U.S. Department
of Transportation
Federal Aviation
Administration

Advisory Circular

Subject: Human Factors Considerations in Commercial Human Space Flight

Date: 08/12/2024

Initiated By: AST-1

AC No: 460.15-1

This Advisory Circular (AC) provides guidance on compliance with Title 14 of the Code of Federal Regulations (14 CFR) § 460.15, Human Factors. It is intended to assist prospective applicants in obtaining commercial space authorizations and operating in compliance with commercial space safety regulations. Section 460.15 requires an operator to take the precautions necessary to account for human factors that can affect a crew's ability to perform safety critical roles.

The Federal Aviation Administration (FAA) considers this AC an accepted means of compliance with the regulatory requirements of § 460.15. This guidance is not legally binding in its own right and will not be relied upon by the FAA as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with the guidance is voluntary only and nonconformity will not affect rights and obligations under existing statutes and regulations.

If you have suggestions for improving this AC, you may use the Advisory Circular Feedback form at the end of this AC.

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Contents

1 PURPOSE.

1.1 This advisory circular (AC) provides guidance and an acceptable method, but not the only method, that may be used to account for human factors when crew must perform safety critical roles in accordance with Title 14 of the Code of Federal Regulations (14 CFR) § 460.15. Safety critical roles refer to crew being able to safely carry out their duties so that the vehicle will not harm the public.

1.2 Section 460.15 requires an operator to take the precautions necessary to account for human factors that can affect a crew's ability to perform safety critical roles, including in the following safety critical areas:

- Design and layout of displays and controls;
- Mission planning, which includes analyzing tasks and allocating functions between humans and equipment;
- Restraint or stowage of all individuals and objects in a vehicle; and
- Vehicle operation, so that the vehicle will be operated in a manner that flight crew can withstand any physical stress factors, such as acceleration, vibration, and noise.

1.3 This AC presents one, but not the only, acceptable means of compliance with the associated regulatory requirements. The FAA will consider other means of compliance that an applicant may elect to present. In addition, an operator may tailor the provisions of this AC to meet its unique needs, provided the changes are accepted as a means of compliance by the FAA. Throughout this document, the word "must" characterizes statements that directly follow from regulatory text and therefore reflect regulatory mandates. The word "should" describes a requirement if electing to use this means of compliance; variation from these requirements is possible but must satisfy the regulation to constitute an alternative means of compliance. The word "may" describes variations or alternatives allowed within the accepted means of compliance set forth in this AC.

2 APPLICABILITY.

2.1 The guidance in this AC is for launch and reentry vehicle applicants and operators required to comply with 14 CFR part 460 pertaining to human factors. The guidance in this AC is for those seeking a launch or reentry vehicle operator license and a licensed operator seeking to renew or modify an existing vehicle operator license. When changes that are material to public health and safety occur within an operator's systems or operations and involve human space flight, the human factor aspects of those changes need to be reassessed.

2.2 The material in this AC is advisory in nature and does not constitute a regulation. This guidance is not legally binding in its own right, and the FAA will not rely upon this guidance as a separate basis for affirmative enforcement action or other administrative penalty. Conformity with this guidance document (as distinct from existing statutes and regulations) is voluntary only, and nonconformity will not affect rights and obligations under existing statutes and regulations.

2.3 The material in this AC does not change or create any additional regulatory requirements, nor does it authorize changes to, or deviations from, existing regulatory requirements.

3 RELATED LAWS, APPLICABLE REGULATIONS AND RELATED DOCUMENTS.

3.1 Applicable United States Code (U.S.C.) Statute.

- Title 51 U.S.C. Subtitle V, Chapter 509, Commercial Space Launch Activities.

3.2 Related Code of Federal Regulations.

The following 14 CFR regulations must be accounted for when showing compliance with 14 CFR 460.15. The full text of these regulations can be downloaded from the U.S. Government Printing Office e-CFR. A paper copy can be ordered from the Government Printing Office, Superintendent of Documents, Attn: New Orders, P.O. Box 371954, Pittsburgh, PA, 15250-7954.

- Section 401.5, *Definitions*.
- Section 401.7, *Definitions*.
- Section 437.55(a)(1)(iv), *Hazard analysis – human errors*.
- Section 450.109(b)(1)(v), *Flight hazard analysis – human factors*.
- Section 460.5, *Crew qualifications and training.*
- Section 460.7, *Operator training of crew.*
- Section 460.15, *Human factors*.

3.3 FAA Documents.

- Federal Aviation Administration (FAA). *Recommended Practices for Human Space Flight Occupant Safety*, Version 2.0. dated September 2023. https://www.faa.gov/media/71481.
- U.S. Department of Transportation, FAA, *Human Factors Design Standard*,[1] HF-STD-001B, dated December 30, 2016. https://hf.tc.faa.gov/publications/2016-12-human-factors-design-standard/full_text.pdf.

3.4 Related U.S. Government Documents.

The documents referenced in this paragraph refer to the current revisions or regulatory authorities' accepted revisions.

- National Aeronautics and Space Administration (NASA), *Guidance for Human Error Analysis (HEA)*," NASA/TM–2020-20205001486, dated April 2020. https://ntrs.nasa.gov/api/citations/20205001486/downloads/20205001486.pdf.

[1] This document covers specific design requirements such as automation of systems responses and user interfaces, designing for maintenance, visual displays and indicators, alarms, audio, and voice communications, computer-human interfaces, keyboards and input devices, workstations and workplace design, system security, personnel safety, environment controls, anthropometry and biomechanics, and documentation.

- National Aeronautics and Space Administration (NASA), *Spaceflight Human-System Standard, Volume 1, Revision C: Crew Health*. NASA-STD-3001, dated September 15, 2023. https://standards.nasa.gov/sites/default/files/standards/NASA/C//nasa-std-3001-vol-1-rev-c-signature.pdf.
- National Aeronautics and Space Administration (NASA), *Spaceflight Human-System Standard*, *Volume 2, Revision D: Human Factors, Habitability, And Environmental Health*. NASA-STD-3001, dated September 15, 2023. https://standards.nasa.gov/sites/default/files/standards/NASA/D/nasa-std-3001-vol-2-rev-d-signature.pdf.
- Department Of Defense (DOD), *Design Criteria Standard Human Engineering,* MIL-STD-1472H, dated September 15, 2020. https://quicksearch.dla.mil/qsDocDetails.aspx?ident_number=36903
- National Aeronautics and Space Administration (NASA), Human Systems Integration Handbook, NASA/SP-20210010952 https://ntrs.nasa.gov/api/citations/20210010952/downloads/HSI%20Handbook%20v2.0%20092121_FINAL%20COPY.pdf
- National Aeronautics and Space Administration (NASA), *Human Integration Design Handbook (HIDH)*. NASA/SP-2010-3407/Rev1, dated June 05, 2014. https://www.nasa.gov/wp-content/uploads/2023/03/human-integration-design-handbook-revision-1.pdf?emrc=65f2e4c77e9ec.

Note 1: The HIDH provides guidance on implementing the requirements in NASA Space Flight Human Systems Standard, NASA-STD-3001.

- National Aeronautics and Space Administration (NASA), *Human Integration Design Process (HIDP)*. NASA-TP-2014-218556, dated September 2014. https://www.nasa.gov/wp-content/uploads/2015/03/human_integration_design_processes.pdf.

Note 2: As a complimentary document to the HIDH, the HIDP describes the "how-to" processes, including methodologies and best practices NASA uses during development of crewed space systems and operations.

4 DEFINITION OF TERMS.

For this AC, the definitions from §§ 401.5 and 401.7 and the following apply.

4.1 Human Factors.

A multidisciplinary field that studies human capabilities, limitations, and behavior, and that applies this knowledge to the design of systems, machines, work environment, and operations. The field of human factors draws from multiple disciplines such as psychology, physiology, engineering, ergonomics, and medicine. It is applied to complex systems and operations that include aviation, maritime, military, human space flight, and nuclear energy where human performance or interaction is critical to safety.

4.2 Human Error.

An action by a human that is not intended or desired, or a failure by a human to perform an action within specified limits of accuracy, sequence, or time that fails to produce the expected result, which leads or may lead to an unwanted consequence.

4.3 Operator.

A holder of a license or permit issued by the FAA to conduct a launch or reentry.

5 ACRONYMS.

- AC – Advisory Circular
- ASA – Office of Operational Safety
- AST – Office of Commercial Space Transportation
- CFR – Code of Federal Regulations
- DOD – Department of Defense
- FAA – Federal Aviation Administration
- HEA – Human Error Analysis
- HIDH – Human Integration Design Handbook
- HIDP – Human Integration Design Processes
- HRA – Human Reliability Assessment
- NASA – National Aeronautics and Space Administration
- STD – Standard
- U.S.C. – United States Code

6 OVERVIEW.

6.1 Scope of this AC.

The part 460 regulatory framework is focused on public safety, which is protecting people and property that are not involved with the launch or reentry. Since 2004, Congress has maintained a "learning period" prohibiting the FAA from promulgating any regulations governing the design or operation of a launch vehicle intended to protect the health and safety of crew, government astronauts, and space flight participants, absent a serious or fatal injury, or an unplanned event during a launch or reentry.[2] The current safety framework relies, in part, on an informed consent regime that requires operators to inform any individual serving as crew that the United States Government has not certified the launch or reentry vehicle as safe for carrying flight crew or space flight participants before employing or arranging for that individual to participate in a launch.[3] This AC discusses the requirement of § 460.15 for operators to account for human factors that can affect a crew's ability to safely carry out their duties to ensure that the vehicle will not harm the public (people or property not involved with the launch or reentry). This AC will be updated if and when Congress lifts the "learning period" in § 50905(c), and the FAA amends its regulations, accordingly, including any new requirements for occupant safety.

6.2 Human Factors Requirements.

In addition to § 460.15, other human factors-related requirements are in 14 CFR parts 437 and 450. For an experimental permit, the § 437.55(a)(1)(iv) hazard analysis regulation requires that hazards resulting from human error be identified and assessed with regard to public risk. For a vehicle operator license, in accordance with § 450.109(b)(1)(v), a flight hazard analysis for a launch or reentry must identify reasonably foreseeable hazards, including those resulting from human factors. Each hazard's likelihood and severity are to be assessed and the risk elimination and mitigation measures are to be identified. Although this AC primarily addresses the part 460 human factor requirements for a launch or reentry with crew, some of the guidance in this AC is relevant or applicable to §§ 437.55(a)(1)(iv) and 450.109(b)(1)(v) such as the guidance on human error analysis and mitigating inadvertent actions.

6.3 Human Factors Analyses.

This AC covers, at a high level, the types of analyses (e.g., task, human error, workload) that an operator may conduct to account for human factors in commercial human space flight as part of mission planning per § 460.15(b). The intent is to identify these types of human factors analyses needed but not describe in detail how they should be performed. Details on how to conduct these analyses are described in the following documents, which are listed as references in paragraph 3.4. These documents also complement and provide additional guidance to chapter 8 of this AC.

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[2] 51 U.S.C. § 50905(c)(9).

[3] 14 CFR § 460.9.

- "Guidance for Human Error Analysis (HEA)" provides valuable guidance on an approach or process for performing a human error analysis.
- "Human Integration Design Processes (HIDP)" provides guidance on conducting a task analysis, workload evaluation, human error analysis as well as other types of human factors-related analyses. The HIDP content is framed around human-centered design methodologies and processes in support of human-system integration requirements.

Human-centered design is a methodology used to ensure that a design accommodates human capabilities and limitations. It is an approach to development of interactive systems that focuses on making systems usable by ensuring that the needs, capabilities, and limitations of the user (e.g., crew) are met. Human-centered design is an iterative activity that leverages data gathered from early user involvement and analyses (e.g., function allocation between users and technology, task analysis) to inform designs.

6.4 **NASA Guidance on Acceleration, Vibration, and Noise Exposure Limits.**

NASA Spaceflight Human-System Standard (NASA-STD-3001), Volume 2[4]and Human Integration Design Handbook (HIDH)[5] provide guidance on acceleration, vibration, and noise exposure limits. These documents also provide human factors-related guidance pertaining to displays and controls, restraint and stowage, and vehicle operations, which provide additional information that are applicable and complement the top-level guidance provided in chapters 7, 9, and 10 of this AC.

6.5 **FAA's Recommended Practices for Human Space Flight Occupant Safety.**

Furthermore, this AC leverages or cites several human factors-related recommended practices from the FAA's document on "Recommended Practices for Human Space Flight Occupant Safety.[6]" Although the recommended practices pertain to occupant (flight crew and space flight participants) safety, they may assist an operator in demonstrating compliance with § 460.15 when the safety of flight crew is essential for them to be able to perform safety critical roles.

[4] NASA Spaceflight Human-System Standard, Volume 2: Human Factors, Habitability, and Environmental Health, (NASA-STD-3001, Volume 2, Revision D), dated September 15, 2023, NASA-STD-3001-Vol-2-Rev-D.pdf.
[5] NASA Human Integration Design Handbook (HIDH), Volume 3407, SP-2010., Revision 2, dated October 20, 2022, Human_Integration_Design_Handbook_Revision-2.pdf.
[6] FAA, Recommended Practices for Human Space Flight Occupant Safety, Version 2.0, September 2023. https://www.faa.gov/media/71481 .

6.6 Verification Methodologies.

Verification that an operator has taken the precautions necessary to account for human factors that can affect a crew's ability to perform safety critical roles includes testing, analysis, inspection, and demonstration. Mockups, simulators, usability testing, and human-in-the-loop testing may be used to help evaluate human-machine interfaces, human-computer interaction, and human performance such as those involving flight crew interaction with displays and controls. Usability testing to assess how well a system is designed for human use should be conducted on hardware, software, and procedures with which crew will interact to perform safety critical roles. Early identification of potential human factors-related issues during design and development is essential. This can be achieved through developmental testing to inform iterative design improvements.

7 DESIGN AND LAYOUT OF DISPLAYS AND CONTROLS.

An operator must account for human factors in the design and layout of displays and controls in accordance with § 460.15(a). The design and layout of displays and controls can affect the ability of the crew to perform safety critical roles when displays are not readable, and controls are not accessible under nominal and non-nominal conditions. Controls may be in the form of physical cockpit flight controls (e.g., hand controllers) or computer input devices such as a touch screen or keyboard in which crew enters information into a system.

7.1 **Instrumentation Displays and Controls**.

Displays and controls need to be designed and located so that displays are visible, and controls are within the functional reach envelope of crew to operate and perform critical tasks under various conditions. This applies to all vehicle conditions (e.g., g--loads and vibration), space suit conditions (e.g., unsuited, suited unpressurized, suited pressurized), and expected crew postures (e.g., standing, seated, restrained, and unrestrained). For example, in the suited conditions, the suit helmet, visor, and glove should be carefully designed to allow these safety critical tasks to be performed.

7.1.1 <u>Anthropometric Data and Ergonomic Principles</u>.

Human physical characteristics and capabilities should be considered by applying anthropometric data and ergonomic principles. The range of motion and reach of crew members of varying body sizes should be considered to ensure displays and controls are arranged and positioned within reach and visibility of crew to perform critical tasks safely. An operator should determine the intended user population and ensure it has population data sets to use as critical dimensions for that population.

7.1.2 <u>Safety Critical Information Displays</u>.

Instrumentation should display safety critical information in a format that is readable in the environment of intended use. Safety critical information that is displayed in a manner that accommodates varying conditions (e.g., vehicle vibration, acceleration, sunlight, darkness) decreases the potential for human error. Operators should take into account certain factors when designing instrumentation displays; these are the use of color, redundant coding for individuals whose color vision is deficient, luminance, contrast, ambient illumination, resolution, display update rate, vehicle vibration, reflections, parallax view, and viewing angle. The use of appropriate font sizes and clear labeling can help to improve readability and minimize errors during safety critical operations. Audible alarms should also be considered if the time to effect for a high-priority caution is a factor.

7.2 Usability of Displays and Controls.

Displays that are designed with legibility in mind (e.g., analog versus digital displays, and larger graphics and text) enhance the execution of safety critical operations during flight phases where vehicle vibration scenarios occur. The manipulation of controls during vehicle acceleration, or while in a space suit, also requires consideration. The ability to use the sense of touch or the dexterity to operate certain safety critical vehicle interfaces may be diminished if space suits or protective gear (e.g., gloved hand) are worn by flight crew or if the crew experience high acceleration and vibration.

7.2.1 Verification of Use of Displays and Controls.

The vehicle instrumentation's ability to display safety critical information should be verified by inspection, analysis, and testing to show that flight crew are able to readily view the safety critical information in all defined environments and mission configurations, in a format that is consistently legible. Legibility and visibility should be tested by human-in-the-loop testing of the full range of critical anthropometric (combination of) dimensions. In addition, § 460.5 requires crew to be trained to carry out their safety critical roles, which for a pilot includes control of the vehicle where the design and layout of displays and control per § 460.15(a) are pertinent.

8 HUMAN FACTORS ANALYSIS AND TESTING.

An operator must account for human factors in mission planning, which includes analyzing tasks and allocating functions between humans and equipment in accordance with § 460.15(b). When analyzing tasks and allocating functions, operators should examine the cognitive and physical demands of the task workloads and assess the potential sources or contributors to human error of those tasks. The following describes the analyses (task, function allocation, workload, and human error) that should be conducted to account for human factors in mission planning. Findings and insight from these analyses help inform test plans, such as for usability testing, to assess and measure user workload and potential errors.

8.1 Task Analysis.

Task analysis in human factors breaks down or decomposes tasks into smaller, more manageable steps to understand how humans interact with systems or perform activities. These help to identify potential challenges, errors, and inefficiencies in human-system interaction. It analyzes tasks allocated to humans by decomposing individual tasks into simpler actions (task steps) and identifies task parameters and conditions that can enable or constrain human interface interactions, including the identification of information required to perform the task. Task analysis focuses on how humans interact, both physically and mentally, with hardware, software, procedures, and other users of the system to perform tasks. The analysis spans across all mission phases that include both nominal and non-nominal operations. Furthermore, task analysis should be used to identify gaps in resources, capabilities, and training that may predispose to error. Mitigating measures should then be established based on the task analysis.

8.2 Function Allocation.

Function allocation is related to both task analysis and human error analysis because it is used to determine which functions or tasks should be performed by humans and which should be automated or delegated to equipment or machines. As operators allocate functions, they should determine which tasks and responsibilities should be distributed among crew members based on their capabilities, skills, training, and workload. Function allocation is informed by task analysis as it relies on understanding the tasks and human-system interactions, which help to identify the cognitive and physical demands of tasks that only humans can perform and identify those tasks that can be performed by equipment or machine. Human error analysis, which is discussed later, also informs function allocation by identifying functions or tasks that are prone to human error and may be better suited to automation to optimize performance and reduce errors.

8.2.1 Automated and Manual Tasks.

There are a variety of vehicle designs and operations, which include partially or fully automated vehicles. For example, there may be phases of flight where an automated operation may change to a manual or human-in-the-loop operation/control. Even for a vehicle that is mostly autonomous, there may be times when human intervention, such as the need for a human to monitor safety critical data and intervene during non-nominal or emergency conditions is required. Other vehicles and operations may involve a fully automated vehicle without flight crew that have only space flight participants on board. Procedures should be documented, and training should be provided to flight crew and remote operators, if any, on which functions or operations are automated and which can be manually overridden or controlled. In the future, there could be remotely operated vehicles such that § 460.15 human factors would apply to a remote operator not on board the vehicle but is considered to be a crew member as defined under §§ 401.5 and 401.7 and has a safety critical role to control the vehicle to not harm the public.

8.2.2 Function/Task Allocation Considerations.

There are tradeoffs to be made in determining which functions should be performed by humans and which functions should be automated and the level of automation for each task. While there may be significant benefits associated with automation to reduce workload and reduce human error, a poor automation design, however, could potentially lead to a reverse effect. Complexity, criticality (or consequence severity), workload, cognitive demands, human capabilities, error likelihood, and response time are factors that should be considered when deciding which tasks or functions should be allocated to humans versus automation. Tasks requiring heavy cognitive load, memory, accuracy, data processing/calculations, or quick response times may be better suited to automation. Tasks dealing with unexpected or novel situations that require complex or creative problem solving or decision-making may be better suited for humans.

8.3 **Workload Analysis**.

The vehicle should be designed so that crew are able to perform safety critical operations under expected physical and cognitive workload. Inadequately designed user interfaces or vehicles designed with significant controlling by flight crew tend to increase the physical and cognitive workload of the user. An increase in the physical and cognitive workload may result in errors. For example, high workload as a result of recalling tasks from memory while performing under time pressure and experiencing high acceleration, vibration, and noise, increases the likelihood of human errors. It is important to ensure that the physical and cognitive workload of crew does not result in errors related to safety critical operations. Workload assessment tools[7] may be used to assess flight crew interfaces, operations, workload, and error rates.

[7] An example is the Bedford Workload Scale or the NASA Task Load Index for measuring workload.

8.3.1 Workload Verification.

The physical and cognitive workload to perform safety critical operations should be verified by simulation and testing to show that crew can consistently perform safety critical operations within the workload limits. Crew resource management training may be provided to emphasize and enhance communication, teamwork, and coordination among crew members in the performance of tasks and to help them make good, informed decisions using all available resources. Lack of clarity concerning roles and responsibilities of flight crew and ground controllers, as well as poor communication among flight crew and ground controllers, can lead to unsafe operations especially during dynamic, complex, or high stress situations.

8.4 Human Error Analysis.

An important aspect of human factors is the identification and mitigation of potential human errors during nominal and non-nominal situations. Human errors may include:

- Inadvertent operator action;
- Failure to perform an action;
- Performing a wrong action;
- Performing an action incorrectly; and
- Performing an action with incorrect timing.

8.4.1 Contributors to Human Error.

Potential contributors to human error include inadequate training and procedures, conflicting roles and responsibilities, poor system or equipment design, fatigue, distraction, high workload, and organizational factors. Design-induced human errors may be caused by poor interface design. Human error is a leading cause of aviation accidents. Although the flight environments are different, some human factors-related lessons learned from aviation may apply to human space flight.

8.4.2 Qualitative and Quantitative Analysis of Human Error.

A human error analysis (HEA) may be performed as a systematic approach to evaluate human actions and identify sources, consequences, and mitigations of human error. An HEA is not performed in isolation but draws on other analyses or activities such as a hazard analysis, workload assessment, task analysis, and the application of human factors design standards to help identify and assess contributing factors to human error. Human error identification may be qualitative (define type of errors that occur within a system) or quantitative (provide a numerical probability that an error can occur within that system). While an HEA is a qualitative analysis that is directed at identifying potential errors and their effects, rather than placing probabilities on errors, a human reliability assessment (HRA) may be performed to evaluate and quantify the likelihood of human error.

8.4.3 Design for Mitigation of Error.

The intent of an HEA is to identify potential human error and apply the appropriate error management to mitigate its effect on the system by designing the system according to the following precedence: (1) prevent the error, (2) reduce the likelihood of the error and provide the capability to detect the error in time for correction and recovery, and (3) limit the negative effects of the error. Mitigating against an inadvertent action should be considered as part of the HEA especially where a single human error such as an inadvertent crew action could result in a catastrophic hazard as discussed in the next paragraph.

8.5 Inadvertent Actions.

No single inadvertent crew action should cause or lead to a catastrophic event. In the unforgiving environment of space flight, an inadvertent crew action could lead to a catastrophic event that could harm the public as well as those on board. Inadvertent actions or errant switch activation could occur due to several factors such as limited crew experience, fatigue, gloved hands, ambiguous procedures, the flight environment (e.g., vibration), a stressed operational environment, and inadvertent bumping of controls. For example, an inadvertent hatch opening and subsequent cabin depressurization while in the vacuum of space would lead to serious injuries to crew and affect crew’s ability to perform safety critical roles. Preventing the hatch from opening inadvertently, in this example, should be part of the vehicle design.

8.5.1 Preventing Accidental Activation.

Use of switch guards, covers, and physically separated controls are some examples to prevent accidental activation. Accidental activation of commands may be prevented if steps are taken to make it more difficult to initiate such as requiring a multi-step command (e.g., two actions are needed such as an “arm-fire” mechanism to initiate an event) or requiring two or more movements to actuate a control (e.g., push and turn a knob, require crew to remove a cover over a button to access a button, etc.). There should also be confirmation of choice, where confirmation may be a message on a display that requires crew to affirm the choice, and if the command could have severe consequences, the system should require confirmation at every step in the process. Furthermore, the ability of the vehicle’s design, controls, and procedures to deter single accidental or inadvertent actions should be verified by analysis, testing, and simulation. Human error analysis, testing, and simulation should show that single actions would not cause serious injuries or damage to safety critical components.

9 RESTRAINT AND STOWAGE.

An operator must make provisions for restraint or stowage of all individuals (crew and space flight participants) and objects in a cabin, so moving objects and individuals do not interfere with the flight crew's operations of the vehicle during flight in accordance with § 460.15(c).

9.1 **Stowage and Restraint of Objects**.

In accordance with § 460.15(c), objects in a cabin must be restrained or stowed properly. Objects in a vehicle cabin may include equipment, tools, supplies, payloads, or carry-on items. The following human factors guidelines should be considered:

- Objects should be anchored, secured, or stowed to prevent them from floating freely in microgravity or coming loose during dynamic phases of flight. Freely floating objects can potentially cause injury or damage to safety critical equipment. They could also interfere with crew operations.
- Analysis and testing should be conducted to ensure restraints and stowage systems can withstand dynamic loading (acceleration and vibration) during launch and reentry to prevent them from coming loose and interfering with flight crew.
- Stowage or restraint should be designed for easy access of equipment or items for use by flight crew for safety critical operations.

9.2 **Restraint of Crew and Space Flight Participants**.

In accordance with § 460.15(c), all individuals must be properly restrained, especially the flight crew, so that they can perform their safety critical roles and functions during a dynamic flight environment (acceleration, vibration, noise, or microgravity) under nominal and off-nominal conditions. Crew seats and restraints (e.g., seat belts, shoulder harnesses handholds, foot restraints, etc.) for flight crew should be able to accommodate varying crew sizes and be compatible with space suits or protective gear while still enabling flight crew to perform safety critical tasks, which include monitoring displays and controlling the vehicle, among other tasks. In addition, space flight participants must be properly restrained, especially during dynamic and critical phases of flight in order to not interfere with flight crew performing safety critical tasks.

9.2.1 Spaceflight Weightlessness.

Although § 460.15(c) requires restraint of individuals, this does not prevent an operator from allowing space flight participants to experience weightlessness during a part of the mission. To allow this experience, the FAA would look at whether the restraints on space flight participants would keep those participants from interfering with flight crew activities. For example, space flight participants separated by a bulkhead might be considered adequately restrained when participants are free floating or experiencing weightlessness. However, space flight participants are expected to be able to return to their seats and be restrained as necessary such as before reentry or landing to not distract or interfere with flight crew activities.

10 VEHICLE OPERATIONS.

A launch or reentry vehicle must be operated in a manner that flight crew can withstand any physical stress factors, such as acceleration, vibration, and noise in order to be able to execute their safety critical duties in accordance with § 460.15(d). The vehicle should be controllable to the extent necessary to allow flight crew to perform safety critical operations to not harm the public.

10.1 Crew Qualifications and Training.

Similarly, §§ 460.5(a) and (b) require flight crew to train for their role in nominal and non-nominal conditions and must demonstrate an ability to withstand the stresses of space flight, which may include high acceleration or deceleration, microgravity, and vibration to safely carry out their duties so that the vehicle will not harm the public. Section 460.7(a) requires an operator to train each member of its crew and define standards for successful completion in accordance with § 460.5.

10.2 Medical and Stress Qualifications for Crew with Safety Critical Roles.

Although § 460.5(e) requires each crew member with a safety critical role possess an FAA second-class airman medical certificate, the FAA also established a performance standard with § 460.5(b), which requires the flight crew to demonstrate an ability to withstand the stresses of space flight in sufficient condition to safely carry out their duties so that the vehicle will not harm the public. Because second-class medical certification may not be sufficient for all space flight missions, this performance standard provides an additional level of safety beyond basic medical certification because flight crew members will have to demonstrate an ability to perform duties in the space flight environment where they plan to operate. In addition to the physical stressors of space flight, there are psychological stressors that may warrant psychological screening of flight crew.

10.3 Acceleration Exposure Protection.

Per § 460.15(d), a vehicle must be operated in a manner that flight crew can withstand the effect of acceleration. A vehicle should be operated in a way that limits flight crew exposure to transient and sustained linear (translational) and angular (rotational) acceleration so that flight crew can successfully perform safety critical operations. The effect of acceleration on flight crew depends on the type (linear or angular), duration (transient or sustained), and direction with respect to the crew member (through the head, chest, or shoulders) of the acceleration. High transient and sustained linear and angular acceleration can increase the risk of flight crew incapacitation, or a serious injury or fatality. High rates and extended periods of acceleration in the G_Z-axis can significantly increase the risk of short-term incapacitation due to cerebral hypoxia. When flight crew have been weightless and then experience accelerations during reentry in the G_Z-axis, loss of color vision, tunnel vision, and loss of consciousness can occur, which could prevent the crew from performing their safety critical operations. Long periods of acceleration can also have psychological effects that can impair decision-making.

10.3.1 Verification of Acceleration Limits.

The vehicle may still experience periods of high acceleration during ascent, abort, reentry, or approach to landing. However, countermeasures for the flight crew, such as a G-suit or specific crew seating configurations, can prevent vehicle acceleration from impairing the flight crew. The vehicle's ability to stay below the acceleration limits of different phases of flight for nominal missions and planned contingencies should be verified through analysis and demonstration. The verification should be considered successful when analysis and demonstration show that the countermeasures protect occupants from exposure to transient and sustained linear and angular acceleration. Flight crew training to develop high-g adaptation may involve using aerobatic or high-performance aircraft or use of a centrifuge.

10.4 **Vibration Exposure Protection**.

In accordance with § 460.15(d), a vehicle must be operated in a manner that limits flight crew exposure to vibration so that flight crew can successfully perform safety critical operations. Depending on the vibration amplitude and frequency, excessive or sustained vibration can increase the risk of flight crew incapacitation, or a serious injury or fatality. Excessive or sustained vibration can also lead to psychological effects that can impair concentration and decision-making, as well as to distorted communications, such that safety critical operations by flight crew may be affected. Vibration may affect flight crew performance by degrading perception or by influencing control movements. As discussed in chapter 7 of this AC, there may be visual performance and manual performance effects on flight crew due to vibration, which may affect the ability of crew to read displays and execute manual control or commands.

10.4.1 Verification of Vibration Exposure Protection.

The vehicle's ability to limit flight crew exposure to vibration should be verified by analysis, demonstration, and testing such as from vibration tests or full integration tests. The analysis should use a validated simulation to identify and assess bounding acceleration cases including guidance, navigation and control, and vehicle and environmental dispersions. The analysis and demonstration should show that vibration levels do not prevent flight crew from effectively performing safety critical operations.

10.5 **Noise Exposure Protection**.

Per § 460.15(d), a vehicle must be operated in a manner that limits flight crew exposure to noise so that that flight crew can perform their safety critical roles. Flight crew should be protected from significant hearing impairment or noise distraction so that safety critical operations can be performed successfully. Excessive sound pressure can lead to psychological effects that can impair concentration and decision-making, as well as to distorted communications, such that safety critical operations by flight crew may be affected. When noise interferes with an alarm or voice communication, there may be missed warnings or misunderstood speech or instructions, which could lead to a significant safety impact because of human error. The ability to limit flight crew exposure to excessive noise so that they can execute their safety critical operations should be verified by analysis and testing.

10.6 **Handling Qualities**.

In accordance with § 460.15(d), vehicle handling qualities should be sufficient to allow the flight crew to operate and control the vehicle while performing safety critical operations. Inadequate vehicle handling qualities could overburden the flight crew with considerable piloting operations, thereby lessening the flight crew's ability to perform safety critical operations or demand more pilot effort or control input than is possible, potentially resulting in loss of vehicle. Handling quality rating systems (e.g., the Cooper-Harper Rating Scale) are often used to assess vehicle design and flight controllability.

10.6.1 Verification of Vehicle’s Controllability.

The vehicle’s controllability should be verified through inspection, testing, and simulation to show that the dynamic handling qualities of the vehicle allow the crew to perform safety critical operations safely and with adequate handling qualities such as defined by the Cooper-Harper Rating Scale (1969). Section 460.5(c)(3) requires a pilot and remote operator to receive vehicle and mission -specific training for each phase of flight by using a simulator, an aircraft whose characteristics are similar to the vehicle, flight testing, or an equivalent method of training approved by the FAA. The training should include nominal and non-nominal flight conditions to enable crew to respond to planned and unplanned events such aborts and emergencies. Furthermore, § 460.7(b) requires that an operator ensure that either the crew- training device used to meet the training requirements realistically represents the vehicle’s configuration and mission or the operator has informed the crew member being trained of the differences.

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