**Ensuring Safety of Government Personnel During Suborbital Spaceflight**

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**The NASA Suborbital Crew (SubC) office is focused on enabling flights by NASA civil servants, such as scientists and engineers conducting research, on suborbital vehicles. A broader goal is ensuring that commercial human spaceflight is both viable and safe. Within the Commercial Crew Program (CCP), the SubC office is exploring game-changing methods to perform safety assessments to enable NASA personnel to fly on suborbital missions. Commercial suborbital space flight capabilities are anticipated to be more accessible, affordable, and available than missions to the International Space Station and could provide additional opportunities for testing and qualification of space flight hardware, human-tended microgravity research, and further cutting-edge research enabled by the space environment. Although NASA currently supports human tended suborbital payloads for non-civil servants under auspices of NASA’s Flight Opportunities Program, the SubC effort will enable civil servant scientists, researchers, and engineers to accompany their experiments and tests into the space microgravity environment.**

1. **Nomenclature**

*AIAA* = American Institute of Aeronautics and Astronautics

*AFRC* = Armstrong Flight Research Center, NASA

*CCP* = Commercial Crew Program

*CDR* = Critical Design Review

*CCP* = Commercial Crew Program

*COMSTAC*  = Commercial Space Transportation Advisory Committee

*CSF*  = Commercial Spaceflight Federation

*FAA* = Federal Aviation Administration

*FAA-AST* = FAA Office of Commercial Space Transportation

*ISO* = International Organization for Standardization

*NAS* = National Air Space

*NSRC* = Next-Generation Suborbital Researchers Conference

*OGA* = Other Government Organization

*SFP* = Space Flight Participant

*SME* = Subject Matter Expert

*SpARC* = Space Flight Aerospace Rulemaking Committee

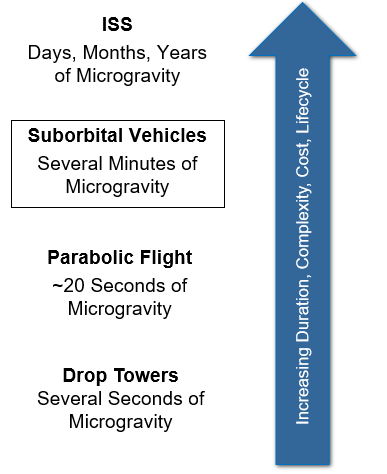
*STMD* = Space Technology Mission Directorate, NASA

*SubC* = Suborbital Crew

1. **Introduction and Background**

On March 20, 2020, then NASA Administrator Jim Bridenstine announced, “NASA is developing the process to fly astronauts on commercial suborbital spacecraft. Whether it’s suborbital, orbital, or deep space, NASA will utilize our nation’s innovative commercial capabilities.” NASA initiated a new effort to enable NASA personnel to fly on future commercial suborbital space flights. Situated within the Commercial Crew Program (CCP), the Suborbital Crew (SubC) office is tasked to “perform a safety assessment to enable NASA astronauts, principal investigators, and other NASA personnel to fly on suborbital missions.”

Commercial suborbital space flight capabilities are anticipated to be more accessible, affordable, and available than missions to the International Space Station and could provide additional opportunities for testing and qualification of space flight hardware, human-tended microgravity research, and further cutting-edge research enabled by the space environment. Although NASA currently flies payloads through commercial suborbital flight providers under the auspices of NASA’s Flight Opportunities Program, the SubC effort will enable NASA scientists, researchers, and engineers to accompany their experiments and tests into the space microgravity environment. Fig. 1 illustrates how the SubC program complements other microgravity experimental platforms.



**Fig. 1 Why SubC?**

The targeted scope for SubC includes end-to-end suborbital capabilities reaching ~80km altitude with several minutes of sustained microgravity. This will greatly facilitate the following research and testing:

* Human-Tended Microgravity Research
  + Materials processing
  + Life sciences experiments
  + Research payloads
  + Experiments for planetary sciences
* Testing and Qualification of Spaceflight Hardware
  + In-flight testing of hardware (e.g., equipment, tools)
  + Provide confidence in new systems & components

to support qualification

1. **Safety Case Approach**

NASA is responsible for understanding the risks to its employees should they fly on a commercially available suborbital vehicle. The SubC office is employing a Safety Case approach, applied to commercial suborbital providers, which is not a traditional certification process as was used for the SpaceX *Dragon* and Boeing *Starliner* vehicles. Rather, it is an assessment using elements of NASA’s Risk-Informed Safety Case and the Airworthiness Assessment process at NASA’s Armstrong Flight Research Center (AFRC). The Safety Case is predicated on each suborbital provider having their own certification plan and demonstrating compliance to that plan. For each suborbital provider, SubC has created a multi-pronged plan that includes:

* A comparison of vehicle standards against applicable NASA/industry standards
* Deep Dives into the systems and subsystems of top risk
* A quality and safety assessment

Government regulations are typically described as either being prescriptive or performance-based. When the original safety requirements for the Eastern and Western Ranges were crafted by the Air Force during the early days of the space age, most were very prescriptive, specifying precisely how the flight safety systems were to be designed, tested, inspected, and operated. There are a number of advantages to such an approach. For example, the contractor knows exactly what the government expects the company to do, and it is relatively easy to conduct inspections that will determine whether or not the government requirements have been met. The disadvantage of a prescriptive approach is that it becomes very difficult, if not impossible, to incorporate new technologies or innovative approaches, since they are usually not mentioned in the regulations. In recent years, performance-based regulations have become much more popular. With this approach, the government specifies what the end objective is, rather than how to achieve that objective. In general, performance-based requirements are more accommodating of new approaches and new technologies. The downside of this approach is that the contractor may not understand exactly what the government is looking for, and how to demonstrate that its system satisfies the stated goals and objectives. The government, in turn, may have a more difficult time determining whether its requirements have been met. More recently, the commercial sector has developed unique suborbital vehicles for which standardized regulations have not yet been established. The development of these vehicles outpaces the government’s ability to regulate them, and the vehicles are being built without requests from the government but rather for commercial use.

*Safety Case methodology* is a promising approach to implementing performance-based regulations. The Safety Case methodology is already being used by the United Kingdom’s Ministry of Defense, which defines a Safety Case as “a structured argument, supported by a body of evidence that provides a compelling, comprehensible, and valid case that a system is safe for a given application in a given environment”[1]. To implement a Safety Case approach, NASA allows flight providers to follow this alternative process, which would fully implement a performance-based regulatory philosophy, along with the requirement for the launch operator to accept the responsibility for operating safely and the necessity to advocate for safety. The process consists of a voluntary review of the applicant’s safety and risk management program, followed by the development of a Safety Case in which the applicant would present evidence, in the form of engineering analysis and test data, showing how their system was internally certified [2].

1. **Deep Dives**

The SubC Deep Dives and quality and safety assessment are conducted by a NASA team of disciplinary specialists to assess the functional area’s readiness for flight, categorization of hazards, likelihood of mission success, and flight/ground/range safety procedures. The SubC team has been collaborating with existing suborbital launch providers for the past two years. Deep Dives utilize a multi-faceted engagement format to interact in-person with the private launch providers, performed in months rather than years using a small team of appropriate NASA subject matter experts (SMEs).

The SubC office is employing the Safety Case methodology because each provider has already designed, built, tested, and is flying their own vehicle – all of which was done independently of NASA. Use of the Safety Case approach for human spaceflight is currently being communicated through NASA technical, program, and agency level forums.

The Safety Case process is based on the launch provider demonstrating the safety of their systems and assumes that each provider has their own Human Certification Plan. The focus of SubC is to understand how each provider complies with their plans through the engineering deep dives and a review of safety and quality processes. The Safety Case goals and objectives are summarized in Table 1.

**Table 1 Safety Case Goals and Objectives**

|  |  |
| --- | --- |
| **Goal** | **Objective** |
| Design is Capable of Handling Mission Extremes and Contingencies | 1. Understand Mission, Environment, and Vehicle Operations and the role of the Crew and Ground Personnel 2. Understand Interfaces with External Systems 3. Demonstrate Understanding of Design Standards 4. Demonstrate Understanding of How Systems are Qualified 5. Demonstrate Understanding of How Hazards are Controlled |
| Manufacturing, Integration, Test and Checkout are Sufficient to Ensure Build Reliability | 1. Demonstrate Understanding and Execution of Company Standards 2. Evaluate Vehicle Mission Readiness Process 3. Demonstrate Corporate Processes for Managing the Build, Maintenance, Refurbishment, and Ground and Flight Crew Safety |
| Operational Plans, Support, Training, and Post-Flight Review Ensure Mission is Maintained Within the Vehicle Design Limits, and Anomalies are Identified and Resolved | 1. Understand Role of Ground Support During All Phases 2. Evaluate Nominal and Contingency Operations Plans 3. Evaluate Post-Flight Assessment Process |
| Organization’s Safety Culture Supports Decision Making Throughout All Elements of the Life Cycle | 1. Understand Organization’s Safety and Decision-making Roles and Communication Channels 2. Understand how Systems Engineering and Integration is Accomplished in Practice 3. Understand How Lessons Learned (Internal, Industry, Production, Flight, Etc.) are Collected and Applied 4. Evaluate How Risks are Managed |

To accomplish the Safety Case assessment in a consistent manner, a generic board structure has been developed (Fig. 2). SubC is leveraging expertise across many NASA centers based on the technology and systems being assessed. Additionally, SubC is applying flexibilities with products and processes to best fit the Safety Case insight framework by opting to use existing processes where practical or experimenting within the agency-level NASA risk-informed processes by utilizing an internally-developed Readiness Level based product.”

Graphical user interface, text, application, chat or text message

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**Fig. 2 Generic Board Structure for Safety Assessment**

The framework for the Deep Dives includes the following:

1. An initial virtual technical interchange to allow the launch provider to provide an overview of the systems being addressed in the Deep Dive – including operations, design, qualification, acceptance, and accepted risks. The intention is to understand the launch provider’s criteria for human flight.
2. A multi-day in-person technical interchange to review the provider’s command media including documentation used for the provider’s internal certification process and face-to-face meetings with the provider’s SMEs. The documentation includes, but is not limited to, Critical Design Review (CDR) packages, work orders, qualification test results, supplier specifications, countdown procedures, and data management systems.
3. A follow-up virtual technical interchange to close out any remaining questions from the in-person meeting.

After each Deep Dive, a draft summary of the NASA team members’ assessment results compared with SubC goals is released to the provider. The assessment includes residual concerns and recommendations for the launch provider to consider. The launch providers are encouraged to provide corrections and comments, as well as participate in an ensuing program control board briefing.

For Deep Dives to be successful, both NASA and the launch provider must agree on certain foundations:

1. The launch provider is ultimately responsible for explaining their certification process and how they internally determined that their vehicle is acceptable for human flight.
2. NASA and the launch provider should agree on specifics on how provider data will be stored and handled for virtual and on-site technical interchanges.
3. Expectations for interactions between NASA and the launch provider should be clearly defined.

Taking the partners’ certification processes into account, and completing targeted reviews via the Deep Dive process, enables NASA to efficiently assess commercially available systems designed and built by launch provider companies.

1. **Flight Opportunities Program**

The Flight Opportunities program, within NASA’s Space Technology Mission Directorate (STMD), facilitates rapid demonstration of promising technologies for space exploration and the expansion of space commerce through suborbital testing with industry flight providers. The program matures capabilities needed for NASA missions and commercial applications while strategically investing in the growth of the U.S. commercial spaceflight industry. These flight demonstrations take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility while reducing the costs and technical risks of future missions. Awards and agreements for flight demonstrations are open to researchers from industry, academia, non-profit research institutes, and government organizations. These investments help advance technologies of interest to NASA while supporting commercial flight providers and expanding space-based applications and commerce [3].

At the 2013 Next-generation Suborbital Researchers Conference (NSRC-2013), Lori Garver, former NASA Deputy Administrator, announced that NASA was open to flying people on suborbital vehicles. This change in policy clarified the original intent of the Flight Opportunities program to support both researchers and suborbital vehicle developers. At NSRC-2017, the NASA-STMD Associate Administrator announced that STMD needed to determine if and how the Agency would fly human tended payloads on suborbital platforms.

Following the latter announcement, extensive research was conducted by the Flight Opportunities program to facilitate development of safety review procedures appropriate and necessary for sponsoring human-tended research by NASA civil servants and government-sponsored space flight participants (SFPs) on commercial suborbital flights. Safety practices for NASA personnel aboard aircraft, orbital rockets and platforms, and a non-NASA vehicle, the Russian *Soyuz*, were reviewed in detail. The valuable “Recommended Practices for Human Space Flight Occupant Safety,” published by the FAA-AST in 2014 and discussed in the next section, was evaluated. Medical recommendations for operationally critical flight crewmembers, published by the Aerospace Medical Association Commercial Spaceflight Working Group, were reviewed. FAA-AST-approved SFP training available at three U.S. commercial companies was summarized. Activities of ASTM International Committee F47 on Commercial Spaceflight, formed in 2016, were reviewed. Finally, safety comparisons were made with another challenging environment, deep sea submersibles. The findings of this extensive research were published as a public paper in 2019 [4]. The findings were reviewed by NASA-STMD, and recommendations were presented to NASA leadership. This ultimately resulted in in a policy for allowing non-NASA researchers to use NASA grant funding for researcher tended suborbital flights and led to the creation of SubC. Subsequent coordination between Flight Opportunities and SubC resulted in the following text in NASA Request for Proposal, Solicitation No. 80AFRC23R0001, Suborbital/Hosted Orbital Flight and Payload Integration Services 4 (FO IDIQ 4): “… the Government intends to acquire space for Government Suborbital Research Specialists to fly as passengers aboard those Qualified Vehicles capable of supporting human flight. The flights and other services provided are for NASA and other Government Agencies (OGAs) use” [5].

# FAA Office of Commercial Space Transportation

The NASA SubC office is working with the Federal Aviation Administration’s Office of Commercial Space Transportation (FAA-AST) and the commercial suborbital space transportation industry to develop an efficient and holistic approach to a safety review and eventual government participation in suborbital flight. FAA is currently under a moratorium from Congress that prohibits the issuing of regulations intended to protect the health and safety of crew and spaceflight participants. As of October 2023 that moratorium was scheduled to expire in December 2023 but is likely to be extended. The moratorium (learning period) was originally put in place in 2004 and was to last for eight years. The rationale was to assure that government regulations would not stifle the industry before adequate experience had been gained to inform the development of an appropriate set of regulations. In light of this moratorium, FAA-AST developed, and in 2014, published recommended practices for human space flight occupant safety and training, to serve as guidelines for developers. This document, “Recommended Practices for Human Space Flight Occupant Safety” [6,7], was intended to be a starting point for a regulatory safety regime after the learning period expires. In September 2023 FAA-AST updated these recommended practices [8]. The revised practices incorporate lessons learned from the CCP and initial commercial human space flight operations.

To develop these documents, FAA-AST worked closely with NASA, industry, and other key stakeholders. The original document was the culmination of a 3-year effort, which involved researching existing human space flight standards, conducting a series of public teleconferences to gather recommendations, and soliciting feedback from the Commercial Space Transportation Advisory Committee (COMSTAC). FAA chose to primarily use NASA’s requirements and guidance for the CCP (1100 Series, Crew Transportation System Design Reference Missions) as a guide [9]. The purpose was not to copy NASA’s requirements but to use them to capture relevant safety concepts.

The FAA documents address occupant safety only. Public safety and mission assurance are not directly addressed. Both orbital and suborbital flights are covered. Orbital vehicles are defined as those that stay on orbit for 2 weeks maximum and can return to earth in under 24 hours if necessary. Orbital rendezvous and docking, long duration flights, and flights beyond earth orbit are not explicitly covered. The period of coverage is from when occupants are first exposed to vehicle hazards prior to flight through when they are no longer exposed to vehicle hazards after landing. The 102-page revised document covers recommended practices in four categories, (1) General (cybersecurity, consensus standards, and configuration management), (2) Design (human needs and accommodations, human protection, flightworthiness, human/vehicle integration, extra vehicular activity, and system safety), (3) Manufacturing and Maintenance (quality manufacturing, lifecycle risk sustainment, system maintainability, and manufacturing facilities), and (4) Operations (management, system safety, planning, procedures & rules, medical considerations, and training). Among the recommendations is a call for system operators to enhance cybersecurity measures in order to ensure protection against unauthorized access to critical vehicle functions. Operators should  also develop and use voluntary consensus standards in support of human space flight occupant safety.

No specific level of safety (risk) is defined due to the wide variety of systems and flight profiles. Two levels of care are articulated: (1) occupants should not experience an environment during flight that would cause death or severe injury, and (2) the level of care for the flight crew when performing safety critical operations is increased to a level necessary to perform those operations. In an emergency the same level of care is not expected to be maintained – only a reasonable chance of survival is mandated. Key assumptions were: (1) Each flight crew member is safety-critical, (2) SFPs may be called upon to perform limited safety-critical tasks, and (3) clean sheet philosophy – no other regulations act to protect occupants from harm. There are several notable omissions: First, although medical consultation is recommended, SFPs are free to assess their individual risk. Second, long-term health issues from ionizing radiation are not addressed. Third, integration of occupant and public safety was stated to be an area for future FAA-AST work.

The FAA has launched a Human Space Flight Occupant Safety Aerospace Rulemaking Committee (SpARC) to examine human spaceflight occupant safety. The committee is working with members of the commercial space industry and “other stakeholders” to provide recommendations to inform a “thoughtful regulatory regime for commercial human spaceflight safety,” according to the committee’s charter [10].

# Voluntary Consensus Standards

Voluntary Consensus Standards are another element being addressed by the SubC team. As mentioned in the previous section, the FAA’s updated recommended practices state that operators should develop and use voluntary consensus standards in support of human space flight occupant safety. Two key international committees developing consensus standards addressing human spaceflight safety are (1) the International Organization for Standardization (ISO) Technical Committee 20 on Aircraft and Space Vehicles, and (2) ASTM International Committee F47 on Commercial Spaceflight [11].

Example standards that have been issued by ISO TC20 include:

* ISO 14620-3:2021 – Space systems – Safety requirements – Part 3: Flight safety systems, 08/04/2021
* ISO 17763:2018 – Space systems – Human-life activity support systems and equipment integration in space flight – main document, 08/28/2018
* ISO 16157:2018 – Space systems – Human-life activity support systems and equipment integration in space flight – Techno-medical requirements for space vehicle human habitation environments, 06/25/2018
* ISO 16126:2018 – Space systems – Human-life activity support systems and equipment integration in space flight – Techno-medical requirements for space vehicle human habitation environments – Requirements for the air quality affected by harmful chemical contaminants, 04/26/2018

ASTM International’s Committee F47 on Commercial Spaceflight, formed in 2016, is developing and maintaining voluntary consensus standards and recommended practices for the commercial spaceflight industry. The voluntary consensus standards are being developed by groups of SMEs through a formal drafting and review process. Technical subcommittees develop and maintain these standards and recommended practices. Specific areas addressed include design, manufacturing, and operational use of vehicles used for spaceflight as well as human spaceflight safety. Stakeholders represented include vehicle operators and parts manufacturers, the Commercial Spaceflight Federation (CSF), regulators including FAA-AST, US Government users including NASA Centers and Headquarters, National Air Space (NAS) users, spaceport operators, medical professionals, the AIAA, academia, and other interested stakeholders.

Example standards that have been issued by ASTM International Committee F47 include:

* [F3479-20 Standard Specification for Failure Tolerance for Occupant Safety of Suborbital Vehicles](https://gcc02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1520%2FF3479-20&data=05%7C01%7Crobert.w.seibold%40nasa.gov%7C9ffd1b3880384e7b91b908db52784747%7C7005d45845be48ae8140d43da96dd17b%7C0%7C0%7C638194448764540108%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=UAdPDBeNZ83zbnOF4VOb%2F2Jbcyw5A699t%2B9Mt18szjs%3D&reserved=0)
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# Conclusions

NASA’s Safety Case Assessment approach is a methodology that is currently used in multiple industries but has not previously been applied to human spaceflight. In the current era of spaceflight, where companies are designing capabilities independent of NASA contracts, completing a Safety Case assessment facilitates NASA insight into the operator’s designs and processes by a small and focused team. In the future, NASA will continue to work with industry providers and international initiatives to find the most effective methods for ensuring success. NASA’s approach seeks to provide value, not just as a risk-assessment activity, but to expand possibilities for how government and industry can work together for a common goal.

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