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HUMAN SPACEFLIGHT SAFETY: REGULATORY ISSUES AND MITIGATING CONCEPTS

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Commercial spaceflight offers significant benefits to society, the economy, and national security. Financial experts project that the global space economy could significantly grow over the next few decades.[1] However, spaceflight is also a risk-prone and capital-intensive endeavor. In fact, as Congress pointed out in the Commercial Space Launch Amendments Act of 2004, "Space transportation is inherently risky."[2] That assessment is certainly reflected in the historical human spaceflight safety record. This paper explores ways to address the issues associated with the rise of commercial human spaceflight.

Introduction

Since the dawn of the space age, the United States has conducted 381 rocket launches with a person onboard (see Table 1). Four of those flights ended in tragedy: an X-15 in 1967, Space Shuttle Challenger in 1986, Space Shuttle Columbia in 2003, and SpaceShipTwo in 2014. That works out to be a fatal accident rate of approximately one percent. The fatal accident rate for commercial airlines has steadily improved over the last several decades, but in 2003, the year Columbia was lost, the rate was approximately one fatal accident for every million flights,[3] meaning that the risk of human spaceflight today is more than 10,000 times greater than the risk of flying on a commercial airliner. If we want to reap the full benefits of human spaceflight in the future, whether it be for exploration, scientific research, business, or tourism, we will need to find ways to improve the safety of those operations.

The Federal Aviation Administration (FAA) is currently under a moratorium that prohibits the issuing of regulations to protect the health and safety of crew and spaceflight participants; however, the moratorium is scheduled to end in October 2023.[4]

Table 1: Human Spaceflight Accident Statistics*		
Program	**Flights**	**Fatal Accidents**
X-15	199	1
Mercury	6	0
Gemini	10	0
Apollo	15	0
Space Shuttle	135	2
SpaceShipOne	6	0
SpaceShipTwo	9	1
Commercial Crew	1	0
Total	**381**	4

*The overall U.S. fatal accident rate is approximately one percent.

Projected Near-Term Activity

The United States is currently in the midst of a major transformation in how we operate in space. Over the next decade, there are plans for five different kinds of human spaceflight missions, four of which will be courtesy of private industry, rather than the government. The five categories are: suborbital commercial spaceflights that take off from and land at the same location, either for research purposes or for space tourism; commercial missions to low Earth orbit (LEO); NASA missions to the moon in support of the Artemis Program; commercial missions to the moon; and commercial point-to-point missions for high-speed, long-distance transportation. Some of these activities might be too ambitious to achieve over the next decade; however, they should still be taken seriously given the significant investments being made in this sector.

- ***Suborbital Commercial Spaceflights.*** Virgin Galactic's SpaceShipTwo has twice completed piloted missions that exceeded 50 miles in altitude as part of the testing required prior to the start of commercial space tourism operations.[5] Meanwhile, Blue Origin has conducted a number of suborbital missions with its New Shepard reusable launch vehicle, and flights carrying people are expected to begin within the next 12 months.[6] Although specific launch schedules have not been announced, both Virgin Galactic and Blue Origin may start regular commercial operations at a pace of about one flight every 1-2 months at first, gradually working up to approximately one flight per week over the next few years.

- ***Commercial Missions to LEO.*** On May 30, 2020, SpaceX successfully launched two NASA astronauts to the International Space Station (ISS), using a Falcon 9 rocket and a Crew Dragon spacecraft, as part of the Demo-2 certification test flight.[7] NASA will be scheduling post certification missions with SpaceX every 6-12 months that will carry four astronauts to and from the ISS.[8] Boeing is planning to conduct a test flight of its Starliner capsule on an Atlas V rocket in late 2020.[9] A crew flight test mission for Boeing will likely take place in early 2021, and if successful, would also be followed by post certification missions every 6-12 months.[10] Separately, NASA recently issued an interim directive that will allow private astronauts to make short-duration visits to the ISS, where they will be able to conduct either commercial or marketing activities.[11] In response to this directive, SpaceX recently completed an agreement with Axiom to carry private astronauts to the ISS in the second half of 2021.[12] In addition,

SpaceX has signed an agreement with Space Adventures to fly customers to LEO on a free-flyer mission in late 2021 or early to mid-2022.[13]

- ***NASA Missions to the Moon.*** Artemis 2 is planned to be the first mission of the Space Launch System and Orion to carry crew, and will include a lunar fly-by. It is currently scheduled for 2023.[14] Artemis 3, currently scheduled for 2024, will be the second Artemis mission to carry crew, and will incorporate the use of a commercially developed lunar lander to allow NASA astronauts to touch down near the south pole of the moon.[15]

- ***Commercial Missions to the Moon.*** SpaceX has announced a plan to fly a space tourist on a flight around the moon, using the Starship, as early as 2023.[16] Whether that flight becomes the first in a series of commercial missions, or whether it ends up being a one-of-a-kind vehicle demonstration, remains to be seen.

- ***Commercial Orbital or Sub-orbital Point-to-Point Flights.*** Richard Branson has long spoken of his desire to operate the world's first commercial "spaceline," and Virgin Galactic recently signed a Space Act Agreement with NASA to study high-speed, long-distance transportation.[17] Although some believe that the technology necessary for conducting hypersonic flights may be a long way off, it is certainly possible that we will see some initial capabilities demonstrated in the next 10 years. As one possible example, according to Elon Musk, the Starship system that SpaceX is developing to fly astronauts to the moon and to Mars would also have the capability to fly hundreds of people from one side of the Earth to the other in less than an hour. Although many are skeptical about the ambitious development schedule, SpaceX is planning to have such a system flying by 2022.[18]

Moratorium on Human Spaceflight Regulations

As mentioned previously, the 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; however, that limitation is scheduled to expire in October 2023.[19] The moratorium was originally put in place in 2004, and was to last for eight years. The rationale was to make sure that government regulations would not stifle the industry before adequate experience had been gained to inform the development of an appropriate set of regulations. When Scaled Composites won the XPRIZE in 2004 by becoming the first private company to launch people to the edge of space, it was assumed that suborbital commercial spaceflights would begin soon afterward. At that point, the expectation was that sufficient data could be gathered by 2012 to allow the FAA to institute at least some top-level regulations. With the delay in commercial flights, Congress extended the moratorium—first until 2015, and then later until 2023, although the development of voluntary industry consensus standards was encouraged. Unfortunately, very little progress has been made in the development of industry standards, and since it is possible that Congress will decide to extend the moratorium once again, there is little incentive for industry to focus on standards development.

An alternative viewpoint is that the United States now has 59 years of experience in human spaceflight, which should be sufficient for the community to come to a consensus on what kinds of top-level safety characteristics would be desirable. Even though most of that spaceflight experience has been gained by NASA, the resulting data has been shared. With the continuing success of the Commercial Crew Program, both SpaceX and Boeing have had an opportunity to perform "clean sheet" vehicle designs, while still taking advantage of lessons learned and technical feedback from the government. If the FAA were to craft true "performance-based" regulations, rather than prescriptive ones, it should be able to avoid a situation in which the regulations limit the use of innovation and new technologies by commercial developers.

Should an accident occur before the moratorium expires, it is likely that the FAA (or perhaps some other government agency) would be directed to assume regulatory responsibility for commercial human spaceflight, even though it may not be prepared to do so. To mitigate that risk, several options should be considered in order for the FAA to prepare for the task of regulating commercial human spaceflight: (1) revising legislative language on requiring a presidential commission on

accident investigations, (2) using a safety case approach for performance-based regulation, and (3) establishing a collaborative framework to create safety guidance and best practices.

Mitigation Options

Update Mishap Investigation Requirements. In response to the Space Shuttle Columbia accident, Congress included language in the NASA Authorization Act of 2005 that required the president to establish an independent, nonpartisan commission to investigate any incident that results in the loss of a space shuttle, the ISS or its operational viability, any other U.S. space vehicle carrying humans that is owned by the federal government or that is being used pursuant to a contract with the federal government, or a crew member or passenger of any space vehicle described in that section of the Act.[20] Although these provisions may have been appropriate for the space shuttle era, they have definitely outlived their usefulness and are not a good fit for the current commercial environment.

To illustrate the point, suppose that a Virgin Galactic flight of SpaceShipTwo or a Blue Origin flight of New Shepard, in addition to carrying several civilian space flight participants, is also carrying a small NASA experiment as part of a contract with the government. Should such a mission have a problem that results in the loss of the vehicle, even if there are no fatalities, the Act requires the establishment of a presidential commission to investigate the loss. Similarly, suppose that during a flight of the SpaceX Crew Dragon or the Boeing Starliner that is carrying NASA astronauts to the ISS, the space vehicle experiences an anomaly that results in the activation of the Launch Escape System. Suppose further that the capsule is rocketed to safety and lands in the water under parachutes, with the crew being rescued, but due to high winds and waves in the area, the capsule sinks (as occurred in Gus Grissom's Mercury flight). According to the Act, a presidential commission would be required to investigate the matter. Although each of these hypothetical events would be serious and very unfortunate, it is not clear that they would warrant the time, expense, and inevitable slowdown of human spaceflight activities that would almost certainly result from a presidential commission.

The Act also specifies that no employee of the federal government shall serve as a member of the commission, nor can a member have, or have pending, a contractual relationship with NASA.[21] Such restrictions may make it very challenging to find knowledgeable and experienced members for the commission.

Based on those considerations, the Aerospace Safety Advisory Panel noted in its 2018 Annual Report, "Language in the NASA Authorization Act of 2005 requiring a Presidential Commission for independent investigations must be reviewed and revised, especially as we are on the cusp of reinitiating U.S. launch of our astronauts."[22]

The Safety Case Approach. 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 requirements. The government, in turn, may have a more difficult time determining whether its requirements have been met.

One promising approach to implementing performance-based regulations is known as the *safety case methodology*. The safety case methodology is already being used by the United Kingdom's Ministry of Defence, 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."[23] To implement a safety case approach, the FAA could allow launch license applicants to choose between complying with existing regulations, or following an alternate 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 alternate process would consist of a voluntary audit 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 public safety would be protected.

In terms of who would conduct the safety audit, the FAA could either conduct the safety audit and safety case assessment itself, or obtain the support of a knowledgeable, experienced, and independent third party to carry out those responsibilities.

A Collaborative Framework: A Space Safety Institute. The Space Safety Institute (SSI) is an organizational concept that has been discussed and promoted over the last few years.[24] It could overcome the challenges associated with performance-based regulatory approaches by mitigating some of the side effects.

For example, the SSI could be a non-profit, public-private partnership (or a similar construct) that would provide space safety expertise and support to both government and industry. Participation could be open to all interested stakeholders, including vehicle developers and operators, insurance underwriters, professional society representatives, researchers, and academia. The SSI could be administered by an independent and objective engineering organization or a federally funded research and development center (FFRDC), which would be supported by subject matter experts from partner research laboratories and academia as needed. A list of potential products and services is provided in Table 2, along with examples of various topic areas.

Table 2: Space Safety Institute Products and Services

Examples of Products and Services	Examples of Topic Areas
◆ Independent Assessments	◆ Launch and Reentry
◆ Licensing Support	◆ Rendezvous and Proximity Operations
◆ Standards and Best Practices	◆ Human Spaceflight Safety
◆ Research and Technology Development	◆ Space Situational Awareness
◆ Infrastructure, Tools, and Data	◆ Space Debris Mitigation
◆ Space Traffic Management Services	◆ Cyber Security Implementation
◆ Safety Education and Training	◆ Space Safety Data Sharing

An SSI would provide two major benefits to stakeholders: 1) Serve as an objective third party auditor and evaluator in reviewing "safety case" proposals prepared by launch license applicants; and 2) provide a collaborative framework that could support the development of much-needed industry consensus standards, and on a much faster pace than is possible today.

Conclusion

The 1920s are sometimes referred to as the "Golden Age of Aviation." During that period, there was plenty of barnstorming and air races, and Charles Lindbergh made his non-stop flight across the Atlantic. Perhaps someday, the 2020s will be referred to as the "Golden Age of Commercial Space." But this time, rather than a definition based on the feats of daredevil

pilots and wing-walkers, perhaps that distinction will be earned based on partnerships and collaboration, and a renewed focus on improving space flight safety.

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