

THE APPLICATION OF LEAN THINKING PRINCIPLES AND KAIZEN PRACTICES FOR THE SUCCESSFUL DEVELOPMENT AND IMPLEMENTATION OF THE ARES I-X FLIGHT TEST ROCKET AND MISSION

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ABSTRACT

On October 28, 2009 the Ares I-X flight test rocket launched from Kennedy Space Center and flew its suborbital trajectory as designed. The mission was successfully completed as data from the test, and associated development activities were analyzed, transferred to stakeholders, and well documented. Positive lessons learned from Ares I-X were that the application of lean thinking principles and kaizen practices are effective in streamlining development activities. Ares I-X, like other historical rocket development projects, was hampered by technical, cost, and schedule challenges and if not addressed boldly could have resulted in cancellation of the test. The mission management team conducted nine major meetings, referred to as lean events, across its elements to assess plans, procedures, processes, requirements, controls, culture, organization, use of resources, and anything that could be changed to optimize schedule or reduce risk. The preeminent aspect of the lean events was the focus on value added activities and the removal or at least reduction in non-value activities.

Trained Lean Six Sigma facilitators assisted the Ares I-X developers in conducting the lean events. They indirectly helped formulate the mission's own unique methodology for assessing schedule. A core team was selected to lead the events and report to the mission manager. Each activity leveraged specialized participants to analyze the subject matter and its related processes and then recommended alternatives and solutions. Stakeholders were the event champions. They empowered and encouraged the team to succeed. The keys to success were thorough preparation, honest dialog, small groups, adherence to the Ares I-X ground rules, and accountability through disciplined reporting and tracking of actions. This lean event formula was game-changing as demonstrated by the success of Ares I-X. It is highly recommended as a management tool to help develop other complex systems efficiently. The key benefits for Ares I-X were obtaining unambiguous schedule margin, defining enabling options for risk reduction, and most importantly a stronger more unified team.

INTRODUCTION

The mission of Ares I-X was to conduct a development flight test of a new NASA rocket and collect data to support the design of the Ares I rocket, Orion Spacecraft, ground processing, and future NASA systems. The launch date of the flight was scheduled to coincide with the Ares I critical design review and provide sufficient time to develop the Flight Test Vehicle (FTV). The integrated master schedule (IMS) reflected a period of approximately two and a half years to develop and launch the rocket following the kickoff of the integrated systems requirements review. The critical path in the schedule was development of the FTV elements, stacking of the FTV, and certification of the system, although other activities such as modifications to the launch pad, training the launch team, and meeting range requirements were also major tasks.

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Mission implementation was driven and structured around the development of the FTV. The first kaizen/lean event resulted in a reorganization of the mission into eight Integrated Product Teams (IPTs) led by the Ares I-X Mission Management Office (MMO). Five of the IPTs were focused on developing elements of the FTV; two of them on ground systems and operations at the launch site; and the eighth team were responsible for overall systems engineering and integration. The management of the mission was performed by the mission manager and MMO staff which included the integration and maintenance of the IMS. The IMS was the central tool used by MMO to evaluate the mission's probability of meeting the launch date. The project integration manager in cooperation with the deputy mission manager developed the IMS, and to ensure consistency with the kaizen/lean events the deputy mission manager was assigned the task of managing schedule margin and conducting the lean events.



Launch of the Ares I-X rocket from KSC Launch Pad 39B on October 28, 2009.

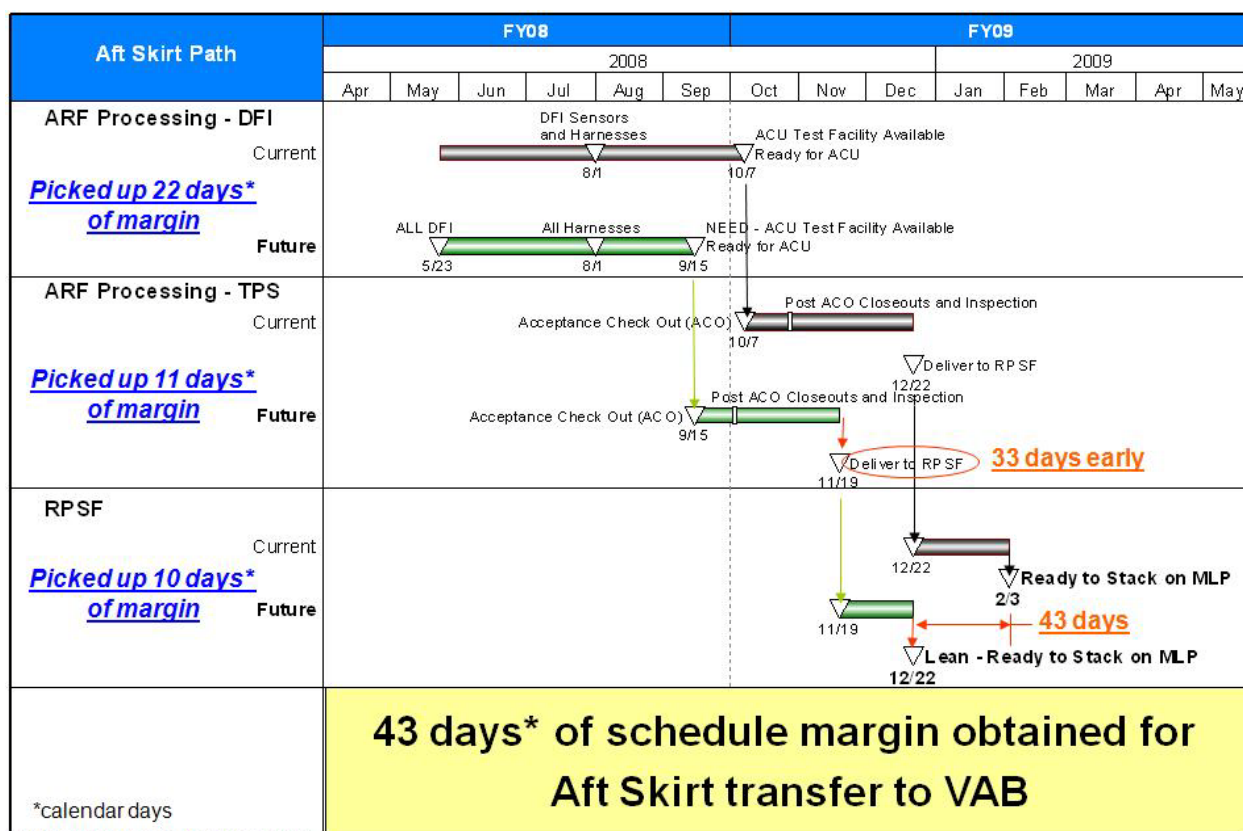
The IPTs were responsible for delivering the hardware and software, and conducting the technical integration and operations to meet the Ares I-X plan. A challenge of the Ares I-X mission, although unwritten, was to pave the way as a pathfinder for NASA's processing of future new rockets for human spaceflight by being the first new rocket, in 30 years, since the Space Shuttle to be successfully developed, integrated, rolled out, and launched. The FTV was stacked at Kennedy Space Center (KSC) in the Vehicle Assembly Building (VAB) atop the Mobile Launch Platform borrowed from the Space Shuttle Program. The Ares I-X rocket was rolled out shortly after midnight on the morning of October 21, 2009 then launched one day late because of weather related conditions. To meet this complex challenge, all of the IPT products maintained detailed schedules. The mission manager was responsible for

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integrating the eight IPT schedules to ensure that the physical integration was conducted in a timely manner to meet the launch date.

To mitigate the risk of a launch schedule slip the mission manager used common schedule tools (e.g., Primavera), conducted Monte Carlo analyses, and held kaizen activities. The kaizen activities, known as lean events, were an effective way to evaluate the baselined schedule, and improve communications within the team. The objective of each lean event was to draw out 30 to 60 days of schedule margin, depending on the process or processes under review, and how close that process was to the critical path. The first lean event was predicated on an understanding that it was possible to obtain 60 days of schedule margin. A key factor in driving out margin was to decompose the schedule into manageable pieces for subsequent lean event evaluation. The first step was attacking the critical path and subsequent steps addressed less critical paths. By obtaining margin in non-critical areas the critical path was more easily managed.

The lean events were conducted in a week's timeframe or less with very significant results in carving out schedule margin and finding the true critical path to launch. The events also improved working relationships between IPTs by serving as a method to improve communication. They surfaced good ideas that may not have otherwise been raised. The following figure shows a snap-shot of a product schedule before and after a lean event. The schedule encompasses three major processes that yielded a total of 43 days of schedule margin. Identifying schedule margin was typical for a lean event in addition to refining plans, improving communication, and building the team.



Results from the Ares I-X First Stage IPT Aft Skirt Lean Event. This figure is used to compare the schedules of three different processes before and after the lean event. The total schedule margin realized from examination of the combined processes is 43 days.

The lean events were an effective way of mitigating schedule risk by eliminating non-value activities and restructuring tasks to improve efficiency. The lean events evaluated plans, procedures, Approved for public release; distribution is unlimited.

processes, requirements, controls, culture, organizations, resource use, and anything that could be changed to optimize schedule or reduce risk. In a post launch assessment of the Ares I-X mission, a positive lesson learned (i.e., an activity that was done well and/or was beneficial to the mission) was identified in which the lesson credited the Ares I-X lean events as successfully enabling the mission to meet its purpose. The success of the lean events can be attributed to a formula that was perfected and applied over ten times throughout the lifecycle of the Ares I-X mission. This formula is based on proven kaizen principles that were tailored for Ares I-X, and is very extensible to other complex missions, programs and projects.

RESULTS AND DISCUSSION

The Ares I-X lean event formula was developed by the Ares I-X lean event core team. It was based upon value stream mapping (VSM) principles introduced by trained Lean Six Sigma black belt facilitators and coaches. A key factor for success was the strong support by high level managers who served as event sponsors and champions. The champion and sponsor expected results, but they also provided the necessary resources to run the events. Other key reasons that the events were highly successful were a good skill mix of committed participants, the leader of the events did not waiver from the formula, solid event preparation, and open communication before, during, and after the event.

The event champion was normally the program manager and the sponsor was typically the mission manager. Some events had the privilege of being championed by the NASA Associate Administrator for Exploration. The names of the participants were published in the event reports, but the participants were not interested in recognition in that they were driven by a passion to develop and launch a new rocket for the Nation. All of the participants had important day jobs, but they had to put their regular jobs on-hold while they committed 100% of their effort to one or more lean events. The participants were grouped in small focus groups to evaluate a process or a concern.

The event leader initiated preparation for each meeting two to four weeks in advance of the event's kickoff. The leader would coordinate with a facilitator (i.e., Six Sigma Black Belt) to select the participants who were chosen based upon the process or topics under review. Considerations for selecting participants included utilizing subject matter experts (SME) who were independent from the process owners, and downstream customers to validate the changes. The SME's provided a fresh set of eyes to affect the process, and the customers examined upstream processes to help produce the desired need state.

The process or processes for each review typically were related to an Ares I-X element manager. The element manager would be responsible for coordinating with his element team, including both government and contractor personnel, to select the right people for the task and prepare input materials. In some cases, a SME was assigned the task of preparing the input/kickoff material. For example, the developer of the acceptance review process diagramed the process on product acceptance. In other events a super process or major schedule items were focal items of those events, and sub-processes and specific element processes were also evaluated to support the overall objective of the meeting. The inputs for a lean event included a focus area (e.g., process), a participants list, location, date, and kickoff material.

The kickoff material included an objective, ground rules, assumptions, agenda, event timeline, scope, background data, instructions, rules-of-engagement, assignments, and a format for reporting. Format templates typically listed the overarching business need, "identify schedule opportunities and risks to support an overall Ares I-X flight day that is 60 days earlier than current baseline". The opportunities represented alternate ways of conducting business to support the early delivery of products. A risk represented a threat to a proposed new way of doing business. The risk had to be mitigated to enable the execution of the new plan. The lean event formula required each small focus group to list enablers, its benefits, an actionee, and a due date.

Actions were derived from the enablers. Each enabler was used to help realize the enabling benefits from an opportunity. For example, moving a step in a process to a later timeframe or earlier, or perform serial tasks in parallel were identified as opportunities. Also, a specific hardware item could be left in an unfinished state until after it was integrated with rest of the structure in that at a less critical time after integration the hardware item could be finished such as spraying on thermal protection foam. The associated risk of moving a step was that the step may not be able to be combined effectively with downstream or earlier tasks. Note: Forming concurrent operations was a very effective way to add schedule margin. The derived actions from moving a step in the process were updating work instructions and ensuring that resources were available to perform the work at a later date. Some risks could not be mitigated because Ares I-X was scheduled to be stacked during the same time period as critical Space Shuttle operations in the VAB. The same people that worked Shuttle were also needed to stack Ares I-X. To the credit of NASA and the Shuttle work force they accommodated Ares I-X by processing the new Ares I-X rocket very efficiently. This was one of the top reasons why Ares I-X was a success as identified in the paper, "Ares I-X Flight Test Development Challenges and Success Factors"; Askins, Davis, Olsen, and Taylor; JANNAF, Dec. 2010. The follow figure is an example of an Enabler Plan.

Item #	Risk Rating	Enabler (Action) Description	Benefit	Actionee	Due Date
1	G	Approve use of Atlas VSS as appropriate	Minimize/ eliminate un-necessary verification re-work	Flynn	8/7/07
2	G	Avionics IPT empowers LSE to approve verification activities (i.e., VSS method, traceability, and criteria)	Minimize/ eliminate additional reviews and table-tops	Flynn	8/7/07
3	G	Assign Verifiers prior to verification activity. Note: Verifiers cannot be testers - must be independent.	Eliminates formal audit	Carter	ACDR (11/11/07)

The above table is an example of an Enabler Plan. This sample plan was developed based on the Ares I-X Avionics Lean Event.

At an Ares I-X lean event kickoff meeting the participants were given rules-of-engagement in which to work. The number one rule was that while one was at a lean event they must be 100% committed to the work of the lean event. Participants were strongly encouraged not to be distracted by other tasks until the event was over or until their contribution to the event was complete. They were asked not to disclose preliminary results to avoid the possibility of misleading somebody that was not at the event. The third rule was unofficially referred to as the Vegas Rule, "what is said in here stays in here". The intent of the Vegas Rule encouraged open communication for participants in that it allowed one to strongly argue their point-of-view. Another rule was that all participants had the right to be heard although the leader was in charge of maintaining order and timeliness of the event. This open exchange of ideas at the first kaizen led to a reorganization of the mission and set the tone for the remaining events. A key enabler that supported the rules-of-engagement was that the sponsor was always available for the final brief by the team and was also open to all recommendations.

Small focus groups were formed to evaluate a specific process. Using VSM, as defined for an Ares I-X lean event, entailed documenting the current state of a process, constructing an ideal state, and formulating a future state. Each state was discussed within its small focus group and then briefed to the lean event leader. If the current state was well understood then the focus group would prepare the ideal state. The intent of the ideal state was to allow the groups to be very creative so that ideas from the ideal state could later be refined into practical future state options. When the future state was adequately

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defined, as demonstrated by a future state aligning with the lean event objective (i.e., 30 – 60 days of schedule margin), the small groups then documented all applicable enablers. The results of the small teams were handed-off to a scheduler and a document lead where they checked the data and prepared it for presentation to the event sponsor. The final product also had to be very clear to ensure that the new plan and associated enablers could be effectively implemented.

The final brief/report was prepared in the spirit of kaizen principles using Microsoft PowerPoint. The brief included an executive summary to highlight the schedule margin that was realized from the lean event. The report contained an introduction that emphasized the event's focus areas/processes, and the key steps that were followed with great discipline during the event:

- (1) Identify current, ideal, and future/target states.
- (2) Identify assumptions and risks.
- (3) Recommended decisions and/or actions to achieve objectives.
- (4) Prepare the enabler plan (i.e., enablers, risks, actions, assignees, and due date)
- (5) Report out several times during the course of the event and at the end of the event.

The final brief included a set of assumptions that were used to support the resulting enablers and actions. Before and after schedules were placed side by side, as shown earlier in this paper, to show the quantity of the schedule margin and its associated processes. The brief also contained a summary of the condition of the focus areas/processes before and after the event, and the final chart was a summary of the kaizen event that included decisions which needed to be made or issues resolved. The report was supported by a copy of the charter, a copy of the processes, and a list of the participants grouped by role. During several of the events, photographs were taken of the team as part of the event esprit de corps.

I. Business Need:

Identify schedule opportunities and risks to support an overall Ares I-X flight day that is 60 days earlier than current baseline.

II. Current Condition:

- Undefined items have slowed progress as noted by the following:
 - Requirements definition and finalization
 - Architecture
 - Environments
- Process is standardized, well understood and proven
- Highly integrated
- System level and DFI testing requirements are unscheduled or optimistic

III. Target Condition (Proposal):

- Established hard dates for requirements, architecture, environments, and early delivery authorizations
- Aligned delivery dates with requested 60 day pull back
- Moved harness deliveries from 8/15/08 to 4/15/08
- Moved stack vehicle back to TBD date to be established at the Ground Operations lean event
- Avionics schedule to be integrated with results from First Stage Lean Event

This figure provides an example of current and target conditions including the business need statement.

After the events the core team would review the progress of the enablers and actions. Most actions were satisfactorily closed, but other actions were only partially completed. Although all of the events did not realize all of its schedule gains, the margin obtained was well used to mitigate problems that unexpectedly arose during final fabrication and assembly of the Ares I-X rocket.

SUMMARY AND CONCLUSIONS

An important positive lesson learned from the Ares I-X mission was that kaizen events, referred to as lean events for Ares I-X, were conducted successfully over 10 times. The majority of the lean events were held during the summer of 2007 following the first major kaizen in May 2007. One of the enablers identified at the first event was to conduct a kaizen for each of the Ares I-X hardware elements. After the third event the team started following a standard approach that yielded excellent results in addition to implementing each event is less than a week.

The lean event approach is based on kaizen principles typically employed by trained Lean Six Sigma facilitators, but the Ares I-X formula added a level of discipline that resulted in very significant schedule enhancements and team building. The formula also used small group meetings to address topics other than processes such as documentation and division-of-responsibility. The formula is summarized as follows:

- (1) In advance of the meeting set clear objectives, prepare base materials, select participants, obtain commitments, and coordinate with the event champion.
- (2) Develop a charter.
- (3) Sponsor should make the lean event a priority.
- (4) Event champion should address the team either via a statement or in person.
- (5) Set effective rules-of-engagement (e.g., 100% commitment).
- (6) Utilize Lean Six-Sigma facilitators/coaches to guide small group discussions.
- (7) Hand-select the participants for small group discussions.
- (8) Develop a core team to run each event.
- (9) Event leader must enforce the rules-of-engagement and implement the formula.
- (10) Review the current state, construct an ideal state, and formulate a future/target state.
- (11) Develop an enabler plan including associated assumptions and actions.
- (12) Establish esprit de corps via a dinner, team photograph or other.
- (13) Create a parking lot for unsolved topics.
- (14) Standardize the report format to include an executive summary, assumptions, results, enabler plan, participants list, conclusion, and back-up data (e.g., processes).
- (15) Core team needs to include a head scheduler and systems engineer to check and integrate the results, prepare the final report, and participate in event planning and post event tracking of actions. Note: the entire core team is composed of an event leader, head facilitator, scheduler, and systems engineer.
- (16) Report out to the sponsor on the last day of the event.
- (17) Track progress after the event.

The above 17 components of the Ares I-X lean event formula was successful because of the dedication of the team members that attended the events and those that supported from their home organizations. Trust was also an important element of the events in that participants trusted each other to be open and honest, and managers trusted the people they sent to the events to make game-changing decisions. The one success factor that stands-out as having made the biggest affect was the objective. When people met they understood what the focus of the event was and how it impacted the overall mission. A true kaizen is accepting what needs to change, honestly assessing the options, making the tough decisions, and following through on the plan.

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This paper acknowledges all of the participants of the Ares I-X lean events because of their dedication and exceptional work that made every Ares I-X lean event highly successful resulting in the spectacular launch and flight of the Ares I-X rocket on October 28, 2009. The participants included NASA personnel from five NASA centers, four prime contractors, and support contractors.

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