National Aeronautics and
Space Administration

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ARES PROJECTS OFFICE
KNOWLEDGE MANAGEMENT REPORT

REVISION AND HISTORY PAGE

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Baseline	-		Baseline	09/23/11
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NOTE: Updates to this document, as released by numbered changes (Change XXX), are identified by a black bar on the right margin.

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1.0 INTRODUCTION

National Security Presidential Directive (NSPD) 31, the U.S. Space Exploration Policy (USEP), directed NASA to retire the Space Shuttle in 2010 and to replace it with a new generation of space transportation systems for crew and cargo travel to the Moon, Mars, and beyond. Crew transportation to the International Space Station (ISS) was planned for no later than 2014, and the first crewed lunar mission was planned in the 2020 time frame (see Figure 1-1).

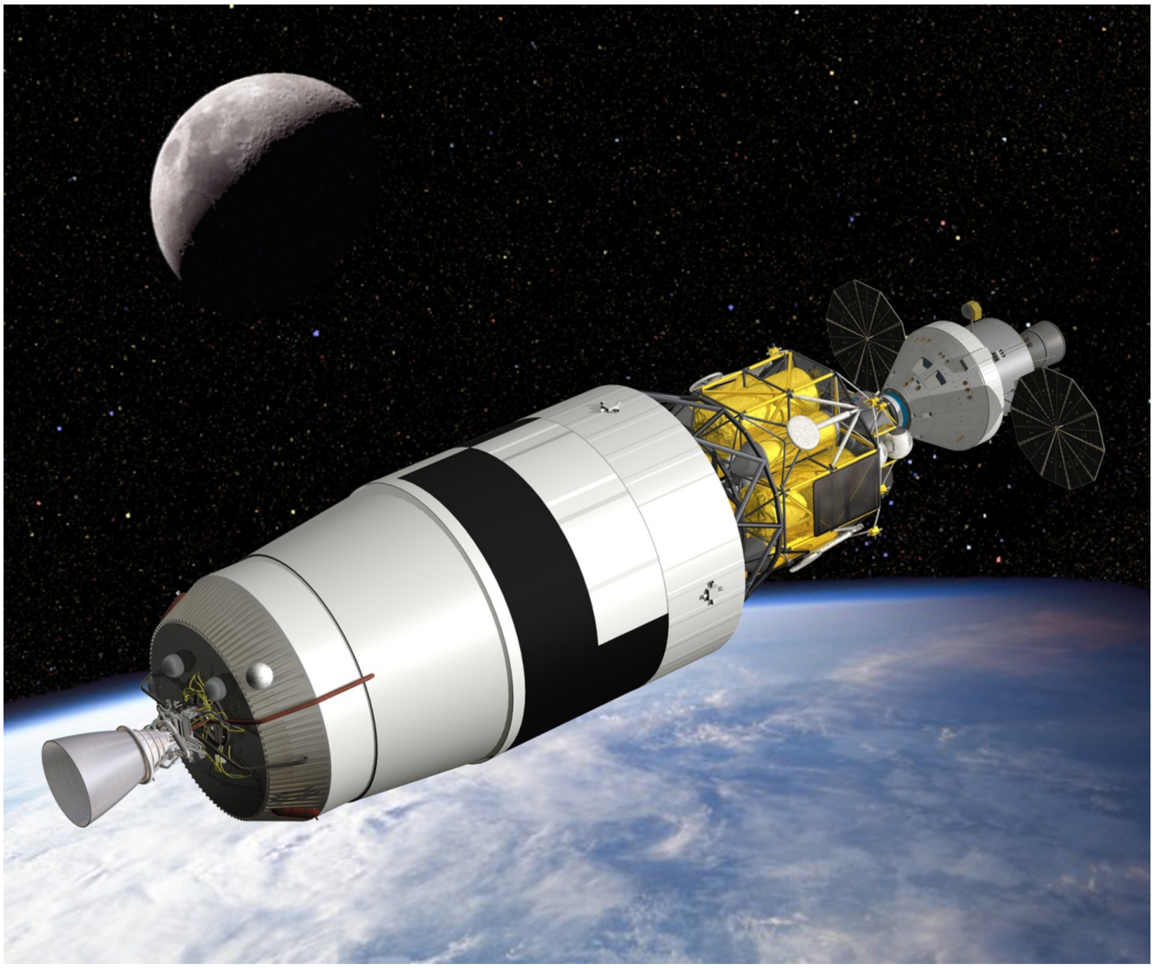


Figure 1-1. Artistic concept of the Orion crew exploration vehicle (CEV) during rendezvous in low Earth orbit with the Earth Departure Stage (EDS) and Altair lunar lander.

The project was driven by a desire to reduce the Nation's human spaceflight gap, as well as to begin work on the Ares V and Altair lunar lander as soon as possible. Further contributing to the project's sense of urgency was the need to rebuild the agency's capacity as the world's recognized leader in the development of launch systems.

Safe, reliable, and cost-effective space transportation is a foundational piece of America's future in space, both strategic and tactical. The Ares Projects Office (APO) endeavored to deliver operational capabilities that supported the agency's responsibility to fulfill the USEP and to help ensure United States (U.S.) preeminence in space through assured access, as outlined in the U.S. Space Transportation Policy (January 2005) and as directed by the NASA Authorization Act of 2005 and the Fiscal Year (FY) 2006 Appropriations Act for NASA.

The APO, located at NASA's Marshall Space Flight Center (MSFC), was chartered to provide the new Ares I crew launch vehicle (CLV) (Figure 1-2) and Ares V cargo launch vehicle (CaLV) (Figure 1-3) space transportation system.

Figure 1-2. Ares I concept.

Figure 1-3. Ares V concept.

The Ares management team developed an aggressive, multiyear plan and implemented a rigorous systems engineering approach in coordination with, and guided by, the Constellation Program (CxP) and the Exploration Systems Mission Directorate (ESMD).

The APO actively employed knowledge management (KM) principles and functions throughout the project's life. Team members were both active learners and knowledge contributors. The formal KM guidelines were defined in the CxP 72027, APO Knowledge Management Plan. As the project faced termination, the knowledge capture (KC) activity became urgent and resulted in the creation of this report and associated knowledge activities.

1.1 PURPOSE

This document is the summation of the knowledge gleaned from extensive capture of lessons learned during the period of time from 2006 until spring of 2011, regarding processes, procedures, and activities that worked well and those that did not meet the expectations or requirements.

1.2 SCOPE

The Ares Projects team members' and the matrixed NASA teams' experiences contained within this report may apply to similarly sized and scoped future projects and programs for NASA. Note that no prime contractor lessons learned are addressed in this report.

It is important to realize that the array of perspectives naturally yield conflicting and sometimes inaccurate perceptions of events and situations on the Ares Projects. Therefore, individual observations do not represent NASA or Marshall Space Flight Center opinions.

1.3 BACKGROUND

Although the knowledge management activities occurred throughout the project's life, as it faced termination a Core team was formed to define the methods to be used to capture the APO lessons learned across the project. The Core team determined the need for several subteams, including teams for Capture, information technology (IT), Distilling, and Sharing.

The Core team provided guidance, direction, resources, and primary communications for this task to the project and center.

The IT team provided IT support through development of the Ares KM Portal, Windchill folders, and the Knowledge Item Description (KID) form database. The Ares KM Portal may be accessed at https://ice.exploration.nasa.gov/ice/site/ares/menuitem.62fc44deca633b858666e7ee4580576c/.

The Capture team supported the knowledge capture workshops using Group System's ThinkTank application in the Integrated Collaborate Environment (ICE) and trained workshop facilitators, including NASA Lean Six Sigma Green Belt trained facilitators. The facilitators subsequently developed the participants' experiences into knowledge objects (KOs). As the capture segment of this activity wound down, the Capture team shifted their focus to helping pre-distill the KOs; essentially grouping the KOs by common subject areas to streamline the Distilling function.

The Distilling team was charged with integrating the KOs into knowledge items (KIs), which are KOs grouped by similarity of content. The Distilling team worked with the center discipline leads and the Ares I Vehicle Integration Deputy Chief Engineer to aggregate the KOs and assign the KIs to the appropriate discipline lead. The discipline lead developed the appropriate actions to perpetuate what worked well and to correct what did not work well.

The Ares KM Manager collaborated with the ESMD KM Manager to develop and produce five Knowledge Based Risk (KBR) videos. These KBRs and the web site links are listed below.

Integrated Vehicle Ground Vibration Test (IVGVT) Test Article Suspension System – KBR 11496

https://ice.exploration.nasa.gov/ice/site/km/menuitem.d24e098f156cbac92673e6104580576c/

Manufacturing and Assembly of the Ares I Upper Stage Common Bulkhead – KBR 11497

https://ice.exploration.nasa.gov/ice/site/km/menuitem.1e029fa651ffb717ef545da34580576c/

J-2X Nozzle Extension – KBR 5919

https://ice.exploration.nasa.gov/ice/site/km/menuitem.961c3e1c5cf4804da36243102a55d40c/

Ares I Vehicle Liftoff Clearance – KBR 11498

https://ice.exploration.nasa.gov/ice/site/km/menuitem.f6f37738d7cad676af545da34580576c/

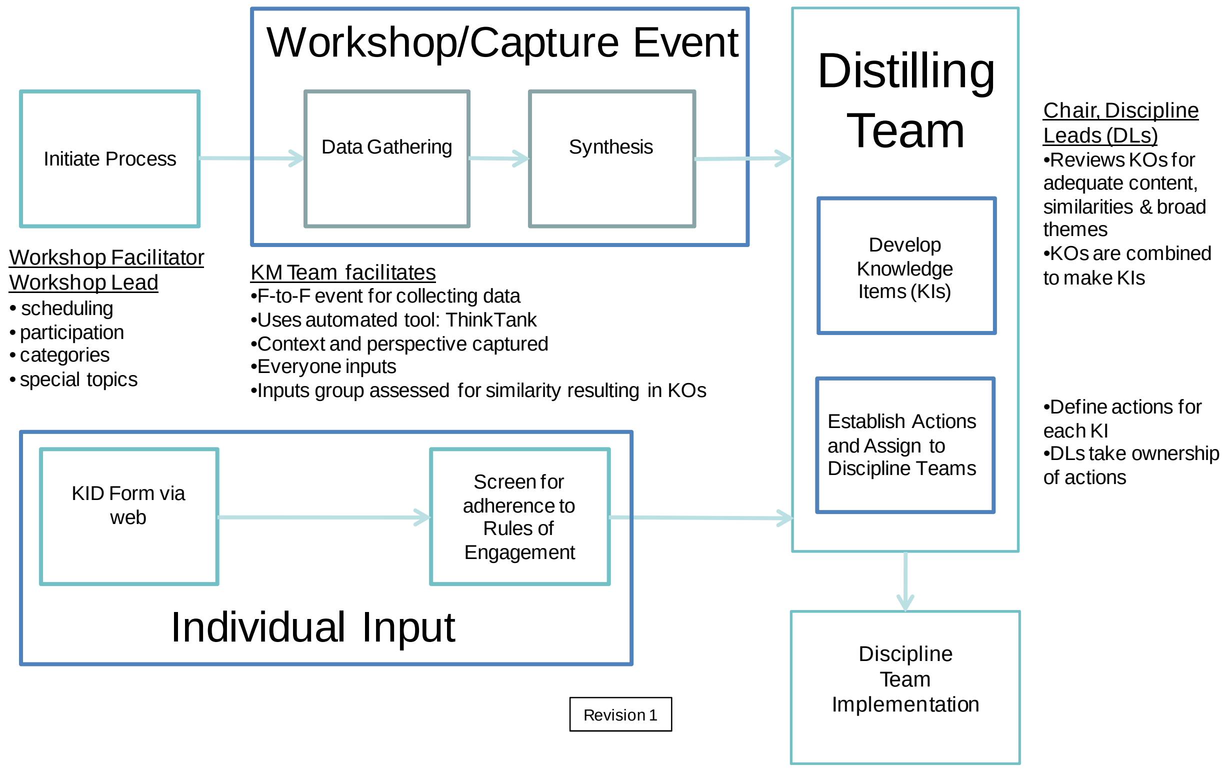
Ares I Performance Risk

https://ice.exploration.nasa.gov/ice/site/km/menuitem.1b68274a1c921a599283e0fad580576c/

Finally, the Knowledge Sharing team was charged with developing this report to distribute the development and refinement of the Ares Knowledge Management process as well as the actionable lessons learned, called knowledge items, across the Ares Projects. Additional support was obtained from specific groups to document the necessary interviews and historical perspectives for the project.

2.0 PROCESS AND EXPECTATIONS

The initial planning led to the development of a detailed, annotated flow chart of this effort, as depicted in Figure 2-1. This chart was presented to the organizational leads during an initial interview to inform them of the overall process to be employed.



DL – Discipline Lead; F-to-F – Face-to-Face; KI – Knowledge Item; KO – Knowledge Object; KID – Knowledge Item Description

Figure 2-1. The Ares process for knowledge capture through distillation.

2.1 OVERALL APPROACH

The Core team recognized that historically lessons learned have not been as effective as intended. Therefore, the goal for this effort was to use the lessons learned to identify discrete observations and delve down to the core point of the observation. Once the root cause of the observation was reached, the Distilling team could then determine the appropriate action to be taken to avoid that situation or to perpetuate the positive outcome for other MSFC projects.

Additionally, the Core team agreed that this effort would focus on capturing the Ares Projects "experiences" in an effort to identify those practices that were beneficial as well as those which needed improvement. For each type of observation some form of action should be associated with it aimed at implementing the lesson in an applicable center policy and process document.

It was agreed at the planning meetings that the participants would need to provide a contact name for individual submissions, but that anonymity could be offered on a case-by-case basis. This contact information was needed so that the Distilling team could seek clarification on the content of the observations, as to the situation, the particular issue, and the recommended correction or implementation.

The planning stages included the development of an internal team wiki page to facilitate communication among the various teams. The page, depicted in Figure 2-2, contained an area to capture the KC data sets, draft presentations, etc.

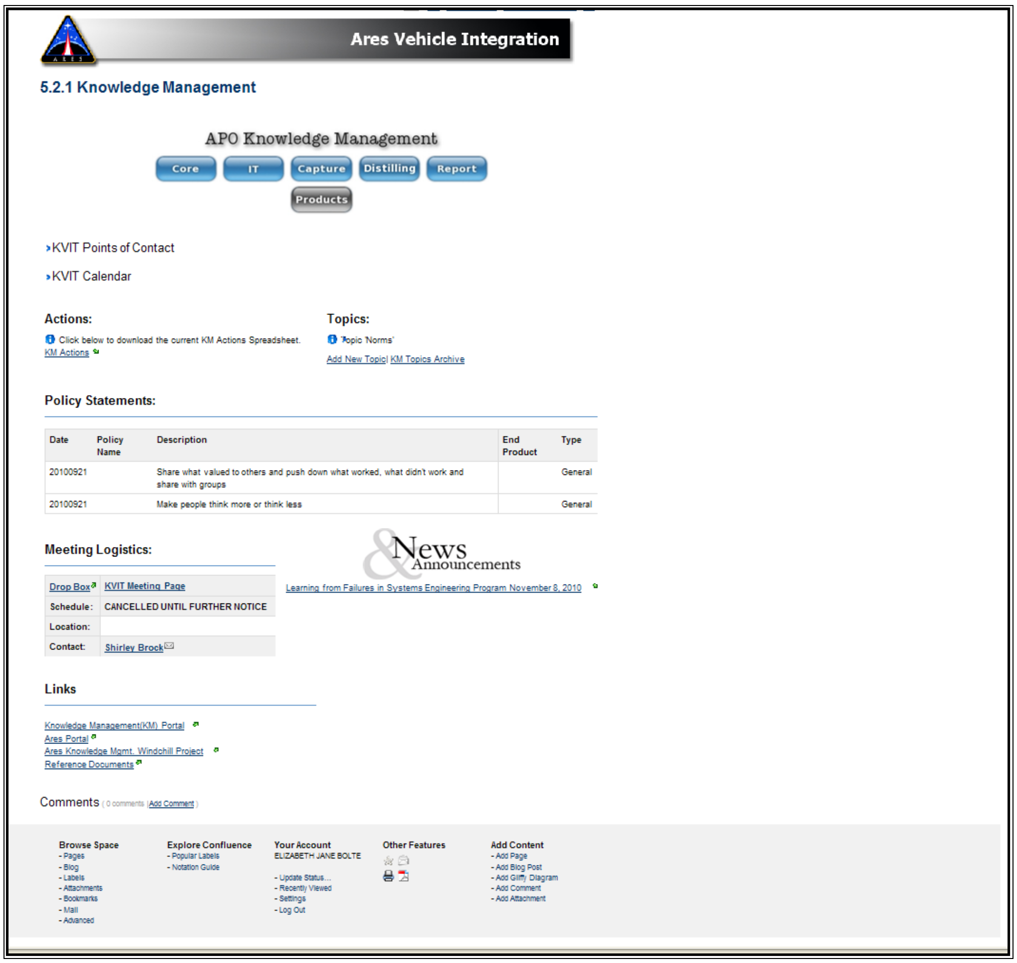


Figure 2-2. The KM Wiki home page.

The APO KM Portal, depicted in Figure 2-3, was used for sharing information related to the effort. The Portal contained the KC Schedule, KO/KI Spreadsheet, KI Report, KM Contacts, KM Overview, Information on using ThinkTank, and the KID Form.

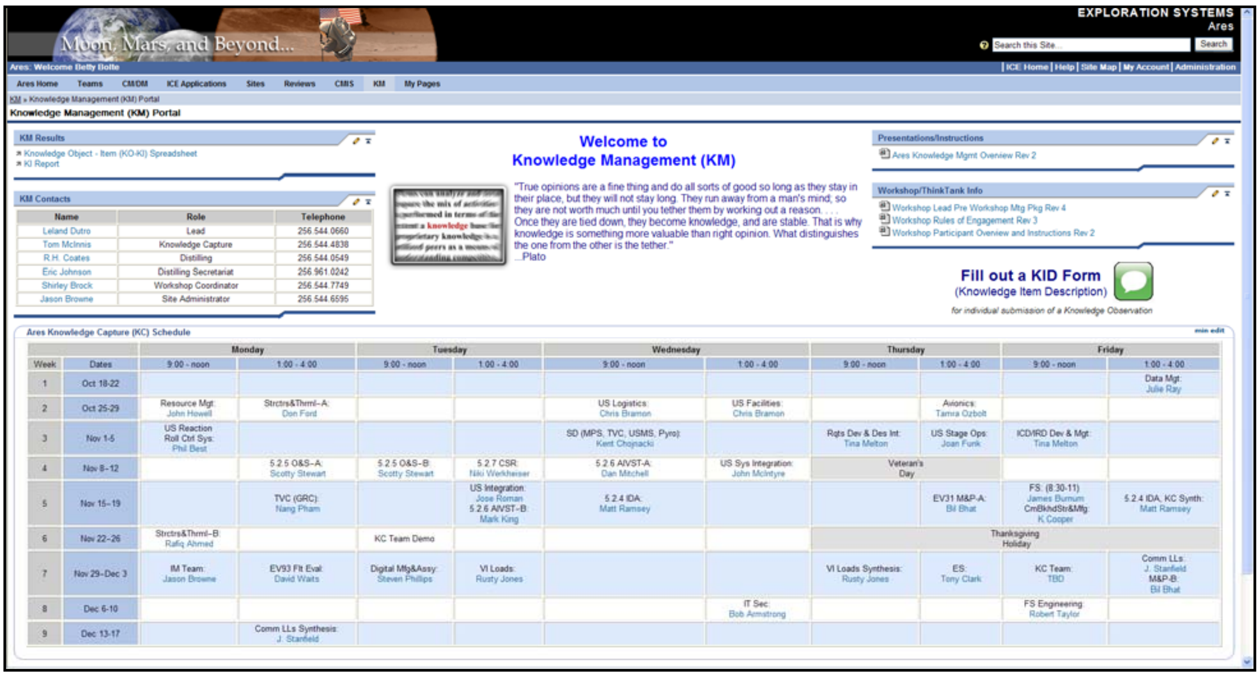


Figure 2-3. Ares Knowledge Management Portal used for sharing information with participants in the lessons learned capture and distilling process.

2.1.1 Knowledge Capture Team Roles and Responsibilities

The Capture team assisted in collecting the draft KOs, focusing on what worked well and what did not. In preparation for the KC activities, the team began to document the recent KC activities and ensured there was a central storage area on Windchill for those documents. The Capture team employed several methods for gathering the observations: guided brainstorming workshops converting previously documented lessons learned into usable KOs; and KID Form submissions.

2.1.1.1 Brainstorming Workshops

The Capture team developed a script for how the workshops should be handled and how the ThinkTank tool would be used. In order to confirm the established capture process would function well and meet the objectives of the activity, the Capture team conducted an internal dry run. This step highlighted the gaps and potential areas of confusion in the process before rolling it out to a wider audience. However, as the capture workshops began, other refinements and adjustments became necessary. One early adjustment was to require that any new facilitators attend at least one workshop as an observer and then assist a veteran facilitator prior to being allowed to lead the workshop facilitation. This mentoring provided on-the-job training for how to use the tools and the computer systems employed, as well as what to do when problems arose.

One of the first steps necessary was to define a standard set of KM categories to enable future integration of the KIs. In addition to the Anchor Categories described in Section 2.4, the discipline lead (DL) for each session was empowered to add additional appropriate categories specific to the team participating in a brainstorming session.

The Capture team used guided brainstorming workshops with 8–12 participants on average (though they determined that 5–7 participants were easier to manage). These workshops were used to elicit and document observations using ThinkTank. This brainstorming tool enabled the capture and synthesis of the individual ideas and comments to form a composite picture of each observation. Participants were able to read and respond to each other’s inputs, which enabled the group to build upon the observations in real time. (As a result of exercising this tool, several enhancements to the ThinkTank application were identified and incorporated.)

Each session was limited to 3 hours to avoid exhaustion of the participants as well as to keep the time commitment for the individuals to a reasonable length. The session consisted of four sections. The first 5 minutes were allotted for an introduction to the session. The second 5 minutes was used to orient the participants on how to use the ThinkTank tool. The remaining time was evenly divided into two 85-minute segments for 1) knowledge capture and 2) synthesis, a consolidation activity for the various observations collected.

The participants were provided with prompts during the initial introduction, shown in Figure 2-4, to get them thinking about each category. During the session, the workshop leader often orally prompted the group with ideas for each category. An example of a list of oral prompts is provided in Appendix B.

Focus on the things within the span-of-control of your group or Project Management.

Ask Yourself.......

- **1. Up front, early on we should have ___________.**
- **2. Our team really did well with _______ because of _______.**
- **3. If I were in charge for a day, the top 3 things I would change are _______.**

Comments should be as specific and as solution based as possible:

Poor - "The requirements were poorly written."

Better - "The widget requirements were unverifiable."

Best - "Many of the widget operability requirements were unverifiable. It should be required to determine verification method concurrently with requirements development to avoid this in the future."

Figure 2-4. The prompts for how to write a KO.

The Capture team found that limiting the number of categories to five allowed plenty of time to capture the observations and kept them relatively short and concise. Note that working through all five categories before doing the synthesis also helped maintain the momentum of the group during the brainstorming part of the session. This way synthesizing could focus on expanding any cryptic or incomplete observations so they could be understood in context. The synthesizing activity aggregated or consolidated the observations in support of another overarching observation. For example, there were occasions when the observation provided a detailed example of a larger problem.

The goal of the KC team was to develop the KOs as much as possible during the session by reviewing and discussing each observation. A few particularly verbose groups needed follow-on synthesis sessions to complete the clarification of content and consolidation of KOs, which added anywhere from 2–4 hours to the session. Additional effort may have been avoided if the groups had been smaller.

After the session, the facilitator would send a ThinkTank tool report of the observations gathered to the group organizational lead in both Word and Excel formats. The lead reviewed the report and had the option to add to or rearrange the content before giving approval for the Capture team to officially convert the observations into numbered KOs. This conversion process included correcting typographical errors and extracting the elements of the observation to complete the predefined fields of the official KO spreadsheet. The fields included submitter’s name and email address, phase of the program, title of the observation, role of the observer, driving event, description, and recommendation, among others. Conflicting observations were kept as separate KOs showing differing perspectives on the same situation. The resulting numbered KOs were then sent to the organizational lead and the KO point of contact (POC) once more for final approval prior to being handed off to the Distilling team.

During the conversion of the data into the spreadsheet format, it became apparent that a cleaner format was needed for reviewing the key fields’ content. Thus, a “mail merge” type of Word document was created that extracted a subset including the KO number, title, driving event, description, and recommendation that enabled easier review by both the organizational lead and the Distilling team.

2.1.1.2 KID Forms and Previously Documented Lessons Learned

The KID Form shown in Figure 2-5 was a Web-based data entry form that requested information to provide the most complete context of the observation as possible. Some fields were auto-populated based on previous answers, to save the submitter from having to research key information for the overall context. Typically, these auto-populated fields included the Level of the project (e.g., L3 for Ares), the Element, the Role of the person providing the input, and the Program Phase. However, most fields, such as Description and Recommendation, were able to accept free text entry for the user’s input.

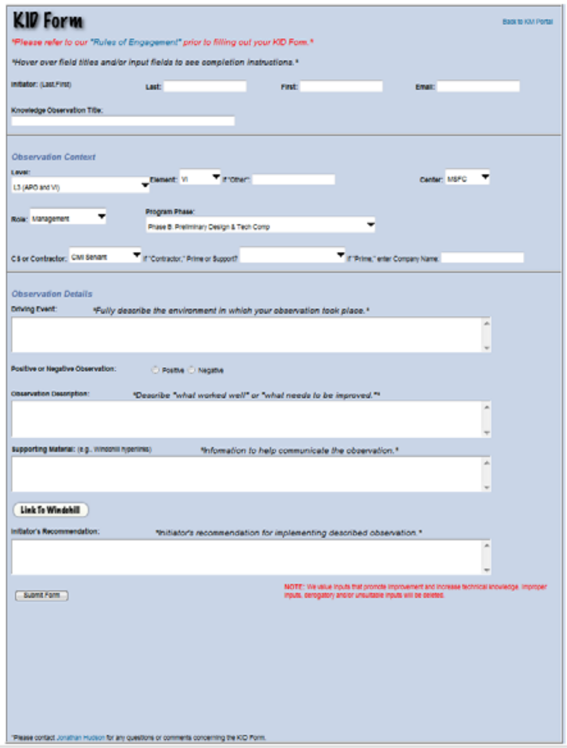
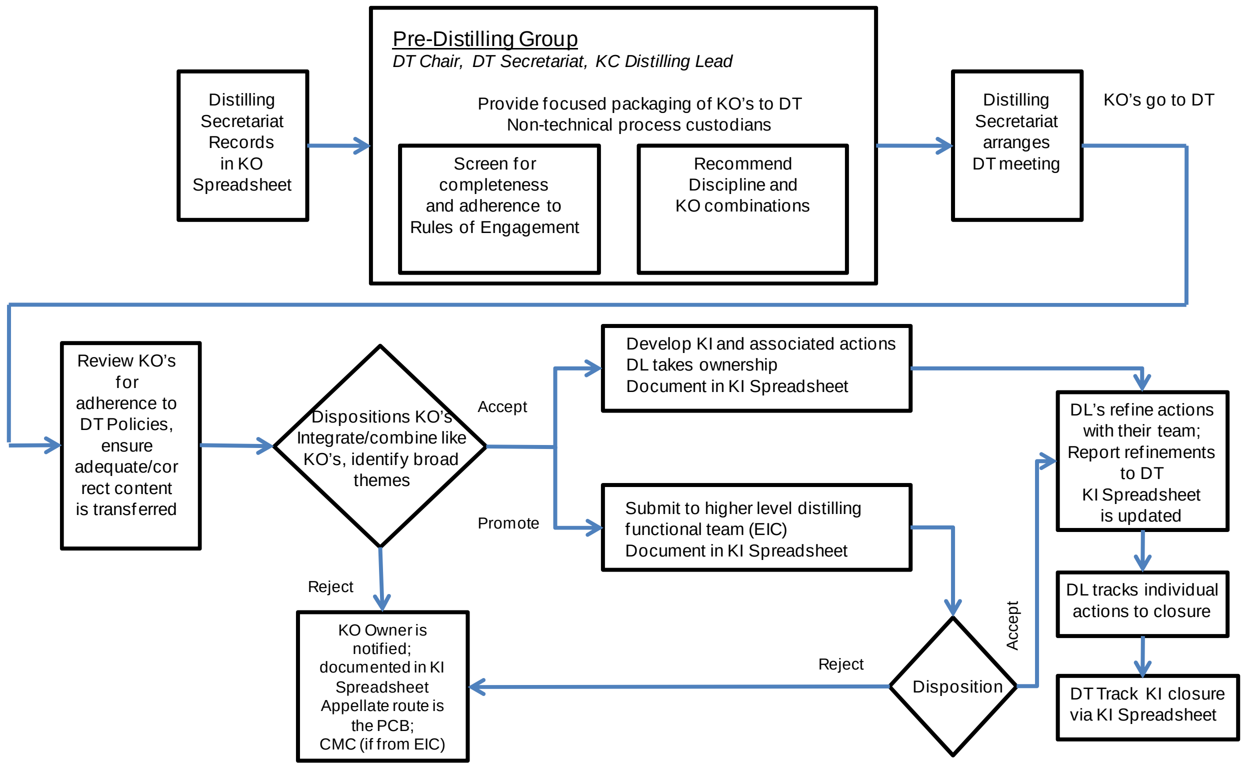

KID Form
Back to KM Portal
Please refer to our "Rules of Engagement" prior to filling out your KID Form.
Hover over field titles and/or input fields to see completion instructions.
Initiator: (Last,First) Last: First: Email:
Knowledge Observation Title:
Observation Context
Level: L3 (APO and VI) Element: VI If "Other": Center: MSFC
Role: Management Program Phase: Phase B: Preliminary Design & Tech Comp
CS or Contractor: Civil Servant If "Contractor," Prime or Support? If "Prime," enter Company Name:
Observation Details
Driving Event: *Fully describe the environment in which your observation took place.*
Positive or Negative Observation: Positive Negative
Observation Description: *Describe "what worked well" or "what needs to be improved."*
Supporting Material: (e.g., Windchill hyperlinks) *Information to help communicate the observation.*
Link To Windchill
Initiator's Recommendation: *Initiator's recommendation for implementing described observation.*
Submit Form
NOTE: We value inputs that promote improvement and increase technical knowledge. Improper inputs, derogatory and/or unsuitable inputs will be deleted.
*Please contact Jonathan Hudson for any questions or comments concerning the KID Form.

Figure 2-5. The KID Form ready for completion.

A separate team was formed to review both the KID submissions and other existing lessons learned documents submitted by various projects, groups, and organizations and to convert appropriate content into KOs. The resulting KOs were added to the database for the Distilling team to integrate and use. Submissions from KIDs, unlike the workshop KOs, were not sent to the submitter for approval as the KIDs were not consolidated into other KOs but left as discrete observations.

2.1.2 Distilling Team Roles and Responsibilities

The Distilling team started with the intent of assessing (pre-distilling) the KOs by screening the content, integrating the KOs into logical groupings to promote knowledge transfer, and obtaining appropriate sponsorship of the resulting KI. The pre-distilling team reviewed, sorted, and packaged the KOs for the Distilling team formal meeting. The pre-distilled package was sent to the Distilling team prior to their formal meeting. However, it was later determined that if the Capture team assisted in the pre-distilling effort by sorting the KOs by discipline and drafting the KI, it increased the Distilling team's ability to disposition the KOs and avoided bottlenecks in the process. The KM Distilling teamwork flow is shown in Figure 2-6.



CMC – Center Management Council; DL – Discipline Lead; DT – Distilling Team; EIC – Engineering Information Center; KC – Knowledge Capture; KO – Knowledge Object; PCB – Project Control Board

Figure 2-6. The Distilling team's workflow for dispositioning KOs.

Once the KOs had been pre-distilled, a discipline, such as Avionics, Program Planning and Control (PP&C), or Configuration Management (CM), was identified. A meeting was then held with the discipline lead to inform them of the distilling process that would occur at a subsequent formal Distilling team meeting. This face-to-face meeting helped to prepare the discipline lead for the expectations of the distilling process, including the identification of actions that the lead would then own.

At the formal Distilling team meeting the members read and assessed the KOs and determined which KOs were actionable and who should receive the action. Sometimes the action needed to be "promoted" to a higher level to address. This formal meeting included engineering management representatives from several division and department levels who could take responsibility for the implementation of the KI actions as well as Ares Projects personnel who had lived through the situation described and could provide more context. Although the original expectation had been that the Distilling team would be able to quickly develop and assign actions, the sometimes lengthy discussions among the team members enabled them to better understand the intent of each KO and therefore more effectively define and disposition each action. Generally, the first couple of KOs they addressed took longer than later ones, sometimes as long as 30 minutes to discuss the meaning and appropriate disposition.

The Distilling team developed a set of policies by which they operated. These policies included:

- Post Knowledge Capture/Knowledge Object (KO) development and prior to Distilling, the Pre-Distilling Group acts as custodians of the process. Their functions are to:
    - Screen KOs.
    - Collect context data – who said it, what did they say.
    - Recommend combinations.
- The objective of the Pre-Distilling Group is to provide more focused packaging of KOs for delivery to Distilling.
- The Pre-Distilling Group has no technical authority over the KOs.
- The Distilling team's objectives are to:
    - Review and identify actionable KOs.
    - Group similar KOs.
    - Refine or "distill" the KOs into one or more Knowledge Items (KIs)—an actionable and traceable knowledge product that addresses the KOs to the best extent possible.
- The Distilling team receives KOs for each capture event via the KO spreadsheet.
- The Distilling team secretariat updates and controls the master KO and KI spreadsheet.
- The Core Distilling team, consisting of the Chair and Systems Managers, reviews KOs for completeness and adherence to Distilling team policies.
- The Distilling team dispositions KOs using the following options:
    - Accept – The KO becomes a KI.
    - Combine – Several KOs are combined to create one KI.
    - Reject – The KO will not become a KI.
    - Promote – The KI resolution requires a higher level distilling team.
- The Knowledge Management team informs KO owners of the status of their KO.
- The Distilling team develops clearly defined KIs, including actions for implementation.
- KIs have a unique identifier; revision numbers will be used when an existing KI is updated.
- KI updates occur when newly distilled KOs correspond to an established KI.
- The Distilling team secretariat enters and maintains KI data in the KI spreadsheet.

- The ability to cross-reference KOs to KIs and vice versa is provided in the spreadsheet.
- Discipline leads participate in Distilling on an as-needed basis to assist in authoring KI actions and to take ownership of KIs for their core functions.
- Discipline leads assess actions with their teams and provide any refinements and action closure dates to the Distilling team.
- Discipline leads have access to the KI spreadsheet via the KM Portal.
- Sensitive But Unclassified (SBU) KO and KI data will be processed according to SBU rules and regulations.
- KO owners in disagreement with Distilling team disposition have an appellate route to the Project Control Board (PCB).

The resulting KIs were then shared through this report, a KM Portal and wiki page, and live knowledge sharing forums. The ultimate intent for sharing this knowledge is to improve the system for future applications by issuing relevant actions to the sponsors to ensure the lessons learned are not lost, through creation of Marshall Work Instructions (MWIs) and updating appropriate Marshall plans and procedures. The entire KC process is shown in Figure 2-7. A template for a KO and KI spreadsheet, as well as other Knowledge Management aids, will be posted with the Ares KM Report.

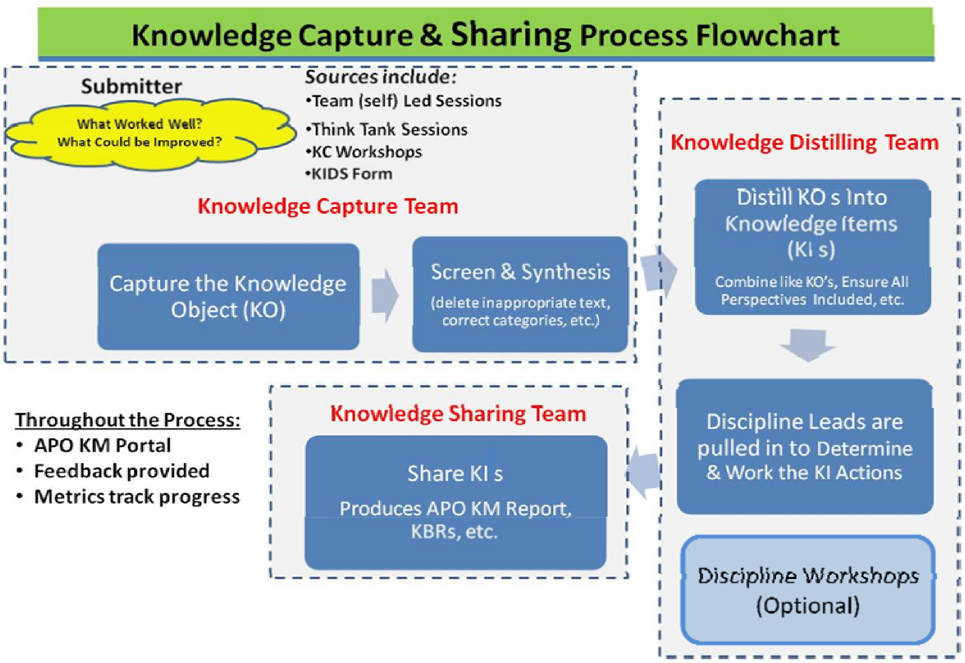


Figure 2-7. Flow of knowledge capture and sharing process.

2.2 NORMS USED

A set of norms was established to ensure all participants in the KC process had the same basis of understanding as to the purpose and usefulness of the activity. These are listed below.

- Everyone gets an opportunity to provide input.
- A safe discussion environment is provided; sharing with other groups requires permission.
- Identification of participants is the default; anonymity can be requested.
- Facilitators guide discussion serving as the "Pace Car" and summarize workshop results.
- Any issues/questions/concerns should be directed to Facilitators as they are trained and prepared to conduct the workshop.
- Participants unable to attend the scheduled workshop are offered the Knowledge Item Description (KID) Form method of knowledge observation capture.

2.3 WORKSHOP RULES OF ENGAGEMENT

The Workshop Rules of Engagement were established to relay the guiding principles to be used during the capture workshops. These rules were provided to scheduled participants prior to each session and also explained at the beginning of the session.

- Integrated Collaborative Environment (ICE) accounts are required for participation in ThinkTank workshops.
- The facilitator has full control over capabilities of the participants.
- Observations concerning subjects classified as Sensitive But Unclassified (SBU) are acceptable; however, the content of the observation shall not contain SBU data.
- Observations should be as specific and solution-based as possible; avoid global statements.
- Observations must be described in relation to the time of the occurrence.
- The initiator's role and organization at the time of the observation are required input.
- Observations will be captured according to general pre-defined categories.
- All inputs/observations will be assessed.
- Observations must be professional; derogatory or unsuitable inputs will be deleted.
- Uncommon acronyms should be defined.
- The facilitator will edit, combine, and/or delete inputs during the workshop, as needed.

- Observations that meet these Rules of Engagement will become Knowledge Objects (KOs); KOs may become Knowledge Items (KIs), which are actionable.
- The Knowledge Management (KM) team will inform the KO owners of the initial status of their KOs.
- The status of KOs may be tracked on the Ares KM Portal.

2.4 CATEGORIES USED

2.4.1 Anchor Categories

For most workshops, the following five categories were used as the "buckets" for prompting and focusing the brainstorming activity. These were deemed appropriate for the existing phase of the project. Different categories might be chosen for knowledge capture occurring at earlier or later phases of a program or project.

- Organization and Culture
- Management Team and Leadership
- Resources and Schedule
- Plans and Processes
- External Interfaces

The facilitators provided appropriate examples for each group to help inspire the individuals as they captured their experiences, both good and bad.

2.4.2 Alternate Categories

Each group's leader had the option prior to the beginning of the session to select other categories more meaningful to the particular group. Some of these include the following:

- Systems Engineering and Integration
- Design and Development
- Fabrication/Manufacturing
- Integrated Test and Verification
- Contract Management

2.5 LENGTH OF EFFORT

The plan was to allow 12 weeks to perform the entire capture and synthesis of the lessons learned. The time was broken down into two main timeframes:

- First 6 Weeks:

  - Conduct workshops using ThinkTank for all APO Work Breakdown Structure (WBS) organizations.
  - Conduct workshops for specific disciplines.
  - Distill KOs into KIs as received.
  - Share KIs and KC metrics at the Monthly Project Reviews to communicate progress. Metrics included showing the progression of the workshops conducted for the individual WBSs and disciplines.
- Second 6 Weeks:
  - Complete Distilling task.
  - Assign KI actions.
  - Share KIs and KC metrics at the Monthly Project Reviews to communicate progress.
  - Begin KM Report (including videos, graphics, etc.)

As the capture workshops evolved, more time was needed to complete both the requested workshops and several follow-on synthesis sessions. The KC Lead had anticipated receiving approximately 500 KOs and the process was defined with that quantity in mind. However, the actual number of KOs received was nearly 2,000, yielding 463 KIs. Additionally, the distilling process was more time consuming than anticipated. The combination of these factors along with technical problems with the ThinkTank application forced the duration of the effort to extend beyond the initial allotted period of 6 weeks to span 11 weeks for the 38 capture workshops to be completed and another 6 months until the resulting KOs were distilled and dispositioned.

2.6 SUGGESTED IMPROVEMENTS TO THE KC AND DISTILLING PROCESS

The knowledge capture process we utilized took longer than anticipated. One of the primary reasons was that we underestimated the level of participation; the Ares team wanted to share their experiences. Another reason was that the grouping of like KOs and the KO to KI distilling processes took much longer than we estimated. The following suggestions could be used to improve the knowledge capture process. We recommend that future projects consider starting the knowledge capture process much earlier and building and working down their list of actionable lessons learned (i.e., KIs) in an open communication environment such as a wiki page.

The KC team's experiences and lessons learned are provided in Section 4.17.

- For the bolder initiative to make recommendations into actions for improvement, the knowledge capture team must work with management to clearly establish and communicate expectations of the knowledge capture and recommendation implementation process with all participants and potential stakeholders. Many good ideas may be gathered but not all may necessarily be immediately acted upon. The knowledge capture process is a path for knowledge (observations, opinions, facts) to be gathered. However, it is not a formal review and thus not all ideas will be addressed. That is, the information will be gathered and considered to the best of the discernment of those collecting the data and within the finite resources set aside for the process.

- The management team must also establish a specific person (or office) that will own the recommendations and any follow-up activity regarding implementation of improvements. This also necessitates that management make sure adequate resources exist for implementation, or improvements are tracked over an extended period as resources come available (hence the need for prioritization). We suggest that a clear and concise set of final KIs (with any supporting KOs) and corresponding recommendations be forwarded to the Office of Chief Engineer for appropriate consideration and implementation by the center management, engineering disciplines, and programs/projects that will eventually benefit from the recommendation improvements.
- Conduct a discovery (document review) prior to holding the workshop to help the facilitators become familiar with the topic area.
- Conduct interviews of managers for specific areas separately/before the workshop to record their point of view in a manner conducive to allowing their staff a more open/honest brainstorming session. This would also provide an opportunity to tailor the categories (listed in Section 2.4) to the specific areas.
- In the brainstorming workshop, the group may record many observations. As a final exercise, the facilitator should work with the group to consolidate the many observations into a reduced number of cohesive KOs and then rank those observations by significance of the issue or by potential benefit to current and future efforts. It could be helpful to have the group describe how they ranked the final observations.
- After the brainstorming workshop, have a Capture team member facilitate at the primary handoff of KOs to the Distilling team to provide session context.
- Route the participation list through the IT personnel to verify that the individuals have access to all needed sources of electronic data and tools (e.g., ICE Windchill, ThinkTank collaboration tool).

3.0 KNOWLEDGE CAPTURE RESULTS

3.1 OVERVIEW OF LESSONS LEARNED RECEIVED AND PROCESSED

Most of the larger number of raw observations or KOs received were assessed and grouped together to form KIs with associated suggested actions for the appropriate discipline lead to assess and refine as needed. Those KIs are included in Section 4. From the KIs some larger key themes were refined and are discussed in this section so that the concepts may inform others.

Remember that individual perceptions do not represent NASA or Marshall Space Flight Center views or opinions.

3.2 KEY THEMES

The following sections provide the high-level key themes that emerged from the knowledge capture efforts. Supporting example KIs are included here, but more KIs related to these themes can be found throughout Section 4 of this report and in the complete searchable database.

3.2.1 Leadership and Discipline

Summary: Clear, concise, and well-communicated definitions of responsibility and authority with individuals in charge, not committees. Arguably, this may be our single biggest lever to making significant improvement on future efforts. We need “benevolent dictators” to be efficient. We need to identify our decision makers and clearly define the decision path and the few needed participants. Then we need to get the decisional information to them, let them decide, document and disseminate the decisions in a timely manner, and maintain the discipline to support those decisions.

Background: Throughout the Ares Projects the chain of command was not always clear, as well as who had the authority to make decisions (i.e., which design change board, panel, or working group to approach with a potential issue or change). The atmosphere was of rapid change and some decisions changed just as quickly, sometimes based on what was perceived to be individual preference vs. sound analysis. This lack of clarity and inconsistent emphasis in who was responsible and who had what authority led to uncertainty, architecture design disconnects, and ultimately lowered morale.

Some example observations include:

- The process to get approval through boards and working groups was very confusing in the Ares Projects. It was unclear what paperwork was required to be signed, and which boards applied to each product or technical decision. Confusion abounded as to which board or working group had the final authority over a particular decision. Recommend that all control boards be established early in the next project. Clearly define and document each board’s authority, boundaries, and associated process requirements. Also, it is recommended that a minimal set of boards be used to cut down on confusion over line of authority.

- Constellation data management (DM) seemed to have been in flux all the time. It lacked leadership. This lack of leadership led to many different use cases of the same tools, causing confusion as to the level of data available and the data's integrity across the program. Project DM seems to have led program DM.
- Decisions regarding testing need to be documented. As time passes, questions will arise and without a good way of understanding the rationale for a decision, confusion may result as to why decisions were made. One example is the decision of why the belly band was 96 inches down from the top of the 5th segment of the first stage. The decision was made via coordination meetings and e-mails with Alliant Techsystems, Inc. (ATK). The conflict between the agency and center standards resulted in baselining documents without these conflicts being resolved. As the program changed and leadership changed, verbal agreements about these conflicts were forgotten and resulted in discrepancies later on. Additionally, some early agreements were later retracted.

3.2.2 Plan Ahead

Summary: Avoid "ready, fire, aim" and walk through how the program should proceed. Take time to argue and plan upfront, in as much detail as possible, on the most crucial areas, to avoid late-breaking requirement changes ("creep"). This should formulate the backbone of the program plan and it should be in clear, concise, and direct language.

Background: The Constellation Program Office was stood up after the project offices, leading to redirection and rework as well as having to adjust/adapt to new software tools imposed by the program on the projects. All of this caused a multitude of problems as the program progressed. Most of the problems were worked out, but it took time and resources to make the often conflicting, and sometimes expensive, changes. Frequently no formal plan or process documents existed to guide the related technical or programmatic efforts, leading to duplication or omission of a required task. This lack of planning and forethought was prevalent across the Ares Projects as well in the startup phase, leading to other gaps in processes, tools, and direction.

Some example observations include:

- Constellation started planning at the component level prior to the program structure being established. Too much bottom-up work flow occurred rather than starting with a system design and then building the parts to fill the needs of the design. This inversion of the process was partially a result of the phasing of staff who were turned on to do low-level design prior to upper-level integration completion. The top-down, system-level design model was never implemented to include critical data, inner and outer mold lines, and critical interface dimensions. The Integrated Master Plan (IMP) was established after the Integrated Master Schedule (IMS). Conversely, for the Integrated Vehicle Ground Vibration Test (IVGVT), bottom-up planning helped to provide the team with a more comprehensive, supportive, and logically sequenced set of events to support milestones and resources.

- Flight vehicle programs need a single timeline maintained at the top level of the program with sufficient detail to drive the processing requirements into the design. Timelines need to be integrated and configuration managed. The Level II timeline didn't contain the level of detail required by Ares to perform their analysis and it was very late before the Level II timeline captured the necessary level of detail. The program needs to have a clear understanding of the users' needs regarding contents and timing for the timeline. Use an integrated configuration managed timeline to drive the design. Timelines need to be coordinated between levels with sufficient detail to be useful at each level.
- The Constellation Program instituted the development of the Mission Assurance System, which is a web-based application intended to house the Safety Hazard Analysis, Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL), and Problem Reporting and Corrective Actions (PRACA) systems and provide the capability to readily link these products to maximize their interaction. Development of the FMEA/CIL application (CxFMEA) began after the projects were already underway in development of their FMEAs. The Constellation Program (CxP) FMEA/CIL methodology (CxP 70043) specified the data fields that were to be contained in the project FMEAs, but not the data structure. As a result, each project and element had a unique FMEA data implementation that had to be accommodated by CxFMEA, resulting in some compromises that limited its usefulness. It is recommended that for any future project, a FMEA data electronic format and structure be established upfront and the program be willing to absorb the cost of requiring all projects and elements to utilize it.

3.2.3 Communication

Summary: More informal communication and better documented and accessible authoritative (decisional) communication must be maintained. Informal and formal decisional communication must both be readily accessible and they must be clearly differentiated. Informal communication and data can be more passive, in that all interested parties can easily find and access the information at their leisure. Formal (decisional) communication must be actively transmitted in a simple, secure, and efficient manner (without delay) to all appropriate personnel in the chain of command.

Background: Due to the rapid-fire changes and decisions, frequently the decisions were not immediately available to disseminate or there was hesitancy about sharing the decisions even informally because they may change. When a formal decision was made, the accompanying memo or directive often took an excessive amount of time to be released, ranging from weeks to months to never. While many people attended board and panel meetings, the information gleaned from the discussion and decisions often was not disseminated back to the attendees' organizations.

Some example observations include:

- Electronic Internal Communication (posted on Integrated Collaborative Environment (ICE)) is not the most effective way to communicate with people. Overall, when possible, structured face-to-face communication is the most effective. Recommend using face-to-face communications such as road shows to communicate internal messages over relying on ICE and wiki pages. This worked very well for Ares, especially when project direction came into question with talk of program cancellation.

- Control Boards, both project and engineering, did not include representatives from all impacted discipline areas. This led to a lack of awareness of technical and project decisions. The discipline areas should have board membership or representation.
- Subsystem managers did not have good communications with the project Resource Managers in the areas of budget, New Obligation Authority (NOA) funds, and Other Direct Costs (ODC) funds availability. Communications concerning resources need to be documented so that both project and engineering team members understand the communication pathways.

3.2.4 Establish Strong CM and DM Functions

Summary: Configuration management (CM) and data management (DM) need a strong centralized function in order for the center to efficiently work within itself and with other centers and contractors.

Background: No formal CM or DM process appeared to be in place at the beginning of the Ares Projects, whether one existed or not. As the CM team attempted to bring order to the confusion, the necessary changes caused more confusion until people began to understand the new processes and procedures. This included disagreements in documentation formats, document numbering, document content, sensitivity markings (Sensitive But Unclassified (SBU), International Traffic in Arms Regulations (ITAR), etc.), and document submittal and control processes. If a center-wide system had been applied at the start up of the project, it was felt, confusion would not have occurred.

Some example observations include:

- The CM change process took too long on the Ares Projects. The change process was excessively long for both the NASA design team (NDT) and prime contractors for a variety of reasons such as excessive review cycle time, too much board deliberation, and too many board meetings. Future programs should develop a streamlined, more efficient change process to increase the efficiency of the CM change process. Possible changes could include pre-coordination (informal tabletops) followed by a shortened CM review cycle. Also, declare resolved issues final and avoid revisiting them unless there is a significant impacting change.
- All personnel must adhere to standard data management processes; failure to do so results in products of poor quality and incomplete documentation of final agreements. Issues with adherence to data management processes should not be worked in boards/meetings as this typically results in a universal belief that data management processes are inconsequential, thus creating a bigger problem for a typically manpower-limited DM

team. Accepting incomplete products in “public” forums reduces motivation to provide quality products and encourages others to repeat that behavior. Ensure team members know and understand DM processes and requirements. In particular, delineate the process for the submittal of the different categories of data. The use of the ICE Windchill tool was cumbersome and stagnating, causing workarounds. Tool maturity and capabilities should be considered prior to selecting a tool for whole project use. MSFC should investigate process changes to better coordinate in data management business processes and their information technology implementations. Data management processes should be standardized and implemented institutionally. All aspects of DM should be considered required unless deviations are officially approved and documented. Process owners should participate in process definition and the development and implementation of process deviations.

3.2.5 Design and Analysis Integration

Summary: Clearly define who is in charge and how design and integration work together and what is needed at the program, project, and element levels to support critical design and analysis milestones.

Background: The analysts and designers were tasked to perform certain tests and create the design drawings and documentation based on ground rules and assumptions that tended to change as quickly as the configuration. With multiple configurations, both baselined and not, to work to, keeping track of which analysis was performed with which configuration became challenging. Additionally, Ares Vehicle Integration (VI) assumed the role of integrating the Elements analyses, yet VI was not seen to have the authority to integrate the analyses based on where they were positioned in the organizational chart, as a peer to the First Stage, Upper Stage, and Upper Stage Engine Elements. This unclear organizational structure and accompanying authority caused rifts between VI and the Elements that were never corrected.

Some example observations include:

- The design analysis cycle (DAC) planning helped greatly to understand where we needed to head to meet future milestones, but often lacked acceptance by elements or other projects. The time and effort to understand the fidelity differences, dependencies, and make up of analysis activities across the vehicle have been very important, costly, and at times painful, but we have been learning what the new vehicle should harvest. Recommend that Spacecraft & Vehicle Systems Department management maintain the DAC planning capabilities across all disciplines. It should be required that element-level DAC planning should be concurrently developed and baselined so that both levels of DAC plans are properly integrated upon submittal for baseline.

- Ares I Upper Stage utilized integrated product teams (IPTs) led by the Upper Stage Element project leads and supported by NASA Engineering Directorate (ED) personnel. Comments from both parties suggest that there was lack of trust between them. IPT leads expressed that they felt that they had limited or no authority over their IPT and that the coordination with ED Branch Chiefs was cordial but not always productive. Engineering Directorate team members expressed similar concerns and included examples where ED IPT members did not receive enough information from the project leads and this hampered Test IPT work.

- *From KBR 11498*: Another lesson learned for me as a result of going through this process is that if you design the ground system before you design the vehicle that it supports, that's a recipe for trouble and that's essentially what led to this risk for the vehicle being created. A little background is that the ground system were tasked with designing the launch tower ahead of the vehicle design and so it was much more mature, they were much further down the road, they knew a lot more about their design and were very close to actually building the hardware before the vehicle design and its behaviors were very well understood. They based that design on some extrapolated shuttle behavior. That proved to be unconservative once we were actually doing a real analysis of the Ares I vehicle and that's what created the situation that led to the risk which was where, once we calculated the real drift with the Ares I vehicle, it was very close to the tower and in some cases, running into it. So, for me, the lesson is that when you're designing two complimentary systems like that you need to evolve them at a reasonably consistent level of maturity so that you don't know a lot about one and a little about another and the lack of knowledge on the one becomes a threat to the other and that's exactly what happened in this case.

3.2.6 Experience

Summary: Personnel experience for many functional areas was brought in from systems that had been in an operational phase for some time, rather than from early product development. There are not a lot of people that have come through the development of large rocket systems. High value should be placed on utilizing people that have come through the "learning curve" on Constellation and Ares, and the cost (schedule and budget) of coming up the learning curve should be factored into a new program.

Background: The design and analysis process for developing a launch vehicle is vastly different from operating and maintaining an existing vehicle. The wealth of experience gained from the design and analysis efforts to develop the Ares I-X and the Ares I should not be underestimated. A large variety of tools, processes, procedures, and approaches were tested, improved, or discarded as appropriate.

Some example observations include:

- Without much recent experience in developing a vehicle, many necessary processes were unknown and/or undefined and had to be developed on the fly and refined by trial and error. This should be smoother next time. I believe that we sometimes are too risk averse and depend too much on analysis methodology that is either outdated and/or ultra conservative. Review existing analysis methodology to determine if historical methods of analysis are too conservative. Newer industry standard analysis techniques should be employed wherever possible to reduce cost and mass while preserving desired crew safety. Allowing for an adequate developmental testing program would go a long way in providing NASA with the confidence to use these new, higher fidelity methods.

- *From KBR 11496*: As far as the things we would do differently. This job, we did this task, I don't feel like we really missed much, where we would just stop and say, I would have done this differently. I guess, just the combination of having someone like me available that's been through this several times, and spent a lot of time on large test stands, knowing what's coming later on. If you do make it back to the large test stand to run a big test, it's been a big help to me, just the experiences we did have. The fact that we were able to get such good people to come on board with us. Which basically that was three engineers, and we've got some real good technicians that help us in the building too. …. I would encourage people to close their program out in a correct manner. I do know that the state of the hydrodynamic stands (HDSs), the condition they were in when I received them, was a direct result of probably not having the funding available to properly close the stand out, and that program out, after they did the Shuttle Ground Vibration Test. I think the HDSs would have been in much better condition, although they are reusable, and we've proven that they are reusable. … When I first came to work out here, on the building where we walked in, we had a sign over the top door that said, "One good test is worth a thousand expert opinions." I've learned that's very true. Test that hardware the way you are going to fly it, and test that ground support hardware the way you are going to use it.

  Do the homework up first. There was a significant amount of information within the documentation generated by the Saturn ground vibration team, and the Shuttle Ground Vibration Test (GVT) team. So in diving into the literature first, and learning all of the ins and outs of this system, and the stumbling blocks which these past teams encountered, and their steps for correcting those situations, we saved a significant amount of time by not having to reinvent those wheels. So it was excellent. The teams in the past did an excellent job documenting what was done, and the difficulties that they had, and they provided us a path, almost a clean path, to go from concept to a system for which we could get up and running and start testing with.

3.2.7 End Product

Summary: It is important to emphasize the completed end product when working through the myriad of functional processes (means) to get there. We need to know what processes are absolutely necessary, which are highest value to the end product, and we need to know when to start and stop processes to gain the best effect on the end product.

Background: Because so much of the project personnel were unfamiliar with development projects/programs, too much time was needed to "re-learn" and ascertain the proper tools and processes needed to design and develop the Ares vehicle components. Often the definition of processes became the work rather than focusing on planning for the actual creation and building of the hardware.

Some example observations include:

- Software requirements that were frequently omitted included test article support. For example, no requirement existed for the flight software to operate in a test mode but various groups expected that the software would support a main propulsion test article. Software requirements need to consider test article support. Disciplines designing test articles need to define any needed software support.
- Manufacturing and Production (M&P) discipline experts were not included in early discussions regarding material and manufacturing-related issues. Since fabrication is near the end of the process, schedule slips often accumulate forcing manufacturing to be accelerated in order to make up the schedule. Ensure M&P is provided time to review and pre-coordinate, despite the fact that they may be able to get quick recommendations by non-M&P support. Even though former M&P personnel are part of the project or other engineering disciplines, the current M&P lab needs to be included in technical decisions. M&P needs to be involved before hardware is to be manufactured in order to prevent problems with hardware late in the design cycle or after manufacturing begins.

3.2.8 Budget and Schedule

Summary: A program needs a set budget over a longer period than year-to-year in order to succeed, with the inherent authority to reallocate funds within that budget to meet the needs and milestones of the program.

Background: The Constellation Program and Ares Projects were inadequately funded to achieve the assigned missions. The budget challenge appeared to increase each year of the project's existence. Numerous budgeting exercises, what-if scenarios, and re-plans of schedule and funding negatively impacted the overall schedule, funding, and morale.

Some example observations include:

- A great deal of time was spent developing schedules and cost estimates for the annual budget cycle. Following approval, these budgets were repeatedly slashed by Headquarters or Congress. Delays in making funding available as planned in the schedule negatively impacted the ability of the project to meet their schedule. The approved budgets never matched the available funding. … At the worker level, enthusiasm and sacrifices to support highly difficult schedule or technical challenges were phenomenal. The repeated cancellation of programs will make achieving this level of enthusiasm and sacrifice unlikely.
- Funding was not properly allocated for several items. Storage facilities for data collected during the design analysis cycles, early testing on hardware and software, and data generated during test and verification phases of the program were unfunded, resulting in

months of effort to attempt to remedy this oversight. … Facility modifications to support tests were continually slipped downstream which would have resulted in a schedule slip if the program had continued. Establish construction of facilities technical and funding requirements early because there is a 2-year lead time for construction of facilities. Ensure that infrastructure needs are funded. Subsystems need to avoid accepting unbudgeted work.

- Design and engineering were understaffed at the beginning of the project. The work load demands increased faster than we could staff for the new work. Staffing levels were not aligned to the schedule phase. … Defining and obtaining resources was difficult when designs were fluid in the project, resulting in unrealistic budgets and schedules. … The learning curve realized when assigning people to the project wasn't considered. The cost/schedule/resource plans did not align and insufficient action was taken to address the alignment early on. Plan for variable levels of support from the design and support team through the project life cycle.

3.2.9 Training

Summary: Important information related to job-specific and programmatic/security issues should be provided to program/project personnel through appropriate training (online, in person), not merely sent via email or posted on a website. Functional organizations must assess what their existing best practices are, compare (or benchmark) against the best in the world, make appropriate plans for improvement and training to implement and maintain the right skill sets for civil servants and contractors alike.

Background: Lack of sufficient knowledge about a given process or procedure led to errors, security breaches, waste of time as new systems were figured out, and at times even faulty architecture design analysis. Many instances occurred when this deficit could have been avoided with proper discussion/training on the topics needed by the personnel involved.

Some example observations include:

- Better IT tools, training on those tools, and security awareness training should be provided to employees and management to foster a better understanding of how and which tools should be used. Security Awareness Training is a relatively low-cost investment for helping to keep awareness of security issues a high priority. The agency must provide better IT tools and training to assist managers and employees. Security Awareness Training modules tailored to the program/project should be developed early and throughout the program rather than solely rely on agency-wide training provided in NASA's SATERN system. There needs to be a way to filter issues back to the agency, as findings from this will more than likely impact the agency. Critical security processes defined for the Constellation Program should be adopted into the systems engineering training modules for new program/project managers, engineers, and support personnel. Processes include identification of mission critical information, selection of security safeguards, threat and vulnerability assessment, etc.

- Engineering managers were not adequately engaged in schedule development. Engineers seemed to lack understanding of the limitation of funds. Managers didn't have a good understanding of the difference between funds management and earned value management (EVM) budgets. Develop a plan and determine who needs EVM training. Hold leads accountable for cost and schedule performance.
- Training did not keep up with new tool development and implementation. Too much time was wasted explaining to individuals instead of groups. New tool development and implementation should include sufficient mandatory group training.

3.2.10 Cautions When Using Heritage Hardware and Ground Support Equipment (GSE)

Summary: Caution needs to be applied when using heritage hardware, as the new application/use may not have been considered when the hardware was developed.

Background: Heritage hardware and GSE was assumed to save money for the project, yet additional analysis, testing, and modifications were required to ensure the hardware would function as expected in the new integrated systems. Over time both regulatory and industry improvements lead to obsolescence issues that the original systems dealt with by asking for waivers or maintaining older processes that are less efficient. All these factors need to be considered when use of heritage hardware is an option.

Some example observations include:

- The usage of heritage hardware in project-level tests to validate models may result in safety concerns. For example, the ammonium perchlorate (AP) leaching of first stage segments. Share previous test data or previous analyses upfront to mitigate safety risks. If safety-related information does not exist, it is important to conduct the proper tests/analysis early to allow the safety organization time to review and determine whether the hardware is safety compliant.
- Heritage GSE is not free. There is a great deal of work and cost to use heritage GSE that was not estimated. Plans and processes for recertification of heritage GSE were not planned or considered. If the decision is made to use heritage GSE, establish clear recertification plans and processes early in the program and estimate associated resources.

4.0 KNOWLEDGE ITEMS AND ACTIONS

The knowledge items were sorted into 30 discrete disciplines to facilitate understanding the issue and the potential corrective actions necessary. These disciplines and their KIs are presented here in alphabetical order, not by area of emphasis.

The observation initiator's perspective plays a role in how the observation is viewed; therefore, it is possible to find conflicting observations. We felt it was important to provide the varying opinions to create a better context for the knowledge item. However, it is important to note that the individual observations do not represent NASA or Marshall Space Flight Center views or opinions.

For each KI, a description and recommendation are provided. When an action has been suggested or initiated by the specific discipline lead, that action has been included as well. Note that Ares Projects did not initiate any actions but left the decision up to the discipline lead as to how to address the KI. Additionally, no follow up has been attempted to ascertain whether implementation occurred, nor the effectiveness of the action.

An Access database is available. The database allows the user to search for a KI by discipline or on specific search terms. The database and the template for the KO and KI spreadsheet, as well as other Ares KM aids, will be posted with the Ares KM Report.

4.1 ANALYSIS

4.1.1 Number of Design Analysis Cycles (DACs)

Description:

The number of conceptual design/cycles has to be well thought out when associated with tight programmatic schedules and budgets. Once the design settles out, the DACs become less and less valuable.

Recommendation:

Consider the depth and scope of design analysis cycles and limit the number of design analysis cycles on future programs based on schedule and budget constraints. Also consider setting criteria that would indicate when sufficient fidelity has been met in the DAC.

4.1.2 Critical Math Models Needed Early

Description:

Critical math models, verification and validation analysis, and other data needed to anchor the models continued to be an issue throughout the life of the project. This may have been improved by developing an agreed-to approach earlier in the project/program life cycle.

Recommendation:

Required analyses should be defined early by the stakeholders, efficiently documented, and appropriately linked to the end item product or function.

4.1.3 DAC Planning

Description:

The DAC planning helped greatly to understand where we needed to head to meet future milestones, but often lacked acceptance by Elements or other projects. The time and effort spent to understand the fidelity differences, dependencies, and make up of analysis activities across the vehicle have been very important, costly, and at times painful, but we have been learning what the new vehicle should collect.

Recommendations:

Recommend that engineering management maintain the DAC planning process capability across all disciplines. Effort should be made to maintain and improve the knowledge and skills to schedule and manage DACs for future efforts.

Also, it should be required that program, project, and element-level DAC planning be concurrently developed and baselined so that all levels of DAC plans are properly integrated upon submittal for baseline.

4.1.4 DACs Too Long in Duration

Description:

The DACs were entirely too long in duration. The DAC process started with the setting of an analytical baseline typically in the form of an outer mold line (OML). The DAC process had about five serial processes with external drivers that caused it to take 6–9 months. By this time, the element designs had changed to the point that the environments that had been generated were very limited in benefit. This was not totally the fault of the analysts. Churn in the design caused many starts and stops along the way.

Recommendations:

The DAC process can be improved by working with the project and element levels of the program. The program must communicate with its project/elements to show them where they fit into the DAC process and how incremental changes should be gathered and appropriately integrated in the DAC cycle.

Also recommend assessing the efficiency of decoupling document revisions (by book managers) from executing the design analysis process.

4.1.5 Track Changes to OML as Part of Ares Design Analysis Cycle (ADAC) Log Book

Description:

The OML document (CxP 72305) was created to put the vehicle OML under configuration management (CM) control until the drawings would be released at Critical Design Review (CDR). The document provides Vehicle Integration (VI) control and communication of the vehicle OML to the element and integrated vehicle design and analysis organizations. The Ascent Flight Systems Integration Group (AFSIG) utilized a memo process in order to distinguish OML changes released for information (RFI) versus changes released for technical use (RFTU). The OML document updates also placed the latest version of the vehicle approved by RFTU memos under CM control. This was communicated to the analysis organizations and the design team which OML changes are approved for technical use by the VI Chief Engineer's office, which would enable them to have an iterative analysis process between major design cycles.

Recommendation:

The documented OML should have been included in the iterative dataset as part of the design analysis process (i.e. part of the ADAC logbook).

4.1.6 Trade Study Involvement

Description:

Many times, trade studies were conducted within individual subsystems, disciplines, or groups, and did not include all appropriate stakeholders. This lack of involvement of stakeholders can also lead to trade study results not being used to make decisions. For example, some of the stakeholders/participants (from Boeing) were not notified during a trade study to determine locations for test facilities (e.g., System Integration Laboratory (SIL) and System Integration Test Facility (SITF)). This lack of involvement resulted in the trade study results not being used to determine the location of the test labs. Also, several Upper Stage issues and trades were not addressed early in the design process, which caused problems later in the project.

Recommendations:

Trade studies need to involve all stakeholders to ensure that all areas are appropriately addressed (avoid studies being buried within a subsystem).

Recommend that all proposed trades are discussed at the next higher integrated level to identify stakeholders.

Also recommend projects and element levels create a "gotcha list" that includes issues and trades that need to be addressed earlier in the design process.

4.1.7 TEAMS Tool Issue

Description:

On the Ares I project, it was discovered that the TEAMS (Testability Engineering and Maintenance System) tool used for Ares, Orion, and the Ground Operations project had a significant problem in that it has the capability to use "function mapping and blocking" in its Designer tool, but that these mappers and blockers are not implemented for the Real-Time (RT) version of the tool. For large-scale models such as are required for a full launch vehicle, the function mappers and blockers are needed for proper long-term use and maintenance of the tool, but the Real-Time version is also required for operations.

Recommendation:

Recommend the TEAMS-RT software be fixed/updated to allow for resolution of function mappers and blockers from TEAMS-Designer.

4.1.8 Stacking Alignment Analysis

Description:

Initial vehicle tolerance calculations for the Ares I baseline design were based on a two-dimensional (2-D) planar integration of the angular offsets at each element interface flanges. This method of calculating misalignment showed potential interferences with the Vehicle Assembly Building (VAB) platforms and would impact cost to make the top three platforms adjustable.

The Systems Test and Flight Evaluation Branch (EV93) created algorithms and performed a three-dimensional (3-D) Monte Carlo analysis with a three-sigma probability of vertical alignment based on the same element interface flange tolerances utilizing normal and uniform distributions. The results showed the risk for VAB platform interference was low and the results were consistent with similar tolerances for Saturn V and Ares I-X. The results supported a program decision to not incur cost to make adjustable platforms.

Recommendation:

Recommend the 3-D Monte Carlo vehicle stacking/alignment tolerance analysis method be assessed by engineering (both vehicle integration and vehicle design) for use on future projects.

4.1.9 Evaluate Cost vs. Benefit for Failure Analysis and Tests

Description:

The gas generator (GG) burn-through analysis and the interstage leak analysis were not utilized by the corresponding elements when results were completed. A lot of time was expended obtaining the necessary data to perform the analyses, and a significant amount of effort was put into areas where the risk could not be significantly changed. A better use of resources would have been to focus on areas where the design could be changed and significantly improved overall risk. The System Integration Failure Analysis (SIFA) team felt the analyses were never utilized by the Elements for two possible reasons. First, due to the time lag of the SIFA analysis, the element designs had moved on to the next design iteration. Second, there may have been resistance to outside input because designers felt the analysis had imposed on their job.

Recommendations:

Recommend that proposed failure analyses and tests be driven by the higher failure risks, especially where significant controls or mitigation capability are lacking. All proposed failure analyses and tests should be assessed to determine if the time invested and costs merit the potential improvement in failure risk.

It is also recommended that the SIFA team and designers establish the scope and parameters of the analysis and set exit criteria to reach a “good enough” solution in an efficient manner.

4.1.10 Link Failure Analysis with Test for Validation

Description:

The SIFA team did a GG burn-through analysis and the analysis may have been helpful for validation efforts once the GG was finally tested. The SIFA team could have a better validation of results by linking to groups who do testing on the components that the team has analyzed.

Recommendation:

Recommend that the analysis lead for a product utilizing SIFA failure analysis coordinate testing results with the SIFA team for validation and future improvements.

4.1.11 Organization of Integrated Analyses

Description:

Integrated analyses, cutting across multiple systems, were difficult to conduct due to coordination of data across those systems (and interfaces).

Recommendations:

Recommend engineering management consider that structural thermal analysis stay within Structures and Thermal (S&T) but thermal environment analysis possibly move into Systems Engineering and Integration (SE&I) or an equivalent integrated analysis area, since it is more of an analysis across systems and project or element interfaces.

Also, in the same line of thinking, consider purge and hazardous gas or purge, vent, and drain (PV&D) analysis be incorporated into an integrated analysis.

Lastly, it is recommended that primary structure deflections due to vibe, thermal, etc., need to be defined early and documented as interface attributes/requirements for subsystems in the interface requirements document (IRD) and interface control document (ICD).

4.1.12 More Robust System for Late Aborts

Description:

Once the launch abort system (LAS) was jettisoned, the Constellation architecture relied on the separation system (used for nominal separation) to be used during an abort. The architecture did not have the performance margin to carry the LAS to orbit.

Recommendation:

Recommend assessing innovative solutions to provide crew abort capability/coverage throughout ascent.

4.1.13 Loss of Crew (LOC) and Loss of Mission (LOM) Analysis Integration

Description:

The fact that LOM analysis results were being used as inputs to the LOC analysis (and aborts) greatly increased the complexity and size of the LOM analysis effort. The transfer of analysis results was not well recognized when the effort was first scoped. The increased complexity was because follow-on analyses needed information that described how the system failed, not just that it had. Interpersonal communication was good, but important information was sometimes missed. Several times apparently insignificant LOM items came out as being LOC drivers that required further iteration.

Recommendation:

Recommend Safety and Mission Assurance (S&MA) LOM and LOC analysts assess their analysis planning and make improvements to work more closely together and establish any necessary parameters and criteria that must be shared between the analyses.

4.1.14 Abort Environments Table

Description:

A lot of time was spent discussing various failure scenarios that would require the crew to abort. We often revisited the same discussions, especially when new people attended the discussions. It was difficult to move forward with firm recommendations. A written down list would help to establish a summary of the system vulnerabilities to help drive safety controls and vehicle design.

Recommendation:

Recommend S&MA work with the system lead at the integrated vehicle level (launch vehicle plus crew) to establish a table of abort environments to list and discern failures that are, or are not, LOC safety scenarios. (Also look at 4.1.15 for possible common solutions.)

4.1.15 Fault Management (FM) and Health Management (HM) Database

Description:

The data being collected for analysis by the HM team for abort conditions definition, abort algorithm development, caution and warning (C&W) condition development, and other HM products should be organized together, possibly in a health management database. This data should be integrated/associated with other failure-related databases, including hazards, failure modes and effects analyses (FMEAs), failure scenarios, LOM initiators, and system/subsystem line replaceable units (LRUs).

Recommendation:

Recommend safety lead for fault and/or health management and the engineering vehicle integration lead assess the need for a centralized and organized set of information or an integrated database for maintaining and relating failure, hazards, aborts, and FM data to ensure proper coverage by the FM system. (Note: Efforts to develop such a database were initiated by S&MA for Ares I through Ames Research center. This effort/group should be consulted as a prospective starting point.)

4.1.16 Invest in Software Tools

Description:

The SIFA needs for analysis tools were not adequately addressed. For example, the SIFA team used the Star CCM+ computational fluid dynamics (CFD) tool through a University of Alabama at Huntsville (UAH) support contractor to do interstage leak modeling for flammability analysis. Many man-hours were expended troubleshooting the CFD software instead of investing in something (with adequate support) early in the project.

Recommendation:

Recommend engineering, specifically integrated systems analysis coordinate with the requesting program/project and the appropriate analysis discipline leads to assess required analysis deliverables. First, the assessment should ascertain if the requested analysis effort is truly needed and determine the actual need date and dependencies of the analysis. Second, the assessment should determine if an existing discipline should take on the task, or if it makes more sense for an integrated system analysis function to take on the analysis. And finally, the assessment should look at the necessary tools across engineering disciplines to determine if existing tools (such as CFD code) exist and can be shared, or if additional seats need to be purchased, or if new tool investments (with appropriate support services) are needed.

For example, in the case of the aforementioned leak analysis, engineering managers might look across the integrated analysis efforts, the existing CFD code(s) being used at the center, and the tasks assigned to the existing fluid dynamics analysts and: 1) decide to keep the leak analysis with the SIFA team and invest in a CFD code more applicable to their needs, or 2) choose to have the SIFA team utilize/share CFD tools currently used by fluid dynamics specialists, or 3) choose to negotiate with the fluid dynamics team to perform the analysis task on behalf of the integrated analysis area.

4.1.17 Priority of System Analyses

Description:

The perception to some analysts was that system-level analyses were considered as requirements verification only; therefore, they were low priority in the earlier phases of the project/program. For example, the reentry analysis results indicated that changes to vehicle design were needed but the decision was made not to design for reentry loads.

Recommendation:

Recommend system-level analyses begin early in the program and be emphasized for identifying potential system (vehicle) design drivers.

4.1.18 Integrated Structural Model Requirements

Description:

Structural modeling analyses were initiated by requests from engineering disciplines and project/elements, rather than being a standard part of the design cycle. Example: the Integrated Vehicle Ground Vibration Test (IVGVT) requested an analysis to determine structural test requirements. Determining structural test requirements should be part of a standard analysis cycle.

Recommendation:

Recommend engineering (design and analysis leaders) assess needs throughout the life cycle and propose planning for integrated structural models and analysis to be part of the standard design cycle instead of doing specific analyses in response to individual requests.

4.1.19 Structural Analysis Methodology

Description:

The structural analysis methodology changed a couple times and the bulk of the analysis was completed in the months right before the Upper Stage Interim Design Review. In hindsight (using Upper Stage element as an example) coordinating secondary structure methodology with subsystems across the element could have been done better.

Recommendation:

Recommend that engineering (design and analysis) leaders work with program leaders to formulate a Structural Analysis Plan in order to improve the coordination within the loads analysis community across program/project/element/subsystem entities.

4.1.20 Support Software Toolsets

Description:

The NASA Structural Analysis (NASTRAN) renewal contract changed vendors. (All NASTRANs are not alike, especially when you are utilizing programming features like DMAP (i.e., Direct Matrix Abstraction Process).) The program should provide the Other Direct Charge (ODC) funding to support maintaining the existing toolset, until time and resources and schedule time become available to formally convert to the new toolset. (The two different NASTRAN toolset versions typically discussed are Siemens NX NASTRAN and the MacNeal-Schwendler Corporation (MSC) NASTRAN.)

Work conducted for DMAP was performed, but additional work is required since DMAP modules are different. Some of the NX NASTRAN DMAP modules/capability were added since 2001 and are not available in MSC NASTRAN.

Recommendation:

Recommend engineering and program planning consider that the toolsets used at the start of a program need to continue for the life of that program to ensure accessibility of necessary data and prevent schedule impacts.

Further recommend that new programs/projects provide the overhead (ODC) budget to maintain their chosen toolsets, until resources and schedule become available to formally convert to the new toolsets.

Also recommend that engineering (structural design/analysis) perform a study to see if the MSC NASTRAN version produces the same results as NX NASTRAN and report any differences.

4.1.21 Integrated Analysis Roles

Description:

Sometimes it was confusing as to *who* would provide integrated analysis (includes loads, data, etc.). There was volatility in how engineering wanted to manage the integrated design and analysis (ID&A) work in some areas. For Flight Mechanics and Analysis Division (EV40) having a product lead worked well. Line management gave this person authority to plan and direct work. This allowed for a single point interface between the project and EV40 engineering for planning resources, schedule, and assuring on-time deliveries of products and reporting of issues and risks. Having one person per discipline to interact with several branch organizations also worked well for the ID&A group. The only difficulty comes with the product lead's authority/ability to direct work in place of the supervisor. Using discipline branch chiefs for this is workable, but more complex with large organizations (like ID&A). First Stage and Upper Stage Engine identified an integrated analysis lead that were the go-to people that had authority and responsibility to interface with ID&A. This helped working together across many disciplines and organizations.

Recommendation:

Recommend detailed roles/responsibilities be identified for integrated analyses, such as thermal analysis, purges, etc. Consider having a product lead for each group (i.e., a single person in charge of work being done with the authority to plan and direct work). This person would be the single point interface between the program/project and engineering discipline for planning resources, schedule, and assuring on-time deliveries of products and reporting of issues and risks. This person would also interface to other branches to negotiate and prioritize needed work. This could potentially be the branch chiefs, if the branches are aligned with the products. Consider using an ID&A management team organization defined to reflect all distinct horizontal and vertical integration functions, rather than a typical top-down/book manager construct. Define each leader’s role to include management of the assigned product as well as the technical integration to facilitate necessary negotiations to assure valid agreements with data providers and determination of the scope of effort included in technical/programmatic baselines. The management and leadership of the ID&A team must be partnered with, and accountable to, the leadership of other organizations where there are process dependencies.

4.1.22 Photogrammetry and Laser Scanning

Description:

Photogrammetry and laser scanning proved very valuable at defining the as-built state of hardware. These techniques were used to correct several problems, speed up operations, and deliver custom tool paths. It was also extremely useful for providing facility models for DELMIA simulations. (DELMIA, or Digital Enterprise Lean Manufacturing Interactive Application, is the the brand name for Dassault Systems’ manufacturing simulation software.)

Recommendation:

Recommend engineering (design, analysis, operations) assess utilizing photogrammetry and laser scanning in future programs/projects, and make the appropriate updates to best practices and engineering planning.

4.1.23 Model and Analysis Technical Interchange Meetings (TIMs)

Description:

Model TIMs and analysis TIMs worked well to capture consensus of scope, fidelity, etc., before the work began. They provided an excellent means to assess adequacy of data transfer on the agreed-to date and provided good face-to-face communication that often highlighted key areas that may had been overlooked. However, for the Ares effort, there was not sufficient Element support when it came to understanding what the Elements were actually requesting (which usually occurred at the earlier model TIMs).

Recommendation:

Recommend engineering develop and propose efficient model and analysis TIM planning for use by new programs in order to provide early (and more involved) participation from subordinate entities (project/element). It is also recommended to provide a summary report (outbrief) back to the involved program/projects at the end of the TIM to better set expectations and adjust forward planning as needed.

4.2 AVIONICS DESIGN

4.2.1 Sensor Procurement Was Confusing

Description:

There was an observation that sensor selection and procurement was "confusing."

"… types/locations [of sensors had to be defined] early in the design. This led us to relying heavily on discipline analysts to define the type of sensor, type of bonding, etc. Analysts … define why sensors are required, where, range, etc."

The process can definitely be more efficient to better meet programmatic schedule and costs; however it is a fundamental part of both analysis and design, and therefore the process requires initial input from analysis experts who will utilize the data supplied by the instrumentation.

Recommendation:

Recommend that a leader be chosen early in the program/project development. The leader must have demonstrated experience in selecting and implementing instrumentation needs to be given responsibility, and be given budget and schedule authority for adjudicating, choosing, and implementing instrumentation needs at the vehicle level, while integrating the subordinate level's needs.

Along with a lead, it is recommended that engineering assemble a very small team of experts to develop a basic process and a template (spreadsheet) for bookkeeping instrumentation selections, location, and pertinent installation requirements. The team should include representatives with recent development and flight experience, possibly utilizing personnel with recent experience on Ares I-X or Shuttle. More specifically, the team should include those with expertise such as: analysts selecting their specific instrumentation needs, design (component level and vehicle level), fabrication/assembly, installation, and operations (electrical and mechanical check-out).

4.2.2 Schedule Delay Due to Wait for Avionics Components

Description:

The Upper Stage Instrument Unit (IU) Structures and Thermal (S&T) design team proceeded with the design prior to the acquisition of the avionics component that would reside in the IU, forcing the design team to use speculated component volumes and performance characteristics to design the IU volume and its respective environmental control subsystems. The eventual result was that the IU design team suffered a schedule hit while the avionics component designs matured.

Recommendation:

A project may choose to proceed at risk with incomplete tasks, but the project must also consider that the cost will likely be paid sooner or later, and the costs at a later time may be much greater than initially estimated.

Recommend that all program/project/element teams considering pressing forward with incomplete component designs that may impact higher level system design tasks give due diligence to two major considerations:

1) What are the pros and cons of slowing the higher level system design process and waiting "now" for component designs to mature versus waiting later when the delays may be more costly?

2) What mitigation, parallel effort, or innovative work-around can minimize the technical and programmatic risk?

4.2.3 Avionics Modeling

Description:

Models can be useful for maturing design and validating assumptions. During development of the simulation and test infrastructure avionics test system (System Integration Test Facility (SITF) and System Integration Laboratory (SIL)) the ability to have software models of the avionics and subsystems delivered with the unit test results was a contributor to the successful initial implementation of the avionics simulation and test environment.

Recommendation:

Recommend this approach (software models of avionics and subsystems delivered with unit test results) be assessed for continued use on future projects and be included early in the contract negotiations with vendors. However, using models for driving design decisions requires presence of a test program to validate the models early in the life cycle to avoid undue risk. Development testing and system modeling prior to and during development of requirements should be supported on the next program.

4.2.4 Controllers Design

Description:

Some end effectors were commanded in position units instead of percent full-scale (%FS). This resulted in some design conflicts.

Recommendation:

Recommend designers of controllers (control devices) consider defining commands for effectors in %FS, thus making the required function unit-less and less sensitive to design details. (Or consider using %FS in addition to absolute position units, if that facilitates detailed design effort.)

4.2.5 Developmental Flight Instrument (DFI) Definition

Description:

More detail was needed earlier to define and document flight instrumentation. Specifically, the DFI definition was not mandated to tie to flight objectives or system requirements. This made negotiating to scale back the number of requested sensors on a data list very inefficient.

Recommendation:

Recommend clearly defining the types of instrumentation (i.e., development, verification, operational) early in the development process. Also, each instrument should also tie back to test or flight objectives or system requirements to communicate what data is needed.

4.2.6 Design Communication in Avionics

Description:

There was no means for the NASA design team to communicate updated design information and requirements to vendors, and thus the avionics box designs (at the vendor level) continued to be based on passive cooling assumptions. One example for Ares avionics was the thermal management for avionics components. Early in the design process passive cooling was the baseline, then it was determined in the Preliminary Design Review (PDR) time frame that active cooling was required for some boxes.

Recommendation:

Recommend that all product teams (program/project/element) clearly communicate the latest requirements to all impacted subsystems and providers (vendors) via an efficient formal change process. It is incumbent upon the program/project authority for a product to communicate changes per the change process.

Recommend more frequent informal communication among key personnel (e.g., design leads) at all levels of a product definition (design) for the expressed purpose of efficiently going over new information and proposed changes that must be elevated in priority to improve the flow through the formal change process.

4.2.7 Structural Failure Case Recommendations

Description:

Due to the uncertainty of structural failures, the Fault Management (FM) team would like to see structural failure cases be taken into consideration in order to develop comprehensive abort capability. In particular, estimated probabilities associated with the failure of composite structures have not been demonstrated adequately. Testing should be performed to adequately characterize failures of composite structures.

Recommendation:

Recommend engineering design work with safety (fault management) team to assess a methodology for taking structural failure cases into consideration to develop a more comprehensive abort capability. This would likely drive testing to characterize failures of representative composite structures.

4.2.8 System Performance Models

Description:

One key area of concern for failure determination, notification, and response is timing: the time it takes for a failure to occur and the propagation of that failure into a catastrophic event. Many Ares I Elements developed models of their systems which mimicked system performance. Utilization of these models, both individually and as a full-up integrated vehicle model, can provide significant timing data needed to determine the proper response to each abort event (e.g., automatic engine shutdown, continue to fly until crew initiates abort) and assess the effectiveness of responses to abort conditions.

Recommendation:

Recommend engineering, specifically leaders from system-level integrated analysis, subsystem modeling (e.g., engine, main propulsion system (MPS)) work with experts in safety and fault management modeling to assess viability of developing and integrating a vehicle-level model to mimic system performance to determine system response and timing to each abort event under study.

4.2.9 Abort Condition Definition

Description:

Abort condition acceptance was based heavily on probabilities allocated to abort conditions to define monitored versus not-monitored abort conditions for the Ares I launch vehicle. The process used to define the abort conditions for the Ares I can be applied to any launch vehicle. After mapping the Failure Modes and Effects Analysis (FMEAs) and hazards together and defining the abort conditions, an overall probability is determined by the Probabilistic Risk Assessment (PRA) team and assigned to the abort condition. If the abort condition probability is *less than* 1 in 100,000 the abort condition is defined as “monitored.” If the abort conditions probability is *more than* 1 in 100,000 the abort condition is defined as “not monitored.” In hindsight, the probabilities allocated to the abort conditions were not fully vetted, had large uncertainty, and were based on an immature vehicle design.

Ares I showed that the functional fault analysis (FFA) models are useful for abort condition definition, abort trigger analysis, launch commit criteria (LCC) analysis, caution and warning assessments, recoverable fault analysis, prelaunch supportability analysis, and support to probabilistic risk assessment. However, it took too long and too many resources.

The process and criteria for defining, analyzing, assessing, and vetting candidate abort conditions and triggers needs to be defined early to allow for a thorough assessment of the abort conditions and triggers and facilitate the subsequent design and implementation of the associated failure detection, notification, and response (FDNR) algorithms.

Recommendation:

Recommend an assessment by engineering, specifically experts in safety and failure analysis at the subsystem level (e.g., engine, MPS) and vehicle-level abort condition analysis. The small team would outline a new process, assess the costs and benefits to developing the more comprehensive abort condition analysis, and present their conclusions of the benefits and costs.

The new process would establish a disciplined approach to failure allocations and probability calculation to provide a higher degree of confidence and a better foundation upon which abort condition status can be judged. Build generic models early in the project to provide cost-saving and schedule-saving efficiencies while making the information for these analyses more accurate. Develop qualitative diagnostic models early in the subsystem design and development process to provide critical support to the systems engineering design process. Involve the Fault Detection, Diagnostics, and Response (FDDR) team in the FFA model development to aid in the cross-development of the FDNR capabilities.

Define the process and criteria for defining, analyzing, assessing, and vetting candidate abort conditions and triggers early to allow for a thorough assessment of the abort conditions and triggers and facilitate the subsequent design and implementation of the associated FDNR algorithms.

4.2.10 Support Abort Triggers Development

Description:

On the Ares I crew launch vehicle project, the process for developing abort triggers was not well defined and was subject to extended debate that did not always contribute to forward progress. For any manned launch vehicle, abort triggers need to be a consideration in the project planning and requirements/design processes.

Recommendation:

Recommend that engineering (avionics) and system safety (S&MA) provide a coordinated definition of and planning for development of abort triggers in support of fault management, including potential drivers to further develop detection (sensor) capability and safety control functionality.

Engineering must work with future programs/projects providing crewed launch vehicles to negotiate the provision of adequate support for abort trigger definition and abort analysis.

4.2.11 Communication in the Area of Avionics and Software

Description:

Communication and coordination between engineering and safety (S&MA) appeared to be only on an “as needed” basis, possibly due to a lack of preplanned support. This was noted particularly between S&MA and the engineering team working the FDNR.

Multiple safety people at project and element levels were helping develop products requiring avionics and software coordination (i.e., failure modes and effects analysis, hazard analysis, hardware reliability assessments). This often created confusion within the engineering team on who to contact within S&MA when design changes were required. Clarification of S&MA avionics support structure is needed for future project support.

Recommendation:

Recommend a lead within the safety organization (S&MA) work with a vehicle integration and avionics (software) lead to assess the issues seen on the Ares Projects and propose clear definitions of roles and responsibilities, and also provide new best practices or planning (or updates to existing planning) to make sure new programs have a clear understanding of the products and services being provided by S&MA and engineering and how they will work together on behalf of the program. (This will help in obtaining adequate resources and support for needed staffing.)

The assessment should also consider S&MA avionics and software available skills mix and determine if there are any deficiencies that might need to be addressed. There may also be some discussion whether a new position for a Software Chief S&MA Officer may be proposed by S&MA.

4.2.12 Operational Design Life

Description:

All operational uses of a product must be considered. Avionics software design decisions based upon the length of use during flight did not encompass the longer length of time powered on the pad.

Recommendation:

Recommend that engineering (avionics software) utilize good systems engineering and update their best practices for design and development to consider all possible operational uses of a software code, that may include significant periods of usage (or power-on standby) on the launch pad and also in a bench-level or integrated subsystem test. The design solution should consider the number and duration of possible operational duty cycles.

4.2.13 Pre-Coordination of Electronic, Electrical, and Electromagnetic (EEE) Parts

Description:

The process of pre-coordination of EEE parts issues has worked well. Nothing is formally submitted before MSFC and the contractor are in agreement.

Recommendation:

Recommend continuing the practice of pre-coordination of EEE parts issues with the contractor, prior to formal submissions.

4.3 AVIONICS – SOFTWARE

4.3.1 Independent Software Test and Evaluation

Description:

Independent software verification and validation is needed for complex system development. It is insufficient for a delivered product to be tested only to ensure that it meets the specification and not tested to prove that it would operate as intended in the environments it could be expected to encounter in flight.

Recommendation:

Recommend that NASA retain and continue to develop the facilities and capabilities that were started to provide for independent assessment of the vehicle. It is further recommended that the vehicle-level assessment task not be assigned to a prime vendor, to retain the insight and working understanding of the integrated system capability.

4.3.2 Develop a Uniform Code and Methodology

Description:

Different modeling and documentation approaches were used by the Guidance, Navigation, and Control (GN&C), Vehicle System Management (VSM), Failure Detection, Notification, and Response (FDNR), and Flight Software (FSW) groups. This resulted in tremendous integration overhead in effort and schedule to reconcile inconsistencies between the functions and to translate the different representations into a single consistent model at the FSW level.

Recommendation:

Recommend the engineering software development discipline develop and propose a uniform methodology for composing and formatting algorithms, code, logic diagrams, and flowcharts to the maximum extent possible. It is also recommended the organization performing the definition of the key system functions should use the same approach for analyzing and defining their systems.

4.3.3 Lack of Fault Management (FM) Analysis of Fault Detection, Diagnostics, and Response (FDDR) Design

Description:

On Ares I there was no analysis performed to assess the completeness of the FM/FDDR design.

Recommendation:

Recommend safety (Safety and Mission Assurance (S&MA)) and FM discipline leads develop planning early in the next program to perform an analysis using a top-down functional decomposition of critical vehicle and ground functions. Then selection of FM strategies in this process should be completed to identify and protect those functions throughout the vehicle development.

4.3.4 Establish Vehicle Time as Global Positioning System (GPS) Time

Description:

The Universal Time Clock (UTC) utilizes leap seconds and is not as precise as GPS time.

Recommendation:

Recommend engineering (avionics and GN&C) assess vehicle time established as GPS time to eliminate the ambiguity with use of UTC without leap seconds, and propose a solution.

4.3.5 Automation and Roles and Responsibilities Never Defined

Description:

Models, automatic code generation, and meta-data all represent levels of automation, yet the automation was never defined, the ownership never established, and work-flows never executed.

Recommendation:

Recommend engineering assess the need for applicable existing standards, and initial planning to achieve maximum efficiency and reliability in achieving automation. If software re-use is a goal, the flow, standards, formats, and tools must be established early. Automated code generation can introduce more challenges than solutions if the workflow is not established early and controlled throughout the life cycle.

4.3.6 Software Test Article Requirements

Description:

Software requirements that were frequently omitted included test article support. For example, no requirement existed for the flight software to operate in a test mode but various groups expected that the software would support a main propulsion test article.

Recommendation:

Recommend software engineering include tasks in their development process to coordinate with hardware design and test disciplines in an effort to make sure software requirements consider test article support.

Also recommend hardware and facility design teams designing test articles add tasks in their design process to define any necessary software support.

4.3.7 Integrated Hardware and Software Reviews

Description:

In the Ares experience, there were several separated design reviews. Software was often separated from hardware and there was no system-level technical review that tied it all together. There was also an observaton that avionics and software were not well-coordinated between Ares, Orion, and Ground.

Recommendation:

Recommend engineering leads work with program/project planning to combine hardware and software design reviews or hold an integrated technical review after the separate hardware/software reviews.

Also recommend new program leadership work with engineering integration and design leads from software and hardware disciplines to establish either a responsible organization or a working group to integrate avionics hardware and software.

4.4 AVIONICS TEST

4.4.1 Hardware in the Loop (HWIL) and Prototyping

Description:

Hardware in the Loop development and prototyping labs are vital assets for early system design/ development, as well as integration, and training test teams. Early integration of prototype products allows the design team to evaluate interfaces and integrated system-level performance. This process in a lab environment allows for the early discovery of problems, typically has impressive turnaround on modifications or “what-if” studies, and provides a wealth of training for a development team that must come up the “learning curve” as efficiently as possible.

Recommendation:

Recommend engineering (design and development leaders) and program/project leaders to encourage and utilize HWIL and prototyping labs in an efficient manner throughout the development effort.

4.4.2 Stand-Alone Non-Real-Time Systems

Description:

On Ares there was the potential to have ARTEMIS (Ares Real Time Environment for Modeling, Integration, and Simulation) and MAESTRO (Managed Automation Environment for Simulation, Test, and Real-time Operations) installed on stand-alone, non-real-time digital boxes. This was not feasible without provision being made to purchase systems that could be dedicated to the purpose. A modified Software Development Facility (SDF) with Storage Distribution Units (SDUs) might be better than attempting to have stand-alone, non-real-time systems.

Recommendation:

Recommend engineering (including avionics and software disciplines) assess these issues and determine an appropriate environment and infrastructure for software development.

4.4.3 Early Involvement of Test and Evaluation (T&E) Team

Description:

Early involvement of avionics T&E personnel in the development lab and system integration effort is beneficial for test team training and orientation as well as to the developers.

Recommendation:

Recommend engineering, specifically avionics discipline leads establishing best practices, to make the appropriate planning updates to their development process to provide for avionics lab development teams and avionics test teams to have closer collaboration commencing at the lab development stage.

4.4.4 Use Similar Plans and Processes

Description:

Using the same plans and processes as the prime contractor can be beneficial. The plans and processes between the NASA avionics and software test team and the Ares instrument unit avionics contractor test team were similar and allowed for a good working relationship between the two.

Recommendation:

Recommend future programs, especially those where NASA performs the design and the contractor is responsible for production, consider a strategy where NASA and the prime use the same (or similar) plans and processes to improve the efficiency and working relationship between the entities.

4.4.5 Integrated Test Data Analysis Capability

Description:

It was observed that there was little support for subject matter experts (owners of the functional requirements) to analyze avionics test data along with avionics designers. It appears some sort of integrated test data analysis task or capability is needed for future avionics test facilities.

Recommendation:

Recommend engineering, led by an avionics test lead, work with discipline leads across engineering, and formulate a simple plan or task steps in a larger analysis plan for getting the appropriate experts to look at avionics test data in the most efficient manner. The responsible avionics lead developing the proposed plan should consult with the disciplines that typically utilize avionics design solutions such as guidance, navigation, and control (GN&C).

It is also recommended that this capability consider support of appropriate tool development to make sure that test requirements verified by tests, along with the test data, are accessible by the discipline experts tasked to look at the test data to determine if the requirements were met.

4.4.6 Test Facilities Utilizing Same Process Would Be Beneficial

Description:

It would be beneficial if all the integrated test facilities (Systems Integration Test Facility (SITF), System Integration Laboratory (SIL), HWIL, Hardware in the Loop Lab (HILL), etc.) used the same processes and test tools (data reduction, etc.) so data could be easily shared between all facilities. It would also be helpful if electronic test procedures could be easily shared between the integrated test facilities.

Recommendation:

Promote standardized test processes and data reduction tools. This concept would be more cost efficient than everyone coming up with their own and spending large amounts of money on the same type of test tools, etc.

4.4.7 Supporting Avionics Integration

Description:

There appeared to not be enough resources budgeted to perform integration between upper stage subsystems. Avionics needed more time and resources to work alongside other groups like main propulsion system (MPS), reaction control system (RCS), and upper stage thrust vector control (TVC) so that we could capture the requirements and create the resultant design. There seemed to be a tendency to continually rush into major reviews and then try to fix things through the review item discrepancy (RID) process, which is more cumbersome.

Treating avionics as a peer subsystem alongside MPS, RCS, and TVC did not seem to work well since avionics was involved in every subsystem and also had cross-element and cross-project integration needs. Electrical integration often seemed to be an afterthought.

Recommendation:

Recommend engineering, specifically avionics leadership, provide the organizational structure and work with next program/projects program planning to propose adequate support and resources to allow avionics to integrate across numerous subsystems and across project/element interfaces.

4.4.8 Software and Hardware Development

Description:

Coupling software milestones with project milestones is difficult. Not all designs mature at the same rate which leads to differences in design maturity. Avionics, and particularly software and sensor development, almost always lag hardware design maturity.

Recommendation:

Recommend engineering, along with safety and program/project leadership, review planning for program/project technical milestone reviews and safety reviews and assess them for ways to improve flexibility and allow for later maturation of avionics (especially software and sensors). This may include ideas such as: synchronizing hardware and software designs at more appropriate intervals (design cycles) or planning for adequate time and resources to consider hardware designs and then at an appropriate later time complete the review of the fully integrated hardware/software system.

4.4.9 Algorithm Test Environments

Description:

Algorithm test environments should be assessed for efficient implementation to maximize commonality where appropriate. The SIL and Fault Detection, Diagnostics, and Response (FDDR) lab made progress in this area.

Recommendation:

Recommend the algorithm test environments be assessed for efficient implementation to maximize commonality where appropriate. (The equivalent of the Ares Vehicle System Management (VSM) code should be included in the assessment.) Consider developing a uniform code and methodology for composing and formatting algorithms, code, logic diagrams, and flowcharts.

Also recommend the organization performing the definition of the key system functions should use a consistent approach for analyzing and defining the systems.

4.5 BUDGET AND SCHEDULE

4.5.1 Budget Issues Beyond Control of the Project

Description:

Arguably one of NASA's biggest challenges is being chartered to undertake long-term efforts and having to battle for short-term budgetary support that often changes year to year under political forces. As an example in the recent experiences for the Ares Projects, a great deal of effort was expended each year developing schedules and cost estimates for the annual budget cycle. Following approval, these budgets were repeatedly slashed. Delays in making funding available as planned in the schedule negatively impacted the ability of the project to meet their schedule. The approved budgets never matched the available funding, thus creating more re-planning efforts.

Recommendation:

Recommend that center-level leadership work with NASA Headquarters and the administration to develop a better relationship with Congress, including longer appropriation periods for large, long-term programs. NASA-HQ (and centers) should work with Congress to establish a law that sets aside a portion of NASA's budget for large program(s) under a longer term budget agreement with appropriate guidance. It is recommended that the extended program budget(s) provide for periods of no less than 5- or 10-year increments since these increments more closely match larger or more complex system turnaround times. The law should still hold NASA accountable (annually) for all expenditures and resultant products and services included in the extended portion of the budget. The law should also provide that changes can be made to the long-term portion of the budget only in extenuating circumstances.

4.5.2 Address Budget Inflexibility

Description:

Without budget reserves, every technical decision became a budget request to project and program levels. In every development program uncertainties exist and there needs to be an allocation to cover these. Having no reserve handicaps the project because the only way of managing a budget is the “zero sum” effort to take away from one area to give to another. All things considered, monthly budget reviews were a positive and brought appropriate attention to the data being presented. Increased flexibility in using the available resources would improve future development efforts.

Recommendation:

Recommend that future programs/projects provide to the lower levels of the organization the flexibility to reallocate funds and track within their budget.

Also recommend that future programs/projects place some reserve funding at each level, commensurate to the uncertainties or immaturity at each level, to cover unforeseen and unbudgeted items.

4.5.3 Unfunded Infrastructure

Description:

Funding was not properly allocated for several items. Storage facilities for data collected during the design analysis cycles, early testing on hardware and software, and data generated during test and verification phases of the program were unfunded, resulting in months of effort to attempt to remedy this oversight. Facility modifications to support tests were continually slipped downstream which would have resulted in a schedule slip if the program had continued.

Recommendation:

Recommend new programs/projects establish construction of facilities (CoF) technical and funding requirements early because there is a 2-year lead time for construction of facilities. Ensure that infrastructure needs are funded.

4.5.4 Overoptimistic Planning Is Risky

Description:

Program/project schedules were overly optimistic. The architecture, design, and manufacturing schedules were success oriented and did not consider uncertainties associated with the size, complexity, and different levels of maturity of portions of the program. Development items, that will inevitably come up (but cannot be specifically predicted), drove significant delays into the schedule. Many product or service providers were unable to produce accurate production schedules for deliverables due to the optimistic schedules. A few examples of newer development efforts in the Ares Projects with higher levels of uncertainty included new engine development, materials development, and the common bulkhead.

Recommendation:

Recommend that engineering and program/project planning discipline owners update or enforce a more rigorous schedule development process. The process must include steps to assess uncertainties in task completion (such as earliest, latest, or most likely delivery).

Also recommend that program/project management and planning leaders need to address areas of increased uncertainty or lower maturity (and increased likelihood of development issues) upfront and incorporate risk mitigation in the project's schedule and budget. This might include:

- Allowing time in the schedule to achieve mature designs prior to embarking on tooling and facilities design and development.
- Monitoring and maintaining flexibility and margin in the schedule for potential late deliverables.
- Considering allocation of time in the schedule for troubleshooting and work around tasks.

4.5.5 Usability of Schedules

Description:

The integrated master schedule (IMS) was not as useful as it should have been due to its complexity and inconsistencies in the process. The size of the schedule made it unmanageable. The IMS was so overly detailed that determining the critical paths was almost impossible. More effort was spent making schedule inputs and manipulating and troubleshooting the schedule than understanding what the schedule said. This created a need for too many people to help manage and maintain the immense schedule. There were also significant variations in the amount of detail between the project- and element-level schedules, and tasks were not always properly linked, especially between product teams. This resulted in large numbers of schedule errors cropping up, such as tests occurring before hardware was delivered. The schedule did not allow activities to make adjustments and maintain schedule. No consistent process existed for providing schedule status. The purpose of the detailed schedule was not communicated to engineering, thus some organizations did not provide adequate input. The IMS was also too fluid due to frequent re-plans and re-baselines to both budget and schedule. (This appeared to be a trickle down of budget and schedule changes from outside of the program/project.)

Toward the end of the project, people were gaining more utility from the schedule and the deliveries referenced in the schedule. The 30-day and 90-day scheduled reviews were good for focusing attention on the schedule.

Recommendation:

Recommend that program planning and business development disciplines establish a small team to assess lessons learned from recent programs (e.g., Shuttle, Ares), establish current best practices and standards, and work to develop a very clear process to define types of budget and schedule products with consistent levels of detail, depending on the size and complexity of the effort. The emphasis should be to provide sufficient information to manage a program and make timely decisions by identifying issues and the affected participant without burdening disciplines with rescheduling due to minor variations in the lower levels of detail in the schedule. One suggestion is for the program/project to manage the high-level tasks and priorities and engineering manage the detailed tasks, dependencies, and uncertainties.

Further recommend the small team define a standard schedule report that is used throughout the program/project to avoid monthly duplication of schedule status reports in varying formats for different organizations.

Recommend the schedule (and budget) process be updated and strengthened to make sure formal schedules are baselined and changes are made through a formal change process. Other specific areas to consider in the process include:

- Ensure IMS guidelines are clearly established and the people responsible for the task are involved to develop the schedule.
- Develop disciplinary analyses all the way down to the component level in order to make sure structural designers have component information.
- Avoid delivering add-on work that is not scheduled and budgeted. Don't generate new data outside the planned schedule. If the budget is not available to perform required work, allow schedule milestones to slip.
- Build in time for contingencies in the schedule.
- Don't reduce schedule durations without coordinating changes with the team members.
- Consider schedule needs for design verification and validation.

Recommend planning for and providing resources to train people on the schedule development and maintenance process to ensure consistency and accuracy across and down through a program/project.

Also recommend the small team work with engineering and consider combining (or at least associating or linking) the drawing release schedule with a program/project IMS to ensure releases are made when most appropriate to support the schedule.

Recommend the improved process and products also be developed with consideration for Earned Value Management (EVM) needs as well as basic work schedule and planning.

Recommend more discipline and rigor in early schedule development, resisting attempts to set a launch or delivery date and then back away from that date using arbitrarily determined milestones. The schedule should be first put together based on real tasks and task dependencies, and then worked on strategically to find the areas where improvement can be made to "pull the schedule in" and meet need dates.

4.5.6 Schedule Tools, Staffing, and Processes Issues

Description:

The processes, personnel, and tools for maintaining the schedule need improvement. For example, the IMS tool for Upper Stage had multiple issues that resulted in wasted time for schedulers and for schedule users. The tool would lock up and lose information. The entire schedule was not available to everyone for viewing; only schedulers had access to the whole schedule. The center's SAP (Systems, Applications, and Products software) didn't work well with the IMS. Microsoft project had trouble with the size of files. Different tools were used by the project and Engineering. Having only one person responsible for the volume of activities and milestones on a project of this size resulted in a bottleneck and created an unmanageable system. Working to integrate schedules between subsystems resulted in one system needing to work with three project schedulers to reintegrate the schedule between projects.

Recommendation:

Recommend that program planning and business development disciplines establish a small team to assess lessons learned from recent programs (e.g., Shuttle, Ares), establish current best practices and standards, and recommend improvements to the scheduling processes and also recommend appropriate staff levels to maintain the scheduling function. Other recommendations include:

- Select a schedule tool (software) that works effectively considering the size and complexity of the program/project schedule and supports processes such as EVM.
- Those authorized from engineering and the program/project to develop or update a schedule must be able to use and work from the same tool schedule tool.
- All members of a program/project should be able to access and read (but not change) a schedule.
- Consider electronically linking schedules.
- Consider the schedule tool should support "what if" scenarios to allow decision makers to work a schedule issue.

4.5.7 Sequence of Planning for Scheduling

Description:

An area that posed issues for traditional scheduling was that Constellation started planning at the component level prior to the overall program structure being established. The "bottom-up" work flow occurred rather than starting with a system design and then building the parts to fill the needs of the design. This inversion of the process was driven by starting with some existing elements (e.g., the shuttle reusable solid rocket motor for the first stage) and partially a result of the phasing of staff who were turned on to do low-level design prior to upper-level integration completion. This may have driven some disconnects with the more typical top-down, system-level design model since it was not fully implemented. For example, the integrated master plan (IMP) was established after the IMS.

Recommendation:

Recommend developing rigorous top-level planning (e.g., the IMP) early on, before the IMS. Very few, if any, program/projects start with pure textbook circumstances. The planning should be developed to enough fidelity to consider and accommodate the specific requirements, peculiarities, and constraints imposed on a program and to show where resources and emphasis must be focused.

Also recommend combining the top-down and bottom-up planning early on as a mechanism to assure a complete schedule, such that the vehicle system can be better assessed.

4.5.8 Resource Phasing

Description:

Design and engineering were understaffed at the beginning of the project. The work load demands increased faster than staff could be allocated for the new work. Staffing levels were not aligned to the schedule phase. The engineering staff did not quickly adjust its size with the changing needs of the project. Defining and obtaining resources was difficult when designs were fluid in the project, resulting in unrealistic budgets and schedules. Every schedule and budget update for testing resulted in increasing costs. The learning curve factors realized when assigning new people to the project weren’t considered. The cost/schedule/resource plans were dynamic and changed so that they did not align. As a result, it appeared that insufficient action was taken to address the alignment early on.

Recommendation:

Recommend engineering leaders and program/project management plan resources based on the historical ability to obtain personnel. Planning should also consider variable levels of support from the design and support team through the project life cycle. Initiate work on long-lead items early in the project cycle. Schedule resource allocation to coincide with more mature designs.

Recommend engineering and program management emphasize establishment and stabilization of requirements and immediately align cost, schedule, and resources to meet the program needs.

Recommend performing upfront planning for the most costly activities to avoid, or at least mitigate, pushing costs and schedule issues out (often with larger impacts).

Also recommend considering the staffing learning curve when building budgets and schedules. It is a reality that people are not as effective at first and take a finite time to learn and come up-to-speed on new tasks.

4.5.9 Cost Reporting for Affordability

Description:

Cost data were not provided on time and much-needed affordability efficiencies were lost. Support contractor and Other Direct Cost (ODC) expenses need to be more accurately tracked. Recurring cost was sacrificed for nonrecurring costs as budgets became tight. There was a lack of support from supervisors on concepts of cost control and reporting. Training and use of EVM data was not rolled out through all levels of the organization. Cost reports were provided less often than schedule reports, and were frequently behind. Also, EVM was not used on advanced development contracts and costs were overrun without early indicators of problems.

Recommendation:

Recommend that program planning and business development disciplines establish a small team to assess lessons learned from recent programs (e.g., Shuttle, Ares), establish current best practices and standards, and work to develop a very clear process to define types of budget and schedule. Items to consider include:

- All supporting organizations of programs/projects should be made aware of and adhere to standard cost control and reporting methods. This should include that development activities be clearly defined with enough detail to accurately track cost and schedule.
- Engineering and program management should consider formally agreeing to and documenting the detailed work activities to firmly establish the budget and schedule.
- Establish an efficient process to form a bottom-up cost model in time to enable the life cycle cost estimates used to support early design option trades and to also drive operability and affordability.
- Programs/projects should continue to support lower levels of the program in the development of resource loaded schedules.
- EVM should be considered for use on Advanced Development Contracts.

4.5.10 Cost Reporting Tools

Description:

The cost and procurement systems do not readily accept corrections. Our current business tools do not adequately track support contractor and ODC expenses.

Recommendation:

Recommend that business development and procurement disciplines work to improve the cost and procurement system tools and methods such that mistakes in the work breakdown structure (WBS) can be accounted for and corrected as issues are found.

Also recommend the center business systems work with appropriate levels to make improvements to tracking support contractor and ODC expenses.

4.5.11 Establish Budget, Schedule, EVM Standards

Description:

No clear process existed for the scheduling team. The upper level schedules were too detailed. Engineering appeared to generally lack an understanding of how the business offices operate, which caused inefficiencies and delays in obtaining needed data for budget and schedule support. Managers weren't trained on EVM and how the center uses it. Scheduling software allowed circular logic. Cost and technical risks were not considered. Too many revisions were made to the budget to keep up with EVM. No discipline existed for maintaining control of a baselined plan. Primes weren't required to provide accurate monthly cost. The EVM process lacked standard documentation and forms. No standard calendar or set reporting date was established for IMS/EVM. Integrated Baseline Reviews (IBRs) were not well done. The WBS should be useful to the program, not an agency mandate. Too much emphasis was placed on changes to forecast dates which are expected to change. Schedule milestones started and ended on holidays. Too many inconsistent databases were used to report schedules. However, Vehicle Integration (VI) did end up with good schedule reporting metrics.

Recommendation:

Recommend the center business office establish MSFC budget, schedule, EVM standards, and guidelines for invoking EVM. Provide engineering access to current project planning. Consider alternate scheduling tools. Examine clarity in the fidelity of schedules. Make resource management tools common across the program, including primes. Element schedulers need better training to understand cost/schedule integration. Prime and support contracts need to require monthly cost reporting in Excel format including EVM where applicable. Train leaders on how to conduct IBRs. Improve the accounting program WBS to separate cost by centers, labor category, etc. Allow the program to set the WBS to be useful for managing the program. Implement a schedule health check as used by the Ares Projects Office. Educate the community that forecast dates are expected to change. Additional suggestions to improve schedule development at the project level include:

- Develop a standard set of control milestones.
- Focus on system/subsystem hardware.
- Use one scheduling database at the program level to maintain schedule dates.
- Develop a formal change control process that is consistent and easy to implement.
- Make sure the schedule change control process addresses changes to baseline dates only.
- Educate people on why forecast dates can and do change from month to month.
- Develop a single "down and in" and "up and out" milestone reporting matrix.

Suggested or Taken Action:

Ares Program Planning and Control Manager to work with center management and Chief Engineer's Office to identify the appropriate leader and/or small team to perform the following actions:

1) Given that EVM shall be used on all MSFC programs/projects of a specified size/value, the center must develop a new or updated guidance to implement budget and schedule reporting, tracking, and control with definition of appropriate data exchange deliverables, format, and intervals that support EVM for in-house and contracted efforts. Include integration between programmatic entities and contracted primes. (The in-house effort "needs help.") This should include definition of IBR entrance/exit criteria and execution expectations. Establish WBS guidance for efficiently implementing standard accounting practices. If EVM is not used (for example, with letter contracts) then an alternate method for program control needs to be identified.

2) Develop center-level guidance on when EVM shall be invoked on programs/projects required to use the process. The guidance should discuss at what time or phasing in the program EVM should be invoked and what data and processes must be in place, and clearly define any necessary parameters for successful EVM (such as "stability" of the budget or schedule). When establishing applicability standards for invoking EVM, the project must consider exempting any level-of-effort activities (as compared to more deliverable-focused activity).

4.5.12 Establish EVM Training

Description:

Engineering managers were not adequately engaged in schedule development. Engineers seemed to lack understanding of the limitation of funds. Managers didn't have a good understanding of the difference between funds management and EVM budgets.

Recommendation:

Recommend the center business office work with the Office of Strategic Analysis and Communications (OSAC) to provide planning for and determine who (e.g., managers) should receive EVM training, when EVM is used. (Emphasis for OSAC org to help a program/project pass an IBR. Also need to discuss distinct differences between funds management and EVM budgets.)

Recommend the business office and OSAC determine where to document the requirement for EVM training and timing prior to invoking EVM.

Also recommend standard operating procedures be updated to place more rigor and attention on holding managers/leaders accountable for cost and schedule performance.

4.5.13 Establish Improved Work Authorization Process

Description:

Engineering and other support efforts within NASA were not required to accept a work authorization with budget and schedule. Support organization should not operate separately with little or no control from the program or project with regard to EVM. A misunderstanding of team tasks and the lack of agreements in writing with other teams caused problems.

Recommendation:

Recommend the center business office establish guidance, and any applicable standards, for establishing a work authorization process, to record and negotiate an in-house (at MSFC) work package and have sign-off by both program and engineering leadership.

Recommend that operating procedures be updated to require support organizations in NASA to accept work authorization within scope, budget, and schedule.

4.5.14 Resources for Training and Tools

Description:

Resources for continuous training, information technology (IT) equipment, tool improvements, and support resources were not included in manpower and costing plans.

Recommendation:

Recommend the center business development area assess the issue and recommend a method to establish budget set-asides for tool development, training, and other essentials required to maintain the workforce, supporting tools/resources, and infrastructure. (This may include working with support organizations on establishing a method to estimate these costs.)

4.5.15 Unrecoverable Cost and Schedule Baselines

Description:

Due to the amount of change, the Ares Projects did not have time to adjust and re-plan as the technical, cost, and schedule baselines changed. This led to more emphasis on the technical baseline and a loss of focus on the actual state of project affairs. This was compounded by the need to manage two sets of baselines (i.e., the project office baseline and the NASA Upper Stage design team technical baselines, to be consistent with the Boeing production contract). As previously stated this resulted in the project beginning to operate with an emphasis on the technical baseline, allowing cost and schedule baselines to become so far out of date they were nonrecoverable.

Recommendation:

Recommend that future program/project managers are familiarized with the issues that drove the Constellation Program and Ares Projects to teach and emphasize the need to manage the cost and schedule baselines just as aggressively as the technical baseline.

4.6 PROGRAM AND IT SECURITY

4.6.1 Information Technology (IT) Security Improvement, Training, and Feedback

Description:

Data access and security presented constant challenges to recent programs/projects. Security processes were updated and defined for the recent programs/projects. Information technology (IT) tools and data security tools need to be reviewed and improved in light of the most recent security requirements to enhance data security, while maintaining ease of access and use. Also, training for these tools, and security awareness training must be provided to employees and management to foster a better understanding of what tools must be used and how to use them. The training should be developed sooner, rather than later, in anticipation of new programs. The training should be in parallel to, rather than relying solely on, the NASA-wide training provided in the SATERN system. There also needs to be provisions to improve efficient feedback of issues to the center and the agency.

Also, the latest security processes should be reviewed and adopted into the systems engineering processes (and training) for new program/project managers, engineers, and support personnel. Processes include identification of mission critical information, selection of security safeguards, threat and vulnerability assessment, etc.

Recommendation:

Recommend that Chief Information Office (CIO) work with center security and engineering data management (DM) discipline to assess current IT tools and IT security tools (including personal computing software suites) and make recommendations for improvement of individual tools and tool suites to improve accessibility, data security, and intuitive ease of use.

Also recommend the team recommend appropriate Security Awareness Training for both managers and employees. Consideration should also be given to more specific (tailored) training for individual programs/projects for the latest security processes.

Recommend that engineering, specifically DM, review and incorporate (or refer to) the appropriate security processes in engineering processes and associated training.

4.6.2 Discipline and Personal Accountability for IT Security

Description:

Personal accountability and rigor in maintaining information (data) security needs improvement. There did not appear to be sincere appreciation of the ramifications of security breaches, therefore, protocols such as Sensitive But Unclassified (SBU) and International Traffic in Arms Regulations (ITAR) are not consistently enforced.

Recommendation:

Recommend the center and new programs/projects first begin improvements to the tools and processes as described in Section 4.6.1.

Recommend center management support information/data security and follow-up to enforce security. Center management should work with security and IT personnel to understand the concerns and the true damage caused by violation of security requirements. Consider the use of training and tests (addressing realistic risk scenarios) to increase awareness and understanding. The training/testing should be for all managers and employees, not just contractors and IT personnel.

Recommend center management assess current methods for ensuring compliance with security requirements, especially data (IT) security, and recommend any needed updates to management responsibility and employee incentives. Consider both positive and negative incentives, including updates to the performance appraisal and awards processes as well as more rigorous enforcement and surveillance by managers, including using verbal (or written) warnings and more formal disciplinary actions for knowingly ignoring or violating security requirements.

4.6.3 Clarify IT and SBU Procedures

Description:

It was observed during the Ares Projects effort that both IT and SBU procedures seemed difficult to understand and implement. The center, as well as new programs/projects, must comply with IT security requirements in NASA Procedural Requirements (NPR) 2810.

Recommendation:

Recommend the CIO work with the data management discipline, and center security personnel to develop very clear procedures and guidance for both IT security and for SBU classified material. This is especially important to establish as early as possible with new programs/projects to minimize potential impacts, and it is crucial that the updated guidance and procedures be bought into by all management and be well communicated to all personnel.

Also recommend the development of a simple data security classification guide to accompany any directive or procedural updates. This will assist in evaluation of data/information types and the applicable security processes.

4.6.4 Data Security Requirements for Prime Contractors

Description:

During the most recent program/project effort, it was difficult to track all systems that process project information, and be assured that all primes and external contractor systems were protecting NASA data.

Recommendation:

Recommend the CIO work with the data management discipline, and security personnel to develop an improved IT enterprise architecture for the center and new programs/projects, and levy specific contract requirements on primes and vendors that address mapping and protecting systems that handle NASA information.

Also recommend data management and security discuss and consider identifying IT security points of contact (POCs) for IT security representation with external contractors.

4.6.5 Improve Process for Controlled Information Shared Between Centers

Description:

Improvement is needed in the level of cooperation between NASA centers (and possibly other agencies such as the Department of State) regarding the protection and control of technical and project sensitive information. This appears to be due mainly to different processes and decision-making paths. The lack of cooperation sometimes hampered the efficiency of data release across multiple centers. More open communication and coordination between centers and federal agencies is needed.

Recommendation:

Recommend the CIO work with a small team from discipline areas at MSFC and the smaller group of other centers and federal agencies that most influence our control of sensitive information. The team should have representation from CIO, IT, DM, configuration management (CM), security, and representative(s) from major program/project(s). It is recommended the team assess the current state of controlling and sharing sensitive information, identify the areas for most significant improvement across MSFC and the agency, and recommend improvements to the process for our center, as well as other centers and federal agencies that share in our information or influence the process.

The small group should also recommend any potential improvements to existing communication tools (e.g., Explorenet, or some wiki-like application across NASA) to provide information to the user community on IT security topics, such as export control, classification of sensitive information, etc.

4.6.6 IT Tool Selection and Standards

Description:

The selection of IT tools is important to the efficiency of a program. There were instances of incompatibility of information systems and browsers. iPhones and iPads had difficulty accessing Flash sites. Mac users had some issues accessing program tools.

More specifically, the requirements tool (Cradle) was difficult to work with. People had to be specially trained and only a few people accessed Cradle because of the difficulty. A requirements tool that allows many people to use and is user-friendly needs to be available.

Recommendation:

Recommend MSFC IT and engineering DM discipline work with the agency to assess and recommend updates to standards for data and IT tools for software and hardware (platform) compatibility to ensure secure and efficient access and speed when using both PC- and Mac-based hardware.

Also recommend MSFC (and agency) consider requiring that new programs/projects data and IT tools MUST be compatible with both PC and Mac hardware and resident software. Use of Internet Explorer for PC, Firefox for PC and Mac, and Safari for PC and Mac should be considered as accessibility requirements for all program Internet/information technology tools. Flash software should NOT be required in order to use a software tool or apps to enable iPhones and iPods to access program tools.

4.7 COMPUTER-AIDED DESIGN (CAD)

4.7.1 Develop CAD Standard Early to Avoid Impacts to the Release Process

Description:

The center did not have a CAD standard or drawing release process in place at the beginning of the Ares Projects. Neither did the Constellation Program. Thus Ares designers started designing with tools and processes they already had.This allowed them to form habits that were hard to change when the CAD standard was put in place. Once a CAD standard was developed, midway through the program, there was no governance to enforce it, so problems continued. The problems included substantial rework to make existing models meet the CAD standard including the renaming of models and revision of layers. Performing this rework took attention off of the details of the component design. This also led to schedule problems because drawings were not being released on time. Pro/E, the CAD tool, also had problems, especially when multiple designers were working on separate parts of the same assembly. This problem showed up in translations of parts to an assembly in DELMIA.

Recommendation:

Recommend that engineering management work with the design disciplines to develop a MSFC CAD or electronic model and drawing standard and a model and drawing release process prior to program/project inception.

Recommend engineering on the next program or project formally establish the CAD/electronic model and drawing standard as the model/drawing release process and enforce the day-to-day usage. In addition, recommend that engineering develop training for the CAD model/drawing standard and the model/drawing release process.

Further recommend that engineering develop training, especially for larger (more complex) programs/projects to provide additional Pro/E training on how to efficiently establish, manage, and control large model assemblies.

4.7.2 Layout Drawings as the Design Baseline

Description:

During the Ares development effort, requirements documents and the integrated CAD model alone did not lead to a clearly understood baseline. The integrated CAD model established a model state that was visible to all; however, some subsystems would perform extensive maturation of their design in the in-work state (prior to going into the integrated model) that was not always available to the wider community.

Recommendation:

Recommend engineering, specifically design and systems engineering, cite existing standards and requirements or develop the same that define what constitutes a program/project design baseline at significant waypoints in the design solution conceptualization and realization. (One specific recommendation might be to use two-dimensional (2D) layout drawings as the detailed baseline from the beginning of the program/project.)

4.7.3 Drawing Release Schedule Interdependencies

Description:

When model and drawing release schedules were developed, little to no consideration was given to supporting the needs of the primary structure release schedule. For example, main propulsion system (MPS) components interfacing with the primary structure were not being designed in time to support the release schedule of the primary structure components.

Recommendation:

Recommend engineering (design) establish fundamental dependencies between the nested levels of designs and between interfacing subsystems when developing drawing release schedules to avoid unnecessary delays.

4.7.4 Establishing CAD Libraries

Description:

The lack of CAD libraries needed to support the design activities was a hindrance. Much work was accomplished on the MSFC Ares I Upper Stage effort to establish a good foundation of CAD libraries. This needs to be elevated to MSFC engineering management and actions taken by the design discipline to more formally establish and maintain the CAD libraries for use by all programs/projects at the center, and not be lost with the demise of Constellation/Ares.

Recommendation:

Recommend engineering (design) capture all of the good work started on the Ares I Upper Stage design effort to develop CAD libraries. Engineering should formally establish and maintain the CAD libraries with a central design discipline starting with the work done on the Ares Projects.

4.7.5 Integrated Vehicle Ground Vibration Test (IVGVT) Test Facility Top-Down Design and Drawing Process

Description:

The IVGVT facility design developed a workable and efficient approach to integrating detailed subsystem CAD models with a more conceptual top-down, system-level design.

CAD design models are often built in a bottom-up methodology where the parts are designed and then put into a more integrated assembly within the CAD work space. Designers often rebuild their own unofficial Pro/E assembly to get a working model. This results in negative impacts to the schedule. For IVGVT, the initial Pro/E modeling approach (top down) was planned to streamline the combined activities of a design team prior to the availability of the Design and Data Management System (DDMS) for the test department. After DDMS was implemented, the methods were still applicable and a seamless transition was made. The IVGVT test stand, as is currently modelled, will be a valuable addition to the work we will do if we design a Ground Vibration Test (GVT) facility for the next vehicle to be tested at MSFC.

Recommendation:

Recommend engineering (design) assess the following process and accept or improve upon the process for a general CAD model process. Also, the resultant model from this Ares IVGVT process can and should be used for the starting point for development of the next GVT facility at MSFC Test Stand 4550.

The following is a summary description of the modeling practice used by the IVGVT. In short, these procedures allowed each subsystem or component to contribute separate designs with or without the benefit of DDMS.

1) A Pro/E “native skeleton” part was made to allow assembly without unnecessary constraints or references that may change.

2) The test stand and all the new designs and modifications to the stand were made part of the top GVT assembly.
3) Each engineer/designer added his various designs in assembly form to the GVT assembly. The parts or subassemblies must be designed in the context of the assembly to ensure that they fit correctly and can be modified quickly when the design changes. It is also recommended that manufactruring (as well as analysis functions) have read-only type access to the parts and top-level assembly being designed. They may be able to provide insight into their design not possible from a printed drawing.
4) All the changes along the way were made to the individual assemblies. This allowed the top GVT assembly to be relatively stable without frequent changes.

4.8 CONFIGURATION MANAGEMENT (CM)

4.8.1 Confusion with Board Approval Process

Description:

At times the process to get approval through boards and working groups was confusing in the Ares Projects. It was unclear what paperwork was required to be signed, and which boards and working groups applied to each product or technical decision, or which board had the final authority over a particular decision.

Recommendation:

Recommend that the control board(s) be established early in the next project and be clearly associated with a deliverable end-item product (e.g., vehicle, first stage). Clearly define and document the board's authority, scope/boundaries, and associated process requirements. The change process must be clearly communicated to all personnel. It must be clarified that all functional working groups are advisory, and are utilized as needed to build a decision (change) package, and only technical or programmatically affected chief engineer review board (ERB) and project control board (PCB) are mandatory.

4.8.2 Improve Change Process Screening

Description:

There were instances where relatively simple changes had already been agreed to by all involved parties, however, the implementation of the change was slowed by a cumbersome board approval process. As an example, changes to the thrust vector control (TVC) controlled design could take as much as 3 months to establish a formally approved design with other subsystems.

Recommendation:

The very nature of a controlled design is once that control is established, all changes must go through a board process (ERB and PCB), however the process can be made more efficient.

Recommend that engineering (CM discipline) review current standards and best practices and recommend an improved process to efficiently (quickly) screen changes and determine what other entities are impacted (thus their respective engineering review boards and control boards must approve the change). If a change does not affect an entity (technically or programmatically) they do not need to approve the change. Secondly, also as part of the screening process, recommend that several (or many) small changes can be handled at one time on a single change package Thirdly, the chief engineer (ERB chair) and project manager (PCB chair) can establish with the CM function a set of criteria in the change process for a more streamlined out-of-board or reduced (ad hoc) board member approval, but that does not remove the fact that the design must be controlled and all changes accounted. Lastly, in the earliest phases of development, change control may be handled by agreement for one person to maintain “the drawing” or “the model” or “the requirements” on behalf of everyone involved.

4.8.3 Improve Change Process Turnaround Time

Description:

The CM change process took too long on the Ares Projects. The change process was excessively long in many instances for both the NASA design team and prime contractors for a variety of reasons, including long review cycle times as well as numerous and lengthy board deliberation.

Recommendation:

Recommend engineering (CM discipline) review current standards and best practices and develop improvements to the change process to improve the overall turnaround time. Potential changes might include precoordination (informal tabletops) followed by a shortened CM review cycle. Also, clearly and efficiently record and communicate resolved issues and change decisions to avoid revisiting them unless there is a significant impacting change.

4.8.4 Drawing Configuration Control

Description:

At the start and end of a design analysis cycle (DAC), the starting configuration was defined (by memo) and the ending configuration defined by the design definition document (DDD). However, there was no reference point for the “baselined” or official configuration as it was changing. There was no designation for the interim design points. For example, the DAC-2A start had a starting configuration, but as design packages were approved by the System Engineering and Integration Working Group (SEIWG), there was no running configuration reference. This was even more confusing when items approved by the SEIWG were held for funding or integrated vehicle decisions.

Recommendation:

Define product structure and configuration management scheme early in the program. (Example: Give the starting configuration a designation, such as DAC-2A v1.0, then as the design evolves and changes are approved, update the designation, as in DAC-2A v1.1 ... v1.xx.) This must be strictly adhered to to ensure program/project accuracy/consistency and efficiency. It is foundational to technical and programmatic success.

4.8.5 Software Configuration Management Process Not Followed

Description:

The software configuration management process specified by NPR 7120 was not completely followed. This prevented tracking of code development, which in turn affects information technology (IT) software security during development.

Recommendation:

Accountability and responsibility for the respective areas within a project need to become part of the culture/process when implementing a project.

4.8.6 Reaction Control System (RCS) CM and Data Management (DM) Approach

Description:

The RCS Integrated Product Team (IPT) implemented an approach for CM and DM to foster some level of control, consistency, and communication of decisions and system architecture for all IPT members. This process was good in that it resolved some miscommunications related to CM and DM. The provision of a single authoritative source (on the RCS Design and Data Management System (DDMS) site) for documenting the latest system architecture characteristics, accessible by all IPT members, would have been an improvement.

Recommendation:

When reviewing CM processes, standards, and best practices, recommend the center-level CM discipline leader review the CM/DM processes utilized by smaller projects, such as the Ares RCS team (at the IPT level), to see if there are unique processes that were used by a small project that better fit a smaller team.

4.8.7 Documents Written by Committee

Description:

Documents were allowed to be written by committee instead of letting individual authors have ownership. The positive of this approach is that everyone was allowed to have a say. However, the negative was that changes were made based on personal preference and the authors did not feel a sense of ownership.

Recommendation:

Recommend that one person be assigned as the document owner for any given document (may be the committee chair). That person should gather, understand, and take full responsibility for management and final content of the document.

4.8.8 Establish CM Discipline

Description:

The configuration and data management (CDM) discipline is most effective as an independent group, not embedded in the projects it supports. As an independent group they can administer consistent processes, maintain objectivity, and correct process execution errors without fear of reprisal. A management that is knowledgeable and accepting of CDM processes will alleviate time and effort wasted reevaluating proven processes. Management must be an advocate of the process, seeking clarification of issues from process personnel prior to judgement. Good CM practices, such as: one standard CDM plan, approval and chartering of boards, adherence to directives, use of audits, reporting techniques between program and project levels, should be worked at program/project initiation with CDM involvement. A strong CDM team with institutional backing is necessary for the success of MSFC programs/projects.

Recommendation:

Establish CDM authority independent of programs and projects. Standardize the CDM process. Redefine CDM placement in the MSFC organization such that they have support from an institutional level. Establish and require a CDM training course geared specifically toward upper management. A prime objective of this course is to understand the impact of engineering changes.

Suggested or Taken Action:

CM lead to review and ensure the CM authority is flowed down through MSFC Red Book (adjudicated by center director) and central authority is with an identified lead in engineering.

4.8.9 CM Define Core Processes and Standards for Programs/Projects

Description:

All managers must understand and support CDM processes. MSFC's CDM processes are proven, changing them can result in a certain amount of risk to data reliability. CDM processes should not be changed without just and verifiable reasons. Resources for CDM need to be adequate so that one person does not consistently perform multiple functions. During early project development, create and agree upon one CDM plan, and follow it.

Recommendation:

Require upper management to take a CM course tailored for them. Objectives of the course should include: process understanding that fosters enforcement, the importance of CDM process center-wide, the risk of not adhering to the process, and the different roles within CDM. Establish and clearly define roles, responsibilities, and authority in the program/project plan early in the planning phase. Ensure the program/project team, including elements, subelements, etc., understand and agree to board authority. Specific recommendations are: strengthen the screening function, limit the number of chartered configuration boards, develop a staffing plan to include each CDM role, use project CDM plan appendices to document element tailoring, and automate processes to minimize human influence.

Suggested or Taken Action:

1) CM central lead identified to establish standards for core engineering CM processses.

2) CM central lead to identify and establish standards for baseline program/project CM planning to establish costs and resource agreements.

4.8.10 CM Define Configuration and Interface Control Process and Needs

Description:

Change requests (CRs) were processed in several ways because we did not use the same CM tool for Constellation. Upper Stage used the DDMS software and had to input all Level II and III CRs into the system which added to our review time. Then we had to create new closeout steps to close out the higher level CRs in DDMS. All this created more work than was necessary.

Recommendation:

The entire program should use the same standards and tool for CDM. A state-of-the-art configuration and status accounting tool that interacts with Level II/III/IV/prime contractors, MUST be funded by the program to make CM a closed-loop system, including reactive IT support. Archival requirements must be established at initiation so as to identify data elements required during input. The tool should NOT drive the process; CDM stakeholders must be the authority. Training in the use of the tool is critical; make it mandatory.

Suggested or Taken Action:

Central CM lead define configuration control process flow and identify fundamental needs at interfaces.

4.8.11 CM Define Change Process and Responsibilities

Description:

Many times, as a sitting Change Control Board (CCB) Secretariat, problems arose due to the wrong personnel being present at the time of the screening, and/or the screening was breezed through too quickly, and the personnel present had no clue what the impact of the changes being screened would have.

Recommendation:

For future programs, the rigor to which change request screening is conducted is critical. We must improve this part of the process in future MSFC programs. The CM plan should require strong systems engineering input in the screening process to ensure that the correct mandatory reviewers are selected.

Suggested or Taken Action:

Central CM lead prescribe a standard schedule and work flow into appropriate planning for the change/CR screening process (pre-Project Control Board (PCB)) and also at the PCB, including identification of appropriate chair, participants, and CM support team.

4.8.12 CM Tool Selection and Final Decision Authority

Description:

Before a decision on a major tool is made, all stakeholders, especially users, should have input in the evaluation and selection process. For example, the update of the DDMS tool was almost complete before the Upper Stage CDM personnel were even aware of it. They were not asked to participate in what was needed to enhance DDMS for Upper Stage even though they were a major stakeholder in the tool. Sometimes upper management decides on the software tool to be utilized across the board but it does not meet the requirements.

Recommendation:

When selecting a major tool, require selection and evaluation input from all types of stakeholders prior to implementation.

4.8.13 CM Training

Description:

Proper execution of CDM processes requires trained personnel. CDM internal systems and methods can differ so that CDM experienced personnel require training when moved from one organization to another. Because this discipline operates at a steady level, having time to train new personnel can be an issue. The CDM organization needs to establish a training program that can be implemented with minimal impact. Choosing the best person for the change package engineer (CPE) function can be challenging. Often, the person most qualified technically is unable to understand or support the CM process. A standardized training program for CPEs would be helpful. Managers that assign the CPEs need to be aware of the expectations and use discernment in making these decisions. This does not preclude the technical expert from analyzing the change and associated comments.

Recommendation:

All personnel working within the CDM organization and/or having a direct interface with the CDM processes must be trained. This training should include reading and understanding all pertinent documentation, i.e., work instructions, plans, instruction on automated tools, and training for specific roles. Trainees must include all CPEs. Develop succinct training materials that will provide effective training in a reasonable amount of time. A CM mentoring and cross-training program would be beneficial and improve workforce versatility. Provide training or criteria to managers for assistance in choosing CPEs.

Suggested or Taken Action:

1) CM central lead establish guidelines for appropriate training for implementers (CM staff) and end users.

2) CM central lead to implement training through the center/engineering, with adequate timing before the program/project is running, and plan for ongoing training and refreshers through the program/project life cycle.

4.8.14 CM Standardized Directive Language

Description:

Consistency in directive writing from the top CCB down through the Element Control Boards is needed. We need clear actions that the Elements must work, rather than ignore, to perform actionable work or update affected documentation in a timely manner.

Recommendation:

Level II, III, etc., need to talk the same language, from discipline definitions (applicable documents, release, etc.) to exchange mechanisms (memos, agreements).

Suggested or Taken Action:

CM lead establish standardized directive action language.

4.8.15 CM Need for Status and Accounting

Description:

The value and importance of CM was not appreciated at all levels. No baseline status and accounting system was ever established to track the design baseline and the CR implementations. The baseline status and accounting system tracks the incorporation of changes and ensures that the baseline is updated with these changes. This system/function must be incorporated in a future vehicle design early in the design process and maintained through the life of the vehicle. Some Ares CM issues were: 1) reworking issues that have been worked to closure, 2) timely dissemination of decisions, 3) tracking the implementation of decisions, and 4) requirements versus process adherence.

Recommendation:

Good standard practice dictates the need to coordinate a proposed change with all stakeholders prior to submitting the CR. This practice should ease the CR process but does not negate the need for the CR process. In addition, each "level of review," i.e., branch, division, directorate, should work together to alleviate any conflicting comments prior to board meetings. Trade studies must be clearly documented and communicated for unified workforce understanding. Requirements documents should contain only the items that need to be verified.

Suggested or Taken Action:

CM lead to assess if current tool has CDM baseline status and accounting capability.

4.8.16 Baseline Documents from Top Down Early in Program

Description:

The Integrated Vehicle Ground Vibration Test (IVGVT) principle documents were built from the bottom up. The lowest level document, the test plan, was written first and the highest document in the test documentation hierarchy, the Ares Integrated Test Plan, was written last. This caused multiple rewrites of the IVGVT principle documents as the next higher level document was baselined. For example, originally all of the IVGVT team's roles and responsibilities were included in the test plan (Level V document). Later most of these roles and responsibilities were included in the new implementation plan (Level IV document) and the test plan had to be rewritten to eliminate redundant and irrelevant information. Still later, the Level III roles and responsibilities were moved to the new task plan and the implementation plan had to be rewritten in response. It would have been much more efficient if the documents were baselined in a top-down manner even if there are a significant number of TBDs (to be determined items) and TBRs (to be resolved items) so that structure to the project is provided.

Recommendation:

A project manager should baseline a project's technical and programmatic documents in a top-down manner rather than a bottom-up method as it will reduce costs. This method should be followed even if it results in a significant number of TBDs and TBRs in the parent documents as this method identifies to the project manager areas where the technical and programmatic requirements are incomplete and indicates where the project's schedule, budget, and technical fulfillment is at risk.

4.9 CULTURE

4.9.1 Lack of Face-to-Face Discussions on Technical Topics

Description:

Various teams (requirements, design, etc.) tended not to interface directly face-to-face with each other on a daily basis. Technical discussions occurred in lengthy emails taking more time than a face-to-face meeting and often the email discussions resulted in a misunderstanding of the intended message.

Recommendation:

Encourage more face-to-face meetings especially when technical issues need to be discussed.

4.9.2 Fear of Failure

Description:

There was an aversion to failure leading to suppressed technical innovation. We should not promote being sloppy or haphazard but there should be a freedom to experiment, fail, and then learn.

Recommendation:

There should be a shift in culture that would enable employees to be innovative. This culture shift is one of the MSFC center director’s three goals.

4.9.3 Engineering Directorate (ED)/Project Interface

Description:

Though Engineering did a great job capturing the scope and sequence of the work to be performed, the interface of ED/project office was rough in the beginning (roles and responsibilities).

Recommendation:

Need to partner with one another early in the development of the program. A clear scope of work statement prepared by the project and agreed to by engineering before the commencement of work by engineering would have minimized the startup issues.

4.9.4 Kennedy Space Center (KSC) Organizational Structure Confusing and Cooperation Lacking

Description:

The organization at KSC seemed to be a mix of Shuttle and Ares personnel. We spent a great deal of time with KSC trying to figure out the organization structure of KSC to understand who would support us. We actually had the KSC team meet with the Integrated Vehicle Ground Vibration Test (IVGVT) team in Huntsville which was essential. Initially it was the Shuttle folks that provided the support but as Ares progressed many of the Shuttle folks transitioned to Ares.

Recommendation:

To prevent confusion, future programs should assure that they have both the technical points of contact (POCs) (Shuttle) at KSC identified and also the associated NASA civil servant lead for a given project (in our case Ares).

4.9.5 Communication Barriers Due To Various Locations

Description:

The physical distance that separated team members was a hindrance to accomplishing work in the most efficient way. Changes would be made by the system group without involving or informing the design group of the decision. An example of this would be some of the cryo valve envelopes that were enlarged without design input.

Recommendation:

Move engineering to a common building or to within walking distance. Co-locate team members with the teams that they directly support.

4.9.6 Lack of Structural Analysts to Support IVGVT

Description:

MSFC did not have enough structural analysts to support IVGVT. So, much of this work was performed by engineers located at Glenn Research Center (GRC). This created a lot of extra work.

Recommendation:

Key core work should be performed in one location.

4.9.7 Teambuilding Activities Were Exceptional

Description:

Teambuilding activities on this project were exceptional. Lunches, picnics, IVGVTINI, etc., were organized activities that helped our group get acquainted and build camaraderie.

Recommendation:

Every project should incorporate outside activities such as these into their culture.

4.9.8 Multi-Level Communication Forums

Description:

Regarding communications from one level of the program to other external levels (for example, Elements at Level IV communicating with Architecture at Level II), there were no forums available to informally communicate and raise issues, concerns, suggestions, and other ideas.

Recommendation:

Top-to-bottom integration forums or integration groups (informal/informational sessions) including representatives from the highest and lowest levels of the NASA programs, projects, and elements should be considered for future programs.

4.9.9 Pre-Coordination with Prime Contractor is Beneficial

Description:

First Stage engineering encouraged precoordination among NASA and Alliant Techsystems, Inc. (ATK) contractor partners which allowed us to work out issues as they arose. This was not the case in other projects where direct contact with contractors was discouraged.

Recommendation:

Encourage coordination between the NASA design team and the prime contractor to keep issues to a minimum.

4.9.10 Branch Chief Rules and Governance Understanding

Description:

Line management (branch chiefs) at GRC got involved late in the game – not well connected upfront, then switched to approval authority role later and had a lot to catch up on. They seemed to have a hard time understanding Constellation rules and governance vs. GRC or Headquarters documents. This was very evident in the drawing approval process. Despite having released specifications through Engineering Review Boards, the specs really got scrubbed at the time of drawing approval .

Recommendation:

Branch chiefs should be well versed in applicable program rules and governance especially when operating in an approval authority capacity.

4.9.11 Too Many Processes

Description:

Having too many processes and too much documentation can and did cause the team to spend more resources proving that they did do something than it took to do the job itself. This is an issue of trust and control. There has to be a balance between what needs to be controlled and what doesn't. There appeared to be limited trust at all levels of the program. The term "trust but verify" is often heard but the problem this causes is that the verification then becomes a huge task. If trust is truly given and some verification is required, then the verification should be simple enough to not take more resources than the initial effort.

Recommendation:

Determine and clearly communicate what really needs to be formally controlled and what does not.

4.9.12 Build Trust Between NASA Team and Production Contractor

Description:

The culture needed to support a production contractor that was never fully embraced within the MSFC engineering teams. A level of trust and open communication was missing from the beginning as evidenced by the differences in the technical and program baseline and it never seemed to be resolved to bring the two into agreement. Roles and responsibilities between engineering and the production contractor were constantly having to be clarified.

Recommendation:

Work to build a better working relationship between engineering, project, and production contractor.

4.10 DATA MANAGEMENT (DM)

4.10.1 Design and Data Management System (DDMS) Limitations in Drawing Release

Description:

The adoption of both a new drawing management tool (DDMS) and model-based design by the Upper Stage Element seemed like a good idea, but resulted in a misrepresentation of the design progress to the Ares and Constellation Program (CxP) community. The release process for drawings was not efficient which limited the amount of drawings that were released. There were also issues with the life cycle states (e.g., the integration and assembly team could not see proposed design changes in some subsystems/areas) which limited timely feedback on proposed design changes.

Recommendation:

The drawing release process, including roles and responsibilities of all involved parties, should be developed and documented in an Organizational Work Instruction (OWI) prior to System Requirements Review (SRR). All the DDMS life cycle states needed to support this process should also be defined. The final system should be tested prior to implementation.

4.10.2 Pro/E Synchronization Between Centers

Description:

The Internet firewall protections may have contributed to issues/differences found in Pro/E software settings as MSFC and other NASA centers attempted to share computer-aided design (CAD) data. Any changes to the configuration settings had to be manually provided. No good way existed of identifying which changes needed to be provided to them.

Recommendation:

Develop a method to ensure all Pro/E accounts are working with the same configuration settings.

4.10.3 DDMS Collaboration Issues

Description:

DDMS was awkward and difficult to navigate. It was very cumbersome to use as a collaboration tool. There was limited accessibility to data between different projects and routing issues (e.g., review documents were forwarded to my branch manager rather than to me).

Recommendation:

Segmented project structure of DDMS should be addressed to reduce accessibility issues. Review documents should be routed directly to the reviewer, rather than a supervisor.

4.10.4 Design Data Difficult for Integrated Vehicle Ground Vibration Test (IVGVT) to Acquire

Description:

Preliminary test article design data were difficult to glean from Element Offices due to the fear that a particular preliminary design would be thought of as the final design and interfaces would be set in stone. The Upper Stage Office (USO) was more open to sharing their preliminary test article design data than the First Stage Office (FSO). This was attributed to the culture and high level of participation of the USO representative in IVGVT meetings.

Recommendation:

Invite all affected teams to participate in early test definition meetings. Also test developers need to communicate that they can accommodate design changes that are expected for systems still in the design cycle.

4.10.5 Duplication of Effort on Documentation Tasks

Description:

Sometimes documentation/transmittal memos of released products seemed like duplication of effort. There may be no way around having two memos, as the group developing the Vehicle Integration (VI) products (often engineering) will always have a signed memo through their line management to release it to the project office. One of the issues we had was that the approval/release process wasn’t formalized until after Preliminary Design Review (PDR), and by that time, each of the product developers already had been the “releasers.” The developers’ memo was always included with the dataset in the library.

Recommendation:

Potentially an engineering organization could reuse another center’s or contractor’s transmittal memo to the project for their transmittal, in order to reduce duplication of paperwork. A dissenting opinion stated that there’s no way around having two memos, as the group developing the VI products (often engineering) will always have a signed memo through their line management to release it to the project office.

4.10.6 Engineering Release Plan

Description:

The Engineering Directorate staff performing the detailed design role needed their own disciplined change control and data management processes and staff. There seemed to be confusion at times between the roles of people supporting engineering (EV94) and those who were direct support to the Ares Projects Office.

Recommendation:

Authority and responsibility. Develop an engineering release plan that documents the process engineering should use internally, prior to release to the project.

4.10.7 Establish DM Discipline

Description:

All personnel must adhere to standard data management processes; failure to do so results in products of poor quality and incomplete documentation of final agreements. Issues with adherence to data management processes should not be worked in boards/meetings as this typically results in a universal belief that DM processes are inconsequential, thus creating a bigger problem for a typically manpower-limited DM team. Accepting incomplete products in “public” forums reduces motivation to provide quality products and encourages others to repeat that behavior. Ensure team members know and understand DM processes and requirements. In particular, delineate the process for the submittal of the different categories of data. The use of the Integrated Collaborative Environment (ICE) Windchill tool was cumbersome and stagnating, causing workarounds. Tool maturity and capabilities should be considered prior to selecting a tool for whole project use.

Recommendation:

MSFC should investigate process changes to better coordinate in DM business processes and their information technology implementations. Data management processes should be standardized and implemented institutionally. All aspects of DM should be considered required unless deviations are officially approved and documented. Process owners should participate in process definition and the development and implementation of process deviations.

Suggested or Taken Action:

1) DM lead review and ensure the DM authority is flowed down through MSFC Red Book (adjudicated by center director) and central authority is with an identified lead in engineering.

2) DM central lead identify and establish standards for core engineering DM processses to be authorized and funded by the center.

3) DM central lead identify and establish standards for baseline program/project DM planning to establish costs and resource agreements.

4.10.8 DM Training

Description:

Training did not keep up with new tool development and implementation. Too much time was wasted explaining to individuals instead of groups.

Recommendation:

New tool development and implementation should include sufficient mandatory group training.

Suggested or Taken Action:

1) DM central lead establish guidelines for appropriate training for implementers (DM staff) and end users.

2) DM central lead to implement training through the center/engineering, with adequate timing before the program/project is running, and plan for ongoing training and refreshers through the program/project life cycle.

4.10.9 DM Data Requirements Process

Description:

In-house data requirements documents should be reviewed and approved individually by a board or panel. They should not be reviewed as a package via a change request to the data requirements list (DRL) because the CR process takes too long. On Ares I most of the documents were completed before their individual data requirements description (DRD) had been approved via the CR process. An individual DRD review and approval process will allow the timely review of new proposed products before significant resources are expended on their development. Such an early review would also allow for the early identification of any problems (content overlap or holes) that may have occurred.

Recommendation:

A board or panel should be established to review DRDs individually. Until the DRD that defines the content of the proposed product is approved by the board, no significant resources should be committed to the development of the product. Also, when a product is put forth to be baselined, the DRD for each product should be used to determine if the product has been adequately developed.

Suggested or Taken Action:

DM lead locate defined process for approval of DRD prior to document development.

4.10.10 DM Tool Selection and Final Decision Authority

Description:

The information technology (IT) systems have a direct and continuous influence on daily work because these systems/tools house data and are used by the whole team. Tool selection must be timely according to program/project maturation and include the DM process owners as well as customers. Clearly defined and communicated schema for tool operation, such as populating, must be known prior to use.

Recommendation:

More attention and detailed planning needs to take place prior to the deployment of such a tool. In other words, the basic project-specific implementation of a tool needs to be mapped out and implemented in advance. Recommend that MSFC institutional DM lead define the process for IT tool selection and have the final decision authority. Recommend a clearly defined and communicated schema for the requirements management tool prior to deployment.

Suggested or Taken Action:

1) DM lead is final decision authority on DM tool selection. (Confirm this is clearly stated in MSFC Red Book and flows from NASA/MSFC policy.)

2) Central DM lead defines process for tool selection. (Lessons learned recommend requirements for tool are based on defined DM.)

4.10.11 DM Plan

Description:

The requirements management process should be documented in a data or requirements management plan in the beginning. Then, you should adapt the tool to fit your process rather than relying on a tool to drive your process for you.

Recommendation:

MSFC should investigate and document process changes to better coordinate in data management business processes and their information technology implementations.

Suggested or Taken Action:

Upon completion of KI-DM-002, DM lead will document in the engineeering DM plan or other appropriate document.

4.10.12 DM Early (First) Data Protocols

Description:

Constellation DM seemed to have been in flux all the time. It lacked leadership. This lack of leadership led to many different use cases of the same tools, causing confusion as to the level of data available and the data's integrity across the program. Data is NASA's most important product. When a DM Working Group was stood up a few times, it was disbanded and rolled into a CDM Working Group. After this occurrence, it almost always lacked teeth to accomplish anything. Baselined DM requirements were obsolete. Project DM seems to have led program DM.

Recommendation:

Until it is recognized throughout the agency that good data management MUST be established at the very beginning of a program/project, there will never be an authoritative, trusted mechanism for integrating data across projects or centers. A larger implementation team with more training earlier in the project would have prevented many of the initial and long-term problems.

Suggested or Taken Action:

Early in the program life cycle the DM lead must establish basic data protocols and interface needs, and require that a DM plan be submitted for baseline no later than SRR.

4.10.13 DM Steering and User Group

Description:

An Ares Cradle implementation team was formed at MSFC so that there would be one voice coming from Ares Levels III through VI interfacing with the Johnson Space Center (JSC) Constellation Program (CxP) Applied Systems Engineering Team (ASET). That tended to be a bottleneck and there was not a good flow of communication coming down from that CxP ASET group to the lower levels.

Recommendation:

New tool development and implementation should include sufficient mandatory group training.

Suggested or Taken Action:

DM lead work with functional leads at center level to establish plans for process definition, tool identification, and invocation of appropriate user groups to steer implementation. (Recommended emphasis on this action is to plan the process, assess the tool for that process, and then implement with user group input.)

4.10.14 Standardization of Software Tools Across Levels, Projects, and Programs

Description:

The use of multiple DM tools (Windchill by Vehicle Integration; DDMS by Upper Stage) from level to level caused multiple problems. Data access and retrieval was limited by using two systems that were incompatible with each other. This incompatibility led to other problems associated with change management, such as causing cumbersome data flow of change packages from level to level (e.g., change packages had to be individually transferred between the two incompatible systems). Each of these DM tools was further limited by the compartmentalized project structure, requiring the user to obtain multiple permissions in order to access needed data.

The use of multiple requirements management systems and processes created multiple problems. Some groups used Cradle (MSFC) and some groups used Dynamic Object Oriented Requirements System (DOORS). Some groups used Task Description Sheets (TDS) and Constellation Analysis and Integration Tool (CAIT) and others did not. All of this made data management and data transfer very cumbersome and inefficient.

Recommendation:

Use only one data storage/life cycle management tool and only one requirements management tool across the entire project. The structure of these tools should be planned and agreed to prior to implementation. Establish and implement consistent associated DM/data transfer processes across the entire project.

Suggested or Taken Action:

Configuration management (CM)/DM manager working with Space Launch System (SLS) Program Office (team) to establish one data system across the program. Coordinate inputs from the model-based tools study to ensure their recommendations are addressed.

4.10.15 Improvements to the Data Exchange Process

Description:

The TDS/CAIT process was not well defined, especially in the area of final distribution and confirmation of released data products. For this reason, memos were used to accomplish this formal documentation. Also, the DRD/DRL process seemed to have quite a bit of overlap with the TDS/CAIT process, which further added to the confusion of the processes.

Recommendation:

Establish a clear vetted process defining data request/exchange between parties. Additionally, this established process should include the capability to distribute and document the “final confirmation of deliverables,” and not require an additional memo.

Suggested or Taken Action:

Recommend verifying that CM/DM manager is currently working this with SLS Program Office to develop updated DRLs. No update to CAIT capability recommended, but make sure the need is addressed in the data requirements process.

4.10.16 Data Access

Description:

All the data/documents in Windchill and DDMS were split up into “projects” which made documents difficult to locate. These “projects” all required privileges that were granted and managed by different points of contact (POCs) in different groups. If you did not have the correct privileges, not only could you not open the document/data, you could not see that it existed. Much time was wasted attempting to figure out who to contact to get required privileges to access the correct "project" to locate the data/documentation for which you were searching. Also, once you found the data, there was no guarantee that it was the latest version.

Recommendation:

Full access to DDMS or Windchill (or whichever tool is used on future programs) should be granted to all NASA civil servants and support contractors at the project level and higher. Also, full library of baselined documents, complete with updated document tree, should be accessible in one repository to all working on the program/project. Also, MSFC standards (DM rules and requirements, including released for technical use (RFTU) and released for information (RFI)) should be followed when implementing any web-based DM tool, and necessary steps should be taken to reduce and/or eliminate the multiplicity of data (allocation of resources to archive/clean as we go).

Suggested or Taken Action:

Recommend the MSFC data management (DM) function stand up the data portal for the SLS Program Office (and any project/program).

The DM lead shall establish within the DM plan the minimum specific access lists that allow all members of a program to access all program data with appropriate safety and security protocols.

4.10.17 Sensitive But Unclassified (SBU) Classification

Description:

The SBU classification of data was applied across the program/project in an inconsistent manner. Many times, people just made blanket assumptions that everything was SBU, with no rationale, just to be on the safe side. This "err on the conservative side" mentality caused many items that probably didn't contain sensitive data to be classified as SBU. The controlling authority of who defined what should or should not be SBU was also not clear. The complexities introduced by inconsistent SBU classification, and the associated walling off of data between teams, caused problems in the coordination of information and product transfers.

Recommendation:

Standardized guidelines should be used to clearly define what constitutes the classification of data as SBU. Possibly create an SBU working group, with representatives from various organizations/levels to help define these guidelines. The controlling authority that will use these guidelines to determine what will be classified as SBU data should be clearly defined. Also, SBU training should include more of what constitutes SBU data, in addition to how to handle that data.

Suggested or Taken Action:

Recommended action to SLS Program Office to perform one of the following options:

1) Nominate a Designating Official to consistently determine SBU content or …

2) Establish an SLS Program Office policy for various document types to be designated SBU. (The latter might be handled by project memo or a data requirement.)

4.10.18 Standardized Document Formats vs. Native Data

Description:

Project CM group/team made it difficult to deliver/publish updates to documents. Often we had unclear directions or a moving target on document formats, figure formats, etc., that made it cumbersome to get documents out on Windchill for other Disciplines and Elements to utilize.

Recommendation:

Standardize or configuration manage document formats, figure formats, etc., so that documents can be released in a timely manner out on Windchill for other disciplines and elements to utilize. Comprehensively populate DRDs with field definitions that distinctly specify the construct of the document. Most DRDs have generic single line field inputs. An alternate viewpoint is to take data in its native form and focus on integrating it into a common form at the systems engineering and integration (SE&I) level, if required.

Suggested or Taken Action:

Recommend MSFC CDM function plan to provide document templates and coordinate with document owners as they are assigned to their respective documents.

4.10.19 Process, Standards, and Guideline Creation

Description:

Since being hired into my position, I have been impressed with our method of creating processes, standards, and guidelines. These are helpful to new and existing IMs, as well as our customers and are vital to the work that our IM team is (or should be) striving to accomplish; efficiency and customer service excellence. I believe this method should continue, and that foundation be built upon in the future.

Recommendation:

Recommend that internal methods for creating processes, standards, and guidelines be continued and elevated to higher levels. This foundation should be built upon for future programs.

4.10.20 Low-Level Design Requirements

Description:

The Structures and Thermal (S&T) website contained some low-level design requirements information, but didn't necessarily communicate that information to the component design teams (CDTs). The dependency on websites did not insure data was actually being communicated.

Recommendation:

Require a forum to communicate low-level design requirements once they are approved. An example would be to communicate to all the CDTs once a Structures and Thermal Engineering Board (STEB) has been created and/or approved.

4.10.21 Retrieving Audio Decision Data

Description:

Most major decisional meetings are recorded. Many people don't realize how difficult it is to actually obtain a recording of a meeting. Conflicting reports over what was said/reported in meetings is the source of much confusion regarding project decisions.

Recommendation:

Post these in an accessible place for review, i.e., Windchill.

4.10.22 Records Management Plan Complete Early

Description:

A records management plan should be in place at the beginning of the program. If this had happened, then the record inventory needed to close out a program and archive records would be fairly simple. As records are created and updated, the record inventory should be kept up to date.

Recommendation:

A records management plan should be in place at the beginning of the program.

4.10.23 Information Manager (IM) "Certification" Process

Description:

It seems there were many attempts to create an IM "certification" process (that would be earned and maintained) – perhaps an IM curriculum should be determined.

Example: IM has a request from customer to delete a previous document "iteration" within ICE Windchill. The IM is new and does not understand Windchill's method of iterating a document. The IM believes they are completing the request by checking the box by the document and clicking delete, thus deleting the entire document object. Later the customer returns asking

"Where is my document?!?!" Valuable time is lost due to the new IM and existing IMs being forced to retrieve and reinsert all iterations of the document.

Example: DDMS 5.0 was recently released, and IMs were not given the training necessary before the release date. We should be trained before the general user.

Recommendation:

Recommend creating an IM "certification" process that would be earned and maintained. Suggest that an IM curriculum should be determined which focuses on initial training in an information manager's primary role with expanded training to all roles over time.

4.10.24 Customer Feedback

Description:

It is extremely helpful and encouraging when our customers let us know, via any mechanism, when we are meeting/exceeding their requirements. If we IMs are not aware of our positive or negative relation to our customer, we are unable to continue our manner of service, or vice versa, remedy whatever negative processes we may have. Perhaps we can come up with a survey for our customers to fill out so that we can pinpoint areas for improvement.

Recommendation:

Recommend creating a mechanism for positive customer feedback to flow up to higher levels. Suggest a survey mechanism for customers that would also allow for process improvements.

4.10.25 Information Management Process Improvements

Description:

Quick turnaround times for user access requests are important. Standardization is important in information management customer communication. Obtaining status information to support tool access authorization was a cumbersome manual process.

Recommendation:

Recommend that information managers continue to strive for providing service as quickly as possible. Suggest that any potential performance metrics or standards be considered for potential negative impact to customer service timeliness before implementation.

IMs of the future should maintain the practice of using email templates. Recommend having a "one place shop" guideline/standard to list the most commonly used email templates so information managers would not have to search for the process first to find the template used.

Recommend identifying or adopting an automated procedure for ensuring that user status information which supports tool access authorization is updated whenever user status changes. Current methods are inaccurate and not easily verified.

4.11 ENGINEERING PLANNING

4.11.1 Communication of Design Reviews

Description:

Design reviews were not adequately communicated and organized in some instances. Meeting notices were not always utilized, or if utilized, not always maintained. Review data packages were also often incomplete, dated, or hard to access on many occasions.

Recommendation:

Recommend system engineering establish or update minimum guidelines for the technical reviews. Systems engineering must specifically establish the lead time for a released technical review plan and the review package content and submission procedures.

4.11.2 Role of Engineering Management

Description:

Engineering management did not play a major role in this program until it was too late and then it became a reaction mode.

Recommendation:

Engineering management needs to make its presence known in the beginning of the program in order to help shape and/or understand the role engineering is expected to perform.

4.11.3 Poorly Defined Systems Engineering Roles and Responsibilities

Description:

The systems engineering roles and responsibilities were ill-defined in some cases.

Recommendation:

There should have been a systems engineer or panel in place to enforce the number of measurements allowed on the vehicle and not have it left to subsystems to fight over the measurement allocation with each other. Should have set it up for measurements.

4.11.4 Systems Engineering Leadership

Description:

Systems engineering leadership requires experienced personnel with a broad depth of knowledge. It appeared that on Ares we were often “seeing who was available” instead of being able to put the right personnel into the job.

Recommendation:

Perhaps bringing in some engineers from other centers to assist us in the area might be beneficial. Also, additional training in SE&I before the next program begins could be beneficial. Having experienced system engineers and following the processes would eliminate a lot of problems.

4.11.5 Electrical Disciplines Being Split Between Two Departments Was Problematic

Description:

Initially, having certain electrical disciplines such as electrical integration split between the Space Systems Department and the Spacecraft & Vehicle Systems Department was very problematic.

Recommendation:

When MSFC tweaked the engineering organization to recombine those split electrical disciplines, it was a great help. It enabled efficiencies in work load distribution and enabled consistent philosophies to be applied to the various elements being supported.

4.11.6 Organization for Ares Work Was Not Efficient

Description:

Organization for Ares work was not efficient. For example, a Space Systems Department, engineer doing work for Ares reported results to the Spacecraft & Vehicle Systems Department, lead organization as opposed to reporting to a single project lead.

Recommendation:

In the future, the launch vehicle project office should have a lead that interfaces with each department so that employees are recognized for their contributions and appropriately included in meetings and reviews.

4.11.7 Realistic Plan for Reporting to Project Needed

Description:

It often seemed that the monthly review was just a repeat of the weekly inputs.

Recommendation:

It is important to negotiate a realistic, meaningful plan for reporting from engineering to the project.

4.11.8 Critical Test Programs Managed at Department Level

Description:

Integrated Vehicle Ground Vibration Test (IVGVT) was managed out of a branch-level organization which limited participation and authority across engineering.

Recommendation:

Consider managing high-visibility, high-cost critical test programs (such as IVGVT and integrated stage test article (ISTA)) at the department level. This might improve participation across engineering and might carry more authority.

4.11.9 Technical Review Preparation

Description:

It seemed we spent an excessive amount of time preparing for various reviews (Constellation, Ares, IVGVT, etc.). Both Ares and IVGVT commonly used subject matter experts (SMEs) and consultants. This required frequent interruptions to test execution to prepare for these events. While the SME inputs are valuable, is it possible to better integrate them with the team rather than having the team stand down to prepare and brief charts? Their input should be throughout. This may be a result of personnel not recognizing during planning the amount of time it would take to support the NASA mandated reviews (System Requirements Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR)) as NASA has not done a major development program like Constellation in 25–30 years.

Recommendation:

Before additional reviews are planned, recommend consulting the entire team regarding purpose, frequency, and timing of reviews and other team events.

4.11.10 Interbranch Conflicts

Description:

EV82 Stage Analysis Branch and EV92 Systems Analytical Integration Branch, both under EV01 Spacecraft and Vehicle Systems Department, brought conflicting recommendations on Mass Allocation to project-level boards. Branches within the same department should bring a unified position to program/project-level boards.

Recommendation:

Engineering should provide a unified response to the program-level boards.

4.11.11 Quarterly Review Works Well

Description:

The quarterly review was an excellent opportunity to show the baselined design.

Recommendation:

Continue quarterly reviews so design changes can be shown in an open forum.

4.11.12 Discipline-Based Engineering Organization

Description:

A discipline-based engineering organization would have been a benefit to this large in-house project. If assembly engineering had been part of a design division, then the issue of who dispositioned routing and placement would have been more clearly defined. Also, this would have minimized issues regarding interaction between design and the disciplines such as interface loads and assembly sequences.

Recommendation:

Recommend instituting a discipline-based engineering organization for future in-house projects.

4.11.13 Lack of a Team Environment

Description:

Work across disciplines and subsystems was difficult due to internal focus and independence. Subsystems, branches, and divisions didn't work together. Systems and design groups were too separated. Team environment between these levels was lacking.

Recommendation:

Combine system and design groups. Have a chief engineer to make the tough decisions when needed and to provide cohesion to the work.

4.11.14 Inconsistencies in Documentation and Review Processes

Description:

It seems that almost all of the subsystems did their documentation differently which made cross functional reviews much more difficult because there was so little consistency between how each subsystem's documents looked. Also each change package engineer (CPE) in charge of reviewing a document handled comments differently, which made the comment consolidation and review process more difficult and time consuming.

Recommendation:

Future programs should maintain consistency in documentation and review processes, even down to the subsystem level.

4.11.15 Inadequate Review Period

Description:

In many cases the normal review period would be reduced by half or more of the standard review period. This did not allow for a thorough review.

Recommendation:

Adequate time should always be allowed to review documents, drawings, etc.

4.11.16 Engineering Review Board (ERB) Document Review Distribution

Description:

Once the ERB began distributing documents to all the ERB members it was very helpful. Sometimes an organization had a valuable input that might have been missed. Before this change was made, ERB members would find out at the ERB that they needed to review a document that was not sent to them.

Recommendation:

Distribute documentation to the appropriate ERB members for review.

4.11.17 Product Definition Needed

Description:

There was much documentation developed due to a data procurement document (DPD) call rather than a true need at a given time. This was the case in several of the documents delivered for PDR which were basically blank except for a table of contents. Additionally, many documents were delivered (design and analysis) that were not reviewed by the SME. There were many prime contractor deliverables that were not sufficiently defined in data requirements descriptions (DRDs), which led to confusion of required content by the contractor.

Recommendation:

We should only require data to be submitted when appropriate and when someone actually needs the data. Many of the DRDs need to be updated to better reflect the data needs of the current center organizations and detail needs.

4.11.18 Continue to Use the MSFC Review Item Discrepancy (RID) Tool

Description:

The “MSFC RID tool” itself was great during Ares Projects execution. Additional functionality that has been built into the tool has facilitated the review process tremendously.

Recommendation:

Recommend the center continue to use this RID tool, or improved version, for future programs/projects.

4.11.19 Changes of Technical Review Process

Description:

It seemed like the review process and RID systems changed for each technical review cycle (SRR, System Definition Review (SDR), PDR, CDR).

Recommendation:

The technical review process should be controlled at the center level and not by the project. The project is only responsible for supplying content and following through on the process.

4.11.20 Product Maturity Levels

Description:

The Ares I SRR and PDR entrance and exit criteria were relaxed to unacceptable levels. For example, excessive time was required to finish the baseline of the verification plans during the Component Design-Technical Interchange Meetings (CD-TIMs). At Vehicle SRR the interface requirements documents (IRDs) were an entrance criteria but the project decided that they did not need them. Also it seemed as though many requirements were nebulous even after SRR.

Recommendation:

The maturity of program products should be appropriately assessed and pass unbiased judgment before proceeding with major efforts. Data reviews (SRR, PDR, CDR) should not happen based on an arbitrary timeline but on design maturity and success criteria.

4.11.21 Ares Element Review Schedule

Description:

The PDR for Upper Stage Engine, Upper Stage, First Stage, and Vehicle Integration was spread out over 2 years.

Recommendation:

Recommend future programs/projects work to synchronize design reviews that build upon one another. (It may not even make sense to have formal design reviews below certain levels in the product structure.)

Recommend that the review content and format needs to be established and strictly adhered to by all participants very early in the program, and revisited immediately after review completion for updates/improvements for the next review cycle.

4.12 FACILITIES

4.12.1 Involvement of Facility Experts

Description:

Upper Stage had an excellent partnership with the MSFC Facilities. Having a “resident” facility planner on staff and delegating most of the Facility project management role to the center paid huge dividends. Reporting up and out of the center was streamlined and fully coordinated between parties. This overcame program/project managers who were lacking in needed experience with the Construction of Facilities (CoF) process (budget, planning, design, and construction). Other lessons we learned were:

There are long-lead times when buildings need to be modified or removed. Environmental and historical experts have to be consulted on the historical value of the building or environmental contamination and disposal issues. Lack of access to production contractor tooling drawings and other information prevented accurate facility interfaces from being developed and also led to problems during construction which could have been avoided. Lack of an on-site Architect/Engineer (A/E) with strong knowledge of site specific facilities posed a significant hardship in supporting planning/design activities.

Recommendation:

The program/project needs to understand the importance of early involvement from the Facilities personnel. Several suggestions for elevating the understanding of facilities needs were made including:

- Provide a list of points of contact (POCs) for facility information at the centers so information can be requested for tooling designs or other user related needs.
- Hire CoF educated project/program managers or have training or a technical interchange meeting to educate the project managers on the laws, regulations, lead times on projects, and contracting for CoF.
- Have a “resident” facility planner on staff and delegate most of the facility project management role to the center. Any program/project contract that involves and/or may involve facilities in anyway should be reviewed by the center’s Facilities office before being released. Any budgets for facilities should come from the facilities offices and should be updated and reported by the same.
- Continue in future projects with the coordination of facilities with the center Facility managers and stakeholders involved. Share best practices of the MSFC Facility manager for streamlining and coordinating.
- Get the Environmental and the Historical folks involved early in the planning process. Provide for their continued involvement, as things will change and new environmental

issues or impacts will need to be evaluated after the planning stage and during design/implementation.

- Form an agency review team made up of facilities cost, design, and construction folks that do critical reviews of facilities that are large and complex before they go into design.
- Improve access to drawings for all parties. Michoud Assembly Facility (MAF) and MSFC facility drawings need to be accessible to allow Manufacturing and Assembly to plan for their equipment and to avoid unnecessary facility modifications. Define facility design/drawing packages as a deliverable to the production contractor. Define production contractor tooling drawings and other information to assure accurate facility interfaces as a deliverable to the government.

4.12.2 Facilities Planning and Control

Description:

Identifying infrastructure requirements through multilayered integrated product teams (IPTs)/construction project teams (CPTs) (and owner) is difficult. The approach to planning for facilities early in the program was that facilities design and construction would just somehow show up on schedule and within the budget. The program schedule did not facilitate a proper facilities acquisition process and the budget was inadequate. Once monies have been reprogrammed into CoF dollars, movement back to program dollars is not easy and is very disruptive. Facility budgets developed for CoF projects are not the same as design budgets, they are not as flexible.

The Facilities team was unable to support all integrated project teams, which limited estimating support. There was confusion from the projects and engineering about the CoF call letters from the logistics manager.

Recommendation:

Facilities Planning suggestions:

- Set the Construction of Facilities Team and its hierarchy (Level I to Level IV) early in the program, so the lower levels have guidance on planning, budgets, levels of approval, requirements development, schedule, and input into the Programming, Planning, Budgeting, and Execution (PPBE) process.
- Designate a project lead/manager for individual construction projects to coordinate between Facilities and Tooling when joint occupancy is required.
- Include Facilities in trade study development and decisions (initial planning and throughout PPBE process).
- Clearly document the user interfaces on all facility designs so that later questions and concerns can be addressed appropriately.

Facilities Cost Management suggestions:

- Establish a clearly defined facility budget planning process with support from the Facilities Management Office. Due to lack of flexibility from institutional facility budgets, project funding can be used for facility development, as long as applicable requirements are met.
- Consider joint occupancy to benefit individual construction projects.
- Maximize use of local projects and special test equipment (STE) type work to minimize CoF requirements.
- Once Facilities programmed amount is approved at HQ, then the element and centers should manage the contingency through the change management process.
- Control CoF and project-controlled facility budgets in the project, not at the program or agency level.
- Train the Facilities team in cost estimating to provide information to the resource people.

4.12.3 Test Facility Readiness

Description:

After Shuttle testing was complete, Test Stand 4550 was effectively abandoned in place. This resulted in a significant investment by the Ares Projects to remove the abandoned-in-place Shuttle STE and to upgrade the building to bring it in compliance with current building codes. If the building had been brought back to a “blank slate” configuration after the Mated Vehicle Ground Vibration Test (MVGVT) and had been kept in a state of readiness over the past 30 years, significant savings would have been realized by the project both in money and time.

Recommendation:

Recommend that future test programs include in the project baseline time and funding for the decommissioning of test stands at the completion of the test program prior to turning them over to the resident center for sustainment.

4.13 FLIGHT TEST

4.13.1 Test Facility Age Problems – Deicers

Description:

The center is in dire need of a high-capacity mobile crane (greater than 300 tons). The concrete on the north apron needs to be replaced, particularly in areas where motor segments will be staged. The pneumatic suspension system alternative and mastclimbers for the Integrated Vehicle Ground Vibration Test (IVGVT) test article access are examples of alternatives used as backup plans.

The Ares Projects was preparing to use Building 4550 for the IVGVT tests that had been used by both the Saturn and Shuttle vehicles for their modal tests. Corrosion at the building column joints resulted in an extensive column joint inspection/repair operation for the crane load path. Corrosion may have resulted from use of salt as a deicing agent for Building 4550.

Recommendation:

Include a high-capacity mobile crane (greater than 300 tons) and a replacement concrete north apron in plans for the test program for upcoming vehicle testing. Also, determine a noncorrosive deicer and add notes in the facility operational procedures to use a noncorrosive deicer to prevent similar corrosion problems.

4.13.2 Test vs. Analysis

Description:

Not all test conditions can be simulated. Both test and analysis are necessary to verify requirements. When the test conditions show that analysis could predict an outcome, confidence is gained that other non-testable outcomes should also be valid. Several development tests were eliminated due to funding constraints. This limited engineering insight and opportunity to work out issues with real hardware.

The emphasis on hardware, testing, and incorporation of vendor information was valuable in providing hardware experience for integrated product team (IPT) members, higher fidelity in the system and component designs, data for model and analysis tool anchoring, and overall enthusiasm for the project. It helped separate issues from nonissues, and helped build personnel skill sets for future testing.

Recommendation:

Delegate authority at the engineering branch level to determine when analysis may be a cost-effective and good solution as an alternative to test. Ensure that eliminated tests have alternative ways of gaining design insight. Recognize that test and analysis planning and development have many positive benefits beyond just gaining test data.

4.13.3 Cross-Program Test Planning and Coordination

Description:

IVGVT wasn’t completely engaged with the Orion modal test planning and with flight test developmental flight instrumentation (DFI) planning. Some accelerometers were expected to be inaccessible and planning needed to be done early to ensure inaccessible accelerometers were installed prior to being mounted. The “Needs Matrix” that was developed to identify deliverables needed was very valuable.

A continual disconnect was apparent in the relationship between the Flight and Integrated Test Office (FITO) and Vehicle Integration (VI). Level II Constellation Program had delegated responsibility for verified models and loads to VI. VI should have been coordinating with Level

II and directing FITO regarding test requirements. Instead, FITO was coordinating with Level II and VI was answering to FITO, despite FITO and VI being peers on the organization chart.

Many loads, stress, and stability assessments have to be done early in the special test equipmrent (STE)/ground support equipment (GSE) design phase to provide a reasonable design space for designers. When the vehicle is in a rapid state of design change, performing assessments becomes problematic.

Inadequate participation was realized from engineering organizations for IVGVT and the integrated stage test article (ISTA) due to these tests being controlled from within a peer-level engineering organization. Structural test planning was impeded by the lack of access to the stakeholder from the design team who was not concerned about testing until the Critical Design Review (CDR) was completed. This could have been corrected; in Saturn and Shuttle, discipline experts for elements were represented on site during tests.

The Operational Readiness Inspection (ORI) board should be the ultimate authority on test readiness. The ORI board needs to be consulted during facility preparation and for selection of contingency scenarios.

Some IPTs performed their own testing, resulting in overlap of testing efforts.

Recommendation:

Ensure test hardware developers engage early with test engineers to coordinate instrumentation planning. Develop a Needs Matrix early and maintain it to identify important information about deliverables. Try to keep all testing under one project organization. Define and document roles and responsibilities for the tests including those for stakeholders. Control test resources at a single point to avoid duplication of effort. And consider having high-visibility, high-budget tests managed at the ED01 level as an ED01 lead would have more authority. The test team needs to develop plans to ensure flight environments aren’t exceeded.

Address schedule items, for example:

Establish the ORI board early in the project and designate them as the ultimate authority on test readiness. Defer commitments to a fixed schedule for STE/GSE builds until the vehicle design has stabilized. Also, ensure that testing stakeholders are available to coordinate with test planners prior to CDR. Finally, make sure that test plans identify the need for elements to provide discipline experts on site for test conduction.

4.13.4 Purpose of Testing/Test Output

Description:

The Ares I-X Flight Evaluation Plan identified distinct study tasks and each one incorporated specific data needs. Creation of this plan forced the Ares I-X data users to think through what they needed from the test. The DFI plans were not similarly evaluated. The final Ares I-X Flight Data Evaluation Report, APO1041, is a good example for flight evaluation reports.

The IVGVT implementation plan was very well vetted. It started as a concept of operations. It was then modified to provide more of an IVGVT overview, then the task plan was added. However, there were too many changes by too many people to the content and structure of the plan.

In the early stages of the Ares I project, no development plan existed for the project. This oversight resulted in subsystem, system, and element tests that were not planned early enough to affect design. Too many different ideas existed about the objectives of the ISTA or main propulsion system (MPS) test article. No resolution was ever reached as to these differences of opinion.

One benefit of component testing would be to rule out design options, or to support a design option. Funding shortages precluded this benefit from being realized. MSFC had difficulty justifying the purpose/need for tests because the basis for performing the test is not defined. Some problems such as thrust oscillation were not integrated into the test program due to the timing of the problem solution. It would have been a major impact to integrate such tests into the program. It is important to baseline testing early in the program. Having a basic set of requirements and a cost estimate with assumptions means new requirements are “out of scope” and bounds the test.

Recommendation:

Conduct a technical interchange meeting (TIM) to brainstorm and organize data necessary to determine the instrumentation needed to obtain data. Develop a more rigid set of instructions and review processes during the early project stages to enable a better understanding of participants for the end product content and format desired for the flight test report.

Suggested or Taken Action:

With the emphasis to push decisions to the lowest level, Office of Strategic Analysis and Communication (OSAC) should establish the program guidance (perhaps requirement) in the Marshall Green Book that resources (budget and schedule) must be allocated when responsibility and authority are delegated to a lower level.

4.13.5 Test Requirements

Description:

Ares didn’t adequately plan the test program (ISTA, green run, Kennedy Space Center (KSC) testing) prior to developing requirements and design concepts, schedule, and budget. An early push to limit test requirements to “in-flight” functions resulted in omitting tests such as the prelaunch checkout (on the pad at KSC). Although manpower was needed to support green run tests, there were no requirements or funding for that support since green run function was not included in project documentation. Testing was only planned for verification of requirements, but the delay in requirements from subsystems resulted in the omission of needed tests.

Subsystems were not identified with adequate detail to support testability. For example, one Test Description Sheet consisted of a PowerPoint sketch of the main simulators and structural test article, but the NASA design team would have had to deliver drawing packages to the Upper Stage Production Contractor (USPC) to build the test articles.

Recommendation:

Perform adequate development planning to budget for anticipated tests. Work to the baseline with the plans that are laid out. Include adequate configuration control of the test article drawings/models to define the test article and applicable subsystems. Assemble teams around test articles as if they were a project to make sure all needed aspects are considered.

4.13.6 Documentation of Decisions and Agreements

Description:

Decisions regarding testing need to be documented. As time passes, questions will arise and without a good way of understanding the rationale for a decision, confusion may result as to why decisions were made. One example is the decision of why the belly band was 96 inches down from the top of the fifth segment of the first stage. The decision was made via coordination meetings and emails with Alliant Techsystems, Inc. (ATK).

Also, the conflict between the agency and center standards resulted in baselining documents without these conflicts being resolved. As the program changed and leadership changed, verbal agreements about these conflicts were forgotten and resulted in discrepancies later on. Additionally, some early agreements were later retracted.

Recommendation:

From the beginning, document how and when decisions were made in test planning and STE design processes. Put the details regarding element agreements and bilateral exchange agreements in writing as soon as possible. Make whichever party that cannot keep their agreement responsible for schedule or budget impacts. If an element has agreed to support a test, the project should insist the element support the test as agreed even if managers change. If the element doesn’t support the test, resources allocated to the element for that test support should be reallocated to the test team.

4.13.7 Risk Associated with Tests Using Heritage Hardware

Description:

The usage of heritage hardware in project-level tests to validate models may result in safety concerns.

Recommendation:

Share previous test data or previous analyses upfront to mitigate safety risks. If safety-related information does not exist, it is important to conduct the proper tests/analysis early to allow the safety organization time to review and determine whether the hardware is safety compliant.

4.13.8 Test Activities vs. Design Activities

Description:

Often designers and analysts that were needed to work test activities were too busy working flight designs. This resulted in adverse impacts to the test products. Development test article drawings took too long to release and were constantly being changed due to minor design changes. Test articles took so long to complete and were of such a high fidelity they ended up being design verification articles vs. development articles.

Recommendation:

Organize a separate test group to exclusively work test activities and allow flight designers to focus on the flight product. Industry (Boeing) follows this construct with good success. Perform preliminary analyses without the final test article configuration including the effects of the test fixture/facility on the overall response. Build development articles to the fidelity needed for the test it is designed for. Do not delay until the design is perfect to build development articles. Do bounding sensitivity analysis for test articles that change frequently.

4.14 GROUND TEST

4.14.1 Overall Test Planning

Description:

There appeared to be a lack of consistent coordination to make sure system-level test needs were met and were coordinated with the components and subsystems feeding into the fully integrated system solution. That is, how do we make sure top-down and bottom-up functions make sense and are covered by a responsible organization?

As one example, on the Ares effort there was some confusion early on with respect to what was going to be tested in the System Integration Lab (SIL). Many people thought that this was to be a test facility for the entire vehicle (mechanical and electrical). However, once it was realized that the SIL would only be used for the integrated avionics there was much concern as to where other aspects of the Ares I design would eventually be tested.

Recommendation:

Recommend that engineering management assess and establish (or reestablish, as the case may be) a singular authority to be responsible for and organize overall test needs and develop the top-level test planning such that all necessary test facilities and funding are considered, and all products comprising the system are aware of their responsibilities for testing.

It is further recommended that this group or leader establish or revisit (if already existent) the overall test planning process and standards for MSFC. The planning must be clear as to who owns what pieces of the system and who performs testing at each level of integration.

4.14.2 Development Plan Needed Early in Project

Description:

A coordinated overall development plan that addresses testing and associated facilities is needed early in the project so that adequate resources and products are planned for and provided to support the various test configurations.

Recommendation:

Recommend new programs/projects and engineering develop a detailed development plan early in the program/project life cycle and define necessary resources and functional needs such that resources, products, and processes can be planned for and adequately support test planning and operations.

4.14.3 Project/Task Planning: Process Too Slow to Develop (Do Technical Planning Early)

Description:

We had several instances where organizations were overlooked or did not provide input when requested or where someone thought a group or task was covered in some other work package. Two examples are the dynamic analysis ending up in a Vehicle Integration (VI) work package and the special test equipment (STE) stress analysis being left out of the engineering work package. Even at the end of the Constellation Program, the board structure was unclear and the change request (CR) process was not well understood. We debated for months about whether or not a property plan was required. The Integrated Vehicle Ground Vibration Test (IVGVT) test plan was developed long before the integrated test plan existed. The process seemed to flow "up" rather than "down." In order to meet schedule, IVGVT execution had to proceed with significant risk since these processes and integrated planning were not in place. Test configurations, hardware fidelity, STE loads, and other early decisions, out of necessity, had to be based on historical information. Another example of processes developing too slowly for IVGVT was the interface definition document (IDD)/interface requirement document (IRD) debate early in the project. Which flight we supported changed many times through the course of the program, from the first flight test vehicle to the first crew-rated vehicle. My opinion is the use of outside consultants was excessive for Flight and Integrated Test Office (FITO)/IVGVT. My opinion is the risk management system was somewhat complex, not well understood, and misused. It seemed to be used more as a method of securing funding than as a tool to make sound risk-based technical decisions.

Recommendation:

Processes should be developed early in the project. Drawing trees, parts lists, and draft drawings of test articles need to be supplied to IVGVT early in the project. Major document and requirements flow down should be put into place before tasks get too far along. Make sure that tools, meetings, reviews, processes, team-building activities, and Lean Events have clear objectives which support the ultimate goal of conducting a test, and that these activities don't themselves become the mission.

4.14.4 Ground Test Hardware/Facilities Options and Needs

Description:

Through previous ET40 experience, a good candidate for the Auxiliary Lift System (ALS) was a system which utilized large bore hydraulic cylinders with integral displacement transducers that could be controlled using a closed-loop Load Control System (LCS) to precisely lift, lower, or position the test article. A 20-inch bore hydraulic cylinder with integral displacement transducer was procured. Available loaner LCS, hydraulic power unit (HPU), and supporting hydraulic servo-valve equipment was assembled. Preliminary testing indicated a large bore hydraulic cylinder rod could be precisely positioned (plus or minus 0.005 inch of commanded value) using position feedback control. Preliminary testing of the assembled ALS system components indicated this approach was a sound candidate for the capabilities required by the ALS. Flight-like gyros should have been an option for the IVGVT. The previous test program's lack of planning and provisioning for closeout left Test Stand 4550 in a degraded state resulting in major work to activate and upgrade the test facilities.

Recommendation:

Upgrade the necessary equipment to perform the necessary IVGVT. Procure any additional large bore cylinders based on the test article weight. Perform proof load testing for the ALS cylinders. Include options to obtain rate gyros for IVGVT in procurements. Test programs should include time and funding for decommissioning at the completion of the program prior to turning them over to the resident center.

4.14.5 Limit Clean Room Access

Description:

In general the clean room team did a great job with keeping up with and ordering clean room supplies. But they went quickly. Some supplies may have been saved by keeping some folks with only a viewing need at the clean room observation windows, rather than letting them enter the clean room. This would help with maintaining cleanliness levels as well.

Recommendation:

Only let people with a legitimate need enter the clean room. Those without a need to enter should view through the clean room observation window.

4.14.6 IVGVT Team Dynamics

Description:

4-D training helped to resolve early lack of transparency and mistrust in the IVGVT team. Good leaders in FITO and engineering worked out their roles and communication issues during the course of the program. MSFC and NASA training was useful to assimilate team members into the NASA culture. The IVGVT organization was not as visible as it should have been due to its being located in the FITO organization. Weekly team meetings of the STE and IVGVT team helped prevent issues. The test lead engineer made sure all required personnel participated in documentation development meetings. This allowed a focused effort without tying up people in unnecessary meetings. The monthly meeting between IVGVT and Facilities was important to track refurbishment progress on the test stand. The internal culture of the Engineering Test Organization was one of participation and allowed the most knowledgeable person to contribute regardless of their organizational level. Having a written “element agreement” between the project and engineering to make sure the external roles and responsibilities were clear would have been helpful.

Recommendation:

Use training, team building events such as 4-D, and mediation meetings to build trust in teams. Define roles and responsibilities between leaders early in the program. Place functions such as IVGVT at a visible level within an organization. Select leaders that are knowledgeable about the broad spectrum of IVGVT. Maintain routine coordination meetings and keep meeting minutes. Be selective about meeting attendance to avoid wasting time.

4.14.7 IVGVT Roles and Responsibilities

Description:

At the beginning of the IVGVT task, roles and responsibilities were not well defined. Each test article required working with organizations with different cultures. Having a consistent, dedicated person to interface with the IVGVT team helped with cultural differences. Orion didn’t have a consistent interface, which led to very little being known about the Orion test article even late in IVGVT. This lack of information was an issue in terms of interfaces with other test articles.

Sometimes organizations were overlooked or inputs were not provided within requested timeframes. There was no evidence of a proactive integrated resource and scheduling function for IVGVT resources.

Recommendation:

Baseline the integrated test plan early to clearly define roles in test planning. Elements should have a dedicated person to interface with the IVGVT team. All organizations should be involved when requirements and work packages are developed. Develop and proactively integrate the resource and scheduling function to drive timely decisions.

4.14.8 Continual IVGVT Rejustification

Description:

IVGVT was forced to continually justify its necessity to senior management. This was a result of the failure of major stakeholders to make clear test goals and requirements before the IVGVT task was initiated. Lack of a specific CxP Level II requirement for the IVGVT resulted in recognition issues within the Ares Projects and the CxP team.

Recommendation:

Recommend early definition of expectations of what test data was necessary to validate models. Develop a top-level requirement for the IVGVT (as existed in Apollo and Shuttle) in order to alleviate issues of recognition within the program.

A Structural Test project should be considered instead of an IVGVT project.

4.14.9 Post-Preliminary Design Review (PDR) Release of Documents

Description:

The IVGVT team did a great job syncing document release with the Ares Projects schedule (Critical Design Review (CDR), PDR, etc.). This worked very well, however, I regret that we did not do a post-PDR release of the documents to capture all the changes from the PDR panels.

Recommendation:

Plan a post-review release after a major program review.

4.14.10 Lack of Formal Internal Configuration Management (CM) Processes for Test

Description:

We really had no formal internal IVGVT CM process for handling planning data needed from the Elements and Kennedy Space Center (KSC) by the test lab for STE design. We had a major Lean Event to try to resolve this and never were able to design this process and relied on email and informal communication (phone calls, meeting notes). [The issue was that data requests were being handled informally between the end user (e.g., an ET-50 designer) and the originator (e.g., Alliant Techsystems, Inc. (ATK)). The documents were not being formally checked out by the supplying organization (e.g., First Stage Office (FSO)) and received by the Task.]

Recommendation:

Develop an internal method of data delivery to be agreed to/explained to the team prior to delivery.

4.15 INTEGRATED PRODUCT TEAM (IPT)

4.15.1 Component Design Team (CDT) Authority

Description:

The Ares I Upper Stage utilized CDTs to design upper stage components. Team members reported both positive and negative experiences. Negative experiences were largely based on the perceived decision authority the CDT leads had. One lead reported that they had no authority over CDT members outside their own home organization and that this led to integration issues. Another lead reported that the CDT could not make design decisions and that getting decisions from IPTs was cumbersome and eventually led to change requests (CRs) to document and authorize decisions. It was also reported that the CDT process appeared not to have the blessing from all engineering managers, making it difficult to implement.

Recommendation:

Clearly differentiate CDTs from IPTs and grant CDT leads authority over their team members and authority to make design decisions using a streamlined process. Also, CDTs requested the ability to request independent reviews.

4.15.2 CDT Effectiveness Dependent on CDT Lead

Description:

CDT lead strengths and weaknesses played a critical role in the effectiveness of a CDT. When the lead clarified the CDT’s role and expectations, positive comments were posted. This was in contrast to CDT leads that were experts in a specific field but lost sight that they were leads now and needed to represent the team as a whole.

Recommendation:

Clearly define the CDT leads’ roles and responsibilities (and relationship to volume integrators, systems engineers, and discipline experts). In addition, select leads that take ownership and promote team morale.

4.15.3 Engineering Team Roles and Responsibilities

Description:

Several teams across engineering provided comments that there was confusion concerning roles and responsibilities. Areas of concern included: Systems Engineering and Integration (SE&I) owning the drawing process, but SD owned the responsibility to release drawings; NASA and Boeing; between engineering departments; confusion over who owns which interfaces on the data and control unit (DCU) box; and upper stage main propulsion system (MPS) thermal specifications where Propulsion Systems Departement personnel assumed Structures and Thermal (S&T) IPT was responsible for this work, yet there were no formal agreements or resources.

Recommendation:

Include roles and responsibilities in the task packages. Also, communicate the agreed to (and funded) tasks to all team members so that they understand their roles and responsibilities (do not assume everyone has access to the task packages and will read them on their own).

4.15.4 IPT Action Tracking

Description:

Action items were poorly flowed down and not tracked early in the program. This got better later, but still lacked good documentation of action resolution.

Recommendation:

Provide direction to future IPTs on how to give and track actions.

4.15.5 Weekly IPT Meetings

Description:

In general, IPT weekly meetings were viewed as positive. IPT members from Langley Research Center (LaRC) reported that these meetings were a good source of project news. Other IPT members reported that the meetings were good, especially when they were focused and short.

Recommendation:

Continue weekly IPT meetings but keep them short.

4.15.6 IPT Technical Integration Meetings (TIMs)

Description:

IPT TIMs were viewed as positive. IPT members reported that TIMs helped them define the changes and understand the design baseline. Also, when coordinated with the design analysis cycle (DAC) schedule they provided an opportunity for the IPTs to capture actions, forward work, and issues requiring resolution.

Recommendation:

Implement TIMs across all IPTs. Remember to schedule them so that they support the DACs.

4.15.7 IPT to Engineering Coordination Plan

Description:

Ares I Upper Stage IPT members expressed a concern that coordination and integration of work between Engineering Departments outside the IPT was difficult. Their observation was that this function was performed by analysts and designers, but it was inconsistent because there were not plans or instructions in place setting the rules of engagement.

Recommendation:

Document the rules of engagement for IPTs and external departments that support them.

4.15.8 Upper Stage IPT Weaknesses and Strengths

Description:

Ares I Upper Stage organized around IPTs and learned that there are strengths and weaknesses associated with this organizational structure. Several IPT members observed that the IPTs did not organize to the classic IPT definition (IPTs did not include multi-disciplines). As a result engineering life cycle issues came up, specifically testability and interface issues. Competing directions (i.e., the focus was on flight drawings at the expense of no work on development test hardware) and too many IPTs that led to independent work that made integration and integration management difficult. Another factor was the lack of a well-defined IPT decision authority. Individuals were given assignments, but not held accountable for documenting the inter-IPT decisions (e.g., no documentation to show all the IPTs agreed with a design decision). Even in cases where a specific IPT worked, results were attributed to the team's “Can Do” attitude.

Recommendation:

IPTs need to include multi-discipline representatives with good communication skills and authority to speak and make decisions for their discipline. In addition, the IPTs need the IPT structure and processes documented, to reduce philosophy disagreements and to formalize decision-making documentation (i.e., empower IPT leads with decision-making capability within project guidelines and to provide informed recommendations to management).

4.15.9 Lower Level Team Development

Description:

Development of integrated design teams (IDTs), halfway through the IPT life cycle, was effective in formulating small working group design/analysis functions to mature the design and address known and emerging design issues. Earlier forums were too large and unwieldy to achieve effective detailed design solutions. Some problems did exist with respect to the limited IDTs formulating design solutions and then putting these forward to the IPT(s) for approval without the overall IPT's input and understanding, though this was far out-weighed by the effective design maturation which was achieved by the IDTs. Examples of effective IDT implemented solutions included flexibility (lines, TM structure), roll control system (RoCS) pressurization system flow-limitation approach solutions, etc.

Recommendation:

The lesson learned is to progress to smaller design and analysis teams in order to effectively solve problems and mature designs.

4.15.10 Co-Located Ares Thrust Vector Control (TVC) Diagnostic Model Team

Description:

Development of the Ares TVC diagnostic model was funded through the TVC subsystem work breakdown structure (WBS), rather than through a diagnostic modeling WBS like other subsystems. Further, TVC diagnostic modelers were co-located with the TVC design team. Consequently, TVC diagnostic modelers were considered part of the TVC design team and were granted ready access to design information and subject matter experts. This resulted in a high-quality diagnostic model, higher modeler productivity, and a product that was consistently delivered on-time.

Recommendation:

Co-locate model teams with the corresponding design teams.

4.15.11 Upper Stage TVC Fault Detection Diagnosis Early Funding

Description:

The Upper Stage TVC Fault Detection, Diagnostics, and Response (FDDR) team was funded early in the TVC design process. As a result, they were able to positively impact a number of important design analyses while the design could be changed without major cost increases. Example analyses include: identification of line replaceable units, launch commit criteria, loss of mission, and recoverable faults requirements verification.

Recommendation:

Continue early implementation of the FDDR team and analyses so that design changes can be made early.

4.15.12 IPTs Lacked Traditional Responsibilities

Description:

The use of IPTs was a good approach but the teams did not have all the responsibility of an IPT. Materials, thermal, and electrical were pulled out of an IPT and combined into one IPT.

Recommendation:

Utilize the full value of IPTs by setting them up as classic systems engineering teams.

4.16 KNOWLEDGE MANAGEMENT

4.16.1 Knowledge Management Agency and Center Support

Description:

Knowledge items that involve cross-center solutions may need NASA Headquarters (HQ) onboard with the process. Any major project of MSFC will likely have other center participation.

The knowledge capture process is an adaptation of lessons learned requirements.

Recommendation:

Develop knowledge management tools, processes, and procedures across the agency.

Make knowledge capture part of the program plan. Consider timing such as program closeout or after key decision points, milestones, or on a quarterly basis. Lead of the knowledge capture should be the chief engineer and systems engineering and integration (SE&I) portion of the project.

NASA HQ should review the MSFC knowledge capture process to possibly make it a permanent process. MSFC should first adapt knowledge capture as an institutional process.

For future use: get general process communicated as soon as possible. Recommend upper level management endorse and kickoff the process. Example: Briefly outline the general process and intent in the initial communication to the team.

4.16.2 Capture Methods

Description:

Varying levels of participation and support existed within the organization for knowledge capture. The process used three methods to overcome reluctance. They were the Knowledge Item Description (KID) Form, knowledge capture workshops, and harvesting data from organizational led activity.

Recommendation:

Recommend maintaining all three methods of knowledge capture to allow for different comfort levels and flexibility.

4.16.3 Knowledge Capture (KC) Kickoff and Follow Through

Description:

Knowledge capture activities did start with some resistance, that this was business as usual, and that nothing would be done with the lessons captured. The KC team communicated that this would not be the case and that management had committed to follow through on these lessons. The development of knowledge items (KIs) was the mechanism used. Discipline leads from across the center were invited to review them and take ownership of associated improvement actions. This process was communicated to lesson submitters in order to continue building credibility.

Recommendation:

In the future, we need to make sure that feedback is faster. Also recommend from an organizational standpoint that this is clearly recognized from upper tier management. Although we did not implement recognition awards, we believe this would have helped communicate the importance of implementing the suggested improvement, especially if these were monthly awards, our team would have been driven to improve the feedback rate.

4.16.4 Knowledge Implementation

Description:

Knowledge capture is done using various proven methods, but knowledge implementation appears to be a greater challenge than the capture. A solid methodology is needed to ensure implementation of lessons. The Ares KC team worked with MSFC policy and requirements developers, the Red Book Team, in this area. This was a good approach for the process-oriented improvements, but we felt that technical knowledge was not sent forward so that it was communicated to the broader team (the Red Book will be a center-wide guidance document).

Recommendation:

Recommend knowledge (lessons learned) "implementation" be established on a continous basis at the center level and that language in current program management requirements be strengthened to require program/project leadership to review knowledge capture and implement mitigation strategies at the beginning of new programs/projects. The planning phase is the most appropriate time for understanding what our predecessors have done and what issues have arisen.

Also recommend program management requirements consider updates to recommend (or require) knowledge implementation at strategic waypoints in a program/project life cycle (such as just after major milestone design reviews), and particularly for programs/projects with significant technical or programmatic uncertainties. Arguably, the design review process should, but does not always, address process improvement, so conducting smaller scale or more focused knowledge capture and implementation may be of benefit to specific product or discipline areas.

Note: The Ares KC team began preliminary discussion with the Chief Engineer's Office to initiate a process that included lessons linked with a systematic closure of the actions. This early process should be further developed with due diligence given to tracking big actions/issues to closure.

4.16.5 Observation Roll Up

Description:

Some groups resisted the idea of rolling up smaller observations because they felt their observation would get lost. They felt that although small and very niche oriented, the observations were so important that they felt the idea should be stand-alone. While this view is valid, it challenged facilitators who saw these same observations grouped differently in other workshops. Few participants understood the bigger picture of the process so there was at times resistance towards getting down to the actionable nuggets.

Recommendation:

Recommend that facilitators capture individual observations as expressed by participants, but also make one more interation with the group while intact to summarize the key actionable points and (if possible) prioritize. The facilitator/gatherer may have to work with the "ranking" discipline lead in the group to maybe go back and ask "why?" the group thinks certain events happened in order to establish the fundamental issues.

4.16.6 Chain of Command Understanding

Description:

There were some issues with conflicting direction from multiple people/leaders. The Knowledge Capture team did not completely understand the proper chain of command. Situations would arise in which direction from leads would contradict each other, leaving the team members unsure of which direction to go. This caused some discord among team members.

Recommendation:

Recommend for the future that the chain of command be clearly defined and conveyed to the team at the beginning of the effort. Any issues with conflicting direction from leaders should be identified, discussed, and resolved at the time they occur. That leader can be from the Chief Engineer's Office or SE&I portion of the program.

4.16.7 Workshop Lead Availability

Description:

During the knowledge capture process an identified workshop lead was moved to another role and a new lead was assigned. The new lead was not knowledgeable about the expectations for a workshop lead. This led to confusion on the part of both the workshop lead and participants.

Recommendation:

Identified workshop leads should be available throughout the process from interview to knowledge object submission.

4.16.8 ThinkTank Limitations

Description:

ThinkTank provided a useful method for capturing observations. However, some issues with ThinkTank included that the number of sessions to support knowledge capture workshops was limited by the number of licenses which were being used by Constellation Program (CxP) and Ares simultaneously. Additionally, there were only two leader accounts with the sessions not being visible to one leader if created by the other leader.

Recommendation:

In the future, recommend creating additional leader accounts if possible and modifying the tool to allow multiple ThinkTank sessions to be visible by both leaders.

4.16.9 ThinkTank Connectivity Issues

Description:

ThinkTank has proven to be a good tool. The connectivity issues proved to be a challenge. The connectivity issues could be related to Integrated Collaborative Environment (ICE) stability and should be considered if ThinkTank is to be used as a capture tool in the future. If the connectivity issues can be resolved, utilizing ThinkTank will be beneficial to groups in the future. There were also issues when wireless was being used.

Recommendation:

Connectivity issues were a big momentum killer and must be corrected if ThinkTank is to be used as a knowledge capture tool in the future. Wireless connectivity should be avoided completely.

4.16.10 ThinkTank Tool Improvement

Description:

On several occasions people signed into ThinkTank with only a first name or had common names and didn't add an initial. Therefore, when processing the raw data into KOs the facilitators sometimes didn't know who the contributor was, so providing an email address was a challenge. Participants were supposed to enter their email addresses when they logged into the session. In ThinkTank you could pull a list of participant's names but you could not access (in the classic edition) a list of the email addresses.

Recommendation:

Recommend Exploration Systems Mission Directorate (ESMD) GroupSystems upgrade ThinkTank so that there is a capability available to pull the participants' email addresses into the report.

4.16.11 KO Development Scheduling

Description:

Scheduling should account for the "real-time" instead of the rush needed to convert to KO objects, pre-distilling, and distilling. After some calculations it was estimated that at least one-half to one day of uninterrupted work time was needed to process KOs from a session.

Recommendation:

If knowledge capture were a continuous process, scheduling could be more dynamic. A continuous process which flows from scheduling to session to distillation without time constraints would be the ideal.

4.16.12 Single Person Control of Scheduling and Set Up

Description:

In the beginning, workshop calendar control was being handled by too many people. There needed to be one point of contact (POC) for the Knowledge Capture Workshop Calendar at the beginning. It took several weeks for this process to get in place and even then there was not one POC taking care of everything. Another person was setting up the details in ThinkTank.

Recommendation:

In the future, one person should be responsible for all workshop scheduling including setting up ThinkTank. This person would be in charge of contacting individuals to set up the one-on-one interviews, schedule the workshops, update the KC calendar, contact facilitators, set up the meeting details in ThinkTank, send out meeting notices to participants, and forward the meeting details to the facilitators.

4.16.13 ThinkTank Accessibility Issues

Description:

There were problems with participants not having access to ICE (not having an account, account expired, didn’t know credentials, etc.) and thus not being able to access the ThinkTank tool.

Recommendation:

Need to make sure everyone has an active ICE account prior to the session. One recommendation is to forward the participant list to the information managers early enough for them to verify that all participants have access (which we did). Another recommendation is to use a different instance of ThinkTank that is not located on ICE to avoid accessibility issues in the future.

4.16.14 Division of Labor for Knowledge Capture

Description:

Originally the ground rules were that if you signed up to lead a knowledge capture workshop you also signed up to write the KOs for that workshop. This was how we, as facilitators, could schedule our time (around other meetings, etc.). As time progressed the perception started to evolve that some people on the team were doing more than others and some thought that others should be taking on more workshops. However, at least three people on the team that I am aware of have other charge codes that they are doing work for in addition to knowledge capture.

Recommendation:

Maybe the percent of time people are working the knowledge capture should have been made clear at the beginning of the process so that people would understand why it appears some are not doing as much as others. Another option could be that in the future the personnel working knowledge capture should be 100% on the project.

4.16.15 Incorrect ThinkTank Set Up

Description:

The ThinkTank buckets were not always created according to what the workshop leaders submitted. If the buckets were not created correctly and the facilitator changes them or adds the correct one and deletes the incorrect one, the facilitator must make sure that no one is entering a comment into that bucket before that bucket is deleted. Also all ideas must be moved out of the bucket before it is deleted. If this isn't done, the ideas/comments may be lost.

Recommendation:

The facilitator should double check with the ThinkTank POC to verify that the bucket titles were received from the workshop lead and created in ThinkTank before the session begins.

4.16.16 Keep Process Simple

Description:

The key thing is to capture a lot of constructive points of view.

Recommendation:

Do not get locked into tools. Keep the process simple and flexible to utilize very basic brainstorming tools.

4.16.17 Inadequate Facilities

Description:

The setup required on the laptops in MSFC Building 4200 Room G13-F was very time consuming and seemingly redundant. Also the Guest network (MSFC network not available in G13) was not reliable and seemed to cause problems.

Recommendation:

Recommend a different facility with a reliable network and hardwired computers in the future.

4.16.18 Knowledge Capture Process Flow and Templates

Description:

Supposedly there is a process chart on the portal or wiki that shows all of the detailed steps for the knowledge capture process. All I can find is a high-level process overview. If there is not one, a detailed step-by-step process or work instruction should be created for future projects/programs/institutions to use. Some of the emails used should be archived along with the work instructions to be used as templates for future knowledge capture team members to use.

Recommendation:

Recommend a concise "how-to" process flow and set of useful templates be kept for use as continuous process improvement.

4.16.19 Lack of Sensitive But Unclassified (SBU), International Traffic in Arms Regulations (ITAR), and Export Control Data Allowed in ThinkTank

Description:

ThinkTank doesn't have a method for allowing SBU/ITAR/Export Control information to be discussed or used as an example during knowledge capture. A work-around was to input a comment with general topic information and refer to an external location where the observation and supporting information would reside.

Recommendation:

Recommend making a permanent sensitive repository for such observations or moving the entire knowledge management process into a protected area.

4.16.20 Communicate KC Process Early

Description:

This was the "first time." The general process should be communicated as early as possible, possibly part of the initial kickoff and endorsement by upper level management. I would have liked to have seen the knowledge capture process nailed down prior to any workshops being held. The process changed as we went which created problems down the road. Example: Outline very briefly the general process and intent in the initial communication to the entire team, such as: 1) The SE&I team shall gather lessons using three methods. 2) A core team of engineering managers, led by the chief engineer (CE), shall sort through to find lessons that can be addressed by a specific action. 3) The core team shall discuss and develop the actions (and associated lessons) with the appropriate actionee. 4) The actionee shall perform the action, and any needed follow up and be accountable to their immediate supervisor and to the center management (as needed).

Recommendation:

Iron out the details of the KC process and have in place before beginning workshops if adopted at the center level.

4.16.21 Process for Chart Package Creation

Description:

When chart packages are being created it is essential for the team members creating the packages to work together and keep each other abreast of changes made to the packages. If direction is given to change information in a package, this information should be communicated to all team members so that everyone is aware.

Recommendation:

Have one “owner” or POC for a chart package. Inputs, suggestions, changes, etc., should be submitted to the chart package owner instead of all team members making changes to the same package.

4.16.22 Capture Process Worked Well

Description:

The process used to capture data worked well. Using the predetermined categories to guide participants while also having a laid-back informal feel to the meeting seemed to work very well. The facilitators made sure that the workshop kept moving forward and that it was completed on time. It seemed participants felt free to be honest in the environment of our workshops.

Recommendation:

Recommend using the same approach in the future.

4.16.23 Teleconference Equipment for Offsite Participants

Description:

Conducting workshops with individuals at remote locations worked fine as long as the participants dialing in could hear what was being said in the room. The G13 meeting room was not equipped for telecons.

Recommendation:

When conducting workshops with remote participants, conduct the workshop in a conference room or other facility that is set up for teleconferences.

4.16.24 Pre-Typed Observations

Description:

It worked well when groups brought typed observations and pasted them into ThinkTank as a way of driving the brainstorming activities and increasing the number of observations. This led to an increase in distillation time, however, as these groups tended to have 150+ observations before synthesis.

Recommendation:

Encourage participants to type their comments before the workshops and bring with them on a thumb drive.

4.16.25 Correct Most Chronic Issues

Description:

I do like to hear what people say – what we can do better…what we did well. Also like to see the hope that people will do specific tasks to improve.

Recommendation:

It is important for our credibility with one another that we do make some headway in fixing the chronic issues. Keep in mind that not all of the lessons/issues are equal. Some must be fixed.

4.16.26 KO/KI Database Needed

Description:

We should definitely have a searchable database to store and track KOs, KIs, and associated actions. For now the Excel approach is working okay but as more of these accrue it will become very difficult to manage. Also, without a database it will be difficult to keep individual contributors statused.

Recommendation:

Recommend the use of a KO/KI database in the future. Possibly a tool like the Center-wide Action Item Tracking System (CAITS).

4.16.27 Knowledge Capture (KC) Team Daily Tag-Ups

Description:

The daily tag-up meeting with the KC facilitators worked well for getting the status of the workshops and KOs, confirming people were covering the workshops and workshop leader meetings, etc. The printed out calendar schedule received daily worked great to track who was doing what workshop. The spreadsheet used to track the workshops was also a good tool to track the workshops scheduled, completed, and the status of KO generation. One POC for the calendar and spreadsheet proved to work well.

Recommendation:

Recommend the use of daily tag-ups in the capture process. They should include a telecon number and all information from the tag-up should be posted on a wiki or portal for the team's benefit.

4.16.28 Grouping Capture Workshops

Description:

We did a systematic job of getting project-oriented (work breakdown structure (WBS)-based) groups of people together for brainstorming.

Recommendation:

In the future we should be strategic about getting other “slices” or demographic groups.

4.16.29 Make Observations and Recommendations More Succinct

Description:

Teams need to be able to grasp the observations and recommendations in one screen.

Recommendation:

Limit the number of characters of observations, descriptions, and recommendations.

4.16.30 Additional Time for Capture Team Member Information Sharing

Description:

The process continued to evolve during the knowledge capture process leaving very little time for KC team members to share what we have learned or observed day to day.

Recommendation:

More time is needed for KC team members to share the information that they have learned.

4.16.31 Processing Data into Knowledge Objects

Description:

Currently there are two methods of processing session raw data into KOs. One method is to copy and paste the raw data into the observation field in the KO spreadsheet then generate a driving event and recommendation from that. The second method involved editing the raw data, removing the names, ordered list/numbers, etc., and generating/editing the driving event, observation, and recommendation.

Recommendation:

The decision needs to be made on which method is to be used.

4.16.32 Facilitator Check Data with Workshop Leader

Description:

It is crucial that the facilitator check back with the workshop leader to ensure that the information was captured accurately. That is critical in assessing if it is indeed actionable and an appropriate action is assigned. We all agreed this was key.

Recommendation:

Add to the policies a step for the facilitator to contact the workshop leader after the raw data and KOs have been sent to ensure accuracy.

4.16.33 Consistent Capture Process

Description:

The KC process needed a more structured process. Some disciplines rehashed Pause and Learn (P&L) discussions from months previous or did their own version of a P&L and others did more formal KC sessions or workshops. There were three main methods of KC chosen for the process. The KID Form is a standard form, but without standardized input. The ThinkTank workshops can be largely standardized, especially as facilitators become more experienced. The third method was left up to the organization and this method allows for flexibility; however, this creates tremendous variability in the knowledge observations and thus the time required to process the observations into knowledge objects.

Recommendation:

Recommend keeping experienced members of the capture team as part of the core for future programs or center-level knowledge capture activities. The capture process should be consistent among all who participate.

4.16.34 KID Form

Description:

Emphasizing the KM portal and the ability to input KIDs is important for individuals that may be wary of voicing their comments/observations in an open forum. Even though their names are still attached to the KID form, there is a sense of “security” by submitting their observation from their desk rather than in a room of their peers.

Recommendation:

Recommend that when KID form submissions and KOs become KIs, the original source (author) should be removed. It should not matter who wrote the KO at the time of implementation.

4.16.35 Knowledge Management Portal Accessibility

Description:

If the knowledge management process is adopted as a center-level function the Knowledge Management portal should be accessible by everyone.

Recommendation:

Recommend placing a link on the Inside Marshall Homepage so individuals can access the portal and also obtain general information, submit KIDs, session information, POCs, and have a link to check status of open KIs.

4.17 MATERIALS

4.17.1 Materials Selection

Description:

Initial choice of materials for upper stage primary pressurized structure (liquid hydrogen (LH_2) and liquid oxygen (LO_2) tanks) Y-rings was the 2195 roll ring forging product. The roll ring forging product offered by the Manufacturing and Assembly (M&A) group did not have well-defined strength and fracture properties at the beginning of design work. This resulted in M&A developing material properties along with their process development and along with structural design of the flight hardware. During preliminary and detailed design, M&A gave properties to the designers that they were confident of meeting for strength and did not give fracture properties but were confident that properties similar to plate stock used in the External Tank (ET) Program would be achieved from coupon testing. What actually happened was that the assumed fracture properties could not be met and questionable strength properties were obtained. As a result, designers were forced to change the material from 2195 roll ring forging to the already-developed 2219 roll ring forging product, which resulted in a mass increase and somewhat of a cost increase with little impact to schedule.

Recommendation:

Recommend that future projects only allow candidate materials that have proven properties (B-basis at a minimum) and that do not require concurrent development with the flight hardware. Using proven materials will significantly reduce programmatic risk.

4.17.2 Optimizing Manufacturing and Assembly Locations

Description:

Optimization of element hardware manufacturing and refurbishment is needed. From Ares I-X experience, we were able to better meet schedule milestones by directing Alliant Techsystems, Inc. (ATK) to deliver forward hardware before it was finished, specifically instrumentation. The automotive industry tries to have subcontractors manufacture components adjacent to the point of assembly. But those things manufactured there are the items that have many variables, like dozens of seat colors and seat styles, not things like engines where there is only a choice of two.

Recommendation:

Clearly define early on in the design/development process the responsibilities for hardware element manufacturing and checkout, vehicle assembly and checkout, and engineering services at the launch site. This should include assessing the most optimum place for element hardware manufacturing and refurbishment. Also minimizing interfaces and handoffs at the launch site is desired. We were unable to negotiate handing off a complete first stage to Ground Operations. Any stage manufactured should be managed by the Element rather than joint control between Ground and Element, which is where we were going. For some items it is suggested to minimize manufacturing at the launch site. For those, the goal should be to deliver a vehicle element in as near to a completed state as possible. For other items, such as the Ares I-X instrumentation from ATK, these can be shipped incomplete and finished at KSC.

This needs to be worked very early in the next vehicle.

4.17.3 Digital Manufacturing Tools

Description:

Integration is lacking between software tools and configuration control on the shop floor. Design software tools are not integrated with manufacturing software tools. Many problems were created by this lack of integration including performance of analysis on old models and time wasted translating geometry from Pro/E to CATIA. Use of Solumina to deliver work instructions was extremely inefficient and the system was only used to record paper-based instructions after the work was completed.

Digital Manufacturing is frequently not included in project planning efforts, and was not seen as necessary to the design process. However, there were benefits from Digital Manufacturing and use of the tools enabled at least $3 million in cost avoidance on demonstration articles.

Tools for handling discrepancy reports, a central work order system, and an as-built data collection system at the center are lacking. Solumina, MAPTIS, and Visual Manufacturing are used by various groups. Currently there are not enough people to support, train, and maintain the Solumina system.

Recommendation:

Use Digital Manufacturing upfront and program-wide to realize cost savings. Make sure that each component development team has a Digital Manufacturing representative in order to integrate producibility analysis into the design process. The Digital Design To Manufacturing (DDTM) project needs to continue. Better integration of these tools is imperative.

Fund an effort to identify requirements, pick a standard system, and implement a central work order and as-built data collection system across the center [NASA-wide would be even better!].

If Solumina is chosen for future in-house work, more people are needed to support, train, and maintain the system.

Work with Safety and Mission Assurance (S&MA), operations, and logistics to determine if use of digital design and manufacturing tools would be advantageous.

4.17.4 Formalization of Manufacturing Engineer Positions

Description:

Many of the duties, roles, and responsibilities of manufacturing engineers are not well defined. There is currently no representative from manufacturing formally tasked with interfacing with the design group, welders, tooling technicians, or tracker and scanning workers.

Producibility analysis is most effective when there is a close relationship between the simulation engineer and the designer. The designer has intimate knowledge of the design and possible problems and he can guide the simulations. Lack of communication between design and manufacturing presented problems. Tooling designs were not communicated from tool designers to shop floor personnel until something became a crisis necessitating the tool designer visiting the shop floor.

Variances between contractor and MSFC manufacturing processes were not well known.

Recommendation:

Establish a manufacturing systems engineer position that would be formally tasked with interfacing with stakeholders including design, welding, tool designers, and shop floor personnel. Responsibilities would also include synthesizing manufacturing information into actionable data to set up assembly models of what is going to be built on what tool. Manufacturing simulation engineers should have a close relationship with designers. Tooling designers need to spend much more time on the manufacturing floor to see what problems are occurring and to be proactive about fixing them.

4.17.5 Upgrade Labview Oven Control Software

Description:

It would be better to have an oven that is capable of controlling the cure cycle per the part temperature.

Recommendation:

An upgrade of the Labview software would provide this capability.

4.17.6 Leverage Manufacturing Opportunities Early in the Project Life Cycle

Description:

The Ares Projects recognized technology manufacturing challenges and the leveraging opportunities. Manufacturing technology assessments helped the project identify low Technology Readiness Level (TRL) Manufacturing areas early in the project life cycle. To mitigate the manufacturing risks, the project initiated several manufacturing demonstration projects. These projects identified issues early so they could be resolved with minimal impact to the schedule. The upper stage common bulkhead manufacturing demonstrator was one of these projects. The results were primarily positive, but identified a schedule critical path problem that was realized.

Recommendation:

Discipline leads need to identify manufacturing technology issues, opportunities for partnering, and leveraging existing manufacturing capabilities early in the project life cycle. Tools like the Technology Readiness Assessment Tool (TRAT) are available to help identify technical, manufacturing, and software readiness levels. Opportunities for partnering often depend upon discipline leads having a good understanding of current work underway in their areas. Participation in discipline-based conferences should be encouraged.

4.17.7 Machine Requirements Verification

Description:

The buyoff on major tools inlcuding the Robotic Weld Tool had inadequate verification of machine requirements.

Recommendation:

Include better verification of machine requirements in buy off on major tools.

4.17.8 Materials Test Plan

Description:

Material properties were unavailable for some “new” alloys and no materials test plan was in place to accommodate design changes.

Recommendation:

A materials test plan should be accepted before the design team changes structural materials. A test plan should be included in the Element Integration Board (EIB) package (or whatever authority is in place) before changing.

Suggested or Taken Action:

1) List which materials lacking current material properties data will likely be needed by the new Space Launch System (SLS) Program (could be started from list of most requested material properties by Constellation/Ares). Consideration should be given to rank, order the likely needed materials by their relative importance and schedule needs (long-lead items), whether or not material properties data can be derived from existing similar material, and if appropriate testing is or is not currently planned.

2) Propose a plan for addressing the materials property testing needs for those materials.

4.17.9 Conduct Feasibility/Manufacturing/Producibility Study

Description:

Design for Manufacturing & Assembly (DFMA) workshops were helpful in getting production contractor input for component designers. The DFMA workshops also allowed the Upper Stage Production Contractor (USPC) and NASA to resolve differences that drove the design. From a performance standpoint, Ares I was a Ferrari. The design was on the edge (tight tolerances) which drove up the cost of tooling and inspections and processing. Design people should be able to provide greater margin in the design that would allow for ease of manufacture. Contractor claims of mature technology were not verified. The maturity of SolGel technology was insufficient for cryogenic applications despite contractor claims. Design allowables take too long.

Recommendation:

Continue with the DFMA workshops. Do not make vehicle architecture decisions based solely on performance. It is important to consider the development issues, manufacturing impacts, and overall complexity it adds to the program. Use mature technologies for materials, processes, and manufacturing in the preliminary design. If an advanced technology is needed it is important to have a technology maturation program that quickly raises the TRL to the correct level. Verify contractor claims of mature technology by supporting documentation containing engineering data. Choose a common material system across the vehicle whenever possible. Allowables should only be developed for critical low-margin properties. Invest in manufacturing and production (M&P) technologies very early in the project cycle—the sooner the better. Impact: project will be forced to use old, high-cost technologies and often result in lower performance. Include a feasibility study as part of the process planning for unique or very large hardware.

Suggested or Taken Action:

Recommend a design lead (likely out of engineering) work with appropriate small group of leader(s) from materials & processes department and SLS Program Office to propose planning and guidance for feasibility assessment, as well as demonstration and validation of fabrication and assembly processes.

4.17.10 Standardization and Commonality

Description:

Standardization and commonality of parts and materials should be included in flight and ground hardware design and development.

Suggested or Taken Action:

Recommend that a design lead (likely out of engineering) should work with appropriate small group of leader(s) from design (system and component), materials and processes department, operations, and SLS Program Office to propose planning and guidance for utilizing standardized or common parts and materials to reduce development or overall life cycle costs.

4.17.11 Assigning a Manufacturing Counterpart to Follow Specific Hardware

Description:

Similar to the design organization assigning people to specific components/hardware, a manufacturing counterpart should also be assigned to follow specific hardware – such as a liquid oxygen tank person, a hydrogen tank person, etc., to lead and coordinate the M&P inputs to the designers.

Recommendation:

Recommend engineering and/or design lead work with engineering functional (discipline) leadership and establish guidance for a best practice design process that discusses which engineering disciplines are typically needed on a design and at what phase in the design and development to be most effective for technical, cost, and schedule. (It is recommended this be guidance. A design lead, responsible for a deliverable solution, must be fully able to request any needed discipline expertise at any time, given available resources.)

4.18 OPERATIONS

4.18.1 Better Define Operations Roles and Responsibilities Between MSFC and Kennedy Space Center (KSC)

Description:

Integration of responsibilities for Operations at MSFC and Ground Operations at KSC to identify rules of engagement to assure full integration and no duplication of capabilities. One example was that there were two Integrated Timelines, one by KSC and one by Vehicle Integration (VI).

Recommendation:

Recommend improving the interface between MSFC and other centers by clearly defining roles, responsibilities, and products planned to facilitate a collaboration environment. This planning should be published in an integrated plan.

4.18.2 Manufacturing Planning

Description:

Need to understand the manufacturing flow to establish facility requirements and move out on long-lead items. The flight testing organization had expected to receive first run/prototype vehicles for testing. Scheduling issues precluded use of prototypes, and had to work with suppliers to independently procure the lowest fidelity article available. Conflicts between the Element and vendors arose when cost reductions were negotiated based on lower fidelity needs late in the project. Time and money would have been saved if the original test data request had specified actual test article needs and had specified that the flight hardware was only a goal.

Recommendation:

Management should clearly communicate with the stakeholders (including teams, vendors, etc.) the schedule and need dates. Risks should be evaluated and mitigated. Contingency/alternate plans should be made in case risk events are realized. Prior to baselining the project’s master schedule, project managers need to decide fidelity of hardware for capstone development tests.

4.18.3 Handle Developmental Flight Instrumentation (DFI) as Payload

Description:

DFI integration into the launch vehicle was too tightly coupled. DFI was a design solution to establish reliability data and to validate flex body models. It was not a requirement in and of itself; it existed to satisfy other system-level requirements.

Recommendation:

Handle DFI as a payload independent of the flight system. Establish separate DFI system requirements document (SRD) and interface control document (ICD) packages.

4.18.4 Handling Flight Hardware

Description:

Some disciplines were not familiar with the processes for handling flight or flight-like hardware. In one case, use of flight hardware during a testing scenario would have required a belly band and handling special test equipment (STE) that interfaced with flight hardware requiring work with the element owner. The definition of “flight hardware” and the handling standards vary from center to center and program to program. Cost estimates were based on incorrect understandings of procedures.

Recommendation:

More training is needed on how to handle flight or flight-like hardware. Early in the project, determine restrictions for test hardware interfacing with flight hardware and provide standards for how hardware will be handled to reduce the chance of miscommunication. Consider an agency-wide standard (or at least a program-wide standard that applies to all centers) based on best practices.

4.18.5 Launch Tower Real Estate

Description:

The liquid hydrogen feedline should not have been oriented facing the tower. It took up too much valuable real estate that could have been used for other components requiring access.

Recommendation:

Do not orient any hardware towards the launch tower that does not explicitly need access from the tower. The real estate facing the tower is "gold" and should not be used for other things.

4.18.6 Test Article/Ground Support Equipment (GSE) Ownership, Roles, and Responsibilities

Description:

Early on, Ares Element Managers agreed to supply all test articles and GSE. Later, the Elements determined that they could not meet the schedule for delivering GSE and test articles. The Elements then acted as communicators between suppliers and Flight and Integrated Test Office (FITO) which resulted in wasted time and misunderstandings. Direct communication via a bilateral exchange agreement with the supplier and FITO would have been more efficient. Support agreements between test and hardware suppliers didn't include a sufficient level of detail. When official GSE was not provided to handle test articles, special test equipment was built, but there was confusion and it was incorrectly called GSE. Calling STE GSE brings a specific set of instructions that results in cost increases. If the STE is only for the test, it does not need to be GSE. Separation of costs between full-stack tests and second stage tests was difficult due to them being managed under different organizations.

Recommendation:

NASA property agreements need to be worked out at the project level so all hardware is handled the same way. Future projects should verify with the organizations from whom they are requesting hardware that they are the property owner listed in the NASA Property Management System. Elements should not have the ability to delete or change test articles or GSE needs for tests without the agreement of the test management team. Properly assign GSE or STE classification as needed for handling of the hardware. Establish agreements between property owners for cost and handling of GSE between users and owners. Develop concise top-level GSE requirements at the beginning of a program. True ownership of GSE and STE needs to buy in for the manner of test usage. Program leadership should provide guidance on what is really in the structural test trade space. All ground vibration test (GVT)-like tests should be managed from the same organization from the beginning.

4.18.7 Project Management for Test Article Design

Description:

The process used by the Upper Stage to design the test article was very effective. The Upper Stage used a set of meetings to go through the different subsystems of the upper stage and have analysts determine and document what was needed and what could be used as a mass simulator. Other elements didn't use this process, and their documentation was less useful. It would have been useful to transfer this information into a parts list and include it in the test plan or element agreements. Having the Element representative at IVGVT documentation preparation meetings was an efficient way to exchange information.

Recommendation:

Use the process that Upper Stage used to design the test article. Transfer information developed through this process into documentation early in planning.

4.18.8 STE Design Guidelines

Description:

Constant vehicle design changes necessitate versatility in STE design. Examples of STE needing versatility included rolling platforms and mast climbers. Consideration of contingency usage of STE is helpful in determining ways to make the STE more versatile.

Recommendation:

Projects need to make STE designs as versatile and robust as possible to account for constant vehicle design changes and contingency planning.

4.18.9 GSE Leadership and Planning

Description:

The Upper Stage GSE team did an exemplary job at early planning. GSE needs to be an early priority in program development. Without the ability to ship and assemble flight hardware, the project will not be complete. A substantial amount of cost and time are required to design and manufacture GSE and STE and development requires the same type of engineering as flight hardware. In contrast, insufficient schedule margin was included in facilities tasks for test programs.

Monthly GSE meetings were led by FITO which worked well because FITO was responsible for agreements with GSE providers. Ares also had a stand-alone GSE team that was responsible for the first stage (FS) and upper stage GSE. The stand-alone team was insufficiently involved in the Integrated Vehicle Ground Vibration Test (IVGVT) GSE. Additionally, the GSE Plan was not developed early in the program and was not located at the appropriate authority level. It was buried in the Integrated Logistics Support Plan giving it limited visibility.

Heritage FS element GSE was more difficult to finalize than the newly designed upper stage. However, there were IVGVT-specific STE identified that had no corresponding GSE designed for a flight upper stage.

Early in the IVGVT task, the lack of needed resources resulted in delays to critical pretest analysis to support the design. Partnership with a team from Glenn Research Center (GRC) was initiated, but suffered due to geographic separation.

Ares Elements and Orion had difficulty supplying data (models, requirements, specs) when needed for test article development since the element design details were not mature enough to support the test article development schedule. The program milestones were based on when designs were needed to support the first flight without accommodating the need for capstone development tests' needs for design maturity to support system-level tests.

Recommendation:

Consider GSE and STE engineering design requirements upfront to ensure the GSE and STE are available and sufficient to support the flight hardware design, testing, transport, and operation. A single GSE team should be responsible for all GSE for a specific test event. The test GSE team should be the same GSE team responsible for the vehicle project GSE. It is important to properly staff engineering teams on time. Teams who must work closely together should be co-located. Also, add appropriate margin for the major test facilities task. It is important to recognize that there are inherent delays to construction including weather and materials delivery.

The GSE plan should be at the same level as the systems engineering management plan (SEMP) to ensure clarity of expectations. Generate the master GSE lists that are specific to the IVGVT test article and test facility capability. Every lift or handling GSE item between the crane hooks and the test article needs to be reviewed. Each test article component must be analyzed for each handling requirement. There needs to be a point of contact (POC)/subject matter expert (SME) very familiar to the test article reviewing configuration changes for any needed equipment for handling the test article. Be sure to include capstone development test programs in the project master schedule. The master schedule needs to include the test program Authority to Proceed (ATP) dates, test data delivery dates, and significant test program data and hardware.

4.18.10 Test Article Agreements

Description:

Without written agreements between project, elements, and test team, changes can be made without approval from one of the groups. Updates to the FITO-Ares Element Support Agreements were boarded simultaneously even though Upper Stage and Upper Stage Engine were submitted months ahead of First Stage. This resulted in personnel working toward un-boarded agreements in the interim. Review of element support agreements should be conducted when the agreements are ready and should not be delayed because one of three elements has not delivered.

Test articles and GSE requests need to be approved at the project, then the elements and the test engineering team. They need an agreement similar to an interface control document (ICD) for each test article to ensure all stakeholders agree to changes. Clear levels of authority need to be established and defined early in GSE development.

The first work package for IVGVT was based on an early, very limited, and low-cost test on the first flight vehicle. After the early GVT was cancelled, the work package was transferred into the more robust IVGVT and years were spent trying to modify the original work package.

Recommendation:

When fundamental test requirements change, agreements, budgets, and schedules need to be renegotiated. The project should require all test changes that are added come with a change package that includes the resources to cover the change.

4.18.11 Integrated Timeline

Description:

Flight vehicle programs need a single timeline maintained at the top level of the program with sufficient detail to drive the processing requirements into the design. Timelines need to be integrated and configuration managed. The Level II timeline didn't contain the level of detail required by Ares to perform their analysis and it was very late before the Level II timeline captured the necessary level of detail. The program needs to have a clear understanding of the users' needs regarding contents and timing for the timeline.

Recommendation:

Use an integrated configuration-managed timeline to drive the design. Timelines need to be coordinated between levels with sufficient detail to be useful at each level.

4.18.12 Heritage GSE Costs

Description:

Heritage GSE is not free. There is a great deal of work and cost to use heritage GSE that was not estimated. Plans and processes for recertification of heritage GSE were not planned or considered.

Recommendation:

If the decision is made to use heritage GSE, establish clear recertification plans and processes early in the program and estimate associated resources.

4.18.13 Single Points of Failure

Description:

We should not be one person deep on anything. This creates a single point of failure.

Example: The Ares I Ascent Timeline was maintained by one person. When that person left the project it was determined that the tool that was developed was not documented and no one else really understood the process that was being used to gather data and develop the ascent timeline. This resulted in a large amount of time and resources to rebuild the capability.

The Ares Projects created several single point failures in the organization by not funding critical skills that were relied upon heavily, i.e., timeline development, availability, operability analysis, and mission operations.

Recommendation:

Recommend that the project not create single points of failure in the organization by not funding critical skills that will be relied upon heavily, i.e., timeline development, availability, operability analysis, and mission operations. There should not be any area that is one person deep on any effort.

4.18.14 DD250 and 1149 Process

Description:

The DD250 and 1149 process needs to be addressed initially at the start of any program. This also applies to any required paperwork for the movement of goods between NASA centers, vendors, manufacturers, etc.

Recommendation:

Arrange for local government quality representatives to support government acceptance reviews of material procured under other contracts and document DD250/DD1149 process/paper requirements between contracts.

4.18.15 Trade Study to Determine If An On-board Automated Execution Environment Was Needed on the Flight Computers to Support Ground Operations Capabilities

Description:

The trade study to determine if an On-Board Automated Execution environment was needed on the flight computers to support ground operations capabilities was performed too soon and did not formally enter a trade space.

Recommendation:

If an on-board script executor had been provided, ground systems could have full capabilities, no trades would have been required.

4.18.16 Design for Operations

Description:

Operations were seen as a booking function only, the result of design limitations. Operations should be a discipline, similar to Logistics, Human Factors, etc. Also, changes to the overall design would be better served by having an Operations impact on change requests (CRs) as they are approved.

Recommendation:

Design for operations should be embedded in processes; “impact” on change requests; check/balance on new concepts; added to affected trade studies; etc.

4.18.17 Team/Organization Nomenclature

Description:

Using the term “Ground Operations” to describe both KSC and MSFC led organizations is confusing to the program. KSC is the GOP (Ground Operations Project) and owns the patent to “Ground Ops.”

Recommendation:

When the new program is developed, a MSFC organization dealing with ground operations needs to be renamed “Ground Operations Systems Engineering” or “Design Operations,” etc. We need to find a term to avoid crossover with KSC.

4.18.18 Supportability/Logistics Consultancy Support

Description:

A globally recognized independent assessor for supportability/logistics was allowed to provide consultancy support within the Upper Stage Element that greatly assisted Upper Stage Level IV, as well as Ares I Level III.

Recommendation:

This practice is typical for Department of Defense (DoD) and other government agencies and should be continued at MSFC at the first opportunity.

4.18.19 Expanded and Integrated Operations Concept

Description:

Program needs ONE integrated Operations Concept (Ops Con) that defines roles and responsibilities for all entities AND requires all parties to utilize it for the design as a quasi requirements document. Every element of Constellation had their own Ops Con with each being different based on their point of view and defining roles and responsibilities based on what they "wanted" to happen!!! Individual elements and/or subcomponents should not have their own Ops Con documents. Each element's Ops Con should be in the vehicle Ops Con.

Recommendation:

Recommend that the program have one single integrated Ops Con document that defines overall roles and responsibilities for all entities and requires all parties to utilize it during the design process. Individual elements and/or subcomponents should not have contradictory Ops Con documents. The scope of this Ops Con should include nominal flight, testing, and logistics.

4.19 PROCUREMENT

4.19.1 Initial Contract Definition in Request for Proposal (RFP) Phase

Description:

Multiple challenging issues resulted from a general lack of contract definition. Specifically, in the areas of hardware procurement methods, the handling of nongovernmental proprietary data.

The acquisitions strategy used for the avionics hardware did not support the development schedule of the vehicle. Using a contractor as a "supply chain manager" buying hardware to government-developed specifications creates an enormous amount of contract change traffic.

A general lack of detail in the production contract created the need to make numerous contract changes throughout the program. Resolving these issues became a huge problem, and the rough order of magnitude (ROM) was typically substantially higher than our predictions.

Recommendation:

Recommend that on future contracts, leadership (NASA) spend more time pre-award to insure completeness and sufficient detail of contract definition, as it costs much less pre-award than post-award to fix contract issues. Possibly consider a more flexible type of contract that allows for modifications with minimal/no costs.

Future contracts should specify (RFP stage) acquisition strategy (make contractor or NASA completely responsible), and define how nongovernment-generated and proprietary data accessibility will be handled (define ground rules).

4.19.2 Insufficient Prime Contractor Insight/Oversight

Description:

There was not sufficient oversight of the prime contractor on some specific areas, such as hardware and tool purchasing, and the development activities with Manufacturing and Assembly (M&A). The prime contractor, using existing requirements, purchased hardware and tools without engineering oversight and insight. There was a huge disconnect between the prime contractor and M&A in the development area. The prime's engineers and technicians were part of the development team, but the prime's management was not. As a result, NASA (project and engineering) was stonewalled by the prime when negotiating the cost and schedule for specific engineering tasks.

Recommendation:

A process should be defined that allows engineering to review and approve prime contractor tasks. Also, the prime's management should be directly involved with development teams to help with future task negotiations.

4.19.3 Contingency Suppliers for Critical Products

Description:

We had single-point failure potential with some component vendors in that there was only one game in town domestically—specifically spin-formed domes for bulkheads, cleaning, primer application, core, perforating, and adhesive. If they raised prices, slipped schedule, or shut down we would be out of a supplier for critical path items. These limited vendor options arose from being forced to make choices very early to meet long-lead deliverables.

Recommendation:

Make multiple awards for critical products and components, if possible. Plan for contingency of a process/manufacturing/design not working. Run two developments/designs in parallel if the budget allows to mitigate the risk.

4.19.4 Prime Production Contractor Should Be Involved Early in the Design Process

Description:

The Upper Stage Prime Contractor (USPC) was not brought on early enough in the design process. By the time the prime was brought on, it was often too late to incorporate design recommendations in the areas of producibility/manufacturability and available industrial base.

Recommendation:

Consider bringing on the production contractor early in the design phase of the project to take advantage of their experience in design concepts and development efforts. Have the contractor involved in producibility/manufacturability studies tied to design development.

4.19.5 Early Involvement of the Upper Stage Production Contractor (USPC) in Component Development was Detrimental

Description:

The production prime contractor got involved much too early which led to much chaos in the design organizations. It is understood that the intention of bringing the production contractor on as soon as possible was to impact the design for producibility. However, the contractor did not always help the design team. For example, the contractor's insistence that the NASA design team

(NDT) did not have an adequate product structure introduced turmoil and discussions that caused NDT personnel to spend many MONTHS defending its position – finally the contractor decided to accept/work with the drawing tree. How did the product structure affect design? Many of the details the contractor insisted upon were not value added to design but were necessary for production planning. Thus the contention that the production contractor came on board too early.

Recommendation:

Bring the production contractor on after design has been completed.

4.19.6 Engineering Change Through Contract Modification Took Too Long

Description:

The time lag between an engineering change and a contract modification was too long. It was going to become a major hurdle as design baseline and contract baseline diverged. Putting a contract between design and manufacturing was an experiment that did not succeed.

Recommendation:

One mitigation to help speed this up would be to have a contracts person present in the integrated product team (IPT).

4.19.7 Procurement Mechanisms Must Be in Place from the Start of a Program

Description:

Do not get into a development program without a procurement mechanism in place. If not, it will be difficult to transfer the technology from the developer to the producer. Having to use contractors to initiate development contracts with vendors because of government contracting inefficiencies adds extra time and money burden to getting the work done and is not a good way to get things done. The irony here is that federal direct contracting has been running faster than contractor procurement. The Blanket Purchase Agreement (BPA) contract mechanism worked well for procurement of long-lead components with minimal drawings and specifications.

Recommendation:

Quick procurement mechanisms must be in place prior to beginning a project. Hiring and procurement processes need to be quick (3 months or less) to reduce the amount of schedule slip.

4.19.8 External Vendors Needed for M&A

Description:

M&A early on needed a contractual source to make large, less-defined, purchases for the developmental effort. The USPC path did not work out because of a lack of definition. The support contractor, Jacobs, did not work out because that’s not their function. Center-wide planning for the ability to establish external vendor contracts was never addressed to support such an in-house owned project. This has to be addressed by Procurement.

Recommendation:

The ability to establish external vendor contracts on an in-house project must be addressed by Procurement.

4.19.9 Problematic Contract Coordination/Communication Mechanism

Description:

The coordination mechanisms between the NASA design team (NDT) and the prime (Boeing) and subcontractors (and their subs) was problematic. These mechanisms were not well defined nor understood, causing confusion of proper communication paths on all sides. Many times it seemed that the prime would make deals with their vendors (i.e., agree to a requirements change) without coming to the NDT, and be working in a different direction than NDT. Also, many times the subcontractor interfaces were very guarded.

Additionally, at one point in time, Vehicle Integration (VI) was allowed to work issues directly with the First Stage prime contractor, which led to rework and additional manpower expenditures at Alliant Techsystems, Inc. (ATK) that was not authorized by First Stage (contract holder).

Recommendation:

Recommend that contract coordination mechanisms be established and implemented at the beginning of a program, especially coordination with subs. The Resource Management Office could be better utilized in technical coordination with primes and subs. Also, the project should have a means for NASA and subcontractors (and primes) to communicate without violating proprietary information. On the Shuttle Program this was done via Ascent Flight Systems Integration Group (AFSIG).

4.19.10 Improve Partnering with Prime Contractor By Co-Locating with MSFC Personnel

Description:

Planning facility offices were not properly allocated for prime contractor. Originally, 250 locations were slated for prime contractors to be on site, but facilities were not ready, forcing them to move off site.

Recommendation:

Co-locating the prime with MSFC personnel can improve partnering. Either have the prime located on-site with MSFC personnel, or place MSFC personnel at the contractor’s site. Past experience shows that this is a good thing to do.

4.19.11 Allow Production Contractor to Propose Manufacturing Locations

Description:

NASA predetermined the location where the new vehicle would be manufactured.

Recommendation:

Do not predetermine the location where the new vehicle will be manufactured. Let the production contractors propose alternate locations that could provide schedule and cost savings. Let the production contractor be responsible for facility modifications. This will require them to integrate facility modification with tooling design and build in order to support their production schedule.

4.19.12 Modeling Format Not Consistently Specified

Description:

Several instances occurred in which modeling data were delivered to MSFC in a format that MSFC personnel were not equipped to process without significant cost and schedule impacts. This was caused by a lack of modeling format/structure standardization upfront in the project, prior to contracts being let.

Recommendation:

Modeling standards must be established early in a project, before contracts are let, to reduce the costs associated with integration.

4.19.13 Required Detail of Component End Item (CEI) Specifications

Description:

Different expectations were established for the detail level of requirements to be used in Instrument Unit Avionics Contractor (IUAC) procurement. The project office seemed to plan the RFP around having detailed specifications, but engineering wanted to deliver less-detailed documents. Either option could well work, but we wound up with half and half, which was not good. This situation, and the following comments, is a good example of how the project office expected engineering to make design decisions. Many engineering organizations, especially in Command and Data Handling, refused to make decisions and document decisions in requirements, thus making it the job of the vendor to make decisions for them. This led to frustrations as each of the two sides (project manager (PM) and engineering) had conflicting desires/expectations. Also, the acquisition strategy was flawed and evolved constantly.

Having a template for the CEI specifications was a great idea; unfortunately, the template changed often, and then was dropped. It would have been nice to develop the template better before releasing it. Copying the methodology of Upper Stage Prime (USP) was not a good approach. Avionics/software is unique both as a discipline, and in the division of labor between the contractor and the NDT. Finally, the IUAC selection and subsequent phased end item vendor selections did not allow for horizontal and vertical integration of the design. Too much black-out time.

Recommendation:

Future projects should consider developing a stable template for the CEI specifications, early in the project, to ensure a consistent level of detail and format.

4.19.14 Contracting CEI Specification Procurement Activities

Description:

We contracted with a company to procure all the CEIs for us, in part because we didn't believe we could manage that many competitions, and it would take too long. What we found was that Boeing had exactly the same issues we would have; only now we had inserted a new layer of management into the middle of the process. For example, the IUAC test team had to plan to outdated revisions of documents because that was what was on their contract. They were planning to the baseline version of the requirements when NASA had approved Revision B but had not added it to their contract. The revision in Cradle did not agree with the version on contract that also caused confusion. There needed to be a much quicker, easier path to modifying the IUAC contracts to keep up with the CEI specs. We cannot add an extra layer of management and middle man and expect it to be done FASTER or CHEAPER.

Recommendation:

Don’t contract a company to procure all your CEIs specifications on an in-house project. This caused more problems than it helped.

4.19.15 BPAs Work Well

Description:

Our BPA contractor did a great job buying our common bulkhead materials and components. Whenever there were hold ups, it was usually on the NASA side. Tech Masters had a detailed schedule which they updated regularly and adapted quickly to our needs. The use of BPAs worked well for acquiring resources quickly.

Recommendation:

Use BPAs where possible to obtain resources, materials, and components quickly

4.19.16 Direct NASA-to-Manufacturer Contract Mechanism Worked Well

Description:

Direct NASA-to-manufacturer contract mechanisms worked very well, were easier to manage, and provided more effective communication between designers and manufacturers which was vital to the success and quality of the deliverable item. For example, they successfully built and tested Heavy Weight Motors (HWMs) 1 and 2 utilizing multiple direct contracts while allowing engineering and manufacturing interaction which promoted learning, experience, and product quality.

Recommendation:

Recommend that new programs/projects continue to use direct-to-manufacturer contracts as the need may arise.

4.19.17 Upper Stage Contract Type and Structure

Description:

The decision to have two Upper Stage contracts (IUAC and USPC) was not completely evaluated upfront to fully understand the pros and cons. Ultimately, this resulted in an extremely difficult integration job and inefficiency. The split between contracts was based upon contract dollar value and not technical execution. Also the decision to use a cost plus fixed fee contract should be avoided as it will typically overrun, as in the case of the USPC. Fixed price contracts will have a higher initial cost but at least will not increase.

Recommendation:

For future projects, additional evaluation and planning should be done as to contract type and structure. Consider using fixed price contracts instead of cost plus fixed fee contracts to keep long-term cost down.

4.19.18 Role of Production Contractor

Description:

The role of the Upper Stage Production Contractor (USPC) was not clearly maintained. While they were expected to provide producibility input, their push for a linear slope to Critical Design Review (CDR) of drawing release and drive for a Design and Data Management System (DDMS) product structure consumed a great deal of NDT leadership resources that would have more appropriately been devoted to oversight of design issues and design processes. Additionally, their approval of drawings represented a conflict of interest in that it was not if the design could be manufactured, but what designs offered the lowest risk of Material Review Board issues or even perception of the highest potential for profit. Since they were a mandatory signature on the drawings this interest undermined the design center’s authority. There were instances of decisions being made between the project and the prime contractor that didn’t include the NDT.

Recommendation:

Engage Organizational Conflict of Interest (OCI)-free hardware manufacturing subject matter experts early in the design process. Avoid NASA’s overreliance on prime contractor’s recommendations over the design authority to avoid appearance of OCI.

4.19.19 Vendor Selection: Systems vs. Components

Description:

Commercial culture has undergone a lot of changes since Apollo/Shuttle, such as more “lean,” more profit driven. Big vendors want to sell systems now, not components. Need to focus on small, niche suppliers for a lot of items. A lot of time was wasted courting big guys unsuccessfully.

Recommendation:

Recommend considering focusing on small, niche suppliers when searching for vendors for some particular items.

4.19.20 Source Control Items (SCI) Requirements

Description:

Clear requirements for SCI information and incorporation into Preliminary Design Review (PDR) and CDR efforts were not imposed on the USPC, and linkage to products at the subsystem levels could not be assured. Subsequently, this information could not be reasonably incorporated into required PDR and CDR products. As such, the identified PDR and CDR products did not/would not meet standard expectations.

Recommendation:

SCI vendor parts need to be procured as soon as possible. Therefore, the drawings schedule is not dependent on vendor parts at CDR.

4.19.21 Contracting Officer’s Technical Representative (COTR) Level of Authority

Description:

Leads were not always provided enough authority to direct the work they were assigned. Oftentimes it was felt that direction provided on a contract had to be run through higher levels first or it was likely to be vetoed. As COTR for a development activity, many decisions (both in-scope, in-budget technical, as well as those that might result in contract modifications) on design implementation had to be carried back to the IPT lead for approval. This seemed to undermine the COTR’s authority when direction could not be given without continually having to get higher-level buy-in.

Recommendation:

The COTR should have the appropriate level of authority in order to make decisions on their contract.

4.19.22 Contracting Process Improvements

Description:

Lack of an automated process for submitting contract letters through the COTR to ATK makes it difficult to know the status of various items at all times (e.g., Pending COTR approval, Submitted to ATK, etc.).

Recommendation:

Develop an automated process for submitting contract letters through the COTR to a contractor to show the status of various items at all times.

4.19.23 Problem Reporting Volume Driven by Contract

Description:

During evaluation of the external tank (ET) manufacturing faults, we found that the number of discrepancies per tank remained at a high level throughout the ET Program. Then we found that the contractor was paid for closing each problem report.

Recommendation:

We should learn how to set up contracts to encourage the contractor to report all errors, but at the same time reduce the number of errors.

4.19.24 Cost Proposals and Contract Renegotiations

Description:

Variations in contractor’s cost proposal submissions make understanding of the accounting to be cumbersome with fact-finding discussions almost always needed.

Schedule slips such as Program Management Recommendation 2009 (PMR09) are very expensive and tedious to place on contract. This is the effect of both cost overruns in the program and reduced funding below what was planned.

Recommendation:

Create a standardized process for submitting prime contractor cost proposals. Require contractors to resource load in detail (quarterly) its phasing of the negotiated contract change in the Earned Value Management System (EVMS). Although painful, this will serve as a basis to modify “existing contracts” for future launch system contract negotiations. In assessing past performance for proposal evaluations, it is important to resource load EVMS with “negotiated” spread per contract timelines. NASA/government personnel should have traceability, access, and understanding of spread for assessing future contract changes and evaluations.

4.19.25 Acquisition Schedule Was Problematic

Description:

Acquisition cycle time is problematic. Delays are incurred for a variety of reasons. Taken together, they make timely settlements of changes all but impossible, thereby creating a serious lag time between need for a change and adjusting contract value for implementation of that change into the contract.

Recommendation:

The COTR should be the project office's central point for tracking receipt and storage of data requirements (DRs). Develop the data procurement document (DPD) based on file retention requirements (NPR 1441.1, NASA Records Retention Schedules), at least as best as can be projected. Closeout costs should be included in our major contracts. Separate contract line item number (CLIN) for ease of adjustment, when necessary, and separate incentive structure. Need a dedicated decision-making process.

4.19.26 Data Requirements and Contracts

Description:

Boilerplate DRs were used in developing RFPs resulting in contractors submitting requests for additional funds just because something was changed.

Recommendation:

Configuration and Data Management (CDM) need to develop the CDM Data Requirements and Statement of Work content. CDM deliverables need to be closely evaluated. Having CDM experts on the Source Evaluation Board (SEB) when contracts are written would ensure these DRs are handled properly.

4.19.27 Engineering Support to Contracting

Description:

Contract adjustment, continual process improvement, and implementation was not accomplished as it was separate from engineering oversight or in-house efforts. It needs to be integral.

Recommendation:

Management needs to have engineering lead contract changes and not leave that to Procurement alone or the project office.

4.20 PROGRAM PLANNING

4.20.1 Roles and Responsibilities

Description:

There were many examples of unclear roles and responsibilities such as:

- The organization of Ares Element Project Offices overlapped the Engineering Directorate responsibilities such as being the technical authority for the engineering discipline.
- Level II personnel went directly to engineering personnel circumnavigating the Flight and Integrated Test Office (FITO). Project office managers circumvented chain of command to acquire schedule data and status.
- There was too much conflict between engineering and the project. Roles and responsibilities across Upper Stage subsystems were not well defined. Some lead roles such as branch chiefs, volume integrators, and assembly leads seemed to be at equal levels and sometimes gave conflicting direction. There were many instances of groups independently working the same issues.
- Division of programmatic and technical responsibilities allowed visibility and coordination of technical and programmatic coordination. The reclama process aided in resolving disagreements. There was, however, some lack of understanding about the division of responsibilities between the project and engineering.

Recommendation:

Clarify the roles and responsibilities in writing throughout the organization. Project/program management needs to ensure delegations are clear and enforced. Eliminate duplication and overlap between engineering and the project offices. Designate a manager to provide final direction to team members. Strive for lowest level reasonable. Document decision authority for support contractors.

4.20.2 Engineering Experience and Expertise Deficits

Description:

Throughout the life of the program and throughout leading and implementing organizations, there were difficulties stemming from lack of applicable engineering experience working in this type of a program. For example:

- The project offices challenged electronic, electrical, and electromagnetic (EEE) parts requirements due to the lack of engineering experience with the basis of these requirements.
- Integration experience was lacking, leaving component- and subsystem-level engineers having to do the interfacing and integration.

- Experienced engineers were continuously picked off from the thrust vector control (TVC) subsystem despite appeals from the subsystem managers.

Recommendation:

The center needs to make mentoring and knowledge transfer a major activity. The Chief Engineer's Office should continue to rotate personnel from a variety of discipline support areas. Having experienced personnel working as chief engineers is critical.

Ensure the project office has broad insight and understanding of engineering disciplines requirements and their basis. Strengthen Vehicle Integration (VI) and Systems Engineering and Integration (SE&I) teams through training and experience. Improve transition and backfill process and use care in harvesting too much talent from subsystems. Process training should be made available on a needs basis. When one manager is lacking in expertise, make sure the deputy can fill in for his deficits.

4.20.3 Grey Beard Availability

Description:

Appreciated the availability of grey beards during the system development process. This allowed for new engineers to take advantage of their experience and knowledge when making decisions.

Recommendation:

Recommend continuing to engage grey beards on future programs.

4.20.4 Phasing of Engineering Resources

Description:

NASA transitioned poorly from pre-Constellation activities to Constellation-centric activities. Many projects were abruptly terminated to free up funding for Constellation. One consequence was the creation of a standing army with little to do. Assigning so many people early on resulted in increased costs and the assignment of some people who were trying to perform tasks before the program was ready for their function.

Meanwhile, some disciplines such as thermal analysis, computational fluid dynamics (CFD), ballistics, and structural analysis were spread too thin and forced to work multiple programs simultaneously, resulting in them working in a reactive mode. The insufficiency of these resources resulted in incomplete or late document review activities.

Integrators and assembly leads were not assigned early enough in the design process. They weren't given authority to make decisions for their volume and they didn't have adequate engineering and project management support.

Recommendation:

Use care in transitioning Constellation engineers to the new program and instead build the program as needed to fulfill the tasks appropriate for the designated stage in the program life cycle.

4.20.5 Establishing Common Units

Description:

The midstream change to Système Internationale (SI) Units was very confusing when interface control documents (ICDs) were being developed.

Recommendation:

If SI or any other specific units are going to be required, the decision needs to be specified at project initiation and limit the number of organizations given exception to the applicability.

4.20.6 Prime Contractor Insight vs. Oversight/Contractor Bias in Their Reviews

Description:

The government became too involved in the details of contractor operations.

Plans and processes for transition to the Upper Stage Production Contractor (USPC) were not well planned and executed. There was a lack of clarity concerning how technical requirements were to transition to the contractor while NASA would maintain ownership. There was a tendency by USPC reviewers to steer design to their preference, rather than to execute it. A fine line between useful critique and corporate preference.

Recommendation:

The government should not work details of how the contractor meets its schedule and cost. Contractors should be able to use their existing plans such as quality assurance, manufacturing and production (M&P) control, and problem reporting that have been accepted rather than the government requiring wholesale rewrites for new programs. Plans and processes for transition from designer to manufacturer must be more clearly defined to be better managed in the future.

4.20.7 Information Technology (IT) Security Programmatic Concerns

Description:

Program security should be viewed as a security risk management process through the life of the program. Program/project security management plans (SMPs) were written, but incorporation of the plan into the actual process didn’t flow. Lack of an IT security subject matter expert (SME) at the beginning of the project resulted in the avionics system engineer becoming the de facto point of contact (POC), but an IT security specialist was needed to do threat and vulnerability analysis.

The investment in an IT security support contract to define mission critical security processes modeled after the Department of Defense (DoD) program protection process should be translated into the next program. Management needs to understand, emphasize, enforce, and support the requirements, implementation, and tools needed for IT security. Security task ownership needs to be identified at the appropriate level. Level II reviews of IT security during the Constellation Program (CxP) effort were disjointed and uncoordinated.

Recommendation:

Detailed SMPs including Sensitive But Unclassified (SBU) protection need to be developed and approved early in the program and should be viewed in terms of security risk management throughout the program life. Headquarters (HQ) security organizations need to be consulted early on policy interpretation, security planning, counterintelligence support, etc. An IT security SME needs to be onboard at the beginning of the project to work these plans, policies, and processes. IT security investments developed under Ares should be carried into the next program.

Center and program management needs to fully support (including adequately funding) IT security and SBU protection. Security Awareness Training modules tailored to the program/project should be developed early in the program. Modules such as these are relatively low cost.

Ownership of security tasks need to be identified at the appropriate level to ensure ownership and funding. Upper level reviews of separate but related IT security controls need to be better coordinated and communicated.

4.20.8 Communication Paths

Description:

Communicating up through Ares and, subsequently, CxP management was burdensome. There were too many forums that added no technical or management value. System integration groups (SIGs) and panels acted as decisional bodies rather than advisory groups to the project manager and chief engineer as described in the systems engineering management plans (SEMPs). Responsibility was diffused but authority was centralized.

Engineering had a desire to allow open communication from the project to all engineering staff. As we got further into the program, we saw the need to have more formal communication of assignments and reporting to the project. Engineering needed more direct communication of top-level schedules, objectives, and actions. Also, post-offsite meeting feedback should be communicated. For short fuse items, there may be a need to operate under parallel communication paths where a project lead works directly with an engineering discipline. In these cases, the project office must at least inform the engineering lead of the action.

Recommendation:

Responsibility and authority for decisions and communication need to be compatible. Centralized authority should be linked to centralized responsibility. Mixture of the types of responsibility and authority is confusing and leads to communication blunders. Improve top-down communications. Share and vet top-level decisions. Any project task, no matter how fast the turnaround time, should be at least worked in parallel with communication to the affected engineering organization leadership.

4.20.9 Task Description Sheets (TDSs)

Description:

Task description sheets had a life of their own and it seems that more time was spent on developing the sheets than doing the work associated with the project. From a management perspective, each TDS board always asked which integrated product team (IPT) had looked at it. There was little direction as to which IPT should have looked at it. Although comments were solicited, the board desired responses from specific reviewers who didn't provide feedback, and the desire from the board to see those reviewers' responses was not communicated until the board meeting.

The schedule for TDSs was presented in different forms over the course of the project. At different times the schedule was put into Data Exchange Matrices (DEMs), Constellation Analysis and Integration Tool (CAIT), etc. First Stage had their own way of tracking TDSs and Vehicle Integration had another.

Recommendation:

Recommend new programs/projects assess and determine the most efficient way to describe, negotiate, agree-to, and track task and data needs across a larger system of both programmatic and supporting discipline entities. This should be done as a part of basic program planning and system engineering soon after program and compatible engineering organizations are established. (As an added note, the planning for task and data tracking may benefit from use of NxN or functional flow type analysis.)

If TDSs are used, when TDSs are negotiated, a point of contact (not the IPT lead) from each organization should be assigned to it in order for the TDS lead to know who is responsible to approve the TDS. Alternatively, each IPT could provide a TDS contact to funnel review requests. Invoke a common integrated schedule for tracking TDSs across the program.

4.20.10 Supportability

Description:

Logistics and support solution related guidance and direction should flow from top to bottom within the organization. Integrated Logistics Support (ILS) should be a Vehicle Integration function and support the elements, versus the elements having their own ILS group independent of Vehicle Integration, to enable the ILS community to pool their resources and work issues in a more integrated function. Separation of Reliability, Maintainability, and Supportability disciplines into different directorates led to lost opportunities to leverage an integrated approach to optimize the operability and affordability of the Ares vehicle.

Recommendation:

Make ILS a centralized vehicle integration function that supports the elements with pooled resources. Reliability, maintainability, and supportability engineering are closely related disciplines that need to be grouped together into an Integration Engineering function.

4.20.11 Manufacturing and Production

Description:

Manufacturing and Production discipline experts were not included in early discussions regarding material and manufacturing related issues. Since fabrication is near the end of the process, schedule slips often accumulate forcing manufacturing to be accelerated in order to make up the schedule.

Recommendation:

Ensure M&P is provided time to review and precoordinate, despite the fact that they may be able to get quick recommendations by non-M&P support. Even though former M&P personnel are part of the project or other engineering disciplines, the current M&P lab needs to be included in technical decisions. M&P needs to be involved before hardware is to be manufactured in order to prevent problems with hardware late in the design cycle or after manufacturing begins.

4.20.12 Trade Studies

Description:

Too many trades were accommodated during the program. The design always seemed to be changing to keep up with what we were currently working to.

Recommendation:

Limit trades to correct substantial problems. Prioritize technical including safety then look for schedule and budget options.

4.20.13 Standing Review Boards

Description:

Prior to each milestone review, an independent team, commonly called the Standing Review Board, submitted comments as to the path the program was on, ways to tackle problems, etc.

Recommendation:

Review the integrated standing review board recommendations for applicability to future programs.

4.20.14 Remote Design Teams

Description:

Small design groups that were remotely located lacked team support to resolve process questions. This lack of support resulted in computer-aided design (CAD) and configuration (outer mold line) related problems.

Recommendation:

Develop a means to have peer support to small isolated design centers if multi-center design is employed in the future. Means of support could involve assignment to a larger design team that would enable instant communications to resolve issues.

4.20.15 Programmatic Tools and Processes

Description:

The Upper Stage Element Offices programmatic tools were not ready at project start up. Examples were earned value management, scheduling, risk management, change control boards, and change control tools. Management used increased accountability to drive success without accepting process changes that would have improved efficiency.

Recommendation:

Upfront emphasis should be placed on project and programmatic systems and processes. Include development of a process for the working level to recommend efficiency improvements.

4.20.16 Documentation Conflicts

Description:

The process for addressing conflicts within CxP documents was not well defined or coordinated. One observer had an issue with a structural design and verification document which according to the document had to be resolved at the document owner (JSC) level, but ended up being addressed by the upper stage engineering board.

The project and center management were (in general) consistent in referencing, leveraging, and executing to architecture/program/project documentation. Management philosophy and emphasis on using and enforcing process documentation (such as the configuration management (CM) plan and master verification plan) as well as requirements products was strictly maintained during the program.

Recommendation:

Continue to be consistent in the use of programmatic, process, and requirements documentation. Clearly define a process for addressing conflicts between CxP documents and communicate the resolution process to all program levels.

4.20.17 Ground Vibration Test Interactions with Level II and Non-MSFC Level III

Description:

Responsibility for the overall test, test configuration, and test changes as the program was implemented was never clearly defined. The SEMP identified the Integrated Vehicle Ground Vibration Test (IVGVT) as Ares FITO's responsibility but activities were delegated to test lab so there wasn't a clear separation between analysts who worked for FITO evaluating the efficacy of the test articles.

- IVGVT had to continuously educate Level II and the Elements as to the need for the test. The debate/issue resurfaced throughout. Without clear requirements and plans for testing this will be a problem in future programs as well.
- Individuals within Level II believed that they were a stakeholder in the IVGVT and that IVGVT was their test and that they could dictate details of the test.
- Lack of a Level II integrated test plan created a huge flow down issue. IVGVT was unable to locate who determined the vehicle fidelity configuration.
- Orion did not believe they needed IVGVT. Level II management didn't intervene until late and after much urging since IVGVT was delegated to Ares.

Recommendation:

Since the primary customers for IVGVT were both Level II disciplines, Level II should have provided the leadership and drive for IVGVT. When tests are added by the program, they should not have to continually rejustify themselves. Instead, the test group should report progress to meeting objectives as part of the overall vehicle picture. Level II should have provided their goals and requirements to the test owner, FITO, and then allowed FITO to prepare the test without interference.

Integrated test plans should be done upfront and the plans should be used as planning tools. A working group should determine the fidelity of the system such as what can be a mass simulation, stiffness simulation, load paths, etc. Define all test articles required for integrated testing and identify who is responsible for providing them early in the program.

4.20.18 Plans and Processes

Description:

There was not a common format established prior to the development of many major documents (requirements, verification plans, and tailored documents). Without a common format, there was inconsistency between the same types of documents and eventually substantial rework with SE&I provided direction.

The Levels II (program), III (vehicle), IV (elements) and V (subsystems) were logical and well understood. The CxP document numbering schema was also clear and consistent.

Process development and control ideas were inconsistently defined, communicated, and enforced. Both the SEMP and CM plans were in this category. Some plans (such as the task plan, test plan, transportation plan, safety, reliability, and quality assurance (SR&QA), and implementation plan) had a lot of overlap and duplicate information.

Recommendation:

Clearly define format and content requirements of major documents early in the program. Clearly define processes upfront. Allow strict process enforcement to be in step with the maturity of the design process.Use SEMPs as the key repository for all systems engineering processes including product and process integration. Implement renewed management focus on consistent use of the SEMP in management-level decision making and program implementation. Changes to the systems engineering approach should be promptly updated in the SEMP.

4.20.19 Needs Matrix Timing

Description:

A helpful item that should have been developed sooner was the “Needs Matrix.” This matrix concisely summarized who (elements, analysts, designer, etc.) needed what data when. If this matrix had been developed upfront, the project would have been more consistent in answering requests. The Needs Matrix was folded into the internal engineering schedule.

Recommendation:

Develop a Needs Matrix (the Nodes projects used a Bilateral Data Exchange List) early in project development and incorporate it into the internal engineering schedule.

4.20.20 Fewer Meetings

Description:

Early on in the project there were so many meetings that we spent a large part of our week sitting in meetings and too little time working the tasks we had been assigned. Many of the meetings focused on topics that did not apply to our discipline. Integrated product team (IPT) meetings, for example, would tie up 40 or so individuals for several hours while we debated at length a topic that was really only critical to 3 or 4 members. Toward the end of the project, the meetings were held more at a working group level. Though this allowed for a lot of decisions and progress to be made it often left those not included within the meetings in the dark. This resulted in a challenge for those included when updating system-level documents or running specific analysis.

Recommendation:

Fewer meetings with a defined goal and limited invitations would be better. Once a week meetings to summarize the week's changes would be sufficient to bring everyone else up to speed.

4.20.21 Meeting Procedures

Description:

There were numerous observations regarding the usefulness, efficiency, and organization of meetings:

- Agendas weren't always available in advance of meetings or even at the meeting. Without agendas, many team members spent valuable time at meetings where they had no direct involvement.
- Presenters frequently exceeded their allotted time without enforcement by the meeting host which resulted in other presenters being deferred or short changed on their time.
- Notes containing important decisions and actions from the meeting were not always available after meetings.
- Some integrated meetings had unclear definitions. Even though they had charters, it was unclear as to what content went to which meeting. There were so many different working groups that many people spent all their time in meetings.
- Integrated assembly meetings for the aft-skirt/thrust cone design were helpful as they were held for a defined and specific purpose.
- Meetings with supporting branch chiefs would have enhanced broad understanding of project issues, goals, and decision making.
- Off-sites that were held "away" to "sequester" attendees were costly. Engineering professionals should be disciplined enough to focus on large meetings locally.

Recommendation:

Recommend all personnel, especially leaders and managers, use prudence in establishing large meetings and follow basic tenants of efficient meetings.

4.20.22 Ground Support Equipment (GSE) Visual Aid (PowerPoint Slides) to Master List was Beneficial

Description:

The GSE list was organized by elements, then each lifting/handling operation considered with all components from the crane hook to test article installation considered and listed as a line item in the GSE Master List in an MS Excel spreadsheet. MS PowerPoint slides with pictures of GSE with lifting/handling operation identified were beneficial. Hyperlinks from a GSE item on an Excel spreadsheet to pictures did not work on all user computers even though all files were on the same test lab server. The ideal GSE item identifier should be either part number or model number; the item identifier would be stenciled on the actual GSE item and the same item identifier/description used in the lifting/handling/stacking procedures. Monthly GSE Master List reviews organized by common GSE usage was beneficial. The initial GSE lists provided by the Elements were for flight configuration only and did not consider any unique IVGVT operations or unique facility-driven requirements such as crane hook adapters and tag line operation. These flight GSE lists were scrubbed several times and reviewed against the developing unique IVGVT vehicle configuration. Concerns/issues were discussed with the element GSE owners/providers and GSE list updated as needed.

Recommendation:

The PowerPoint slides with pictures of GSE with lifting/handling operation identified should be archived with a copy of the current GSE Master List. These visual aids should be created for future parts lists to enhance identification of the individual parts.

Suggested or Taken Action:

Recommend GSE design/development function discuss with operations and test personnel and then recommend new (or updated) DRD that adds requirement for pictures to GSE Master List.

4.20.23 Efficient Control and Recommendation Process

Description:

For projects as large as Ares, there must be explicitly defined and strictly obeyed levels of authority. The initial planning for a level should not take place without coordination with the level above, this is very important with contracts. Due to cost, on Ares it was easier to change the end product performance requirements than direct contractor changes. We may not have done an adequate job in putting consequences into our contracts. When decision authority is clear, issues with decision compliance, technical authority versus technical recommendation, and the tiers of authority should be negated. The program focus should have been on the Level I design instead of engineering the specs and requirements. The authority of the Ares Vehicle Integration (VI) level vs. the Ares Projects level was always very confusing. Within the Ares Projects management structure, Vehicle Integration, considered to be part of Level III, was at the same management level as the Level IV Elements. The element managers did not report to the VI manager, they reported directly to the Ares Projects manager. Therefore, VI had responsibility for integration of the elements, with little or no authority to direct them.

The Task Description Sheet (TDS) process that was utilized to coordinate data exchanges between VI and the Elements was not effective. In addition, the Ares Projects had these issues of note: lack of SE&I experience needed for a project of this scale, unclear or cumbersome decision models, frequent changes to organizational models, operational models (changed four times), and schedules. Immaturity of the configuration/data management (CDM) processes and IT tools at program inception caused long-term issues. Efforts to manage the design documentation were hampered by: conflicting documentation, lack of integration (stove piped), inability to accurately track dependencies, synchronization between Levels II/III/IV, ineffective distribution of design/requirements changes, and processes authority. Management should choose the processes they want and give the process developers guidance. Once established, management must be an advocate of the processes. The number of boards and misunderstood board hierarchy was confusing and led to a significant amount of work to comply with the presentation requirements for each. Criteria should be specified (maybe dollar threshold, schedule, etc.) for requiring a board approval. Early in the design process, subsystems should be given more flexibility to change (within specified limits) without a board.

Recommendation:

With the implementation of standardized institutional processes, future programs/projects will be able to develop concise SEMPs by using links and references to the standards. Establish organizational and operational models early and be consistent with them throughout the program/project life cycle. Functional and process engineering disciplines are equally required for program implementation. Mutual understanding of these two perspectives is needed. Understand that schedule, cost, and performance are all variables and trade space that considers more than performance is needed. A systems management office with ample authority is needed to manage the vehicle design, processes, and document tree. Changes will occur, prepare for them by maintaining both performance and budget reserves. Decisions on how to manage/implement cuts need to be made with input from all stakeholders. Keep responsibility and authority together; Elements must be directly accountable to integration. An integrated master schedule must have ownership at the responsible and accountable lower level to have credibility and be useful to everyone. The organization needs to reflect authority. This can best be achieved through the boards. Fewer boards, reflective of a more streamlined decision-making process, or one overarching configuration control board, are recommended if the result would improve the design process. Streamline, clarify, and communicate the process for getting changes through the board system so that everyone understands and complies. The effectiveness of boards and panels is optimized when participants are of the proper level. Combine memberships from multiple panels to discuss specific issues if needed. Reduce the number of splintered engineering groups to eliminate a large amount of conflicts. More active coordination between engineering groups would also aid in the elimination of conflicts.

Suggested or Taken Action:

Premise: To develop an efficient (simple) decision process and stick to it, and make sure resources (budget and schedule) to make decisions, and the corresponding support staff to run the boards/panels go with authority and responsibility.

1) Develop simple requirement (or possibly template or guidance) for program/project decision process flow and authority and to emphasize that control/decision authority be pushed as low as possible and clearly connected to a delivered product or process. (Determine if necessary source is Red or Green Book and geared toward levying a requirement on program/project SEMP.)

2) Also, establish guidance (or requirement) in Red Book that Systems Engineering and Integration is at the same level as the controlling program/project office, and above the organizations being integrated, i.e., acts as an implementing arm of the program control.

3) Also, Chief Engineer (CE) and Office of Strategic Analysis and Communication (OSAC) establish guidance in Red Book for establishment of fundamental recommending panels to serve and be chartered in the appropriate program/project plan (e.g., SEMP). This is not intended to edict a mandatory minimum/maximum number of panels, but to agree upon a core set of basic panels. (CM should be working a process in screening to make sure the path through panels and working groups is determined and heads most efficiently to the Engineering Review Board/Project Control Board (ERB/PCB) decision gates.)

4) Also, with emphasis to push decisions to the lowest level, OSAC should establish program guidance (perhaps requirement) in the Green Book that resources (budget and schedule) must be allocated when responsibility and authority are delegated to a lower level.

5) Also, in the same line of thinking as #4, resources (budget, personnel, equipment, etc.) must be allocated to support the needed CM and DM functions for operation of control boards for the deciding/controlling entities (chief engineer and program/project offices).

4.20.24 Define ERB Membership and Responsibilities

Description:

Increased management attention is critical for in-house work to ensure adequate technical products, proper integration, and communication.

Recommendation:

Much of the critical Upper Stage communication occurred at the ERB/Element Integration Board (EIB), the engineering discipline quarterly reviews, the Upper Stage–Upper Stage Engine monthly review, and other project meetings; these were critical points of engagement for management.

Suggested or Taken Action:

1) MSFC management to clarify the role of line management with regard to product technical integrity and describe required tasks. And also define the support services that will be available to the line managers. (The key idea here is that we keep layering more tasks onto branch/divison leads. We need to clarify what is priority for them and also decide what can be taken off of them by support organizations, made more standardized, or more efficient.)

2) CM to determine policy/guidance for formal board quorum and level of delegation. (Examples: Does the ECB “must have” a project manager (PM) and CE, with chair’s discretion. Should we give guidance that we delegate no lower than one level below board members.)

4.20.25 Establish Improved Work Authorization Process Between Centers

Description:

No clear established standards existed for engineering work authorizations and negotiations on the Constellation Program. This lack of defined standard resulted in many instances of confusion with roles and responsibilities of personnel and organizations.

Recommendation:

Recommend that roles and responsibilities be clearly defined early in the project. Standards for engineering work authorization and negotiation between groups/elements/levels/centers should also be established and implemented.

Suggested or Taken Action:

Recommend Green Book provide guidance for establishing standardized task agreement/work authorization process, to record and negotiate center-to-center work package and sign-off by center, program, and engineering leadership.

4.20.26 Improve IPT Implementation

Description:

The IPT processes were not consistent or understood by all. Early on, IPTs seemed to work independently. Without functional IPTs, NASA has difficulty transitioning from an “insight and subject matter expert” role to an organization that owned and needed to deliver final products.

Recommendation:

Further define the IPT process and roles and responsibilities. Mature a horizontal integration organization and structure. Having an SE&I representative on each team may help with horizontal integration. They should be responsible to raise the cross-subsystem issues that we may be missing.

Suggested or Taken Action:

Recommend evaluating incorporation into MSFC Handbook 3599. Is there an industry best practice for implementing IPTs? Should this be pointed to by the Red or Green Book?

4.20.27 Infusing Experience and Expertise in Program Leadership

Description:

There were a lot of Shuttle people that had never worked a design, development, test, and evaluation (DDT&E) or “start up” program and they struggled at times with starting a new program compared with a production program. However, what Shuttle people lacked in development experience, they proved very valuable in bringing previous flight experience, especially about processing at KSC and working with the Range. Shuttle experience both within

Ares and as shared personnel with Shuttle provided this perspective, although there existed a huge cultural clash between Shuttle and Ares folks in "ways of doing things." Shuttle people were resistant to change and Ares people did not want to do anything the way Shuttle did it. Ares seemed to have many "paper study people" that never had worked hardware.

Recommendation:

A broad cross-section of personnel versed in DDT&E programs as well as existing production programs will be needed. Going forward, a good mix of many skills, including "paper skills," is critical for success. Those people need to be willing to negotiate between the old and new ways of doing things. We need people who know how to be responsible for their products: people that know how to write requirements to be responsible for that, people that know DDT&E to be responsible for that, people that know manufacturing/production to be responsible for that, etc.

Suggested or Taken Action:

Recommend evaluating incorporation into MSFC Handbook 3599, or identify where this may be documented. Identify a best practice process for establishing expertise and experience in developing an organization? (May drive hiring and training policy.)

4.20.28 Strategic Plan Must Be Reviewed and Agreed To

Description:

Projects initiated before the program resulted in significant rework and limited communication across centers, projects, and prime contractors. This required CxP documentation was not baselined until after Ares Preliminary Design Review (PDR), resulting in significant rework of Ares Projects documentation and Ares contract modifications. More than a year after Ares PDR, CxP Level II was still modifying plans, methodologies, and requirements documents, all of which should have been baselined prior to PDR. In addition, since the ground facility was already built, it drove design, rather than the other way around.

Recommendation:

All stakeholders (center, program, and engineering management) must review, agree to, and manage to the strategic plan. Do not initiate detailed project development before the program-level documents (requirements, plans, etc.) have been established. Be careful because one element design too far ahead of others can cause a less than optimum vehicle design solution. If the launch operations need to be ahead of everyone else to build infrastructure for political purposes, then they should also be built in a manner that allows easy and cheap modification. Put cost driving requirements in contracts. Don't let the ground drive the vehicle design.

Suggested or Taken Action:

Advise Space Launch System (SLS) Program Office (PO) and MSFC CE of the lesson. No technical recommendations from distilling to change/update current systems engineering and program planning guidance. Strategic program plan and schedule with dependencies (serial and parallel) must be discussed, agreed-to, and will be managed-to by program and engineering.

4.20.29 Develop the Program Planning Early

Description:

While some design activities worked to include operability in early program planning, it was included as a late addition in many of the trades and decisions.

Recommendation:

Further define the IPT process and roles and responsibilities. Mature a horizontal integration organization and structure. Having an SE&I representative on each team may help with horizontal integration. They should be responsible for raising the cross-subsystem issues that we may be missing. Establish key operability design considerations upfront to include in design trades and decisions.

Suggested or Taken Action:

Recommend Red Book invoke early development of a program implementation plan and a development plan to ensure visibility and adequacy of development tests.

4.20.30 Role of Safety Review Panel

Description:

The purpose of the meeting with the Constellation Safety and Engineering Review Panel (CSERP) and expected outcomes (e.g., acceptance of hazard report as Phase I complete or just requesting technical input) should be clear before the meeting starts. This should be coordinated with the Executive Officer (ExO) when scheduling the meeting. There should be more technical meetings to discuss design issues instead of the whole hazard report.

Recommendation:

The role and function of the Safety Review Panel (SRP) should be defined and the SRP ExO or co-chair with the program/project should be co-located. A broad cross-section of personnel versed in DDT&E programs as well as existing production programs will be needed. Going forward, a good mix of many skills, including “paper skills,” is critical for success. Those people need to be willing to negotiate between the old and new ways of doing things. We need people who know how to be responsible for their products: people that know how to write requirements to be responsible for that, people that know DDT&E to be responsible for that, people that know manufacturing/production to be responsible for that, etc.

Suggested or Taken Action:

CSO and CE office define the role and functions of the SRP, including necessary inputs/outputs, needed support staff and resources, and coordinate implementation on the SLS Program. Another recommendation was to co-locate the Safety Review Panel ExO with the program/project.

4.20.31 Establish Best Practices for Developing and Implementing Interface Requirements Document (IRD) and Interface Control Document (ICD)

Description:

On Ares, we had very late ICDs created by the vehicle and had to rely on our own point of departure ICDs that we negotiated with other elements, because the vehicle was behind in creating them. KSC got too far ahead of the vehicle in some designs, and while they certainly need sufficient lead time, they need to be following vehicle requirements, not driving them, because platform heights are fixed already, for example. It appears and is quite common for design organizations to have their own design philosophy. When the time comes to work the interface details, one or both organizations across the interface are embedded in their philosophy.

Recommendation:

IRDs and ICDs need to be established between elements very early and controlled/baselined. Insist on identifying key parameters as early as possible during the design process, so the transition occurs easily. Let the CM system work out the to be determined items (TBDs) and to be resolved items (TBRs). External interfaces almost appear to be a negotiation in the making. Sit down with the two sides and agree on common ground to work towards and have some sort of understanding that one side or the other will be the decision maker, so progress can be accomplished. People with the right personalities are critical as well.

4.20.32 Define Interface Ownership

Description:

We experienced a lot of difficulty in managing vehicle ICDs in the pre-PDR to post-PDR timeframe due to late involvement of VI in ICD management, tool integration issues, and process difficulties. Initially the Level III element-to-element ICDs were drafted by the Elements. Later they were brought under the management of VI prior to baseline. They were drafted in MS Word, but were to be input into Cradle upon baseline. In some cases, the Elements had devised ICD change processes prior to the handover of the ICDs to VI. Because VI did not manage the ICDs from initial development, there were inconsistencies in the scope and layout of the documents. This proved to be a very significant problem when ICD traceability to the system requirements document (SRD) was being established, and when the Upper Stage–J-2X ICD was transitioned to Cradle. It was a very inefficient way to develop the ICDs because there was so much reformatting and/or adjustment to the current formatting that had to be made. In the case of the upper stage–J-2X interface, Upper Stage and J-2X had already established an interface control process by the time VI took control of the ICD. Because VI did not have a baselined interface control plan when the ICD was transitioned, there was a lot of confusion and delay in getting changes flowing efficiently again.

Recommendation:

Recommend that new programs/projects identify the responsible entities to integrate at the interfaces from the beginning of a program. The integrating or responsible organization could be the next higher tier (e.g., a vehicle person integrating two major elements), or one side of the interface integrating both sides. Regardless, the integrating organization or person must be responsible for ICD development from the beginning in order to maintain consistency across ICDs. The integration organization should be responsible for defining and baselining an interface control plan and an ICD template around the System Requirements Review (SRR) timeframe in a new program. If ICDs are to be maintained in a tool (such as Cradle or Dynamic Object Oriented Requirements System (DOORS)), the ICD template should take this into account.

4.20.33 Integrate Design Analysis Cycle (DAC) Schedules and Allow for Assessment Time Between Cycles

Description:

Back-to-back load cycles (LCs) were inefficient and did not allow VI Loads the opportunity to do their job. Primary task was to identify, explore, and assess system interactions. This is best done with a period after each major LC where the just-completed LC is used as a tool. This tool allows sensitivity and change impact studies, but these studies are lost after spinning up a complete new LC. This, coupled with the different schedules for the elements, led to load cycles that would not end. The management team (both CE office and Loads team leaders) need to be better synced as to which load cycles support what program milestone, which element models flow into the load cycles, and which specific analyses are required in the particular load cycle.

Recommendation:

Recommend providing adequate time between LC reviews so that the output can be used to better understand the needs for the next LC review and to influence the design. Also suggest better synchronization of element schedules to vehicle integration so that LCs are not adversely affected by schedule disparity between elements.

Suggested or Taken Action:

Program scheduling needs to add an assessment time in between repetitive efforts, specifically DAC, and integrate program-to-project schedules to minimize schedule issues/conflicts.

4.20.34 Define Make/Buy Policy

Description:

Ares demonstrated that MSFC could take on a large development project. In-house skills allow “smart buyer” capability for MSFC. However, the procurement process led to schedule complexities. Make/buy decisions need to consider realistic view of the capability and capacity.

Recommendation:

Need to do a better job on selecting the work we do in-house. Make/buy decisions need to consider realistic view of the capability and capacity. Factor in the strategic decisions (e.g., in-house work trains us to do better insight) and will the agency take a risk on this decision.

Suggested or Taken Action:

Red Book team to assure make/buy decision criteria are addressed in policy.

4.20.35 Policy for Establishing Resources for Program Development and Change Process

Description:

The Constellation budget had no reserve to allow the projects to implement changes that were imposed on them. The program direction was to implement and reprioritize. Many times the requirements were not flowed to the prime nor implemented by the projects.

Engineering change review process for the Elements (First Stage, Upper Stage, Upper Stage Engine) takes months to get accurate review/cost impacts from their prime contractor. The implementation process was definitely a problem on Ares. It should not takes months or over a year to implement a customer approved change into a contract.

Recommendation:

The contract language needs to be clear with the primes and include the review process. There are some Shuttle practices that were tried and true that could be used.

Suggested or Taken Action:

Red Book team to establish policy for program resources for change and to provide capability for contractor cost estimates incorporated into change evaluation. Reassign to Program/Project, Budget lessons.

4.20.36 Develop Procurement Strategy that Supports Design to Cost

Description:

Cost plus award fee contracts do not have adequate incentives to reduce life cycle cost. Reducing cost involves both NASA and contractor culture. The cost control mantra may not have been adequately pushed down to the NASA team leads. If they don’t embrace cost control, then cost won’t be controlled no matter what type contract you have. Both sides have expectations based on shuttle heritage about levels of engagement expected or needed between the separate workforces. We have learned that to reduce cost, we must change our expectations to allow sharing of facilities and people to reduce overall cost. There is some disagreement if a cost plus contract encourages more cost or not.

Recommendation:

Push the cost control mantra from the top down all the way to the team leads and workers. Also contracts should incorporate some sort of fixed price component and share lines to encourage the contractor to reduce cost on their own to make more profit. If the contractor spends less than the target, then they get to keep a large portion of that savings as profit. If they spend more, they have to eat a large chunk of the overrun. But in all of these contracts, changes are expensive. Firm fixed price contracts penalize the most for changes, while cost plus penalizes you the least. Something in between is needed.

Suggested or Taken Action:

Forward to SLS Program to establish a procurement strategy to enable implementation of design to cost policy defined in the Red Book.

4.20.37 Develop Criteria and Level(s) of MSFC Insight

Description:

Alliant Techsystem, Inc.'s (ATK's) pyro subsystem managers started with a DoD mentality where they expected NASA to give them requirements and then go away until Design Certification Review. It took several meetings early on to get them to understand that NASA has more insight and expects to be involved in the process.

Recommendation:

Make clear upfront the level of involvement NASA is going to have in subcontract management and oversight/insight of design and development.

Suggested or Taken Action:

Red Book to provide MSFC insight requirements (established by engineering and S&MA) for contracted activities in order to establish: 1) areas of insight, and 2) associated hours of effort to be negotiated with contractors.

4.20.38 Establish Criteria for Contracted Deliverables

Description:

There were too many data requirements (DRs) to cull in a combined Solid Rocket Booster (SRB)/Reusable Solid Rocket Motor (RSRM) Data Product Document (DPD). NASA has often just put standard deliverables in these books for completeness purposes, but they may be only nice-to-haves. These are cost drivers.

Recommendation:

The SRB and RSRM DPDs should be separate. The DPDs should be scrubbed by the element office and engineering early in the process to reduce deliverables. Do not include standard deliverables in these books if they are only nice-to-haves. NASA needs to be very careful to only ask for what data is really required to control or understand the design. Frequency of submittals also should be scrubbed to be realistic.

Suggested or Taken Action:

Red Book team to establish criteria for contracted deliverables. (Example: One such consideraton might be if the product does not affect performance of deliverable, or if product is needed for insight versus integration.)

4.20.39 Update Integration and Management Interfaces

Description:

Roles and responsiblities for members of interface working groups were not clear and specific. Engineering personnel do not have the required authority to be interface managers.

Recommendation:

External interfaces must be managed by the responsible interfacing project offices and not engineering personnel. Vest interface decision-making authority for each interface in a responsible interface manager, supported by an interface working group comprised of element representatives, S&MA, engineering, Mission Operations, Ground Operations, and Crew Office (as applicable). Establish clear and specific roles for the members of the interface working groups and document those roles/responsibilities in appropriate project documentation. Establish relationships with external groups (centers, elements, etc.) early in the development process. Agreements should be documented at the project level.

Suggested or Taken Action:

CE office to develop updated policy to integrate and manage interfaces, especially across projects (i.e., updates to Red Book or more appropriate document that implements 7123.1.)

4.20.40 Improve Efficiency of Communicating Status

Description:

Too many management status reviews. Appropriate for cross-project issues but not for all technical issues. Ares I organizations, especially on the engineering side, were extremely overburdened with unnecessary and repetitive management “status” meetings. Chief engineering technical telecons were valuable for vetting technical decisions. However, too much time was spent preparing similar reports to engineering and the project.

Recommendation:

Minimize or combine status reviews. Only review integrated issues in cross-project-level boards. Let more technical issues be addressed and resolved by lower level boards and panels to the extent possible. Ensure supervisor-to-worker ratio is at a level that enables the workers to actually get work done in addition to providing status at appropriate meetings.

Suggested or Taken Action:

Current program planning being worked to make official problem/issue/change (ERB/PCB) process more efficient from elements to projects to program. However, recommend SLS Program Office accept this to establish a standard and minimal status reporting to address three key issues: 1) only status those issues/items for which you have direct involvement/authority/responsibility; 2) minimize and set standard reporting interval and format; and 3) include a way to “communicate” or get to the data for status on any effort without large devoted “status” meetings that expend large amounts of resources to repackage existing data.

4.20.41 Communicating Organization and Efforts in Work

Description:

It was often difficult to interface with other people and groups across elements because of different organization structures and names for groups, i.e., IPT, work breakdown structure (WBS), teams, offices, etc. Roles and responsibilities (R&R) should be the same with each element.

Recommendation:

All major projects elements should have a common organization structure to enable project-level integration. R&R should be the same with each element.

Suggested or Taken Action:

Establish policy and requirement set to develop, maintain, and control a simple, intuitive location for communicating the team structure and the issues currently in work (with assignees).

4.20.42 Implementing Affordability

Description:

The Ares Projects attempted to introduce affordability to the design process. This concept has been used in the Construction of Facility (CoF) area for many years. Ares affordability suffered as several of the elements resisted participation in the affordability requirement. There was an expectation that costs reported would vary significantly from one reporting period to the next. In actuality, the cost reports were only updated at major milestone reviews. There was no “continuous” effort to monitor costs and maintain current cost estimates by any of the Ares I elements – only a minimum effort was made and some made no effort at all until an element received a Review Item Discrepancy (RID) at a major review. The basis of the objective and goals were “S” probability cost curves produced by “mathematical” models. The parametric models do not update as engineering drawings are revised and should only be utilized to establish the original threshold and goal requirements.

Recommendation:

Recommend engineering, business management, and costing discipline leaders review industry best practices and then establish fundamental standards and requirements for establishing affordability goals/requirements as well as appropriate methods and intervals for assessing and reporting to managers/leaders.

4.20.43 Technical Assessment Process Improvement

Description:

Several teams provided feedback on the Ares technical review process. Observations included number of participants, RID process, and identification of products and required reviewers. Selection of personnel that participate in milestone technical reviews ((e.g., SRR, SDR, PDR, CDR) should be limited to individuals with knowledge in the technical areas being reviewed. These individuals could include junior engineers, but they should have a discipline mentor that works with them.

Positive comments provided for reviews that allowed RID initiators to talk to the product owners. It was noted that this helped reviewers understand the product and in some cases prevented a RID from being written. Review product identification and allocation of sufficient time to review the products should be managed. One observer noted that they did not have enough time to adequately review the products due to conflict with pre-board activities.

Recommendation:

Update the MSFC technical review standard (MPR 7123.2) to capture these observations (i.e., limit reviews to the required disciplines; have face-to-face discussions with product owners and RID writers; and schedule the review period with the scope of products in mind).

Suggested or Taken Action:

Recommend action to engineering to determine appropriate place to document more specific requirements and guidance to conduct reviews (i.e., more specific than MPR 7123.2).

4.20.44 Define the SE&I Process Early and Beware the Applicable Document Trap

Description:

The Ares Projects kicked off without having well-defined systems engineering processes and lower level instructions. As a result, the Elements used SE&I processes that they were familiar with or fell back on SE&I via applicable documents. It was difficult to integrate across the project. When the SEMP was published it was too long, making it difficult to keep up-to-date.

The tendency to reference applicable documents in lieu of stating the specific applicable sections in these documents also led to confusion. One observer noted that we should reference applicable center process documents instead of repeating them. This could reduce the SEMP page count, but one still needs to keep it up-to-date so that tailored processes used by the project are not inadvertently lost when the reference is updated.

Recommendation:

Clearly define MSFC systems engineering processes that are to be used at the start of a project. Keep the SEMP a manageable size and avoid overuse of listing applicable documents.

Suggested or Taken Action:

Recommend action to Engineering to determine appropriate place to document more specific requirements and guidance on how to implement systems engineering early in any given project/program startup.

4.20.45 Project Readiness to Schedule and Conduct Design Reviews

Description:

Several teams commented that the Ares technical reviews were treated as “lines in the sand” instead of key technical decision gates. The concern was that reviews were also driven by schedule instead of design maturity. In addition, numerous reviews overlapped each other or were not combined when logically the design needed to have an integrated review. This led to products still in “draft” state after PDR that were needed by the next engineer in the design process. Software and hardware design timeframes were not coordinated in an effective manner and this led to delta-reviews.

Recommendation:

Reviews should be planned with product maturity considerations. Instead of arbitrarily setting a review date, planners need to schedule product development and then lay in the review milestone. When schedule pressures dictate milestone review dates, it is critical that the reviews be coordinated to avoid overlapping reviews. Also, when review criteria are not met, declare an unsuccessful review and schedule a delta review. Reinforce and document in center policy and project plans that unsuccessful reviews can happen and declaration of an unsuccessful review is the better alternative to declaring a successful review when that was not the case. A softer approach would be to state that critical RIDs (those that must be addressed so that another downstream task is not impacted) must be closeable (corrective action completed) within 3 months to declare success.

4.20.46 Standardize Hardware and Manufacturing Process Tracking Tools

Description:

Different Manufacturing disciplines (Welding, Non-destructive evaluation, Machining, Quality, etc.) used different tools for tracking and processing hardware through their areas. Some examples were Maptis, Solumina, other work order systems, or spreadsheets. These different systems caused confusion in the process plan.

Recommendation:

Standardize the tracking and handling processes across manufacturing disciplines within the program/project. The use of a common tool for tracking manufacturing processes, flow, and associated traceability and tracking documentation would be beneficial in this effort. The common bulkhead team had great success using Solumina and would recommend this tool for future programs.

Suggested or Taken Action:

Engineering must develop a Product Life-cycle Management (PLM) System. It should be one of the tools maintained by the CM/DM process once it is stood up.

4.20.47 Defined Modeling Standards

Description:

It is not ideal to start a major project with a new CAD package, a new Product Data Management (PDM), a new drawing and model release process, no release standard, no CAD standard, and no desk instructions. For example, the Ullage Settling Motor System (USMS) Technical Task Agreements (TTA) with JPL did require products to be delivered in Pro/E, but did not require the products to be developed in Pro/E. Therefore, we did not receive a model that could be manipulated like the other subsystem models.

Design efficiency was reduced when the project manager decided to go to model-based design without fully understanding the implications of the decision and without processes and training to make model-based design work well from the beginning.

Recommendation:

Recommend standing up CAD/computer-aided manufacturing (CAM) processes and procedures early in the program and applying a systems-level engineering approach. Adequate training must be provided to designers before they begin work. Also, TTAs with other centers should clearly define what CAD/CAM standards will be used for products and design.

Suggested or Taken Action:

Recommend engineering establish: 1) an electronic drawing/model standard; and 2) a data requirement, or drawing exchange requirement at interfaces between design organizations. (Consider needs for configuration status and accounting across interfaces.)

4.20.48 Maintain a Program/Project Glossary of Terms

Description:

Maintain a program/project glossary of terms for consistent interpretation. This would be a big help in verification requirement development. On the Constellation Program and Ares I project, the lack of clear terminology for fault management (FM) and FM-related telemetry requirements caused many difficulties in understanding and implementing the requirements into designs and into a variety of documents, including Instrumentation Program and Command List (IP&CL), IRDs, ICDs, SRD, and Element Requirement Documents (ERDs). For example: "Inspection" of lower level verification products is not the correct use of the verification method named "inspection." A clear understanding of verification methods should already be understood and established by NASA. It should not be something we are trying to figure out during the design part of the life cycle.

Recommendation:

Maintain a program/project glossary of terms for consistent interpretation. These terminology ambiguities need to be addressed and cleared up at the start of the next project to enable proper development of requirements.

Suggested or Taken Action:

Recommend SLS Program or SE&I lead develop and maintain a SLS Program Glossary. Further recommend this be coordinated with Data Management – may be able to utilize a web-based "wiki" type format that allows wide access and monitored updates from users.

4.20.49 Lack of Top-Level Program Functional Decomposition

Description:

The lack of a top-level program functional decomposition caused us innumerable problems across all of Ares. Proper functional decomposition of requirements and applied constraints is the only means by which to determine valid content for performance specification, mission/event sequence timelines, source data for generation of vehicle software, and verification compliance methodologies (both component unique and interface requirements). Determination of assured critical functionality must take into account application of time correlated, unique, combined induced and natural environments. Without functional modeling this is simply impossible.

Recommendation:

Codify in program-specific systems engineering and integration-related agency/center level issuances (and project-specific SEMPs) that systems modeling and functional modeling are a required aspect of launch vehicle development. Utilize a functional modeling tool(s) such as: MathCAD Simulink (et al) and SysML with the capability to output software code as a means by which to maintain one critical data source encompassing requirements, critical models, and analysis technical content. This approach will provide a distinct technical baseline reflective of the true configuration and that is both horizontally and vertically integrated.

Suggested or Taken Action:

Recommend action to Tool Selection team. Functional decompositions should be performed per Systems Engineering guidance (handbook, 7123, etc.).

4.20.50 Prioritization of Decision Criteria

Description:

Throughout the life of the project, it was difficult to determine which was "king"—performance, affordability, or schedule. This lack of priority came up in a variety of trades. Determining which was "king" would greatly affect the outcome. Sometimes the trade was between cost and mass.

Tension between engineering management and project offices over program priorities resulted in impacts that were discovered late in the CR process resulting in cost impacts that were not known when decisions were made. Formation of the Element Integration Board (EIB) helped to facilitate the identification of the impacts across multiple disciplines and subsystems.

Recommendation:

Prioritize criteria for decisions. Develop weighting method to assist in making objective decisions. Managers need to understand the success criteria of the project.

Continue an EIB-like function for future programs. Place chief engineers over trade studies and give authority to the chief engineer to make decisions and to move forward.

4.20.51 Use of Agency-wide Skills

Description:

Other centers have people with skills that can contribute to program success. As an example, the Ames Intelligent Systems Division provided important failure modes for Ares abort analysis. This was extremely valuable to characterize the effectiveness of abort triggers.

Recommendation:

Recommend MSFC operations support and engineering work with other centers and the agency to develop an agency (inter-center) directory, or equivalent, to list experts. This may be similar in nature to the Engineering Services Directory at MSFC.

4.20.52 Understanding and Use of Program/Project Plans

Description:

The recent program/projects made a large investment in establishing a vision, an operating and communication model, and top-level planning such as the SEMP, CM, and PM plans that appeared to largely fall on deaf ears. It seemed to be a continuous struggle to execute to the plans that were baselined.

Recommendation:

Engineering and project offices should work together to understand, agree to, and then enforce operation under released planning. Especially in the early phases of a program, a "New Program Plan and Processes 101" type training class may be able to assist in this effort.

4.20.53 Visual Understanding of the Design

Description:

There was a huge need for visual understanding of the design that could not be accomplished in real time with the tools/processes we were using. The meetings where this was used, for example the fly throughs, were effective in communicating real design issues and the associated space/volume/constraints.

Recommendation:

Provide a method for real-time visualization of design that can be used to communicate design issues.

4.20.54 Living Acronym List

Description:

The acronym list on Inside Marshall is out of date and incomplete. Projects can provide acronym lists that apply to their work.

Recommendation:

A clear, cohesive, and living acronym list should exist and all members of NASA should provide that detail. Use a Wikipedia type interface and include information on the program/project/center use of the acronym would enhance the ability of project members to communicate.

4.20.55 Workforce Planning Expertise

Description:

It has been over 30 years since such a major vehicle design/development. Center and agency management did not appear to understand the breadth and depth of skills and number of people needed to have a government-led major vehicle component design. Every change to “heritage” hardware further complicated the need for manpower. Heritage hardware cannot be used to avoid hardware development when design changes radically alter the original hardware or its mission.

Recommendation:

Recommend that experienced (possibly retired) and successful program/project managers from similar large, complex systems be consulted in the early planning phases to review (in detail) the program plan and scope of work and help establish the workforce skill sets and rough numbers needed to do such an ambitious undertaking.

4.20.56 Develop Long-Term Leadership Training Policy

Description:

There is a need to improve management leadership skills. A process should be put in place to ensure the top management team can acquire the needed leadership, interpersonal, technical, and business skill sets to effectively perform the job. Ensure managers are dedicated to meeting the assignments they are given by appropriate incentives. There should also be appropriate checks on progress to correct or mitigate inefficiencies or chronic issues impeding progress. A concerted effort must be made early in program planning to ensure program/project managers and key leaders (especially interface and integration leaders/managers) are capable or have appropriate support to efficiently perform the demanding roles they are given.

Recommendation:

Recommend the center develop a more rigorous management development program.

Suggested or Taken Action:

Develop updated and more rigorous policy for assigning critical leadership positions (program/project manager (PM), system integrators, or lead systems engineer) based on prior experience, work assignments, and training.

4.20.57 Research and Development (R&D) to Development Transition

Description:

Many of the team members in the Thrust Vector Control (TVC) Subsystem were from a R&D background and there was somewhat of a learning curve involved in understanding manned vehicle development. Most team members adapted fairly well in spite of the organization challenges of the Ares Projects.

In general, new programs/projects will necessitate formation of new teams filled with personnel of varying levels of experience or familiarity with NASA and center process requirements (or guidance).

Recommendation:

Though the original input was specific to one area for Ares (e.g. Upper Stage Thrust Vector Control) the following recommendation is equally applicable among any new teams formed from varying backgrounds that may be new to a large flight system development.

Recommend (as one potential strategy) for leaders to hold training sessions with their teams to review NPR 7120.5, NASA Space Flight Program and Project Management Requirements, and other associated procedures and policies with people coming into a spaceflight project to acquaint them with the programmatic operating world.

4.20.58 Upper Stage 101 Class Very Useful

Description:

“Upper Stage 101” was a familiarization briefing / class and was a very useful way to inform new members of the team about the technical make up and organizational structure of the Upper Stage. It was very well received particularly by new team members trying to get oriented to the far-flung nature of the participants.

Recommendation:

Recommend new programs/projects consider using familiarization briefings or classes, especially in the formative phases of an effort. A briefing or class similar to the Ares "Upper Stage 101" is worth consideration as a template.

4.21 PUBLIC AFFAIRS OFFICE/COMMUNICATIONS

4.21.1 Communication and Consistency of Information

Description:

We were fortunate to have a project manager who believed in the value of communication and filtering that down to his management team. Unfortunately, as communication was filtered down through the management chain, some managers were not as effective in dispersing this communication. Also, sometimes the message at each level (directorate, program, project) was inconsistent.

Many Element Offices had project/technical coordinators to serve as a point of contact for information for external information, but it didn't always function as designed. This caused technical writers and television producers to routinely do extra legwork to get needed information.

Recommendation:

Recommend having top-level messages, bought into and developed, at the very beginning of the effort. The messages may be different at the directorate, program, and project level, but they should be coordinated and consistent. Recommend that this be done early on when the effort starts. It should be one of the very first activities to occur. These messages should be revisited on a regular basis to maintain relevance. These messages should be understood up and down the management chain. They should be shared with all appropriate communications team members and with project and center personnel. There should be a strategic plan to guide message development with tactical implementation plans for message disbursement and maintenance. Additionally, recommend separating strategic communications efforts at each level to ensure adequate attention and funding.

4.21.2 Continuous Improvement in Communication Process

Description:

The agency's organizational culture of "message control" was often at odds with the highly dynamic social media communications. Communication products need a more streamlined approval cycle to keep information flowing to stakeholders on a rapid turnaround. Non-NASA sources shouldn't end up being the "go-to" source for up-to-date information. Creative brainstorming was not built into the process, which could have led to innovative and cost-effective ideas that would have helped overcome some of the communication obstacles. For example, the video team allocated about an hour a week for continuous improvement brainstorming activities, which led to a well-defined, routinely updated process flow, and on-time deliveries for an aggressive production schedule.

Recommendation:

Recommend creating a streamlined product development and communications process that leverages a team with diverse creativity and skill base. This process flow should include time for creative brainstorming meetings for the team to periodically refine the processes and avoid process flow break downs. The Ares video production process flow was an example of a well-refined and effective process flow because of using continual process improvement.

4.21.3 Communicating Program and Project Challenges (Sensitive But Unclassified (SBU)/International Traffic in Arms Regulations (ITAR))

Description:

It is very important to have appropriate levels of review for all technical materials for SBU and ITAR sensitivity. The Ares video process worked quite well because it included the project export control representatives and center-level export control representatives.

Despite a well-defined process involving appropriate export control representatives, the process was repeatedly second-guessed by individuals with no knowledge of the approvals process, and this led to much confusion and, in two cases, a product pulled after or very near release due to outside objections

One of the least enjoyable processes at the center is the export control/NF 1676 process. The only way to learn it is to be thrown into the lake to see if you can swim. Until you do, you end up irritating a lot of people unnecessarily along the way. I believe more extensive, upfront training (renewed/reviewed annually) would be of value to people preparing or submitting papers.

Recommendation:

Recommend providing wider scale training on the export control, ITAR, SBU classification review and release process and the proper means to complete the NF 1676. An approval process should be established and supported by program/project management.

4.21.4 Integrated Communications Team Approach

Description:

Communication and outreach are not always considered a core priority at NASA, as they should be. The overall communication strategy was not fully considered at the inception of the Constellation Program. Because of this, Exploration Systems Mission Directorate (ESMD) to Constellation to Ares to Orion communications and outreach were not well coordinated. Ares Communications had to go through Headquarters and the Constellation Communications Office which added precious time to release schedules. Also, the external communications and internal communications teams were under different leadership which often created an “us” and “them” mentality.

Recommendation:

Recommend that the structure of the communications team be well thought out and designed to facilitate the type of communication required by the program/project. Recommend fully integrating communications management/leads into the project office strategic decision-making process early in the project formulation. Also, recommend structuring the communications team so that internal and external communications efforts are managed by the same approval chain. This integrated communications team strategy needs to be bought into by management and maintained for the life of the project to ensure proper and efficient communications.

Each project-level communications team should stand alone to reduce approval lag time and help to ensure adequate staffing levels for all projects. Crosstalk between centers to share ideas, innovative media approaches, and help with overall communication consistency is highly encouraged.

4.21.5 Communications Strategy of Effective Media Type

Description:

Decisions about TV resources were made largely without input from the Public Affairs Office (PAO). The quarterly progress reports were wonderful projects, but had limited audience scope. Also, much of PAO’s time was spent talking to insiders (“preaching to the choir” mentality) rather than attempting to reach out beyond known stakeholders. “Preaching to the Choir” is largely counterproductive because it focuses dollars and efforts away from attempting to win over audiences that aren’t already NASA supporters. The value of communicating to the community in the form of papers is not supported as much as it should be at NASA.

Recommendation:

Recommend that the communications strategy focus on expending resources in areas that provide the highest return on investment. Efforts to reach new and expanded audiences through innovative and even nontraditional media (i.e., YouTube, Flickr, FaceBook) encourage wider support for project efforts. Focus should not be on redundant messages to smaller forums of existing supporters as this brings very little value back to the project. Video and audio recordings of key events or interviews should be planned to allow for and encourage reuse. Video reuse is a very cost-effective means of producing products for multiple forums.

Time should be allocated for writing papers and attending conferences, at the very least, for key team representatives to ensure positive communication of project/team accomplishments.

4.21.6 Internal Communication Methods

Description:

Electronic internal communication (posted on Interactive Collaborative Environment (ICE)) is not the most effective way to communicate with people. Overall, when possible, structured face-to-face communication is the most effective.

Recommendation:

Recommend using face-to-face communications such as road shows to communicate internal messages over relying on ICE and wiki pages. This worked very well for Ares, especially when project direction came into question with talk of program cancellation.

4.21.7 New Technologies Approach to Communications

Description:

Management was initially resistant to message channels that couldn't be tightly controlled. This led to Ares communications being a couple of years behind the curve on social media, and scrambling to catch up. The PAO culture was at first (2006–2007) very resistant to social media. They gradually loosened up, but each request to expand the scope of our communication efforts had to be reviewed and blessed. On the plus side, the Ares PAO gradually accepted the notion that new media are going to be the primary means of communicating with the public—especially a tech-savvy public, which the NASA "fan base" generally is.

While communications must be strategic and well coordinated, it must also be nimble and able to respond quickly to the external environment. Ares did this well through PAO, blogs, and status updates but going forward this can be improved especially in the social media arena.

Recommendation:

Recommend that NASA, or the program/project, pull in outside expertise in the communications arena to inject new ideas and approaches into the broader NASA culture. This is necessary to remove resistance to newer, more innovative communications media that the audience expects. It also facilitates development of a coordinated strategic message with more nimble response to circumstances and audience demand.

4.21.8 Accurate and Timely News Releases

Description:

Leadership was comfortable telling positive stories, but resistant to routinely and honestly address budget, technical, and schedule challenges. To remain credible, we have to tell the hard stories, too. Importantly, if we don't tell the hard stories, someone else will, and often with inaccurate data or portraying the project in a much more negative light than is accurate. The only way to fight misinformation is with consistent good information.

It fascinated me how, when things were rolling along pretty well with Ares, Marshall people who were NOT on the project thought we were in trouble. The primary reason was that they were getting their information from NASA Watch, not internal sources. This is an unfortunate side effect of the project's unwillingness to address bad news head-on. In the absence of credible information from the project, others stepped in to fill that void, most with axes to grind with the agency or project management.

Recommendation:

Recommend that program/project management at all levels be prepared to address and communicate difficult or negative information to stakeholders and public audiences in order to ensure accurate and timely information is provided so as to prevent biased media from dictating the public/stakeholder opinion of the program/project. Efforts should be made to work just as hard to get the negative information out as the positive information to provide a balanced and accurate portrayal of the program/project reality.

4.21.9 External Communication Partnerships

Description:

External partnerships with industry, government, and other NASA team members are critical to our communication success. The external interfaces with the Marshall Center and NASA HQ history offices were wonderful. The annual history meeting provided excellent training and information that was valuable to the project, especially about recordation. The project office was very supportive of providing funding for the training, and the History Office kept the training fairly low cost. Alternately, the business side of the house (procurement, industry forums) was divorced from the PAO.

Partnerships with useful outlets, for example the U.S. Space and Rocket Center and The Future Channel, was very beneficial. Partnerships were mutually beneficial and made Ares communications more effective by providing venues for wider audiences and providing museums and others with the most up-to-date NASA information and messages.

Close ties with the prime contractor communications team was very important for providing them with NASA messages and for obtaining their support. Ares tried to meet with them on a regular basis and obtained support for filming video at their locations and obtaining support for collateral materials development. One thing that could have been improved was for the performance award process to include gradable contract requirements to incentivize the prime contractor.

Recommendation:

Recommend building strong partnerships with external stakeholders and information sources. Although some relationships were healthy and facilitated communications, others were challenging and hindered the flow. Recommend planning for the development of such partnerships upfront and incorporating specific guidance into plans and contracts. Contracts should also contain incentives or grading criteria to ensure proper and timely communications of activities and accomplishments from the primes.

4.22 REQUIREMENTS

4.22.1 Thermal Protection System (TPS) Requirements

Description:

TPS requirements were often buried in the individual component specs and were too vague. Continuous requests were made to understand break-up analysis and how it drove TPS requirements, and this systems-level analysis was not addressed early enough to properly impact fundamental manufacturing and production processes.

Recommendation:

The TPS needs to be treated as a separate component from the beginning of a project. As a separate component, it should develop its own TPS components specification. Requirements need to be specified early if significant development activities may be involved.

4.22.2 Requirements Developed Out of Order

Description:

Requirements were developed in the wrong order between program levels. The Level III systems requirements document (SRD) was developed before the Level II Constellation Architecture Requirements Document (CARD). The Level IV Upper Stage Element Requirements Document (ERD) was developed before the SRD. Level V procurements were occurring while the component specs were still under development. Avionics component end item (CEI) specs were required before many common and outside discipline requirements were available resulting in specs that were not ready for procurement. Too much time was spent working flow down of requirements between elements and debating changes between the multiple levels.

Recommendation:

Clear requirements should be developed to flow from the top down. Levels should be stood up in a hierarchical manner and have sufficient schedule to do so. Purchase of items should not be done before the specifications are finalized. Vehicle-level documents should be at a high level and that document's size should be much smaller. Verification plans should be baselined prior to verification testing costs and schedules being requested by the project. Merge requirements development with the integrated design analysis function so that the end-to-end requirements process can be agreed upon as an entrance criteria for System Requirements Review (SRR) and so the true technical scope and critical aspects of process integration are defined at the right phase of the development cycle

4.22.3 Maintaining Requirements Flexibility in Development or Design Phase

Description:

Level II levied qualification requirements upon developmental testing. This overburdened developmental testing team members without adding value to testing activities. Varying perspectives during specification review may have led to more comments. The Upper Stage Production Contractor had a flight- and production-oriented perspective where the technical community desired a more developmental perspective. Lack of flexibility due to requirements during the design phase impeded making intelligent decisions.

Recommendation:

Manage flight and development hardware requirements in separate documents. Don't apply the qualification testing requirements to development units. Do not write specifications until development is concluded.

4.22.4 Ground Rules and Assumptions

Description:

Misunderstandings occurred due to unclear assumptions. Examples of pre-decided but uncommunicated assumptions related to Integrated Vehicle Ground Vibration Test (IVGVT) included: no additional security, no viewing area, no additional rest rooms, tank pressurization levels set at low levels to allow personnel nearby, and no hardware staging areas. Furthermore, much time was spent pushing back on unfunded mandates such as Système Internationale (SI) units, Problem Reporting and Corrective Action (PRACA), and Earned Value Mangement (EVM). While these all have value, they also require resources. The program lacked top-level programmatic requirements and goals including those goal items that must be considered in design such as operability. Too much time and too many resources were spent trying to develop requirements late in the design effort because requirements were used as a reason to avoid making the right decisions.

Recommendation:

Ground rules and assumptions should be put in writing. When work packages are developed, known inclusions and preclusions should be stated. Top-level programmatic requirements and goals need to be included. These top-level requirements should be broad enough to enable design options and innovation and should not constrain the design team to options that are ineffective, costly, or have unintended consequences.

4.22.5 Ownership and Allocation of Requirements

Description:

Ownership of requirements was unclear due to the flow down between the CARD/SRD/ERD. In some cases disciplines such as Logistics developed requirements that were given to other disciplines. Therefore, there was no way to ensure the intent of the requirement was met by the design organization. There were cases where one subsystem had requirements from another and no good way to levy that requirement. For example, Structures and Thermal had thermal control needs that would be fulfilled by the purge system. However, there was no thermal control requirement on the purge system. Design requirements were implemented at an inappropriate level, for example, pipe connections were levied at the valve level when the assembly mounting method created additional clearance.

Recommendation:

Need a way for subsystems to levy requirements upon other subsystems. There needs to be a way for retention of ownership or approval from the group who levied the requirement. Requirements need to be clearly separated to designate ownership/approvers. Separate performance requirements into the appropriate subsystem specification. The subsystem responsible for design should carry the requirements in their spec. Allocate requirements based upon needs for final designed product.

4.22.6 Requirements Traceability

Description:

Requirements traceability was unclear. Functional and programmatic were not separated. Guidance, Navigation, and Control (GN&C) lacked a systems requirement document to trace GN&C avionics. Technical Representatives (T-Reps) were assigned by work breakdown structure (WBS) not discipline. Since T-Reps were in charge of writing a detailed verification objective (DVO) for each requirement they were assigned, it was difficult to know what analysis was required to verify a requirement and this impacted flow-down linkage. Structural design and verification requirements imposed requirements that were not defined by Upper Stage. Each Upper Stage subsystem handled the requirement differently.

Recommendation:

Clarify the traceability of requirements by using the requirement number and including the parent number as a prefix for the child requirement. Vehicle programmatic requirements (such as software builds) should flow to applicable management plans, not through SRDs. Make sure requirements are traceable down to the end item specifications. Assign T-Reps by discipline. Higher level requirements must have enough detail to flow down to subsystems without the need for varying interpretations.

4.22.7 Return on Investment as a Basis for Requirements Development

Description:

Many requirements were blindly included in Ares requirements documents leading to incomplete, invalid, or creeping requirements. Heritage requirements were used without employing current tools to model physics of failure to help establish the right requirements for today’s program. Much effort was spent writing contingency requirements that should have had to buy their way in through demonstration of risk reduction rather than being imposed without providing safety benefit. Subsystem subject matter experts were not available to support upper level requirements. Traceability between requirements was improper and there were too many orphan requirements. Due to inadequate selection and development of requirements early on, there were many requirements changes following Preliminary Design Review (PDR). Invalid heritage requirements drove technical design and created inefficiencies. Requirements were set in order to bound analysis, not for actual success requirements. Too many requirements tailoring documents were required which resulted in a large cost to review and write these documents.

Recommendation:

Program should "push back" on high-cost, "low return" issues. Rule-based requirements must show return on investment. Avoid blind use of heritage requirements in the next program. Use tools that are available today to model and analyze the physics of failure to establish a basis for abort-related requirements. Include and develop contingency mode requirements through "buy in" by demonstration of risk reduction. Provide subsystem subject matter experts to support upper level requirements development. Make sure that requirements are mature and validated prior to baselining and proceeding through design reviews. Employ requirements writing experts in development of specifications, requirements documents, and material usage agreements (MUAs). Set requirements based on mission success, not just to bound analysis. Consider documenting known exceptions in a parent document.

4.22.8 Early Involvement of Manufacturing Discipline in Requirements Development

Description:

Design needs to include disciplines early on in requirements development. Manufacturing and quality were not adequately included. Materials and processes early participation is needed to assure that the project meets NASA standards and that requirements are consistent with vehicle architecture, manufacturing, and production capabilities.

Recommendation:

Design needs to meet with material, processes, manufacturing, and quality early on to develop realistic and verifiable requirements that comply with NASA standards.

4.22.9 Supportability and Operability as Design Requirements

Description:

Supportability bottom-up cost estimating, using iterative design changes, applied affordability as a tool for flight hardware design which can influence cost-effective planning for the support infrastructure.

Recommendation:

Use supportability bottom-up cost estimating to apply affordability as a tool for flight hardware design influence and cost-effective support planning. Make sure that non-design groups (logistics/operations/systems engineering and integration (SE&I)) particpate in design reviews. Require design organizations to provide information on how they are meeting requirements that are intended to reduce life cycle costs.

4.22.10 Prohibit Design Solutions as Requirements

Description:

The design solution was dictated by earlier study results and political pressure. Requirements included the design solution from the beginning of the program and were reflected in the CARD. The result was a solution less than best all around.

Recommendation:

Requirements should not specify the design solution. Program requirements should be limited to the "functional" and specified with the widest possible trade space.

4.22.11 Interface Requirements Document (IRD)/Interface Control Document (ICD) Issues

Description:

Information regarding interfaces was consistently lacking from IRDs and ICDs. Additionally, there was duplication of information in the IRDs and ICDs. These problems resulted in several specific issues including many problems with command and data interfaces (command validation, getting command definitions, command timing, and ordering requirements). Part of the reluctance to develop IRDs was likely due to the fact that IRDs were not written prior to the award of the J-2X and First Stage prime contracts and the potential contract costs to fix the problem.

Not only was information lacking and duplicated, but many users had a misunderstanding of the purpose of an ICD and an IRD. ICDs are not design-to documents but are a documentation of the agreement between the two interfaces. Also, problems occurred with lack of ownership between sides of an interface leading to potential problems verifying one design matched the other side of the interface. In the case of the ICD for the Integrated Vehicle Ground Vibration Test (IVGVT), the process went well.

Induced environments were captured in the ICDs. Instead they should be captured in their own document similar to other environments.

Recommendation:

Write IRDs prior to prime contract award or plan for costs to approve IRDs to levy after the contract award. Interface requirements between ground and flight should be incorporated into a single ERD. Use a two-phase ICD and don't use an IRD to allow for verification and control of interfaces to occur in one reference. Use a single set of ICDs for all information on internal and external interfaces so that information is available from design through hardware mating. Define physical interface ownership early in the program. Don't refer to the ICD within the SRD because it is a reference to a design solution. Capture induced environments in an induced environments document, not in the ICD.

Study the survey results for the IVGVT ICD development process which recommend the following. Use two interface document developers to take the lead on different books and to have one available for meeting support and one to attend meetings to document meeting minutes to resolve conflicts and raise potential technical issues when non-attendees read the ICDs. Apply more program resources to ICD drawing development earlier in the program. Identify drivers of each interface early in order to assist in test article and interface documentation development. Use element-specific meetings group discussions focused on a single element and all of the interfaces that particular element has.

Integrate interfaces in pertinent specifications to ensure suppliers get all requirements. Use IRDs for all external interfaces to drive design and scope intended verification. Develop IRDs early in the program parallel to performance requirements. Designate a clear owner of each interface.

4.22.12 Allocation of Loss of Crew (LOC) and Loss of Mission (LOM) Requirements

Description:

The initial numerical LOM requirement was set at too high of a challenge by Level II despite objections by Ares and the flow-down requirements were worded to allow for numerical manipulation. Although setting numerical requirements for LOM is a good goal, many arguments resulted on how to measure LOM across the program and a decision was never made.

Recommendation:

Treat LOC and LOM requirements as a technical performance measure rather than as a pass/fail criterion. Utilize probablility base requirements as figures of merit rather than hard requirements unless that calculation can be validated.

4.22.13 Lightning Requirements

Description:

Lightning monitoring was discussed in the risk management process for over a year with a realization that it was a value-added requirement/design solution for the program. The mishandling of this requirement was an impact to the Operations Concept (Ops Con) of the vehicle.

Recommendation:

The next program needs to carefully consider the implications of the Ops Con on the vehicle design. Address lightning monitoring requirements early in the program to avoid cost impacts later. Assess the design reference mission for future programs to decide if the launch availability is a legitimate requirement. Conduct a trade study to compare launch availability required for the program of interest to the launch availability dictated by the lightning launch commit criteria to decide if lightning direct effects requirements are applicable to the program of interest.

4.22.14 Avionics Latency

Description:

Various latencies (measures of time delays in systems), including vehicle internal latency, element internal latency, system latency, interface latency, and/or end-to-end latency requirements with verification, were captured in too many different documents and specifications. The latencies lacked traces to drive software, sensor, and data bus schedule design at the lower levels and resulted in confusion.

Recommendation:

Capture all latency requirements in a single Level III data book to be referenced by the SRD and ICDs to avoid confusion. Allocate latencies at the design organizations. Manage latency margins at the system level.

4.22.15 Component Minimum Frequency Guideline

Description:

The Ares I Upper Stage Element did not have component minimum frequency guidelines early in the program. Having minimum frequency requirements enables the attainment of an appropriate envelope of the low-frequency components design load without having it represented in the Coupled Loads Analysis (CLA) finite element model. Also, if a component or that subsystem has dominant modes within the frequency range of interest of the CLA, that would necessitate the hardware undergoing a modal test and model correlation. That activity has a cost that carries with it the risk that at a very late time in the program it is realized that coupling between the component in question and the forcing functions occurs and could result in redesign efforts later.

Recommendation:

Set up minimum frequency requirements or guidelines to avoid future cost and schedule impacts with loads and test issues.

4.22.16 Test Requirements

Description:

We were too late determining test requirements for certain phenomena that are known to cause rocket failures. Slosh testing should have been identified earlier. Separation testing requirements were never resolved. Green run was dictated to the Element without baselined requirements or test objectives.

When special test equipment (STE) is designed to substitute for unavailable ground support equipment (GSE), the GSE must comply with GSE design standards plus STE design standards. The cost of complying with GSE design standards and verification were not included in the task baseline.

Recommendation:

Identify needed testing early. Each major test program should have set requirements and objectives. Planning should be in place early with clear needs for tests. Tests in the critical path with potential cost impacts should have clear requirements in place before committing resources.

Establish test article fidelity requirements early in the program to allow for proper planning for the development of STE. STE and GSE should be designed to the same engineering requirements to ensure safety.

4.22.17 Component End Item (CEI) Specifications

Description:

There was confusion about whether CEI specs were best estimates or not to exceed. Contractually, they had to be not to exceed, but there was an expectation of negotiation of final specs prior to contract award. Most specs were written with overkill to make sure they could be built within spec. CEI specs were written too early. Specs were inconsistent in content and format across the program.

There is a conflict when the production contractor's approval of a specification brings that company's economics into the specification. Specifications should be written to ensure the quality of the component and allow procurement to address the contractor's specific issues with the spec. Manpower skill mix for spec generation was not originally robust enough. Over-focus on building hardware to meet schedule resulted in delays in specification generation.

Recommendation:

Clarify whether specs are written as a best estimate or not to exceed. Write generic specifications and avoid tailoring to a specific contractor. Combine element agreements with corresponding ICDs and specifications. Determine a common framework for element specifications so they are standardized across all elements of the vehicle. Properly plan and write specifications before moving forward with testing and building. Write specs only after higher level requirements are complete. The program office should provide a standard specification template to have consistency and to avoid noncompliance due to formatting.

4.22.18 Requirements Verification

Description:

Activity-based performance verification is good for the prime contractor for scheduling purposes, but it is almost impossible to tell if all the activities have been identified to ensure the requirement can be verified. Verification Logic Flows is a useful tool to ensure adequate verification and was valuable for assessing required verification activities.

Recommendation:

Approve performance requirement verification by the requirement, not by activity. Require the government to approve verification logic flows and statements for each requirement. Focus early requirement verification and validation planning on determining verification method definition and key strategic events such as integrated tests or analysis. Build more detailed verification objectives after the design has matured. Work Test and Verification Requirements–Operations (TVR-Os) upfront in concurrence with the design phase to identify operability issues relating to testing and verification. Define overall measures of performance and effectiveness prior to SRR.

4.22.19 Applicable Documents

Description:

Enormous numbers of applicable documents were levied through architecture and system-level requirements at the highest levels of the program with unintended verification consequences at the lowest levels of the program. The resulting hundreds of "hidden" shall statements had to be addressed for verification even though some were clearly not intended for technical verification. The invocation of requirements from external documents varied from references to entire documents vs. specific requirements within the external documents.

Recommendation:

Explicitly place individual "shall" statements in requirements documents and assign specific verification methods. Do not just generically point to lower-level documents. Leave design and construction standards at the lowest level of the program controlled by NASA. Provide clear direction on the use of references to external documents. Headquarters needs to decide what mundane, daily requirements will apply to the program and the program should make better use of MSFC and NASA Procedural Requirements standards while reducing project customization and product development.

4.22.20 People, Processes, and Tools for Requirements

Description:

Engineers were not experienced with writing system requirements. Some stakeholders were not included late in the IVGVT task. There was a conflict of interest in having the same personnel from engineering preparing requirements on behalf of the Vehicle Integration Office (VIO) and preparing models on behalf of the Flight and Integrated Test Office (FITO).

There were not enough resources provided for specification development and review by technical branches. Spec development and review tasks had to be completed by already overextended analysts in the engineering branch. Technical integration and system engineering was not apparent in test requirements and integrated analysis.

There was no "Requirements Engineering Plan." There were too many data requirements description (DRD) deliverables submitted to MSFC by the prime contractor. The requirements process changed several times. Clearer requirements would have made the test development process mature more efficiently and quickly avoid the numerous assumptions that had to be made for STE designs. Information Technology (IT) Security Federal Acquisition Requlations (FAR) clauses were inconsistently applied across the program. The Cradle tool was not used throughout the levels of the program from the beginning.

Recommendation:

Requirement writers and verifiers need to work together to make sure requirements are written in a way that the outcome is what was originally meant. Requirement writers need to make sure their requirements are verifiable. Include all stakeholders in early requirements development process. Separate people who prepare vs. build verification models. Designate one or two senior people within a branch whose main function would be to review specs. This would also facilitate consistency between subsystems.

All disciplines and elements should have a rigorous process for developing requirements. There should be a model analysis discipline to determine how accurately they can predict the model characteristics for use by other disciplines. Include additional requirements and verification process detail within the systems engineering management plan (SEMP) or consolidate the master verification plan (MVP) and requirements engineering management plan (REMP) into a single requirements and verification (R&V) management plan.

Minimize the volume of deliverables due to the associated costs with Type I and II data. Multiple stakeholders at MSFC (technical and programmatic) should be involved in the review of type assignment of deliverables. Recommend that the test and verification (T&V) document be thoroughly discussed with all team members including the test lab so that the process is clearly understood and followed. Establish understandable and consistent requirements early in the process to make adherence and enforcement easier and effective. Place all levels of requirements in the program-selected database (Cradle, Dynamic Object Oriented Requirements System (DOORS), etc.) from the start. Develop a means to catch duplication of requirements.

4.22.21 Allocation of Performance Requirements

Description:

Performance requirements were not always allocated to the appropriate subsystem specification. Also, sometimes performance specifications included programmatic requirements.

Recommendation:

Separate the performance requirements into the appropriate subsystem specifications. A good rule of thumb is the subsystem responsible for the design should carry these requirements in their spec. This also means the group that used to have it on Shuttle needs to let go and give it to the appropriate subsystem. Also, avoid having programmatic requirements in a performance specification. Programmatic requirements are addressed by the DRD and require no formal verification.

4.22.22 Margin Process Issues

Description:

Margin within the system was ambiguous, inconsistently applied, and its origin was unknown. Did it come from external requirements? Did anyone beside the designers know the margin was there? In some cases margin was forced on the robust side via Constellation Environmental Qualification and Acceptance Testing Requirements (CEQATR)/Structural Design and Verification Requirements (SDVR) and in other cases it was forced through a low vehicle mass requirement. Engineers always want to be right, and one way to keep this is by adding margining to cover the unknown-unknowns. The problem is when to release the margin. We have well-defined practices on some design areas like mass growth allowances, where it changes with the maturity of the design, but other areas are not. Example: thermal design margin on avionics boxes are kept with the specs plus ~30 degrees but it does not change with design maturity. Coupling static and dynamic loads (or trying to convert dynamic loads into a static equivalent) yielded incredibly high “design to” loads.

Recommendation:

Technical knowledge of the system from the Office of Primary Responsibility (OPR) upwards needs to be communicated in order to know where margin is and what parts of the system have margin. Engineering disciplines need to establish well-defined practices of releasing margin and use them.

4.23 RISK MANAGEMENT

4.23.1 Risk Database Configuration Management

Description:

There was no formal configuration management (CM) system in place for the Constellation Integrated Risk Management Application (CxIRMA) database, but instead was controlled by the risk manager. Input was submitted from the Risk Management Working Group on what changes should be implemented to the database, but apparently none of the changes received were implemented.

Recommendation:

It is recommended that a program’s risk database configuration be controlled by a CM system. Any changes to the functions, features, etc., should follow a CM process for changes made either to the database or the Web interface. The Risk Management Working Group should have input to the CM review and approval. Report formatting should not be configuration managed. The reports should be user configurable. The suggested changes should be prioritized and those published as to what will be funded.

4.23.2 Process for Managing Risk and Capture of Knowledge When a Program or Project Is De-Scoped or Cancelled

Description:

Currently there is no process in place to manage the potential risks or processing of knowledge for the de-scoping or cancellation of a program or project. The de-scoping of a program or project can range from small reductions in budget to cancellation of the entire program. It can be a response to a problem, or to avoid a problem, or it can be a risk mitigation strategy. A preplanned de-scope plan is a good mitigation for a risk of a budget cut. It not only gives the project a plan to follow in case of a budget cut, but liberal communication of the de-scope plan (to budget holders) may PREVENT a budget cut. For example: “If you cut our budget, the first part of the project that will go away....”

Recommendation:

The de-scoping plan for a program or project should include the following recommendations:

1) The project manager should assemble a team and begin capturing lessons learned before personnel are laid off, resign, or are reassigned to other projects.

2) Review the open, closed, and accepted risks and mitigations for lessons learned (check box), for use on the next project (check box), or changes to existing risks.

3) Interview managers for what went well, what they would have done, or what they need to do differently.

4) Conduct follow-up focus groups with the teams under the managers to find out what they would have done or need to do differently.

5) Identify and create knowledge-based risk video productions.

6) Determine what should be done with the Accepted Risk List and Closed Risk List. For example, for accepted risks does a project need to “close” these risks at the end of the project or leave them in the accepted state for historic purposes?

4.23.3 System/Method for the Escalation/Transfer of Risks with Approval

Description:

The Constellation Program lacked a system/method for formally escalating risks to other levels or the transfer to other organizations and an alert of that action. So when risk reviews were conducted, new risks showed up on some organizations’ lists without their prior knowledge.

Recommendation:

It should be clearly stated in the risk/knowledge plan that you cannot add to the element/project/program or ESMD risk list (through the escalation key or affected work breakdown structure (WBS)) without their approval. If no resolution is reached between organizations that the risk is being transferred/escalated, then it should be taken to the next higher level in the organization. The risk tool software could be programmed to only allow escalation or transfer of risks with approval by the receiving organization's risk or project manager. It may already be implemented with Integrated Risk Management Application (IRMA) edit privileges, which need to be reviewed on a consistent basis. Training for IRMA users should address this issue as well.

4.23.4 Generic Risk Management Plan Templates

Description:

There are no risk management plan templates available for small, medium, and large projects. Often the previous program risk management plans are used for new projects and programs, and those can sometimes be under or overkill for the project/program being executed.

Recommendation:

Generic risk, issue, and opportunity plans (one each for small, medium, and large projects) should be developed to use as a template for future projects/programs. For building a template for a large project based on the CxP 70056, Constellation Program (CxP) Risk Management Plan, the following are recommended: references to CxP should be removed; the document should make references to a generic organization (should use Project Office, Integration, and Test instead of Ares Projects Office (APO), Vehicle Integration (VI), or Flight and Integrated Test Office (FITO)) or a to be determined (TBD) organization (that can be filled in later); the document should refer to generic (or higher NASA-level) documents (i.e., remove reference to CxP 70056 and replace it with TBD or generic document name).

4.23.5 Independent Reviews of Risks

Description:

Subject matter experts (SMEs), "grey beards," were brought in to independently evaluate risks. They were given the risk lists, went off to evaluate them, then at the end came and asked the risk owners to defend their risks.

Recommendation:

SMEs should be brought in to independently evaluate risks. Something about periodic independent reviews should be added to the risk plan. However, reviewers should not be allowed to work in a vacuum. When doing an assessment of a particular set of risks, they should call the risk owner and ask questions and work along with the risk owners to obtain the exact story, not speculate from just the risk text that is in the risk database, and assess and give feedback, not ask the risk owners to defend their risks.

4.23.6 Risk Process Integration with Program Planning and Control (PP&C)

Description:

Even though the Constellation Program (CxP) Risk Management Plan, Section 3.2.2, stated that "effective CRM [continuous risk management] is to become integrated with PP&C process" there was still a lack of integration with PP&C.

Recommendation:

Risk Management and PP&C Management should conduct a technical interchange meeting (TIM) to determine how the risk process and PP&C process should be integrated. Items to identify and subsequently document in the risk management and/or PP&C plan should be: by what avenue risk management will be integrated into PP&C processes including a list by title/name for who interfaces with whom and at what forum; how and for what purposes the integrated information is to be used; and roles and responsibilities for resource and risk managers. Issues to address could include schedule and budget/cost threat risk and data coordination, traceability processes, and reporting periods and processes.

4.23.7 Mitigation Methods and Steps

Description:

A lot of risks existed in the CxP that did not have mitigation steps. Often mitigation steps were not completed on time. Also, several times in the CxP, risks were assigned to be "watched" instead of mitigated.

Recommendation:

Mitigation steps must indicate outcome, not a milestone. Mitigation steps should be critically assessed for effectiveness and timeliness. What may appear to be a (late) mitigation action may merely be a milestone beyond which the risk can no longer exist. If this is the case, then it is likely the risk will be realized as an issue much earlier, or that the risk actually needs more mitigation earlier. Be aware that this critical assessment may "upset the risk apple cart" by highlighting the fact that the fundamental risk identification and analysis was inadequate.

Criteria as to when you will use "watch" as a response plan should be clearly defined. Research, Watch, and Mitigate responses require a customized plan for each specific risk; Accept and Close are responses for which the plan and justification should be predefined for the organization in the risk management plan by the project/program manager. Risks with a "near" timeframe (i.e., that could turn into an issue soon) should never be "Watched." If this is too aggressive, then restate the risk and or consequence, and then rescore. The revised (lower) score may be appropriate for "accepting."

4.23.8 Opportunity Management

Description:

Opportunities, design changes, or process improvements that could improve performance or decrease cost or schedule were not tracked project/program-wide in the CxP. Thus they were not easily prioritized or strategically implemented.

Recommendation:

Opportunities should be tracked project/program-wide so they can be strategically prioritized and implemented. Choose a tool that supports the opportunity activity. Several things will need to be accomplished to handle this:

- Develop an Opportunity management plan (or included as part of a risk, issue, and opportunity management plan).
- Develop an Opportunity score card that allows prioritization of low to high costs vs. low to high improvement (impact) on the project/program.
- Develop an Opportunity tracking process (or devise a way to use the risk tracking system to accommodate this).

4.23.9 Risk Parent/Child Relationships

Description:

Too much time was lost trying to organize and manage parent/child risk relationships. A risk can be related, but do not get bogged down in the relationship.

Recommendation:

Most of the time, the parent risk adds no value to the overall risk picture. Ideally, risks should be transferred to another organization (i.e., the one that will mitigate it) and/or flag the affected organization's WBS. If parent/child relationships are to be used, they should be better defined in the risk management plan. Risk relationships (parent/child or other) should have a defined purpose and characteristics, rather than subjective "seat of the pants" purposes, and casual references to "parent" and "child" relationships that lack common definitions and intents. That is, what does a child risk do for a parent risk? What does a parent risk do for a child? Do they or must they share common causes? Common consequences? Does a parent risk need a mitigation plan, or can it just "follow" the children's mitigation plans? The advantage of a parent/child process is that it should get people to look outside "their risk," i.e., take off their blinders to see what else is associated and see where synergy and planning can be coordinated.

4.23.10 Risk Informed Decision Making in Systems Engineering Processes

Description:

The risk informed decision making (RIDM) process is being forced into the risk management process from the top levels of NASA.

Recommendation:

There are different types of decisions that need to be addressed. Lower level decisions specific to risks need to be made as well as project decisions as to what direction to take, etc. For the decisions specific to risks, those should be made in the risk review meetings and based on the options presented. Those options should include an analysis of the risk of the options just like any other decision. (For example, if a risk mitigation plan requires funding in order to proceed with a step, the responsible managers needs to know that they need to make a decision (fund/not fund-accept risk) and why or why not is should be funded.) However, the RIDM process should not be part of the CRM process. The RIDM process should be integral to the systems engineering process, and risk managers can and should be the "risk professionals" that facilitate the integration of uncertainty into the systems engineering process, i.e., RIDM as a part of the system.

4.23.11 Risk Closure Criteria

Description:

Due to a requirement in CxP that risks must be mitigated to a score of 2×2 or lower before they can be closed, some risks that were realized were artificially "lowered" in score so they could be closed.

Recommendation:

The requirement to mitigate a risk to less than 2×2 should not be included in future projects or programs. If a risk is realized, it should be closed at the score it is at and transferred and tracked in the issue tracking system and documented as to the reason for the closure. If risks cannot be mitigated further they should not be closed, but accepted instead and reviewed later (per the risk plan frequency) to determine if the risk has changed or if new technology or circumstances can allow further mitigation for a reasonable cost.

4.23.12 Risk Definition for Development Projects

Description:

Risk was not always adequately defined on the Ares Projects.

Recommendation:

When defining risks two issues need to be resolved:

Issue A: "We" need to resolve the issue of whether a risk consequence should (always) be 1) not meeting a requirement/objective, or 2) the necessary redesign to meet the threatened requirement? For #1, the impact is purely related to the requirement; for #2, the impact is primarily the cost and schedule needed to redesign. The mitigation plan will be completely different for these two "opinions," and the safety score polar opposites. The consequence statement should also take into account the phase of the project (redesign is a possibility when...).

Issue B: For a risk, the timeframe should state the earlier of two events: 1) earliest that the stated consequence can occur (if unmitigated), or 2) the latest a necessary mitigation step can be started and still significantly mitigate the risk. Context information should justify the timeframe and state an actual date or milestone, if possible. If a timeframe is not assigned, then risk responses cannot be prioritized.

4.23.13 Risk Matrix and Levels

Description:

Of what value is a 5×5 scoreboard in managerial decisions? A decision maker is probably concerned with the likelihood and consequence of a risk at three levels (e.g., high/medium/low or red/yellow/green), the cost, and urgency.

Recommendation:

Simplify the scoring and expedite the risk process so urgent risks of high severity can be elevated rapidly without first checking all the boxes in the tool. Dissenting: The 5×5 risk matrix, along with the program score card, does provide a systematic method for evaluating (prioritizing) and identifying red (high), yellow (medium), and green (low) risks. Without this method, lower-level managers could identify risks as high to their organization, but those risks might be inconsequential to the project/program. If something is a high risk, all the right boxes will quickly be checked in the tool and forwarded up the management chain.

4.23.14 Evaluate "Value Added" for Additional Risk Processes

Description:

Linking risks to each other (parent/child, etc.), linking risks to requirements/key driving requirements (KDRs), cost threats—these were all added to the risk process with little value added (at least at first). While a poorly devised and clumsily implemented "new capability" is being matured, the credibility of risk manager "enforcers" is undermined, and users become intimidated, overwhelmed, and jaded with all the fields in the risk tool. Fields in the database should all be evaluated for need. Some may be valuable only for certain type risks or risks that are elevated.

Recommendation:

No capability should be added to the risk process until/unless they have been validated as truly value added.

4.23.15 Risk Working Group Definition, Roles, and Responsibilities

Description:

The CxP Risk Management Working Group (RMWG) is mentioned but not defined (i.e., roles and responsibilities described) in the risk management plan. Since it was recently created, the Risk Vehicle Integration Team (RVIT) is not defined in the risk management plan.

Recommendation:

Add project/program-level risk working groups (e.g., RVIT, RMWG) to Section 3.3 of the risk management plan (or whatever section of the future program/project that describes roles and responsibilities for various organizations in the project/program) and clearly list their responsibilities. Alternatively these groups could be mentioned with general roles and responsibilities with reference to the groups' Charters. Only the Risk Management Panel's charter is referenced in the risk management plan. The Charter option is probably better since those can be updated without updating the project/program-level risk management plan. Either way these should be included in Figure 2-1 "Risk Communication Pathways" or equivalent in the new program.

4.23.16 Risk Management Roles and Responsibilities

Description:

We can write all the risk plans we want, but implementation requires buy-in by the project. Section 3.2.3, Responsibilities for VI and Element Manager Offices, of the Ares Risk Management Plan, is the only place that "establishing risk management thinking" and embedding that into the culture is mentioned. Engineers in effect already think about risk when they consider reliability, i.e., if a component/system operates correctly 99.9% of the time there is a 1 in 1000 chance it will fail. When engineers work to increase the reliability, they are mitigating the risk. Probabilistic risk analysis vs. subjective risk analysis (scoring) is what generates the reliability numbers.

Recommendation:

Roles and responsibilities should be well-defined and communicated. The project/program should "elevate" the Risk Management Office (RMO) (or risk discussions in general) to the forefront and support risk management. The risk manager should prod/coach/assist the manager with promoting risk management. Mitigating risk (i.e., increasing the reliability and emphasizing probabilistic risk assessments) should be ingrained in the culture by training for all engineers, preaching by management, etc. The chief engineer of the program (or designee) shall chair the risk meeting monthly and all affiliated projects chief engineers (or designees) shall be the spokesperson for their subprojects. [Dissenting: NOT to be dictated by risk plan.] In the current risk plan in Section 3.2.3 it should clearly state that Element Risk Managers should conduct risk reporting, conduct RMWG meetings, prepare minutes to be archived, and provide the feedback to the group regarding program and project risk requests and schedules. Risk owners are the responsible party to "feed" the risk system, i.e., provide updates such as status, check mitigation steps for tardiness, and update risk scores using whatever risk tool has been delegated by the program/project, and executing the handling strategy. The risk owner should also take personal responsibility to perform or have performed the mitigation tasks.

4.23.17 Safety Scoring Discrepancies

Description:

Safety and Mission Assurance (SM&A) has a separate risk reporting avenue. For Ares there was a disconnect in scoring between the chief systems engineer and the chief safety officer on several risks. Shuttle S&MA also have their own risk review to review the safety scoring of the risks. S&MA people also participate in all of the technical meetings along with the project. In formal Shuttle Risk Reviews, there was an agenda item for the S&MA representative to ask if their folks concur with all of the project risk scores.

Recommendation:

Note that S&MA has a separate risk reporting avenue. The relationship between the project office's safety score and the chief safety officer's (CSO's) safety score needs to be clarified. The CSO's roles with regard to updating IRMA should be spelled out, especially with IRMA's newly released safety scoring abilities. There are currently two safety scores which are not linked. The CSO's score could be used as a sanity check to identify when CSO personnel should work more closely with the project personnel to iron out differences between opinions. In that process, each should be able to provide objective and quantifiable evidence to the score. Ideally these should combine into an agreed-upon safety score, i.e., S&MA should be part of developing that and approving the safety score from the beginning of a risk's development. We need to follow-up with S&MA to resolve where we go from here. What were S&MA's lessons learned regarding independent safety scores and the S&MA funnel? See if they concur with the process above. The risk management plan needs to capture these in an S&MA section (probably part of the Scoring a Risk Section).

4.23.18 Individually Flag Risks as Sensitive But Unclassified (SBU)

Description:

Risk tools have the capability to mark individual risks SBU. One entity should not deem that everything residing in the tool is SBU. This was an incorrect usage of SBU rules!

Recommendation:

The risk data base should not be SBU across the board. When an item within is SBU, checking the field in the database on individual risks should isolate those SBU risks. The IRMA database has that capability, and future risk databases should also.

4.23.19 Review Accepted Risks and Linking to Closure/Acceptance Rationale Documentation

Description:

A list of accepted risks is a very valuable tool for managing and communicating risks. The existence of this highly visible and active list will encourage explicit acceptance of risks that have only been implicitly Accepted, while presented as Watched or Closed.

Recommendation:

The Top Risk List should include the accepted risks at every review level, so that management can be aware of the risks they have accepted, or if any new information or possible mitigations become available for those risks. Staleness and tardiness risk metrics for the risk database should also be considered at the risk reviews. When risks are closed at boards other than risk boards, a link to the minutes of the board where a risk is closed should be put in the risk status field and the risk closure rationale field in the risk database. Also put the URL link to the minutes of the RMWG where it was discussed in the status and closure rationale fields. This provides NASA with ISO 9001 documentation and protects the risk manager under an audit situation.

4.23.20 Risk Tool Selection

Description:

CxIRMA was a homegrown NASA tool and is often slow and clumsy to navigate and search, especially CxIRMA 7.0. Our ability to reconstruct the life cycle of an individual risk, or our risk posture at any given point in time, is extremely limited with the IRMA database. We periodically manually extracted risk reports, took snapshots of the risk lists and summaries, and posted them in the Windchill/wiki to preserve the data to create the history for risks if needed. Reasons for changes to a risk were manually tracked by putting a comment in the status field. Also in the risk database tool, there was no way to easily indicate which mitigation steps were funded or not. Additionally, if there is value in identifying parent/child relationships (due to common causes), then there is value in actively searching for common causes amongst risks at every level in a project. This type of search is not practical unless the risk tool has the capability to assign multiple attributes to each risk (i.e., each risk can be assigned to many categories). As a work around for this, categories were manually tracked and added to the status fields of risks. Additionally, at some risk reviews, when viewing risk status slides, there were arguments over what the risk actually was. The risk statement was usually in backup.

Recommendation:

The risk management tool/database for a large project/program should not be a “home grown” tool but rather an industry-wide tool such as Active Risk Manager (ARM). The tool should fit the process, not the process fit the tool. A generic set of requirements should be generated for a tool selection trade study before choosing a risk database. One requirement for the risk tool: custom report configuration/formatting, i.e., drag and drop for the fields you want on the report, similar to an Access database.

Additional recommendations include that the risk management tool chosen for future programs should be updated to include or have the feature to track and generate risk histories. The historical report for each risk should show every change made to the risk with the reason for the change (if available). The risk database tool should also allow for designation of which risk mitigation steps are funded or not and which ones need funding. If parent/child relationships (due to common causes) will be used, then the risk tool should have the capability to assign multiple attributes to each risk (i.e., each risk can be assigned to many categories). There should be a process for creating and maintaining a set of categories for the risk tool, and users should be able to assign categories to risks, as well as recommend new categories. A report template should be generated that shows differences between the safety scoring and project scoring. The risk owner should have read access to see the safety tab score in IRMA, so that he/she can contact the safety person if there is a discrepancy in the scoring or evaluation. Risk reports and slides should subtly or blatantly encourage reading the risk statement before discussing the risk. In other words, in general the risk system should discourage managing risks solely by their title i.e., for any reports more than just a risk list, the risk statement “Given that..., there is a possibility that...” should be on risk slides in addition to the titles.

4.23.21 Integration of Risks and Margin Management

Description:

There was a lack of relationships of risks to quantifiable data such as Technical Performance Measures (TPMs) or Earned Value Management (EVM) data. The three methods of tracking risk status and efficiency described in Section 4.7 of the Ares Risk Management Plan, Rev. C (mitigation status, number of days to develop a candidate risk, and count of risks by category), were not really utilized in CxP.

Recommendation:

The relationship between margin management (TPMs, EVM System (EVMS)) and risk management should be described in the risk management plan and reflected in the related plans (SEMP, margin management plan, TPM management plan, etc.). The risk plans should describe who is responsible for checking the TPMs for margin. When possible it may be desirable to consistently define risks and write risk statements so that for all risks, a requirement or TPM is always in the Condition portion of a risk statement, or in the Consequence portions of the risk statement. For tracking risk status and efficiency, it is recommended that instead of the three metrics mentioned in Section 4.7 of the Ares Risk Management Plan, use staleness for updating risks, tardiness for the risk management plan's steps, and possibly the Joint Confidence Level (JCL) assessment.

4.23.22 Risk Training: Four Types for Four Audiences

Description:

Risk statements and mitigation plans for Constellation were often nonexistent or required a lot of help from the risk managers to write the risks. Risk identification, risk reporting, integrated risks, and cost threats were often not understood well by risk owners and management.

Recommendation:

Management must support and require comprehensive and consistent training on risk management. It should be based on industry standards (possibly from the International Council on Systems Engineering (INCOSE) or Society of Risk Analysis). The classes could be offered online and/or as part of the Academy of Program, Project, and Engineering Learning (APPEL) program (they have a APPEL-RM risk management course already). Four types of training should be provided for four audiences. Not all audiences should take all types.

Types of training:

A. Basic Awareness/Risk Identification (APPEL-RM): Awareness to help engineers identify risks, intro to writing risks and mitigations. Includes some theory, but also a hands-on example or assistance with identifying their risks for their projects.

B. Detailed Risk Development and Management – Writing and Management: How to write risk statements, how to write and what constitutes a good, valid mitigation plan, risk escalation, board reporting, cost threats/mitigation funding, parent/child relationships (if used in the program), and handling integrated risks or those affecting other organizations. Includes some theory, a hands-on example, case studies, and/or assistance with developing their risks for their projects.

C. Risk Tool/Updates training (updates when new versions are released).

D. Risk Manager/Admin training: Facilitation, Knowledge Capture, Lessons Learned and Knowledge Based Risks, and other RMO responsibilities.

Audiences and required training:

- All Personnel (contractor or civil servant): A
- Project/Program Managers: A, B
- Risk Owners: A, B, C
- Risk Managers: A, B, C, D

4.23.23 Configuration Control the Risk Lists

Description:

There was confusion as to what changes were made to risks at each review, what mitigation steps had already been funded, and if a risk list was the current one or a draft. Configuration control of the risk lists would also mean that the appropriate manager/board at a particular level has seen the risks and has approved them and their statuses.

Recommendation:

The risk list (or certain risk "data fields") at each level of the program should be configuration controlled and thus the changes tracked. Fields to be controlled for the Level I, II, and III risks at a minimum are risk title, context, statement, score, status, and mitigations funded. The fields to be controlled and tracked should be documented in the risk management plan.

4.23.24 Regularly Scheduled Risk Meetings

Description:

Irregular business rhythm causes problems, i.e., irregularly scheduled risk reviews.

Recommendation:

Normal risk review schedules should be defined and adhered to on a periodic basis and not a random nor an on-call activity. Another solution could be that higher level organizations should agree to post dates a specified number of days (at least 45 days) before the top-level meetings. These should be posted in a standard location (web site) and also passed down via the risk management points of contact. The exception for unscheduled risk reviews (although these are usually scheduled) would be milestone reviews.

4.23.25 Integration of Contractor Risks

Description:

Conflicting methodologies were used between Upper Stage, Upper Stage Engine, and First Stage in reviewing and determining how the contractor's risks were reviewed and which ones should be included in the project/program risk database.

Recommendation:

Need to define how NASA oversight is handled for contractors who have their own risk system. Need to include a section in the risk plan on the contractor's roles and responsibilities in the NASA risk management scheme and what has to be escalated into NASA's system. This needs to take into account the various relationships between NASA and the contractors that are experienced in a large program (e.g., first stage is a NASA purchase, upper stage is a NASA design/contractor build). Contractor risks need to come from three different methods:

1) Bottom-up: The NASA and contractor teams should work together at the lowest level possible to develop risks that will be entered into the NASA system.
2) Top-down: NASA should conduct periodic assessments of the contractor's risk database to determine which risks should be incorporated into the NASA database. All risks at a level equal to or lower than the level reviewing the risks should be reviewed. Those should be reviewed to decide if any risks should be carried in the project/program risk system.
3) A government insight team independently identifies expected risks and compare those with the contractor's risk. Then evaluate contractor risk management effectiveness by the results of the comparison.

A plan for this oversight of contractor risks needs to be concise and be limited to about 3–5 pages. It needs to say something to the effect that the element risk manager, project manager, and contractor reviews contract risk on a X period basis. Review includes closed, changed, and new risks. If not done as a plan, this should be defined in the data requirements document (DRD). There should also be a periodic review of the contractor risks by an external Standing Review Board, although not as often as the review by the project/element. This plan or DRD should provide that contractor management should go through NASA training regarding this process, but the contractors should be able to develop/use their own system provided it can provide the required data to NASA. In fact, the contractor may or may not need to do risk management. They may be able to call it reliability management or something else but still meet the contract requirement. (For example, what does SpaceX provide to NASA under the Commercial Orbiter Transportation System (COTS) agreements as far as risk management and/or meeting their milestones?)

4.23.26 Cost Threat Processes

Description:

Early on, the lack of a process created havoc with our reporting and management of cost issues. In CxP, the risk system was being used as a way to obtain budget for the project, i.e., to fund overruns due to incorrect cost estimations or cuts in budget allocation. The cost threat process can completely undermine risk management. Accountability is not established at the outset or enforced when cost threats short circuit the need to identify and manage risks and actively manage according to the project plan: A) Why enter a risk (and suffer scrutiny, be forced to manage/report the risk, use risk tool, etc.) when you can just do a cost threat AFTER it becomes a problem? B) It is easier to get forgiveness (cost threat) than permission (risk mitigation), so the risk system will be neglected, and crisis management will dominate. The eventual process that was created was a good system; the element business manager controlled the cost threat tab entirely. Although the cost threat process was still being used to obtain budget without a specific risk and mitigation plans. For example, one risk was "there is a likelihood that we will not meet budget (or schedule)." Mitigation was to obtain more money.

Recommendation:

A cost threat process is necessary to manage risks related to things such as unfunded critical activities, long-lead items, and other activities (such as testing) that can have serious schedule impacts. The IPT or element resource manager is responsible for turning on a cost threat, assigning its level, and entering in the cost data that was provided to them by engineering (i.e., rough order of magnitude (ROM)). Only they should have the ability in the risk management software to do that. The Program Control Board should define the cost threat level and what they should be used for.

The Constellation risk system is as much about communicating problems to management as it is about managing risks. That being the case, a cost threat process is a natural outgrowth of the risk system. However, the cost threat process should be reserved for unfunded risk mitigation plans. The budget threats themselves may be risks and that is okay, but these budget risks (e.g., Continuing Resolution) do have programmatic impact especially to schedule. If there is a shortfall in planning where funding was not identified, then a change request for the budget should move through its own system and not tax the risk system more than necessary. Let technical people evaluate the technical necessity and estimate the cost; let the programmatic people manage the budget.

4.23.27 Issue Management

Description:

There was no formal issue management program/plan for the CxP.

Recommendation:

The risk process (or a separate issue tracking process) should include a follow-on process for risks that have been realized (turned into issues) by the organization. The process should explain what to do with a risk when it is realized (i.e., should it be closed and entered into an issue tracking system or set to a likelihood of 6 (probability of 1 (i.e., 100%)); should it be continued to be mitigated the same way or does the contingency plan need to be implemented or worked using some other plan?; how should issues be tracked and dispositioned?). Someone suggested Problem Reporting and Corrective Action (PRACA) 2.0.

4.23.28 Management of Reserves for Risk Mitigation

Description:

The entire “cost threat” process in CxIRMA undermined the integrity of credible risk management, but was a natural reaction to program management NOT requiring or allowing subordinate managers to carry and apply reserves to solve emergent problems and mitigate risk. Holding all reserves at the top level may increase top management’s flexibility in distributing reserves, but it undermines the accountability of lower level managers for overall level of overruns (total cost over budget), and disincentivizes early project planning and risk identification. The cost threat process was a dysfunctional Band-aid™ for this flaw.

Improvements we have made to the cost threat process (returning it to focus on risk mitigation) effectively brought the focus back to accountability for managers.

Recommendation:

Upper management should hold subordinate managers accountable for managing cost, schedule, and technical performance. This accountability includes anticipating and planning for "overruns" or problems with these (i.e., risk management) and having appropriate reserves at each level to manage these risks. Top management must also distinguish between causes of overruns before responding with discipline and/or reserves: A) Unforeseeable overruns: use unallocated reserves from appropriate level, and provide summary of what happened to knowledge management to document for the future. B) Known risks cause overruns: Use allocated reserves (probabilistically allocated at project start) for mitigation and/or contingency—optimize mix. C) Failure to effectively execute the plan or manage risks causes overrun: Apply higher-level reserves to solve current problem, fix the processes that failed (risk management (RM), knowledge management (KM), etc.), and reidentify "knowable" risks vs. reallocate higher level reserves for "new" risks as requested by the new manager.

4.23.29 Successful Planning Incorporates Risk Identification and Mitigation Tasks

Description:

The Ares I manufacturing and test organizations utilized the risk management process to identify potential threats and then put mitigation tasks in place to successfully limit schedule impacts after the risks were realized.

The Upper Stage manufacturing team and the IVGVT test team both utilized the risk management process to identify potential threats and mitigations in their areas of responsibility. The Upper Stage common bulkhead team identified risks to their machining center. By mitigating these risks (i.e., they ordered extra components and supplies prior to needing them) they were not impacted when the risk was realized. Similarly, the IVGVT test team identified potential threats to the test facility and mitigated them by utilizing mast climbers to install and access test instrumentation and equipment. In both cases the proactive risk mitigations prevented schedule impacts that would have been realized if no mitigation had been taken.

Recommendation:

Managers and schedulers should incorporate risk identification and mitigation into planning efforts and then ask the "have you considered risks in your plan" question.

Suggested or Taken Action:

Develop a policy to invoke risk identification and mitigation planning early in the planning/formative phases of a project/program.

4.23.30 Risk Management Underutilized in the Design Process

Description:

The Ares risk management process was not well integrated into the design processes. Numerous technical risks were identified and design changes were implemented as a result, but a clear description of integration was not provided. Later changes in the Ares issues and risk processes started addressing this, but not all Ares Elements applied the process updates equally or in the same manner.

Recommendation:

Clearly describe the relationship of the risk management and design processes. Ares incorporated the chief engineer's working groups (e.g., Vehicle Integration risk and issue teams) to establish closer linkages.

Suggested or Taken Action:

Action to Space Launch System (SLS) Program (SLS Program Plan or implementation planning). Action to Program Plan Book Manager: wherever role of the "blue box" duties and WBS are defined, we must require support for risk management effort. (Note: Work with risk management planning.)

Recommend risk management be implemented with adequate resources (war chest or manager's reserve) and in the simplest and most efficient manner to quickly communicate risks in front of program manager (PM) and chief engineer (CE) (Engineering Review Board (ERB)/Program Control Board (PCB)), make decisions, and effect change.

4.24 SAFETY AND MISSION ASSURANCE

4.24.1 Fault Management Methodologies

Description:

Methodologies for developing "integrated" products such as failure modes and effects analyses (FMEAs), fault trees, hazards, etc., must be consistent across the program and reconciled before developing systems engineering processes/analysis tasks.

Recommendation:

The methodologies should include: reconciling related products (e.g., FMEA and Vehicle Integration (VI) FMEA); reconcile prior delivery to systems engineering processes; reconciliation performed by product developers. Reconciliation timing is crucial to feed systems engineering products such as the Abort Condition Analysis Report, Caution and Warning Analysis Report, etc.

4.24.2 Use of Failure Scenarios vs. Abort Conditions

Description:

The abort conditions established in the Abort Conditions Report (ACR) do not contain some critical probabilistic information (i.e., false positives) that are in failure scenarios. This information is critical in decision making.

Recommendation:

Failure scenarios should be used to communicate the mission risk. It is the language used by the quantitative risk assessment groups and provides additional granularity that the abort conditions do not. Include all stakeholders in the development of abort conditions and/or failure scenarios.

4.24.3 Quality Function Implementation

Description:

There was always a disconnect or disagreement as to when and how flight quality approvals should be implemented.

Recommendation:

Update/improve the process for implementing quality functions in development programs. Provide details for when and how flight quality approvals should be implemented.

4.24.4 Balance Manpower/Resources Funding

Description:

We could have better balance of manpower and resources between fault recovery/ascent reconfiguration and finding reasons to get off the launch vehicle.

Recommendation:

Specific to launch vehicles: Assign resources (manpower and funding) equally between two efforts: 1) recovery/ascent reconfiguration, and 2) finding reasons to get off the launch vehicle (i.e., abort).

4.24.5 Fault Management Organizational Model

Description:

Two different organizational models were used during the Ares I project. One model funded and worked employees in an organization other than that of the subsystem they were modeling. The other model had employees embedded with and funded by the subsystem team.

Recommendation:

Establish the Fault Management organizational model early in the program to provide a single, consistent funding source.

4.24.6 Management's Use of Risk Assessment as a Decision Tool

Description:

Risk estimates are comparative in nature, not absolute numbers like metrics.

Recommendation:

Reinforce the notion that risk is not an absolute number (not a metric). Don't assume that slight changes in risk estimates means things are getting better or worse without statistical evidence. Uncertainty in assessments should be addressed earlier than they were.

4.24.7 System on System Failure Analysis

Description:

System on system failure analysis is a key function to perform and fund for development of a launch vehicle.

Recommendation:

System on system failure analysis is a key function to perform and fund for development of a launch vehicle. Per pre-distilling, should be promoted to Space Launch System (SLS).

4.24.8 Review S&MA Tasks Given to Outside Centers

Description:

S&MA analysis was conducted by organizations outside of MSFC S&MA (e.g., maintainability, loss of crew (LOC)). This appears to be in conflict with NPD 8700.1E, NASA Policy for Safety and Mission Success, and the MSFC S&MA Charter. This also resulted in great difficulty in assuring complete and accurate analysis results and accountability as well as organizational confusion/conflict. (Note: Some of these issues were being addressed by the Ares V team via the VI reorganization that was cancelled due to the February 1, 2010, redirection.)

Recommendation:

For any S&MA analysis performed outside of the MSFC S&MA organizations, clear Memoranda of Understanding (MOUs) should document roles and responsibilities (R&Rs), authority, and accountability. As a minimum, S&MA should have approval authority over such analysis.

Suggested or Taken Action:

S&MA representative to verify that the Red Book is updated that tasks assigned outside the center are reviewed by the assigning organization before official release to the project/program.

4.24.9 Determine Support for Quality Assurance Function

Description:

Ares included two significant “in-house” activities (VI and Upper Stage). This required both of these organizations to operate much like a prime contractor. A “NASA assurance function” to oversee the “in-house” developed products was not well defined. Over the years, a series of fixes were used to get some quick peer reviews or products, but content of review comments appeared indicative of relatively unfamiliar external folks being pulled in for a relatively quick review. For safety products, the Constellation Safety and Engineering Review Panel (CSERP) basically emerged as the primary (and arguably sole) assurance function.

There are instances where the Chief Safety Officer (CSO) is asked to provide technical authority (TA) opinion on the product he/she was involved in developing. The CSOs were so busy at times there were disconnects between the safety team and the CSOs. For example, there were times that the CSO may not have been aware of some of the issues the safety team was having that could have been raised.

Recommendation:

For any programs/projects that involve “in-house” activity, a NASA assurance function should be clearly defined and staffed. CSOs should not endorse passing a milestone review unless they receive endorsements from both the performing organization and an assurance organization that products/processes meet requirements, and requirement departures, if any, are satisfactorily documented and justified. Consider the structure of the S&MA/TA/CSO to provide true independence for the CSO, where there is an independent CSO office similar to the Chief Engineer’s Office. Provide support for CSOs (deputies and/or support staff).

Suggested or Taken Action:

S&MA representative to verify that support for an assurance function is addressed in the Red Book.

4.24.10 FMEA/Critical Items List (CIL) Data Requirements

Description:

The Constellation Program instituted the development of the Mission Assurance System, which is a web-based application intended to house the Safety Hazard Analysis, Failure Modes and Effects Analysis/Critical Items List (FMEA/CIL), and Problem Reporting and Corrective Actions (PRACA) systems and provide the capability to readily link these products to maximize their interaction. Development of the FMEA/CIL application (CxFMEA) began after the projects were already underway in development of their FMEAs. The Constellation Program (CxP) FMEA/CIL Methodology (CxP 70043) specified the data fields that were to be contained in the project FMEAs, but not the data structure. As a result, each project and element had a unique FMEA data implementation that had to be accommodated by CxFMEA, resulting in some compromises that limited its usefulness.

Recommendation:

It is recommended that for any future project, a FMEA data electronic format and structure be established upfront and the program be willing to absorb the cost of requiring all projects and elements to utilize it.

Suggested or Taken Action:

Identify and update in-house and external data requirements for FMEA/CIL for a standard data requirement.

4.24.11 Issues with Using "Heritage" Hardware

Description:

The Ares Projects utilized Space Transportation System (STS) heritage hardware elements. Early on, it was understood that the FMEA for the heritage hardware would be used as a starting point for the Ares FMEA, but that it would be modified as necessary and appropriate to satisfy Constellation Program requirements. As time went on, there was a reluctance to make changes to the heritage FMEA since "that's not the way it was done for Shuttle."

Recommendation:

Any future program that utilizes STS heritage hardware must have a clear understanding of the limitations associated with the existing heritage analyses and be willing upfront to absorb the cost of modifying the analysis to meet program requirements, if desired.

Suggested or Taken Action:

Risk and issues that come with utilizing heritage hardware and processes. This should be worked through the Chief Engineers Office.

4.24.12 Document Position on Fault Tolerance

Description:

On the Constellation Program, the Office of S&MA (OSMA) NASA Procedural Requirements (NPRs) 8715.3 and 8705.2 initially required two failure tolerance (2FT). The latest revision adds some exceptions (e.g., structure) and changed the FT requirement to failure tolerance to catastrophic events (minimum of one failure tolerant), with the specific level of failure tolerance (one, two, or more) and implementation (similar or dissimilar redundancy) derived from an integrated design and safety analysis. This caused engineering to design to 1FT without the supporting rationale, and in some cases FT was reduced immediately (the design was changed!) because it was thought that it was not required. Safety had to buy its way back in. This provides an allowance for "Other potentially catastrophic hazards that cannot be controlled using failure tolerance are excepted from the failure tolerance requirements with concurrence from the Technical Authorities provided the hazards are controlled through a defined process in which approved standards and margins are implemented that account for the absence of failure tolerance."

Recommendation:

We should definitely try to better define this requirement for a launch vehicle. Leave the requirement 2FT and process paper for why 1FT is sufficient.

Suggested or Taken Action:

MSFC S&MA to evaluate and make a recommendation on how to resolve and provide feedback and recommended documentation to the Distilling team and to SLS Program & Chief Engineer.

4.24.13 Define Structure or Template for FMEA

Description:

The main objective of the Integrated FMEA was to expand upon the Element FMEAs where appropriate to ensure that vehicle-level details (vehicle/crew failure effects, failure detection, software response) were appropriately captured and documented since these were outside the scope of the Element FMEAs. This approach resulted in considerable effort by Level III to get the Element FMEAs into a common data format, presented serious configuration management issues with the use of the Elements' data, and resulted in much confusion regarding the differences between the Element FMEAs and the Integrated FMEA.

An alternate approach for FMEA integration was recommended by S&MA shortly after Ares System Definition Review (SDR). In the alternate approach, rather than developing and maintaining a separate Level III Integrated FMEA to contain the vehicle-level details, Level III would still be responsible for identifying the vehicle-level details, but would "push" these details to the Elements to be incorporated into the Element FMEAs, thus each Element FMEA would be an "integrated" FMEA. Despite S&MA's preference for this approach, it was rejected by Ares Projects management because it was considered additional scope for the Element contractors since their contract data requirements docouments (DRDs) were based upon the Shuttle FMEA approach.

Recommendation:

For a future program, consideration should be given early on to the alternate approach so that appropriate provisions can be incorporated into the Element contracts to make this approach feasible.

Suggested or Taken Action:

Define appropriate structure of FMEA document in the appropriate Marshall Procedural Requirement (MPR)/Office of Primary Responsibility (OPR) or Red Book.

4.24.14 Document Position on Design for Minimum Risk (DFMR)

Description:

Several times during the project the engineers would claim that an item was DFMR when it was not, it was zero failure tolerant (FT). DFMR could be bought off by CSERP, Zero FT required a waiver, and both require analysis and supporting data.

Recommendation:

Eliminate references to DFMR. If additional requirements are necessary to control specific hazards (i.e., mechanisms), consider writing interpretation letters like the Space Shuttle Program (SSP) Payloads and International Space Station (ISS).

Suggested or Taken Action:

S&MA to define and document position on DFMR versus fault tolerance or cite current authoritative documentation and work with S&MA and Chief Engineer's Office to update implementation (via Red Book, NASA, or center-level guidance) and inform new program/projects such as the SLS (heavy-lift).

4.24.15 Define System Safety Reporting Processes

Description:

While an Integrated Risk Management Application (IRMA) type system is not limited to "safety risks," the fact that it does include a requirement to capture and manage safety risks creates confusion between IRMA's purpose and the purpose of hazard reports (HRs). (Too) much time was spent discussing/debating which system should be used to capture/manage a safety risk.

Recommendation:

S&MA (and any risk management (RM)) requirements documents should clearly define the relationship between these two reporting systems. In my opinion, the HRs should be used to capture all hazards/causes; their "defined" control strategy in verifiable terms; and characterize the resultant residual risk. The RM system should be used for safety risks for which a "defined control strategy in verifiable terms" has not been agreed upon and needs to be developed or the residual risk defined in the HRs is undesirably high such that additional mitigations should be pursued. This approach would allow the RM system to help "manage" activities associated with exploring and/or developing additional safety risk mitigations (e.g., development of options, trade studies, and tests). Following the selection of a risk mitigation strategy, it would be documented in verifiable terms in HRs.

Suggested or Taken Action:

Resolve and document the S&MA postion within the System Safety methodology.

4.24.16 Hazard Report Database

Description:

The hazard report database was useful in providing safety integration with the capability of real-time access to project/program/element data which created a better product and reduced the time to create. This allowed us to integrate across the elements and understand what other projects were covering. Windchill had limited access to some data and it was so spread out that it was difficult trying to find data. The database also provided a standard format which aided in finding information. The face-to-face access with the CSERP Executive Officer (ExO) was helpful; he was co-located with the project. The accessibility of the CSERP ExO helped expedite actions to closure before formal reviews and precoordinated review topics.

Recommendation:

Have a hazard report database and keep the ExO co-located with the project.

Suggested or Taken Action:

Determine appropriate documentation (recommend methodology document).

4.24.17 Develop Documentation for Hazard Reports

Description:

HRs had some overlap and sometimes were just pointers (transfers). Some HRs were not clear and causes were not definite. Background information that explained rationale was not always included. Cause ordering was sometimes not logical.

Recommendation:

HR should present the full story but not overlap an HR from another level or project. The HR should not be only a pointer. The integration role should be clear and obvious in the HR. Transfers should be handled carefully so that reports are not merely pointing to each other with no one having the responsibility (an endless circle). Transfers (scope, what could be transferred, what level) were never fully defined on this program. Define transfer process and expectations.

The HR must be clear and unambiguous. Scope of HR should be clear, such that the causes included/omitted make sense and provide the reason for why they were included or omitted. All causes must be definite, precise, cover all aspects of the hazard but not overlap another cause or causes from another HR. A clarification in CxP 70038 that recommends a place to record background information on items such as this would be helpful. Internally we need to train our authors.

If causes and narrative (description) are chronologically dependent on the state/mode/event or mission phase, order the causes and narrative chronologically. If causes and narrative are not chronologically dependent, order causes by some logical means agreed to with CSERP on first review to eliminate reordering of causes.

Suggested or Taken Action:

Determine appropriate documentation (recommend methodology document).

4.24.18 Assure Well-Developed Probabilistic Risk Assessments (PRAs) and FMEA/CIL

Description:

Too little resources are used on FMEA/CILs and PRA reviews. Similar to hazard analysis (HA), the FMEA/CILs systematically identify sources of flight safety risks (critical failure modes) and document the risk mitigation strategies (i.e., hazard controls in HRs and retention rationale in CILs). In reality, MSFC historically has captured more risk mitigations in CILs than HRs, yet CILs are not subjected to the same level of scrutiny as HRs. While Safety Panels may occasionally review CILs, the amount of time spent by Safety Panels reviewing CILs is negligible when compared to HRs.

Regarding PRA, the SSP had no formal panel to review PRA documentation (e.g., models, assumptions, and results). The Constellation Program created a PRA Panel, which met infrequently and served more as a working group at best to share ideas/information, but did not perform a detailed panel-type review of PRAs being developed to verify compliance with the agency/ESMD’s loss of crew/loss of mission (LOC/LOM) requirement.

Recommendation:

A more consistent assurance function/approach for these analyses should be developed.

Suggested or Taken Action:

Take to Safety Review Panel lessons learned group for consideration.

4.24.19 Develop Process for Well-Integrated FMEA

Description:

Within the Ares Projects, each Level IV element was responsible for developing the FMEA for their hardware, and Level III was responsible for consolidating the Element FMEAs into the Ares I Integrated FMEA. The main objective of the Integrated FMEA was to expand upon the Element FMEAs where appropriate to ensure that vehicle-level details (vehicle/crew failure effects, failure detection, software response) were appropriately captured and documented since these were outside the scope of the Element FMEAs. This approach resulted in considerable effort by Level III to get the Element FMEAs into a common data format, presented serious configuration management issues with the use of the elements’ data, and resulted in much confusion regarding the differences between the Element FMEAs and the Integrated FMEA.

An alternate approach for FMEA integration was recommended by S&MA shortly after Ares SDR. In the alternate approach, rather than developing and maintaining a separate Level III Integrated FMEA to contain the vehicle-level details, Level III would still be responsible for identifying the vehicle-level details, but would “push” these details to the elements to be incorporated into the Element FMEAs, thus each Element FMEA would be an “integrated” FMEA. Despite S&MA’s preference for this approach, it was rejected by Ares Projects management because it was considered additional scope for the element contractors since their contract DRDs were based upon the Shuttle FMEA approach.

Recommendation:

For a future program, consideration should be given early on to the alternate approach so that appropriate provisions can be incorporated into project management and element contracts to make this approach feasible.

Suggested or Taken Action:

Take to FMEA Methodology team for consideration.

4.24.20 Planning and Early Involvement of S&MA Activities

Description:

S&MA was not sufficiently involved in the design process. Prior programs had regular safety reviews. On Ares, redundancy was added or taken away effortlessly and hazard reports were not in the forefront of the design effort.

S&MA milestones, deliverables, and committees or working group meetings were not defined and planned for each year. Also, S&MA requirements were not easily integrated into SE&I planning. The Upper Stage S&MA plan was followed, but it was insufficient and didn’t define all deliverables.

FMEA decision boards as planned in the CxP 70043, Constellation Program Hardware Failure Modes and Effects Analysis and Critical Items List (FMEA/CIL) Methodology, were not stood up in time to be effective in the design cycle. For TVC, no meaningful CIL was created to be effective for Critical Design Review (CDR).

Recommendation:

S&MA needs to be very involved during the design and planning phase of the program. A full-time S&MA engineer who can focus on a systems engineering approach to S&MA requirements, milestones, deliverables, and committee and working group meetings should be part of the early program team.

Once a HR has been drafted, the design team should present the HR and their implementation of the mitigation at each design review (PDR, CDR, Initial Layout Review (ILOR), Final Layout Review (FLOR), Critical Layout Review (CLOR), etc). The integrated system should also be assessed to assure that the current design is within acceptable risk. Safety should be a separate agenda item at the reviews. Any design change (via Element Control Board (ECB), Element Integration Board (EIB), or Vehicle Integration Control Board (VICB)) should have a customized statement from MSFC S&MA stating that the design change has been assessed and describes its impact prior to approval.

4.25 SPACE SYSTEMS AND AVIONICS

4.25.1 Integrated Avionics Systems Engineering and Integration (SE&I)

Description:

Lack of an integrated avionics systems engineering and analysis function. SE&I tasks and planning were left to the designers.

Recommendation:

Avionics SE&I function should be a part of the overall SE&I task planning and requirements development instead of a sub to it.

4.25.2 Vibration Isolators

Description:

Early characterization of avionics vibration isolators was needed. The dynamic stiffness and damping of isolators can vary significantly from catalog data.

Recommendation:

Identify the characteristics of chosen vibration isolators early in the design analysis cycles.

4.25.3 Avionics Interactions with Suppliers

Description:

There was no Vendor Preliminary Design Review (PDR) for the flight computer. The NASA design team had no input on the selection of the flight computer vendor. The selected vendor had inadequate experience building flight computers including implementation of redundancy. Furthermore, the avionics vendor was selected too late in the design process. Engineers were asked to provide design support for avionics where little or nothing was known about the components.

Recommendation:

Ensure that critical boxes always have a Vendor PDR. Allow MSFC subject matter experts to weigh in on the selection of vendors by the prime by including this opportunity to provide input in the statement of work. Select vendors as early as possible in future programs to reduce the risk of late vehicle design changes to accommodate the as-built avionics.

4.25.4 Avionics Cooling

Description:

The thermal team determined that the Ares I avionics boxes needed cooling on the ground during prelaunch. Requirements were not defined to address thermal issues during off-nominal events. The active thermal control option for cooling the avionics was dismissed too soon in the design development.

Recommendation:

The purge and hazardous gas system should have requirements to provide cooling to the avionics boxes during prelaunch to ensure the system is designed to specifically handle this function instead of addressing it as a “fringe benefit” of the purge process.

Parallel and active design paths should have been considered until greater confidence in the passive system was achieved. For example, the primary option pursued would be a passive design with scarring included for an active design if the passive design was inadequate.

4.26 STAGE INTEGRATION

4.26.1 Communications/Integrated Product Team (IPT) to IPT

Description:

The IPT managers did not communicate with other IPTs on a regular basis. Communication was initiated only after issues rose to critical levels.

Recommendation:

None provided, but regular IPT to IPT communications should be conducted. Consider adding a standard agenda item to the Chief Engineer’s Board meeting (or another regularly scheduled meeting) where the IPT leads communicate their current concerns.

4.26.2 Communications/Subsystem Managers to Resource Managers

Description:

Subsystem managers did not have good communications with the project resource managers in the areas of budget, New Obligation Authority (NOA) funds, and Other Direct Costs (ODC) funds availability.

Recommendation:

None provided, but communications concerning resources need to be documented so that both project and engineering team members understand the communication pathways. The center needs to establish a resource process that allows engineering to solicit resources from the projects they support.

4.26.3 Communications/Upper Management to Subsystem Managers/IPT Leads

Description:

There were not enough face-to-face opportunities for subsystem or IPT leads to communicate concerns. This led to second or third hand conveyance of an action or issue (both to and from) that lost meaning or intended emphasis.

Recommendation:

Additional direct communication recommended to improve those relationships.

4.26.4 Communications/Engineering Management

Description:

Engineering management participation in project quarterlies was not evident. This led to engineering leaders being uninformed or armed with second/third hand knowledge.

Recommendation:

None provided, but communications is a critical factor in project success and engineering needs to establish and reinforce communication expectations. Bi-weekly notes could be part of the solution, but the process needs to be updated to include a feedback loop.

4.26.5 Third Party Hardware

Description:

The addition of third party hardware between two subsystems added complexity to the interface, especially when funding was not available to analyze the hardware interface or design efforts.

Recommendation:

Limit adding third party hardware between two subsystems. If you have to add it, include additional resources for analysis, design, etc.

4.26.6 Design, Manufacturing, and Production Coordination

Description:

Ares I Upper Stage Manufacturing and Production (M&P) team members noted that some hardware designers failed to incorporate “design for manufacturing principles” in their designs. This was likely due to the lack of manufacturing knowledge/awareness of the design personnel. A simple tour/overview discussion of specific meeting processes could be very beneficial for design personnel prior to designing hardware. For example, the Spacecraft and Vehicle Systems department submitted a liquid oxygen tank design with external isogrid structure and asked for TPS M&P processing impacts. Understanding the TPS process limitations and general knowledge of impacts caused by complex external geometries on external tank processing beforehand would likely have kept this proposed change from ever being submitted. This issue caused valuable time to be spent generating a package to explain the impacts and then multiple inter-IPT meetings to resolve. The issue was resolved by a simple change to the isogrid geometry which allowed cleaning solutions to drain from the tank interior surfaces.

Recommendation:

M&P has developed a package that was used to explain "Design for Manufacturing Principles" to Upper Stage designers. Using this package and tying it to the Memorandum of Understanding (MOU) between the two teams may be a good way to prevent this issue from reoccurring.

4.26.7 Material Data Request Sheet Process

Description:

Ares I Upper Stage M&P and Engineering Analyses team members started with no clear means of addressing design/analysis requests for material data. The teams developed a process to address this where they used a Material Data Request Sheet.

Recommendation:

Continue using the Material Data Request Sheet.

4.26.8 Military Intergovernmental Purchase Request (MIPR) Utilization

Description:

The Ares I Upper Stage Ullage Settling Motor team utilized the MIPR process with the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) to produce prototype motors. This proved to be efficient and exemplary and the team recommended continued use of this process.

Recommendation:

The KO author referenced MSFC internal directives. I found MPR 1050.2, Procedure for Executing Agreements with Non-MSFC Entities, that discusses MIPRs.

4.26.9 Development of Drawing Trees

Description:

Drawing trees were developed on the fly, instead of being initiated at the start of the design. This led to multiple drawing trees.

Recommendation:

Provide a drawing tree with interfaces defined within it to start the design drawing process. Also, be vigilant to produce only value-added products.

4.26.10 Timing of Ground Support Equipment (GSE) Definition

Description:

The GSE design started late for Upper Stage and took a hit because funding was not available. There were several thoughts on when GSE should be started (early versus late) and how to define GSE requirements (interface control document (ICD) or interface requirements document (IRD)). In general, GSE needs to be defined, documented, and planned for so that resources are available to design and provide it.

Recommendation:

Consider a GSE IPT that works with the other teams to define the GSE requirements and plans.

4.26.11 Management Accountability

Description:

Management did not always provide realistic resources (funds or schedule) and as a result became ineffective. This was compounded with cases where managers did not want to listen to experts and went ahead with their own decisions. Accountability for bad decision making did not appear to be present.

Recommendation:

Leadership needs to set realistic goals based on available resources and then be held accountable.

4.26.12 Planning to Address Subsystems with Different Maturity Levels

Description:

Several teams across engineering provided comments associated with schedule disconnects that impacted their work. The concern was that there appeared to be little planning associated with component and subsystem maturing at different rates. The Upper Stage Integration Analysis team reported that they needed to be brought in earlier to support design analyses earlier in the life cycle. Integration analyses that result in changes to post-Critical Design Review (CDR) subsystems carries greater change costs.

Recommendation:

Planning needs to consider different maturation rates (System Requirements Review (SRR) to Preliminary Design Review (PDR) to CDR) for different subsystems and components. The resulting schedule and tasks need to accommodate system integration early to minimize system changes and associated costs.

4.26.13 Control Boards, Both Project and Engineering, Representatives

Description:

Control boards, both project and engineering, did not include representatives from all impacted discipline areas. This led to a lack of awareness of technical and project decisions. The discipline areas should have board membership or representation.

Recommendation:

Control boards, both project and engineering, should have board membership or representation for all applicable discipline areas.

4.26.14 NASA Design Team (NDT) and Upper Stage Management Relationship

Description:

Ares I Upper Stage Management appeared to side with the Upper Stage Production Contractor (USPC) more often than with the NDT. This led to tension between Upper Stage management and the NDT. Examples how this manifested include the rejection of NDT drawings and USPC independent assessment of the interstage without the NDT's knowledge.

Recommendation:

If this deisgn to production hand-off method is used in the future, it is recommended the new programs/project work with engineering (and the prospective production lead) to establish clear definition of deliverables, ownership, as well as roles and responsibilities before, during, and after the design-to-production hand-off.

4.26.15 IPT Project and Engineering Relationships

Description:

Ares I Upper Stage utilized IPTs led by the Upper Stage Element Project leads and supported by NASA Engineering Directorate (ED) personnel. Comments from both parties suggest that there was lack of trust between them. IPT leads expressed that they felt that they had limited or no authority over their IPT and that the coordination with ED Branch Chiefs was cordial but not always productive. Engineering Directorate team members expressed similar concerns and included examples where ED IPT members did not receive enough information from the project leads and this hampered Test IPT work.

Recommendation:

Co-location of project and ED IPT team members is a possible solution.

4.26.16 Electrical Integration and Electromagnetic Environmental Effects (E3) Fragmented on Ares

Description:

Electrical Integration and E3 were extremely fragmented on Ares between Elements, and even internally. Subsystems such as the reaction control system (RCS), thrust vector control (TVC), and main propulsion system (MPS) were focused on their prime technical issues and items such as grounding, lightning, voltage drop, and bonding. Other electrical items were afterthoughts instead of being integral to their design. No allocations for this support were normally planned.

Recommendation:

Recommend engineering and new programs/projects negotiate and establish appropriate level of E3 support.

4.26.17 Stage and Assembly Integration Teams

Description:

The Integrated Assembly team should fully support Stage Integration, instead of being a shared resource. The team was productive, but lost sight of "who" they worked for and how they should be proceeding with integration of their assigned volume. Looking after the "system" is a full-time job.

Recommendation:

Fully fund the Integrated Assembly team to support Stage Integration. Develop layouts with envelopes, keep-out zones, deflections (due to vibe, thermal, loads, and other), integrated stack-up tolerance early, and maintain this effort until the hardware is defined.

4.27 STRUCTURAL DESIGN

4.27.1 Hardware Familiarity Needs To Be Planned

Description:

"Play with the new hardware in the lab to understand it" was not an acceptable schedule task. Squeezing it in between managerial tasks means morale drops, and when an Apollo 13 type of an event requires someone to know the detailed workings of a box, they don't.

Recommendation:

Plan all tasks to ensure adequate time and attention is allowed for thoroughly understanding the system hardware.

4.27.2 Guidance, Navigation, and Control (GN&C) Analysis Demise Criteria: Vehicle Load Indicator Issues

Description:

Significant problems existed with the vehicle load indicator (VLI) used to analyze abort success of loss of control failures. The indicators worked well for some elements but not for others. As a result, the most recent analysis cycle did not provide meaningful data. So loss of crew (LOC) studies could not have used the data, and it is not known if either of the abort procedures would have resulted in successful abort (or not). This situation is unacceptable at this phase of the program where Ares was moving towards Critical Design Review (CDR).

Recommendation:

Load indicators are needed that represent the structural capability of the vehicle and not just the capability to withstand some particular trajectories for some parts of flight. The methodologies for determining these load indicators needs to be standardized across the program/project.

4.27.3 Layout Review Process

Description:

The Layout Review Process that Structures and Thermal (S&T) personnel used worked very well instead of the traditional style Preliminary Design Review (PDR) and CDR. The Initial Layout Review (ILOR), Final Layout Review (FLOR), and Critical Layout Review (CLOR) produced an impressive amount of data that were easier to review in smaller chunks. We (Kennedy Space Center (KSC)) fully supported the concept of interim design reviews (such as checkpoint reviews), and recommend that philosophy be adapted by more programs/projects.

Recommendation:

It is preferable to create structural layouts under project control earlier and avoid a Memorandum of Understanding (MOU) that constrains/over-constrains dimensions. Perhaps setting basic dimensions and then scheduling milestones to reduce the tolerances may be a more appropriate approach than artificially “freezing” some design variables.

4.27.4 S&T Subsystem Specification

Description:

S&T should have had a subsystem specification from day one. Trying to write one after several revisions into the Upper Stage Element Requirements Document (ERD) was very difficult.

Recommendation:

On future programs, recommend that the S&T subsystem develop a subsystem specification at the beginning of the program.

4.27.5 Structural Analysis Plan

Description:

The Ares I Upper Stage Thrust Vector Control Subsystem did not complete a structural analysis plan early enough in the program. Because of this, the methodology changed a couple of times in order to get more in line with the rest of the Upper Stage community. Thus, the bulk of the analyses was completed in the last few months before the Intermediate Design Review. Therefore, undue analyses were performed early on.

Recommendation:

Having a structural analysis plan for subsystems in place early on, including the coordination of the plan across different subsystems in a project, would eliminate extra work and time later in a program.

4.27.6 Loads Data

Description:

Loads are sometimes delivered to be directly applied and sometimes delivered as to be combined with other loads before applying. The lack of specification led to the stress analyst assuming the loads were in one format instead of the other and applying the loads inappropriately.

Primary structure was not designed with the attachment of the secondary structure in mind early enough in the program, especially large mass item secondary structures. Because of this, both the primary and secondary structures had to be redesigned to accommodate each other.

The task of developing integrated vehicle design loads for an entire launch vehicle is tremendous. The “VI Loads Team” made significant improvements each loads cycle and got better and more efficient as time progressed. The loads team leads (civil servant and support contractors) did a great job of organizing and setting priorities to complete load cycles and load analyses.

Recommendation:

Include specifics as to loads data sets where derived, describe the data sets’ intended use and if there are any limitations. It should not be assumed that all personnel are familiar with processes that some or most folks here are familiar with. This is especially true when we are working on a very large program and many competent folk come here from many different places and with different backgrounds. To prevent this in the future requires addition of only a couple of sentences to memos or reports.

Identify and consider large mass secondary structures from their interface loads perspective early in the primary structure design effort.

Because of the learning curve involved and due to the task of developing integrated vehicle design laods for an entire launch vehicle being tremendous, recommend that maintaining the VI Loads Team on the next launch vehicle should be a high priority.

4.28 VEHICLE DESIGN AND INTEGRATION

4.28.1 Induced Environments Definition

Description:

Induced environments and the plans for their development were not initially defined well. Specifically, this includes the released for information (RFI) and released for technical use (RFTU) dataset release process. Also, the induced environments dataset and related test numbering was inconsistent because there was not a formally established numbering convention.

Recommendation:

Need better definition early on of *all* induced environments and plans for their development. This should include: common numbering conventions for induced environments dataset and related tests; all generators and tolerances; system-to-system, integrated vehicle, element-to-element, interfaces; and the entire life cycle (transportation, integrated ground tests, etc.). Also need to establish (vet and formalize) responsibilities, priorities, plans for development, etc. This includes setting up a dedicated project Design Analysis Cycle (DAC) logbook worksheet and dataset release processes, such as RFI and RFTU.

4.28.2 Mission Phase Definition

Description:

There were four mission phases (MPs) defined by Vehicle Integration (VI) for use on the Ares I project. Ares I Mission Phases included: Mission Phase A Pre Start; Mission Phase B First Stage Boost; Mission Phase C Separation; Mission Phase D Upper Stage Boost. These MPs are ambiguous and do not show the detailed phases that a launch vehicle goes through during ascent. Because the MPs were defined as they are above early on in the program they were used in the failure modes and effects analysis (FMEA) assessment. This led to problems during the J-2X abort condition/FMEA mapping process. Because of the differences in J-2X FMEA and VI FMEA MPs it made it very difficult to accurately map the FMEAs to appropriate abort conditions. Also when developing algorithms for the abort conditions, a deeper understanding of the MPs was needed to ensure that particular abort conditions were not being analyzed by the flight computer when the launch vehicle was actually in an in-between state of the defined MPs.

Recommendation:

Need to define the methodology for the integration process, the format of data between the products, and the interrelationship of the products, i.e., Ares I mission phases and modes, Vehicle Systems Management (VSM) phases and modes, flight software (FSW) states and modes, and J-2X mission phases.

4.28.3 Volume Integrator Function

Description:

The volume integration function was brought into the Upper Stage project too late in the process. This caused late integration decisions and forced late design changes that could have been identified earlier in the design process. Once the volume integration function was instituted, it was very beneficial to the rest of the team in information flow and interface definition. One negative about the volume integrator role was that it lacked allocated funds to cover any needed system-level analysis needed to help guide the development of the necessary enabling assemblies and components (had to rely on the willingness of the analyst's branch chief for assistance).

Recommendation:

Recommend that on future programs the volume integration function be instituted early (pre-design phase) to reduce the number of late design changes and integration conflicts. Also, recommend that volume integrators have system design and analysis resources allocated to them to increase their effectiveness in this role.

4.28.4 Design Discipline Organizational Structure

Description:

Multiple Ares vehicle disciplines were organized in such a way that limited their ability to impact other applicable disciplines/groups. For example, Ares Flight & Integrated Test Office (FITO) was not able to direct vehicle elements which made it nearly impossible to come to a consensus as to what was needed for testing of the vehicle. Electromagnetic Environmental Effects (E3) is organizationally under Avionics, even though this is a multi-disciplined function that deals as much with mechanical (i.e., non-avionics) disciplines as with avionics. Also, ground support design activity excessively drove launch vehicle design decisions and forced a more complicated reaction control system (ReCS) design.

Recommendation:

Recommend establishment of design disciplines appropriately such that they are able to impact needed areas of design. Some specific recommendations include: E3 should be placed at a systems integration level to more readily have impact on multiple engineering disciplines; Avionics should be placed at the same level as other major vehicle elements; VI and Ares FITO should be above the elements with the authority to direct; and Ground Support design activity should not be able to drive design decisions for the launch vehicle.

4.28.5 Liaison between Project Office and Engineering Support

Description:

First Stage seemed to have a better project-to-engineering relationship than VI due to employing a liaison between the project office and engineering support. This allowed the engineers supporting First Stage to focus on the technical work, while the liaison focused on budget and schedule type issues. This system works very well in the Shuttle organizational model in my opinion. In Ares VI, engineers were forced to focus on budget and schedule tasks, while their talents may be more useful elsewhere. (The liaison functions as a resource/schedule manager.)

Recommendation:

Recommend employing the liaison function between the project office and engineering to reduce the time spent by engineering on budget/schedule activities and maximize the effort of the engineering workforce.

4.28.6 Limit Detailed Engineering Processes

Description:

There is a tendency to develop processes or requirements to ensure things happen instead of allowing good engineering judgement with checks and balances to develop flight and ground systems. This sometimes drives people to say “well I followed the process identified” and not really think about what they are doing.

Recommendation:

Recommend limiting the number and detail of processes in favor of fostering an environment that encourages the use of engineering judgement with checks and balances.

4.28.7 Clearly Defined Chain of Command

Description:

The chain of command between the working levels and project offices was not clear. Program management seemed to have excessive authority in technical decision making, while the Chief Engineer’s Office didn’t seem to always have the final word. Authority and integration responsibilities within the Engineering Directorate were also unclear, and sometimes the decision process rules would change without regard to the working community. Also, design authority and insight/oversight were not clear with regard to the prime contractor and NASA. This lack of a clear chain of command and associated decision-making processes led to inefficiencies, inconsistencies from branch to branch, and general confusion in the development process.

Recommendation:

The chain of command and associated decision-making processes should be defined and communicated at the start of a program. These processes should also be clearly defined (contractually) for the prime contractor.

4.28.8 Technical Decision Board Implementation

Description:

Many design changes were approved, but never implemented because of a lack of funding (i.e., common bulkhead, liquid oxygen (LOX) dome geometry, slosh baffle design). Also, areas affected by design changes were not always informed when a change was made.

The Ascent Flight Systems Integration Group (AFSIG) was delegated technical oversight over much of the program. AFSIG routinely made technical decisions but struggled to implement them because of a lack of authority.

Recommendation:

Recommend that decisional boards not approve design changes when the resources required to implement those approved changes is not available. If a board delegates technical oversight to a working group, that board should also ensure that the appropriate authority to implement that oversight is also delegated to that working group. These boards must ensure that all affected areas impacted by an approved change be informed in the change process. Also, recommend that rather than equal voting by all disciplines on proposed design solutions, a more targeted approach, based on those with the most insight to the proposed design solution, be employed.

4.28.9 Integrated Product Team (IPT)/Component Design Team (CDT) Authority

Description:

The project office/chief engineer was asked to make design decisions instead of the CDT with the most visibility into the decision. For example, early coordination with aero could have prevented roll control issues that were prevalent early in the design phase.

Recommendation:

Design decisions should be made at the CDT or IPT level rather than at the project office or chief engineer level.

4.28.10 Chief Engineer Responsibilities of Integration and Design

Description:

The culture in vehicle design, unfortunately, is to not consider the entire system and processes in performing the design of the flight hardware and software. Individual elements worked independently of Vehicle Integration and worried about their piece, but not that of the entire system. This same thought process was also evident, with respect to Orion’s interfaces with Ares. Volume integrators were brought in late in the process to help with integration, but lacked the authority to make decisions quickly and efficiently.

Recommendation:

The chief engineer (CE) must assure that the entire system design is considered and integrated. The CE must have final authority for all technical designs. Authority of some technical decisions could be delegated to CE representatives, such as volume integrators, with the CE always having final authority if needed. Specifically the Level III CE must have clear understanding of all the elements and the authority to ensure proper design and integration. The Level II CE must have a clear understanding of the entire system and be responsible for all design and integration.

4.28.11 Product/Data and Personnel Coordination

Description:

There were multiple cases on the Ares Projects in which product development was slowed by depending on products and data not available when needed. For example, Level II did not complete their induced environments definitions and requirements, necessitating Level III to develop their definitions and requirements independently. Later, Level II developed their induced environments definitions and requirements which were inconsistent with Level III and created a lot of rework. There were also cases where the appropriate personnel were supporting multiple organizations and availability was not well coordinated.

Recommendation:

Overall applicability and life cycle of products must be defined early in the program to ensure that products are at the required maturity and available to other dependent products. The use of a "black box" system model would be beneficial in establishing naming conventions which could flow to other design products. Roles and responsibilities of engineering departments with personnel supporting multiple organizations must also coordinate tasks such that the appropriate resources are available at the appropriate times.

4.28.12 Good Systems Engineering

Description:

System engineering and integration (SE&I) was treated as a process and document management function. SE&I is a true hardware/software integration function, with specific individuals and board members responsible for the specifications, interfaces, and design conflict decisions. For Ares I Upper Stage, this was done at an Element Integration Board (EIB) through a peer review process, but was not combined with other elements. No one person was the owner of the "design."

Recommendation:

Management must emphasize the importance of good systems engineering at the very beginning of a program and ensure that the organizational structure accommodates it. Suggest that there be a forum in which representatives of each IPT come together to take "big picture" looks at the system, and then be a shepherd working on specific issues. Also, goal should be less paperwork, and more expertise development time for subject matter experts.

4.28.13 Specific Design Recommendations

Description:

The flight termination system (FTS) on the upper stage added complexity and weight to the upper stage.

Designers and analysts ran into difficulty completing primary structure designs because little was known about secondary structure configuration, requirements, and associated data (i.e., loads, mass, attachments).

Recommendation:

If the next program uses large strap-on solid rocket motors, consider a design such that an FTS action on the solids will take out the core as a consequence (i.e., so the core does not need its own FTS).

For future launch vehicle work, the design team must consider secondary structure mass/center of gravity (CG), and attachments earlier in the design.

Also, assessment and establishment of commonality requirements early in the design life cycle would help in overall design.

4.28.14 Orion-Related Interface Documents

Description:

The Orion-related interface documents were required to pass through the Johnson Space Center (JSC) Level II panels while all other interface documentation development for Integrated Vehicle Ground Vibration Test (IVGVT) was not required to be approved via those panels. This added time and complexity to the documentation release process.

Recommendation:

A more streamlined process for external interface documents is needed for future projects.

4.28.15 Monitor Design Integration to Highlight Challenges

Description:

Integration between assembly sequence and integrated design was not actively monitored to highlight challenges. An example of this was the planning of the reaction control system service panel which was planned to be installed after green run which would have been problematic.

Recommendation:

Make available a product (computer-aided design (CAD) models, layouts, etc.) that can be used by manufacturing and assembly to develop value stream maps for assembly sequences.

4.28.16 Duplication of Interface Control Document (ICD) Data

Description:

ICD data were duplicated within separate non-CAD documents. The opportunity to easily and accurately control information by using interface skeletons was overlooked.

Recommendation:

Use the ICD data contained in interface skeletons during drawing production to easily and accurately control interface data.

4.29 VEHICLE INTEGRATION

4.29.1 Early Development of Requirements and Interface Requirements Documents (IRDs)

Description:

Define responsibility for and development process for documenting requirements early in the program phasing, including customer requirements, standards, external requirements and constraints, and IRDs.

Recommendation:

Clearly define requirements and responsibility for requirements early in the process. Requirements need to be defined clearly by someone with the authority to do so. Build organizational structures, process, requirements flow down, etc., so that people don’t have to repeat work. Need a top-level document that logically flows to the elements. Need early definition and control of the interfaces. Interfaces need to be effectively managed in the best interest of the vehicle using formal interface agreements. Requirements need to pass design data to specs. Make interface changes simple. The goal should be, “Keep rework low.” Discuss analysis requirements with customer early.

Suggested or Taken Action:

Lead systems engineer to identify SLS team lead working the requirements management plan.

4.29.2 Define Review Process

Description:

Develop and document a consistent and high-quality review process (at center level and for each program) and must have accountability on the quality of each review.

Recommendation:

The program should clearly state the expectations for all phases of design reviews prior to the Authority to Proceed is given before the System Requirements Review (SRR).

Suggested or Taken Action:

Define and document review consistency, accountability, and guidance (review item discrepancy (RID) tool, review process) in the program implementation plan, or appropriate planning (such as a systems engineering management plan (SEMP)). This may be a candidate for further detail in the MSFC Red Book. (See 7123.2 for current design review criteria.)

4.29.3 Define and Provide Guidance for Documenting and Tracking Reports, Analysis, and Trade Study Decisional Data

Description:

Define and provide guidance for documenting and tracking reports, analysis, and trade study decisional data. Conflict in completion status of trade studies resulted in confusion between integrated product teams (IPTs).

Recommendation:

Establish a consistent approach to documentation of design decisions and system trades. Recommend using engineering report or memo format, not PowerPoint slides or meeting minutes, to document these decisions. Communication between IPTs needs to be synced and decisions needs to be clearly communicated.

Suggested or Taken Action:

Action to Red Book book manager to establish definition of and guidance for program/project and engineering to document, track, and maintain reports, analyses, and trade study and decision information.

4.29.4 Develop Data Requirements for Loads Data Book

Description:

The loads data book was baselined too early in the program. With the numerous loads updates being needed, it was inefficient to try and update a baselined document on a regular basis. The Integrated Design Analysis Team (IDAT) logbook helped offset some of the rigidity, although it would not have been necessary, if allowed to implement an internal version-control process that would have evolved into a configuration management (CM) baselined document. Loads data book, which contains the official design loads, should not be baselined until the loads community decides that it’s mature enough for baselining.

Recommendation:

Recommend waiting to baseline the loads data book, which contains the official design loads, until the loads community decides that it's mature enough for baselining. Suggest implementing an internal version-control process that would evolve into a CM baselined document.

Suggested or Taken Action:

Recommend to establish a standard data requirement for a loads data book (that can be the basis for any program/project).

APPENDIX A
ACRONYMS AND ABBREVIATIONS
AND GLOSSARY OF TERMS

A1.0 ACRONYMS AND ABBREVIATIONS

%FS	Percent Full Scale
1FT	One Failure Tolerant
2-D	Two Dimensional
2FT	Two Failure Tolerant
3-D	Three Dimensional
A/E	Architect/Engineer
ACR	Abort Conditions Report
ADAC	Ares Design Analysis Cycle
AFSIG	Ascent Flight Systems Integration Group
ALS	Auxiliary Lift System
AMRDEC	Aviation and Missile Research, Development, and Engineering center
AP	Ammonium Perchlorate
APO	Ares Projects Office
APPEL	Academy of Program, Project, and Engineering Learning
ARM	Active Risk Manager
ARTEMIS	Ares Real Time Environment for Modeling, Integration, and Simulation
ASET	Applied Systems Engineering Team
ATK	Alliant Techsystems, Inc.
ATP	Authority to Proceed
AV	Avionics
C&W	Caution and Warning
CAD	Computer-Aided Design
CAIT	Constellation Analysis and Integration Tool
CAITS	center-wide Action Item Tracking System
CaLV	Cargo Launch Vehicle
CAM	Computer-Aided Manufacturing
CARD	Constellation Architecture Requirements Document
CCB	Change Control Board
CDM	Configuration and Data Management
CDR	Critical Design Review
CDT	Component Design Team

CD-TIM	Component Design-Technical Interchange Meeting
CE	Chief Engineer
CEI	Component End Item
CEQATR	Constellation Environmental Qualification and Acceptance Testing Requirements
CEV	Crew Exploration Vehicle
CFD	Computational Fluid Dynamics
CG	center of Gravity
CIL	Critical Items List
CLA	Coupled Loads Analysis
CLIN	Contract Line Item Number
CLOR	Critical Layout Review
CLV	Crew Launch Vehicle
CM	Configuration Management
CMC	center Management Council
CoF	Construction of Facilities
COTR	Contracting Officer’s Technical Representative
COTS	Commercial Orbiter Transportation System
CPE	Change Package Engineer
CPT	Construction Project Team
CR	Change Request
Crit	Criticality
CRM	Continuous Risk Management
CSERP	Constellation Safety and Engineering Review Panel
CSO	Chief Safety Officer
CxFMEA	Constellation Failure Modes and Effects Analysis
CxIRMA	Constellation Integrated Risk Management Application
CxP	Constellation Program
DAC	Design Analysis Cycle
DCU	Data and Control Unit
DDD	Design Definition Document
DDMS	Design and Data Management System
DDT&E	Design, Development, Test, and Evaluation
DDTM	Digital Design to Manufacturing
DELMIA	Digital Enterprise Lean Manufactuturing Interactive Application
DEM	Data Exchange Matrix

DFI	Developmental Flight Instrumentation
DFMA	Design for Manufacturing and Assembly
DFMR	Design for Minimum Risk
DL	Discipline Lead
DM	Data Management
DMAP	Direct Matrix Abstraction Process
DoD	Department of Defense
DOORS	Dynamic Object Oriented Requirements System
DPD	Data Procurement Document
DR	Data Requirement
DR	Discrepancy Report
DRD	Data Requirements Description
DRL	Data Requirements List
DT	Distilling Team
DVO	Detailed Verification Objective
E3	Electromagnetic Environmental Effects
ECB	Element Control Board
ED	Engineering Directorate
EDS	Earth Departure Stage
EEE	Electronic, Electrical, and Electromagnetic
EIB	Element Integration Board
EIC	Engineering Information center
EIM	Engineering Integration Manager
ERB	Engineering Review Board
ERD	Element Requirements Document
ESMD	Exploration Systems Mission Directorate
ET	External Tank
EVM	Earned Value Management
EVMS	Earned Value Management System
ExO	Executive Officer
FAR	Federal Acquisition Regulation
FDNR	Failure Detection, Notification, and Response
FFA	Functional Fault Analysis
FLOR	Final Layout Review
FM	Fault Management
FMEA	Failure Modes and Effects Analysis

FS	First Stage
FSIWG	First Stage Integrated Working Group
FSO	First Stage Office
FSS	Fixed Service Structure
FSW	Flight Software
FT	Failure Tolerance
F-to-F	Face-to-Face
FTS	Flight Termination System
FY	Fiscal Year
GG	Gas Generator
GN&C	Guidance, Navigation, and Control
GOP	Ground Operations Project
GPS	Global Positioning System
GRC	Glenn Research center
GSE	Ground Support Equipment
GVT	Ground Vibration Test
Hazgas	Hazardous Gas
HDS	Hydrodynamic Stand
HILL	Hardware in the Loop Lab
HLV	Heavy-Lift Vehicle
HM	Health Management
HPU	Hydraulic Power Unit
HQ	Headquarters
HR	Hazard Report
HWIL	Hardware in the Loop
HWM	Heavy Weight Motor
IBR	Integrated Baseline Review
ICD	Interface Control Document
ICE	Integrated Collaborative Environment
ID&A	Integrated Design and Analysis
IDAT	Integrated Design and Analysis Team
IDD	Interface Definition Document
IDT	Integrated Design Team
IHA	Integrated Hazard Analysis
IHR	Integrated Hazard Report
ILOR	Initial Layout Review

ILS	Integrated Logistics Support
IM	Information Manager
IMP	Integrated Master Plan
IMS	Integrated Master Schedule
INCOSE	International Council on Systems Engineering
IP&CL	Instrumentation Program and Command List
IPT	Integrated Product Team
IRD	Interface Requirements Document
IRMA	Integrated Risk Management Application
ISO	International Organization for Standardization
ISS	International Space Station
ISTA	Integrated Stage Test Article
IT	Information Technology
ITAR	International Traffic in Arms Regulations
IU	Instrument Unit
IUAC	Instrument Unit Avionics Contractor
IVGVT	Integrated Vehicle Ground Vibration Test
JCL	Joint Confidence Level
JIMO	Jupiter Icy Moons Orbiter
JPL	Jet Propulsion Laboratory
JSC	Johnson Space center
KBR	Knowledge Based Risk
KC	Knowledge Capture
KI	Knowledge Item
KID	Knowledge Item Description
KM	Knowledge Management
KO	Knowledge Object
KSC	Kennedy Space center
LaRC	Langley Research center
LAS	Launch Abort System
LC	Load Cycle
LCC	Launch Commit Criteria
LCS	Load Control System
LH_2	Liquid Hydrogen
LM	Launch Mount
LO_2	Liquid Oxygen

LOC	Loss of Crew
LOM	Loss of Mission
LOX	Liquid Oxygen
LRU	Line Replaceable Unit
M&A	Manufacturing and Assembly
M&P	Manufacturing and Production
Mac	Macintosh computer
MAESTRO	Managed Automation Environment for Simulation, Test, and Real Time Operations
MAF	Michoud Assembly Facility
MAPTIS	Materials and Processes Technical Information System
MIPR	Military Intergovernmental Purchase Agreement
ML	Mobile Launcher
MOU	Memorandum of Understanding
MP	Mission Phase
MPS	Main Propulsion System
MS	Microsoft®
MSC	MacNeal-Schwendler Corporation
MSFC	Marshall Space Flight Center
MUA	Material Usage Agreement
MVGVT	Mated Vehicle Ground Vibration Test
MVP	Master Verification Plan
MWI	Marshall Work Instruction
NASA	National Aeronautics and Space Administration
NASTRAN	NASA Structural Analysis
NDT	NASA design team
NGLT	Next Generation Launch Technology
NOA	New Obligation Authority
NPD	NASA Policy Directive
NPR	NASA Procedural Requirements
NSPD	National Security Presidential Directive
OCI	Organizational Conflict of Interest
ODC	Other Direct Costs
OML	Outer Mold Line
OMRS	Operations and Maintenance Requirements and Specification
OPR	Office of Primary Responsibility

ORI	Operational Readiness Inspection
OSAC	Office of Strategic Analysis and Communication
OSMA	Office of Safety and Mission Assurance
OSP	Orbital Space Plane
OWI	Organizational Work Instruction
P&L	Pause and Learn
PAO	Public Affairs Office
PC	Personal Computer
PCB	Project/Program Control Board
PDR	Preliminary Design Review
PLM	Product Life-cycle Management
PM	Program Manager
PMR09	Program Management Recommendation 2009
POC	Point of Contact
PP&C	Program Planning and Control
PPBE	Planning, Programming, Budgeting, and Execution
PRA	Probabilistic Risk Assessment
PRACA	Problem Reporting and Corrective Action
PV&D	Purge, Vent, and Drain
R&D	Research and Development
R&R	Roles and Responsibilities
R&V	Requirements and Verification
RBAM	Risk Based Acquisition Management
RCS	Reaction Control System
ReCS	Reaction Control System
REMP	Requirements Engineering Management Plan
RFI	Released for Information
RFP	Request for Proposal
RFTU	Released for Technical Use
RID	Review Item Discrepancy
RIDM	Risk Informed Decision Making
RMO	Risk Management Office
RMWG	Risk Management Working Group
RoCS	Roll Control System
ROM	Rough Order of Magnitude
RSRM	Reusable Solid Rocket Motor

RT	Real Time
RVIT	Risk Vehicle Integration Team
S&MA	Safety and Mission Assurance
S&T	Structures and Thermal
SAP	Systems, Applications, and Products software
SATERN	System for Administration, Training, and Educational Resources for NASA
SBU	Sensitive But Unclassified
SCI	Source Control Item
SDF	Software Development Facility
SDR	System Definition Review
SDU	Storage Distribution Units
SDVR	Structural Design and Verification Requirements
SE&I	Systems Engineering and Integration
SEB	Source Evaluation Board
SEIWG	Systems Engineering and Integration Working Group
SI	Système Internationale
SIFA	System Integration Failure Analysis
SIG	Systems Integration Group
SIL	System Integration Laboratory
SITF	System Integration Test Facility
SLS	Space Launch System
SME	Subject Matter Expert
SMP	Security Management Plan
SR&QA	Safety, Reliability, and Quality Assurance
SRB	Solid Rocket Booster
SRD	System Requirements Document
SRP	Safety Review Panel
SRR	System Requirements Review
SSP	Space Shuttle Program
STE	Special Test Equipment
STEB	Structures and Thermal Engineering Board
STS	Space Transportation System
T&E	Test and Evaluation
T&V	Test and Verification
TA	Technical Authority

TBD	To Be Determined
TBR	To Be Resolved
TDS	Task Description Sheet
TEAMS	Testability Engineering and Maintenance System
TIM	Technical Interchange Meeting
TPM	Technical Performance Measure
TPS	Thermal Protection System
TPWG	Technology Protection Working Group
TRAT	Technology Readiness Assessment Tool
T-Rep	Technical Representative
TRL	Technology Readiness Level
TRR	Test Readiness Review
TTA	Technical Task Agreement
TVC	Thrust Vector Control
TVR-O	Test and Verification Requirements-Operations
U.S.	United States
UAH	University of Alabama at Huntsville
US	Upper Stage
USE	Upper Stage Engine
USEP	U.S. Space Exploration Policy
USMS	Ullage Settling Motor System
USO	Upper Stage Office
USP	Upper Stage Prime
USPC	Upper Stage Production Contractor
UTC	Universal Time Clock
VAB	Vehicle Assembly Building
VI	Vehicle Integration
VICB	Vehicle Integration Control Board
VIO	Vehicle Integration Office
VLI	Vehicle Load Indicator
VSM	Vehicle Systems Management
WBS	Work Breakdown Structure

A2.0 GLOSSARY OF TERMS

Term	Description
Discipline Lead (DL)	Owner of the KI core function with authority to implement change. As members of the Distilling team, they assess and complete actions.
Distilling	The act of integrating and screening KOs into actionable KIs and assigning the actions to discipline teams.
Facilitator	Workshop Facilitator. A KM team member trained to prepare, organize, and execute a knowledge capture workshop.
Knowledge Capture (KC)	The act of gathering knowledge observations.
Knowledge Item (KI)	A unique knowledge product, which can result from an individual KO or the grouping of like KOs.
Knowledge Item Description (KID) Form	A web-based form used to capture a single knowledge observation.
Knowledge Object (KO)	A synthesized observation that describes "what worked well" or "what needs to be improved," i.e., lessons learned.
KO/KI Spreadsheet	The authoritative, configuration controlled data file containing KO and KI data.
Observation	The initial idea for change that may eventually become a KO. The observation should always be described from the viewpoint at the time of the observation.
Session Sheet	The mechanism to transfer KOs from an individual workshop to Distilling.
Sharing	Distribution of the knowledge process results.
Synthesizing	The integration of like observations into one KO. Synthesis is a team effort.
ThinkTank	An automated knowledge capture tool.
Workshop	Using ThinkTank or Knowledge Capture. A safe forum through which structured brainstorming is used to collect and codify actionable ideas and recommendations.
Workshop Lead	The organizational lead representing the discipline participating in the workshop.

APPENDIX B
KNOWLEDGE CAPTURE SESSION
ORAL BRAINSTORMING PROMPTS BY CATEGORY

Remember to be specific with your ideas, offering recommended corrective actions when possible and writing them so that the ideas are actionable. Or if you are offering positive feedback, explain what you would like to see continued and why it worked for you or your team.

Category	Prompt
Organization and Culture	Is there organizational clarity – do you know who to contact? Are the roles and responsibilities of all of the players clearly defined and enforced? Did the organizational structure aid or impede decision making? Include communication issues in this category.
Management Team and Leadership	How was the stability of your management? Was there effective communication from management – was their direction always clear? Is there something that your management did that was especially helpful to you in making your job easier or more productive?
Resources/Schedule	Discuss resource availability. Budget issues? Schedule or integrated master schedule issues. Availability of tools or facilities – was everything you needed to get your job done available to you?
Plans and Processes	Discuss how different processes you used in your task aided or hindered your job performance. Did you experience any issues with the board process or the change request (CR) process, etc. Are the processes performed consistently within the group?
External Interfaces	Anything that pertains to success or issues working with other groups outside of your organization such as other levels of management, subsystems, or other centers.

APPENDIX C
TEAM MEMBERS

Last Name	First Name	Subteam	Employer	Role
Armstrong	Bob	Core/Knowledge Sharing	NASA	Lead
Bartlow	Byron	Distilling	NASA	Member representing ER
Bolté	Betty	Knowledge Sharing/Capture	SAIC	Tech Writer, Facilitator
Brock	Shirley	Core?	Gray Research, Inc.	Member
Browne	Jason	IT	Freedom IS	Member
Butcher	Lynn	Core?	Qualis/Jacobs ESTS	Member
Carter	Anne	Core	NASA	Deputy
Coates	R.H.	Distilling	NASA	Lead
Dutro	Leland	Core	NASA	Lead
Fazah	Mike	Distilling	NASA	Member representing EV
Frazier	Melissa	Knowledge Sharing	SAIC	Member
Glass	Cliff	Capture	ERC/Jacobs	Member
Gregory	Renaee	Core/Capture	Jacobs ESTS	Facilitator
Harris	David	Distilling	NASA	Member representing QD/CSO
Hudson	Jonathan	IT	Freedom IS	Member
Huebner	Larry	Distilling	NASA	Member representing APO
Johnson	Eric	Distilling	Jacobs ESTS	Secretariat
Kulpa	Vyga	Core/Capture	NASA	KVIT Lead
McInnis	Tom	Core/Capture	Jacobs ESTS	Facilitator
O’Neil	Dan	IT	NASA	Member
Self	Tim	Knowledge Sharing	Self & Associates	Member
Shaughnessy	Ray	Distilling	NASA	Member representing EO
Shelby	Jerry	IT	NASA	Member
Shelton	Beth		NASA	Member
Stinson	Tom	Distilling	NASA	Member representing ED
Tyler	Chris	Capture	SAIC	Facilitator
White	Aaron	Core/Capture	Jacobs ESTS	Facilitator
Wood	Leslie	Capture	Jacobs ESTS	Member
Wright	Michael C.	Distilling	NASA	Member representing ES

APPENDIX D
LESSONS LEARNED REPORTS FROM ARES AND OTHER NASA PROGRAMS/PROJECTS

Title	Document Number
Ares I Preliminary Design Review (PDR) Checkpoint Review Pause and Learn, March 10–11, 2008	N/A
Ares I Preliminary Design Review (PDR) Pause and Learn (PaL) Final Report, October 14, 2008	APO-1038
Ares I Upper Stage PDR Pause and Learn Survey (PowerPoint presentation)	N/A
Constellation Program (CxP) Knowledge Capture (PowerPoint presentation)	Implementation 10.4.10
Epilog of Ares	N/A
EV90 Pause and Learn for Ares I, January 22, 2010	N/A
JPL Lessons Learned Requirements (D-15553), Rev. 3, November 27, 2001	Doc ID 35531
Lessons Learned from Challenger, Headquarters, NASA Safety Division, February 1988	N/A
Next Generation Launch Technology (NGLT) Program Lessons Learned, July 2004	NGLT-PROG-00018
Next Generation Launch Technology and Orbital Space Plane Programs Lessons Learned Comparison, July 2004	N/A
Orbital Space Plane (OSP) Lessons Learned Summary, June 15, 2004	OSP-DOC-065
Report on Project Management in NASA by the Mars Climate Orbiter Mishap Investigation Board, March 13, 2000	N/A
Systems Development Lessons Learned, Circa 1998–2000	N/A
Top 10 Skylab Lessons Applicable to ISS Operations and Experiments, November 11, 1999	N/A