



Remarks on Human Rating Requirements for US Space Systems

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Agenda



- Technical Standards mandated by NASA
- Human-Systems Integration Standards
- Other Human-Rating Requirements



Technical Standards Mandated by NASA



- NASA mandates technical standards to ensure a safe, habitable environment for the crew
- The level of design safety sought by NASA's standards will be revealed upon an understanding of the approach to failure tolerance



We'll come back to the standards in a little bit.

Human-Systems Integration Standards



- NASA STD 3001 Vol. 1, Space Flight Human-Systems: Crew Health
- NASA STD 3001 Vol. 2, Space Flight Human-Systems: Human Factors, Habitability, and Environmental Health



NASA-STD-3001 is a NASA Agency level document which has been established by the Office of the Chief Health and Medical Officer to minimize health and performance risks for flight crews in human space flight programs. Volume 1, Crew Health, sets standards for fitness for duty, space flight permissible exposure limits, permissible outcome limits, levels of medical diagnosis, intervention, treatment and care. It considers human physiological parameters as a system. Volume 2, Human Factors, Habitability and Environmental Health focuses on human physical and cognitive capabilities and limitations. It defines standards for internal environments, facilities, payloads and related equipment, hardware and software systems with which the crew interfaces during space operations. The focus is on human-system integration, to ensure that the human and the system can function together to accomplish mission success.

The amount of work for implementing ISO standards on Human Space Flight is significant. There are different approaches of interested countries, due to different experiences and consequent requirements; the empiricism of some requirements could not discern specific avenues, and some existing ISO drafts include Both Russian and US approaches (i.e. on toxicity limits of offgassed compounds). An intended translation of Russian standards should contribute to better understanding by our experts.

Other Human Rating Requirements



- NASA NPR 8705.2:

Technical requirements regard:

- Systems Safety
- Human Control of Systems
- Crew survival and aborts



NPR 8705.2 is a Procedural Requirement which defines the Human-Rating certification process and related technical requirements for NASA human space flight programs.

The technical requirements are contained in Chapter 3 of this document.

Some specific requirements beyond the ability to provide a safe, habitable environment



- Failure tolerance
- Tolerance to inadvertent operator actions (human error)
- Tolerance to malfunction of critical software
- Ability to detect, isolate and/or recover from faults
- Ability to perform critical functions autonomously without communication with Earth
- Ability of crew to access equipment in emergencies



Failure tolerance



- Risk-informed design
- Specific failure tolerance and risk mitigation results from integrated design and safety analysis
- Emergency equipment (fire extinguishers, emergency breathing masks, launch/entry pressure suits, abort-exclusive systems) may not be counted as part of the systems failure tolerance



NPR 8705.2 is based on a risk-informed design approach, with decisions made with an understanding of an acceptable level of safety and the safety risks involved. Specifically, the specific level of failure tolerance and risk mitigation should result from an integrated design and safety analysis, with a minimum of one failure tolerant. The failure tolerance requirement pertains to systems that PREVENT the INITIATION of a catastrophic event rather than mitigate consequences once an event occurs. Safety analysis sought by NPR 8705.2 combines Hazards Analyses, Fault Tree Analyses, Failure Modes and Effects Analyses and Probabilistic Risk Assessments. **Address the issue of uncertainty.**



Example 1:

Mitigation of Fire Risks in Habitable Compartments

- General strategy: prevent fire
 - Materials control
 - Minimizing potential ignition sources and materials that can propagate a fire
 - Controlling the quantity and configuration of flammable materials to eliminate fire propagation paths



Spacecraft fire safety emphasizes fire prevention, which is achieved primarily through the use of fire-resistant materials. Materials selection for spacecraft is based on conventional flammability acceptance tests, along with prescribed quantity limitations and configuration control for items that are non-pass or questionable. ISO 14624-1 and -2 are the major methods used to evaluate flammability of polymeric materials intended for use in the habitable environments of spacecraft. The methods are upward flame-propagation tests initiated in static environments and using a well-defined igniter flame at the bottom of the sample. The tests are conducted in the most severe flaming combustion environment expected in the spacecraft. However, using only non-flammable materials would make building a spacecraft prohibitively expensive. So, we use also flammable materials (Velcro is one example); we trade off an accepted worst case fire event with practicality. JSC TM 29353 on configuration flammability assessment provides useful information on potential safe uses of flammable materials. Historically, we have had several very serious fires before the current fire control strategy has been implemented. The 1966 Apollo fire geared us towards the current approach. In the STS we had few events (STS 6 – odor caused by fusing overheated wires; STS 28 – arc tracking; STS 35 – overheated resistor in a digital display; STS 50 – blown capacitor in a medical apparatus). **In addition to preventing fires**, spacecraft are equipped with fire detectors and extinguishers. For comparison, FAA requirements appear to not include fire prevention. **14CFR Parts 401, 415**, et al. (December 29, 2005) on **Human Space Flight Requirements for Crew and Space Flight Participants; Proposed Rule**, Section 8 on Smoke Detection and Fire Suppression indicates that “FAA would require an operator or flight crew to have the ability to detect smoke and suppress a cabin fire to prevent incapacitation of the flight crew. Prior to a fire occurring, smoke can rapidly incapacitate a pilot or obscure the pilot’s vision such that the vehicle cannot be flown safely. A crew should be able to respond to a vehicle fire so as not to risk the public.” **Title 14 on Aeronautics and Space of the Code of Federal Regulations, Part 460 – Human Space Flight Requirements: Section 460.13**, Smoke detection and fire suppression: “An operator or crew must have the ability to detect smoke and suppress a cabin fire to prevent incapacitation of the flight crew.”

Current NASA trends: A few deficiencies have been noted with the existing test method (epistemic uncertainty related to testing under fixed conditions; statistical uncertainty related to the test logic). The pass/fail test logic of ISO 14624-1 and -2 does not allow a quantitative comparison with reduced gravity or microgravity test results; therefore their use is limited, and possibilities for in-depth theoretical analyses and realistic estimates of spacecraft fire extinguishment requirements are practically eliminated. To better understand the applicability of laboratory test data to actual spacecraft environments, a modified ISO 14624 protocol has been proposed that, as an alternative to qualifying materials as pass/fail in the worst-expected environments, measures the actual upward flammability limit for the material. A working group established by NASA to provide recommendations for exploration spacecraft internal atmospheres realized the importance of correlating laboratory data with real-life environments and recommended NASA to develop a flammability threshold test method. The working group indicated that “the flammability threshold information will allow NASA to identify materials with increased flammability risk from oxygen concentration and total pressure changes, minimize potential impacts, and allow for development of sound requirements for new spacecraft and extravehicular landers and habitats.” An approach to the flammability threshold testing has been published (ISO TS 16697). Recent research using this method has shown that current normal gravity materials flammability tests do not correlate with flammability in ventilated, micro- or reduced-gravity conditions. Further experimental correlation using the flammability threshold approach are being conducted (Hokkaido Univ. JAXA, NASA, Univ of California at Berkeley). Currently, the materials selection for spacecraft is based on the assumption of commonality between ground flammability test results and spacecraft environments, which does not appear to be valid. Materials flammability threshold data acquired in normal gravity can be correlated with data obtained in microgravity or reduced-gravity experiments, and consequently a more accurate assessment of the margin of safety of the material in the real environment can be made. In addition, the method allows the option of selecting better or best space system materials, as opposed to what would be considered just “acceptable” from a

flammability point of view and realistic assessment of spacecraft fire extinguishment needs, which could result in significant weight savings. The knowledge afforded by this technique allows for limited extrapolations of flammability behavior to conditions not specifically tested and that could potentially result in significant cost and time savings.



Example 2:

Mitigation of Fire Risks in Oxygen Systems

General strategy: Prevent ignitions



An ignition in oxygen systems may be conducive to a fire, which could have catastrophic consequences.

NASA STD 6001 establishes NASA program requirements for evaluation, testing, and selection of materials to preclude unsafe conditions related to oxygen compatibility. Until about 2008, materials intended for use in LOX or GOX systems of space vehicles and ground support equipment had to meet the criteria of Test 1 (ISO 14624-1) of STD 6001 for nonmetallic materials in environments less than or equal to 375 kPa, or test 17 (ISO 14624-4). In addition, materials had to meet the criteria of Test 13A or 13B (mechanical impact), as applicable. The practice was to use Test 13 as the sole discriminator for accepting or rejecting a polymer for aerospace oxygen systems. Materials that did not meet the criteria of the required tests but remained candidates for use had to be verified in the use configuration by analysis or testing and specifically approved by the responsible NASA Center materials organization. It has been noted that the practice of selecting materials based only on Test 13 criteria requirements could subject aerospace oxygen systems to unnecessary risks, and an alternate approach was adopted, following the NPR8705.2 requirement for integrated design and safety analysis, which includes hazards analyses, failure modes and effects analyses and risk assessment. The approach is described in detail in the latest version of NASA STD 6001.

Provide a brief review of the process delineated by STD 6001.