NEXT GENERATION LAUNCH TECHNOLOGY PROGRAM

LESSONS LEARNED

JULY 2004

Next Generation Launch Technology Program

Lessons Learned

July 2004

NGLT-PROG-00018

Lessons Learned for the Next Generation Launch Technology Program

Prepared by:

Stephen Cook
NGLT Program

7-5-2004
Date

Concurred by:

Garry Lyles
Deputy Manager for
Project Constellation

7-5-2004
Date

Approved by:

Craig Steidle
Associate Administrator
for Exploration Systems

7-13-2004
Date

Foreword

Thanks go to all the participants in this effort to collect and organize lessons learned for the Next Generation Launch Technology (NGLT) Program. Many NGLT team members participated in collecting inputs for this document and associated materials; many more participants, some outside of the Program itself, contributed inputs.

Table of Contents

Preface

Lessons learned from the NGLT Program were based on either observed successes, solved problems, or unsolved problems. This document presents crucial information—lessons and recommendations—for ease of access and use; background information is limited to discussions of driving events or other indications of significance. A total of 315 lessons were assessed, combined, and otherwise narrowed to a final set of 68 lessons learned for NGLT.

This document summarizes and reports the lessons learned from the NGLT Program. Section 1.0 contains the background of the NGLT Program and an introduction for this lessons learned activity. Section 2.0 describes the approach to this activity, including how the participants in this exercise defined, collected, and organized these lessons learned. Section 3.0 summarizes key findings. Section 4.0 describes the 68 lessons learned from NGLT. Appendix A provides a detailed description of the NGLT Program/Projects. Appendix B contains an index of the NGLT lessons learned. Appendix C is an acronym list.

1.0 Introduction

The NGLT Program was created in November 2002 as the result of merging elements from the Advanced Space Transportation Program (ASTP), which focused on 3rd Generation Reusable Launch Vehicle (Gen RLV) systems and in-space applications, and technology elements of the 2nd Gen RLV Program, which focused on nearer-term applications.

1.1 Precursor Programs

1.1.1 The Advanced Space Transportation Program (ASTP)

The ASTP began as the National Aeronautics and Space Administration's (NASA's) "Technology Central" for future space transportation systems in 1997. The primary emphasis of ASTP was on technologies for 3rd Gen RLVs and in-space propulsion systems that could be operational in the 2020 timeframe. The goal was to develop space transportation systems that would be 100 times cheaper and 10,000 times safer than today's launch vehicles. These true "space liners" of the future could take off from aerospace ports that would accommodate both air and space vehicles.

Air-breathing propulsion, magnetic levitation, highly integrated airframe structures that adapt in flight, and integrated vehicle health management systems were some of the technologies being considered for a 3rd Gen RLV. The ASTP was also investigating technologies for a 4th Gen RLV that could be operational in the 2040 timeframe. The goal was to make space travel 1,000 times cheaper and 20,000 times safer than today's systems.

1.1.2 2nd Generation Reusable Launch Vehicle Program

NASA's Space Launch Initiative (SLI), also known as the 2nd Gen RLV Program, was introduced in 2000 to develop technologies and identify options for future space transportation systems, performing the critical analysis necessary for NASA to eventually proceed with full-scale development of a new RLV system.

The 2nd Gen RLV Program was the central element of NASA's Integrated Space Transportation Plan (ISTP), the Agency's long-range strategy for safer, more reliable, and less expensive access to space. The 2nd Gen RLV Program addressed 2nd Gen RLV risk reduction, NASA-unique systems risk reduction, and enabling alternate access to the International Space Station (ISS). Building on 20 years of success with America's 1st Gen RLV—the Space Shuttle—the 2nd Gen RLV defined the plan of action to design and develop America's next generation RLV. The 2nd Gen RLV Program was based on the philosophy that frequently launching NASA payloads on highly reliable RLVs would significantly reduce the cost of space access, allowing the Agency to focus resources on its core missions of scientific discovery and exploration.

1.2 The Next Generation Launch Technology (NGLT) Program

In November 2002, NASA revised the ISTP to evolve SLI to serve as a theme for two emerging programs. The first of these, the Orbital Space Plane (OSP), was intended to provide crew-escape and crew-transfer functions for the ISS. The second, the NGLT Program, developed technologies needed for safe, routine space access for scientific exploration, commerce, and national defense.

The NGLT Program was comprised of 12 projects, ranging from fundamental high-temperature materials research to full-scale engine system developments (turbine and rocket) to scramjet flight test. The Program included technology advancement activities with a broad range of objectives, ultimate applications/timeframes, and technology maturity levels. An over-arching Systems Engineering and Analysis (SE&A) approach was employed to focus technology advancements according to a common set of requirements. Investments were categorized into three "segments" of technology maturation: propulsion technologies, launch systems technologies, and SE&A.

At the time of cancellation, the Program was pursuing the following major technology thrusts:

- Development of a reusable liquid-oxygen/liquid-kerosene rocket booster engine.
- Development of hypersonic, air-breathing propulsion and airframe systems.
- Development of cross-cutting vehicle system technologies, intended to support a broad variety of launch and flight vehicle architectures.
- Systems analysis activities to guide program investment and to ensure an appropriate fit with both NASA and Department of Defense (DoD) needs.

The NGLT Program was intended to bring an array of technologies to a state of readiness appropriate to facilitate decisions near the end of the decade on whether or not to initiate a program for development of NASA's next generation of launch vehicle(s). The resulting new program would then be built, in large part, on the selected technologies from NGLT. In short, NGLT was NASA's investment in new space launch technologies for use primarily beyond the OSP. A more complete description of the NGLT Program and projects appears in Appendix A.

The salient features of the NGLT Program were the diversity of featured technologies, their range of technology maturity levels, the levels of risk, and the integration of project and program work executed by many NASA Centers, industry, and academia. While there were ways to group projects as either air-breathing or rocket engine focused (or associated airframes and operations), there was much interplay and a spirit of common purpose that unified the Program. Other aspects of program management and the wide-spread use of systems analysis also contributed much to program and project successes for NGLT.

These lessons learned may apply to program and project planning at NASA Headquarters to varying degrees. Many of the higher-level or more generalized lessons can be relevant for all of the Office of Exploration Systems (OExS) program/projects . Additionally, lessons derived from projects emphasizing development and demonstrations will probably be more valuable for Project Constellation; lessons from research and technology projects are probably better suited for use by Human and Robotic Technologies (H&RT); and the unique aspects of safety and operations for Project Prometheus call for care in applying lessons learned from any source.

2.0 Approach

The team charged with collecting and processing lessons learned began with a call to all Program personnel. Subgroups of the team reduced an initial set of 315 inputs by assessment and combination to 100; a second cycle of assessment reduced those to a core set of 70. Another round of review and analysis produced a final set of 68 lessons learned accepted as potentially valuable for use in the nearer term by OExS. Document development and highlighting of key findings remained focused on OExS as customer.

2.1 Input Collection

The call for inputs left the scope of topics unrestricted and unaffected by a statement of expectations for content. The resulting inputs covered topics ranging from generalities of program management to specific programmatic issues—encountered with the interplay of organizational entities at NASA Headquarters—to particular aspects of key technologies. Inputs came from top-level managers, an independent consultant, and contractor employees, as well as NASA researchers, engineers, finance analysts, and managers.

Participants contributed lesson statements either through a web-based system or by a form that contained an identical set of data fields. Instructions provided were as follows:

1. **Subject/Title/Topic(s)** – This reflects the primary topic of the lesson learned. A carefully written Subject should contain some of the Topic(s) that will help other users find this lesson in the future.
2. **Driving Event** – This is a brief description of the event or problem that resulted in the lesson being learned.
3. **Lesson(s) Learned** – A lesson learned is knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Successes are also considered sources of lessons learned. A lesson must be significant in that it has a real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result.
4. **Recommendation(s)** – This is the positive recommendation(s) that should be taken to mitigate or eliminate the risks or to improve performance as described in the lesson learned. This recommendation is not necessarily a corrective action that is applicable to one specific situation, but a suggestion that could have wide applicability.

In order to enhance the likelihood of receiving contribution(s) from throughout the Program, several "input-bucket managers-led" subteams in collecting and initially analyzing inputs. The "buckets" typically consisted of sets of related projects, including: (1) *Focused Technology and Development Projects*, (2) *Research and Technology (R&T) Projects, (3) Systems Engineering and Integration (SE&I) Projects*, and *(4) Program and Other*. This grouping of lessons into subsets from related sources facilitated some initial combination of two or more inputs into a single lesson. It also provided a basis for checking after subsequent processing to ensure that the results still preserved the perspectives unique to the various buckets.

2.2 Evaluation and Criteria

The team evaluated each input regarding suitable disposition. The three options were: acceptance, deletion for submittal to OExS, or rework, either to achieve clarity or to combine it with another, very closely related input. Clarity of information and potential value for application in the work of OExS were the criteria for acceptance. The team accepted inputs of recommendations or lesson statements if they judged that such inputs had potentially high value to OExS.

The team also evaluated each input with respect to relative ranking: higher, medium, or lower. The values were a subjective product of the potential significance (impact) and the likelihood of occurrence. This closely parallels the concept of risk as applied in traditional risk management assessments. The team often gave higher ranking to broadly applicable management lessons, whereas they usually gave lower ranking to lessons focused on more specific, technological topics less likely to have direct application to OExS.

An analysis of the accepted inputs led to development of a framework for creating subgroups, or themes, of lessons. After being evaluated, inputs were grouped according to one of 10 themes, as illustrated in Figure 1 and discussed in detail in Section 4.0.

In brief, six themes cover most steps in any program or project. The plan process and products delineate how to move from requirements into signed agreements, the basis for allocating resources that enable execution. These elements, or themes, are held together as an entity by program integration and communication, which must include formal and informal aspects of leadership and teamwork, as enabled by trust, respect, and communication. Technology integration provides feedback and guidance while organizational design and development responds to or anticipates larger changes of all kinds. Safety and risk are typically embedded throughout all program themes, but also deserve a place for those lessons that are too specific or pervasive for a good fit elsewhere.

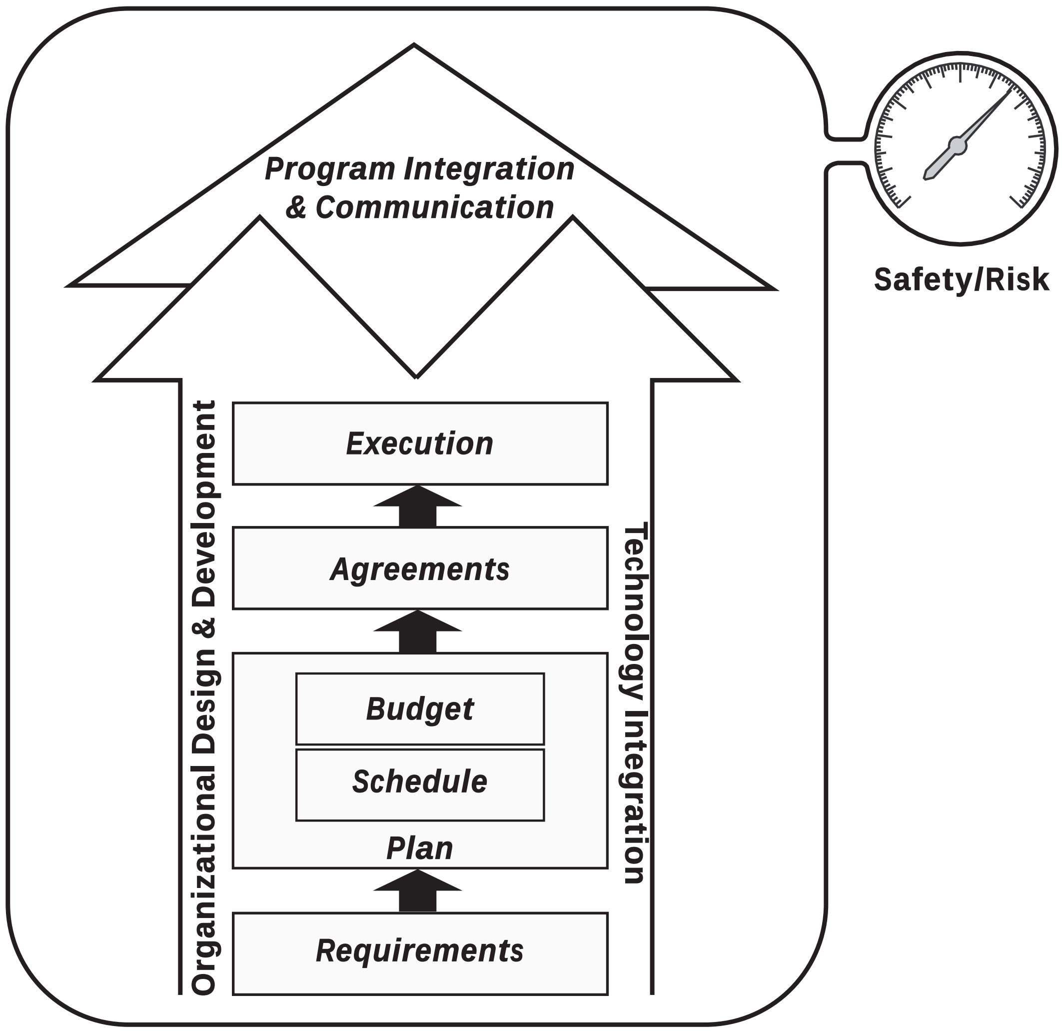


Figure 1. Themes for NGLT Lessons Learned

3.0 Key Findings

Of the total number of lessons learned, the following were considered to be the “key findings” from each theme. (These are cross-referenced to supporting lessons learned (unique identifier in parentheses) in Section 4.0.)

Requirements

- Systems analysis should be used to guide and assess technology development, beginning early in the program. Systems analysis should develop quantifiable priorities and requirements against which technology projects execute (R1, R2).
- Programs should establish reference mission and vehicles/requirements and then implement standard, well-documented flow-down practices to all technology activities, properly educating all personnel regarding those practices (R2, R3).
- Programs should carefully assess the impacts and relevancy of legacy projects toward program goals and objectives before committing resources (R4).

Plan

- Programs should define roles and responsibilities early and all the way down to the supplier level, and communicate and enforce established protocols, responsibilities, and team core values early and often so that expected standards of operation are established for the life of the program (P1).
- The formulation process should not be shortchanged—many critical issues will surface that will later drive cost and schedule (P2, P3, P4, P5).
- Programs should perform a thorough assessment of the manufacturing vendor capability required to produce space-qualified hardware for each development spiral (P6).

Schedule

- Adequate planning should be performed early and realistic schedules developed with both sufficient and visible margins. This should be done initially from as low a level as possible and integrated in coordination with functional leads and analysts (S1, S3, S4).
- An integrated master schedule should be developed early in the formulation phase, which can evolve to accommodate the maturity of the program (S2).

Budget

- Credible, independent cost estimates are required early in the project life-cycle (B1, T8).
- Initial budget estimates must include budget reserves and schedule margins for each major period of performance, with those reserves and margins assigned in proportion to the risk in each period. (B2).
- Program management should establish a centralized resource-integration function early; the resulting team should have the capability for program-wide budget planning, analysis, tracking, reporting, and change control (B3).
- Budget plans should take into account "real world" budget issues, such as delays and disbursements, continuing resolutions, and current limitations in the Integrated Financial Management (IFM) System (B4, B5).

Agreements

- Inter-Agency coordination of technology development should be pursued at the performing level (versus high-level, broad-based agreements), capitalizing on hardware developed and unique capabilities of the partner agencies (A1, A2).
- Partnering agreements should be comprehensive. These should include resources (including reserves and procedures for addressing cost growth) and Safety and Mission Assurance (S&MA), as well as a clear definition of the roles and responsibilities of each team member (A3, A4, A5).
- International relations require constant attention. The NASA international agreements process should be streamlined. Programs should leverage existing international agreements to the greatest extent possible (A6, A7).
- When Centers perform work for contractors (e.g., through Government Task Agreements), the contractor must be given full responsibility and accountability for managing resources (A8).
- Programs should ensure that contracts allow for effective utilization of both government and industry resources: ask only for what the government can effectively use—no more—(A9, A10)—and enable flexibility in the execution of future work (A11, A12, A13, A14).

Execution

- NASA engineering staffs should be utilized to provide technical insight/ independent analysis in high-risk, mission-critical areas. NASA should plan and budget for the appropriate level of insight early in the program. Government insight teams and their industry counterparts should communicate on a regular basis and continuously look for ways to improve implementation methods (E1, E2, OD7).
- Greater prime contractor involvement in technology development programs helps to ensure that the products developed have more immediate utility and require less rework (E3, E4).

Technology Integration

- Rigorous systems engineering and systems analysis processes should be utilized for identifying technical risk to accomplish requirements, technical performance metrics (TPMs), and figures of merit (FOMs) in the formulation stage. These should be used continuously to check progress against goals and objectives (T1, T3, T5).
- Programs should define, plan, and document the processes, procedures, and products for the SE&A function as early as possible in formulation (T4).
- Programs should plan for and require adequate configuration control of analytical tools, models, and data sets and lock down the tool suite during analysis cycles (T6, T7).

Organizational Design and Development

- Dual project reporting paths cause confusion and introduce duplication of efforts. Clear lines of responsibility and authority are necessary for project success (OD1, OD2, OD4).
- Execution of broadly scoped, long-range programs requires an environment of demonstrated trust coupled with appropriate delegation and empowerment to lower-level management (OD3).
- Attention to the organization's discipline, structure, and development is vital to the success of the mission. Opportunities to improve these at all levels should be encouraged (OD4, OD5, OD6, OD7).

Program Integration & Communication

- Integration is a key building block to an effective organization and should be performed on an on-going basis, especially at the middle-management level. A lack of integration, cited in the Columbia Accident Investigation Board (CAIB) Report as one of the causes of failure, is an issue in NASA's culture. This lack of integration results in turf battles, "stove-pipes," and chains of command issuing duplicate and confusing directives. These, in turn, adversely impact budget, schedule, and risk (PC1, PC3, PC5, PC6, PC7, PC8).
- Management should acknowledge employee concerns and have open, frank, and mutually respectful discussions. Such communication would allow for sharing "bad news" early and could shift the NASA culture to one of openness—with two-way, value-added, top-driven communication (PC2).
- Reporting and readiness reviews should be streamlined. Projects should use standardized practices where practical (PC4, E5).

Safety and Risk

- Risks should be identified and tracked early and mitigation options incorporated into the acquisition strategy and systems analysis process (SR1, SR4, SR5).
- A consistent, continuous risk management system should be utilized across the program and clear pass/fail criteria should be developed for risk reduction activities (SR2, SR3).

4.0 Lessons Learned

4.1 Requirements (R)

This section addresses requirements for products as derived from organizational vision and mission statements and/or from specific charters or directives issued by higher authorities. They may be refined through architecture studies, feasibility studies, and other concept exploration.

Establish an Early Link Between Systems Engineering & Analysis and Technology Projects (R1)

Driving Events

Several technology development activities from 2nd Gen RLV and ASTP were combined to form the NGLT Vehicle Systems Research and Technology (VSR&T) Project. Initially, there was no strong link between the VSR&T Project and the SE&A projects. This link was needed to ensure that the proper architectures and, hence, technologies were being addressed.

Without the proper linkage to SE&A, the VSR&T Project may not have been addressing the critical technology requirements for the NGLT architectures under consideration. Later, the System Analysis Project (SAP) attempted to remedy the situation by interacting with the various NASA Centers conducting technology development. An Architectural Design and Technology Initialization Workshop was also held to bring together the various systems analysts and technology developers for NGLT, albeit after the fact.

Lessons Learned

A strong linkage between systems analysis and technology development is needed from the start of the program.

Recommendations

Systems engineering and analysis should be linked to the technology development projects early in the program. Systems analysis should be used to develop quantifiable priorities and requirements against which technology projects should execute. The systems analysis activity should actively engage technology developers throughout the life cycle in developing requirements (working with hardware developers—e.g., utilizing the “Value Stream” process), ensuring models are valid, assessing the progress of the project, and ensuring the continued relevance of the investment against other, competing priorities.

Develop a Set of Reference Mission Requirements Early (R2)

Driving Events

Due to the nature in which NGLT was formed, the SAP was forced to make certain assumptions regarding Program requirements in order to perform initial technology cost/benefit analyses. Once the first annual cycle started, requirements began to flow down from the Program, resulting in disconnects. This necessitated restarting the full cycle.

Lessons Learned

Mission requirements must be provided and frozen at the start of each systems analysis cycle. A "mission manifest" is critical to performing true launch systems analysis. The manifest should include up/down mass, annual frequency, surge rate, and other mission-specific data.

Recommendations

Programs should spend the time prior to each systems analysis cycle to develop and validate a reference set of mission requirements with customer, stakeholder, and analyst approval.

Need for Early Reference Vehicle Conceptual Designs (R3)

Driving Events

In the 2nd Gen RLV Program, the prime contractors developing the vehicle architectures held their proprietary design information very close. Subsystem-level technology developers, e.g., those focused on propulsion and thermal protection systems (TPSs), were forced to derive a broad set of performance requirements due to the lack of a focused vehicle architecture. It was difficult for the subsystem technology developers to determine an appropriate set of environments and performance/life cycle requirements. Although NASA attempted to generate top-level requirements documents, a reference mission, and vehicle architecture, the information flow was slow and, in many cases, non-existent. In this case, the sub-element manager was forced to piece together design information from various prime contractors to arrive at a preliminary set of requirements encompassing all known vehicle architectures and environments.

Lessons Learned

System-and subsystem-level requirements should be developed early in the design phase to ensure a truly meaningful subsystem design and testing phase. Timely requirements flowdown from the prime contractors and lead NASA organization(s) must be improved. The late establishment of program-level requirements requires project restructuring, causing cost over-runs and schedule slips due to constant contract redirections.

Recommendations

A reference vehicle architecture, or clear performance specifications, should be in place prior to the initiation of technology development. A clearly defined process is required for both generating and flowing down system requirements (e.g., associated flight environments) to the subsystem level.

Plan Early for Incorporating Legacy Technology Programs (R4)

Driving Events

All NGLT activities were legacy projects from either the 2nd Gen RLV Program or the ASTP. While the legacy content represented strong candidates for any RLV application, it was not derived by applying consistent systems engineering practices (due to different parent programs). As a result, it was not possible to initiate a classical systems engineering process that would have driven out the needed technologies. This greatly complicated the NGLT systems engineering task.

Lessons Learned

Validated system-level requirements should be in place before technical content of the system can be identified. While the SE&A process did substantiate the need for the technical content of NGLT, it put an added stress on developing systems engineering processes while they were being used to justify pre-selected content.

Recommendations

The systems engineering team should be provided sufficient time to assess the cost/ benefit of legacy projects and impacts of the new requirements on these projects.

4.2 Plan (P)

This section is an articulation of the methods and systems to be employed for satisfying the requirements as well as their relationships. A plan typically combines considerations for technology, resources (e.g. budget, workforce, etc.), and schedule. As used herein, this includes the plan—both as a concept and document—as well as the actions required to develop the plan. Sections 4.3 and 4.4 will address issues specific to budget and schedule.

Clearly Define Roles, Responsibilities, and a Common Set of Values (P1)

Driving Events

The Rocket Based Combined Cycle (RBCC) Project consisted of a consortium of prime contractors. Responsibilities were distributed throughout the consortium, but suppliers would only discuss issues with key decision makers, leaving the expediters and coordinators out of the information loop. In a multi-contractor consortium, the team eventually developed a set of core values: trust, teamwork, and critical knowledge; unfortunately, this came late in the program. A system that encourages team behaviors and discourages divisive behaviors should have been developed and matured earlier.

Lessons Learned

Definition of roles and responsibilities should take place early, be communicated clearly, and continually reinforced all the way down to the supplier level. There should be two-way, open communication so that all parties agree on the responsibilities and understand what is expected of all team-members. The team's core values should also be developed early in the team-building process, and encouragement of desirable behaviors should take place throughout the project life.

Recommendations

Programs should define roles and responsibilities early all the way down to the supplier level with a clear focal point for communication. The government should play a key role in enabling the full team to communicate and enforce established protocols, responsibilities, and the team's core values early and often. This will provide expected standards of operation that are both established and fully understood for the life of the program.

Plan for and Adequately Staff the Project Team (P2)

Driving Events

The X-43C Project was executed by the ASTP without performing a Non-advocate Review. This was based, in part, on similarity to the X-43A (Hyper-X) Project. The scope of effort was also not fully understood or supported by the executing Center management. The first person assigned to the project was the Chief Engineer (CE), who also performed the Project Manager (PM) and Business Manager (BM) functions for nearly a year with minimal help from X-43A staff, who were working return-to-flight activities. The CE was eventually promoted to PM and a new CE and a BM were assigned. Project staffing continued to lag needs, thereby forcing existing project staff to work long hours under stressful conditions. A lack of adequate workforce in the early days of the project delayed development of plans and complicated the project's formulation. The X-43C's similarity to X-43A did not reduce workload during formulation as assumed.

Lessons Learned

Lack of adequate staff during planning and formulation phases causes decreased quality of work output, forcing later revisions to correct problems. Lack of timely and adequate staffing places an unfair and stressful burden on the existing project management team.

Recommendations

Each project should be treated as a new effort with adequate staff from the outset. A PM, CE, and BM should be assigned when a project is initiated. Technical leads for critical areas, a Deputy Project Manager, a Mission Assurance Manager, and Risk Manager should also be assigned as soon as possible.

Allow Time for Adequate Project Formulation, Even When Task Appears Low Risk (P3)

Driving Events

Government cost estimates generated by the Booster and Launch Services (B&LS) Project were in the $48M to $52M range. Initial Rough Order of Magnitude (ROM) estimates from the contractor were 80% higher than the government estimates. The final proposal for this effort was approximately 58% higher than government estimates, despite the fact that government estimates were derived from X-43A actual costs and were considered to be quite accurate. Differences between the previous X-43A effort and the X-43C effort were either unknown or underappreciated. Examples included contractor claims of hardware commonality and reusability, changes in governing range requirements, impacts due to both schedule and funding profile requirements, as well as increased technical and programmatic data requirements.

Lessons Learned

Program should allow adequate schedule for working through the formulation process. This will uncover sources of cost and schedule risk; it may not eliminate them, but the project can at least begin to set stakeholder expectations. Approach the cost estimation effort with the same zeal and require the same breadth of knowledge as one would for a major system design. Project formulation is often the first thing to be sacrificed as funding is allocated, schedule pressures build, and contracts are initiated.

Recommendations

Do not underestimate the need for thorough project formulation and cost estimation, even when the project appears to be a straightforward follow-on effort.

Thorough Preparation is Needed for Successful Acquisition Strategy Meetings (P4)

Driving Events

The X-43C Project initially planned to award a sole-source contract for the Demonstrator Vehicle (DV) based on similarity to the Hyper-X Program (X-43A). An unexpected level response to a sources-sought announcement revealed that a competitive procurement was feasible. Due to the size of the procurement, an Acquisition Strategy Meeting (ASM) was required.

A successful ASM briefing was developed by the PM and Contracting Officer. Briefing charts were developed in a multi-step approach. Two "realistic" rehearsals were held by the head of the langley Research Center (LaRC) Procurement with numerous questions for the presenters. After the charts were reworked and preparations were made for potential questions, a final briefing was completed. This level of preparation enabled the presenters to provide required information and perform well at the actual ASM, answering all questions and providing a well-rehearsed and smooth briefing. The ASM was conducted with excellent results and no action items were assigned. As requested, all subsequent actions were delegated to the LaRC Procurement Office.

Lessons Learned

Adequate preparation prior to conducting the ASM yeilded excellent results without ambiguity and rework. All information and materials required for a decisional meeting were identified and well understood prior to holding the meeting. Expected outcome was clearly identified with a well understood plan for reaching the stated objectives.

Recommendations

Program should repare well for ASMs, spending significant time rehearsing in realistic settings and answering questions from review teams. Programs should be prepared for the unexpected in major procurements by including Risk Based Acquisition Management (RBAM) in the Risk Management Plan.

Provide Early, Comprehensive Test Facility Needs Definition (P5)

Driving Events

In an effort to reduce duplicity and cost, NASA has evolved and consolidated its test facilities over the past 10 years. This reduction in duplicity makes it unlikely that similar facilities will be available for "fly-offs" required under a competitive environment. Additionally, test facility investment and sustainment is required to ensure that the facilities remain in a state of readiness to support program/project objectives. Relevant work in such facilities ensures retention of staff expertise for safety and for effective real-time management of the testing process. As an example, an independent assessment performed by the ARES Corporation determined that the test facilities available for RS-84 component and prototype testing were insufficient. In addition, during 2003, NGLT unsuccessfully attempted to execute multiple test programs at the Stennis Space Center's (SSC's) E1 Test Facility. These included the Integrated Powerhead Demonstrator's (IPDs) Oxidizer Turbopump (OTP), Fuel Turbopump (FTP), RS-84's Battleship Preburner (BSPB), and TR-107's Preburner (PB)/Thrust Chamber Assembly (TCA). Ultimately, the TR-107's PB/TCA testing was removed from the contract due to limitations in facility capability and capacity.

Lessons Learned

The processes that produce, maintain, and sustain test facilities—especially unique and high-energy facilities—are not as dynamic as the programs or projects they support. Typically, investments must be made long before the anticipated project need. Programs or projects have not been front-loaded to support the required facility build-up and theredore, have suffered from either a complete lack of facility capability or a severe schedule impact required to make ready facility systems. "Core" facilities should be identified, upgraded, and sustained to ensure that project formulation is not disproportionately driven by the available facilities. Limiting the amount of competition may be required if duplication of test facilities is prohibited. Detailed evaluation of test facility capabilities and capacities should be performed prior to contract negotiations. The evaluations should be performed with visibility into existing projects and pending contract awards that could impact planning for such test facilities.

Recommendations

Limit test projects if required facility systems are not available. Avoid overly optimistic phasing of test facility projects and rely more heavily on historical capabilities. Allocate funding, as necessary, to allow for construction or modification of back-up facilities for mission-/schedule-critical tests. During proposal evaluation, incorporate a process/procedure for evaluating the test requirements against known capabilities and capacities. Verify that existing and future test projects are considered along with built-in contingencies to reduce the schedule risks associated with overlapping tests.

Assess Project Vendor Base Early (P6)

Driving Events

A contractor proposed to deliver a sub-scale preburner for the RS-84 Project to SSC within 6 months. The premise was its similarity to previously constructed hardware. However, as the design evolved, the similarities began to diminish, due primarily to differences in life and operating pressure requirements. A failure during the single-element testing also showed the need to make significant modifications to the original element design. Testing eventually began 9 months late, causing numerous schedule conflicts with other programs at SSC, as well as cost increases, which resulted in scope reductions. Delays in sub-scale main injector testing were estimated to be 12 months or more at project cancellation. Additionally, the ability of vendors to meet manufacturing schedules based on proposal estimates was greatly exaggerated. Schedule delays were caused by low production rates and by defects, which required rework of various parts.

Lessons Learned

The manufacturing infrastructure for space-qualified vendors is deficient. Second- and third-tier manufacturing vendors often lack the experience to perform fabrication of space-qualified hardware. Regardless of experience with similar hardware built years before, a critical evaluation and comparison must be made between the previous and current designs, accounting for differences before detailed planning and cost estimates are made. Prior performance may not be an indication of current capability due to a number of factors, such as projected workload, layoffs, and changes in management. Other vendors, though new to producing a particular part, may be in a better position to support schedules than previous suppliers. Early process development (material development, fabrication method development, and fabrication planning development) is essential, and a clear understanding of vendor experience and manufacturing capability is mandatory. Finally, clear and constant communication with vendors (involving the prime and government experts) is necessary to acquire adequate hardware.

Recommendations

Programs should perform a thorough assessment of a manufacturing vendor's capability to produce space-qualified hardware and invest strategically to maintain necessary skills and capability for both near-term and far-term milestones. The government should critique proposals based on current requirements, not on past concepts with similar requirements. Programs should choose vendors based on current ability to perform, not solely on prior performance.

4.3 Schedule (S)

This section covers creating a nominal timetable for use of resources and achievement of result, tracking, and updating (i.e., planned versus actual), and the systems and teams involved in accomplishing those activities.

Develop Detailed Schedules as Early as Possible (S1)

Driving Events

NGLT Systems Analysis 1st Launch Vehicle Design Cycle (should cite a specific scenario or provide more explanation like the other Driving Events).

Lessons Learned

Inadequate understanding of the expectations combined with an inadequate schedule assessment resulted in abbreviated and compromised activities, and insufficient time for review. External events impacted the team's ability to complete some critical efforts.

Recommendations

Perform adequate planning and develop realistic schedules with adequate margins in coordination with the analysts and functional leads. Allow internal events to drive the schedule within the preplanned margins. Perform adequate assessment of the impact of external events and re-baseline the schedule if warranted.

Develop an Integrated Master Schedule in the Formulation Phase (S2)

Driving Events

Due to the creation of NGLT as a merger of two different programs, the Program had not fully achieved one integrated master schedule linking all NGLT projects with standardized schedule formats at the time of Program closing. There was some difficulty identifying all key interrelationships between the projects. Another hindrance was the discrepancies with the Integrated Budget and Performance Document (IBPD) milestone dates and the milestone descriptions, especially during the merger process. Later, NGLT placed the milestones under full configuration management.

Lessons Learned

The level of participation by schedulers in all relevant project and program activities limited the NGLT schedule process.

Recommendations

Programs should clearly identify milestones that all projects need to meet (versus a roll-up of project-level milestones) during formulation. This would allow the projects to produce schedules with direct links to a program integrated master schedule. The programs should require early compliance with schedule standardization guidelines, with some accommodations for contractor issues.

Ensure Adequate Schedule/Staffing for Procurement Phase (S3)

Driving Events

During the X-43C procurement phase, the project failed to fully appreciate the timeline to execute respective procurement actions resulting in extended schedule. The full timeline duration from source evaluation board review to award was approximately one year.

Lessons Learned

During project formulation, adequate time should be allotted for understanding and scheduling of procurement actions (i.e., Request for Proposal (RFP) development, proposal solicitation, review, selection, and award). The responsible contracting officer should provide historical timeline data to the project to establish project schedule, and the project should retain schedule margin, as well.

Recommendations

The project should work with procurement staff to ensure that all issues have been addressed in developing a realistic procurement schedule, and then staff the procurement appropriately to ensure that the schedule can be met (right skill mix/number).

Ensure Adequate Margin in Test Scheduling (S4)

Driving Events

ARES Corporation conducted an independent assessment at NASA's request. At the time of the independent assessment, it was determined that the RS-84 prototype phase duration and funding were likely to require either a schedule extension or the immediate start of fabrication of intermediate generations of major new components in order to complete component development testing, engine system testing, and possible hardware modifications due to design changes. Contingency cost and schedule to address several potential technical issues such as combustion instability, coking, ignition, durability, and material compatibility were not defined.

Lessons Learned

Adequate schedule margin and budget reserves should have been identified during the formulation phase to address technical risk.

Recommendations

Formulation-phase schedules should include a realistic developmental test phase with margin that takes into account hardware repairs, facility maintenance, shift operations, re-engineering, and other real-world issues.

4.4 Budget (B)

Budget is, as noted above, part of the plan. It covers the location, tracking, and fiscal processing of resources. This categorization breaks "budget" out as a distinct element simply because it received so much attention.

Credible, Independent Cost Estimates are Needed Early in a Project (B1)

Driving Events

The X-43C Project was a complex hypersonic flight demonstration. Three flight elements were linked to perform the mission. This scenario was similar to the Hyper-X (X-43A) Program, with the exception of the DV propulsion system. The X-43C Project developed an internal cost effort using X-43A actual cost data and heritage United States Air Force (USAF) engine cost data. Two independent cost estimates were performed that were within 10% of the project estimate. Contract proposal estimates came in more than 50% over these estimates. This created significant problems for NASA and the USAF, ultimately contributing to its cancellation.

Lessons Learned

Inaccurate cost estimates place project and program continuity in peril. Project staffs do not have cost-estimating experience and NASA independent cost estimates are lacking. Contributing factors to poor cost estimates are immature understanding of complex requirements, transition to a full-cost environment, "never-been-done-before" content, and insufficient time for program formulation. Badly under-predicted costs wreak havoc on projects, resulting in slipped schedules, de-scope of content, and, potentially, cancellation.

Recommendations

The Agency should possess the ability to perform credible, independent cost estimates. This expertise could be externally procured from DoD or industry contractors. Major procurements should not be awarded before such a cost assessment is accomplished. NASA should implement multi-phase procurements, with options for major development in later phases and/or competitive awards of a separate conceptual design/ cost development contract prior to competition for major hardware development contracts.

Clearly Establish Reserves, Schedule Margin, and Spending Profile Early (B2)

Driving Events

The X-43C Project budget and milestones were established well ahead of detailed cost and schedule analysis. Per Office of Aerospace Technology (OAT) policy at that time, no budget reserves or schedule margins were allowed. As project cost and schedule requirements grew, the only choice was to slip the first flight. The original spending profile was also not compatible with efficient procurement of flight hardware. Inability to adjust the spending profile forced the project to rearrange cost elements to match the profile, adding risk and extending the schedule. Lack of effective reserves, complicated by OAT 1-year spending metrics, exacerbated the problem.

Lessons Learned

Firm budgets should not be established until sound cost and schedule estimates have been developed. Funding and schedule reserves should be provided and managed at the project level. Funds appropriated as 2-year money should be spent as 2-year money. Funds from the first year can be held in reserve and rolled into the second year for immediate spending. This would establish new reserves in current year that can be rolled into the third year, and so on. Overall funding, including reserves, should be consistent with project life-cycle costs, accounting for schedule margins.

Recommendations

Programs should establish preliminary project budgets with adequate reserves and schedule margin adjusting budget and spending profiles as better information is developed. Programs should allow rollover of unspent first-year reserve funds into the next year. The program should track and reclaim unspent reserves if they accumulate to excess.

Centralized, Standardized Resources Integration is Critical to Success (B3)

Driving Events

Budget errors, omissions, and inconsistencies during formulation, coupled with the need for a focal point to respond to and coordinate with Headquarters Management and Center Chief Financial Office (CFO) personnel, were driving events. Complicating factors were introduced into the current resource environment as a result of the implementation of full-cost accounting and the IFM System. There was also a constant stream of questions and requests for budget information.

Lessons Learned

It is important to establish a central program integration team and business staff as early in the formulation phase as possible. Having a program integration team as a single focal point for Headquarters and the Centers was critical. NGLT utilized a single point of contact for sending all NGLT guideline change requests to Headquarters. This allowed the program integration office to field questions and inquiries from Headquarters and Centers. It also gave the Program Office the ability to handle questions and inquiries from a multitude of sources, thus insulating the project managers from unnecessary actions.

Recommendations

Programs should establish a central resources integration office and baseline the budget as quickly as possible, using a formal mechanism for tracking and approving changes (e.g., NGLT Program Requirements Control Board (PRCB). Detailed example: annotate budget spreadsheets with full configuration-control information, including a revision log).

Diligence is Required to Prevent Unauthorized Expenditures Under the Current Integrated Financial Management System (B4)

Driving Events

Currently, it is possible to charge to a project code without a project manager's or business manager's approval. This has happened at least once on a particular project; it was not detected until it was too late to recover the funds. In cases like this, it is difficult to effectively manage the project budget and assess cost performance against the plan; at best, cost data are 4 weeks old.

Lessons Learned

Managers should keep a close eye on budget expenditures against their project to detect unauthorized purchases and effectively track cost performance. Communication between the project manager and the project business officer is critical to enable both to track resources against planned expenditures.

Recommendations

Currently, IFM is not mature enough to effectively manage in-house project expenditures (e.g., no Earned Value Management (EVM) capability). Managers need a backup system until IFM evolves this capability.

Project Plans Should Accommodate "Real World" Funding Disbursements (B5)

Driving Events

Procurements and schedules have been significantly impacted by Continuing Resolutions (CRs) and other budget cycle issues. In addition, Centers often take a large percentage of (incremental) CR fund allotments for operating accounts, leaving a much smaller percentage for the project's tasks, causing schedule slips due to the inability to fund contracts on-schedule. Problems are exacerbated by the uncertainties and risks associated with advanced technology development.

Lessons Learned

Programs should use a budget strategy that addresses risks introduced by CRs and related factors, including costing metrics.

Recommendations

Project managers should develop a strategy for planning and scheduling that accounts for worst-case budget disbursement scenarios. Projects should also keep Headquarters offices informed of impacts such as Center use of CR allotments.

4.5 Agreements (A)

This very broad concept addresses the understandings reached so that resources can be allocated—or other actions taken—based on expectations of results and criteria for achieving those results. These agreements include contracts, grants, cooperative plans, articulation of a partnership, etc.

Teaming Between Government Agencies for Early Technology Development Can Provide Significant Leverage (A1)

Driving Events

The development of the VSR&T Hypersonic Technology Experiment (HyTEx) Re-entry Testbed demonstrated that a properly constructed government partnership, which utilizes the most appropriate technical competencies and unique national assets, can provide a very efficient and unbiased approach for the demonstration and assessment of component technology performance. This model also minimizes duplication of effort and provides opportunities for leveraging, collaboration, and cost sharing where synergistic technology needs exist between various government organizations. With shrinking research and development funding available for technology development and maturation, significant benefits can be realized through pooling inter-Agency resources to increase leveraging opportunities between government organizations. The flexibility afforded by the use of existing government assets can allow for timely demonstrations of component technologies, allowing those technologies to be incorporated at a more mature level (reduced risk) earlier in the system development process.

Lessons Learned

The HyTEx government partnership has shown that partnerships can benefit from: (1) Utilization of each organization's unique expertise, capabilities, and infrastructure (national assets); (2) streamlining the acquisition process by taking advantage of agreements in place between NASA and other government organizations and task agreements between various NASA Centers; and (3) allowing a government-led team to act as a broker to coordinate and integrate the component technology demonstrations between the appropriate platform providers, both ground and flight, and the technology developers.

Recommendations

A government teaming approach provides a viable option for the demonstration and assessment of component-technology performance. Specifically, in the case of a government-team approach, utilize each organization's unique expertise, capabilities, and infrastructure (national assets); streamline the acquisition process by taking advantage of agreements in place between NASA and other government organizations and between various NASA Centers; allow a government-led team to act as a broker to coordinate component-technology demonstrations between appropriate test platform providers and the technology developers.

Leverage Technology Expertise and Hardware from Other Government Programs (A2)

Driving Events

The Turbine Based Combined Cycle (TBCC)/Revolutionary Turbine Accelerator (RTA) project needed a high-performance turbine engine core. A new Centerline turbine engine development would cost at least $1B. The project was able to utilize existing assets from the DoD to provide the core of the turbine engine (i.e., YF-120 engine). The Project included DoD personnel on Integrated Technology Development (ITD) teams to leverage their expertise in turbine engine development, extensive experience with testing aggressive engine systems, and knowledge base of the YF-120 engine. It also included government technical experts from NASA and DoD in ITD teams to leverage their knowledge/involvement in base technology programs/projects such as Ultra-Efficient Engine Technology (UEET), Propulsion Research and Technology (PR&T), Integrated High-Performance Turbine Engine Technology (IHPTET) and Versatile, Affordable, Advanced Turbine Engine (VAATE).

Lessons Learned

The use of Integrated Product Teams (IPTs) with membership from DoD, NASA, and industry expertise enabled the project to leverage knowledge and resources from all sources to reduce cost and technical risk while maximizing return on investment.

Recommendations

Programs should canvas the government and leverage as much technology expertise, hardware, and facilities as possible from other programs to maximize return on NASA investments.

Partners Need Open, Honest Communications (A3)

Driving Events

The X-43C Project was a partnership between the United States Air Force Research Laboratory (USAFRL) and three NASA Centers. The Project's management team aimed to utilize the strengths of each partner and minimize duplication of efforts to conserve resources. One NASA Center repeatedly tried to dramatically increase their management role in the program. Even though this Center appeared to accept their assigned role, they continually appealed to every level of authority in an attempt to have the Project structure altered. Eventually, an independent review of the project's organization by the Independent Program Assessment Office (IPAO) validated the basic formulation of the project and its assignment of roles.

Lessons Learned

Misconceptions and misunderstandings about roles and responsibilities can greatly impact the probability of success. Early understanding, negotiation, and acceptance of roles and responsibility for all involved participants are critical.

Recommendations

Select partners based on demonstrated strengths, matched with project needs. Construct partnership agreements with in-depth descriptions of how the partners will actually execute. (See lesson learned A2.) Hold face-to-face negotiations with all partners in attendance, so everyone benefits from the total of communications. Ensure that all participating partners understand and fully subscribe to their roles from the outset.

Complex Projects Require Detailed and Specific Agreements Between Agencies (A4)

Driving Events

X-43C began as a Joint NASA-USAF flight project involving three NASA Centers and the Air Force Research Laboratory (AFRL). The Project Manager inherited a relatively simple, brief Memorandum of Understanding (MOU) with the USAF that was based on a preliminary understanding of complexity and costs. USAF responsibility was for the development and procurement costs of the propulsion system. As contract costs for the propulsion system increased, the USAF was unwilling to increase funding above the level in the MOU. This forced the project to look for ways to reduce complexity and costs in a crisis management mode. OAT policies and differences in NASA and USAF culture made it impossible to indicate reserves in the MOU. This placed a severe strain on partnership relations when inevitable cost growth occurred and ultimately contributed to the Project's cancellation.

Lessons Learned

A simplistic agreement between partners cannot provide guidance as unforeseen events occur. In-depth understanding and agreement are required to achieve true teamwork. Partnership Agreements for complex programs/projects need to go beyond simple, high-level summaries. The level of detail in the X-43C MOU was not sufficient for costs associated with testing and it did not provide adequate definition of responsibility for cost growth.

Recommendations

Develop detailed Partnership Agreements that are based on sufficiently mature project formulation, or specify a definite schedule for revisions to incorporate details as understanding is achieved. Agreements should have the detail to ensure a true understanding of each party's responsibilities. Specifically address responsibility for cost growth and indicate both budget and schedule reserves in the agreement. Sign agreements at levels high enough to ensure budget commitments can be met.

Ensure Safety Requirements are Agreed to by Government Partners (A5)

Driving Events

On the IPD Project, a significant contract modification was made on a DoD-managed contract with MSFC serving as the technical lead. MSFC had no input on the modification and, as a result, hardware that failed to meet minimum NASA S&MA and accepted industry standards was accepted into the test article. Specifically, the hardware was "proof-tested" at only 80% maximum power level (with standard practice for pressure vessels being 125-150%) and no post-proof non-destructive evaluation was performed. As a partner with DoD on the subject project, MSFC reluctantly accepted hardware that failed to meet minimum Agency S&MA requirements.

Lessons Learned

S&MA requirements should have been fully understood prior to entering into the partnership. Test and Acceptance criteria should have been part of the initial negotiations.

Recommendations

In partnering agreements, all partners should be able to influence contract requirements and make changes as necessary. All partners should have the ability to impose additional S&MA requirements when deficiencies are discovered.

International Relations Must Be Continually Nurtured (A6)

Driving Events

In the fall of 2002 and 2003, a few members of NGLT's staff visited several countries in Europe to evaluate potential cooperative efforts. Upon these visits, the staff found that the cancellation of the X-38 in 2002 left very bitter feelings toward NASA by the European aerospace community. During these visits, the staff was able to initiate relationships with several companies and government organizations. Contact has continued at a very low level.

Lessons Learned

Failure to follow through on NASA's commitment to fly the X-38 resulted in distrust of the Agency. International relationships must be continuously maintained. They cannot be turned on and off quickly and remain effective and beneficial. Like any "business development" activity, it is based on personal relationships and there should be continuity of contact.

Recommendations

NASA needs to continuously build international cooperation at the performing level. If NASA maintains a small effort, the Agency can ramp up quickly, as needed.

International Agreements Process Within NASA Needs Streamlining (A7)

Driving Events

NGLT determined that it would be advantageous to partner with the Australian Centre for Hypersonics at the University of Queensland to obtain flight data for hypervelocity scramjet flow physics in a cost-sharing arrangement. The process, from initial discussion to approval from NASA Headquarters for a sole-source procurement involving a foreign entity, took approximately 15 months. Difficulties in budget phasing, technical progress, and communication resulted due to the duration of this process. (The effort was ultimately not pursued due to changes in program direction.)

Enterprise-level approval was required for policy compliance. However, due to Center roles and responsibilities, approval of NGLT program management at MSFC, as well as line management at LaRC, was required. Guidance from Center and Headquarters export control officials was inconsistent at times, resulting in delays to interpret policy guidance and ensure approval of appropriate agreements. The DoD identified existing data exchange mechanisms that appeared to cover the scope of data exchange between the U.S. and Australia for this project. However, NASA could not provide clear guidance on the use of these mechanisms or partnerships with DoD agencies that involve international cooperation.

Lessons Learned

Guidance from Center and Headquarters export control officials was inconsistent at times, resulting in delays interpreting policy guidance and ensuring approval of appropriate agreements. A binding set of procedures at the Headquarters level was not in place to provide guidance on how to partner with DoD and international Agencies.

Recommendations

Streamline the process by coordinating all international agreements and procurements (if necessary) through Headquarters functional offices, instead of the corresponding Center offices. Initiation of requirements should be made through program, and enterprise-level management. Engage appropriate Agency personnel to consider policy options (i.e., procurement, export control, legal) and identify areas of concern as early as possible. Maximize the use of existing project arrangements and data-exchange agreements (including those established through the DoD) to eliminate the need for NASA to pursue separate agreements if a suitable mechanism already exists.

Industry Must Control Resources When Tasking a Government Laboratory (A8)

Driving Events

NASA Centers often desire to provide support (tasks) to industry-led proposals. This is typically accomplished via a Government Task Agreement (GTA). This agreement is essentially a subcontract to a NASA Center to perform work for a company. However, funding for this work does not come from or through the company to NASA. As a result ,the company does not have full management control over the NASA task. For example, a TPS technology developer requested a NASA Center to perform a series of tests. In fact, the Government facility did not have the test capability they claimed to have in the GTA and was unable to perform the testing. In another case, the Government facility did not perform the work agreed to in the GTA because other higher priority tasks bumped the work from the facility. Industry does not control the resources and, therefore, cannot redeploy to another test facility, thus endangering project success.

Lessons Learned

GTAs have historically been problematic and confusing. Having a NASA Center directly responsible to a contractor without the contractor having complete management control, including funding, creates an awkward, risky situation.

Recommendations

Avoid GTAs where the industry partner does not control the resources. Until other avenues are developed, industry should utilize other mechanisms, such as Space Act Agreements, to engage unique government laboratory capabilities.

Streamline Contractor Data Deliverables (A9)

Driving Events

The original 2nd Gen RLV Program contract awards contained excessive contractor data deliverables that NASA did not have the resources to evaluate. The Airframe contract was renegotiated prior to the Option 2 award. At that time, the Contracting Office Technical Representative (COTR) generated a reduced set of data deliverables for the Northrop Grumman TA-2 program in order to lower overhead costs. Monthly reports became quarterly reports, and many documents were eliminated outright. The result was an increased number of engineering hours available to perform technical work within the budget constraints for Option 2.

Lessons Learned

NASA must balance the desire for insight and measurable, detailed program metrics against the fact that these items are costly. Industry is unlikely to “push back” on these requests in an RFP or negotiation for fear of being non-responsive. NASA should streamline the deliverable data requirements to a minimal set in order to maximize the technical hours available for risk reduction and product maturation.

Recommendations

Streamline data deliverables to prevent large contractor support labor costs; avoid inserting Data Requirements Documents (DRD) “boilerplates” into RFPs. Do not request more financial or technical data than the organization can actually analyze.

Standardize and Assure Earned-Value Clauses in Contracts are at the Lowest-Possible Level (A10)

Driving Events

Due to different (ASTP, 2nd Gen RLV) contract clauses pertaining to business-related reporting requirements (deliverables), some prime contractors were not required to report EVM data and schedules at a low enough level to facilitate adequate schedule and budget analysis. Business data deliverables were interpreted to be reportable only at the top Cost Performance Report (CPR) level, which is much too high to perform analysis or projections of problems and issues that may need to be addressed.

Lessons Learned

Contractors should already have and use EVM data at the lowest planning level. Therefore, it should be straightforward to provide the same level of insight to NASA. This lower-level information provides early warning of problems before they surface at the higher reporting level.

Recommendations

Assure clauses are incorporated into the contract that require contractors to provide electronic EVM data at the lowest planning level, as consistent with NASA/Program-level guidelines for level of EVM.

Contract Statement of Work Should Address Critical Spares (A11)

Driving Events

The failure of a pressure control valve during a test caused two pilot-operated relief valves to lift on the run tank, which was a driving event for the Auxiliary Propulsion Project (APP). A lack of spare hardware and soft goods resulted in several weeks of schedule impact that could have been mitigated. During testing of the Aerojet Reaction Control Engine (RCE), there have been several hardware failures. The lack of ready spares has significantly delayed the completion of testing. The Aerojet RCE is a new non-toxic, dual-thrust technology development with many unknowns. The spares philosophy should encompass manufacturing spares as well as test spares.

Lessons Learned

Identify critical spares needed in the risk assessment of the project. During technology development, hardware failures may occur, depending on the maturity of the technology and type of testing. In order to stay on schedule, it is important to keep sufficient spares on hand in case of testing problems. Secure the spares needed for the project prior to activation tests. The overall cost of personnel and test stand time is generally greater than the hardware spares. In addition, conflicts with other programs for test stand time may preclude the timely resumption of testing, resulting in an overall schedule slip and increased cost.

Recommendations

The statement of work (SOW) for new contracts should request a risk analysis of the testing/manufacturing planned for the project with critical hardware items identified and a spares plan included. The contract should have sufficient funding to initiate the spares procurement. Manage critical spares as project risk items.

Contracts Should Allow Industry to Plan Future Work at an Adequate Level of Depth (A12)

Driving Events

An NGLT contractor not yet under contract requested a schedule change during one project phase that would impact another project phase. The government was unable to evaluate the change because the contractor was not allowed to produce a detailed schedule for future phases of the project.

Lessons Learned

Lack of detailed planning for future work impairs the decision-making process. Project managers need insight into future work in order to assess the impacts of proposed changes.

Recommendations

Program should allow contractors to plan future work to a level of detail necessary to facilitate assessment of proposed changes.

Tie Technology Contract Option Periods to Work Scope and Limit the Number of Options Per Year (A13)

Driving Events

As part of the 2nd Gen RLV Program, contracts were developed for technology development with plus additional option periods. The option periods were not based on the technical milestones but were based on program funding cycles and did not allow the contractor to optimize their SOW across the option periods. Long-lead procurements were a particular issue. As certain parts of the technology development incurred schedule slips, the project ended up with overlapping options so that work did not have to be stopped on other activities. At the end of the option period, the project was often not at a logical stopping point. If the next option period was not awarded

NASA would have lost the return on the previous investment. In some cases, NASA negotiated multiple options in the same fiscal year, diverting time and energy from the technology development task.

Lessons Learned

The technical milestones should drive the phasing of contract options.

Recommendations

Programs should tie contract option periods to the technology development work plan, allow for long-lead procurements of effort needed for future options, and minimize the number of option periods to one per year.

Increase Time Between Option Award and Acceptance Test Plan (ATP) (A14)

Driving Events

Awarding tasks in options is problematic for industry. A 30-day period between a cancellation decision of an option and a new task inception did not allow sufficient time to re-deploy staff to other programs. Option "gates" created anxiety and uncertainty at the contractor level and disturbed the efficient flow of technical progress.

Lessons Learned

Plan option conversions carefully. Inform management and staff of pending option decisions earlier. This will reduce program uncertainty and staff attrition, enhance program continuity, and permit better planning for the new option activity. For example, it may be necessary to order some long-lead materials for an upcoming option as part of the previous SOW in order to meet program schedule commitments.

Recommendations

The Agency should increase the period between option award notification and the authority to proceed from 30 days to 60 days.

4.6 Execution (E)

This section includes all lessons about implementation of the plans, the implementers, the associated sites and environments. These are lessons related to technology development and/or demonstration, especially where a specific technology is considered.

Proper Government Insight Planning is Required (E1)

Driving Events

Due to various internal and external drivers, recent space transportation programs have performed several cycles of program formulation, initiating and canceling projects prior to completion. Several models and management strategies have been employed related to teaming and contracting with industry. The RS-84 government/industry team developed an excellent insight relationship that should be considered by other projects. Recent experience within NASA has revealed the need to maintain adequate skill and insight levels for complex space initiatives. The CAIB Report cited lack of adequate technical insight for critical safety issues and recent development experiences such as X-33 and X-37 also reveal a lack of government involvement in key assessments such as technology readiness and design margins.

Lessons Learned

Government insight is essential to success of large and complex projects, which significantly aids in risk identification and risk mitigation. Both industry and government have responsibilities to support insight activities: industry has the responsibility to provide open and detailed information on technical and programmatic issues, while the government has the responsibility to use the information in a productive way. The government cannot overreact to issues and must allow the contractor time to resolve problems. Communications between the insight team and the contractor must be based on the desire to understand and add value. These are considered appropriate roles for government to support high-risk space technology and space system development efforts.

Recommendations

NASA should provide technical experts to review contractor data deliverables and provide independent analysis in critical, high-risk areas. Projects should decide early on the level of insight required and should allocate resources for that work. Government insight teams and their industry counterparts should communicate on a regular basis. The government should not relieve the contractor of responsibility for success. However, contracts must account for the role of government, and the contractor should be rewarded for working with insight teams.

Independent Analysis of Critical Items can Save Money (E2)

Driving Events

The IPD Project conducted liquid-oxygen powerpack-test operations that required that detailed test requests be generated, processed, and approved by multiple entities. The test request was generated by the contractor, converted to the test area format, reviewed by the contractor and government personnel, and then released to the test operations personnel to execute. On two separate occasions, this process was followed and the request was released to test operations personnel, only to be found in error. Because of the criticality of the request (i.e., IPD had only a single hardware unit) an independent civil service review of the test request was performed. When the test request was compared to the predicted test profiles provided by the contractor, performance redline errors were discovered that would have resulted in premature cut-off of a good test. Catching these errors saved the project the cost associated with conducting a second test and subsequent test turnarounds (approximately $100K apiece). This check avoided cost overruns and schedule delays; however, errors in other performance values could have resulted in a loss of test articles.

Lessons Learned

An independent review should be performed for items and activities that are critical to the project. This does not imply a distrust of the capabilities of those performing the task, but that space projects are very unforgiving. A single mistake can be costly or even catastrophic.

Recommendations

Programs should ensure there is an independent review of mission-critical functions before executing them.

Prime Contractor Should Be Responsible for Inspections (E3)

Driving Events

The IPD Project utilized contracts based on Air Force standards with prime contractors. For a research and development system, this allowed the contractors to define inspections and quality control requirements. In a cost-saving measure, the engine integrator contractor chose to delegate to their subcontractors the responsibility for performing final inspections on hardware they fabricated prior to shipment. Much of the delivered hardware configuration was correct; however, there were several pieces that were not manufactured to print, which impacted the engine assembly schedule. Similar problems occurred during duct, turbopump, and preburner fabrication. The root cause of most of these issues was subcontractor methods of operation. If the final inspection process was performed by the prime (or possibly by an independent inspection group), it is likely that these hardware discrepancies would have been detected prior to installation (at which point the greatest schedule impact is experienced). The prime contractors appeared to have higher quality inspection standards and capabilities than many of the subcontractors.

Lessons Learned

NASA should require the prime contractor to identify all critical features of a part and ensure that they are sufficiently inspected. A subcontractor may evaluate non-critical dimensions, but critical features need the added attention of prime contractor inspectors.

Recommendations

In contracts involving hardware manufacturing or processing, NASA programs should stipulate that primary and final inspection responsibility be maintained at the prime contractor level. The prime should perform as many of the required inspections as possible.

Involve Industry Early in Research and Technology Activities (E4)

Driving Events

In the 2nd Gen RLV Program task, "Ceramic Matrix Composite Control Surface Technology Development," the in-house/vendor team elected to use a processing approach that reduced processing risk by fabricating multiple, separate components, subsequently assembling them using fasteners. Much success was realized using this approach: a Carbon/Silicon Carbide (C/SiC) structural element and a half-scale C/SiC subcomponent were successfully fabricated and tested under extreme environments never before experienced by any hot structure component. However, through participation in the X-37 hot structure control surface program, the project learned that the separately processed and bolted assembly approach cannot meet tight manufacturing tolerances required for flight control surfaces.

Lessons Learned

If active participation from aerospace industry prime contractors had been solicited, the development of the C/SiC hot structure control surface technology within the NGLT Program could have been even more successful and further along in the development process.

Recommendations

Increasing the involvement of knowledgeable personnel from aerospace prime contractors in technology development programs ensures that products will have greater utility to aerospace applications.

Streamlined Design Review Processes can be more Effective (E5)

Driving Events

The VSR&T Project HyTEx Re-entry Testbed Preliminary Design Review (PDR) process was performed using concurrent engineering techniques to significantly reduce the overall design review cycle time and travel requirements without compromising the comprehensive breadth of the design review process. The HyTEx government partnership took advantage of best design review practices followed by the various NASA Centers, DoD, and the Department of Energy (DoE) to derive a streamlined design review process.

Lessons Learned

Lessons learned from the HyTEx PDR process include:

1. Define design review objectives, exit criteria, and process criteria to convene the Board early on;
2. Management buy-in on process to be followed is critical early on;
3. Identify reviewers, screening teams, review teams, pre-board members, and board members that are willing to engage in the process;
4. Require electronic server-based tools to capture design review documentation and to support the Review Item Discrepancy (RID) process;
5. Provide review data packages prior to formal presentations with a short pre-review period where pre-RIDs are accepted (with time needed to review before presentation);
6. Design review presentations are limited in duration with a hard cut-off for RID submission at the end of the presentation process; this requires reviewers and screening/review teams to be present and engaged;
7. Screening teams assign RIDs to the appropriate review teams at the end of each day's presentation;
8. Review teams disposition present RIDs for pre-Board actions following formal review presentations (i.e., do not solve the problem but assign the appropriate action);
9. Pre-Board makes recommendation whether or not to convene the Board based on pre-determined criteria; and
10. Management out-briefs of the review process and results should be planned and scheduled up front.

Recommendations

A streamlined design review process can save time and money, while maintaining an appropriate depth in the review process. NASA programs should carry out proper planning prior to the review and utilize fully engaged participants.

Automated Tools Cannot Replace Experienced Analysts (E6)

Driving Events

In the NGLT SAP, the automation of life-cycle tools was attempted, but the automation was not sufficiently flexible to eliminate the need for experienced expert human analysts.

Lessons Learned

Automation cannot replace analyst and designer interactions. Automation was not sufficiently flexible for all configurations in the space environment (with the "expert" out of the loop). Expert interaction needed to be increased and in-depth understanding of system design was essential for a quality life-cycle analysis.

Recommendations

Programs should not rely solely on automated tools. Human experts should remain in the loop.

4.7 Technology Integration (T)

This theme addresses SE&A as applied to provide feedback and adjustments within "program-phase themes" (i.e., "requirements" through "execution") regarding considerations for technology per se. For example, this covers the formulation, measurement and analysis of TPMs as well as modifications—due to TPM-based feedback—to plans and agreements.

Rigorous Systems Engineering is Needed in Technology Projects (T1)

Driving Events

It was noted by the TBCC Project that timely detailed systems analyses/engineering was needed within projects to make effective cost/benefit decisions regarding configurations and technologies. For example: early in the TBCC Project, legacy hardware (HiMATE augmentor rig) was proposed for flame stability testing. However, cost benefit analysis, systems analysis, and leak testing of hardware showed that new rigs (flame stability and annular/sector rigs) would be technically beneficial and financially prudent. The RS-84 Project identified a single-shaft turbopump as the baseline at the time the proposal was negotiated. Over time, it was discovered that a single shaft for the turbopumps would require significantly more risk management than previously identified. The systems engineering process allowed this to be incorporated into the program decision-making process. During the Northrop Grumman Reaction Control System (RCS) Liquid

Oxygen (LOX)/Ethanol testing, the project experienced three occurrences of a failure of the disilicide coating on the C103 chamber. The project team was under significant pressure due to schedule delays, so an attempt was made to apply a quick fix of the problem without fully understanding the issues. However, the Project Office required the contractor to perform a full fault tree analysis of the problem before attempting any solutions. The team subsequently determined that a new Platinum-Iridium (Pt-Ir) chamber, rather than the coated C103 chamber, could be used to meet the test objectives without having to solve a coating problem not in the task objectives.

Lessons Learned

For the TBCC Project, detailed contractor analyses/engineering, complemented by parallel NASA studies, proved effective in Project decision-making. The RS-84 Project continued to use a systems engineering process throughout the life of the Project, continuously questioning and reevaluating previous decisions, since decisions made early in the project may need revision once more information is gathered. Applying a disciplined systems engineering process helps to manage stress and emotion of the moment to find solutions not evident while working the details. Good systems engineering practices help identify these details and ensure the overall system works well.

Recommendations

SE&A should be executed within technology projects to ensure timely decisions (which are supported with an appropriate depth of analysis e.g., cost/benefit) and coordinated with top-down program-level systems engineering and analysis/requirements flow-down. Programs should ensure the systems engineering discipline is applied even when stress is high and time is short.

A Rapid Response Systems Analysis Team is Invaluable (T2)

Driving Events

Routinely, questions (many hypothetical) from Program stakeholders arose during Program progression. Answering some of these questions called for analysis of various concepts and architectures that were not previously identified.

Lessons Learned

A rigid process that does not allow for flexibility in exploring the trade space and the “reserve” resources needed to address developing ideas may prevent discovery of the “best” solution.

Recommendations

Programs should set aside a quick response "reserve" of resources (manpower and budget) to perform mid-course checks and respond to senior management "what if" inquiries as necessary.

Effective Use of the "Value Stream" Method Requires Active Engineering Organization Participation (T3)

Driving Events

The Program incorporated "Value Stream" as a method to link goals and objectives to tasks being performed. Because of competing priorities, Value Stream often did not have the right level of engineering organization participation adversely affecting the results.

Lessons Learned

For Value Stream to be effective, it needs to be supported by in-depth vehicle and propulsion systems analysis.

Recommendations

Programs should ensure performing engineering organizations are tasked and funded to support activities as a part of on-going design activities, rather than as "add-ons."

Early Development of a Systems Engineering Management Plan is Critical (T4)

Driving Events

NGLT experienced continual disagreement over processes, procedures and products to be used by the Program's SE&A teams, all of which came from different legacy programs, each possessing different requirements and Center perspectives (e.g., esearch versus development). For example, inconsistencies in weights and sizing models and differences in definitions of subsystems, combined with insufficient technical exchange with the various architectural teams, led to incorrect interpretation of data, and inaccurate and/or misleading results that required rework.

Lessons Learned

An agreed-to set of processes, procedures, and products, documented in a baselined and approved Systems Engineering Management Plan (SEMP) would have greatly enhanced the effectiveness of the systems engineering and analysis teams. The SEMP should have been the first item addressed by the SE&A leadership to create a common understanding of definitions, methods, and processes to be utilized.

Recommendations

Programs should define, plan, and agree to processes, procedures, and products for the SE&A process as early as possible and formally document in a SEMP.

Establish and Flow-down Technical Performance Metrics (T5)

Driving Events

ARES Corporation completed an independent assessment of the IPD Project at the request of NASA. At the time of the independent assessment, it was determined that IPD Project TPMs (e.g., achieve 250-KLb thrust, to throttle between 50% and 100%, etc.) were not appropriate for project objectives, i.e. development of a start sequence and validation of key components and tools. Unresolved component issues (such as oxygen-turbopump lift-off seal, fuel preburner-combustion instability and oxygen PB ignition) threatened the success of system tests. At the time of the independent assessment, it was determined that NGLT Level 1 TPMs and goals had not been formally translated to Level 2 system TPMs or Level 3 component TPMs. As a result, the technologists had generated Level 3 TPMs without input from the Systems Integration Project (SIP)/SAP on Level 1 goals.

Lessons Learned

Without adequate attention to the relationships between higher level goals and lower level TPMs, the linkages can be weak.

Recommendations

Programs should develop trackable, requirements-based TPMs that will help manage the project performance based on stated objectives.

Provide Configuration Control of Models, Methods, and Data Sets (T6)

Driving Events

Many NGLT analyses had several iterative runs that were captured only by the analyst performing the analysis. The acceptance of this "tribal knowledge" capture is something that costs time and money in the future by driving the need to "reinvent" analyses to validate the touted solutions.

Lessons Learned

The lack of adequate configuration control on analytical tools, models, and data input impairs the ability to validate any original analysis for a given topic.

Recommendations

Adequate documentation must be coupled with configuration control on analytical tools, models, and data sets actually applied.

Freeze Methods/Tools During the Analysis Cycle (T7)

Driving Events

In performing simultaneous tools development and systems analysis, it was discovered that analysis activities must be insulated from on-going tool development activities and that tools configuration, and methodologies must be frozen during each design cycle.

Lessons Learned

Programs should freeze tools and processes configurations during an analysis cycle. Analysis activities must be insulated from tool development activities. Adequate time for process and tool testing is also essential.

Recommendations

Programs should separate tool development activities from analysis activities and freeze the methodologies and tools prior to initiation of each design cycle.

Space Transportation Life Cycle Analysis Tools Need an Overhaul (T8)

Driving Events

It was realized early in the NGLT SAP that the analysis tools and underlying databases for life-cycle analysis needed an urgent upgrade. To address this need, SAP created a team called the Life Cycle Analysis Team (LCAT) to develop methodologies to improve the analysis of reliability, supportability, development cost, recurring cost, safety, availability and other life cycle-related parameters. One example of needed improvement is the area of operations costs. Current tools do not allow for the evaluation of creative new methods of performing operations. All current tools are based on Expendable Launch Vehicles (ELVs) and Shuttle; accurate cost cannot be developed for operations designs that vary significantly from these operations approaches. One method would be to develop a discrete event simulation to model the operations costs and allow the program to represent costs for more creative operations approaches more accurately.

Lessons Learned

Investment in LCAT database development and validation is required to move beyond Shuttle-based parametric operations analysis. Discrete Event Simulation (DES) capabilities require further focused effort and much still needs to be done to improve the ability to perform stochastic life-cycle analyses. Most existing tools are still parametric; deterministic tools are adequate for top-level trades but not suitable for in-depth analysis with variability. There is a need for a common, validated life-cycle data repository to provide a solid foundation for all life-cycle analysis tools and models: historical system data, validated Shuttle data, validated ELV data, and as other system data (B-2, SR-71, Concord, etc.).

Recommendations

Continued investment is needed in life cycle analysis tools, methods, and databases. During the development of systems, it is essential to understand impacts on the life-cycle costs, safety, reliability, etc.

Utility Curve Analysis Method Aids Complex System Trades (T9)

Driving Events

To design a new rocket engine for the NGLT Program, numerous trade studies had to be conducted. In each trade study, a choice had to be made between competing designs to select the optimal solution for the engine. Potential design options also had to be evaluated against multiple program objectives, some of which conflicted at times. The prime contractor for RS-84 implemented a utility curve analysis to help drive decisions during difficult, complex design trade studies. The method involves polling or surveying of the applicable customer base to allow numerical determination of utility indifference curves. The customer preferences toward program goals such as low-cost, high-reliability, high-thrust to weight ratio, etc., were then weighted appropriately. The utility analysis allowed the determination of a numerical score for each potential design solution. The design option with the highest score best met the customer objectives and was selected for the final engine design.

Lessons Learned

The utility curve analysis was able to provide a realistic and quantifiable assessment of the value of a given technology or design against the program-established criteria. This analysis had the flexibility to perform repeatable and rigorous trades with different weighted values for the given criteria derived from program FOMs.

Recommendations

A utility curve analysis approach to assessing detailed trade studies should be considered in future activities, especially where numerous design solutions exist in an environment with multiple program goals and objectives.

4.8 Organizational Design and Development (OD)

This section addresses the formal and informal organizational structures and element-to-element relationships. Roles and responsibilities for individuals and groups are key here. Emphasis is on changing to meet changing needs and situations.

A Simple, Clear Management Chain is Critical (OD1)

Driving Events

The X-43C Project was required to report up two management chains to the Center level, one for "programmatic" issues and one for "implementation" issues. These areas of a project are not separable, as they continually interact. In addition, there was also a direct management chain to the Headquarters-level, NGLT Program Management Team. Often, an action would be levied on the project from two or more sources, with slightly different interpretations, disguising the fact that it was a single action. Management issues surfaced that were addressed through one chain, often offending the other. One chain sometimes challenged the other in overlapping areas, causing confusion for the project.

Lessons Learned

Within a Center, a single management chain is a necessity. Multiple reporting chains within one organization cause confusion, difficulty, and inefficiency in project management. Multiple management chains result in "turf" battles, duplication of effort and other distractions for the project staff in status reporting.

Recommendations

Projects should report through a single, clear Center management chain. Programs should minimize the number of levels between the Project Manager and the Center Director for significant and/or highly visible projects. A single Center-level manager should be responsible for making final decisions at that Center for a particular set of projects.

Project Plans Must Clearly Specify Roles and Responsibilities (OD2)

Driving Events

Organizationally, the Booster and launch Services (B&LS) Project Manager was at the same level as the X-43C DV Contract Manager. The Level III Project Office possessed all technical and managerial expertise required to execute the project scope. The DV Contract Manager did not have budget and schedule authority. DV technical insight was provided by the Level II technical staff. Difficulties arose as the Level II staff attempted to exert the same influence on the B&LS Project as it had on the DV Contract. A Level II Project Plan that fully explained the project roles and responsibilities and clarified project controls was not approved prior to project cancellation. In contrast, the NGLT SAP management established and documented clear goals and individual responsibilities at the beginning of the project formulation, so that all team members understood what was expected of them.

Lessons Learned

Managers should ensure that the need for visibility into a subordinate activity is not transformed into an approval loop. Projects are autonomous entities charged with executing defined scope. When sub-projects are formed, they will expect to act as autonomous entities with full authority to accomplish the scope of the project within agreed-to budget and schedule boundaries. Organizational roles and responsibilities must be complementary to the autonomous nature of projects. If an autonomous entity is not desired, then the sub-project should not be formed. Organizations that place superordinate staff in an approving role over the project's (or sub-project's) decision-making authority risk creating confusion over roles and responsibilities and building animosity between the groups.

Recommendations

Programs and Pprojects should write a Project or Program Plan early, leaving some place-holder sections in order to establish the control mechanisms that will be employed on the project. Early releases of the plan can be baselined at the project- or program-level only. Specify how critical financial, schedule, and technical decisions will be made. Controls (i.e., approval gates and processes) should be clearly defined in concert with the level of responsibility delegated to the project or sub-project.

Delegate Responsibility and Then Follow Through (OD3)

Driving Events

The ASTP (and later NGLT) Program delegated much responsibility for the X-43C Project to LaRC. A single Project Manager was given authority to manage the project for the parent programs. The Program Manager provided general guidance without interfering with project management. Appropriate status reporting was required of all projects by the Program. This arrangement applied a sound management approach and demonstrated trust in the Project Manager and his Center managers. In effect, the Program Manager defined and enforced a chain of command that fully supported the Project Manager's authority.

Lessons Learned

Effective and realistic delegation of responsibility, with authority to match, created a supportive and cooperative atmosphere in which Project Managers could work. Project Managers were supported without interference in day-to-day decision-making activities, which facilitated timely and effective decisions.

Recommendations

1. Program Managers should delegate responsibility for project execution, with matching authority, to the subordinate Project Managers. Enforcement of this chain of command facilitates effective project management at supporting Centers.

2. All projects should have a single manager with appropriate authority to execute the project.

3. Status reporting to the Program should be enforced at the lowest level of detail and frequency, consistent with project complexity and visibility.

Identify a Single Leader and Properly Staff Systems Engineering Activities (OD4)

Driving Events

The NGLT Systems Engineering Office was not fully capable of meeting expectations due to inadequate staffing, unclear roles/responsibilities, and inadequate planning. Multiple organizations performed systems engineering functions across multiple Centers with unclear lines of authority.

Lessons Learned

A method and plan for performing systems engineering should be established during the planning phase of the Program based on actual needs of the Program. Any divisions of responsibilities should be based on natural splits within the work as it is defined and should be delegated based on validated capabilities and commitments of the Centers to undertake the efforts.

Recommendations

Programs should have a single authority for systems engineering and integration, obtaining clear commitments from participating Centers on both lines of authority and the deliverable work package. Related staffing issues should also be resolved up front.

Encourage Management and Organizational Development (OD5)

Driving Events

NGLT contracted with professional organizational consultants to facilitate the development of management skills within the organization. Workshops focused on developing understanding of individual roles as well as roles of those above, below, and beside them. This basic understanding led to increased effectiveness at all levels of the organization.

Lessons Learned

The use of an outside consultant can surface issues that are not apparent to those within the organization. A professional with the capability to recognize needs and develop personnel can greatly increase the effectiveness of even the best managers.

Recommendations

NASA programs should provide regular organizational development opportunities to all Program personnel.

Establish Formal Change Control at All Levels (OD6)

Driving Events

A formal change control process was not in place at the X-43 Project level (Level II). The Level III project incorporated DV design requirements such as outer mold line, mass properties, and separation point requirements into its Launch System Requirements Document (LSRD). Over the life of the project, changes were made in the DV baseline by the Level II office without official notification to the B&LS Project (Level III).

Lessons Learned

Changes to technical and programmatic baselines have far-reaching ramifications to all elements of management, modeling, and analyses. The need for methodical change control is more crucial when critical vehicle elements are produced by separate Centers or under separate contracts.

Recommendations

NASA programs should establish a formal change control process and critical baselines early at all levels of an activity (Levels I, II, III), and ensure that these baselines are communicated clearly across all elements.

NASA's Unique Organizational Perspective Can Help in Problem Identification and Resolution (OD7)

Driving Events

The IPD Project was the first project to test a liquid oxygen turbopump fully supported by hydrostatic bearings. This unique bearing design benefits include "floating" the rotating shaft on a thin film of liquid oxygen fluid. Because NASA technical experts were not part of the design team (being designed when IPD was an Air Force-only project), a detailed technical review was held prior to the initial test. During this review, concern over electrostatic discharge was raised. The contractor responded that the phenomena had not been encountered in liquid oxygen before and therefore was not a concern. NASA reviewers were aware of similar issues with other contractors and from in-house experience. NASA personnel disassembled a similar in-house turbopump looking explicitly for evidence of electrostatic discharge. Evidence showed that the phenomena had occurred in liquid oxygen, and indicated that the severity of the arcing was sufficient to ignite the carbon lift-off seal in the oxygen turbopump should the arc occur at that seal, with potential catastrophic results.

Lessons Learned

Detailed technical review of a mission-critical design by NASA subject experts is a prime opportunity to catch obscure technical issues that may not have been experienced by a contractor's design team. NASA subject matter experts are exposed to many contractors and varied design alternatives providing an expanded experience base that a single-contractor design team may not possess.

Recommendations

Critical aspects of contractor designs and tests should be reviewed by NASA subject matter experts to increase the likelihood of success.

4.9 Program Integration and Communication (PC)

This section covers the relationships and interactions between program elements—by formal or informal mechanisms—that correlate to achieving the greater good of the program objectives/goals. Transmittal of information—communication—is an essential precursor to any decision or action. Hence, communication is an integral part of successful program integration in its broadest sense.

Middle-Management Integration is a Powerful Tool (PC1)

Driving Events

The NGLT middle-managers forum for integration across the program greatly improved overall program execution. This forum was championed by one middle-manager who knew that his peers would have a tendency to pull away from each other and work in their own "silo." This would have caused a lack of integration across the program and likely less teamwork among the program office staff. The forum set-up caused these middle-managers to take integration seriously and avoided costly breakdowns in communication at their level.

Lessons Learned

Creating a middle-manager's, peer-level forum for integration at the Program Office increased teamwork and improved communication across the Program. These middle managers were able to support each other's efforts and avoid isolation where lack of integration could result in duplicate efforts and less than optimum progress on projects. Lack of middle-management integration impedes communication of unique critical information each manager possesses, and potentially creates silos that work against each other. The CAIB Report identifies a lack of integration as a driver of accidents wherein one element of a program is not cognizant of what another is doing. The program-level middle managers took it upon themselves to pre-empt this potentially harmful issue.

Recommendations

NASA programs should create a middle-managers' forum for integration at the Program Office-level. Program managers should pay close attention to how middle managers integrate with their peers and ensure communication is flowing, thus contributing to improving safety, eliminating duplication, and promoting good working relationships across the elements of the Program/Centers. Programs should also explore the potential for applying this concept at other levels of the organization.

Create an Environment That Will Accept "Bad News" by Management (PC2)

Driving Events

A program's accomplishments depend on good, open, and integrated communication. The CAIB Report highlighted the issue of keeping a "code of silence" and its detriment to the success of a program. This occurred within NGLT as well. One example was how the SE&A function's project-level management had issues in working with each other and the Program Office; as hard as they tried, they could not be as open as they needed to be to resolve their issues.

Lessons Learned

The driving event reinforced the fact that NASA as a whole does not like to hear bad news. Therefore, people fear bringing bad news forward to the Agency. The level of discussion around monthly status reports and the influence of Center management regarding what "could be shown to the Program Office" was an example of keeping bad news under wraps. Upon further examination, a strategy of "containment" was discovered that was driven by the overarching theme of "image management" within NASA.

Recommendations

Programs should consider the "Crucial Conversations" approach used in NGLT, which effectively deals with organizational cultures that historically encourage silence or retribution. Educate/train people at all levels of the organization and give them a set of tools that will help in overcoming this detrimental way of operating.

Document Decisions and Supporting Rationale (PC3)

Driving Events

In some instances, there were not enough details regarding the decision rationale for technology and/or launch vehicle analysis for validation of analytical results to prevent duplication of effort.

Lessons Learned

There are times when the selection of one option over another is not led by analytical data, but rather by political or other influences. The proper documentation of assumptions and conditions that drive decisions is vital to eliminate the potential for performing the same analyses again in the future.

Recommendations

NASA programs should provide adequate documentation of decision rationale for validation of analytical results to prevent later duplication of effort.

Standardize and Minimize the Number of Different Project Reporting Mechanisms (PC4)

Driving Events

The X-43C Project reported progress to ASTP (later NGLT) first on a monthly basis and later in a Quarterly Report, each with a unique required chart format. During the same timeframe, X-43C reported to the LaRC Center Program Management Council, which required yet another chart format. All chart sets contained largely the same project management data and status reporting. However, the formats were different, requiring the project team to create multiple versions of the same data. This increased the workload and added risk of error due to the rework process.

Lessons Learned

Production of different versions of status reports added no value but created potential for errors. This practice created confusion when one group of reviewers saw charts in another, unfamiliar format, often requiring explanation. Project management status reporting requires a nearly universal set of data generated by project management tools (schedule, budget, workforce, risk management, and technical accomplishments); therefore, one format should be sufficient for multiple forums.

Recommendations

Programs should adopt a common format for project management reporting and coordinate with Headquarters and each Center's Systems Management Office to enhance communication and reduce workload on project staff. Programs could also develop a "super-set" of formats to cover anticipated reporting needs at all levels.

Project Teams and Systems Analysts Need to Work Closely When Performing Technology Assessments (PC5)

Driving Events

Due to the nature in which NGLT was created, there was not initially a tight integration between SE&A and the technology projects. Technology projects were not cognizant of what was going on within SE&A activities. In early FY04, the SE&A team held a "road show" that took the results of the previous cycle of analysis to all Centers to demonstrate their activities to the technology projects. This team also conducted an Architecture Design and Technology Integration Workshop prior to the start of the next analysis cycle to discuss the technology impacts on system designs and identify a viable baseline and alternate technology options. This workshop provided a forum for technologists to discuss how their technologies impacted system designs with the systems analysts. In the past, Value Stream workshops were held at the end of each cycle to facilitate a meeting between technologists and systems analysts to identify shortfalls in capability versus need.

Lessons Learned

Close integration between systems analysts and technology projects is necessary to properly identify viable baseline and alternative technology options at the start of an analysis cycle, and then to identify shortfalls in capabilities versus requirements at the end of the cycle. System definition should start with a state-of-the-art technology baseline, identify the technology portfolio that enables FOM achievement, and then consider additional technologies that enhance FOM achievement, limiting additional enhancing technologies to those that have cost, schedule, and risk-to-develop data already in hand.

Recommendations

Technology projects should be made aware of systems analyses that are being performed and the parameters that are being used throughout the assessment process. The use of structured forums at the beginning of the analysis cycle and a Value Stream workshop at the end of each cycle should be a part of any technology program. Representatives from each technology project should be represented on the systems analysis team(s).

Set Clear Expectations in Design Reviews (PC6)

Driving Events

At a recent PDR, it became obvious to the Government team that the contractor did not understand NASA's expectations and requirements for the review.

Lessons Learned

NASA standards for reviews need to be clearly communicated to contractors before the contract is signed.

Recommendations

NASA should ensure that expectations and requirements for contract items such as milestones and deliverables are clearly stated in the contract SOW and understood by the contractor.

Effective Vertical Communications are a Necessity (PC7)

Driving Events

During the life of the RS-84 Project, several team members expressed frustration with their lack of knowledge regarding activities at the project, program, and Headquarters levels. Team members felt that there was inadequate "top-down" communication.

Lessons Learned

Top-down communication from Headquarters to program to projects to IPD/ITD (subproject-level) teams is recommended to assure good systems integration and decision-making. This type of communication also ensures that team members understand the reasons behind Headquarter's program and project decisions. The RS-84 Project utilized a biweekly newsletter, which was well-received by their project, in which articles were written by individuals from the project, Program Office, and NASA Headquarters. Later, the Deputy Program Manager made quarterly visits to the NASA Centers, meeting with working-level employees and reviewing their work in the lab. This was well received by the employees and gave the Program Office good insight into project progress.

Recommendations

NASA programs should consider interactive communications rather than the one-way variety such as e-mail. Senior program personnel should schedule times to conduct project team "all-hands" to speak to team members and answer questions.

Capture "Lessons Learned" Throughout the Project Lifecycle (PC8)

Driving Events

During X-43C Project development, many lessons learned from the X-43A Project were incorporated informally by shared technical and management personnel. Because of shared resources, many management and technical decisions and subsequent activities were not formally captured. This situation drove the need to repeat communications regarding decision rationale to new personnel and outside reviewers.

Lessons Learned

Project and systems engineering plans should formally capture and address lessons learned with direct correlation to past experience. If relevant information is not available in documented databases, the Project Office should actively pursue and document respective information through formal interview if relevant ongoing activities exist. Lessons learned should be included on a continuous basis in risk management activities to enhance communication.

Recommendations

Lessons learned activities should be performed at the working level on a continuous basis throughout the life of a project, as are risk management reviews. Lessons learned activities should be tied to risk management activities because they often result from unidentified, unmanaged, or misunderstood risks.

4.10 Safety and Risk (SR)

Safety and risk are affected, often to a first order, by changes anywhere within the Program. Lessons learned in this section are limited in number, since safety is best appreciated as being "everywhere." Additionally, managers of advanced-technology-development projects are increasingly using risk management as a primary tool to guide most aspects of their projects.

Identify and Track Risks Early and Incorporate into Acquisition Strategy (SR1)

Driving Events

The X-43C Project compiled and managed risk early in the project formulation. By initiating the risk process early on, project plans and associated reasoning could be explained early and effectively.

Lessons Learned

A thorough risk management plan and database keeps risks at the forefront of the decision-making process and provides a foundation checklist for the project team to communicate consistently both internally and externally.

Recommendations

NASA programs should prepare risk management plans early in project formulation and include budget analysis and Risk-based Acqusition management (RBAM) activities to serve the project during formulation and startup.

Use a Consistent Risk Management System Across the Program (SR2)

Driving Events

NGLT technology content represented risk mitigation activities for RLV. Risk assessment and management were the responsibility of each project team, each of which brought a different system from their legacy programs. The most commonly used system was resident in the Space Transportation Information Network (STIN), but some projects used other Commercial Off-the-Shelf (COTS) tools. While risk management was performed, it was not performed at a uniform level across the Program. The STIN risk tools were under constant development, which also complicated matters.

Lessons Learned

A complete and proven risk management tool should have been selected for use by all projects. Project-level risk mitigation plans should have been reviewed in a more stringent manner to ensure they were realistic and consistent with Program directions.

Recommendations

Programs should select a proven risk management system that represents an industry standard and then train the users in its application, making sure that expectations are understood from top to bottom in the organizations that are to be using the system. Programs should also provide mandatory risk management training to all members of a program/project team (including contractors) with periodic refresher training to accommodate personnel changes.

Develop Specific Pass/Fail Criteria for Risk Reduction Activities (SR3)

Driving Events

The RS-84 Risk Management Program evolved as the Rocket Engine Prototype (REP) Project matured. Each IPT conducted monthly meetings, with NASA participation, during which a status of each risk was discussed. Descriptions of risk mitigation/reduction steps were updated and refined, and actions were assigned for implementation of the plans. New candidate risks were presented for review/validation and, if approved, new risks were assigned owners for assessment and planning.

Lessons Learned

Consistency among IPTs in methodology for risk definition, assessment, planning, and review was difficult to achieve and maintain. Many of the risk mitigation/risk reduction activities included in the risk plans lacked specific pass/fail criteria. For critical project/program risks, backup/contingency plans should be developed as early as possible.

Recommendations

Programs should ensure pass/fail criteria are established as an integral part of the planning phase for risk reduction and mitigation activities. Programs should develop specific decision criteria for implementation of back-up/contingency plans or modification of the design or development effort.

Perform Technology Risk Assessment as an Integral Part of Systems Analysis Efforts (SR4)

Driving Events

A technology risk assessment was performed for NGLT on an uncertain schedule, often hurriedly at the end of an analysis cycle. In some cases, there was inadequate time to fully validate the results of the assessments.

Lessons Learned

Technology risk assessment process should have been applied in the NGLT integrated SE&A process in the continuous and integral fashion required to provide a thorough and validated assessment of technical risk for technology investment planning.

Recommendations

Programs should plan for continual interaction between the end-users and the design analysts, such that performance of the risk assessment process will provide the desired benefit.

Develop Alternate Strategies when Incorporating New Materials and Processes (SR5)

Driving Events

ARES Corporation completed an independent assessment of the IPD Project at the request of NASA. The following lessons learned were part of the resulting findings.

Lessons Learned

At the time of the independent assessment, it was determined that numerous fabrication processes (alloy duct forming, joining processes, powdered metallurgy formation of large parts) must be developed in conjunction with the use of super alloys in order to achieve optimum oxygen compatibility/durability and engine weight objectives. The REP design would have essentially been complete and fabrication would have begun by the time critical operational experience was obtained with the key technologies on the IPD Project. In addition, sensitivity of new materials to high-pressure, high-temperature oxygen conditions in sizes larger than coupons is unknown.

Recommendations

Projects should develop and demonstrate qualification processes for flight hardware fabrication and inspection during the prototype design and fabrication phase and develop proven, fall-back approaches (e.g., heavy welded ducts, oxidation resistant coatings, etc.) to control expenditures if fabrication or testing difficulties arise on prototype components.

Appendix A — NGLT Program/Projects Overview

The NGLT Program's purpose was to advance the state-of-the-art in critical and high-payoff technologies to enable low-cost, reliable, and safe future generations of space transportation systems. All NGLT elements sought to advance enabling technologies that were currently not technically or economically feasible. The missions included safe, routine, Earth-to-orbit transportation to enable NASA's exploration and development of space, thus enabling new commercial space markets, and enhancing the Nation's security through partnerships with the DoD.

The NGLT Program was organized into three segments (see Figure 2): (1) Propulsion Technology, (2) Launch Systems Technology, and (3) SE&A:

The Propulsion Technology segment addressed critical, high-payoff technology risks associated with future launch propulsion systems. The core projects in the Propulsion Technology element were the development of a prototype LOX/Kerosene rocket booster engine, an RBCC ground demonstration engine test bed, and a TBCC ground engine test bed. In addition, cross-cutting propulsion component and subsystem technologies were being developed in support of these test beds and operational engine needs.

The Launch Systems Technology segment addressed critical, high-payoff technology risks associated with future launch vehicle systems. This payoff technology included aerosciences, propulsion/airframe integration, structures and materials, vehicle subsystems, IVHM, and operations. A central project in the Launch Systems Technology segment was the flight demonstration of a dual-mode scramjet propulsion system integrated with an airframe (X-43C).

The SE&A segmentprovided SE&A to integrate the activities within NGLT. These analyses were utilized to focus and guide technology investments.

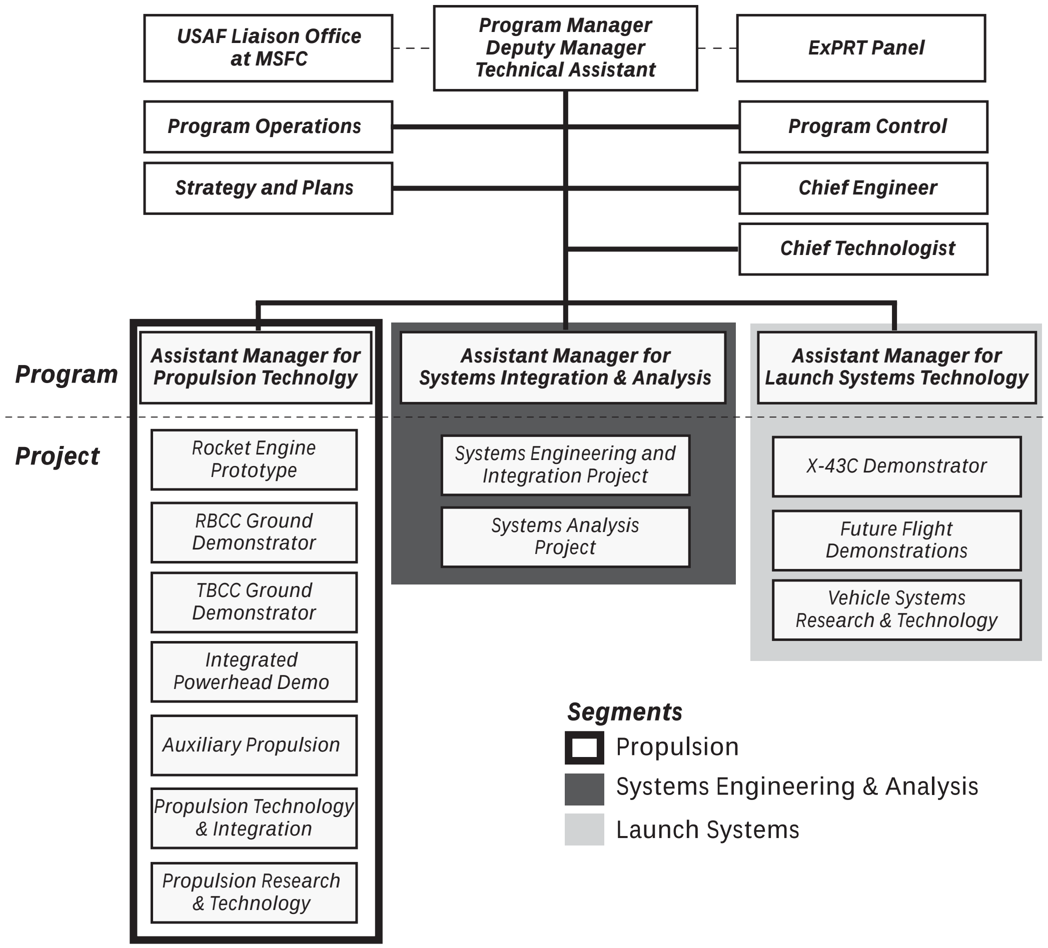


Figure 2. NGLT Organizational Chart

Rocket Engine Prototype (REP) Project

The 2002 2nd Gen RLV Studies identified a large LOX/Rocket Propellant (RP) engine as the probable best choice for a next generation booster engine. Subsequently, NASA contracted with Boeing-Rocketdyne for the design of a 1.1 Mlb-class thrust engine prototype, using an Oxygen Rich Stage Combustion (ORSC) engine cycle.

The objective of the REP Project was to provide risk mitigation for a large class ORSC engine. REP was designing and planning to test a high-fidelity prototype engine that supported NASA's increased safety and reliability goals and reduced operations and cost goals. REP was to validate existing analytical tools needed to support prototype engine development by correlating data from subscale and full-scale testing, as well as developing and validating new analytical tools as required to develop the flight ORSC engine system. This included the RS-84 subproject with Rocketdyne, which designed and performed risk mitigation experiments towards REP goals.

The REP Project was discontinued in 2004 as a result of a review to determine project relevance to the Nation's Exploration Vision.

Integrated Powerhead Demonstrator (IPD) Project

The AFRL initiated the IPD Project in August 1994. The objectives of the IPD Project were to design, fabricate, and test the power packs of a 250,000 lb- thrust rocket engine that would meet the performance requirements of the Air Force Vehicle Technology Directorate. These requirements were to demonstrate continuous engine throttling capability to 20% on a LOX/hydrogen engine while achieving the lowest life cycle cost. Boeing-Rocketdyne was selected to develop and test the high-pressure turbopumps. Aerojet was selected to develop the full-flow cycle preburners. In 1996, AFRL received additional funding for the Project and expanded the scope to include a complete demonstrator engine system. Rocketdyne received the contract to produce the main injector and control engine integration tasks, while Aerojet received the main combustion chamber and stub nozzle activities. The new items were special test equipment (STE) and were not required to be flight-like designs.

In 1999, AFRL and NASA entered into a partnership for IPD. NASA/MSFC provided the funds to support the initial testing build-up activities for the IPD activity under the ASTP. IPD is a jointly managed project between MSFC and AFRL. The IPD Project was selected for continuation as a result of a review to determine project relevance to the Nation's Exploration Vision. IPD testing will be completed in 2005.

IPD Project goals are:

- Demonstrate Feasibility and Benefits of the Full Flow Cycle
- Provide Key Component Technology Validation for Rocket Engines:
  - Channel Wall Nozzle
  - Hydrostatic Bearings
  - Hot Isostatic Pressure-bonded high PC Main Combustion Chamber
  - Gas-Gas Main Injector
  - Single piece turbine blisk
  - LOX-rich Material development
  - Platelet Injector design
  - Clutching Bearings
  - Fuel Turbine tip damper system
- Provide Validation of Tools being used by prime contractors

Rocket Based Combined Cycle (RBCC)/Integrated System Test of an Air-Breathing Rocket (ISTAR) Project

The RBCC/ISTAR Project was a risk-reduction activity intended to advance the state-of-the-art for RBCC engines through design, development, fabrication, and testing of a Ground Test Engine (GTE). An RBCC engine is one in which rockets are integrated with the air-breathing, dual-mode, ramjet flow path such that they thermodynamically impact one another. The rockets provide thrust up to the point where the ramjet achieves enough compression of the ingested air to produce positive thrust, typically about Mach 3. As the Mach number increases further, the aerodynamics of the flow path change until all internal flow is supersonic, at which point the engine is termed a scramjet. This generally occurs by Mach 7. After conducting thorough trade studies and factoring in on-going activities in other hypersonic programs nationally, the RBCC/ISTAR Project decided to use the propellants JP-7 and 90% Hydrogen Peroxide (H2O2). The GTE phase would have been considered successful if an RBCC engine was designed and fabricated and tested in all modes: Air-Augmented Rocket (AAR), ramjet, and scramjet. The engine performance would, after additional flight design iteration, be sufficient to accelerate a self-powered vehicle from Mach 0.7 to scramjet take-over around Mach 7.

A unique aspect of the RBCC Project was the successful contractor collaboration arrangement, the Rocket Based Combined Cycle Consortium (RBCCC), which was comprised of the team of Boeing-Rocketdyne, Pratt & Whitney, and Aerojet.

The RBCC Project was discontinued in 2004 as a result of a review to determine Project relevance to the Nation's Exploration Vision.

Turbine Based Combined Cycle (TBCC)/Revolutionary Turbine Accelerator (RTA) Project

The TBCC/RTA Engine Project was intended to deliver a Mach 4+ hypersonic propulsion system in this decade. Intending to demonstrate high mach turbine performance and durability for space access, and to mature promising turbine-engine technologies, the Project would have culminated in a system-level ground test of a TBCC engine at Mach 4 flight conditions. Test results should have validated performance gains from advanced technologies and provided an initial system-level database for dealing with performance, operability and durability issues. In addition, the TBCC/RTA Project was developing a plan for a potential flight test of a TBCC to address the critical issues associated with propulsion/airframe integration (PAI) and transition from a low-speed propulsion system TBCC to a high-speed propulsion system. The TBCC/RTA Project was maturing a turbine-accelerator design through the preliminary design phase for a potential flight demonstration on an X-43 class of flight vehicle.

The TBCC/RTA Project was discontinued in 2004 as a result of a review to determine Project relevance to the Nation's Exploration Vision.

Auxiliary Propulsion Project (APP)

The focus of the APP is advanced technology development in the areas of in-space auxiliary propulsion systems. The current Project content is reflective of the high-priority technology development efforts required by previously anticipated NGLT vehicle architectures. Project content was modified based on updated risk reduction requirements identified during the Interim Architecture and Technology Review (IATR) of the 2nd Gen RLV Program, the predecessor of the NGLT Program. The IATR was concluded in March 2002 to coincide with the end of the base period of performance of contracts awarded under the NASA Research Announcement (NRA) 8-30 Cycle I solicitation. Based on results of the IATR, selected contract options were exercised, and others were not. The 2nd Gen RLV Propulsion Projects Office was subsequently reorganized to support overall Program goals. As a result of the reorganization, elements of the Upper Stages and the Main Propulsion System/Auxiliary Propulsion System (MPS/APS) Projects were combined to form the On-Orbit Propulsion Systems Project, now named the APP under the NGLT Program. That current Project content was found to be relevant to the Exploration Initiative during formal Relevance Reviews with OExS in March 2004. The current Project includes technology development activities for the following elements:

1. Non-Toxic Reaction Control Systems (RCS) Engine
2. Cryogenic Fluid Management (CFM) Systems
3. Auxiliary Propulsion System (APS) Design and Integration

The Project defined the following goals:

- Develop APS technologies, reducing risk for Exploration Transportation Systems elements.
- Demonstrate significantly improved auxiliary propulsion system safety, operability, and reliability while reducing costs.
- Demonstrate operational concept of LOX-based, non-toxic RCS.

- Develop limited CFM technologies to reduce the risk for Exploration Transportation Systems elements.
- Develop and test prototype Auxiliary Propulsion hardware.

Propulsion Research & Technology (PR&T) Project

The PR&T Project was initiated in October 2000 with the intent to advance the state-of-the-art for key rocket-based and turbine-based combine cycle propulsion technologies—capabilities capable of significantly enhancing mission performance, safety and cost savings for future development of next generation, RLVs and space transportation systems.

The PR&T Project was advancing key propulsion technologies for vision vehicles that complemented and supplemented work in other NGLT projects. The prime PR&T customer base included the OAT, as well as other NASA programs, the DoD, the DoE, and private industry, i.e., any work focused on next generation aerospace vehicles, as well as possible spin-offs to other air-breathing propulsion systems and commercial applications.

The primary technical areas addressed by PR&T were: propulsion flow path components, rotating components and seals, and engineering capability development. The interplay between the technical areas used guidance and feedback from the Program's systems analysis competence.

The PR&T Project was discontinued in 2004 as a result of a review to determine project relevance to the Nation's Exploration Vision.

University Institutes Project

The University Institutes Project was originally a subproject of the PR&T Project. University Institutes was approved by the OExS in March 2004 after a review of project relevance to exploration. This Project will oversee research efforts, perform financial management, and manage the peer review process for the fixed-price cooperative agreements with universities that have migrated from the NGLT Program.

The project organization encompasses three institutes which address problems of fundamental importance to Project Constellation. The three institutes, listed below, all follow the same format of lead university and multiple supporting universities.

Institute for Future Space Transport

- University of Florida - ***LEAD***
- University of Alabama-Birmingham
- Cornell University
- Syracuse University
- Georgia Institute of Technology
- Mississippi State University
- North Carolina A&T University
- Prairie View A&M University

Space Vehicle Technology Institute

- University of Maryland - ***LEAD***
- University of Michigan
- Johns Hopkins University/Applied Physics Lab
- University of Washington
- North Carolina A&T University

Rocket Engine Advancement Program (2) Institute

- University of Alabama-Huntsville - ***LEAD***
- Pennsylvania State University
- Auburn University
- Purdue University
- Tuskegee University

The overarching goals of the University Institutes Project are:

- Strengthen NASA's ties to academia through long-term, sustained investment in innovative and exploration technology critical to Constellation;
- Enhance and broaden the capabilities of the Nation's universities to meet the needs of NASA's science and technology programs;
- Perform research and development that moves fundamental advances from scientific discovery to basic technology that addresses critical Project Constellation needs; and
- Expand the Nation's talent base for NASA Mission-related research and development and technology maturation.

Propulsion Technology & Integration (PT&I) Project

The Propulsion Technology and Integration Project (PT&I) is composed of a collection of heritage tasks that originated either under SLI and migrated into the NGLT Program, or under the NGLT Program itself. These tasks are NASA led in-house technology maturation activities with broad application in several areas to the new Agency Exploration Enterprise. Upon completion of a relevance review with OExS, these selected tasks were re-baselined to comply with direction from Project Constellation. This summary reflects Project agreements between the OExS Management and PT&I. Each task is an independent activity with its own objectives and products and will be completed in 2005.

The PT&I Project will develop and demonstrate four key main propulsion technologies that support the lunar exploration effort:

- **GRCop-84 materials development**
  - Develop technologies required to scale-up the production of GRCop-84 to a capacity and size sufficient for a full-scale Main Combustion Chamber.
  - Reduce the time to manufacture a coated liner from years to months.
  - Reduce costs and improve performance of future engines by utilizing GRCop-84's greatly enhanced properties compared to NARloy-Z.
    - Miniaturized Leak Detection Sensor
    - Provide the base leak detection technology for O2, H2, and hydrocarbons (RP-1) all in postage stamp size package ("Lick and Stick") to improve safety and operational readiness.
- **Combustion Devices Injector Technologies (CDIT) - formerly (Staged Combustion Injector Technology (SCIT)**
  - Develop injector technology and model capability for oxygen/hydrogen upper stage engine development.
  - Reduce local peak combustion chamber heat flux due to injector.
    - Improve injector ignitability.
    - Improve combustion stability margin.
- **Propulsion High Impact Avionics Technologies (PHIAT)**
  - Develop advanced avionics technologies that will increase reliability and safety of propulsion and avionics systems.
  - Decrease development, sustaining engineering, and operations cost of propulsion and avionics systems.
  - Decrease overall avionics system and propulsion system weight.

Systems Integration Project (SIP)

The primary objective of the SIP was to provide the systems engineering and integration (SE&I) functions necessary to develop a set of valid requirements, technology plans, and the resulting next generation launch architecture roadmaps in support of NASA architecture development and technology decisions. The supporting objectives were to: (1) integrate OSP, DoD, exploration, science, and other launch system customer needs into Level 1 interim analysis requirements; (2) recommend technology development strategies; (3) develop project technology development requirements and priorities from Level 1 launch system requirements; (4) develop integrated set of lower level technology roadmaps from the ISTP roadmaps; (5) develop systems engineering integration and analysis capabilities; (6) support the development and analysis of architecture concept development; and, (7) provide support to the NASA decision process. The Project was organized according to a Work Breakdown Structure (WBS) consisting of three primary elements: System Integration Management, System Requirements Validation and Planning, and Technology Requirements Validation and Planning.

The Project defined and managed a rigorous systems engineering (SE) process and implemented this process to create a clear and traceable path from launch architecture scenarios through requirements definition to the generation of technology plans and candidate architecture roadmaps. This Project, through the SE process, provided the integration between the technology projects and the potential launch architectures. The information generated by the project would be used to validate the Agency's launch architecture requirements and would enable NASA to make sound technology investment and full-scale development decisions.

The SIP would define the steps of the NGLT systems engineering process to cover mission, requirements, design, and technology analysis cycles. This process was executed, at a minimum, on an annual basis in order to deliver investment decision information in time for the annual NASA Program Operating Plan (POP) cycle. The purpose of the mission analysis cycle was to translate stakeholder needs into mission requirements, FOM, Design Reference Missions (DRMs), Concept of Operations (ConOps), and Level 1 requirements (for analysis purposes). The requirements analysis cycle involved a functional decomposition of Level 1 requirements to lower-level requirements validated through analysis at each level. The design analysis cycle involves definition and analysis of candidate launch architectures that meet these requirements. (Note that this phase of the SE process was owned by the Systems Analysis Project (SAP).)

The technology analysis cycle involved performing a risk identification and assessment of the technologies under consideration. The approach for this last cycle would be to perform a Value Stream analysis that identified all necessary technologies and assisted in the determination of the appropriate risk reduction plans for a concept. Each analysis cycle was used to validate ground rules, assumptions, and requirements at the previous level. This Project was then responsible for turning the data into useful information that would enable decisions. This Project would use an advanced engineering environment (AEE) that was a secure, integrated analysis capability to be used by the distributed analysis teams to perform requirements decomposition and architecture and technology analysis at each level. This system would be the repository for all analysis data conducted for NGLT. These functions will be performed under Project Constellation Systems of Systems Engineering in the future.

Systems Analysis Project (SAP)

The objective of the SAP was to apply a disciplined systems analysis process in order to support NGLT research and technology development investment decisions. Activities and deliverables within the Project were organized according to a WBS consisting of four primary elements: System Analysis Management, Focused Analysis Team, System Definition, and Assessment. The first element supported the management of the overall Project. The second element was responsible for addressing Program quick -turnaround analysis requests. The third element was responsible for defining and assessing architectures against and assessing technology impacts on the FOM.

The SAP was guiding NGLT technology investment decisions. This process was producing and delivering to NGLT a set of linked missions, concepts of operation, system requirements, characteristics and architectures, and conceptual system designs to serve as the basis for evaluating the impact of portfolios of advanced technologies. These technology evaluations were providing invaluable information to NGLT for prioritizing and allocating funding to develop launch vehicle technologies.

An integrated team (government, industry, university) was being used to execute a disciplined annual process of top-down requirements-driven system analysis. The following NASA Centers had Project responsibilities:

- LaRC - Lead: System Analysis Management; Task Leads for System Definition; Support System and Technology Assessment.
- MSFC - Task Leads for System Definition; Support System and Technology Assessment.
- GRC - Task Leads for System Definition; Support System and Technology Assessment.
- ARC, DFRC, KSC, JSC - Support to System Definition, System Assessment and Technology Assessment.

Three industry airframe prime contractors were contracted to support the definition of system concepts in FY03 via level of effort support to the integrated NASA/Industry team. Propulsion industry expertise was also engaged to support the integrated team concept development tasks, via support provided by the RBCC and TBCC projects. These functions will be performed under Project Constellation Systems of Systems Engineering in the future.

X-43C Demonstrator Project

The X-43C Project was intended to demonstrate autonomously controlled, accelerating, free-flight of a hydrocarbon-fuel-cooled, dual-mode scramjet powered vehicle from Mach 5 to Mach 7, including combustion mode transition from ramjet to scramjet. Specifically, the goals of this Project were:

- To demonstrate/validate the flight performance of three hydrocarbon fuel-cooled, dual-mode scramjet propelled, hypersonic vehicles in steady/ maneuvering flight;
- To demonstrate/validate the flight characteristics of air-breathing scramjet powered/un-powered vehicles in autonomously controlled hypersonic flight;
- To provide ground and flight data to validate computational methods, analytical predictions, test techniques, and propulsion operability to enable design of future operational vehicles; and,
- To execute an affordable plan focused on key propulsion technologies, using existing designs, analysis methods, databases, and existing hardware to the maximum practical extent.

Development of the X-43C hydrocarbon-fuel-cooled propulsion system was a joint effort between NASA and the USAF, using propulsion technology developed in the Air Force HyTech Program. The X-43C Project was supporting the verification of computational predictions and ground-test methodologies for design and performance prediction of air-breathing hypersonic vehicles. Each flight was intended to explore a portion of the flight envelope for specific propulsion issues and aero-propulsive interactions. The plan was to boost the X-43C DV (approximately 16 feet long, identical vehicles) to Mach 5 using a Carrier Aircraft (CAC) launched, Pegasus-derived booster. At the Mach 5 takeover point, the X-43C DV would separate from the booster and accelerate to Mach 7 over 3 to 5 minutes of powered flight. The vehicle would then descend in un-powered flight to a predetermined point where it would splash down in the Pacific Ocean. The X-43C DV was planned to be expendable and non-recoverable.

The X-43C Project was discontinued in 2004 as a result of a review to determine project relevance to the Nation's Exploration Vision.

Future Flight Demonstrations (FFD) Project

The objectives of the FFD Project were:

- To reduce future operational vehicle development risks; to demonstrate, validate, and advance the technology, experimental techniques, and computational methods and tools for design and performance predictions of air-breathing hypersonic vehicles;
- To flight-validate hypersonic vehicle/propulsion system performance and design methods;
- To validate cost and operational models; and,
- To flight-demonstrate selected key vehicle reliability and maintainability technologies.

The Project consisted of a collaborative NASA/Air Force hypersonic flight demonstration effort, X-43A (not managed by the NGLT Program), and multiple potential demonstration efforts, X-43B and X-43D.

The FFD Project was discontinued in 2004 as a result of a review to determine project relevance to the Nation's Exploration Vision.

Vehicle Systems Research & Technology (VSR&T) Project

The VSR&T Project began in November 2002 when ASTP and SLI were reformed into the NGLT and OSP Programs. The focus of the VSR&T Project was to create inherent reliability through the application of innovative technologies in robust vehicle system design to achieve safe and affordable access to space. The VSR&T Project combined all non-propulsion related 2^{nd} and 3^{rd} Generation technology development projects, including: 2^{nd} Gen RLV Projects (Airframe, Flight Mechanics, IVHM, Operations and Vehicle Subsystems) and 3^{rd} Gen Airframes.

The objectives of the VSR&T Project were to develop and demonstrate advanced vehicle systems technologies (which included aerosciences, airframe structures and materials, subsystems, and spaceport and range) that would have provided a significant reduction in the costs of space transportation systems while dramatically improving the safety and operability.

The Project was in the process of developing and demonstrating advanced methods and technologies, from an integrated vehicle systems perspective, that had the potential for dramatically increasing reliability, safety, and reducing the cost of future space transportation systems. Successful implementation of the Project would have provided the technology foundation and confidence to allow a decision to proceed with a focused risk reduction activity for a next generation space transportation system.

The VSR&T Project was de-scoped in 2004 to focus on the subsystems subproject as a result of a review to determine relevance to the Nation's Exploration Vision. See the following paragraphs.)

Vehicle Subsystems Project

The Vehicle Subsystems Project was originally a subproject of the VSR&T Project. This project was approved by the OExS in March 2004 after a review of project relevance to exploration. Specifically, the Project will complete the current power and actuator contracts and related activity through FY06. The Vehicle Subsystems Project focuses on the following two elements:

- **Mechanical Systems (Actuators):** The Actuators Element includes the development and demonstration of high horsepower, robust electric actuation technologies with reduced complexity and cost.

- **Power:** The Power Element will develop and demonstrate technologies for advanced power generation, energy storage, and power distribution and management systems. Included here is development of proton exchange membrane fuel cell (PEMFC) technology.

The goals of the Vehicle Subsystems Project are: to develop and demonstrate vehicle subsystem technologies (fuel cells and other advanced power technologies, electric actuators) that provide a significant reduction in the cost of space transportation systems while dramatically improving their safety and operability. The Vehicle Subsystems Project will enable all-electric launch and space vehicles through:

- **Mechanical Systems (Actuators) technologies** - elimination of vehicle hydraulic systems and incorporation of electric actuator technologies (Electro-Hydrostatic Actuators (EHAs)).

- **Power Component technologies** - application of advanced energy storage and power generation, management, and distribution technologies (lithium battery, non-toxic turbine power unit), as well as maturation of PEMFC power plant for space vehicle applications.

Appendix B - Index of Lessons Learned

4.1 Requirements (R)

4.2 Plan (P)

4.3 Schedule (S)

4.4 Budget (B)

4.5 Agreements (A)

4.6 Execution (E) Page

4.7 Technology Integration (T)

4.8 Organizational Design and Development (OD)

4.9 Program Integration and Communication (PC)

4.10 Safety and Risk (SR)

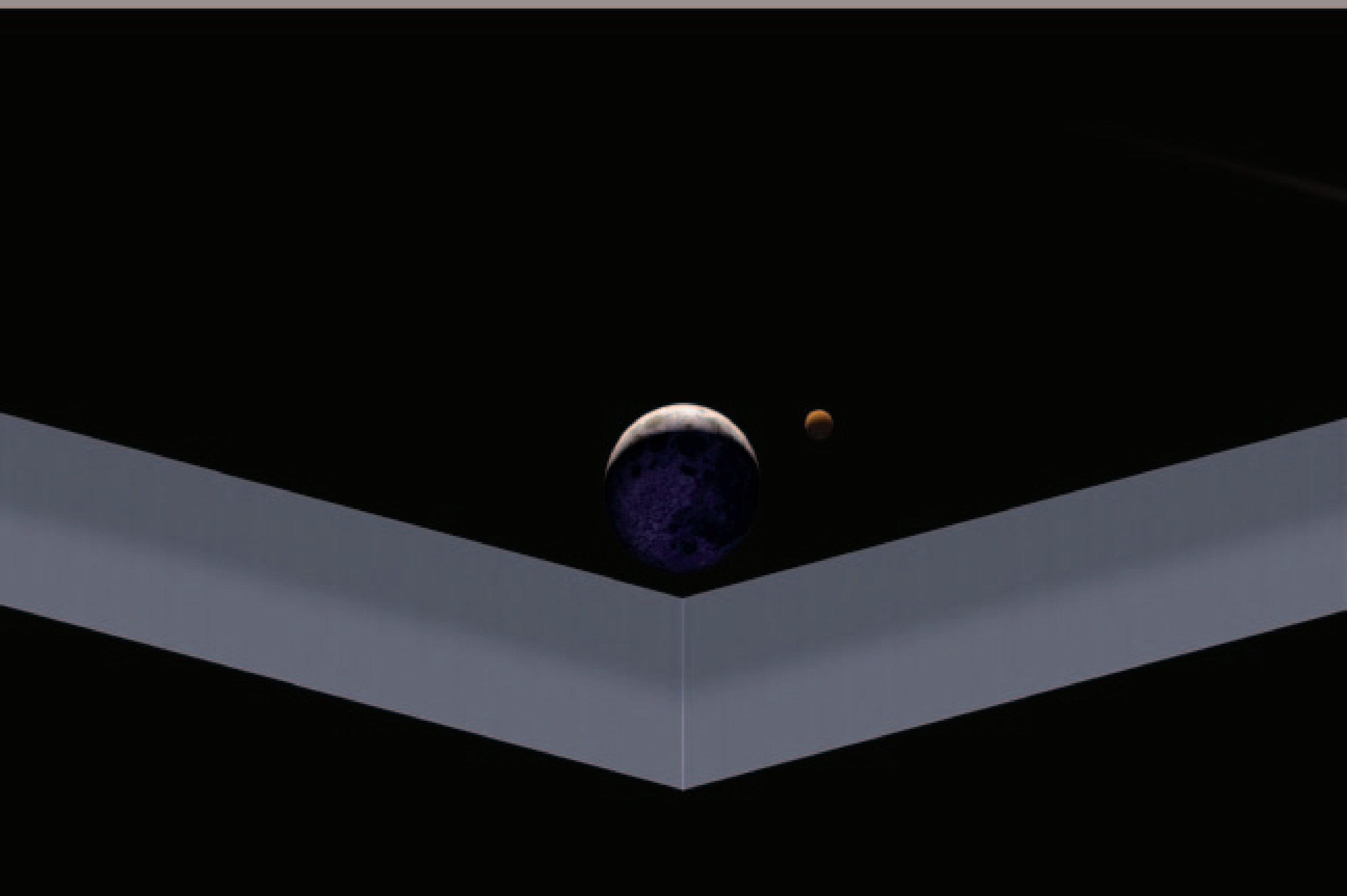
Appendix C – Acronym List

AAR	Air-Augmented Rocket
AEE	Advanced Engineering Environment
AFRL	Air Force Research Laboratory
APP	Auxiliary Propulsion Project
APS	Auxiliary Propulsion System
ARC	Ames Research Center
ASM	Acquisition Strategy Meeting
ASTP	Advanced Space Transportation Program
ATP	Acceptance Test Plan
ATP	Authority to Proceed
B&LS	Booster and Launch Services
BM	Business Manager
BSPB	Battleship Preburner
C/SiC	Carbon/Silicon Carbide
CAC	Carrier Aircraft
CAIB	Columbia Accident Investigation Board
CDIT	Combustion Devices Injector Technologies
CE	Chief Engineer
CFM	Cryogenic Fluid Management
CFO	Chief Financial Office/Officer
CMC	Ceramic Matrix Composite
ConOps	Concept of Operations
COTR	Contracting Office Technical Representative
COTS	Commercial Off-the-Shelf
CPR	Cost Performance Report
CR	Continuing Resolution
DES	Discrete Event Simulation
DFRC	Dryden Flight Research Center
DoD	Department of Defense
DoE	Department of Defense
DRD	Data Requirements Document
DRM	Design Reference Mission
DV	Demonstrator Vehicle
EHA	Electro-Hydrostatic Actuators
ELV	Expendable Launch Vehicle

EVM	Earned Value Management
FFD	Future Flight Demonstrator
FOM	Figure of Merit
TFTP	Fuel Turbopump
GLS	Government Lead Solicitation
GTA	Government Task Agreement
GTE	Ground Test Engine
H&RT	Human and Robotic Technologies
H2O2	Hydrogen Peroxide
HQ	Headquarters
HyTEx	Hypersonic Technology Experiment
IATR	Interim Architecture and Technology Review
IBPD	Integrated Budget and Performance Document
IFM	Integrated Financial Management
IHPTET	Integrated High-Performance Turbine Engine Technology
IPAO	Independent Program Assessment Office
IPD	Integrated Powerhead Demonstrator
IPT	Integrated Product Team
ISS	International Space Station
IPT ORSC	Integrated Project Team Oxygen Rich Stage Combustion
ISTAR	Integrated System Test of an Air-Breathing Rocket
ISTP	Integrated Space Transportation Plan
ITD	Integrated Technology Development
IVHM	Integrated Vehicle Health Management
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LCAT	Life Cycle Analysis Team
LL	Lessons Learned
LOX	Liquid Oxygen
LSRD	Launch System Requirements Document
LSE	Lead Systems Engineer
MOU	Memorandum of Understanding
MPS/APS	Main Propulsion System/Auxiliary Propulsion System
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NGLT	Next Generation Launch Technology
NRA	NASA Research Announcement

OAT	Office of Aerospace Technology
OExS	Office of Exploration Systems
ORSC	Oxygen Rich Stage Combustion
OSP	Orbital Space Plane
OTP	Oxidizer Turbopump
PAI	Propulsion Airframe Integration
PB	Preburner
PDR	Preliminary Design Review
PEMFC	Proton Exchange Membrane Fuel Cell
PHIAT	Propulsion High Impact Avionics Technologies
PI	Platinum Iridium
PM	Program/Project Manager
POP	Program Operating Plan
PR&T	Propulsion Research and Technology
PRCB	Program Requirements Control Board
PT&I	Propulsion Technology and Integration
Pt-Ir	Platinum-Iridium
R&T	Research & Technology
RBAM	Risk-Based Acquisition Management
RBCC	Rocket Based Combined Cycle
RBCCC	Rocket Based Combined Cycle Consortium
RCE	Reaction Control Engine
RCS	Reaction Control System
REP	Rocket Engine Prototype
RFP	Request for Proposal
RID	Review Item Discrepancy
RLV	Reusable Launch Vehicle
ROM	Rough Order of Magnitude
RP	Rocket Propellant
RTA	Revolutionary Turbine Accelerator
RTM	Resin Transfer Molding
S&MA	Safety and Mission Assurance
SAP	Systems Analysis Project
SCIT	Staged Combustion Injector Technology
SE	Systems Engineering
SE&A	Systems Engineering and Analysis
SE&I	Systems Engineering and Integration
SEMP	Systems Engineering Management Plan

SIP	Systems Integration Project
SLI	Space Launch Initiative
SOW	Statement of Work
SSC	Stennis Space Center
STE	Special Test Equipment
STIN	Space Transportation Information Network
TBCC	Turbine Based Combined Cycle
TBD	To Be Determined
TCA	Thrust Chamber Assembly
TPM	Technical Performance Metrics
TPS	Thermal Protection System
UEET	Ultra-Efficient Engine Technology
USAF	United States Air Force
USAFRL	United States Air Force Research Laboratory
VAATE	Versatile, Affordable, Advanced Turbine Engine
VSR&T	Vehicle Systems Research and Technology
WBS	Work Breakdown Structure



National Aeronautics and
Space Administration

NGLT-PROG-00018