NAC Technology, Innovation and Engineering Committee Meeting
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OCE Update/Discussion on Processes to Evaluate Technology Implementation

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Topic/Action

- **Office of Chief Engineer Update and Discussion of Processes to Evaluate Technology Implementation**
  - Dr. Ralph Roe, NASA Chief Engineer

- **Clarifications:**
  - Share how OCE saw the Commercial Crew providers employ new technologies so that STMD can learn from those processes to get the STMD technologies flying
  - Lessons Learned either way (good or not so good)

Agenda

- **Action**
- **Background**
  - CCP Insight/Oversight Model
  - Engineering Team Engagement
- **Examples of Technology Implementations Evaluated**
- **Specific Examples**
- **General Observations, Lessons Learned in New Technology Development**
- **Summary**

Background - CCP Insight/Oversight Model

- **Lean approach with minimum prescription to allow innovation in for hardware design, management, and processes across the board**
- **Leverage partner processes, standards and innovation**
- **Shared assurance/accountability between NASA and Partner**
- **Risk based assessment with safety focus**
- **Imposed reduced set of Engineering (D&C), SMA, and HTMA Standards for safety**
  - Alternate approaches accepted that met or exceed the NASA Standard
- **Selected critical systems for deeper insight penetration (GN&C, Propulsion, Structures)**
  - Audit based-not full/equal coverage across all systems

Background - Engineering Team Engagement

- **Lean Engineering Team**
  - Very lean initially then grew over time as issues/challenges arose in various systems
  - Remains lean compared to traditional insight/oversight model
- **Insight based relationship with partners**
  - SSM-RE relationships important and varied widely depending on individuals and partners
- **Responsible for concurrence on design certification (VCN signoff) and COFR**
- **D&C standards discussion/negotiations became very important tool for NASA team leverage to gain sufficient insight and to ensure safe and reliable systems**
- **ERB afforded broad communication across the engineering team and SME's to work through technical issues, risk characterization and form recommendation for the program**
- **Program Control Board (PCB) used by PM to make risk based decisions**
- **As CCP matured through the life cycle the engineering team grew and adjusted over time as issues came up and worked through them with the Program and the Partners (ERB and PCB)**

Technology Implementations Evaluated

- **Action to Engineering Team:**
  - During the past few years working with the Commercial Partners, there have been several designs that were deployed on the spacecraft/launch vehicle/ground systems that lacked adequate understanding of the fundamental physics/margins, potential failure causes, and inadequate controls – unfortunately the result was catastrophic failure and loss of critical hardware
    - Tech issues: COPV, Merlin Engines, Parachutes, NTO-Ti flammability, etc.
    - High visibility failures: F9-20, F9-29, IFA Static Fire anomaly, OFT SW issues, etc.
  - Review and Identify areas within the Commercial Partners designs that are "new" to human spaceflight or "limited experience"
  - Both Commercial Partners have introduced designs that within our human spaceflight experience there is very limited to no data/experience to reference
  - Do we understand the design/technology to identify the margins and controls to certify the designs for NASA crew?

Technology Implementations Evaluated (continued)

- **Specific Question to Engineering Team:**

  1. Identify examples that need to be added to the list?

  2. Is there an adequate review of the technology/analysis that allows NASA to understand the potential impact to the design?

  3. Is CCP controlling critical design parameters via Hazard Reports (Causes/controls/verifications), Qualification/Acceptance, Verifications, and changes? If not, please list gaps and/or suggested improvements."

  4. Of the items identified, does NASA/Partner need to perform additional testing/development/analysis/exploration of operating constraints?

  5. Has NASA/Partner researched previous use/studies of technology? (e.g. after recent anomaly, similar concerns were quickly found in literature search).

Technology Implementations Evaluated (continued)

- **Summary of Results:**
  - Matrix developed by Engineering Team resulting in 91 entries
  - Spans multiple systems/subsystems including unique approaches in the following areas:

System	Number	Subsystem/Examples
Analysis	9	Composite damage tolerance NDE/Analytical approach, Water landing modeling/secondary impact, Negative margin control authority related to slosh
Avionics and Software	14	EEE Parts using automotive/commercial grade parts, Distributed pyrotechnic (SI) architecture with common serial databus, Non-deterministic SW Architecture
ECLSS/ATCS	7	R134A cooling system, High pressure ECLSS tanks within pressurized cabin
Integrated Systems	16	Pusher Escape Systems, Autonomous Range Termination Sys, Separation Systems-ZFT Frangible joints, hydraulic launch release sys., Land landing utilizing airbags and parachutes
Operations	10	Crew insertion prior to LV Loading with active escape system, No LCC for LV – all logic built into auto sequences and alarms
Parachutes	2	Model based certification for 3 and 4 parachute systems
Propulsion	19	High Pressure Helium Prop system for Abort, LV COPV in Cryo, Additive Manufactured parts in Fracture Critical applications, Densified Prop (LOX/RP), Transient combustion 3D CFD modeling, Composite thrusters
Prop/Aerothermal	1	Abort engine protuberances in OML
Pyrotechnics	4	Non-Pyro Sep nuts, ZFT Frangible Joints, Alternative pyrotechnic screening approaches, Pneumatic sep sys
Structures/Mechanical	4	Composites, Windows-acrylic thermal and pressure panes, Deployable/retractable nosecone,
TPS	4	Boeing Lightweight Ablative TPS, Tiled (vs monolithic) Ablative Heatshield, Centaur Foam insulation

Specific Examples

- **Additive Manufacturing – a win-win!**
  - Extensive use of additive manufactured parts in propulsion system components
  - Significant benefit to cost, schedule, design efficiency with use of AM
  - NASA is also heavily engaged in AM research and development at MSFC and other centers
  - Team recognized this as an area where good collaboration between NASA and commercial partners would be required, especially given this maturing capability was intended to be used in critical HFS applications
    - Many applications in fracture critical applications (propulsion system components)
    - AM material properties and fracture properties would be needed for certification (fundamental physics)
  - Initially there was no formal NASA standards or guidance on AM
  - Joint NASA/Provider team including NESC expertise assembled to work the issue
    - Develop interim guidelines for AM parts intended for use in fracture critical applications
    - Team continuing to work and develop NASA-STD-6030, “Additive Manufacturing Requirements for Crewed Spaceflight Systems”, scheduled to be released in June timeframe, which is based on inputs from NASA team and industry partners
  - Seeing very good results in AM part performance in ground test, flight test, and in evaluation of parts inadvertently exposed to other high energy failure environments

Specific Examples (continued)

- **Pusher Escape Systems-Challenging Integrated System New to HSF**
  - Both partners selected pusher type crew escape system, new to human space flight
  - Innovative and has a number of performance/efficiency benefits compared to the more traditional puller/tractor system
    - Full envelope coverage with ability to safely abort at any point in flight
    - Eliminates need for protective faring that eventually required to be jettisoned with tractor system
    - Eliminates a critical separation event simplifying the mission sequence of events-safety improvement
    - Liquid fueled with hypergals for simple, quick, reliable start and are throttleable/steerable
    - Propellant, common with RCS, now available for other uses if abort not required
    - Integrated system can enable multiuse with propulsive landing and supports reusability philosophy
  - Complex and highly integrated system requiring multiple discipline, systems and SEI focus
    - Liquid propulsion and integrated with other Spacecraft propulsion systems/functions
    - Automated Abort from triggers/cmds (milliseconds), abort timing, and various abort modes along flight path
    - System analysis/verification with less stable unstable platform with center of mass close to center of thrust
    - Ability to throttle engines
    - Parachutes integral to control and reorientation
  - Required significant joint NASA/provider team engagement with disciplines, systems and SE&I to get to successful the integrated verification/validation (different approaches used by each partner)
    - Stressing the importance of the SE&I even early on in the development effort

Key Observations/Lessons Learned in New Technology Development

- **Found many areas of hardware design and process innovation in new technology development, however often found challenges/issues impeding ability to get to flight certification**
  - A comprehensive long view of the end goal seemed to be missing in some cases
- **Spiral design evolution approach with rapid iterative design, build, test cycles is really good, enabling quickly maturing the design, however a few pitfalls were evident**
  - Found to be mostly empirical based approach which limits ability to explore key parameters analytically
  - Found a hesitancy to lock-down the design at appropriate time to manage the configuration and control quality blurring the line between development and qualification
- **Found lack of rigorous System Engineering & Integration/Process Controls which is an essential ingredient for eventually certifying safe and reliable flight hardware**
- **Missing important fundamental physics early development efforts**
  - Lacked building block/material level testing/analysis addressing compatibility issues and potential hazards in appropriate environmental conditions (press, temp, shock, commodity, ox, fuel, etc.)
  - Tended to focus on component or system level testing performance testing while missing some of the fundamental physics that would be discovered at material level testing

Key Observations/Lessons Learned in New Technology Development (contd)

- **System Modeling/Analysis is really important tools to enable physics insight**
  - Can bridge between material level testing, component testing and system level testing
  - There should be a healthy balance of analytical work complementing and augmenting the testing
  - The maturity and validation of these models need to evolve with the maturity of the hardware and be appropriately anchored as part of certification and V&V
- **Having the NASA Standards imposed was important for setting appropriate expectations**
  - Proved invaluable in process of jointly getting to certification
  - Important early when innovating for awareness

Summary

- **In general found many areas of hardware design and process innovation in new technology development with the commercial partners in CCP**
  - however often found unintended consequences/issues impeding ability to get to flight certification
- **Lean Engineering Team with appropriate expertise was able to successfully engage with partners, gain sufficient insight, and work jointly to get to hardware certification**
- **Rapid iterative design, build, test cycles coupled with strong analytical approach enable rapid hardware development with appropriate physics understanding**
  - Mostly empirical based approach which limits ability to explore key parameters analytically
- **Need to lock-down the design at appropriate time and manage the configuration and control the quality as hardware matures and moves into qualification**
- **A rigorous System Engineering & Integration process is essential ingredient for successful certification and safe and reliable flight hardware**
- **Understanding the fundamental physics that new technology will be experiencing is key to success**
- **System modeling is valuable too that should be employed throughout the design life cycle in the appropriate balance with component and system testing**
- **Having Standards and guidelines early in the development process is essential to the end goal of safe and reliable hardware**