

NASA Pilot Benchmarking Initiative: Summary of the Final Report

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NASA Pilot Benchmarking Initiative report was released in October 2007, which was the result of a NASA initiative to engage in a collaborative “Pilot Best Practices – Benchmarking” study with selected “best of the best” industry partners who are recognized leaders in complex systems developments. One focus driving this report is “Exploring Design Excellence Leading to Improved Safety & Reliability”.

A large number of interactions and dependencies exist in large enterprises between processes, technology, people, and leadership. The need for continuous improvement throughout the enterprise to mitigate the risks of uncertainty makes the synchronization of key elements in an “optimized” way severely challenging. The benchmarking initiative report is part of NASA’s efforts to generate continuous improvement of core competencies and capabilities in response to the challenges posed by the new era of Space Exploration.

NASA Contract Assurance Service (NCAS) pilot benchmarking study was a follow-on to the first benchmarking study pursued by this NCAS team lead as part of the Shuttle Independent Assessment (SIAT) report March 2000. At that time, one of the key focus was on “Process Control” for Reliability.

The NCAS Benchmarking Core Team is composed of: Prince Kalia, Team Lead, Ken Crane, Richard Stutts, Andrew Sexton, and John Juhasz. The NCAS benchmarking team wishes to dedicate this Pilot Benchmarking study to the memory of the Columbia Astronauts who, as their explorer colleagues before them, risked all to venture into the unknown for the cause of advancing human space exploration and maintaining our nation’s space leadership to benefit all mankind.

This study focuses on practices that have proven to be successful in large scale “complex system” programs, including commercial, space, or DoD programs, seeking to identify best practices leading to “Safe, Reliable, Affordable, and Sustainable Operational Systems”.

The specific top-level objective established for this NCAS study is given as follows:

***Pursuit of Excellence:** Help identify Key (upfront)¹ Engineering Practices/Tools that leads to SMARTLY Designing and Developing Robust, Reliable and Safer Systems in pursuit of NASA’s future programs in line with NASA’s Vision and America’s Space Leadership.*

The intent of the study is not only to focus on methods of Safety or Reliability practice per se, nor even just the engineering process alone. To be consistent with CAIB, one must look also at the “Producing System”, the entity that produces the target system to be deployed, namely the program and organization that is responsible for its creation and likely operation. This need motivates a second, derived objective, which (as stated in the Executive Summary) is:

***Organization Capability:** Explore Organizational Leadership, Policies, and Enterprise Foundation Principles which serve as enablers and motivators to foster a positive culture and environment for system safety, reliability, and technical high performance.*

¹ The meaning of “upfront” in this context is intended to reflect those critical early stages of the life-cycle which drive program outcomes and Life-Cycle Costs (see figure 1)

The basis for this study is a non-scientific, qualitative industry survey of development methods (with Safety & Reliability focus) at leading companies. The general intent was to discern and capture those highly effective practices and methods which, if properly exploited and adapted to the practicing environment of the development entity, may result in significant added improvement in the safety of crewed systems, as well as enhanced reliability of the operational systems.

Specific objectives of the study are to survey leading companies with reputations for outstanding achievement in developing safe and reliable complex systems, and to capture the findings related to their “best practices” and the environment in which they are enabled. In the general pursuit of excellence, the following statements establish the intent of the study:

KEY OBJECTIVES: Help identify Key Engineering Practices/Tools that leads to SMARTLY Designing and Developing Robust, Reliable and Safer Systems in pursuit of NASA’s future programs in line with NASA’s Vision and America’s Space Leadership.

ENABLERS: Explore Organizational Leadership, Direction and Commitment, and Enterprise Foundation Principles which serve as enablers and motivators to foster a culture and environment for technical high performance.

The basic approach was to solicit collaborative partnerships with the best in the industry, constructively engage and partake in site visits at key development centers, and learn from observation and productive interview/ dialog centered around a set of key questions. Collaborative review and assessments by NASA team members were instrumental in determining which of the myriad practices observed constituted a “best practice” for the aims of this initiative. For selected observations, literature studies were conducted as feasible to further examine practiced methods and the underlying principles.

Around these basic objectives, the NASA study team established an approach to investigating the “best of the best” in industry to delve into their essential processes and organizational methods for achieving excellence. The NASA team was successful in establishing cooperation in the collaborative effort with several leading companies.

Each site visit was documented with a report detailing aggregate (non-statistical) data and observations from collected team notes, with the aim of extracting useful insights into common principles and practices being successfully applied among the partners. These observations led to judgments about likely common success practices in these companies, which became the “Focus Topics” for this report. A literature search in support of these focus areas was also undertaken to more thoroughly examine relevant facets of the practices. The collective insights from these focus topics became the general basis for the overall report findings and conclusions.

The following seven special focus topics are summarized and presented here as representative of some best practices observed during this study. Team review and discussion of the collected survey results facilitated a focus on the success factors at the root of the partner’s experiences, which are captured herein as both “enabling” factors as well as “best practices”, including:

- 1. Leading with Vision, Sharing the Vision and Demonstrating Commitment**
- 2. Focusing on Mission Success Driven Requirements & Validation Process**
- 3. Achieving Safety and Reliability by Robustness of Design**
- 4. Models & Simulation combined with Experts**

5. **Visible Metrics for Better Decisions**
6. **Methodology for Excellence in Systems Management**
7. **Building Culture on Foundation Principles**

Of the seven identified Focus Topics listed, it is noteworthy that not all are common, visibly manifest practices, indeed different levels of emphasis exist for their adoption within each partner organization. The topics were selected because they appeared to represent a unique strength and exceptional competence that was judged to be a major success element contributing to the partner's specific purpose and strategy. To illustrate their potential value in the systems development lifecycle, a composite view of a notional "Lean Systems Value Stream" diagram is included in Appendix C, showing areas of application or influence of each of the practices in a hypothetical "lean" lifecycle. The graphic shown in Appendix C of the report, the Conceptual "Ideal" Life-Cycle process figure is a notional composite view of the core of a complex system development process, constructed as a reference framework from which the "Focus Topics" of this benchmarking study can be visualized. It is not comprehensive, and does not reflect any single partner process, rather it is a minimalist but collective "Lean Thinking" life-cycle view, assembled from partner provided information of the critical steps involved in system development. One could conceive of this flow representing the "value stream" of information flow through the various stages in the early formation of a major project or program, from stakeholder need to design and production.

While there are differences in practice implementation, there were also clear indicators of commonality of basic "essential conditions" and core competencies across the full set of collaborative partners. Each of the partners exhibited strong overall capabilities in their specific markets, with positively unique, innovative approaches to problems in their domains. They also exhibited certain key attributes in common, which the team concluded are some of the key essential environmental factors or "enablers" for the achievement of excellence in complex systems.

The summary findings of some key cultural enabling factors shared by each of the surveyed companies are:

VISIONARY LEADERSHIP - Role of organizational leadership in establishing a clear overarching purpose, deriving and articulating a compelling but credible vision to fulfill that purpose.

CAPABILITY MATURITY – Organization attainment of high levels of "Capability Maturity" to support and facilitate the undertaking of complex systems development

SYSTEMS ENGINEERING CULTURE – A pervasive mental state and bias for systems engineering methods applied to problem solving across the development lifecycle and at all levels of enterprise processes.

DESIGN ROBUSTNESS MINDSET – High levels of focus on system safety and reliability driven by a bias toward achieving robustness, supported by the cultural attitude of "Failure is not an Option".

ACCOUNTABILITY STRUCTURE - Effective decision making accomplished through clearly defined structures of assigned responsibility and accountability for decisions at appropriate levels and phases of system development.

In general, a non-scientific, qualitative survey of the type described herein has various limitations in its effectiveness and likely accuracies. However, this pilot Benchmarking Study provides ample opportunities to NASA Constellation Program and other new Program's at NASA to pursue the proven Design Excellence Tools and processes smartly leading to Robust, Reliable and Safer Systems. Adoption of key "best practices" can be facilitated through focused Tiger Teams, Lean Engineering Design teams, Six Sigma processes, Theory of Constraints approaches, and other means. These types of studies have been found to be of enormous value to organizations striving for Excellence in a competitive environment. Such learning has been instrumental in delivering superior systems over their competition, tapping the best of technology combined with human creativity and innovation.

Although these findings are primarily a composite set of observations, some specific recommendations for NASA should be considered for implementation in a "pilot project" form. Consideration is suggested in the areas of:

- Requirements management and traceability with strong systems discipline throughout the lifecycle
- Design certification / qualification, including design "robustness" and
- Overall "lean practice" implementation for excellence in life-cycle systems management.

HALT (Highly Accelerated Life Testing) and HASS (Highly Accelerated Stress Screening) are cited in the report in the focus area of achieving safety and reliability by robustness by design, as methods that provide early, potentially valuable insight into critical design parameters, which can be used to modify / strengthen the design to achieve a desired level of "robustness".

Throughout the course of the benchmarking study, the team observed a wide range of "Excellence" in practice, not only in engineering, but also in manufacturing, management, and in a number of organizational functions. Many activities were noted in the site visits that created a strong impression and possibly qualification as a "best practice". However, given the constraints of the program as well as the partners proprietary concerns, the team concluded that the best examples were those addressed in the Focus Topics section. These selected 7 areas were considered exemplary practices, and likely to be among the most significant factors accounting for the "excellence" in each enterprise. In similar fashion it was observed that in each of the partner organizations, evidence of the key "cultural enablers" was persistent. As discussed earlier, these enablers represented the set of discernible cultural factors that were likely at the core of environmental conditions favorable to best practices.

It is with the notion that culture is an essential "enabler" that the suggestion is made to consider the full picture before a rush to implementation of a desired practice. In support of that consideration, a relational cross-reference matrix (Table 1) was created to provide further views linking the best practices with their essential enablers.

The table below contains a "relative strength" indication which associates each of the focus practices (rows) with the identified cultural "enablers", using a 3-point scale of A, B, C. The letter entry in each cell indicates a relative strength (subjectively assessed by the team) of the association, or dependency, which is presumed to exist between each identified enabler and the corresponding best practice. For example, the practice of "Sharing Vision" is highly dependent on the enabler of "Visionary Leadership", but less so on the other cultural factors.

It is important to note that the relations shown are neither validated nor objective, and should be used merely as a starting guide for planning possible implementation strategy. The primary point

of this subjective assessment is to establish the likely areas of emphasis in targeting practices for improvement. In other words, the implementation of a desired “best practice” will likely be dependent on the pre-existing condition shown as an enabler, to the degree of the strength of the relationship.

A = High B = Medium C = Low	Visionary Leadership	Capability Maturity	Systems Engineering	Mindset of Robustness	Culture of Accountability
1. Sharing Vision	A	B	C	B	B
2. Reqmts Driven	B	A	A	B	B
3. Design Robustness	B	A	A	A	A
4. Models & Sim	B	A	A	B	C
5. Visible Metrics	B	A	B	A	A
6. Manage LC Excellence	A	A	A	A	A
7. Building Culture	A	B	B	B	A

Table 1 – Relationship of Best Practice areas with Organization Enablers

In conclusion, it must be noted that a generic, qualitative survey of this type has various limitations in its effectiveness and likely accuracies. There are several potential uncertainties and obstacles that prevent a thorough assessment of a company’s full capabilities or possible shortcomings, especially in the management of a complex system development lifecycle. However, this pilot Benchmarking Study provides ample opportunities to NASA Constellation Program and other new Programs at NASA to pursue the proven Design Excellence Tools and processes smartly leading to Robust, Reliable and Safer Systems through focused Tiger Teams, Lean Engineering Design teams, Six Sigma processes, Theory of Constraints, and other means within the framework of legal agreements for the proprietary nature of information provided in this report.

It further is recommended to pursue a follow on activity to determine how “Lean System Engineering” and these key best practices could be adapted to the NASA environment in general, and some Constellation projects in specific. While the degree of emphasis may differ for each project, they could all benefit from thorough “Integrated Systems” focus on:

- Requirements – focus on Key Driving Requirements (KDR), ensuring completeness, effective traceability, performance, safety & reliability related requirements focus.
- Implementation – Overall excellence in integrated lifecycle “Systems Management”, including timely identification, risk mitigation, and responsive corrective actions.
- Certification and Qualification – Modeling and Simulation validated by actual test data and expert review, including fully defined environmental performance to requirements

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The appendix to this report contains some notional flow diagrams for reference in comparing some best practices against currently known of de-facto practices within the chosen project. It provides a convenient and useful starting point for conduct of a first-level “gap analysis”.