at one IPT were not clearly communicated to other IPT so that the overall ripple effect could be quickly understood.

4.9. CME and AME were very effective in helping to manage Ares I-X change request and action approvals.

4.10. There was a loss of confidence with the Solumina (software used for work steps) work authorization documents tracking closure of Operational Test Requirements (OTR). Buying a step in Solumina was set up in the software to automatically trace to an appropriate OTR and close it as verified. Significant resources were expended in physically trying to verify closure of an OTR within the Solumina work document.

4.11. Solumina work steps should be able to be printed in a readable format when required.

4.12. Windchill access should have not been so painful to obtain up front. It took six months to obtain access.

4.13. Launch team (LAT) communications were not always crisp and concise. This was one factor that cost us the first launch attempt window.

4.13.1. Emphasize to new launch teams the difference between meeting communications and launch countdown communications. Clearly state problem and proposed resolution, etc. Avoid too many congratulatory remarks in time critical situations although these are certainly important after launch.

5. Resources

5.1. It seemed everyone managed and counted money differently. The different CxP Projects (Ares, GOP) seemed to have different priorities and levels of sensitivity for approvals and management of money

5.1.1. Remove budget from various and multiple projects and provide single common source of budget through the single lead project management office (for AIX this would be MMO)

5.2. Did not capitalize on using available skills at the launch site, e.g., integration problems interfacing user requirements with Range

5.2.1. Use existing KSC Range personnel to communicate/interface with the Range. The GS IPT should assume the responsibility.

5.3. Heritage processes were ignored resulting in conflicting documentation or duplication, e.g., SRQA, OTR, LCC

5.3.1. Should have looked at existing products and apply to processes.

5.4. Recapturing Skills - Manifested at CDR 1, e.g., Ares I-X induced loads calculation and methodology and the integration of a project

5.4.1. We are learning more about what we don't know or have forgotten (the why?) as a result of designing, processing, and launching Ares I-X.

5.5. Each IPT seemed to have different routes and methods for tracking performance. In most cases there seemed to be little to no fiscal management or accountability at the IPT level. It seemed as if the government had lost control of contractor spending and accruals.

5.5.1. This ties back into the comment made under organization. Each IPT needed to have a project manager who equally focused on cost, schedule and technical. A common reporting mechanism should be developed and used across all IPTs and determined at the beginning of the project.

5.5.2. Impacts both Ground side and Flight side. Make sure you have ConOps prior to procurement and requirements prior to design.

5.6. Ares I-X had to create its own unique document for every plan, process, etc… even when heritage documentation was readily available. This creation and approval of many documents again was a cost and resource drain to AIX with minimal value adds.

5.6.1. At times we seemed to be more focused on the forms instead of the substance. Over time we got better. In the beginning everything needed to be documented whether it was a plan or requirement or something to do with AIX. This required a CR and subsequent reviews and approvals. Finally MMO just started issuing directives on certain things that did not warrant review. Also we documented things that were not always value added.

5.7. AIX really struggled with CM. We struggled with hardware transfers and hardware acceptance. It was not clear when the hardware, systems, and software stopped belonging to the IPTs and became MMO's.

5.8. Requirement maturity and Operations concept is needed prior to awarding contracts to reduce ambiguity and change orders (cost uncertainty).

5.9. Leveraging KSC shuttle heritage systems and processes saved a significant amount of time and cost.

5.10. Sufficient funding needs to be provided to support the resource utilization.

5.11. The CxP long term Lightning Protection System was successfully used with a single catenary wire for Ares I-X. This was not in the original plan for Ares I-X, however resulted in some significant cost savings.

5.12. Resources should be reassessed when a significant change in scope is experienced. Without doing so, higher than expected costs than those based on the original scope should not be a surprise.

5.13. Cost should not be a driver to remove testing of complex never before design hardware. Testing of the VSS ended up eliminating significant vehicle coupling issues we would have experienced at the Pad that would have resulted in extremely high cost impacts to correct in the field.

5.14. There are certain key or major systems within each test that cross multiple IPTs or organizations. There should be a recognized and authoritative person assigned to those critical areas to ensure technical completeness, focus, integration, and budgetary management (i.e. - DFI, IDA, etc...).

6. Safety and Mission Assurance / Technical Authority

6.1. Widely varying requirements for ADP material delivery to KSC resulted in very inefficient DD1149 processing

6.1.1. Require identical ADP material requirements regardless of the hardware delivered

6.2. Multiple layers of tools (Solumina/iPRACA/CxPRACA) resulted in excessive time to understand and communicate real non-conformance status and constraints to processing. Provide a single tool that all IPTs and contractors would use across the Program/project.

6.3. There are widely varying processes used across the Agency for processing Material Reviews, resulting in massive inefficiencies in a vehicle integration environment. Establish a single MR process across the Program/project regardless of IPT/contractor responsibility.

6.4. There is a significant level of responsibility for the integration and processing of the vehicle at KSC. The KSC CSO function should be defined within Program/Project documentation in the same way and at the same level as the Ground Operations Chief Engineer was for Ares I-X.

6.5. It got confusing within the last week about who was the technical authority representing Flight Vehicle/First Stage. CE representing MMO appeared to be replaced by Ares CE.

6.6. An example of equal consideration between GS and Flight Systems successfully occurred with the advent of the fly-away maneuver. This was performed to minimize damage to Pad infrastructure due to the significantly different drift profile of Ares I-X from shuttle. The damage that occurred on the MLP zero-deck and 95 ft hinge column was minor in comparison to the damage that this same environment would have impacted the upper levels and VSS. Flight systems were modified that increased flight environments, but a compromised was developed that ensured mission assurance, both in GS and flight. It was a perfect example of two IPTs from two different centers working together.

7. Schedule

7.1. Mainly prior but even after hardware arrived at KSC there was zero schedule accountability. Understand there are many factors involved but as far as I can remember we in AIX did not meet a single planned milestone prior to March 2009.

7.1.1. There has to be accountability by supporting organizations to the schedule. Each supporting organization has to realize that the other parts of project are planning to certain dates that are driving resources and costs. Repeated failure to meet schedule drives unnecessary costs by all the other supporting organizations.

7.1.2. Schedule mainly suffered due to insufficiently mature requirements and scope changes.

7.2. The lean events and workshops that were held turned out to be excellent forums for identifying ways to improve performance. Execution of those enablers to realize improved performance was not as well executed

7.2.1. This could have almost been a full time position with the requisite authority to enforce the implementation of those enablers.

7.3. Lean events provided excellent opportunities for several centers to provide inputs to save cost and schedule. A perfect example is the RoCS design. Prior to the lean event the RoCS system was integral with the interstage segment. This required huge issues with how to load the system with hypergols either in the OPF or at the Pad. The lean event allowed GO and GS and the RoCS IPT to work together to manage risks and requirements to determine separate removable modules were the appropriate re-design. This allowed parallel processing and opened new facilities to provide servicing using mostly heritage hardware. This saved processing and design schedule and costs.

NOTE: Clarification/correction provided by RoCS IPT Lead Ron Unger

The commenter may not have been knowledgeable about the RoCS CONOPS until attending the Lean Event or else he/she confused it with the KSC workshop held several months before.

RoCS has stated in Vol II section 7.3 to the contrary. We had good, open communications with GS/GO from early on, in our PDR/CDR and GFE planning meetings, demonstrations, and exercises. The Lean Event facilitated some side GSE design conversations, but was outside the original scope of the Lean Event; the Event was viewed as superfluous by RoCS.

The RoCS originally being an integral part of the USS is erroneous. The modular approach was ALWAYS the design approach from TBE. It was a matter of where in the integration process that the modules were to be loaded with propellants, as a Safety concern was expressed about the handling hazards of loaded modules before integration into the Interstage, or of having loaded modules in the VAB, thus potentially requiring loading at the Pad. The RoCS CDR, kicked off in August 2007 (and preceding the Lean Event) had already finalized the propellant loading scenario (with GO/GS in attendance), as the planning for the loading exercise at the HMF using spare tanks was well underway.

8. Design

8.1. Lightning Protection Design Considerations. Lightning Protection System: “There are three towers out there. If you look over on the Cape side, you will notice that their launch pad had four towers.” What our folks found is that you can achieve the same thing with three towers and save a significant amount of money and just be creative in the way you string the catenary wires between the three towers”

8.2. Leveraging Shuttle Infrastructure. “When I came on to the mission two years ago, it was there from the get-go to leverage shuttle system as much as we could. It has been in the planning for quite some time. In addition to using the existing equipment, it really does keep cost down. We did not have to go build a new mobile launcher, we just modified one. We did not have to go build a new launch pad, we just modified one. Same with the VAB and the LCC. It saved a ton of money. In most cases the long term modifications, we did not have the requirements three, four, five years earlier for Ares, we just would not have been ready. It was a choice to keep the cost down and fly this mission earlier or try to accelerate the long term which would have cost more. A huge success and an huge risk reduction were possible with using existing infrastructure."

8.3. Supposedly inexpensive design decisions were made that resulted in large operational costs. Examples of excessive operational costs were providing a Five Hole Probe cover vs. designing in a Five Hole Probe heater and providing a manually operated Vehicle Stabilization System that was manipulated very late in the count vs. providing a T-0 disconnecting stabilization system.

8.4. VAB USS platform exceeded OSHA requirement of no greater than a 12" gap.

8.4.1. Place emphasis on drawing review as part of 30%, 60%, and 90% as well as CDR I and II. Do not use drawings alone for verification. Verify that models have actually verified appropriate clearances, etc. Even if a current process exists for drawing verification, final verification should still show that process actually occurred prior to closing out a verification requirement. Example: VAB USS platform gap issue. USA has implemented additional drawing checks/process.

8.5. Test valve damage during VSS testing at vendor due to bump with test fixture during operation

8.5.1. Employ similar test team briefings, test setup walk downs, move director communications, cameras, and quality controls while testing systems at a vendor as would have onsite at NASA center to avoid inadvertent damage to test equipment hardware.

8.6. MLP mount mechanisms at Pad found to be 2" different than VAB. FSS was leaning 3" or so compared with drawing. VSS had to be adjusted to accommodate these differences

8.6.1. Conduct initial surveys/measurements early in design process to verify current Pad configuration. Need to know as-built for critical elevations / dimensions for design. MLP mount mechanism had been adjusted to avoid scraping deflector plate (unknown to Ares I-X team) and FSS alignment had shifted slightly throughout the years (creep, settling issues, etc. for long-term consideration). VSS had to be adjusted to accommodate these changes, and it was good that the design was flexible enough to accommodate these differences.

8.7. Design methodology error

8.7.1. Need to make sure we capture the whole lifting lug issue and somehow incorporate those lessons into 8719.9 Lifting Standard or NASA-STD-5005 to make sure other projects and programs don't repeat this same mistake.

8.8. A significant amount of VSS testing was not identified prior to the implementation phase. Several weeks of additional testing was added to accomplish dynamic testing which impacted the VSS completion schedule and budget.

8.9. The CxP long term Lightning Protection System was successfully used with a single catenary wire for Ares I-X. This was not in the original plan for Ares I-X, however resulted in some significant cost savings.

8.10. Fly-away maneuver can point SRM plume onto ML decking. This will deflect the flame and can cause significant erosion of structural members. An ablative coating and deflector is a must to protect tower. Another option would be to perform a fly-away maneuver that is in a transverse direction to the tower instead of directly away. This would be similar to shuttle having a north trajectory to a tower to its west. For Ares I, could fly-away toward the east with a tower to the north--this would deflect SRM plume away from tower structural members and still clear the tower for re-contact concerns.

9. Manufacturing

9.1. Having good sub-contractors lead to good products and on time deliveries.

10. Test & Verification

10.1. New and complex hardware should ALWAYS be tested. Cost and schedule should not remove that requirement. The cost and schedule impacts that can occur in the field, after the fact, are typically more significant if things go wrong because testing was not funded or accounted for.

10.2. Distinction between Product Verification and Design Verification needs to be understood up front. Is product verification required to verify designs meet requirements?

10.2.1. USS Access Platform in VAB was built exactly to print but we were still off by 24 inches. More effort should have been spent in design verification. Levy and trust in product verification processes already in place.

10.3. Verification should not be pre-declared as part of the requirements document. The design team should have the responsibility to determine that appropriate verification means as part of that design. The verification process/plan should be approved by management prior to fabrication/manufacturing beginning.

10.4. All requirements are not created equal. Need to determine which requirements are the ones that can hurt you and focus more energy on those that can hurt you. Critical Dimensions, redundancy, critical data paths (ICDs) these are things that can hurt you.

10.4.1. CxP should look hard at all requirements and identify or delegate requirements to different groups or projects that become that requirements ROR. Look at NSTS-07700 Vol X Book 1 Table 4.1 requirements matrix

10.4.2. True. Those requirements that apply across several IPTs should be managed by SE&I. Those requirements that are specific to an individual IPT should be managed by that IPT and should not have to have SE&I involvement.

10.5. Requirements being created for operational controls need to remain in requirement language and not design solution description. Requirements need to be clear about exactly what is being protected.

10.5.1. This is true for OTRs, LCCs, and any other type of operational controls that are being passed onto the operations community. Lightning OTR indicated that you could not power up the vehicle when it really meant you could not power up the pyro system. This caused the launch team on launch day several hours of issues trying to figure a way out of that box. Crawler speed is another example. Need to identify what the specific environments that are detrimental to the vehicle are and then let ops figure out how to avoid. This allows prevents change traffic in the future as ground systems are modified or as technology is updated.

11. Project Management

11.1. Project Management versus Technical competency - After lean event existing technical experts automatically became the project manager

11.1.1. This issue is covered repeatedly in the Formal Lessons Learned class sponsored and endorsed by NASA. There is a significant difference between a good project manager and technical competency. Both are needed to make a successful project.

11.2. Multiple boards

11.2.1. If it takes more than three boards to make final decision then schedule and cost are uncontrollable

11.3. Involving Ground Operations during initial design concepts provides a superior product and reduced actual design and implementation costs.

11.4. Providing pre-agreed amount (typically 15%) in each design/build tasks for Field Change Notices/RFIs allows contractor to accomplish job with maximum flexibility and able to react much quicker to unexpected issues. This improves schedule performance.

11.5. One of the observations from the reorganization after the original lean event is we should have reviewed each management position based on their new expanded roles and responsibilities. At a minimum we should have communicated these higher expectations to make sure the existing personnel clearly understood the new roles and the associated responsibilities.

11.5.1. There should be more accountability of IPT or Project managers for performance.

12. Ground Systems Top 3

12.1. Establish consistent Project Management performance measures for Cost, Schedule, and Technical. Allow lower levels to have more flexibility within existing cost and schedule box. Reward Project managers who consistently beat their cost, schedule, and technical performance measures.

12.2. Realign Requirement management to eliminate Section 4.X within CxP requirement documents, identify core requirements and not design solutions, and use incremental requirement (design vs. product) buyoff.

12.3. Remove methods and artifact identification when establishing requirements. Method of verification should be determined by PDR, but not documented in the requirements document. Artifacts should be identified at CDR, but not made a part of the requirements document. Methods and artifacts should be documented in the IPTs verification document, not in a requirements document.

2.3 1st Stage IPT Knowledge Capture

1. Engineering Management / Systems Engineering and Integration

1.1. Testing Philosophy – Human-Rating versus Test Flight? - Different opinions existed regarding the necessary test, verification, and acceptance criteria for the parachutes. Fundamental differences of opinion exist with regard to test and verification philosophy – test flight? Or human rated mission?

1.1.1. NASA management (Program, OCE, and OS&MA) can assist by coming together on verification expectations and methods early in the formulation phase.

1.1.2. First Stage designed structures to a FoS of 2.0 to avoid testing, acceptable for a test flight

1.1.3. Component Level Testing based on AIX Environments, case by case basis

1.2. Disconnects in Test and Verification Process - Fundamental disconnects existed between SE&I and 1st stage regarding the test and verification process and the implementation of design verification reviews, boards and document approval and control

1.2.1. SE&I can assist IPTs by clearly articulating verification requirements and process expectations early in formulation.

1.3. Write it down. A communications guide will do wonders. Such a guide can have a defined set of program endorsed meetings and products that are in standard formats and rollup to the top level program status. The roles of key members can be defined too.

1.3.1. Ares IX was a good example of a project that needed to get up to speed fast. The forming stage could have been shorter if a project document making detailed choices of which groups with roles and products will meet and how their products feed to the top level products and contribute to project success.

1.4. Respective IPT's should do their respective testing

1.4.1. First Stage IPT did specialized testing for the Avionics IPT

1.4.2. Multiple contracts led to confusion over roles and responsibilities

1.5. SE&I is not nor should it be considered management

1.6. Organization structure did not align with the Center organization. LaRC and MSFC organizations did not necessarily align. MSFC realigned part of the way through and caused even more disruption in roles and responsibilities within the IPT. Chief Engineer roles and assignments, LSE roles, IPT authority did not fit for FS structure. MSFC engineering management expressed confusion throughout the process. Future projects should assess cross-center structure and R&R as part of the upfront planning and communication to Center management.

1.7. Management by committee is generally a formula for disaster

1.8. I feel the Integration role was not involved as much as it should, especially in the earlier project days. Many times, the direction I received from SE&I was to work directly with the other side of the interface. This was fine but needed SE&I's involvement to maintain an overall "feel" or direction which is critical as the vehicle moves from separate systems into an integrated vehicle.

1.8.1. SE&I performed more of a management function than an integration function

1.9. Form, in advance, emergency MRB teams for each broad discipline. Folks at the processing site need design center (IPT) authority. Task teams eventually were used for this, but some critical path schedule was lost before this action was taken.

1.10. Clear understanding of contract types and structure needs to be considered as part of the SE&I management. While some contracts were "hands off" and some were "hands on", First Stage was approached as a typical Shuttle type contract. MSFC engineering provided insight and recommendations based on review of ATK products. SE&I process needed to understand that the contractor did not have authority to directly report to higher level without authority of FS ERB/ECB. Once a decision came out of First Stage - it was considered reviewed and accepted by FS.

1.11. SE&I should be engaged at the IPT level. With strong representation at the IPT Chief Engineers review board and all internal IPT design review.

2. Requirements Management

2.1. Establish the requirements early and perform an early design study to assure feasibility

2.2. Requirement Definition: 1. Requirements should be set early and reviewed and agreed to by the involved parties. Initial requirements included "reporting" on mass rather than providing specific verifiable requirements. Pushback was provided to the system, but not accepted until the interstage mass properties caused issues in the design. 2. Requirements should be clear and non-duplicative. When requirement flow-down was done we found that we were verifying multiple requirements with the same data. 3. Clear review by the requirement owners at the top level to the lower levels should be done to assure that the flow-down requirements clearly represent the intent of the top level requirement. In the verification process, we found the system was looking for additional detail beyond what our deliverables covered (environments - transportation, assembly and operations)

2.3. MMO should not be controlling the IPTs requirement document. This caused lots of unnecessary paperwork and confusion. They should control the system level only.

2.3.1. MMO controlled element ERDs

2.3.2. Got into a time consuming loop

2.3.3. If we do an Ares 1X Prime--the SRD should be owned by MMO

2.3.4. Create an extra document ERD which is controlled at a lower level board

2.3.5. The two docs then need to be lined up

2.3.6. The Element requirements (derived) need to be controlled at the element level. Higher level system requirements document should contain and control specific allocated requirements.

2.3.7. Or--MMO control SRD and IPTs control ERD

2.3.8. Didn't have a baselined ERD until a few weeks before flight

2.4. Requirements and Drawing Reviews should include discipline experts and engineering management representation from IPTs who have the authority to resolve configuration and design issues.

2.5. Requirements were established early. Unfortunately some requirements did not fit the vehicle and should have never been included. On some cases, this involved heritage hardware trying to meet the new Constellation requirements. A better technical review of early requirements would have better served the project.

2.6. Requirements where often difficult to understand. Cost and schedule most of the time seemed to over ride a technical solution.

2.7. More rigor was needed in the Interface Requirements area. Stronger "book managers" were needed (SE&I?) to manage the interfaces. Too often the IPTs were left to negotiate their own ICDs. Maybe issues like "aluminum tape" could've been avoided.

2.7.1. Aluminum tape issue went all the way to FTRR

2.7.2. Shuttle experience was different--made sure there was a real integrator

2.7.3. Got into a trap--integration wasn't getting down--ATK had to step up

2.7.4. MMO/SE&I wanted to control and be the integrator, but didn't have the right skill to perform that function. FS acted as an integrator, but wasn't supposed to be performing that role. Became an issue with FS and ATK management.

2.8. Contract owners MUST own the contract requirements. This does not mean that the flow from above is incomplete - just that the process becomes cumbersome and convoluted when a primary contract management tool gets away from the contracting entity.

2.9. There was TOO many last minute SRD and thus ERD requirement TDB's or unclear requirements that had to be resolved via the waiver process. It is inappropriate and should be mandated that TBD's be eliminated prior to entering CDR.

2.10. Requirements and their verification should stand alone with explicit inputs on a requirement-by-requirement basis as opposed to being buried in technical reports with references

2.10.1. So only a single verifiable requirement per requirement statement.

2.11. We have requirements "sneak in" from LCC. Maybe from other areas. Future programs need to assess all other areas where requirements may come in informally. (tribo-electrification)

3. Organization and Culture

3.1. Review process and expectations are different based on Centers and historical Projects. MSFC engineering anticipated similar historical reviews for PDR, CDR, DCR with a kick-off, data review, RID process, Pre-board and Board. With the MDR process, there was a data review and then a board where RIDs (comments) could only be input by Board members. We did not get a complete engineering review of all the data at the appropriate levels.

3.1.1. In some cases such as Avionics, it seemed that early on, there was not the Engineering support needed for all the review. The engineering support was not clearly defined early on due to unclear agreements between the project and engineering.

3.2. Have contingency planning in place based on common (industry known) processing problem scenarios. Bent pins are one example, count on it happening--it did on AIX. Top common scenarios need to be chosen and a way out needs to be planned during the formation of the project.

3.3. Role of S&MA in the verification process should be clearly denoted in the verification planning before hardware build. Research Center and Flight center expectations on this hampered forward progress on verification closure.

3.4. The vehicle integrating location should recognize the whole job, e.g. interfaces, how to do it and assume and perform that function

3.5. SE&I/LaRC culture is very different than that of MSFC. Research culture vs. design center culture? Smaller projects vs. larger programs?

3.5.1. For example, SE&I requiring "as-built" data to verify System Level Requirements. Government grading the government paper.

3.6. All cultures of participating Centers should be understood by the MMO level

3.7. The team was put together for reasons other than technical background. Cultural background often made small problems BIG ones (manned spaceflight vs. research programs). structured reviews and what is necessary for completing such a review was a moving target

3.8. Everyone needs to understand that while we are doing Shuttle, test-flight implications on flight hardware must be considered. Folks did not understand the rigor FS used in review and assessment of each small piece, but Shuttle considerations had to be addressed for like hardware.

3.8.1. Future test flights will have to consider how decisions will impact Ares I human rating

3.8.2. This should take care of itself after the Shuttle flies out their manifest

3.8.3. 1st Stage failure could have grounded the Shuttle until the anomaly was resolved

3.8.4. Same comment applies to LM's Atlas V avionics

3.9. Need to have Vehicle Integration (VI) at MSFC doing the SE&I function since that is the way it is to be for the Ares program. They need to get the experience and work out any kinks in preparation for the mainline program, AIX' would be a good place to start.

4. Communications

4.1. Level 3 Communications Issues - Level 2 – Level 3 communication issues and role and responsibility issues must be addressed.

4.1.1. Program leadership emphasis is required to address communication issues between Levels 1, 2, and 3 within the program.

4.2. Communication was key to sensor integration on 1st Stage - Excellent teamwork and communication was key in implementing hundreds of sensors on the 1st Stage vehicle

4.3. Communication is a two-way street. There did not seem to be an effective way for elements to express issues without bringing things up to the highest level of management - so XCB became a technical board for addressing technical issues rather than working at a lower level. This may have been organization structure issue?

4.3.1. Huge agendas
4.3.2. Did Upper-level meetings not trust lower level meetings?
4.3.3. Roberts Rules needed

4.4. Many, many meetings. Near the end, some meetings were counterproductive due to not having the proper support or data packages available due to the extreme short turnaround. WebEx was very useful unless someone did not have the proper log-in or could not broadcast to the other participants.

4.5. Windchill. While Windchill is an excellent tool for the sharing of data across the Constellation Team, there were too many gates (permissions) each user ID must pass through. Many man hours were lost due to the time it took to upload documents for the different reviews for I-X. Windchill could speed up there processes by eliminating some of the allowance barriers that they have placed on the different sections.

4.6. Lack of a closed-loop process throughout the program. During the major review milestones, RFAs (intentionally not RIDs) were determined to be the method of documenting discrepancies. This approach not only disallowed initiators to defend their issues (all RFA had to be filtered through a specific POC), but it was unclear which RFAs were accepted and even harder to follow closure to RFAs. Another example was the change from OMRSD to OTR, which put an extra burden on FS IPT to track through implementation specific requirements that were leaned out of the OMRSD closed loop system. During the document change process, it was practically impossible to completely review the sheer volume of change traffic at the multiple change boards that were setup. Without a clear closed-loop process, non-comments were treated as concurrence. This created a system in which issues got missed because of limited resources, heavy change traffic at multiple boards, and processing changes without input from all stakeholders. Even a test program needs to ensure that all stakeholders have reviewed and impacted changing requirements or be allowed to properly "non-concur" if the rationale is strong.

4.7. Communication methods were far too remote not enough face-to-face. Thousands of e-mails and documents to review does not equal communication.

4.8. The IPPT process review was intended to provide communication of detail design, interface, and build process information between IPTs and SE&I. There were some indications that communication was not effective. For example the silver tape wrap of all harnesses and availability of alternatives and the final test and checkout of harnesses following installation (continuity, IR, & DWV).

4.9. Having remote capability was GREAT - but it also let TOO many meetings drag on for hours outside "normal business" time. Much discussion could have been much more concise!

4.9.1. Some form of "Robert's Rule of Order" would be helpful with this same issue.

4.9.2. Meets needed to be controlled by leader. Stop the discussion. State the facts then move on.
4.9.3. Everybody does not have to express their feelings on each topic. If polled - say yes or no.

5. Resources

5.1. Bring each essential person and part to the proximity of the processing site. This prepares resources for hardware failures discovered after installation testing. AIX realized this when the First Stage project was set up to process 5 segment simulator articles. The processing involved installing DFI instrumentation on the element. DFI flat pack amplifier installation on the 5th Segment Simulator hit a snag and this hardware belonged to Lockheed/ULA and their representatives were not planned until after the problem occurred--parts and engineering procedure weren't ready either. This resulted in weeks of delay which could have been minimized.
5.2. Don't under allocate to "fit the box". We all looked at schedule and realized it was 10 pounds of stuff to go into the 5 pound box. For political reasons, schedule drove keeping schedule. Without bringing on many more people, the workers had to carry the burden and work many extra hours to achieve.
5.3. Flexibility in the use of alternative facilities and personnel to support program schedule was important in supporting some key delivery milestones. Example was the use of the Astrotech facility for 5SS processing and the availability of USA & ATK technicians to support operations off KSC
5.4. Having a "streamlined team" does not always pay off when you have other constraints such as time and risk. You need to size teams based on the true need - not on arbitrary staffing allocation based on set manpower budget.
5.5. Lack of adequate skills in Loads, EMI, SE&I.
5.6. There were some personnel usage conflicts with the Shuttle involved with USA and its electronic technicians. These generally got resolved with minimal impacts but the potential was there for major delays. Understand it's hard to staff up for a one-time test flight as compared to Shuttle use.
5.7. Cross-IPT resource necessities should be recognized and fulfilled.
5.7.1. Early on in the ARF
5.7.2. Related to Avionics
5.7.3. For other IPT involvement maybe would have expedited solving problems, if not preventing them
5.8. Funds were extremely tight for Ares I-X. That being said, critical flight hardware, especially something as large as the frustum should be able to be shipped through a safer means than a flatbed trailer truck (through the snow). We had been working with the NASA Super Guppy team and they would have been able to accommodate our needs. In the future, the Super Guppy Team would be an excellent asset to use.
5.9. Hardware processing locales became what appeared to be a political issue. KSC wanted the motor delivered from FS before the DFI had been completely installed arguing it could've been done more efficiently at KSC, although they had no plan.

5.10. Dual roles for key folks in FS Ares I and FS Ares I-X was difficult and conflicting. Some folks were also supporting Ares V. In many cases the key personnel were called to do key activities for both so one would suffer. In the end the "main line" Ares I activities had to be put on hold to facilitate Ares I-X activities to get to flight.

5.11. The Avionics IPT did not have the resources to support the processing of their hardware in the FS facilities.

6. Safety and Mission Assurance / Technical Authority

6.1. Coupled Loads Analysis and Impacts on Range Safety Approval - The latest load-set (coupled loads) indicates range safety radio receiver qualification criteria an exceeds requirements at 90 seconds into the flight.

6.1.1. - require completion of analysis (or at least mature analysis) prior to design and/or fabrication

6.2. FS had too many chief engineers. It was confusing to other IPTs actually who was the FS CE.

6.3. The Chief Engineer hierarchy was not recognized between system and FS until late in the process. "Lead engineers" were assigned FS. This caused confusion such that CE and CE boards were not formally recognized until very late in the process (in the last 6 months prior to flight).

6.4. S&MA/TA were key to a successful evaluation of the submitted verification documents. The thorough review at the IPT level ensured minimal issues as the verification documents were submitted to MMO.

6.5. CxPRACA Reporting vs. work (Solumina, problem resolution, IPRACA). Using both CxPRACA and IPRACA to track DRs caused duplicate work in preparing and closing out documentation. DRs should be captured in one system for the program with reference to appropriate work paper in Solumina. Developing the work paper in Solumina worked well.

6.6. IPTs needed some schedule margin to work with.

6.7. Lack of a closed-loop process throughout the program. During the major review milestones, RFAs (intentionally not RIDs) were determined to be the method of documenting discrepancies. This approach not only disallowed initiators to defend their issues (all RFA had to be filtered through a specific POC), but it was unclear which RFAs were accepted and even harder to follow closure to RFAs. Another example was the change from OMRSD to OTR, which put an extra burden on FS IPT to track through implementation specific requirements that were leaned out of the OMRSD closed loop system. During the document change process, it was practically impossible to completely review the sheer volume of change traffic at the multiple change boards that were setup. Without a clear closed-loop process, non-comments were treated as concurrence. This created a system in which issues got missed because of limited resources, heavy change traffic at multiple boards, and processing changes without input from all stakeholders. Even a test program needs to ensure that all stakeholders have reviewed and impacted changing requirements or be allowed to properly "non-concur" if the rationale is strong.

7. Schedule

7.1. Schedule—The Key Driver - "schedule has been the number one issue"

7.1.1. Greater willingness of Management/Leadership to push-back on schedule may be warranted

7.2. Technical rigor cannot be excluded due to schedule.

7.3. Single article hardware needs rapid response and real-time task tracking. AIX had one set of hardware--there was not multiple sets of hardware that you could interchange (sometimes even large integrated hardware like the AFT Skirt). At start-up the ARF processing was not accustom to critical path processing without the option to swap things out. Consequently, there lacked real-time tracking and broad reporting of the installations and reaction time was slowed. After a few snags the team adjusted and processed this set differently than the Shuttle hardware. Preplanning real-time tracking and reporting of each nut and bolt will avoid the delays.

7.4. Note: Many of the lessons related to AIX have important value because of the nature of this project. Schedule was tight from the beginning and this was a single set of hardware. Most of the lessons here are things that hurt the schedule. A project with less schedule urgency and the ability to trade hardware will not care as much about these lessons.

7.5. Schedule Lean Events should include adequate engineering technical representation to ensure technical assumptions and decisions used to bring schedule within desired bounds do not conflict with technical requirements

7.5.1. Had we done this in a meaningful way-- e.g. at KSC to go resolve specific issues

7.5.2. Too many people involved

7.5.3. Scheduled too late to be helpful

7.5.4. If we do this again we should do a "Phase A" study to document what needs to be done

7.5.5. Used as a band aid for poor planning upfront

7.5.6. Lean events did NOT save the day

7.5.7. MMO's perception that you needed help -- then told to conduct lean event

7.5.8. You don't need a lean event to issue a management challenge

7.6. Build a COMPLETE integrated master schedule to plan upfront rather than lean events later as an emergency fix.

7.7. IPTs needed some schedule margin to work with.

7.7.1. Issues arise in manufacturing, test, analysis.

7.8. MMO needed to have more faith in their IPT's. Lean events on FS hardware processing should have been internal to FS. We had those daily without the title. Although the outside help was genuine, it was more detrimental to both the days lost for the lean event, and the moral of the FS team.

7.9. An Ares IX type project will always require the Project head to hold the line on schedule milestones; even when all the piece parts do not add up. Project success depends on keeping the challenges in place. It seems that this comes at the cost of trust relationships with those working on the project. Actions that include and invest the individuals working on the projects (starting with the leads) needs to be planned up front and reviewed throughout the project. The IPT lead types need to be able to understand the piece parts and how they stack up AND be on board with why we are holding the milestone in place. Also, those leads need to help their team members trust the best interests for the project are being considered. Easy to say, harder to do.

8. Design

8.1. Level II/III MUST have a controlled process for math models. This includes approved inputs, validation & approval by the appropriate panels and boards, user validation, appropriate archival.

8.2. Less critical task applications (like cork runs and painting) should be designed for application in large sections. Strategic processing discussion with the folks that have experience installing hardware must occur and designers should push for larger consolidated applications and installers should push back where necessary. When a processing job is first laid out it usually has a multitude of focused tasks. a follow up effort is needed to integrate and consolidate tasks with the guidance of engineers and installers who have direct experience with the hardware.

8.3. Design for one set of environments/use does not ensure design is satisfactory in new conditions. FS had to be looked at as a new design from an analysis perspective.

8.4. Design status should have more visibility and Reviews should be a "line in the sand" where independent design review occurs; as opposed to a process where responsible parties perform a working session review.

8.5. Waivers should not be used in lieu of document update. Imposed increased burden on IPTs to show compliance/deviation to obsolete requirement documentation.

8.6. Design, Fabrication, Test and Qualification not always done in that order. Overall Vehicle was in reality built to multiple design standards based on that center's heritage.

8.7. The list of Shuttle-rejected hardware was extensive

8.7.1. Analysis or test was used to ensure components were acceptable

8.7.2. Issues with Booster Separation Motors (BSMs)--igniters / Foreign Object Damage (FOD)

8.7.3. This was a risk that we bought into

8.7.4. ASAs - Altitude Switch Assembly - we picked the best one on the shelf - if USA's testing exposed problems we would have lost 1st Stage

8.7.5. Wouldn't take these risks again

8.7.6. Would put more funding into fixing these problems

8.7.7. We can't rely on using Shuttle heritage H/W on Ares 1 Prime (assuming we could even find the hardware)

9. Manufacturing

9.1. You have to assume that manufacturing issues will arise. Appropriate plans need to be in place, i.e. MRB authority, schedule margin, alternate design options, design margins...

9.2. All manufacturing efforts by the various IPTs did not follow the same standards. Avionics cables by LeBarge did not have any mandatory government inspections during their process. Given the use of heritage connectors for some, we were lucky that there were not more problems. Post- build testing did help.

9.2.1. The quality of shipment of these cables were lacking as well. 70 pound cables should not be shipped in a 40 pound capacity crate. The IG has better things to do than sift around at FedEx in Memphis, TN.

9.3. Field Engineering Changes/KSC Integration • Delegate FEC approval authority to KSC resident support. Items such as changing a bolt length or adding an equivalent paint with a different part number to a drawing are straight-forward and could be handled locally. Items which reflect a more significant change, such as changing the design in a drain plug, should still be brought forward for MSFC review. • Have a full-time IPT rep at KSC during build-up to provide continuity in TxRB, RAC, and other local boards as well as to provide a clear point of contact among the IPTs.

9.4. Qualification of vendor's parts was generally just accepted, follow-up lot testing not generally performed.

9.5. Quality audits should be scheduled in up front. Vendors and sub-vendors should be approved by NASA quality. All teams should understand the meaning of this in terms of verification products.

9.6. There should be more on-site presence of contractors to monitor over-all manufacturing process than occurred on FS.

10. Test & Verification

10.1. On less critical things (like the DFI) you need to plan a way out. If hardware doesn't pass test after initial installation checks…have procedures ready to fix it. Since DFI was less critical hardware. it was not completely qualified prior to installation. But, it was on the critical schedule path. Once we realized some of the sensor installations were going to extend the processing schedule we decided that some were allowed to be "terminated" if necessary. The engineering was not in place so developing it challenged the schedule--engineering should be done in advance.

10.1.1. Another simple example would be the paint blemish on the FSE at Major Tool pre-shipment.

10.1.2. Establishing some Sensors as LCCs. When these sensors did not function properly, they were just waived. Were they really LCCs?

10.2. Verification plan and process needs to be owned and controlled by the element not the system. Issue: the System owned the element VRD (Verification Requirement Document). Verification closure by the Element could not start until the VRD approved by the System - and this was not done until very late in the process (initial thought to be months before flight but ended up weeks before flight). FS did verification at risk.

10.3. There was not a clear understanding of the verification expectations from system to element. We "missed" hitting system's expectations - (see org/culture). This became a sticking point in getting agreement on verification plan approval.

10.4. Clearly define the verification logic with all the appropriate people providing buy-in. This should be early - before test and analysis starts for final verification.

10.4.1. This means the environments need to be in place when you START analysis and testing for verification rather than lagging.

10.5. Plan for test issues. MRB, schedule margin, test anomaly resolution, design margin, contingencies...

10.6. Fully understand the requirements for margins and built in conservatisms for test.

10.6.1. USAF Range expectations and Shuttle expectations

10.6.2. Need to fully understand the data we captured on DFI and compare to what we tested to

10.6.3. May be able to reduce some things

10.6.4. It is not just the data but also the mindset across centers / USAF/etc.

10.7. Many items that required qualification testing or retest due to current vs. heritage requirements happened far too late in the schedule.

10.8. There has to be a better way to do verification. The whole process at ATK and at the project level needs to be re-evaluated. a. It felt like there was duplication in verifying a requirement that the flow down of requirements was confusing. I. In addition to these intermediate TRs that all they did was point to another analysis document. Why couldn't we go directly to that document to begin with? I could understand having one document point for all verification for one subsystem to find, but sometimes you had to go down 3 to 4 tiers of documents before getting to the meat of the analysis. b. Need to do a better job in requirement owner identification and TREPs. (I would suggest leaving the requirement owner to identify a sponsoring TREP and then the sponsoring TREP will tell the requirement owner who the enabling TREP(s) were because it always wasn't just one person. c. Also the definition of a TREP versus the enabling TREP is a little confusing, especially when looking at how it was identified through the matrix Bob Williams had created d. Also need to identify a requirement owner at the integration level who knows all the disciplines to coordinate with.

10.9. Verification process is, fundamentally, straight-forward. It should be addressed from a Systems Engineering point of view and modifications to the process should not occur; especially to match other programs,

10.9.1. For structures we designed to a factor of 2.0 to eliminate test

10.9.2. did a lot of component testing

11. 1st Stage Top 3

11.1. Realistic Schedule / Provide Schedule Margin to the IPTs.

11.2. Spend more time up front developing good system level requirements--Pre-mission definition study before starting.

11.3. If the new vehicle is the true vision of the future of human spaceflight for NASA, then you need to fully back up your program.
11.4. Clearly define Center responsibilities and state their authority/expectations--includes management structure

2.4 RoCS IPT Knowledge Capture

1. **Engineering Management / Systems Engineering and Integration**
   - 1.1. Heritage Hardware Design Verification Philosophy Challenges - "The design verification philosophy for ROC was an issue – the high reliability heritage system was subjected to extensive design verification testing and analysis"
   - 1.1.1. - Expectations and philosophy for test and verification must be better articulated across program/project participants
   - 1.1.2. The expectations evolved over time from a test vehicle to man space requirements
   - 1.1.3. There was a lot of vagueness as to whether the CEQATR or the MVP would be governing, and we should have had an ARES I-X MVP produced early so as to eliminate being intimidated by the CEQATR.
   - 1.1.4. Program/project participants need to be limited to those who have some background in the actual hardware that they are creating requirements for. RoCS had requirements articulated from SE&I that did not reflect an understanding of the hardware, e.g. vibe testing pyro valves.
   - 1.2. Environmental Loads Data Books Stability - Requirement stability "environmental loads was a moving target" – "some data books simply came out too late"
   - 1.2.1. Structures Data Book final revision was published within a few days of launch after COFTR's were signed.
   - 1.2.2. Only by the good judgment of TBE did we overdesign the system so as to encompass all these changing loads.
   - 1.3. Schedule—The Key Driver - Schedule is the real risk driver – "perhaps SE&I should have ensured that the designs did not move forward until the requirements were locked in"
   - 1.3.1. - Management needs to temper, balance, or pull-back on schedule pressure when critical requirements remain undefined or are changing - A stronger SE&I function must be implemented.
   - 1.3.2. IPT scheduling should be included are part of the process from inception
   - 1.3.3. RoCS was able to stay off critical path by having over-designed early.
   - 1.4. Testing Philosophy – Human-Rating Versus Test Flight? - The imposition of Human Rated – style test and verification methods and approaches on a fast-track demonstration test flight was deemed onerous—"people need to be aware of the type of mission you are flying"
   - 1.4.1. Expectations and philosophy for test and verification must be better articulated across program/project participants
   - 1.5. Up front we need stable engineering requirements that are appropriate for a Test Flight (As opposed to human-rated requirements). This should include loads, thermal, environment, etc.
   - 1.6. Engineering Management did not like the contractual arrangement at MSFC of having the contractor work with a project office rather than directly with Engineering.

1.7. Engineering Management appeared insensitive to providing adequate, requested support per original plan.
1.8. Engineering Management got involved with Project Office when difficult testing issues arose potentially affecting schedule or technical outcome
1.9. Upfront a less flat management structure could have been created. The Ares I-X project had a relatively flat structure. As a result a large number of documents went through the project level ERB and project board. This lead to long telecons involving large numbers of people for documents or concerns involving relatively few people. Eventually a Demonstration Flight Instrumentation Board was set up to handle some of this work short of taking it to the project level board. This could also have been done with regard to interfaces. Interface boards might have been a more efficient way to resolve interface issues.
1.10. Need give and take on dynamics loads with SE&I. Loads assessment was impacted by SE&I active participation on RoCS that was inconsistent with other IPTs)
1.11. SE&I needed to provide more/stronger interface management (RoCS interface panel analysis and IS-1 doubler analysis needed stronger involvement early on, particularly in the development and compliance planning of the ICD.
1.12. It was very helpful to MSFC SE on-site support at TBE during the design, manufacturing, test and Verification process.
1.13. 1-X RoCS experience may not be utilized to its fullest on the flight system
1.14. Need crisp inputs from SE&I GN&C to aid in all facets of the design.
1.15. Upfront the role of S&MA and the requirements related to S&MA were not well defined. The SR&QA document was formulated late in the project. This resulted in a lack of understanding what was expected of the IPTs with regard to S&MA. Quality requirements varied greatly between IPTs as a result.

2. Requirements Management

2.1. FTV Requirements needed to be nailed down sooner, and those that were non-value added (like requiring a VAB for assembly) should have been tossed early so as to minimize the processing later in crunch time.
2.2. Upfront the RoCS requirements were written without subject matter experts who would be involved in review of verification documentation. As a result, there was uncertainty in the meaning of some of the requirements and what would be the appropriate verification.
2.2.1. Engineering abdicated the writing of the ERD and felt RoCS should go straight to EIS. The draft ERD was certainly available for engineering review and comment before it had ever gone out for general review and baselining.
2.3. ICD and baselined requirements need to be coordinated prior to baseline and approval of changes. (RoCS LCC changed without RoCS coordination)
2.4. RoCS did a good job of addressing requirements verification as we saw the importance of getting the easy ones behind us as early as possible so as to minimize the bow wave later on of the more difficult closures

2.5. Chief Engineering function should review and vet requirements prior to implementation to insure that they meet test philosophy and that they are not simply the most conservative requirement that can be implemented.

2.6. Partially, due to uncertainty in higher level requirements, RoCS test procedures were developed late. These were level III documents, were not required to be reviewed by NASA, and were not always exactly performed as NASA would have preferred. Examples include not having a filter on an engine valve test procedure and not making actual flow measurements on lines containing check valves.

2.7. KSC should not request data inputs for GO that they do not plan to implement. (IPT facility requirements)

2.8. The IPT Lead an LSE/Requirements Owner developed and maintained very good verification tracking tool, very graphical and quantitative, to show progress of closures.

2.9. RoCS to USS ICD was not adhered to by USS, even though it was baselined and agreed to at the XCB, including a concurrence vote by USS.

2.10. Upfront it was decided to have Demonstration Flight Instrumentation on only one of two modules. This probably did not save money since there were two sets of drawings that were required.

2.11. Need more organized approach to document and reference requirement documents on-line. Wind Chill and other such systems should be organized, accessible and user friendly to avoid misunderstandings and errors.

2.12. USS asked for the panel interface between RoCS and USS to be matched drilled. This provided tolerances in excess of NASA standards for such a joint. As a result the modules were not longer interchangeable and no backup module could easily be exchanged if one should not be usable.

2.13. Test requirement inflation was a constant challenge for the RoCS Program (Qualification and Acceptance testing became a requirement late in the program). Functional testing was planned but not QTP and ATP.

2.14. The project did not have a fastener control plan or details of fastener requirements. Therefore there was uncertainty of what was appropriate. One IPT did not have quality documentation on fasteners. RoCS made a late switch of fasteners to provide a locking mechanism on fasteners for the propellant tanks.

2.15. The contractor needed specific requirements/expectations from MSFC Engineering early so as to incorporate into test procedures, rather than getting expectations communicated late while testing was ongoing or imminent.

2.16. SE&I understanding of verification was superficial and did not listen to IPT inputs. SE&I had a theoretical understanding but not an actual understanding of how this process works.

2.17. When MSFC Engineering is put into an insight role with a contractor, there needs to be clear cut roles and responsibilities defined (documented) consistent with the contractual mechanism, among Engineering, project office, and contractor. This would avoid problems of walk-on requirements, last minute changes to contractor test plans demanded by Engineering, etc., and verifications being held "hostage."

2.18. The verification tracking tools (CRADLE) were never made available as sold by SE&I. Verification was left more for the IPTs to come up with their own methodology.

3. Organization / Culture

3.1. Double standard of IPT involvement at KSC – MMO wanted side-by-side involvement; Many in GO wanted to know why IPTs even were showing up. Difficult to walk the fence between being involved and being in the way.

3.2. Design standards at individual centers needed to be respected, in spite the heritage or age of the standard (RoCS panel bolt hole sizing vs. the GRC new analysis) We easily spent many $$ and hours coming full circle on the MSFC bolt hole design standard.

3.3. Solumina accessibility was oversold, had to be accessed from desktop. Could not create PDFs of WADs so that they could be reviewed by non-Solumina reviewers.

3.4. Research center cultures tended to turn technical issues into science experiments instead of resolving the problem. Example RoCs panel and bolt bending issue. Considerable extra effort and money was spent to avoid a problem that didn't exist until testing was completed to prove that the issue did not apply.

3.5. The NESC role/function did not appear well defined at all. NESC is supposed to be composed of engineering management but that does not assure a single opinion. For example, Peacekeeper hardware was not acceptance vibration tested which is a Constellation standard for fluid devices. MSFC engineering management stated that this was an acceptable risk. SE&I asked for a separate opinion from some faction of NESC and got a recommendation to perform acceptance vibration testing.

3.6. KSC culture seemed inconsistent as to role that they expected of the IPTs. Some KSC areas were happy to have our support others seemed antagonistic to our support. There is a school of thought at KSC that when they receive the hardware then KSC personnel are the technical authority.

3.7. SE&I often had talked about providing personal support to the IPTs as verification process was going on at IPT level, this may have help speed verifications at the next level up. RoCS encouraged this, yet no one ever showed up.

3.8. Research Centers tended to listen to technical counter parts at other RC's (probably due to familiarity but this resulted in making other IPT engineers inferior in problem resolution. RoCS structures and dynamics.

3.9. SE&I does not understand the function of System Engineering and Integration. They did not function as a Lead Systems Integrator.

3.10. RoCS developed good rapport with a few key KSC folks and the RoCS IPT lead felt a good level of trust (even amongst the friction) was established.

3.11. Solumina was not accessible to the IPT and Solumina data could not be easily shared within the IPT.

3.12. One of the RoCS engineers told the project manager, "I don't give a damn about your schedule (or budget)." NASA encourages engineering personnel not to think about such things and concentrate on engineering excellence. That is a mistake since making schedule and budget should be a goal of everyone on a project. After all, achieving the perfect system will eat up all the budget and schedule and still not be ready to fly. The system that meets requirements with acceptable risk should be the goal.

4. Communication

4.1. The IPT Lead appreciated the Engineering-generated weekly tag-ups.

4.2. Windchill needs to better organized and more user-friendly.

4.2.1. Nothing can be found in Windchill. A document tree or directory should be on each folder and an overall tree should be found on the top level folder for each project on Windchill.

4.3. It helped having an engineering representative at the prime for the RoCS project. This greatly improved the NASA understanding of the verification and build activities.

4.4. Solumina needs to be more user-friendly and function better so that the Solumina System does not hold up GO work.

4.5. The Contractor (TBE) held daily telecons amongst MSFC engineering, Project office, sub-contractors, etc. and always had an open door for folks to attend in person. very good.

4.6. The RoCS LSE was co-located at the contractor site and allowed me (RoCS IPT Lead) to have eyes at the contractor site without having to constantly bug the various contractor folks.

4.7. SE&I and Chief Engineer functions need to act as honest brokers for technical issue resolution between IPTs.

4.7.1. RoCS to US issue resolution. Also RoCS dynamic issues with SE&I (Load increases without clear explanation and ATP and QTP requirements levied)

4.8. Data books and baselined requirements should not change without coordination.

4.9. The weekly generation of notes for MMO and CxP is good in that it forces one to evaluate the IPT progress, maintain accountability on a frequent basis. Other tools such as the issues tracking tool seemed to be duplicative and of limited value.

4.10. The prime and engineering tried to schedule tests so that engineering could witness and tried to mutually review procedures in advance so that all parties understood and agreed that the test was adequate. While this did not always occur it was for the most part successful and should be emulated by other projects.

4.11. KSC should define their expectations for IPT support so that we can meet their needs.

4.12. Need to avoid adversarial situations on problem resolution. CE and SE&I enhanced roles would help.

4.13. WebEx was effectively used, PBMA was a pain. Was glad when we went back to WebEx. It really saved a lot of travel.

5. Resources

5.1. Suggest that MSFC Test Lab expand capability to do more testing that will required for the Ares I. (Vibe testing of pressurized systems)
5.2. RoCS was always able to maintain within budget, even after taking on extra hot fire testing at WSTF, and having to transfer vibe testing from MSFC Engineering responsibility to TBE (eventually conducted at Wyle)
5.3. Suggest MSFC Materials Lab test materials for seals for Hypergols. Current test data is old and needs to note more acceptable materials.
5.4. Engineering Dynamics personnel support for RoCS changed several times due to changing priorities and assignments. This meant that personnel had to be brought up to speed more than once and that is not very efficient.
5.5. The Hypergolic Maintenance Facility at KSC dry run capability for loading of propellant / pressurant tanks was a huge plus in early procedure development, done in a benign environment.
5.6. WSTF 300 area needs to continue to upgrade is capabilities and personnel to support development testing
5.7. Additional access to MSFC engineering subject matter experts would have been beneficial.
5.8. The WSTF test capabilities are very much focused on shuttle support and there seemed to be some difficulty in transitioning to a new program to support the PK engine testing. End to end check outs prior to bringing in the live test article resulted in dissimilar electrical loading conditions, blown circuit breakers, and aborted test periods.
5.8.1. This may be more applicable to the 300 area of WSTF than the other test facilities.
5.9. Stability in ER lead resources was extremely helpful and their onsite interaction with the contractor was invaluable
5.10. Program Management was always supportive and involved. They understood the resources required to do the job. As a result we were able to add tasks without impacting schedule while minimizing our cost impacts
5.10.1. Example was dynamics testing additions
5.11. The KSC resources provided for the handling exercise at TBE, though probably overkill, and were valuable in identifying some handling issues as well as early procedure development.
5.12. KSC resources to complete tasks, such as modifying the fairings, or to handle and fill the modules, needs to be enhanced. RoCS sent tools required to modify the fairings (drill bits, reamers, etc). Availability of air bearings would have been useful for handling the modules during filling.

6. Safety and Mission Assurance / Technical Authority

6.1. The Chief Engineer Function should actively work to resolve technical issues between IPTs. (Example: RoCS OML Panel Loads and Bolt Bending issue.)
6.2. S&MA expectations were more closely aligned with manned vehicles than a test vehicle.

6.3. The RoCS IPT was fortunate to have a very proactive, very involved S&MA lead and support personnel. Government Inspection (DCMA) issues were addressed quickly. The S&MA processes (CxP Safety and Engineering Review Panel, Hazard analyses, Safety Verification Tracking Log, etc.) were handled very efficiently and timely with no need for the IPT lead to have to push.

6.4. Upper S&MA leadership was not inclined to understand the IPT and its hardware. This produced a gulf between their expectations (manned rated shuttle requirement) versus the RoCS system that was designed and built from PK heritage hardware.

6.5. As RoCS IPT lead , I was uncomfortable having the Lead Engineer charging to a RoCS Project Number, while supposedly being an agent of the Chief Engineer's Office. This probably also cause the LE to be conflicted as well, as to whether to be an advocate for the design or provide the "healthy tension" as required of the Technical Authorities (TAs).

6.6. On Ares I-X the S&MA role seemed to have evolved to the point that it was somewhat redundant with Engineering in terms of review of documentation. Redundancy is inefficient. S&MA is the expert on quality and safety. It should not expand that role unless there is some clear management definition of the expanded role.

6.7. RoCS S&MA Lead did an excellent job supporting the IPT and bridging gaps.

6.8. Roles and responsibilities between engineering and S&MA are not clear. S&MA should not attempt to duplicate engineering as technical authority.

6.9. The technical authority model treated the Lead Engineer as independent of the project, essentially a reviewer only to whom the project would bring their "rocks". The RoCS Lead Engineer did not follow this since review is an after the fact event. Efficiency requires the Lead Engineer (and for that matter S&MA lead) to be proactive and be involved upfront in the writing of requirement, plans, and procedures.

6.10. SR&QA requirements were imposed after contractual mechanisms were in place. This originally caused difficulty in Material Review Board delegations, but was eventually worked out by re-writing contract language. This was true in other areas as well as far as having contracts in place then retroactively writing the specifics of the contract.

6.11. Roles of Engineering, S&MA, and NESC are getting unclear and overlapping. NASA seems to believe that the more voices involved the better the result. That is just not true. Those most involved with the best background are the voices that should be heard. Management needs to structure the project so that occurs as opposed to allowing anyone to address anything.

7. Schedule

7.1. RoCS worked proactively in the design phase against very conservative loads so that we could get something down as quickly as possible, as mitigation against waiting for definitive requirements.

7.2. KSC GO schedules should be more accurate and definitive. GO schedules were high level and the margin was invisible and consequently under GO's control.
7.3. Lean Events were not value-added for RoCS. RoCS (to the high satisfaction of the IPT lead) were constantly working parallel paths, spare material and parts. We staffed off-site meetings with only value-added personnel, and kept folks back home working the problems.
7.4. IPT's needed to be involved with scheduling from inception of the program.
7.5. A wise man at the RoCS prime said that, "Schedules are the figments of management's imagination." OK, that's an exaggeration, but we spend a lot of resources writing very detailed schedules that are based on wild guesses as to what and when facilities, personnel, and equipment are available. It would be more efficient just to say, "something similar to those tasks would normally take a couple of weeks," rather than waste time detailing things to the day or hour.
7.6. A big push to get RoCS delivered to KSC and integrated (as very much driven by GO) showed that the RoCS were integrated 5 weeks off the critical path, yet were being told that that RoCS was on the critical path. Crying wolf on this "critical path" issue occurred too much, and reduced the credibility of what was really critical.
7.7. Ares I-X program was milestone schedule driven from the top down. It was not driven from the bottom-up. This sometimes raised schedule expectations about what was achievable.
7.8. Test schedules were not allowed to occur as planned as changes were always forthcoming.
7.9. Because of the short schedule RoCS was designed to assumed requirements using heritage components. It was assumed that this design could satisfy the requirements once they were determined. There was no off ramp or alternative possible. The RoCS project could have failed easily if not for the fact the heritage components were robust and the design was very conservative (heavy, big volume, not elegant or high performance.)

8. Design

8.1. Atlas avionics and Lockheed did an excellent job in support of Ares I-X
8.2. RoCS design was heavily influenced by the PK heritage hardware. Fortunately this hardware was robust enough that it was able to perform beyond its qualification limits.
8.3. RoCS design was altered by US and ATK without being coordinated with to understand the issue.
8.4. Ultimate design of the final configuration weighed heavily on the highly proven and reliable PK configuration. MSFC Engineering had to come full circle regarding in-house design philosophies (redundancies, dual regulators, parallel check valves, etc.) to show that the PK configuration was the best configuration for reliability in the context of this mission.
8.5. NASA acceptance of Air Force hardware and methodology was always a challenge and concern. Particularly for Engineering and S&MA.

8.5.1. For example: Single regulator traded in reliability the quad redundant parallel regulators. Air Force did not conduct vibe ATP testing.

8.6. Design was intentionally approached to be conservative since RoCS was not weight constrained, so as to get thru the design process early. This conservative approach paid off in all areas except the fairings, where field modifications had to be implemented after delivery to KSC. This was due to aero buffet loads not being made available until just before delivery of hardware. The RoCS showed that using PK configuration was more reliable than the old NASA paradigm of more complexity.

8.7. NASA should consider the incorporation of Aging and Surveillance (A&S) program for Ares

8.7.1. Use of hardware procured to be used in the future (due to obsolescence) will require and A&S program

8.8. NASA and Constellation tend to prefer redundancy in design to achieve a high overall system reliability. The Air Force Peacekeeper hardware used on RoCS was designed to be reliable through highly reliable individual components. It was not designed to be used in systems where components were redundant (wrong flow rates/pressure drops). The Peacekeeper hardware could not be used in the redundant manner that NASA typically would require.

8.9. The RoCS fairing required redesign to stiffen it. The reason is that the Structures Data book indicated that assuming random loads were twice quasi-static loads would be a conservative assumption. This did not prove to be the case for RoCS since the fairing was not ribbed and could flutter. Assumptions such as the one that lead to this problem should not be made.

9. Manufacturing

9.1. DFI transfer logistics to the IPTs was very much left to the interpretation of the property folks – too nebulous and extremely inefficient.

9.2. By using the Cold Flow unit as our engineering pathfinder, we had a good fit check methodology before committing to doing final machining of the flight unit hardware.

9.3. Lessons learned from Ares I-X could aid in the manufacture of Ares I production hardware. Orbital welding lessons learned in regards to flow restrictors and bends. Materials used in the fairing assembly.

9.4. Some manufacturing processes were new to TBE and had to go thru more process development (tube bending and welding in particular). These probably should have been identified earlier so more attention could be given them, as the final tubing ran late in the process.

9.5. Minimize need for match drilling by good design and analytical techniques.

9.5.1. Cost $1M -- perturbed the schedule

9.5.2. The structures person at GRC was a "modeler" -- this was something that he couldn't model

9.5.3. The interface manager should have been stronger

9.5.4. Two IPTs should have been able to go to a higher level to get the issue resolved

9.6. DFI interfaces and requirements should have been better understood and coordinated with RoCS IPT.

9.7. The interface panel bolt hole position and sizes was well understood by TBE, but being an interface, had to go thru a match drilling process at GRC which greatly perturbed the assembly flow of the hardware at TBE. Ultimately the match drilling was proven to be unnecessary.

9.8. The need to have to pull the DFI fairing of at KSC drove the need to put an intermediate connector in the DFI harness in order to avoid a much more involved routing and disassembly to get the fairing off for re-work. The domino of late requirements had a much bigger effect to the design and manufacture than just "pulling the fairing to mod it."

9.9. Wherever possible OML panels should be manufactured from a flat billet of material and not use rolled material. OML diameter should be machined into the panel.

9.9.1. US RoCS doubler

10. Test and Verification

10.1. Test and Verification requirements evolved into Acceptance Test Procedures and Qualification Test Procedures as opposed to functional hardware testing to specified environments.

10.2. Test requirements and test planning documents flow was not managed well at the IPT lead level - we needed more observance of contractual protocol or change the contract so that test planning documents would REQUIRE approval of MSFC engineering.

10.3. NASA requirements for pyro testing were based on manned shuttle experience with no allowance for anything less rigorous. Air Force data was not accepted and was presumed to be suspect because of a different approach.

10.4. Original plan only required Cold Flow Testing however as the program proceeded forward we completed 3 Hot Fire tests

10.5. Verification actually was started in July 2008 in order to get as many of the easy task behind us ASAP. This led to only the real difficult closures being open at the pre-ship review and the acceptance review that were truly dependent upon a test activity to occur. Kudos to TBE for early submittal and MSFC Engineering for early processing.

10.6. Constellation requires fluid devices and pressure vessels to be acceptance vibration tested. Air Force did not require this of the Peacekeeper hardware used on RoCS and the hardware was designed accordingly. SE&I, S&MA, and NESC personnel all asked for RoCS to acceptance vibration test these components for Ares I-X despite not being very familiar with the hardware. This testing was not done. MSFC engineering viewed the risk of using hardware not acceptance vibration tested as being acceptable. The fact that the hardware was already in assemblies that did not allow complete functional checks and/or inspections after or during testing meant that an acceptance vibe test would have increased the risk of using this hardware not reduced it.

Also, the Air Force had a very extensive acceptance program for this hardware that did not involve vibe testing.

10.7. We did not appreciate the difficulty of testing at or above operating pressures for the .25 inch lines on the pressurant system. Pressure source requirements are quite high.

10.8. NASA should not attempt to invoke their center safety requirements on contractors outside the center. Test safety at the contractor facility is a contractor liability issue not a NASA issue.

10.8.1. Pressure systems testing

10.8.2. If TBE is abiding by their industrial safety requirements that's OK

10.9. The recognized plan for "re-qualifying" the PK pyros was recognized very early amongst the S&MA and Engineering folks, and we talked it frequently in order to get and maintain buy-in and understanding of the pyro limitations. As it was, once the final cold flow testing was complete, the waiver on the PK ordnance limitations was not a hard sell.

10.10. The Ares I-X Master Verification Plan needed to be published very early so as to usurp the CxP level CQATER, as the CQATER was overly restrictive and applicable to the mainline program, yet it was all we had for a verification plan for almost a year.

10.10.1. CEQTAR was never an AIX requirement

10.10.2. It was overkill

11. Top Three

11.1 Front end load the schedule, as other unplanned problems will come up later. Get the easy stuff behind.

11.2 Ares I-X project had many personnel involved in decisions (much like NASA as a whole.) The roles and responsibilities for such projects need to be stated very clearly with great detail so that there is quick and final decision making occurring at the appropriate level.

11.3 Define detailed verifications as much as possible when the requirements are established

2.5 Avionics IPT Knowledge Capture

1. Engineering Management / Systems Engineering and Integration

1.1. Establishment of Systems Integration Lab - Establish a systems integration laboratory (SIL)

1.2. IPT Self Integration Challenges - The IPTS had to be self integrators – there should have been a stronger the SE&I function - Interfaces should be managed top-down, not bottoms-up - SE&I needs to verify requirements at interfaces - need a strong integrator above the IPTs

1.2.1. A stronger SE&I organization should be established for future Ares and Constellation projects.

1.2.2. Sometimes bottoms-up interface management is necessary when using existing hardware / interfaces.

1.3. Had an Organizational / Contractual structure that matched the specification tree structure and MMO defined processes

1.3.1. Impact: IPTs were not always contractually committed to meet the intent of the requirements flow, integration or schedule activities.

1.3.2. Mitigation strategy: managing requirements and associated expectations; maintained focus on doing what was right, working with other IPTs to ensure requirements were clear and that desires were considered as appropriate.

1.4. Need to establish a clear definition of work split /responsibilities

1.4.1. AIX attempted to do this fairly successfully as part of the ICDs

1.4.2. the definition needs to include authority and accountability (so the interfacing IPTs are bound to follow the ICD)

1.4.3. There were some "holes" in responsibility as well as overlap (confusion of roles)

1.5. For Ares I-X the SE&I organization lagged all other IPTs; SE&I should lead the project in the proper direction. The introduction of a Mission Manager helped this issue but also caused a reorganization of SE&I. This aggravated the attempt to get SE&I in a lead posture.

1.6. Decision making / authority / responsibility needs to be optimized

1.6.1. AIX was no different than most programs that morph between a single decision making board (bottleneck) and multiple boards (gauntlet) seeking an optimum (happy medium between paralysis and adequate review) – In many cases, it seemed like the “issue” could have been resolved at a lower level – AIX did recognize the situation and attempted to restructure to optimize

1.7. Program management needs to reside in a single organization

1.7.1. I don’t believe that AIX would have been accomplished without the change from “competing NASA centers” to a mission with a mission manager

1.8. The program would have benefitted by having a Vehicle Integration Team with responsibility and authority to control integration at different facilities. The Avionics IPT delivered hardware to be integrated by 6 different organizations. Each 'receiving' organization had different interface / process / interfaces. A single organization could eliminate duplications and rework, and provide efficiencies.

1.8.1. For example, delivering products to six other IPTs -- need consistent approach (logistics)

1.9. The Avionics IPT was very well organized. The manager realized very early that all other organizations needed awareness of avionics issues and resolutions. He proceeded to establish an Avionics Control Board with representation from each IPT. This control board allowed Avionics to resolve issues at our level and bring a solution to the proper upper level board.

1.9.1. Only IPT to have their own control board

1.10. Needed system level requirements document completion early in the project with significant participation by experts in the design and integration of launch vehicles. The Ares I-X SRD completion was late with respect to design efforts and not comprehensive enough for a new launch vehicle, e.g. tribo-electrification, common specs for basic components (fasteners), exposure to lightning, vehicle bonding.

1.11. Need to integrate ES Department Management (MSFC engineering) and ES engineering support in an effective manner early in the project to lessen the impact of bringing them "up to speed" late in the flow.

1.12. Avionics organization responsibility should cover the entire vehicle (not split by stage or other physical partitioning)

1.12.1. Avionics should be viewed as a vehicle level system versus a stage “subsystem” – Avionics issues / changes evaluated at “avionics” level versus “vehicle” (US / FS) level – Enables vehicle level system optimization – Enables commonality to be employed (e.g. Atlas URCU/BRCU, ORCA) – Eliminates separate management organizations – Eliminates inter-organizational interface coordination – Reduces inertia (layers of coordination, approval, & authorization) of the design & development process

1.13. Lacked knowledge in technical areas of responsibility

2. Requirements Management

2.1. When using software for layout design, be sure to have a requirement for all layouts to be standardized so all contributors are using the same type, version etc. (especially across different contracts) Ares I-X had short cables which was blamed on a mismatch in the layout tools. The layout was a combo of a CADD and Pro E models--the end result? Cable lengths were too short at times

2.1.1. The integration of the design effort should include ensuring that the designing entities use the exact same software package to do their detailed design. Many hours were spent reconciling differences between software packages and compensating for them. The time to convert files and check them when they were transferred between the IPTs was substantial. (CAD packages, sharing of models)

2.2. Requirements verification typically occurs in conjunction with CDR to demonstrate that the design satisfies the requirements

2.2.1. Requirements immaturity resulted in this activity occurring very late in the program – Activity became blend of design and “as built” verification, adding confusion and further delay to requirements closure – There needs to be a means to separate true requirements from "desirements" in order to separate the "must have" from the "nice to have" (especially in a program being based on existing hardware). The SRD/ERD did assign requirement priorities, but these were not really used. There should be a distinction between requirements and desired system attributes.

2.2.2. Requirement verification planning should be complete; some verification may be started but not complete. e.g. 90% drawings complete so not all associated verifications would be complete.

2.3. SE&I should write and maintain the ICDs. The ICDs define the interfaces that SE&I is responsible for integrating.

2.4. Aggressively manage schedule / milestone achievement early in the program

2.4.1. Schedule is typically "lost" early in the program where a week (or two) "slip" is not scrutinized at the same level as during the final 6 months of the program – Avionics supplier contracts (and others) were let prior to definition of system level requirements (assumptions were made that didn't always end up supporting the system level "desirements") – Late requirements definition (e.g. environments & DFI definition post avionics CDR) contributed to schedule delays. Early DFI effort concentrated on sensor identification – a system baseline (hardware & wire harnesses) could not be established until sensor types, quantity, & location were known. – Late system level requirements definition resulted in assumptions being made by subsystem personnel that were not universally correct or consistent

2.5. Project-level requirements need to be recognized by all parts of a project. For Ares I-X, GO did not recognize the ICDs as a document to draw requirements from. This caused rework for the IPTs and missteps in integration and processing.

2.6. IPT should have a solid System Requirement Specification at SRR. Avionics early design and contract set-up was scoped based on assumptions, not defined requirements. Mitigation strategy: managed and communicated changes to Avionics ERD, worked early incorporation into sub-system level design and verification planning.

2.7. Had a defined and acknowledged CM process at SRR. Key requirements documents were not baselined when necessary, review process was timely and resource intensive. Mitigating strategy: maintaining consistency of avionics interface, functional, and performance-based requirements; extensive heritage knowledge and regular technical

2.8. System level planning should be defined prior to subsystem details (at least at a top level)

2.8.1. – Results in bottoms up versus top down planning and assumptions versus directions – AIX had no system level E3 plan or expertise

2.8.2. Planning should accommodate program baseline - use of heritage hardware requires some top down and some bottoms up.

2.9. Environmental control should be strictly and detail planned at all places during processing. Define "clean environment" and humidity levels to the greatest detail for processing hardware. AIX worked hard at requirement for the internal flight environment for the avionics equipment when in was installed in the rocket...but not so much processing before they were installed. At one point First stage was sanding one of the Fifth Segment Simulator sections right next the FSAM with most of the avionics boxes and exposed. "How clean is clean?"

2.9.1. Need to consider storage and both operating, non-operating environments. The assumption should not be made that ECS will provide clean air when initially turned on. (It wasn't, introducing FOD into vehicle.)

2.10. At the program level a released System-level Specification Tree prior to the Avionics Systems Requirements Review would have added clarity to requirement hierarchy and flow structure.

2.10.1. There was little early buy-in by all members on requirement flow prior to attempting requirements allocation and integration.

2.11. Interface Control Requirements were considered desirements by key members of the SE&I team. SE&I book managers for the ICDs did not ensure enforcement of requirements.

2.12. Requirements documents should not be used to control contract scope or define contract work content. The contract's Statement of Work (SOW) is for this purpose.

2.13. Lack of a requirements management tool delayed the implementation of requirements and prevented the orderly allocation of requirements.

2.13.1. Requirement allocation was done per document and not tracked in one place

2.13.2. Some IPTs didn't realize requirements were allocated until late. CM\LAS was unaware that they were responsible for meeting bonding requirements

2.13.3. Requirements came in different forms - word documents, excel files, etc.

2.14. Ares I-X considered Lockheed Martin processes and requirements adequate for our project. This saved many hours of demonstrating 'meeting the intent' of NASA documents and hours for the contractor to understand the NASA requirements.

2.15. Organizations should sign off installation drawings for their hardware

2.15.1. AIX attempted to use an ICD (supplemented with installation memos) to convey data – Installation drawing folks were not universally aware of ICD/memos – there may be a separate lesson here – GO did not recognize the ICD as requirement source for installations performed at KSC – Hardware organization (e.g. avionics) required to ferret out drawings that installed their hardware in order to review – had no authority to ensure that installation requirements were included on drawings – Required additional coordination to ensure requirements in installation procedure

2.16. Process for ensuring flow down of vehicle ICD requirements to the Ground Operations requirements documentation was not clearly defined. Resulted in some key requirements being in "limbo", e.g. ECS

2.17. The rationale for a requirement should not be considered a requirement.

2.17.1. The rationale statements were not kept "current"

3. ORG / CULTURE

3.1. It-wasn't-made-here attitude exists at NASA that excludes advances made by EELVs over the past 30 years. For instance, the EELV office at KSC was excluded from working I-X in lieu of Shuttle processing personnel.

3.1.1. Would have better to have EELV personnel as part of the team

3.2. Viewing contractors as team members instead of merely product providers help IX solve many problems that would have otherwise taken longer

3.3. Many “issues” that were experienced were cultural in nature - primarily Shuttle versus EELV

3.3.1. “MPE” of P97.5/50, 5Hz BW versus P95/50, 1/6 octave BW (essentially Shuttle versus 1540), also MPE +0db versus MPE+6dB – Shuttle versus ICD (LM) wire harness routing requirements (usage of metallic tape. Post installation DWV testing)

3.4. SE&I should have been given ownership (authority & accountability) for all requirement documents (e.g., ICDs, OTRs, and LCCs). ICDs should be applicable to all IPTs. Lack of appropriate authority resulted in requirement hierarchy and flow structure that was unclear; there was not buy-in by all IPTs on requirements, even during integration and verification activities, leading to increased analysis or hardware risk associated with violations.

3.5. Open communications between suppliers was successfully used to reduce communications inertia – program was operated as an “integrated team” effort (scope changes still required program approval / contractual direction)

3.5.1. – Working groups used to facilitate communications, but direct contact encouraged

3.5.2. The Communications document should highlight the different ways the subgroups do business at their companies/centers (ex Requirements handling) and then address how the project will operate.

3.6. Made an effort to define the Ares I-X "culture" early by leveraging Shuttle and Atlas. Through the entire program, "shuttle" vs. "Atlas" difference caused strife, miscommunications, and added risk to integration activities.

3.6.1. Also found culture differences within USA organizations (KSC-based electrical groups: OEL vs. INS vs. SRB).

3.6.2. An example of 'Shuttle v Atlas' was decision to perform DWV testing of harnesses post installation. This is Shuttle practice and was added late, causing additional cost and schedule.

3.6.3. 1st Stage C&C Cables

3.7. Just because we've always done it that way, doesn't mean that way always works in all cases

3.8. Organizational and cultural differences were under estimated. The projects had many groups and companies that came together. A communication document should have been created at the beginning of the project working across these barriers could have been planned for in that document. It seemed to be an assumption that that stuff will work itself out gracefully. Some energy was wasted on these things "working out", but it's tough to quantify.

3.8.1. Once the differences were acknowledged, everyone worked well to improve communications and work as a single integrated team.

3.9. Avionics installation was performed by receiving organizations instead of the Avionics provider. This resulting in many integration issues as installing IPTs balked at requirements for Avionics components installations that were different from how that IPT would install them or expected Avionics to provide step by step installation procedures.

3.9.1. It makes sense in a development project for the designers to install their equipment as they are most familiar with it. It does not make sense to have a 3rd party lay their own processes on top of what the designer is trying to achieve.

3.9.2. As an example - The GO contractor allowed nearly all integrations on FSAM to be handled by the Avionics contractor. This allowed the issues to be worked more quickly and effectively. It also allows the personnel to be more involved with their system.

4. COMM

4.1. Impacts from Test Flight Experience - The entire test flight experience has been invaluable in terms of developing critical communication pathways between sometimes differing engineering cultures

4.2. Meetings (committees) are not an effective forum to “create” products

4.2.1. Meetings should be utilized to coordinate/review comments or approve products – Table top reviews were used effectively in many areas to review products

4.3. Windchill was the "haystack" of the project. It was very difficult to find information needed without a direct link to the folder or the document

4.3.1. This was partially an organizational issue as it was much easier to "find" things on WGC (the LM equivalent (actually superior) to Windchill.

4.4. had a defined communication plan for identifying/contacting on-site personnel. Wasted time due to poor communication/pre-coordination on planned activities; wasted time looking for support, added risk when schedule didn't accommodate proper support. communicating with pad leaders and launch vehicle directorate regarding on-site technical support and providing contact information for all key POCs

4.4.1. Example: vehicle integration activity required Avionics, there were several avionics reps in the VAB at the time but they were not notified. this resulted in a GO schedule delay.

4.5. The face-to-face TIMs and meetings helped reduce tensions between the various cultures.

4.6. Use of Table Top Reviews for drawings and procedures reduced release cycle time.

4.7. Working groups can be very effective in accessing and completing integrated design. WGs need to be closely monitored as their effectivity is greatly dependant on the person in charge of the meetings. They should also be terminated after design is completed.

4.7.1. Work groups are effective when they supplement ongoing work, not the only source of communication / coordination

4.7.2. LCC and Sequencing WG were very well run.

4.8. A communication document needs to be crafted and established in phase A of the project development.
4.9. Too often we worked the same issue multiple times through numerous meetings, Boards, and forums.
4.9.1. Working issues too few times would be bad.
4.9.2. Yes! Issue closure needed a clearly defined path that everybody from the lowest to highest levels understood
4.9.3. Need a definition of board responsibilities and hierarchy to minimize repetition. (MRB vs. SERF vs. ERB vs. TXRB vs. DXCB)
4.9.4. If you think there were too few meetings on the I-X, you need to leave the room!
4.10. Communication of constraints and pre-requisites for scheduling the execution of procedures during vehicle integration was difficult at times. There were scheduling meetings held by GO that did not always include the other IPTS and the daily scheduling meeting could not provide all the details of what was being done in each scheduled procedure. This resulted in major schedule impacts at times as some work had to be re-versed and re-done or the schedule re-organized.
4.10.1. This would have been resolved with the use of a credible IMS, with dependencies and links included.
4.11. A team physically located together (on the same floor of one building) is optimum. A team located over several different states brings problems that cannot be overcome. Whenever possible, an integrating representative should be present at each center and rotated throughout the project.
4.11.1. This is especially true the closer to launch we got
4.12. In addition to necessary reporting within the project organization was the requirement to report activities to line management. A great deal of time was spent just reporting status to someone.
4.12.1. "You haven't explained something to NASA, until you explained it to everyone at NASA"
4.12.2. communication plan should include a centralized status reporting structure
4.12.3. Way too much time spent on explaining the same item over and over. The same topic would get explained at the IPT management level, engineering review boards (ERBs), XCBs, Technical Authority meetings, etc.
4.12.4. I had to defend waivers to up to as many as 4 boards. This wasted a lot of time especially considering many of the boards had many of the same members
4.13. Many meetings at KSC related to integration did not have call in numbers. This made it extremely difficult to provide necessary expertise
4.14. Some issues were discussed at a seemingly endless line of forums. The task of repeating, explaining, and defending a single issue again and again was a morale killer for the team.
4.15. Maintain constructive communication while disseminating plans, especially plan changes mid-stream. Do not demoralize your frontline troops!! Ex. plan changed for DFI TC5 during the testing. The plan was communicated with

tone and context that undermined test team's morale. Focus on the technical reasons for re-plans and acknowledge the impacts to on-going activities.

4.16. The IPPD process required physical presence for participation. The pace at which these reviews took place prevented having necessary personnel participate and key requirements for installation had to be added later, after drawings had been "released"

4.17. The review process for installation documents and procedures was defined by the individual IPTs and not clearly communicated. This should have been controlled by SE&I or at least clearly defined by SE&I to the other IPTs prior to starting the review process.

4.18. A weekly one-on-one was held with the mission manager and each IPT lead. This is a strong management tool.

5. RESOURCES

5.1. Top-Level Guidance on Cost Containment - More top level guidance and management is necessary to define requirements and contain costs as opposed to allowing individual IPTs to drive cost

5.1.1. Establish stronger SE&I function

5.2. Scheduling did not always take resources into consideration. Because Ares I-X was such a fast-paced project, integration began prior to acceptance reviews and verification closures. This caused tremendous resource issues.

5.3. Additional dedicated/effective system-level support from MSFC Engineering would have lessened the work load on the IPT Engineering team.

5.4. Availability of environmental test facilities at MSFC reduced risk

5.4.1. Provided a cost effective alternate to supplier “in house” or affiliate facilities

5.4.2. The use of MSFC test facilities for qualification of some of the avionics boxes and sensors provided relief to contractor facilities and resources.

5.5. The integration of the design effort should include ensuring that the designing entities use the exact same software package to do their detailed design. Many hours were spent reconciling differences between software packages and compensating for them. The time to convert files and check them when they were transferred between the IPTs was substantial. (CAD packages, sharing of models)

5.5.1. LM used Pro-E, ATK used some other package, and USA used another package. Many hours were wasted waiting for model conversions.

5.6. All required interfacing/participating contractors on contract for authorized tasking. Lockheed Martin was authorized/directed to perform a GSE Pathfinder at KSC. However, ATK was not. This resulted in wasted Avionics cost and schedule (utilized resources associated with GSE activities). Risk was significantly increased because first time use occurred when working with/around actual flight hardware. mitigation strategy: coordination with First Stage and GO on GSE usage; we held weekly coordination meetings with the affected parties to overcome the lack of actual pathfinder activities

5.7. Had a streamlined document release process that accommodated the Ares I-X schedule (i.e., Tabletops). Document reviews were time compressed and often required multiple reviews by same personnel. having SMEs work with procedure authors early, holding regular technical interchanges with procedure stakeholders, and dividing review responsibilities as efficiently as possible; flexibility and willingness to work with GO to create a process that leveraged both shuttle and Atlas heritage processes. We successfully implemented the following for later DFI channelization and integrated test procedures: Hold First Article Review (to set expectations and outline), draft distribute for review, hold TTR and incorporate comments, update and release for signature.

5.7.1. Definition of priority for procedure approval was very haphazard the last month of vehicle integration

5.8. Had the Electronic Development Fixture (EDF) officially supported and had adequate funding flowed down to the related IPTs (including contractors). No officially supported model/drawing group or system at the NASA level, leading to multiple work-arounds for sharing models across IPTs. There was no integrated vehicle model until end of vehicle assembly. Managing models between LM and integrating IPTs; designating specific POCs to work between the companies to effectively and efficiently share info.

5.9. Had document release tools that targeted change notice to interested parties only and included track changes. Documents out for review had to be completely re-reviewed because there was no mechanism for identifying the changes.

5.10. The Avionics Integration Services contract was awarded before most requirements were in place. This caused constant battle with additional scope resulting in cost growth and resources. This seems to have been unavoidable as waiting to award the contract would have resulted in grave schedule slips.

5.10.1. The effort needed to support the integration at KSC was not understood and therefore not adequately planned for by the Avionics IPT.

5.10.2. Inadequate integration support was compounded by cultural differences between Shuttle (throw people at the problem) and Atlas (single string in many cases)

5.10.3. Inadequate integration support was compounded by the extremely compressed schedule as everything moved to the right, except the launch date

5.11. Had adequate asset (logistics and property) management support to address hardware handling (transportation, storage, handling, custody transfer, etc.)

5.11.1. Logistics and property management were treated as afterthoughts, not addressed until hardware deliveries and transfers were beginning; technical specialties such as EMI/EMC were poorly staffed until late in the program; post-flight disposition plans do not align with contractual mechanisms in place.

5.12. Staff / organize to reduce “critical” resources – Cannot be eliminated (especially on program with accelerated schedule and tight budget), but should strive to minimize

5.13. Windchill is not an adequate CADM package. There are several other packages available, some owned by NASA, that provide drawing information that are documented in a relational database format. This allows easy searching and moving up and down drawing trees and parts list information.

5.14. Program was a perpetual fire drill. Everything had to be done yesterday.

6. S&MA / TA

6.1. Technical Authority - S&MA and OCE technical authority support was outstanding

6.2. S&MA should not use review boards to learn the technical aspects of an issue.

6.3. The Chief Engineer's role should be altered, making him a contributor, not simply an auditor.

6.3.1. The CE personnel should have an active role in the development to more effectively utilize the resources - folks need to have a product

6.3.2. The Chief Engineer should have THE final say on technical issues. They should not have to be elevated to an XCB.

6.4. The Flight Vehicle Chief Engineer boards were not well led. The discussions went on and on to little or no point. There was much 'bring me one more piece of information'. The CE didn't control the board meetings. This resulted in decisions not being made in a timely manner as well as wasted resources.

6.4.1. Technical information supplied to the ERB was not reviewed prior to the meeting resulting in extended discussions.

6.4.2. Too much view graph engineering and meetings.

6.5. S&MA must be involved in the project from the inception. S&MA requirements for hazard reporting were imposed a year after the project inception and required a significant amount of effort to accommodate.

6.5.1. Process NASA uses for Hazard analysis is different than that used by LM/ULA for Atlas. Resulted in extended discussion and unexpected effort to develop an acceptable report format and development process

6.6. Role of chief engineering office should be more defined and should be staffed accordingly. Chief engineers did not always have ability or authority to make decisions in time to implement recommendations as presented.

6.7. Having an on-site (KSC) liaison between S&MA and Avionics that was vested in avionics success was invaluable. Numerous times they assisted in working impending issues and worked real-time to avoid hardware damage. (e.g. FSAM center plug removal prior to XL closeout)

6.8. The SR&QA plan baseline came too late in the project. It impacted all IPTs with a contractor. This is not surprising for Avionics since Lockheed Martin is not usually a NASA contractor but ATK and Teledyne contracts were affected as well. This could have been avoided by introducing the plan earlier.

6.9. During integration of avionics onto the vehicle, multiple methods for the recording of nonconformance’s were used: Avionics contractor system, the FS contractor system at the ARF, GO contractor iPRACA system, and the Constellation CxPRACA system. These multiple systems were confusing, and in some cases not value added when some nonconformance’s had different documents in different systems to disposition the hardware non-conformance’s.

6.9.1. This problem was compounded because the system owner did not have access to any of the other systems and could not review, disposition or close out non-conformances in other systems. This became extremely difficult during paper close-out because each system lacked traceability to the parallel nonconformance systems for most non-conformances. Because of this, additional personnel resources were required to facilitate nonconformance documentation close-out.

6.9.2. This process should have been examined, modified, and agreed to by each IPT to assure an efficient method was implemented.

6.9.3. Many of us did not have access to the other PRACA systems

6.9.4. One mitigating item was cross-referencing within systems. ex. NC number, PRACA number was included in Avionics Q-notes. Q-note number was included in as run stand alone procedure.

6.10. Too much time/effort was spent reporting separately the same topics to SERF, ERB, and CSERP. Need to consolidate/streamline reporting.

6.11. The CE and S&MA should educate themselves by reading project documentation, participating in development activities, etc. Their approach is to sit by and expect to have information spoon-fed to them.

6.12. The use of Aerospace Corp. as the I-X SW IV&V was excellent. Aerospace is already familiar with and equipped to evaluate Atlas. This also positioned them to provide inputs for other studies where an independent technical opinion was needed.

6.13. Risk assessment was assigned to waivers after risks were assigned to hazard reports. There was no coordination between the approach used for Hazard reports approved by the CSERP and waivers approved by the ERB and XCB. This resulted in mismatch between approved hazard reports and waivers

6.13.1. ERB did not want to take credit for future integrated testing but preferred to assess risk based only on successful testing performed to date

6.14. S&MA should write or at least help write the hazard analyses, rather than simply auditing what engineering wrote.

6.15. The TxRB was a much more efficient "ERB" than the Flight Vehicle Chief Engineer's ERB was.

6.16. The Avionics S&MA was outstanding. Our support was invaluable in helping Avionics work through reviews, issues, and day-to-day operations. Avionics S&MA was on time with all requested reviews and provided insightful comments.

7. SCHED

7.1. Had a fully linked credible schedule that included all elements and IPTs. Lack of IPT review resulted in poor visibility into dependencies and potential conflicts. Avionics did not have adequate time to coordinate major hardware delivery items, resulting in modified deliveries. Necessary time was not provided to address issues correctly, driving cost and risk significantly. Mitigating impacts by adjusting plans to support hardware delivery, integration

& test focus of both parties on mission accommodating changing schedules; we were able to work with receiving IPTs to mitigate schedule and risk impacts.

7.1.1. The lack of a linked program IMS resulted in CM/LAS, US and FS all requiring harnesses to be delivered by the Avionics IPT at the same time. (My harnesses are number 1 priority!)

7.1.2. The lack of insight into the integration phase of the program resulted in hardware being delivered out of phase to when it was integrated: Example the FSE harnesses were given the top priority for delivery and were delivered in November. They were not installed until late January.

7.2. Lean event "success" needs to consider likelihood of implementation (when considering resources, technical rationale, and risk). They must have follow-up to ensure the enablers are implemented as required. IPT level lean events (goal of 90 schedule decrease) results included unrealistic assumptions, there was no follow up on any enablers, SME inputs were not considered during events (regarding realism of enabler and impact). While some processes were streamlined, the net result was no change to overall product delivery schedule. For example, the verification process was implemented even though the necessary decision points were not met.

7.3. Recognize & acknowledge requirements creep

7.3.1. "Acknowledgement" can be adding budget & staff or reigning in requirements – AIX experienced "new" activities (hazard analyses & CSERPs), activities requiring more "attention" than had been planned, and additional requirements assessment cycles (e.g. vibro-acoustics, structural loads, control system analysis)

7.4. Schedule pressure resulted in "bad decisions" that would not have been made if expected launch date were accepted communicated earlier.

7.4.1. DFI was abandoned during integration at ATK due to the launch date being set at 4/15, even when it was evident that date was not realistic

7.4.2. FSAM was shipped to KSC months before it was needed, resulting in work that could have been done in Denver in the spring to complete the FSAM slipping and not being done until late summer. FSAM experienced extended exposure to excessive humidity as a result

7.4.3. This could also have a political slant: It was important to have the FSAM delivered to KSC, even though it would not be integrated into the Fifth Segment Simulator for a month after delivery. This resulted in inefficient completion of avionics onto the FSAM prior to and after delivery to FS.

7.5. The first schedules were adequate from the beginning to middle of the project. We were too far along before the schedule was evaluated from the launch backwards. This caused a severe disconnect and eventually a re-baselining of the schedule.

7.6. Aggressively manage schedule / milestone achievement early in the program

7.6.1. Schedule is typically "lost" early in the program where a week (or two) "slip" is not scrutinized at the same level as during the final 6 months of the program

7.7. Ares IX was the most tightly scheduled project that many of us worked on. And for many of us, it was the only project we worked that went to fruition. Coincidence? I think not.

7.8. Schedule pressure resulted in a lot of additional work by having reviews with a lot of open work that had to be tracked and closed before closing out the review. Also, many unnecessary RFAs resulted from the open work.

8. DESIGN

8.1. Design cables with extra length…always! Well, almost, if space is limited then you have to be close to right on (ex. systems tunnel. But AIX had many cables running through the wide open internals of the rocket. FSE had short cables…extra length should have been planned.

8.1.1. This was successful because baseline design included "20-30% "margin".

8.2. Field installation of connectors should be available for contingency. Cables can be built and tested just about anywhere. This could be planned for makeup and test at the launch site, but it is most important that failed cables can be repaired locally--this saves the transportation time and money while fixing them. AIX cables were made, tested any repaired at a great distance from the launch site.

8.2.1. This requires: The necessary hardware, the necessary paper, the necessary budget, and above all, the necessary expertise. Not all connectors are created equal!

8.3. Electrical parts and water don't mix. The recoverable booster needs a graceful way of powering down. The project had concerns about the recovery phase of the booster. We needed a cleaner way to know that NASA Standard Detonators (NSD's) and risk of electrical shock to divers if the booster was still energized while in the ocean. Much time and effort was spent getting comfortable with these issues. The hardware should be designed safe to process all the way through recovery.

8.3.1. Many issues arose during installation of the DFI sensors that could have been avoided if the design information had been available and properly reviewed prior to installation.

8.3.2. This issue was driven by the decision early in the project to locate the flight control computer on the USS, ensuring there is no way to gracefully power down post separation.

8.4. DFI should be a standalone system (e.g., payload) complete with its own SRR, PDR, CDR, CI Spec and ICD

8.4.1. Many issues arose during installation of the DFI sensors that could have been avoided if the design information had been available and properly reviewed prior to installation.

8.4.2. The DFI would have benefitted from a Test Like You Fly (TLYF) philosophy. A working system including a small percentage of sensors should have been assembled and tested, in a similar fashion as to how the command and control hardware was tested in the SIL

8.4.3. Certain DFI vendors were selected by the requirement owner and not the design implementer. This resulted vendors that were not qualified to deliver space flight hardware that needed a lot of hand holding to get satisfactory hardware delivered.

8.5. Procure spares of long-lead connectors in case electrical cables need to be remade during integration.

8.5.1. This comment could apply to all electrical re-work parts.

8.6. Place emphasis on the design & integration portion of the program

8.6.1. Many of the “issues” “discovered” late in the program were discussed at design reviews – There were fewer “issues” where there was active system level personnel participation in the design process (e.g. control system software analysis, development, & test / sequence document development / FSAM integration with 5SS) – AIX demonstrated the importance of integration in that much of the hardware was already existing (design & integration are two distinct activities)

8.6.2. Thorough system design should capture all systems required for vehicle integration and hardware environments. ex: initial baseline was distributed avionics mounted on heritage SRB structure even though structure did not provide environments that supported heritage Atlas- avionics capabilities.

8.6.3. The PDR and CDR were not as scrutinized as later program activities

8.7. Requirements should be baselined before design and procurement takes place.

8.8. Development risk was greatly reduced by basing AIX avionics on an existing system

8.8.1. The “core” avionics and GC3 utilized existing Atlas hardware / designs tailored for AIX – Provided known system, experienced personnel, existing tools, existing documentation, and structured processes – Atlas personnel located at KSC and familiar with range operations

8.8.2. Maintain knowledge that combining multiple heritage or heritage with COTS systems will have some of the same issues as integrating new hardware.

8.9. Especially applicable to software

8.10. Each PDR should establish a standing review board that follows the subsystem or system throughout the project. This board should maintain some awareness of progress as the project progresses. Bringing in a new review board at each review is unproductive and does not result in a thorough review.

8.11. Common specifications and approaches for structural design and mounting were needed

8.12. Organizations should sign off installation drawings for their hardware

8.12.1. AIX attempted to use an ICD (supplemented with installation memos) to convey data – Installation drawing folks were not universally aware of ICD/memos – there may be a separate lesson here – GO did not recognize the ICD as requirement source for installations performed at KSC – Hardware organization (e.g. avionics) required to ferret out drawings that installed their hardware in order to review – had no authority to ensure that installation requirements were included on drawings – Required additional coordination to ensure requirements in installation procedure

8.13. Interfaces need to be defined in detail (actually look at the circuitry) – For example, interfaces “advertised” as “discretes” actually required a switch closure

9. MANUF

9.1. Bring each essential person and part to the proximity of the processing site. This prepares resources for hardware failures discovered after installation testing. AIX realized this when the FS project was set up to process 5 segment simulator articles. The processing involved installing DFI instrumentation on the element. DFI flat pack amplifier installation on the 5th Segment Simulator hit a snag and this hardware belonged to Lockheed/ULA and their representatives were not planned until after the problem occurred. Parts and engineering procedure weren't ready either. This resulted in weeks of delay which could have been minimized.

9.2. Save strain gauge installation for after the rocket is assembled.

9.2.1. The loads encountered by the strain gauges after assembly already pegged the measurements.

9.2.2. This was mitigated by having a DFI design that allowed software updates after vehicle assembly.

9.3. Define clear expectations regarding procedure content and detail. As-run documentation did not provide enough fidelity to understand what specifically happened during installation/test activities. This fact, coupled with schedule pressures, limited troubleshooting options. Working with installing IPTs, providing real-time support as required to work anomalies; on-site personnel knowledge of hardware and associated installation requirements

9.4. Solumina was a bottleneck for timely execution of installation and vehicle hardware integration

9.4.1. Training appeared to be OJT

9.4.2. I watched as the 5 hole probe was installed. 6 bolts - 7 hours.

9.4.3. Ease of execution and modification was driven by approach to designing the procedure

9.4.4. Minimal list of required signatures should be used

9.4.5. Was more effectively and efficiently utilized for integrated system testing

9.5. Avionics should be more involved in the installation of avionics hardware. Where practical, Avionics IPT should install the avionics hardware.

9.5.1. Especially on a development project.

9.5.2. Especially for a first of a kind, non-production vehicle

9.6. Avionics should have signature authority on all installation drawings and installation procedures.

9.6.1. AIX attempted to use an ICD (supplemented with installation memos) to convey data – Installation drawing folks were not universally aware of ICD/memos – there may be a separate lesson here – GO did not recognize the ICD as requirement source for installations performed at KSC – Hardware organization (e.g. avionics) required to ferret out drawings that installed their hardware in order to review – had no authority to ensure that installation requirements were included on drawings – Required additional coordination to ensure requirements in installation procedure

9.6.2. Lack thereof resulted in significant effort to correct deficiencies, especially with respect to electrical bonding

9.6.3. This should be true for ALL installations. This was a requirement in the AIT Plan but not enforced.

9.6.4. This was an AIT plan requirement that SE&I did not enforce

9.7. Better flow of vehicle unique requirements to design and manufacturing centers. For example, materials used on portions of US did not meet Ares I-X requirements as documented in LCCs and OTRs.

9.8. The Mission Manager's declaration that Atlas processes were considered adequate for Ares I-X saved much time and money. Particularly for harness design and build. LM had an existing relationship and contract with LaBarge. This allowed for getting into processing as soon as they were ready; it also allowed LM to request a 'big push' by LaBarge when needed.

9.8.1. S&MA and FS did not agree, resulting in significant effort with respect to post harness installation testing

9.8.2. Although there were some inconsistencies between LM procedures and Shuttle procedures

9.9. Tours should be scheduled to minimize production impact. Due to man-load rating of the platforms, the number of personnel was restricted. There were a number (at least 3) occasions when work had to be stopped on the FSAM to accommodate tours of the vehicle.

10. T&V

10.1. Requirements verification typically occurs in conjunction with CDR to demonstrate that the design satisfies the requirements

10.1.1. Requirements immaturity resulted in this activity occurring very late in the program – Activity became blend of design and “as built” verification, adding confusion and further delay to requirements closure – There needs to be a means to separate true requirements from “desirements” in order to separate the “must have” from the “nice to have” (especially in a program being based on existing hardware). The SRD/ERD did assign requirement priorities, but these were not really used. There should be a distinction between requirements and desired system attributes.

10.2. Verification of ICD requirements involved collecting information from other IPTs. This was not well executed by SE&I.

10.3. Availability of environmental test facilities at MSFC reduced risk

10.4. A hardware rich development program is a low risk development program

10.4.1. Limited DFI resources became an issue as E3 testing and integration activities were in parallel

10.5. The System Integration Laboratory (SIL) was responsible for the resolution of countless problems prior to vehicle integration. I can't overemphasize its importance. Having a test-like-you-fly SIL enabled the avionics system testing to operate almost flawlessly.

10.6. Early testing reduces risk

10.6.1. SIL testing of the integrated avionics & GC3 directly contributed to minimize vehicle integration issues (conversely, vehicle integration DFI issues were at least partially due to less SIL testing – typically, what you don't test bites you) – ATVC development testing provided risk reduction for the development of the ATVC itself as well as the simulator used in the SIL and for ATVC environmental testing – Include cognizant personnel for the hardware / software under test to verify functionality & completeness of testing – Early RF testing identified issues with receiving hardware that were corrected – Test configuration fidelity WRT vehicle configuration needs to be characterized in order to identify potential "issues" (heat sinks need to be provided for transmitters) – Utilize SIL as preview of vehicle level tests & procedure development & tests – Being able to link the SIL to KSC for simulations enabled launch procedure development / training

10.7. Use of simulators/pathfinders for critical component installations reduced risk and allowed installation teams to wring out procedural and GSE kinks. ex. FTINU mass simulator was installed on US 1 at GRC.

10.8. Avionics should have signature authority on all test procedures addressing avionics hardware.

10.9. Extensive use of the Ares I-X SIL resulted in extremely successful integrated testing for the airborne avionics system

10.10. The integrated testing on the vehicle was smooth and virtually anomaly free. This is a direct result of the SIL facility and TLYF philosophy.

10.11. The SIL also saved cost and schedule in the development of launch simulations. For AIX, all simulations were run from the SIL.

10.12. The launch simulations were useful in the successful launch. They were not as important to the front room operators, since these operators had a lot of experience. They were more important for the launch support team, which was largely staffed with personnel not familiar with launches.

11. Top 3

11.1. Build and use a SIL and implement a "Test Like You Fly" philosophy.

11.2. Early developmental testing and usage of a SIL.

11.3. Requirements need to be baselined early and requirements creep controlled.

2.6 Upper Stage Simulator IPT Knowledge Capture

1. Engineering Management / Systems Engineering & Integration

1.1. Flow down of requirements from SE&I (particularly loads and interfaces) needs to occur earlier in the design cycles when they can be captured in the design with minimal impact.

1.1.1. But when the requirements are not provided up front, uncertainty factors need to be used on the things like the loads so that the requirements do not increase.

1.2. The design lead should have been a design lead and not an analyst. Which leads to a bigger issue of selecting the correct person in each discipline. This is easier said than done though.

1.2.1. Basically what we ended-up with was the way to go (i.e. having a Design Lead (Branch Chief) and person who could effectively manage the Structures and Design Teams)

1.3. Need to establish a chain of command that lists the roles and responsibilities for each team member, and what are the limits of authority they hold. Need to define who is in charge of reviewing real time changes to the design and who has the authority to allow changes to the design after drawings have been released to the shop floor.

1.4. If we could start Ares I-X over again I would like to see the FTV SE&I take more of an integration role and do more than just provide oversight to the IPTs. I think that they needed to do more of the integrated analysis, assessments, and take a stronger role managing the integration of the IPT products. They left too much up to the IPTs to figure things out amongst themselves and usually the more dominant IPT would take the lead.

1.4.1. Had the SE&I team been in place [earlier] and their role defined they would have been able to provide a schedule for requirements and load releases that the IPTs then could have used to schedule their work. The disconnects between the SE&I plan and the IPTs need dates would have then been apparent at the mission level and could have been possibly been worked prior to work being held up or rework being required.

1.5. Systems engineering should be the umbrella Engineering Authority for underlying disciplines.

1.6. SE&I activity at LaRC was late being established (i.e. behind the Elements/IPTs) due to inter-center struggle for control between MSFC and LaRC. In addition, need for full scope of SE&I functions in Ares I-X were not fully appreciated during formulation phase (Jan-06 to May-06). During formulation, LaRC developed a sound Integrated Design & Analysis (IDA) approach/proposal, but it did not include other key SE&I functions like requirements development/decomposition and interface management. Moreover, it was not put in place to get started when provisional Authority to Proceed (ATP) was granted in May 2006, at which point all the other IPT/Elements started moving out on their preliminary designs. This was due to MSFC's desire to put in place an MOA with LaRC formally delegating roles/responsibilities for AIX leadership. The MOA wasn't signed off until late July (to best of my current recollection), which led to LaRC SE&I (called AVIO at the time) being late to the party. We paid the price ever since, in fact all the way to launch, i.e. the entire loads situation.

1.7. Engineering support for all shift operations-- on the ground support.

1.7.1. Project and Engineering management needs to commit to double staffing to implement this, not reliance on the same individuals to work long shifts.

1.7.2. Have proper Engineering support and management for all shifts of operations.

1.7.3. Perhaps not "double staff" but staff appropriately - with backups especially to leads.

1.7.4. I believe this is when double and triple shifts are used in manufacturing; you need to support those shifts with the proper personnel and not have a first shift engineering and QA staff trying to cover all shifts.

1.7.5. Two shifts require two individuals. That is appropriate.

1.7.6. Also double shift means having qualified personnel to work both shifts. Efficiency went down on 2nd shift.

1.8. We never establish clear delineation between roles of USS IPT Avionics in relationship to Avionics IPT too many assumptions lead to misunderstandings and missed coordination.

1.9. There were too many IPT products that were controlled at the Ares I-X Control Board (XCB)-level which resulted in a lot of pain to get documents approved and revised.

1.10. Firm Configuration Management was not established at start of program. Drawing changes were not entered into the Windchill system.

1.10.1. GRC needs to implement integrated requirements --drawing-configuration/change management - manufacturing enterprise software system, to link changes to requirements to changes to drawings, etc.

1.11. Beta testing of new tools such as schedule or design software needs to be accompanied with implementation time. If schedule is most important, beta tests should not be done.

1.11.1. Specific software betas were Primavera for schedules; Windchill for data management; and Pro-E for design. Pro-E was not a Beta test but it was drop on the project without the time to implement it. Windchill is clucky for software and not user friendly. So it is apparent it was not integrated and actually beta tested at all.

1.11.2. We also found that the thermal analysis code of choice (Thermal Desktop) had different issues with different compilers that caused USS model to run for USS but not for LaRC/SE&I, and vice versa. The whole issue of keeping the versions compatible was detrimental, too. We would find a bug and then there would be a new version of TD to fix it that we would have to spend the time up upgrading.

1.11.3. Another issue was using a FLUINT model in Thermal Desktop that was linked to the thermal model. This caused much grief because linking the two is not widely done or understood on how to best do. The shame was that accurate results could have been obtained without ever going there but it cost

USS a ton of time in modeling, debugging, and maintaining after every change.

1.12. SE&I review of IPT verifications was not expedient.

1.12.1. The time frame to have verifications get through XCB typically was one month or so - this resulted in a huge paper back up.

1.13. Design group should have better Windchill/Pro-e training so that the design process can be streamlined. The segment design could have been easier with the proper use of the design tools.

1.13.1. Proper training before the beginning of the design phase could have helped our designers to utilize the design tools at a much higher level instead of the "brute force" style that they had to utilize. Use of simplified reps, shrink-wrap, etc.

1.13.2. This is a problem when the initial Pro-E training teaches the novice an easy way to do something that is actually the wrong way to do a task if you want to take advantage of all of the Pro-E features.

1.14. Beef up design group so that they have the proper amount and type of design support to keep up with drawing changes and change requests. [Add] more checkers, more detailers, etc.

1.14.1. This also includes keeping their hardware up to date and able to run all of those monster models. I had to "donate" 4 gig of RAM from my computer to a designer. This was just to allow his machine to open the model he needed to open to get the ECS work done. The hardware MUST keep pace with technology if we are going to properly use these tools.

1.15. SE&I could have consider utilizing other IPTs/Centers to ensure that we meet our analytical milestones to the best of our ability for the IDA analyses instead of waiting for the right people of their own Center. An example would be that we waited a long time for Sam Unis to become available to do the couple loads analysis. GRC could have provided this capability.

1.16. Given that some people entering the project lack a broad range of manufacturing experience, some regular briefing or one-on-one sessions on the manufacturing process would have been helpful.

1.17. Observation: USS System Engineering Management Plan (SEMP) and Risk Management Plan (RMP) were sections of USS Implementation Plan. This tailoring worked for the RMP but not for SEMP which required more frequent revisions as the formal review process evolved. In addition, the SEMP should have called for development of separate Review Plans to govern entrance/exit criteria and process for each of our technical milestone/gate reviews. We only wrote a separate baselined plan for the final Acceptance Review. Best Practice: Write and maintain separate SEMP, Review Plans, RMP, and Project Plan configuration controlled documents.

1.18. USS SE&I should have internally managed or overseen all of the IRDs/ICD and provided enough attention to them. The Avionics ICD was managed by our Avionics/DFI Lead and the GS to FTV IRD did not get enough attention. USS had a couple of system level waivers that could have been prevented because a lack of review and communication.

1.19. USS SE&I were under staffed to handle the amount of planning, review, and integration that was required which did overburden SE&I team. As the SE&I Lead and looking back at our planning for this project, I would have taken the opportunity to add additional team members that were offered at times to level our work load. Adding one person to oversee the design integration and reviewing design documentation would have been helpful.
1.20. I felt that the lean 6 sigma event were very value added at the FTV and IPT levels to make us focus on what was important and allow us to save valuable schedule time.
1.21. AIX SE&I had not coordinated loads combinations methodology until USS held peer review (after the hardware shipped)
1.22. AIX SE&I Acoustics did not participate actively in the USS Peer Review (Dec '08) of random loads generation. Specific problem then ensued was the concern/desirement of the USS (for random loads generation) to use the SEA Mean results, as opposed to (the higher) P95 results. At the Peer review, USS argued case for using Mean values for large, multi-attachment point secondary structure - the platforms and ECS ducting were not S&MAll, simple boxes being assessed via Miles' equation. USS identified structural design margin problems at that peer review, if forced to use only P95 levels. SE&I lack of participation led to 6 month delay before USS was given guidance to use "only P95" levels. This caused huge risk of retrofit of flight hardware in the VAB, while several more rounds of model enhancements and analyses refinements were made nearly up until launch. These could have been more easily addressed in the winter '09.
1.23. Day of launch loads cycle not expressed in advance to alert IPT's.
1.24. GRC USS dynamics team lacked documented history or established methodology for random loads generation. This was a setback, but was a moot point considering SE&I had not prepared IPTs. USS led the way.
1.25. Requested that SE&I decide (in advance of upcoming environments updates) if AIX would use lateral random loads and who would generate them. Did not decide until a few months later to make a change in methodology and use the lateral loads. This was after loads calculations were already underway.
1.26. SE&I did not provide a consistent vibro-acoustic methodology plan across all IPTs. This led to each IPT adopting unique prediction methods which were not necessarily compatible. As a result, the various environments had to be enveloped possibly causing excessive conservatism. When coordinating IV&V (which is highly desirable) a best practice would be to poll NASA, or decide within NASA, how best to handle differences in NASA methodologies, or differences in results obtained, and in a timely manner. Waiting several months to see if there might be a difference or conflict in results--"we'll worry about that later" (if it happens) is not a good approach.
1.27. SE&I guidance typically was lagging; we frequently proposed needed guidance and had them bless it
1.28. SE&I generated environments. Track conservatism more closely and schedule its reduction (avoid double bookkeeping and padding).

2. Requirements Management

2.1. We needed an interposing requirements document (controlled at IPT level, not XCB) to capture some of the specific key engineering requirements of our design that were not necessarily impacting on system requirements if not met. Examples: segment level diameter, height, perpendicularity, parallelism.

2.1.1. Another way to view this would be to say that our SE&I team needed to lead the structured decomposition of the SRD/ERD requirements all the way down to the drawing feature/note level. Per AS9100 best practice, this would have resulted in features/notes being asterisked if they were decomposed from SRD/ERD requirements. This would have helped tremendously in identifying where we needed system level waivers.

2.2. Lowest level requirements [were] not clearly defined. [We experienced] almost weekly changes to requirements. Even simple changes to requirements can have an impact across the entire USS IPT.

2.2.1. One case would be where the ECS flex couplings were all assembled with the blue hose. Then a new requirement for not building up static was raised and rather than fight the requirement, we simply rebuilt all 10 of the ECS flex couplings with different hose that we would have used if we had known about the anti-static need.

2.2.2. Another example is in the ECS KSC interface. The tube bead was inadequately defined in the requirements. The final solution was to simply do a fit check to see that it would work with the KSC hose.

2.3. There should have been a more reasonable cut off point for changing the requirements documents to allow for the design to be completed and verified earlier in the process. Overall there was too much requirements change.

2.4. Need proper process (i.e. checklist) so that thought process is followed to ensure all requirement and perceived requirements are captured. (i.e. to look at internal to IPT, external to IPT, and possible external to the project)

2.4.1. Includes lessons learned system to provide these stories

2.5. SE&I and the Chief Engineer need to provide guidance with the interpretation of governing documents (NASA and MIL Standards, GRC Instructions, etc.) We had several crucial misinterpretations of requirements (most notable grounding and bonding) that resulted in extensive, untimely, costly reworks. The documents are out there, but the implementers may lack experience and be unaware of them. Guidance is needed.

2.6. An issue that arose was the IPT requirement documents were under the control of the IPTs. When these documents were raised to Ares I-X Control Board (XCB) control, all the requirements contained within had to be verified at the XCB level. If that would have been known up front, the IPT document would have stayed at a higher level and not contained the detail that it had.

2.6.1. The documents that are being discussed are the Element Requirements Document and Verification Plans. They were created as a IPT level document. They were created to support the IPT. When MMO decided to raise these to the MMO level they pulled more than they wanted. They want the trunk of the tree but also got the roots. This caused too much control at a high level.

2.7. There should have been USS requirements decomposition for the interfaces from the IRDs/ICD down to the engineering drawings to ensure that critical requirement from the interfaces were controlled and could not be changed without changing the controlling IRD/ICD document.

2.8. In a concurrent engineering environment the need for a Requirement Manager is essential, along with dedicated Interface Managers.

2.8.1. Imagine if each IPT had a requirements manager that could share issues across the board.

2.9. Requirements may need to include things like material certifications, part compliance certificates, etc.

2.9.1. Yes, determining what level of material certifications (CofC or higher) is needed up front will eliminate grief in the end.

2.9.2. Requirements for procurements need to be identified and sent to the receiving department for validation. Many of the receiving documents were signed but there was no information on what they were accepting with their signature.

2.10. At the PDR and CDR, we should have made certain that requirements captured in all their various locations were captured or accounted for. It would be helpful for the Project SE&I group to monitor all requirements to track them much earlier and act as project watchdog for requirements.

2.11. Tribo-electrification should have been a requirement. Range safety requirements were not communicated in a timely fashion and it became a problematic launch commit criteria.

2.11.1. Range unique requirements should have been flowed back to USS months earlier

2.12. Requirements Communication - Issue between avionics and USS - USS provided welded studs for attachment of RRGU mounting plate / RRGU - approved at USS CDRs - after fabrication and while at KSC, avionics objected to use of welded studs - resulted in USS action to inspect, etc.--this was time consuming. If another attachment method required - should have been captured as a requirement - or accept as is since it was approved at a USS CDR

2.12.1. This appears to be an SE&I issue. Miscommunication between IPT's should not have happened in this case. Avionics should have been aware by asking questions on how their hardware would be mounted and provide requirements for USS to meet.

2.13. Requirement advocates should be established so that compliance could be cleared through that advocate - all these “orphan requirements” need guardians.

2.14. SE&I should have taken the lead to develop and write the IRDs for non-heritage hardware with the help from the required IPTs, not the other way around. USS took the lead to develop the CM/LAS, FS, and RoCS IRDs because we needed the design details finalized to move forward towards a completed design early on. This was caused by the need to fabricate our hardware much earlier than the other IPTs in order to keep schedule for delivery to KSC.

2.15. Poorly communicated requirements were subject to misinterpretation so, that the requirement is not implemented as intended.
2.16. The issue of welded studs for the RRGU was not clearly rejected by Avionics IPT at the design phase so, it proceeded forward under the assumption that if we proved it, it was fine.
2.17. Across the vehicle we should have submitted waivers and deviation soon after they were discovered instead of all towards the end of the project. This would have helped to reduce the amount of paper to be reviewed and approved before flight and possible issues might have been able to be re-designed or resolved differently.
2.18. Coupled Loads assessment / preliminary values to use are highly desired prior to design reviews. Risk / Concern about delayed coupled loads noted 3+ years ago. Desire to have some established loads for PDR/CDR, and a plan for when coupled load cycles would occur. In early phases of AIX Project, GRC concern over use of simplified (3-DOF rigid body analysis) loads analysis was discounted by SE&I. GRC had recommended typical, elastic body coupled loads analysis and this was met with great resistance.
2.19. No "As-Built" configuration USS dynamic FEM or SEA analysis was planned. This was removed from the project plan despite recommendations from branch DEV.
2.20. Need consistent determination of vibro-acoustic environments (included mix of SEA & Scaling) to minimize confusion

3. Organization / Culture

3.1. We are a research center trying to become a space center. 180 degree change in direction. Most of our fabrication and assembly technicians are not familiar with the strict requirements for space flight hardware. Forcing some team members to think like a space center can cause cultural shock and resistance to change.
3.1.1. GRC has built and delivered over 150 space experiments so there was an experience base with flight hardware design, build, test, ship and process at KSC
3.1.2. The cultural dynamic that was the hardest to overcome was the need for the center to act as a single body. As a research organization, GRC has several S&MA tasks that at their choice will use the center infrastructure or not. This job required all the different organizations to step up and perform their charter. It truly became a center effort with the matrixed organizations performing their function and working with the other organizations at the center.
3.2. The culture of the project became a 24/7 obsession that impacted the health, family and well-being of team members. This will create problems with turnover of key individuals if not addressed. Personal boundaries must be respected (e.g., weekend, evening time with family).

3.2.1. The people also need to have a commitment to the project, especially on a long project like AIX. Too many times leads and experienced personnel were pulled off AIX, for various reasons, forcing a retraining of a new person, loss of time, increased cost, and potential errors.

3.2.2. An example was related to the IS-1 ECS system. The design was done by one designer but when it came time to put the design into the assembly drawing, it was given to a designer that had no experience with AIX or its ECS. This resulted in at least one part being misidentified in the parts list and resulted in USS buying the wrong part and the ECS hitting the floor of the cart. The wrong part number was called out on the assembly drawing and the part was bought from the assembly drawing which resulted in an elbow with longer than needed straight sections. Luckily, a fix was found and we were able to get past it without having to track down the error (at that time) and buy a new part.

3.3. Need to look at interactions with other centers as ONE NASA, and not worry about which documents that we use for our processes.

3.4. Center management at times hindered or did not deem the project important. Put up many roadblocks instead offering to help resolve problems. Only at the end when we were going to deliver did they step up to be in the spot light.

3.4.1. There were "competing" projects at the center that seemed to be management "pet" projects. But sometimes management from the other centers had to go up and over through the management chain to get the proper commitment from GRC management.

3.5. The space systems technical breadth, depth and excellence at the research centers, and GRC in particular, are under appreciated at the manned flight centers (JSC, KSC, and MSFC). GRC demonstrated this in the rigor of our AIX USS operating processes (e.g. our verification regime, which was adopted as a model by SE&I), our technical review processes (e.g. our Acceptance Review process was adopted by Avionics IPT and helped them be successful), and our timely delivery of engineering products and the USS flight hardware itself (e.g. the USS segments were first to arrive at KSC, and were first to be turned over formally to GO IPT).

3.6. Need to have what is best for the center focus, not “what’s in it for me” attitude.

3.6.1. My experience is that management has this attitude more than the general workforce does. And perhaps it should be a focus of what is best for NASA, the government, and the USA. NASA is, after all, for the benefit of all.

3.7. The interactions with other centers were for the most part very productive and it did feel like the push toward ONE NASA advanced quite a bit on Ares I-X. Still room to improve. Perhaps by having more cross-center participation within an IPT. As an example, I know at least one GRC engineer has a significant role on LaRC's SE&I team.

3.7.1. The "One NASA" concept, even though it is no longer a used buzzword like it was under O'Keefe, really matured and paid off for Ares I-X. As an Agency level team, we developed esprit de corps in which our primary allegiance was to the AIX team and our shared goal first and foremost, and secondly to our center or home organization.

3.8. The concurrent engineering (CE) process was put in place at the start of the processing phase to allow the integrated drawings to be developed in parallel with the processing due to the compressed schedule. In my opinion, this process was extremely successful due to the folks on the team being open minded and having willingness to learn and adapt to each other's way of doing business. As AIX crossed many centers and contractors the CE team had members from multiple centers and contractors so the cultural differences were not small. Through the CE process everyone stepped out of the box and took the best parts of the different ways of doing business and combined them to get an efficient AIX way of doing business. Unfortunately the process only arose to put out a "fire". If this process had been put in place ahead of the hardware arriving at KSC, I believe that a lot of time could have been saved. The first few months after the USS arrived at KSC were extremely inefficient due to the cultural differences and the "our way is the only way to do it".

3.9. It's great to give the centers their own responsibilities for a large portion of a space flight project however; the centers with oversight roles needed to perform those roles earlier.

3.10. Better Union project understanding, i.e. union and non-union cooperation.

3.10.1. The GRC manufacturing union too often took a confrontational stance, and seemed more interested in throwing their weight around and saying "No, but..." rather than teaming with the project leadership to get this project done. It seemed we had to work around the union at every turn.

3.10.2. The contracts need to reflect the requirement of the contract personnel to work with non-union personnel when it comes to ensuring project success. We do not want an issue that happened during the build of USS segments, a discrepancy was discovered during a shift, and work that had been done on the prior shift (non-union), the union person would not correct the problem because it was originally done a non-union member. Contract should be written to make sure the work standards of NASA are met and expected.

3.11. There were instances where too many folks were involved with issues and communications - early on in the process KSC provided 2 POCs to USS and information funneled between the KSC POCs and USS POC. This was an efficient process - the 2 KSC POCs went on to another job and retirement and it never seemed to be the same.

3.11.1. There were many instances of what was termed the "e-mail death spiral" as an issue was worked and distributed to more and more people

3.12. Ares I-X brought the team members very close together, creating very good, open relationships and was part of what allowed this team to succeed.

3.12.1. Yet, how many of those team members actually got to see the rocket fly, get their photo taken at that launch pad, etc.? Management got to do those things and the "grunts" generally didn't.

3.12.2. I believe the more we worked together the better we appreciated each other. I know I felt the AIX team was like a family member.

3.13. For the most part Ares I-X should be looked at as a shining star for showing that we can pull together organizations from multiple Centers and contractor and we were able to come together to design and build this incredible launch vehicle.

3.14. Internal culture - GRC IPT needs to be co-located with enough space for leads, configuration management, etc. - this dedicated space is needed for the life of the project for efficiencies - In addition to the War Room - other work spaces are required.

3.14.1. Running back and forth between buildings wore us out.

3.15. A good aspect to the GRC culture was the majority of the government employee's acceptance and cooperation of contractor assistance and inclusion into our workplace.

3.16. For the most part, the USS Avionics issues were left up to USS to resolve; the impression gained from Avionics IPT was they could not be bothered with USS - they aren't big enough players.

3.17. Many times it simply comes down to the people - and how they work with others - not the culture

3.18. The JSC/Shuttle Program culture was prevalent in the management of AIX. Specifically, what I like to call the Oxford Debating Society mode of debating the technical issues ad nauseam, developing technical rationale, etc. was the dominant decision making mode. Moreover, in the post-Columbia agency environment we operate in today, anyone in the room is given equal voice on any issue, whether they are technically qualified to ask questions / comment or not.

3.19. Co-Locating team members was an excellent idea. It was very easy to resolve minor issues by just talking over the cubical wall.

3.20. No established NASA methodology for secondary structure, what are size limits (mass or physical connections) for generating random loads. Frequency ranges where SEA / FEM is allowed. Guidelines for mesh sizes and modal density. Use of uncertainty factors for random [vibration]. Were SE&I planning to take the lead and work the loads, or hand off to the IPTs? USS was first in line and volunteered to tackle the task, but without a plan from above.

3.21. It appeared that IPTs assumed that SE&I would take charge and lead activities and inform IPTs of what they need to do, and by when. In reality, seemed that IPTs had to step up on their own, show what they had done, and then find out if this was what was wanted. This set things back and often required additional engineering or analyses, well after teams/staff were broken up to work on other projects.

3.22. People were rewarded during all phases of the project through DE division awards, monetary awards, group achievement awards, and project MVP awards etc. This is great for morale and good team building environment.

4. Communication

4.1. For high visible and highly aggressive scheduled projects, contacts need to be available when ever operations are in process.

4.2. Trying to find something on Windchill was difficult, to say the least. It's no wonder they have full training classes on this topic, now. eRoom did help in locating things, however.

4.3. Ultimately communication relies on individuals to make it happen. Individuals need to make personal commitments to share, to document, to listen, to review, to organize as appropriate.

4.4. AIX successfully utilized all the tools of "virtual" project execution, e.g. e-mail, telecons, web casts, etc. However, the webcast meetings in particular could have been structured with more breaks and more sensitivity to team members needs (i.e. many XCBs went for 6+ hours and into the evenings, interfering with family time; remember those Saturday morning XCBs?).

4.5. The thermal/fluids weekly telecons were generally helpful in keeping all the thermal/fluid people from the various IPTs on the same page with respect to requirements, etc.

4.6. Windchill was not being used to the best of its capabilities - making [it] hard to find anything. People were using it more as a file server which it was not.

4.6.1. NASA rolls out these data management tools and provides BASIC training and then expects the user to be able to use the tool at an advanced level.

4.6.2. The tool is the not the issue, it is the implementation of the tool and the lack of training for the tool. This occurs across NASA, a tool is rolled out, but the appropriate training for that tool comes out to the center employees a year later. For a tool to be well utilized, the implementation and training must be planned across all of the centers.

4.6.3. Timing is everything. You can [provide] people with the best training available but if they do not have the opportunity to use the tool for a year, they will need retrained.

4.6.4. Training should have been repeated for those people who came onto the project later. I, personally, had to learn systems by asking others or by trial and error because I got on the project 6-12 months later than others.

4.7. The standup morning meeting which was put in place within the USS IPT was a very useful meeting. While it was at times very long and painful, it was a daily meeting in the morning which allowed the team to get on the same page. With the compressed schedule and work that was being performed daily to meet that schedule a daily tag up was essential to keeping the work moving and the team on the same page.

4.8. The daily standup meetings were very helpful however; they got bogged down with schedule issues where it would have been better as a status briefing followed by a schedule session - lot of time spent getting to present status.

4.9. A better understanding of how to use the communication tools that were available to us upfront would have allowed for an easier use of each tool. Examples are how to properly write a Waiver / Deviation, CPAR, CxPRACA, etc.

4.10. Meetings, boards, etc. were a huge part of Ares I-X - for the IPTs separately and for the entire project - as a result, meetings fell on top of meetings - many times at the expense of the participants - simple considerations such as time for lunch and breaks were overlooked at times

4.10.1. There were days and weeks that were consumed by meetings and then folks had to perform work - yet the meetings were important

4.10.2. Which is why a lead is to lead and they needed other reliable people to do the work while they led. Sometimes that occurred and other times it did not. The leads basically had no time to do the real work, but in many cases had to do it, anyway.

4.11. Some people did not always send the meeting agenda, and a couple times not the WebEx and dialup info, they placed that in a Windchill link. Then if Windchill was down, no one had the agenda. Send the agenda in the body of the e-mail always.

4.12. WebEx does not allow two sessions on Internet Explorer or Mozilla. Only one allowed, but you have two meetings to watch and participate in. Solution, good old Netscape still works and could be used as the second WebEx.

4.13. With a project that was as aggressive as this one it would have been good to have a small team at SE&I and the IPTs that was focused on planning for the next six months to help get the plans, templates or formats for reviews or processes out to the IPTs to allow for us to hit the ground running instead of the IPTs controlling the pace. The USS IPT set the pace on several issues and activity planning like T&V products, waiver documentation, and tracking tools.

4.14. Enforcing strict ending times on meetings and rigorous adherence to the agenda encourages discipline, avoids wasting time and boosts morale. Meeting leaders have to enforce both to make this happen, even if unresolved items remain at the end. After a time, the team's meeting discipline will evolve to a point where all agenda items get accomplished and resolved fully and on time.

4.15. Better and timelier Windchill Training is needed (i.e. Project vs. Product vs. Library).

4.16. It may be valuable to have liaisons from the SE&I IPT at the subsystem IPT to understand us.

4.17. We did not use the solid model visualization tools in Windchill.

4.18. ECR acceptance would not be passed down in a timely manner to manufacturing, sometimes due to the time involved in writing or in delays while in signature status. Also, some were never submitted and by the time it was checked on, the memory of the requirement was forgotten.

4.19. The review process of FTV level documentation needed to be improved. The time allowed to do a good quality review of those documents was too minimal. One week might seem reasonable but not if you have six or seven documents to review plus your internal work. The comments then needed to be dispositioned and the reviewers did not get a chance to see the comments of the other reviewers, which I think was a flaw in the process.

4.20. How things get done was very ad hoc because the normal way things got done was not broadly communicated

4.21. Lack of coordination of USS Dynamic FEM & Integrated Vehicle Models. During the design of the USS several dynamics FEM's were created by GRC and delivered to SE&I for integration and coupled loads analysis. There were several instances where there was some confusion as to which model iteration was being used for a given load cycle. There were also some general concerns about the models. Models were submitted to SE&I via email with documentation attached. It might make sense to also have a telecom between SE&I and GRC during the model handoffs. This telecom would ensure that SE&I is comfortable with the model understands what GRC expects the model to be used for. The telecom would also ensure that GRC is clear on what the model will be used for and what results to expect. More communication between GRC and SE&I would be beneficial. Would be best to have an SE&I approval cycle or handoff/signoff process for loads models. USS models were not included in overall vehicle model until 5+ after delivery - as caught by USS team double checking the overall models.

4.22. Instead of including all leads in ERBs, eventually the USS project identified subject experts to lead and resolve issues in a more time efficient manner.

4.23. Expectations from SE&I for USS structural dynamic deliverables, requirements, methods, milestones, and schedules was never well communicated to GRC DEV.

5. Resources

5.1. Fasteners require the full time attention of one knowledgeable individual on the project (who does nothing else) to handle all aspects (requirements, procurement, receiving inspection, verification of certifications and testing).

5.1.1. This person is required at the start of the project.

5.2. Projects need to have single point of contact (i.e. Procurement Lead)

5.3. In working with the other centers, I have noted that for every GRC team member the other space flight centers have 5 to 10 people doing the same task as a single team member at GRC.

5.3.1. Interesting - Very efficient teams however - The USS Team that loaded the hardware on the Delta Mariners consisted of ~ 12 people - yet the offload at KSC had 50+? Not a criticism - USS typically had a small, efficient team - but folks did work tons of hours.

5.4. Too often one deep on functions and the Technician that did that - retired so, the work was personally done instead of being delegated to a skilled practitioner.

5.5. NESC helped to fill the gap when resources at the center or a discipline were not available. This was a good resource to tap into and was helpful several times, to perform work, or look for other resources (contractors) to assist, offload or perform IV&V.

5.6. Need to have well defined roles/responsibilities. Individuals need to know their responsibilities and what resources they are in charge of.

5.6.1. The USS IPT was wide, as far as skills are concerned, but only one to two people deep. If a critical team member was on travel or on leave there may be not have been a backup person. This made it very hard to take time off

5.7. GRC needs an electronic processing system (i.e. NOT paper) to implement flight hardware manufacturing, assembly, and T&V. We had enough (literal) paper on the USS IPT to fill a conference room. Revision control became onerous and our paper got in such bad shape we had to spend months on an internal audit in order to get the hardware accepted. KSC has Solumina for this purpose, but a suitable product should be identified.

5.8. USS IPT had insufficient engineering support for floor activities during fabrication and management support during fabrication.

5.9. Computer tools were often so expensive that multiple copies were not procured and personnel time shared the tools.

5.10. The workload was so great, it was a real challenge to take a day off or go to a doctor's appointment. If you did, you typically stayed in touch via phone or e-mail

5.11. Many people worked long hours and did not charge them all on the books. Management should be aware that relying on the AIX historical staffing hours to estimate future work will bias those estimates toward understaffing the job yet again.

5.12. The CIPS/Solumina system used by KSC for processing of the AIX hardware is a very powerful, and in my opinion, a very useful product. It is a step in the right direction for processing, by providing full closed-loop accounting for requirement verification, hardware configuration documentation, etc. However, during AIX it appeared that the processing was being forced to conform to the software which in my opinion makes the processing less efficient and is a dangerous path to follow. When using a tool like CIPS/Solumina it should be the tool, it should NOT be driving additional unnecessary requirements into the processing and integration phase.

5.13. Needed to provide bigger/faster computers before the project started so the designers did not have to wait around for the computer to process the extremely large for vehicle assembly models.

5.14. If you consider the resources at GRC and the full scope of AIX, you will come to the conclusion you can't do AIX, but we did anyway.

5.15. Need to have a consolidated resource availability tool to assist, with accessing outside expertise which are available to the center. (i.e. there are contracts that NASA has secured for the knowledge base, that are to be used by projects). GRC needs to identify these resources and have them in a consolidated location with how to use.

5.16. Aggressive USS staffing plan (offloading of engineering too early) did not initially allow for sufficient resources to address the delayed, or additional coupled loads cycles & updates. AIX SE&I [was the] probable cause for not scoping that out for IPTs to follow.

5.17. Different loads development tools such as MSC Random, the VRS method, or using CAM tool were identified by the peer review committees. These may have helped, if identified earlier, when USS had staff and budget to request to implement these.

5.18. Inadequate USS structural dynamic resources were utilized from CDR through Ares I-X vehicle launch. Historically in support of launch vehicles at NASA GRC, structural dynamics has its main support from CDR thru launch. When peak demand hit and resources were not available, the engineering division funded interns were used to support in-line USS vibro-acoustic tasks to meet deadlines.

5.19. No USS IPT resources have been formally planned or requested for post-flight data analysis of the Developmental Flight Instrumentation (DFI) measurements versus vibro-acoustic predictions. The main emphasis of the project/test was to investigate and estimate and generate better predictions and enhance models for the inline Ares I vehicle.

5.19.1. SE&I requested that USS provide thermal support for post-flight data reduction and model comparison but I have yet to get any idea of what WBS to charge such work to. But, I'm getting the data in and looking at it as it comes in.

5.20. Establish analysis tools needs early (NASTRAN, SEA, etc.)

5.20.1. Also keep in mind the machine to run it on and make sure you have consistency across centers if models are to be shared. For thermal analysis models using Thermal Desktop, using different compilers at LaRC and GRC caused some major headaches.

5.21. Establish SSC bullpen early. Harder to get key individuals when they might be needed later.

5.22. Mechanical minded Chief Engineer or deputy was needed due to structural / mechanical nature of project. Loss of Deputy Chief Engineer, who had these mechanical skills, was a tough loss.

5.22.1. Changing structural analysis leads was detrimental, too. And the need for a thermal lead wasn't even considered until later in the project.

5.23. Take advantage of synergy, skill mix early. For example, during the summer of 2007 the Loads & Dynamics personnel added a junior engineer to offload the team lead and enable growth and potential to become team lead later. Plan team growth to ensure good transitions if key personnel are reassigned / transferred.

5.23.1. Starting with a junior engineer as a lead doesn't necessarily work. Assigning a junior engineer to do a lead job led to the thermal area falling behind until a real lead was pulled in to lead the area. The thermal area suffered this initial fate. A lead tends to know their limits and get the needed help when the project requirements grow. For example, when the exterior paint was to be considered, the lead knew to get an experienced engineer on the task to handle the exterior paint and coatings. Yes, add the motivated junior engineer and allow them to call on the experienced prior lead for counsel but don't throw them to the wolves right off the bat.

5.24. Cost Growth. Cost growth in a fast paced, high risk flight demo project like Ares I-X is to be expected and should be considered the norm, not the exception. This lesson learned implies that each project element needs access to program reserves, with a well defined process to applying for the reserves. USS IPT saw cost growth from $34M at ATP to $53M by flight date. Root cause analysis of this growth revealed that approx 2/3 was due to external factors beyond the IPTs control (scope growth, departure from original "lean & mean" philosophy at ATP, late delivery of requirements/loads & environments definitions, etc.) and 1/3 was due to internal factors within our control, but for which one should expect to be able to access reserves to cover (i.e. maturing estimates, underestimation due to insufficient budget & schedule during formulation phase, etc.).

5.24.1. A Best Practice that should be adopted to deal with this expected cost growth is to utilize Joint Cost / Schedule Confidence Level (JCL) S-curves to set expected reserve levels. See new JCL guidance from HQ OCE for methods to develop JCLs.

5.24.2. If it heats up, cools down, or flows, you will need thermal support. Plan for it up front and throughout a project because it is required and can be a source of under-estimation in schedule and budget resources.

6. Safety & Mission Assurance / Technical Authority

6.1. Need a resource for services that have been NASA certified.

6.2. Watch out for requirements creep.

6.2.1. Agreed. This was a key driver in USS cost growth, part of the external factors that accounted for 2/3 of our cost growth.

6.2.2. We had requirements creep right up to the week of the launch ... when that tribo-electrification requirement came up.

6.3. The Ares I-X Chief Safety Officer was a strength. His detailed involvement with the project culminated with a strong recommendation to launch at FTRR

6.4. QA was signing MIPs well after the actual work was done. Technicians would move on to other work because they could not locate QA rep. QA needs to be the eyes on the floor to insure the work is done and done correctly.

6.4.1. QA at times would be involved with lengthy procedure verifications inside segments and could not address immediate requests for MIP signatures. Better scheduling of testing and procedure completion would have helped.

6.4.2. This could be resolved with more heads, cost/benefit needs to be established.

6.4.3. QA needed to be alerted when a MIP was being performed. In that way the MIP would get witnessed and signed. Many times QA was not notified in a timely fashion. The result was delay in signing of MIPs.

6.4.4. Do we need more certified QA people? Can people other than strict QA people get certified to be a QA person and help to lift the QA load?

6.4.5. SM&A was often the most productive reviewer of procedures; providing the best corrective comments. This was in addition to all their QA floor work.

6.5. Workmanship standards were not well understood by the design and manufacturing teams, particularly the electrical ones. Part of this may have been exacerbated by unclear roles with electronic hardware (i.e., GRC installed and verified, but did not design or procure) S&MA's early involvement in decomposing these standards into implementable instructions to the teams would have been a great help.

6.5.1. Workmanship standards were not well defined until the majority of the work was complete.

6.6. Need to ensure a proper understanding of what the role the S&MA should be in the projects. (are they a Quality Assurance, Quality Control, or just a witness to the accident?)

6.6.1. At the beginning of the project the thought was that S&MA would be the Quality Control authority, but we were informed that was not their function--need to have a better definition.

6.6.2. Need to define the roles, responsibilities and authority of S&MA, QA, Mission Safety, and Risk Management. Who is responsible for what needs to be communicated to the full team.

6.6.3. S&MA was basically Quality Assurance. It was the Q.A. role to ensure that all assembly procedures were being followed correctly, to verify DFI installation and testing, to ensure that all procedures were completely signed, and to assure that all other quality issues were addressed.

6.7. The workload of AIX did not allow for the S&MA Lead to support other projects and work and still be fully and efficiently engaged in AIX. Due to some members of the S&MA team trying to support multiple projects, they were not fully engaged and therefore could not support as required. This caused inefficiency.

6.8. When entering information into a CPAR, please identify drawing numbers and other location information. Also enter what is the current configuration and what is the potential new configuration. (Change From-To or Was-Now)

6.9. Safety verifications were well leveraged from the engineering verifications without a lot of additional requirements being heaped in to address safety. We also did not seem to have a problem with getting safety verifications closed that could not be leveraged from engineering.

6.10. Lack of comprehensive inspection program (little if any acceptance inspection or fabricated part inspection) hurt the verification process; often had to re-inspect to product paperwork.

6.10.1. This was an area that was lacking. Many of the items received in were not properly inspected due to lack of an inspection procedure or information.

6.11. Is GRC's S&MA organization going to operate as an independent auditor, or will they perform in-line functions? This was a much debated question early on during USS design and early manufacturing operations. It impacted us most directly in terms of quality inspection on the shop floor. We got it all worked out eventually, however the larger policy question remains: where will we organizationally locate QA inspection for future in house space flight-related manufacturing operations, in Code Q or in Code DM?

6.11.1. At a minimum, S&MA must track safety verifications and also verify compliance to the Product Assurance Plan and any other requirements or planning documents that they own. These were in-line functions on AIX USS.

6.11.2. This is still an open policy issue.

6.11.3. Bought more inspection services thru Code Q contract

6.11.4. GRC should keep the in line QA/QC inspection function in Code Q, and not re-establish the manufacturing inspection branch in Code DM, to avoid obvious conflict of interest problems. The professionalism and training of the QC inspectors needs to be improved.

6.12. Project problem reports had to be handled differently from "center" PRACAs or CPARs. Utilizing the GRC CPAR system was a good idea but all the CPARs were tracked the same way and appeared as center level ones. This was fixed so the project ones would not appear at the center level. The way each is handled had to be defined. Project CPARs are closed with a project perspective, what do I have to do to keep moving forward. Center level ones require a full root cause analysis. While the project ones could spawn a center level CPAR, the project is looking for a immediate action in most cases.

6.12.1. Clarification: If we continue to use a GRC-based PRACA system, then the existing CPAR system needs to be tailored to allow cleaner, more routine opening and closing of non-conformances as they occur and are worked off. The CPAR system proved very cumbersome for this purpose, and resulted in a tremendous amount of unneeded effort to track and close the hundreds of CPARs we opened on USS. CxPRACA turned out to be more user friendly and worked well once we arrived at KSC.

6.13. The aggressive schedule of AIX led to long hours for design/analysis, fabrication, and assembly of the hardware. Need to look at setting better guidelines and limitations to keep workers healthy and safe.

6.14. The Chief Engineer needs to be cognizant of the applicable standards and governing documents and ensure their enforcement throughout the design, analysis, manufacture, assembly and T&V.

6.15. Need a permanent Deputy Chief Engineer. In the beginning, AIX had a deputy, but they were removed to do other duties, making the role of chief engineer almost impossible to do in a 12 hour day.

6.16. AIX evolved into three separate, parallel projects over time: the mainline MMO-led, IPT-executed project that produced the flight/ground hardware, and two parallel, "shadow" projects/teams, one led by the Chief Engineer, then other by the Chief Safety Officer. This often led to human resource conflicts, as my Chief Engineer was often on a AIX Chief Engineer telecon when I needed her to be elsewhere supporting the IPT.

6.16.1. This shadow Technical Authority issue also was seen at GRC. Specifically, our Chief Engineer had to go support the EMB every Thursday morning for two hours, which many times took her away from pressing USS IPT issues/meetings. Who does the project Chief Engineer answer to first: the Project Team, the Center Engineering chain of command, or the customer/program CE chain of command? This needs to be clearly delineated for future GRC projects (same for Chief Safety Officer Technical Authority).

6.17. Roles of the Chief Engineer and SE&I lead need to be clearly defined. The Chief Engineer time needs to stay somewhat independent of the daily activities so they can head the tiger teams and work off nominal issues.

7. Schedule

7.1. Get a competent scheduler on early and let them do their magic.
7.1.1. It would be advantageous for consistency - try to maintain the skilled scheduler for the project duration.
7.2. Need to develop a complete resource loaded schedule to track work priorities and take advantage of leveling work that is not on the critical path.
7.3. Dealing with a tight schedule is easy - spend more money.
7.3.1. Faster, better, cheaper, and safe. Pick two. AIX, like any project, wanted all four but got fast and safe.
7.4. Develop a flow chart from the schedule, and post a copy in the fabrication shop to inform technicians on how the schedule is driving manufacturing
7.4.1. Concur to some tool for this as the fabricators did not necessarily know the milestones.
7.5. Don't use Primavera - the common engineer and manager does not have the knowledge or access to the system.
7.5.1. Mandating the use of Primavera as a "pilot" demo on a fast paced, high stress flight test project was a huge mistake.
7.5.2. Attempting to develop a resource loaded master schedule after the IPTs were out of the gate and you're into executing was not possible. The key lesson learned is to develop a solid, resource loaded, logically linked master schedule during project formulation. This is perhaps the single most important rigorous project management best practice that we can implement to ensure a successful project.
7.6. We were able to accelerate schedule by assuming risk and doing many normally serial operations in parallel and consolidating reviews on AIX. This worked for a developmental flight test, but hopefully we are not getting used to that mode of operation for future man-rated work that will require much more due diligence.
7.7. MS Project is preferred software for creating internal schedules
7.8. Need to add more engineering resources to prevent one person being over committed and always on the critical path. This can be identified in the scheduling tool earlier in the process.
7.8.1. Many times Engineers were occupied with immediate fabrication issues and were not able to address other issues
7.9. DFI work ended up occurring (nearly) all at KSC anyway because of handling concerns with sensitive sensors. If we do AIX', why not plan on that up front to accelerate delivery?
7.9.1. This may actually add time to schedule
7.10. When a project is working the compressed schedule that the AIX USS IPT was, the team members are under extreme pressure and working an intense workload. The center management needs to be fully aware of this and step up and find ways to provide as much support as it can. While the support provided may be minimal, it gives the employee the sense that the management is aware of the time and sacrifices of the individuals of their organization for the betterment of the center and the project.
7.10.1. That can include approved overtime for engineers and such.

7.11. It's hard to think schedule when you grow up in research community so, better schedule training will help emphasize the importance of schedules.

7.12. When individual IPTs were processing hardware, KSC daily schedule required too much information from the IPTs - This became a burden and was inefficient - of course activities that required KSC resources was important to track.

7.13. Utilization of the War Room to have weekly schedule meetings to discuss critical path and the next two weeks workload was a key. Having all WBS leads present to address issues was also a key.

7.14. Across the vehicle we need to spend more time trying to define the work and the detailed activities that are need to make the schedules are as informed and realistic as possible. Schedules need to be revisited often.

7.14.1. I thought weekly revisions was acceptable for critical work and less revisions required (every other week or every month) for less critical path work.

7.15. Earned Value Management (EVM) was not implementable in the AIX project, because we didn't have a fully resource loaded schedule from the outset. We attempted to finesse a set of EVM metrics in the USS IPT, but found they didn't make sense and were not nearly as useful as a different, tailored set of metrics we custom developed turned out to be. Perhaps the most useful was the schedule margin to delivery metric we developed and measured weekly. Getting a multi-tiered Integrated Master Schedule / Engineering Manufacturing Master Schedule developed was the key to getting the visibility we needed to manage the project.

7.16. Project environment was that of a reactionary, continuous fire-fighting mode. Compressed schedule was often offered as an explanation of this environment but based on past experience with other schedule driven flight projects, this explanation seems inadequate. In our opinion, poor planning was the primary reason for this Project environment. We're concerned that the ultimate success of AIX validates use of the " continuous fire-fighting" project approach and work environment that existed on AIX.

7.16.1. My experience was that AIX USS was one of the best planned projects I've ever been a part of. Unfortunately, good planning can only carry you so far. Once you start executing the plan, issues are encountered that then require reaction / replanning. We encountered our share of technical and programmatic issues that could have killed the project, but didn't because of our team's resiliency and focus on the end goal.

7.17. Don’t have late loads cycle. Unknown if increased loads can be easily accepted. Significant risk of structural failure or delays and costs in modifying flight hardware may be required to adequately address late, increasing loads.

8. Design

8.1. Design engineering needs to have adequate staffing

8.1.1. Design work was lagging the fabrication process, and drawings were not updated in a timely manner if at all.

8.2. The backlog of designer's time caused priority of drawing work which placed a long queue on getting designs resolved; this delay gives the misperception that design solutions were design changes which caused management to request change orders estimates.

8.3. Thermal/Fluids was way underestimated for USS. Needed thermal/fluid support to answer and resolve issues up until launch of AIX. There should be an experienced thermal/fluids lead from the start of the project.

8.4. Treating a complex segment with an extensive amount of details as a single piece element is not a good policy.

8.4.1. Treating all the individual pieces as how the final product is classified made verification activities very difficult. A good example was the gussets for IS-1 had unique gussets but the drawing never identified them as unique.

8.5. We over-toleranced the USS because we defaulted to tight tolerances and only backed off when we had to resolve an issue or waiver because we didn't meet them. For a development flight test, the default should be loose tolerances which only tighten with technical justification, traceability to requirements or other well-substantiated need.

8.5.1. Only critical dimensions need to meet requirements and interfaces should be held tight.

8.5.2. Allow field fit up wherever possible on large fabricated structures, to minimize need to tolerance every dimension and minimize change control traffic. We wrote far too many minor ECRs for small dimensional changes and/or to document the as built to every last minute detail.

8.5.3. Should have flag notes that also tie dimensions to analyses and the verification of requirements so that this dimension could not be changed unless the analysis is re-run or is understood that it is affected.

8.5.4. Interface dimensions from our IRDs/ICD should have flag notes for associated dimensions so that people know that the IRDs/ICD needs to be looked at and negotiated before a change is made.

8.5.5. Parts that are bent up should not have their length held to +/- 0.01. They should be held to +/- 0.25 and match drilled or fit up at assembly.

8.6. Rectify Factors of Safety for design for GSE vs. flight hardware - issue with lifting lugs in USS.

8.6.1. The Agency needs to better define/change the design standards for what is considered flight hardware vs. ground support lifting hardware. There was a lot of confusion about this topic after the lifting lugs were fabricated and assembled to the segments.

8.7. A great deal of information is lost when shrinking a 18 foot diameter segment to a drawing. On the drawing 18 feet is about 18 inches. Fine detail is lost.

8.8. [Provide] electronic approval of drawings to speed the process of getting the drawing to the manufacturing floor.

8.9. Once designs came out of the CAD they needed analysis by engineering however, that process flow didn't appear to be automatic or a normal way of doing business.

8.10. Too much time was wasted in revising and re-releasing drawings manually. Need to use Windchill to release and revise drawings electronically.

8.10.1. The drawing revision system was not prompt. Many issued drawings being used on the floor were out dated and did not project the correct information.

8.10.2. This doesn't even cover the rework performed when somehow a designer's work from the previous day was all lost.

8.11. We needed to perform a Design Integration function distinct from either Chief Engineer (CE) or Lead System Engineer (LSE) under current governance model. Neither the CE nor LSE had the time, experience, or charter to properly oversee the holistic design process. Especially with a “One NASA” project like AIX, the CE, CSO, and LSE spent a large fraction of their time on "up and across" telecons. Best Practice: Designate a Lead Design Engineer (LDE) for future in-house projects. The LDE will be responsible to integrate all the design & analysis disciplines to ensure horizontal communication across these disciplines, proper and timely execution of Design Analysis Cycles, and Functional Configuration Auditing to ensure the design is satisfying the decomposed system requirements (working in partnership with the LSE). The LDE would then bring specific technical issues up to the CE for partnering in resolving those and bringing additional resources to bear on their resolution. The LDE would be the single most expert person on the system design.

8.12. Inconsistent drawing view conventions created confusion on the shop floor. A standardized drawing view convention should be generated and adhered to.

8.13. The project had rogue designers at times. The USS Avionics lead at times tried to perform mechanical designs instead of working through the mechanical design team. This was the case in the structural design team where the Interstage was using different loads than the rest of the USS. ECS design was not flushed out completely until after installation, clips used that could vibrate out. These issues may have been avoided if a lead design engineer or product engineer was in charge so the entire design would work to the same requirements. As well as all designs would be flushed out before they got to the control board.

8.14. Need to standardize design tools in engineering to allow for common usage and ability to easily review hand calculations and analysis. One example is the use of spreadsheets for bolt calculations. It seemed that there were multiple versions of similar spreadsheets and we should be able to create, verify, and accept one standardized spreadsheet for all engineers to use.

8.15. Utilize real time 3-D CAD viewing of ProE models as a field fabrication aid, in addition to 2-D drawings.

8.16. Dynamic FEM Post Processing differences may occur. A NASTRAN output, when looked at by a visualizer / post-processor (IDEAS or PATRAN) will bring in or recognize elements differently. Weight properties and lumped masses can come in slightly off in value from one to another 10% or less.

9. Manufacturing

9.1. Manufacturing should have their specialty operations "how to" documentation plans (i.e. welding activities, inspection, contract requirements, etc.)

9.2. eManufacturing needed to have proper leadership/management support and oversight to capture time frames and proper schedule follow throughout the manufacturing flow. Not second hand info or opinions.

9.3. Lack of regular processes for upfront / acceptance inspection or attention to detail in drawings caused several parts to be improperly made or be accepted without inspection.

9.4. Metal will distort when welded. That said, final or irrevocable operations (e.g., final dimensional measurements or final machining) must occur after all major welding operations have concluded.

9.5. Develop a plan to utilize two or three shift operations, with mitigation plans for sick leave, annual leave and other personnel related issues. Stick to the plan.

9.6. The USS shipping and transportation was flawless - excellent detailed planning, dry runs and coordination.

9.7. Manufacturing was not setup to deal with a project such as this. Manufacturing was just a manufacturing shop at the inception of the project that was not setup to handle a project of this magnitude.

9.8. The most concern goes to the fabrication procedures in terms of the format, the verbiage, and signature requirements

9.9. Develop proper procedures for the required disciplines. Examples are welding not clearly defined (in the beginning) and don't be locked into traditional ways of doing manufacturing-related tasks.

9.9.1. Manufacturing should identify persons with the knowledge of welding terms and definitions to help translate the procedures into manufacturing documents.

9.10. Manufacturing technicians had trouble visualizing the segment design based on 2D drawings. A solution is to convert Pro E solid models into the PTC Product View format. This would allow the techs to view the solid model without having a seat of Pro E. Techs could zoom into the solid model to view fine detail. Product view is in the utilities section of Windchill

9.11. The GSE designs (especially the carts) for USS on AIX were an outstanding example of multi-purpose design and promoting efficiency in operations. We could have used another SSAS at KSC to expedite operations.

9.12. Procedures used at KSC were improved at that point, however, drawings still lagged behind in terms of being current and providing all torque details.

9.13. Fabrication shop personnel should be familiar with how to read a drawing, build procedure or work instruction. Learning on the job creates mistakes and uncertainties.

9.14. The IPTs participated in a Launch Site Support Plan (LSSP) Working Group with KSC to ensure all items, services, etc. would be ready when the IPTs arrived. The LSSP document captured these items - Upon arrival at KSC, several of the items were not available and resulted in startup inefficiencies: use of laptops in VAB, printer availability, etc. Ultimately, items were made available.

9.15. To a newly formed team that didn't know how manufacturing worked, a upfront briefing on manufacturing would have helped with knowing where to direct work (even if that means giving it to one input person). When I needed manufacturing to do something, I didn't know where to direct my work order or requests.

9.16. We built several segments based on drawings from a different segment. When revisions were made it was unclear if the revisions applied only to the segment under construction, the segment drawing or both.

9.16.1. Most (~10) of the segments should have been able to utilize one drawing with a table to capture various features. Having a unique drawing for each segment caused a mechanics to use their best judgment on how to manufacture items in some cases.

9.17. Should develop a plan for one shift and a fall back to two / three shift ops.

9.18. Redlines were sloppy. [It was] difficult to determine what was changed and what work was actually done.

9.18.1. This is why, red lining of the drawings is very important to ensure everyone has the same picture.

9.19. The timeliness of lifts was not adequate. Many times lifts were too long in being initiated. Once the lifts were started, the crew would stop for various reasons, extending the lift time.

9.20. Developing the Pathfinder segments was perhaps the single biggest enabler for our overall USS IPT manufacturing success. Best Practice: build an engineering/manufacturing test article early in the project life cycle. The learning benefits are too numerous to mention.

9.21. The USS Fabricators did an outstanding job - heroic in fact - to produce the Upper Stage Simulator - this goes to show what a small, dedicated, highly motivated team can do.

9.21.1. Yes, but schedule drivers did not allow for adequate understanding of what was happening and why (i.e. segment warpage due to welding, never learned)

9.22. DO NOT reuse a document or procedure from one segment to build a different segment. One Document = One Segment

9.23. The "dry run" process for the stacking and processing of the segments that occurred in GRC Building 333 was a very important to finding and resolving the processing issues prior to getting to KSC. Due to the tight schedule and the drive to get the hardware manufactured, parts of the "dry run" were often thought of as something that could be dropped. I believe if we had "dry run", even more issues could have been found and the processing at KSC could have been even more efficient.

9.24. We should have conducted manufacturing operation / procedure training sessions with the technicians and QA staff BEFORE starting each procedure.

9.25. Too many jumps between built different documents. There should be one document to build one segment.

9.26. The Manufacturing organization is made up of 3 disciplines, Instrumentation, Machining, and Fabrication. All these disciplines were required to build the USS. But the job required fabrication mostly. So many of the machinists and instrument makers had to learn and perform several fabrication tasks. The success of AIX can be attributed to the versatility of manufacturing team. There were skills that were not as transportable such as welding that required hiring outside support to perform.

9.27. Having small electronic items fabricated seemed to be very ad hoc - had to borrow technicians from other areas/projects; it may be more effective to be managed by manufacturing as a unique function.

9.28. Recommend that IPTs that deliver hardware still have hands-on technician involvement through final processing - mating super segments for example.

9.29. The flange machining process was the most innovative idea of the project. This process was mentioned to the team by Q.A, using an outside vendor well before the decision was made to use it.

9.30. We experience significant problems procuring from out of house a combined rolled / machined RoCS doubler pair. The rolled portions were over rolled, which led to countless problems integrating them into the Interstage and then matching up the RoCS panels. Next time around, machine a single doubler piece out of a big block of steel.

9.31. If AIX' is indeed pursued and is built at GRC, we should plan to spot face the bolt holes on the non-contacting flange surfaces (post-machining) in order to prevent any bolt bending.

9.32. Don't "Hold on" to a bad decision. Decision to have untrained technicians as welders was bad decision.

10. Test & Verification (T&V)

10.1. Test and Verification needs to work closely with SE&I--this is to ensure requirements can be closely tracked and captured in the proper reports.

10.1.1. Ideally, T&V is a function within the SE&I team/organization.

10.2. Inspection activities should be a function of Manufacturing Quality Branch.

10.2.1. Need to ensure Manufacturing has the resources to have a functional inspection department--and a plan for workflow flux. Many of the manufacturing tools were not maintained and calibrated for users.

10.2.2. Due to the fact that the facility had reduced QA personnel, it was impossible to assign inspectors to handle basic inspections. This left the inspection responsibility on the shoulders of fabrication technicians, who sometimes used the very items they inspected. Inspections should be independent of the user.

10.3. Requirements formatting and specific location for Acceptance Data Packages were defined late in the project resulting in some costly and time-consuming "busywork" late in the project.

10.4. Subsystem leads who own requirements need to understand that they also own the verification of those requirements. This could have been better communicated in hindsight.

10.5. There did not seem to be sufficient time to review verifications

10.5.1. Time for verifications was a problem. Many of the verification requirements were very detailed and time consuming (such as the DFI verifications) and consumed QA for a considerable time of the day.

10.6. Need to make a judgment call to determine if a quick test is a better use of resources as opposed to a lengthy analysis.

10.7. The huge bow wave of verifications in the last month of Ares I-X almost delayed the flight - this situation needs to be improved for a future test flight.

10.7.1. The large number of verifications was the result of ECNs which are due mostly to the need for improved engineering ideas and plans. "Measure twice, cut once".

10.8. First Stage (FS) IPT got a free pass on their verification approvals, as they got so far behind. Also, FS brought some heritage waivers in the last week, which was a reflection of Shuttle FRR review culture/practice. From a USS IPT perspective, there appeared to be a double standard applied relative to the intensity/scrutiny of the review our verifications and system waivers were subjected to, as compared to FS IPT for example. The message seems to be: wait as long as possible to bring verification paper forward for final approval--the longer you wait the quicker and less onerous the review will be.

10.9. FTV could have implemented the DCR for verification appropriately shortly after the FTV and IPT CDRs to make completion and the review process more easy and effective.

10.10. Test and Verifications need to only perform the work that is required. Once in a while extra work was performed to feel better.

10.11. Avoid premature roll off of key staff. If anything, effort increases as the project nears launch, rather than declining.

10.12. Wanting to retrieve actual flight data. All project long we used Windchill. Now we are using the HOSC--but why? Just place the data on Windchill. After several e-mails to learn how to get the data or where it is, and now phone calls, still no word back from the folks at the HOSC on how to get access. Why all the extra hassle - just point and shoot everyone to the data.

11. Top Three

11.1 The lack of a timely and strong SE&I organization at the FTV-level caused late requirements causing a large amount of re-work and inefficiencies. Specific examples of this were the grounding and bonding requirements, interpretation of the safety factors as applied to the flight and GSE hardware, and the very late data load book releases.

11.2. Cultural differences between the centers and contractors are large. Overcoming and appreciating these differences is a difficult and time consuming process, but rewarding if accomplished. If at the highest level of the program, the management accounts for this and tries to bring the team together early in the process, the team will be more efficient.

11.3. Cost Growth. Cost growth in a fast paced, high risk flight demo project like Ares I-X is to be expected and should be considered the norm, not the exception. This lesson learned implies that each project element needs access to program reserves, with a well defined process to applying for the reserves. USS IPT saw cost growth from $34M at ATP to $53M by flight date. Root cause analysis of this growth revealed that approx 2/3 was due to external factors beyond the IPTs control (scope growth, departure from original "lean & mean" philosophy at ATP, late delivery of requirements/loads & environments definitions, etc.) and 1/3 was due to internal factors within our control, but for which one should expect to be able to access reserves to cover (i.e. maturing estimates, underestimation due to insufficient budget & schedule during formulation phase, etc.).

2.7 CM/LAS IPT Knowledge Capture

1. Engineering Management / Systems Engineering & Integration

1.1. Board meetings should be better structured and regulated - there were too many 4-6 hour meetings where only 20 minutes or so involve me personally - that is 3.5 hours wasted in many cases.

1.1.1. Learned multitasking - accepted that I my attendance was often "required" but kept laptop handy in meetings to keep efficiency and accessibility up during times I was not needed in the meeting.

1.1.2. Meetings had the personnel necessary (generally), but the agenda was often a joke. Consider the number of people involved in a meeting and manage the time appropriately - I once heard of a good meeting management practice of showing a running tally of the money spent on a meeting (assuming the number of people involved).

1.1.3. In this virtual world, it is generally the practice that everyone 'multi-tasks', this inherently makes the meetings less productive because only 10% of the folks are engaged at any one point. Which leads to longer meetings.

1.2. Ensure that all management leads are well versed in managing and leading technical teams. Case in point, the best leader is not always the most technically proficient individual.

1.3. Clear lines of authority. Boards, panels, etc. For example, was granted waiver by a control board who thought they had authority to do so, then was told that they did not by another board that wanted to review it.

1.4. Managers and leaders need to be able to run meetings and lead the team to a resolve of any issue in a timely manner.

1.4.1. Sat in some 14 hour XCBs! Either needed to guide discussions, or resolve issues in another forum prior to that meeting. Doesn't require another board - have resolved issues one-on-one with interested parties before going into XCB (doing your homework).

1.5. Redundancy of meetings. Ties into the clear lines of authority. Applicable both across Mission and within Center.

1.6. Managers at all levels need to be able to communicate across centers, agencies, contractors to ensure adequate support & resources

1.6.1. It is important the managers are capable of getting the right people talking to one another - managers talking to one another are not always the best way to resolution - let the people that are doing the work talk to one another.

2. Requirements Management

2.1. Granted, all requirements need to have a verification statement but we must also ensure that the verification is "verifiable". That we can actually test, demonstrate, analyze etc.

2.1.1. Requirements documents should be living. We were told to provide a waiver to a requirement that the writer determined was superfluous - and did not fulfill the intended need.

2.2. Proper requirements definition. Do not allow design solutions to fall into requirements.

2.2.1. Had restricted transportation options in earlier requirements iteration - opening up to simply "get hardware to KSC" allowed alternate transportation to be considered, which reduced cost, loads, and time.

2.2.2. Defining an interface ring as being made up of six segments when just needed to defined interface ring itself. Ended up manufacturing with only three segments - resulting stronger - but required a waiver to the requirement.

2.3. Interface requirements need to be very clear about ownership and must consider all of the elements that cross the interface. For example - we had an interface with another IPT with a clear line of demarcation, but the bolts joined the two pieces of hardware - who 'owns' the bolts - it was unclear.

2.3.1. Interface requirements need to be verified at the interface and not on both sides of the interface as we did with IX.

2.4. Standards & Requirements need to be synchronized across the agency, centers and across disciplines (aero, thermal, range, loads etc)

2.4.1. Had issues at Langley with longstanding Langley standards not fully compliant with corresponding Agency standard. Took massive effort on part of our S&MA and fabrication folks to provide proper documentation to show met - fortunately was able to for the most part. To review/confirm the Center standards is a huge undertaking, but perhaps should be addressed at some point.

2.5. Clearly define scope of requirements. Clearly define expected requirements acceptance criteria. Assign appropriate personnel to address requirements verification.

2.5.1. The requirements should address a particular need head on rather than secondarily. For example, the need for a frequency requirement was written as a stiffness requirement instead.

2.6. Ensure the range requirements are captured early on along with the system requirements. The "tribo-electrification" range requirement should have been captured as a design requirement and would have permitted a much larger launch window. The Launch Commit Criteria (LCC) WG did not get the proper support early on in the mission (again due to limited resources-personnel). So this range requirement may have gotten overlooked and not worked back as a design requirement.

2.6.1. Shuttle had a longstanding exemption from this requirement

2.6.2. The requirement was in the LCC but was not elevated to the IPTs until a week before launch. Should have been in the SRD

2.7. C&DM: Tool should have been decided upfront. Instead of using one tool to allot for traceability of requirements, we used two. NX by Xerox for LaRC Reviews and Windchill for the main repository. This proved to be difficult with mirroring, especially at the time for verifications of requirements.

2.8. Get agreement within/between agencies early on. Coast Guard had a plan to shoot out the LAS if it floats - then started to waffle. CM/LAS had to work to evaluate whether or not the LAS would float, thought this was not necessary with the Coast Guard plan.

3. Organization / Culture

3.1. Sensitivity to other Centers. We are one NASA, but we are also different Centers. Rude awakening once arrived at KSC. Did not feel they appreciated our differences and questioned why we didn't do everything like they did.

3.2. One NASA means more than just changing all of our e-mail address to remove the individual centers. Each center still has their own set of cultural and institutional processes and "how we do business". We needed more cross pollination of team members earlier on in the mission.

3.3. Groups working on interfaces should have had some sort of opportunity to meet to develop the human interfaces that would have made this interaction simpler

3.3.1. CM/LAS to USS specific. Once relationships developed it makes it more efficient going forward.

3.3.2. When key people change--particularly on interfaces, management needs to step in.

3.3.3. IRDs did not have enough "strength" to enforce the agreements on both sides. How much authority did the book managers have over the IPTs?

3.3.4. Resulted in actions not being followed up.

3.3.5. Avionics group was working with contractors which were another level of separation between the people actually working the interface on CM/LAS.

3.4. Maintaining Shuttle vs. integrating a Flight Test Vehicle 'should' follow slightly different processing rigor which still maintaining safety and vehicle integrity.

3.5. This was NOT a human-rated vehicle, yet was treated as such once at KSC, calling in much overhead probably not required for this vehicle. Was told it was a fast-paced experimental vehicle, but did not feel given latitude required to properly take advantage of this.

3.5.1. Have Center agreed on an approach. For example, for 1149, was provided 30+ different ways by KSC to fill out this "simple" two-page form, yet unable to get agreement over two months of discussion prior to shipment and three days of intense meetings once hardware delivered.

3.6. Clearly defined (and accepted) hierarchy between Centers and Mission. IPTs sometimes acted as a stand-alone project - but need to act as though part of a larger Agency-wide project of which they're a part.

3.7. AVIO vs. SE&I the philosophical change at Mission PDR had an effect...

4. Communications

4.1. Too many meetings, running for too long, involving the same personnel and too many levels of meetings lead to various inefficiencies.

4.2. Tools often impeded communication due to ponderous operation, intermittent access, and lack of experience on part of users.

4.2.1. Access to tools - had limited number of team members with Solumina access so had to work responses around their availability.

4.2.2. Define tools required to do job. Get access process defined and clear to allow adequate and appropriate personnel access.

4.3. Learn to run an effective meeting; follow agenda, discuss topic, assign actions, follow-up, resolve issue, move on (don't bring same issue back up).

4.4. ICE/Windchill proved very difficult when searching for necessary documents - part of this is the software, part of this is the user. A clear definition of the folders and where to find particular things would have greatly helped.

4.4.1. Clear definition of where to put things - so this is where people can find it is necessary.

4.4.2. It was after CDR that we devised an index of where items were to be officially housed (identified, numbered, structured within both tools, etc) to ease locating documents for reviews and retrieval. This could have been devised up front with an appendix to the CMP (e.g., data management plan and a records management plan). There are plans that could have been devised; filtered from the NPR.

4.5. Openness of management was beneficial. Felt could call, write, or walk into as discuss problems with much of the management. Regular Mission Manager updates e-mailed to team was appreciated.

4.6. Co-location of the CM/LAS IPT helped human interaction which greatly simplified resolution of issues.

4.7. E-mail and meeting scheduling tools where ineffective due to large amounts (volume) of information to exchange.

4.8. Could not complete necessary training courses on-line due to being blocked by Langley's firewall

4.8.1. KSC-based SSPF training

4.9. Define WHAT is required by the Mission. Was not clearly stated until nearly launch that CxPRACA did NOT have to be closed as long as Solumina and/or iPRACA were closed.

4.10. Provide better communication between LaRC Contracting personnel and QA to maintain proper oversight at contractor facilities.

5. Resources

5.1. CM/LAS benefitted from continuity in a number of key people. It proved very helpful at the end of the project to talk to people that were there from the beginning.

5.2. Continuity! Both of personnel and agreements. Rapid turnover of certain key people impacted progress. Literally cannot name all of my IPT's C&DM and schedule analysts. And as personnel change, agreements and corporate knowledge are impacted.

5.3. Sync resource priorities across & within centers, agency and mission. LaRC Center priorities for CM/LAS were lower than Mission expectancies for CM/LAS.

5.4. Schedule at KSC highly driven by access to small groups within the VAB. Crane was a large one, equipment crews, even the door contractor allowed to open the VAB doors (the last one cost ~15 people 6 hours waiting for the temperature in the bay to get high enough as the contractor was a no show and it took that long for the bay to warm up without being able to open the door).

5.4.1. Providing this information to incoming partners would be helpful so we know what to expect. We have not worked there before to understand the interdependencies.

5.5. Environment within the VAB was not conducive to instrument and sensor installation. Either too cold, too humid, or too dry.

5.6. Risk assessment for shipment would have been different had understood additional overhead required at KSC. Balancing additional time required to perform tasks and scheduling in these tasks could have shifted balance to taking hit for paying penalty for delaying transportation and completing work at home center over shipping "on time".

5.7. Extra wire not initially provided for pull tests required by NASA workmanship standards.

6. Safety and Mission Assurance / Technical Authority

6.1. Different problem reporting methods used between LaRC and KSC.

6.1.1. No training or information on KSC's reporting methods prior to arrival at KSC.

6.2. Felt we had EXCELLENT ITA support for the project, both from IPT level and Mission level. Typically provided guidance for either avoiding problems before they occurred or recommendations for resolution if something did occur.

6.3. Needed to define S&MA roles between the Centers. For example, from CM/LAS perspective, when getting KSC to fabricate the Stack-5 Lift Fixture, should have ensured expected S&MA oversight from KSC clearly stated in TTA - we had differing expectations.

7. Schedule

7.1. Meetings dominated my calendar. Difficult to schedule other tasks against mandatory meetings. And once at meetings, have presenters prepared. Many instances where XCB topic comes up and there is no presentation available.

7.2. Time management was difficult given the number of boards where attendance was expected - I never proved as effective as I would have liked multi-tasking.

7.3. Schedules could slip while awaiting engineering decisions or drawing updates

7.4. Tough to keep schedule with limited resources (personnel).

7.5. Scheduling and CM should communicate more (sync-up)

8. Design

8.1. Get design defined quickly. Locking down OML took some time. Could not follow Orion changes - had to pick one and build.

8.2. CM/LAS was required to maintain the possibility of ballast in the CM - unnecessarily so as it turns out.

8.3. Fasteners! Was the largest issue for fabrication. Long lead times, incorrect delivery dates, changing availability drives change in design (and thus schedule and cost impact), lack of depth in Center procurement process led to issues.

8.3.1. Center evaluation issues (upon delivery) proved difficult - fasteners were supposed to be tested, were not.
8.3.2. Disagreement between center and agency evaluation procedures.
8.4. Changing/evolving requirements to design. Notably the LAS nose cone. After pointing out issues with nose cone fabrication and welding, we were levied tighter requirements for tolerances than originally provided.
8.4.1. Changing load cases also drove design. LAS had to be largely redesigned to meet higher loads - fortunately occurred prior to main fabrication.
8.5. Make sure you get any out of scope work documented properly before you take it on (across IPTs, Mission, within Center) etc.
8.6. Sync design and analysis processes across centers, IPTs and within Mission

9. Manufacturing

9.1. Do as much manufacturing, assembling and integration (at the home center) prior to delivery to KSC to preclude increased schedule processing time and increased cost.
9.1.1. Also maximizes use of personnel familiar with the design and fabrication techniques.
9.2. Secure adequate fabrication resources (and schedule) for all agreed in-house work and maintain appropriate certifications (welding, machining etc.)
9.2.1. Confirm certifications also kept up for contractors. Had concern with one subcontractor having to get re-certifications prior to being allowed to perform work.
9.3. Designed largely around fasteners, with two weld areas. The two weld areas (the only steel structures) provided the most difficulty. CM lower ring delayed due to stack up of schedule slips that lost the welding window of our contractor. Nose cones redesigned to allow welding after unsuccessful rolling of steel plates into cone halves.
9.4. Ensure Fabrication QA & engineering are on the same page to spot check appropriate dimensional requirements that lead back to system and/or mission verifications. We had some SRD and/or ERD verifications that we could not close because we did not take (callout) the proper QA inspections.
9.5. Some last minute design changes due to availability of billets and other raw materials (changes sectioning based on size of billets obtainable).
9.6. Consider welding method consequences. Extra heat generated by TIG welding, slag generated by SMAW

10. Test and Verification

10.1. Verification of system level requirements should flow in to verification of sub-level requirements. The system level modal test provided verification of the system (and sub-system) stiffness, but CM/LAS was still required to put in a waiver for stiffness.
10.2. Testing of fasteners - do adequately as noted in previous requirements note. Maintain testing equipment calibration and certification.
10.3. Properly plan for limited resources - laser tracker teams in high demand.

10.4. Properly process verification data - lost one key laser tracking exercise as data not properly saved and processed so final "stitched" overall scan corrupted and unusable.

11. Top 3

11.1. More effective meetings for virtual teams that minimize multi-tasking of participants. Control meeting overlap and duration. May require some prior planning on part of organizers, but will save time and frustration for all participants. Improve meeting effectiveness - fix a realistic agenda, stick to it, push for resolution in the time allotted or move it to another discussion/time.

11.2. Put more emphasis, planning and structure on all interfaces (technical, managerial, cultural, operational etc.) Given our own vices, we do excellent work; it is only at the interfaces where we have any issues. This is often the most overlooked aspect of integrated team dynamics.

11.3. Set clear lines of authority where appropriate. Had instances where someone with valid and necessary input and direction would not be given adequate voice. Conversely, some without apparent useful input would be allowed to impact progress.

2.8 Systems Engineering & Integration Knowledge Capture

1. **Engineering Management / Systems Engineering and Integration**

1.1. The Joint MRB process was developed to resolve technical issues between IPT's. Reviews were called with very little lead time (sometimes in a few hours, usually less than 24 hours) with data either not available until the review or a few hours prior to the review. This led to insufficient time to review and understand the issue. Concern: The short review time resulted in excessive discussions during the actual MRB meeting as well as the need for rejecting the recommendation for further review. Recommendation: Either mandate that reviews and the associated data be provided with sufficient lead time to allow the board to review and ask questions prior to the review (>24 hours), or have a standing board meeting time so the work can be better planned.

1.1.1. This process was broken.

1.1.2. A chronic problem with MSFC-ATK

1.1.3. Had to real-time the SE&I inputs

1.1.4. This process needs to be better vetted - and followed

1.2. Don't contract out the task before you know what we are going to do. (LM Avionics task) - this ends up having the contractor bias things in the direction they are used to going (for instance, payload is data didn't work so well), and causes lots of changes or compromises downstream.

1.2.1. DFI as payload was discussed but never actually implemented

1.3. Item: Use of multiple different and incompatible data storage and virtual meeting methods. The data storage servers were behind other center firewall so team members at other NASA centers could not access the data. Also, other virtual meeting methods were used so that personnel at other NASA centers could not participate. Concern: Use of the limited access elements reduced ability for other team members to participate or interact during meetings leading to impaired communications. Recommendations: (1) While use of separate or corporate data storage servers has its place, all project data should be stored on a common server where all team members can access the data in a timely manner. The issue is that much of the ATK data was stored on the "D-Drive" that folks outside of MSFC could not access. This also is true of the KSC "e-Boards" where personnel outside of KSC cannot access as well. (2) Virtual meetings should be conducted using a common means where all team members can participate vs. using Team Center where only MSFC personnel can participate.

1.4. Deliverables should include a detailed requirements description with all potential users of the deliverable (e.g., database)

1.5. Huge data server with high speed needs to be setup with someone available and helping with organization. Windchill's horrible response time, timeouts with "page limit exceeded" messages, etc. is totally unacceptable if it is to be a useful and productive tool. Good search capabilities need to be available too to make sharing things across teams and between teams better. Also needs to be consistent with PC naming - i.e. not put things like %20 instead of spaces in file names. Windchill caused extensive delays just in opening pages, and was down on L-1!

1.5.1. Thousands of man hours were wasted due to the long wait times and inability to effectively search for Items on Windchill. The mission management office also did not have adequate policing of folders to eliminate junk files. Only through the heroic efforts of the XCB secretary, who provided CM of the baselined documents was catastrophe averted. This person maintained items in an orderly and easy to find area.

1.5.2. The Verification folders were set up with a subfolder for the systems and for every element. These subfolders then had a folder for every requirement (i.e. FTV-001). This made it easy to place and find verification artifacts.

1.6. SE&I products should have had a more thorough internal review process prior to release of data. We relied too heavily on the TQR process as the review strategy - while this helps with technical quality, need more project centric integrated review.

1.6.1. Review process could take longer than to actually generate the database

1.6.2. LaRC Technical Quality Reviews initially did not produce a peer review report. The Peer Review Reports are key verification artifacts and must be baselined and placed under CM. When the peer review reports were produced there was a large amount of variation in the level of detail that was provided. Need to have better standardization on the format of peer review reports.

1.7. Synchronize review forums so the same material is not being presented to 2 or 3 boards over the course of a week.

1.8. Do not award contracts until requirements have been determined. This also includes requirements for Safety, Reliability, and Quality Assurance. Contracts often drove the requirements instead of vice versa. A significant number of constraints are imposed by contracts. In some cases, requirements had to be changed to satisfy contractual limitations. Changes had significant impact to cost estimates

1.8.1. Investigate ways to bring in competing contractors at low fixed level of effort to provide comments on requirements until the requirements get baselined.

1.9. XCB - Frequently too much technical detail. In an ideal organization, many of the technical details would have been worked out outside of XCB, and only reported at that level. Encourage project management to look for opportunities to empower the team to solve problems at a lower level.

1.9.1. This might have helped to reduce the amount of time spent in XCB

1.10. Ares I-X was successful, yet we did not follow NASA processes. Cause or effect?

1.10.1. We succeeded in part because of not using established processes that our model did not fit in. Our people were dedicated enough that we were able to innovate through not having other, useful processes.

1.11. Data sources should not be defined prior to list of deliverables (along with requirements) is laid out (e.g., wind tunnel tests described and funded prior to knowing what databases are required by all the teams)

1.12. LaRC, KSC and MSFC could not work together effectively until Bob Ess better defined roles and responsibilities during the ReSync activity. This was caused by multiple project managers (I-X and Ares I). KSC never directly worked for Bob Ess prior to that event.

1.13. Lessons learned activities have been conducted on every project yet we continue to repeat the same mistakes - this means either we have met our ISO-9000 threshold or we do not review these elements. Need to evoke the conscious need to review previous lessons learned - especially for one of projects before and during a project - or we will again have Lessons NOT learned.

1.14. Never had a ConOps upfront

1.14.1. The lack of a ConOps was partly mitigated after the development of the Assembly, Integration and Test Plan which defined R&R and handover points. An approved ConOps upfront may have avoided the setback caused by the Ares I-X resync (reorganization)

1.15. SE&I should be stood up before all other elements

1.15.1. Developing system level requirements before starting the design is paramount to avoid re-work.

1.16. TIMs and SuperTIMs early on should have been focused on defining requirements.

1.17. Participation in engineering working groups by some IPTs was inconsistent; consider modified organizational structure that would give SE&I more authority.

1.18. Develop acquisition strategy. DFI should not be carried as an Avionics cost. As avionics cost grow, DFI is seen as an area ripe to cut.

1.19. The Chief Engineer meetings did not start until after CDR, start this working group at the start of Phase C at latest.

1.20. Early on the Ares I-X SE&I offices was co-located in one area of Bldg 1244. This proved essential in improving communication and improving meeting attendance

1.20.1. This is a common IPT problem

1.21. While Windchill is a great idea in principal and a tool like what it is meant to be is required, the actual performance of the Windchill tool produced a lot of stress and wasted time. We have generally become accustomed to search and access times consistent with Google at our home. Resources expended to improve Windchill from an access speed and search capability point of view would be money well spent.

1.22. Develop management plans very early in the mission. Systems Engineering Management Plan, Data Management Plan, Configuration Management Plan, Risk Management Plan, Requirements Management Plan

1.22.1. SE&I initially tried to use SEMPs, CMPs, DMPs, and RMPs from the Ares I program. In general these documents were huge and full of fluff that identified why Cm of RM was important and not specific processes on how to implement these systems engineering functions on the project. These items ended up being written from scratch based on standard formats found in the NASA systems engineering document.

1.23. Project Matrix – works better in some areas, worse in others. KSC has a well established culture that prevents staff from accepting direction outside their line management; while KSC staff participate in working groups, direction must come through their management

1.23.1. This caused difficulty for SE&I because it slowed communication and information flow.

1.24. In the middle of the mission, we ended up in a major re-organization. This re-sync was much needed but costly to schedule. Top management did not have a handle on organization in the beginning.

1.25. Did not have the proper management tools in place along with the proper management plans upfront when the mission was under way. Caused many delays in getting started.

1.25.1. Management structure was confusing with the introduction of Project Integration. Those roles are typically in SE&I.

1.26. There was not a real integrated master schedule available until very late in the flow - like after all the hardware was at KSC. Caused lots of angst and misunderstanding regarding what drove what type of deliverable.

1.27. SE&I cannot be at the same level as the Element IPTs. Needed the authority to get the IPTS to conform to system level processes. The Re-sync later did help this considerably.

1.28. Records Management not fully in place. RMS is not being applied.

1.29. The Project Integration lead was in the MISSION Manager's Office however expertise in project planning and control was not demonstrated; SE&I had more experience in this area but the Project Integration Lead was not responsive to the processes and procedures for project planning suggested by SE&I. As a result, the plans that were put into place were not fully integrated across the Mission. Schedule management is one of these areas.

1.29.1. Roles should have remained in SE&I

1.29.2. The Ares I-X XCB Secretary became the de facto integration lead because of past experience with CM/DM, technical knowledge and excellent communication skills. This was done almost exclusively via telecommuting. This was the most successful example of effective telecommuting I have seen and proved it could be just as effective as collocation.

1.30. As the loads & environments were worked in a very fast paced environment, I regret at some point not being firmer in my concern about V&V and providing backstop or protection for the analysts who were literally generating results overnight. A simple oversight of not going back and revising previously released ascent loads after corrections had been found through a V&V process made the day of launch decisions regarding loads much harder than it needed to be. I do not know exactly what would have helped, but fatigue and simple desire at some point to have the pain end was contributory.

1.31. Design vs. product requirements. Verification often centered around design and not product verification. Verification should always focus on the final as built product. The end results. Contracts must specify As built verification artifacts as deliverables.

1.32. It is essential that SE&I implement consistent requirement formats across the project. Many "heritage" formats included process requirements with the product requirements. If one entity uses different formats, tracking becomes a nightmare. You will pay for the quicker start up.
1.33. Rational statements must be included in the requirements because they are essential when writing the verification plans so that the reader knows what the key thoughts are.
1.34. Interface development must include specifics on who is responsible for each part of the specific interface.
1.35. The system level SE&I activity must have approval authority of element level product requirements and verification requirements to ensure traces are implemented.
1.36. Interface requirements do not belong in the interface documents but are from the each side of the requirements documents calling this out. Interfaces are the success criteria of these requirements.
1.37. Traces often were bogus and did not appropriately trace back to the correct requirement.
1.38. Allocations should always go to product requirements and not organizations.
1.39. Requirements should not mix product and SOW requirements.
1.40. The schedule push caused the plan to be out of phase -- requirements development overlapped with design and fabrication.
1.41. SE&I was not as integrated into the IPTs as needed. The project started with IPTs and SE&I continually fought IPT centric viewpoints. We may have gotten this done but it was VERY painful sometimes.
1.42. SE&I needed to have a MMO directed mandate as system integrator/requirement owner earlier in the mission.
1.43. managers, lead and chief engineers talk too much and listen too little
1.44. Eastern Time Zone IPT Centers and contractors are expected to attend late evening meetings while little effort is made for early meetings to keep the ETZ centers from running their employees in the ground.
1.45. The ID&A approach should have partial leadership with engineering design and manufacturing experience within the organization.
1.46. When there is a situation where contactors are managing other contractors, NASA loses its ability for insight into the work.
1.46.1. Again deliverables need to be much better defined. This is especially true for test and verification plans procedures and reports which are all over the map. This would help prevent the loss of artifacts when a contractor subcontracts to another contractor.
1.47. All agreements should be in writing as oral agreements were either forgotten or ignored.
1.47.1. Defining the MOAs needed up front should get higher priority.
1.48. A strong systems engineering leadership position is needed to coordinate not just hardware, but also cohesive physical modeling. The lack of consistent leadership and frequent loss of corporate knowledge at the IDA position hurt the cohesiveness of the models and ultimately caused a lot of the problems pointed out in other comments. As an example, GN&C was forced to develop

a consistent set of mass, aero, structures, propulsion, and actuator models which appeared to dramatically improve not just GN&C, but the whole analysis cycle through Mass, Propulsion, Aero, Trajectory, GN&C and Structures technical disciplines.

1.49. The intuitive documentation naming conventions was a huge help. This was defined early on in the Ares I-X SEMP and implemented at the system level and by several IPTs. Those IPTs that used a "heritage" numbering convention required the users to go to a document cross reference. The Ares I-X SEMP describes the flexible document naming conventions that were used.

1.50. How do we ensure that people in key positions to make important project changing decisions have read and are cognizant of the associated requirements documents?

1.51. At the Ares I-X resync, the Ares I-X Integration and Control Manager was moved to MSFC. Key functions such as CM, DM, Drawing management, were defined far too late and Model Management for the ID&A team was an issue all the way until FTRR. The Integration and Control Manager should be collocated with the SE&I function.

1.51.1. The functions should reside with SE&I to eliminate confusion; however, the talent to perform these jobs can physically reside where ever as the XCB secretary demonstrated.

1.52. Co-location to LaRC and KSC by the Mission Manager was very successful and speeded up decision making processes and transfer of information and communication since Bob Ess ran an open door policy. It also strengthened SE&I authority which did not have much empowerment till the Mission Manager co-located at LaRC.

1.53. The Ares I-X review board (XCB) was very effective in getting decisions made. One of the most significant changes by the Mission Manager was to have votes by the board members substituted for document signatures. This reduced document baseline schedules significantly.

1.54. Having most ARES 1-X personnel on as full time, one project persons helped improve efficiency. It would be difficult to be effective if attention was split between different projects.

1.55. Have designated back-ups for all managers and team leads.

1.56. Do not let managerial money concerns trump technical concerns.

1.57. Track lessons learned from the start. Review lessons learned from past missions (e.g. Apollo/Saturn, Delta, Atlas, and Titan) at the start.

1.57.1. Collect lessons learned after each major milestone

2. Requirements Management

2.1. Schedule training early for those involved in developing requirements o KSC uses requirements to describe procedures o Requirements must be developed in a consistent manner. o All SHALLs must be verified

2.1.1. Training should be reference able throughout the lifecycle of the project.

2.2. Item: Misunderstanding between SE&I and FS regarding intent of Product Verification vs. Design Verification led to extensive discussions and interactions and delays in reviewing and approving FS verifications. Concern:

Excessive effort and time expended trying to understand these differences led to delays. There is a philosophical difference between product verification of the physical hardware vs. design verification (which is essentially lot acceptance). There is an opinion that the design verification is appropriate for the fleet deliveries but may not be so appropriate for a "one-of" type configuration. Recommendation: Invest the time early to reach common understanding of verification strategies and methods to be used.

2.3. Need to define interface management roles and responsibilities better - what SE&I will do and not do and capture requirements accordingly

2.4. Verifying a standard involves multiple requirements. You can get into a circular loop of referencing documents many of which are old.

2.4.1. A generic reference to a standard should not be used. The requirement should reference specific sections of a standard when needed. A generic reference to most standards is unverifiable due to cascading references to other standards until the original note is so old that it is no longer available. Verification managers must carefully review these requirements to avoid major headaches down the road.

2.5. Requirements (and end users) should be defined prior to a deliverable date set in the schedule

2.6. Need better strategy for distinguishing between goals and requirements - where we had goals related to similitude, should have been very clear what features were real requirements and what were goals.

2.7. Contracts present particular challenges o ERD’s are not decomposed for contractors in the same manner. o SE&I has full approval authority one level down (ERD); however, SE&I has no insight at the contract level (below ERD) to determine if they are decomposed all the way down to the design. o Not all IPT’s developed true ERD opting instead to do a “pass through” to the contractor ATK developed the ERD for FS o Verification reports must be spelled out in contracts

2.7.1. Since contracts were in place prior to requirements being developed there were several contractual constraints that crept into the requirements that caused a lot of confusion. One example is that the Lockheed Martin ground C3 system was documented as part of the Flight Test Vehicle because that was the way the contract was written. The contract also stated that all avionics would be treated as heritage items for qualification even though the item was a completely new design.

2.8. Trivial or non-value-added requirements stayed in there - like no definition of what constitutes flight phases. Had to define what the requirements meant to show compliance, while doing the compliance documentation. Need to think about what really needs to be demonstrated to ensure a successful flight.

2.9. Make it easier to change a requirement or remove it. Over the course of a three and a half year project there are a lot of factors driving some modifications.

2.9.1. This was a major problem when the sep plane changed. This made us go toward new databases and thus new wind tunnel tests and CFD to generate those databases

2.10. Format of database(s) should be spelled out in requirements (save time in developing databases and users up front work)

2.11. Problem is that the folks who write the requirements are not really the ones who implement them - need some sort of process to bring in the users or end item implementers to capture what that requirement really means to them and amend if needed.

2.11.1. There were cases of this happening, however end users were involved with all requirements development at the system level starting in the beginning along with being involved with all the final reviews to baseline the system requirements. This was not applied as rigorously at the IPT levels.

2.12. Work with Chief Engineer and SR&QA to develop applicable standards list

2.13. Contracts often drove requirements rather than requirements controlling contracts.

2.14. Verification method should be spelled out in more detail in the requirement than just the 4 methods used in 7120.5 (test, analysis, inspection, demonstration). If, for example, if the verification method is inspection, detail the inspection method. Is there a particular type of equipment that should be used or is inspection of drawings adequate?

2.14.1. Verification method needs better flow-down with requirements all the way to the contractor.

2.15. It would have been very instructive for me to simulate doing the project in reverse. Once I lived through decisions required on DOL, things I would have done differently became clear. The products being developed 3 months before started making sense.

2.16. Some system level requirements cannot be allocated to each IPT. Do not force each requirement to have child requirements.

2.16.1. Example (Bending Modes, stability margins, trajectory)

2.17. Activities within the Verification Requirements Document must be captured with appropriate links o The Verification Requirements Document should define exactly what must be done (inspection report, analysis, or test) to close out an artifact

2.17.1. Contract requirements flow down needs to support verification activities

2.18. FS utilized a task on an existing ATK contract that was put in place before many Ares I-X plans and processes were established. The mapping from ATK deliverables to Ares I-X products was performed very late in the process. This late mapping was a constant source of difficulty in successfully completing Ares I-X milestones. Recommend if similar aggressively scheduled projects lead to major project elements that are established too early to be consistent with project processes that: 1) the differences be identified and accepted. 2) change the contract, change the project, or develop a map to get between the two.

2.19. I think the IPTs struggled at the start in understanding what was required of them in the way of requirements identification, ICDs, IRDs, and verifications. Perhaps they needed very specific examples. Also, were expectations of when the requirements were going to be verified and closed out not understood or were they ignored?

2.20. Q&A requirements of the 'As-built' FTV were not defined well. Post-flight analysis requires detailed OML 'cloud-of-point' data (some sections of the FTV had this detail others did not)

2.21. Quality Assurance Reviews should begin near the beginning of the mission; ensure IPT QA is standardized and effective

2.22. Deliver requirements (i.e. FCS design) in the form anticipated to use. Initial designs were provided with continuous representations, whereas the real FCS would be in digital. Then, when the NASA design went discrete, it did not match the LM/ULA code since they used different representations for integrators, filters, etc.

2.23. Moved to Org/Culture

2.23.1. Move this comment to Org/Culture bucket

2.24. Due to differing cultures, KSC had a different/more restrictive definition of requirement. They define requirement as an instruction on a drawing or operation needed to be performed.

2.24.1. There were endless discussions on the separation of people requirements from product requirements. KSC primarily dealt with people requirements and SE&I dealt with product requirements. KSC uses the term requirement for operational procedures.

2.25. KSC does not recognize Interface Control Documents or Interface Requirement Documents. They only recognize requirements communicated on a drawing or as an Operational Test Requirement. So duplicate work had to be performed in developing an ICD and then re-writing it as an OTR.

2.26. Program Requirements Document (PRD) must be given higher priority and must start earlier. The PRD to the Range must be a separate document, and lead times must be observed.

2.27. There should be no such thing as modified-heritage. It is either heritage or it is non-heritage and should be assessed as such to meet requirements.

3. Organization and Culture

3.1. Co-locating with the rest of the GN&C team was tremendously effective in getting the group to work together well and interact as a real team instead of individual researchers. Overheard phone conversations, or discussions at other desks and nearby offices often lead to group discussions that brought new information to light and feed off each other.

3.2. The culture of Ground Operations (GO)/KSC underutilizes their technicians. The technicians at KSC are highly trained & skilled individuals that have been beaten down to the point where they will not speak up. They need to be included in the writing of processes and encouraged to speak up to give better ideas.

3.3. Removing center tags was very effective in getting over cultural bias.

3.4. The SE&I ID&A team was effectively managed using weekly meetings and ad hoc meetings; and there was a culture of openness and professionalism.

3.5. Different centers interpreted standards and best practices differently - or had their own - so led to confusion or misunderstanding discovered too late.

Related to requirements - but need to reach common understanding on what terms/standards mean.

3.6. It was difficult reviewing databases in the Branch and RTD levels because the reviewers were typically researchers and expected the detail of the data used for databases to be at the level of a 1, 2, or 5 year research project instead of a 1, 2, or 3 month effort. If additional research was specified by the Review Panel, the schedule and the budget may not have been available to meet those requirements.

3.7. Big difference between a "requirements based" culture and a "do-based" culture. Often presented with, "No requirement for that", instead of "have to do this to make if fly correctly". For organization charged with making the vehicle work, have to look beyond requirements.

3.8. Various cultures need to recognize that they do not have the lock on engineering excellence. In general, all centers have people with the capability to make tasks happen. Traditional Research centers may even have folks closer to the technical forefront than those that may be used to contracting out more in recent past.

3.9. The project management talent and experience held within the LaRC Flight Projects Directorate and other areas at LaRC should have been recognized by CxP and more authority in project planning and control given to LaRC.

3.10. Putting school schedules on the calendar was helpful for planning. MSFC practically shut down during spring and fall breaks.

3.11. Weekly DFI Meetings assisted in educating the participating IPTs on what was expected of meeting particular Requirements

3.12. Difficulty in accessing other center's networks led to delays in work (and negative feelings) - basically the space centers (KSC, JSC and MSFC) were all "trusted domains" yet the research centers (LaRC and GRC) were not so we had many more hoops to jump through to be able to access the needed networks.

3.12.1. Not really one NASA

3.13. Bringing in personnel from other centers to work with and SE&I "hat" was key in integrating the project.

3.13.1. In a few instances, it was counter-productive has people were only concerned with their own Center's initiatives.

3.14. The Shuttle culture/mentality was continually imposed upon the Ares I-X team. New methods needed to be found at KSC to get things done and GO insisted on saying this is the way we do it on Shuttle. This is a new vehicle and more flexibility needed written into the processes to facilitate troubleshooting.

3.14.1. FS had considerable Shuttle mentality also.

3.15. Having a master calendar with weekly review of events kept everyone informed. One person managed the calendar for consistency and all had access to it.

3.16. Paradigms had to be changed when going from a "research" mode to "development" mode (also, going from aircraft mode to rocket/missile mode)

3.17. There were at least three distinct cultures on Ares I-X. KSC with shuttle processes and loyalties, MSFC established relationships with ATK, LaRC/GRC researcher attitude. In all cases, the cultures had to be adapted to support the Ares I-X mission. The whole team could have done better at recognizing the various cultures and recognizing that each culture was adapting to support the same mission.

3.18. KSC operational processes are not user friendly for outside organizations. They were not easily accessible and existing management systems made it difficult to get status and data.

3.19. The Project Integration Lead was reluctant to accept advice from experienced project management personnel at LaRC. I believe that we had ideas for planning work, cost and risk management, and coordinating work that would have prevented some of the problems we saw on the project.

3.19.1. There was the Langley way, Marshall way, and Glenn way.

3.19.2. Recommendation that areas of expertise be recognized when planning future missions. The Schedule Management group at LaRC has been in place at LaRC for several decades; many have worked large flight projects; schedule management processes are strong; many analysts have worked for NASA for over ten years, and many of the schedule analysts have Project Management Professionals.

3.20. NESC was a very valuable resource. It provided a very valuable backstop, source of help, and way of finally putting issues to bed. We need to keep NESC.

3.21. Culture clashes were often on which way processes would be carried out. My way or your way decisions. Rather than SE&I and MMO deciding how processes would be performed.

3.22. Paradigms had to be changed when going to a "development" mode from an "operations" mode. Operations personnel were reluctant to adapt to something new.

3.23. Learned to work with Chief Engineers and NESC to accomplish specific tasks that would otherwise be "swept under the rug"

3.24. Traditional "manned" flight centers need to understand that a huge part of NASA successfully launches vehicles to orbit and in the solar system. There is a huge amount of expertise that exists at other centers. Highly recommend you have multi-center representation (beyond KSC, JSC , MSFC) in early planning activities at ESMD

3.25. The operational centers culture seems to allow much less empowerment of the working level personnel than the research centers. This seemed to reduce flexibility because people were reluctant to "rock the boat". This cause issues to remain unresolved longer.

3.26. Should be roles given to Centers - or should roles be given to individuals that are the right ones pulled from whatever Center or contractor that works the best? Most effective cases seemed to be when working across Centers (SE&I with Ground Ops, contractors, etc.) and not through Centers themselves. Support of the project by the Center extremely important and that was evident.

3.26.1. At the resync, staffing seemed to be determined by which center would own the box rather than who had the correct skill set. Often the work still got done but by people who were not listed in the box. A description of the various position should be listed up front and filling positions should not be determined by what center the person works for since it filters out many people that may be better qualified for the position.

3.27. Co-location with personnel from different centers helped develop mutual respect. A similar mindset should be encouraged for those at the other end of the telecon.

3.28. MSFC refused to use 7120 milestone reviews since they were had traditionally used a different set of reviews. This cause quite a bit of differences in expectations.

3.29. Co-location is necessary early in the project. There should be large amounts of travel to let the team member get to know each other. Then more telecommuting can be more viable once trust is developed.

3.30. Maintaining an accurate mission roster was helpful for identifying points of contact for different areas of the mission.

3.31. For problem solving and plans forward, agreement was often reached at the working group level but at the IPT management level there was disagreement. If the plan was workable to those doing the work, then it seemed strange that managers pushed back?

3.31.1. This often played out during XCB's.

3.32. The Mission needed to sponsor more parties to celebrate major accomplishments along the way.

3.32.1. The reward for completing a milestone was running to the next milestone.

3.33. A few key people under the KSC culture had a Shuttle-centric arrogance that and were at times violently aggressive toward other IPT's when they came to KSC.

3.34. Engineers with experience working flight projects with ESA, Russia with Vandenberg felt that they were treated with hostility at KSC as compared to any other space flight center experience. Both visitors and hosts need to understand this problem to improve the working relationships for team members working at KSC.

3.35. Initially MSFC treated SE&I like a contractor and assumed that they would be defining SE&I deliverables, getting constant SE&I status reports and would be specifying SE&I schedules as they would do with their contractors staff. This caused a lot of friction at meetings since SE&I is composed primarily of NASA personnel. There was also quite a bit of difficulty getting MSFC to accept the System Engineering Management Plan since they wanted approval authority over all of the SE&I functions for Ares I-X. When Ares I-X was more cleanly separated from the Ares I organization at the resync and the Mission Manager relocated with SE&I this situation started to improve since he was able to see directly what was being done.

3.36. The First Stage policy of marking every document as SBU/ITAR caused a lot of unnecessary work. Several documents such as ERDs and Verification Artifacts that contained no sensitive information could not be E-mailed. The requirements and verification artifacts could be added to the Requirement and Verification Database since it would restrict the use of that utility. The Ares I-X Integration and Control Manager challenged First Stage on the designations but nothing was done since it is difficult to change a designation once it is marked. The LaRC Export Control Manager did not provide any assistance on this since the ITAR regulations are so vague that virtually anything associated with a rocket can be marked as ITAR. Future projects need to have an effective way to determine what is to be marked as SBU/ITAR and have a single point of control with the knowledge and authority to makes the decision for each document. Allowing each IPT to make their own policies will cause problems if some are allowed to interpret the policy in different ways.

3.37. Multi-tasking does not work. Please attend only one meeting at a time.

3.38. Be sure that everyone on the team is taking a day per week off for rest and family time throughout the mission development. This applies during the pre-launch crunch as well. Mistakes, poor decisions, low morale and short tempers result from mental fatigue.

3.38.1. Or add additional staffing so the demands are not so great.

3.39. Do not expect instant reply to emails sent outside of regular business hours. Email sent at 2:15 AM may not be received until 8:00 or 9:00 AM. Get some sleep and don't harangue people about it the next day.

3.39.1. Same for instant messaging (IM)

4. Communication

4.1. The worst communication path was because of how the Avionics contract was done. Because of schedule issues, this was let through Marshall to Jacobs, to LMCO, who then subbed a lot of it to ULA. So, for communication from LaRC to Avionics, the management path was LaRC-MSFC-Jacobs-LMCO-ULA. Not conducive to getting things done fast and efficiently. In my opinion, the contract should have been let from LaRC directly to LMCO. Would have saved a lot of headaches, gotten faster decisions, and given LaRC leads a better understanding of the hardware. Luckily, my LMA/ULA contact was very willing to provide products, and we rarely had to involve the full management chain, but I saw plenty of time wasted on this in other areas.

4.2. Communication at the ID&A level worked well with face-to-face weekly meetings.

4.3. Terminology between organizations was frequently different so that individuals had to learn multiple sets of vocabulary or spend time establishing a unified set of terminology. Communications were often distributed in an adequate manor but the meaning could be skewed from one organization to the other, to the other, to the other.

4.4. Telecom and WebEx allowed participation from home, on travel, vacation.

4.5. Better meeting management principles should have been used across the board. Agendas with duration for agenda items. An understanding of who was required to attend the meeting.

4.6. Storing data at a common location (Windchill) is a necessity. However, Windchill seemed to be struggling under the weight of AIX data and documentation.

4.7. Minor nit – all the email from MMO had identical long all cap phrases for the first 5-7 words in the Subject. Made sorting and triaging email more difficult. Pet peeve.

4.8. We had to hire a dedicated person to work through communication issues with meetings etc, so we could start meetings on time. High priority should be placed on having good goals in placed and people trained to use them across the project

4.9. Need face-to-face often early, then periodic with customers (MSFC Ares I team). Lack of their information and trust maybe caused a lot of fires that had to be put out last few weeks before launch. This was done well with core GN&C team, but not well with further-out Ares I working folks and might have caused the "Phantom Force" emergency and "stage sep anomaly" flare-ups before even getting to the celebration of the successful flight picnic.

4.9.1. All levels of personnel, not just management face-to-face.

4.10. Teams need training in what words to use to facilitate meetings. For example, how does one politely tell a person who has only a need to know that the meeting will continue without answering their questions. At times, there were consultants calling into meetings who had not participated in the previous 2 meetings on the subject, but they slowed the process down by asking to be caught up. Give the Team Leads and Managers the tools to facilitate and professionally handle situations like this.

4.11. Electronic communications derailed communication in meetings. Concentration on email and IM on blackberries and laptops distracted key people during the course of meetings.

4.11.1. If we spent less time in meetings we could get real work done.

4.12. Many meetings seem to rehash the same information and decisions are sometimes lost. After several weeks the same people that made decisions will ask for detail discussion as if "groundhog day."

4.13. There were too many meetings where individuals wanted to be educated on the topic being discussed. An online meeting with 30-40 individuals is not the place for this.

4.14. Lead Sys Engineer often made the point to me that models and documents needed to be loaded and pulled from Windchill rather than passed around by email. Difficulty of Windchill made this preferable process harder than it needed to be. Too easy to call someone up and say, send the latest version of “X”.

4.15. Not allowing direct communication with Avionics Contracts caused lengthy delays in obtaining information and hence, wasted time

4.16. The agency needs to unify the center practices on computer security. One center has a wireless login page (LARC) another does not (KSC). MSFC, KSC, JSC are all on the "approved" list for connection to SOLUMINA. The other centers had a very difficult time getting through.

4.17. There were too many simultaneous meetings.

4.18. We waste a lot of time figuring out how to transmit SBU material. Email encryption needs to ubiquitous and easier.

4.18.1. Entrust seemed to work great for sending encrypted documents near the end of the project. Unfortunately many Ares I-X documents exceeded the size requirements for emailing.

4.19. The Mission needed help in managing the scheduling of meetings and preventing conflicts. For example, there were times when the Systems Engineering Manager was scheduled for three meetings that all overlapped. Perhaps there could have been a dedicated person at the MMO level to work on meeting planning. I think what was needed exceeded the capability of MS Outlook.

4.20. Meetings were very inefficient sometimes. This was in part due the time to review prior to the meeting. Also we have a need to come to consensus. That drive conversations out very long sometimes.

4.21. Getting a common agreement on scope and processes were key. Glossary of terms and definitions were worked out early successfully. Data books could not get out early enough to support requirement development due to lack of tests and analysis that needed to be done in parallel to this development. This caused a large delay in design. This needed to be in place earlier in the program. Technical Interchange meetings, summits, SE&I weekly tagups, newsletters, SE&I verification reviews and working groups were essential to the success of the program.

4.22. People not paying attention during the meeting would break in later to ask a question already answered.

4.22.1. Mostly either in another meeting (telecon by cell phone) or checking email/internet.

4.23. SE&I invested a significant level of project management participation in the requirements verification process. This provided needed management support to drive IPT and system level verification activities. With the crush of conflicting responsibilities, this level of management involvement helped with scheduling and prioritizing requirement owner's tasks as required to complete the verification activities.

4.24. ATK's contract was with MSFC. It was an awkward relationship between ATK and SE&I with the MSFC middleman.

4.24.1. The Ares I-X FS Managers seemed to have little control over ATK deliverables. ATK seemed to provide what they wanted, in the format they wanted, and the FS IPT at MSFC had to make do with what was received.

4.25. Data / Model providers - don't just assume what other groups need. ATK is prime example - didn't worry about stuff after 50 psi so didn't give to us, since Shuttle didn't do anything after 50 psi, Lots of time this from ATK - systematic drift (no mention of before flight), hot null bias changing at end of flight (not mentioned), etc. Let users figure out what is important--suppliers should be there to help users figure that out.

4.26. Focused face-to-face TIMs should be used more to develop mutual respect and understanding between IPTs. Emphases on focused.

4.27. First Stage deliverables did not require SE&I review prior to acceptance. As a result deliverables often did not contain the information that was needed.
4.28. Need to be sure and check models - groups providing models (aero, mass props, structures...) do not necessarily understand how data will be used - need to try to be able to at least be able to make some physical sense. Don't just take models at face value - plan time to go over and understand before implementing and using.
4.29. Finding out that FAM was not part of Lift-Off loads analysis happened in the context of a TIM. There is considerable value to having technical specialists explain what they do and the processes they use and assumptions they make at one level lower than their pure technical discipline and to have key players in other disciplines hear that story and identify gaps and mismatches.
4.30. Contracts often prevented direct communications to occur and caused much tension and delay of technical data. Never could review contracts to see if there were conflicts and constraints imposed SE&I. SE&I should be involved with the contract developments and be part of the approval process.
4.31. Bringing in all the stakeholders (including external) early in a group such as the Trajectory Working Group allowed us to develop relationships and exchange information. We were able to negotiate later delivery dates.
4.32. Too many meetings; folks stopped participating
4.33. Relocation of all team members and dedication 100% allocation of manpower worked very well.
4.34. Lean Events - were not as useful as intended, results were not followed but they did act well as to understanding how all the IPTs are carrying out their processes and work and the next set of events to be accomplished. Personnel running the lean events din not seem to understand the work that needed to be done and were pencil-whipping the schedule.
4.34.1. Were statistics collected to compare LEANED verses actual?
4.35. Having one POC for each external organization allowed the development of stable relationships between the mission and external stakeholders
4.36. KSC did not have LaRC or GRC as a "trusted" site. We needed to get login accounts at KSC to gain access to Solumina or CIPS or any of their schedules.
4.37. Before launch, needed to communicate to the public what was expected and desired during flight. Example: the USS would tumble after separation.
4.38. Though there were quite a few cases of not following NASA policies due to the nature of being a flight test vehicle, defining how we were going to implement processes, with success and safety in mind, communicating this to the team and then staying the course, helped towards the success of the mission.
4.39. Never underestimate the effort needed to properly run and implement a working group. A successful working group will require the lead to expend between .3 and .5 FTE of effort to prepare, run, record and implement actions properly. The value of a properly run working group is huge but conversely an improperly run working group will be a big drain on resources. SE&I ran many

successful working groups that had a direct impact on the success of the project. These were defined in the SEMP.

4.39.1. Need to cancel or even disband working groups when not/no longer needed. This was done effectively to help avoid wasting time.

5. Resources

5.1. Computer resources and staff resources were handled very well. However, when a new requirement came up, additional funds for a wind tunnel test which would have cut down on computer resources needed and staff time, was not seen as much of a requirement as other issues. But it could have saved time and generated detailed analysis required for database development.

5.2. Adding a project coordinator was incredibly helpful for logistics of regular meetings, reviews, TIM's.

5.3. Early on, the project identified resource shortage in structural analysis. Our project and the Orion FTA project needed this skill, and it took a very long time to resolve this resource shortage.

5.4. Center resources were hard to get at the beginning of the project. Once the center began to see the real impacts of low support then massive changes and mindsets were altered. Lesson: It is critical that resources need to be tied to specific outcomes. Then it is easier for centers to understand impacts for their reduced support

5.5. Windchill was a great help in organizing and tracking data when it worked. It was incredibly, ponderously slow at critical times.

5.6. It is key to decide that schedule is king and funding will be made available as needed to make the schedule work (within reason).

5.7. Technical expertise with hands-on experience is in short supply. Especially needed in requirements and verification development and contract oversight.

5.8. Personnel shortage was evident as both Civil Service and Contractors alike consistently worked 60+hr weeks

5.8.1. It is impossible to add people late in the mission when the extra bodies are needed most.

5.9. People with critical skills were often working Ares I when needed for more time critical Ares I-X analyses.

5.10. Early on there was a lot of delay caused by having the incorrect skill mixes put into specific positions when developing work products.

5.10.1. Lots of unfunded people were put on the mission early on even if the skills didn't match the need.

5.11. SE&I had requirements for wind tunnel model fabrication, and the lack of an integrated, detailed fabrication schedule made it difficult to predict the planned start and finish of fabrication.

5.12. Obtaining additional people with the right skills was a struggle. Some of the subject areas for AIX were highly technical with only a few experienced engineers available.

5.13. Creating teams that spanned NASA centers and external partners developed a sense of team and ownership. Each member had to learn cooperation, and log-jams were identified early.

5.14. SE&I covered several budget short-falls for Avionics in providing sensor implementation hardware and testing apparatus

5.15. super computer time and node allocations for CFD analysis were not available early on.

5.16. Adequate personnel should be assigned early. Adding people late in the project could actually slow things down while they get brought up to speed.

5.17. More knowledgeable bodies were needed to cover the plethora of meetings and document reviews. People were multitasking during meetings frequently needing a synopsis of the discussion before they could answer questions. Important documents were frequently given a cursory review (if any) instead of the thorough going over they deserved. The only way to get knowledgeable persons is to have them on-board and engaged early on.

5.18. LaRC did a good job of providing surge support to the Ares I-X team to support system level verifications. When verifications were stacking up, the center provided both general support and requested discipline support to augment the team.

5.19. SE&I members stepped up and helped out when areas were identified outside of their discipline that needed help.

5.20. SE&I did a good job of spending money where needed over the last 8 months where it was needed. Did not quibble over small amounts on needed contracts.

5.21. Resources for independent peer review were difficult to find. As a result real technical peer reviews were often skipped. in favor of less effective reviews.

5.22. Contract work force was understaffed causing delays in deliverables and thus, late understanding of Requirement short-comings that could have been otherwise corrected

5.22.1. SE&I often had to provide technical assistance where IPT was not adequately staffed

5.23. For FY2008 planning for the Integrated Design & Analysis team, we loaded resources in the Integrated Master Schedule and then reviewed the resource requirements reports. We used this to compare to the FY08 Phasing Plan (managed by the SE&I Deputy Project Manager for Resources) and make adjustments.

5.24. If a team member is not making a significant contribution to the team, then the Project Manager should have the ability to quickly get a replacement rather than an extended period of months and years of trying to make it work.

5.25. More time and expense wasted in re-doing and re-analyzing to save money than would have been lost doing it right the first time.

5.26. Drawings in Windchill should be filed according to the project drawing tree to facilitate getting information. Having the drawings filed by number is fairly cumbersome.

6. Safety & Mission Assurance / Technical Authority

6.1. Risk management was less effective due to the fast pace of the mission. Issue management became more important for down and in whereas risk management was used to communicate up and out.

6.2. S&MA and TA considered themselves an independent reviewer. That is not their role. TA is a separate reporting path when necessary. They need to be much more engaged in solving the problems the project has as part of the project not as an independent body. TA was moved away from the "independent" function to get highly qualified technical folks in the projects. Over the past few years they have turned into an independent organization with independent reporting paths. This is not efficient or necessary.

6.3. In general, the Ares I-X project worked very well with the TA (S&MA and CE) team. TA duties were delegated to TA deputies that were collocated at each IPT and SE&I. One good example was in the system level verification process. Both S&MA and CE ensured that at least one deputy or IPT TA lead was always available to support the verification reviews. The TA reviewers not only participated, but were well prepared with comprehensive verification activity reviews. They set the example for how it should be done, which encouraged all reviewers to put in the extra effort to provide a comprehensive review. Quality TA support ensured that the verification process maintained its needed rigor.

6.4. Learned to utilize Technical Authority "opinion heavily weighted" as a means of accomplishing certain tasks (derived requirements) that were deemed necessary yet disapproved by MMO

6.5. SR&QA requirements should have been determined much earlier in the project. It is a basic requirement

6.6. NESC was useful in helping clarify agency and end user needs when there were conflicts between programmatic and technical priorities.

6.7. Postulated hazards and safety issues should be filtered by a chief engineer's panel before they show up as tasks at the IDA or IPT level. This would be similar to RFAs at CDR. Some would be accepted and passed on and some would not.

6.8. S&MA and Office of Chief Engineering were always present from beginning to end. Heavily participated in all decisions at all levels. Material Review Boards and PRACA were used to cover any discrepancies in requirements and processes. Fair Wear and Tear were appropriately defined early on. Waiver process was thorough but the lack of a common database of waiver information caused problems when performing requirement verifications. S&MA should have maintained a searchable database of problem reports and waivers. Sometimes excessive review times caused problems.

6.9. The discipline leads had different approaches and experiences with Technical Authority (TA). I believe GNC did not find the TA reviews performed (either IDA or RTD) to add a lot of value. Ruth organized an extensive line-by-line TA review of her model by discipline experts and got a lot of value from it. GNC had an extensive shoot-out process involving multiple organizations building and running independent simulations that forced examination of a host of issues. GNC got a lot of out this self-defined process. Trajectory developed a plan where results for every product had to be generated by an independent group. This worked well. On the other hand there was no organizational review.

6.10. Risk management suffered from churn. Risks morph depending on participation at reviews. Often discussion would dwell when the topic was covered heavily in the past.

6.11. S&MA and TA should take more onus in setting up real technical quality reviews and bring in the discipline expertise needed. Instead the developer often had to find and bring in personnel needed for the review and track their own actions.

6.12. S&MA needed to be stood up sooner and the responsibilities of each center better defined.

6.13. SE&I did not have QA personnel to track actions, take minutes and ensure actions were closed. This reduced the rigor and often made it difficult to find verification artifacts.

6.14. Some of the IPT risks that were tossed over to SE&I were more CYA in nature than real risks. The IPT would then become offended when their risks were not accepted for transfer.

6.15. Ground Operations QA did not record adequate detail during testing and integration activities. The verification artifacts for major GO procedures often consisted of only "accept"

6.16. SE&I was not able to have on-site inspections/oversight of manufacturing at each IPT. The Avionics IPT sidetracked S&MA with definition of Safety requirements that were very different than the rest of the Mission.

7. Schedule

7.1. Some of the people had never worked a flight project, and didn't really understand how to estimate their schedule conservatively instead of optimistically, and then stick to it, regardless of technical glitches. It would have been better to give the entire team, up front, some education in how to estimate a schedule, and then the importance of sticking to it, and not spending time investigating interesting research off-shoots, or perfecting the product, as you would on a research project.

7.1.1. The corollary also applies where operations people need to recognize that technical delays will arise during developments that are uncommon in operations.

7.2. The Primavera tool was not managed the way that it was designed to be managed. The "Status Date" should be move daily with the current date. Consultants to the project and the Schedule Lead determined to only move the status date monthly (and toward the end of the mission twice a month). This caused calculation errors for SE&I who used the tool to update status daily or weekly. The other IPTs were not updating schedule as frequently. The fix that was recommended was to enter "expected finishes" but this created a schedule that was overly constrained. Overly constrained schedules do not allow the Analyst and Project Managers to see the affect of task slips.

7.3. The concept of working in one schedule tool on the Web could have worked if there had been a Schedule Management Plan that was consistent with how Primavera worked best. The Management Plan would have specified how frequently updates were required by each IPT, reporting requirements, and analysis requirements.

7.4. Deliverables were set due to a requirement by the user, however, they may not have been realistic for generating the data in a timely fashion to generate the database.

7.5. There is fine art to using a scheduling tool that lends itself to sequential process to plan an all-hands-on-deck short-term process that will have a lot or parallel paths. You get hesitant to use the scheduling tool. The tool is great for defining the problem and laying out all the tasks. Statusing can be a headache. Scheduling analysts that know their tools and stay flexible because the plan changes every 2 days, are very valuable.

7.6. The drive to meet delivery dates at the risk of completing IPT work drove excessive costs. While it did give the illusion of progress real progress was impeded and more costly at the remote site. Sometimes improper decisions were made due to unrealistic schedule

7.7. Monthly reports should have been required from each IPT showing progress on all work that was scheduled to start or finish that week, variances to the baseline, critical path assessments, and status of risk mitigation tasks. Toward the end of the project, variances to baseline were reported but standard schedule progress was not.

7.8. Schedule adjustments and re-planning could have been accomplished in smaller working groups rather than holding "Lean Events" attended by 50+ people.

7.9. Schedule was frequently compressed for integration and testing activities. The Ares I-X vehicle was a first-of-its-kind and needed reasonable schedule to work out bugs. The compressed schedule caused many people to work severely long hours to accomplish the tasks. Schedule considerations need to be made for new integration/testing processes.

7.10. Identifying inputs, outputs, and deliverables across the IPTs was a good plan; however it was only partially implemented. SE&I identified its outputs (databooks, analysis, etc), however the IPTs did not consistently identify what the input milestones were and the dependent tasks were.

7.11. There needs to be a check and balance system associated with Schedule. DFI was allocated over a week or more of testing for each of five test configurations. Each configuration was late starting (uncontrollable circumstances not associated with Testing Team) and thus, were granted only the remaining scheduled timeframe (usually three days or less) causing the Testing Team to work ridiculously long hours (16+ hrs) that could have compromised the System. Luckily for our Team, we were able to pull much of the testing off with great success. However, there were some measurements that were not completely channelized and thus, are suspect as part of the Post Flight Data Analysis.

7.12. Over time, the schedule in Primavera lost its integration across IPTs, and the schedule did not accurately portray the work planned and accomplished. For high level reporting, a Master Schedule created in a separate schedule tool (not Primavera) was used to show a one-page Master Schedule. Confidence that the detailed schedules of the IPTs coincided with the Master schedule was low in my mind.

7.13. The schedule should be based on work products. There were far too many schedule items that did not have an end product associated with it and there was no way to determine whether it had been completed.

7.13.1. Items such as "On Pad Loads" should be replaced with the appropriate technical analysis report baselined so that it is clear that the task has been completed. This is also true with design analysis cycles (DACs).

7.13.2. Milestone reviews seemed to be schedule based and not based on completion of specific work products (such as the SRD and ERDs). The FS ERD was not baselined until about 3 months prior to launch.

7.14. We could have done a better job at identifying when we could only apply a rough order of magnitude duration estimate and apply schedule margin for these tasks. Risk mitigation tasks probably needed schedule margin too.

7.15. Ares I-X was so schedule driven that we tended to operate with two schedules. 1) A forward looking task oriented schedule. 2) A rear looking milestone schedule that tracked backwards from launch, to key milestones. The forward looking task could be managed. Once a launch date was set, the rear looking milestones became requirements. We often pretended that we could make rear looking milestones, when the forward looking schedule showed that we could not. Due to a hesitation to change the launch date, we were very slow to acknowledge the differences. For a test flight, recommend not nailing down the launch date until much later in the project. Start with a target year, and evolve to a target season, and then month and finally a launch date as late as possible.

7.16. Lean Events were not used correctly in that only token tasks were leaned, not all of the results were bought in to by all the IPT's; even though the "positive" results were taken forward.

7.17. Schedule was never a weighted process or involved statistics to justify that the master schedule was realistic. Lack of a well understood Con Ops (none developed) and AIT (out late and not well adhered to) contributed to shifting schedule and a schedule that became a list of sequential events. The schedule should have been set by real weighted estimates and not political agenda. Realistic schedules estimates showed that the launch date were about six months after the original Aril 15th 2009. Similarly, cost estimating for the mission was not realistic either. You cannot make a realistic estimate till you have a thorough understanding of the system requirements. From this you can back out a realistic WBS/PBS and determine a good ballpark cost estimate. A weighted schedule and the cost estimate would have provide what it really took to meet the goals and objectives for the mission. Then if this was not acceptable you de-scope till you meet the schedule and budget you are allotted.

7.17.1. The integrated master schedule was baselined even with IPTs admitting there was little probability the dates would be met.

7.18. Lean events were not conducted at the system level. They were done at the IPT level. This was a failure as the links at the low levels were not made in the schedule so impacts of changes were not really known.

7.19. Ares I-X was extremely schedule driven - despite management saying that we would "launch when we are ready, " schedule pressure was present throughout.

7.19.1. Working weekends, evenings, and holidays killed moral.

7.20. We really did not have an integrated schedule. We had an integrated milestone schedule. Many IPTs did not have schedule that connected at the lowest levels. The cost of this is little things bit the project as it was not known delivery of a connector from Avionics to FS would cause the project to slip launch by weeks. The solution was fire drills to get things in the box as they were identified

7.21. TIMs between operations and development personnel need to be scheduled early to iron out processes. This could be an alternative to Lean events

7.22. More schedule design planning up front would have been helpful. Determine level of detail managed by contractors and reporting requirements by contractors. Determine level of detail managed by IPTs and the level of reporting by IPTs to the integrated team and reporting for MMO.

7.23. It needs to be determined how to link the Mission schedule with the launch readiness schedule. The Mission schedule tool was Primavera Enterprise; and launch services were provided by ULA/KSC who used Primavera linked to their internal systems and access was not given to the schedule management team.

7.24. SE&I created schedules in MS Project in order to establish plans and set baselines and perform variance analysis. In addition, MS Project has add-in programs that can print network logic and PERT charts. Primavera did not have this capability. The advantage of plotting PERT charts is that you can see the logic relationships and activity paths. You can also verify that all tasks have predecessors and successors. We also created MS Project schedules in order to load resources and understand our resource requirements. In Primavera, we were restricted to loading resources by org code.

7.25. Schedules should be reflective of a developmental activity and not based on a vehicle in operation with over 100 flights.

7.26. The WBS should have been based on a product level emphasis since Ares I-X had 2 significant products; the rocket and the data.

7.27. Every team lead needs read access to the KSC work schedule (KIC)

7.28. Do not hold reviews before the analysis is complete. This lead to such as CDR 1 and CDR 2.

8. Design

8.1. Review the aero-heating loads by using graphical methods (color map of the heating on the surface of the vehicle), rather than reviewing thousands of

Excel files for each separate body point. We spent a lot of time reviewing the Ares I-X heat loads using the separate body point method, with all the Excel charts, and then as soon as we plotted the heat loads over the vehicle graphically, we found many errors.

8.2. For disciplines such as thermal and structural analysis (and perhaps others), where the lead in SE&I is responsible for taking models from each element and integrating them into a full model, establish up-front guidelines for product quality, review, and schedule. Make sure that the IPT is held accountable for giving a good product to SE&I, according to schedule, and that it has been reviewed at the IPT level, prior to delivery. Then, hold their feet to the fire and provide some punishment and intervention if the IPT misses on any of those items. Also, use the IPT performance in technical areas to decide where work for future missions will be assigned (like, don't take the Center that has habitually produced a poor thermal product and make them lead on thermal for a future Constellation mission. In other words, provide and enforce accountability.

8.3. Have a cleanliness and humidity lead assigned early, and keep them on the project. Also have an ECS and venting lead.

8.4. When the sep plane changed, it drastically changed the requirements for stage sep and post stage sep databases.

8.5. When Ares I changed its OML, this changed the available data that was supposed to feed from Ares I wind tunnel tests to the Ares I-X aero. Since this source of data was no longer available, additional wind tunnel tests should have been put on the Ares I-X schedule, but because of cost and schedule these did not occur.

8.6. Finish the environments development BEFORE starting detail design.

8.7. Not-invented-here attitude encountered when problem fixes from SE&I were suggested to IPTs.

8.8. All Design IPT's should follow the SAME design requirements and standards.

8.9. Centers have various handbooks on design practices. Projects need to decide the standard to be used and make that decision upfront

8.10. CDRs had too much emphasis on presentations and not completed baselined documentation. Design verification should have been closed after CDR. Instead certain IPTs were providing design verification at FTRR. At the SE&I level design certification review was not needed since this was covered already under the system level verification process. This cut down on unnecessary reviews.

8.11. Have the IPTs publish updated hardware margins of safety with each succeeding load cycle. It does not matter if a load goes up by 15% if the hardware is only being asked to perform at 30% or 40% of its capability. Never let the discussion go to a loads increase. Force the discussion to be on current margin of safety.

8.12. too log into the design cycle modified-heritage was claimed as heritage rather than new hardware.

8.13. The designed structure in CMLAS and USS had a lot extra capability in the primary load path that were somewhat set aside as ascent loads were refined. Where refined estimates of environment or envelope lead to lower loads in places where capability is known to be high, why not keep the “qual” loads at the higher level, knowing that in a flight test it might come in handy.

8.14. Drawing Standards - Each Center and contractor should use the ASME Y14.100 suite of standards for drawing design as multiple and obsolete standards were used.

8.15. Drawing and design software should be the same among Centers and contractors to facilitate file translations.

8.16. Heritage hardware caused many problems - since not using the same way, but those supplying information only relay information used by previous "heritage" uses. Analysis of heritage components (old structures, motor, etc.) used tools not used anymore and people working not really familiar with hardware and why it was modeled the current way. Should use new tools to look at capabilities for use with rest of current design.

8.17. Load capabilities should be based on actual strength of structure - not just "certified" OK to design loads. Certifying to just design loads meant big inter-IPT work needed as analysis of flight conditions changed.

8.18. We needed to remember that this was a test flight. Even failing some objectives should have been considered a success. We should have been allowed to use this flight to test what our environments might be. Instead the intense pressure of possibly killing the entire CxP if we "failed" caused us to risk averse.

8.19. Qualification margins should have been agreed to PRIOR to completing CDR. Disagreements with "heritage" definitions delayed agreements on qualification margins because vendors did not want to re-qualify heritage components. Many significant late changes to the mission design were required because heritage systems were not qualified to meet the environments.

8.20. Need load calculations available for design of flight controls - overall vehicle modeling combining the loads, structure, aero, controls, etc. needed for effective controls issues. Problems with not having that kind of capability kept causing finger pointing at FAM, PTI's, IOP, winds, etc - when really nothing really there to point to legitimate concerns with real models and data.

8.21. We should have realized the true value of imagery and the HOSC early in the requirements development. The attitude of less is more in the area of imagery almost caused us not to have tools to evaluate our flight. We also needed to recognize the responsibility of providing data to the HOSC to support Post-Flight evaluation.

8.22. Constraints caused because contracts were made to early limited design flexibility because components were already selected. An example is DFI where bandwidth limitations caused endless de-scopes.

8.23. Define terms such as what constitutes Commercial Off the Shelf (COTS) and will it meet the mission’s needs Heritage – applies to configurations previously flown

8.24. In a fast paced fight project, risk has to be taken and gambles made. As the understanding of loads and environments matures, as long as margins of safety are preserved, whether or not a loads spec changes should be immaterial.

8.25. The project was initiated with the knowledge that environments would be based on Ares I tests. These tests were very late in the cycle (e.g. aero acoustics in 11/08). These tests surprised us as well as Ares I. Unfortunately our design decisions had to be made in 07 and early 08. After that time it is all about understanding margin of safety. This was a risk that paid off in that it allowed us to design and build hardware very quickly even though we are fighting through final environments. This is very common for first time flight vehicles, not even mention Test Flights.

8.26. Need to consider DOL during early loads calculations and as designs and analyses are re-done. We got to flight week without ever having run loads all the way through to show DOL loads calculations.

8.27. Heritage is just a starting point. Due to the early contracts leads it was assumed heritage would be ruled good. That was not the case. All components must meet the environments they will be exposed to.

8.28. For future follow-on missions, Wallops Flight Facility should be utilized as telemetry downlink assets. Integrating with Tel-4 was extremely problematic and expensive. We could have used WFF to bring mobile assets, including antennas, and setting up at MILA or PDL for a good deal less without interfacing with external partners.

8.29. IPT Assembly drawings were reflective of IPT hardware ownership versus how the rocket was to be assembled. The drawing tree should be defined very early in the project.

8.30. Top level assembly drawings were contracted to KSC Contractor who did not visit the IPT sites to gather design requirements.

8.31. Using the IPT concept leaves a void for vehicle assembly and assembly drawings.

8.32. Some protuberances were designed in two pieces to facilitate venting but this caused OML conformance issues where the venting gaps were positioned. Make protuberances one piece and vent to the internal side of the rocket.

8.33. Locational tolerances of specific hardware like DFI should encompass the overall dimensional tolerances of the rocket so non-conformances for position become minimal.

8.34. Analysis products should be executed for a whole calendar year so as the schedule slips, analysis does not have to be revisited.

8.35. Need to document the rationale behind assumptions so new team members know why (example: load factors)

9. Manufacturing

9.1. Manufacturing QA artifacts provided by subcontractors were not made available for SE&I review. Verification processes had to be changed for one of the IPTs so that verifications did not have to be approved by SE&I for acceptance because there was nothing to review.

9.2. Acceptance Data Packages were spread out and not easily available for review for some of the IPTs. SE&I had great difficulty in getting data from these packages.

9.3. First Flight requires everyone on deck for processing. The design team has to be integrated during integration. The first few flights of the Ares I vehicle will required huge amounts of integration. This needs to be corrected next time around. More folks with EELV experience on the integration flow would also help

9.4. Tracking of documentation of delivered components was not consistent. Serial numbers and calibration sheets for sensors were not available for delivery for some components.

9.5. Many times it was difficult to understand where the holdup was. It was often stated that SE&I or IPTs were holding up work when the reality was comments were submitted and the holdup was getting them in the system but they were not marked as such. Lots of time was wasted pointing fingers because of system limitations

9.6. KSC tried to implement a new document control/development software program while building a new vehicle with new processes. There were too many "news" at one time. Solumina should have been incorporated at some other time. Connectivity to the server was very difficult, especially from other centers.

9.7. Processes (WADS) were being written very rigidly and flexibility was needed to get DFI testing completed in a timely manner. Once a WAD needed a change it would take as long as 3 days in the beginning to get it written and approved before work could be performed. This lag in the rewrite caused a considerable amount of consternation. As the testing went along the processes began to show more flexibility in them and ways were found to make the rewrites faster. Flexibility in the WADs is essential to facilitate troubleshooting or rework.

9.8. Ares I-X should have utilized more ELV personnel at KSC instead of all Shuttle. Ares I-X was more representative to an ELV than Shuttle. Also, the Shuttle attitude of "bring it and leave it - we'll call you if we need anything from you" was counter-productive most of the time.

9.9. Each IPT should finish their hardware respectively before delivery to KSC as early turnover increases costs and delays schedule because of Shuttle and other activities sharing the VAB requiring safety clears.

9.10. Processes for flight critical hardware were not followed.

9.11. Welds that are not grinded down impact OML conformance.

10. Test and Verification

10.1. Validation (both in-house and independent/external) of databases requires simulation tools.

10.2. Heritage documentation and lack of good examples of system level verification documents made it difficult to develop common processes. Need to get examples out to the IPTs as quickly as possible and force consistency so that expectations can be managed.

10.3. Verification management requires a good database utility. The verification manager will be bombarded with various verification status requests and if there is not a good tool to provide reports automatically, significant time will be wasted. The tool must also be able to manage traces to lower level requirement verifications.

10.3.1. Do not use a tool that cannot be easily tailored to the specific project (tables, reports, queries must evolve with the project). Initially attempted to use the Cradle tool but having a remote group control inputs and updates did not work at all.

10.4. The FASTER testing and hardware in the loop testing of GNC software went well and was time & effort well spent

10.4.1. A system-level requirement was added early on that basically stated that the Vendor shall use existing heritage SW development processes. You do not want to request changes to a software development process that works well and has been institutionalized across the team.

10.5. The SIL was very instrumental in validating the telemetry system. It was an invaluable asset.

10.5.1. Ares I-X avoided a lot of software development effort by selecting a very mature set of flight software that only required routine maintenance update to work with the Ares I-X.

10.6. Trajectory Analysis predictions were largely validated by flight test. IV&V of products and ability to incorporate latest aero data improvements was important to quality of final product.

10.7. Day of Launch loads should be based on comparison of peak values of load indicators. The hardware capability should be used instead of values from a certified load cycle.

10.8. Testing plans relying on late Ares I tests lead to open risk that could have been completed earlier. Next time consider moving up Ares tests. or work out Ares I-X tests earlier

10.9. Instrumentation (OFI and DFI) needs to be tested and verified at the completed system level. The piecemeal process that was required for many measurements leaves uncertainty in the channel assignment and connection for many sensors. Cases were found where some sensors that were initially tested as inaccessible turned out to have channels swapped when they were tested with direct stimulus.

10.10. SE&I applied verification flow down just like requirements flow down. This was a new concept. All element verification approaches were reviewed by SE&I to ensure that the verifications flowing up would meet the system level verification requirements. This was a very successful approach in the verification process. Did have trouble with FS since they did not have final requirements baselined until just prior to launch and were using a lower set of contract requirements and different verification process to close out their verifications. This delayed final SE&I verification to just before launch.

10.10.1. First Stage never provided a consistent decomposition of the first stage. First stage verification artifacts often overlapped or did not have complete coverage because what ATK provided was based around a changing set of sub elements. This contributed to the many of the problems with the first stage verification effort.

10.11. SE&I assigned specific discipline experts as a "requirement owner" for each system-level requirement. This helped enforce rigor for the owners.

10.11.1. The Requirement owner followed the requirement all the way until the verification compliance statement was approved by the XCB. Approval also included review by an independent panel of each compliance statement.

10.11.2. System-Level Requirement owners had to approve the verification 0f every element requirement that traced to their system requirement before it could be approved at the XCB.

10.11.3. Due to workload and personnel changes many requirement owners could not complete their verification workload. A group of technical support personnel were identified early on to support the requirement verifications. This was essential as we neared launch.

10.12. Have personnel assigned ownership of each requirement

10.13. The OMRS process was supposed to be streamlined for Ares I-X but it was only renamed to OTR.

10.14. Lubrication of flanges causes problems with OML Laser scans so the surfaces need to be clean for scans.

10.15. Put schedule constraints into OTRs as the OTR will be pushed to the right for rework of other problems.

11. Top 3

11.1. Stand up SE&I activities prior to establishing contracts, implementing product organizations, etc. Requirements must be established first. Allows more time for upfront planning thus reducing overall time

11.2. Have systems level requirements in place before awarding contracts.

11.3. Give SE&I the authority over IPTs commensurate with the SE&I responsibilities.

2.9 Safety and Mission Assurance Knowledge Capture

1. Engineering Management / Systems Engineering & Integration

1.1. XCB/ERB/SERF meeting organization. The Project was very effective in the technical process of moving the Project forward to get things accomplished. Most importantly, it was critical to the success of the process to having the right group of people to perform the work on the SERF, ERB, and XCB.

1.2. Overall management approach worked well following the 2007 re-organization which created an MMO, this brought a more fragmented approach together in a tighter circle resulting in enhanced communication and direction flow.

1.3. For development of pre-declares for a test flight, Engineering, SE&I, MM and S&MA should be involved at the beginning instead of one person developing them alone.

1.3.1. The AIX CSO was involved in the development of the pre-declares

1.3.2. SE&I S&MA was involved in the development of pre-declares as was other personnel within SE&I

1.4. Management structure was relatively flat which reduced bureaucracy and better, more timely flow of information

1.5. If I could change anything, I would have fewer boards since the AIX team was relatively lean. The creation of DXCB and TxRB in addition to XCB/ERB/SERF created too many forums which challenged the ability for S&MA to be fully active in all these forums

1.5.1. The gap between multiple lengthy decisional boards and limited S&MA resources was significant.

1.5.2. The creation of numerous boards in addition to the various levels of MRBs (IPT, Joint, Senior) was overwhelming to try to support as many times there were overlapping meetings

1.6. Launch Support Team roles and responsibilities should to be re-visited for future flights. All the issues worked during the countdown (e.g., Day 1 and Day 2 loads waivers, clearing the vehicle after lightning strikes, ECS door panel fasteners, even whether to pull harder on the 5-Hole probe) were all worked and resolved by the LST with minimal technical assistance from the PLT.

1.6.1. LST spent excessive time in conferences during the launch countdown timeframe and were unavailable for discussions with PLT. This could have resulted in a missed launch attempt for that day. PLT was fully aware of these technical issues.

1.6.2. LST members needed to be off in the meetings (they were working the issues that the LST was designed to address). The only thing here is that we may want to consider adding a few more individuals for IPT console positions so that one person could be off in the meeting and the other could be monitoring the appropriate communication nets. I believe that if PLT needed to contact someone that there were enough folks on line to be able to go into the conference room and grab someone).

1.6.3. The technical depth resides in the Launch Support Team. The goal should be to make the resources of this team's broader communities readily available to the PFT and Launch Authority Team. CxP (and NASA in general) launch rates are low, so there is no need to worry about consuming LST / Design resources during the rather infrequent launch countdowns.

1.7. S&MA community operated as tightly coupled community sharing information, concerns, and progress. There was synergy as a result of this close coupling

1.8. There is a significant level of responsibility for the integration and processing of the vehicle at KSC. The KSC CSO function should be defined within Program/Project documentation in the same way and at the same level as the Ground Operations Chief Engineer was for Ares I-X.

1.8.1. The above comment seems to demonstrate a cultural problem at KSC where too often KSC employees do not appreciate being a "member" of a bigger team and feel the need to be "in charge" or equal to those leading the bigger team. On Ares I-X, KSC GO was one of several "Processing IPT's". While GO was a very important processing IPT, it was one eight IPT's. All of the AIX "Processing IPT's" were very important as were each of the Design IPT's. The biggest cultural challenge associated with understanding their role and place within a larger team was KSC GO. KSC leadership personnel need to change their mindset from seeking to be "in charge" to being a "team member."

1.9. Engineering Drawings: a. Late Engineering from the Design Centers was a major impact to operations at KSC. Procedures could not be developed as scheduled and ADPs were not ready at hardware turn-over to KSC, resulting in a significant bow-wave of work to be performed very late in the flow and incredibly inefficient, ineffective, and time intensive turnover processes. As a result, procedures had shortcuts taken to baseline the document with the expectation that the procedure would be "corrected" during tests and ADPs were not fully completed until the week before roll-out. Engineering must be ready as scheduled and no later than hardware delivery to KSC b. Engineering drawings need to reflect current configuration at time of delivery. c. For Ares I-X drawings often did not reflect current configuration and Engineering Change Orders were sometimes not released until after the modification or change had already been implemented. d. For centers/contractors unfamiliar with NASA's cradle to grave paper trail requirements, extra effort must be made at the time the contract is written to inform management of NASA requirements to allow for proper staff levels and adequate training that assures compliance with NASA's Engineering and Quality Assurance documentation

1.9.1. Clearly, part of this is due to the expedited flow required of all IPTs in order to meet the mandated schedule. Let's remember that this project was completed in far less time than other developmental rocket programs in the past. For developmental programs of the future, I would expect issues like this to exist as well and they will have to be worked by KSC and the IPTs real-time just as they were for Ares I-X.

1.10. 1. Establish formal data/parameter transfer mechanisms a. If code, data or parameters are to be passed to/from NASA and contractor a formal process is needed early to reduce confusion and risk of errors. This process needs to be in place and understood well before it is needed.

1.11. The weekly S&MA tag up with representatives from each IPT S&MA team present was a good forum to share information within the S&MA community.

1.11.1. Need to see if there is a way of streamlining these meetings as they tended to last very long each time and this impacted available work time for other actions

1.11.2. Agree. Meetings were too long; establish a rule for meeting length and spin off issues to another forum.

1.11.3. Don't agree with the policy that was often used which allowed IPTs that had already presented their slides to leave the telecon. The advertised purpose of the meeting was to share information across the IPTs and this is impossible if all IPTs are not on the line for the entire meeting. If the meetings are too long then change the meetings for all, not just the lucky few that present first. And if the purpose was really to keep MMO S&MA up to speed, then there really needs to be some streamlining accomplished and perhaps many times IPTs providing slides or a weekly written summary would be a better way of doing business.

1.12. Obtain early access to data and people a. Access to formal SW development documents released by contractor may not be enough. You may need access to informal development and test artifacts. Access to passed contractor efforts is useful, so older slides and data may be helpful. b. You will need early and at times frequent access to the development & test staff. A regularly scheduled phone call is a good idea, maybe to discuss the monthly/weekly metrics report.

1.13. Process and development requirements need to be clear and released early. Get waiver and risk appetite from the program so you know where to push and where you might be wasting your time

1.13.1. Not sure that I agree with this statement. Seems like S&MA should be pushing whenever safety is a concern and we should not be concerned with the "risk appetite" or the perceived willingness of management to waive requirements to maintain cost and schedule. S&MA needs to continue to be the honest broker.

1.14. Get V&V plans, justifications & understandings on paper early. Talk with NASA IV&V managers to determine what effort NASA may provide. Talk with the project managers to get a good understanding of the IV&V that is justified for the project and where the major risks exist.

1.15. System Engineers and Design IPTs - need to fully understand Functional Criticality especially during OTR development.

1.16. Representation for IRT/Engineering Experts/Impoundment Managers should be spread throughout the IPTs and not just representation from the launch site personnel. This would also allow training for support of these teams would be accomplished on an earlier basis.

1.16.1. Contingency Response plan should have mandated this and the plan itself should have been produced and published far earlier (not in last month before launch).

1.17. Early face-to-face with developers. You need to get a thorough understanding of the contractor development process and effort. Formal documents will not tell the entire story. Formal documents are not released often enough to keep up with the changes due to errors found and requirements that are updated

1.18. Need to insure safety involvement in the early stages of design to alleviate changes in design due to S&MA requirements.

1.18.1. Not sure what the writer of this intended to be saying. S&MA WAS involved early on in this process! All IPTs had S&MA personnel assigned. Pl

1.19. Early on there was too much resistance to data and info from the Avionics/Jacobs/LM team, it took a persistence to breakdown some of these barriers and facilitate a better flow of information.

1.20. SE&I requirements were very late, including loads which had a negative effect on the project

1.20.1. What was the negative effect? Additional work at the last minute, yes. But remember, this was a developmental flight. This is not yet a production vehicle and the developmental cycle was shortened by 2 years, so one can certainly understand how and why this would occur. How would we change the processes so that this would not happen again? Perhaps the only way would be to lengthen the development cycle...

1.21. Hazard Analysis Working Group was a good forum for use in working Hazard analysis issues across IPTs.

1.22. SE&I requirement for low released mass was never established, and left the IPT's to define the requirement on their own, which meant lack of an integrated approach

1.23. SE&I struggled defining the environments and loads which resulted in IPT's having to continuously workloads compliance issues throughout the mission life cycle.

1.23.1. Additional data was becoming available at various times throughout the development cycle which then required additional analysis and modification of loads environments. Only way to avoid this would probably be to lengthen development cycle for new programs so that all analysis, wind tunnel testing, etc., would be done prior to IPT-level component design. Unfortunately, this was not possible for this mission and cost and schedule.

1.24. Integrated hazard Fault Tree TIM was instrumental in laying foundation for overall Integrated Fault Tree and ensured IPT buy-in and also helped to ensure all possible faults would be covered. This was also pointed out by the Independent review panel as a good practice.

1.25. Need to plan for allocation of additional dedicated SE&I S&MA personnel for future programs of this type. Only two CS personnel combined with support from contractor personnel was available. This resulted in CS personnel being spread very thin for duration of project.

1.26. Plan for two SE&I S&MA personnel on console in the LST. We had numerous issues which required SE&I S&MA participation in spontaneous meetings off console. Luckily we had arranged for a back-up to be present and this worked extremely well to ensure SE&I S&MA coverage of on-console communications while other person was handling meetings.

1.26.1. Conferences should be held to a minimum during launch countdown as supported by preplanned contingencies and design analysis prior to day of launch.

1.26.2. All of the conferences that were held amongst LST were needed and were exactly what the LST should be doing. I ask that the commenter explain which topics should not have been discussed by the LST. Remember, this was the first launch of a new vehicle, one would expect that there would naturally be more issues for LST to work!

1.27. SE&I appeared to perform less integration than was expected. KSC should be recognized as having a greater responsibility for the ground SE&I integration function.

1.28. It was very important to get engineering participation in the development and review of Integrated Hazard Reports and this helped to ensure higher quality reporting.

1.29. Roles in the CxP Ares I-X Project were not clearly defined, especially S&MA. LARC S&MA was told by Ares I-X project management that they were to be S&MA for the LaRC SE&I function. MSFC Ares S&MA personnel stated that LaRC S&MA was also to be S&MA for all of ARES I-X and provide S&MA coverage for SE&I and several of the MSFC IPTs, due to a lack of resources, but MSFC was organizationally still in charge of the project. LaRC had insufficient resources to cover this increase in scope of work. This was later resolved with a flattening of the Level II/Level III structure, resulting in the MMO and MSFC S&MA leading the S&MA management effort and obtaining resources, but vital time was lost in fixing this problem. KSC S&MA also had staffing issues early in the Project and had changing personnel that made it difficult to establish requirements and processes.

1.29.1. Ensure clear roles and responsibilities and resource issues early in the Project. Obtain proper buy-in approval by all involved stakeholders.

1.30. Ensure clear roles and responsibilities and resource issues early in the Project. Obtain proper buy-in approval by all involved stakeholders.

1.31. Face-to-face meetings with SE&I personnel were extremely effective in identifying sources of information and appropriate points of contact for integrated hazard reports.

1.32. The need for a thorough technical of waivers and Verification and Validation (V&V) documentation close to launch created conflict because the required technical experts were often torn between conflicting responsibilities.

1.33. The Ares I-X launch weather analysis was originally accomplished based on an April launch. As launch schedules slipped, it became necessary to continuously evaluate analyses to determine how they might be impacted by adverse weather conditions at KSC.

1.33.1. One of these issues would be the whole Tribo-electrification issue which would be more of an issue in the fall (see design section for additional Tribo-electrification comments).

1.34. Risk Management. AIX's use of 5x5 on waivers was very helpful. This promoted risk characterization discussions at Boards and allowed quick sorting of "more significant" waivers. Recommend that CxP have a standard waiver form that includes a required 5x5 risk matrix field. RM Opportunity for improvement – Managers too often didn't understand they were trading within the risk space (technical/safety vs. schedule vs. cost) and wanted to write risks such that they were artificially limited to being only about schedule or cost threats when in reality, schedule/cost risks and their mitigations typically have a technical/safety implication. Resisted applying "safety" scores to risk that clearly had potential technical/safety consequences as schedule/cost risks were mitigated. The CxP and AIX 5x5 Matrix seemed to drive a "Red" risk fear in that 3x5 and above colored "Red" on 5x5--this appeared to inappropriately influence risk scoring 5x5 Matrix and Hazard (CxP 70038) consistency problems (R/Y/G). 5x5 Matrix's "red boxes" appear inconsistent with Hazard Analysis only "Red" in upper right quadrant

1.35. SE&I had an excellent working relationship with NASA Range safety which facilitated smooth and expedited processing of required documentation and waivers

1.36. The Contingency Response Plan should be written, coordinated, and published long in advance of the launch NOT during the last month leading up to launch. If some pre-declares need to be added or changed during the development, that could be done via the Configuration Control process. There are several comments in this list which address issues that could have been addressed if the contingency plan had been produced far earlier.

2. Requirements Management

2.1. Acceptance Data Packages (ADP). ADPs were not delivered at time of hardware delivery due to late engineering. This caused verifications of ADPs to be extremely difficult due to the time gap and work performed during that gap. Ultimately, KSC constrained vehicle roll-out with delivery of some ADPs in order to push Design Centers into proving completion of their ADPs. ADPs must be provided as a "contract item" at hardware delivery to KSC to improve the hardware transfer process, improve configuration control, and minimize confusion and delays late in the flow trying to track down the status of ADP delivery. Each Design IPT had tailored requirements for ADP products, making verification of ADP compliance and hardware configuration at turnover very difficult and inefficient. Standardize and implement ADP product requirements for all centers, contractors and vendors supplying parts/components to KSC for integration. Coordinate tailoring of ADP product requirements with KSC S&MA. Verifying the delivery of ADPs was complicated by each Center having their own format, nomenclatures and holding places for their ADPs in Windchill. All center ADPs were rounded up and finally placed in their respective Windchill sections labeled ADP. Standardized formats, nomenclatures and holding places must be required for all ADPs. Acceptance was at the highest drawing level due to schedule pressure and late engineering. Acceptance should have been at the piece part level to verify configuration at turnover. Complete ADP packages need to accompany hardware at turnover to facilitate configuration verification at the proper level. Hazardous Analysis and Critical Item List need to be delivered with flight hardware f. Approved Project documentation and requirements should be enforced and not used as a guideline. For example, the Hardware Acceptance Review and Acceptance Data Packages were well defined in the Mission Implementation Plan (AI1-SYS-MIP). However, when it can time to accept hardware, the MIP was disregarded or tossed aside in favor is making schedule.

2.2. SR&QA plans need to be developed early in the process.

2.3. DD1149: There was little to no guidance on the value, limitations and requirements of utilizing the DD1149 as a temporary transfer document in lieu of DD250. As a result, there was a great deal of confusion between Design IPTs and KSC on how to use DD1149 for temporary custody of hardware. Standardize and publish regulation/guide for DD1149 use as a temporary custody transfer document. In addition, clarify the DD250 process. Offsite centers and vendors did not produce DD1149s in a timely manner. Often the schedule required installing a part that was on hand, but the DD1149 was not available, was incomplete, had improper part/serial numbers, or lacked the required signatures. Establish requirements for DD1149 turnover and require these be complied with at hardware turnover by all parties.

2.4. S&MA requirements should have been established early, they were not established until after the 2007 re-organization when an Ares I-X Chief Safety Officer (CSO) was assigned

2.4.1. Ares I-X contracts were let prior to establishing AIX S&MA requirements. AIX S&MA requirements were not baselined until after PDR. This hindered the influence that the HA process had on the design.

2.5. MRCAP needs to be developed early in the program to cover the program for mishap investigation requirements during all periods.

2.6. The majority of SERF/XCB reviews had to do with requirements documents and the constant updates to those documents mixed in with other design presentations of the technical nature. These documents could have been reviewed at an ERB/SERF level only (maybe a Requirements Review Panel) for approval and could have forgone the same review at the XCB where the majority of the panel members were the same people.

2.7. Loads requirements were defined much too late in the program.

2.7.1. Load issues ended up as pre-declares that required an extensive effort to meet approval time frame for launch.

2.8. FOS requirements for ultimate and yield were still under discussion at the end of the program, weeks before launch. These requirements need to be agreed upon by everyone early

2.9. ESDS Part Handling and installation. Design agency took exception to clothing requirements for handling ESD sensitive parts. According to the rules, USA Operations can either wear an ESD Smock or non-static generating natural fiber clothing. The requirement is based on test data that shows static generation is well below sensitivity levels required for handling.

This decision is also supported by industry data. Lockheed Martin's local laboratory procedures required the use of non-static generating smocks when in the presence of ESDS flight hardware. This requirement was not called for in drawings or considered prior to processing. The requirement was transferred via a drawing update to the hardware and USA implemented the process via corrective action bulletins, WAD updates, and procurement of resources. The topic expended many labor hours that could have been avoided through prior collaboration. Suggestion for future work: All aerospace companies are required to have an ESD Prevention Plan in place. Requiring pre-coordination between ROR of each company's ESD program would have prevented the lost labor hours and threats to the schedule.

2.10. NASA and Atlas have some significant differences of opinion on workmanship standards such as post-installation testing. This caused many debates. The owners of the applicable NASA workmanship std should work with LM to understand their rationale and determine if any changes to the NASA-STD are warranted.

2.11. Business Plan. There were many questions from Design IPTs about Business and processing processes at KSC. There were also disagreements about how business was performed at KSC. Develop a single Business Plan for KSC operations that KSC develops and is concurred with by all Design IPTs at the project level. Enforce the use of these documented processes by all project parties at KSC. Get the Business Plan document prepared early, before hardware delivery. Establish a comprehensive Tool Control policy early and up-front as part of the Business Plan and enforce. Establish a policy for better accountability of individuals for tool control across the team as part of the Business Plan and enforce. Vendors brought in tools that were not calibrated to KSC requirements nor traced to KSC requirements, resulting in working on the vehicle to unclear standards. Establish expectations of Design Team involvement in the Launch Team up front and don't change those expectations. As the S&MA Team approached the launch of Ares I-X, there were excessive meetings between the GO/GS S&MA IPT and the Ares I-X CSO/Flight S&MA IPTs on how KSC approached quality. Multiple meetings were held to rehash the same arguments and explaining the GO processing over and over. After the second or third meeting on this same topic, it became an inefficient use of personnel time and resources. A single Business Plan, prepared by KSC and approved by IPTs would help reduce this inefficiency through a better understanding of the processes to be followed long before issues became the focus of discussion (e.g. constraints process).

2.11.1. Recommend that the business plan be developed by NASA or maybe the Project at the outset (with KSC involvement) but NOT developed "by KSC". The design IPTs know their hardware and GSE better than KSC. It's that simple. The paradigm of KSC being the only ones who know how to process rockets needs to be changed. KSC might know best about all things shuttle, but this was a new vehicle! One NASA!

2.12. Agency and/or CxP FOS requirement(s) for lifting attach points that "fly with the hardware" need better definition. On AIX, the lifting attach points could have been designed much more robustly since AIX was not weight challenged.

2.13. Requirements flow down. Constellation requirements and documentation need to flow down from the prime contractor and all sub tier vendors to the prime contractor. Several waivers were required to the Avionic requirements, as Jacob Engineering (Avionics Prim Contractor) did not impose Constellation documentation of its subcontractor (Lockheed Martin). Flow down requirements to all prime contractors and the prime contractor's sub tier vendors

2.14. Lifting requirements on USS Stack 1 lifting lugs had three different standards which applied. Each analysis had different margins and factors of safety. The technical authorities (CSO and CE) at the various centers imposed the Agency lifting standard completely different. Standardize the implementation of lifting standards across the project.

2.15. Interpretation of "Heritage" and "Modified Heritage" components with regards to qualification and design standards (safety factors, etc.) was an issue throughout the project. Would recommend that this be better defined at the very beginning of the project.

2.16. It is important to have a target date to lock down requirements.

2.16.1. Any specifics? Does the writer think we did it right or is there something specific that can be addressed?

2.17. S&MA requirements for the Ares I-X Test Flight were not developed in a timely manner. This flight test was well in front of the CxP Program requirements being completed. There was no flow down of S&MA requirements to ARES I-X until approximately a year after project start up. S&MA in JSC Flight Test Office was asserting they would develop the requirements for all CxP flight tests, to include Ares I-X, but this never occurred. The Project was moving too fast to wait for this to occur and started developing their own set of requirements. This lead to confusion about who was doing what. Contracts to each of the hardware IPTs had already been let by MSFC. All IPTs were told to use S&MA products for hardware as they were developed by that original IPT – no matter what project they were used on. The projects ranged from Peacekeeper, Shuttle, Atlas as well as new hardware. This conflicted with the attempt to write requirements in the usual fashion, especially after the fact, especially impacted the integrated hazard analysis. Lesson Learned – Work requirements early with respect to Flight tests that may have different requirements than the Program baseline and establish who is flowing what to whom.

2.18. Tailoring of the Air Force Space Command Manual 91-710 (Range Safety Requirements) in combination with NPR 8715.5 into one, combined (one stop shop) for all Range Safety Requirements worked extremely well and should be the standard for future projects. Numerous working group meetings with AF, NASA Range Safety, and project engineering and S&MA was key to this effort and was guided by the Launch Constellation Range Safety Panel (LCRSP)

2.19. All IPTs must agree on a fair wear and tear requirement.

2.19.1. Requirement should be developed and then implemented through the requirements process.

2.20. Launch Constellation Range Safety Panel was an excellent forum to ensure Range Safety Requirements were being addressed throughout the duration of the project. It was important to have SE&I S&MA representation on this panel.

2.21. Why have separate SR&QA Plan and SR&QA Requirements documents? These two could have been rolled into one governing document.

2.21.1. There is no reason to have multiple documents. One stop shopping is best otherwise some elements of a requirement could be lost if it is contained in one document and the user refers to the other one.

2.22. We were confronted many times during the project with the situation that a certain requirement was not in the baseline contracts. Clearly, the best solution would have been to have the requirements much more mature prior to contracts being let

2.23. Final program CoFTR deliverables should be defined very early on in a program so that the IPT contract with prime contractors can be flowed properly and timely.

2.23.1. NASA should have a core set of COFTR for all projects (if there is a need for a difference between types of programs-flight test versus production vehicle) that should be so stated in NASA-level documentation. This would then allow for COFTR requirements to be included not matter when a contract was let.

2.24. An opportunity for improvement involves better defining how NASA program/project/element boards should be conducted. Boards are typically chaired by the “Programmatic Authority” chain, not the “Technical Authority” chain. This adds confusion when a TA-owned STD requirement and/or waiver is being discussed. Perhaps the Chairmanship should actually shift – if TA is authority - when a TA owned requirement change/deviation/waiver is being processed.

2.25. OS&MA (and possibly OCE) NASA-STD’s should be revised to make it clear that compliance with these STD’s is required “unless” a deviation or waiver is approved by the "applicable Technical Authority." The current "approval authority" wording in existing OS&MA NASA-STD's such as NASA-STD-8739 series seem inconsistent with the current NASA Governance Model / TA approach.

2.26. Maintenance of Avionics environments became a significant, underestimated issue at KSC, and this area should be considered early on, when requirements for hardware are being defined.

3. Organization and Culture

3.1. AFSOP (Ares I-X Flight Safety Operating Plan). There were many questions from Design IPTs about safety practices at KSC. KSC documented Safety practices in the AFSOP. To help minimize questions on future projects, the

AFSOP (or similar document) should be a KSC developed document that is concurred with by all Design IPTs and the project. The AFSOP was based on the corresponding Shuttle safety practices document (FSOP) assuming that many processes would be Shuttle-common to facilitate a quick generation of the document. Many processes were not common. As a result, there were many disconnects that were discovered over time in the AFSOP. The REs I-X Flight Safety Operating Plan (AFSOP) should be prepared early, long before hardware delivery, to allow time to consider unique processing for the new vehicle and to coordinate amongst the larger vehicle team.

3.1.1. Recommend greater IPT involvement and recommend this be a project-produced document NOT a KSC produced document. This would ensure buy-in by the design and production IPTs as well as KSC processing folks.

3.2. Standardize Program/Project Processes. There are widely varying processes used across the Agency for processing Material Reviews, resulting in massive inefficiencies in a vehicle integration environment. Establish a single MR process across the Program/project regardless of IPT/contractor responsibility. The Agency has standards for quality; however, each center has different interpretation and ways of implementing the Agency's standards. There are cultural differences of how the quality function is performed at each center. Standardize the implementation of quality standards across the project.

3.3. There was strong teamwork across Centers--and "levels." Bob Ess broke down the historical barriers that can be created by "Centers" and "Levels" The focus was always placed on the test flight team and its objectives, not "other" org structures.

3.4. Embassies - The use of "Embassies" at KSC, where Design IPTs or associated contractors worked on their hardware within a KSC facility using their own practices, created great difficulties. Contractors worked to their own processes, did not use CxPRACA, did not provide full visibility into their activities, and asked for support from KSC personnel using software systems the KSC personnel were not familiar with. Hardware needs to be delivered to KSC as a contract item ready for integration and not to be worked on in isolation on KSC property. Action required – Eliminate the use of Embassies at KSC.

3.4.1. Let's not just look at Design IPTs, lets also look at traditional KSC processing paradigms and see if improvements/changes can improve the way NASA does rocket launch. The old ways are not necessarily the best just because we did it with shuttle. We are looking to streamline the way all of us do business.

3.4.2. KSC GO needs to better understand their role as a member of a bigger team and adjust their approach to be trying to "help" the other team members, and thereby the larger team, succeed.

3.5. The Mission-level team (MMO, IPT Managers, CE and CSO) worked very well as team. Communication flowed well and traditional "Center" stove-pipes and bureaucracies were broken down or minimized.

3.6. The multi-Center S&MA community worked well together as a team, routinely sharing information concerns, issues, and recommendations. This significantly enhanced the S&MA community's ability to have a positive effect on the team.

3.7. KSC practices and approach warrants changes to better allow customers delivering hardware to maintain insight into the downstream processing off their supplied hardware. This includes better insight and concurrence ability associated with Work Instructions, non-conformances, etc.

3.7.1. There was an impression augmented by personal interaction during telecons that KSC wanted only minimal IPT involvement once hardware was delivered.

3.7.2. The term "customers" should be revised. Hardware deliverers would be more appropriately considered "vendors" and KSC better considered the "customer" with responsibility to integrate the hardware.

3.7.3. KSC sometimes exhibited a "KSC-center first" mentality.

3.7.4. It is quite evident by some of the comments throughout this entire ThinkTank session that there are some very well entrenched paradigms at KSC. Even the comment #2 is very telling and only goes to make the point that KSC is KSC-centric. The way that NASA has decided to go for the future of manned space flight is to break down the traditional paradigms and this means KSC too!

3.8. Train Design IPT members on Tools, Processes, and Procedures at KSC prior to arrival.

3.8.1. KSC needs to be more involved from the beginning so that they can ensure that folks are thinking of things like this. KSC was NOT as involved early in the program as they should have been.

3.9. Need timely resolution of non-conformance (NCs) at KSC and at Design Center as these NCs related to major milestones in processing flow.

3.10. S&MA deliverables on the project were developed by S&MA reliability and safety engineers who were not as close to the hardware details as necessary, which left some parts of the hardware un-assessed until the end of the project, when the oversights were identified. The same was true for the engineering analysts. Examples of the oversights were the USS ECS ducting and clamps.

3.11. An example of a good working relationship was the equal consideration between GS and Flight Systems on the fly-away maneuver. This was performed to minimize damage to Pad infrastructure due to the significantly different drift profile of Ares I-X from shuttle. The damage that occurred on the MLP zero-deck and 95 ft hinge column was minor in comparison to the damage that this same environment would have impacted the upper levels and VSS. Flight systems were modified that increased flight environments, but a compromised was developed that ensured mission assurance, both in GS and flight. It was a perfect example of two IPTs from two different centers working together.

3.12. KSC communicated philosophy / approach to launch countdown teams should be re-visited. KSC seemed too focused on reducing the size of the launch countdown teams. Considering NASA's launch rate, this is not a sound nor logical approach. The primary goal should be to have quick, direct access to personnel most familiar with the design basis for the hardware and/or software. All these folks are likely on the NASA payroll during the countdown, so accommodations to make their knowledge readily available should be provided.

3.12.1. The launch team philosophy was developed by the Launch Team Design Team (LTDT). The philosophy was coordinated and approved at the highest level within OS&MA and the Chief Engineer's office.

3.12.2. Well maybe it needs to be modified, no matter who approved it. This was the first test of this new "lean" way of doing launch. One would expect some tweaks to need to be made.

3.12.3. We jammed as many people into the back room as possible and we had numerous folks in Hangar AE. Once we have a real upper stage and a real crew capsule and real LAS, I doubt that the launch team will be very S&MAll.

3.12.4. Recommend that NASA (and KSC) take a look at how the commercial launch providers do business. The experts on console on launch day (the primary launch team) are the engineers and technicians that are most familiar with the vehicle AND are good on console.

3.13. Importance of DFI was underemphasized by project management. For test missions where data can and will affect future design decisions, DFI needs to receive more consideration and emphasis. Numerous decisions were made which de-scoped DFI and which affected performance and collection of data. For instance, decisions to abandon defective sensors in place, under emphasis on calibration concerns, and decision by management NOT to have DFI environmental covers as "T-0" were significant. Additionally there was definitely the appearance that DFI would suffer in order to meet schedule. This was a test mission! Data is what we really should have been motivated by NOT just to launch and see fire.

3.14. The process for future vehicles needs to be developed with the mindset that Design IPTs deliver completed hardware to KSC for integration/processing with support from the Design IPTs limited to design issues. The Design IPT's level of involvement necessary for Ares I-X created extensive confusion and inefficiencies for all parties in a processing environment. KSC is primarily an integration processing site.

3.14.1. Again, KSC-centric paradigm alert! Please, we need to have an open mind about how we are going to process our vehicles in the future (especially in the case of first-time launches).

4. Communication

4.1. Working group meetings were effective. Working group meetings were a valuable use of resources, to allow the entire community knowledgeable in a specific discipline, to make real-time decisions. These decisions flowed up into requirements documents or the participants resolved new quality processes and outstanding issues.

4.2. WebEx was a very effective tool for this Project. I believe this Project was successful by having a way to organize people quickly and effectively to communicate unresolved issues, design and requirement changes. Highly recommend it for future work.

4.3. The project needed to have a single CxPRACA system within which everyone could communicate. The CxPRACA, iPRACA, Solumina super system was awful.

4.3.1. Completely agree, the use of different nonconformance systems created confusion. It was allowed for flexibility, but in hindsight it would have been better to bite the bullet and go to a single nonconformance system, especially as hardware custody was passed from a design IPT to downstream "processing IPT's"

4.3.2. There was a single CxPRACA for this project that was made available for all the IPTs. IPTs chose not to familiar themselves with the system until on KSC where it was a requirement. The tool used for populating the CxPRACA system (iPRACA, Solumina) should not be considered as the “official record” of nonconformance.

4.3.3. Disagree with response #2 above, the "on-site" KSC system (Solumina / iPRACA) was not designed with other Centers or IPT's in mind where as the CxPRACA system was. Early on, KSC decided to use iPRACA instead of the easier access (CxPRACA) system. The Solumina/iPRACA system was not easily accessed by others and required folks to be behind the KSC firewall. It would have been much easier if KSC GO had chosen the requested CXPRACA system as their base operating system. KSC had promised all parties that GO's use of iPRACA would be transparent to everyone else as they would promptly "push" problem reports to CxPRACA. This "transparency" vision never materialized.

4.4. Windchill had numerous problems (downtimes and slow operation) which affected performance of particular tasks throughout the duration of the project

4.5. WebEx worked well, PBMA secure meeting did not and was abandoned.

4.6. Lack of a closed-loop communication process throughout the program. During the major review milestones, RFAs (intentionally not RIDs) were determined to be the method of documenting discrepancies. This approach not only disallowed initiators to defend their issues (all RFA had to be filtered through a specific POC), but it was unclear which RFAs were accepted and even harder to follow closure to RFAs. Another example was the change from OMRSD to OTR, which put an extra burden on FS IPT to track through implementation specific requirements that were leaned out of the OMRSD closed loop system. During the document change process, it was practically impossible to completely review the sheer volume of change traffic at the multiple change boards that were setup. Without a clear closed-loop process, non-comments were treated as concurrence. This created a system in which issues got missed because of limited resources, heavy change traffic at multiple boards, and processing changes without input from all stakeholders. Even a test program needs to ensure that all stakeholders have reviewed and impacted changing requirements or be allowed to properly "non-concur" if the rationale is strong.

4.7. It was very difficult to search for a particular document in Windchill—need a better search engine.
4.8. The multi-Center S&MA team established and maintained very good communication networks sharing status info, concerns, recommendations, and awareness information.
4.8.1. Established org structure early.
4.8.2. Meet on schedule - twice monthly.
4.8.3. Maintained open communication and sharing of ideas.
4.9. Communication within the USS IPT was exceptional, and resulted in an extremely high performing team, including S&MA.
4.10. Change Requests (CRs) appearing before the XCB were sometimes incomplete, didn't have sufficient review or technical rationale, reviewer's comments were unresolved, dissenting reviewers were not present, and the proper technical expertise was not available during the review. This problem appeared mostly within the last 6 months prior to launch, and showed communications problems among team members.

5. Resources

5.1. Tool and Parts Control: Some offsite personnel came to KSC with their own tools that were not serially controlled. These tools were not planned to be used directly on flight hardware but had the potential to migrate with no form of accountability. Tool control by outside vendors, contractors, centers while at KSC must be as stringent as it is for KSC processing personnel. Tools used for processing were re-located from HB storage to the MSC. The movement of the tools was poorly coordinated and caused GRC personnel great concern over tool use and traceability. The root cause was the result of poor coordination. It was complicated by inadequate control over storage areas. The storage area was being used by multiple contractors. Access was poorly limited, and keys to the area were not properly managed. This allowed for easy process deviation from USA's normal procedures. USA committed to talking with two different GRC personnel for direction which lead to further communication concerns between the companies. The tools were quickly located, catalogued and confirmed in working order by USA logistics personnel. This catalogued list was then balanced against GRC data. The tools were then properly transferred to USA Logistics. Establish and enforce tool control processes that: Prevent cohabitation of multiple vendors in a single storage area. Properly control access to storage areas. Transfer tools and commodities as quickly as possible to processing personnel and in place logistical processes. Discourage Hybrid or multiple processes between companies/entities. Designate a single POC for coordination of all parts and tools between companies for each IPT. RFID tagging of tools could have mitigated the potential for lost tools.
5.2. The working pace was too fast and not enough stand-down periods during the Project. Information came in like water from a fire hose. 100 e-mails a day was extreme. Very difficult to take a sanity check and keep up will all the ever changing details of the Project. We had one stand-down that I can

remember, 4th of July 2008. We were asked to take a few days off to re-connect with family. After that it was a full court press to launch for the next 15 months.

5.3. Solumina. QE's were not granted authoring permissions in Solumina, causing inspection Work Authorizations Documents (WADs) to have to be written by Systems Engineering. Provide Solumina authoring permissions to QE's. When utilizing COTS software with no customizations, system functionalities and limitations must be fully understood and explored in order to curtail discrepant conditions. Additional personnel training may be required to circumvent known software pitfalls. (e.g. MR disposition worked prior to NASA QE approval). Many alterations were generated without rational/justification for why they were needed, and only explained what the alteration was doing. All alterations should include rationale/justification. Some part number callouts in the WADs were not "tagged" as required in order to provide easy configuration management. Safety personnel should verify with Quality personnel before approving alterations which change quality requirements/issues. (Hazardous walk downs were missing QC coverage due to alterations removing QC, and signed by safety). QE found areas where "Ok to Install's" were coded with MFG buys, allowing SE to buy. The use of MFG buys negate the quality requirements required per the QPRD. "It was easier to generate alterations than NCs", and alterations were easier to approve. Sometimes engineers tried to use an alteration where iPRACA was required. Engineers need to be taught when it is appropriate to initiate iPRACA and when to use an alteration. QEs need to pay particular attention to this problem. Solumina was not user-friendly, not intuitive, did not provide change bars, had no traceability of changes, and had missing controls for signatures (the engineer could determine who needed to sign the documents). Address these deficiencies. Solumina was too complicated for some personnel to process NCs. NASA needs to work out firewall issue if we are to operate as a virtual team across the Centers. Team members could not see into Solumina from other Centers.

5.3.1. The Solumina system including its embedded non-conformance component was not designed with Design IPT's (or other customers) in mind. This system created too many unnecessary challenges.

5.4. Solumina/iPRACA/CxPRACA: Solumina/iPRACA/CxPRACA/Attentus etc… training and certification should be required for all personnel that travel from other centers to perform work at KSC prior to arrival at KSC. Training, certification and access to KSC computer tools is particularly important for engineering disciplines to allow access to photos, problem reports, drawings and specifications. Clear requirements outlining which form of Work Order Documents (Solumina, Marshall Paper, Vendor Paper, Cover Sheet with paper etc. will be used for hardware processing by personnel from different processing groups (USA Ground Ops., ARF, GRC, LaRC, ULA, Lockheed Martin etc…). Quality Engineers need more training in the review of Solumina documents to preclude the many format errors, certification requirement errors, and improper MIP assignments that slowed the work completion. Multiple layers of tools (Solumina/iPRACA/CxPRACA) resulted in excessive time to understand and communicate real non-conformance status and constraints to processing. Provide a single tool that all IPTs and contractors would use across the Program/project. There were too many systems and too much training introduced for a test program.

5.4.1. Solumina should be NOT be used on CxP. It is a poorly designed system for folks outside KSC such as hardware design owners and other customers. Considering today's IT capabilities, this should not be a problem. A more web- based, user friendly system should be employed. One that easily allows participation by the various Design teams that are transferring custody of the hardware to KSC GO for downstream processing.

5.4.2. Solumina has not been adopted by CxP. The use by Ares -IX was a test process. The EGLS contract will present their own process.

5.5. CxPRACA. All IPTs and Prime contractors (at a minimum) shall use the Constellation Problem Reporting and Corrective Action (CxPRACA) System. For Ares I-X, CxPRACA was an option for the design/fabrication centers to use. However, CxPRACA was imposed by Ares I-X on all users once their hardware arrived at KSC. The Design IPTs waited too late to receive training on CxPRACA. The various design/fabrications problems reporting systems did not or could not interface with CxPRACA. The lack of a centralized problem reporting system made it difficult to determine if all non-conformances were closed and resolved. The lessons learned from using a single database could be used to help mitigate Risk #9287 “GO Cost Impact driven by CxP Acceptance Data Package (ADP) data format requirements.”

5.5.1. Might be possible to use CxPRACA for next build, need input from IPTs on how MRB would work.

5.6. Project resources were not sufficient, which required overtime and excessive work by the assigned personnel on some of the IPT's, and burned out some employees.

5.7. Windchill access was extremely difficult to get. Provide better access. Once access to Windchill was obtained, there was very little training made available as to how to navigate in order to find specific types of information. Provide better training. There was no apparent segregation of Ares I-X documentation from Constellation, causing USA to be very cautious (ongoing contract competition). Windchill’s password update module seemed to never work. When a password would be changed using the module, the help desk would still have to be called to correct it in the system. Correct this deficiency. It was incredibly difficult to find documents within the Windchill folder structure or with the search tool. Develop a better search engine for Windchill or communicate and enforce use of a Windchill folder structure.

5.8. Having two SE&I S&MA on the flight console worked well. It would have been difficult to effectively man the SE&I S&MA console on the DOL with only one person. There were several project meetings held on the side during the T-4hrs that removed SE&I S&MA from the console for long durations, leaving the console unmanned, which can result in a complete loss of information exchanges that occurred during that time.

5.9. Windchill was essential for this project but more resources should be used for improving and maintaining it. The document system was unorganized and too slow to access. If you didn't have a direct link to a document, you couldn't find it. The search function was not functional.

5.10. Windchill is only effective with a front-end tool like the Wiki pages or eRoom.

5.11. SE&I should have had an S&MA expert from each IPT.

5.11.1. This would have been a benefit to development of the IHAs/IHRs since it was the opinion of the center IPT folks that felt they were not being heard through the HAWG.

5.11.2. S&MA needs to have systems engineering resources on board to assure this is seamless. We ran too lean to cover this cleanly. Should be embedded in the S&MA teams at IPTs

5.11.3. This would give a rounded IPT/center perspective on issues that were handled at the SE&I level.

5.11.4. Other forums such as HAWG, S&MA weekly meeting could be adapted better to ensure this occurs to everyone's satisfaction. CSERP did provide additional check and the CSERP phased reviews of the IHA provided yet another opportunity for IPTs to ensure their points were considered.

5.12. There were multiple quality inspectors (DCMA, USA, KSC NASA QA, ATK, LM) for flight hardware, causing some confusion as to responsibility and authority.

5.12.1. There is a QA function that is required to be performed at each location that h/w is being designed, manufactured, processed.

5.12.2. Yes, and it seemed that ALL were "active" while at KSC.

5.12.3. This was a test mission! The Hardware was one of a kind (for the most part). KSC had NEVER processed this hardware before! So what if all were active. If work was being done by IPT personnel, then the IPT QA should have been there and active. And if someone is turning a wrench on IPT hardware, there is nothing wrong with IPT QA looking over the shoulder. In the event of a non-conformance having to do with a IPT piece of hardware, it will ultimately be the IPT who will have the responsibility of making a recommendation because there is no way that KSC can know the design or manufacturing details of the hardware as good as the IPT. This was NOT shuttle.

5.13. Searching in Windchill was challenging and it was difficult to find documents even when they were known to be uploaded into Windchill.

5.14. Resources were very limited for Ares IX, but that was mainly by design. Team organization and strong communication was required to supplement limited personnel and FS S&MA was successful at that.

5.14.1. With limited human resources, an outlook calendar was set up so the team understood what the priorities were day by day and meeting notes were captured for virtual communication. Face to face meetings occurred for additional up and out & down and in communication flow.

5.15. SE&I S&MA Integrated Hazard Analysis personnel either Civil Service or contractor (those writing the reports) should be resident at SE&I center to encourage more face-to-face interaction with engineering and day-to-day issues. Reliance on telecon and several site visits worked, but believe that in-residence would work even better.

5.16. S&MA resource levels were very lean and challenged the ability of the S&MA team to penetrate and/or participate. Many folks worked many extra hours, most for free.

5.16.1. Many hours spent in meetings limited the amount of time to review material and pre-educate yourself prior to being required to make a decision.

5.17. Solumina access was not available for S&MA support contractors, making WAD tracking difficult for closing integrated hazard reports.

5.17.1. Federal Law restricts the access to government IT resources. While there were problems with firewalls, and access to Solumina as a result, many contractors are restricted by law to not have this access to these government sources.

6. Safety and Mission Assurance / Technical Authority

6.1. CSERP meetings worked very well. Having a group of people familiar with the AIX process was essential for a productive face-to-face meeting and through WebEx. It was imperative to have the Panel knowledgeable with AIX safety requirements. There were very few, if any, delta safety reviews on this Project.

6.2. S&MA Management needs to spend a little more effort on developing a day of launch processing and communication plan. Everyone supporting the launch regardless of their role should be briefed at one time. Separating the briefing by group only sets up mistrust and miscommunication. During the launch rehearsal, there was confusion on which channel to use, who was polling who, when to poll, who had authority to speak for the S&MA team, and agreement on resolution of problems.

6.3. The Technical Authority was respected and heard on Ares I-X. Inputs were formally solicited (required) at all AIX and CxP boards (XCB, CxCB, Mate Review, LAT, etc.). The TA perspective / status assessments routinely presented at forums such as monthly ICMC's, CxCB's, Briefing to NASA Administrator, etc. This greatly facilitated awareness of different perspectives and fostered balanced solutions to issues.

6.4. There were too many O&SHA Boards. Reduce and streamline the O&SHA review process.

6.5. CxP Gap assessment was conducted on USS IPT in addition to Ship readiness review internal audit. All "observations" were shared with a CxP distribution while internal audit corrective action was underway for all areas. Much unnecessary confusion and ill will was generated between centers.

6.6. The Engineering and S&MA Readiness Review (ES&MARR) was a good forum for the Technical Authority communities to have a clear understanding of the outstanding work and risk level prior to entering the Flight Test Readiness reviews and Safety and Mission Success Review (SMSR).

6.7. The S&MA Technical Authority group had a weekly telecon to stay in touch on key issues, but the meeting very often went a long time (3 hours) reviewing details, which became a burden to IPT's without enough resources that needed to cover other meetings at the same time.

6.7.1. Could shorten by streamlining presentations and perhaps not having all IPT slides briefed at each any every meeting.

6.8. Strong S&MA leadership on Ares I-X model for future programs. Multiple "decisional" boards towards the end of the program were difficult to support S&MA leadership.

6.8.1. This strong leadership was across the board (across all IPTs).

6.9. The CSERP decision to allow integrated hazard reports (IHRs) to reference large IPT hazard reports rather than to duplicate all the appropriate information in the IHRs worked extremely well and streamlined the hazard analysis process.

6.10. An S&MA team spread across several NASA Centers played together very well. The overall S&MA community was lean, but there was terrific synergy created by how well they played together. Solid teamwork.

6.11. The Ares I-X Chief Safety Officer was a strong leader. He often asked the hard questions in decision forums and was a good balance to the Mission Manager. With the fast pace of the Ares I-X mission, it is vital to have a strong S&MA presence to assure a successful mission.

6.11.1. The entire S&MA Team was very strong and provided insight into all aspects of IPT design, analysis, manufacturing, integration, and launch. Believe it was the S&MA personnel across the board (top to bottom) who made this a success.

6.12. The weekly S&MA tag-up charts were extremely useful in maintaining awareness of all Ares I-X S&MA activities, and made it possible to stay up to date on current issues during the times when direct participation in the teleconference wasn't possible.

6.13. Consider S&MA team visits face-to-face at all stakeholders facilities to share best practices and reality-checks regarding Quality systems as partners, not with external audit teams with no vested interest. Might smooth out interfaces up front. Thinking specifically about GRC base plate scratches on avionics plate "scratch" vs. "gouge". Would need to be done early.

6.14. Early in the program, establish a central S&MA management office with adequate manning for the scope of the project. Early in the program, establish S&MA requirements applicable to all providers of hardware. Prior to production, establish a Quality Surveillance Program to, thru over-sight; assure implementation of requirements and validation of quality assurance verifications in all phases of fabrication, assembly, testing and integration. Require that Quality Engineering and Design Engineering be represented during fabrication planning and establishment of MIPs. Establish Test Program requirements that define the expectations of an Integrated Test Plan, testing environments and levels, functional verifications, and procedures with pass/fail criteria. Provide early training and implementation of across the board “e” systems; i.e., for work authorization, assembly and test procedures, nonconformance documentation and closure, etc. Assure S&MA is represented on all standing panels such as the E3 Panel.

6.14.1. Need to ensure that S&MA requirements are established prior to IPT contracts being let.

6.15. The Ares I-X launch weather analysis was originally accomplished based on an April launch. As launch schedules slipped, it became necessary to continuously update weather-related risk to the Flight Test Vehicle (FTV).

6.15.1. This happens in space launch when slips occur. There is little that can be done other than doing an analysis for an entire year, but that takes additional time and resources.

6.16. Initiation and sustainment of the weekly S&MA meetings at KSC with all the IPTs present was a good communication forum.

7. Schedule

7.1. The problems identified upon receipt of the CM LAS caused more work activity to take place at KSC than was originally planned. It was a case where it seemed that the delivery of the hardware was more important than the completion and quality of the hardware before delivery.

7.2. The project schedule was "typical" for a crash project, and required more resources than expected, and more than what was available many times.

7.3. It was more important to get the hardware here than deliver a final product or to get it right before shipment. Hardware should be delivered to KSC as a completed “contract item”, regardless of development by a contractor or by a NASA fabrication shop and regardless of project schedule pressure.

7.3.1. This was a development project outside of the normal production and processing procedures. We would not have made the launch date if we had waited to deliver any of the hardware to get everything perfect and a "completed contract item." KSC is a NASA facility and other NASA personnel from other center should be allowed to work in the facility. I am sure over time as the soother centers learn more of the KSC ways, things will smooth out. KSC could better communicate their specific requirements prior to folks arriving.

7.4. There was an increased hazard to KSC to re-perform work at KSC

7.5. Delays in the delivery of engineering created a bow wave of procedure preparation that resulted in shortcuts in the baselined procedures that had to be addressed during the actual operations

7.6. Due to the aggressive schedule, integrated hazards were scheduled almost concurrently with IPTS hazard development. When IPT hazard schedules slipped, this impacted the integrated hazard development. Additionally, late changing loads impacted closure of many hazards. a. Extension/slippage of original schedule allowed recovery along with a CSERP which was exceptionally flexible and helpful in solving process issues b. Hazard development and products were varied across the IPTs and contractors and took a major effort to organize. Some of this was contractual, schedule driven and based on Center hazard experience base. c. The up-front agreements based on a few folks didn’t hold up to the expectations/requirements of the other later involved organizations. Lesson Learned – Allow for realistic integrated hazard development schedules and work process discrepancies aggressively

7.7. The launch was schedule driven which could have resulted higher risks.

7.7.1. Ares I-X S&MA management stayed on top of the schedule pressure and made sure to alert Constellation Program management of the associated risk so that they could make a risk informed decision.

7.8. The Mission Manager placed too much emphasis on the schedule in his communications. I believe the "verbalized" messages painted a picture that only the schedule mattered...even though I know he was also worrying the technical. A better balance of technical vs. schedule in MM communications would be beneficial

7.8.1. Overemphasis on schedule above all else, runs the risk of developing a culture of "launch fever" which could result is something being missed during the rush to meet schedule for instance, what effect did this have on the whole loads issue which was being worked furiously the last few months and which an error was discovered on the day before launch...

7.9. Ares I-X S&MA management stayed on top of the schedule pressure and made sure to alert Constellation Program management of the associated risk so that they could make a risk informed decision.

7.10. Multiple "lean" events occurred as a solution to resolve schedule problems. They seemed to be unsuccessful primarily due to the fact that all the stakeholders were not as involved during the lean events. Also, some of the decisions made at the inception of the Ares I-X program were difficult to redirect. Initial schedule planning should involve S&MA and Chief Engineer input.

7.11. Processes were streamlined to facilitate schedule; however, the effects may have reduced the level of due diligence (e.g. Material Review Board)

8. Design

8.1. M&P was somewhat invisible on this program, except for welding. Was USS IPT the only IPT who did a rigorous screening for SCC, NASA 6016, via the traditional MIUL approach? M&P is an S&MA discipline at GRC. If not in AIX-SYS-SRQA, where was it?

8.1.1. Disagree. As an example, the First Stage hardware had very strong M&P processes.

8.2. Supposedly inexpensive vehicle design decisions were made that drove large operational impacts. Continue to improve operational impacts in vehicle design trade space (consider ops cost of 5HP and non-T-0 stabilization system).

8.3. FTINU Handing should have had a requirement to use vibration sensor thru installation. FTINU installation resulted in a "jarring" of the box that was un-quantifiable.

8.4. Extension of the Linear-Shape Charge was a very good engineering design decision made early on during TIMs. This resulted in greatly reduced residual debris risk and improved launch availability. This provides better protection to the public in the event commanded flight termination.

8.5. A common approach to conducting Milestone Design Reviews including how RID's or RFA's are to be captured / approved and tracked to closure would be beneficial.

8.6. Design based Lessons Learned from Ares I-X should include better definition and mitigation of: (a) upfront definition of environments / loads; (b) lifting lugs/attach points structural strength requirements; (c) tribo-electrification; (d) harness workmanship requirements including post installation testing requirements; (e) identification of "canary" circuits to drive post-lightning strike re-test requirements; (f) First Stage use of "conductive Aluminized tape" on LM-supplied harnesses; (g)

8.7. Strongly recommend the identification of "Canary Circuits" with regards to Flight Termination System retest requirements in the event of lightning strike near (or on) the pad. It was recommended that these circuits be identified, but a management decision based on additional cost versus perceived benefit was made which resulted in no canary circuits being identified. Only the low intensity of the lightning strikes we experienced kept us from being confronted with a situation where Canary Circuits could have helped.

8.8. A rather obvious lesson learned that future vehicles need to appropriately address tribo-electrification. Either meet the coating requirement or prove to range ahead of launch day that the vehicle falls into one of the designated exception categories. Otherwise, future vehicle may be confronted with reduced launch availability.

8.9. FTS design for any future vehicle will need to address CRD operational frequency requirements (we were able to use 416.5 MHz but ranges have been directed to use other frequencies).

8.10. There was a highly aggressive concurrent design process that often times resulted in delivered product ahead of a matured design documentation.

8.10.1. Examples include delivery of flight hardware prior to completion of design qualification testing that occasionally led to waivers in flight hardware in lieu of redesign considerations.

8.10.2. Another example is delivery of flight hardware prior to resolution of loads!

8.11. The use of COTs hardware tended to circumvent a design vetting process that incorporates good Reliability and Maintainability practices and provisions.

8.11.1. Does S&MA need to develop a new vetting paradigm for heritage space flight hardware?

8.12. The use of heritage hardware requires careful consideration of their past history, including design, testing, and storage conditions, and a thorough understanding of how the new application of this hardware is different from the original design. Answering these questions as-you-go, rather than up front at the beginning of the design consumed a lot of meeting time as the project progressed.

8.12.1. The use of heritage hardware relied heavily on "past experience" as a basis for use rather than using a clean sheet "buy its way into the project" approach.

8.13. Any important sensor environmental covers MUST be "T-0" pulls and their design should be tested more vigorously to avoid failures. Hopefully the hang-up of the 5-hole probe cover showed the importance of additional testing. And then the fact that were unable to launch after the pull and then subsequently received rain which may have affected performance of the probe when we did launch the next day should show that the relatively small amount of money it would have cost for a T-0 would have been money well spent.

9. Manufacturing

9.1. Manufacturing/assembly of IPT hardware at KSC, via KSC personnel who were not completely familiar with the hardware, created some errors in identifying what hardware belonged to a specific IPT in CxPRACA's.

9.1.1. There was an impression augmented by personal interaction during telecons that KSC wanted only minimal IPT involvement once hardware was delivered.

9.1.2. Much of this “problem” will be addressed when hardware is delivered to KSC as a completed end item, ready for integration by the processing organization. Until such time, there are going to be opportunities for any organization writing non-conformances to miss necessary and appropriate responsible parties.

9.1.3. If KSC would be more open to IPT involvement (especially in a first of a kind development flight test integration, problems with KSC unfamiliarity would be mitigated.

9.2. While developing the MRB and non-conformance reporting requirements, KSC pushed to limit Design IPT’s to one signature that represented the IPT manager, the Lead Engineer, and S&MA Lead. The one signature was to coordinate with all parties. The rationale is that additional signatures would lead to slower processing times. Need to make sure that the Design IPT is fully aware of issues while processing their hardware since they are most familiar with the potential technical implications. If the one person was already communicating with all responsible parties (Engineering & S&MA) then there should not be an additional time delay in getting those people to sign in an electronic system.

9.2.1. Completely agree with this comment. KSC approach to limit Design IPT concurrences is inappropriate. Such inclusion is in the best interest of h/w quality and thereby flight safety. In today's internet world, including others in concurrences should not have been a problem.

9.3. Use of MSFC S&MA Resident Offices at manufacturing sites such as ATK-Utah and the ARF greatly enhanced the ability of S&MA to implement QA programs with highly experienced personnel who were intimate with the hardware and contractor's processes.

9.4. Manufacturing pedigree was a general challenge whether processing flight hardware at KSC or reviewing documentation at prime and vendor locations. For example, initial planning at KSC by systems engineering was marginal; however, after incorporating the IPT reviews and Table Top meetings, the fidelity improved significantly. Select supplier documentation was less than robust as discovered during select onsite visits (Avionics).

9.5. Processing at KSC relies on the Systems Engineering Organization to incorporate quality engineering and requirements (i.e. QPRD).

9.5.1. It looked like GO System Engineering were performing too many functions that are typically (and appropriately) performed a more independent QE'ing organization. as example, at KSC, QE'ing was not required to review WAD's before they are released to the floor. This is highly unusual as the QE organization should be making sure that appropriate inspection points are incorporated into the WAD's and that the WAD's are clearly written and include appropriate pass-fail criteria. Also, GO System Engineering fell behind in getting non-conformances to closure, this function should have been being performed by QE'ing.

9.6. IPT with hardware design responsibilities should install hardware or transfer to GO for installation. FS IPT installing Avionics IPT hardware led to multiple issues involving responsibility disconnects and resolution challenges. Joint MRB between FS, Avionics, and SE&I was never a consistent workable process.

9.7. CXPRACA as a single clearing house for all non-conformances needs some modifications (As a developmental program, this is to be expected). Data fields requiring IPT input was not fully defined until late in the program. This caused a contractual disconnect with a program requirement. Clearly documenting and flowing down to the IPTs CXPRACA data entry should occur early in future programs.

9.7.1. CxPRACA should also be modified to allow for problems to be "temporarily or interim" closed prior to launch for scenarios where longer-term preventive actions are being pursued to prevent recurrence of the problem or escape provided the specific h/w on a given flight has been cleared.

9.8. Manufacturing flow down of requirements to suppliers appeared largely absent from contracts with Avionics suppliers. Those suppliers tend to utilize their own processes based on their respective business models and past customer influences.

9.9. Fabrication procedures proved to be an extremely time intensive activity which required interfaces with all stakeholders, and an electronic routing and approval system implemented during the project improved efficiency greatly.

9.10. Use of "heritage" hardware and associated processes greatly facilitated the deployment of Ares I-X in a much timelier manner. Only key areas I would recommend revising if a similar approach is used in the future is (a) require all parties to use a single non-conformance system; and (b) require downstream "processing IPT's" to provide better mechanisms for the Design IPT's to concur with WAD's that will be used to process their supplied h/w.

9.10.1. NASA needs to be very careful to ensure that by using "heritage hardware" in a completely different load environment or a completely different operational environment, that NASA does not overlook the need for analysis and testing.

9.11. The level of quality surveillance provided by the Avionics IPT was adequate; however, the level of effectiveness was an increasing slope function based on the need to develop relationships and overcome organizational barriers.

While this is not atypical, the degree of effort and time was underestimated. In effect, early integration is a key component to a fully realized surveillance process.

9.11.1. Early on there was too much push back by the Avionics IPT management and their Jacobs/LM team

9.12. The use of conductive aluminized tape for First Stage harnesses caused significant effort to be expended late in the project to fully understand the risk associated with this practice. It also caused the prime contractor to refuse to fully certify the Avionics for flight.

9.13. There was not an overall quality oversight surveillance requirement developed by the IPTs. In effect, each IPT was left to determine their own needs and methods. Recommend development of an integrated surveillance/oversight plan that extends to all area including the flight center, IPTs, prime and subcontractors. Leverage the DCMA and other support organizations as appropriate.

9.13.1. This overall QA oversight could be at the MMO or the SE&I level.

9.14. Fastener Integrity - several IPT's, notably CM/LAS and USS, struggled with fastener integrity issues. Better processes to control fastener procurements including supplier control, traceability, and in-house receive inspection & testing should be pursued.

10. Test and Verification

10.1. Approving all VRDS's at the highest level XCB caused significant schedule delays. The integrated review process would take 3 to 4 weeks to get comments from all reviewers, including the SE&I wrapper. The timely closure of VRDS's was impacted by this long review cycle.

10.1.1. This is a reasonable amount of time to close important documentation. The main issue with VRDS closure was that due to the condensed development schedule on this project. The VRDS closure was concentrated during the last two months of the project. Ideally, many of the verifications would have been written and approved prior to IPTs shipping their hardware, but due to the way we had to work this project, that was not possible 9imn most cases.

10.1.2. The delay in IPTs completing their Verification did delay the SE&I VRDS completion.

10.1.3. Some IPTs released huge numbers of VRDS at one time. When this occurs, it cannot be expected that all will be reviewed in as expedient a manner as when a smaller number are released at once.

10.2. Strengthen the verification process. H/W integration process got way ahead of the verification process at both the IPT and SE&I levels. Short cuts were developed (directives) to get around and move the process forward which could have a high impact to the safety of personnel, flight vehicle and processing facilities. I believe this was our greatest accepted process risk.

10.3. Need to have a full and complete modal analysis / fibro-analysis before conducting Modal test for any new vehicle development.

10.4. The lack of an Integrated Test Plan led to confusion as to required testing both functional and environmental including qualification and flight acceptance levels. Highly recommend an ITP early on in the process so that all know what is required. As an example; required DFI testing was always unclear.

10.5. Verification planning and communication of final deliverables was limited and too late in the Ares IX program (and in a lot of other programs as well). At CDR, the verification plan should be 90% mature. For Ares IX, the VRDS process should have been defined so that all IPT would have been able to identify disconnects between the System level needs and the IPT planned activities. If the System level VRD had clearly identified the “inputs” then the design IPT would not be in as much of a guessing mode. The design IPT also need to clearly show all planned verification deliverables by requirement so the vehicle system level can ensure correct verification flow up is being met.

10.6. EMI testing and test procedures for the integrated Flight Test Vehicle (FTV) was not well-understood or thought out until very late in the development process. There were important questions to be answered about what could and could not be tested on the pad in terms of EMI, and it would have been better to have understood these issues early in the design process.

10.7. It appeared in several examples where the qualification of hardware following the build, testing and delivery of flight hardware. In some cases, the results of qualification testing could have resulting in design changes; however, the timeliness of information generally resulted in waivers to requirements. In effect, there was a risk multiplying effect in order to preserve an aggressive schedule. The lead times and planning for these events is an opportunity for improvement.

10.7.1. This was a recognized and accepted risk and part of the way we had to do business for this development program.

10.7.2. As far as lead time, etc. I think we did this faster cradle to grave than any other new NASA launch vehicle, isn't that right?

10.8. SE&I level verifications ended up being crammed into the last two weeks before launch. Additionally, verification process/requirement owners often were not able to write the verification at the end of the development cycle right before launch because they were involved in other pre-launch activities deemed higher priority. Both the required speed of review and the fact that folks previously not familiar with the process could have contributed to something being missed during the verification process. Pressure from MMO to meet schedule forced this only solution which was extra hours and a very speedy review. Rushing things increases the likelihood of missing something. It should also be said that the process that was used by SE&I to get the VRDS's reviewed and approved during the last two weeks worked well and accomplished the review in time. This comment is trying to say that even though we got it done in time, this was not the best way to do things by being so rushed at the end.

10.9. KSC discrete and integrated testing was generally effective. Planning utilized the IPTs in table top discussions that captured various ideas and experiences. It appeared that adequate time was provided to execute each test and generally the required equipment and materials were available.

11. Top 3

11.1. Requirements must be established prior to contracts being let.
11.2. Teamwork, cooperation, and communications were the keys to S&MA's ability to influence the direction, and subsequent success of Ares I-X.
11.3. Provide adequate resources to support the multiple meetings and technical reviews to assure that there is appropriate technical review and risk acceptance and to prevent over-worked, and burnt out conditions.

2.10 Engineering / Technical Authority Knowledge Capture

1. Engineering Management / Systems Engineering

1.1. The roles of lead system engineer and lead engineer were unclear. The roles seemed to overlap and caused some confusion in the institutional engineering community.

1.2. Lack of engineering review board until the very end [of the project] delayed decisions being made and made for very long Ares I-X control board meetings.

1.2.1. The sole source XCB format resulted in the same technical discussions occurring at three lower levels before being rehashed at the XCB in the same level of detail.

1.3. SERF vs. ERB. Neither entity was granted any authority until very last in the mission cycle, when the ERB was allowed to approve waivers.

1.4. As a result the SERF & ERBs ended up just being technical discussions that were rehashed again at the XCB.

1.4.1. The good part of this format was that a lot of much needed technical discussions occurred without a specific time limit.

1.5. The bad part was that the SERF and ERBs went too long and often did not require the entire board/panel.

1.6. The appropriate discipline experts were engaged to assist with technical challenges. This was beneficial with the tight schedule.

1.7. Ares I participation changed after the reorganization to a mission with very little participation until we got closer to the flight and we started having problems with DFI. The Ares I Project was more engaged prior to AIX reorganization.

1.8. SE&I late production of environments in the mission cycle caused issues. Assumptions of conservative margins in some areas were proven wrong as new analyses and tests resulted in increase environments.

1.9. Weekly and monthly meetings with the chief/engineers/lead engineers were very beneficial with keeping up with issues and progress.

1.10. Technically, the right processes were implemented. Lead engineers ensured appropriate policies and standards were appropriately implemented.

1.11. Procedurally, The CE's & LE's maintained adequate "independence" from the programmatic side of the mission and/or IPTs.

1.12. There was healthy tension and open discussion between the Mission Office (technical side) and the CE. In other words, the Mission Office did not try to suppress the Technical Authority (or Mission Assurance) sides of the house.

1.13. Engineering TA flowing though LaRC was a benefit, since resources were needed that could not be provided by the program level TA. Having another advocate assisted in resolving issues.

1.14. Having two chief engineers (MSFC & KSC) was confusing at times when decisions were being made.

1.15. Multiple lead engineers for one IPT led to not understanding their roles and responsibilities

2. Requirements Management

2.1. Requirements traceability was not very tightly integrated and/or flowed down to the IPT level.
2.1.1. This made it more difficult to fully track/trace specific requirements.
2.2. SE&I requirements management was not adequate at the offset of the mission, which resulted in differences in IPT implementation.
2.2.1. I would say also the verification expectations of those requirements as well.
2.3. Several requirements were not needed, such as you shall use the VAB for vehicle assembly.
2.4. I'm not sure if all of the LEs were involved in the requirements flow down workshops or reviews and their "technical" inputs would have been beneficial.
2.5. Interface requirements were managed by the IPTs as opposed to being managed by SE&I. Therefore, issue resolution took longer to implement. SE&I was not appropriately engaged in managing interfaces.
2.5.1. It was a very difficult concept to try to "verify" an interface requirement from "both" sides of the interface independently of the integrated requirement.
2.5.2. Authority of SE&I was lacking on interface requirements and verification.
2.6. The mission did not know what it was 'buying" when heritage processes and hardware were employed for Ares I-X. There were conflicts among the heritage processes and requirements that caused problems late in the mission flow.
2.6.1. Example would be the DWV testing of harnesses.
2.6.2. A second example would be the metallic tape issue.
2.7. Verification of requirements became a major bottle-neck at the SE&I level and a majority of "verifications" did not receive sufficient 'vetting" before final acceptance.
2.8. There was a lack of adequate definition of what were heritage, modified heritage and non-heritage hardware which led to confusion on standards and requirements.
2.8.1. These requirements need to be completely understood, up front in the program and by all parties involved.
2.9. Lack of upfront involvement by the verification managers resulted in some requirements that were not verifiable by the set method or unclear.
2.10. Contracts were either let or already in place before adequate requirements were developed. First Stage and Avionics are examples that come to mind.
2.11. Involvement of the customer in requirements development changed throughout the mission. It is important to have customer involvement in requirements development/alteration to assure the relevance of the mission/final product.
2.12. IPT requirements controlled at the Mission level often led to more time and effort.

3. Organization/ Culture

3.1. Mission manager did not delegate enough authority to boards (such as ERB) until late in the mission. This resulted in long, marathon XCBs.

3.2. Nothing negative about the KSC culture, but it is very different from the research centers' culture. Much more time should have been devoted up front to acclimate the rest of the centers to the KSC way and time should have been allotted to acclimate KSC to the other center's cultures.

3.3. MMO directed us to have separate lead engineers and lead system engineers this could have been the same person.

3.3.1. I believe that it was best to have separate LEs & LSE due to the amount of work required of both and also to maintain the technical independence.

3.3.2. Need buy-in from [center] engineering organizations in the beginning of the program. They need to support the program on a moment's notice. Early on, it was difficult for MSFC engineering to help with I-X technical issues, until they were pressed by higher authorities. All were just too busy to help. In the end, engineering worked to save us.

3.4. Communication within and among the TAs and Mission was effective. All involved were willing to hear and in most cases consider different perspectives.

3.5. The change from AVIO to MMO was a major cultural shift which also resulted in significant organizational changes.

3.5.1. More thought and foresight should have been devoted to looking at the far-reaching implications of that change.

3.6. The differences between research and space flight centers were noticed during implementation of Agency standards. Research centers in some cases interpreted the standards incorrectly, which resulted in waivers.

3.7. Ares I-X mission being equivalent to Ares I, etc. allowed it to bypass the various boards/forums that would have bogged down the mission.

3.8. The reporting structure/routine communication between Ares I-X SEI and CxP SE&I did not seem to be in place.

3.9. Ares I-X demonstrated that some long held practices/traditions/requirements were/are due for a revisit. Ares I-X flew with reduced Agency requirements.

4. Communication

4.1. Communication within and across the Mission and TAs was very effective. All were willing to hear and consider different perspectives.

4.2. Routine TA meetings were beneficial and allowed the mission TAs to stay aware of current and forthcoming issues.

4.3. Routine meetings (outside of the XCB) between the CEs and Mission Manager allowed the discussion of concerns.

4.4. Access to vehicle processing data at KSC was only available while at KSC and if you had an account.

4.5. Many presentations were made. It took a bunch of time to make/build the presentations. These were necessary, but maybe excessive at times.

4.5.1. There needs to be a searchable database of presentations. Or better, do not use PowerPoint to build presentations but some other database program.

4.6. At times, the shear amount of communication (e-mails, reports, presentations, data books, technical exchange minutes etc.) was overwhelming and did not allow adequate time to read/comprehend all details.
4.6.1. As a result, a lot of written communication was verbally rehashed at various meetings for the folks who did not read the written communication.
4.7. Communication up the TA path was routine (weekly CxP CE meetings, monthly EPTR meetings with LaRC CE, routine communications on issues) and effective.
4.8. The Windchill format was an extremely poor choice for a Lifecycle Management tool and did not lend itself to rapid retrieval of key information.
4.8.1. Also, Windchill was not used as a true (linked) Lifecycle Management tool where information was linked and grouped properly.
4.9. SE&I assumed the IPTs knew how to utilize the information in the databooks. Meetings to discuss updates to databooks and appropriate implementation discussion would have been beneficial and eliminated a few missteps.
4.10. The IPTs utilized different communication/data storage tools (NX, d drive, eRoom, etc.), which made data retrieval difficult and challenging.
4.11. The CRADLE tool was supposed to help us with requirements and verification. We had a dedicated person at MSFC putting in the data but I am not aware of anyone using it or helping us.
4.12. Multiple meetings overlapped and required same attendees, which caused people to partially participate in multiple meetings and the meetings to last longer due to repeating of information.
4.12.1. Needed meeting manager to assist with overlapping of key meetings at Ares I-X, CxP, Agency, Center levels.
4.13. The norm was to multi-task for the entire virtual team--this is a fallout of having virtual meetings vs. face-to-face meetings.
4.13.1. Several people had to attend multiple overlapping meetings (i.e. two different WebEx, telecons simultaneously) and that resulted in less productive participation.
4.14. Some face-to-face meetings were needed to build team relationships and not just at the mission level.
4.15. Meeting agendas (if provided) were not followed or adhered to and meetings always ran long. Need to implement stricter time limits for topics to be presented, discussed, and then either resolved or actions assigned.

5. Resources

5.1. SE&I was not properly staffed to implemented its tasks, which resulted in late delivery of databooks.
5.2. We needed additional support for major reviews and verifications. Had to obtain additional people at LaRC multiply times.
5.3. Engineering TA did not have adequate administrative support (had none).
5.4. The norm seemed to be a "fixed" set of workforce resources that were then asked to spread themselves "thin" and cover all technical & organizational aspects of the mission.

5.5. Support at design and acceptance reviews was limited. Appeared that review of data supporting the reviews was limited. Seemed that review board members focused on the presentations and not on the in depth test and analysis reports, drawings, etc.
5.5.1. As a result, I don't believe that the design, ship or acceptance reviews received adequate review and the assigned actions were not fully followed up on.
5.6. Adequate support in the field of vibro-acoustics was lacking up front and took us several iterations to get someone to stay with it to develop the vehicle environments.
5.7. Resources were so thin that the CM/LAS TA was often required to do project related tasks in addition to TA related tasks.
5.7.1. Lead Engineers were asked to do multiply jobs on top of their chief engineering job.
5.8. Engineering technical folks (TA engineering support) were not involved as much as should have been, especially at program beginning.
5.9. Early on, the AIX Project limited the amount of people working on the project.
5.10. Competing with Ares I for resources at MSFC was challenging and resulted in delays in FS verification and loads issues.
5.11. KSC was not adequately funded and was always asking for more funds when asked to do something that was in the baseline.
5.12. LaRC CE assisted Ares I-X CE with review and verification support, without this assistance, the CE could not have effectively functioned.
5.13. Not enough funding and people resources to support DFI. We could have had a much better system if allowed to fully test and calibrate the system.
5.14. Schedule was king and thus personnel worked long hours and Safety of personnel became a concern. It is critical that personnel understand that meeting schedule does not come at the expense of cutting corners.

6. Technical Authority / Safety & Mission Assurance

6.1. Very strong Chief Engineer and Safety and Mission Assurance.
6.1.1. Kept all on their best technical guard.
6.1.2. This was a major contributor to the overall success of the Mission that resulted in most technical issues being properly identified and assigned risks and mitigations.
6.2. Communication up and down the engineering TA path was effective and routine (weekly meetings, written reports, monthly status briefings, etc.).
6.2.1. This included CE Constellation and CE at HQ.
6.3. The CE and S&MA had a very good working relationship which led to good resolution of issues and acceptance of risks.
6.4. The TAs participated in critical meetings to resolve issues, discuss progress and eventually sign off on the COFTR.
6.5. S&MA requirements were developed late but after Ares I-X restructure the new S&MA TA effectively generated them and negotiated their acceptance with the mission.

6.6. TAs supported all mission efforts including lean events, tiger teams, review boards, schedule meetings in addition to routine responsibilities.
6.7. TAs effectively communicated their positions on issues and elevated concerns timely for appropriate resolution.
6.7.1. Only counter, is that the same issues were addressed at multiple SERFs and then elevated to the ERB for several sessions before finally being elevated to the XCB. Prime example is the Nose Cone issue.
6.8. Early one, the lack of decision authority of the TA (SERF/ERB) diminished the power of the TA since all "decisions" had to go thru the XCB.
6.9. TAs ensured the program, Centers and Agency management were aware of risks and technical issues so they were making informed decisions.
6.10. Lack of S&MA requirements created some issues early on. Once we got a permanent S&MA he was instrumental in getting the S&MA requirements set and working toward a viable mission.

7. Schedule

7.1. The schedule was driver for the mission.
7.1.1. Though the schedule drove the mission, the pace did not allow any technical issues to become to stale and be forgotten.
7.1.2. The schedule prevented some technical data from being gathered. (DFI for instance - we could have done better)
7.2. Everything was solely schedule driven based on the 1st and then 2nd flight dates rather than what it would take to thoroughly do a competent job.
7.3. Reviews were held just to meet schedule which led to more than one review. For example CDR 1 and 2.
7.3.1. In the long run, it requires more resources (stop & start) to conduct two mini reviews than to just conduct one complete review.
7.3.2. Several IPT Pre-Ship and Acceptance reviews were driven by schedule and they most always had to have a follow-up (delta) ship or acceptance reviews where all issues were finally addressed and closed out.
7.4. Risks were most often couched as schedule or cost issues, although there were performance and safety implications as well.
7.5. Schedule and cost were a higher priority from the projects point of view than technical for this mission.
7.6. The schedule never adequately depicted the links/fore-runners to milestones therefore the schedule was dated before we even approved updates.
7.7. The benefits from the lean events were never properly tracked. Therefore the full benefits were not realized.
7.7.1. Actions assigned were not tracked adequately to closure.
7.8. Lack of linked input data needed for each milestone led to delays and inadequate products (e.g. loads).
7.9. Schedule was king. IPTs were directed to ship hardware before they were ready--paperwork was not ready. This resulted in additional reviews.
7.10. Testing was limited do to schedule and cost.
7.11. KSC appeared to not provide adequate insight into its schedule. Thus the mission never had a truly integrated schedule.

7.11.1. There was a disconnect between what the IPTs allotted for integration tasks at KSC and the "true" amount of time that KSC actually took to perform the tasks. KSC always took much longer to perform a tasks versus what the IPTs could do the same tasks at their home Center.

8. Design

8.1. Hardware was designed and built before some databooks were in a final state. This caused a lot of pencil sharpening and workarounds since the hardware was built.
8.2. In order to meet the schedule and since we were not weight critical a higher factor of safety was used (ult. FOS of 2.0).
8.3. Ares I-X was a $400+ million dollar mission. Therefore it was critical that engineering best practices/standards were implemented to ensure mission success. We had to be good stewards of the tax payer's money.
8.3.1. Appropriate use of workmanship standards was key to success.
8.4. Lack of CM requirements for drawings resulted in a variety of methods implemented by IPTs (i.e. listing of parts, etc.).
8.5. Various models/analysis tools were utilized by the IPTs and SE&I which caused problems when the data needed to be integrated for system-wide application.
8.6. It took several cycles to converge on accepted design loads and by this time some IPTs had made decisions to "over-design" their hardware based off high early design loads and other IPTs chose to design to the anticipated "lower" design loads. This cause lots of problems during reviews and verifications.
8.7. Model control requirements were implemented late in the mission.
8.7.1. This caused several issues with the models that had to be corrected before loads could be released.
8.8. Several IPTs used the normal PDR, CDR approach with clear objectives and others resorted to major design reviews that led to confusion as to what we are reviewing and was it adequate for what we should be doing.
8.9. The generation of capability curves was not required. This caused problems when the loads issues were realized late.
8.9.1. Thus it took some IPTs longer to assess updates to the databooks.
8.10. Design certification review (DCR) was not accomplished according to the baseline plan. Do we really need this review?
8.11. At the time of IPT and System level CDRs, design verifications were not ready for review. So were the reviews really effective?
8.12. Decisions/actions made at the design reviews were changed without approval of the board.
8.13. Clarity regarding factors of safety for a test flight were unclear.
8.14. Hardware configuration management was not adequately implemented.
8.15. A face to face review covering system engineering expectations including models, testing, factors of safety, etc. is needed for future projects.
8.16. Design for the mitigation of tribo-electrification effects of the vehicle.

9. Manufacturing

9.1. Hardware CM was not adequately implemented and this resulted in confusion during shipping and acceptance of hardware.
9.2. Hardware was built before CDR and environments were finalized.
9.2.1. Schedule was king.
9.3. The IPT MRB via Solumina seemed to work well, with the one exception that all members needed to have Solumina access which was not always the case.
9.4. USS use of a pathfinder was beneficial for improving manufacturing processes and as a learning tool for its personnel.
9.5. Match drilling and fit checks if at all possible will save on cost and schedule in the long run even though up front it costs you in schedule.
9.6. Use of manufacturing experts across the Agency helped the mission, specifically regarding welding.
9.7. Before manufacturing any harnesses, verify that the models are correct.
9.8. Solumina, in general, was a good choice for manufacturing at KSC, since all work orders and their status was readily available. More time should have been devoted to getting the most out of the system. Also, not everyone had access and that was a problem.
9.9. LAS nose cap had inadequate requirements for its OML which led to issues with its manufacturing. Earlier communication of manufacturing results may have led to different solution/fix of the nose cap.
9.9.1. In addition to poorly (or actually missing) requirements, schedule actually drove the fix for the nose cone repair "fix".
9.9.2. The design for the nose cap did not lend itself to welding, which was implemented.
9.10. Lack of resources and a compressed schedule caused most hardware to ship to KSC (pre-mature) (i.e. to meet schedule) when it would have been better to complete the majority of the manufacturing, assembly and integration at the design Center and then ship to KSC
9.11. Appropriate documentation of waivers/MRs needed improvement. When reviewing documentation for some IPTs, it was unclear how the MR was resolved.
9.12. Harnesses came up long and short in places. Not enough conservatism was included.

10. Test & Verification

10.1. Need more testing on avionics systems, especially for the DFI system.
10.1.1. SIL testing provided us with a very good level of confidence that the Atlas system would work as designed and modified.
10.2. Product vs. design verification. The mission was never clear on this.
10.3. The schedule and resources (lack of) did not allow sufficient time to thoroughly vet the requirements at the IPT level and then the subsequent SE&I level.
10.3.1. SE&I was overwhelmed by the sheer number of requirements for verification and FS requirements were not fully verified at the SE&I level.

10.4. If I did not review the IPT verifications prior to the late received system level verifications, there is no way I would have signed off of the system level verifications. For a lot of the system level verifications, it did not appear that the systems requirements owner reviewed the IPT verifications. The system level write-ups typically just referred to the IPT verifications, no analysis of the IPT level verifications appeared to have occurred.
10.5. Testing was kept at a minimum because of cost and schedule. This led to higher risk being accepted for a test flight.
10.6. CEs and LEs stressed the need for adequate tests such as on pad TVC hot fire test to increase confidence.
10.6.1. TAs should not have had to bring this forward, that is, this should of been part of the baseline for a first time test flight.
10.7. Again verification was never adequately depicted on the schedule. The supporting documents, steps were not linked.
10.8. Interface verifications were not adequately defined in terms of who ultimately was responsible for pulling together all necessary data to insure that the interfaces would be verified. More involvement and control should have been exercised by SE&I.
10.8.1. Actually, SE&I philosophy was that interface requirements were not verified by SE&I but by "both" sides of the interface (independently), which was not a good approach, in my opinion.
10.9. System level requirements that could have been reviewed and closed earlier were not for no apparent reason.
10.9.1. Agree this confused and caused us to carry additional issues on verifications that may of not been needed.
10.9.2. The somewhat apparent reason was lack of staffing from SE&I or lack of skill mix to spread out on those easily verifiable requirements.
10.10. Late verifications ended up being the main issue during mate review, roll out and FTRR. If we didn't need some of these verifications for mating or roll out why have them at all?

11. Top Lessons

11.1. Very strong CE and SMA.
11.2. Mission manager did not delegate enough authority to boards (such as ERB) until late in the mission. This resulted in long, marathon XCBs. TAs supported all mission efforts including lean events, tiger teams, review boards, schedule meetings in addition to routine responsibilities.
11.3. The mission did not know what it was 'buying" when heritage processes and hardware were employed for Ares I-X. There were conflicts among the heritage processes and requirements that caused problems late in the mission flow.

3.0 Configuration and Data Management Knowledge Capture

3.1 It's the same old problem; implementation prior to requirements definition and design is a bad idea, in any discipline. 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, specified in the project's high-level documentation (System Requirements Document "shall" statements that 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.

3.2 Effective CDM implementation 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. 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 System Requirements) is generated as a basis for project management decision making.

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

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

3.5 Communication. The distributed project environment lends itself to miscommunication and a feeling of isolation by team members. It is important to first identify the team members and then develop mechanisms to keep all team members plugged-in.

3.6 The CDM Plan should reflect a common understanding of the all team members. Approval of the plan should be provided by the Project Manager before implementation activities begin. This approach authorizes the CDM activities at the proper level and prevents misconceptions and false starts of 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? Decisions on tools to facilitate the CDM activities, change authorities for proposed changes to baseline products, and how CDM procedures are documented and approved are all found in the CDM Plan.

3.7 It is important to establish requirements that meet the needs of the distributed environment without compromising the intent of the CDM objectives. Establishing 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.

4.0 IPT Telephone Interview Matrix of Observations and Comments

The ESMD knowledge capture team employed a structured engineering management framework for one hour telephone interviews with IPT Leads and mission managers. The interviews were conducted from May to November 2009. The process employed a "storytelling interview" format that addressed the following eight elements (Thematic Areas).

1. Leadership and Management
2. Organization (Roles & Responsibilities)
3. Requirements Management
4. Communication
5. Test & Verification
6. Facilities
7. Resource Management
8. Scheduling

The eight elements were derived from a fishbone analysis of Ares I-X risk records contained in the ARM and IRMA data bases. Interviews were recorded and transcribed then abstracted into the short summaries provided in the matrix below.

The results of this phase of the knowledge capture assisted in refining the taxonomy used in the full IPT team capture events.

IPT Leads and A1X Management / Telephone Interview Abstract Compilation

4.1 Ground Systems

4.1 - Implementation Insights: Ground Systems
Interview: Mike Stelzer

ID	Theme	Description / Context / Ref Docs	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
GS1	REQ RES	Project Plan Versus Resource Disconnects - The MLP vertical stabilization system (VSS) was in the project plan but had no funding in the resource plan. The requirement firmed up only after CDR. - The analysis conducted by LaRC was the basis for the decision and late requirement. - "One of the lessons learned is when you add a big requirement like with the VSS, everyone just needs to understand that there is a huge schedule risk"	- TBD Requirements must be carefully managed with consideration of their dependence on critical analyses and linkage to schedule and resource planning	
GS2	ITL DSGN	Lightning Protection Design Considerations - Lightning Protection System: "There are three towers out there. If you look over on the Cape side, you will notice that their launch pad had four towers." What our folks found is that you can achieve the same thing with three towers and save a significant amount of money and just be creative in the way you string the catenery wires between the three towers"	- NASA and USAF lightning protection specialists have an opportunity to collaborate on design options	
GS3	EM/SE	Leveraging Shuttle Processes - "For the maximum extent possible, we tried to levy not only shuttle equipment, but also processes. All these folks are very familiar with	- Ensure all project participants have a thorough orientation to the engineering management and systems engineering processes to be employed on the project	

4.1 - Implementation Insights: Ground Systems
Interview: Mike Stelzer

ID	Theme	Description / Context / Ref Docs	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		how we do design, how we do design review, how we do design certification, how we do operational readiness reviews, engineering review boards. Everybody was familiar with the processes we had in place. Maybe a lessons learned is by using those processes that they are familiar with our job was very straight forward. I cannot recall any areas of friction."		
GS4	DSGN	Leveraging Shuttle Infrastructure - "When I came on to the mission two year ago, it was there from the get-go to leverage shuttle system as much as we could. It has been in the planning for quite some time. In addition to using the existing equipment, it really does keep cost down. We did not have to go build a new mobile launcher, we just modified one. We did not have to go build a new launch pad, we just modified one. Same with the VAB and the LCC. It saved a ton of money. In most cases the long term modifications, we did not have the requirements three, four, five years earlier for Ares, we just would not have been ready. It was a choice to keep the cost down and fly this mission earlier or try to accelerate the long term which would have cost more…. ………….A huge success and an huge risk reduction were possible with using existing infrastructure.".	Leverage existing infrastructure to the extent possible	Cost containment and risk reduction
GS5	EM/SE T&V	CxP Verification Complexity Adds Time - "Most of our testing and verification validation has gone real well. The only thing……. I noticed was that Constellation is so much more cumbersome (than Shuttle). As a matter of fact, we tried to leverage the Shuttle process to address the verification process to Constellation. With the Shuttle process, the folks involved in the verification validation, they are watching the testing, they are looking	- There are some very important lessons here related to co-location, communication and complexity. - It raises the question of fidelity of the verification that you get with people remotely involved in verifying a design change in an environment where they are thousands of miles	- Verification quality - Mission Assurance - Schedule - Cost

4.1 - Implementation Insights: Ground Systems
Interview: Mike Stelzer

ID	Theme	Description / Context / Ref Docs	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		at the reports that they develop so it is really is easy for them to sign off at our verification reviews and our operational readiness reviews that these systems are ready to go. What we are doing here with I-X we are able to sign off internally at KSC within days or weeks and say that this modification is ready to go. Then the verification enters the Constellation cycle and they go off to a wide audience including SE&IE at Langley and different IPTs at their centers and now we start working with a group of people who have not been down here not watching the testing, not reviewing the reports and they have to go and try to get the equivalent level of familiarity that the folks down here have and it is hard to do that over the internet. It is hard to go into Windchill and look through some documentation and it takes a lot of time where we are able to do this stuff in a week down here. When we went to the Constellation process, the first set of verifications we put through took two months to process to get everybody so that they were looking at the right stuff, that they understood what they were looking at. We got just a ton of questions that would have been answered if they were down here. We went ahead and addressed their comments or questions and finally got their verifications closed out. We have been able to cut that in half. We can now get a set of verifications closed in within a month maybe a little more than a month but we are still no where we were on shuttle where we have the right folks right there.”. - If you have to do it over again, what would you do differently? There has got to be a simpler way. It should not take even a month to close a verification. I had fifteen years in Shuttle and I have spent 10 years in launch services and in both of those areas in closing requirements the verifications took days and weeks, not months. Probably what Constellation is doing is a lot more thorough and maybe that is needed for some requirements but not for all requirements.	away. It is a whole lot different in trying to read something versus looking at it.	

4.2 Ground Operations

4.2 - Implementation Insights: Ground Operations
Interview: Tasso Abadiotakis

ID	Theme	Description / Context	Opportunity / Recommendation(s)	POCs / Relevant AIX Documents
GO 1	EMSE REQ T&V	Lack of Detailed Assembly Drawings - Design IPTS (and SEI) did not provide assembly drawings / GO spent enormous time and money "putting all the requirements together" - LaRC (SE&I) should have developed the detailed operational test requirements and IPTs should have developed detailed assembly drawings. – did not happen - Timely delivery of complete requirement set is #1 concern. Need design IPTs to consider, define, and document integration and assembly integration, and test requirements.	- More thoroughly define roles and responsibilities	
GO 2	EM/SE REQ	Challenges in Detailed Integration at Design Level - Detailed integration at design level was less than adequate Examples Include: - ATK uses metal tape for TPS shielding of wiring. LM (Orion) never uses metal tape for shielding - Welded joints (GRC) verses bolted joints (LM)	- Implement detailed integration at design level, especially at interfaces. This area needs management focus and emphasis	
GO 3	REQ	Definition of Avionics Requirements - GS avionics requirements were not fully articulated to GO - Make-shift environmental conditioning systems had to be created in High-Bay 4 to support avionics requirements	- Re-emphasize the importance of defining and flowing down life-cycle requirements	
GO 4	EMSE T&V	Clearly Defined Test & Verification Roles and Responsibilities - Need more clear roles and responsibilities for Test and Verification - Zero system level verification completed with only 3 months prior to flight. No clear path to completion available.	- Strengthen SE&I organization (staffing, authority, capability) - Management to articulate (define-	

4.2 - Implementation Insights: Ground Operations

Interview: Tasso Abadiotakis

ID	Theme	Description / Context	Opportunity / Recommendation(s)	POCs / Relevant AIX Documents
			communicate) more completely roles and responsibilities	
GO 5+	SMA	Hazards Analysis Success Factors - KSC TSMA Team has done an outstanding job of conducting System Safety Hazards Analysis and addressing integrated hazards and implementing control and mitigation in processes and procedures	- Develop a KBR Best Practice) based on GO / SMA interaction	
GO 6	EMSE RES	Requirements Ownership and Resource Conflicts - A disconnect exists between requirements ownership and funding – Bob Ess (Mission Manager) has requirement but must go to Pepper Phillips (KSC Ground Ops) for funding - The requirement owner needs to also own budget	- Realign accountability and budget authority	
GO 7	EM/SE SMA COMM	Ground Ops Process Orientation - Different approaches existed between GRC Upper Stage Simulator project team and KSC GO concerning work discipline and control processes. It took a period of time before the GRC team and KSC GO “got on the same sheet of music.” They eventually worked it out.	- Provide orientation to project participants from other centers with respect to SMA expectations and assurance requirements - Expect a learning curve and education process.	
GO 8	REQ	**Design “Plus” Requirements Definition Essential** - Facility requirements need better definition.		

4.2 - Implementation Insights: Ground Operations

Interview: Tasso Abadiotakis

ID	Theme	Description / Context	Opportunity / Recommendation(s)	POCs / Relevant AIX Documents
		- Interfaces requirements need better definition - Manufacturing and assembly requirements need more focus and attention by SEI folks		

4.3 Upper Stage Simulator (USS)

4.3 - Implementation Insights: Upper-Stage Simulator (USS)
Interview: VJ Bilardo

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
USS 1	DSGN REQ	Conservative Structural Design Considerations - Conservative structural design (uncertainty factors and margin) avoided huge cost and schedule impact when the predicted coupled loads incrementally increased	- Coupled loads always grow up. Ensure adequate margin in design. - Allocate and manage mass properties as early as possible	
USS 2	ORG ESME REQ	Impact of Late SE&I IPT - Delays existed in resolving and articulating the SE&I management structure, responsibilities, authority, and accountability (in particular between MSFC and LaRC) which hampered Ares I-X implementation resulting in: late delivery of requirements; late delivery of system level specifications; late delivery of environmental data book	- Define roles and responsibilities and implement requirements management Systems Engineering organization prior to initiating design activities - The need exists for a stronger systems engineering and integration organization that incorporates a viable Integrated design and analysis functional capability	
USS 3	ESME REQ	Upfront Requirements Analysis Criticality - Place more emphasis on up-front requirements analysis, requirements allocation, iteration, trade-studies and having a set of mature set of requirements before you jump to the design. - WBS is a powerful and necessary tool		
USS 4	EMSE SMA	Tailoring NASA Standards	- Establish rules up-front on applicable standards and acceptable tailoring	

4.3 - Implementation Insights: Upper-Stage Simulator (USS)
Interview: VJ Bilardo

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		- NASA standards must be selectively tailored to support logical implementation of program objectives	approaches	
USS 5	DSGN	Impacts of Late Analysis - Roll Control System interface doubler location tolerances were set by judgement rather than analysis leading to costly rework and delay	- Perform tolerance stacking analysis as early as possible.	
USS 6	SMA	Impacts of Late Product Assurance Processes - Failure to Implement Product Assurance processes (and training) early in project resulted in excessive audits.	Implement Product Assurance processes (and training) early in project.	
USS 7	DSGN	Design Software Selection Impacts - ProEngineer Design Software deemed cumbersome	Reassess design software	
USS 8	EMSE	Drawing Release Process - Drawing release process cumbersome (too many signatures – not enough time)	- Review both signature chain and time allocation for review	
USS 9	EMSE	CAD Engineers Span of Control - CAD technicians assumed authority to make changes independently of design engineers	- CAD technician and design engineers roles and responsibilities, authority and accountability should be reviewed	

4.3 - Implementation Insights: Upper-Stage Simulator (USS)

Interview: VJ Bilardo

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
USS 10	DSGN	Impacts of Fasteners on Design / Manufacturing - Over 200 different fasteners were used on the USS	- Consider development of common fastener inventory early in design. Establish lead fastener engineer	
USS 11	MFG	Establishment of Early Manufacturing Capability - Establish Manufacturing Engineering capability early in program	- Establish Manufacturing Engineering capability early in program	
USS 12	EMSE MFG	Need for Strong Segment Engineer - Need stronger segment lead engineer function to facilitate better communication between engineers and shop technicians		
USS 13	MFG	Identification of Critical Processes - Iridite processing of aluminum structures often failed.	- initiate analysis of process key characteristics and implement appropriate controls	
USS 14	MFG	Impacts from Bent Materials - Parts made from bent materials often had to be remade	- Caution should be exercised in assembling bent materials	
USS	MFG		- conduct workforce capabilities study	

4.3 - Implementation Insights: Upper-Stage Simulator (USS)

Interview: VJ Bilardo

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
15	SMA	Need for Strong Segment Engineer - Had to rebuild manufacturing inspection capability from scratch	up-front and ensure proper skill-mix	
USS 16	EMSE SMA	Requirements Compliance Verification Documentation Process - Requirement compliance verification documentation process need improvement and need EDA WBS lead engineer support		
USS 17+	MFG	Transportation Planning - Flawless handling and transportation from GRC to KSC	- Implement careful and thorough planning for critical moves / develop a KBR or Best Practice based on experience	

4.4 Avionics

4.4 - Implementation Insights: Avionics
Interview: Kevin Flynn

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
AV 1+	COMM	Impacts from Test Flight Experience - The entire test flight experience has been invaluable in terms of developing critical communication pathways between sometimes differing engineering cultures		
AV 2	EMSE REQ	IPT Self Integration Challenges - The IPTS had to be self integrators – there should have been a stronger the SEI function - Interfaces should be managed top-down, not bottoms-up - SEI needs to verify requirements at interfaces - need a strong integrator above the IPTs	- A stronger SEI organization should be established for future Ares and Constellation projects.	
AV 3+	SMA	Technical Authority - SMA and OCE technical authority support was outstanding		
AV 4	ORG T&V	Establishment of Systems Integration Lab - Establish a systems integration laboratory (SIL)	- Establish a systems integration laboratory (SIL)	
AV 5	RES	Top-Level Guidance on Cost Containment	- Establish stronger SE&I function	

4.4 - Implementation Insights: Avionics

Interview: Kevin Flynn

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		- More top level guidance and management is necessary to define requirements and contain costs as opposed to allowing individual IPTs to drive cost		

4.5 First Stage

4.5 - Implementation Insights: First Stage

Interview: Chris Calfee

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
1st 1	SCH	Schedule—The Key Driver - "schedule has been the number one issue"	- Greater willingness of Management/Leadership to push-back on schedule may be warranted	
1ST 2	EMSE TV REQ	Testing Philosophy – Human-Rating Versus Test Flight? - Different opinions existed regarding the necessary test, verification, and acceptance criteria for the parachutes - Fundamental differences of opinion exist with regard to test and verification philosophy – test flight? Or human rated mission?	- NASA management (Program, OCE, and OSMA) can assist by coming together on verification expectations and methods early in the formulation phase.	
1ST 3	ESME TV REQ	Disconnects in Test and Verification Process - Fundamental disconnects existed between SE&I and 1st stage regarding the test and verification process and the implementation of design verification reviews, boards and document approval and control	- SE&I can assist IPTs by clearly articulating verification requirements and process expectations early in formulation.	
1ST 4	COMM ORG	Level 3 Communications Issues - Level 2 – Level 3 communication issues and role and responsibility issues must be addressed	- Program leadership emphasis is required to address communication issues between Levels 1, 2, and 3 within the program	
1ST 5+	COMM	Communication Was Key to Sensor Integration on 1st Stage - Excellent teamwork and communication was key in implementing hundreds of sensors on the 1st Stage vehicle		

1ST 6	SMA REQ	Coupled Loads Analysis and Impacts on Range Safety Approval - The latest load-set (coupled loads) indicates range safety radio receiver qualification criteria an exceeds requirements at 90 seconds into the flight.	- require completion of analysis (or at least mature analysis) prior to design and/or fabrication	

4.6 CM/LAS

4.6 - Implementation Insights: CM/LAS
Interview: Kevin Brown + CM/LAS LL Document (Volume III)

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
CML 1	SCH	Schedule—The Key Driver - "schedule was a huge driver" Both project-level schedule issues and tactical scheduling issues created inefficiencies. Lack of an integrated program schedule coordinating center-to-center activities was highlighted as a problem	- In nearly every interview "schedule" has been highlighted as an underlying problem without specifics … It is inferred that schedule pressure may be the root cause of moving forward without all the necessary systems engineering details adequately addressed ……………	
CML 2	EMSE COMM	Communication Issues – Human-Rating Versus Test Flight? - Center-to-center communication and teamwork was an issue - Different expectations existed wrt assurance and work process (test demonstration project v. human rated project)	- Directive leadership needs to articulate requirements up-front	
CML 3	REQ	Late Definition of Environmental Requirements - Definition of environmental requirements and outer mold-line was an issue - interface requirements definition was an issue		
CML 4	MFG	Fastener Availability - Fastener availability and management was an issue		
CML 5	EMSE	Milestone Reviews Redundancy	- consider meeting with review chairmen weeks in advance of the review to calibrate on expectations	

4.6 - Implementation Insights: CM/LAS

Interview: Kevin Brown + CM/LAS LL Document (Volume III)

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		- Milestone reviews were “too many” and redundant		
CML 6	RES HR	Workforce Experience and Stability Issues - Human resource issues were a prominent concern – workforce experience, capability, and stability created problems and delays	- Bring HR into the process early-on	
CML 7	EMSE	Facilities / GSE Coordination Challenges - Prioritization and coordination of project elements competing for access to facilities and services was an issue. Scheduling of cranes and facilities at KSC was an example.	Increased capability and authority for SEI would mitigate	
CML 8	EMSE	Technical Authority - The need exists to strongly articulate roles and responsibilities of program elements and the Agency Technical Authorities (SMA and Engineering)	- Directive leadership needs to articulate roles and responsibilities up-front	
CML 9	RES IT	Information Management and IT Challenges - IT Resource management was a hassle leading to delays. Examples included ODIN changes in software and policy without consideration of program/project impact. Windchill was also considered a huge obstacle – slow, hard to use, intermittent access, poor search.	- bring IT Management into the process early-on	
CML 10	EMSE Coord	KSC Facility Access and Work Process Communication Many issues were identified in coordination facility access,	- initiate planning early-on	

4.6 - Implementation Insights: CM/LAS

Interview: Kevin Brown + CM/LAS LL Document (Volume III)

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		security, parking, badging at KSC		
CML 11	REQ DFI	Define Flight Instrumentation Requirements Early Flight instrumentation requirements were not well defined, new requirements were imposed late in the hardware integration phase.	- a stronger SE&I requirements management role will help	
CML 12	DSGN Transport	Consider Transportation and Material Handling in Design Design failed to consider transportation, handling, and lifting constraints and	- use design review (gate) process to ensure consideration of all necessary functional requirements (transportation, handling, interfaces, drawings, work instructions) design reviews	
CML 13	RES HR	Overtime Policy Challenges Issues arose concerning overtime and comp time policies and management during operational activities	- engage Center HR management early in the process to ensure policies are clarified and issues are addressed	
CML 14	EMSE REQ	KSC Hardware Acceptance Process Challenges Need to better communicate and articulate requirements for hw acceptance at KSC (DD1149 process)	- plan ahead / engage KSC early / requires SE&I coordination role	

4.7 RoCS

4.7- Implementation Insights: RoCS

Interviews: Ron Unger

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
ROC 1	EMSE TV SMA	Heritage Hardware Design Verification Philosophy Challenges - "The design verification philosophy for ROC was an issue – the high reliability heritage system was subjected to extensive design verification testing and analysis"	- Expectations and philosophy for test and verification must be better articulated across program/project participants	
ROC 2	EMSE REQ	Environmental Loads Data Books Stability - Requirement stability "environmental loads was a moving target" – "some data books simply came out too late"		
ROC 3	EMSE SCH	Schedule—The Key Driver - Schedule is the real risk driver – "perhaps SEI should have ensured that the designs did not move forward until the requirements were locked in"	- Management needs to temper, balance, or pull-back on schedule pressure when critical requirements remain undefined or are changing - A stronger SEI function must be implemented.	
ROC 4	EMSE SMA TV	Testing Philosophy – Human-Rating Versus Test Flight? - The imposition of Human Rated – style test and verification methods and approaches on a fast-track demonstration test flight was deemed onerous………………… "people need to be aware of the type of mission you are flying"	- Expectations and philosophy for test and verification must be better articulated across program/project participants	

4.8 SE&I

A.8.1 SE&I IPT Narrative Summary <INSERT HERE>
A.8.2 SE&I IPT Top 3 <INSERT HERE>

4.8 - Implementation Insights: SE&I
Interview: Marshall Smith

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
SE&I 1	EMSE	Impacts of Late Implementation of SE&I IPT The SE&I function was established too late and without the necessary authority	- Management/Leadership must ensure early implementation	TBD
SE&I 2	REQ	Challenges from Early Project Initiation and Late Requirements Definition 10 months into the project before technical requirements were defined. Many many problems resulted from moving out too soon – (pushing the SE process out of shape)		
SE&I 3	REQ	Challenges from COTS (HW/SW) Use Rules for dealing with COTS (HW/SW) were not defined with necessary rigor leading to disconnects and misunderstanding in the verification process requirements	- Strong proactive SE&I function required at start to address this type of issue	
SE&I 4	REQ	Heritage Hardware Design Verification Philosophy Challenges Rules for dealing with Heritage (HW/SW) were not defined or characterized with necessary detail to avoid problems in verification	- Strong proactive SE&I function required at start to address this type of issue	
SE&I 5	SCH	Schedule—The Key Driver Schedule was the root cause driver for many Ares I-X problems. Three years is a very fast time-line to stand-up a launch vehicle capability. The get-it-done		

		attitude went a long way to making it work – despite numerous schedule-derived problems		
SE&I 6	EMSE	Impacts from Partitioning SE&I Functions to Mission Management Team Traditional SE&I functions were collapsed into the Mission Management function and controlled by a Project-level Board, the "XEB." The XEB was considered cumbersome and the source of ongoing delay. Another effect was to limit SE&I authority and influence in implementing it's important integration function.	- Rethink relative roles of SE&I v. Mission Management organization	
SE&I 7	EMSE	Establishing Ground and Flight Article Coordination Early Ground-side / Flight-side coordination has been a difficulty. Integration of the two sub-cultures needs to take place "early-on"		
SE&I 8	REQ	Impacts from Use of Center Standards Versus NASA Standards Center standards differ and do not necessarily correspond with NASA standards. Time was wasted debating and adjudication the application of disparate standards. Everyone needs to get on the same sheet of music "early-on"	- Strong proactive SE&I function required at start to address this type of issue	
SE&I 9	EMSE	Center SE&I Staffing Challenges SEI staffing at participating centers were in difficult positions with local Center and element perspectives often trumping the SEI (integrated system) perspective.	- A stronger, more directive SE&I function and organization required	
SE&I 10	SCH	Integrated Master Schedule Challenges Each center and each contractor maintained a separate calendar using disparate software applications or versions of the same software (Primavera). The result was no mutually acknowledged and shared Integrated Master Schedule. Innumerable problems resulted.	- Management/Leadership must direct coordinated effort	

SE&I 11	EMSE RR	Technical Authority Roles and responsibilities of Technical Authority (v. Independent Technical Authority) needs to be established "early-on." Technical Authority, involved in the program flow is preferred over an arms-length role.	- Management/Leadership must clarify and articulate up-front	
SE&I 12	T&V REQ	Testing Philosophy – Human-Rating Versus Test Flight? Much discussion and delay resulted from debating Flight Test verification approaches verses Human-Rated Flight Program verification approaches. The program needs to define the verification ground rules " (risk posture) early-on" and stick with it.	- Strong proactive SE&I function required at start to address this type of issue	
SE&I 13	REQ T&V	Importance of Adequate Requirements Authorship Many verification problems stemmed from the inability of project elements to write complete, rigorous, verifiable requirement statements. This was the root cause for much delay and inefficiency. Complete requirements must be developed prior to contracts and task agreements	- Implement training and enforce discipline through strong SE&I	
SE&I 14	T&V REQ EMSE	Challenges from SE&I Authority / Span of Control Some IPTs simply "did it their way," failing to acknowledge SE&I authority. "Why do you need this," characterizes the dialogue. The entire system-level verification process is rendered ineffective without a coordinating authority	- A stronger, more directive SE&I function and organization required	
SE&I 15	RES Change	Resource Impacts from Launch Date Changes Program Management must recognize the resource impact of changes in launch date which require rework of multiple trajectory, thrust, and Range Safety products.		

SE&I 16	T&V	Importance of Element-Level Verification Before Shipment to KSC Complete element verification "before you ship." The current dilemma is a "mountain of paper," necessary to complete (from element verification) before system-level verification can be accomplished. "It is never, never, never faster to ship before verification is complete."	- Management/Leadership along with SE&I must clarify and articulate up-front	
SE&I 17+	RES	Integrating KSC Personnel Into SE&I Brining KSC personnel to LaRC to assist in SE&I implementation was effective and important in mitigating many problems and facilitating effective integration		
SE&I 16+	ESME	Positive Outcomes from a Flat Organization Cutting red-tape and flattening the organization was a positive step.		
SE&I 17+	EMSE	Embedding SE&I Within IPTs Embedding an SE&I representative within each IPT was a good strategy		

4.9 Engineering Technical Authority

4.9 - Implementation Insights: Engineering Technical Authority Interview: Glen Jones (MSFC – Deputy, Tech Asst MMO-Chief Engineer, Engineering Technical Authority, Ares I-X)				
ID	**Theme**	**Description / Context**	**Opportunity Recommendation(s)**	**POCs / Relevant AIX Documents**
Eng1	EMSE	**Benefits of a Single, Coordinated, and Integrated Engineering Management Approach** Employing a single, coordinated, integrated engineering management approach from the beginning would have ultimately been better. The "Ground-side / Flight-side" approach sowed the seeds for many subsequent problems.	TBD	TBD
Eng2	SCH	**Schedule—The Key Driver** The program was conducted under an implied "schedule as an Independent variable" (SAIV) paradigm. Schedule was the driver for too much concurrency.		
Eng3	SCH EMSE	**Synchronizing Maturity of IPT-Level Products / Processes** With different elements moving forward in an uncoordinated fashion one element would get ahead of the other and effectively limit the trade-space of the other		
Eng4	ESME	**Challenges Created from Separate Ground and Flight Systems Requirements documents** Maintaining two separate (Ground-side/Flight-side) system-		

4.9 - Implementation Insights: Engineering Technical Authority

Interview: Glen Jones (MSFC – Deputy, Tech Asst MMO-Chief Engineer, Engineering Technical Authority, Ares I-X)

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		level requirements documents also created difficulties.		
Eng5	EMSE ORG	**Challenges from Design Maturity Mismatches** As various elements found themselves out-of-sync and working with different design solutions, at different points of maturity the integration or coming together resulted in broad conflict. Conflict resolution was a big deal – who changes? – do you both change? – who is the deciding authority?		
Eng6	REQ SCH	**Integration Challenges Due To Lack of Synchronized Requirements Flow Down** Requirement flow-down occurred along separate time-lines, also contributing to the disconnect in development maturity and ultimately interface conflicts		
Eng7	ORG COM	**Center Integration / Cultural Differences Impact on Communication** Organizational stress and communication stress was a challenge bringing together, 2 spaceflight centers, 2 research centers, role reversed contractors (Boeing and ATK) wih respect to nomenclature, methodology, interface management, documentation	Needed stronger centralized management leadership to overcome inherent stresses within project.	
Eng8	RES	**Personnel Skill Levels and Training Challenges** Staffing of critical tasks and activities with inexperienced people		

4.9 - Implementation Insights: Engineering Technical Authority

Interview: Glen Jones (MSFC – Deputy, Tech Asst MMO-Chief Engineer, Engineering Technical Authority, Ares I-X)

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		resulted in many problems. One cannot rely on OJT with a fast-paced, project like Ares I-X.		
Eng9	EMSE ORG	**Clearly Defined Roles and Responsibilities** Clarifying roles and responsibilities up-front across the entire project is super-critical. The confusion concerning integration management and shift from one paradigm to another was very disruptive to many elements.		
Eng10	RES IT	**Information / IT Architecture Impact on Technical Reviews** The project IT infrastructure was an obstacle to integrated management. Access to element records in Windchill was difficult –impossible because of differences in implementation and organization. Security and access hampers successful implementation of critical systems engineering functions. A simple task of determining the number of waivers /deviations and their status across IPTs or elements was nearly impossible. Some waivers may affect other elements - some may be safety critical – no way of knowing.	Plan and implement a coordinated information/knowledge management architecture for the entire project	

4.10 Project Integration Management

A.10 - Implementation Insights: Project Integration Management

Interview: Bruce Askins

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
PI1	EMSE SCH ORG RES SMA	**Make CMDM Work** Up-front & early on – develop and Implement an agreed upon and accepted CMDM Plan with all program/project participants (NASA Centers and contractors) Issues, delays, re-do, and extra work has been associated with uneven implementation of Windchill and Primavera across IPTs. Further, program oversight, (OCE and SMA Technical Authority) integration, and management was hindered by Center-based IPT reluctance to use common project information systems.	TBD	TBD
PI2	REQ	**Agree Upon Verification Approach** Up-front & early on – establish agreement on how to conduct verification on elements and on the integrated system		
PI3	EMSE ORG	**Command & Control Authority Essential in CMDM** Require co-located CMDM liaison within IPTs to report first to the MMO and their IPT secondly. Mission-level CMDM implementation was chaotic with disparate IPT numbering systems, design models, CAD-CAM applications, storage methods, information architecture		
PI4	SCH	**Integrated Master Schedule Must Be Developed & Maintained**		

A.10 - Implementation Insights: Project Integration Management

Interview: Bruce Askins

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		Some IPTs employed Primavera-X - others used Primavera-Y (incompatible) while SE&I used MS Project. The lack of CMDM authority resulted in inability to efficiently develop and maintain an Integrated Master Schedule creating major management challenges and contributing to delays (repetitive manual integration)		
PI5+	SCH EMSE	**Lean Event Schedule Improvement** The use of ""Lean" events focusing on "long pole schedule items helped "pull-back end-dates on many IPT schedules. Even more benefit might have resulted from ability to assess the overall Integrated Master Schedule.		
PI6	EMSE SMA	**SRB Activity Can Help or Hinder** Continuous-linkage SRB reviewers were deemed a net-plus, providing independent oversight but also contributing to the product. "Drop-in" SRB review (and reviewers) resulted in uneven outcomes – sometimes helpful more often not – resulting in delays and non-value-added activities..		
PI7	SMA REQ	**Clarify & Define SMA Requirements Up-Front** A great deal of time (delay) had to be devoted to tailoring / defining SMA requirements and the project SMA and reliability philosophy too late in the project life-cycle – after contracts and task agreements had been established		
PI8	RES ORG	**"They Had The Slots But Not The People"** The SEI organization never got up to speed, in part due to the inability to staff open positions with experienced, qualified		

A.10 - Implementation Insights: Project Integration Management
Interview: Bruce Askins

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		people at the responsible Center. This contributed to many SEI related issues including delays in producing the Loads Data Book and system-level verification		
PI9	EMSE ORG	**Common Mission - Calibrating Philosophy & Approach Essential in Multi-Center Project** Must start with a common understanding, common training regarding the Common Mission. Disconnects and delay ultimately resulted from fundamental philosophical (cultural) differences in how to implement Ares I-X. Examples include: operational project orientation with schedule focus v. research project orientation with “ultimate design” focus. The challenge was to sever Center and IPT-centric bonds and outlook and create a Mission-centric viewpoint		
PI10	EMSE SEI	**Stronger MMO Role Compensated For Underpowered SEI Role** The challenges associated with late and incomplete SEI implementation resulted in more decision authority being invested in MMO. This worked well, because of “the people” involved but is not a best practice for future projects. For example CMDM is usually in SE&I but was implemented (with problems) from the MMO organization		

A.10 - Implementation Insights: Project Integration Management

Interview: Bruce Askins

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
PI11	RES ORG	**Web-Meeting Woes** The Ares 1-X program struggled with NASA IT infrastructure support for web-meetings (WebEx). Future projects with widely distributed teammates must put in-place the necessary collaboration functionality.		
PI12	EMSE	**NDA Hassles / Access To Information** Delays, confusion, and frustration arose from the need to implement Non Disclosure Agreements (NDAs) between the multiple contractors supporting the project. The NDA delays compounded the already difficult security access requirements for Windchill. Future projects must address these details earl-on.		
PI13	EMSE	**Control Boards: Critical Function – Must Not Become a Bottleneck** An effective program and project control board process must be implemented early and must be designed to move activities along without becoming a bottleneck		
PI14	EMSE REQ	**Build Critical Governance Documentation Early-On** Early on establish, develop, implement necessary project documentation ”command media” an communicate the “must comply” requirements clearly and with force		

4.11 Mission Management

4.11 - Implementation Insights: Mission Management
Interviews: Jon Cowart / Steve Davis

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
MM1	EMSE	**Make SEI Stronger**	TBD	TBD
MM2	RES HR	**Ensure Critical Functions Are Staffed With The Right People, with the Right Experience, and Right Orientation** The SEI function was not adequately staffed. Critical positions were vacant and i-place staffing frequently lacked the necessary experience.		
MM3	REQ T&V	**Calibrate Approach on Requirements Definition and Allocation** Verification problems resulted from differences and unclear authority for defining and flowing down requirements(from Functional Requirements to System-level, to sub-system level organizations). Ownership of the requirements and responsibility for defining and managing verification was / continues to be a continuing issue. Who owns functional requirements – who owns design detail requirements - ?		
MM4	T&V	**Co-location Is Key To Successful System-Level Verification** Many problems and delays were/are associated with system-level verification using a virtual team structure.		

4.11 - Implementation Insights: Mission Management

Interviews: Jon Cowart / Steve Davis

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
MM5	DSGN	**Heritage HW and SW May Not Be A Bargain** Do not become enamored with the assumption the heritage hardware or software will is a good idea. The elements of Ares I-X with the greatest schedule and cost problems were heritage, specifically, First Stage and Avionics IPTs. RoCs was heritage and actually performed well.		
MM6	EMSE	**Implement Integration at the SEI Level** The XCB process worked but it is not a "best practice" model. Integration decision authority is better implemented at the level of a well staffed, capable SEI organization		
MM7	REQ T&V	**Define Verification Methods & Requirements Up-Front – You Will Not Have Time Later** The Ares i-X project was implemented with too much concurrency. Assumptions were made that "we can do this later." This was a bad assumption.		
MM8	REQ SMA	**Define SMA Requirements Up-Front & Early-On** "We kept waiting for Level-2 to flow-down the SMA requirements."		
MM9	RES ORG	**Training Can/Could Have Mitigated Cultural Disconnects** Training, or an intensive orientation session might have been offered to key project team members to define, articulate program philosophy, roles and responsibilities, verification approach, and expectations for integration and interface		

4.11 - Implementation Insights: Mission Management

Interviews: Jon Cowart / Steve Davis

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		management.		
MM10	EMSE	**Risk Communication** What is a Red Risk? – what does Red Mean? – Is Red a70% probability of success? or some other number - 90% or 92% or 95%? Different people and/or organizations have different yardsticks and assumptions. Long debates/discussions resulted with different stakeholders with operating under assumptions (human rating, or demonstration test flight) and with different ideas concerning what is yellow and what is red.		
MM11	T&V	**Complete Assembly and Verification Before Shipping** Many issues and problems were associated with shipping elements with incomplete assembly and without having conducted verification testing.		
MM12+	ORG	**Flattening The Organization Helped** The re-organization to a flatter model (IPTs) was considered a factor contributing to success.		
MM13	RES	**IT Systems & Applications Became Barriers** The Ares I-X Project was dependent on ineffective, cumbersome IT communication, collaboration, and CMDM infrastructure. Center IT functional managers and Center-		

4.11 - Implementation Insights: Mission Management Interviews: Jon Cowart / Steve Davis				
ID	**Theme**	**Description / Context**	**Opportunity Recommendation(s)**	**POCs / Relevant AIX Documents**
		based project elements must come together with overall mission management up-front to iron out what is expected and what is mandated.		

4.12 Project Manager

4.12 - Implementation Insights: Project Manager
Interviews: Bob Ess

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
PM1	EMSE	**Systems Engineering Framework Challenges** I wish we had spent more time in the Systems Engineering framework (documentation, ICDs, roles and responsibilities, change processes, configuration management)	TBD	TBD
PM2	EMSE	**Shift from Book Manager to Systems Integrator** The SEI function implementation was less than adequate because: "Book Managers" were too passive. The title "Book Manager" was also probably a mistake in that it conveys an actuarial or bookkeeping posture – they needed aggressive, proactive interface managers.		
PM3	EMSE RES	**Systems Integrator Personality Profile** The ideal Integration Managers should have an aggressive, extraverted, personality, willing to dig deeply into issues and details. The GS grade level of the integration managers may also be a factor to consider – senior GS 14 or GS-15		
PM4	EMSE RES	**Get the Right People on the Bus** It is necessary to spend more time up-front to ensure you have the right people from the start		
PM5	EMSE REQ	**Requirements Verification Process – A Ticking Time Bomb** The requirements verification process was "broken." We were talking past each other thinking we understood each other. We didn't. Discussions went down to the second level of detail. We should have gone down to the 4th level. We should have taken a couple of examples and walked through the complete		

4.12 - Implementation Insights: Project Manager

Interviews: Bob Ess

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		process. That would have exposed the disconnects in our thinking and assumptions.		
PM6	EMSE ORG COMM	**NASA Center-Level Cultural Challenges** The multi-center, multi-cultural project team approach created challenges. It was a huge challenge to get people to be mission-centric in their thinking. The tendency was to defer to their Center, institutional way of doing things and interpretations of policy and/or technical issues. <More work needs to be done up front to create a Mission culture – Also NASA Senior Management must make it clear that the Center can push but that the decision resides with the program authority.		
PM7	EMSE RES	**Critical Skill Set Challenges** LaRC did not in fact have the capability to implement the SEI function for the Ares I-X project. Changes had to be implemented in personnel.		
PM8+	EMSE	**Streamlined Boards and Panels** The XCB functioned effectively to disposition issues and allocate resources. The ARES Program Board structure is multi-tiered and more cumbersome.		
PM9	EMSE SMA	**Independent Review** The SRB (Independent Review) Process was helpful in that they focused on specific issues. With a number of noted exceptions, the PDR/CDR Independent Board was less specific and less useful to the Ares I-X Project team. Technical peer review (sub-system expert with independent experts) would have been useful.		
PM10	EMSE	**WANTED: Expendable Launch Vehicle (ELV) Experience** Ares I-X is more of an ELV than a human-rated space vehicle. It would have been beneficial to involve ELV program engineers		

4.12 - Implementation Insights: Project Manager

Interviews: Bob Ess

ID	Theme	Description / Context	Opportunity Recommendation(s)	POCs / Relevant AIX Documents
		and experts early on in a technical independent assessment capacity.		

Appendix A. Acronyms

A&S	Aging and Surveillance
ACWP	Actual Costs Work Performed
ADMS	Automated Data Management System
ADP	Acceptance Data Package
AF	Air Force
AFSCM	Air Force Systems Command Manuals
AFSOP	Ares I-X Florida Safety Operating Plan
AG	Attitude Gyro
AIT	Assembly, Integration, and Test
AIX	Ares I-X
AMS	Automated Material System
APO	Ares Project Office
ARF	Assembly Refurbishment Facility
ASA	Altitude Switch Assembly
ASME	American Society of Mechanical Engineers
ASOC	Atlas Space Operations Center
ATP	Acceptance Test Procedure; Authority to Proceed
ATVC	Avionics Thrust Vector Control
AVIO	Former organizational name for LaRC SE&I
BCWP	Budgeted Cost Work Performed
BCWS	Budgeted Cost Work Scheduled
BOE	Basis of Estimate
BRCU	Booster Remote Control Unit
BSM	Booster Separation Motor

BW	Bandwidth
C&C	Command and Control
C&DM	Configuration and Data Management
CAD	Computer-aided Design
CADD	Computer Aided Design and Drafting
CADM	Core Architecture Data Model; Computer-Aided Design and Manufacturing
CAM	Computer Aided Manufacturing
CAT 1	Category 1
CAT 2	Category 2
CCC	Command, Control, & Communications
CCLS	Computer Controlled Launch Set
CDM	Configuration and Data Management
CDR	Critical Design Review
CE	Chief Engineer
CEQATR	CxP Environmental Qualification & Acceptance Testing Requirements
CFD	Computational Fluid Dynamics
CI	Conformance Inspection, Configuration Item
CIL	Critical Item List
CIPS	Computer Integrated Process Systems
CLV	Crew Launch Vehicle
CM	Configuration Management; Crew Module
CM/LAS	Crew Module / Launch Abort System
CMP	Configuration Management Plan
CMQC	Configuration Management Quality Control
CofC	Certificate of Conformance
CoFTR	Certification of Flight Test Readiness

ConOps	Concept of Operations
COTS	Commercial Off-the-Shelf
CPAR	Corrective Preventive Action Request
CPR	Cost Performance Report
CR	Change Request
CRADLE	(requirements management software)
CRM	Continuous Risk Management
CSERP	Constellation Safety and Engineering Review Panel
CSO	Chief Safety Officer
CSRP	Constellation Program Safety Review Panel
Cx	Constellation
CxCB	Constellation Program Control Board
CxP	Constellation Program
CxPRACA	Constellation Problem Reporting and Corrective Action
CxSECB	Constellation Systems Engineering Control Board
CxSERP	Constellation Safety Engineering Review Panel
DAC	Design Analysis Cycle
DCMA	Defense Contract Management Agency
DCR	Design Certification Review
DD 1149	DoD Form 1149 – Requisition or Invoice Shipping Document
DD 250	DoD Form 250 – Material Inspection and Receiving Report
DDT&E	Design, Development, Test, and Evaluation
DE	Design Engineering
DEV	Development
DFI	Development Flight Instrumentation
DGA	Designated Government Authority

DM	Data Management
DMP	Data Management Plan
DoD	Department of Defense
DOF	Degree of Freedom
DOL	Day of Launch
DR	Discrepancy Report
DRM	Design Reference Mission
DWP	Digital Wave Processor
DWV	Dielectric Withstanding Voltage
DXCB	DFI Control Board
ECB	Engineering Change Board
ECN	Engineering Change Notice
ECS	Environmental Control System
EDF	Electronic Development Fixture
EELV	Evolved Expendable Launch Vehicle
EEE	Electronic, Electrical, and Electromagnetic
EGLS	Exploration Ground Launch Services
EGSE	Electrical Ground Support Equipment
EIS	Environmental Impact Statement
EMB	Engineering Management Board
EMI	Electromagnetic Interference
EMP	Environmental Management Plan
EO	Earth Orbit; Earth Observation
ER	Explanation Report
ERB	Engineering Review Board
ERD	Element Requirements Document; Environmental Resources Document

eRoom	(collaboration software for distributed work teams)
ES	Engineering Specification
ESA	European Space Agency
ESD	Electrostatic Discharge
ESDS	Electrostatic Discharge Sensitive
ESMARR	Engineering and S&MA Readiness Review
ESMD	Exploration Systems Mission Directorate
ESS	Executive Summary Schedule
ESTS	Engineering Support and Technical Services
ETZ	Eastern Time Zone
EVM	Earned Value Management
FAM	Functional Analysis Model
FAR	Federal Acquisition Regulation
FCS	Flight Control System
FEC	Field Engineering Changes
FEM	Finite Element Method
FLUINT	(NASA standard tool for thermo-hydraulic analysis)
FMEA	Failure Mode and Affects Analysis
FOD	Foreign Object Damage; Flight Operations Directorate
FOM	Figures of Merit
FOS	Flight Operations Support; Factors of Safety
FR	Flight Rule
FR1	Firing Room 1
FS	First Stage
FSAM	First Stage Avionics Module
FSE	Flight Support Equipment

FSOP	Florida Safety Operating Plan
FSS	Fixed Service Structure
FTE	Full-time Equivalent
FTP	Flight Test Plan
FTINU	Fault Tolerant Inertial Navigation Unit
FTRR	Flight Test Readiness Review
FTS	Flight Termination System
FTV	Flight Test Vehicle
GC3	Ground Command, Control and Communications
GCE	Ground Chief Engineer
GCEL	Ground Control Experimental Laboratory
GCS	Ground Communications System
GFE	Government-Furnished Equipment
GN	Ground Network
GN&C	Guidance, Navigation, and Control
GO	Ground Operations
GOP	Ground Operations Project
GRC	Glenn Research Center
GS	Ground Systems
GSE	Ground Support Equipment
GSRD	Ground Support Requirements Document
HAWG	Hazards Analysis Working Group
HB	High Bay
HMF	Hypergolic Maintenance Facility
HOSC	Huntsville Operations Support Center
HQ	Headquarters

HW	Hardware
HWL	Hardware in the Loop
I/O	Input / Output
ICBM	Intercontinental Ballistic Missile
ICD	Interface Control Document
ICE	Integrated Collaborative Environment
ICM	Interim Control Module
ICMC	International Cryogenic Materials Conference
ID&A	Integrated Design and Analysis
IDA	Integrated Design and Analysis
IDEAS	Initial Design and Evaluation Analysis System
IDOS	Integrated Development and Operations Systems
IFTS	Integrated Flight Test Strategy
IG	Internal Guidance; Instrumentation Group; Inertial Guidance
IHR	Integrated Hazard Report
ILS	Integrated Logistics Support
IM	Instant Messaging
IMS	Integrated Master Schedule; Information Management System
INS	Inertial Navigation System
IPD	Integrated Product Development
IPM	Integrated Project Management
IPPD	Integrated Product and Process Design
iPRACA	Integrated Problem Reporting and Corrective Action; Interim PRACA
IPT	Integrated Product Team
IRD	Interface Requirements Document
IRIS	Incident Reporting and Information System

IRMA	Integrated Risk Management Application
IRT	Incident Response Team; Icing Research Tunnel; Integrated Real Time
IS	Information Security
IT	Information Technology
ITA	Independent Technical Authority
ITAR	International Traffic in Arms Regulation
IV&V	Independent Validation and Verification
JCL	Joint Cost Level
JDMTA	Jonathan Dickinson Missile Tracking Annex
JSC	Johnson Space Center
KBR	Knowledge Based Risk
KC	Knowledge Capture
KDP	Key Decision Point
KSC	Kennedy Space Center
LaRC	Langley Research Center
LAS	Launch Abort System
LAT	Launch Team
LC	Launch Complex
LC39B	Launch Complex 39B
LCC	Launch Commit Criteria; Launch Control Center
LCRSP	Launch Constellation Range Safety Panel
LDE	Lead Design Engineer
LE	Lead Engineer
LLIS	Lessons Learned Information System
LM	Lockheed Martin
LMA	LM Aeronautics

LMCO	LM Corporation
LPE	Launch Package Engineer
LSC	Launch Service Contractor; Linear Shape Charge
LSE	Lead Systems Engineer
LST	Launch Support Team
LTDT	Launch Team Design Team
M&P	Materials and Processes
Max Q	Maximum Dynamic Pressure
MFG	Manufacturing; Major Functional Group
MCC	Mission Control Center
MILA	Merritt Island Launch Area
MIP	Mission Implementation Plan
MIUL	Material Identification Usage List
MK	(Space Shuttle Program Launch Integration [MK] organization)
MLP	Mobile Launcher Platform
MM	Mission Manager
MMO	Mission Management Office
MOA	Memorandum of Agreement
MOD	Mission Operations Directorate
MPE	Maximum Permissible Exposure; Mean Percent Error
MPR	Monthly Progress Report
MR	Material Review; Material Request
MRB	Material Review Board
MRCAP	Mishap Response Contingency Action Plan
MS	Microsoft
MSC	With Random – Approach/Tool to Random Analysis from MSC company

MSF	Mission Success Factors
MSFC	Marshall Space Flight Center
MVP	Master Verification Plan; Most Valuable Player
NAR	Non Advocate Review
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis Program
NC	Non-conformance
NESC	NASA Engineering and Safety Center
NISN	NASA Integrated Services Network
NPR	NASA Procedural Requirement
NSD	NASA Standard Detonator
NSTS	National Space Transportation System
NX	NASA/Xerox Knowledge Network
O&M	Operations and Maintenance
O&SHA	Operating and Support Hazard Analysis
OCE	Office of Chief Engineer
OCIO	Office of Chief Information Officer
OEL	Orbiter Electrical
OFI	Operational Flight Instrumentation
OIO	Operation Integration Office
OJT	On-the-Job Training
OML	Outer Mold Line
OMRSD	Operations and Maintenance Requirements and Specifications Document
OPF	Orbiter Processing Facility
ORCA	Ordnance Remote Control Assembly.
OSHA	Occupational Safety and Health Administration/Act

OSMA	Office of Safety & Mission Assurance
OTR	Operating Time Record
PATRAN	(Prototype Development Associates Engineering finite element analysis [FEA] software)
PBMA	Process Based Mission Assurance
PBMA-KMS	PBMA-Knowledge Management System
PBS	Program Breakdown Structure
PDF	Portable Document Format
PDL	Ponce De Leon (Tracking Station)
PDR	Preliminary Design Review
PERT	Program Evaluation and Review Technique
PK	Peacekeeper
PLT	Production Lead Time
PM	Project Management; Project Manager
PMB	Performance Measurement Baseline
POC	Point of Contact
POP	Program Operating Plan
PP&C	Program, Planning, and Control
PRACA	Problem Reporting and Corrective Action
PRD	Program Requirements Document
ProE	Professional Engineering (used with PATRAN)
QA	Quality Assurance
QC	Quality Control
QE	Quality Engineer
QPRD	Quality Planning (or Program) Requirements Document
QTP	Qualification Test Plan

R&D	Research and Development
R&R	Roles and Responsibilities; Remove and Replace; Rendezvous and Recovery
RAC	Reliability Action Center
RAM	Random Access Memory
ReSync	Reorganization
RF	Radio Frequency
RFA	Request for Action
RFI	Radio Frequency Interference; Request for Information; Remote Facility Inquiry; Remote File Inquiry
RFID	Radio Frequency Identification
RID	Review Item Disposition
RM	Risk Management
RMP	Risk Management Plan
ROC	Request of Change
RoCS	Roll Control System
ROR	Rate of Return
RPE	Reliability Project Engineer
RPSF	Rotation Processing and Surge Facility
RRGU	Redundant Rate Gyro Unit
RSRM	Reusable Solid Rocket Motor
RT-455	Trowelable Thermal Ablative Compound
S&MA	Safety and Mission Assurance
SA	Spacecraft Adapter
SAR	Safety Analysis Report
SAP	Systems Applications and Products (financial data processing software)
SBU	Sensitive But Unclassified

SDP	Safety Data Package
SE	Systems Engineering
SE&I	Systems Engineering and Integration
SE&IE	Systems Engineering and Integration Engineering (LaRC)
SEA	Scanning Electrostatic Analysis
SECB	Systems Engineering Change Board
SEI	Systems Engineering Integration
SEMP	Systems Engineering Management Plan
SEP	Systems Engineering Process
SERF	Systems Engineering Review Forum; Space Environment Research Facility
SIL	Software Integration Laboratory
SIM	Scientific Instrumentation Module
SM	Service Module
SMA	Safety and Mission Assurance
SMAW	Shielded Metal Arc Welding
SMSR	Safety and Mission Success Review
SOW	Statement of Work
SOWG	Science Operations Working Group
SPOC	Shuttle Payload Operations Contractor
SQ&MA	Safety, Quality and Mission Assurance
SR&QA	Safety, Reliability, and Quality Assurance
SRB	Solid Rocket Booster
SRD	Systems Requirements Document
SRM	Solid Rocket Motor
SRR	System Requirements Review
SSAS	STS/SSPE Attachment System

SSC	Stennis Space Center
SSP	Space Shuttle Program
SSPE	Space Station Program Element
SSPF	Space Shuttle Processing Facility
STD	Standard
STS	Space Transportation System
SUX	(Tied to Primavera Scheduling)
SW	Software
SWRD	Software Requirements Document
T&E	Test and Evaluation
TA	Technical Authority
TBD	To Be Determined
TBE	Teledyne Brown Engineering
TBR	To Be Resolved
TD	Thermal Desktop
TIG	Time of Ignition
TIM	Technical Interchange (Interface) Meeting
TLYF	Test-Like-You-Fly
TPM	Technical Performance Measurement
TPS	Thermal Protection System
TQR	Technical Quality Review
TR	Technical Report
TREP	Technical Representative
TSMA	Transition Safety Mission Assurance
TTA	Technical Task Agreement
TVC	Thrust Vector Control

TxRB Transition Review Board

ULA United Launch Alliance

URCU Upper Stage Remote Control Unit

USA United Space Alliance

USAF United States Air Force

US Upper Stage

USS Upper Stage Simulator

VAB Vehicle Assembly Building

VCE Vehicle Chief Engineer

VI Vehicle Integration

VPN Virtual Private Network

VRD Verification Requirements Document

VSS Vehicle Stabilization System

WAD Work Authorization Document

WBS Work Breakdown Structure

WG Working Group

WGC (the LM equivalent to Windchill)

WO Work Order

WRT With request to

WSTF White Sands Test Facility

WYE Work Year Equivalent

XCB Ares I-X Control Board