MSFC-726

Ares Launch Vehicles Lean Practices Case Study

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Abstract— The Ares launch vehicles team, managed by the Ares Projects Office (APO) at NASA's Marshall Space Flight Center, has completed the Ares I Crew Launch Vehicle System Requirements Review and System Definition Review and early design work for the Ares V Cargo Launch Vehicle. This paper provides examples of how Lean Manufacturing, Kaizen events, and Six Sigma practices help APO deliver a new space transportation capability on time and within budget, while still meeting stringent technical requirements. For example, Lean philosophies have been applied to numerous process definition efforts and existing process improvement activities, as well as the Ares I-X flight test's Certificate of Flight Readiness (CoFR) process, risk management process, and the number of review boards. Ares executives learned Lean practices firsthand, making the team a "smart buyer" during proposal reviews and instilled a sense of what is meant by "value-added" activities. Adopting Lean philosophies and practices will be crucial to the Ares Project's long-term success.

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1. ARES PROJECT INTRODUCTION

Vehicle Background and Mission Scenario

The National Aeronautics and Space Administration (NASA) has been designing and building the next generation of vehicles to enable human exploration of the Moon, Mars, and other destinations in the solar system. These vehicles will be key components of the nation's strategic future in space.

The Exploration Systems Architecture Study (ESAS), completed in 2005, established the high-level requirements (including design reference missions) for the launch vehicles and spacecraft necessary to fulfill the requirements for NASA's exploration mission [1]. Since that Study concluded, the team has performed extensive vehicle analyses that refined original recommendations made by the ESAS and that resulted in hardware commonality decisions to reduce technical, schedule, and budget risk.

Following the Global Exploration Strategy and based on the ESAS recommendations, NASA will retire the Space Shuttle in 2010. Ares I and Ares V will replace the Shuttle for missions to the International Space Station (ISS) as well as provide safe, reliable, and cost-effective space transportation systems for crew and cargo travel to the Moon, Mars, and beyond. The Ares I (Figure 1) that lofts the Orion crew exploration vehicle into orbit early next decade is an in-line configuration with a Space Shuttle legacy 5-segment Reusable Solid Rocket Booster (RSRB) as the first stage and a new upper stage powered by a J-2X engine, an evolution from the J-2 engine used to power the upper stages of the Apollo Program's Saturn IB and Saturn V. The heavy-lift Ares V, seen in Figure 2, also builds on legacy hardware, consisting of two RSRBs and a Saturn-class core propulsion stage with five expendable RS-68 engines. Late next decade, the Ares V Earth Departure Stage, also powered by the J-2X engine, will carry the lunar lander to orbit to rendezvous with Orion and initiate the Trans-Lunar Injection (TLI) burn to send the Orion and lunar lander on toward the Moon. After arriving in lunar orbit, the crew will transfer to the lunar lander, which will transport them to and from the Moon's surface while the Orion vehicle waits in orbit. After completing their mission, the astronauts will return to the crew capsule for the return trip to a landing on Earth.

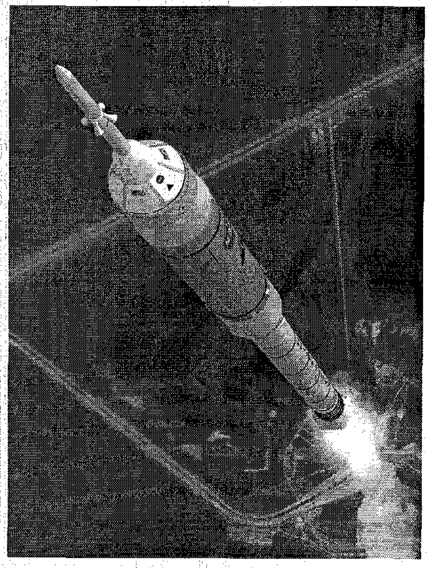

Figure 1 – Ares I Crew Launch Vehicle.

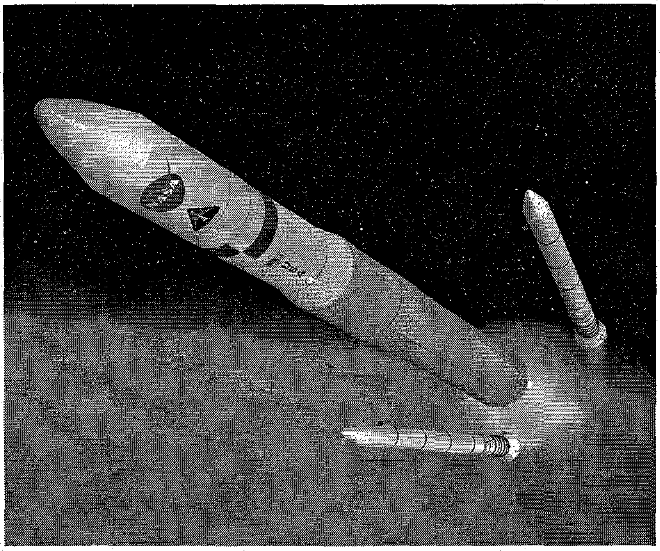

Figure 2 – Ares V Cargo Launch Vehicle.

With the nation's strategic goal of returning humans to the Moon for scientific exploration and preparing to place astronauts on Mars, APO has analyzed its business practices extensively to adapt them to the current design phase. The desired goal is to dramatically reduce the cost of owning and operating the Agency's next-generation space fleet, as directed in the Constellation Program's Architecture Requirements Document [2].

Background of Lean Practices in the Ares Projects Office

This paper provides several examples of how Lean Manufacturing, Kaizen, and Six Sigma practices are helping to deliver a new space transportation capability on time and within budget, while still meeting the technical requirements of human-rated spaceflight. Lean and Six Sigma practices are defined by the Constellation Program's Affordability Plan as a business improvement methodology that combines the best attributes of Lean Manufacturing—which focuses on the speed at which a product is delivered—and of Six Sigma, which focuses on delivering products that meet stringent quality standards.

2. LEAN SIX SIGMA IN ARES I-X

Ares I-X Flight Test Background

Like the Apollo-Saturn program, the Ares launch vehicles will undergo a series of development, verification, and orbital flight tests as well as static ground tests before the first humans are sent into orbit in Orion aboard Ares I in 2013, and regular missions to the ISS begin no later than 2015. Ares V will begin testing in 2018, with the first lunar mission occurring in the 2020 time frame. The first Ares I flight test, known as the Ares I-X mission, will occur in April 2009, and will test NASA's ability to control a vehicle with a similar size and shape, as shown in Figure 3.

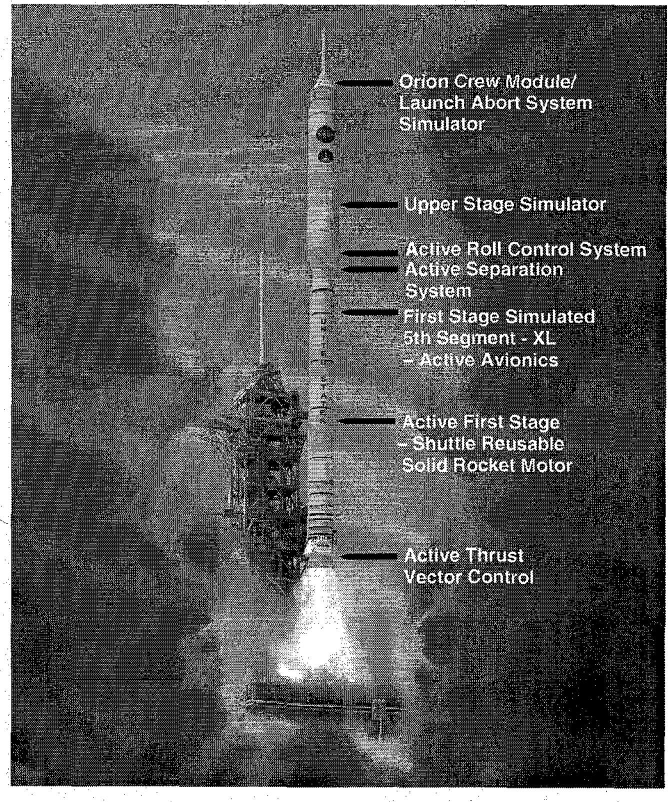

Figure 3 – Ares I-X flight test vehicle elements.

The Ares I-X flight test vehicle will incorporate a mix of flight-like and mass simulation hardware, reflecting a configuration similar in outer mold line, mass, and weight to the operational vehicle. It will be powered by a four-segment RSRB, which is currently in Shuttle inventory, and will be modified to include a fifth, inert segment that makes it approximately the same size and weight as the five-segment RSRB, which will be available for the next flight test in 2012. The Ares I-X flight profile will closely approximate the flight conditions that the Ares I will experience through Mach 4.5, at an altitude of about 130,000 feet, through maximum dynamic pressure ("Max Q"), which is around 800 pounds per square foot. To maintain a constant attitude throughout flight, the vehicle will include an active Roll Control System (RoCS), which also will measure the amount of roll torque generated during flight. The flight will aid the timing of first stage burnout, first stage separation, and upper stage ignition, which should occur around 130 seconds into flight.

Lean Practices Applied to the Ares I-X Organization

The Constellation Program was designed to return human beings to the Moon in preparation for the first human footprints on Mars—and to do so within NASA's existing budget. This program philosophy demands reduced costs to enable NASA to spend less money on human spaceflight operations and more on actual exploration activities. To meet this live-within-its-means objective, the Agency is instituting industry best practices, such as "Lean Six Sigma" in an effort to reduce costs and increase efficiency in the post-Shuttle era.

Lean Six Sigma is a combination of two well-known business improvement disciplines: Lean Manufacturing and Six Sigma. Lean processes emphasize reducing the overall cost of doing business and improving the value stream [3]. Six Sigma is a quality improvement process, designed to reduce incidences of defects in manufacturing processes [4]. Lean Six Sigma, then, seeks to reduce waste in the form of non-value-added activities in business processes while improving technical quality [5].

In late April and early May 2007, managers from across the Agency met at Langley Research Center (LaRC) to discuss how to implement Lean Six Sigma processes within the Ares I-X test flight CoFR, which will occur in April 2009. The need for Lean Six Sigma was identified, in part, because different levels of the Ares I-X organization had conflicting notions about what level of safety to apply to a one-time uncrewed test of a prototype Ares I vehicle. While flying without a crew, Ares I-X will serve as test case for the Constellation Program's ability to implement Lean processes safely and affordably. As a result of this meeting, individuals from the Constellation Program, APO, the Flight and Integrated Test Office (FITO), and Safety and Mission Assurance (S&MA) organizations developed a revised, more streamlined process flow for certifying the Ares I-X test vehicle for flight. Lessons learned from this exercise will shape certifications of future flights of the operational Ares I to the ISS and Moon.

In addition to streamlining operational processes like the CoFR, the Ares I-X team had been facing organizational challenges regarding appropriate levels of risk and experiencing delays in getting design decisions made and approved. One way to address these challenges was to unify the Ares I-X team under one Mission Manager reporting to the CxP Office and to reduce the amount of bureaucracy. To this end, the Ares I-X test flight organization was made a separate Mission Management Office (MMO) under Constellation, with both the Flight Test Vehicle (FTV) and Ground Operations (GO) elements reporting to a single Mission Manager. Further, to reduce decision-making and approval times, the Ares I-X Mission will reduce its number of independent review boards from 10 to 4. These organizational changes are necessary if Ares I-X is going to react quickly and achieve its April 2009 launch date.

Lean Practices Applied to the Ares I-X Schedule

Following the decision to establish the Ares I-X MMO, the team held a series of meetings to apply Lean practices to their hardware development processes. The goal of this "leaner" effort was to incorporate 60 calendar days of additional margin into the overall flight test schedule—by managing to the earlier launch date rather than potentially face slips that would push the launch date past April 2009.

Each Lean event included senior members of the MMO and interested parties with authority to make decisions for the individual vehicle elements, including the First Stage (FS), Upper Stage Simulator (USS), Avionics, RoCS, Command Module/Launch Abort System (CM/LAS) simulator, Ground Systems (GS), Ground Operations, and Systems Engineering and Integration (SE&I).

The general flow of each of these events included identifying:

- The current state
- The ideal state
- A realistic future/target state
- Assumptions, decisions, and/or actions to be taken to achieve the future state
- Meeting outputs

Each element area had its own particular activities which, under the Lean Manufacturing philosophy, could be described as value added. These included hardware manufacturing, delivery, assembly, and integration. To meet the 60-day goal, participants were required to clearly state which activities were required to deliver their particular work on time. Sometimes this meant reordering the sequence of hardware deliveries or tests; shifting work (such as integration or inspection) from production sites to the vehicle preparation site at Kennedy Space Center (KSC); or reducing the number of times hardware was handled or inspected.

First Stage Lean Event Results—The first business need that needed to be met for the Ares I-X First Stage was to expedite the delivery of finished components to support the assembly schedule to move launch back 60 days. This need applied to all of the stage's new forward structures, including the inert fifth segment, forward skirt, forward skirt extension, Main Parachute Support System (MPSS), and frustum.

The primary adjustments made to the First Stage hardware were to change the sequence of hardware delivery, to pre-drill some hardware to facilitate quicker assembly, and to defer avionics testing until the hardware reaches KSC. These changes significantly reduced the amount of touch-labor time on the hardware 4 to 30 days, depending on the hardware.

Avionics Lean Event Results—
The vehicle's avionics required adjustments to hardware and software development, testing, and inspection (verification). The primary methods of adjusting the schedule included establishing clear and hard deadlines for items which had been delayed, allowing work to go forward; condensing and reducing the number of check points; verifying work on-site at KSC; and rescheduling the delivery of some hardware components.

Roll Control System Lean Event Results—The Roll Control System (RoCS) will use existing rocket engines harvested from Peacekeeper missiles, thus reducing the amount of new hardware to be built for this element. In addition, the RoCS schedule already had 30 days of margin. The RoCS team was able to find an additional 50 days of margin by agreeing to procure support hardware prior to the element's Critical Design Review (CDR) and by handing the hardware over to KSC's Hypergolic Maintenance Facility (HMF) for priority handling. The team also eliminated a fit check of the RoCS system into the vehicle. Instead, the team will use a qualification module to test the fit of the RoCS. Previously, the flight hardware was to have been put through the fit check before being moved to the HMF. Now, the RoCS will be delivered directly the HMF upon arrival at KSC.

Upper Stage Simulator (USS) and Command Module/Launch Abort System Simulator (CM/LAS)—Like the RoCS, the USS and CM/LAS schedules already had schedules that supported a 60-calendar-day pullback.

Ground Systems/Ground Operations Lean Event Results—Ground Systems (GS) comprises hardware devoted to servicing and supporting the Ares I-X flight test vehicle (FTV) prior to launch; Ground Operations (GO) are those activities associated with stacking and launching the FTV. With most of the up-front work going into the FTV, GS and GO were behind in development. Their biggest challenges were in procuring long-lead items and obtaining access to Launch Complex 39B to start modifying it for the Ares vehicle. Because the Ares vehicle is so much taller than the Space Shuttle 39B currently supports, several modifications will be needed, including a new lightning rod and launch pad stabilization to keep the FTV from swaying due to rollout or winds.

To resolve the long-lead issues, NASA streamlined its procurement process with United Space Alliance (USA), the prime contractor for GS/GO at KSC, by reducing the legal review time from 42 to 28 days, enabling USA to go to work earlier. KSC's subcontracting procurement process was also reduced from 77 to 63 days. The most important change, however, was made to stacking operations. GO will modify existing cranes and support equipment within the Vehicle Assembly Building (VAB), to perform multiple operations simultaneously instead of handling one stack at a time. In addition, by having increasing the number of work shifts, and by installing some avionics hardware prior to delivery, some activities can be completed more quickly. These modifications reduced vehicle stacking time from 1,400 to 1,201 hours. A reordering of activities on the launch pad reduced pad flow from 7.5 days to 5.5 days.

Systems Engineering & Integration Lean Event Results—The SE&I group at LaRC was facing delays due to inefficient approval processes for Structures Integrated Design and Analysis (IDA), Development Flight Instrumentation (DFI), and Assembly Integration and Test (AIT). The Lean event for this group focused on streamlining (reducing the number of) review cycles for IDA and DFI. In the case of AIT, there was a lack of integration between the various vehicle element teams, which required clearer definition of roles and responsibilities within and among the element teams.

When all of these events were completed, each of the elements was able to restructure its processes to meet a 60-day schedule shift to the left. The next steps will be to implement the changes recommended in the Lean events and re-baseline the schedule to match the new plans. It will also be important for the Ares I-X management team to communicate the assumptions made in the Lean event meetings and to execute any agreements or scope and budget changes based upon them.

3. ARES PROJECTS OFFICE LEAN PRACTICES

Understanding that an organization must adapt to internal and external challenges, the Ares executive team has taken measurable steps to improve process and product efficiency by maximizing quality and reducing resource requirements. In the spring of 2007, the Ares executives were trained on-site at the Boeing 787 production facilities in Seattle, to learn firsthand how Boeing regained its market share in part through Lean practices. This experience inspired the Ares leadership team to become champions through formal Lean training. The training has had at least two immediate impacts: (1) it made the team members "smart buyers" during the rocket hardware proposal review process; and (2) it instilled a better sense of what is meant by "value-added" activities. This mindset will enable APO to live within an austere budget, made even tighter by the continuing resolution imposed on the Agency's Fiscal Year 2007 operating plan.

Previously, Lean processes have applied only to production and operations activities. In-house instructors at MSFC (Figure 4) provided senior members of APO with three days of Lean training to find ways of identifying and concentrating on the value-added activities in the Ares launch vehicles' design and development processes. The Lean training provides leaders with the tools they need to identify value-added activities in their individual parts of the project and then allows them to create their own solutions.

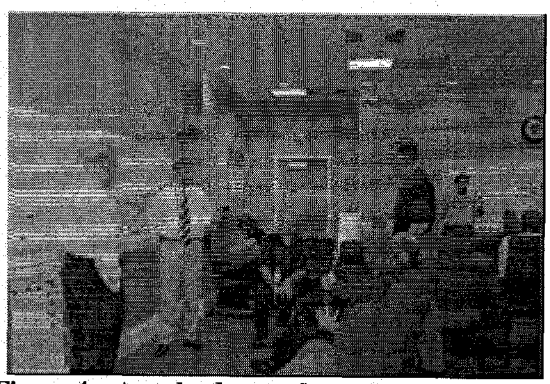

Figure 4 – Ares leaders undergo "Lean Six Sigma Champions" training at MSFC.

One example of improving Ares design and development related to the design teams' relationship with the S&MA organization. There was some inefficiency present related to when S&MA personnel were brought into the design loop. This resulted in S&MA identifying problems later than desired, only to result in slipped schedules as the design teams strove to mitigate S&MA findings [6]. The Lean process identified the critical need to include S&MA earlier in the process to avoid such circumstances. As a result of this change, the S&MA team can help designers identify potential problems with safety, availability, reliability, and maintainability before the vehicle design has already been established.

Beyond the S&MA process, the Ares I Upper Stage team has used Lean processes extensively for many of its activities, including manufacturing and assembly flow at the Michoud Assembly Facility (MAF), design reviews, approval flows, task descriptions, and configuration management.

Meanwhile, the overall Ares team has used Lean events to identify and improve communications both between vehicle elements (First Stage, Upper Stage Simulator, Launch Abort System, etc.) and among the various engineering disciplines (avionics, propulsion, thermal, etc.). Lean events related to communication processes resulted in a reorganization of how Marshall Space Flight Center's Engineering Directorate was configured to support Ares better.

More Ares personnel have been trained on Lean processes, including lower-level managers, Contracting Officers' Technical Representatives (COTRs), and procurement personnel. By broadening this training throughout the project, APO has become a "smart buyer" of products and services. The more focused team members are on value-added activities, the better stewards they become of taxpayer resources.

Given the forces affecting NASA's business and political climates, adopting Lean philosophies and practices will be crucial to the Ares Project's long-term survival across the coming uncertain decades. They are proving to be a source of insurance for the project, as they reduce risk and increase the probability of mission success by minimizing waste and maximizing value to NASA's customers and stakeholders. Lean thinking will be necessary as the Agency continues this significant nationwide effort.

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[1] National Aeronautics and Space Administration. Exploration Systems Architecture Study, Final Report, November 2005.

[2] National Aeronautics and Space Administration. Constellation Architecture Requirements Document, July 7, 2006.

[3] Womack, James P. and Daniel T. Jones. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation.* New York: Simon & Schuster, 1996.

[4] "Six Sigma – What is Six Sigma?" *iSixSigma.com.* http://www.isixsigma.com/sixsigma/six_sigma.asp.

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[6] Mark Adrian and Patricia Fundum (NASA Lean Process Instructors). Personal Interview, September 26, 2007.

BIOGRAPHIES

Tim Self (need content)...

Dr. Rajiv Doreswamy is the Project Integration Manager of the Ares Projects Office at the Marshall Center. He also serves as the chief operating officer for the Ares Projects Office -- ensuring resources are in place to successfully execute this multi-billion dollar launch vehicle development project.

Before assuming this position in July 2007, Dr. Doreswamy spent more than five years at NASA Headquarters in Washington. Most recently, he served on the executive staff of the Associate Administrator. Prior experience includes more than two years of leadership positions within NASA's Exploration Systems Mission Directorate and nearly two years as Space Transportation Manager for the Office of Aerospace Technology.

Before transitioning to NASA Headquarters, Dr. Doreswamy spent more than 13 years at the MSFC, most recently as resident manager for the ISS. He has earned three degrees in electrical engineering – a bachelor's in 1986 from the University of Florida in Gainesville; a master's in 1988 from Auburn University in Auburn, Ala.; and a doctorate in 1999 from the University of Alabama in Tuscaloosa.

The final element in the paper should be a short biography for each author, which can include items such as fields of expertise, areas of research, affiliations, work experience, education, and personal information. A 1.25" w x 1.5" h picture (at 300dpi) of each author should be included, a headshot.

MSFC-714

National Aeronautics and Space Administration

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Ares Launch Vehicles Lean Practices Case Study

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Agenda

- Ares Project Introduction
- Lean Events in Ares I-X
- Lean, Six Sigma, and Kaizen Practices in the Ares Projects Office

Ares Project Introduction

- The next chapter in human space exploration—Moon, Mars and beyond
- Building on experience from 50 years of Saturn and Shuttle ops
- Exploration Systems Architecture Study (ESAS) established requirements
- Global Exploration Strategy
  - Complete the International Space Station
  - Retire the Shuttle
  - Develop and fly the Crew Exploration Vehicle (Orion)
  - Explore and establish an outpost on the Moon
  - Send humans to Mars
- Separate crew and cargo launch vehicles

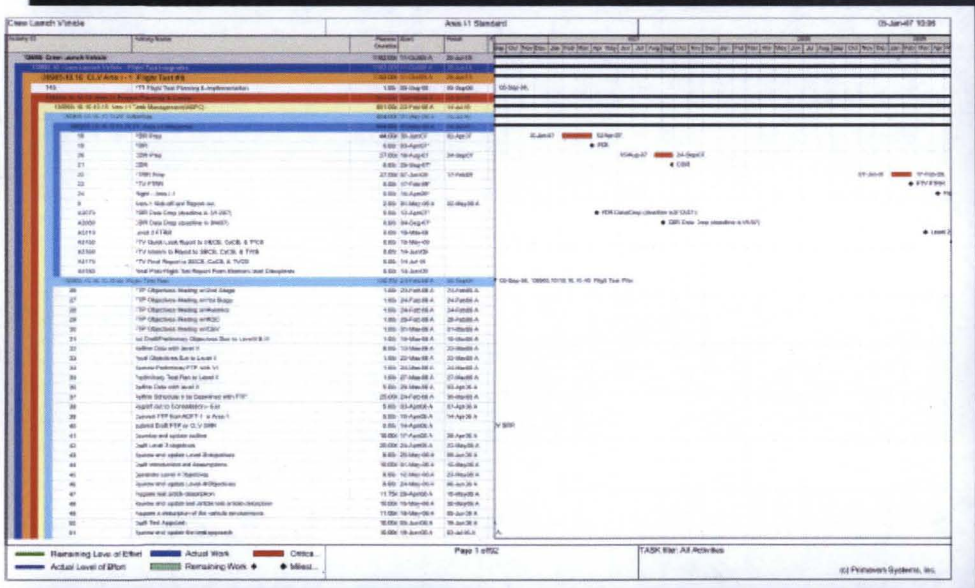
Testing Strategy

- "Test as you fly" strategy
- Ground, flight, and orbital tests
- Ares I-X
  - April 2009
  - Suborbital flight test
  - Combination of operational and mockup hardware
  - Demonstrate ability to control Ares I vehicle
- Additional Ares tests
  - Ares I-Y: First flight of five-segment RSRB
  - Orion 1: First flight of J-2X and Orion
  - 2015: First crewed flight to International Space Station
  - 2018: First flight of Ares V

Lean Practices in Ares I-X

- **Identified management need for Lean processes:**
  - Different parts of Ares I-X organization had conflicting notions of safety conservatisms in flight test
  - **Resolution:** Combined all Ares I-X activities under one Mission Management Office (MMO) under the Constellation Program
  - Lean activities also reduced number of review boards from 10 to 4

Lean Practices Applied to Ares I-X Schedule



- Meetings conducted for each vehicle element to incorporate an additional 60 days into the schedule
- Events consisted of identifying the following activities:
  - The current state
  - The ideal state
  - A realistic future/target state
  - Assumptions, decisions, and/or actions to be taken to achieve the future state
  - Meeting outputs
- Assuming 60-day change could be made, Ares I-X MMO would manage to the earlier launch date

Lean Event Results

- **First Stage**
  - **Actions:** Changed hardware delivery schedule, pre-drilled some hardware for quicker assembly, and deferred avionics testing until the hardware reached Kennedy Space Center (KSC)
  - **Result:** Reduced amount of touch-labor time from 4 to 30 days, depending on hardware
- **Avionics**
  - **Actions:** Established hard deadlines for delayed items; condensed and reduced number of check points; verified work on-site at KSC; and rescheduled delivery of some components
  - **Result:** Met 60-day goal
- **Roll Control System**
  - **Action:** Procured support hardware prior to the element's Critical Design Review (CDR)
  - **Result:** Met 60-day goal
- **Upper Stage Simulator / Command Module / Launch Abort System Simulators**
  - The USS and CM/LAS schedules already supported a 60-day pullback
- **Ground Systems / Ground Operations**
  - **Actions:** Streamlined procurement process with United Space Alliance (USA) by reducing the legal review time from 42 to 28 days; reordered activities on the launch pad, reducing pad flow from 7.5 days to 5.5 days
  - **Result:** Met 60-day goal
- **Systems Engineering & Integration**
  - **Actions:** Streamlined (reduced number of) review cycles for Integrated Design and Analysis Development Flight Instrumentation, and Assembly Integration and Test
  - **Result:** Met 60-day goal

Lean, Six Sigma, and Kaizen Practices in the Ares Projects Office

- **Leadership commitment**
  - Ares Projects Office (APO) leaders visited Boeing to learn about 787's market share improvement through lean practices
  - APO leaders requested in-house training for all managers on Lean and Kaizen

Lean and Kaizen Success Stories

- **Lean success stories**
  - Integrated Safety & Mission Assurance earlier in design process
  - Developing and improving manufacturing processes for Ares I Upper Stage
  - Improved communications between vehicle element offices
  - Trained Contracting Officer's Technical Representatives on value stream mapping
- **Kaizen process improvement success stories**
  - Improved the workforce planning process
  - Reduced the length of project integration meetings
  - Improved APO's risk management process
  - Improved requirements change, trade study, and design review processes
- **Kaizen new process development success stories**
  - Optimizing the ground support equipment flow for handling the Ares I Upper Stage
  - Merging the manufacturing flows at the Michoud Assembly Facility
  - Resolving differences in welding and manufacturing processes between NASA and the Upper Stage prime contractor (Boeing)
  - Optimizing the cleaning and corrosion protection processes
  - Automating task description sheets

Ares Six Sigma Practices

- **Ares I Upper Stage Friction Stir Welding Tool**
  - Uses high rotational speed and frictional heat to crush, "stir" together, and forge a bond between two metal alloys
  - At the end of the weld, the single-piece pin tool is retracted and leaves a "keyhole"
  - To overcome these drawbacks, a Marshall Center welding engineer helped design an automatic retractable pin tool to prevent keyholes
  - Manufacturing and assembly team applied Six Sigma processes to design an experiment to find the optimum machine settings for ensuring a nominal weld
  - The analysis developed a set of values for determining the proper settings for welds, as well as determining the effectiveness of a weld if the settings are known but off-nominal
  - **Result:** Unprecedented level of accuracy and minimization of weld stress (less than 1 kilo-pound per square inch)

Conclusion

- Adopting Lean philosophies and practices is crucial to sustaining the Ares Project's long-term survival across decades
- These progressive business practices reduce risk and increase the probability of mission success
- They minimize waste and maximize value to NASA's customers and stakeholders
- Lean thinking is key to accomplishing this complex, ambitious, and historic national exploration endeavor

Questions?

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