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FORMULATION OF NASA's CONSTELLATION PROGRAM

IAC-07-B3.1.06

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Acronyms

CAIB	*Columbia* Accident Investigation Board
Con Ops	Concept of Operations
CLV	crew launch vehicle (since named Ares I)
CEV	crew exploration vehicle (since named Orion)
CaLV	cargo launch vehicle (since named Ares II)
ERTT	ESAS Requirements Transition Team
ESAS	Exploration Systems Architecture Study
ESMD	Exploration Systems Mission Directorate
IC	Initial Capability
ISS	International Space Station
KSC	Kennedy Space Center
LAS	Launch Abort System
LC	Lunar Capability
SRBs	Solid Rocket Boosters
SRDs	system requirements documents

ABSTRACT

NASA has recently formed the Constellation Program to achieve the objectives of maintaining American presence in low Earth orbit, returning to the moon for purposes of establishing an outpost, and laying the foundation to explore Mars and beyond in the first half of the 21st century. The Constellation Program's heritage rests on the successes and lessons learned from NASA's previous human spaceflight programs: Mercury, Gemini, Apollo, Space Shuttle and International Space Station (ISS). This paper describes the rationale behind the formulation of the Constellation Program, including organizational structure, and workforce structure, as well as the approaches to requirements generation, budget formulation, operational philosophies, and procurement strategies.

INTRODUCTION

NASA's human spaceflight history of program formulation, development and operations was a primary resource in the formulation of the Constellation Program. We researched historical records from the Apollo Program, and its predecessors Gemini and Mercury, as well as the more recent Space Shuttle and ISS Programs. Most importantly, consultation not only with histories, but also with individual managers involved in key decision making in past programs, formed the basis of the structure of today's Constellation Program. Moreover, much of the Constellation hardware traces its history to previous programs and that corporate history and existing management structure have been leveraged to a great extent. This paper summarizes the rationale for the Program structure. We note that current technical descriptions of the program content may be found elsewhere[1].

BACKGROUND

Following the loss of *Columbia*, NASA established the *Columbia* Accident Investigation Board (CAIB) to perform an in-depth review of the Space Shuttle Program. As a result of this review, the CAIB concluded that it was in the best interest of the U.S. to develop a replacement for the space shuttle. The CAIB concluded that it should be possible using past and future investments in technology to develop the basis for a system, "significantly improved over one designed 40 years earlier, for carrying humans to orbit and enabling their work in space"[2].

In January 2004, The White House issued a new exploration initiative[3] to return humans to the moon by 2020 in preparation for human exploration of Mars and beyond. As part of this initiative, NASA will continue to use the space shuttle to fulfill its obligation to complete assembly of the International Space Station and then retire the space shuttle by 2010. NASA will also build and fly a new crew exploration vehicle (CEV, since named Orion) by 2014. In 2005, Congress expressly endorsed the President's exploration initiative and provided additional direction[4], authorizing NASA to "…establish a program to develop a sustained human presence on the moon, including a robust precursor program to promote exploration, science, commerce and U.S. preeminence in space, and as a stepping stone to future exploration of Mars and other destinations."

In response to the Presidential direction, the Agency formed the Exploration Systems Mission Directorate (ESMD) at NASA Headquarters in 2004 to oversee development of exploration programs. The Constellation Systems Division was initiated to oversee the human exploration mission development.

In May 2005, NASA Administrator Michael Griffin commissioned the Exploration Systems Architecture Study (ESAS), a sixty-day study to perform the tasks of defining the top-level requirements and configurations for crew and cargo launch systems to support exploration objectives. The study concluded that the launch vehicles should be derived from existing technologies, leveraging the lessons learned from past programs. The ESAS recommended an architecture that included a crew launch vehicle (CLV, since named Ares I) to ferry crew and cargo to the ISS and to carry crew to Earth orbit. A heavy-lift cargo launch vehicle (CLV, since named Ares V), to support missions to the moon and Mars was also defined.[5] The resulting architecture formed the basis of the Constellation Program.

In August that year, the NASA Administrator formed the ESAS Requirements Transition Team (ERTT) charging them to complete an architecture-level specification that defined the elements and their top level functionality; and to complete a draft of the Crew Exploration Vehicle System Requirements Document, validating its consistency with the architecture and providing the basis for subsequent prime contractor selection. It is also notable that the ERTT was asked to lead the first of many internal NASA cultural changes, including the adoption of a 'zero-based' requirements philosophy, in which only the minimum necessary and cost-effective requirements are included.

CONTEXTUAL DIRECTION

No modern program is created from whole cloth, and the Constellation Program is no exception. We note here the major themes, forces, situations, guidelines, constraints and environmental considerations underway at the time of the Constellation Program formulation. These are provided for contextual understanding of the Agency expectations of the Program.

Continue Human Spaceflight

The Agency's primary objectives are continued safe operations of the space shuttle and completion of the ISS. The human spaceflight work force within the Agency is engaged in continuous operations in support of those objectives.

Transition the Space Shuttle

With the retirement of the space shuttle planned for 2010, the Constellation Program should plan to utilize the space shuttle workforce, hardware and infrastructure that support the Constellation mission, in a manner that enables a smooth transition from one to the next, but does not interfere with on-going operations.

Plan for Level Budgets

The Constellation Program should expect the Agency's allocation of the Federal budget to remain at levels consistent with the current environment. No increases other than modest cost-of-living increases should be expected, thus the Constellation Program development is constrained by completion of the Space Shuttle Program.

Lead an Agency-wide Team

The Constellation Program should leverage expertise across the Agency where possible, in keeping with Agency objectives to maintain all 10 NASA Centers in healthy posture. Indeed, the Program should transform the 10 NASA Centers into a unified agency-wide team.

As the Crew Exploration Vehicle and the Crew Launch Vehicle organizations were previously formed in the Fall of 2005, the Constellation Program should establish a strong program to lead the integration of these established organizations.

Lead Culture Change

The Space Shuttle and ISS Programs were developed in the context of their times, facing challenges and unknowns that humble us in appreciation of the efforts it took to make them successful. There is an inherent legacy to efforts of that magnitude; some appropriate for direct adaptation by a new program, some not. The Agency leadership has given the Program license to explore new methods and approaches to developing and procuring future human spaceflight and ground systems. We've also been charged with using the Constellation Program to do nothing less than reconstitute systems engineering capacity within NASA's human spaceflight community, to smoothly transition the human spaceflight workforce to the next generation of capabilities and to lay the foundation of a program that will be cost-effective and sustainable into the far future. While remaining attentive to the lessons learned from current and prior programs, Constellation Program should lead the Agency in cultural changes—to re-invent how human spaceflight development is done.

Meet Commitments

The Constellation Program should meet its commitments; that is, do what we said we would do, when we said we would do it, within the allocated budget, schedule, and technical requirements. If the budget is cut, let stakeholders know the impact to our schedule and/or technical commitments. The practice of maintaining unrealistic schedules in the face of budget cuts should not be continued.

Improve Spaceflight Risk

Achieve an order-of-magnitude improvement in risk to crew and mission over that of the space shuttle. Current probabilistic risk assessment puts the risk of loss of crew for the space shuttle on the order 10^{-2}. Constellation should improve this to the order of 10^{-3}.

Simplify Operations

The Constellation Program should plan and require simplified operations such that operational costs are minimized, particularly with respect to space shuttle heritage operations. New developments for lunar and Martian expeditions are only possible if budget is made available due to decreased operational costs. Thus Constellation will only be sustainable if the operational infrastructure and workforce are more efficient than today.

Recognizing the need to establish a program office co-located with the NASA program experience base, ESMD established the Constellation Program at the NASA Johnson Space Center in November of 2005. The following sections describe the decisions that were made in its formulation in the context of the guidelines discussed above.

ORGANIZATION STURCTURE

Constellation Program

The structural model that most closely resembles the current mission is the Apollo "5-box" management structure[6] and was selected because it worked effectively. These five organizational functions are comprised of program planning and control; test and verification; operations integration; systems engineering and integration; and safety, reliability and quality assurance. This was adapted and tailored to the Constellation Program's more evolutionary objectives. Constellation is envisioned to have developmental aspects throughout its life cycle in that new developments to support the next mission will start in phases as current developments become operational. For instance, lunar outpost development will start after the low Earth orbit portions of the Program are operational. The adapted organizational structure is shown in Figure 1. Note that an advanced development function (Advanced Projects Office) has been added to the Apollo "5-box" structure. This organization houses research and development activities for 'pre-projects' envisioned to support lunar missions and beyond. Organizations outside of NASA, such as international partners and commercial parners, could be involved in these later phases of the Program[7].

The Constellation Program was staffed with recognized leadership within the Agency (e.g., from the ISS Program, Space Shuttle Program, and Mission Operations Flight Director Office) and the contractor/DoD space community between November 2005 and March 2006, seeking project managers with demonstrated experience in executing projects and discipline-area leaders able to assemble strong teams, articulate a clear vision of the task, and integrate horizontally and vertically.

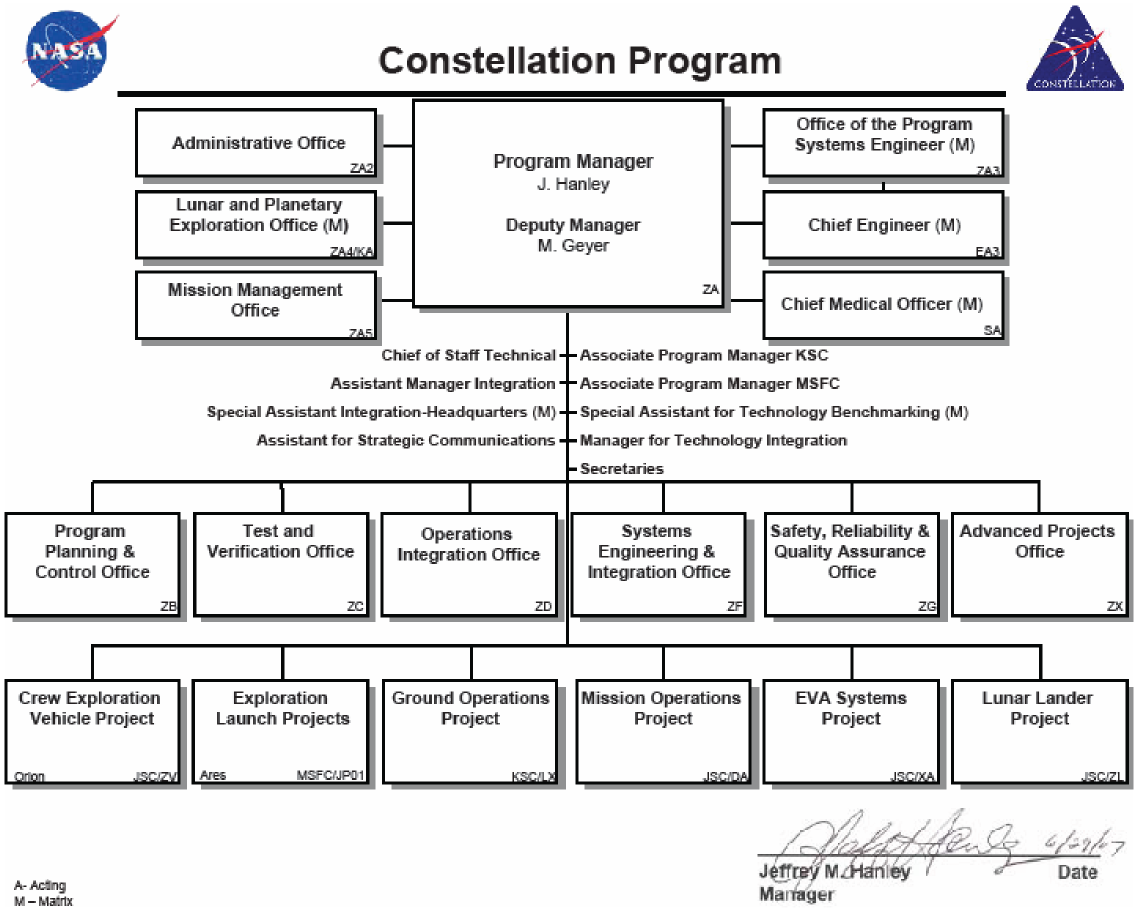

Figure 1: Constellation Organization Structure. Program Management (first row boxes); the Program Offices adapted from the Apollo 5-box structure (second row boxes); Project Offices (third row boxes).

Constellation Projects

The projects that comprise the Constellation Program are listed in the bottom row of Figure 1. Table 1 describes major responsibilities for each project in the development and operational phases of the Program.

Program/Project Integration

We know from Agency history that our success depends on a strong program leading strong projects. As soon as the program office was staffed, we began a process of negotiating roles and responsibilities between the Program and projects. All recognized the importance of having a program office integrate project interfaces, as well as the importance of allowing projects maximum flexibility in managing their assigned element. However, a detailed examination of integration processes was necessary to truly understand and assign responsibilities. The program and project deputies conducted integration process decomposition in order to understand and agree upon ownership for each step in the integration processes. This understanding is paramount for implementation of hardware and software interface agreements and is a key element leading into the design definition phase.

Constellation Project	Lead NASA Center	Function	
		Developmental Phase	Operational Phase
Project Orion	JSC	Develop and test the Orion (CEV) spacecraft to transport crew to and from space.	Provide Orion spacecraft.
Project Ares	MSFC	Develop and test the Ares I (CLV) and Ares V (CaLV) launch vehicles.	Provide Ares launch vehicles.
Ground Operations Project	KSC	Perform ground processing and integrated testing of launch vehicles. Plan, construct and/or reconfigure integration, launch, and recovery services for Orion Crew Module, Ares I and Ares V.	Provide logistics and launch services. Provide post-landing and recovery services for the crew, Orion Crew Module, and spent Ares Solid Rocket Boosters.
Mission Operations Project	JSC	Configure, test, plan, and operate facilities, systems, and procedures. Plan missions and flight operations.	Train crew, flight controllers, and support staff. Coordinate crew operations during missions.
Lunar Lander Project	JSC	Develop and test the Lunar Lander to transport crew to and from the lunar surface and to provide a habitable volume for initial lunar missions.	Provide Lunar Lander.
Extravehicular Activities (EVA) Systems Project	JSC	Develop EVA systems (spacesuits, tools, and servicing and support equipment) to support crew survival during launch, atmospheric entries, landing, abort scenarios, and outside the space vehicle and on the lunar surface.	Provide spacesuits and tools.
Future Projects	To be deter-mined	Develop systems for future applications including Lunar Surface Systems (equipment and systems for crew operation on the lunar surface) and systems for future human exploration activities.	Provide future systems as needed.

Table 1: Constellation Project Descriptions

Agency Governance

The Constellation Program is the first new program within the Agency to implement the NASA Governance Model that resulted from the CAIB recommendations[2]. In brief, the Governance Model provides for checks and balances between the program and the independent technical authorities established within the Agency. For the Constellation Program, the Program Manager (and staff by delegation) has authority over mission performance, programmatic, cost, and schedule requirements. The Office of the Chief Engineer, the Office of Safety and Mission Assurance, and the Office of the Chief Health and Medical Officer have authority over engineering; safety, reliability and quality assurance; and health and medical standards, respectively. They also have the responsibility to provide informed technical recommendations on programmatic issues throughout all stages of a program life cycle. In addition, they provide an appeal path for program office personnel or line organization personnel who disagree with a program decision. NASA and industry standards, ranging from human rating standards to conformance to the metric system, are owned by the technical authorities. However, not all requirements in these documents are applicable or appropriate for the Constellation Program. It is the Program's responsibility, with the assistance of the technical authorities, to develop and recommend a tailored set of these requirements. It is the technical authorities' responsibility to review and approve the tailored set of requirements. Risk acceptance is the Program Manager's responsibility, including the acceptance of residual safety risks that result from ground or flight anomalies, hazard analyses and FMEA/CILs[*]. However, the technical authority may appeal if they determine that a risk is unacceptable for flight.

Decision Making Structure

The Constellation Program uses a board/panel structure for making decisions that affect the baseline, as well as for making technical implementation decisions at a program level. An example of the decisions that affect the baseline would be anything that requires a change to a Program approved document. An example of a technical implementation decision would be whether to approve a design modification requiring additional funding. The Constellation Control Board is chaired by the program manager, and membership includes each project and program office appearing in Figure 1.

In order to implement the Governance Model, the technical authorities are also board members on the Constellation Control Board. This avoids the 'shadow organization' that has evolved in past programs. These representatives cannot be program office personnel, nor can they be funded by the program. In this board structure, program office personnel (SE&I, Program SR&Q, etc.) are responsible for providing a recommendation to the program manager for their functional area. It is the responsibility of every board member, whether within the Program or part of the technical authority, to ensure that the board is aware of dissenting opinions, that they are discussed, and that the dissenter is advised of the disposition. If an individual or individuals disagree with a Program Manager or Technical Authority decision, and believe that the decision poses a risk to safety or mission success, there is an established appeal path.

WORKFORCE

As noted in the Background section, the Constellation Program has been formulated, and must execute, during continuous operations of the space shuttle (through 2010) and ISS. Moreover, we must be prepared to make best use of the expertise resident in the space shuttle workforce, when it becomes available as that program phases out. Constellation has developed a phased development program in anticipation of this workforce availability. This phased approach is described in more detail in the Schedule section of this paper.

The Program Office workforce is comprised of engineers, scientists, and administrative personnel and was sized utilizing experience from past programs as well as guidance on availability of key personnel to support three human spaceflight programs at the Johnson Space Center. The initial size estimate was based on previous human spaceflight programs and was set at approximately 8% of the total program content. After the Program System Requirements Review, there was sufficient experience in the office to attempt a reduction in the budget to only approximately 6.5% of the total Program content. This was based on expected workload and products and a better understanding of the Program integration responsibilities. The Program team continues to track risks incurred with this funding level and to reprioritize work as needed to meet the Program milestones.

[*] FEMA=failure modes and effects analysis; CIL=critical items list

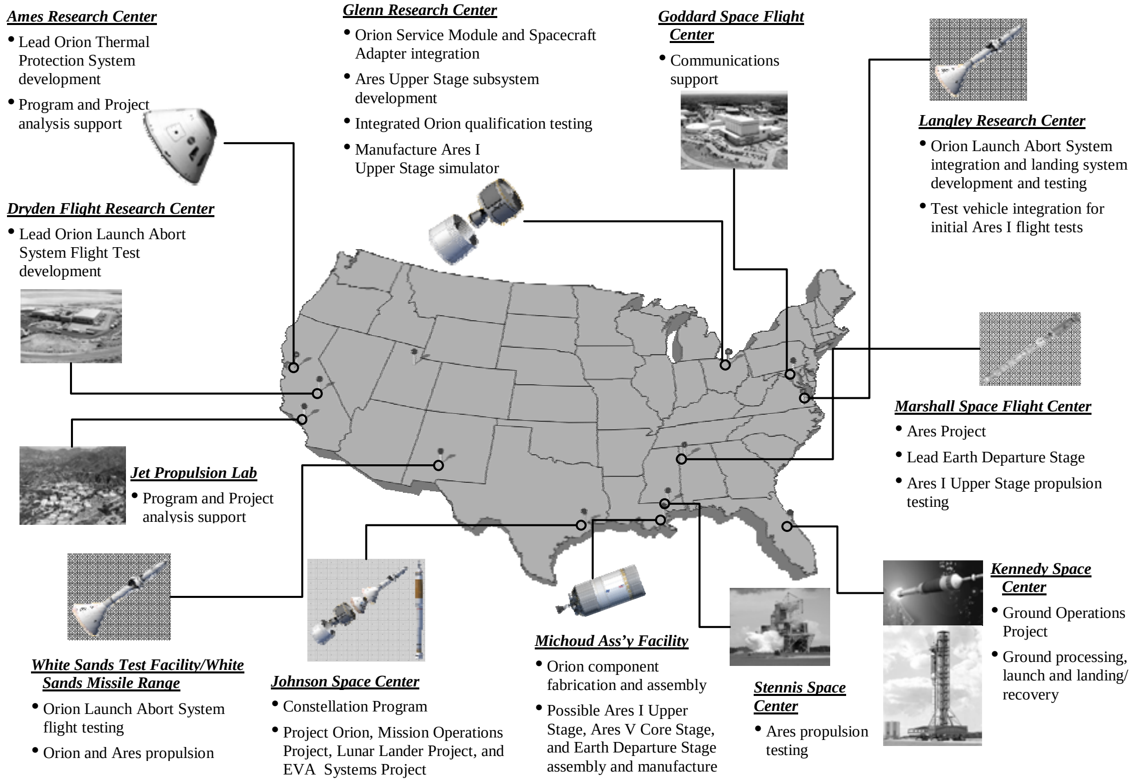

Figure 2: Constellation work assignments at NASA Centers

Distributed Teams

The projects are staffed by leveraging expertise across the Agency. Project work assignments at the 10 NASA Centers (and the White Sands Test Facility/White Sands Missile Range) are described in Figure 2.

We recognize that managing a team distributed to this extent is a daunting challenge; indeed it is only now possible with current communications technology that enables real-time electronic meetings, single-source record keeping, and maintenance of the requirements baseline in a single database accessible by all program elements. All members of the workforce must use the selected electronic tool suite in order to make this distributed team work.

Sage Advice

Though NASA has considerable talent in its workforce, programs intended to carry humans to and from space are characterized by design, development and testing challenges that differ greatly from those encountered by the orbiting International Space Station or operational space shuttle. To reach back and capture launch and return vehicle experience, the Constellation Program created a ready resource—SAGES - Shuttle and Apollo Generation Expert Services. This contract provides a simple pathway to enlist the aid of retired experts from NASA's past (e.g., George Mueller, Chris Kraft, Glynn Lunney, etc).

Beyond review and advice, SAGES was created to transfer knowledge through mentoring. It is based on relationships between Apollo and shuttle-era program managers and discipline experts, and the Constellation team. SAGES provides mentors on an as-needed, targeted basis in areas ranging from technical design and analysis disciplines, to ground and flight operations, to program management. Twenty four tasks have been initiated to date, including margins management; relationship between Level II program office and the Level III project office responsibilities; lunar lander requirements; test and verification planning; and launch abort design and operations.

REQUIREMENTS

The ESAS team had developed an Exploration Architecture specification and draft system requirements documents (SRDs) for both the CEV (Orion) and the Ares I (CLV). In lieu of an established Program Office, the follow-on ERTT formulated, as its primary task, a requirement set consistent with the architecture defined by the ESAS team and a CEV SRD sufficient to support a down-select of CEV contractors in 2006 as part of the Call for Improvement (CFI) process. Thus initial requirements for the basic architecture, Orion, and Ares I were established at the time the Constellation Program office began work. The Program team had to quickly establish processes, roles, responsibilities, and team organizational structure to align an integrated set of requirements that would unite the elements together into a strong program that could integrate and execute missions.

Zero-Based Requirements Approach

Requirements development was the linchpin for concurrent maturation of Program cost and schedule. A zero-based requirements philosophy has been adopted in which only the necessary and cost-effective requirements are included. Projects are directed to "drive-out" unnecessary requirements, write requirements in terms of outcomes and not solutions or "how-to" and drive out non-value-added steps in achieving outcomes. This approach is requisite for all contracts and 'in-house' work. The need for data deliverables, reviews and applicable/reference documents is carefully scrutinized in order to be sure that these requirements are necessary, value-added and cost-effective, and are required to achieve the desired outcome of a project. This will be a continual process not only in the pre-award phase, but also in the post-award administration of contracts.

Evolving the Architecture

With an integrated Program team under development, several significant improvements to the architecture outlined by the 60-day ESAS team became apparent through trade-study and risk analyses. The Program base-lined the Apollo-heritage J2-X engine as the primary upper stage engine for both the Ares I and Ares V configurations. A cluster of five RS-68 engines (common with the Delta IV) was selected as the baseline first stage engine configuration for the Ares V, and the first stage solid rocket booster configuration was lengthened to include 5 segments (rather than 4) for both the Ares I and Ares V configurations. Architecture requirements were also established for the EVA suit systems, ground operations and mission operations[8].

Program Requirements Reviews

The Program embarked on a season of System Requirements Reviews (SRRs), commencing with a Program SRR in the Fall of 2006, progressing through project SRRs, and culminating in Program baseline synchronization in May 2007. The SRR is conducted to ensure that the Program requirements are properly formulated and correlated with the Agency and ESMD strategic objectives. Specifically, the SRR assures that: the high-level Program requirements are complete and approved, the interfaces with other programs are approved, the Program requirements are cost-effective, the Program requirements are decomposed and adequately levied on projects, the plan for controlling changes to Program requirements is approved, the approach for verification of requirements is approved, and mitigation strategies for addressing major risks are approved. After project SRRs, the Program baseline synchronization was conducted to resolve discontinuities identified among project requirements and between project and Program requirements.

In January of 2007, Constellation gathered Apollo and shuttle veterans (via the SAGES contract mentioned earlier) in a "greybeard" review of the program baseline to seek advice and management guidance through the early phase of the program. This advice is currently being integrated into the program, particularly in our approach towards risk management. We intend to continue involvement of our space flight veterans as we move forward towards program implementation.

Projects are beginning System Definition Reviews at this writing, to ensure the readiness of the program for making a program commitment agreement to approve project formulation startups and move into the program implementation phase.

Safety, Reliability and Quality Assurance (SR&QA) Requirements

It is the goal of the Constellation Program to achieve an order-of-magnitude improvement in risk to crew and mission over that of the space shuttle. Some of this improvement can be achieved through design improvements. The Ares I/Orion system is estimated to be much more reliable for the crew than the space shuttle, primarily due to its in-line design and incorporation of the Launch Abort System for crew escape.

Other improvements must focus upon changing the way we 'do' SR&QA. This centers around: the early identification of requirements driving safety and mission success, the performance of safety and mission success analyses throughout the life cycle, but early enough to influence design and operations, and an assurance framework that verifies that the system is designed, built and operated in accordance with requirements.

SCHEDULE

The primary schedule requirements for the Constellation Program are to develop the CEV (Orion) to transport humans to and from ISS by 2014[†], and to return humans to the moon by 2020. These two goals lead to a phased schedule approach, illustrated in Figure 3 (through 2011). Figure 3 shows two primary elements of schedule execution: Initial Capability (IC) development and Lunar Capability (LC) development. The IC includes the elements necessary to deploy the CEV/CLV (Orion/Ares I) configuration that will support ISS, including the ground and mission operations capabilities and the spacesuits (EVA systems) needed for the crew. The LC includes the Cargo Launch Vehicle (Ares V), the Lunar Lander and the Lunar Surface Systems (e.g., rovers, habitats, scientific equipment). The current focus of the Program is development of lunar capable elements that support the ISS. Many of the elements of the IC now under development are accelerating the LC. For example, the J2-X engine is the primary engine on the upper stage of both the Ares I and Ares V vehicles. This aggressive development for the Ares I will provide higher confidence during the Ares V vehicle development. The five-segment solid rocket motor first stage of the Ares I is common with the twin solid rocket motors on the first stage of the Ares V. In addition, the crew's EVA and pressure suits for the IC are being developed as a modular single-suit system with capability to add/exchange elements necessary for the LC.

While the continued operations of the space shuttle constrain the budget and workforce available to develop Constellation through 2010, we also must prepare to make best use of the experienced workforce as it becomes available though the phased retirement of the space shuttle. Responding to that need, targeted activities in the LC development have begun. Requirements must be developed to a level to enable contract acquisitions in the 2010 timeframe in order to deploy and utilize the resident expertise in the Space Shuttle Program's civil servant and contractor work force to the extent possible. Initial concept development of the lunar lander and Ares V are underway to mature the requirements set to the necessary level.

[†] Reference discussion of confidence level in following section resulting in current commitment to field Orion and Ares I by 2015.

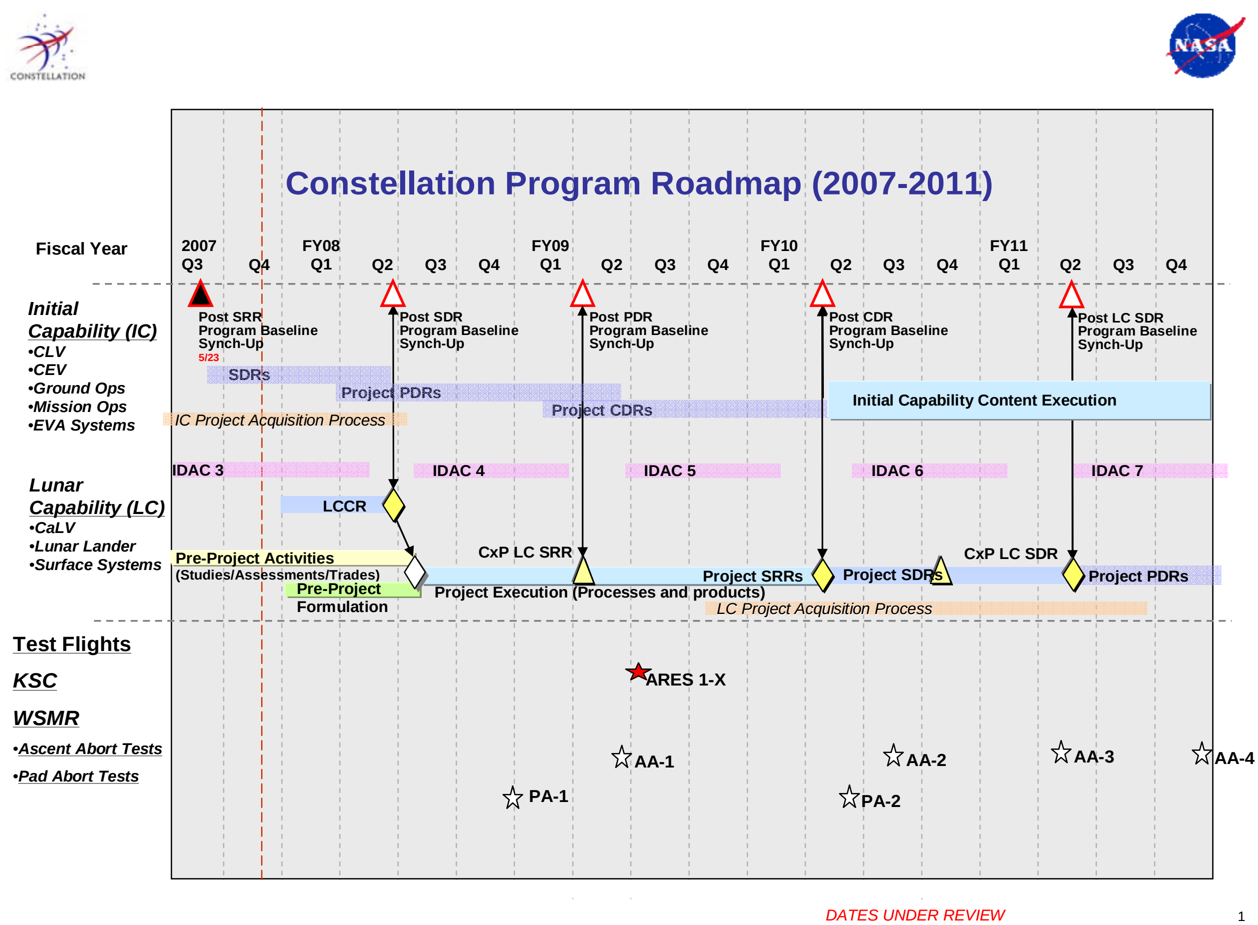

Figure 3: Constellation Program Roadmap through Fiscal Year (FY) 2011

The lower portion of Figure 3 illustrates the flight test program planned for the remainder of this decade. The Orion design incorporates a Launch Abort System (LAS) that would pull the crew module to a safe landing if necessary in the event of an abort during launch and early phases of ascent to orbit. While this system is based on Apollo heritage, it must be thoroughly tested prior to utilization with a crew on board. A series of flight tests of the LAS is planned for the White Sands Missile Range that will include both pad abort and ascent abort tests. In 2009, Ares I-X—the first developmental flight test of the 'integrated stack'—will be launched from the Kennedy Space Center (KSC). Ares I-X will test the integration and performance of a simulated Ares/Orion 'stack' prior to Critical Design Review so that resulting design changes could be incorporated before production of flight articles. Further flight testing at KSC is planned into the next decade.

BUDGET AND ACQUISITION

Budget Development

The ESAS team had assembled a preliminary budget estimate for execution of the recommended architecture. In the spring of 2006, the Constellation Program developed an unconstrained "bottoms-up" budget estimate for the purposes of establishing a "first cut" understanding of the drivers for costs and schedule from present to the lunar landing phase of the Program. This analysis provided the element break-down and the raw data for building a subsequent budget that was realistically constrained by Agency priorities and needs. By the summer 2006, the Program was able to establish the first budget baseline meeting Agency schedule commitments of deploying Orion by 2014, and landing on the moon by 2020.

These were updated in the Fall of 2006 as Program requirements matured. Completion of the Program's SRR, provided a further level of requirements development that allowed for more refined estimates in the Agency's FY07 budget development cycle.

Confidence Level

The history of human spaceflight is replete with examples of cost overruns due to confluence of under-funding, insufficient or poorly phased reserves, misunderstood risks and complexities, overly aggressive schedules, and difficulties meeting ambitious technical requirements. We have no illusions that we will not encounter these challenges; therefore the Constellation Program is pioneering within NASA the implementation of probabilistic techniques to assess the confidence level expected that the Program can achieve given schedule milestones within the budget allocated[9]. Our guidance within the Agency is to maintain a confidence level of 65% that we can meet our schedule commitments within the allocated budget and technical base-line. Program confidence level is calculated incorporating project-level confidence levels, project-level risks, and program-level risks, along with assumptions on dependencies among the risks. The Program conducted confidence level assessments during the budget development process, and plans to refine these during annual budget cycles. This analysis is key to assuring that we maintain our commitments to our stakeholders and have underpinning rationale for dialogue when requirements changes to the baseline are under consideration.

During 2007, the Program was allocated less funding than planned in the Federal appropriation bill. Since the Constellation Program proceeds as a 'go as you can afford to pay' program, this resulted in a 6-month delay in our commitment to fielding the first Orion crew vehicle and Ares I launch vehicle for Initial Operating Capability. This date is now March 2015, rather than 2014[10].

Acquisition Strategy

As plans are made for the retirement of the space shuttle, NASA is assessing possible synergies to be gained between the contracts and acquisition strategies already in place. The Integrated Acquisition Roadmap Team has been chartered to map all existing and planned space shuttle, ISS and Constellation contracts and to identify opportunities to save costs, including life cycle costs, to utilize lessons learned and best practices, to address transitions across Program phases, to maximize the effective use of both the existing civil service and contractor workforce, and to facilitate strategic competitive opportunities.

Where appropriate, the Constellation Program is utilizing current, proven technology in order to achieve safer, more reliable and affordable solutions. For example, the Ares I and the Ares V are based on proven systems from the Space Shuttle and Apollo Saturn V Programs, enabling NASA to reduce development costs compared to designing and building an entirely new launch vehicle. This approach maximizes the value of existing facilities, certified parts, production tools and expertise. Common propulsion elements help reduce operation costs for a more sustainable exploration program. The Constellation Program has entered into sole source production contracts for heritage-based elements; ATK-Thiokol for the Ares I first stage and Pratt & Whitney Rocketdyne for the J2-X engine.

Lockheed-Martin was selected as the prime contractor for the Orion development through full and open competition. The production contract for the Ares I upper stage was recently awarded to Boeing through full and open competition. Further prime contract awards are expected over the coming year.

The Constellation Program acquisition strategy places an emphasis on the criticality of reducing and controlling life cycle cost in each acquisition phase because NASA plans to produce and fly these vehicles for decades to come. Understanding and managing life cycle cost is pivotal to the overall long-term success and viability of the Program.

OPERATIONAL PHILOSOPHY

As noted in the contextual discussion in the Background section, the cost burden of space shuttle operations cannot be inherited by this Program if the Lunar Capability and the eventual Mars Capability is to be developed concurrently with Initial Capability operations. It is interesting to note that minimization of life-cycle costs, particularly operational costs, was an important objective of the Space Shuttle Program during its development[11]. This is not to point out folly, but indeed to illustrate how difficult this objective can be even under proactive management. We believe that we have the advantage of a much simpler system to operate, but are also cognizant that we inherit operational processes ingrained over a 30-year history. To that end, the Program has undertaken a number of efforts aimed at life cycle cost reductions. Examples are discussed below:

Stretch Requirements

The architecture requirements include 'stretch requirements' defined as those that enable ground and flight system supportability and reductions in operational life cycle costs. Modeled after the Boeing 777 development, stretch requirements specify a desired outcome believed to simplify operations. For instance, a 'clean pad' concept has been specified to challenge designers to minimize services and interfaces required at the launch pad as well as location/access on the vehicle. Each service or umbilical (e.g., cooling) attached to the launch vehicle is thus challenged for relevance or 'must have' capability. The Ground Operations Project and Mission Operations Project are focal to manage the stretch requirements; these are incorporated into flight design via negotiation of Interface Requirements Documents with each of the flight projects (Orion, Ares, EVA, and Lander).

'Con Ops' Development

Constellation has developed a Concept of Operations (Con Ops) for operation of the Program through its mission phases, in order to drive out operational features that influence hardware, software and interface requirements. This is a typical best practice in NASA program development. Design reference missions have been developed for ISS missions, lunar sortie missions, lunar outpost missions, and a Mars mission so that operational design drivers are identified early.

Moreover, we've also initiated similar but perhaps unique con ops efforts for targeted processes that can influence life cycle costs. For example, the current practice of quality assurance in the Space Shuttle Program is being bench-marked for efficiency improvements. By developing a con ops for how quality assurance is conducted through the life of the program, a more efficient path to quality assurance may be determined a priori.

Life Cycle Cost Evaluations

Change evaluations to the Program baseline must include an assessment of the life cycle cost impact of each change to the baseline. Constellation procurements – both 'end-item' and 'award fee' types – include incentives to reduce life-cycle cost.

Lean Efforts

Lean six-sigma and Kaizen studies were conducted on some early developments, such as the Ares 1-X test flight. This has proven successful and the Program is seeking further opportunities to gain process time reduction and simplification.

The 'handoff' between designers and the sustaining engineering and operational communities is being studied for efficiency improvements. Current practice includes overlapping responsibilities and designer involvement in post-design processes. Efforts are underway to identify and minimize this to ultimately reduce costs.

Industry Advice

The Ground Operations Project conducted feasibility studies under the Broad Area Announcement capability; requesting novel ideas from industry on how to streamline processing, launch and recovery operations. The concepts are intended to produce 'cleaner' techniques and processes in the belief that fewer anomalies are possible with simpler processes. Examples of concepts include new approaches to emergency egress system for the crew, isolation of the launch pad lightening protection system, and alternatives to hypergolic fuel loading to reduce processing time.

If we are truly successful in driving down operations costs such that the cost per flight is as low or lower than we project, and we've designed the supremely operable system that can be processed, flown, recovered and refurbished with a minimum of effort, then we've opened the door to other acquisition strategies in the production phase that would not be open to us with a more labor intensive system. Specifically, the option to buy services as a commodity would be available so that we can then devote our expertise to designing the next Constellation element in the plan.

SUMMARY

As the long-term objectives of U.S. space exploration evolve, the near-term goals remain the same: to develop the flight systems and ground infrastructure requireed to enable continued access to space and to enable future crewed mission to the ISS, the moon, Mars and beyond.

The initial formulation of the Program requirements baseline was completed in November 2006 at the Cx Program SRR. The Program is evolving within this structure of organization, requirments and funding as its foundation. A major challenge is to stand up an organization that draws on the best expertise in the Agency while maintaining primary focus on the currently operational Space Shuttle and ISS Programs.

The formulation of the Constellation Program is a robust system, based on the best of NASA's heritage, and designed to evolve as technical and programmatic needs demand.

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13. ABSTRACT *(Maximum 200 words)*
NASA has recently formed the Constellation Program to achieve the objectives of maintaining American presence in low Earth orbit, returning to the moon for purposes of establishing an outpost, and laying the foundation to explore Mars and beyond in the first half of the 21st century. The Constellation Program's heritage rests on the successes and lessons learned from NASA's previous human spaceflight programs: Mercury, Gemini, Apollo, Space Shuttle and International Space Station (ISS). This paper describes the rationale behind the formulation of the Constellation Program, including organizational structure, and workforce structure, as well as the approaches to requirements generation, budget formulation, operational philosophies, and procurement strategies.

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