PURPOSE, PRINCIPLES, AND CHALLENGES OF THE NASA ENGINEERING AND SAFETY CENTER

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ABSTRACT

NASA formed the NASA Engineering and Safety Center in 2003 following the Space Shuttle Columbia accident. It is an Agency level, program-independent engineering resource supporting NASA's missions, programs, and projects. It functions to identify, resolve, and communicate engineering issues, risks, and, particularly, alternative technical opinions, to NASA senior management. The goal is to help ensure fully informed, risk-based programmatic and operational decision-making processes. To date, the NASA Engineering and Safety Center (NESC) has conducted or is actively working over 600 technical studies and projects, spread across all NASA Mission Directorates, and for various other U.S. Government and non-governmental agencies and organizations. Since inception, NESC human spaceflight related activities, in particular, have transitioned from Shuttle Return-to-Flight and completion of the International Space Station (ISS) to ISS operations and Orion Multi-purpose Crew Vehicle (MPCV), Space Launch System (SLS), and Commercial Crew Program (CCP) vehicle design, integration, test, and certification. This transition has changed the character of NESC studies. For these development programs, the NESC must operate in a broader, system-level design and certification context as compared to the reactive, time-critical, hardware specific nature of flight operations support.

1. CREATION AND PURPOSE

The Space Shuttle Columbia accident occurred on the morning of February 2, 2003 in the skies over Texas. NASA immediately formed an accident investigation board, the Columbia Accident Investigation Board or CAIB. As the investigation progressed, the CAIB Chairman provided briefings and updates to NASA, the U.S. Congress, and the American public. On one such occasion in July 2003, speaking publically following a Congressional briefing, the CAIB Chairman stated

> *"The safety organization sits right beside the (Shuttle) person making the decision, but behind the safety organization there is nothing there, no people, money, engineering, expertise, analysis ... there is no 'there' there."*

NASA responded within weeks to this statement announcing in late July 2003 the formation of the NASA Engineering and Safety Center or NESC. The NESC was to be operational by the end of 2003, and provide the NASA Safety and Mission Assurance Director and the NASA Chief Engineer with the independent engineering capability the CAIB had pointed out publically was missing.

NASA's traditional safety philosophy of

- Strong in-line checks and balances
- Healthy tension between organization elements
- Value-added independent assessment

defines the NESC's role relative to the technical functions of the inline engineering organizations that support NASA programs and projects. Using its own funds, the NESC performs independent analyses and testing to bring challenging or confirming data to complex technical issues, and provides or supports alternative viewpoints on program or project technical decisions. If necessary, the NESC can and does make these alternative viewpoints known to the highest levels of NASA management, including the Administrator, to help make sure NASA's development and operational decisions are fully risk informed. The NESC vision is to be a high-performance, world-class technical resource routinely sought out by NASA's programs, projects, and organizations for its ability to provide timely, value-added solutions to difficult problems.

2. ORGANIZATION AND OPERATION

The NESC is organizationally part of the NASA Chief Engineer's Office supporting the Chief Engineer in his role as the Engineering Technical Authority for the Agency, reporting to the Administrator. The NESC is a distributed virtual organization, with the Director and management offices located at the NASA Langley Research Center (LaRC) and permanently assigned technical personnel located at each of the other NASA Centers. The NESC operates in a "tiger-team" model when conducting studies and assessments, forming a dedicated team of subject matter experts to address a well-defined technical issue.

2.1 Organization

The NESC is organized into five complimentary functional offices.

1) Principal Engineers Office, providing study leadership and management, particularly for longer term, multidisciplinary assessments. The office is currently staffed by three Principal Engineers and one Associate Principal Engineer at LaRC, one Principal Engineer at NASA Johnson Space Center (JSC), and two Associate Principal Engineers, one located at NASA Marshall Space Flight Center (MSFC), and the other at NASA White Sands Test Facility (WSTF).

2) NESC Chief Engineers Office, one at each of the ten NASA field centers to be the "eyes and ears" for the NESC and provide a conduit for alternative opinions. The NESC Chief Engineers track program and project technical progress and risks at their respective Centers, help identify and facilitate assignment of subject matter experts to support NESC teams, and manage pre-positioned resources to ensure ready and timely support. NESC Chief Engineers also lead assessments suited to their technical interests and capabilities.

3) NASA Technical Fellows Office, currently staffed by eighteen NASA Technical Fellows, each recognized by NASA as a technical leader in their specific discipline. They, along with the NESC Chief Scientist and the NESC Chief Astronaut, each maintains a technical discipline team consisting of experienced subject matter experts from other NASA Centers, U.S. Government Agencies, academia, and industry. These technical teams are often the source of subject matter expertise supporting NESC studies. The NASA Technical Fellows often lead discipline specific NESC assessments, however; recently the role of Technical Fellow has expanded to include an Agency-Level capability leadership role. The capability leadership role is to help ensure NASA has the necessary capability in each discipline, including people, facilities, and tools, for future missions and programs. As a result, each NASA Technical Fellow has one or more Deputies to assist with their responsibilities. Fig. 1 lists the 19 current technical discipline teams, with a new one for Sensors and Instrumentation in the process of being formed. Fig. 2 shows the typcial annual affiliation of subject matter experts participating on NESC Technical Discipline Teams.

4) The NESC Integration Office (NIO, formerly the Systems Engineering Office) provides technical integration and coordination between the NESC and the major NASA Program and Project Offices, and administers the NESC Review Board review and approval processes. The technical integration function has become increasingly important and complex as NASA's current major development programs are completing design and beginning hardware build and test.

5) The Management and Technical Support Office (MTSO) provides financial, budgetary, and procurement support for the NESC. The ability of NESC study teams to form and respond quickly to urgent technical issues is dependent on the ready-access procurement instruments and pre-positioned resources managed by this office. The MTSO also provides contract technical editing, project logistics and coordination support, and audio and video services to support NESC assessments.

2.2 NESC Review Board

NESC Principal Engineers, NESC Center Chief Engineers, NESC assigned NASA Technical Fellows, the NESC Chief Scientist and Chief Astronaut, the Deputy Director for Safety, the Heads of the MTSO and NIO, and the Deputy Director and the Director of the NESC are voting members of the NESC Review Board (NRB). The NRB evaluates and approves each technical study and plan, monitors assessment progress, and reviews and approves the final report and recommendations to ensure technical rigor and accuracy. The NRB meets approximately weekly, and voting members attend in person or via web-video links.

The NRB decides on accepting new studies or assessments according to the following priorities

1. Technical support of projects in the flight phase
2. Technical support of projects in the design phase
3. Known problems not being addressed by any project
4. Work to avoid potential future problems
5. Work to improve a system

2.3 Technical Reports

In the CAIB final report, NASA was criticized for lack of technical reports supporting many Space Shuttle technical decisions and rationales. In many cases, the only source of documentation was view-graph presentation materials, which did not contain the technical data and analysis details to reconstruct conclusions or recommendations. During formulation of the NESC, this shortcoming was clearly noted, and the NESC adopted as a core value documenting all studies and assessments with technical, peer-reviewed final reports.

Final reports are required for any assessment containing NESC performed independent analyses and/or testing, and must fully document models, analyses and assumptions, test articles, test procedures, test data, and conclusions and recommendations. Conclusions and recommendations are written in terms of Findings, Observations, and Recommendations (FORs). A finding is a relevant fact derived from analyses or tests, and an observation is a technical statement or opinion that could or should be of interest to the project requester, but not necessarily strictly derived from the tests or analyses. Recommendations are statements, directly traceable to one or more specific findings or observations, of the action or position the NESC recommends the project adopt. Each final report is peer-review internally and externally to the NESC, and receives final scrutiny and approval from the NESC Review Board before publication. Since in some cases, assessment results must be delivered to the requester before the final report is complete, the NESC Review Board may also review and approve FORs separately from the report, with the expectation that they are final and will not change.

In some cases where the NESC does not perform independent analyses or tests, but instead reviews existing technical documentation or provides direct technical support to a project, resulting NESC opinions or recommendations may be documented as a "white paper", also approved by the NESC Review Board.

Depending on any distribution restrictions, for example due to export control laws or proprietary contents, the NESC publishes each report through the NASA publication system with appropriate availability. The NESC maintains a cadre of technical writers and configuration control specialists to assist with and manage the technical report process.

2.4 Individual and Team Recognition

The NESC recognizes that the individual subject matter experts, acting separately and as part of the assessment team, are the key to NESC operations. Without the ability to identify, recruit, and support highly skilled and capable technical experts external to the NESC, the NESC could not be effective, timely, or value-added. Because of this, the NESC has established its own annual recognition (awards) program to ensure that key individuals and teams are recognized for the impact their work makes. Awards are given for Leadership, Engineering Excellence, Administrative Excellence, and Group Achievement. The highest award, the Directors Award, is given to an individual that takes personal accountability and ownership of a controversial technical issue.

3. SIGNIFICANT MISSION SUPPORT

The technical studies conducted by the NESC are typically performed at the request of NASA management, program or project managers, project technical leads, and Center engineering organization leadership. However, the NESC also maintains an online presence for requests that bypass normal program or organizational reporting and chains-of-command to ensure alternative technical opinions can be made known and independently evaluated.

Fig. 3 shows the historical breakdown for the source of the assessment request, and Fig. 4 shows, by year, the number of assessments supporting each of the major NASA Mission Directorates. Evident in Fig.4 is the long-term annual average number of assessments, slightly over 50, or about one per week. Since inception, the NESC has accepted 684 of 1122 assessment requests, completed 583, and has 101 either currently active or in final report preparation and closeout.

A comprehensive listing of all active and completed NESC assessments is beyond the limits of this paper; however, the list of current assessments below is representative of NESC mission support assessments.

- CubeSat Radiation Environments and ISS (International Space Station) Radiation Dose Data
- Additive Manufacturing Structural Integrity Initiative
- Burst Factor Assessment for Pressure Vessels
- (Electronic) Parts-level vs. Board-level and Box-level Screening Testing
- JWST (James Webb Space Telescope) Space Environment Launch Constraints
- Wear Resistant Titanium Bearing Technology for Spacesuits
- Independent Crew Vibration and Shock Requirements and Compliance Assessment
- Commercial Crew Aerodynamics Peer Review
- Review of the Orion-ESM (European Service Module) Interfaces

4. RISK REDUCTION AND EXTERNAL PROJECTS

The NESC, in addition to assessments addressing near-term mission needs, has undertaken several large-scale, risk-reduction projects for major NASA programs that, for one reason or another, the program could not undertake on its own. These projects include the Max Launch Abort System (MLAS), the Composite Crew Module (CCM), and Shell Buckling Knockdown Factor (SBKF) projects, among others. Each of these projects required the design, development, and test of full-scale hardware over several years.

The NESC undertook the Max Launch Abort System project to develop and flight-test an alternative launch abort (escape) system design, as compared to NASA's traditional tower-based design used during Projects Mercury and Apollo. This design was risk-reduction for the Orion escape system, which at the time was experiencing development delays. This project defined a passively stable, aerodynamic faired, side-mounted rocket motor configuration as a potential drop-in replacement for the Orion Launch Abort System (LAS). With the configuration defined, the project designed and built full-scale flight hardware to confirm the stability characteristics during a pad-abort type scenario. The flight test vehicle launched on July 8, 2009 at the NASA Wallops Flight Test Facility, as shown in Fig. 5(a). Post-flight data analysis showed good agreement with pre-flight prediction [1].

The NESC performed a second risk-reduction project for Orion in the same period, investigating the potential use of composite materials for the Orion crew-module pressure vessel. The Composite Crew Module designed, sized, and built a full-scale pressure vessel including hatches, mounting blocks, and access ports, Fig. 5b. The NESC tested the fully instrumented composite pressure vessel to failure in 2009 at the NASA Langley Research Center [2].

A third risk-reduction project, still on going, is addressing shell buckling design-knockdown factors for orthogrid launch vehicle tanks. A knockdown factor reduces the analytical tank design stiffness in order to account for material and geometric imperfections and defects that can affect buckling loads and behaviour. This project has tested sub-scale and full-scale tank shell structures at the NASA Marshall Space Flight Center. The objective is to validate buckling prediction methods for tank structures, and identify and reduce knockdown value conservatism, leading to lighter weight tank structures. Fig. 5(c) shows the full-scale test setup, along with equipment supporting a high-resolution, surface-deflection photogrammetry measurement system. This risk-reduction project will benefit future NASA launch vehicle developments projects [3].

The NESC, on occasion, also participates in or conducts technical or safety-related assessments for requestors outside of NASA. The reason for these requests vary, ranging from the need for total independence from another U.S. Government Agency, or because of the NESC capability to form subject matter expert teams quickly. Significant examples of NESC led outside assessments include

- Toyota Un-Intended Acceleration Study for the National Highway Transportation Safety Administration (NHTSA) [4], looking for latent hardware or software faults that could lead to sudden, un-commanded accelerations.
- Chilean Miners Rescue [5], in which the NESC over several days assembled an expert team of human factors, physiology, and structural designers to write requirements for the rescue capsule.

In each of these cases, the NESC assessment provide needed, un-biased or time-critical technical data on issues of national or international public concern.

5. FUTURE CHALLENGES

In recent years, the NESC's human spaceflight focused activities have changed from Shuttle Return-to-Flight, completion of the International Space Station (ISS), and major operational science missions such as the Hubble Space Telescope. Today the focus is much more directed to the Orion Multi-Purpose Crew Module (MPCV), Space Launch System (SLS), Ground Systems Development and Operations (GSDO), Commercial Crew Program (CCP), and James Webb Space Telescope (JWST) design, integration, test, and certification activities. For these programs, the identification and resolution of technical issues must come early enough in the development cycle to influence design decisions and/or minimize cascading system-level or architecture interactions. To do so, the NESC must engage directly with program engineering teams, but must also maintain independence in case of major technical disagreements or apparent compromises to safety or mission success requiring elevation to NASA senior management.

A lesson-learned from NESC engagement with the predecessor Constellation development program was that creating complex flight, guidance, control, avionics, structural, and/or aerodynamics models and simulations independent of program efforts requires long-lead times. Independently developed models allows the NESC to challenge modeling assumptions, implementation, and interpretation of results, which is not possible if the NESC must rely on the program developed models because of time criticality. Consequently, the NESC has undertaken a long-term modeling and simulation effort to develop several key simulation capabilities in parallel to program efforts, specifically a comprehensive flight dynamics/controls/flexibility/slosh model of the SLS, and an entry/descent/landing model adaptable to either CCP provider. In this manner, the NESC models can be compared and validated with program or contractor models to ensure proper capture of system physics, but still be based on independent assumptions, tools, and techniques.

Farther in the future, Orion, SLS, CCP partners, and JWST will transition from development to flight operations. While an operational focus is more like the NESCs original role, the number of flight programs, the change in mission types, and, in the case of the CCP partners, commercial operations, will further challenge the NESC to adapt.

6. REFERENCES

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3. Hilburger, M. W., Waters, W. A. Jr., and Haynie, W. T. Buckling Results from the 8-Foot-Diameter Orthogrid-Stiffened Cylinder Test Article TA01, NASA TP-2015-218785

4. Technical Support to the National Highway Traffic Safety Administration (NHTSA) on the Reported Toyota Motor Corporation (TMC) Unintended Acceleration (UA) Investigation, available at http://www.nhtsa.gov/UA

5. http://www.nasa.gov/feature/how-nasa-helped-the-33-chilean-miners

19 Technical Discipline Teams

Aerosciences
Avionics
Electrical Power
Flight Mechanics
Guidance, Navigation & Control
Human Factors
Human Spaceflight Operations
Life Support/Active Thermal
Loads and Dynamics
Materials
Mechanical Systems
Non-Destructive Evaluation
Passive Thermal
Propulsion
Robotic Spaceflight
Software
Space Environments
Structures
Systems Engineering

Figure 1. List of NESC Technical Discipline Teams

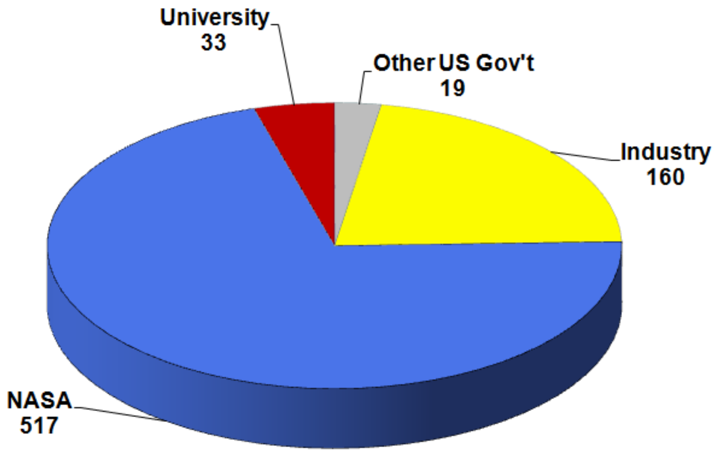

Figure 2. Affiliation of NESC Technical Team Membership, 2015

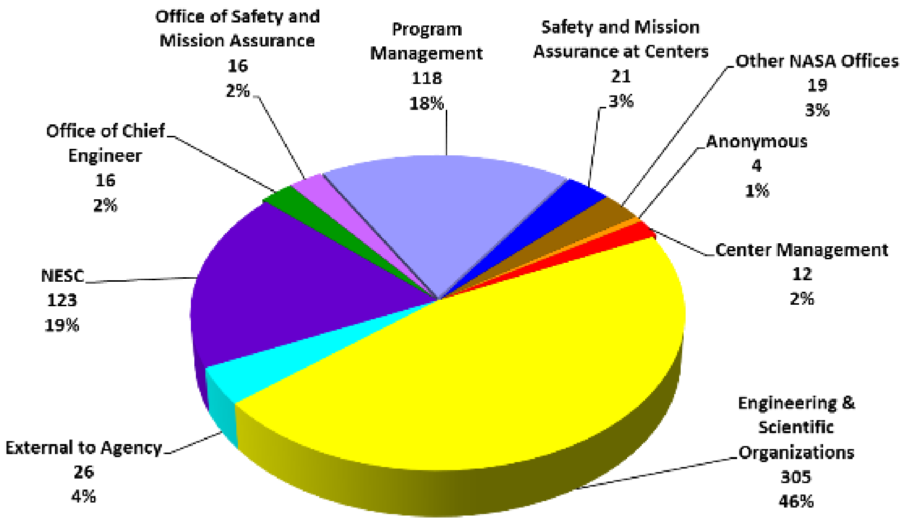

Figure 3. Historical Breakdown of Assessment Request Source

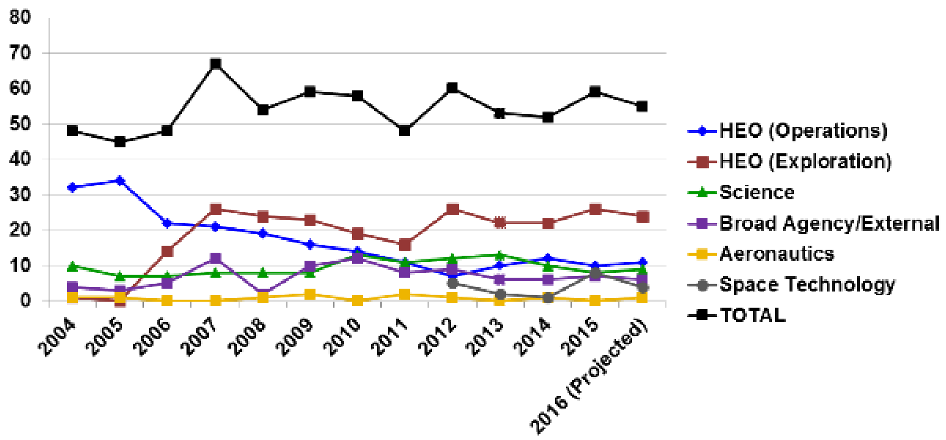

Figure 4. Historical Breakdown of NASA Mission Directorate Support

(a)

(b)

(c)

Figure 5. Major NESC Risk Reduction Projects (a) Max Launch Abort System, (b) Composite Crew Module, (c) Shell Buckling Knockdown Factor