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NASA ENGINEERING EXCELLENCE: A CASE STUDY ON STRENGTHENING AN ENGINEERING ORGANIZATION

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Abstract
NASA implemented a system of technical authority following the Columbia Accident Investigation Board (CAIB) report calling for independent technical authority to be exercised on the Space Shuttle Program activities via a virtual organization of personnel exercising specific technical authority responsibilities. After the current NASA Administrator reported for duty, and following the first of two planned "Shuttle Return to Flight" missions, the NASA Chief Engineer and the Administrator redirected the Independent Technical Authority to a program of Technical Excellence and Technical Authority exercised within the existing engineering organizations. This paper discusses the original implementation of technical authority and the transition to the new implementation of technical excellence, including specific measures aimed at improving safety of future Shuttle and space exploration flights.

Key words: technical authority, technical excellence, organizational effectiveness, return to flight, Space Shuttle, Space Exploration, safety, mission assurance.

Objective
This paper discusses the direction the CAIB report gave to NASA regarding improving safe and reliable operations through a system of technical authority, NASA's original implementation of technical authority and the transition to implementation of technical excellence to replace the independent Technical Authority. Conclusions and recommendations are not offered in this case study since the paper provides details and status of the new implementation. The status as of the writing of this paper is that both the independent Technical Authority and the new Technical Excellence are both extant in NASA during a transition period, and plans are subject to change.

Background for Technical Authority
NASA's Space Shuttle program has conducted 114 missions, two of which ended in catastrophic failure with the loss of 14 astronauts and the Shuttles Challenger and Columbia. The two accident investigations readily determined the specific hardware failures responsible for each accident. Both investigations (the Rogers Commission for Challenger and Columbia Accident Investigation Board also identified organization and management shortcomings that contributed to the accidents. The CAIB determined that organizational and management issues were significant contributors to the loss of Space Shuttle Columbia. In addition, the CAIB observed similarities between the organizational and management climate that preceded the Challenger accident and the climate that preceded the Columbia accident (Keissling, et al).

NASA program and project managers have the ultimate responsibility for safety. The NASA Safety and Mission Assurance Offices (SMA) at the various NASA field centers assist the project managers with their safety responsibility. The CAIB found a lack of rigor imposed on project activities regarding responsibility for technical authority and lack of influence of the SMA offices on key technical decisions.

The CAIB concluded that NASA's safety organization was not an effective voice in discussing STS-107 (the final Columbia mission) issues due to a lack of capability independent of the Shuttle program (Gehman et al., 2003). The CAIB also observed that NASA managers at many levels are placed in positions without completing a standard training and education program to prepare them for their roles (Gehman et al., 2003). Program and project managers, although ultimately responsible for the safety of their programs and projects, are not required to complete system safety training, for example (Keissling).

NASA defined technical authority for safe and reliable operations and implemented a management and organizational scheme to implement that authority. The strategy was aimed at eliminating adverse organizational and management climates in the technical activities. Under the direction of the newly named NASA Administrator, after one year, NASA changed the paradigm of implementation of the independent Technical Authority (iTA) (The lower case "i" in iTA is used in the acronym since independent is an adjective that means the technical authority is within NASA but independent of the program/project organization and funding) by utilizing the existing organizational structures with the technical authorities imbedded therein rather than via a virtual organization as was the iTA. In addition, NASA dropped the term "iTA' in favor of Technical Excellence and Technical Authority.

NASA Independent Technical Authority for Safe and Reliable Operations
NASA originally established the technical authority and provided these definitions in the first policy document regarding the independent Technical Authority:

1) "Technical Authority – Technical Authority is the authority, responsibility, and accountability to establish, approve, and maintain technical requirements, processes and policy.

2) Independent Technical Authority – Independent Technical Authority is the execution of Technical Authority in support of mission-related programs and projects without organizational or financial control by such programs and/or projects (NASA NPD 1240.4)."

The policy document included the following major policy statements:

1) "The Technical Authority for technical requirements and processes is delegated from the Administrator to the NASA Chief Engineer.

2) A system of Technical Warrants will be used to further delegate Independent Technical Authority. The technical warrant holders are to be proven subject matter experts with mature judgment.

Individuals delegated Independent Technical Authority shall: 1) be funded independently from Program and Project funding, (b) not report to a Program or Project Manager, and, (c) hold authority for technical matters under their warranted cognizance separate from any program management structure (NASA NPD 1240.4)."

The NASA Administrator delegated the Chief Engineer as the Agency's Technical Authority. The independent Technical Authority (iTA) was set up not as an organization but as an authority and responsibility vested in individuals called Warrant Holders. A warrant holder is not a position; it is a person to whom the NASA Chief Engineer delegated the authority and responsibility for safe and reliable operations within the scope and bounds of the particular warrant. Warrant holders were given authority for establishing technical requirements and overseeing the implementation of technical requirements in NASA systems.

The Warrant Holders were established for systems and disciplines. Every major NASA system, for example the Shuttle Program had System Warrant Holders for Orbiter, Propulsion Systems, and Ground Operations, while a fourth System Warrant holder was named for the International Space Station. Discipline Warrant holders were also named in many engineering disciplines across NASA.

While the iTA was applied to all NASA programs that have human safety considerations, the iTA did not replace the functions and responsibilities of the various safety organizations across the Agency. The iTA is a "first look" at human safety that is imbedded in engineering activities and the safety organizations, in a sense, are a "second and independent" look at safety compliance. Tailoring of the specific iTA implementation was done depending on the size and type of flight program. Funding was from a general Headquarters pool.

The authority of a technical warrant holder was equal to the authority of program and project managers only on issues of human safety. Program and project managers still exercised their authority to execute their programs/projects, and balance schedule and costs, but any disagreements between the iTA and program management about safe and reliable operations could be raised to NASA Headquarters management level for resolution.

To carry out the distinct iTA activities as planned, the NASA policy also stated responsibilities of various functions (NASA NPD 1240.4):

1) "Center Directors are responsible for implementing the NASA Chief Engineer's Technical Authority policies and processes in engineering activities at their Center.

2) Mission Directorate Associate Administrators are responsible for ensuring the implementation of technical authority policies, procedures, and responsibilities by programs and projects as well as providing the resources for the Agency Service Pool for the execution of Technical Authority.

3) Program and Project Managers are responsible for incorporating technical authority processes and procedures in their programs and projects and following the requirements established by the Technical Authorities in the conduct of technical decision-making in order to ensure safe and reliable operations and missions.

4) The Chief Safety and Mission Assurance Officer is responsible for assuring compliance with technical requirements established by Agency Technical Authorities.

5) Technical Authorities are responsible for executing their authority diligently and dispassionately, and with primary attention to quality, completeness, applicability, timeliness, and clarity of technical work.

6) The Chief Engineer establishes budgets for Independent Technical Authority using an Agency Service Pool concept that provides for the execution independent of direct program/project and flight/mission funding.

7) The Operations Management Council approves funds for the execution of Independent Technical Authority and the Comptroller provides the mechanisms for the execution of an Agency Service Pool by Technical Authorities independent of direct program and project funding."

Another NASA document, NASA Procedural Requirement NPR 1240.1, "NASA Technical Warrant Systems," describes the technical warrant holders (TWHs) process:

1) "Systems Technical Warrants – TWHs at the total systems level will be systems technical experts who have the authority, responsibility, and accountability to establish, monitor and approve all technical standards and requirements, processes, products, policies, and variances for their assigned systems. At the systems level, TWHs provide the checks and balances on the execution of technical work conducted in support of mission-related programs and projects. These Systems TWHs (STWHs) will utilize discipline TWHs and their network of experts as required and appropriate.

2) Discipline Technical Warrants – TWHs for the specific disciplines will be subject matter experts in particular technical disciplines who have the authority, responsibility and accountability to establish, approve, and maintain technical standards and requirements, processes, products, policies and variances for their assigned technical area across the Agency. These Discipline TWHs (DTWHs) are recognized throughout NASA as experts in their technical field and, along with their network of trusted agents, will be utilized by STWHs."

NASA NPR 1240.1 also delineated the responsibilities of the TWH. "TWHs are subject matter experts in their systems or their technical disciplines. Within the areas defined by the warrant; TWHs shall:

a. Provide leadership and are accountable for all technical standards and requirements;

b. Establish and maintain technical policy, technical standards, requirements and processes;

c. Exercise integrity and discipline in providing sound technical judgments;

d. Ensure technical products are in conformance with technical policy, standards and requirements. Where they are not, identify and approve any non-conformance via an engineering variance (i.e. change, waiver or deviation);

e. Ensure risk, failure and hazard analysis are conducted and the results are incorporated into technical products and requirements;

f. Identify and evaluate technical alternatives, determine which are technically acceptable, and perform associated risk and value assessments;

g. Provide activities conducting verification, validation and certification functions (e.g. FRR, Assurance, etc.) their positions on the technical requirements in their areas;

h. Support Program and Project Managers by providing the engineering, technical standards and technical products, and decisions necessary to ensure safe and reliable operations;

i. Assure technical principles, capabilities, and concepts meet defined technical standards and requirements;

j. Maintain technical area expertise, competency, and personal credibility through professional development, certifications, and new technology awareness;

k. Develop personnel certification requirements and succession planning;

l. Maintain technical infrastructure in order to effectively perform their duties;

m. Establish a subordinate network of center discipline leads, technical leads, engineering agents, technical/engineering managers, etc. as necessary to fulfill their responsibilities across the Agency (with accountability remaining with the TWH). The supporting network will be comprised of individuals having the requisite technical expertise, organizational independence as necessary, experience, and maturity to perform the work that TWHs need to execute their warrant appropriately;

n. Interface with other TWHs promoting communications throughout the Agency technical community to ensure appropriate individuals and organizations are aware of and involved in technical issues;

o. Interface with the Science, Technology, Human Resources and Education communities of NASA;

p. Ensure lessons learned are captured, evaluated, incorporated into technical documents and made available to others;

q. When performing their warranted function, TWHs will charge to an Agency Service Pool as will their network of engineering agents, engineering managers, and others when they are performing technical work for the TWH in the execution of the warrant functions; and

r. Identify future resources needed to properly execute their responsibilities."

Actual implementation involved deep penetration by the Warrant Holders into the technical issues and decisions of the major NASA space flight systems. All TWHs identified "trusted agents" around the Agency to assist them in collecting and analyzing data relative to these technical issues. In addition, the STWHs used the DTWHs and their network of trusted agents as a tool. A NASA Engineering and Safety Center was also

set up to provide ready access to Agency technical experts in a variety of disciplines to resolve technical issues of an important or urgent nature in a short time.

Importance of an Independent Safety Organization

The CAIB report recommended an independent safety organization and highlighted that an independent safety organization must have the ability and authority to speak openly and with effect, and must have sufficient technical resources to effectively penetrate issues and provide credible positions with solid supporting rationale and evidence. An independent safety organization must have sufficient stature in the organization to be able to promptly communicate issues and concerns to the relevant decision authority in order to assure the proper focus on safety. To be truly independent, an independent safety organization should be funded by a neutral element of the organization structure rather than by the supported program or project office. The CAIB also reported that the Space Shuttle "operational and system safety program is flawed by its dependence on the Shuttle program... the safety apparatus is not currently capable of fulfilling its mission... An independent safety structure would provide the Shuttle program a more effective operational safety process (Gehman et al., 2003)."

For example the Safety and Mission Assurance (SMA) Offices were funded by the supported programs and projects. Consequently, SMA could be limited by the amount of resources a given program or project was willing to fund and hence in the amount of service provided to that program or project. The CAIB also observed that NASA "could not obtain budget increases during the 1990s" and did not "adjust its ambitions to this new state of affairs (Gehman et al., 2003)." The CAIB noted that SMA organizations had not received adequate funding in recent years. Furthermore, there is a natural human tendency to agree with the judgments of one's benefactor. Thus, SMA employees so funded may be predisposed to be more understanding and less critical of the programs and projects supported (Keissling, et al). As stated above, an initial move was made to alleviate the perceived influence of direct funding on the SMA organizations.

Parallel with that move toward a more independent safety organization, the independent Technical Authority, implemented as a virtual organization, and the creation of the NASA Engineering and Safety Center, combined to establish what NASA hoped would be a strong technical entity that would improve safe and reliable operations.

NASA Technical Authority

After some initial consideration of how NASA should function strategically and in a sense of governance, the newly appointed NASA Administrator clearly described how the Technical Authority is to be implemented in NASA in an early 2006 email to a broad audience of NASA executives: "The Program Manager (PM) has the Authority, Responsibility, and Accountability (AR&A) to manage the program risks so that the program meets all funding, technical and schedule requirements. Funding requirements are set by law for government programs, or by stockholders/owners in the private sector. Technical requirements for the safe operations of the program are set by a technical authority not under program direction. Schedule requirements are set by a variety of outside factors not under the PM's control (e.g., statute, treaty, contract, etc.). The organizational Comptroller and IG assure funding compliance. SMA assures compliance with the established critical technical requirements. Schedule compliance is assured by third parties depending on the source of the schedule requirement. That is why the Comptroller, IG, Technical Authority and SMA are not in the PM's chain of command.

The PM may not change the funding requirements, critical performance requirements, critical technical requirements for safe operations, or the schedule requirements. The PM has the AR&A to comply with those requirements. The PM's discretionary decisions within those constraints require controlling expenditures, mission content, and/or schedule as necessary to comply with requirements for safe operations, funding limits, and mandatory schedule dates.

The technical authority for requirements necessary for safe operations is set independently by the designated engineers, in a separate line of AR&A, ultimately responsible to the same position (i.e., NASA Administrator) as is the PM. At NASA, this is done through the Center Directors, in the institutional chain of command. The independent SMA group assures compliance with the safe operations requirements controlled by the Technical Authority. At NASA, as prerequisites to flight, the Technical Authority certifies that the established requirements will support safe operations. The PM certifies that the requirements for safe flight have been met. SMA certifies that the PM has complied with the requirements. These three independent inputs give the Administrator the confidence that everyone has properly exercised AR&A (Griffin, 2006a)."

The Administrator, in another email, provided additional clarification a few weeks later lest anyone not be sure on his intent:

"... In particular, it seems that there continues to be some confusion over 'ownership' of requirements,

with some institutional folks believing they own "all requirements", including programmatic requirements such as the SRD and CARD, and not just the engineering standards and policy documents and OSMA requirements.

Nothing could be further from the truth. The only place in NASA where both institutional and programmatic requirements come together is in the A-Suite; they are otherwise separate (Griffin, 2006b)."

The Administrator went on to say that the institutional chain of command has nothing whatever to say about mission performance requirements at the Program Office level – those being settled between and among Mission Director Associate Administrators and the Office of the Administrator. Institutional management can an should make their case to Mission Directors and Program Managers when they believe that performance/technical trades and decisions are being done wrong, and the Mission Directors and Program Managers should listen. The final call is that of the Mission Directors and Program Managers unless overruled by the Administrator's Office. The Administrator further states that such an overrule should and would be "a big deal" and that the institutional managers have a voice at the Strategic Management Council and Program Management Council, not in the program office (Griffin, 2006b).

This clarification is to make certain that NASA managers understand the separate responsibilities of the program and project management and technical management organizations when it comes to requirements. The message also makes it clear that the level of joint programmatic and technical responsibility and authority comes at the NASA Headquarters level (the A-suite is a name for the Administrator's Office).

The Technical Excellence Process

In general, NASA is transitioning from the warrant holder method of providing technical authority to a process that uses the existing technical organization structure to implement the authority. Within the existing engineering directorates, for example, the chain of command now implements the technical authority, along with the Chief Engineers who are identified specifically for each project. This implementation puts the technical authority in the hands of the technical experts performing the work for projects in addition to the chief engineers, who are usually well-seasoned technical persons with a broad background of technical competence. The requirements ownership resides within the organizations responsible for the technical discipline and not with a single individual. NASA Centers are now engaged in developing implementation plans to delineate specifically how each Center plans to implement the Technical Excellence within their existing structures.

Center SMA organizations have technical authority for system safety, reliability and maintainability, quality, software assurance, and risk management and work in a matrix fashion to the programs and projects, developing their technical products while working closely with engineering. As with engineering technical authority, SMA technical authority maintains and establishes the system safety, reliability and maintainability, quality, software assurance and risk management requirements for meeting mission performance requirements. SMA grants waivers and deviations to these requirements and elevates safety and mission success disputes through the appropriate Center Director and NASA Chief SMA Officer.

To achieve the goals of the Agency, and to correct the current lack of broader technical expertise, there needs to be a strong focus on technical excellence across the Agency. NASA chose to implement a Technical Fellows Program to identify discipline leaders across the Agency who can serve as shepherds of the disciplines. These high-ranking technical positions will be compensated on an equivalent basis with the executive managers of the Agency. By implementing a Technical Fellows Program, NASA is selecting the technical leaders in the Agency who will set the example for technical excellence, increase the focus on technical excellence Agency-wide, recognize outstanding engineers and scientists who have distinguished and sustained records of technical achievement, and provide role models for NASA engineering and science communities.

NASA, therefore, is moving from the Technical Warrant concept to that Technical Excellence/Technical Authority (TE/TA) concept. The general tenets (subject to change at the time of this writing) of the Technical Excellence concept are:

- No Discipline Technical Warrant Holders (DTWHs)
- No System Technical Warrant Holders (STWHs)
- Center implementation plans identify specific implementation for their organizations
- A Technical Fellows (TF) program is part of the concept
    - Tiered = Senior TF, TF, Associate TF
    - Senior Fellows = technical discipline experts with Agency responsibilities paid at ST level
    - Some of these responsibilities are now done by Discipline Technical Warrant Holders (DTWHs)
- Technical Fellows disciplines identified so far include:

- Aerodynamics
- Avionics / Electronics
- Electrical
- Flight Mechanics
- Human Factors
- Loads and Dynamics
- Materials – Polymer based
- Non-Destructive Evaluation
- Propulsion
- Software
- Statistical Sciences
- Systems Engineering
- Aerothermal
- Communications/Tracking
- Electrical Power
- Guidance, Navigation & Control
- Life Support/Active Thermal
- Materials – Metals/Ceramics
- Mechanical
- Passive Thermal
- Robotic Operations
- Space Environment
- Structures
- Systems Safety Engineering (SSE)
- Recent additional consideration has been placed on Technical Fellows for the Reliability, Maintainability, Quality, and Risk Management disciplines.

Technical Fellows are envisioned to exercise several specific responsibilities, as shown in this list (compiled from a variety of presentations on the subject by several people):

- Serve as senior technical expert in support of the Office of the Chief Engineer with regard to improving the discipline and the NASA Engineering and Safety Center (NESC)
- Serve as an independent resource to the agency and industry
- Foster consistency with creation and maintenance of agency level standards and specifications – using center discipline leads and others
- Conduct workshops and conferences to enhance discipline awareness (e.g., SSE Awareness Training)
- Identify and address critical discipline issues
- Do not exercise Technical Authority
- Prerequisites:
  - Must be a full-time, permanent NASA employee with a minimum grade of GS-15 or equivalent for at least one year
  - Must have earned an advanced degree in science or engineering
  - Must have demonstrated sustained technical leadership
  - Must have published technical papers and/or engineering reports
  - Must have received recognition for technical achievements

Summary

The implementation of the new Technical Excellence approach in NASA offers a unique opportunity for the technical organizations to step up to a critical responsibility for assuring the technical readiness of NASA's space flight hardware and software. The technical organizations will be responsible for safe and reliable operations, as they have always been, by properly implementing their discipline requirements, methods and techniques with no ambiguity of technical responsibility. Improving on the technical capabilities of the engineers within the Agency is a necessary part of that process. Implementing technical authority within the technical organizational structure and clearly communicating that process along with providing technical experts to shepherd the disciplines is truly a concept whose time has come.

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