THE CHALLENGES OF INTEGRATING NASA'S HUMAN, BUDGET, AND DATA CAPITAL WITHIN THE CONSTELLATION PROGRAM'S EXPLORATION LAUNCH PROJECTS OFFICE

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Abstract

The U.S. Vision for Space Exploration directs NASA to retire the Space Shuttle in 2010 and replace it with safe, reliable, and cost-effective space transportation systems for crew and cargo travel to the Moon, Mars, and beyond. Such emerging space transportation initiatives face massive organizational challenges, including building and nurturing an experienced, dedicated team with the right skills for the required tasks; allocating and tracking the fiscal capital invested in achieving technical progress against an integrated master schedule; and turning generated data into useful knowledge that equips the team to design and develop superior products for customers and stakeholders. This paper discusses how NASA's Exploration Launch Projects Office, which is responsible for delivering these new launch vehicles, integrates these resources to create an engineering business environment that promotes mission success.

Introduction

The U.S. Vision for Space Exploration directs NASA to retire the Space Shuttle in 2010 and replace it with safe, reliable, and cost-effective space transportation systems for crew and cargo travel to the Moon, Mars, and beyond.[1] The Ares I Crew Launch Vehicle (CLV) that lofts the Orion Crew Exploration Vehicle (CEV) 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, as shown in Figure 1. The heavy-lift Ares V Cargo Launch Vehicle (CaLV), seen in Figure 2, also builds on legacy hardware, consisting of two Reusable Solid Rocket Boosters 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 Surface Access Module to orbit to rendezvous with the Crew Exploration Vehicle and initiate the trans-lunar injection (TLI) burn to send the Crew Exploration Vehicle 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.

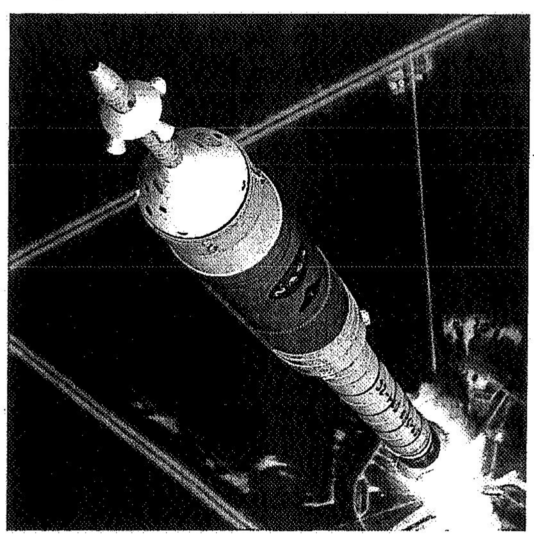

Figure 1. Ares I Crew Launch Vehicle.

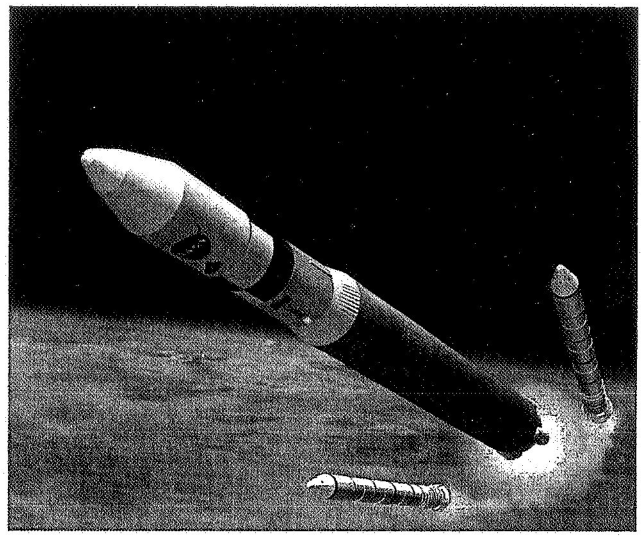

Figure 2. Ares V Cargo Launch Vehicle.

It has been more than 30 years since the Space Shuttle was designed; therefore, the current aerospace workforce has limited experience with developing new designs for human-rated spaceflight hardware. One risk reduction strategy NASA is employing is to build upon legacy systems (see Figure 3) and a foundation of extensive lessons learned from Apollo-era veterans and Space Shuttle experts.

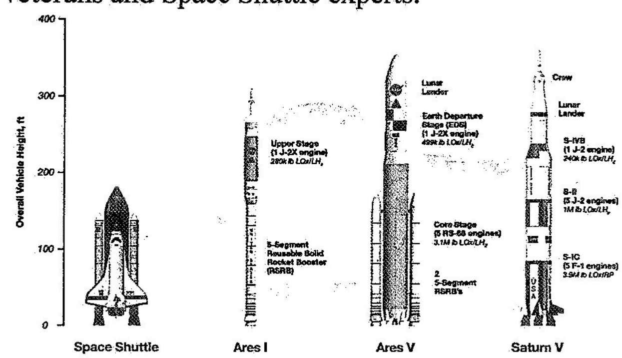

Figure 3. NASA's launch vehicles draw upon heritage hardware. The arrows show legacy and common hardware features.

This paper focuses on the challenges of, and methods for, integrating the human, budget, and data capital used by the Exploration Launch Projects Office (also referred to in this paper as "the Ares team") to fulfill the agency's goals to return to the Moon and go beyond.

To accomplish these activities, NASA uses a wide range of state-of-the-art information technology tools to connect its diverse, decentralized teams and to provide timely, accurate information for decision makers. In addition, business professionals are assisting technical managers with planning, tracking, and forecasting resource use against an integrated master schedule that horizontally and vertically interlinks hardware elements and milestone events. Furthermore, NASA is employing a wide variety of strategies to ensure that it has the motivated and qualified staff it needs for the tasks ahead.

I. Human Capital

Human capital is defined in this analysis as the people that make up the project team, with emphasis on the leadership team that manages the project team. The department of Industrial and Systems Engineering and Engineering Management at the University of Alabama in Huntsville has conducted extensive observational studies of teaming, focusing on eight team development characteristics identified by Carl Larson and Frank LaFasto.[2] These same characteristics have been used to assess the Ares project team.

Larson and LaFasto define a team as having "two or more people; … a specific performance objective or a recognizable goal to be attained, and coordination of activity among the members of the team is required for attainment of the team goal or objective." Without a doubt, the Ares project team meets these criteria. The eight principles for effective team performance are described below. Where applicable, this paper provides anecdotal evidence to confirm the presence of these characteristics within the Ares team.

A. Clear, Elevating Goal

Once the team is formed, it must identify a clear, concrete, significant mission for the individual members. This goal must be challenging and include a sense of urgency.

It is clear that the ambitious U.S. Vision for Space Exploration fulfills this requirement, as it calls for:

- Returning the Space Shuttle to flight and completing the International Space Station by 2010.
- Developing, testing, and flying a new Crew Exploration Vehicle by 2014.
- Returning to the Moon by 2020 and establishing an extended human presence there.
- Sending human missions to Mars and beyond.[3]

B. Results-driven Structure

A team's structure must include clear roles and accountability, an effective communication system, individual performance monitoring and feedback, and fact-based judgments. Furthermore, a team must be structured to accomplish the goal (or goals) it was created to achieve. The current team structure for the Exploration Launch Office is decentralized and broken down by major vehicle components, including the First Stage, Upper Stage, Upper Stage Engine, and Ares V Core Stage. Separate sub-teams have also been created for project planning and control (primarily business functions), vehicle integration, and flight testing (see Figure 4). The Vehicle Integration Office has the technical focus of ensuring that interfaces between all of the vehicle elements function properly, while the Flight and Integrated Test Office has the role of producing real-world data to validate the analytical design models. All of these teams must work together to achieve a crewed flight of the Orion to the International Space Station by 2014, with a developmental flight test as early as 2009.

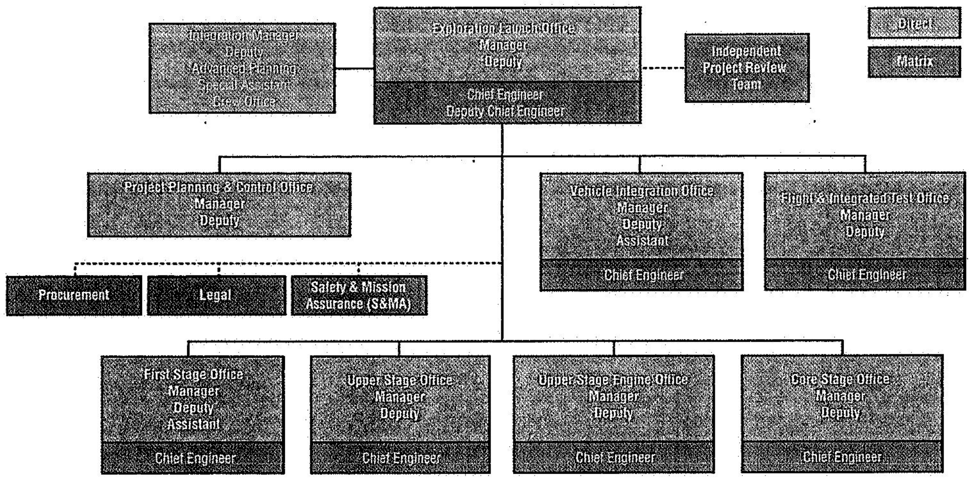

Figure 4. Exploration Launch Projects Office organization.

The team structure allows the Exploration Launch Projects team to design, develop, integrate, and test the vehicles in logical, self-contained units, as well to clearly delineate roles and responsibilities (see Figure 4).

Communication occurs at all levels through electronic and face-to-face opportunities, as well as configuration control boards and interface working groups. Meetings include standing meetings of all interested personnel and smaller leadership meetings, weekly schedule reviews, all-hands gatherings and quarterly reviews, staff meetings, and topic-specific briefings and meetings. Furthermore, an organizational development expert personally assists project executives with self development and effective management approaches.

NASA's personnel system provides for typical performance feedback loops. Also, the teams resolve disputes by relying on strategies described in the book *Crucial Conversations*[4], by Kerry Patterson, et al.

A "crucial conversation" occurs when the operational and/or personal stakes of a situation are high, but individuals would usually seek to avoid the confrontation. The recommended strategies for conducting crucial conversations include:

- Focusing on individual and team goals and carefully considering what to say to achieve those goals.
- Being aware of body language and emotional responses that lead to crucial conversations.
- Considering communication methods that will not escalate conflict.
- Observing and acting on the content and conditions of discussions.

NASA's systems engineering approach[5] guides engineering teams to use fact-based analysis for decision making. This is done via milestones in the development process. NASA's program and project management approach[6] ensures proper oversight via independent panels and bodies to validate the results of the engineering process. Table 1 describes the most critical internal fact-finding reviews.

Table 1. NASA project technical reviews.

Review Title	Review Purpose/Outcome
System Requirements Review (SRR)	Ensures that requirements are properly defined, verifiable, implemented, and traceable, and that the hardware and software are designed and built to the authorized baseline configuration.
Preliminary Design Review (PDR)	Provides completed design specifications, the identification and acquisition of long-lead items, manufacturing plans, and life cycle cost estimates; the design is 30 percent complete and element specifications are baselined.
Critical Design Review (CDR)	Discloses the complete system in full detail; ascertains that technical problems and design anomalies have been resolved; and ensures that the design maturity justifies the decision to begin fabricating/manufacturing, integration, and verification of mission hardware and software. The design is 90 percent complete.
Design Certification Review (DCR)	Serves as the control gate that ensures that the system can accomplish its mission goals. Requirements are verified in a manner that supports launch operations.
Flight Readiness Review (FRR)	After the system has been configured for launch, the FRR process examines tests, demonstrations, analyses, and audits that determine the system's readiness for a safe and successful launch and for subsequent flight operations. The project manager and chief engineer certify that the system is ready for safe flight.

Through its organization, communication methods, feedback and performance monitoring systems, and risk management reviews, the Ares team is positioned to achieve its goals.

C. Competent Team Members

In order to function properly, all teams must be composed of competent individuals with the appropriate skills. Program and project managers must identify the necessary technical skills required to perform the job and select individuals who have the needed expertise. The Constellation Program is drawing from a nationwide pool of talent from within both government and industry (Figure 5). The team members possessing these critical technical and personal interaction skills must achieve excellence while working well with others.

Figure 5. The Constellation Program integrates government and industry partners nationwide.

Serious thought also went into selecting the leadership team to assure competence was achieved vertically and horizontally across the organization. The Ares team capitalized on heritage experience from the existing Space Shuttle team, and sought individuals with extensive project management expertise in propulsion projects. As the project has evolved over the past year, so, too, has the leadership team.

D. Unified Commitment

A unified group is one defined by intense identification with the team, while also demonstrating commitment and dedication to the endeavor.

Identification with the team is sometimes difficult to assess, as participation in the Ares project requires membership in several teams, including the project team, element teams, leadership teams, technical teams, and so forth. Recently the Ares team has employed an organizational assessment survey, which will be repeated routinely to measure unified commitment and identification to the team (as well as several of the other principles described in this paper).

E. Collaborative Environment

Adjectives used to define a collaborative environment among the team include trust, integrity, openness (willingness to share and be receptive), consistency, and respect.

Behaviors used to cultivate a collaborative environment include working the problem, using Crucial Conversations[7], and applying agreed-to team norms (see Section H, Principled Leadership). The Ares team also provides many different forums for building trust through sharing information. Individuals raise concerns and ask questions at all-hands meetings and other working forums. In addition, the Ares team has a variety of methods for sharing information among team members, including a NASA intranet site and the agency-provided integrated collaborative environment (ICE) tool suite, which includes the Cradle requirements management tool and Windchill, NASA's secure file server system, which maintains and protects information that is sensitive but unclassified or that is subject to International Traffic in Arms Regulations (ITAR). Maintaining this collaborative environment is easier when other principles (clear goal, competent team, etc.) are established first.

F. Standards of Excellence

Standards provide pressure to perform. They make a difference in team performance by setting expectations up front and providing a picture of what success should look like. Standards require hard work to attain and are easy to ignore. An effective team will exert pressure on itself to make changes that improve its own performance standards.

The use of the organizational assessment survey discussed previously is another way of imposing standards on the Ares team because it lets everyone know if the group perceives that standards are being followed. Team norms, which will be discussed later, are also examples of the team's commitment to standards of excellence.

G. External Support and Recognition

Both Marshall Space Flight Center's management team and the Constellation Program management team have provided timely recognition and support to the Ares team, and to individuals within the team. Marshall's Office of Strategic Analysis and Communications (OSAC) encourages internal and external support for the Ares project by disseminating key messages to stakeholders both inside and outside the agency through a variety of media, including Internet, intranet, internal newspapers, exhibits, e-mail messages, teleconferences, and live briefings. Through these messages, OSAC keeps NASA Headquarters and other governmental stakeholders, NASA employees, and the general public continually informed of the Ares mission, upcoming milestones, and progress.

H. Principled Leadership

Principled leadership can be seen as adherence to a dependable set of values and the communication of a consistent message. Principled leadership helps to keep individual egos in check and unleashes talent to do the work. Principled leadership fosters an open decision-making climate and enhances the individual team members' ability to directly contribute to team choices, team risks, and team success.

These norms (see Table 2) are used to measure our performance and, without much effort, can be seen to individually or collectively represent Larson and LaFasto's eight principles for effective teams.

Table 2. Ares team norms.

- **Have fun!**
  - We are running a marathon, not a sprint, with a once in a career opportunity!
- **Teamwork is essential.**
  - "Our" instead of "my." "We" instead of "I." "Us" rather than "me"... we're all important.
- **Integrity is expected.**
  - Look each other straight in the eye, tell the truth, full disclosure.
- **Not in 24/7 emergency mode all the time (there should be peaks and valleys).**
  - Respect our families – healthy balance between work and family is important.
- **Integration among the project and with partner organizations (e.g., Engineering, Safety & Mission Assurance, other centers) is essential.**
  - Communicate, communicate, communicate with each other.
  - Don't wait on someone else to initiate.
- **Believe the best about each other (assume no malicious intent).**
- **Constructive feedback leading to decisions (closure).**
- **Failure due to unknowns is acceptable – we learn from our mistakes.**
  - Don't worry about losing, think about winning.
- **We will hold each other accountable.**
- **EARLY identification and highlighting of issues.**

As mentioned previously, the Ares team regularly deploys an organizational assessment tool to assess its adherence to these norms.

In addition to establishing team norms, the Ares team must cope with change management issues, as former Space Shuttle engineers, managers, and other workers must make the transition from operating existing hardware to developing new hardware and processes on an ambitious timeline. To facilitate that transition and build teamwork, Ares team members have begun attending Shuttle Flight Readiness Reviews (FRRs) and sharing RSRB test data.

The Ares team also is mindful of the management culture issues cited in the Columbia Accident Investigation Board (CAIB), which noted: "Cultural traits and organizational practices detrimental to safety and reliability were allowed to develop [at NASA], including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements/specifications); organizational barriers which prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an informal chain of command and decision-making processes that operated outside the organization's rules."[8]

Throughout the project life cycle, requirements and decisions are monitored by the NASA engineering Technical Excellence (TE) program. TE is an agencywide effort to ensure that well-considered and sufficient technical thoroughness and rigor are applied to NASA programs and projects under an uncompromising commitment to safety. It directs that engineering organizations be independent from the programs and projects to which its representative is assigned. Technical authority is invested in the engineering organizations to control program and project technical requirements below the top-level goals. Technical authority includes both systems technical authorities working in partnership with a program or project, and discipline technical authorities working with specific discipline areas.[9]

A final means of managing human capital is through risk management. For instance, Exploration Launch Projects has put in place strategies to reduce the following risks[10], which members of the Ares team are responsible for executing (Table 3). The risks cited impact cost, schedule, and performance, with schedule and performance ultimately impacting project cost and budget.

Table 3. Exploration Launch Projects risk mitigation strategies.

Risk	Mitigation Strategies
Launch Vehicle Operability – The launch vehicle might not be maintained and operated at a substantially reduced cost (compared to the Space Shuttle Program) because there is no requirement for Ares' operations' costs to be reduced.	Work with the Constellation program to develop a requirement for launch vehicle operations costs. After cost targets are established, identify and prioritize operability factors and incorporate them into the launch vehicle design.
Ability of Ares I to Meet Performance Requirements – The Ares I team might not be able to maintain the performance and margins needed to meet performance requirements.	Establish and document the performance margin and mass allocation processes. Conduct design analysis cycled to determine shortfalls. Work with Ares element offices to increase performance and reduce mass.
J-2X development schedule – Given the aggressive schedule for developing and testing the J-2X, the project might not meet the 2012 OFT flight dates.	Work with the prime contractor to develop the integrated master schedule and engine system development plan. This includes identifying risks and associated mitigation plans.
Requirements maturation – Stable top-level requirements may not be available in a manner to allow for successful and timely System Requirements Reviews and subsequent design cycles.	Identify and prioritize Constellation and Ares System Requirement Review schedules to allow time for successful requirements development.
Enhanced Flight Termination System (FTS) – NASA is considering decertifying the High Alphabet Receivers, requiring a new Enhanced Flight Termination System.	Determine new FTS requirements to be incorporated into the design. Draft integrated master schedule and identify any major schedule sensitivities.
Human space flight development summary – Given the current skill availability, mix, and culture in NASA's work force, the team may not be able to execute the project in a timely manner.	Determine skill availability and implement staffing activities to align with project life cycle.
Fault tolerance requirements – The Ares I Human Rating Plan has not been approved and the vehicle's mass, cost, and schedule are uncertain until flight test requirements are agreed to and baselined. Therefore, trades and requirements might not be updated in a timely manner to support the design and development cycle.	Use reliability models to understand where critical failure modes are in ARES I and work with element offices to identify rationales for any deviations.
Vehicle controllability – There might be some vehicle control issues that prevent a successful flight due to concerns with increased stack length and associated dynamic response.	Perform wind tunnel test, high-fidelity modeling of stack dynamics, and analysis of stack to identify vehicle controllability issues. Size reaction control system and vehicle structures accordingly.
Inability to meet Earth Departure Stage (EDS) loitering time requirement – Given the 100-day loitering time requirement, the EDS might not be able to deliver the required 66 metric tons of payload to TLI.	Work with Constellation program to determine loitering requirements and conduct design analysis cycles once requirements are set. Perform Vehicle Integrated Performance Assessment of CaLV.
Ability of heritage hardware to meet new Ares I requirements – Given the new ascent/re-entry loads, vibration and acoustic environments associated with Ares I, the SRB heritage hardware might not meet qualification requirements, resulting in cost and schedule impacts due to redesign and/or requalification efforts.	Identify and quantify the environments and loads to for Ares I. Assess differences and required design changes.

The ultimate end of the Ares team's Human Capital management efforts is to have the right people in the right places with the right tools to build the safe, reliable vehicles that will take the U.S. and international partner astronauts to the Moon, Mars, and beyond.

II. Budget Capital

The Constellation Program initially adopted the Exploration Systems Architecture Study recommendations as the point of departure for developing crew transportation to the International Space Station, the Moon, and Mars. The Exploration Launch Projects (ELP) Office was established at Marshall in September 2005, and began its formulation phase in October 2005.

As stated in *NASA's Exploration Systems Architecture Study Final Report,* "It is anticipated that the concepts [recommended] will be analyzed further and refined. By the time some of the activities addressed are implemented, certain assumptions on which the report's conclusions are based will likely evolve based on this new analysis."[11]

Subsequent to the Exploration Systems Architecture Study, trade studies were commissioned by NASA Headquarters and the Exploration Systems Mission Directorate's Constellation Program in early 2006 to select a space transportation architecture that could deliver critical transportation elements required for an earlier Moon mission, yet stay within budget caps and acceptable risk positions. The Exploration Launch Projects Office conducted system analyses, and formulated schedule and cost models to determine if, and how, Crew Exploration Vehicle and Ares I designs could be re-phased to accommodate hardware changes while staying within the agency's relatively flat spending limits.

Three alternatives for the Ares I Upper Stage were considered during the Study: a single expendable version of the Space Shuttle Main Engine, a pair of J-2S engines that are derivatives of the J-2 engine flown on the Saturn V launch vehicle's S-II and S-IVB stages, or a cluster of four new expander engines. The Study group preferred the Space Shuttle Main Engine (RS-25)—redesigned to be an expendable variant—for its long performance history and proposed commonality with the Ares V, which was going to use the Shuttle Main Engine on its Core Stage.[12] The Earth Departure Stage would use two J-2S engines.

In January 2006, the agency streamlined its hardware development approach for Vision for Space Exploration launch vehicles based on the results of systems engineering trade studies conducted in tandem with independent cost estimating and acquisition planning. The first stage of the evolved Ares I configuration is a 5-segment Reusable Solid Rocket Booster using polybutadiene acrylonitrile (PBAN) propellant.

The J-2 design was a human-rated engine capable of restarting in flight, something the Space Shuttle Main Engine was not designed to do. Because of these features, the Ares I upper stage and Ares V Earth Departure Stage use a single J-2X engine (as shown in Figure 6). This change retires the RS-25 air-start modification risk.

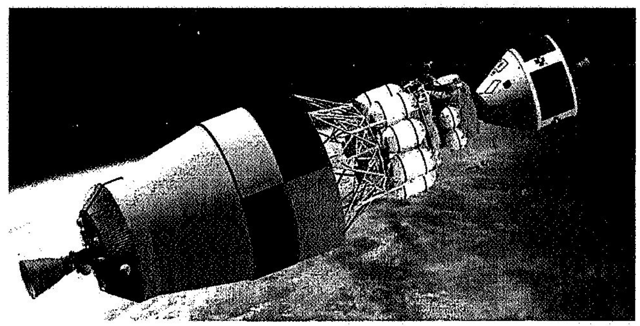

Figure 6. The Ares V Earth Departure Stage, docked with the Orion Crew Exploration Vehicle, prepares to ignite its J-2X engine for the trans-lunar injection burn toward the Moon.

Costs and the steep investment ramp-up after 2010 are reduced by increasing up-front investments in propulsion design, development, test, and evaluation. The Ares team also adjusted its development approach, resulting in a more sustainable funding profile across multiple Government administrations.

By developing common Ares I and Ares V propulsion systems, the Ares team also will be using common manufacturing facilities, ground support systems, and launch infrastructure modifications and improvements, thereby reducing both recurring and nonrecurring operations costs throughout each system's life cycle.

The Ares I System Requirements Review (SRR) planned for 2006, is focused on thoroughly understanding agency, program, and project requirements related to technical performance, target milestones, and budget allocations before beginning the implementation phase leading to the Preliminary Design Review and Critical Design Review. The SRR process also identifies and reduces risks to mission success.

All of these planning and study activities have a direct impact on the Program's current and future budget. The budget process for supporting the Exploration Launch Office is consistent with and integral to the agency's and center's budget processes. The hardware elements' business managers have primary responsibility for the development, analysis, review, and coordination of their respective budgets. All Exploration Launch Projects budget exercises are initiated and governed by requirements as specified in written guidelines specific to each budget call, as issued by NASA Headquarters, Constellation Program, and the Marshall Center's Chief Financial Officer.

The Ares team uses the following program controls to ensure that it operates according to plan, on budget and on schedule.

A. Monthly Status

Monthly status checks are in place within the Project Planning and Control Office of Exploration Launch Project to brief Project Management, Marshall Management, and Constellation Program Management on Ares I programmatics including schedule, budget, and personnel.

The Ares I element offices—i.e., those offices charged with developing the various vehicle components such as the First Stage, Upper Stage, and J-2X engine—are required to present a monthly report to the Project Planning and Control manager. This report includes graphical and bulletized presentations of status of actual versus planned progress for obligations, costs, manpower, and major procurements. The report includes the element's top risks and schedule, as approved by element-level control boards, and a list of accomplishments for the previous month and any issues or concerns.

These reviews are separate from the program milestone reviews, such as the System Requirements Review or Preliminary Design Review.

B. Earned Value Management

NASA continues to be a pioneer in using Earned Value Management (EVM) to monitor and control costs. Put simply, Earned Value Management is an integrated management control system for assessing, understanding, and quantifying what a contractor or field activity is achieving with allocated dollars.[13] EVM helps predict future performance based on trends.[14] It makes these predictions by comparing the planned amount of work with what has actually been completed ("earned"), to determine if the cost, schedule, and work accomplished are progressing in accordance with the plan.

EVM provides an integrated method for ensuring that the Ares program continues operating in a manner that is both technically proficient and financially efficient, measuring progress for both against a baseline.

Additionally, on a more tactical level and in keeping with the Earned Value Management strategy, the Ares project is integrating full-cost accounting (FCA) into its budget process by actively tracking when dollars are actually spent on products and services.[15] This ensures that NASA Headquarters receives regular, accurate, and up-to-date information on when and how money is spent.

As part of the Earned Value Management strategy, the Ares team is developing thorough program plans early in the program. In connection with these program plans, the Ares team must create, maintain, and update data related to technical and financial plans carefully, making project data a capital asset item unto itself.

III. Data Capital

A. Transforming Data into Knowledge

1. Gathering and Validating Requirements

Although the overarching philosophy to achieve the goals and objectives of the U.S. Vision for Space Exploration includes using legacy systems to the greatest extent possible, space launch systems continue to remain complex. However, new elements also will be required in the new designs, creating new systems integration challenges for the agency.

NASA's product validation process is used to confirm that a verified end product generated by product implementation or product integration fulfills (satisfies) its intended use when placed in its intended environment and ensure that any anomalies discovered during validation are appropriately resolved prior to delivery of the product.[16]

The process for validating system requirements begins at the top level—in this case, with the Vision expressing the goal of the customer (the administration and, ultimately, the voting public), which is to send human beings to the Moon, Mars, and other destinations. NASA's systems engineering process then derives and validates an increasingly specific set of requirements to fulfill those goals, from the overall mission down to the systems, subsystems, and ultimately component level.[17] The Ares launch vehicles present a complex systems integration challenge, as they result from designs using both heritage and new flight hardware. This demands a new level of technical design and development discipline. Ares I and Ares V integration also includes incorporating various payloads and interfacing with a number of logistical applications—from manufacturing and processing, to shipping, testing, and launching.[18]

After the requirements are validated and as the product is developed, the product verification process is used to demonstrate that an end product generated from product implementation or product integration conforms to its original design solution definition requirements.[19]

The ultimate aim of the validation and verification (V&V) process is to ensure that the customers receive the product they want and that the product delivered fulfills those requirements in a satisfactory manner. Figure 7 depicts the steps that the Ares team uses as part of its V&V process.

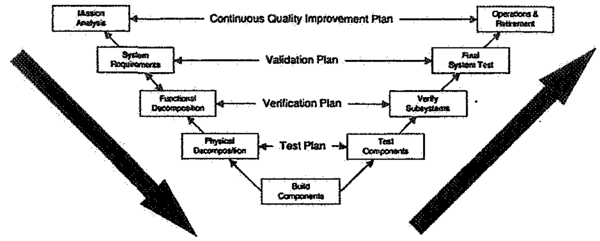

Figure 7. The Ares team's cycle of verification and validation.

2. Information Technology and Engineering Tools

The Ares team uses a variety of information technology and engineering tools to validate and verify requirements as well as to integrate the design and development of its launch vehicles. For instance, to develop credible designs, the team uses a number of innovative, tailored tools to mine information from past databases, including the Integrated Rocket Sizing (INTROS) application, which is a launch vehicle design and sizing model used to assess advanced concepts.

The launch vehicle design developed in INTROS provides a basis for further analysis by the Launch Vehicles Analysis (LVA) program, which is a stand-alone application that provides extremely fast structural design and analysis.

One of the most sophisticated tools the Ares team uses is the modeling and simulation capability provided by Virtual Integrated Performance Analysis (VIPA), which provides valuable data about machine/machine interface and human/machine interactions by allowing a subject to interact with a computer-aided design (CAD) animation.

The VIPA capability projects a two-dimensional world into a virtual three-dimensional space, where the operator can interact with the design drawing. In addition to using new design tools, the Ares team is incorporating lessons learned and best practices from previous NASA space launch endeavors, including Department of Defense and industry programs.

B. NASA Program and Project Management and Requirements/Systems Engineering Processes and Requirements

1. Requirements Development Responsibilities

The Exploration Systems Mission Directorate's Constellation Program is responsible for baselining the architecture as defined by the Exploration Systems Architecture Study and identifying a first-tier, mission-level set of requirements.

The Exploration Launch Projects Office is responsible for developing the next level of requirements for Earth-to-orbit and lunar transfer capabilities associated with the selected Ares I and Ares V architectures. The Constellation Program and Exploration Launch Projects will implement the processes and systems for performing, supporting, evaluating, and refocusing NASA's systems engineering procedures and guidelines.

The Exploration Launch Projects Office is developing the requirements for its architecture elements and will manage the design and development of these components and subsystems.

A proven, classical systems engineering approach has been tailored and incorporated by the Constellation Program to support the unique requirements, design, manufacturing, testing, and verification and validation activities performed by multidisciplinary teams under NASA's guidelines for both the Ares I and Ares V Launch Vehicle Projects. The mission-level engineering effort must employ a rigorous systems engineering process that ensures successful integration from component to subsystem, system, and, finally, to the overall mission level.

2. Using the Provide Aerospace Products and Capabilities (PAPAC) Process

In concert with the Exploration Systems Mission Directorate, the Constellation Program Manager, along with customers and stakeholders, defines a validated set of first-tier requirements derived from the Vision's goals and objectives, which are then distributed by the Constellation Program to its subordinate organizations.

More specifically, project-level requirements are developed by the Exploration Launch Projects, which will further drive the development of component-level requirements for both the Ares I and Ares V. Once baselined, these requirements will be closely tracked throughout the project's lifetime through the Provide Aerospace Products and Capabilities process—from formulation and approval to implementation (see Figure 8).

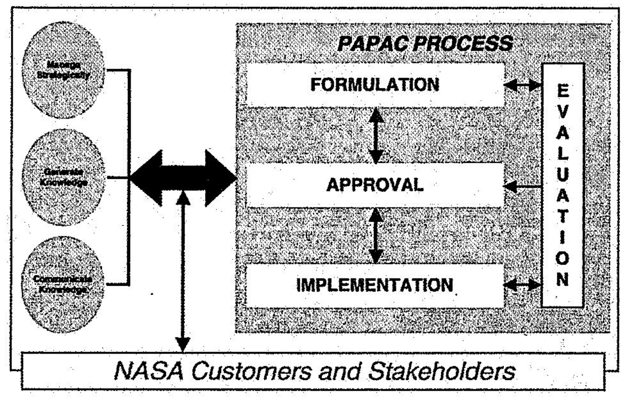

Figure 8. Interrelationships of the Provide Aerospace Products and Capabilities sub-processes.

3. Formulating Requirements and Plans

The goal of the formulation sub-process is to develop a program or project concept with requirements leading to a defined plan, which is implemented to meet mission objectives. The Constellation Program Plan and associated project plans are products of the formulation process, which will establish the guidelines for achieving the mission set forth in the Vision.

4. Implementing the Plans

Following the formulation process, the Exploration Launch Projects Office will be evaluated for authority to proceed from formulation to implementation.

The products of this process include an approved Program Commitment Agreement, as well as project plans, which will include revisions based on safety (risk), budgetary, technical, or strategic redirection.

Implementation is the execution phase of Constellation's projects. The implementation process shall deliver program and project products and capabilities that meet the customer's needs *within approved resources*.

5. Evaluating Execution

Finally, the evaluation process provides an independent assessment of the project team's ability to meet its technical and programmatic commitments. The evaluation process will ensure the benefits of peer experiences and provide opportunities for customer participation. Evaluation occurs throughout the project to ensure the successful completion of the formulation, approval, and implementation sub-processes. The evaluation process also provides recommendations for proceeding with, modifying, or terminating the project.

The Cost Analysis Data Requirement (CADRe) is a comprehensive document that provides a technical and quantitative description of the project in terms that permit a Life Cycle Cost Estimate (LCCE) to be developed. The project team develops and configuration-controls the CADRe. Typically, the contractor and/or NASA project engineers, assisted by cost estimators and the Marshall Office of Strategic Analysis and Communication, construct the CADRe. The CADRe should be considered a "living document" that is matured at major milestones.

Through its systems engineering processes and collaborative software tools, the Ares team is able to carefully validate, verify, and deliver the Ares launch vehicles that fulfill the requirements. The data obtained in the development process also feed into the team's cost estimates, ensuring that the vehicles are being built according to the original technical, budget, and schedule requirements. The human capital assets of the team, together with the data they obtain, will provide the necessary intellectual capital and creative synergy needed to put the Ares launch vehicles on a path to the stars.

IV. Summary

The Exploration Launch Vehicles Project Office has made significant strides in its goal to field the Ares I and Ares V vehicles per the timeline outlined by the U.S. Vision for Space Exploration. The challenges of integrating and managing the human, budget, and data capital of the project are daunting considering the span of project control and required depth of understanding. The leadership team is committed to working these problems on a daily basis to enable the element teams to achieve the strategic goals and objectives set forth in the Vision.

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Acknowledgement

The authors wish to thank Bart Leahy, Technical Communicator with Analytical Services, Inc. for assisting with the preparation of this paper.