Infusing Stretch Goal Requirements into the Constellation Program

Young H. Lee*
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

Roger A. Galpin†
Lyndon B. Johnson Space Center, Houston, TX 77058, USA

and

Kevin Ingoldsby‡
Booz | Allen | Hamilton, Melbourne, FL 32940, USA

In 2004, the Vision for Space Exploration (VSE) was announced by the United States President's Administration in an effort to explore space and to extend a human presence across our solar system. Subsequently, the National Aeronautics and Space Administration (NASA) established the Exploration Systems Mission Directorate (ESMD) to develop a constellation of new capabilities, supporting technologies, and foundational research that allows for the sustained and affordable exploration of space. Then, ESMD specified the primary mission for the Constellation Program to carry out a series of human expeditions, ranging from Low Earth Orbit (LEO) to the surface of Moon, Mars, and beyond for the purposes of conducting human exploration of space. Thus, the Constellation Program was established at the Lyndon B. Johnson Space Center (JSC) to manage the development of the flight and ground infrastructure and systems that can enable continued and extended human access to space. Constellation Program's "Design Objectives" call for an early attention to the program's life cycle costs management through the Program's Need, Goals, and Objectives (NGO) document, which provides the vision, scope, and key areas of focus for the Program. One general policy of the Constellation Program, found in the Constellation Architecture Requirements Document (CARD), states: "A sustainable program hinges on how effectively total life cycle costs are managed. Developmental costs are a key consideration, but total life cycle costs related to the production, processing, and operation of the entire architecture must be accounted for in design decisions sufficiently to ensure future resources are available for ever more ambitious missions into the solar system….It is the intent of the Constellation Program to aggressively manage this aspect of the program using the design policies and simplicity." To respond to the Program's strong desire to manage the program life cycle costs, special efforts were established to identify operability requirements to influence flight vehicle and ground infrastructure design in order to impact the life cycle operations costs, and stretch goal requirements were introduced to the Program. This paper will describe how these stretch goal requirements were identified, developed, refined, matured, approved, and infused into the CARD. The paper will also document several challenges encountered when infusing the stretch goal requirements into the Constellation Program.

---

*Operations Engineering Program Element Manager and JPL lead for the Constellation Ground and Mission Operations Systems Integration Group, Exploration Systems System Engineering, 4800 Oak Grove Drive, MS 301-490, Pasadena, CA 91109, United States of America.

†Chief, Cargo Integration and Operations Branch, Operations Division, NASA-JSC/DO5, 2101 NASA Parkway, Houston, TX 77058, United States of America.

‡Co-lead for the Constellation Ground and Mission Operations Systems Integration Group, NASA-KSC/BAH, 6767 North Wickham Road, Suite 400, Melbourne, FL 32940, United States of America.

I. Introduction

NASA has gained development and operations experiences from two major manned programs, Shuttle and the International Space Station (ISS). NASA has intended to obtain the reduction of long-term production, processing, and mission operations and training costs as major goals of these programs by aggressively controlling the long-term operations phase costs and risks of the vehicles. However, early programmatic choices and decisions in these programs have resulted in the limited ability to minimize these costs during the operations phases. Consequently, the result of such choices and decisions was an unanticipated increase in these programs' life cycle costs. Life cycle cost is defined in NASA Procedural Requirements[1] as "The total of the direct, indirect, recurring, nonrecurring, and other related expenses incurred, or estimated to be incurred, in the design, development, verification, production, operation, maintenance, support, and disposal of a project. The life cycle cost of a project or system can also be defined as the total cost of ownership over the project or system's life cycle from formulation through implementation. It includes all design, development, deployment, operation and maintenance, and disposal costs."

As NASA embarks on a new program that can enable sustained and affordable exploration of space by developing new capabilities, supporting technologies, and implementing the Vision for Space Exploration (VSE) within available resources, the Constellation Program has responded to the Exploration Systems Mission Directorate's (ESMD) direction by recognizing the need for the life cycle costs management early in the program development phases. Thus, Constellation Program's design objectives[2] call for an early attention to the program's life cycle costs management through the Program's Need, Goals, and Objectives (NGO) document, which provides the vision, scope and key areas of focus for the Program. For example, the CxPO-11 requirement from the NGO document states, "Provide early and constant attention to life cycle costs," and the CxPO-34 requirement states, "Significantly decrease the cost of ground and flight operations over legacy systems."

Moreover, one of the Constellation Program's general program policies[3] states:

> A sustainable program hinges on how effectively total life cycle costs are managed. Developmental costs are a key consideration, but total life cycle costs related to the production, processing, and operation of the entire architecture must be accounted for in design decisions sufficiently to ensure future resources are available for ever more ambitious missions into the solar system. Historical data shows that typically life cycle costs of a program are set within the first 10% of its life and that design solutions (to problems encountered during development) often are not adequately scrutinized for their potential impacts on Ground and or Mission operations impacts over the remaining balance of the program. It is the intent of the Constellation Program to aggressively manage this aspect of the program using the design policies and simplicity.

In an attempt to effectively infuse life cycle cost-related requirements early in the program development phase, the Constellation Program manager asked the Lyndon B. Johnson Space Center (JSC) and the John F. Kennedy Space Center (KSC) to assess the current ground and flight operations cost drivers and to recommend specific requirements for either ground operations, flight operations, or vehicle designs that can reduce operational costs. Subsequently, the Flight Operations Improvement Team (FOIT) at JSC and the Ground Ops Improvement Team (GOIT) at KSC were formed to respond to the challenges of identifying operations requirements that could reduce life cycle costs of the operations phase and improve operability, supportability, and extensibility of the Constellation Architecture. FOIT and GOIT started to examine their operations processes and assessed current operations cost drivers to identify candidate ground and flight system infrastructure design targets to reduce operational costs. As a result, Stretch Goal Requirements concepts were introduced to the Constellation Program.

II. Flight Operations Improvement Team

Although the NASA Administrator and the Constellation Program Manager have both recognized the great value mission operations has brought into the increasing probability of mission success, they have also stated that the Constellation Program cannot afford infrastructure of the past with the new program. Since the Constellation Program was still in the formulation stage, where program architecture definitions and requirements for the operations system were not yet fully finalized, the window of opportunity existed for the mission operations community to introduce flight operations requirements to influence flight vehicle and ground infrastructure design in order to impact the life cycle operations costs. The mission operations community could re-examine decades of mission operations experience to identify and define operational requirements that could contribute to the development of significantly improved, cost-effective Constellation Program operations systems. It was also noted that it was a great opportunity for this community to look for any fundamental changes in how operations are performed for the Constellation operations era as opposed to looking for incremental improvements of the current Shuttle and ISS operations phases.

In April 2006, FOIT, a multicenter team, was formed at JSC with an objective of assessing the current flight operations cost drivers and recommending specific requirements for either flight operations or vehicle designs that could reduce operational costs for the Constellation program. This team's major approach was to review significant cost-driving key functions and current flight operations approaches with the Mission Operations organization, the Constellation Operations Integration Office, and the Constellation Mission Operations Project. Three major process areas were considered and three sub-teams were assigned to those areas in order to conduct assessment activities.

A. Team A: Flight Design Process

Team A's objective was to significantly simplify and streamline the flight design process based on years of flight design experience and by focusing on safety critical functions. The team's specific tasks were to:

1) Maximize the use of standard products with minimal mission-to-mission change for all mission phases (ISS missions: Earth ascent, orbit insertion, rendezvous, undock/separation, and de-orbit).
2) Minimize ascent monitoring, placing abort monitoring and abort calls onboard. As a boundary condition, include in the assessment, the option to eliminate Mission Control Center (MCC) monitoring after six flights.
3) Minimize MCC involvement in rendezvous targeting and monitoring by placing capabilities onboard. As a boundary condition, include in the assessment, the option to eliminate MCC monitoring after six flights.
4) Assess options to minimize day of launch I-loads and simplify process.
5) Determine ways that system inputs into flight design processes (e.g., propellants and consumables) can be minimized or eliminated.

B. Team B: Facilities and Recon Process

Team B's objective was to streamline software reconfiguration process for flight software, Mission Control Center (MCC), and simulator. The team's specific tasks were to:

1) Significantly reduce MCC and Integrated Planning System development and sustaining cots
2) Significantly reducing training simulator development and sustaining costs.

C. Team C: Operations-Systems/Planning/Extra Vehicular Activity (EVA)

Team C's objective was to reduce operations and training costs by requiring operations friendly vehicles. The team focused on requirements that would drive straight-forward and easy-to-operate vehicle designs, and that would minimize rapid response by either the crew or MCC. They identified that increased onboard autonomy and use of vehicle automation via MCC–controlled, auto-executable procedures tables can reduce operations costs. The team's specific tasks were to:

1) Substantially reduce systems flight control positions and combine sustaining engineering function with operations systems flight control functions.
2) Significantly reduce operations cost for mission planning, pointing, cargo stowage and transfer, flight procedures management and real-time staffing for these positions.
3) Significantly reduce or eliminate Neutral Buoyancy Lab costs.
4) Significantly reduce training costs for crews and flight controllers.

Assessment activities were performed and a number of program and project-level requirements that could result in improved efficiency in the operational phase of the Constellation Program were identified. Major items included addressing reconfiguration process (e.g., reconstruction standards, separation of flight software variable operations data from flight, software, reconstruction process definition, etc.), design for simple operations (e.g., vehicle safety mode, vehicle autonomous for nominal steady state operations, simple identification of vehicle failures, etc.), and increased crew autonomy and vehicle automation. These recommendations were presented and submitted to the Constellation program for review and future actions.

III. Ground Operations Improvement Team

The Constellation Ground Operations Project (GOP) office at KSC was challenged in their initial bottoms-up budget submission to cut the projected development costs for KSC infrastructure by more than 60% from their initial assessment. These dramatic cuts demanded a fresh approach to Constellation Ground Systems from the Space Transportation System (STS)-derived systems approach. To help find a fresh approach, Ground Systems (GS) commissioned a set of four operations concept studies by major aerospace operations teams under a Broad Agency Announcement (BAA). These four studies provided GOP with many suggested concepts not only for the ground infrastructure, but also with a shopping list of enabling Flight System design requirements, which would enable broad reduction in the ground processing flow.

The outbriefs were collected and key items were prioritized by GOIT. Many concepts were incorporated into the GS Operational Concepts document (GS-OCD).[4] One of the key conclusions reached was to limit ground processing time spent at the launch pad to the bare minimum possible. This has remained a key tenet of the "Clean Pad" concept for Constellation ground processing. Coupled with the pad processing decision was the desire to minimize active services to flight system elements during transportation.

The current Constellation budget limits only allow development of a single string of integration facilities. This drives a concentration on streamlining the critical path for ground processing, which encompasses the cycle time of the Mobile Launcher, as only one is being developed for the Initial Ares-I/Orion launch support capability. The focus on reducing the critical path timeline and labor hours was used as the ranking and prioritization criteria for filtering the GOIT list of key enablers. This helped GOP focus on what they could achieve in internal design decisions and identify the list of key enabling Flight System design limitations and concepts that could be forwarded to the Program Office for incorporation into design specifications for the Flight System projects.

The Ground and Mission Operation (GMO) Systems Integration Group (SIG) examined 39 BAA and 21 GOIT-originated operability related concepts. Upon examining them, the GMO SIG categorized them into four groups: Clean Pad, Reduced Ground Processing Complexity, Streamline Integrated Testing, and Minimize Flight Vehicle Access Points. The GMO SIG evaluated the concepts by applying the concept-weighting scores (based on scale one through three) against the following criteria: mission success and safety, cost investment needed, recurring cost savings, operability, schedule risk, performance risk, and phasing attributes. Out of 60 concepts, the GMO SIG selected six BAA and eight GOIT proposed concepts to be combined with a number of Constellation Program System Readiness Review (SRR) review item discrepancy (RID)-originated concepts. The GMO SIG was assigned to generate Constellation Architecture Requirements Document (CARD)[5] threshold and objective requirements, create operations concepts to link to the Constellation Design Reference Missions (DRM) and Operational Concept Document (OCD),[6] define system applicability, establish parent-and-child requirement relationship, assign mandatory and secondary requirement stakeholder, address proposed time phasing between threshold and objective requirements, and identify issues and develop action plans to implement those identified issues. Five concepts were deemed more appropriate to be matured by Common Command Configuration Information (C3I) and Software Integration (CSI) SIG, Human Systems (HS) SIG, Ops Integration and Level 1 with Supportability, Operability and Affordability (SOA) leadership. Therefore, those five concepts were not handled by the GMO SIG.

IV. Constellation Program

A major stretch requirements goal is to lower the life cycle cost of mission and ground operations and their infrastructures by introducing a set of requirements that enhance operability, sustainability, and safety, which can in time affect the System Definition Review (SDR) process. Stretch goals are recognized to be intentionally difficult and intended to push the designs for more operability, supportability, and affordability, not merely reflecting current design baseline capabilities.

The Constellation Program Systems Engineering and Integration (SE&I) office formed the Stretch Team to meet the stretch goal development challenges. The Stretch Team established the concept of evolutionary goals within the requirements space to be proposed. The concept would set a minimum value that must be met and an aggressive improvement value that would promote continuous improvement over initial design concepts. Modified definitions from the Chairman of the Joint Chiefs of Staff Manual[7] were applied to the stretch goal requirements definition for the Constellation Program. The definition of "threshold" is a minimum acceptable operational value below which the utility of the system becomes questionable. The definition of "objective" is the desired operational goal associated with a performance attribute, beyond which any gain in utility does not warrant additional expenditure. The objective value is an operationally significant increment above the threshold. Objectives should offer an architecture-level requirement that crosses more than one Level 3 project. It was noted that these objectives are not immediately applicable requirements since they represent the eventual state the Program desires to achieve at some future phase. However, it was agreed that once they have been decomposed and allocated to Level 3, the projects must develop a plan and analysis to show progress toward the objectives to be completed before the Preliminary Design Phase (PDR). Progress toward objectives will be reported to Level 2 and Level 1 at major program milestones. Projects should continue to decompose and allocate these objectives. Objectives should drive fundamental changes in design, manufacturing, or operations. See Figure 1 for the Stretch Requirements Schedule, which the Stretch Team was working toward.

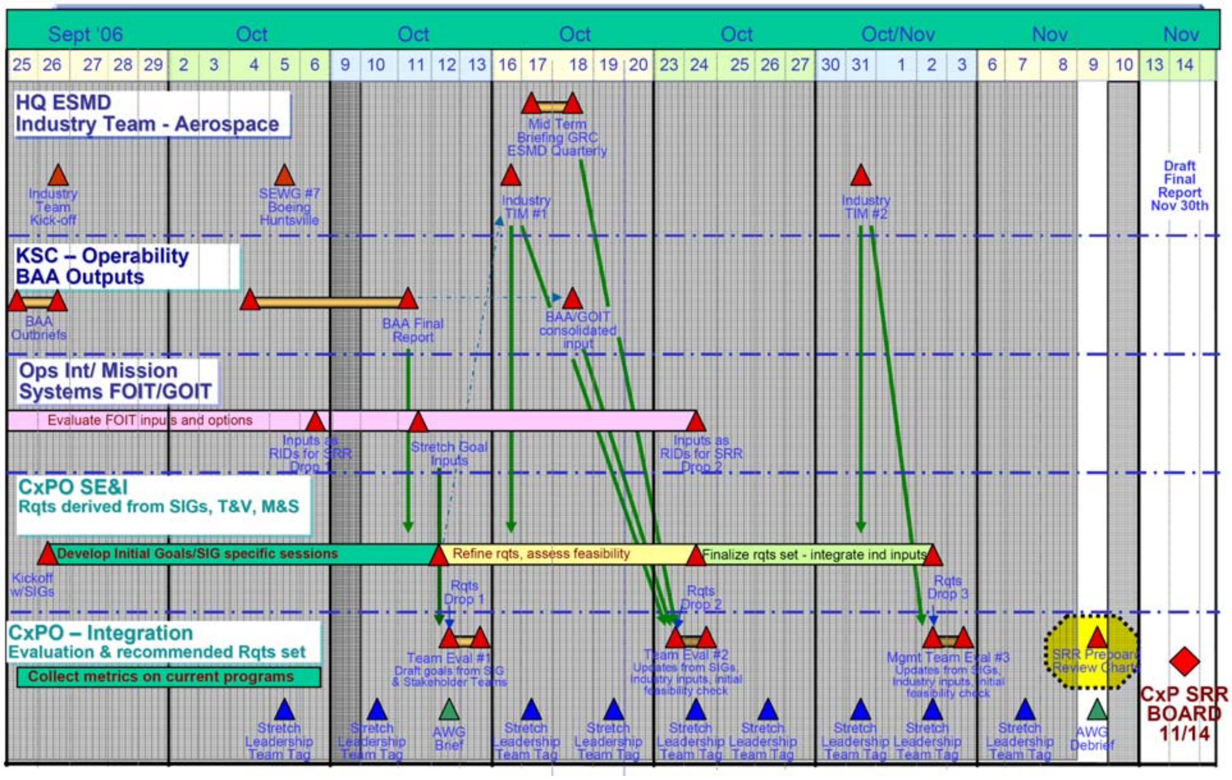

Figure 1. Stretch Requirements Schedule

The Stretch Team used the following selection criteria for choosing highly reasonable concepts for further refinements from approximately 100 operations cost reduction concepts:

1) Delta operational cost must be lowered by this requirement.
2) Delta development cost must not be a significant impact to the Program.
3) Performance delta must be positive, or, if not, be acceptable to the Program.
4) Impact to development schedule must be acceptable to the Program.
5) Estimated development risk such as likelihood of compliance must be acceptable to the Program.
6) Ground Operations risk must be acceptable to the Program.
7) Mission Operations risk must not increase as a result of this requirement.
8) Flight mission risk must not increase as a result of this requirement.
9) The decrease in the life cycle cost must be significant enough to warrant any trade-offs with respect to performance, schedule, or risk.

Each concept was weighed against the following criteria: estimated delta development cost (scale 1–3), estimated delta operations cost ($/year) (scale 1–3), estimated delta performance (scale 1–3), estimated delta safety (scale 1–2), estimated delta development schedule (scale 1–3), and estimated operations risk (scale 1–2). Then, total score was tallied.

V. Ground and Mission Operations Systems Integration Group

The Constellation SE&I Office chartered the SIGs under the Program Technical Integration (PTI) group to align with specific systems and functions (e.g., environments and constraints, thermal, or power), or to align with a category of functions or requirements sets (e.g., Human Systems, SOA, or Ground and Mission Operations). The main functions of the SIGs were to represent Level 2 program requirements, to interface with and coordinate and allocate these level requirements to Level 3 projects, and to provide horizontal integration across the program SIGs, requirements and analysis groups for interdependent requirements and analysis management.

The GMO SIG was chartered to represent the set of requirements governing the generation of the infrastructure to support the mission operations and the ground operations functions. For mission operations, this included planning systems, training systems, and systems to execute real-time mission operations. For ground operations, this included infrastructure to integrate launch vehicle to crewed vehicle; to process the vehicles; and to perform integrated testing, launch, recovery, refurbishment of reusable systems, and disposal. Commonality between procedures and processes to test and service a vehicle preflight with procedures and processes to execute missions in space was a driving factor in combining the two major functions into one SIG, as well as the program goal to determine operability and reduced life cycle operations costs requirements. Even though the SOA office included operability as a function, the stretch goals predominantly affected mission and ground operations aspects of handling and operating the vehicles. These phases were deemed to have the largest potential for life cycle operations cost savings. Hence, in November 2006, the Constellation Program delegated GMO SIG the authority and responsibility to integrate and coordinate the necessary assessments of stretch goal requirements with Project support and mature the requirements deemed appropriate to meet the program's operability and reduced life cycle operations cost goals. Some requirements were led by HS, SOA, and CSI SIGs as well as Level 1 and the Operations Integration office, with the GMO SIG providing project oversight and guidance. The GMO SIG was later moved under the Constellation Operations Integration Office, whose focus is on considering operability and life cycle costs in the design of the vehicle, as this was a better alignment of function to responsibility.

VI. Stretch Goal Requirements

A. Stretch Goal Requirements Candidates

Seven categories of approximately 31 total concepts that were deemed highest potential for life cycle cost reductions were assigned to the GMO SIG for further refinement. Those concepts include stretch goal concepts originated by the Stretch Team via proposed requirements from SRR RIDs and suggested concepts from the GOIT team. These concepts were combined and assigned to the GMO SIG to be further developed and matured.

1. Mission Production Category

The Flight Software (FSW) Reconfiguration and Software Improvement suggestion, originated from BAA, was selected. It was noted that shortening the turn-around time of FSW updates has a huge potential for development and operations cost savings. For example, there would be no need to develop and maintain test or operational workarounds for a problem that could be fixed with a software update, since improvements in automated code generation and test make this objective feasible.

The current Shuttle mission integration production template generation effort takes approximately 13 months whereas the assessed mission integration production template for the Constellation Program is assessed to be approximately 12 months. This fact illustrates the Constellation Program's need to find methods to produce a minimized standard mission integration process template to keep recurring costs down, to increase manifest flexibility, and to provide a rapid mission turnaround.

2. Streamlined Integrated Testing

One BAA-originated and two GOIT-recommended items were examined to reduce overall testing time as well as post-test, close-out time. Confined spaces require significant amount of infrastructure when sending personnel into those spaces, and increases overall testing time. Eliminating the need to build unique access platforms would reduce overall testing time, and post-test close-out time. In addition, this category's goal is to reduce life cycle costs by eliminating special liquid ground cooling during testing; although flight systems may utilize fluid cooling for flight in order to meet mission requirements.

3. Limiting Access Points

One BAA-originated, one GOIT–recommend, and three RIDs were assigned to this category to promote a common access point concept. This category's goal is to provide common access platforms for nominal and contingency ground operations and common access points for crew operations, preferably internal to habitable volumes. Thus, the need was recognized to eliminate access points for contingency only and locate access points to simplify ground processing, reduce platforms needed, and protect separation of safety critical functions.

4. Reduced Ground Processing Complexity

Three GOIT recommended ideas were included with a notion that streamlining ground operations processing, during Vehicle Assembly Building (VAB) through launch operations, would significantly reduce ground operations life cycle costs as compared to the current Shuttle ground operations costs. Test and checkout procedures at the launch site that duplicate those operations nominally accomplished at the manufacturing facility were proven to increase cost and schedule. Conducting unscheduled processing of flight hardware at the launch site not only drives redundant facilities and personnel but also shifts the schedule burden from the manufacturer to the launch site.[8] However, processing, nominally planned to be included at the launch site instead of the manufacturer, are excluded from this scenario.

5. Clean Pad

The Clean Pad concept was introduced since it minimizes the duplication of launch and ground processing infrastructure between the launch pad and integration facility, thus, reducing ground system development, maintenance, and sustaining costs. The concept also allows for all integration and checkout of the flight vehicle in a controlled environment, including connection of all launch umbilicals and servicing of all commodities (except cryogenics). This controlled environment reduces or eliminates operational holds/impacts due to weather, shelters flight systems from weather until just before launch, and shelters servicing and test equipment from weather. In addition, this concept provides flexibility (scalability) of launch rate since multiple launch configurations are possible off a single launch pad, and rapid launch succession is possible off a single launch pad if multiple mobile launchers are used. Finally, this concept provides for quick "rollback" capability to integration facility in the event of a contingency such as a hurricane or hardware failure. This is a key driving requirement to reducing life cycle costs of ground operations projects by reducing ground infrastructure cost.

6. Crew and Mission Systems

Many items that can lower the life cycle cost of mission operations were examined under this category. It is highly desirable the Constellation Architecture balances the spacecraft design requirements with the operational considerations to reduce life-cycle costs. The systems capabilities should be designed, configured and sized to reduce, with the goal of eliminate, any conflicting flight operations constraints based on power, thermal, communication, and structural loads. When these interactions between systems are not considered in the design, the resulting systems may require additional operations analyses and real-time monitoring to ensure certification limits are not violated. For example, an attitude good for one system, e.g. solar arrays, may prove to be incompatible with active or passive thermal, or may interfere with communications between spacecraft or mission systems.

The option of minimizing real-time consumables planning was considered. Failure to plan for future growth results in increase of life cycle cost due to the detailed, case-specific analyses driven by changes in mission requirements, system failures, or other contingency event. For example, the tanks holding the consumables will be a fixed size, once built, and options to increase vehicle capabilities is limited without major modifications. Adding additional margin to the tanks' capacities upfront allows flexibility. The propellant tanks for the Orion Service Module (SM) are sized for the lunar missions and include margin for the case where the SM main engine failures and the SM Reaction Control System (RCS) jets are used for Target Earth Intercept (TEI). For the standard missions, the additional margin reduces the detailed analyses required to track consumables and re-work plans to find the optimal case.

Limiting commanding and ground control interaction with a quiescent vehicle to specific periods and specific manpower intensity will contribute to reduced operations life cycle cost. It is expected that a quiescent vehicle, namely Orion, docked to ISS would require very little routine command interaction with ground controllers and limited telemetry monitoring as well. Managing this interaction within a specific period and to a limited amount of manpower enables reduced life cycle cost through reduced real-time ground control manning. Greater onboard autonomy and less reliance on the ground for nominal and off-nominal, including critical hazards, operations can have the potential to reduce Mission Operations life cycle costs.

Internal diagnosis of failures to the repairable level or operable system will reduce troubleshooting effort by flight crew and ground personnel. In turn, this will expedite maintenance and repair operations and facilitate failure response determination and reconfiguration by flight control personnel since current technology should enable diagnosis to this level. Reducing the time required for replacement of Orbital Replacement Units (ORUs) will reduce workload on the crew.

Reduced reliance on ground networks for launch through orbit of space vehicles was seen by Constellation Program officials as an another method to control costs, both initial upgrade of and for long term sustainment, of ground sites. Specifically, those sites used for launch and ascent telemetry, command and tracking were to be evaluated against services that could be provided instead by space born assets. Since space born assets would be required for orbit and trans-lunar phases of missions anyway, they posed no additional financial burden on the program.

7. Ops Phase Affordability

In the "go-as-you-can-pay" mode of the space systems development and operations, the development of the planned lunar mission capabilities highly depends on or would be ensured by substantial decrease in the cost of the Low Earth Orbit (LEO)/ISS operations since the Constellation Program budget is fixed. It was recognized that establishing threshold and objective cost targets for the Program and projects would clarify and bound the magnitudes of change from the Shuttle baseline as are needed for Constellation Program planning and design purposes. Thus, it was agreed to develop Stretch Goal requirements in this category. See Figure 2 for Objective Requirements Summary and Figure 3 for GOIT Proposed Threshold Requirements Summary.

	Crew and Mission Systems	Mission Production Template	Ops Phase Affordability	Reduced Ground Processing Complexity	Clean Pad
SO1: Flight SW Reconfiguration		■			
SO2: Launch Processing Flow at KSC (Ares I/Orion)				■	
SO3: Launch Processing Flow at KSC (Ares V/LSAM)				■	
SO4: Internal Failure Diagnosis/Onboard Autonomy/Recovery	■				
SO5: ORU Replacement Time/Maintenance	■				
SO6: Mission Integration Production Template Reduction		■			
SO8: Minimize Real-Time Analysis	■				
SO9: Ship to Integrate for Launch Processing				■	
SO10: Ares I/ Orion & Ares V/LSAM Interfaces Launch Processing Commonality					■
SO11: On-board Consumables Management	■				
SO12: Real-time Support During Quiescent Operations	■				
SO13: Automatic System Safing	■				
SO15: Affordability of Operations Phase			■		
S099: Reduce Reliance on Ground Networks			■		

Figure 2. Objective Requirements Summary

	Clean Pad	Reduced Ground Processing Complexity	Streamline Integrated Testing	Limiting Access Points
Hypergolic Loading Prior to Integrated Activities (G3)	■			
No Weather Protection Covers (install/remove at Pad) (G5)	■			
No Services Required for Rollout/Roll-back (G8)	■			
Non-intrusive Integrated Testing (G12)			■	
Non-pyrotechnic Hold-down (G19)		■		
Consolidated Ordinance Arming Connection Points (G22)				■
Limiting LRU Access Points (G24)				■
Integrated and Stacked Vehicle Time Limit (G29)		■		
Streamline Routine Maintenance after a Launch Scrub (G30)		■		
Reduce Cooling GSE Requirements & Reduce Complexity (G31)			■	
Closed Out for Flight Prior to Rollout to Pad (G48)	■			
Commodity Servicing Complete Prior to Rollout (G49)	■			
TCDT or Sim Testing in VAB (G60)	■			
Design for Access/Handling (G27)		■		

Figure 3. GOIT Proposed Threshold Requirements Summary

B. Formulations Process

During formulation of these stretch goal requirements, the goal of the Constellation Program was to determine the operations concepts, functional decomposition or analysis of those concepts, and to develop the requirements to achieve those functions and concepts. The Constellation Program chose the Cradle database as a means to document operational concepts, functions, requirements, rationale, verification requirements with rationale, and several other attributes, such as allocating program level requirements in the CARD to applicable projects and stakeholders of the requirements. Cradle is a relational database allowing linkages to be established among operations concepts, functions, program, and project-level requirements, lower-level project concepts, functions, and requirements for easy traceability. Activities involved during this formulation process were to develop and refine preliminary stretch concepts into full operational concepts, to analyze the functions that necessitated requirements to be developed upon the design, and to define the verifications methods and specific texts in order to ensure those requirements are eventually met. Since the concepts for the various stretch goals had been determined at a high level by the original Stretch Team during the pre-SRR timeframe, the GMO SIG-led Stretch Team were challenged to make a critical decision during this phase, with a program milestone approaching, namely the Program Baseline Sync (PBS).

The major objective of the PBS was to ensure the Constellation Program (Level 2) and all Level 3 projects were working toward consistent operations concepts and requirements goals from their respective SRRs. The results of the SRRs, disposition of the various RIDs, and forward action plans were to be reviewed jointly as part of the PBS process to ensure all parties were headed in a consistent direction and methodology to converge upon an appropriate set of design criteria and a requirements set for the Level 2 and Level 3 SDRs. The Level 2 SRR was completed in December 2006 with PBS scheduled by mid-April 2007. The Constellation Program requested that all stretch threshold and objective requirements be baselined by the PBS. The SDR was regarded as the last major milestone by which the operations life cycle costs would be set and any design changes beyond this point would become cost prohibitive.

With only four months to refine the original stretch concepts into fully validated Level 2 requirements with allocations to appropriate projects, the GMO SIG proposed to Constellation Program management that the most efficient path forward was to begin the maturation process immediately and work on operations concepts development in parallel with requirements maturation. Functional decomposition and analysis of the operations concepts was performed briefly with inputs from the functional analysis documentation used as a validation tool. The goal was to make sure that the stretch goals meshed with existing functions and to help identify missing functions to obtain at least a high level of detailed information to map the missing functions into Level 3 functional analyses. This would ensure that proper and appropriate lower level requirements would be defined.

C. Maturation Process

The effort to mature the stretch goal requirements was documented as a GMO SIG Stretch Goal Maturation Project Plan (See Figure 4 for the GMO SIG Stretch Goal Maturation schedule). The project plan was reviewed and approved by the Constellation Program management. Key aspects were included in the Level 2 Integrated Master Schedule (IMS). The GMO SIG held a series of GMO SIG technical interchange meetings (TIMs), provided status briefings to the Constellation Program, obtained inputs from integrated design analysis cycle 3 (IDAC-3) analysis reports (initial, interim, and final results reports), cost trade analyses results, and program schedule information. Then, the GMO SIG prepared a series of program change requests to the CARD, OCD, and the Human System Interface Requirements (HSIR), as applicable, for introducing the matured stretch threshold and objective requirements for program and project-wide reviews.

Some requirement concepts were more straightforward than others. The GMO SIG identified those that required no further technical analysis and were viewed as containing the least controversial content among stakeholders as Group 1. The GMO SIG identified those that had some minor level of controversy and needed some additional data for validation as Group 2. Then, the GMO SIG selected those that had significant controversy and required IDAC-3 technical and/or cost analysis as Group 3. This grouping scheme allowed the SIG to prioritize limited resources and IDAC-3 studies and to manage the stretch goal requirement development effort through the maturation and approval processes. Figure 5 contains the stretch requirements overview with a color scheme to indicate the three groupings.

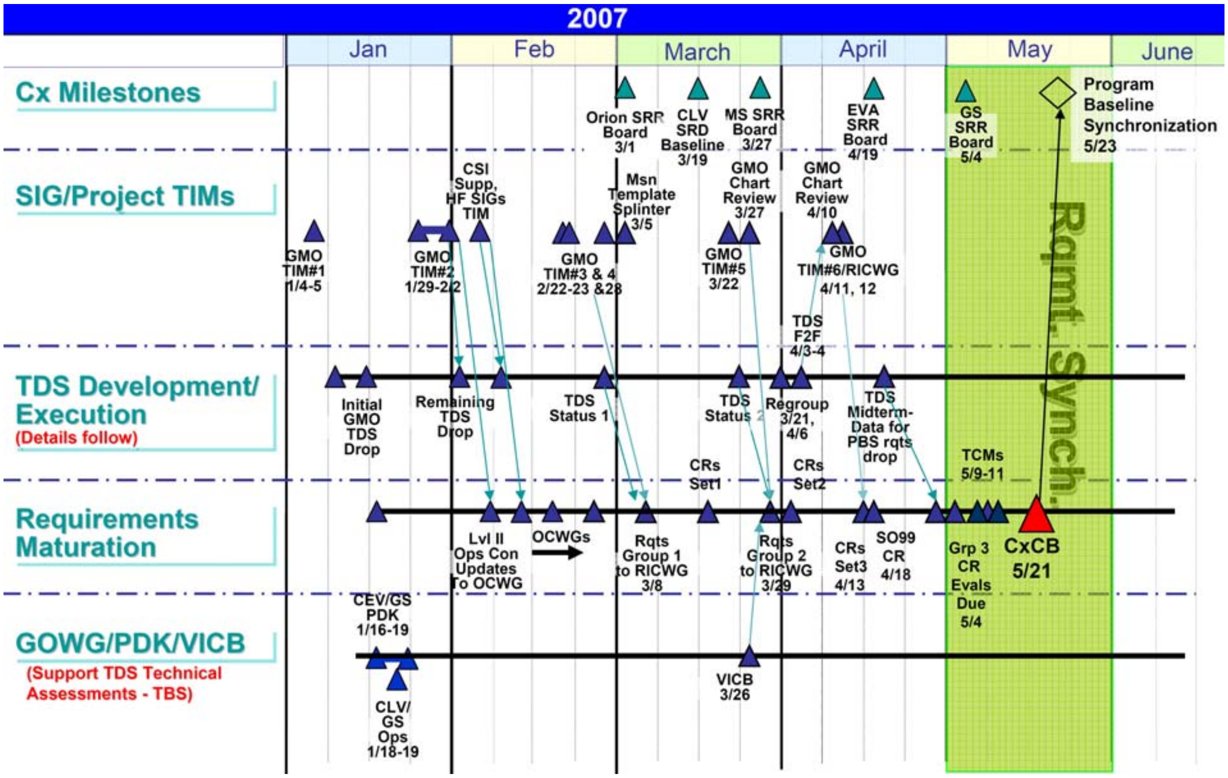

Figure 4. GMO SIG Stretch Goal Maturation Schedule

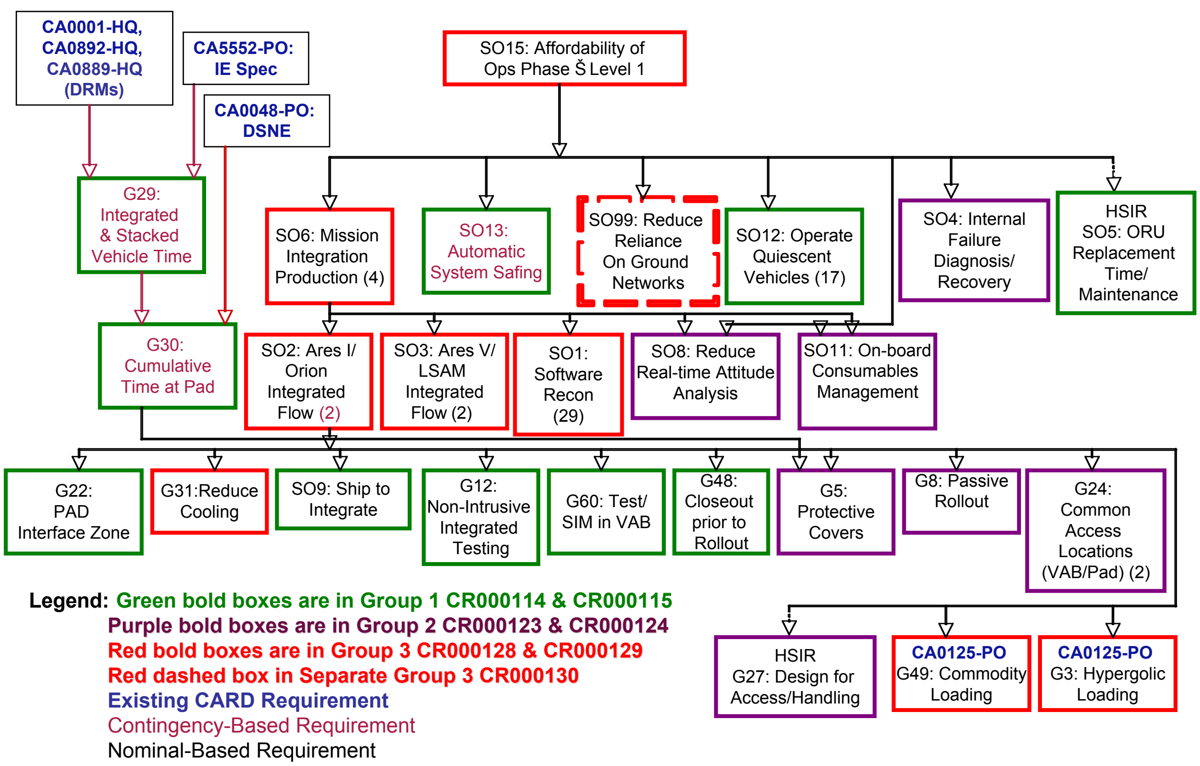

Figure 5. Stretch Requirement Overview and Flow Down

Representatives from various Level 2 teams and all affected Level 3 projects participated in TIMs. The predominant SIGs that participated with the GMO SIG included Environments and Constraints (E&C), CSI (pertaining to flight software reconfiguration processes), HS, SOA, EVA, and Test and Verification (T&V). The project representatives were from MOP, GOP, EVA systems project, and the Ares-I and Orion vehicle projects. Ares-V and Lander projects were included only in limited capacities as required as this effort was focused on initial operations capability (IOC) supporting ISS. The crew office also provided support at various times. It was extremely important to obtain a wide set of representatives especially from these requirements' mandatory and affected stakeholders to ensure that validated operations concepts and requirements through these TIMs were further developed and matured. It was also deemed essential in baselining these requirements in an efficient manner.

A total of six TIMs were ultimately conducted between January and April 2008 to mature the operations concepts and requirements, including rationale and verification requirements. The GMO SIG's nationwide teleconferences with virtual meeting capabilities were used to determine progress of action responses, schedules, and plans for future TIMs and the baseline process. The implementation status of the GMO SIG Stretch Goal Project Plan was presented at Level 2 Constellation Program boards (e.g., Constellation Control Board [CxCB]) to apprise Constellation Program managers of progress made, issues encountered, risk to reaching PBS baseline schedules, and list of stretch goals still under consideration for maturation.

The IDAC-3 process was utilized to identify technical analysis and/or cost benefit trades required to further develop and/or validate requirements to be comprehensive. Many of the stretch goal concepts lacked the technical analysis to understand if there were unintended negative consequences, to understand the full extent of operations and/or vehicle design impacts that might be considered, to better understand design tradeoffs open to be explored, and to understand the cost benefit or business case. A major consideration for each stretch requirement was to estimate vehicle design, manufacturing, and recurring cost compared to costs accrued by the ground and mission operations team throughout the life cycle of the program. Comparing these costs would determine if the stretch requirement would lower operational life cycle costs sufficiently to offset investment costs, or if the investment was appropriate for the improvements to operability and supportability. Operability and supportability are as important as affordability to the Constellation Program NGOs.

Several task description sheets (TDSs) detailing the need for technical and cost analysis studies were submitted to the program as a IDAC-3 and sponsored by the GMO SIG to assess feasibility, vulnerabilities, cross systems impacts, and cost for investment versus life cycle cost deltas. CSI SIG's integrated build for flight software tiger team, HS, EVA, and E&C SIGs also sponsored their own tasks or participated in the GMO SIG analysis tasks associated with the broad spectrum of stretch requirements. Managing and maintaining the oversight of progress for the many GMO SIG sponsored TDSs resulted in several challenges described later in this paper.

All Constellation Program forums available to the GMO SIG were utilized to maintain key stakeholders' participation, drive analyses, and make decisions on which candidate stretch goal requirements to pursue and which to abandon. Such forums were those where all SIGs were represented, where technical analysis schedules and focus were maintained, and where requirements integration was conducted, including Level 3 project forums where potential requirements implementation and impacts were discussed. To produce high quality stretch requirements, it was imperative to have Level 3 projects, especially governing vehicle designs, to discuss design implications. This ensured that improvements to ground or mission operations did not impose non-feasible or high cost consequences or incompatibilities for the vehicles. A Ground Operations Working Group (GOWG) was chartered to focus ground processing discussions between the GOP and vehicle projects. Launch vehicle and crew vehicle bilateral discussions with the GOP were held as well as crew vehicle flight operations discussions with the MOP. Results from these valuable discussions had to be continually factored into the stretch requirements maturation process. Horizontal integration among program elements and across multi-Level 3 projects and vertical integration, among all levels of the program and projects, was a fundamental goal of the program and was also key to the success of the stretch requirements maturation.

Operations concepts were identified and reviewed as part of the requirements maturation process during TIMs. Results of the operations concept development were presented and validated during the Level 2 chartered Operations Concept Working Group (OCWG). Any changes to the concepts agreed to in this forum had to be rolled back into the requirements maturation, continuing through GMO SIG TIMs to ensure requirements were in sync with these agreed concepts changes. This became an important step in ensuring broad buy-in to operations concepts across program and projects. For instance, Level 3 operations concepts were compared against Level 2 stretch concepts. Many instances of divergence among them were identified and corrected as a part of this process.

As PBS approached, a risk was entered in the Constellation Integrated Risk Management System (IRMA). This risk identified a schedule threat against having adequately validated, vetted stretch requirements and to completed baselining by PBS. Even with the PBS delayed one month (to start in May 2008), several of the most important stretch requirements were still awaiting results from the IDAC-3 studies. Without the adequate results, there was a risk that the proposed stretch requirements would not bring the desired reduction in life cycle operational costs and might instead result in a higher cost to the program due to design investments. The original plan under the Operation Phase Affordability category was anticipated to obtain the life cycle cost benefit data from each affected project for each stretch requirement as a way to build a strong business case. Cost analysis data was not compiled from each project in a timely fashion to address this concern. Availability of detailed cost data prior to a mature design concept and implementation strategy became a large challenge in understanding the business case. Although cost savings were not evident or available, a decision could still be made on whether the operability or supportability improvement was worth the cost to the Program. Ultimately, there was a risk that an inappropriate set of requirements could be baselined, and not identified quickly enough to prevent a design change that would result in an escalated cost and schedule impact to the Constellation Program. As a result, possible delay in PDR and/or first launch was the eventual concern. The GMO SIG decided to use this risk as a means to raise awareness with program and project management as well as secure agreements for program intervention to make decisions where the data were not compelling. This methodology was defined in a risk mitigation strategy.

The risk mitigation strategy included requesting Constellation Program decisions at key points throughout the maturation process, for example, to streamline the overall IDAC-3 analysis effort affecting stretch requirements. In response, Constellation Program management decided to allow closure of lengthy and resource intensive IDAC-3 studies where making the decision with lack of detailed analysis was seen as a relatively low risk to the overall program objectives. IDAC-3 studies that were viewed as necessary in order to provide sufficient information to buy down risk to significant program objectives were continued. This approach streamlined roughly 20% of the analysis work, for example, foregoing analysis based on “best engineering judgment.” Additional mitigation approach to this risk involved implementation of programmatic decisions to help weed out requirements that were too detailed or that targeted too low a level of responsibility for the Level 2 CARD. These decisions included making a programmatic “best engineering judgment” where inadequate cost benefit data were not available or were inconclusive. In the long run, these mitigation strategies allowed the GMO SIG to meet the PBS deadline for baselining the stretch requirements while providing the Constellation Program opportunities to make risk trade decisions and guiding the resultant requirements set formulation for baseline evaluation.

D. Approval Process

The approval process was set in general terms early in the maturation process as the GMO SIG Stretch Goal Maturation Project Plan was approved. The stretch requirements would be divided into threshold and objectives and inserted into the baselined CARD via program CRs. Other affected requirements documents (e.g., HSIR) would also be updated via CRs. Stretch objectives would have verifications added to their corresponding threshold requirements, delineating allocated projects to report progress toward meeting the improvement criteria of the objectives over time as part of each program milestone leading up to PDR. CRs to the OCD would incorporate operations concepts associated with the stretch requirements. By the time the requirements were matured, Constellation Program had suspended further refinement of the functional decomposition and analysis document.

The Constellation Program management initially provided divergent opinions on how to submit the stretch requirements materials in CRs. Would CRs be grouped by similar content, lumped all into one master CR, or provided as individual stretch requirement CRs? It was the GMO SIG’s position that logical grouping of stretch requirements should be provided in several CRs, submitted in a series over time. The amount of overhead associated with each CR processing versus the need to provide logically grouped material for evaluators to adequately weigh the merits was discussed. Ultimately, a combination of the schedule remaining before PBS and the need for logical grouping for projects to adequately evaluate the requirements determined the outcome. The vehicle projects had expressed a concern that many requirements affected each other and were not standalone, hence making a grouping scheme for review and evaluation even more important. The requirements were grouped according to their readiness for review and by mission operations or ground operations themed subject matter. The readiness for review followed the ordering of the CR groups 1–3 as identified during the maturation process (see Figure 5).

As a group of requirements, verification requirements, allocations to projects, and operations concepts were ready to start the final quality check and begin the approval process, final review TIMs were scheduled for a specific group. Upon successfully passing this screening TIM, the group of requirements and associated attributes and concepts were scheduled for the Constellation Requirements and Interface Configuration Working Group (RICWG). The RICWG constituted the pre-CR release review of the material to ensure all materials were addressed and ready to be released in CRs. Required materials included the threshold; where applicable, the objective requirement; the rationale; the verification requirements; the operations concepts; all attributes that show linkage to parent and children requirements; allocations to projects; and mandatory and affected stake holders of requirements. Once the required material was confirmed and quality checked by the RICWG, authorization to proceed to CR release was obtained for that requirements grouping.

CRs were prepared in two sets for each group. All mission-operations-related material for that group was placed in one CR while all ground-operations-related material was placed in a second CR regardless of whether CARD and/or HSIR were affected by the content. See Figure 5 for Stretch Requirement Overview and Flow Down. The exception to this rule was that all operations concepts for a specific group were placed in a separate CR-specific only to the OCD. CRs were submitted following the approval process outlined in this section in three waves according to the group determination. Each group was released approximately two weeks apart with a minimum of two to three weeks available for evaluators to provide comments. The CRs directed projects to not only evaluate the technical merits of the requirements but to also provide more detailed cost investment versus life cycle cost savings as this data had not been successfully collected in advance of releasing the CRs. Building a stronger business case for the requirements was still a highly desired goal to aid the Constellation Program Control Board (CxCB) in making a final decision on the recommended requirements and arbitrating unresolved evaluation comments. In the end, each project requested additional time to review groups 2 and 3 and evaluate interdependencies before providing their official evaluation comments. This resulted in the bulk of evaluation responses coming at once and only two business days prior to the technical coordination meeting (TCM).

TCMs were conducted for all groups of CRs after evaluation comments had been received; preliminary determinations on dispositions of comments had been made by the GMO SIG and other affected SIGs, applying rating scales per operability (e.g., ground operations work, training, mission planning, flight operations and recovery operations), supportability (e.g., sustaining activity, logistics activity, and extensibility activity), safety (e.g., reliability, safety, quality assurance, and software assurance), and affordability (e.g., Design Development Test and Evaluation [DDT&E] cost, production cost, other operations cost, and other support cost) attributes. The TCM reviewed comments and dispositions for all the CRs in one several day meeting. The recommended dispositions were reviewed with all mandatory participants and affected parties of the requirements during the formal TCMs. Dispositions, agreed-to final requirements, and concept wording and actions were recorded in TCM minutes. See Table 1 for stretch requirements stakeholder list.

The approval process ended with the formal CxCB dedicated to the stretch requirements and concepts CRs. A high level summary of the TCM package was reviewed with more details provided on significant changes accepted for individual requirements and concepts. Where a complete agreement could not be reached at the TCM, the opposing view points were presented with a recommended set of requirement words provided by the GMO SIG for the CxCB Board members to evaluate and make a final determination. In general, the Board decided to eliminate some very detailed ground processing requirements in lieu of higher level ground processing timeline requirements. Other requirements were accepted with changes as presented or with a compromised wording as determined by the Board. Actions were assigned to all affected projects to provide cost impacts and life cycle cost savings as the CR evaluation comments still had not provided the depth of cost information expected. Once again, the cost data were requested to utilize a last opportunity to validate the requirements prior to the Board acceptance.

Table 1. Stretch Requirements Stakeholder List

				Mandatory Stakeholders																			
				Level I	Level II												Level III						
Document	CR	Stretch ID	Description	ESMD	SOA	SR&QA	T&V	GMO	ARDIG	CSI	HS	ECLS	ILSM	EVA	Power	E&C	Ares	Eva	Ground Ops	Mission Ops	Orion	LSAM	CaLV
HSIR	CR 114	SO5	ORU Replacement Time/ Maintenance		X					X				X				X		X	X	X	
CARD	CR 114	SO12	Real-Time Support During Quiescent Ops							X										X	X		
CARD	CR114	SO13	Automatic System Safing				X			X				X				X			X	X	X
HSIR & CARD	CR115	G22	Pad Interface Zone				X			X	X						X	X	X		X	X	X
CARD	CR115	S09	Ship to Integrate				X						X				X		X		X	X	X
CARD	CR115	G12	Non-Intrusive Integrated Testing				X			X							X		X	X	X	X	X
CARD	CR115	G60	Test/Sim in the VAB				X							X			X	X	X	X	X	X	X
CARD	CR115	G48	Closeout for Flight Prior to Rollout													X	X		X		X	X	X
CARD	CR115	G29	Integrated and Stacked Vehicle Time										X				X		X		X	X	X
CARD	CR115	G30	Cumulative Time at Pad										X			X	X		X		X	X	X
HSIR	CR123	G27	Design for Access		X									X			X	X	X		X	X	X
CARD	CR123	G5	No Remove-Before-Flight Covers													X	X		X		X		X
CARD	CR123	G8	Passive Rollout		X								X				X		X		X	X	X
CARD	CR123	G24	Consolidated Access Points		X								X				X		X		X	X	X
CARD	CR124	SO4	Internal Failure Diagnosis			X		X		X				X			X	X	X	X	X	X	X
CARD	CR124	SO8	Minimize Real-Time Attitude Analysis							X		X			X					X	X	X	
CARD	CR124	SO11	Onboard Consumables Management							X										X	X	X	
CARD	CR128	SO15	Affordability of Operations Phase	X				X						X			X	X	X	X	X	X	X
CARD	CR128	SO6	Mission Integration Production							X				X			X	X	X	X	X	X	X
CARD	CR128	SO1	Software Re-configuration			X	X	X	X	X							X		X	X	X	X	X
CARD	CR129	G31	Reduce Cooling									X			X		X		X		X	X	X
CARD	CR129	G3	Hyper Loading		X	X											X		X		X	X	X
CARD	CR129	G49	Commodity Loading			X						X					X		X		X	X	X
CARD	CR129	SO2	Integration Flow Ares 1/Orion		X		X							X			X	X	X		X		
CARD	CR129	SO3	Integration Flow Ares V/LSAM		X		X		X					X				X	X			X	X

E. Infusion Press

As a result of the CxCB decisions on May 21, 2007, a total of 81 new requirements were added to the program specifications. Out of 26 architecture-level requirements, 5 requirements were allocated directly to Systems Requirements Documents (SRDs) and 55 were introduced into the CARD as system-level requirements. Several of the proposed stretch requirements (approximately 18) were deemed more appropriate for integration into the program outside of the CARD. Although they were of significant value, it was noted that the proposed requirements as formulated were driving at optimized design solutions and required an integrated design approach to achieve system design optimization. To address this challenge, the Program Manager issued a Constellation Program Management Directive on the Constellation Operability Optimization List (COOL) Process.[9]

The COOL as a process tool collected and quantified the proposed specifications into a detailed set of design-to goals to be incorporated by the flight and ground systems projects wherever practical. The list of items has been developed into a continuous assessment scorecard that is applied at architectural reviews, TIMs, and formal systems design reviews. The COOL is a qualitative measuring stick as implemented, which encourages design for operability principles. The Program SOA office maintained this COOL, with review and assessments contributed to by representatives within each project as well as affected Level 2 SIGs.

In addition to the COOL, a set of operability-oriented Technical Performance Measures (TPM) has been proposed. These will provide the Program Manager a level of tracking and visibility of operability metrics similar to more traditional flight system design TPMs (such as injected mass, landing accuracy, margins, etc.). An initial Operability TPM for the Ground Processing critical path has been established and is currently under the program's active monitor. Future Operability TPM are envisioned for Fixed and Variable Operations Cost, direct processing labor, production capability and others measures of operational performance,

Many of the stretch goal requirements were incorporated with To-Be-Determined (TBD) or To-Be-Resolved (TBR) items in the requirement details, which require continuous effort from involved organizations for refinement. See Figure 6 for status and overview of the stretch items from the CxCB decision.

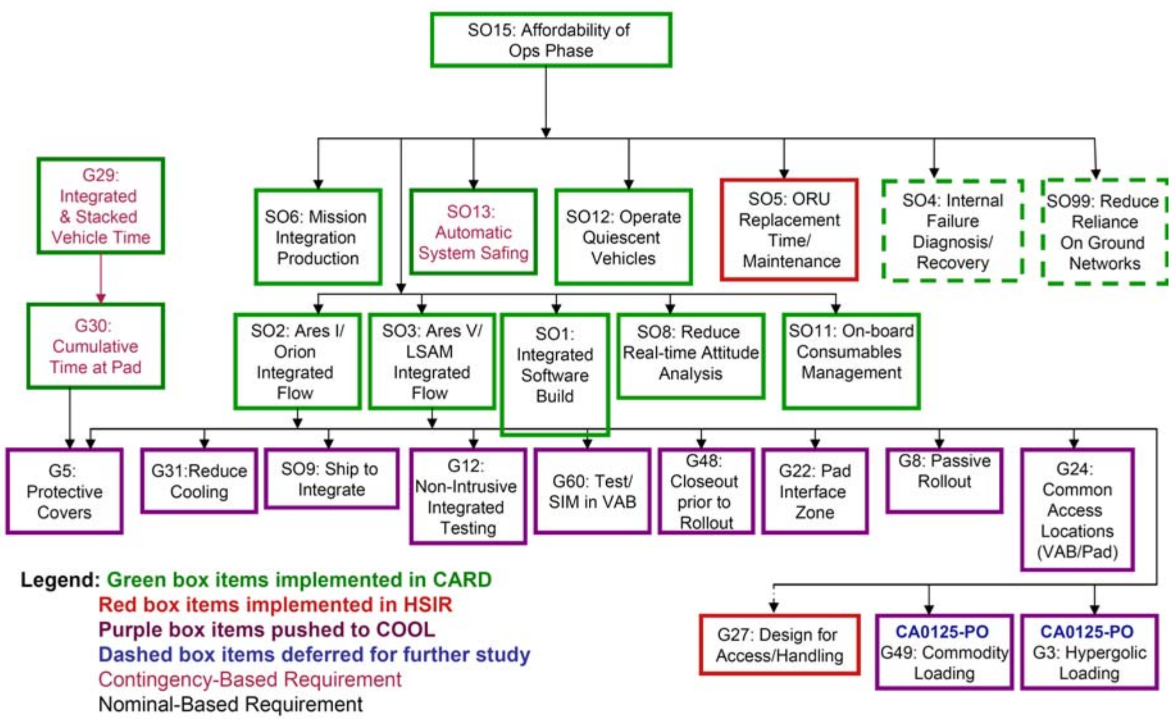

Figure 6. Status and Overview of the Stretch Items

VII. Challenges

Several challenges encountered in identifying, developing, and infusing the stretch goals into the Constellation Program are documented below. These challenges were documented to benefit others attempting to develop and integrate stretch goals into the initial design phase of programs or projects.

1. Project buy-ins (SRD level): It is absolutely essential to work collaboratively with all affected implementing projects and stakeholders. Support from the projects during the formulation process was impacted by competing tasks. The projects that were able to maintain a consistent participation in the TIMs and workshops were better accommodated in the final proposed specifications. Opposition to proposed stretch content was most apparent from projects that only sporadically participated in the formulation process.
2. TBD/TBR burn-down challenges: A significant portion of the stretch goals was incorporated into specifications with still TBD and TBR values. This was reflective of the limited resources available to the team during the formulation process. One year later, a significant number of these TBD/TBR values are still awaiting baseline through trade studies and analysis.
3. COOL: The ground operations enabling items that were rejected from inclusion into program specifications were instead published as Design Guidelines for the flight systems to use in maturation of their preliminary design trades. The list was established via a Program Management Directive and has been used as a subjective assessment measure at Architecture TIMs and SDRs. Unfortunately, it is a qualitative measurement tool and allows for a wide range of interpretation. However, it has proven useful and will undoubtedly help to guide the future system reviews as the architecture expands to the Lunar and Mars DRMs.
4. TPM development: Attention to the development of TPMs associated with the stretch goals was deferred until after the formulation process. As of this report, only two TPMs have been established to track project and program progress toward thresholds and objectives requirements. Future stretch infusion activities must include performance metric development as an integral part of the process.
5. Building a business case for the stretch goals: Obtaining detailed estimates of cost investment versus life cycle savings was needed to build a business case. These estimates were planned to be defined through the maturation process of the requirements to guide decisions on which to pursue and which to modify or abandon. The challenge arose in gaining access to Level 4 and 5 design experts within the vehicle projects to discuss and clarify stretch goals and requirements, and thus obtain the best cost estimates possible early in the maturation process. This challenge persisted through the approval process and only began to show improvement through the TCM process as evaluation comments and initial cost impacts were made available for discussion. This made it too late to effectively change course or re-negotiate strategies for the requirements and goals before presenting to the CxCB. On the other side of the business case were estimations of life cycle cost savings. The challenge here was that ground and mission operations projects showed extreme reluctance to provide cost estimates indicating a lack of trust or confidence that the vehicle design implementation would meet the intent of the stretch requirement goals. Cost estimations, as with vehicle project investment estimates, came very late in the maturation process and were continually refined to lower savings through the approval process. This was a clear indicator that the operations projects believed the requirements were "watered down" from their original intent and/or design implementation was so questionable as to greatly reduce confidence in actually reducing life cycle costs and operational complexity of the vehicles. This also provided evidence that attempting to write "optimization goals" in verifiable requirements presented unintended challenges.
6. Requirements language versus optimization goals: The exact nature of requirements language is intended to ensure the ability to verify compliance of the design against a requirement. By its very nature, a verifiable requirement structure works against attempts to impose optimization goals. This formed a fundamental challenge in developing and maturing stretch requirements. Many of the stretch goals were aimed at reducing access points to vehicles during ground processing, limiting services after stacking and interface testing, minimizing time for rollout to the launch pad, and limiting time from rollout to launch. Other examples included reducing crew and ground interaction, procedures, and training regarding vehicle mission operations. These goals were intended to simplify ground and mission operations personnel interactions with the vehicle (reduce infrastructure) and hence operational life cycle costs. However, a requirement is unverifiable when written with subjectivity (e.g., limit, reduce, optimize). This led well intentioned engineers to focus on fairly "point solutions" written from the perspective of what was a more optimum solution for mission and ground operations projects, but seen by the launch and crew vehicles as causing undue design restrictions and increasing development costs. Significant time and manpower was

spent negotiating to wordsmith such draft requirements, and in several cases resulted in not reaching the truly optimal position. Not until the final approval processes was this realization evident and the Program decided to switch gears with a subset of these goals. The new goals integrated the concepts via interface requirement negotiations to truly work toward optimal solutions for operations and vehicles. This gave rise to the COOL.

7. Managing and maintaining oversight of the many GMO-SIG-sponsored TDSs: With very limited team resources available, managing and maintaining the oversight of the seven studies simultaneously was extremely difficult. A majority of the stretch study objectives called for a comprehensive (qualitative and quantitative) evaluation to draw agreements among requirement stakeholders. Therefore, most studies demanded continuous team member dedication and created a challenging schedule with competing resource demands from other tasks. Future endeavors of this magnitude should secure dedicated resources and strong commitments from participating team members to facilitate consensus and to ensure high quality, timely study results. It is very challenging to assess feasibility, vulnerabilities, cross systems impacts, and cost for investment versus life cycle cost deltas on stretch goal requirements. However, it is still very desirable to document this information for creating historical cost data to calibrate future system cost estimates.

VIII. Conclusion

The stretch requirements effort has been very useful to the Constellation Program. The visibility of the operational consequences of early system design decisions has been effectively communicated throughout the flight and ground system projects. While not all of the early goals have been achieved, the learning process of developing targeted stretch goals, formulating them into draft requirements, evaluating and maturing the drafts into proposed specification changes, and infusing the final agreed-to requirements into program specifications has been of great value to the program. The work of stretch and COOL is not complete. The resolution of TBD/TBR values continues, the assessment of operability impacts is undertaken in each design trade decision, and the next round of Constellation systems development for Lunar capability has not yet begun. The stretch goals will continue to guide and craft the evolution and refinement of systems throughout the life of the program.

Acknowledgments

This research was carried out at the Lyndon B. Johnson Space Center, Kennedy Space Center, and Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Special thanks to the requirement leads from other SIGs and offices: Leslye Boyce (IBP Tiger Team, CSI); Susie Mauzy (RMO); Barbara Teague, Don Pearson, Geoffrey Lochmaier and Frank Moreno (OI); Kim Ess and Mariea Dunn-Jackson (HS); Stan Rhodes (GMO SIG and Ares Project); Ben Sellari and Eulalio Nandin (Orion Project); Gordon Aaseng and Dr. Kevin Watson (Supportability); Andy Prince and Henry Apgar (Affordability); Tammie McGrath (EVA SIG); Nick Cummings, Steve Clarke, Phil Weber, Kirk Logsdon, Mike Haddad (Ground Ops Project); Nancy Srb (PTI); Andy Algate, Robert Armstrong, Dave Allega (Mission Ops Project); and members of FOIT, GOIT, and Stretch Team.

References

[1]National Aeronautics Space Administration. NASA Procedural Requirements, NPR 7120.5D, March 2007.

[2]National Aeronautics Space Administration. "Section 3.3.3 Design Objectives," Constellation Program Plan (CxP 70003-ANX01), Annex 1: Need, Goals, and Objectives, 17 March 2008.

[3]National Aeronautics Space Administration. "Section 3.1.2.4 Life Cycle Cost," Constellation Architecture Requirement Document (CxP 70000), Rev. B, 13 February 2008.

[4]National Aeronautics Space Administration. Ground System Operational Concepts Document (GS-OCD, CxP 72119), Rev. B, 23 January 2008.

[5]National Aeronautics Space Administration. Constellation Architecture Requirements Document (CxP 70000), Rev. B, 13 February 2008.

[6]National Aeronautics Space Administration. Constellation Design and Reference Missions and Operational Concepts Document (CxP 70007), Rev. B, 7 January 2008.

[7]Department of Defense. DoD CJCSM 3170.01, 24 June 2003.

[8]National Aeronautics Space Administration. NASA Access to Space Study—Summary Report, NASA-TM-109693, 1994.

[9]National Aeronautics Space Administration. Constellation Program Management Directive, CxPM Directive No. 124, 20 September 2007.

[10]National Aeronautics Space Administration. "Section 3.2.13 Maintainability, Supportability and Logistics," Constellation Architecture Requirements Document (CxP 70000), Rev. B, 13 February 2008.