NASA Exploration Systems Mission Directorate
Ares I-X Knowledge Capture

Volume III: Compendium of Lessons Learned

Ares I-X Project Management and Integrated Product Teams

ESMD Risk & Knowledge Management Office

May 20, 2010

Introduction

Introduction

This volume of the Ares I-X Knowledge Capture (KC) activity is a compendium of lessons learned narrative white papers, documents, spreadsheets (database records), and presentations developed by Ares I-X integrated product teams (IPTs), technical authority (S&MA and Chief Engineer) organization, and management organizations during the course of the project. Some are formal, version controlled documents, others are lengthy presentations with extensive background, still others are informal “brainstorming capture” bullet lists.

A number of the documents were developed early (pre-launch) by design IPTs and posted to the flight test project document server, several were generated at the January 25-26, 2010 (post launch) flight test project lessons learned retreat. Other documents were assembled during the first quarter of 2010.

Most documents provide a strong down-and-in focus on detailed issues associated with a specific work group implementation, subject area or discipline while at the same time providing some discussion of “up-and-out” engineering management concerns.

The structure or format of each document is different (as one might expect) and no attempt has been made to integrate the opinions, recommendations, and perspectives. Rather, the reader is called upon to review the body of content as a complement (elaboration, validation and verification) to the structured knowledge capture in Volume II and the synthesis in Volume I.

#1 Ares I-X Lessons Learned Mtg Overview Charts (Bob Ess)

I-X Lessons Learned Mtg

Jan 25 – 27, 2010

Agenda

- LL Approach
- Starting 12
- Inputs from Group
- Talk LL that are ready
- Break into groups to divide and concur

Overview

- I-X was extremely successful!!!
  - Vehicle and ground performed well
  - Integrated many aspects of NASA into a dedicated test flight
- Don't lose sight of this fact as we go through lessons learned
  - Tend to dwell on negatives to find something to fix
  - Majority of all aspects of this flight test worked well
  - Need to emphasize the positives as well

"Intra" and "Inter" Levels Of LL

- Intra LL
  - Completely Internal to an IPT or an Org
    - ATK to FS communication, Internal SEI or GO processes , FR-1 launch team comm, etc
  - Should be performed by the IPT/Org and documented
    - Key findings need to be provided to I-X MMO (Cowart) for a I-X Lessons Learned Report
    - Not a group I-X, or CxP activity unless affected another group
    - Should NOT include words regarding another groups actions/process etc.
      - "XXX IPT should have provided….." "Our group should have done xxx instead of another group"
  - Not focus of this week, but status needed

- Inter LL
  - Between IPTS, Orgs
  - Require all sides of topic to meet F2F and talk through process
    - Loads, verification etc
  - Can't be done as a series of unilateral discussions
  - THIS WEEK

What is a "Lesson Learned"

- Something pos/neg that if followed/discontinued would benefit:
  - The next test flight (equally fast-paced)
  - Mainstream CxP activities (reduces cost, schedule, risk etc)
  - NEEDS TO HAVE CONSENSUS FROM AFFECTED ORGs
    - Otherwise it is just an opinion, not a LL
- It is NOT
  - A solution w/o a problem
    - "Don't have late loads updates " (as opposed to "given a late loads updates the impacts could have been less if…)
  - Opinions from one group on what would be "better" for them
    - "Provide xyz product earlier"
  - A change that makes people comfortable or able to stay in their paradigms or better follow an established process, document..
    - "Follow CxP CM process.." (as opposed to "the I-X CM process did not adequately provide for abc resulting in delays in decisions or h/w delivery or extra cost to FTRR…)
  - A statement of the obvious
    - "Baseline all requirements/standards up front..." (as opposed to "a more efficient way to identify standards that were identified late would have been….")
  - *Comments for "theoretical" projects without cost/schedule constraints*
    - *"take more time up front to ….." (as opposed to: Given the aggressive schedule, it would have been better if ….."*

Groundrules

- LL timeframe starts with I-X Reorg in May of 2007 (created I-X)
  - Eliminates "start SE&I earlier", "no clear R&R" "late S&MA requirements" etc
  - Not looking for reasons to create MMO, history lessons etc
- To be a LL, must have consensus from at least 2 orgs
  - Otherwise just an opinion, possible minority report

Process

- MMO Established Top 12 that had a big impact on I-X and/or could have a big impact on II-X/CxP
  - Used ESMD LL draft report as an input of common themes
  - Reviewed LL provided by orgs/people
  - Culled out comments related to I-X PRIOR to May 2007 reorg
- There are many more that could benefit from group discussion
  - Review list
  - Verbal inputs from group on other key items
  - Talk through mature ones
  - Break into groups to discuss and return
  - Can be Positives, too!

Top 12 Topics

(* F2F discussion Topics)

1. Organizational structure
   - I-X was given Authority for team to make decisions
   - A positive
   - Applicability to Other flight test
2. Distributed Team Challenges
   - How to improve performance of distributed team (what helped, what didn't)
   - Co-location at final phase made a very big, positive difference
   - Consider similar for Formulation Phase
3. Tech Panels/SIGS (address R&R for II-X)
4. Working Groups
   1. Decisions took a long time to be made
   2. Were WG decisions not followed by IPT/Org leads even though their person agreed to it
   3. OR, were decisions not made quickly enough

(order changed since sent out)

Top 12

5. *Interface Management, (M. Smith, K. Flynn)
   – IRD/ICD process and follow through by orgs
   – Interface managers roles, authority vs responsibility
6. *Center Responsibility vs Mission Responsibility (Davis)
   – CoFTR, Shipping review, center/engineering reviews, [IRP coming out from HQ]
7. *Verification (Barry Bryant)
   – Difficult verification process
   – What would we do differently to balance proper system verification with efficiency and rigor
8. *Board Structure, (Ess)
   – SERF, ERB, TxRB, DXCB, XCB R&R, authority etc
   – Risk acceptance
9. *Technical Authority (Ess, Brunty, Mullane)
   – For small team, how did implementation work out?

Top 12

10. *Loads Process (M. Smith)
    – Given likely late changes in loads, how do we minimize impact..
    – Slow response by team to converge
11. *Scheduling (Bruce Askins)
    – Level of detail of integrated schedule
    – What would we do to have a better schedule with less effort
12. *Vehicle Integration and Testing R&R (Cowart)
    – SE&I, GO, Av seemed to have differences in opinion on R&R
    – What would we do for IPTs, SE&I, and GO regarding R&R to reduce overlap miscommunication
    – RoCS (good exap) as compared to USS, FS, or Avionics

Others? 1/2

- PAO
  - Center, Program, HQ R&R
- CM Process (+/-)
- Requirements Management
- Risk Management
- ADP, Acceptance etc
- Working through the existing systems-formally set process up front (top LV down to working LV [HOW])
- Policy changes not implemented into existing processes; processes not implemented throughout chain of CMD
- PRACA (Cx & i & contractors sys.)
- LAT process
- Issues & Waiver Management

Others? 2/2

- DFI Development & negotiation (From beginning to end)
- Range Requirement development
- Missed Opportunities with the right person in the room (nozzle bias info, using the right expertise to calibrate the team)
- Custody turn-over
- Business lessons leaned/contracting flexibility for a flight tests (developing requirements)
- Integration/operation and test at the mission design reviews (too much on design at PDR-CDR) [concurrent engineering]
- Integration test process defined and understood early
- Transition from design to operation phase upfront planning

Groups

- Discuss item for ~ 1 hour
- Consensus is desired, BUT
- Brings differences to group for further discussion
- 1st Session:
  - Verification
  - Board Structure
  - Center vs Mission R&R

- Document the way the org was setup and why as of May 2007

#2 Ares I-X Avionics Lessons Learned 1-15-10 (Kevin Flynn)

Ares I-X Avionics Lessons Learned

1-15-10

Lesson #1 - SIL

(By far, the most important lesson learned by the Avionics IPT)

- A single System Integration Lab (SIL) should be assembled as early as possible
  - The SIL should consist of flight-like (form, fit, & function) hardware
  - All systems should be represented to the greatest extent possible
  - Assets should be dedicated engineering units (not qualification units and spares)
  - Special attention should be given to the newest and least understood part of the system (e.g. COTS, new designs)
  - Thorough nominal and off-nominal testing should be completed
  - Systems and interfaces that can only be modeled in the SIL should be defined early so that on-site testing can be accomplished (e.g. hotfire, RF)
  - Executing simulations with parameters extracted directly from the mission parameter database is extremely valuable and important
    - This process caught flight control parameter errors that escaped visual inspection by both ULA and NASA and would have compromised stability margins
  - Regression testing should be performed for each HW and SW change
  - All differences between the SIL and flight vehicle should be precisely defined and maintained

Lesson #2 – Drawing/Procedure Review

- The Avionics IPT should have signature authority on all drawings and procedures related to installation of avionics HW
  - While this was a requirement on I-X, it proved difficult to enforce between IPTs
  - The result was incorrect installation of many DFI sensors, harnesses, and some boxes
  - This caused rework (cost, schedule delays) and the complete loss of some sensors

Lesson #3 – E3 Panel

- An Electromagnetic Environmental Effects (E3) working group should be established during the design phase and maintained throughout the project
  - Begin a dialog early in the design flow with the team responsible for the avionics installation
  - E3 qualification programs at the component level are generally tailored to the unique threats associated with the full system; E3 engineering effort to reconcile the qualification status of each component should begin very early in order to better focus any required delta qualification effort at the component level and/or design system level testing aimed at augmenting any component test “holes”
  - Involve E3 Engineering in the component selection and requirements definition process
  - Ensure that E3 expertise is available at the vehicle integration level; this is be particularly important when integrating hardware and personnel with significantly different heritage backgrounds

Lesson #4 - ECS

- Launch vehicles should have ECS (Environmental Control Systems) based on pad systems
  - ECS should be available continuously from installation until umbilical eject (T-0 / launch commit)
  - The benefits are well-controlled temperatures thru numerous scenarios (including fine-tune control)…AND control of air quality for FOD/salt/debris/etc
  - ECS should not be a weak point in the vehicle design, it's too easy to provide a system which can eliminate this issue

Lesson #5 – Lightning Recovery Approach

- Intentionally design one or more "canary circuits" into vehicle for lightning detection & retest
  - None on Ares I-X, and the team was working lightning retest on the day we launched
    - Vehicle never saw any electrical disturbance, would have been immediately closed on Atlas which has canary circuits
    - Large group effort for Ares I-X team to get waivers in place for launch
  - For a one-time flight this may be considered an acceptable risk; however, to avoid unnecessary launch delays, a stand-alone circuit(s) would be useful in quickly resolving lightning issues at pad

Additional Lessons Learned

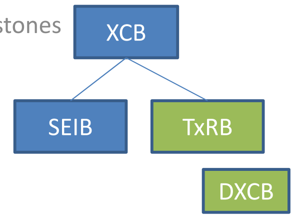
- SE&I should define requirements for shipping HW between NASA centers and to contractors
  - Each NASA center and I-X contractor levied different requirements for receiving HW
- Each IPT should assign a property manager
  - Having an IPT POC for property exchange will ease the burden of keeping track of HW during and after the project
- To the greatest extent possible, a common CAD design tool should be used by all IPTs
- To the greatest extent possible, requirements should be defined prior to IPT-level CDR
  - The late Ares I-X DFI requirements resulted in a system re-design post-CDR
- Environments should be defined as early as possible to avoid late delta-qualification of heritage and/or COT HW

#3 Ares I-X Boards & Panels (Bob Ess)

Ares I-X Boards & Panels

Did Ares I-X have the right number & type of boards to facilitate decision making?

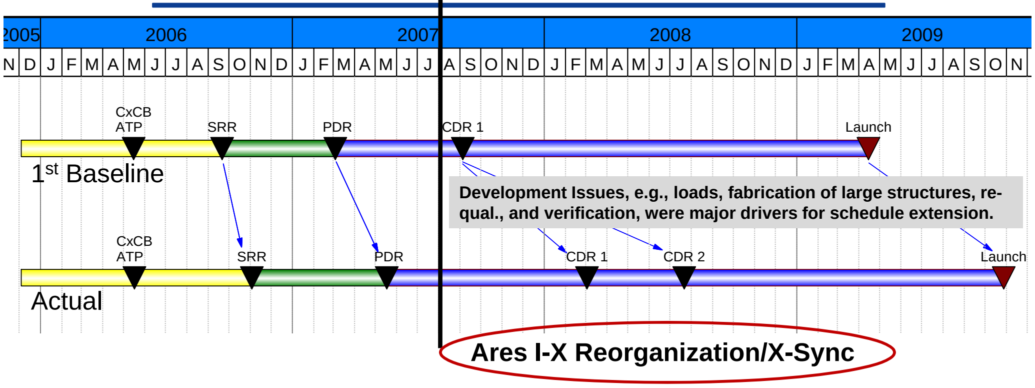
Manage @ milestones



- XCB (super board at the end)
- SERF/ERB:
  - Decisions for the technical team
  - Long discussions
- Add SE&I Board (SEIB): {add TA}
  - *Interfaces
  - *Technical baseline hold & communication
    - Maintain the technical baseline/requirements definition for the team to focus on (chief system engineers was the DDD & design cycles)
  - Cost/Schedule/risk authority [caps?](technical recommendation to XCB)
  - DFI requirements management
  - CM for technical documents
- ERB:
  - Waivers & Technical Standards
- TxRB
- DXCB
- IPT boards & Lead SE Working Group(technical work)

#4 Ares I-X MMO IMS Lessons Learned Overview January 2010 (Bruce Askins, Jon Cowart, Keith Heitzman)

1st Baseline vs. Actual Schedule



- **18% schedule growth after CxP Authorization to Proceed**
- **Managed to the 4/15/09 Launch date for 2 years**
  - Started with zero Margin, success oriented schedule, to Launch

2

Ares I-X Schedule Architecture

- **Used Internet-based schedule environment that allowed the entire mission to work in one logically tied, integrated, and live schedule**
  - 15 primary schedulers with 9 in Primavera & 6 in MS Project
  - 9 major contractors
  - 6 geographic locations
  - 1 IMS covering entire scope of mission (IPT up to 3 LV below IMS and not all in IMS)
- **Schedules – 3 Levels of Detail:**
  - **Working detail held at ITPs:** - detailed IPT LV schedules and up to 2 to 3 contractor task LVs below.
  - **Detailed IMS** (Primavera) – detailed integration *(~2,800 lines) manual*
  - **MMO Summary IMS (Primavera) –** logically tied to the Detailed IMS and is *where the MMO manages schedule (~600 lines) with manual updates by GO until GO opted to use an independent schedule.*
  - **Executive Summary IMS** - *1 page quick-look*
- **Two versions of Summary IMS:**
  - Baseline Version (locked at XCB & CxCB)
  - Current Version (working)
    - Used to track deviations and report variants from the baseline

Managed IMS to the Right Level

Schedule Key Lessons Learned

- **Derive and document all key milestones at ATP**
  - Note: this was done late and partial for I-X and Was started late.
  - Needs to match up with IPT agreements and Mission Plans as developed
- **Define schedule structure at ATP**
  - Note: I-X redefined the schedule structure each week.
- **Hold mission manager variance reviews weekly**
  - Note: Mission management reviewed the schedule weekly, but rationale for variances including recovery plans were not addressed weekly.
- **IMS should be automated based on lower level schedules**
  - Note: For I-X the data was pulled manually from each IPTs to update IMS
- **Centralize schedule control by permitting mission management involvement in developing lower level/IPT schedules**
  - Note: For I-X, accountability was based on the honor system. Also, MMO had no visibility into the IPTs working schedules unless IPT shared.
  - Supported a more rapid development timeline with LEAN events
- **Set schedule expectations early (e.g., structure, communication, consequences, process, and tools)**
- **Utilize one tool at MMO so changes are visible and linked.**

Schedule Key Lessons Learned

- **Manage to the milestones and status to the supporting task with stop lights**
  - Note: this was done late with I-X.
- **IPTs & GO did task at the same time that were transferred**
  - This went very well with I-X
- **Open dialog on where we are and why with the MM keeping pressure on**
  - Note: Mission management pressure was hard but positive to meet the launch.
- **For a TEST do it "GOOD Enough" for the test**
  - Note: this is a critical cultural change that has to be communicated & understood
- **Critical pate items forecasting needs to communicated upfront**
  - Note: There were IPT deliveries that were not linked in to the critical path were not caught and came late to some IPTs (FS –v- Avi)
- **Requirements & Loads products were not tracked as aggressively as hardware but should have been in the schedule with links**

National Aeronautics and Space Administration

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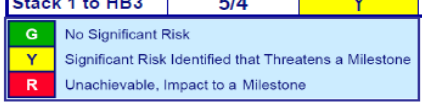
Sample Milestone Stoplight Chart

Milestone	TIM Milestone Completion Date	Status	Last % Complete	Current % Complete	Comments/Threats
Super Stack 1		Y	CRITICAL PATH FOR UPPER STAGE BUILD UP		
B On Dock	1/31	Complete	100	100	
A On Dock	2/6	Complete	100	100	
B Fit Check	2/12	Complete	100	100	
A Fit Check	2/14	Complete	100	100	
5th S S to HB4	4/08	Y	0	0	Potential slip of delivery to 4/10
RoCS Propellant Loading in HMF	3/2	R	10	10	Acceptance Review 3/10, Fairing modification required, propellant servicing delayed to 3/13
RoCS B to HB4	3/17	R	3	0	Delayed propellant servicing, milestone 3/27
RoCS A to HB4	3/26	R	0	0	Delayed propellant servicing, milestone 4/7
DFI Test Config 1 GRC Stack 1,2,3	4/8	G	0	[illegible]	Additional IS-1/RoCS DFI Installation, milestone 3/28, need GSE to support a 3/23
Stack 1 IS-1/2 B/U Complete	4/17	Y	0	0	Delayed propellant servicing, milestone 4/21
IS-1/2/RoCS W&CG	4/20	Y	0	0	Delayed propellant servicing, milestone 4/22
FWD Assy to HB4	4/15	R	0	0	Milestone [illegible] NET delivery of 4/30
DFI Test Config 3 Stack 1	4/27	Y	0	0	Late delivery, milestone U/R
Modal Test	4/27	Y	0	0	Late delivery, milestone U/R
Stack 1 B/U Complete	5/2	Y	0	0	Late delivery, milestone U/R
Stack 1 to HB3	5/4	Y	0	0	Late delivery, milestone U/R



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Ares II-X Proposed Schedule Architecture

- **Used Internet-based schedule environment that allowed the entire mission to work in one logically tied, integrated, and live schedule**
  - ~15 primary schedulers feeding a common tool (Primavera or MS Project Server)
  - Schedulers reporting to one lead scheduler & one manager (deputy level in Ares II-X)
  - IPTs use the schedulers for support – all under MMO
  - Schedulers at IPT's geographic locations but meet together regularly
  - 1 IMS covering entire scope of mission (development, build up, testing, flight, close out)
- **Schedules – 3 Levels of Detail in one tool:**
  - **Contractor Task Schedule – full detail where the IPTs pull the IMS detail** IPT Manual Hard-line
  - **Detailed IMS** – detailed integration *(~2,800 lines plus) – IPTs manage here at milestones and supporting links*
  - **MMO Summary IMS –** logically tied to the Detailed IMS and is *where the MMO manages schedule (~600 lines)* [external milestones, internal milestones (deliverables, and interfaces between ITPs)]
  - **Executive Summary IMS** output - *1 page quick-look* at Key milestones
- **Two versions of Summary IMS:**
  - Baseline Version (locked at XCB & CxCB) & Current Version (working statused to baseline)
- **Summary IMS Developed by MMO from a Mission Perspective & supported by IPTs and can be in Primavera or MS Project Server as long as linked**
- **IPTs would like to hold some margin at their level and not have all at MMO**
- **All contracts should be set where the Government has real-time access to their schedule**

EVM Here?

Managed IMS to the Right Level for the Mission Phase

7

Good practices for the Ideal State Schedule Architecture

- **Deputy level owning the schedule with MM authority from the start**
- **Leave dynamic up to PDR time and manage margin but hold at MMO**
- **Have the right level of Schedule detail at each phase of the test (concept, design, fabrication, assembly/integration, integrated testing, launch, and post flight task)**
- **<u>Fight scope creep or growth in the test schedule since this almost canceled Ares I-X</u>**
- **Have a plan for planning at the IPTs to meet the milestones report upward**
- **Have the contractors required to support schedule as part of their contract**
- **Schedule status meeting needs should match the phase of the test (SRR ~ 2 weeks till PDR then weekly till after CDR then twice a week status is encouraged) (periodic update to MM directly)**
- **Some points past Ares I-X as a whole**
  - Agency does not have functional manager that sets schedule standards/practices
    - It appears scheduling is bought as a commodity not treated as a discipline
    - NASA does not have one way to do schedules
    - It appears there is not a common tool across the Agency
    - There is much rework that happens with every new project or schedule
- **The creation of a tracking tool is encouraged as LM did in the "Rainbow Chart" for Ares I-X to track and project the harness production and deliveries. Do it at start.**
  - This tool allowed Avionics to provide status to the program and provided a forecast/communication to the other IPTs as to when they could expect deliveries.
  - Harnesses were always a threat to impact the schedule, but the utilization of the "Rainbow Chart" as a tool helped mitigate and understand this risk.

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Lean Events and the Schedule

- **A good schedule will only need a lean event when faced with a PM challenge (e.g., new scope, risk mitigation, and issue resolution)**
- **How Ares I-X used Lean 6 Sigma events**
  - Held Lean events early with each IPT
    - Each IPT participated
    - IPTs participated in each others events [KEY LESSON LEARNED]
  - What Management gained
    - An understanding of the "true" schedule drivers
    - A working core team "trust"
    - Obtained insight into potential issues

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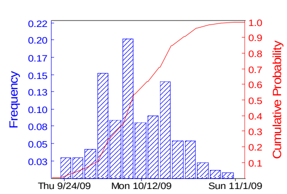
The Monte Carlo tool: Good Practices & Use With Caution

- **Started using Monte Carlo a few months after CDR**
- **Can approach diminishing returns – K.I.S.S.**
  - Use a separate, high level network (no open ends, no constraints)
  - Keep it simple and do not burden the whole team
  - Do analysis in small team, close to Project Manager
- **Focus on Top Critical Paths & Paths that are at Risk**
- **Results – May learn more in the journey than the destination**
- **Attack the tasks with most uncertainty (Tornado Chart)**
  - *Ares I-X Success Story – Integrated Testing ➔ Duration 2 wks to 8 wks*



- **Lesson: Monte Carlo with the schedule should be use with caution as we did**
  - **It's a tool and not an exact science**
  - **Needs to be planned for if used**
  - **Garbage In → Garbage Out**
  - **The tool can help you drive out uncertainty**

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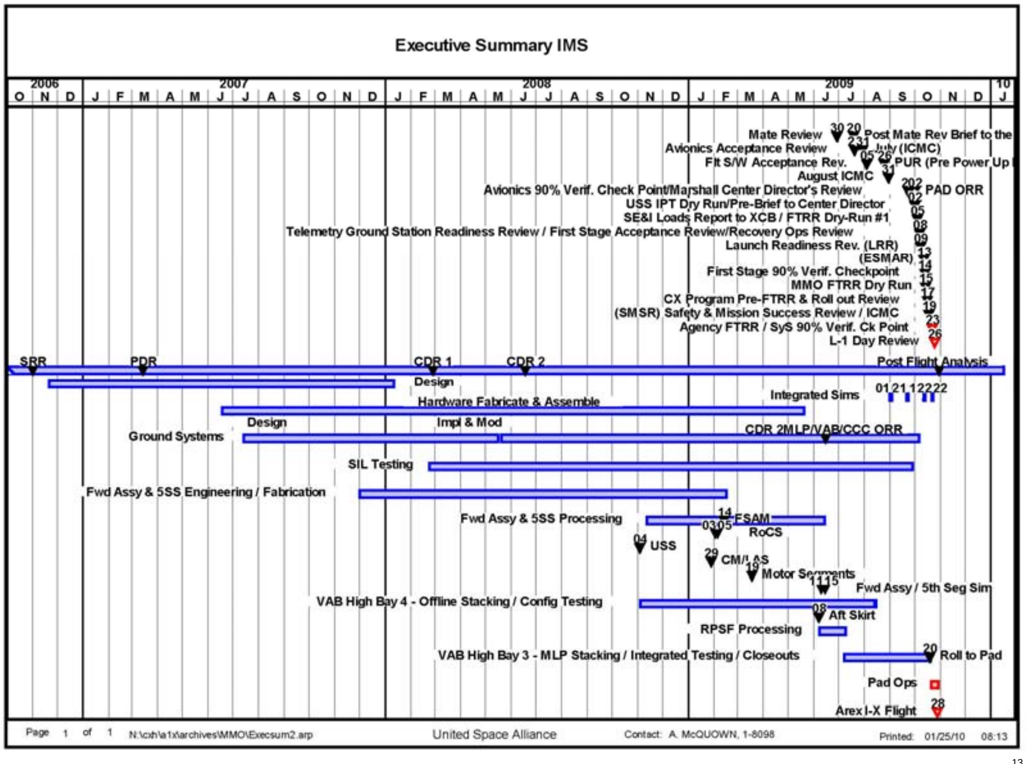
We did fly a successful test flight!

Where are the IPTs Today

- **Schedule Tools in use**
  - Ares I FS office uses MS Project Server
  - ATK uses Primavera
  - GRC/USS uses MS Project but did work in Primavera for Ares I-X
  - Ares I Avionics uses MS Project Server
  - Ares I US uses MS Project Server
  - Ares I VI uses MS Project Server
  - LM uses MS Project
  - SE&I likes MS Project but has worked in Primavera
  - GO uses Primavera (USA)
  - GS uses Primavera (USA)
  - RoCS uses MS Project convert to Primavera
  - CM/LAS uses MS Project convert to Primavera
  - LV 2 functions use Primavera
- **Note: for about 3 months all IPTs were up and working in Primavera for Ares I-X**
- **Note: All MS Project schedules can be converted to Primavera from MS Project data weekly (logically tied MMO IMS at some level)**


Executive Summary IMS
2006
2007
2008
2009
10
Mate Review
Post Mate Rev Brief to the July (ICMC)
Avionics Acceptance Review
Flt S/W Acceptance Rev.
PUR (Pre Power Up)
August ICMC
PAD ORR
Avionics 90% Verif. Check Point/Marshall Center Director's Review
USS IPT Dry Run/Pre-Brief to Center Director
SE&I Loads Report to XCB / FTRR Dry-Run #1
Telemetry Ground Station Readiness Review / First Stage Acceptance Review/Recovery Ops Review
Launch Readiness Rev. (LRR)
(ESMAR)
First Stage 90% Verif. Checkpoint
MMO FTRR Dry Run
CX Program Pre-FTRR & Roll out Review
(SMSR) Safety & Mission Success Review / ICMC
Agency FTRR / SyS 90% Verif. Ck Point
L-1 Day Review
SRR
PDR
CDR 1
CDR 2
Post Flight Analysis
Design
Integrated Sims
Hardware Fabricate & Assemble
Ground Systems
Impl & Mod
CDR 2MLP/VAB/CCC ORR
SIL Testing
Fwd Assy & 5SS Engineering / Fabrication
Fwd Assy & 5SS Processing
FSAM
RoCS
USS
CM/LAS
Motor Segments
Fwd Assy / 5th Seg Sim
VAB High Bay 4 - Offline Stacking / Config Testing
Aft Skirt
RPSF Processing
VAB High Bay 3 - MLP Stacking / Integrated Testing / Closeouts
Roll to Pad
Pad Ops
Arex I-X Flight
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United Space Alliance
Contact: A. McQUOWN, 1-8098
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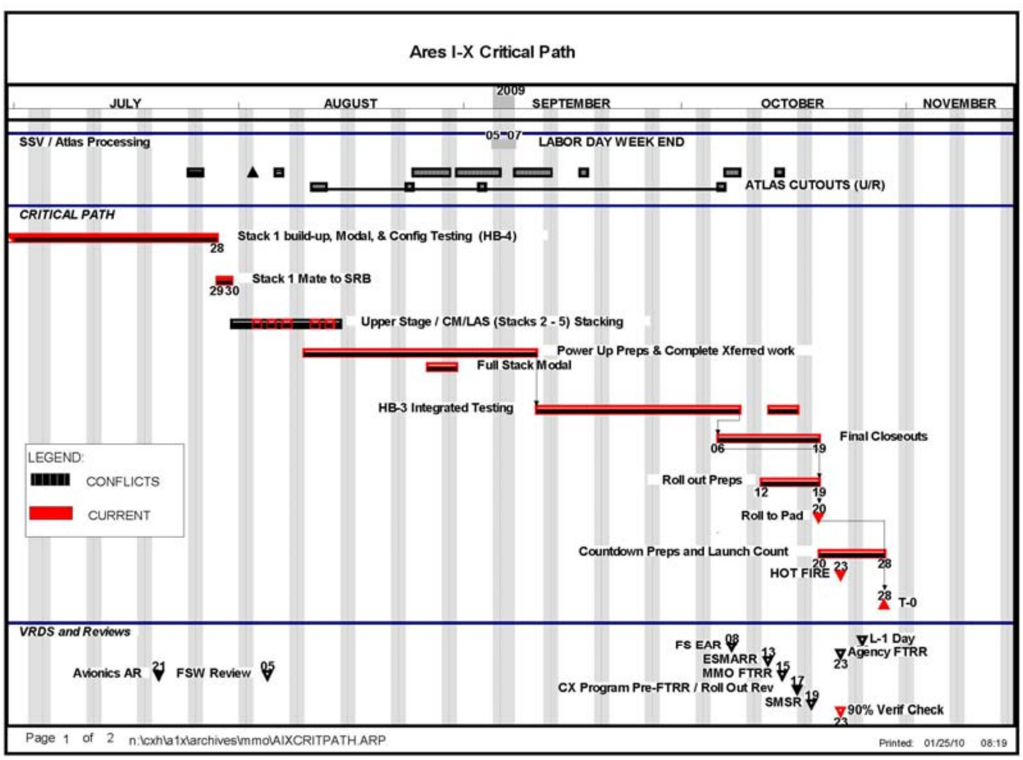
Ares I-X Critical Path
2009
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
SSV / Atlas Processing
LABOR DAY WEEK END
ATLAS CUTOUTS (U/R)
CRITICAL PATH
Stack 1 build-up, Modal, & Config Testing (HB-4)
Stack 1 Mate to SRB
Upper Stage / CM/LAS (Stacks 2 - 5) Stacking
Power Up Preps & Complete Xferred work
Full Stack Modal
HB-3 Integrated Testing
Final Closeouts
LEGEND:
CONFLICTS
CURRENT
Roll out Preps
Roll to Pad
Countdown Preps and Launch Count
HOT FIRE
T-0
VRDS and Reviews
Avionics AR
FSW Review
FS EAR
ESMARR
MMO FTRR
CX Program Pre-FTRR / Roll Out Rev
SMSR
L-1 Day
Agency FTRR
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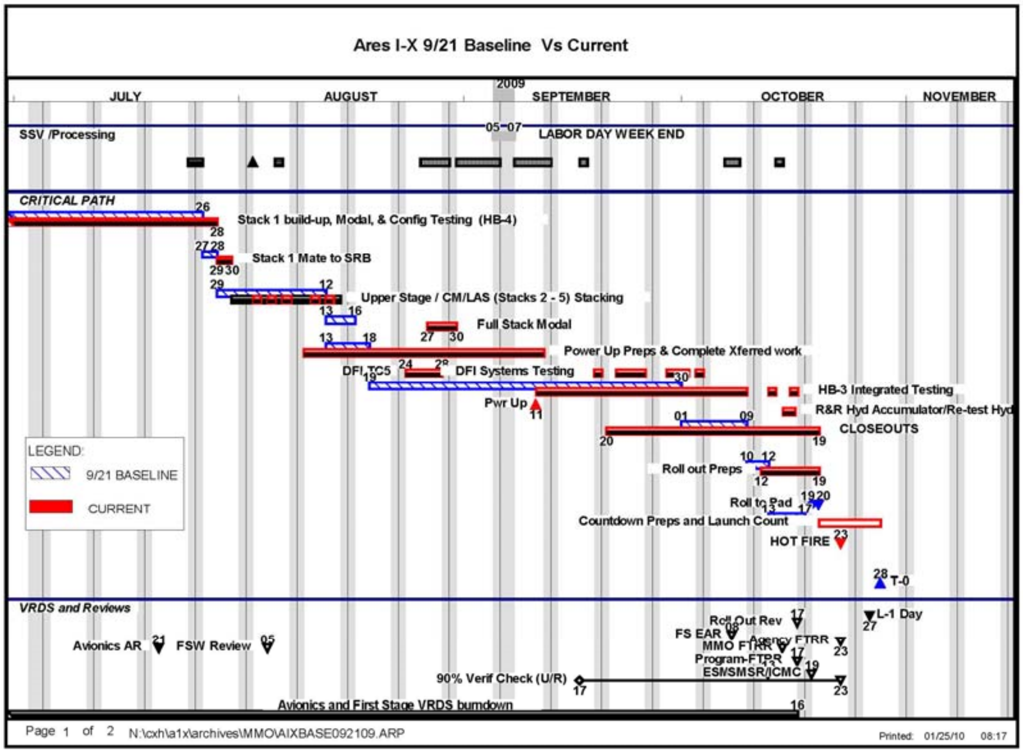

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Integrated Master Schedule (IMS) Before 1st Lean Event

- **The early life cycle version of the first IMS was A confederation of Level 3, 4, & 5 elements from GRC, LaRC, MSFC and KSC**
  - Managed by a Complex board structure
- **The rhetoric of how to best integrate the IMS was complicated by intra- and inter-center politics**
  - More energy was expended to break through barriers than actually building a good schedule
  - There was a Lack of ~~trust~~ confidence
- **Before the 1st Lean Event:**
  - There was No mission-level margin
  - Not all elements were working in Primavera
  - Integration of the element schedules was difficult because of multiple ways of doing business.
  - IMS integrations were done manually
- **The early life cycle scheduling efforts were effective, but not efficient.**

The First Lean Event was a pivotal point in schedule integration

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1st Lean Event Recommendations to CxCB

10 to 4 Control Boards

- **Control Boards**
  - Current State – up to 10 boards (from contractor to CxP)
    - Example: ~44 days (9 work weeks) of preparation and wait time for FTINU mod
  - Ideal State – only value added boards
    - Up to 4 boards (Contractor, Element, Engineering, and Project)
    - FTINU mod could have been done in significantly less time (40 – 60 %)
      - Benefits include increase in productivity and/or cost savings
- **Rework Cycles (expected)**
  - Current State – high probability of rework
    - Examples: FTINU, T-0 umbilical, vehicle stabilization, etc.
  - Ideal State – eliminate rework cycles
    - Integration up-front leads to ½ time reduction
    - Eliminate rework (T-0 rework, vehicle stabilization, etc.)
- **Schedule Margin**
  - Current State – None or risk of going over schedule
  - Ideal State – Add ~45 to 60 business days of margin
    - Provide incentives for contractors and civil service personnel
- **Priorities**
  - Current State – unclear/everyone marching to a different drummer
  - Ideal State – consistent

Charter for Lean

One Team "Mission"

Ares I-X was a Primavera Pilot

- **Primavera kicked-off by CxP in early 2006**
- **CxP required 3 projects to test Primavera**
  - {Ares I-X was selected} to test:
    - Primavera Project Management (PM) for scheduling
    - Primavera Cost Management (CM) for Earn Valued Management (EVM)
- **Some growing pains experienced early ~~in~~ during implementation**
  - Primavera consultants were provided to help each IPT
  - Most PM issues were a result of how it was set-up in ICE by CxP
    - Examples of problems included:
      - Deleted activities resurrected
      - Printers disappeared
      - Trouble developing reports
  - CM issues seemed to be a combination of network and software issues
    - CM task was Abandoned
- **Required training and a culture change (all in one tool)**
- **The Schedule Tool (i.e., PM) worked as expected**
- **Integration was not seamless**
  - KSC used their own Primavera Database outside of MMO

A real-time integrated schedule would have been impossible without Primavera

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Ideal State Schedule Architecture

- **Used Internet-based schedule environment that allowed the entire mission to work in one logically tied, integrated, and live schedule**
  - 15 primary schedulers in a common tool
  - 1 company with all schedulers
  - Schedulers reporting to one functional manager (deputy level)
  - IPTs use the schedulers for support
  - 6 geographic locations
  - 1 IMS covering entire scope of mission (development, build up, flight, close out)
- **Schedules – 3 Levels of Detail in one tool:**
  - **Detailed IMS** (Primavera) – detailed integration *(~2,800 lines plus) – ITPs manage here*
  - **MMO Summary IMS (Primavera) –** logically tied to the Detailed IMS and is *where the MMO manages schedule (~600 lines)*
  - **Executive Summary IMS -** *1 page quick-look* at Key milestones
- **Two versions of Summary IMS:**
  - Baseline Version (locked at XCB & CxCB)
  - Current Version (working statused to baseline)
- **Summary IMS Developed by MMO from a Mission Perspective & supported by IPTs**

Managed IMS to the Right Level for the Mission Phase

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#5 MMO (Bruce Askins)

- MMO Manager has ultimate responsibility to make sure program is success.
- MMO should own cost, schedule & technical.
- Center Management must buy off on technical and resources required. Also, responsible for addressing risk to safety, technical and medical. Center is responsible for characterizing risks and engaging with the Program for resolution.
- Deputy Managers/IPT managers should have dual role to MMO Manager and Center Management/Element Managers.
- Cost effects Centers also Program, ie. Ares, Orion & Ground.
- Not enough flag watchers.

#6 Technical Authority (Brunty, Stanley, Green, Mullane)

Technical Authority

Discussions with Brunty, Stanley, Green, Mullane

Key Points

- Engineering TA path was "muddled"
  - Maybe tried too hard to force fit 7210 into I-X (DGA)
  - Brunty to LaRC etc
  - Cleaner: Brunty (I-X) to Labbe (CxP) similar to S&MA (Mullane → Jeff Bye, Noriega)
- 2 CE's
  - Discussion about whether that is best approach
  - KSC S&MA suggest having 2 S&MA leads (Vehicle, Ground)
- LSE vs LE
  - Just need one of these per IPT
  - (Have SE&I –badged person on IPT)

Key Points, Cont.

- SERF/ERB Performance
  - Timeliness of decision making
  - Ability/authority to make decisions
  - How to have MM risk acceptance level consistent in subordinate boards
- Level/number of subordinate boards
  - More up front R&R discussion for all boards and initiate boards as required
    - DxCB, TxRB

#7 Ares I-X Lessons Learned TIM January 2010: Missed Opportunities (Teresa Kinney, Dawn Stanley)

Ares I-X
Lessons Learned TIM
January 2010

Missed Opportunities

Observations

- Scientist versus Engineer approach
  - Science : only one correct answer to a given problem
  - Engineering: multiple correct answers (e.g., designs, analytical approaches, verification methodologies, etc.) to satisfy a given set of requirements
- Difference in analysis, approval process (boards), and verification approaches is more a function of the programs managed at a center than on the centers themselves
- "If it was easy, anyone could do it" Bob Thoren/TBE ISS Structures Manager

Ares I-X Team Synchronization

- “Motherhood” analogy is appropriate
  – There is no single, correct way to execute “motherhood” (parenthood)
  – Successful implementation is directly correlated to
    - tailored approach
    - Continuous monitoring and evaluation of processes (eye on the ball, focus on the endgame)
    - Emphasis placed on most critical requirements
    - flexibility in satisfaction of requirements
    - Sometimes it really doesn’t matter what happened (how you got here), only what is the go-forward position

Chief Engineer - Recommendations

- **IV&V: Utilize capabilities and expertise within NASA and program contractors, at all centers, across all programs (IV&V) –**
  – **Encourage IPTs to perform IV&V at all phases of project.**
  – IV&V can be implemented by soliciting and seriously considering the recommendations from technical areas of expertise from other programs and Centers
  – Utilize NESC expertise on specific, exact, acceptable technical methodologies not just large integrated system issues
- Efficient use of ELV expertise in specific technical and verification issues (overview of ELV process, consultation on concrete issues)
  – 3 different launch vehicle contracts
  – 5 launch vehicles with 3 LV contractors
  – Design certification completed on several vehicles in the past 30 years (many in the past 7 years, 1 ongoing)
  – Timeline is similar to that desired by Ares test vehicle project
- Minimize dependence on external expertise that is not forthcoming with substantiation of recommendations (some external organizations do not answer to NASA)

Chief Engineers Recommendations (cont)

- Define terms, requirements, verification methodologies, and processes (including ERB process) early to get everyone on the same page
  - JA-418 type of document
  - Kickoff TIM to review existing program methodologies and customize go-forward
  - Bring in chief engineers and documents from other programs to start from (no blank piece of paper)
- Develop templates to be used at ERBs/MRBs or other technical forums so all expectations are addressed (hence minimize the " come back when you have "xyz"):
  - Overview of technical issue , description of system
  - Require contractors/IPTs/etc to provide detailed models, analysis and design information when addressing various issues
  - Recommendations and trades on impacts
  - Risk assessment
  - Etc, etc, etc..
- Use COTS with discretion and careful consideration of requirements and how they can be satisfied

#8 SE&I Verifications Lessons Learned (Bryant, Kempton, Vipavetz)

Ares I-X Verification Success Story

- Verified 100% of all system and element level requirements
- All verifications formally reported and stored on Windchill including supporting documentation
- Had full accountability
- Had top to bottom requirements flow down and bottom to top verification
- Multiple NASA Centers successfully implemented a common verification process
- Had complete traceability between verification and requirements
- Tracked and closed all system waivers

- *Positive Lesson - Independent reviews contributed extensively to the success of the mission*

2

Lessons - SEI

- **Description**
  - There was limited system buy-in from the beginning
    - Weakened SE&I influence and limited verification collaboration
    - Common processes were not established until late in the mission
- **Lesson**
  - Need all parties ingrained in the system formulation before they start running
- **Cause**
  - IPTs were running before SE&I was stood up
  - Contracts in place prior to SE&I involvement
- **Recommendation**
  - Establish SE&I's role in the verification process at the beginning of the mission
    - Need to link IPT contracts (prime contractors) to address both the IPTs and the SE&I roles, processes and requirements – this will be difficult
    - If contracts are already in place then the contract must be set up to allow incorporation of SE&I's roles, processes and requirements
  - Co-location of verification managers or leads until identified plans/documents in place

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Lesson – System Engineering Process

- **Description**
  - Verification in one step, from product to requirement was problematic
- **Lesson**
  - Don't shortchange core system engineering processes
- **Cause**
  - We did not perform a separate system level design verification
  - Ares I-X CDR was a tech review and a requirement status
  - Requirements were not sufficiently mature to complete verification
- **Recommendation**
  - Perform system level design verification **at some point prior** to final verifications
  - Even in a fast paced program, utilize standard system engineering process

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Lesson - Product vs Design Verifications

- **Description**
  - At verification time, SEI's expectation for product artifacts challenged element verification closeout
- **Lesson**
  - Need to identify where product or design verification apply
    - Affects when verification paper closure occurs
    - Affects quality of engineering documentation at CDR
- **Cause**
  - SE&I expected and planned for product verification due to the new development mission with a single one of a kind FTV
- **Recommendation**
  - Tailor verification processes between design and product verification
  - Recognize the impact of the verification plan and ensure pre-engaged contracts/processes will support verification artifacts needed

Lessons – Verification Requirements Document

- **Description**
  - Required heroic effort at the end to close all Verification Definition Requirement Sheets (VRDSs) at the element and system level
    - In quite a few cases, we did not have an element verification artifacts that would "Meet" the SRO needs for the system level VRDSs
- **Lesson**
  - Need good compliance statement examples to communicate expectations
  - Need better SRO communication with the elements
  - Need better measurement activity and success criteria verification content
- **Cause**
  - SE&I late in getting a complete verification implementation in place and SRO participation
  - Conflict between accepting design verification artifacts versus product verification artifacts
- **Recommendation**
  - Baselined system level verification implementation plan by PDR
    - *This is not in current PDR Success Criteria*
    - Use a Lean Event type activity with SE&I and IPTs for verification processes and verification artifacts needed for ADPs (consider available templates)

Lessons – System Requirement Owners

- **Description**
  - Some element verifications held up due to lack of SRO availability
- **Lesson**
  - Need improved resource loading for SRO
- **Cause**
  - Key personnel were fully engaged with other duties and could not focus on SRO verification responsibilities
  - Surge team, meant to help SROs, did not always meet the technical level needs
    - learning curve required
    - High cost to IPT's
  - Not all requirements were weighted evenly
- **Recommendation**
  - SROs are assigned when SRD is written
  - SROs are available for verification reviews
  - Tap IPT opportunities to act as a SRO
  - Delegate SRO responsibilities as soon as backlog is identified
    - Discipline knowledge
    - Within mission

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Lessons - Waivers

- **Description**
  - When verifying requirements, it was difficult to determine what waivers applied to the requirement being verified
    - Could not readily call up a requirement and all of the associated waivers for verification compliance statements
    - Caused considerable delays in closing compliance statements
- **Lesson**
  - Every waiver must identify a requirement and database search needs to able to identify all waivers being tracked with the requirement
- **Cause**
  - Cumbersome waiver process and missing database field
- **Recommendation**
  - Ensure that every waiver traces back to a requirement number
  - Entire set of waivers should be searchable by key word
  - Set up a specific field in the verification database to link waivers and requirements

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Lessons - Tools

- **Description**
  - Cradle tool not helpful for requirements management
    - Could not find broken links easily
    - Remote access was not practical
  - Windchill system slow and directory structure did not allow quick searches to be implemented
- **Lesson**
  - Need tool for requirements management within SE&I office
  - Need document repository that is quickly accessible and easily searchable
- **Recommendation**
  - If Cradle not right for you, use another tool
    - Ares I-X used a Microsoft Access Requirements and Verification Engineering database (RAVEN)
  - No matter what tool is used, SE&I should validate requirement traces when requirements documents are approved

Additional Items for Consideration

- **IPTs own ERD/VRD**
  - Pushs more into SRD
- **IPTs own some system level requirements that do not include an interface**
- **Consider requirements/verification class for leads at beginning of project**
- **Agree on Definitions**
  - Design verification
  - Product verification
- ***These verification recommendations recommend doing more earlier - consider that (as hard as it was) we may have found the right balance and saved time/money by performing product verification at the end***

#9 Ares I-X Interface Management Lessons Learned (Kevin Vipavetz)

Ares I-X Interface Management Lessons Learned

Interface Definition

- SE&I should lead interface definition
  - Each ICD/IRD should have a document a SE&I owner
    - For I-X, the prime (LaRC) SE&I was recognized but the IPT SE&I remained less visible
  - Complexity of the interface and the project schedule should drive man-loading of this task
  - In order to adequately support SE&I each IPT should have an Interface POC with an internal support team
  - The SE&I and IPT Element Requirement Owners (EROs) must work closely with each the System Requirement Owners (SROs), and interface working group

- Interface requirements definition should be tightly linked to verification
  - This is true for all requirements
  - Requirement documents should call out interfaces
  - Did I-X make the best decision to have combined IRD and ICD?

Interface Definition (cont.)

- Working groups can be very effective during the early stages of interface definition
  - It is essential that each affected party be represented at all meetings
  - When multiple NASA centers and corporations interface, much diversity exists within the established processes
  - Process and decisions should have an established communication path to keep project management, designers, and operations cognizant
    - Discussions that lead to technical understanding and agreement improve final documentation review and approval
- ICD content and definition should be precisely defined and controlled at the project level
  - Specific content/depth was different between centers in each ICD
  - KSC does not recognize the ICD as a defining document
    - This was not well-understood by some/most of the I-X team

Interface Document Approval

- It is critical to successful integration that interface definitions be well understood beyond the technical community
  - Agreement from each center's management, IPT lead, CE, Operations, and CSO (S&MA) representative is needed
  - As currently defined, major reviews do not un-cover detailed interface issues; lower-level, peer reviews should be established to ensure correctness
    - For I-X result was continuous evolution of the requirements
- Drawings and procedures should be reviewed and approved by all affected IPTs
  - Drawing trees should established by each IPT and required approvals for each agreed to at the system level
  - While this may cause delays in final approval it allows issues to be uncovered before cost and schedule impacts escalate
  - Changes on either side must be approved by all affected IPTs

Interface Management

- There should be clear control on how models and drawings are used in the ICDs
  - This must be established early and levied on existed and new contracts
  - A process to keep model and drawing databases current must be established at the system level
  - All contracts & ITPs should have drawings and models as deliverables through one change process
- A detailed schedule for HW deliveries between IPTs should be established so that deliveries can be prioritized
  - Example: harness production process

Interface Change Requests & Waivers

- ICD changes are often technically complex; the interface working group (or Interface Control Board) recommendation should be presented to the project-level control board
  - The ICD working group (led by SE&I) decision should be considered final
  - Dissenting opinions and impacts may be presented to the project
  - CRs and waivers must be tracked with the ICD

Uncovering Interface Issues

- SE&I should maintain an active role during drawing/procedure approval *and* integration to ensure understanding and compliance to interface document
  - Example: The interface of USS RRGU and FTINU mounting plate to box interfaces had a well-defined flatness requirement
    - The reason for this requirement was not fully understood by USS; measurement was taken on the bench prior to installation
      - Rationale may need to be included with requirement so all understand
- Interface management should encompass drawing, schematic, and procedure reviews
  - Peer reviews, Subject Matter Experts (SBEs) reviews (that is, technical reviews not a management review)

Uncovering Interface Issues (cont.)

- A single System Integration Lab (SIL) should be assembled as early as possible; this allows for interface issues to be discovered and worked with minimal cost and schedule impacts
  - The SIL should consist of flight-like (form, fit, & function) hardware
  - All systems should be represented to the greatest extent possible
  - Assets should be dedicated engineering units (not qualification units and spares)
  - Special attention should be given to the newest and least understood part of the system (e.g. COTS, new designs)
  - Thorough nominal and off-nominal testing should be completed
  - Systems and interfaces that can only be modeled in the SIL should be defined early so that on-site testing can be accomplished (e.g. hotfire, RF)
  - Executing simulations with parameters extracted directly from the mission parameter database is extremely valuable and important
    - This process caught flight control parameter errors that escaped visual inspection by both ULA and NASA and would have compromised stability margins
  - Regression testing should be performed for each HW and SW change
  - All differences between the SIL and flight vehicle should be precisely defined and maintained understood by all

Interface Verification

- It is not necessary to have both sides of the interface verified before either side can close out a VRDS (you only have to show proof that you meet your side of the interface agreement/definition)
- Each side of the element verification can be closed at the acceptance review prior to shipping
- After that it is the system's responsibility to perform checkout or integration verification of the interface

#10 SE&I Loads Lessons Learned (Smith, Detweiler)

SE&I Loads Lessons Learned

Smith, Detweiler

January 26, 2010

Ares I-X Loads Success Story

- **Bottom line – Loads were a success**
  - Understanding that we would be developing and manufacturing WHILE we are completing analysis and design - Released initial conservative loads
    - Remaining work was pointed toward validating these assumptions and refining our models and loads
- **Predictions were good**
- **Performance was as expected**
- **Late test results (some planned, some surprises), late models were integrated, IV&V was completed, load updates were incorporated**
  - It was painful but this is NOT out of family with other first mission systems (not even considering our pace)

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Loads & Env (L&E) Background

- ID&A was formulated with idea of close knit discipline communities to facilitate extreme fast timeline of flight test (skunk work mindset).
- This was/is typical of a concept study method. HyperX (X-43A) followed this formulation and was fundamental driver for selection of original AVIO management and ID&A team

- Such formulation requires the following to be successful:
- Highly skilled analysts
- Tight knit team who understands cross-discipline feeds
- IPT Modeling inputs and review
- Design Cycle Rigor

L&E Lesson – Highly skilled analysts

"Critical Discipline Staffing "

- **Description**
  - Staffing leads was quickly done. Staffing for complete team was limited during AVIO. It took 3-6 months following reorg before a sufficient team was in place.
  - Staffing of lead and supporting analysts for the unique vibro-acoustic discipline proved difficult. Black art characteristic and pocketed expertise on subject tended to reliance on committee ruling on methods/results. Led to delays and "conservative" vibro-acoustic loads.
  - Resource availability – Dedicated Staff
- **Lesson**
  - Loads and Environments are fundamentally requirements. Critical staffing must be addressed during formulation and NOT design phase.
- **Cause**
  - Lack of early discipline lead and lack of management attention
- **Recommendation**
  - Identify critical ID&A discipline staffing immediately and clearly communicate shortfalls and related expertise needs.
  - Discipline lead must assert/communicate subject analysis plan understanding analyst capabilities and tools to illuminate shortfalls.

L&E Lesson – Tight Knit Team

"Cross Discipline Feeds"

Description

- Fast paced projects requires key highly experienced leads in many areas. Tools and methods for that discipline must be clearly understood but also key leads need to have an understanding what other disciplines will need

Example: Ares I-X trajectory lead had strong structures background and had developed methods for mapping distributed aero onto structure to define ascent structural loads.

Lesson

- In formulation, match analyst experience level against project pace/schedule; experience must include cross-discipline understanding

Cause

- Upfront management acknowledged analytical process to support a fast paced flight test and need for such cross discipline characteristics within analysts selected (Frank Vause, Jay Brandon …)

Recommendation

- None

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L&E Lesson – Tight Knit Team

"Intra-cross feed of information"

Description

- Understanding that the SE&I ID&A analytical team was close knit, the "typical" tendency of the team was to pass information informally within the group. Again the intent was to facilitate quick analytical turnaround with the "latest and greatest" and was typical of LaRC concept study "process". Passing of the "latest and greatest" gave way to instances of lost lock on design cycle synchronization.

Example: Trajectory updates due to time of year changes were passed informally causing difficulties and time required to sort out and justify.

Lesson

- Configuration control of intra-organizational data must be maintained.

Cause

- Lack of SE&I configuration control resources to maintain lock and capture of models; Systems Configuration and Integration function within SE&I was dismantled following reorg and not rebuilt.

Recommendation

- SE&I must identify internally controlled items and capture from beginning to end; additional SE&I staffing must be included to facilitate critical model/data capture to feed the design cycle process for this data. CM of models and analysis must be maintained in the SE&I organization.

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L&E Lesson – Ground rules/assumptions/ICs

"IPT Modeling inputs and review"

- **Description**
  - SE&I assembled IPT provided models into system level models. IPTs were **responsible** for ensuring these models were valid and had appropriate technical review. Due to the fast nature of development (i.e. fast schedule), limited review of these models occurred at the SE&I discipline and system engineer level. SE&I maintained trust that delivered models were "approved". Late in the verification process questions arose as to validity of IPT model inputs leading to further review and analysis re-do.
- **Lesson**
  - Analytical model (forcing functions, etc.….)review and approvals must occur before use in system-level integration
- **Cause**
  - Lack of related IPT and system level defined model reviews and deliverable schedule milestones (see next topic).
- **Recommendation**
  - IPT models and analysis should have schedule defined review milestones prior to delivery milestone
  - SE&I should develop delivery checklists at the beginning of each design cycle to ensure ground rules/assumptions are maintained facilitating model expectations and integrity

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L&E Lesson – Ground rules/assumptions/ICs

"Design Cycle Rigor"

- **Description**
  - Late definition of loads and environments proved a vexing problem for SE&I and the element IPTs which continuously worked loads compliance issues though the launch timeframe.
- **Lesson**
  - Loads typically are dependent on design and are subject to change as design develops. Change timeline within the design cycle process is important upfront to ensure expectations are managed and communicated
- **Cause**
  - Original ID&A planning was formulated around multiple design cycles. The rigor of maintaining synchronization during and between design cycles was exacerbated by:
    - Lack of integrated schedule communicating needed supporting deliverables between IPTs and SE&I
    - Late supporting wind tunnel tests (by definition at formulation)
    - Elimination of SEI staffing supporting critical models and data capture and configuration
    - Some loss of consistency during ID&A manager transitions (3 total)
- **Recommendation**
  - SE&I and IPTs should work together to formulate and develop an integrated design cycle schedule with agreed upon long lead supporting tests, required IPT deliverables, and entry/exit products/checklists. Provide supporting infrastructure/personnel to maintain supporting data configurations.
  - Independent reviews
  - Develop plan for de-scope and process plan
  - Communicate

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Summary of the Lessons

- **Dramatic improvement in all of these areas can be achieved by Co-locating main design leaders and managers (LSEs, Designers) for short period (3-4 months)**
  - Development and understanding of requirements early in the process (Loads and environments)
  - Forces highly qualified resources to be assigned and integrated in the project very quickly
  - Allows the team to develop a detailed DAC cycle plan so all understand the fidelity and schedule of the products required
  - Established CM baseline

#11 Ares I-X Lessons Learned Topic #12: Vehicle Integration & Testing Roles and Responsibilities (Jon Cowart)

National Aeronautics and Space Administration

ARES I-X Lessons Learned Topic # 12: Vehicle Integration & Testing Roles and Responsibilities

Jon Cowart

26 Jan 2010

www.nasa.gov

The Action

- Determine the Initial Plan for Vehicle Integration and Testing Roles & Responsibilities (R&R)
- Determine the Evolved Plan as hardware delivery to KSC approached
- Determine the Actual R&Rs observed during Integration and Testing activities
- Propose Future State R&Rs in light of the above

National Aeronautics and Space Administration 2

Bottom Line Up Front (BLUF)

- **Key Observations:**

Both Project and IPTs had initial plans to be involved with Vehicle Integration and Testing efforts to some degree. Was not documented clearly at Project Level.

C.E. process was stood up to support Assembly Requirements mostly led by KSC personnel. Test Integration worked well very early with good lean teaming approach.

Learning curve experienced for personnel supporting KSC operations. Test Integration worked well very early with little learning curve experienced for KSC operations.

- **Proposed Recommendations:**

Project Level Documentation should be established VERY early in the project lifecycle to define R&R, based on product deliverables, as well as the STANDARDIZED processes to be used for integration and test

Recognize and utilize the Concurrent Engineering Process as early as possible in the Project

Retain the TXRB; it was a value added board that could respond quickly to floor issues

GO needs to provide KSC 101 course that is value added, project centric – not SSP centric, that is mandatory attendance for personnel planned to co locate to support integration or testing efforts

Initial Plan for Integration/Testing R&Rs

- **Project Level rough definition defined in AI&T plan**
  - GO: Design IPTs assumed some degree of involvement above and beyond what was stated (med to high level)
  - GO IPT assumed little to no Flight IPT involvement. Flight IPTs always assumed more involvement than GO. SE&I assumed responsibility at KSC during assembly and testing
  - GO: AIT plan would have been better if product centered vs. process centered.
  - Opinion: FS, AV, & GO (despite concurring) never truly bought into the plan
- **Other than AIT Plan, no Project level document existed that documented R&Rs for the lifecycle of the project for any IPT**
- **Other than AIT Plan, no Project level document existed that documented detailed processes that would be used during Integration & Testing**
  - Thus, the R&Rs, and supporting processes, for this effort were not clearly defined

Evolved Plan for Integration/Testing R&Rs

- **Project accepted logic of implementing Concurrent Engineering Process to expedite the products needed to support Assembly and Test Integration at KSC**
  - This effort was led by KSC personnel in a Project Integration Role. (Not enough CM!)
  - GO: The effort needed to be instituted earlier for optimal results. Flight IPTs seemed not to understand need for assy dwgs.
  - However, the effort produced requirements that were considered Just In Time Engineering (J.I.T.E), good but can be improved upon
- **KSC 101 class**
- **Additional processes to support Integration were also being developed and changed during this time frame:**
  - Receiving & Turnover process of 1149s and Data Packs
  - OTR baseline and change management process
  - TxRB
  - Task Team Leader (concept worked well with AV & FS)
- **Positive: Test Integration Team "gelled" very early on in this time frame**
  - Test Integration began to work early (especially Firing room team)

Actual R&Rs Observed during Integration

- **HUGE learning curve for personnel supporting KSC activities**
  - All Flight IPTs: Significant learning curve for all IPTs supporting assembly and testing of their HW at KSC. KSC safety culture of processing flight HW is much different than other NASA centers
- **CE Process continued to progress slowly**
  - However, the effort produced requirements that were considered Just In Time Engineering (J.I.T.E), good but can be improved upon
    - This late delivery of drawings/OTRs that flowed into WADs impacted the baseline schedule on a daily basis
- **TxRB process utilized as much as possible to resolve day to day issues or delegated tasks from XCB**
- **Actual R&Rs observed for Testing**
  - Testing proceeded almost nominally as planned with minor speed bumps; except for all DFI testing – which was difficult
  - Attributed to having a very lean team that gelled early on in the process working together at the SIL, Dry Runs, Procedure Validations, etc.
  - Was invaluable to have IPT support and cohesion early

Proposed Future State R&Rs

- **Project needs to document early in the planning phases**
  - Clearly define GO, SE&I, & Flight IPT R&Rs throughout the entire lifecycle of the Project
    - Not just for their design phases, but all the way through launch
    - Products AND Processes that each is responsible to deliver and support
  - Clearly define standardized processes (which are lean), across the project, to be utilized by all IPTs, flight , GO and GS, during all phases of the project to include assembly, integration, testing, and launch at KSC
  - GO recommends GO be budgeted to lead the integration effort for requirements and process development associated with HW turnover, assembly, testing, and launch (SE&I?)
- **Recognize and utilize Concurrent Engineering as early as possible**
- **TxRB was a good idea; retain this board**
- **GO hold a value added KSC Processing 101 with mandatory attendance**

National Aeronautics and Space Administration 7

#12 Triboelectrification Lessons Learned (Jim Price)

Bottom Line Up Front (BLUF)

- Ares I-X Launch Availability was severely reduced due to Triboelectrification Weather LCC
- Impact of LCC realized very late
- Ares I-X FS external coating did not meet exception by test
- Late attempt at exception by analysis was not completed in time
- Recommend addressing triboelectrification at system level during requirement development phase

Triboelectrification LCC

- **From AIX-SYS-LCC v.13, 6.5.9 (AFSPCMAN 91-710, v6, A7.2.5.4.10) -**
  - Triboelectrification. Do not launch if a vehicle has not been treated for surface electrification and the flight path will go through any clouds above the –10oC level up to the altitude at which the vehicle's velocity exceeds 3,000ft/sec. A vehicle is considered "treated" for surface electrification if:
  - All surfaces of the vehicle susceptible to precipitation particle impact have been treated to assure
  - That the surface resistivity is less than 10^9 ohms/square;
  - *and*
  - That all conductors on surface (including dielectric surfaces that have been treated with conductive coatings) are bonded to the vehicle by a resistance that is less than 10^5 ohms;
  - or
  - It has been shown by test or analysis that electrostatic discharges (ESDs) on the surface of the vehicle caused by triboelectrification by ice particle impact will not be hazardous to the launch vehicle or the mission. In A7.2.5.4.10.1.1 above, the correct unit for surface resistivity is ohms/square. This means that any square area of any size measured in any units has the same resistance in ohms when the measurement is made from an electrode extending the length of one side of the square to an electrode extending the length of the opposite side of the square. The area-independence is literally valid only for squares; it is not true for other shapes such as rectangles and circles.

How was it missed?

- **Since Ares I-X used heritage Shuttle assets, Volume 6 was NOT tailored.**
  - Volume 6 addresses Ground and Launch Personnel, Equipment, Systems and Material Operations Safety
  - Per Joint Operating Procedure, 45SW 15E-3-14 (NASA-KSC KCA 1308), operations occurring on KSC to include Ground and Launch Pad Safety, excluding operations specific to Vehicle Flight Safety, are the responsibility of NASA-KSC
  - Range LCC's included in this volume
- **Range Weather LCC's not addressed until Feb – 09**
  - Ares I-X Range LCC's derived from Shuttle LCC's
  - Triboelectrification LCC not applicable to Shuttle
    - Flight history used as justification
  - Ares I-X was new vehicle, so LCC applied
    - First flight of new design
    - First flight under 91-710 (updated Range Safety Requirements Manual)
  - Natural Environments Group felt this was not significant based on launch date
    - Launch targeted for morning of 11 July
- **Weather LCC's not adequately evaluated against each IPT or SE&I**
- **LCC not re-addressed until Oct 09**

Lesson – Triboelectrification

- **Description – Triboelectrification LCC severely limited launch availability**
- **Lesson – Need to address Triboelectrification requirement during systems level requirement development phase**
- **Cause –**
  - This requirement was not impacted correctly
  - Impact information did not flow from Working Group
  - Incorrect assumption that RS LCC's would not exceed Shuttle LCC's
  - LCC's not reviewed/understood completely by SE&I and IPT's
  - SE&I did not require flow-down/verification of individual Range Safety Requirements
- **Recommendation**
  - Apply a system level Triboelectrification requirement during the requirement development phase
  - SE&I Allocate and Verify individual Range Safety Requirements
  - Adequate document review process

Lesson – Document Approval

- **Description – Inadequate review of LCC Document resulted in late notification of Triboelectrification requirement**
- **Lesson – Information contained within the weather section of the LCC document was available early enough to accommodate an analysis to support an exception to the triboelectrification LCC**
- **Cause –**
  - Schedule pressures
  - Preponderance of documents
  - Insufficient SE&I and IPT staffing
  - LCC's not reviewed/understood completely by SE&I and IPT's
- **Recommendation**
  - Provide adequate time, priority and staff for document review

Lesson – Transfer of Information

- **Description – Information was not always transferred from the working groups to the Mission**
- **Lesson – Information may come out and decisions made in a working group that has impacts outside the group participants.**
- **Cause –**
- **Recommendation**
  - Provide better and more consistent communication of issues and status discussed in working groups
  - Ensure that meeting minutes are produced and communicated

#13 Ares I-X Lessons Learned/Knowledge Capture Session Waivers (Dawn Stanley)

Ares I-X Lessons Learned/Knowledge Capture Session

Waivers

12-7-09

1. Topic: Post Processing of Waivers
    a. Incident: Time consuming manual processes for Waivers combined with the rapid pace of the project caused much additional work and stress to CM personnel, and possibilities for mistakes
    b. Lessons:
        - No automated CM tool to capture/process waivers,
        - Wait for meeting minutes approval,
        - Format of meeting minutes required per CxP,
        - Funneling all waivers through one person was a bottleneck (still processing waivers) → need a team to process
        - Note: The Process was successful because of capable secretariats
        - Question; would ending the process at approval board level (Vendor or IPT) meet requirements without XCB post processing?
        - XCB post processing has been used to ensure complete closure
        - DXCB had four documents to control (not including the minutes) causing redundancy for posting.
        - Reduce processing (e.g. eliminate 'pending' waiver category)
    c. Recommendation: Use of same CM tool (Project Wide) to process waivers

2. Topic: Automation of work flow from beginning to end. And get CM involved much earlier.
    a. Incident: Waiver/deviation process evolved over the life of the mission (single board to multiple boards but used same process to post process);
    b. Lessons:
        - Processing of waivers by different board (CR vs. Waiver) caused confusion
        - Use of a single form could provide clarity/ease documentation;
        - Due to rapid schedule an automated system was not implemented and
        - Modifications made as needed;
        - Training of personnel on use of process and form in real-time
    c. Recommendation: Use of same Form/Template and CM tool (Project Wide) to process waivers. Include initial training for standardized understanding of desired form content.

3. Topic: No Project Baseline of IPT level documents (requirements were changed as waivers were being approved to the parent document)
    a. Incident: Interdependency of requirements across documents would have triggered changes in lower documents;

b. Lessons:
   - Relied on board chairs/reviewers to determine related impacts (not sure if appropriately implemented);
   - Required manual labor and knowledge of CM staff to determine impacts

c. Recommendation:
   - Automated requirements tool to link all elements together (Change in one displays impacts to all others)
   - Baseline IPT level documents as Project level (With requirements flow-down)
   - Waivers only against "Frozen" or "Baselined" requirements documents

4. Topic: Approval level of waivers (Vendor, IPT, XCB or TA)
   a. Incident: Typically board that approved requirement, should have authority to approve waivers/deviations to that requirement
      - Approver of waiver for TA owned documents is the TA not the mission/project/program per the Agency governance model.
      - CSO tracked SMA owned document waiver and notified Agency CSO of any approvals (unbeknownst to mission).
      - It was noted that minutes and CR input documented CSO and CE approval/non-approval/comments to waivers (Notation of approval authority on agendas may help)
   b. Lessons:
      - Lack of true CPE impacted assessment of waiver (Time constraints)
      - Lack of approval authority at lower levels (must be elevated)
      - Lack of Waiver notification across all levels
   c. Recommendation:
      - Implement approval of ERDs/VRDs at the IPT level instead of MMO; this would allow IPT to process related waivers
      - Again, automated requirements tool to link all elements together (Change in one displays impacts to all others)

5. Topic: Use of waivers to process requirements changes
   a. Incident: Instead of processing change requests to update requirements documents; waivers were processed to denote requirement changes;
   b. Lessons:
      - CM requires a baselined document for effective tracking,
      - Waivers should be against a "frozen" set of requirements
      - Ex: Late release of loads databook (5.0 vs. 6.1) led to generation of several FS waivers to 5.0 (and lower level documents) due to late release of updated SDB → (automated system would have helped with tracking)
   c. Recommendation:
      - Needs more discussion! What other "Change" vehicle could/should be used?

- Could changes have been incorporated at IPT level "pending" release of higher level document, averting so many waivers?
- Again, automated requirements tool to link all elements together (Change in one displays impacts to all others)

6. Topic: What led to waivers
   a. Incident: Use of heritage requirements, contract implementation, ICD definition led to need for waivers
   b. Lessons:
      - Need well defined/baselined requirements as early as possible
      - Need clear definitions upfront for Heritage, Non-heritage
      - Need a Working Group to manage ICDs
   c. Recommendation:
      - Levying consistent requirements early and across the project
      - Clear guidelines and definitions for
        1. Heritage,
        2. Non-heritage,
        3. Related terminology
      - Charter "Interface Requirements Working Group" for life of Project

7. Topic: Waiver Risk Assessment
   a. Incident: Risk assessment as a Waiver requirement not well defined up front. It was implemented better as the mission progressed;
   b. Incident: Use waiver package for board presentation instead of generation of a PowerPoint presentation.
   c. Incident: IPT risk assessment vs. System risk assessment for waiver; understanding system/vehicle level implications at IPT level
   d. Lessons:
      - Use of waiver package for board presentation instead of generation of a PowerPoint presentation proved to be an efficient use of engineer's time,
      - Allowed review of actual waiver package to ensure completeness
      - Risk assessments need to be considered for the System, not just IPT
   e. Recommendation:
      - A waiver form/template (with fields for risk assessment, etc.) to assist with completeness of waiver package
      - Training in use of the 5 x 5 Risk Matrix and
      - Documenting risk mitigation as well as risk justification

Attendance

Dawn Stanley - Meeting Chairperson
Joe Brunty
Heather Altizer
Mary Sumner
Richard Amedee
Renee Currie
Gerald Watson
Martin Johnson
Beth Cook
Mike Phipps
Richard Bathew
Dan Mullane
John Cowart
Teresa Kinney

#14 Ares I-X Lessons Learned (Johnson, Clark, McGrath, Roberts, Wesley, Downey)

INITIATOR/ Phone #	Submitting Org.	DATE INPUT	Subject/title	LESSON LEARNED (Incident/Date/Lesson/Recommendation)	Documents Related to Lesson Learned
Martin Johnson	Avionics LE	11/3/2009	Harnesses/Too Long, Too short	**Incident:** In more than one instance, during the integration of harnesses onto the flight vehicle, harnesses were discovered to be too short. Some cases, they were too long. This could lead to violations of MIL-STD 8739.4 bend radius rules and 16" attachments. **Lesson:** In one of the short harness cases, it was discovered that the model wasn't correct. In this case, it was an oversight of particulars of the connectors required. Thus, the harness was 5 inches short. The model was corrected, an the harnesses were returned to print. **Recommendation:** Verify all harness models. Plan for implementation by MIL-STD 8739.4. Take into account any bending of structure into the harness models. Just because it lays out a certain way in a computer model, isn't always reality. Some structures may not be exactly as modeled.	MIL-STD 8739
Martin Johnson	Avionics LE	11/16/2009	Understanding requirements vs. heritage processes across contracts (expectations); examples - Metallic tape, 8739.4,	**Incident:** This program was established using current standards and processes by the heritage hardware providers. Because all hardware providers do not adhere to the same processes and specs, there is a mix of specs and processes that abound. All providers are not working from the same requirements, though the final goal may be the same, for example, FS wraps their harnesses with metallic tape in the AFT Skirt area and then foams the harnesses in place. The harnesses were provided by LM and built to LM processes and supposedly installed per their requirements. FS processes allows metallic tape overwrap, LM processes do not allow it. Example 2, FS follows 8739.4 when they install a harness. Post installation, FS performs DWV testing. LM processes do no require, or desire, DWV testing. **Lesson:** There needs to be a continuous review of all heritage system requirement specifications and processes and document all overlaps and shortcomings. **Recommendation:** Understand, in the beginning, what each heritage system requires.	
Martin Johnson	Avionics LE	11/16/2009	Kulite pressure sensor utilization; Is there a better sensor available?	DFI: Kulite pressure sensors applicability (due to drift issue, calibration, environmental test); **Incident:** It is a known fact that Kulite pressure sensors have a drift problem over time. Most of these sensors were installed nearly a year before flight. All the calibrations for these sensors are based on vendor provided cal sheets. Unless these sensors see a calibrated source applied to them, on the LV, it will not be known how much they have drifted. This puts all Kulite data in suspect as to its true accuracy. On ARES I-X, it is not known how far off we are from actual. We have to assume that the vendor cal sheet is accurate. **Lesson:** Do not use a specific sensor manufacturer just because they work in a short term ground test. Evaluate other vendor's sensors and choose the best qualified, especially looking at drift and calibration requirements, as well as environmental limitations. **Recommendation:** Know the LV environments, well in advance, and choose a sensor that closely matches the requirements. Up screening may be necessary, and qual/atp testing should be performed on a batch of the sensors. A batch, of the chosen sensors, should be set aside for independent calibration. This calibration should be repeated on a routine basis (6-month) and checked with previous calibrations.	
Martin Johnson	Avionics LE	11/17/2009	EU data vs. raw counts	**Incident:** During channelization, if engineering units, (EU) were available, the sensors under test, plus the data system's range settings, would be verified. Changes in software could be made earlier. For ARES I-X, raw counts were used during channelization and can only tell if a sensor was on a certain channel (harness). **Lesson:** During sensor checkout (channelization), provide both raw counts and EUs, for a complete checkout. **Recommendation:** Provide both raw counts and EUs.	
Martin Johnson	Avionics LE	11/17/2009	DFI Channelization Improvements	DFI Channelization improvements (appropriate upfront planning, equipment availability (BOBs, etc.) **Incident:** During channelization, early on, the process was ground to a halt, when an issue was discovered. It took up to 3 days to correct a WAD, get the approvals and be in configuration to continue the work. **Lesson:** The ability to understand the KSC processing is a must. Knowing the Solumina, paperless system, in the beginning would have provided a leap forward. **Recommendation:** Advanced planning, from TPRs to the WADs, to being flexibility working the WADs and making Solumina changes, as work progresses, is necessary. Each IPT should have several people trained to use the system in place at that time. Those trained folks should be empowered, by the IPT, to make decisions and authorize work.	

INITIATOR/ Phone #	Submitting Org.	DATE INPUT	Subject/title	LESSON LEARNED (Incident/Date/Lesson/Recommendation)	Documents Related to Lesson Learned
Martin Johnson/Tony Clark/Matthew McGrath	Avionics LE/ES Engineering	11/18/2009	Effective Electromagnetic Environment Compliance	**Incident:** Effective Electromagnetic Environment compliance programs have a number of elements that summed together provide success. The Ares I-X had some unique aspects that could not be totally accounted for by Electromagnetic Interference (EMI) testing of the individual Avionics components. **Lesson:** Some examples of variability: • The Lockheed Martin (LM) Avionics components were EMI tested to a military requirement (MIL-STD-461C). The Shuttle Derived Avionics (SDA) was EMI tested to a NASA Shuttle requirement (SL-E-0002). • Electrical cabling was a duke's mix of LM/United Launch Alliance and ATK/USA (different styles to meet the same objectives). • Some of the electrical cabling was outside the vehicle along the System Tunnel. • Telemetry transmitter configuration that had never flow before. • Development Flight Instrumentation located outside the vehicle vulnerable to RF. **Recommendation:** The solution to filling the gaps was to perform a 0dB Test that operated the entire vehicle Avionics at Launch Pad 39B, while bathing the Ares I-X vehicle with the Range Tracking Radars and Command Carrier. This solution did add a small amount of work to the schedule, but a Self-Compatibility Countdown and Flight Simulation is a normal part of a vehicle Check-out at the Launch Pad. We added the Range Tracking Radars and Command Carrier to enhance the total compatibility envelope. The 0dB Test did not provide a Safety Margin for the Vehicle Avionics, but did show that we had an acceptable risk from a vehicle operation and Electromagnetic Compatibility compliance view point.	
Martin Johnson/Tony Clark/Barry Roberts	Avionics LE/ EV 44	11/19/2009	Triboelectrification	**Incident:** The Ares I-X Launch Commit Criteria (LCC) Document AI1-SYS-LCC contained a LCC for triboelectrification under Weather Rules, paragraph 6.5.9. The triboelectrification rule is part of the Lighting LCC that is dictated by the Range to all launch customers, must be included in their documentation, and cannot be waived. The triboelectrification rule is unique in that it can be satisfied in one of three ways: 1) weather criteria can be used to limit triboelectrification, or 2) vehicle surface design features can be used to limit surface electrostatic discharges, or 3) electrostatic discharge test/analysis can show vehicle immunity to surface arc discharges. **Lesson:** Unfortunately, the potential design features or potential test and analysis options were not included in the I-X hardware requirements and verification documentation. Also, when the triboelectrification LCC rule was included and discussed in February 2009, the weather portion of the rule was not expected to seriously impact launch availability for the planned late spring or summer launch date. **Recommendation:** The simple lesson learned is that LCC Documents should be reviewed to determine if there are potential vehicle design requirements imbedded in the LCC that should be included in the Systems Requirement Document. As an aside, it can be noted that the Ares I E3 Requirements Document (CxP 72043) does contain requirements for electrostatic charge control including precipitation static (p-static), which is the primary concern from triboelectric charging.	
Martin Johnson/Tony Clark/Jeff Wesley	Avionics LE/ES Engineering	11/20/2009	Electrical Integration	**Incident:** The ARES I-X design requirements were quickly established and in many cases mandated to be the standard Lockheed Martin requirements without input from MSFC Engineering. **Lesson:** NASA-STD-8739.4 for Interconnecting Cables, Harnesses, and Wiring is a well established NASA core standard and would have been the desired standard for Ares I-X and would have resolved many of the issues ultimately encountered during integration. **Recommendation:** Many of the major issues experienced on ARES I-X such as cable harness bend radius, support between p-clamps, shielding termination concerns, strain relief issues, recessed contacts, etc could have been prevented or greatly mitigated had the proper requirements been utilized.	
Martin Johnson	Avionics LE	11/16/2009	5 Hole Probe - On a Launch Vehicle	T-0 pull for 5 hole probe cover, Pito tube use on a vertical launch vehicle(pre-launch) **Incident:** ARES I-X used an unheated, roughly covered, pito tube. Launch vehicles typically use an air data system, which is covered and heated. **Lesson:** The use of a pito-type data systems on a vertical arranged launch vehicle, unless it is designed to keep out FOD/water infiltration, should not be allowed. Even the best designed cover may have problems if exposed to the elements for an extended period. A T-0 pull will help keep out FOD/water, but as seen on ARES I-X, it can still be problematic. **Recommendation:** Use an Air Data system specifically designed for vertical launch vehicles. FOD can still be an issue, but water can be removed by using the heater designed in the system. If a cover is necessary, the cover should be designed to be removed at T-0 and not before. It should be designed to pull off first, then rip apart if it gets caught.	

INITIATOR/ Phone #	Submitting Org.	DATE INPUT	Subject/title	LESSON LEARNED (Incident/Date/Lesson/Recommendation)	Documents Related to Lesson Learned
Martin Johnson	Avionics LE	11/17/2009	Electrical Integration	Incident: Electrical integrator (from concept to delivery); to assist with installation, handling, etc.;involvement of customer. ARES I-X used a different integrator for each IPT. Each IPT was installing LM provided avionics. In doing so, each IPT had to follow there heritage processes. This led to requirements not being met and confusion on the MR rationale. Lesson: Plan for a single electrical integrator, working across IPTs. They would be responsible for all electrical interfacing and hardware installations. When a NC arises, they would have the process to correct it. Multiple IPTs involvement would not necessarily be required. Recommendation: In the beginning of a hardware build, have only a single electrical integrator, that works across IPT lines. They are completely responsible for the design, installation, integration and function of the complete electrical system for the entire flight vehicle and ground system interfaces.	
Patton Downey	RoCS Lead En	10/30/2009	Flatness of Engineering Boards/ Organization	Ares I-X had a relatively flat structure in which many documents were Level II. Changes to these could only be approved at a project level. This resulted in many project level ERB or TXRB meetings in which only one or two IPTs were actually impacted. This was an inefficient use of personnel. Eventually an exception was made for DFI and a separate board was made for DFI issues to improve the efficiency of decision making. The creation of lower level boards (between IPT and project level) could also have been implemented to deal with changes to interface documentation more efficiently.	Project Plan, System Engineering Management Plan
Patton Downey	RoCS Lead En	10/30/2009	Broadening of Personnel Involvement in Requirements Writing for RoCS	Only one representative of NASA and the prime contractor for RoCS were substantially involved in the writing of the RoCS System Requirements Document. As a result there was some confusion over the intent of the requirements and how they would be verified. In the future it would be preferable to have those responsible for verification to also be involved in the writing of requirements.	
Patton Downey	RoCS Lead En	10/30/2009	Interchangeability of RoCS hardware	The two RoCS modules were not interchangeable due to match drilling of the interface panels and the flight instrumentation which was on only one module. This resulted in two sets of drawings and the inability to readily replace one module with a spare. The match drilling did not appear necessary based on NASA Standards for similar joints and the use of DFI on only one module probably did not save money due to the resulting two different sets of documents. It would be preferable to design interchangeable hardware and single sets of drawings.	
Patton Downey	RoCS Lead En	10/30/2009	RoCS Test/Verification Ambiguities (Check Valves)	The RoCS test procedures were not necessarily reviewed in detail by NASA in advance since they were level III documents. During testing of the flight check valves the prime contractor elected not to measure the flow rates. This resulted in some ambiguity in whether there was sufficient evidence of verification of check valve function. Advanced review of test requirements, plans, and procedure should be able to prevent this from occurring.	
Patton Downey	RoCS Lead En	10/30/2009	RoCS Test Setup Risk (engine valve)	The RoCS test procedures were not necessarily reviewed in detail by NASA in advance since they were level III documents. During testing of the flight engine valves the prime contractor elected not to place a filter between the regulator and the flight hardware. This resulted in some minimal risk that debris caught within the regulator could migrated into the flight hardware. (The risk was accepted by the project since the flight hardware had an internal filter and the regulator had gone through cleaning.) Advanced review of test requirements, plans, and procedure should be able to prevent this from occurring.	
Patton Downey	RoCS Lead En	10/30/2009	Fastener requirements	Ares I-X did not have any specific fastener requirements. In the case RoCS, a concern developed that the propellant tanks were fastened using only torque with no secondary locking mechanism. To reduce the risks fasteners with a secondary locking mechanism were obtained and sent to KSC to replace the original fasteners. Fastener requirements and control plans should be used to avoid similar uncertainty over the requirements and acceptable risks associated with fasteners.	
Patton Downey	RoCS Lead En	10/30/2009	Protuberance Loads	RoCS had a late fairing redesign. The reason is that RoCS did not initially receive specific loads on the protuberance. instead, the Ares I-X structures databook indicated that assuming random loads on protuberances were twice the quasi static loads should be conservative. This was not the case for the original RoCS fairing design as was shown when SEI generated a specific load case for that protuberance. In the future we should not make or rely on such generic statements, but analyze the specific configuration.	

#15 Ares I-X Technical Lessons Learned (Dawn Stanley, Henry Wright)

Ares I-X Technical Lessons Learned

Submitted by: Dawn Stanley and Henry Wright

Topics	Issue	Recommendation
Fasteners	Disparate fastener requirements and interpretations by Centers and contractors (e.g. pre-load, lot testing).	Select a standard and common set of requirements and levy it across the entire project/program.
Grounding and Bonding	Different interpretation of terminologies and expectations for the arena.	Select a common terminology and definitions to alleviate confusion and variation in implementation.
Loads	Loads approach started as envelopes (normal approach) then moved to time consistent (combinations matter; proper checks and balances were not always in place).	Select approach for loads development approach and enact proper independent reviews of data.
Verifications	-SRB uses lot verifications (in spec vs. out of spec; if out of spec them MRB); -Experimental, aircraft world reviews all verifications; key part of verification is reviewing the inspection results and verifying these occurred. -Accessibility to verification supporting data was an issue at times due to designation as proprietary and location of data.	Clearly define expectations to elements/integrated product teams regarding verifications and system level review of element/IPT verifications including availability of supporting data.
Testing vs. analysis approach	-Various Defining factors and margins and values -What is meant by testing? One pull test on a fastener is not testing which is used to justify lowering factors of safety.	Clearly define project/mission factors of safety and margins with values listed. Employ good engineering practice and document associated requirements as to what constitutes a test.
Gapping Margins of Safety	Different interpretation of gapping factor of safety requirements by the IPTs (1.4 per SDB vs 1.2 used by FS per MSFC engineering)	Set down the requirements for factors of safety for gapping up front with better definitions for use such as pressure vessels vs structural joints. Be consistent.
Modal tests and damping	-Positive → taking time to appropriately plan (models in good shape) provided confidence/risk reduction, worked with GO to understand what could be implemented -Negative → rollout damping value – better job on understanding the relevance	Better management of expectations regarding the modal test. Ensure aspects of test are appropriately vetted prior to inclusion.

	to load cases and how to explain its impact; Damping is a physical parameter (like natural frequency); look at similar deflections; damping was never in baseline test; damping was thrown in at the last minute to modal test	
Concurrent Engineering Process for Integrated Drawings	-System level drawings were an after-thought (drawing strategy not assessed at beginning of mission, this would have allowed issuance of certain requirements to IPTs to make the process work better and consistent.) -Centers processed drawings differently (e.g. different package for drawing and parts list) -Reviewers had difficulty tracing lower level drawings to higher level assembly drawings. -Coordinate system for sensors/protuberances – OML did not include tolerances; therefore waivers were generated to address.	-Develop and document project/mission level drawing requirements to ensure consistency in implementation. -File drawings by top level assembly tree instead of lower level. This would allow traceability from lower level drawing to top assembly tree. -Determine and document tolerances for sensors and protuberances in the OML document.
DFI channelization testing	First time major portions of system interfaced was test configuration 1. Reconciling test hardware and software idiosyncrasies/trouble-shooting caused delay in test initiation. Programming errors in GSE were documented.	-Proper planning/checkout of test approach and flight hardware/test hardware and software compatibility and availability prior to testing.
Joint MRB Process	Issues included (1) Late notification of meetings (although issue was in work for weeks), (2) data not available until meeting, which caused joint MRB members to constantly play catch-up during meeting and did not allow enough time for independent assessment (3) First Stage use of Team Center and D drive use for data instead of using Windchill and Webex	-Plan accordingly, set standard MRB meeting time, cancel meeting if not needed, and distribute data as soon as possible to allow proper review and assessment prior to meeting. -Use standard systems/tools accessible by mission team members so that all participants have access to the data.
SE&I Internal review process	-Needed internal System Engineering (SE&I) review prior to release of data (LaRC Technical Quality Reviews used but needed assessment in relation to Mission perspective).	-Implement SE&I and Integration review of technical data prior to release to greater community to ensure system level considerations were incorporated/assessed.
Waivers	**Will address at 12/7/09 lessons learned session.**	

#16 Ares I-X Lessons Learned/Knowledge Capture Input (Scott Croomes, Dawn Stanley)

MSFC Center Director and Engineering Management
Ares 1-X Lessons Learned/Knowledge Capture Input
11/30/09 and Written Submission

1. Topic: Synchronization of Agency, Center, Program and Project Requirements

1a. Incident: Contracts were let before mission requirements were set.
1b. Lesson:
- Metallic tape issue: Heritage requirements for Shuttle allowed metallic tape use but heritage requirements for Atlas did not allow its use. At integration, this introduced additional risk to the mission.
- Std 8739.4 application: Cable testing and standard interpretation varied by center and contract. Again heritage requirements allowed varied implementation of a NASA standard. At element integration, disagreement regarding extent of testing resulted in reduced implementation of the NASA standard and introduced additional risk to the mission.

1c. Recommendation: Basic requirements must be established before contracts are let.

11a. Incident: Clear definition of heritage, modified heritage and non-heritage hardware (e.g. chassis, box, card, piece part) needed and applicability of heritage vs. heritage requirements were inconsistent.
11b. Lesson: Deliverables between integrated product teams were complicated by the varied interpretation of heritage and non-heritage requirements. There were inconsistencies and disagreements over the application of the terms and which requirements were applicable (e.g. "Flown before" does not eliminate verification/requalification of environments).
11c. Recommendation: Ensure clear definitions of heritage and non-heritage (including which category modified heritage hardware falls) with examples.

2. Topic: Post flight data assessment plans took a back seat to getting to launch

2a. Incident: HOSC had to justify its existence. HOSC not included in relevant Ares I-X contracts, although contractors informed early on (2 – 3 yrs) of what was needed.
2b. Lesson: Although available prior to launch, *B59 Decom* for telemetered data was provided after launch to HOSC for post flight assessment. Ares I-X had no requirement to supply live data during flight to HOSC.
2c. Recommendation: Plan for post flight assessments earlier in the mission cycle.

3. Topic: Communication of Ares I-X (AIX) approach and progress to Ares 1

3a. Incident: The AIX philosophy was not bought into by Ares 1. Initial approach was thought to have Ares 1 propose to AIX, then harvest what was needed. As it turned out AIX was set up to be its own entity. The AIX and MSFC Ares 1 teams were set up separately.

When AIX required assistance from Ares 1, confusion ensued due to a lack of upfront communication. Larry Huebner, Ares 1 liaison to Ares I-X, worked to keep the two communities connected.

3b. Lesson: There was a perceived disconnect of Ares I-X requirements from the main line program, although MSFC engineering did participate in the SRR and design reviews. This disconnect limited the learning opportunities and information for Ares I personnel. However, AIX did fly and that was the main objective. There is a challenge in finding the right balance of involvement.

3c. Recommendation: Program/project/Center management inform working level personnel of decision/approach.

4. Topic: Requirements development and evolution had limited input from Ares 1

4a. Incident: Relevance of Ares I-X requirements to Ares 1 altered. Initially, Ares I-X requirements started with direct linkage to Ares 1. Ares I-X changed its requirements approach at its PDR. This resulted in Ares I requirements having to buy their way onto the Ares I-X list.

4b. Lesson: This resulted in a general disconnect (including requirements) from the main line program, which limits information and education to the mainline program.

4c. Recommendation: Involve mainline program throughout the test flight life cycle from requirements development, alteration and verification.

5. Topic: Verification implementation

5a. Incident: When management says “we will accept the risk” engineering does not know what that ultimately means. Verification was not handled as importantly as it normally would due to the perceived “higher than normal risk acceptance”.

5b. Lesson: This lack of communication led to various interpretations as to the priority required.

5c. Recommendation: Related risk acceptance and expectations need to be determined, documented and communicated early.

55a. Incident: First Stage verifications were processed and approved late in the mission cycle.

55b. Lesson: As a result, system level verifications were processed late (up until about L-5 days), which introduced additional mission risk. To enable verification review and approval completion within the set launch schedule, the Ares I-X verification process was altered to require only First Stage (including First Stage S&MA and Chief Engineer) review and approval of the First Stage verifications (~420). All other IPTs’ verifications were reviewed by System Engineering and Integration (SE&I) as well as the mission level technical authorities. Perception was First Stage applied the same rigor as for the shuttle boosters.

55c. Recommendation: Critical processes need to be identified and properly planned (resources and schedule) including review by SE&I. Establish priorities to identify which systems are more critical and attack them first.

Other comments:

- Same process unfolded as did on X-34. Started out with willingness to accept risk which manifested itself in less design and verification rigor. Then as we get closer to flight rigor was forced back into the system. This is very costly and very stressful on the team.
-Roll Control System verification process was implemented well; review their process.
- The mission was perceived as an “as built” effort.

-Verification implemented differently across MSFC integrated product teams.
-Ensure system level requirements are understood.
-Keep S&MA involved in the verification process.
-We only know one way to implement verification and that is to process a lot of paper to show verification.
-Ares I-X was perceived to be an as-built vs. as-designed effort.

6. Topic: First Stage material usage agreement (MUA) and material usage identification list (MIUL) process implementation
   6a. Incident: The MUA/MIUL process was new to the assigned First Stage contractor personnel, who reverted to internal processes, not following the government process, causing extra work.
   6b. Lesson: Change package engineers were assigned and distribution loops enacted, when only one or two signatures were needed.
   6c. Recommendation: Communicate the government process for efficiency and to eliminate rework.

7. Topic: Ares I-X Organization/Structure
   Items of Note:
   7a. Not clear to whom First Stage engineers were reporting. Were they working for 1st stage Project or Ares 1-X?
   7b. Streamlined personnel approach utilized initially, then the focus dramatically increased at L- 6-10 months which required additional MSFC support for loads issues and to close verifications.
   7c. Having LaRC as the SE&I lead was difficult. Perceived lack of connection between Ares I and Ares I-X
      - What was the real objective? To fly something or to get closer to the Ares 1 vehicle.
         - Didn't train the Ares 1 people
         - Products didn't come out of these organizations
   7d. Need to have one center be responsible for the mission,
   7e. Must work better with aligning Center responsibility with authority and personnel and and providing appropriate support.
   7f. In the end MSFC wanted more involvement at the Mission Level, even though they did not have mission responsibility.
   7g. There was confusion regarding the roles and responsibilities of the Ares I-X lead engineer and lead system engineering. Meetings were held with MSFC engineering management to explain the roles and differences from the MSFC model.
   7h. Ares I First Stage management began to insert itself into the process more as the project progressed.

8. Topic: Ares I-X Reviews

   8a. Incident: There was pushback during the entire mission on the execution of Center reviews, with the Program saying the reviews were not "value added".
   8b. Lessons Learned: The Centers were responsible for the technical products and is expected to ensure products are appropriately reviewed per the Agency governance model. Further, the Center reviews and the good work done by all, allowed the Agency to have a clean Agency FTRR and a clean flight. Center management was flexible and utilized joint ICMCs and combination of Center Director FTRR with SMSR for efficiency.
   8c. Recommendation: Flexibility among program, projects and Centers to ensure products are appropriately reviewed to ensure mission success.

88a. Incident: The Ares I-X system CDR and PDR process utilized a 15-20 independent expert panel.

88b. Lessons Learned: The board members wound up being responsible to ensure a thorough review occurred. This approach limited review completeness. Other requested reviewers (from technical authorities) had difficulty finding board members to sponsor their RIDs, which limited comments. It appeared that the focus of the board was on the presentations and not the supporting data package, which contained the test and analysis reports, models and drawings.

88c. Recommendation: Utilize a system-level design review process that ensures the review of technical data package and facilitates the submission of review input.

Other comments:
- RoCS reviews were appropriately planned and executed at Center and Mission levels.
-Monthly Ares I-X reviews dropped off at EMC.

9. Topic: Lean launch team support approach

9.a. Incident: Ares I-X fielded a lean launch team with launch support team personnel scattered in various facilities including Hangar AE, the Block, HOSC, and other locations. The team members were supposed to be able to handle all issues that may arise during the launch countdown.

9b. Lesson Learned: This approached worked fairly well until the loads problem had to be addressed. This required bringing in personnel that were not granted access to the launch team communication loops and the use of teleconferencing to facilitate discussions with the discipline experts during the launch countdown. Thus these discussions were not being recorded as conversations are on the launch communication channels. Further, it was discussed among senior Agency management if we had a violation and the folks weren't there to work it, we would scrub and come back the next day. You can't have it both ways – it is critical the support is on hand to address the real time issues that will pop up.

9c. Recommendation: Understand the needed discipline support required to support a launch and provide seating and access to the launch communication channels to allow recording of the discussion.

#17 Ares I-X SRB Lessons Learned Report December 2009 (John Paulson)

Ares I-X
Standing Review Board

Lessons Learned Report

DECEMBER 2009

The Ares I-X Project resulted in many lessons learned. These should be utilized, as appropriate, by the Constellation Program (CxP), Exploration Systems Mission Directorate (ESMD), and applicable future Agency endeavors. The SRB observations provided include items that were not completely resolved or the root cause was still to be determined at the time this report was submitted. As these lessons learned are further explored and understood, they may significantly contribute directly to the betterment of future NASA activities.

1. The new NASA Governance model was thoroughly exercised during the Ares I-X Project life cycle and the following findings were observed.
   a. The involvement of the Technical Authorities (S&MA/Engineering) produced a mixture of "policing" versus "helping" during the implementation phase of the project.

   b. Since NASA had sole responsibility for the technical leadership including the SE&I functions for Ares I-X, it was not clear who, if anyone, was "watching" NASA perform their technical roles and responsibilities. The exceptions were the Independent Review and the IV&V efforts which were performed for certain functions. (i.e.- The concern is who is performing the role of a "second set of eyes" in much the same manner as NASA performs over its Prime Contractors for things like technical decisions, integration, problem resolution, application of specifications and standards and etc.)

   c. The Ares I-X CoFTRR process created a lot of confusion, misinterpretation and overall misunderstanding as to intent, as well as, participants roles and responsibilities. In addition, the number of "formal" reviews (i.e.- The ESMARR, SMSR and ICMC) originally planned including the three separate CoFTR reviews may have been necessary for Ares I-X but if continued as the CxP matures will become inefficient and cumbersome to implement. The CoFTR process is a vital activity and is very critical to the overall success of the CxP, therefore, it must be matured as a lessons learned.

2. The Ares I-X Integrated Product Teams (IPTs) were from multiple NASA centers and the choice to select heritage hardware from SSP, Commercial Atlas, and DoD Peacekeeper produced a number of lessons learned.
   a. The decision to choose heritage/proven systems for Ares I-X produced positive results in the assembly, integration, checkout and flight test. NASA was able to benefit from both the use of proven hardware/software and its

associated corporate capability (i.e.- ATK factory and engineering know-how and LM Atlas-Denver Engineering and System Integration Laboratory, ensuring successful integration of these heritage systems into the newly developed rocket. Future NASA developed launch systems should strongly consider this approach to system integration.

b. During the KSC assembly, integration and checkout phases there was some confusion or lack of understanding of the definition of terms and processes between the Ares I-X IPT's and, at times, within the CxP. This was observed during each of the various project level milestone reviews, including the CoFTRR development and signoff. To eliminate/minimize confusion and miscommunication, identification of a common set of processes/practices and formal training for implementing these is recommended (i.e. Simple definitions for defining vehicle processing "Constraints" and CoFTRR exceptions and a better understanding of the processes for managing non-conformances).

3. The Ares I-X Project had difficulty closing out two life cycle products required to ensure success to the flight test. They are as follows: 1) final definition and acceptance of the rollout, liftoff and ascent loads and environments for the elements and integrated FTV and 2) closure of element level and system level verifications documented in the Ares I-X ERD's and SRD. These life cycle products should have been closed during a "proactive" development environment as opposed to having to deal with the open tasks during a "reactive" operations environment. The late closure of these two issues put the project at risk throughout the KSC assembly, integration and pre-launch portion of the project life cycle. The risk was predominantly one of schedule and cost; however, considerable pressure was felt by the whole team and if not managed properly, could have resulted in an increase to technical risk based on loss of rigor and/or discipline in properly closing out these two sets of product deliverables. In addition, the project governing authorities decided to delete the KDP C for Ares I-X, which if properly conducted, would have discovered both of these issues. The lesson learned is to ensure full lifecycle product deliverables are completed in a timely manner as required by to NASA NPG 7120 or at a minimum understanding project posture on entrance/success criteria for progressing throughout the life cycle.

4. The Ares I-X Flight Test appeared to be quite successful in meeting the pre-defined flight test objectives; however, there were several events that occurred during the test

flight that warrant full engineering investigation in order to gain critical knowledge for future applications.

a. The requirement to mitigate triboelectrification effects on the Ares I-X as a system level requirement was missed in the requirements development and vehicle design phase. This requirement is documented in the 45th Space Wing Range Requirements document. In order to ensure proper design occurs, a thorough review of all applicable operational requirements documents that are available should occur and those applicable design drivers should be properly captured to ensure proper design for operability and also launch availability.

b. During the staging and separation portion of the flight test, several events occurred that will benefit from more in depth engineering investigation:
   i. There is still question as to whether a re-contact event occurred between the FS and the USS. This issue should be completely resolved as soon as possible.
   ii. Main Parachutes #'s 1 and 3 failed to completely open during descent. The following fundamental question should be addressed: was the parachute system failure attributable to Ares I-X configuration or staging conditions or was the failure generic for this 3 parachute configuration and may be expected to reoccur in Ares I flights? An engineering investigation has already started on this event.
   iii. There was a staging disconnect failure - three separation connectors did not separate as planned. An engineering investigation has already started on this event.
   iv. A well understood and a historically successfully "trigger" for stage separation sequence on Shuttle using booster chamber pressure was replaced for Ares I-X with guidance accelerometers as the "trigger" for the separation sequence. Ares I is also planning to use accelerometers. Usage of a different separation "trigger" should be reevaluated and should include reasons for a selection away from a historically successful approach.

c. An earlier SRB recommendation to exercise the day of launch winds aloft analysis system using real, measured winds with real Ares I-X redlines well in advance of the flight was apparently not fully understood or implemented. This resulted in a massive amount of "last minute" effort to clear Ares I-X for flight with no shelf life for the changes implemented. SRB recommendation should be reviewed and implemented for future flights. Concern from CDR Part 2 as follows:

   Concern # 10 – Launch availability

The project should understand the launch availability percentage both from a loads and guidance perspective. Limitations on launch availability are caused by no day of launch flight software update capability, mean monthly winds being used for an April launch with a slip of launch month probable and the VSS being disconnected hours before launch.

Recommendations

- Verify the launch probability with a single I-Load against a data base of measured winds.
- Develop mean monthly winds flight software tables for an additional number of months past the April timeframe to maximize launch availability for the actual launch month.

In addition to the lessons learned documented in this report, the SRB observed a number of strengths which could be considered lessons learned for future Agency applications. These strengths are grouped as follows:

a. Program/Project Management Strengths:
   i. At both the Mate Review (MR) and the follow-on Executive Session (ES) there was excellent participation from Senior Management (Center Directors, Program Management, and all stakeholders). As a result, there was an assigned action at the ES to establish an achievable launch date. On 7/14/09 the new launch date of 10/31/09 was established. The team proceeded through the remainder of the KSC Pre-launch processing and launched earlier than predicted on 10/28/09.
   ii. Immediate action was taken by the Deputy CxP PM, when the Ares I-X Manager asked that additional expertise be applied to help the team get through some critical "offline" activities that if not closed in a timely manner could have an adverse affect the schedule.
   iii. The MMO demonstrated many times during the assembly, integration and checkout phases of the project the unique ability to correctly balance the risk of proceeding through the launch site critical path while managing open items (i.e.- Stacking with open loads assessments not finalized).

b. Organizational Strengths:
   i. The Ares I-X team has integrated the talents of the supporting NASA Centers, heritage hardware and software from DoD, industry and support contractors into a well organized grouping of Integrated

Product Teams (IPT's). Strong evidence of this was the success achieved by the Avionics team in utilizing Atlas heritage hardware/software and at the same time utilizing the LM test facilities for flight and ground systems development and testing utilizing the "test like you fly" philosophy and then integrating the LM test engineers into the checkout and launch team proved to be invaluable. The First Stage ATK heritage hardware and modified heritage hardware along with the ATK engineering development, modeling, analytical and problem resolution capability proved to be invaluable especially in solving the loads and dynamics final assessments. The use of heritage peacekeeper for roll control was predominantly self contained and simple to implement as well as proving to be fully capable of accomplishing its flight test objectives. The KSC processing capability of the ATK/USA contractor teams were critical to the huge success of Flight Test Vehicle Assembly, Integration, pre-launch checkout and successful flight test. This was especially evidenced in the last several weeks in meeting the CoFTRR requirements for paper closure just in time to support the planned launch date.

ii. Special recognition should be given to the KSC Ground Operations Test and Launch Team preparation and training efforts. The team developed a very thorough process for training and preparing the Prime Launch Team, the Launch Support Team and the Launch Authority Team. This included a fully certified team through the KSC "Standboard" process, various training simulations and test, launch and mission rehearsals.

iii. The fact that a small team of individuals from across the Agency and Industry worked diligently for up to three years and performed the major event of the Ares I-X flight test with such tremendous success will result in many valuable lessons learned applications.

c. Process Strengths:

i. The Project Face-to-Face Risk Review was comprehensive, timely and helped provide consistency in each IPT's risk summaries. The review provided a deep level of understanding of the projects risk history and risk acceptance posture that was used in the commit to flight process.

ii. The management process of requiring Independent Review along with Independent Verification and Validation (IV&V) for the Ares I-X flight test was practiced throughout the life cycle. It was especially evident when NESC and the Aerospace Corporation were asked to provide independent assessments of several issues discussed at the CoFTRR's and L-1 Day briefing.

iii. The Ares I-X Hazards Analyses accomplished through the CSERP should be labeled as a "Best Practice". The keys to success were as follows:

1. Adopted a flexible unencumbered process that allowed SME's to focus on technical analyses
2. S&MA, Engineering and MMO/IPT Managers were fully engaged
3. Resulted in a thorough product which significantly reduced Ares I-X technical risk.

In addition to the above items, the history and final disposition of the Ares I-X SRB total set of findings are documented in the SRB reports for CDR Part 1, CDR Part 2 and the recently completed Ares I-X KSC Assembly, Integration, Checkout and Launch flow. For a copy of each of these reports please contact Dianne Cheek, NASA IPAO at dianne.l.cheek@nasa.gov, 757-864-2761 (O) or 757-593-3844 (C).

#18 Ares I-X Interface Development Lessons Learned (Kevin Vipavetz)

AI1-SYS-IDLL
Version: 1.1
Release Date: June 4th, 2010

National Aeronautics and
Space Administration

ARES I-X
INTERFACE DEVELOPMENT
LESSONS LEARNED

VERSION 1.1

The electronic version is the official approved document.
Verify this is the correct version before use.

Document Revision History

Status	Revision	Release Date	Description
In Work	Draft	Pending	Initial draft created by custodian
Final	1.0	May 19th, 2010	Added two appendices, one for avionics lessons learned and one for interface lead lessons learned
More Final	1.1	June 4th, 2010	Edited Appendix H

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Figures

Tables

1.0 INTRODUCTION

1.1 Purpose

For the NASA to be fiscally responsible stewards of the taxpayer's money and to be a learning organization, it is necessary to capture lessons learned in a format that may be effectively transmitted to follow-on Agency projects and programs. This effort is intended to convey experiences deemed to be potentially helpful in improving both process efficiency and product quality. The purpose of this report is to document and communicate lessons learned by the interface custodian / Book Manager. Additional lessons learned by the interface technical lead and avionics element are incorporated as appendices. This document may be used to provide input to more comprehensive SE&I and MMO lessons learned activities.

1.2 Scope

This report covers the three Ares I-X FTV IPT Element-to-IPT Element IRD's. Specifically:

- AI1-IRD-C2U, "*Ares I-X Interface Requirements Document Upper Stage Simulator to Crew Module/Launch Abort System*" Revision 3.01
- AI1-IRD-R2U, "*Ares I-X Interface Requirements Document Upper Stage Simulator to Roll Control System*" Revision 2.04
- AI1-IRD-U2F, "*Ares I-X Interface Requirements Document Upper Stage Simulator to First Stage*" Revision 2.02

Seen in Figure 1 is the hierarchy of the requirements flow/trace of the document sub-tree for the relevant MMO configuration controlled system, element and interface documents.

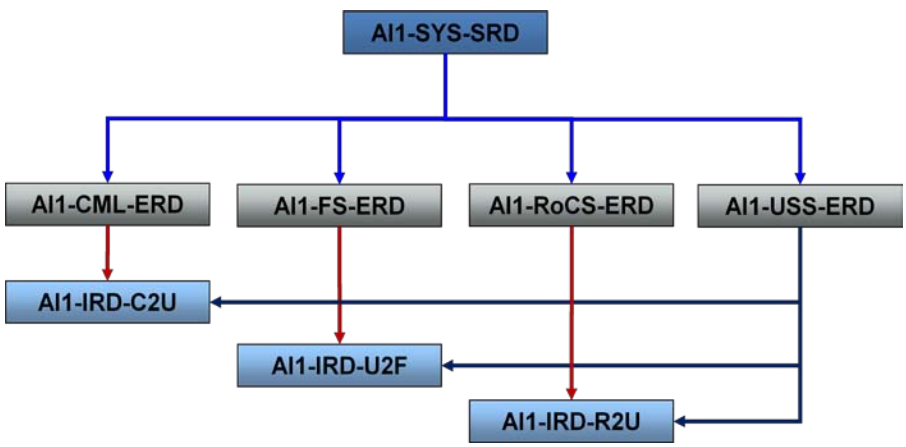

Figure 1 – System to Element to Interface Requirements Flow

1.3 Lesson Learned Format

When appropriate (Section three), the following format will be used in this document to relate the lessons learned (LL's)

- LL-xx (unique ID and title)

- POC (Principle contributor)
- Issue (Explain what was good or bad)
- Cause (Explain plausible reason(s) why this issue may have occurred)
- Recommendation (Describe what could potentially be done in the future to eliminate or maintain the item)

Section two does not currently follow this format, however the section number and title satisfy field one, “Mark McMillin” satisfies field two, the narrative generally addresses fields three and four and there is usually a recommendation to satisfy field five (i.e. all the information required to complete the above data record should be provided).

2.0 PROJECT LIFE CYCLE AND MANAGERIAL CONSIDERATIONS

2.1 Teaming Considerations

2.1.1 Interface Control Reference Publication

The document: NASA Reference Publication 1370, “*Training Manual for Elements of Interface Definition and Control*”, Vincent R. Lalli, Robert E. Kastner, Henry N. Hartt, January 1997, is recommended as being helpful in understanding the purpose of interface control and selecting types of interface control documents. Interface categories are identified and defined with examples for; electrical, mechanical, software and supplied services given. There are sections on analyzing interface compatibility and verifying design compliance with interface control requirements. There is discussion on ways of tracking and resolving missing interface design data (TBD’s) through the use of IDDR’s. Setting up and running an Interface Control Working Group and a Configuration Control Board (to review each document, obtain technical approvals, and create a baseline version and to manage change requests) is also discussed. There is a version of the ICD Guidelines included in this document as Appendix B. This is a well written and concise document and served as a good point of departure for the team to use as it customized the IRD development process for application to the Ares I-X mission. In addition, the Requirements and Verification Manager provided a useful checklist to aide with initial interface document generation. This checklist is also included in this document as Appendix C.

2.1.2 Interface Development Team Roles and Responsibilities

The initial process was set in motion with the following organizational roles and responsibilities:

- **The Custodian** position was set up to provide unbiased control of interfaces through the role of an objective mediator. Their responsibilities were to provide a verification checklist to track interface requirements and traceability and to ensure document completeness (and correctness) by identifying, tracking and closing out voids (TBD’s).
- **The IPT Leads** were to coordinate with their Element management to provide status and issues to interface custodians and to work schedules and close action items.
- **The Book Manager** was the author of the Interface Requirements Document (IRD) and was responsible for document maintenance including updates and configuration control.

The initial book manager for all three of the subject IRD's was a member of the USS Element IPT.

This eventually evolved into:

- **SE&I Book Manager**
  One custodian became the book manager for all three documents after their initial baseline was approved. This handoff was accomplished smoothly as the USS personnel were experienced and produced a quality product. It was however somewhat difficult for the new author to inherit a foreign writing style and maintain format continuity. This awkwardness was compounded by two additional issues, the evolutionary document development environment (discussed later) and that the MS Word skill level of the new author was somewhat limited. For example, the choice to use non-standard page sizes complicated printing and not publishing as PDF files caused figure corruption during review distribution. It is recommended to not switch authorship of these documents unless otherwise unavoidable circumstances would dictate the need.
- **SE&I Technical Lead**
  The other custodian assumed the role of technical lead and was responsible for resolving any technical issues that would arise. The teaming between the custodian and technical lead worked well in providing a level of redundancy to ensure that matters were always adequately covered.
- **IPT Element Interface POC**
  Each IPT provided a single POC for handling IRD issues. They were responsible for attending meeting and assuring that the appropriate IPT support was available. This concept worked very well.
- **IPT Element Technical Lead**
  The technical lead was the engineer in charge of development of the IPT hardware element or sub-element that the interface was involved with. Again, the teaming on the IPT sided worked well in providing a level of redundancy to ensure that matters were always covered appropriately.
- **Technical Support Experts** provided discipline specific analysis based guidance as required to make crucial design decisions. The level of competence shown across the entire mission by these experts was extraordinary!

2.1.3 Not Invented Here

There was a certain level of frustration experienced by the SE&I team members in that it was hard, being an engineer, to stick to the role of mediator and not to want to recommend design solutions (even when they were as obvious as just adding a second lockwire to an existing fastener to satisfy a redundancy requirement). The lesson here is that SE&I's input in this area was neither desired nor considered. There was one exception in the case of the RoCS interface where SE&I did recommend match drilling of the RoCS Panel at GRC and SE&I was required to perform a "joint confidence test" as the design solution devised by the IPT's was of an unprecedented nature for the application at hand.

2.1.4 Pathfinders

The position of negotiating interfaces required a personal demeanor with specific qualities. It was obvious from an early point in the project that the position would require a “thick skin”. Although all team members were always professional and usually courteous, the interface guys were in the middle of many heated discussions and it was important to remember to not take comments personally. Aside from the unavoidable tensions arising from the interface definition development itself was the compounding factor that the interfaces were many times on the threshold of developing management practices for the mission. This battering ram feeling was felt several times as the interface guys served as pathfinders for several items such as TBD tracking, CM, Solumina access, System Level Waiver process…

Recommend using lessons learned from previous projects.

Recommend permanent portal site for capturing lessons learned on the fly.

2.2 Communications

2.2.1 SIIWG – Systems Interface Integration Working Group

This was the formal interface control working group that provided the over arching level of communication and generally more programmatic decision making for all the SE&I level interface development. It met weekly or bi-weekly as required, was held via telecon and WebEx, was recorded with published minutes and tracked action items. This meeting was chaired by the Requirements and Verification Manager, was very well run as was evidenced by the exceptional level of attendance at each meeting and always had a published agenda.

2.2.2 Technical Meetings (AKA Interstage Telecons)

These meetings were similar in format to the SIIWG meetings (telecon, WebEx, agendas, minutes, actions). They were where the technical presentations, discussions and decision making happened with actions to capture the agreed to design details into the IRD’s. This meeting was chaired by the USS technical lead and was very well run as was evidenced by the exceptional level of attendance at each meeting.

2.2.3 Technical Interchange Meetings

Several TIMS were held early in the development cycle. These involved travel to each IPT and SE&I location. Beyond the obvious benefit of the actual technical interchange was the importance of the opportunity afforded to develop an appreciation for each organization’s working environment and cultural style. The personal relationships developed by meeting face to face and sharing a team building meal (and perhaps a beverage) were instrumental in forming a cohesive, well functioning team over such a large geographic and diverse organizational program structure.

2.2.4 Restricted Information Designations

The IRD’s were scoped to a narrow enough purview that neither an ITAR nor an SBU designation was necessary (i.e. system level details could not be reversed engineered). This greatly facilitated communications given the diverse organizational program structure. Thus, e-mails did not require encryption which allowed much bypass of the cumbersome Windchill application and WebEx could be used instead of the more temperamental PBMA system.

2.2.5 Windchill Debacle

A secure data exchange and repository is an essential part of any project of this magnitude and Windchill worked, but other projects have had better systems. The two prime areas where the system lacked capability were speed and clarity. The response time was too slow to allow exploratory traversing of the hierarchal structure in order become familiar with the system. The search capability was confusing (to the point where it required a class to learn to search). So "Its on Windchill" actually became a running joke. The modus operandi became, "send me the link" so a hierarch was almost not required, a link in a single large bin with would have worked. The Portal was OK, but a site map of the data structure hierarch would have been instructive. Should not duplicate links to keep is simple. It would be instructive to estimate the hours if idle engineering time (#people X #access-attempts/person/day X delay-time/access X #days-in-project).

2.3 Document Development

2.3.1 Early Baseline

The documents were to be written as requirements documents and then morphed it into ICD's. This was intended to be a time saving device that would enable early baseline of the documents. The requirements format used in the SRD and ERD's included the fields:

Requirement - binding shall statement that must be verified for acceptance
Rationale - clarification, justification, purpose, and/or the source of the requirement
Trace - parent requirement or the source of the requirement
Allocation - Elements at the next lower level responsible for decomposition of the requirement
Verification - method implemented to verify the requirement (test, demonstration, analysis, or inspection)
Priority - mandatory, enhancing or desirable

For the IRD's the only fields necessary were ***Requirement***, ***Rationale and Trace***. The requirement contained the "shall" statement and was followed by the rationale. The trace for each IRD requirement was back to a requirement in section 3.4 of each interfacing IPT's ERD. There was then a series of "will" statements that constituted the success criteria for the verification each of the ERD requirements. The "will" portion of the document constituted the more classical definition of an ICD. It was necessary, however, to show both sides of the design as neither IPT's side was of existing hardware. It seemed that from the number of questions received; that this morphing concept was somewhat confusing to most team members. It is recommended to develop two documents, an IRD and a separate ICD. This may satisfy the desire for early baseline and actually be easier in the end.

For convenience, a sample idealized yet representative TOC for these IRD's is included in this document in Appendix D. It is recommend to invest the time necessary to start the process with a good template (design must be reasonable understood).

Also toward the goal of achieving early document baseline, was the development of the "Draft, Pending" incremental review and approve scheme outlined here:

> *Sections in an IRD where trades and/or analysis work is in progress will be marked as "Draft". These sections may have TBD's. Negotiated modifications to these sections will not require formal review. Once sections in an IRD are considered 100% complete they will be relabeled from "Draft" to "Pending" and the custodian will initiate the CR process to conduct Element IPT reviews and obtain formal approval. Once approved, the sections will be relabeled from "Pending" to "Baseline" and the IRD version number will be incremented. Sections in an IRD labeled "Baseline" may not have TBD's. Modifications to a "Baseline" section will require execution of an additional CR review and approve process cycle.*

This concept also required multiple explanation cycles. It is recommended, and this function was, ultimately accomplished by strict use of the document change log (i.e. only items entered in the log were comment-able during each review cycle).

All this being said, these documents were based lined too early as was evidenced by the fact that TBD burn down efforts were being performed while the designs were still in evolution (i.e. there was not a stable set of TBD's to burn down.) Related to this situation was that the implementation of a unique requirement numbering scheme in the IRD's, while this is a good thing, it was somewhat cumbersome to deal with and caused further awkwardness in the document. One recommendation that would have helped to alleviate some of the added document maintenance workload and help to maintain requirement commonality would have been to combine the three documents into one IRD and to provide separate sections for individual IPT's unique needs.

2.3.2 Agreements

A unique and very useful innovation in the IRD's was the incorporation of the "Agreements" feature. This was an extremely clean and efficient way of providing documentation of IPT responsibility to provide certain items relevant to the interface whether they be actual hardware (ex. fasteners) or and analysis… These agreements were recorded in the rationale section of each main requirement and a summary table was placed in an appendix. It is recommended to retain this feature and to elevate it to its own section heading to provide greater exposure and ease of identity.

2.3.3 Cross IPT CM Challenge

One challenge that had to be met was the fact that the IRD's were MMO level configuration controlled documents and IPT level drawings were not. ICD drawings were requested from the IPT's; however there was no mechanism in place (at the time of IRD development) to enforce/guarantee update of the IRD in the event that an IPT drawing should change. The solution was to incorporate figures into the IRD containing the required interface information as derived from submitted drawings. In this way, the IRD remained the official agreed to data and if IPT drawing changes were implemented, it was the responsibility of the IPT to have the IRD renegotiated. The method worked but created a large workload on the custodian to maintain the figures (with increased potential for error) during the design evolution. It is recommended to have a more rigorous CM system in place before document baseline.

2.3.4 Capture of Assembly "Requirements"

There was good participation by the GO IPT during the design concept development and refinement discussions. This was necessary to ensure that the hardware delivered to KSC was indeed able to be assembled in a reasonable fashion. There was an expressed desire to capture this assembly information into the IRD. Although the IRD was ultimately deemed to not be the appropriate place to document this information, (it was to be on assembly drawings and/or in the AIT plan) it is recommended that a non-reviewable appendix (diary) be kept during similar developments to be used for reference during subsequent assembly drawing generation efforts.

2.4 Document Maintenance Recommendations

a) Recommend to clarify who assigns major vs. minor document version numbers and what the criteria is.
b) Recommend having a global acronym list, perhaps a web interface to a data base (from the portal) where people could search for an acronym or add one on the fly. This would be self maintaining.
c) Recommend using "Latest Revision" in the Applicable Documents section for project level documentation unless otherwise necessary.
d) Recommend having a document dependency tree link from the Portal.
e) Recommend maintaining the Waiver Log as an un-reviewed appendix in each document.
f) Recommend removing the "table" format from the XCB Change Request form.
g) Recommend keeping the XCB presentation template.
h) Recommend distinguishing between Deviations and Waivers.
i) Recommend keeping the OSB approval mechanism.
j) Recommend longer period for review comment resolution.
k) Recommend keeping the consolidated comment template.

2.5 Vehicle Assembly

2.5.1 Drawings

The IRD's provided a substantial amount of information to the generation of the system level assembly drawings. Therefore the custodian and technical leads were heavily involved with the review process. There was much concern that the drawings were generated from non system level configuration controlled CAD models. It is recommended that a system level CAD model CM system be in place prior to the generation of system level assembly drawings.

A missed opportunity toward this end and one that would have greatly facilitated the development of the IRD's in general would have been to upgrade the EDF to an MMO official level status.

On another note, although this was not an IRD issue, it appeared that the assembly drawings should have been under greater control of the AIT Plan author and manager.

Also, it should not be necessary to rev. the IRD in order to put a note on an assembly drawing. The drawing is a negotiated, formally approved and controlled document. This was pushed by the drawing developers but was no value added (ex. Preload was in IRD to certify design, torque to achieve preload only needed on drawing).

2.5.2 Solumina

A considerable amount of valuable time was in gaining initial access to the software system. It was not set up to be accessed by multiple organizations. Beta testing should have been done before expensive engineering hours were expended in troubleshooting the IT hurdles. The training was of little or no use, as most people just clicked through the slow moving demos to check the box in order to gain access to the system. A minimum of three logins are required to get on to the system (computer, server, software). The WAD review period was non-existent and the modification cycle was not implemented uniformly (pen & ink used if convenient, multiple signatures require if working on Saturday). All that said, the system was not without merit and once its basic operations were understood, the system did appear to work well. It was apparent that this application was designed more for a mature operational production environment and that this was likely the first time it was applied to such a fast paced development environment. The FEC process was developed and worked through Solumina to provide a quick fix capability when obvious minor engineering changes were required. The process worked well with the TxRB; however, it was confused with or misused as an MR or waiver process on several occasions.

2.5.3 GO Responsibilities

There was apparently conflicting views or at least a misunderstanding of the roles and responsibilities between the GO IPT and SE&I. There should have been worked at the highest level a formal agreement as to what the expectations and mode of operations would be for instance, defining the difference between performing the work vs. owning the responsibility for getting the work done.

There was a perception of a coached attitude of animosity perpetuated by a few bad eggs. It only takes one rotten apple to give the appearance that KSC management were ungracious hosts. From the interface perspective, not being able to obtain something as simple as acceptable seating space was inexcusable.

There was an appearance that GO did not grasp a firm understanding of the role of SE&I. Access to the vehicle was overly limited with a sense of “I don’t’ want to know if you think something is wrong”, and “get out of the way”. This was evidenced by an instance of inappropriate reengineering of an IRD controlled interface (ex. the radius block vs. grinding the weld, not communicated to SE&I and not analyzed by USS).

2.6 Requirements Verification

A unique feature that proved useful was the Verification Cross Reference Matrix provided in an appendix to each IRD. A sample is seen in this figure.

	FS				USS			
FS–USS IRD req. number	ERD section title	ERD req. number	Verification method	VRD number	ERD section title	ERD req. number	Verification method	VRD number
001	IS-Frustum mechanical interface	FS–102	Inspection	PLN96015	FS mechanical interfaces	USS–053	Inspection	USS-053
002	Surface alignment features	FS–178	Inspection	PLN96015				
003	FS to USS Joint Stiffness	FS–179	Inspection	PLN96015				
004	FS to USS material compatibility	FS–103	Inspection	PLN96015				
005	FS to USS cable envelopes	FS–104	Inspection	PLN96015				
006	Mass Properties	FS–028	Inspection	PLN96015				
009	FS to USS electrical bonding	FS–180	Inspection	PLN96015	FS to USS electrical bonding	USS–121	Inspection	USS-121
007	Frustum to USS interface marking	FS–181	Inspection	PLN96015	FS to USS interface markings	USS–115	Inspection	USS-115
008	Human access in the Frustum	FS–175	Inspection	PLN96015	FS human access	USS–117	Inspection	USS-117

Figure 2 – Verification Cross Reference Matrix

During the generation of the Custodian Interface Verification Summary Report, used to help show interface requirements compliance, the format was extended as seen in the figure. During this activity it was recognized that it may have been helpful to have identified the verification artifacts at an earlier point in the process as a way of tracking progress towards verification. This may have helped alleviate the necessity for the mad push at the end of the project. Also as can be seen in this figure is the inconsistency in the way that requirements traces were cascaded by the different IPT's. It is recommended that a requirements tracking tool such as CORE or Rational Rose by employed early in the project conception to identify and correct this issue. Also, the tool may well be capable of handling the task of providing the waiver log functionality discussed earlier.

E-mails should not be used as verification artifacts.

IRD Requirement Number (*) # of sub reqts.	IRD Requirement Title	ERD Requirement Trace	VRDS CR Number	Verification Artifact(s)	SRD Requirement Trace	ERD Requirement Trace	VRDS CR Number	Verification Artifact(s)	SRD Requirement Trace	Waiver CR Number
IFS-USS.001 (11)	Mechanical Assembly Joint	FS-102	AIX-0469	TR022959 REV A TR022962 Rev A TR023899 REV D	FTV-101	USS-053	AIX-0570	GRC-Ares-I-X-RPT-072 GRC-Ares-I-X-RPT-117	FTV-001	AIX-0356 AIX-0470
IFS-USS.002 (1)	Surface Alignment Features	FS-178	AIX-0560	TR022962 Rev A TR023899 Rev D	None	USS-053	AIX-0570	GRC-Ares-I-X-RPT-117	FTV-001	
IFS-USS.003 (1)	Joint Stiffness	FS-179	AIX-0xxx	TR023816 VOL 1 Rev B TR023816 VOL 2 REV B TR023816 VOL 3 REV A	None	USS-053	AIX-0570	GRC-Ares-I-X-RPT-117	FTV-001	AIX-0595
IFS-USS.004 (3)	Material Compatibility	FS-103	AIX-0xxx	TR022962 Rev A TR023094 REV B TR023899 Rev D TR024765 Rev B	FTV-105	USS-053	AIX-0570	GRC-Ares-I-X-RPT-117	FTV-001	
IFS-USS.005 (1)	Avionics Cable Harness Envelope	FS-104	AIX-0xxx	TR022962 Rev A TR023899 Rev D	FTV-101	USS-053	AIX-0570	GRC-Ares-I-X-RPT-117	FTV-001	
IFS-USS.006 (1)	Mass Properties	FS-028	AIX-0554	TR018580-015	FTV-044	USS-053	AIX-0570	GRC-Ares-I-X-RPT-117	FTV-001	
IFS-USS.007 (2)	Interface Markings	FS-181	AIX-0554	TR022962 Rev A TR023899 Rev D	None	USS-115	AIX-0377	GRC-Ares-I-X-RPT-117	FTV-001	
IFS-USS.008 (1)	Internal Access	FS-175	AIX-0xxx	TR022962 Rev A TR026511 Rev A	None	USS-117	AIX-0570	GRC-Ares-I-X-RPT-117	FTV-001	AIX-0356 AIX-0518
IFS-USS.009 (1)	Electrical Bonding	FS-180	AIX-0554	TR022962 Rev A TR023899 Rev D	None	USS-121	AIX-0377	GRC-Ares-I-X-RPT-117	FTV-001	

Figure 3 – Verification Requirements Cross Reference Matrix

3.0 TECHNICAL INTERFACE REQUIREMENTS

Unique ID	Title	Issue	Recommendation
LL-01	Dissimilar metals		
LL-02	Specify Torque spec standard upfront	Fasteners, selection-worst case vs. RSS	
LL-03	Loads and required analysis	Induced Environments (aerodynamics, vibroacoustics, thermal, inertial) Loads (Applied-induced, Derived-line, running, bending)	
LL-04	No welding on parts after precision machining has been performed		
LL-05	Make sure both IPT's understand implication of the design (RoCS no-load panel)		

LL-06			
LL-07	No mass		
LL-08	Recommend that hardware used for lifting should satisfy GSE certification requirements even if it will fly.		
LL-09	TIR log is acceptable substitute for RBF ex. removable Ladders		
LL-10	Removable ladders should be GO GSE not IPT designed		
LL-11	RoCS Alignment Pins	RoCS panels bolt holes did not align after hand reaming of the doubler holes.	Use single purpose (do not use bolt holes as alignment holes) conical alignment pins

Table 1 – Interface Technical Lessons Learned

Fluids, software and supplied services did not apply to or were not covered by the IRD's discussed in this document.

See Appendices G & H for more Lessons Learned.

APPENDIX A: ACRONYMS

AIT	Assembly, Integration and Test
AKA	(Interface Group at Glenn Research Center)
CAD	Computer Aided Design
CM	Configuration Management
EDF	Engineering Drawing File
ERD	Element Requirements Document
FEC	Field Engineering Changes
FS	First Stage
GO	Ground Operations
GRC	Glenn Research Center
GSE	Ground Support Equipment
ICD	Interface Control Document
IDD	Interface Definition Document
IPT	Integrated Product Team
IRD	Interface Requirements Document
ITAR	International Traffic in Arms Regulations
KSC	Kennedy Space Center
MMO	Mission Management Office
MR	Materials Review
OSB	Operations Support Building
PBMA	Product Based Mission Assurance
RBF	Remove Before Flight
RoCS	Roll Control System
RSS	Root Sum Squared
SBU	Sensitive but Unclassified
SE&I	Systems Engineering and Integration
SIIWG	System Integration and Interface Working Group
SRD	System Requirements Document
TBD	To Be Determined
TIR	Temporary Installation and Removal
TxRB	Ares I-X Technical Review Board
USS	Upper Stage Simulator
WAD	Work Authorization Document
XCB	Ares I-X Control Board

Software Products Assessments:

WebEx, PBMA
Solumina/ICE Constraints management
Windchill
Cradle, CORE, Rational Rose
Primavera
MS Office Outlook Access

APPENDIX B: REFERENCE PUBLICATION ICD GUIDELINES

- ICD's should not require the designer of the mating interface to assume anything.
- ICD's should only include the definition that affects the design of the mating interfaces.
- ICD's should not specify design solutions for the mating interfaces. (Note: Unless this is not a special control or constraint then it is better to allow for multiple approaches or designs for a solution. You should only provide what needs to be met and let the contractor find the best way to get there)
- ICD's should be compatible with each other and stand alone.
- ICD's should capture design detail per designer's specifications.
- The ICD custodian should be independent of the design organization.
- The ICD custodian should verify that the ICD design specification is necessary and sufficient to allow develop the mating interface.
- An interface control system should be in place at the beginning of system development.
- Each TBD/TBR (data void) should be tracked and:
  - Have a unique identifier
  - Describe the exact data to be supplied
  - Establish due dates
  - Identify the data supplier

APPENDIX C: INTERFACE REQUIRMENT IDENTIFICATION CHECKLIST

- *Is there a function that involves an interaction between two systems?*
  - Yes go to the next step.
- Are both systems under development?
  - Write the interface requirements that will go into the SRDs or ERDs invoking the appropriate interface characteristic definition in the system-system IRD.
- *Are the characteristics of the interface defined in an applicable design and construction standard and no tailoring is required?*
  - Clarification: If you answered no, then write a requirement in the SRD or ERD that invokes the applicable section/subsection of the existing document.

- *Does the interaction between the two systems involve an operation or constraint, contractor actions, project requirements, or flight rules whose implementation will be performed by people or organizations rather than the systems themselves?*
  - Clarification: If you have answered yes, please consider whether there is a real interface requirement needed between systems in order for the people to do their job. If there is, then a real interface requirement needs to be written and not the people requirement.
- *Is the interface or a characteristic at the interface defined in the IRD?*
  - Clarification: If you answered no, define the interface or the characteristics that must exist at the interface in the IRD. If multiple values are needed to describe the characteristics, consider using a table. If the values are not known or cannot be defined at this stage of definition, use TBDs. Include rationale defining the source of all numbers or statements that define these characteristics. Once defined, continue to the next step.
- *For the case when both systems are in development, are there paired interface requirements in the IRD pointing to the interface definitions referred to in the previous step?*
  - Clarification: We would expect to see both sides of the interface pointing to the same IRD definitions. If not there is a problem! If only one points then is there a missing requirement in the other SRD? If neither side points to the IRD section then why is it in the IRD?
- *For the case when one system is in development and the other system exists, is there an existing system interface requirement in the IRD pointing to the existing system's ICD/IDD?*
  - Clarification: When one system is in development and the other exists, write the interface requirement in the SRD for the system in development invoking the appropriate interface characteristic definition in the existing systems ICD/IDD.
- *Comment: As a management tool, have in an appendix in the IRD, a table showing all the SRD requirements that point to an IRD section or specific definition. Requirements should have Rationale, Verification and Traceability.*

APPENDIX D: SAMPLE IRD TOC TEMPLATE

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4.2.4 Shims and Retainers
4.2.5 Compatibility – materials, corrosion, contamination…
4.3 Electrical
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APPENDIX – Acronyms
APPENDIX – Glossary
APPENDIX – TBD Tracking
APPENDIX – Provided Items / Agreements
APPENDIX – Verification Cross Reference Matrix
APPENDIX – Assembly Information

APPENDIX E: SYSTEMS ENGINEERING V-DIAGRAM REFERENCE FIGURES

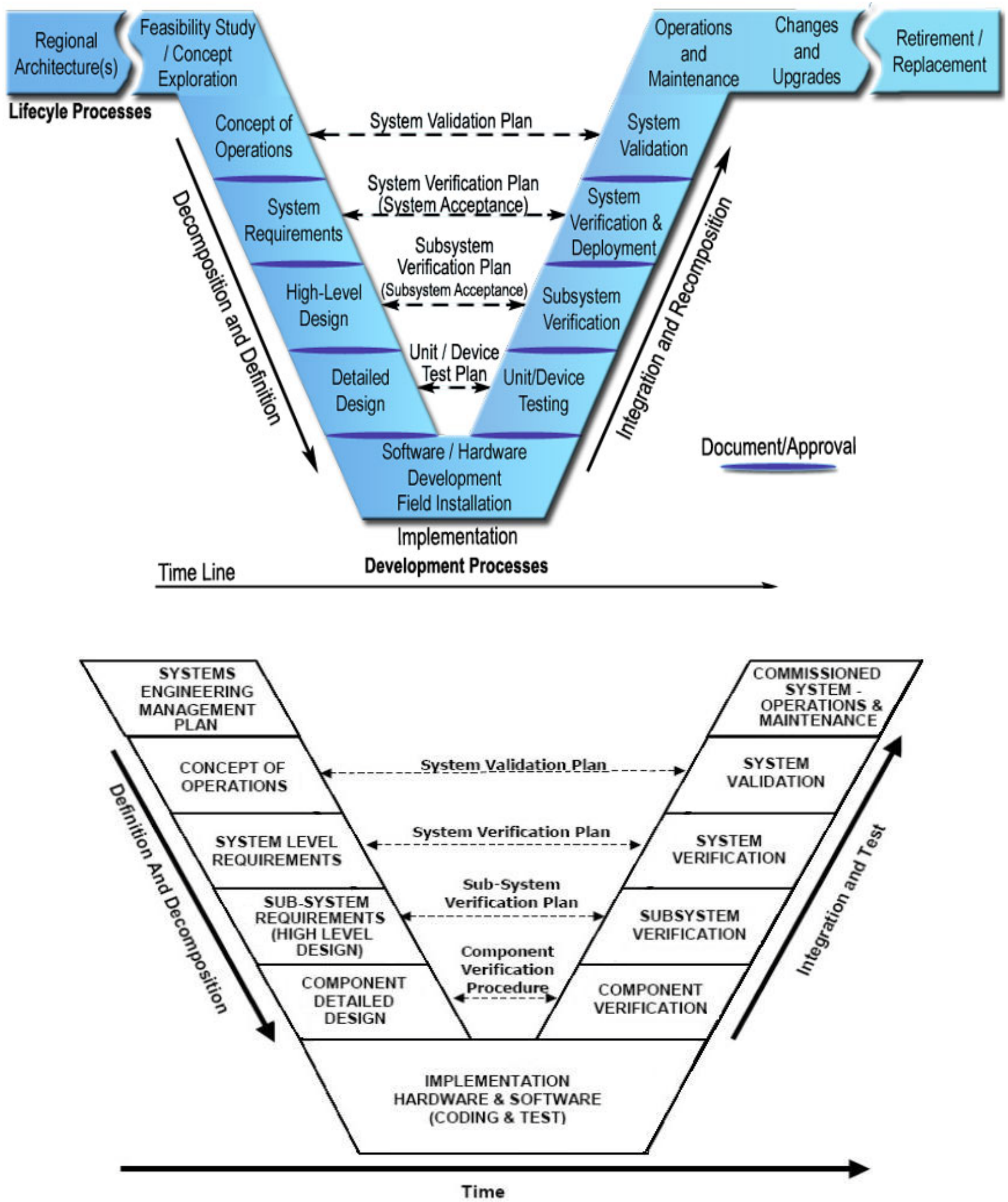

Figure 4 – Systems Engineering V-Diagram

APPENDIX F: EXCERPT FROM THE ARES 1-X MISSION ACTIVITIES LESSONS LEARNED SURVEY

This survey has been created to solicit feedback on the Ares I-X Mission activities, to identify how the project was conducted. This survey is meant to capture lessons learned from the Ares I-X Mission (activities) while they're fresh in people's mind. This survey focuses on the actions - not people - to identify what worked, what did not work, and identify areas for improvement. The results of this survey will remain anonymous (to encourage people to be honest in their assessments). The survey results will be compiled and discussed in detail at future Lessons Learned meetings. The feedback received from the survey can help point to particular areas that should get special attention and emphasis in the group meetings, and identify potential areas for process improvement. The results from this survey and from the Lessons Learned meetings will be used to further refine and develop Ares I-X Lessons Learned. Recommendations from this effort will be passed on to the Ares I-X team members as well as the Ares 1 and Ares V Projects.

1. Are you satisfied with the finished Ares 1-X deliverable products?
2. How efficient and effective were Ares 1-X project and IPT team meetings?
3. Was the entire team committed to the Ares 1-X schedule?
4. How involved did you feel in Ares 1-X decisions?
5. How efficient and effective was communication between the CxPO Ares 1-X MMO and IPT's team members?
6. How clearly defined were the objectives for Ares 1-X Mission?
7. How clear were you on your role and responsibility in the Ares 1-X Mission activity?
8. Are you satisfied that Ares 1-X Mission has a high probability of meeting all of the mission objectives?
9. How effective was the design (or implementation specs)?
10. How effective were Ares 1-X design reviews?
11. How effective was the functional specs?
12. How well were Ares I-X design and interface decisions defined and documented?
13. How effective were the Ares I-X test plan activities?
14. How effective were the Ares 1-X training activities in supporting your role and responsibilities?
15. How effective and adequate was the Ares 1-X hardware and software testing?
16. How effective and adequate was the Ares 1-X Risk Management process?
17. How effective and adequate was the Configuration/Data Management process?
18. How effective was the interaction/cooperation between IPT technical sub-teams?
19. How effective was the Ares 1-X initial deployment process?
20. How effective and adequate was the Ares 1-X Safety and Mission Assurance activities?
21. What were the main causes for Ares I-X schedule slips?
22. Was the Ares I-X Mission activity significantly delayed/hampered by dependencies outside of the project?
23. What were the main sources of frustration in working the Ares I-X Mission?
24. Considering the next Ares 1 Flight Test, what is the one thing that you would change (related to process, not to technical solutions)?
25. Did you rely on the NASA Lessons Learned Information System (LLIS) or any other Lessons Learned data base in the performance of your job assignment for the Ares I-X Mission? 26. Were Lessons-Learned from previous programs/projects used on the Ares I-X Mission?
27. For the Ares 1, Ares V and future NASA Projects, what recommendations could you make that would enhance or improve the way these projects are or will be implemented?
28. Add any other comments here:

1) Was the entire team committed to the Ares 1-X schedule?
2) What were the main causes for Ares I-X schedule slips?
3) Was the Ares I-X Mission significantly delayed or hampered by dependencies on factors outside the control of the project?

4) How satisfied are you with the finished Ares 1-X deliverable products?
5) How clearly defined were the objectives for Ares 1-X Mission?
6) How satisfied are you that Ares 1-X Mission had a high probability of meeting all of the mission objectives?

7) How could implementation of Ares 1, Ares V and future NASA Projects be improved?
8) How effective was the Ares 1-X initial deployment process?
9) How effective were the Ares 1-X design reviews?

10) How efficient were the Ares 1-X project and IPT team meetings?
11) How efficient was the Ares 1-X MMO communication between the CxPO and IPT's team members?
12) How effective was the interaction/cooperation between IPT technical sub-teams?

13) How clearly defined was your role and responsibility in the Ares 1-X Mission activity?
14) How effective were the Ares 1-X training activities in supporting your role and responsibilities?
15) How effective were Lessons-Learned from the NASA Lessons Learned Information System (LLIS) or any other Lessons Learned data base used in the performance of your job assignment for the Ares I-X Mission?
16) What were your main sources of frustration in working the Ares I-X Mission?
17) How involved did you feel in Ares 1-X decisions?

18) How effective was the design or implementation specifications?
19) How effective was the design of functional specifications?
20) How effective were the Ares I-X interface design decisions defined and documented?
21) How effective were the Ares I-X test plan activities?
22) How effective was the Ares 1-X hardware and software testing?
23) How effective was the Ares 1-X Risk Management process?
24) How effective was the Ares 1-X Configuration/Data Management process?
25) How effective was the Ares 1-X Safety and Mission Assurance activities?

26) Add any other comments here:

APPENDIX G: LESSONS LEARNED SUBMITTED BY AVIONICS INTERFACE CUSTODIAN

AIX Avionics and SW Technical Integration Lessons Summary:

Establish an E3 Panel as an advising body to the technical ERBs. The E3 Panel also served as an advising body to IPTs to interpret and assure compliance with governing standards and governing requirements. The E3 panel requires a system-level perspective: vehicle, MLP/Pad and surrounding facilities. Membership needs to include expertise on all E3 aspects, IPT relevant technical representation, Safety and Mission Assurance representation, qualified independent consultants, and a process to make decisions and recommendations.

1. Lightning protection and contingency procedures:
    a. Include Lightning protection requirements for flight and ground elements [structural, box-level, a well as active equipment and harness installations] into the flight vehicle and GSE specifications.
    b. Include Canary Circuit analysis as part of the Avionics system. This analysis includes relative lightning qualifications of the different [heritage, modified heritage, or new] components making up the Avionics element.
    c. Invest on and include lightning protection tools, and features in the PAD, FSS, and the vicinity of critical CC and ordinance controllers.

   d. Develop lightning re-test criteria and contingency procedures early-on, criteria needs to be agreed to by all stakeholders owning/ providing active equipment
   e. Have a back-up criteria [approved] to overrule and waive pre-established procedures in the event of repeated false alarms scenarios, borderline violations, and compelling reasons to launch.
2. EMI/EMC qualifications, analyses, and testing
   a. Establish and mandate a common EMI qualification [i.e. MIL-STD 461E] standard early on in the project. Plan to re-qualify all active components to the adopted standard – to include components which were built to previous old versions of this standard, heritage equipment to be installed in a different configuration than its flight history, or any equipment that has been modified in any manner.
   b. Redacted for ITAR Reasons.
   c. Redacted for ITAR Reasons.
   d. Quantify the aggregate EMI/EMC emission [conducted and radiated] levels for the vehicle. Develop an EMI/EMC data book as an environmental specification and make it a requirement.
   e. Task an independent entity to conduct an overall EMI/EMC compatibility analysis. Engage the system EMI entity early on the design process.
3. EMI compatibility inspections and testing
   a. Include provisions for incremental EMI compatibility testing.
   b. Budget for qualification units, test set-up, and test conduct [include operational impact]
   c. Allow EMI/EMC inspections and approval during sensor, harness, and controller installations, and require EMI/EMC sign-up for major element mate events.
   d. Anticipate and plan for EMI testing during incremental vehicle integration and power-up.
   e. Plan to conduct an overall powered vehicle, powered PAD environment, and all transmitting and tracking sources ON [for AIX this test was known as the 0-dB test]. Instrument the vehicle to measure margins, this is to assure that a 20 dB margin for ordinance, and 6 db margin for flight critical non-ordinance is achieved and verified by test.

f. A level of 20 V/m is sufficient for the ETR to track a rocket through flight. Get test and track levels into the PRD. Plan for EMI RF surveys, and radar calibrations.
g. Coordinate plans to test at the PAD the ETR and KSC safety. In the case of the 0dB test the KSC safety establishment ruled out radiating the AFT skirt with portable equipment at the PAD, forcing the E3 team to consider doing a separate test at the VAB as plan B.

4. Electrical shielding, grounding, bonding, and exceptions
   a. Do inspections early.
   b. Expect bonding exceptions and be willing to discuss alternative acceptable options.
   c. Redacted for ITAR Reasons.
   d. For sensors with anodized housings bond the shield within less than 2 feet away from the sensor.
   e. Protuberances with embedded sensors require a class R bond (if external class L), protuberances with no sensors require a class S bond.
   f. Redacted for ITAR Reasons.
   g. Size, type, and number of bolts can be used as a path for lightning currents and are acceptable as an alternate method for Class L bond. Use bolts only when shimming prevents metal to metal structural mating.
   h. Structural Class L bond can be verified via six equally spaced Class R [equal or less than 2.5 milliohms DC resistance measurement]
   i. No floating structural elements allowed in the vicinity of volatile fuels. Tightly bond all components to the vehicle reference ground with at least a Class S bond.
   j. Bond straps are NOT acceptable for a Class R bond
   k. The use of aluminum tape is a questionable method to meet the Class R bond.
   l. The eccobond material degrades over time, and can crack degrading the bond
   m. Best method for class R bond is metal to metal, case to structure – no paint, flatness, free of debris, and treated for corrosion.
   n. Components subjected to touch and use, or exposed to air flow, and/or structural elements that has the potential to build capacitance [ladders, gates, ducts, ballast

plates, protuberances] need at least a Class S bond [less or equal to 1 ohm DC resistance] to the vehicle structure.

o. Examine carefully hybrid heritage designs that come together on ordinance activation systems. Redesign the controller to actuator path such that Pyro activations parameters meet specifications without the need for cable splicing.

p. Reconcile different shielding methodologies [360 degree termination at connector back shells vs. pin-through shielding] before integrating system.

q. Reconcile bonding verification methods among vendors, and KSC ground operations, some resistance measurements are deemed unnecessary by one team but mandatory by another.

5. EMI X-talk issues
   a. Differing heritage cabling designs can induce EMI cross talk issues.
   b. Do not share returns. Do not use the structure as signal return. Do not twist digital signals on the same shielded bundle.
   c. The Shuttle CRD heritage configuration uses structure as the return between the MDU/RDU and the CRD. In addition there are indicators HI side signals twisted together without a return in the shielded twisted wiring.
   d. False LATCH indicators were detected. LATCH indicators are [as the word suggests] expected to stay ON following a LATCH command. The fact that these are so short [[10 ms]] is the first FALSE discriminator. The indicators occur when the LATCH mechanisms are mechanically inhibited – not supposed to happen. In addition, a true LATCH indicator will stay continuously ON and these will ONLY be commanded during an actual flight termination [inhibits removed]. Furthermore, a true latch indicator will need to occur necessarily in conjunction with latch command voltage drop. Latch command & voltage drop go together, i.e. if a voltage drop does not occur the indicator is FALSE. These 10ms false pulses occur only 10% of the time. This is expected due to discrepancies of different heritage designs coming together on this interface i.e. the AIX RDU is much more sensitive than the Shuttle MDM. This is not a threat to the "command" signals.
   e. The OPS team needs to be structured to detect these issues. Even though these are FALSE indicators, the OPS team CAN'T ignore them. The OPS team is obligated to treat all indicators the same until reviewed. If these turn out to be FALSE indicators [a list of similar FALSE indicators was provided] they should be able to recognize them, record the occurrence, and disposition them faster than others. Operators should have readily access to the pertinent expertise in each case.
6. ESD marking and handling

   a. Lesson: clearly label all ESD sensitive (ESDS) sensors prior to shipping for installations. A number of sensors types [accelerometers, and others] were declared ESDS after handling threatening the survival of these sensors to these effects.
   b. Adopt an overall ESD Control Plan spanning for the entire project [all sites and all active equipment, electronics and sensors] early in the development schedule, as part of PDR. Plan needs to include handling of sensors during installation, storage and transportation of ESDS hardware, ESD bleed-off, and precautions i.e. to prevent arching during lift-off and staging.
   c. Share usage of anti chafing and thermal protection [aluminum tape and application of foam] methods among equipment owners prior to application. This will alleviate headaches later when one team finds out what the other did to their equipment after installation.
7. ECS Monitoring

8. Triboelectrification
   a. Triboelectrification it is a much more serious deal than anyone estimated when designing and building the AIX rocket. During technical discussions with the Range, E3 Panel members offered a summary of all the features incorporated on the design [all metal and well bonded vehicle, all protuberances bonded, all the internal EMI/ESD design features we took into consideration] to tightly seal electronics and signals for EMI, RF effects and lightning, but these were not enough to satisfy the Range, and the AIX mission managers. The range was concerned that these effects were external to the vehicle and could interfere with their ability to track and terminate the flight if warranted. Mission management was concerned that these effects will interfere with data telemetry. AIX held emergency E3 Panel meetings in the timeframe preceding and leading up to vehicle launch. The E3 team had to learn a lot fast about the p-Static phenomena and effects. The purpose was to analyze the materials used on the vehicle and the possible effects on to communications. These effects were NOT considered by designers, and that includes the AIX talented contractor team, and the "heritage" flight-proven pieces in the AIX arsenal.
   b. Did not complete the analyses to prove exception #2 of the rule. This phenomenon is too complex to analyze and rule out. Best it to treat the vehicle for effects or use appropriate paint to coat. This was NOT in AIX FTV design-to requirements, so we had neither.
9. Avionics to Flight Test vehicle Interfaces
   a. When in doubt: which heritage specification takes precedence? Lesson: reconcile heritage specifications before prescribing interface requirements, examples are

bend radius, separation of harness supports, ESD specifications, attachment bolts specs, etc. [example SAE-AS50881, "WIRING, AEROSPACE VEHICLE"]

b. Do not mix requirements and ICD-level specifications in the same document. A hybrid document like this is asking for trouble since lower level details will continue to change till the last minute while requirements remain fixed, requiring continued updates of the document. As a result we had to process late changes on the document as waivers.

c. Clearly define installation and verification roles and responsibilities and capture in a separate document and NOT in the ICD. This includes environmental qualifications [all aspects] and compliance analyses of Avionics components provided. Who analyses, who installs, who witnesses, who inspects, who verifies?

d. Lesson: Avionics ECS requirements in the absence of conformal coating: Atlas V uses a T0 umbilical to maintain environmental conditions on their electronics. For AIX, decision was made early on the development not to include [cost and schedule] an Atlas-like T0 umbilical for the vehicle. It then became a challenge to maintain suitable ECS conditions on the respective Avionics compartments [USS, FSAM]. Avionics components are not conformal coated making it critical maintain these specifications/ constraints. The Avionics environmental specifications were specified as requirements in the Avionics to FTV ICD. It then became a challenge to maintain proper conditions using purged air and cooling fans. Measurements had to be monitored constantly and borderline conditions were raised in numerous occasions. The fans introduced EMI problems.

e. The short cable fiasco; what caused it and how to avoid it? Lockheed insisted on manufacturing cables to the exact specification provided by the CAD models. As a result, Cable connection to the P02 connector of the B050 panel was found to be 8 to 10 inches short. A problem report was created and approved and an emergency action issued to manufacture and install a cable extension.

f. Cracked bus couplers finding [we got lucky]. The 1553 bus couplers in the aft skirt needed to be removed and replaced due to an issue that surfaced during initial power-on operations for an Atlas vehicle. The potential for cracking in the solder joints may have affected signal integrity and cause communication errors between flight critical components with catastrophic consequences.

g. T0 Deadface power finding.

h. After the vehicle was fully assembled, we painfully found out that there were some protuberances crossing IPT boundaries, which were not fully analyzed for environmentally induced loads effects. Examples of these are (1) the camera protective fairings provided by Avionics and installed on USS, and (2) loads analyses on the S-band antenna mounting bolts. In the case of the S-band antenna

Avionics provides the Antenna, and FS was responsible for the installation. In both cases [Camera fairing survival, and bolts loads analyses] one team assumed that the other did the analysis, and as a result the analysis was not done. The analyses had to be done via emergency XCB mandated actions by the USS, FS and the Avionics teams.

i. Reconcile change control, authority, and flow between system-level interface requirements [CRs] and changes on the floor [FECs].

j. Instead of having a separate interface requirements specification, make interface requirements part of each respective element requirements documents (ERD's). This way interface requirements will flow nicely on each element designs and will alleviate verification issues later.

10. Software Development, integration, and test [Robert pls. expand]
    a. Dead Code and reuse issues
    b. GNC Parameter refinement, validation, and updates
    c. Flight model resolution discrepancies among vendors.
    d. IV&V
    e. Other…
11. DFI Measurement list and instrumentation [Nick and team pls. expand]
    a. Design and CM of the DFI measurement list
    b. Criticality Classification of DFI measurements
    c. Configuration testing, excitation of sensors, and measurements validation
    d. Installation R&R

APPENDIX H: LESSONS LEARNED SUBMITTED BY INTERFACE TECHNICAL LEAD

Action Items

Description: Tracking action items from meetings.

Lesson Learned: If not tracked, action items can be forgotten.

Cause: Lack of system

Recommendation: All action items from all meeting should be tracked in some dependable manner. Action items should be addressed in CMP

Extremely Aggressive Schedule and Limited Resources

Description: The available resources, aggressive schedule, and expected deliverables did not make sense from the outset. Everyone knew that we would not make a 04/15/09 launch, but nobody would say it in an official forum. We were all worked hard to the point of being unhealthy.

Lesson Learned: Even though the CAIB report was very critical of the way schedules are handled and mistreated, we still do not produce affective schedules.

Cause: Schedules are often not weighted and therefore the estimates are not realistic. Most often schedules are already politically pre-decided or come as an Agency decision constraint.

Recommendation: Regardless of the reason you are stuck with a schedule that is handed down to you , an attempt should be made to do the appropriate schedule analysis and present the real schedule so the scope of the mission can be appropriately sized early on. Then add sufficient margin to initial schedules. A schedule will always have to be updated or changed due to new data/knowledge. Necessary slips in schedule should not be viewed as a failure. Finally a real integrated schedule is needed and all levels need to provide input to this.

Lessons Learned

Description: Recording of lessons learned

Lesson Learned: Although lessons learned were "learned" throughout the project, they were mostly recorded after the project was completed. Lessons learned were requested in several formats.

Cause: A single, unified lessons learned system was not available at the beginning of the project.

Recommendation: A lessons learned system should be set up at the beginning of the project. There should only be one, simple, well thought out format for lessons learned. The form should have a block to select which IPT you belong to, and another block to select applicable category/categories. The IPT and category blocks can then be used to sort. If a NASA-wide format template is used, lessons learned from multiple projects can be efficiently utilized simultaneously.

Alignment Marks

Redacted for ITAR Reasons.

Bolt Assembly for Highly Loaded, Large/Critical Bolts

Redacted for ITAR Reasons

Bolt Bending

Redacted for ITAR Reasons.

Main Bolts for Joint Electrical Bonding

Redacted for ITAR Reasons.

CAD Model Application During Project

Description: Discussions occurred early on concerning the use of an assembly CAD model. It was decided not to use a configuration controlled assembly CAD model due to schedule/resource considerations. There were many instances where a non-baselined assembly CAD model with limited configuration control could have been useful for non-detail design decision, and to point out obvious, big picture issues. Also, due to schedule/resource issues, it was very difficult to get IPT's to swap CAD files for interfaces.

Lesson Learned: Even if they are not tightly/officially configuration controlled, assembly CAD models are very useful. The user just needs to be aware that they are not tightly/officially configuration controlled, and ask appropriate questions if discrepancies are found.

Cause: Due to schedule/resource issues, it was difficult to get IPT's to share CAD files.

Recommendation: Baseline a configuration controlled assembly CAD model just after vehicle CDR, but utilize a non-baselined assembly CAD model at least by vehicle PDR. IPT's need to swap CAD files as appropriate for interfaces. IPT and assembly CAD files should contain GSE, GSE operation envelopes, stay-out zones, access zones, etc.

Countersink Heads

Redacted for ITAR Reasons.

Drill Templates or NC or "Other Methods" for IRD Interfaces

Redacted for ITAR Reasons.

Flatness Requirements for Manufacturing.

Redacted for ITAR Reasons.

Limited Hardware Access at KSC

Description: It was highly obvious that KSC GO was coached by their management to disallow access to personnel other than KSC GO to inspect hardware. I believe this was done because they didn't want to have to fix any problems found. This led to a lot of bad blood, and SE&I & MMO did very little to resolve the problem. In more than one occasion, this led to hardware assembly problems that were not discovered until later than desired.

Lesson Learned: Lack of reasonable access to hardware during assembly can lead to faulty assembly.

Cause: The desire to hold schedule at the expense of doing things right.

Recommendation: Re-read the CAIB report and re-think the management by schedule philosophy.

IPT and Vehicle PDR/CDR Order

Description: The vehicle/IPT PDR/CDR's were poorly scheduled relative to each other. There were cases when one of two interfacing IPT's conducted their CDR long before the other. As the first IPT was cutting metal, it limited the possible design solutions for open issues with the other IPT.

Lesson Learned: Orchestration of vehicle/IPT PRD/CDR's is important.

Cause: Aggressive schedule.

Recommendation: Specify order and timeframe of vehicle/IPT PDR/CDR's in CMP.

IRD Action item Burn Downs

Description: During a time when all IRD's were changing constantly due to design changes, management got concerned with TBR/TBD's in the IRD's and started requiring weekly IRD action item burn down meetings. For the most part, the major TBD/TBR's did not get closed any faster as a result of the meetings. The due dates would get changed to the following week, and, if the action item was again not closed, the due date would be slipped another week. Preparing for and attending these meetings further distracted from already limited resources.

Lesson Learned: Cracking the whip cannot fix a lack of resources issue.

Cause: Incorrect perception by management that this was a tracking and follow-up issue.

Recommendation: Recognize the output limitations resulting from limited resources.

Relationship Between IRD and Manufacturing Drawing

Description: The relationship between the IRD and manufacturing drawing was never officially documented.

Lesson Learned: Document the relationship between the IRD and manufacturing drawing early on.

Cause: No guiding document to site.

Recommendation: IRD drawings take precedence with all IRD dimensions highlighted on manufacturing drawing. Manufacturing drawing cannot internally board IRD dimension changes without prior IRD board change.

IRD Baselining

Description: In July of 2007, SE&I management stated that IRD's would be baselined in one month. I pointed out that the IRD's should not be baselined until the designs settled out. The purpose of the requested baseline was to support vehicle PDR (or was it CDR1?). Although the baselining did not make the IRD's any more complete, it did cause more work to write waivers as the designs continued to evolve.

Lesson Learned: The IRD designs should be mostly settled before baselining. A later IRD baseline should be expected for an aggressive schedule and high degree of concurrent engineering.

Cause: Lack of acknowledgement of aggressive schedule and high degree of concurrent engineering

Recommendation: Do not baseline IRD's until designs are acceptably mature. Resist premature baselining for the sake of convincing a review board of readiness.

IRD Interface Loads Documentation

Description: The philosophy of where to document IRD interface loads changed constantly.

Lesson Learned: Need to decide early in the project where to document IRD interface loads.

Cause: Various opinions and circumstances.

Recommendation: Discuss early in project, make decision, and include in CMP.

Lifting Lugs that Fly

Description: There were main, super segment lifting lugs that flew. They were analyzed with flight safety factors, even though they were really GSE that wasn't removed before flight.

Lesson Learned: GSE should be analyzed with GSE safety factors even if it flies.

Cause: Rule interpretation.

Recommendation: Modify rule that states that anything that flies is not considered GSE.

Loads Cycles

Description: The ever changing loads cycles, a result of an overly aggressive concurrent engineering process, resulted in frequent, large design changes.

Lesson Learned: Schedules need to be more realistic.

Cause: Business as usual.

Recommendation: Allow those that actually have to perform the work to have an input into the schedule up-front.

Multi-IPT Protuberance

Description: Many of the Avionics protuberances that were mounted on another IPT had roles and responsibilities that were not well defined. This led to some structural analyses not being performed and subsequent confusion for some verification responsibilities.

Lesson Learned: Avionics mounting roles and responsibilities need special attention.

Cause: The primary role/charter of Avionics is more instrument/electrical than mounting/mechanical. As a result, mounting/mechanical issues were naturally lower on the priority list.

Recommendation: Avionics mounting roles and responsibilities need to be clearly delineated in the appropriate place such as the Avionics ICD/IRD.

Protuberance Venting

Description: Unvented protuberances (or other contained spaces), can experience delta pressure due to ascent.

Lesson Learned: Protuberances (or other contained spaces) need have vent holes.

Cause: Lack of top level requirement

Recommendation: Have a top level requirement for venting of protuberances (or other contained spaces).

Rainwater Intrusion Criteria

Description: Although the DSNE talks about preventing rainwater intrusion for the expected environment, there is no criteria such as allowable flange gaps to insure that water intrusion will not occur. The rainwater intrusion issue kept cropping up over and over. For a “low cost” program such as Ares I-X, rainwater intrusion verification testing may be too costly, and verification analysis would be questionable.

Lesson Learned: Rainwater intrusion requirements and acceptable verification methods need to be more defined.

Cause: It is easy to state a requirement that rainwater intrusion is not allowed, but expensive/difficult verify by test/analysis.

Recommendation: Perform a literature search to see if there is any past experience tests, analysis, rules of thumb, etc. that could aid in further defining what constitutes an acceptable design to mitigate rainwater intrusion. If there is not sufficient past experience data available, then some acceptable means of verification, such as test or analysis, needs to be defined up-front.

RoCS, Modular Versus Distributed System

Redacted for ITAR Reasons.

RSS Analysis for Bolt Stack-Up

Redacted for ITAR Reasons.

Windchill Inadequacies

Description: Windchill was highly disliked by the vast majority of Ares I-X. It was slow and the search feature was not reliable to the point that it was best to supply/ask for a link up-front. I used to be a CAD power user and frequently read CAD professional post sites to keep up with the CAD industry. The general consensus was that Windchill was a terrible data management system (and that Team Center was one of the best). I now agree that Windchill is a terrible data management system.

Lesson Learned: Windchill is a terrible data management system.

Cause: I was not a part of the decision making process to use Windchill; therefore, I do not know what lead to the decision to use windchill.

Recommendation: Find a better data management system than Windchill. Chose the team to pick a better system wisely, without regard to politics.

Welding Effects

Redacted for ITAR Reasons.

USS Doubler Mis-Manufacture

Redacted for ITAR Reasons.

Min/Max Thread Protrusion Beyond the Nut, and Running Torque Criteria

Redacted for ITAR Reasons.

Stiction

Description: The cohesive/suction force encountered during disassembly.

Lesson Learned: Stiction is easy to overlook.

Cause: Stiction is seldom encountered.

Recommendation: Stiction should be mentioned in, perhaps, the Loads Data Book?

Sheer Loads at Interfaces

Redacted for ITAR Reasons.

Recording Running Torque

Redacted for ITAR Reasons.

Inclusion of Ground Ops personnel during the design process

Description: Ground Ops personnel were included in working meetings, as well as reviews, during the design process.

Lesson Learned: Ground Ops personnel provided important inputs to the design process that may otherwise have been overlooked.

Cause: Good forethought.

Recommendation: Include Ground Ops personnel at working meetings, as well as reviews, during the design process

#19 Ares I-X CMLAS Lessons Learned (Jonathan Cruz)

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AI1-CML-RPT-LL

BASELINE 1.0

National Aeronautics and
Space Administration

RELEASE DATE: APRIL 29, 2009

ARES I-X

CREW MODULE/LAUNCH ABORT SYSTEM (CMLAS)

LESSONS LEARNED

Approved for Public Release; Distribution is Unlimited

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REVISION AND HISTORY PAGE

Status	Revision No.	Change No.	Description	Release Date
Initial	1.0		Baseline Release	4/29/2009

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

Revision: 1.0	Document No: AI1-CML-RTP-LL
Release Date: April 29, 2009	Page: 3 of 11
Title: CMLAS Lessons Learned	

SIGNATURE PAGE

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1.0 INTRODUCTION

1.1 PURPOSE

Following is a listing of lessons learned through the life of the Ares I-X CM/LAS project. They are broken up into large period of time: Fabrication at Langley, Post Pre-Ship/Acceptance Review, and at KSC. The list will be updated as additional lessons are captured.

Requests for inputs were requested by all project members and interfaces. All pertinent responses have been incorporated.

1.2 CHANGE AUTHORITY/RESPONSIBILITY

Proposed changes to this document shall be submitted by CMLAS Change Request (CR) to the CMLAS CCB for consideration and disposition.

2.0 LESSONS LEARNED

2.1 FABRICATION AT LANGLEY

1. Fasteners – order early! Better/cheaper to have extras you can't use vs. losing schedule and paying exorbitant prices for when in a crunch
    a. Thought we had learned this from FTA early on, but were destined to repeat.
    b. Need adequate support at fab to do this – which may entail additional personnel (or provide adequate support at project level – FTA defined a fastener lead, but still had to go through fab for ordering).
    c. When you find a fastener the project feels it may need, buy it! MUCH cheaper (both budget and schedule) than later rush ordering custom-made fasteners, or doing a redesign and reanalysis for currently available fasteners (which sometimes are also out of stock after the redesign/reanalysis is completed).
        i. Custom ordered rush fasteners ($50k) delivered extremely later than promised when ordered – schedule impact.
    d. Perhaps set up a fastener storehouse on LaRC similar to GRC? Have open stores for sharing between Centers (GRC helped us out in this manner). Also have the paths to these stores defined – looked several times at GRC, and was only third or fourth attempt when it was determined they in fact had some of what we needed.
    e. Also clearly define alternate paths to stores. Attempts to purchase fasteners from GSFC stores delayed when sole person with account was out sick.

2. Materials – order early!
3. Integrated schedule for project. Needs to be correct and align with fab schedule. Which needs to be correct and complete and integrated across all activities. It's iterative – correct estimates as gain more information. Ideally have Center recognize this & make effort to rectify (including providing additional resources for scheduling).
4. Experienced personnel – need to have a reasonable percentage on a project – we were largely inexperienced/fresh out.
5. Allow continuity of personnel – lots of changes – I've literally lost track of the number of program analysts and schedule analysts that we've had over two years.
6. Maintain level of competency for when personnel changes are required – has hurt our productivity having to train or bring people up to speed, in addition to lag time in hiring replacements.
7. Clearly define manager/supervisor responsibilities for enforcing personnel performance standards.
8. Coordinated schedule between projects/priorities for Center resources. Ex. riggers – set up communications with FTA for priority scheduling – and keep this updated – if one project reserves resources for a blanket period to cover potential operations, cancel those reservations as plans change.
9. Define roles & responsibilities:
    a. Mission, between IPTs, interCenter, IntraCenter
10. Define priorities intraCenter – difficult getting resources even though "no other project has a higher project" when there are other projects that have the same priority.
11. Aircraft – plan for appropriate load times on both ends, and factor in mandatory crew rest times. FTA stayed on-ground for a crew rest time & left a day late. We're planning to load a day early, provide time for crew rest, & fly down the following morning and off-load at KSC the same day as the flight (minimizes time on the ground at KSC).
12. Project space – have it available! Was a major undertaking/battle to get it. Colocated team is a huge imperative for efficient interactions.
13. Critical lifts/lifts in general: include all parties up front – riggers, safety, facility coordinators, etc. – look for their advice, desires, or concurrence early on to avoid issues during a lift.
14. Work within resources'' schedules and define as critical only those resources that need to be. We learned from difficulties with other projects and, in the example of critical lifts: (a) set up lifts to begin earlier in the morning so as to align with the riggers' schedule and provide more time to perform lifts, and (b) limited the

project's critical personnel as we saw other lifts that had to be cancelled when someone defined as critical was unable to attend (we reviewed lift plans, then delegated authority to lift manager).

15. Include review panels in discussions prior to reviews – e.g. regular tagups with the CDR chairman in the weeks leading up to CDR to determine what he expected to see, to explain what we intended to show, and reach a mutual agreement prior to start of actual review.
16. Identify capabilities and capacities up front (accurate estimates) – even with sending out work to two other Centers schedule still slipped significantly.
17. Proper oversight/dependency on contracted fab work. Lots of second-guessing/hindsight on machining entire nose cone out of a single billet – we could not find a billet of sufficient size nor does LaRC have a machine capable of turning that out. But could have searched for a contractor to have done so (similar to lower ring – which was of course very late).
18. Have all parties understand and respect dependencies within the project – engineering, technical authority, and S&MA.
19. Services interruptions – do not have ODIN push patches on computers without prior project approval. Especially during Christmas break – with maybe 10 people working out here it's a good chance they're here for a reason – a simple "10 minute" patch put my logistics manager out of commission for almost two days during a critical period preparing for shipping.
20. Facilities coordination. When planning facilities use, have all potential conflicts clear up front. Ex. Hangar – found out after we were located in it that we did not have access for two days (filming and Christmas party). OK these things are going on, but should be a factor in our facility selection process.
21. Understand responsibilities for critical hardware moves. For one move, logistics manager had to get phone numbers off vehicles in CU parking lot and call all owners to move vehicles prior to a critical move. I felt should be a Security function – project does not have the manpower or the authority to do this. Resolution – spoke to security supervisor – CU was responsible for moving of POVs – security stepped up after call & took over & made it happen. May move "for sale" lot to side of CU.
22. Difficulty with sharing hardware between two active projects. Ex.: Load test fixture – conflicts between FTA and CM/LAS – as part of our maximum commonality we made use of FTA's load test fixture, but shifting schedules between both projects sometimes delayed access by other project.
23. KSC access – should be a defined process. Painful process drug out individually. Both for personnel and computers. Follow-on – better defined now – we have forged relationships with KSC that have helped in providing access for project personnel who arrived later.

24. 5HP – requirement specifications – inadequate for DFI mandatory sensors. Have PIs or others responsible specify appropriately and timely to avoid requirements creep.
    a. Impacting project schedule-wise with numerous meetings to discuss our problems and nonconformance's (there were none as we maintained our specs – but new requirements caused some rework).
25. Forethought on all aspects of design.
    a. LAS raceways interfered with support cradles & thus could not be permanently fastened (will have to wait until we're vertical at KSC).
    b. Small number of holes for mounting platforms to trailer (4 on Access Platform, 8 on Shipping Platform) required to be drilled just prior to shipping per AF agreement (because project put them in the plan – not communicated clearly across project). Drilling of these holes at last minute mandated re-load testing both items AND caused rush to locate bolts as called out in agreement (project called out aerospace grade bolts).
    c. Further analysis on Shipping Platform discovered inadequate strength for supporting casters. Originally looked at all four casters load case; peer review mandated looking at two-caster load case as on uneven floor; finally realized single caster case required as in sudden stops or catching of caster on FAD on surface. Faced with considerable redesign/rework two weeks prior to shipping, decided to just remove casters as KSC had indicated they would not use this function.
    d. Removal of LAS lifting lugs – dry runs performed at Langley prior to shipping. When came time to do so at KSC, mandatory sensors had been installed and created potential interference issue with lifting straps. Required modification of lifting procedure to avoid damaging mandatory sensors.
26. Multiple levels of regular project reviews. Within Mission and within Center – can we combine these or minimize them? Considerable impact to project for time required to prepare, or simply present in case of somewhat repetitive presentations.
27. Leave issues – exigencies, conversion of lost CTE to paid OT, etc. Set up process for implementing as no clear Center direction available. DPM did provide exigency process to FPD and was initial test case of new NSSC lost CTE to paid OT process.
28. Non-intrusive scanning isn't always (was told hand held scanning unit did not require completely static trailer, but determined it did when actually performing scan). Lost 6 hours due to nose cone scan keeping fab workers off trailer during critical assembly period when we needed them working. Even rumbling of crane doing FTA lift adjacent to our trailer disrupted scan (the scan was performed for SE&I for capturing nose cone geometry).

29. Test/check everything required for a procedure – don't assume!
    a. Scanning of OML – setup and execution right on schedule – output greatly delayed. Required export software license expired – not maintained as not typical output format for the scanners. Should have confirmed ability to provide data in required format.
    b. Lifting straps not same length, although marked/sold as such. Discovered during initial LAS lift (although had directed to measure them prior) – reordered for use at KSC.
30. Fasteners – specify only grade of fastener required – defined aero grade fasteners for attaching platforms to trailer for C-5 flight are proving troublesome to obtain.
31. Photography plan – think about early. From QA photographic plan, to arranging photographers for specific project events, and setting up time lapse cameras for capturing ongoing work. There are only three time lapse cameras available on-Center, and they must be shared among the projects.
32. Maintain active lessons learned document throughout project. Intended to do so early on and only started later. More difficult to recall and capture all lessons the later the process is started.
33. Tracking DWG updates through other orgs. COD "subcontracted" for Stack-5 GSE package. DWG revisions done by COD per KSC requests, but not initially passed through project CCB.
34. Maintain personnel through agreements even if Contractor/CS status changes. Can we make finishing tasks part of hiring/transition agreement? Lost personnel through unexpected transfers, and this impacted our schedule.
35. Transportation Officer – did not have current authority – had to get Lesa to delegate authority to him for our project to allow use of external resources to transport our hardware.
36. Cranes – need to maintain Center capabilities.
    a. Ordered new one to replace 38-year-old one. Certification issues caused it to never be available during our project. Plus DPM was directed to work crane requirements, justification, and funding, which took time from project tasks.
    b. Critical overhead crane in fab shop operating on safety waiver for over a year – needs to be repaired as directed for continued safe and reliable use.
37. New IT policies can cause unwanted impacts to project. AUID transition two days prior to PS/AR. AUID not valid until week prior to transition even though certain Center tools (such as LELAS) required it prior to that time. Even Agency NSSC help desk could not help when needed during Christmas break – it took until

January 11 to resolve. And lost access for the entire weekend preceding the PS/AR so reviewers could not access docs during that time.

38. Windchill difficult and lumbering for document exchange – slow, access lost frequently, and search functions don't work well.
39. Plan all optical scanning needs up front. SE&I made later request to leave laser pucks in place for scanning at KSC. Will require removal and paint touchup at KSC – doable, but adds transferred work to KSC.

2.2 POST – PSAR

40. Straps – check prior to final packing to ensure have enough and of adequate length. Some needed double strapping (singles not long enough, and AF preferred double straps vs. chains), also needed additional for holding down ramps,
41. Ramps – make fork-liftable – pre-stage forks at both ends of flight. Ramps required to extend C-5 cargo ramps to prevent bottoming out of center of trailers. Design evolved during fabrication – setting up features for easy forklifting improved handling, and getting forklifts set up at both airstrips made loading easier.
42. Test metal-to-metal bonding during each assembly step. A little extra each step, but saves enormous time generating a bonding test plan and then having to execute the plan.

2.3 KSC

43. Need to work confusing documentation requirements up front. DD1149 is a KSC custodianship transfer form that needs to be properly filled out when delivering hardware to KSC. Unclear requirements for format led to several days of heated discussions with project. Eventual agreement amongst KSC organizations allowed forms to be signed and accepted.
44. Seize any opportunity to work that we can as we do not know when the next opportunity may occur – crane availability in the VAB is especially hard to come by. Lost an entire day on the CM lift and placement on the access platform upon arrival at KSC.
    a. There are two groups required at KSC for lifting/handling different types of hardware. Unable to get both available again until following day.
45. Understand and follow all applicable STDs.
    a. NASA-STD-8739.4 – required pull testing of crimped connectors for QA verification. Was not done due to cost and schedule issues. And project was not informed this was done … working with Langley S&MA to prevent repeat.

   b. Bolt testing – existing Langley standards did not adequately follow NASA-STD-6008. Waiver required for CM/LAS – Langley standards being updated to address this for future projects.

46. Fit check on hardware. Perform either virtually or actually. Stack-5 Lift Fixture (LF) did not fit – had minor interference. Had optically scanned CM and used dimensions to size test fixture (TF) that was used to fit LF. However, scan approach used did not reference points to each other on TF – verified distance across each radial beam and corresponding pair of pads was correct, but did not check between the radial beams.
47. Fit check as soon as possible. Don't rely on optical scans only – turns out some were improperly applied (see above) plus pads only checked at center point – didn't catch that were out of alignment about two axes.

#20 Ares I-X Lessons Learned: Verification of Product Requirements (Vipavetz, Kempton, Gilfriche)

Defining the Verification Effort (I)

- **Good Examples Hard to Find**
  - References and Examples for Verification Documents and Processes on Other Projects/Missions are Limited
    - Most could not be tailored for use on Ares I-X
    - Most contractors resist any changes to existing formats. Must be persistent in asking for useful verification artifacts. Examples of artifacts are test reports, analysis reports, QA documents etc. Contracts should be detailed enough to show verification artifact deliverables.
- **Wrote Verification Activities as a Set of Requirements**
  - Verification Tasking Requirements: Specify **"Who shall do what"** to verify
    - Acts like an MOA between organizations
    - References Name of Specific Test Procedures/Reports or OTRs at the Launch Site (placeholder for future work products) ♪
  - Verification Product Requirements: Specify work products/deliverables/artifacts needed for verification
    - "The Analysis shall include…"
    - "The Simulation shall use…"
    - Identify who shall do what for Interface verification up front
- **Insist on a Clear Product Requirement Decomposition at Lower Levels**
  - Simplifies verification data management

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Defining the Verification Effort (II)

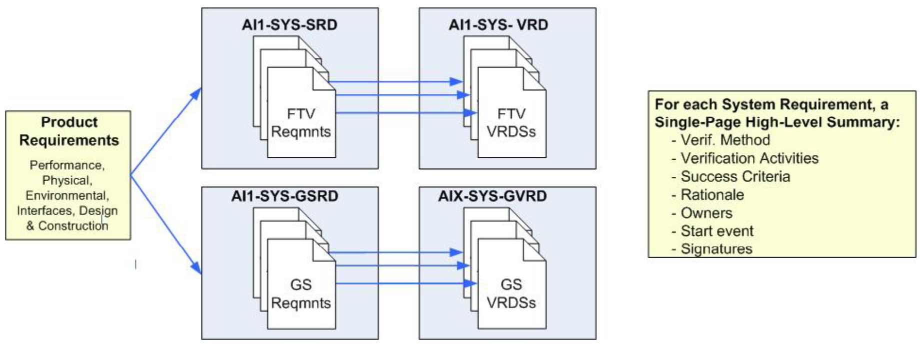
- **When is Verification Complete**
  - It is Difficult to Provide Guidance That Defines When Verification is Complete (Inspect Design Drawings, Inspect End Product, Test End Product)
    - Verification of Each Requirement Presents a Decision that is Often Subjective to the Verification Requirement Owner and their Organization
    - Get specific examples out as early as possible to improve consistency among the teams ♪
  - Typically When All Closure Artifacts Are Complete the Verification Can be Closed.) CDRs should be used to close out design verification activities.
  - Partial Verification Could Involve Completion of subsets of Closure Artifacts
  - All Verifications should be closed prior to Acceptance Reviews and not after integration checkout. Acceptance milestones need to be determined early on. (Usually before shipment)
- **Conflicts between Product Verification and Design Verification**
  - SE&I Wanted "As-built" *product* verification.
  - Had issues with Contractors providing drawing/design verification after product was built and often could not provide "As-built" data since it was subcontracted.
  - Need to have some authority over contract developmental and to implement cultural changes.

Defining the Verification Effort (III)

- **SEMP**
  - Development of the SEMP delayed due to disputes over authority, responsibility, and system definition (SE&I, IPTs, GS, and GO)
  - Released after X-Sync Redefined Responsibilities (part of re-org that occurred due to lack of clear responsibilities)
  - CM processes must support the management of verification artifacts (data, models, drawings, docs) - *Recommend a Verification Data Manager*
- **Master Verification Plan (MVP)**
  - Required Extensive Negotiation with GS and IPTs
  - Developers Already on Contract Resisted Change to Existing Verification Process ♪
    - Getting process institutionalized across project is very difficult on a one shot mission
  - Guidance on Qualification and Acceptance Levels Should Have Been Defined Prior to Contract Awards ♪
  - One IPT using a different verification process caused extensive rework on management tools and many "special rules" that adversely impacted the verification.
- **VRD**
  - Stable Product Requirements Are Needed Before Verification Requirements can be Fully Defined or Rework Becomes Excessive after CDR ♪
  - The Verification Workload was never incorporated into the Integrated Schedule♪
  - The Rational Statement in the Requirement is critical to defining the Verification Activities ♪
  - Specific Format of the VRDSs Evolved Over Time ♪
  - MVP Lagged Behind in Defining Verification Process Because of Delays in Getting the Qualification and Acceptance Plan Approved

Documenting the Verification Effort

- **Create a Verification Requirement Description Sheet (VRDS) for each System-Level and Element-Level Requirement**
  - Requires extensive communication with discipline experts *at all levels* ♪
- **Compile the VRDSs into Verification Requirements Documents (VRDs)**
  - A Combined Product Requirement/Verification Requirement Document Would Not Have Gotten Baselined in the Time Frame Needed



VRD Development

- **Technical discipline leads provided significant input to the content of the VRDSs**
- **Discipline Leads Typically Assigned as Requirement Owners**
  - Defining the role of the Requirement Owners Occurred Later than it Should Have ♪
- **Upper Portion of Sheet is More stable than lower portion**
- **VRD Uses same section numbering as the SRDs**
  - 3.2 - Functional/Performance
  - 3.3 - Design & Construction
  - 3.4 - Interfaces
  - 3.7 - Single Element Allocations

Example VRDS

Ares I–X FTV System
Verification Requirement Definition Sheet

FTV SRD Requirement to be Verified

Verification Number:	Requirement Number:	Priority (1-3):
VR-FTV-027	FTV-027	1

Requirement Title: Separation Re-Contact

Verification Requirements

Verification method: Verification that the FTV will separate without re-contact shall be verified by **Analysis.**

Description of verification activities to be performed: The Ares I-X ID&A Trajectory Lead shall perform an analysis to determine the time history of the position and orientation of the integrated FTV, using the prescribed vehicle coordinate system, through primary separation. The analysis shall be done using a NASA approved 6-DOF non-linear flight dynamics model of the integrated vehicle. The analysis shall be done using Monte Carlo simulations that vary input parameters that model vehicle performance, loads and environmental conditions with up to worst case (3-sigma) dispersions.

This study shall be compared to a re-contact analysis provided by the First Stage IPT for consistency.

Success Criterion: The verification shall be considered successful when the analysis results show that the FTV first stage and upper stage will avoid re-contact during separation with a 95% (TBR) confidence level.

Rationale: Because of the wide variation of possible inputs and because of lack of access to the flight-like mission environment, analysis with an accredited simulation is appropriate for this verification.

Verification Implementation

Level: FTV System

Applicable documents: FS Separation Analysis Report, AI1-SYS-MAB, BDM/BTM Specifications, SRB Thrust Profile, Ares I-X Aerodynamic Data Book: AI1-SYS-ARO, Avionics Element to Flight Vehicle Elements Interface Control Document, AI1-ICD-A2V

Nonconformance history:

Closure data/documentation required:

Verification Report: Ares I-X Primary Separation Analysis Study Report

Event preceding Verification Activity: Aero Data Book Complete (A2210), Ares I-X CDR Complete (21)

Estimated Duration of Verification Activity: _30__ Days

Closure Of FTV SRD Requirement

Date Closed:	[N] Safety Critical (Y/N)		
Test engineer:	Requirement owner:	Element/SE&I Manager:	S&MA:
	Brett Starr	Marshall Smith	

Starting the Verification Effort

- **Identify a Specific Owner for Each Requirement Early On**
  - Helps Define the Requirement
  - Helps Define the Verification Activities
  - Reviews and has Approval Authority Over Compliance Artifacts of Children Requirements
    - This was the big stick that ensured good IPT verification artifacts ♪
  - Provides Ownership and Accountability to Ensure Verification Activities are Planned
  - Verification Requirement Owner - Selected for technical expertise from SE&I or the IPT
    - Assignments Are Often Difficult to Make Since Requirements may Span Several Disciplines and Good Experts are Typically Oversubscribed♪
    - Verification Requirement Owners Need a Lot of Guidance on the Verification Process and Expectations ♪
    - Turnover and Availability of requirement owners must be carefully considered
    - Replace SRO early if they are not working out ♪

Starting the Verification Effort

- **Verification Activities Need to be schedule events**
  - Work with schedulers to add Verification Activities into the Integrated Schedule
  - Verification Activities Must Result in the Creation of an Artifact (Test Report, Analysis, Inspection Report, etc.) ♪
    - If the Verification Activities Include a Peer Review then a Report Shall be Produced ♪
    - Track Verification Through the Completion and Baselining of Artifacts so Progress Can be Confirmed

Example VRDS (Upper Portion)

- One primary verification method (analysis, test, inspection, demo) that:
  - Provides adequate verification; Is appropriate; Is <u>practical</u> (cost, schedule, technical); prevents mixing up of levels and resources. Should only see more than one method if there are multiple requirements such as standards
- A decomposition of the verification activities
  - Specify responsible positions/groups ♪
  - Specify how the verification products will be developed ♪
  - Specify qualities and content of the verification work products ♪

Verification Requirement IDs match Requirement ID ♪

Rational for verification method (not the requirement) ♪

Ares I–X FTV System Verification Requirement Definition Sheet		
FTV SRD Requirement to be Verified ♪ Removed		
Verification Number: VR-FTV-017	**Requirement Number:** FTV-017	**Priority** (1-3): 1
Requirement Title: Control Algorithm		
♪ One primary method **Verification Requirements**		
Verification method: Compliance with the usage of Ares I/Orion ascent control algorithms shall be by **inspection.**		
Description of verification activities to be performed: Ares I-X Flight Software Specifications and Flight Software Source Code shall be inspected to verify that NASA provided GN&C algorithms have been implemented as intended. The SE&I ID&A Lead shall compare the SIL test and TRAJEX results with the LaSRS results for compliance with the GN&C algorithms.		
Success Criterion: NASA provided GN&C algorithms defined in the final version of AI1-SYS-CAP are being implemented as intended in the Ares I-X Flight Software.		
Rationale: The flight control system supports the major flight test objective which is to demonstrate control of the large, aerodynamically unstable, flexible vehicle with a control system that is relevant to the design of the control system for the Ares-I vehicle. Due to time and budget constraints, the flight test vehicle will not be exactly the same as the Ares-I and therefore the flight controls will have some differences as well. P1 stipulates the use of same Ares I/Orion ascent control algorithms. The algorithms are tied to the control Ares I/Orion architecture functions. It is assumed that only control parameters (e.g. rates and gains) will be different.		

Example VRDS (Lower Portion)

- **Applicable Documents - List of items needed to complete the verification** ♪ Archive
- **Closure Data/Documentation Required - Identify specific name of closure report** ♪
  - Putting a specific name makes it planned work and gets it put on a document list
  - Use intuitive document numbers (AIX-SYS-VRD, AIX-USS-ERD, AIX-TAR-DRIFT) ♪
- **Event Preceding Verification Activity - Specific schedule event from IMS to help manage verification activities**

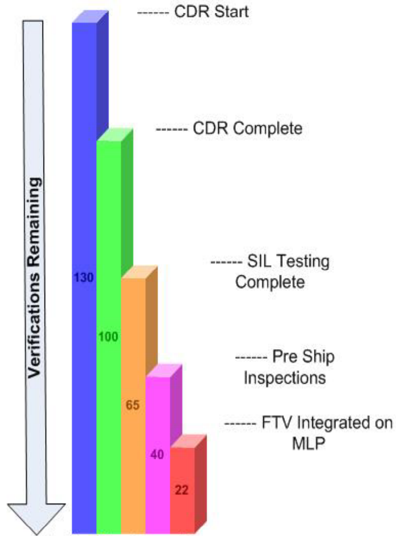
Verification Implementation			
Level: FTV System			
Applicable documents: Ares I-X Control Algorithm & Parameters: AI1-SYS-CAP, Guidance and Control Software Implementation Requirements Document for the Ares 1-X FTV: SIRD-G&C-300, Ares I-X Source Code for Guidance and Control Module, Ares I-X Flight Software Specifications, Avionics "Fly the SIL" Test Output			
Nonconformance History: ♪ (Note Pass/Fail and track waivers/deviations in here)			
Closure data/documentation required: Electronic/Written statement of verification from the ID&A GN&C Lead **Verification Report:** **Event preceding Verification Activity:** Airborne Flight Software Test Readiness Review Complete (A17140) **Estimated Duration of Verification Activity:** ♪ ___ Days			
Closure Of FTV SRD Requirement			
Date Closed:		[N] **Safety Critical (Y/N)**	
Test engineer:	**Requirement owner:** Jay Brandon	**Element/SE&I Manager:** Marshall Smith	**S&MA:** ♪ Went with 5 Signatures

FTV Verification Burn Down was Optimistic

- Most Analysis completed after CDR
- Most Inspections Post Ship
- Most Testing occurs at Avionics System Integration Lab or on the Integrated Vehicle

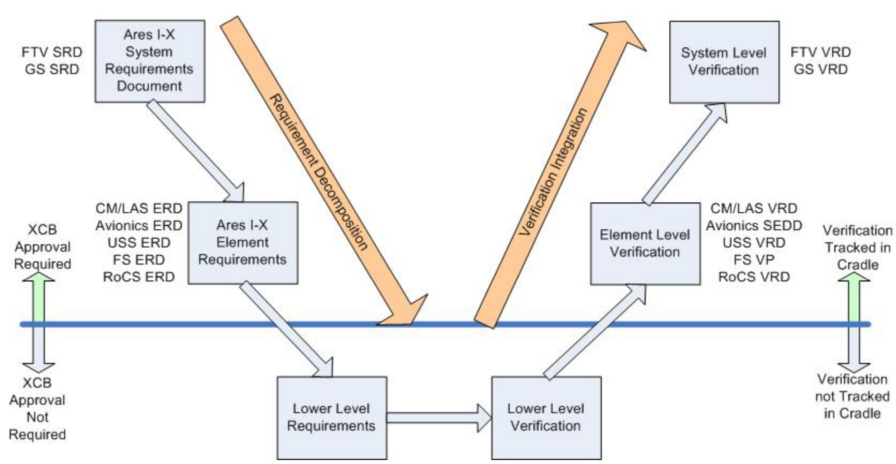
- Several verifications waiting on another update to a Loads Data Book with More Refined Data
  - It is be difficult say what is good enough for verification and when to stop ♪

- Since most contracts are finalized before the verification requirements are baselined negotiation skills are essential ♪



Verification Burn Down (Approximate)

Verification Flow

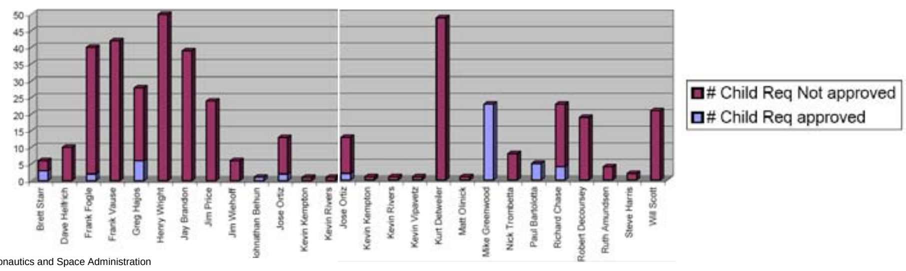


- Lower-Level Closure Artifacts Support Element-Level Verification
- Element-Level Closure Artifacts Support System-Level verification
- Note that Verification Integration is the verification agreement between the levels as approved by SE&I. It has to be useful to the next level up. IPT verifications required SE&I approval that it “meets” the system verification requirements.

Support the Verification Requirement Owners

- Support Includes
  - Clarify tasks required for verification ♪
  - Providing simplified access to verification artifacts ♪
  - Colored text indicated: Green approved by XCB, Yellow approved by IPT, Red not ready

Number	Verification Method	Supporting IPTs in requirement Allocation	Requirement Title	Requirement Owner	CM/LAS	RoCS	USS	Avionics	First Stage
FTV-012	Analysis	ALL except RoCS	Mach – q Curve	Brett Starr	CML-018 CML-019			AVI-017	FS-035
FTV-027	Analysis	FS,AVI	Separation Recontact	Brett Starr				AVI-017	FS-019 FS-025
FTV-099	Analysis	FS,USS,AVI	FS Separation and Dynamic Pressure	Brett Starr				AVI-017	FS-035
FTV-143	Inspection	ALL except AVI	Human Factors Engineering	Dave Helfrich	CML-067	RoCS-036	USS-026 USS-103 USS-105 USS-095 USS-107		FS-089 FS-154 FS-162
FTV-036	Test	FS	Manual Launch Initiation Inhibit	Frank Fogle					FS-002 FS-062 FS-127 FS-105
FTV-037	Test	FS,AVI	Pre-launch Ignition Arming	Frank Fogle				AVI-037	FS-127
FTV-054	Inspection	FS	Launch Site Propellant and Pressurant Loading	Frank Fogle					FS-150
FTV-055	Inspection	FS,USS,RoCS	Launch Site Prop and Pressurant loading/unloading	Frank Fogle		RoCS-017	USS-044		FS-151



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Verification Status Tracking and Reporting

- Align Verification with Unique Schedule Activities
- Provide Stoplight Chart
- Provide Detailed Closure Status
  - Develop a consistent set of status descriptions early on and force lower level element to report using the standard set of status descriptions ♪

Number	Verification Method	Supporting IPTs in requirement Allocation	Requirement Title	Requirement Owner	IMS Event for Verif Activity	Stop Light	Meets	RCN # or OTR #	Closure Status
VR-FTV-001	Inspection	ALL	FTV Elements	Kurt Detweiler	21	Activity Not Started		N/A	In Work
VR-FTV-002	Analysis	FS,USS,CM/LAS	1st Mode Bending Freq and Mode Shape Similitude	Frank Vause	21	In Work			Failed-Waiver
VR-FTV-004	Analysis	FS,USS,CM/LAS	2nd Mode Bending Freq & Mode Shape Similitude	Frank Vause	21	In Work			Failed-Waiver
VR-FTV-006	Analysis	FS,USS,CM/LAS	3rd Mode Bending Freq & Mode Shape Similitude	Frank Vause	21	In Work			Failed-Needs Rework
VR-FTV-008	Analysis	FS,USS,CM/LAS	Bending Stiffness Profile	Frank Vause	21	In Work		TBD	Pending Lower Level Verification
VR-FTV-009	Analysis	FS,USS,CM/LAS	Joint Stiffness	Frank Vause	21	In Work			Pending Lower Level Verification
VR-FTV-010	Analysis	FS,AVI	Rigid Body Mode Stability Margins	Jay Brandon	A28890	In Work			Pending Lower Level Verification
VR-FTV-011	Analysis	ALL except RoCS	Flexible Body Mode Stability Margins	Jay Brandon	A28890	In Work			Pending Lower Level Verification
VR-FTV-012	Analysis	ALL except RoCS	Mach – q Curve	Brett Starr	A28450	In Work			Pending Lower Level Verification

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"Heritage" Qualification Data

♦ "Heritage" Designations Complicated Qualification

- Vendors avoided qualification testing requirements with several types of "Heritage" designations.
- Contracts allowed new or modified components products to be considered "heritage".
- Heritage qualification data considered proprietary and difficult to obtain ♪.
- Heritage qualification data difficult to translate into the qualification levels required by the Master Verification Plan based on expected loads defined in the Ares I-X Loads Data Books ♪.
- Contract should define how developers will provide qualification data ♪.
- Need to develop utility to manage qualification data and have each developer provide information in the format defined by the utility♪.
- FTV-140 (Induced Loads) Verified Qualification Data using the Component Assessment to Loads and Environments (CALE).
  - "Mother of all Verifications"

Documenting Requirement Compliance

♦ Compliance Statements

- A Compliance Statement was produced for every VRDS.
- Often developed by people supporting the Requirement Owner.
- Required Formal Review prior to Closure at the Axes I-X Control Board.
- SE&I performed goodness checks prior to sending to any external reviews.
- Summarizes why requirement is met and provides links to technical data to back it up. ♪
- Similar to the CxP Verification Closure Notice (VCN).
- Recommend creating examples and making them available to projects as soon as possible.♪
- Included Links to children verification data.
- Included Links to associated Waivers.

First Stage "Heritage" Artifacts

- **"Heritage" Verification Artifacts Not Adequate**
  - Vendor provided artifacts reflected a maintenance activity (Shuttle) and not a new development (Ares I-X).
  - Personnel Turnover of First Stage IPT verification managers weakened verification effort. Delays caused by turnover helped mask the fundamental problems until it was to late to fix them ♪.
  - First Stage IPT verification managers seemed to have no control over what verification data was delivered.
  - Final verification artifacts for FTRR more appropriate for a CDR
  - Obtaining artifacts from First Stage QA was very difficult especially for existing hardware.
  - Ares I-X Mission Management did not provide adequate upper level support to resolve First Stage requirement development and verification issues.
  - MMO directives were issued to handle First Stage verification products (i.e. "Compliance Artifacts approved automatically by submittal with no review required" and "Verification During Integration").
  - Never really received a full Acceptance Data Package (ADP) from the FS. There were some ADPs but these were really log books.

Special FS Verification Summit

- **Due to the FS culture, contracts and duel project offices (MMO and Flight Project Office) a special verification summit was needed to demonstrate that the design verifications would meet the product "as built" verifications.**
- **QA provided sufficient confidence that the FS products would meet the FS designs.**
- **The SE&I Verification Management put together a special directive to allow the FS process to by pass SE&I approval before XCB approval. MMO approved the directive.**
- **SE&I also accepted all contract verifications as element verifications. This added a great deal more effort on the system level verification since there were four times as many verifications that needed to be reviewed than would have been required at the element level.**

Operational Test Requirements (OTRs)

- **Heritage OTRs and New OTRs used for Assembly, Integration, and Test**
  - Specific OTRs referenced for some system-level verifications that had to be done after integration (i.e. OML, CG Offset).
  - OTRs are closed when their associated Work Authorization Documents (WADs) are “accepted”.
  - SE&I could not get a cross reference/traceability between WADs and OTRs.
  - WAD closure artifacts often consisted only of “Accept”.
  - Needed special access to see any documentation on the results of the WADs.
  - OTR format is unchanged from format used for line printers. Difficult to input , copy or paste between documents.
  - Information during I&T limited to reports from SE&I personnel located on site.
  - SE&I had to maintain a constant presence at the launch site during I&T in order to have reasonable insight into what is happening. The culture at KSC is not conducive to having others looking over their work. ♪

Need Verifiable Requirements

- [R.EA1023] CLV Liftoff Clearances
- **The CLV shall provide liftoff clearance between the CLV integrated stack vehicle and the launch facility.**
- **Rationale: The GN&C subsystem and ground structure to launch vehicle physical interface need to be designed such that recontact is an extremely low probability event. Recontact at any point in the vertical rise phase of flight may be catastrophic and could mean loss of crew, loss of launch elements or ground infrastructure. This involves clearances such as CLV and CEV access arms, umbilicals and the SRM nozzle. Specific clearance envelopes will be defined in the CLV/GS and the CEV/GS IRDs.**

- FTV-035: Launch Pad Ascent Clearance
- **The FTV shall have a clearance margin with Launch Pad Complex 39 B following lift-off for a combined system and environmental dispersions at equal or greater than 99.865-percentile.**
- ***[Rationale: Re-contact at any point in the vertical rise phase of flight is almost certainly catastrophic and would likely mean loss of elements and ground infrastructure. To ensure that contact is a very remote occurrence, best practice suggests a design clearance margin under combined system and environmental dispersions of at least 99.865--percentile. This is accomplished by controlling roll, and yaw, release of hold downs, and by providing adequate initial clearances between the launch pad hardware and the flight vehicle. Design clearance margin is defined as: MS=(gap provided)/(closing displacement) – 1, where “gap provider” is the static reference gap between the FTV and the launch pad and “closing displacement” is the total motion together experienced during launch. FTP calls out that the launch is from Launch Pad Complex 39B in Section 3.0.]***

Verification is Subjective

- **Each Requirement Owner Has a Different Level of Verification Comfort/Discomfort**
  - Disagreements on fidelity of verification go to the Verification Working Group for resolution.
- **The IPT VRDS Should Clearly Define What Will Be Provided to Close the Verification**
  - If the Rock is not good enough you must ask for a different rock!
  - Once the IPT VRDs are Approved it Will be Much Harder to Get What You Need
  - Think of the VRD as an MOA between the IPT and SE&I
- **Closure Artifacts Must be Available For Review or the IPT Cannot Close the Requirement**
  - If you cannot find a closure document ask the IPT Verification POC or the IPT Requirement Owner.

Hunting for Artifacts

- **Have intuitive directory structure for keeping Closure Artifacts and Applicable Documents Listed in the VRDs**
  - **Had a verification folder for every product requirement**
  - **Very limited write access to folders kept junk out**
- **Maintain a Requirement Traceability Table**
  - **Children should trace to one parent requirement**
  - **Traces must be justifiable! We had a lot of bogus traces.**
  - **Keep it up to date since it gets used often**
- **Requirement Owner Lists (System and IPT)**
- **VRDs available (System and IPT)**
- **Applicable Document List with Links**
- **Intuitive naming conventions saved huge amounts of time finding and identifying documents**
- **Have a Data Manager to Maintain Verification Artifacts**

Independent Verification Efforts

- **Independent Teams Essential for Formal Review**
  - Catch items insiders miss
  - Provide legitimacy
- **Independent Teams Provided Critical Analysis**
  - GN&C, Structures, Sequencing, Hazardous Systems
- **Information from independent experts used by requirement owners as part of the verification activity**
  - Software Code Analysis & Testing Results
  - Induced Loads Analysis
  - Stability Margins Analysis
  - Simulation Results
  - Bending Mode Analysis

End Game

- **Dependencies on children verifications**
  - System Level Verifications piled up until children verifications were completed
  - IPTs often wanted to wait untill the vehicle was integrated or operational tests during integration before closing out their verifications. At this level this belongs to SE&I and not the IPTs. IPTs should always close out verifications at *acceptance and before system integration*. IPTs should however provide further integration checkout info to SE&I to be carried as part of the system-level verification. Should be part of OTRs. ♪
- **SROs not available due to higher priorities**
  - SE&I Formed a verification surge support list early on which turned out to be a key factor in completing the system level verifications since SROs are often not available. ♪
  - Needed three full time people to lead the system-level verification effort
- **Always be ready to streamline or tailor the process**
  - Schedules will require this. Okay as long as integrity maintained! Always perform goodness checking.

Misc

♦ Entrance Criteria for Major Integrations

- You will need to identify the requirements that must be verified prior to major integration mate reviews (FS to USS, RoCS to USS, etc.)
- Discussing any open requirements allows an honest assessment of the risk involved

- SE&I should have a fastener expert, ESD expert and EMI expert involved all through design, development and verification ♪

Configuration and Data Management

♦ **Windchill**

- Wait required when moving between Windchill folders easily wasted hundreds of hours
- Directory structures became convoluted
  - o especially IPT data structures which were not controlled at the mission level
- Ares I-X secretary provided a beacon of light by maintaining Mission Level documentation and Control Board Information
- Use the CM to control versions within requirement documents.
  - This prevents useless churning of documents for every version or revision update to applicable documents.
  - Provide a link to the Configuration Item site within you requirements document.

♦ **Good Utilities for Verification Management and Metric Reporting are Needed**

- Custom database application had high value for supporting verification management.
- Spreadsheets were often used in applications better suited for a database (i.e. DFI List)♪
- A custom database requires more effort to initially set up but often pays for itself when capabilities need to be added later.

Waivers

♦ Handling Waivers

- Force clear associations with requirements.
- If a Waiver Affects Multiple Requirements it should be decomposed into separate waivers
- Lower-Level Waivers Should be Verified at Lower-Levels
- Waiver Database should be searchable by Key Words since the Impacts can be Broad
- Waiver Database should provide links to requirements
- Waivers should be in specific formats with required fields

Milestone Reviews

♦ Ares I-X Dropped System level TRRs and DCRs

- Realized that the system verification and XCB review process made this redundant.
  - Every requirement verification is totally separate
- Verification is a continuous process and not a distinct phase like in software.
- Verification Status Reporting is Continuous
- Closure of each Requirement Closely Tracked by Management
- Have contingency plans for expedited reviews

Interface Control Documents

- **IRDs are developing ICDs. They provide the final compatibility specs for assembly details between parties. They are *not requirements but success criteria for requirements coming from requirement documents belonging to each side of the interface.***
  - Should not have shall statements, except for use as a header to a section. Try to avoid all together. Otherwise you will find that you are doing redundant verifications because you have shall statements! They are still binding without shall statements and must be met.
- **Interfaces should never impose requirements on requirement documents, other contracts, IPTs or different Org levels. They can act as MOAs between IPTs.**
- **Requirement documents should call out the specific interface function and the associated ICD section.**
- **Verifications are against the requirement documents using the ICD as success criteria.**
- **Watch out for overly tight tolerances. Need to decide if an ICD success criteria isn't met the requirement isn't met. This is a waiver issue.**

Interface cont.

- **Have a way to link final changes to ICDs to cover updates late in the schedule or due to changes in the final "as built" product. This should be linked to waivers or to field engineering changes if the ICD cannot be updated.**
- **ICDs have to contain all the final data can be found. Either this is in the ICD or it points to where it can be found (this is a baselined configuration controlled document, point to drawings instead of models).**
- **IRD Book managers**
  - Each IRD had Book Manager to act as a facilitator and obtain agreements between parties. Agreements were added to the IRDs since they were not covered elsewhere.
- **Interface Requirements in SRD Section 3.4 reference the specific IRD sections**
  - Many Element to Element Requirements trace to FTV-001 (FTV shall have 5 elements)
  - FTV-001 Compliance Statement references all Element Level 3.4 Verifications for compliance and a difficult verification due to its numerous sub verifications that needed to be reviewed for compliance.
    - This happened because the SRD did not call out IRDs, missing requirement in SRD which caused a lot of traces to requirement FTV-001.

Standards

- **Standards are a nightmare to verify**
  - They can be a never ending verification loop.
  - They have more than one requirement and often have multiple verification method needed to verify a standard.
  - Many standards are poorly written requirements. You will need to decide how you will interpret this and get CE and S&MA to approve.
  - Until recently there were no " Master Standards List " or guide to help find your way through the maze as to which standard applies to your project.
    - Chief Engineer should be responsible for specifying standards Early On ♪
  - You stop verifying when you are willing to accept the risk of not verifying further.
  - Example would be meeting English Units of Measurement. Are you going to examine every component and drawing to see if you met the requirement? We looked for this in all the critical interfaces, did random checks across all levels and looked to see if the requirement was decomposed properly at the lower levels.
  - You will have to count heavily on the IPTs to meeting standards that are allocated to them. You must be sure that they do get flowed down and agreed to by the IPTs.

Working Groups

- **SE&I Ran the Major Technical Working Groups**
  - Systems Engineering Working Group (SEWG), Interface and Integration Working Group (IIWG), Verification Working Group (VWG), Demonstration Flight Instrumentation Working Group (DFIWG), System Operations Working Group (SOWG), Systems Engineering Review Forum (SERF), E3 Panel, etc.
  - Key factor in successful communications
  - Critical to the SE&I Activity
  - Huge amount of effort to run but essential to SE&I success
  - All were formal working groups (Charter, Lead, Agenda, Minutes, Dedicated Telecon #, Recorder, etc.)
  - Started and Stopped the Working Groups as Needed
  - Identified responsible person from each IPT (Attendance Mandatory/ Have alternate if not available)
  - Tasked by XCB to resolve issues before they get approved by the board

Links

Ares I-X Homepage:
https://ice.exploration.nasa.gov/ice/site/cx/menuitem.0c5f6ca909e7c45560bf987c3a55d40c/

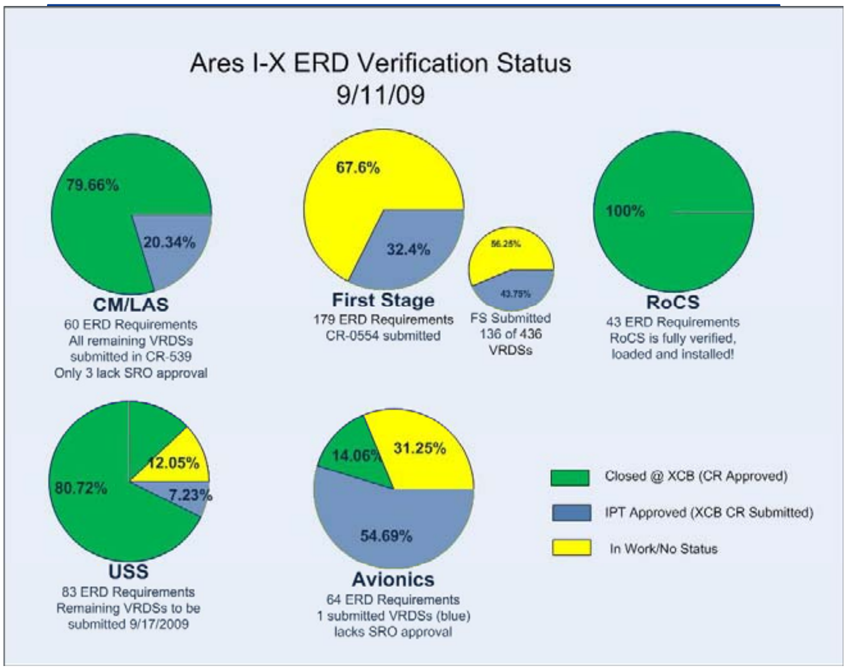
Verification Folders:
https://ice.exploration.nasa.gov/Windchill/netmarkets/jsp/folder/view.jsp?oid=folder%7Ewt.folder.SubFolder%3A687377134&u8=1

Verification database:
https://ice.exploration.nasa.gov/Windchill/netmarkets/jsp/folder/view.jsp?oid=folder%7Ewt.folder.SubFolder%3A1253639390&u8=1#P153

Status

- **SE&I needs good status reporting tools**
  - Have an unambiguous way to show requirements have been approved. Ares I-X requirements considered closed only when specified in XCB minutes.
  - Weekly Status Meetings with Mission Manager focused on verification status and burn down estimates
  - Quad Charts, & Pie Charts, X-Y burn down
  - Throughout the development honest assessments were provided and with few exceptions team members raised issues and those issues were resolved ♪
    - Never shot the messenger

Pie Charts – The Great Motivator



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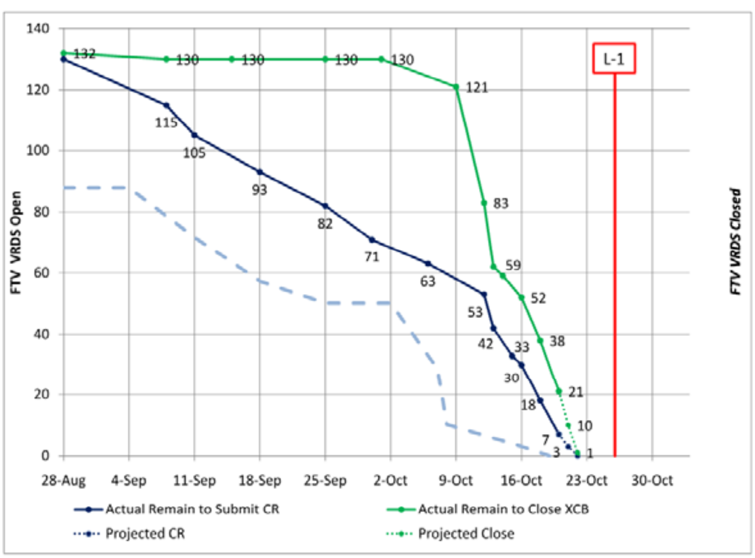
Burn Down Plots



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Random Example From CEV MVP Volume V

AV.1594 Abort Mode Selection from Mission Systems

Text: The Avionics Subsystem shall select abort modes upon receipt of the command from Mission Systems.

Success Criteria: Verification is successful when test and analysis show that Mission Systems is able to select the appropriate abort mode(s), including designation of a preferred abort mode. Testing must include mission phases and segments where a) only one abort mode is defined; and b) multiple abort modes are defined, necessitating a prioritization by Mission Systems to determine the preferred abort. The transitions from one preferred abort to another based on timeline, current conditions, etc., must be analyzed.

DVM's Linked to AV.1594 : T1

- **Is the verification artifact the T1 Test Report?**
- **Is the test done on a Hardware in the Loop test or on a Software Development system?**
- **Who shall do what?**

KSC GO

- **Need to have reps collocated at all IPTs and SE&I.**
- **Need to have KSC coordinate with the IPTs and SE&I early on and have KSC write up the OTRs if you are going to continue to use the KSC process.**
  - However I would insist on a new OTR format. KSC OTRs are complex, hard to use, and to interpret.

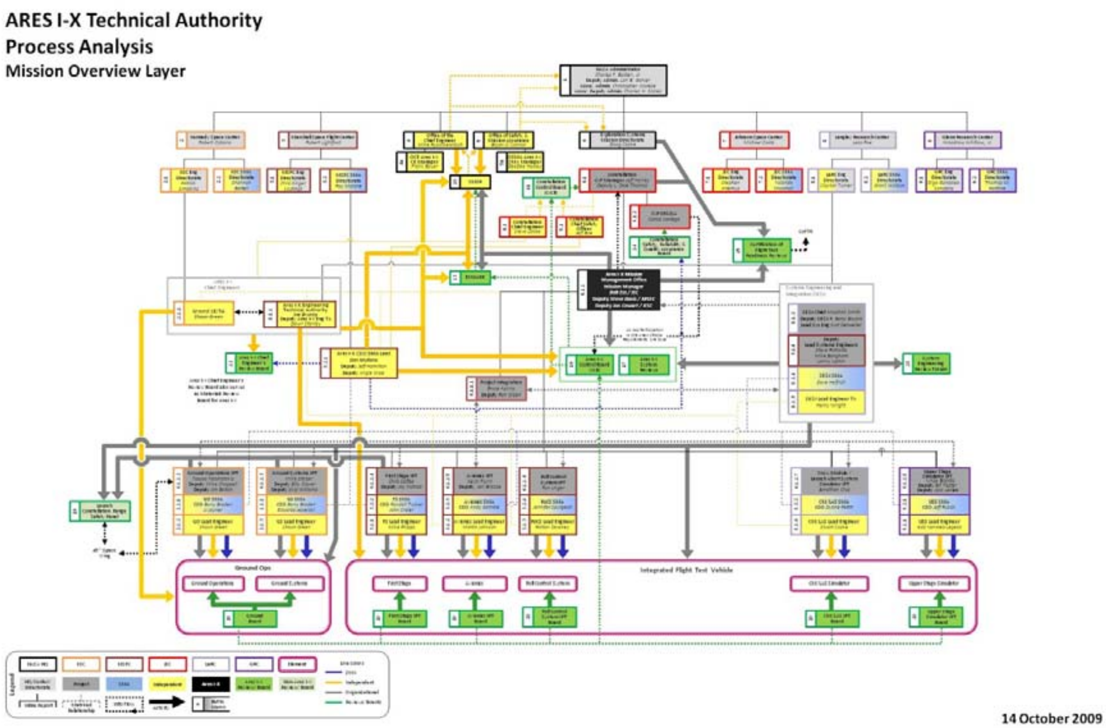
Control and Authority

- Need to have all the contracts responsive to you (SE&I). Either as a CoTR or directly in the contract DRDs.
- You do not want to have to go through another contractor to speak to another contractor.
- This will also solve the problem of SE&I being present at all times during KSC integration.

#21 Technical Authority Process Map (Thad Gutshall)

Appendix E: Technical Authority Process Map

The Safety & Mission Success Review (SMSR) was held on October 19, 2009. The process map and matrix (prepared by the HQ Office of Safety & Mission Assurance) are used to orient and prepare the Chief Safety Officer and Chief Engineer for their review role in the SMSR. The matrix below accompanies the Technical Authority process map providing a description of relative roles, responsibilities, boards, panels, and accountability.



	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
1	**NASA Headquarters**	Charles Bolden
2	**Kennedy Space Center (KSC)**	Robert Cabana
2.1	**KSC Engineering Directorate**	Patrick Simpkins

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
2.1.1	**Ground Chief Engineer/Technical Authority (CE/TA)** One CE will focus on the development of the FTV and the second CE will focus on development of ground systems and operations. The CEs will collaborate to ensure that the overall integrated flight test system can meet the flight test objectives. Per NPR 7120.5D, a chief engineer assigned to a project "is the Engineering Technical Authority for the program/project and is the single Point of Contact (POC) for the engineering technical authority process within the program/project." To ensure independence, the chief engineer "is assigned to the program/project, but is organizationally in the Center Engineering Directorate".	Shaun Green
2.1.2	**Ground Operations (GO) Lead Engineer**	Shaun Green
2.1.3	**Ground Systems (GS) Lead Engineer**	Shaun Green
2.2	**KSC Safety & Mission Assurance Directorate**	Shannon Bartell
2.2.1	**Ground Operations Safety & Mission Assurance (GO S&MA)**	Barry Braden
2.2.2	**Ground Systems Safety & Mission Assurance (GS S&MA)**	Barry Braden
3	**Marshall Space Flight Center (MSFC)**	Robert Lightfoot
3.1	**MSFC Engineering Directorate**	Dan Dumbacher
3.1.1	**First Stage (FS) Lead Engineer**	Mike Phipps
3.1.2	**Avionics Lead Engineer**	Martin Johnson
3.1.3	**RoCS Lead Engineer**	Patton Downey
3.1.4	**Deputy Lead System Engineer**	Steve Richards
3.2	**MSFC Safety & Mission Assurance Directorate**	Roy Malone
3.2.1	**Ares I-X Chief Safety Officer (CSO) / Safety & Mission Assurance Lead** **1)** The S&MA Lead will serve in another role as the Ares I-X Chief Safety and Mission Assurance Officer (CSO), in which capacity the chief/CSO acts as the S&MA Technical Authority. S&MA Technical Authority personnel are organizationally separate from the program/project. The Technical Authority via the Chief Engineer, CSO, and their teams will provide a continual independent assessment of technical progress. **2)** The SR&QA Lead for the flight test vehicle will serve as the primary interface to the Mission Manager for SR&QA and will coordinate overall SR&QA activities for the Ares I-X mission. The MMO level SR&QA Lead is independent from the Ares I-X mission management chain and funding. The SR&QA Lead is supported by the SE&I SR&QA and IPT SR&QA personnel with appropriate technical expertise and resources from the applicable NASA Centers.	Dan Mullane

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
3.2.2	**First Stage Safety & Mission Assurance (FS S&MA)**	Randall Tucker
3.2.3	**Avionics Safety & Mission Assurance (AV S&MA)**	Andy Gamble
3.2.4	**Roll Control System Safety & Mission Assurance (RoCS S&MA)**	Jennifer Spurgeon
4	**Office of Chief Engineer (CE)** **1)** Ares I-X will be supported by the NASA Technical Authority (TA) as defined by NPR 7120.5D. Ares I-X will follow the TA process for Engineering and the TA processes for S&MA. A Chief Engineer will implement the Engineering TA process and a Chief Safety Officer (CSO) will implement the TA process for S&MA. **2)** Ares I-X CSO and CE will support a SMSR chaired by Headquarters Office of Chief Engineer and Office of Safety and Mission Assurance.	Mike Ryschkewitsch
4a	**OCE Ares I-X Chief Engineer Manager**	Frank Bauer
4.1	**Constellation Chief Engineer** The Constellation Program Chief Engineer performs the independent technical authority function for CxP products. The CxP Chief Engineer is the Designated Governing Authority for the CxP. The DGA is assigned primary responsibility for evaluating technical content to ensure that it is meeting the commitments specified in the key management documents. While overall management of the CxP is the responsibility of the program manager, the DGA has the final approval signature to ensure independent assessment of technical content and waiver authorizations.	Jeff Labbe
5	**Chief of Safety & Mission Assurance** **1)** The Office of Safety and Mission Assurance (OSMA) assures the safety and enhances the success of all NASA activities through the development, implementation, and oversight of Agency wide safety, reliability, maintainability, and quality assurance (SRM&QA) policies and procedures. **2)** Ares I-X CSO and CE will support a SMSR chaired by Headquarters Office of Chief Engineer and Office of Safety and Mission Assurance.	Bryan O'Connor
5a	**OSMA Ares I-X S&MA Manager**	Deirdre Healey
5.1	**Constellation Chief Safety Officer**	Jeff Bye
6	**Exploration Systems Mission Directorate (ESMD)**	Doug Cooke
6.1	**Constellation Program (Cx)**	Jeff Hanley

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
6.1.1	**Ares I-X Mission Management Office (MMO)** **1)** The Mission Manager will be assisted by two deputies, appointed by the MMO Manager, one from Marshall Space Flight Center (MSFC) and one from Kennedy Space Center (KSC). A lead Chief Engineer (CE) and a lead Safety and Mission Assurance (S&MA) Officer will support the MMO. The MMO CE will also serve as the Technical Authority for Engineering. The MMO S&MA Lead will also serve as the Technical Authority for S&MA, in which capacity that individual is termed the Chief Safety and Mission Assurance Officer (CSO) for Ares I-X. The MM will report to the CxP Program Manager. **2)** The Mission Manager is the lead of the MMO and is primarily responsible for the day-to-day planning, organization, leadership, and control of the flight test development and mission activities. The Mission Manager ensures that Ares I-X is focused on meeting the flight test objectives and overall mission and system requirements.	Bob Ess
6.1.1.1	**Project Integration (PI)**	Bruce Askins
6.1.1.2	**Ground Operations Integration Product Team (GO IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An SE&I representative is assigned to each IPT. IPT's will elevate decisions that affect overall IPT cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Tassos Abadiotakis
6.1.1.3	**Ground Support Integration Product Team (GS IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An SE&I representative is assigned to each IPT. *IPT's will elevate decisions that affect overall IPT* cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Mike Stelzer
6.1.1.4	**First Stage Integration Product Team (FS IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An SE&I representative is assigned to each IPT. The First Stage IPT manager will be assigned by the MSFC Ares Project Office. IPT's will elevate decisions that affect overall IPT cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Chris Calfee

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
6.1.1.5	**Avionics Integration Product Team (AV IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An SE&I representative is assigned to each IPT. The Avionics IPT will be managed by the MSFC. IPT's will elevate decisions that affect overall IPT cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Kevin Flynn
6.1.1.6	**Roll Control System Integration Product Team (RcCS IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An SE&I representative is assigned to each IPT. The RoCS IPT will be managed by MSFC. IPT's will elevate decisions that affect overall IPT cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Ron Unger
6.1.1.7	**Crew Module / Launch Abort System (CM/LAS IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An SE&I representative is assigned to each IPT. The CM/LAS IPT will be managed by the Langley Research Center (LaRC). IPT's will elevate decisions that affect overall IPT cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Jonathan Cruz
6.1.1.8	**Upper Stage Simulator Integration Product Team (USS IPT)** Each IPT Lead reports directly to the Mission Manager. The interfaces between the elements are managed by SE&I and controlled by the Mission Manager. An E&I representative is assigned to each IPT. The USS IPT will be managed by Glenn Research Center. IPT's will elevate decisions that affect overall IPT cost, schedule, and integration issues to the XCB. The IPT managers will report directly to the mission manager and will include representatives from S&MA, SE&I, and GO.	Vince Bilardo
6.1.2	**CxP Safety, Reliability & Quality Assurance (SR&QA**) The MMO level SR&QA Lead is independent from the Ares I-X mission management chain and funding. The SR&QA Lead is supported by the SE&I SR&QA and IPT SR&QA personnel with appropriate technical expertise and resources from the applicable NASA Centers.	Carlos Noriega
7	**Johnson Space Center (JSC)**	Michael Coats
7.1	**JSC Engineering Directorate**	Stephen Altemus
7.2	**JSC Safety & Mission Assurance Directorate**	Yolanda Marshall
8	**Langley Research Center (LaRC)**	Lesa Roe
8.1	**LaRC Engineering Directorate**	Clayton Turner

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
8.1.1	**Ares I-X Engineering Technical Authority (TA)** For Ares I-X, there is both a Vehicle Chief Engineer and a Ground Chief Engineer. The Vehicle Chief Engineer (CE) serves as the overall Mission CE. One CE will focus on the development of the FTV and the second CE will focus on development of ground systems and operations. The CEs will collaborate to ensure that the overall integrated flight test system can meet the flight test objectives. Per NPR 7120.5D, a chief engineer assigned to a project "is the Engineering Technical Authority for the program/project and is the single Point of Contact (POC) for the engineering technical authority process within the program/project." To ensure independence, the chief engineer "is assigned to the program/project, but is organizationally in the Center Engineering Directorate".	Joe Brunty
8.1.2	**System Engineering & Integration Chief**	Marshall Smith
8.1.3	**SE&I Lead Engineer Technical Authority**	Henry Wright
8.1.4	**Crew Module / Launch Abort System Lead Engineer**	Stuart Cooke
8.2	**LaRC Safety & Mission Assurance Directorate**	Grant Watson
8.2.1	**Systems Engineering & Integration Safety & Mission Assurance**	Dave Helfrich
8.2.2	**Crew Module / Launch Abort System Safety & Mission Assurance (CM/LAS S&MA)**	Duane Pettit
9	**Glenn Research Center (GRC)**	Woodrow Whitlow, Jr.
9.1	**GRC Engineering Directorate**	Olga Gonzales-Sanabria
9.1.1	**Upper Stage Simulator (USS) Lead Engineer**	Ada Narvaez-Legeza
9.2	**GRC Safety & Mission Assurance Directorate**	Thomas W. Hartline
9.2.1	**Upper Stage Simulator (USS) Safety & Mission Assurance**	Jeff Rusick
10	**Safety & Mission Success Review (SMSR)** The SMSR is conducted prior to launch to prepare OSMA and OCE for their participation in the ESMD-chaired FTRR. The SR&QA lead and lead Chief Engineer are the internal Ares I-X focal points for planning and coordinating this review. The SE&I and IPT SR&QA Lead and Lead Engineers along with the Ares I-X CSO and CE will present their respective launch readiness assessment to the OSMA/OCE chairs at the SMSR.	

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
11	**Constellation Control Board (CxCB)** The Constellation Control Board (CxCB), chaired by the Cx Program Manager, is the final approval authority for accepting Headquarters-owned requirements and for CxP requirements, new content, designs and programmatic planning. The CxCB provides checks and balances in areas such as inter-project integration and control of budget and schedule allocations for Program requirements/design changes. The Cx project managers are members of the CxCB. This provides the projects with forums for understanding Program strategies and plans and for raising any issues, concerns or dissenting opinions.	
12	**Ares I-X Chief Engineer's Review Board**	
13	**Engineering and S&MA Readiness Review (ESMARR)** In preparation for the CoFTR reviews and the Headquarters' chaired Safety and Mission Success Review, the Ares I-X Chief S&MA Officer (CSO) and Ares I-X Chief Engineers will conduct an Ares I-X Engineering and S&MA Readiness Reviews (ESMARR). The objective of this review is to obtain readiness certification from SE&I/IPT S&MA Leads and SE&I/IPT Lead Engineers and their associated Center S&MA Director and Center Engineering Director prior to CoFTR and the Headquarters' SMSR. An ESMARR may also be conducted prior to the Ares I-X Mate Review. At these readiness checkpoints, each IPT S&MA and SE&I S&MA will certify readiness for the applicable items as specified in AI1-PLN-SRQA, Ares I-X SR&QA Plan, Section 7.1.	
14	**Constellation Safety, Reliability & Quality Assurance Board** The CxP SR&QA Board was established for assuring the development and implementation for SR&QA programmatic and technical requirements within the Constellation Program. The SR&QA Board also reviews technical and programmatic issues associated with risks to safety and mission success and coordinated the Program SR&QA position on those issues. Furthermore, the SR&QA Board will hear alternate/dissenting opinions on issues within its purview and elevate as required.	
15	**Certification of Flight Test Readiness Reviews**	
16	**Ares I-X Control Board (XCB)** **1)** The XCB shall include a supplemental member, selected by the Cx SR&QA Director, to serve as an ad hoc member of the XCB for changes, deviations and waivers to the SR&QA requirements. Any XCB non-concurrences to the requested changes, deviations, or waivers at the XCB shall be elevated to the CxP SR&QA Board including proposed waivers to Level I requirements. The chairperson for the XCB is the Mission Manager. **2)** Technical approval of Ares I-X documentation and decisions will be via the XCB. Membership on the XCB includes the Mission Manager and deputies, the Chief Engineers, the SE&I Chief, the IPT Managers and the S&MA Lead. The charter letter for the XCB is maintained by the Mission Manager and a link to it will be provided in the Ares I-X	

	SMSR Role and Responsibility Matrix	
ID	Description	Point of Contact
	Configuration Management Plan.	
17	**Ares I-X System Reviews**	
18	**Systems Engineering Review Forum (SERF)** The SERF is a forum for reviewing Ares 1-X technical information for correctness. The SERF will ensure technical products have agreement from the Ares I-X Lead Systems Engineer, the Ares I-X Chief Engineers, the IPT Systems Engineers, the IPT Lead Engineers and also the SE&I technical leads. Technical experts will be brought in as needed to present material and answer technical questions. The SERF determines whether an issue should be elevated to the XCB in the form of a CR.	
19	**Launch Constellation Range Safety Panel (LCRSP)** **1)** The MM via the SE&I S&MA Lead and SE&I Range POC will coordinate issues concerning range safety. **2)** The Launch Constellation Range Safety Panel (LCRSP), as directed by Constellation Program Management Directive CxP MD-103, shall serve as the technical forum to facilitate formulation and joint approval of NASA/USAF Range Safety policy agreements, to identify Range Safety requirements, and propose tailoring.	
20	**IPT Control Boards** IPTs shall conduct internal reviews to determine IPT product readiness to ship or certify readiness for use. These reviews are intended to encompass both flight and ground hardware, software, documentation, and open work. A summary of these reviews will be presented at the system level reviews as required. The scope and timing of these reviews will be detailed in the IPT developed plans approved by the XCB.	

#22 Ares I-X S&MA Lessons Learned (Dan Mullane)

LESSONS LEARNED – Compiled by Ares I-X Chief S&MA Officer (CSO)

Below are summary of Ares I-X Lessons Learned from the Ares I-X CSO's perspective. A significant input to this list was gathered via an AIX S&MA community "Knowledge Capture" session conducted on 20-Nov-2009, this session was led by ESMD.

- **Very strong teamwork across Centers…and "levels"…enabled Ares I-X's successful deployment relatively quickly.**
  - Bob Ess broke down the historical barriers that can be created by "Centers" and "Levels"
  - Focus was always placed on the test flight team and its objectives, not "other" org structures
  - Multi-Center S&MA team worked closely together routinely sharing status info, concerns, and recommendations.
  - Integrated S&MA document evaluation process (CR's, deviations, waivers) allowed CSO to represent the broader S&MA community and Mission Manager chaired boards and reviews.

- **Ares I-X benefitted greatly from careful use of heritage systems**
  - Use of existing SSP RSRB, Atlas-based avionics, and Peacekeeper hardware for roll control greatly facilitated Ares I-X's relatively quick deployment
  - Reduced risk by basically re-certifying these heritage systems for their "new" applications
    - "new" loads & environments certs
    - integrated Avionics and s/w testing in Denver SIL and FASTER
    - use of directly-experienced s/w IV&V group (Aerospace group that performs IV&V for Atlas s/w)
    - integrated testing at KSC, including TVC APU hot-fire test
    - heritage waivers and existing PR's re-assessed in light of the AIX application
  - However, the "Aluminum tape issue" was an example of an issue missed early on due to reliance on heritage processes

- **Technical Authority respected and heard**
    - Inputs formally solicited (required) at all AIX and CxP boards (XCB, ERB's, etc)
    - Perspective / status assessments routinely presented at forums such as monthly ICMC's, CxCB's, briefing to NASA Administrator at SSC, and at major milestone reviews such as CDR's, Mate Review, Mission-level FTRR, CxP FTRR, Agency FTRR, etc.
        - Greatly facilitated awareness of different perspectives and fostered balanced solutions to issues
    - CSO embraced as a key part of AIX Leadership Team by multi-Center Ares I-X Management Team
    - 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
            - Adds confusion when a TA-owned STD requirement and/or waiver is being discussed
                - Chairmanship should actually shift – if TA is authority
            - OSMA and OCE NASA-STD's should be written to make it clear that compliance with these STD's is required "unless" a deviation or waiver is approved by the applicable Technical Authority

- **Requirements not properly defined upfront**
    - Ares I-X contracts were let prior to establishing AIX S&MA requirements
    - AIX S&MA requirements were not baselined until after PDR
        - Hindered the influence that the HA process had on the design
        - Increased desire to reach compromises on items such as "workmanship standards" and nonconformance systems…which proved challenging later on
    - Too much time/energy spent debating / justifying these requirements while the design matured
    - S&MA was playing catch-up for much the test flight activity

- **Hazard Analysis process**
    - SE&I S&MA led development of a top-level fault tree to drive the AIX HA process and assure completeness while allowing use of existing heritage hazard assessments
    - Development led by S&MA….but supported by Engineering and the Mission Management Team
    - CSERP was flexible with format provided technical content was there

- **Nonconformance Reporting**
    - Use of multiple nonconformance reporting systems added confusion on Ares I-X, especially as hardware's "custody" was transferred to downstream "processing IPT's"
        - Biggest example was that Avionics IPT shipped hardware (sensors, harnesses, etc) to other IPT's for installation and testing
        - Transfers happened with open PR's that had to be manually tracked or tracked in multiple systems with duplicative PR's
    - Contractors and Centers wanted to use their "own" systems
    - Existing Material Review Boards (MRB's) had to be modified to allow AIX required MRB membership (e.g., Design IPT Engineering and S&MA reps had to be added to downstream "Processing" IPT's MRB's
    - Most challenging example was at KSC where the use of Solumina and iPRACA systems hindered the inclusion of "Design IPT" members
        - Systems required MRB participants to be "behind" the KSC firewall to access
        - KSC routinely pushed to limit Design IPT's to "one super-signature" who was preferably "onsite" at KSC
        - Unnecessarily hindered ability for remote Design IPT's reps to participate…especially given today's IT capabilities. We need to learn to operate in the 21st Century

- **Post-installation testing of harnesses**
  - Ares I-X use of heritage NASA systems (First Stage) and non-NASA heritage systems (Atlas Avionics) revealed a significant disagreement on the value of post-installation testing of electrical harnesses via DWV (hi-pot) testing
    - DWV required by NASA-STD-8739.4
    - Atlas does not perform this testing and considers it low value, costly, and presenting some risk to its avionics
  - In light f this disagreement, I recommend that CxP…and NASA HQ's revisit the current NASA-STD's required post-installation testing requirements to determine whether they are cost-beneficial.

- **Range Safety and other outside organizations can drive design requirements**
  - An example was the "Triboelectrification" launch constraint requirement imposed by the 45th SW/CC's Weather LCC Vehicle
    - implications not understood until very late in life cycle
    - Should have driven selection of outer skins materials or earlier pursuit of an LCC exception (provided sufficient technical rationale could be generated)

- **NASA-STD's (at least OSMA's) require updates to reflect NASA Governance Model**
  - Some OSMA NASA-STD's wording is too vague/soft (written to allow Project managers the right to invoke or waive all or part of the STD)
    - Not clear who has "Authority

- **Risk Management**
  - AIX's use of 5x5 on waivers was very helpful
    - Allowed quick sorting of "more significant" waivers
    - Recommend that CxP have a standard waiver form that includes a required 5x5 risk matrix field
  - Opportunity for improvement – Managers too often didn't understand they were trading within the risk space (technical/safety vs schedule vs cost)
    - Resisted applying "safety" scores to risk that clearly had potential technical/safety consequences as schedule/cost risks were mitigated
  - 5x5 Matrix seemed to drive a "Red" risk fear3x5 and above colored "Red" on 5x5…appeared to influence risk scoring 5x5 Matrix and Hazard (CxP 70038) consistency problems (R/Y/G)
    - 5x5 Matrix's "red boxes" appear inconsistent with HA only "Red" in upper right quadrant

- **Launch Countdown Teams roles & responsibilities**
  - Multiple teams comprised the Launch Countdown Teams
  - Team roles unofficially evolved into right roles despite fallacies of the initial definitions
    - Bulk of technical knowledge resided in the Launch Support Team (LST) located in Hanger AE
  - Appeared that the Primary Firing Team (PFT) did not fully understand it's limitations
    - It needs to be understood that not all potential countdown issues reside in LCC's

- **Technical content of Launch Commit Criteria**
  - Ares I-X LCC's contained the basic LCC requirements….but did not have technical depth when it came to items such a "technical basis" for the LCC and/or preplanned contingencies
  - Fortunately, AIX did not have many LCC violations to work during the actual countdown, but the SIM's proved very challenging without this type of ready information