This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

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Standard Guide for Occupant Survivability in Orbital Vehicles[1]

This standard is issued under the fixed designation F3668/F3668M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The purpose of this guide is to provide guidance for current and developing space flight operators who intend to fly humans on spacecraft. The occupants include the crew and spaceflight participants in the orbital vehicles. This guide is targeted primarily toward ground launched, Low Earth Orbit (LEO) spacecraft which provide transportation from the surface to orbit followed by subsequent rendezvous with an orbital complex or short-duration free flight orbit operations, and safe return to Earth's surface. As used in the guide, LEO is an approximate circular orbit within ~2000 km of Earth's surface. Longer duration spaceflight (>approximately two weeks) aboard an orbital space station poses unique design and medical constraints which are not specifically addressed in this guide.

1.2 The methods in this guide are best practices. Having prior positive performing systems may be a basis for compliance to this guide.

1.2.1 This is a non-comprehensive subset of best safety practices for crew survivability of catastrophic hazards for which all failure tolerance has been exhausted. This is further elaborated upon in 1.5 and 4.2.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 Each spacecraft will present its own set of safety hazards that the user of this standard is expected to analyze and implement survivability options where practical. Also, note that safety is an inherent characteristic of a system, not the product of a few key post-hazard mitigation features. History has shown that a safe and successful spaceflight system is built and operated to the highest possible standards of design robustness, manufacturing quality, inspection, test, and operation, including maintenance and sustaining engineering. The addition of the design features and capabilities as recommended in this guide cannot and is not intended to make up for deficiencies in these basics. It is the responsibility of the user of this standard to establish appropriate safety, survivability, health, and environmental practices and determine the applicability of regulatory limitations prior to use. For example, with regard to survivability, certain operators will likely require additional crew survivability capabilities be provided prior to permitting their space vehicle to fly a crew.

1.5 *This standard does not purport to address all of the safety or survivability design concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, survivability, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F3479 Specification for Failure Tolerance for Occupant Safety of Suborbital Vehicles

2.2 *NASA Standards:*[3]

NASA Standard CCT-REQ-1130 ISS Flight Crew Transportation and Services

NASA Technical Standard NASA-STD-6016C; Standard Material and Processes Requirements for Spacecraft

2.3 *Federal Regulations:*[4]

CFR Title 14, Chapter III, Subchapter A, PART 401 (Definitions)

CFR Title 49, Chapter VIII, PART 830 (Definitions)

[1] This guide is under the jurisdiction of ASTM Committee F47 on Commercial Spaceflight and is the direct responsibility of Subcommittee F47.01 on Occupant Safety.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from the National Aeronautics and Space Administration (NASA), https://ntrs.nasa.gov/citations/20150010757.

[4] Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, http://www.gpo.gov.

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3. Terminology

3.1 *Definitions:*

3.1.1 *abort, v*—the forced early return of the crew when failures or the existence of uncontrolled catastrophic hazards prevent continuation of the mission profile and a return is required for crew survival; escape is a specific instance of an abort and is defined below.

3.1.2 *automated, automatic, adj*—ability of a space system to perform operations independent of ground control team or flight crewmembers as opposed to human control of a system or operation.

3.1.3 *autonomous, adj*—ability of a space system to perform operations independent from any ground-based systems or other external command and control center; this includes no communication with or real-time support from mission control, other ground systems, or other spacecraft.

3.1.3.1 *Discussion*—This definition excludes any devices or systems which contribute to the cooperative rendezvous with and docking to participating spacecraft such as transponders, broadcast of ancillary data such as state vector from a target spacecraft, or radar reflectors on the target spacecraft which contribute to the accuracy of the relative state vector between the chaser and the target.

3.1.4 *catastrophic failure, n*—an event resulting in death or permanent disability to flight crew and/or public, or complete safety-critical system loss; for the purposes of this guide, this is further defined as a failure which either causes the loss of the spacecraft or the loss of the launch vehicle.

3.1.5 *crew or flight crew, n*—any employee or independent contractor of an operator who performs activities directly relating to the launch, reentry, or other operation of or in a launch vehicle or reentry vehicle that carries human beings; a crew consists of flight crew and any remote operator; as this guide is focused on safety of all those onboard, spaceflight participants are considered crew or flight crew.

3.1.6 *critical failure, n*—an event causing serious injury (as defined in 49 CFR § 830.2; Definitions) or illness to the flight crew or public, or major system failure which can result in the early termination of a mission; for the purpose of this guide, this is further defined as a failure of spacecraft system(s) which can compromise the ability of the vehicle to achieve the mission.

3.1.7 *Downrange Abort Exclusion Zone (DAEZ), n*—The Downrange Abort Exclusion Zone (DAEZ) is specific to ground-up rendezvous to the International Space Station (ISS) from Kennedy Space Center (orbit inclined at 51.6 deg); it is a region in the North Atlantic that extends roughly 150 nm east of St. John's Newfoundland to 150 nm west of Shannon, Ireland; the intent of any exclusion zone is to avoid possible ascent escapes into known hazards such as rough seas and cold-water temperatures in the North Atlantic.

3.1.8 *emergency egress, n*—capability for a crew to exit the vehicle and leave a hazardous situation or catastrophic event within the specified time; flight crew emergency egress can be unassisted or assisted by ground personnel including first responders.

3.1.8.1 *Discussion*—During the launch countdown, flight crew may continue by taking an elevator, slide wire, or a similar system to a safe distance or place (shelter) outside a defined hazard area. However, they may also stop at a safe shelter still inside a hazard area that provides adequate protection until the hazard is cleared.

3.1.9 *emergency equipment and systems, n*—systems (ground or flight) that exist solely to prevent loss of life in the presence of imminent catastrophic conditions; examples include fire suppression systems and extinguishers, emergency breathing devices, Personal Protective Equipment (PPE), emergency communication and crew escape systems; emergency systems are not considered a leg of failure tolerance for the nominal, operational equipment and systems, and do not serve as a design control to prevent the occurrence of a catastrophic condition.

3.1.10 *escape, n*—separation of the crewed spacecraft from its launch vehicle/booster in an off-nominal scenario to avoid a hazardous condition during ascent to orbit.

3.1.10.1 *Discussion*—There are several different escape scenarios depending on the phase of ascent (all the way from pad escape through the ascent to orbit). The final possible phase of escape is an escape to orbit; in this case, the spacecraft continues to temporary, sub-optimal orbit rather than immediately returning to the ground.

3.1.11 *failure tolerance, n*—the ability to sustain a certain number of failures while still retaining the capability to satisfy safety objectives.

3.1.12 *flight crew survivability, n*—the capability of the flight crew to avoid or withstand a hostile environment caused by a catastrophic condition without sustaining death, or the impairment of their ability to accomplish their designated mission.

3.1.12.1 *Discussion*—This includes the ability to keep the flight crew alive using such capabilities as abort, escape, safe haven, emergency egress, rescue and emergency medical equipment.

3.1.13 *hazard, n*—any real or potential condition that can cause a serious or fatal injury.

3.1.14 *hazard analysis, n*—identifies hazards within the integrated system and the means to control or eliminate them.

3.1.15 *human rating, n*—the process of evaluating and assuring that the total system can safely conduct the required human missions.

3.1.16 *MMOD, n*—Micrometeoroid and Orbital Debris; naturally occurring micrometeoroids and man-made debris orbiting the Earth within the bounds of LEO.

3.1.17 *operator, n*—a holder of a license or permit under 51 U.S.C. Subtitle V, Chapter 509: Commercial Space Launch Activities.

3.1.18 *remote operator, n*—a crew member who *(1)* has the ability to control, in real time, a launch, orbit or reentry vehicle's flight path, and *(2)* is not on board the controlled vehicle, for example, a Ground Control Team.

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3.1.19 *spacecraft, n*—all system elements that are occupied by the crew during the space mission and provide life support functions for the crew. The crewed element includes all the subsystems that provide life support functions for the crew.

3.1.20 *spaceflight participant, n*—any human on board the spacecraft while in flight that has no responsibility to perform nominal mission tasks but who is trained to deploy and operate specific emergency systems.

3.1.21 *time to criticality, n*—the time it takes for failure effects to propagate from the failure mode to the critical failure effect (for example, loss of vehicle, loss of control).

4. Significance and Use

4.1 Flight crew safety is a complex and all-encompassing goal of human spaceflight. The entire spacecraft is designed to get the flight crew safely to and from their Low Earth Orbit (LEO) destination. In the spirit of Specification F3479, Failure Tolerance for Occupant Safety of Suborbital Vehicles, failure tolerance, or an equivalent means of control where failure tolerance is impractical, is the primary control for prevention of catastrophic hazards that cannot be eliminated from the design. This is true for all hazards which may result in a catastrophic event. The spacecraft can be also be designed with increased levels of failure tolerance to enhance the likelihood of mission success.

4.2 This guide is focused upon the design and operational capabilities necessary to support flight crew survivability when failure tolerance has been exhausted. For example, a spacecraft may have three mission computers that perform identical functions. Typical rules that govern the flight operations might allow continuation of the mission after the first failure. Following the second failure, a mission abort is likely using the single remaining mission computer to return the spacecraft to safety. Should this third computer fail, emergency systems are available to assist the return of the flight crew to safety when possible, and it is those systems that are the focus of this guide. Note that for each emergency situation described herein, a set of emergency procedures and the equipment to implement them will be available in order for the crew to survive.

4.3 LEO missions are divided into pre-launch, ascent, orbit, reentry, and landing. Note that there are separate, additional considerations for transport of humans beyond LEO and for missions having crewed durations in LEO of greater than approximately 30 days which are not within the scope of this guide.

5. Applicable Phases of Flight

5.1 *Pre-launch*—The pre-launch phase includes the time from flight crew ingress into the spacecraft up to the launch. During this phase, dynamic operations should normally be avoided (fueling, significant tank pressure changes, arming, venting, and so forth) so as to minimize risk to the flight crew. Given that this is not always possible, the flight crew should be provided a means to egress from a spacecraft to a safe area where they can be protected from hazards. The flight crew may self-egress or be assisted by a ground team. In either case, the flight crew and any ground team involved in the egress should be afforded the ability to reach the safe area within the time it takes failures to reach criticality as defined by a hazard analysis. Where egress is a necessary part of mitigating hazards, features of a system that provides this egress capability include:

5.1.1 Vehicle mechanical systems that permit the flight crew to self-egress the spacecraft in approximately 90 seconds.[5]

5.1.1.1 Self-egress systems include the ability to self-extract quickly from the vehicle seating (for example, a single-point harness) and mobility aids to help the flight crew reach the exit hatch, equalize pressure across the exit hatch, open the hatch to the primary egress route without requiring specialized tools, and safe access to an exit platform without using fall protection. Inward opening, pressure-sealed hatches have been implicated in delayed rescues (Apollo 1) therefore the risk of post-liftoff cabin leakage and rapid decompression should be weighed against the risk of delayed hatch opening during the pre-launch phase when designing the proper egress method.

5.1.2 Personal Breathing Apparatus (PBA) systems that support the egress.

5.1.2.1 Conditions which warrant an emergency egress are varied, but can include leakage of propellants or other liquids which are toxic. PBAs should be available for donning if pressure suits are not available or the crew is unsuited prior to leaving the protective confines of the egress platform and should protect the nose, mouth, and eyes.

5.1.3 A clearly marked egress pathway to provide guidance to flight crew.

5.1.3.1 The egress route can be encumbered by smoke, toxic gasses, poor lighting, fire deluge systems, and limited communication with rescue forces or each other. A clearly marked path will avoid disorientation and expedite the egress.

5.1.4 Expeditious movement to a safe area during egress.

5.1.4.1 Booster/spacecraft design should include passively safe systems that can prolong the time between a failure and a catastrophic event. Only through a hazard analysis can the time to criticality be determined. This time to criticality will determine how quickly the flight crew should move from the spacecraft to the safe area. In some cases, stairs or an elevator may be acceptable. In others, a more expeditious system such as a slide wire, zipline, slide, or blast-proof conveyance will be necessary. Where the time to criticality is less than that needed for flight crew egress, additional hazard controls, mitigations, and/or protective measures should be added (for example, enhanced factor/margin of safety).

5.1.5 A safe area outside the hazard/blast danger area reachable by protected transportation at which the flight crew are met with rescue and medical assistance.

5.1.5.1 Flight crew may initially stay in a safe area (that is, a protected shelter) inside the hazard area until the hazard condition is cleared, and then they can move to a safe area outside the hazard to receive assistance. If, during the egress, the crew could be exposed to a hazard, the transportation method should be protected against the hazard.

[5] Reference for 90 seconds here: https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25.803-1A.pdf. 90 seconds is also referenced in NASA-STD-1130.

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