BEYOND EARTH INSTITUTE

Achieving Safety And Reliability In Human Spaceflight

The Basic Requirements For A Human Existence Beyond Earth

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I Introduction

In this age of renewed space exploration, where humans will travel further away from home, safety and reliability will be the paramount consideration for engineers, policymakers, and industry leaders. The Beyond Earth Institute envisions a future where thousands of people will eventually work in outer space, fostering a vibrant economy with permanent settlements.

The last sixty years of human spaceflight have built a rich foundation of experiences and knowledge on safety and reliability. Safety and reliability hinge on policies and engineering decisions in each journey's planning stages. The knowledge from these experiences informs the ongoing research and development about safety and reliability. Such R&D, in turn, will drive and shape government and industry practices for decades. As the industry shifts to a new age of space exploration and settlements beyond Earth, there will be a need to consider what policies have worked, what policies need to be changed, and what new policies need to be developed.

The future of safe and reliable space exploration and habitation will require new ideas, technologies, and the right policies, including rethinking the relationship between industry and government and relations between international partners. Policymakers and industry leaders will have to consider the effect of rules and regulations while encouraging innovation and supporting research and development. It will also be incumbent on space-faring nations to establish good conduct and norms of responsible behavior in space.

II Data & Risk Assessment

The discussion on safety and reliability in human spaceflight must be framed in the context of its unique risks. In 2020, scheduled U.S. air carriers operating under 14 CFR 121 flew more than 4 million flights and suffered no fatal accidents.[1] The accident rate for the Space Shuttle was 2/135 (1.48%). According to one assessment, If airlines suffered the same accident rate as the Space Shuttle, there would be 270 daily accidents.[2] Yet such direct comparisons do not reflect acceptable risk postures for similarly risky endeavors. The inherent risks to space travel are not substantially different from those of extreme sports or other risky activities. The importance of participant consent elevates accurate risk assessments as a necessity. Determining the appropriate Risk acceptability will also inform policymakers and regulators in approval of standards in commercial space travel. For space travel to truly become safe, it will require orders of magnitude better rates of accidents. Such safety developments will likely develop in tandem with the expansion of private and commercial space. With the expiration of the 2004 commercial space regulatory moratorium coming up in October 2023, this is the perfect time to renew discussions on when and what regulations will be necessary for a more open and accessible space future.

[1] National Transportation Safety Board, "U.S. Civil Aviation Fatalities and Flight Activity Decreased in 2020," U.S. civil aviation fatalities and flight activity decreased in 2020, November 17, 2021, https://www.ntsb.gov/news/press-releases/Pages/NR20211117.aspx#:~:text=The%202020%20fatal%20accident%20rate,to%202019%27s%20rate%20of%201.064.

[2] Alan Levin, "If Planes Failed like Space Shuttles, 272 Would Crash Daily," The Seattle Times (The Seattle Times Company, October 31, 2014), https://www.seattletimes.com/life/travel/if-planes-failed-like-space-shuttles-272-would-crash-daily/.

Commercial providers have recently conducted missions demonstrating the potential for private citizens to travel to space and participate in essential research.[1] Those providers have also earned international headlines for allowing people of all ages and backgrounds to travel to space. While these achievements are laudable, such missions still involve risks—both well characterized and those less understood. Hazards in space include the effects of microgravity, partial gravity, space radiation, and isolation. These risks elicit biological and psychological, which have both short-term and long-term health impacts.

Communication of risk and exposure to hazards, yet to be fully characterized, to potential passengers is one of the most important aspects of forming an ethical framework to assess safety and reliability. Like any dangerous activity, participants sign waivers with a clear understanding of the risks or unknown risks they take. For example, the death rate for wing-suiting is 1/500, a number garnered from thousands of jumps over decades.[2] The lack of sufficient data poses an initial obstacle to creating an accurate risk assessment for new space systems, one that will be overcome through time and experience.[3] (Only a total of 635 people have gone into space as defined by FAA criteria.) There is also the added difficulty of assessing different vehicle types, different destinations, and different body types.

Shared Database

The policy of a shared safety and reliability database among industry members should be adopted. Such a database may be modeled after the FAA's near accident reporting database or the Aviation Safety Information Analysis and Sharing (ASIAS) program.[4] The ASIAS is a database jointly funded by the FAA and Aviation Industry run by a third-party non-profit organization. ASIAS data is collected from dozens of airlines, industry partners, and government agencies. The information collected removes any information on the operator to ensure privacy and peace of mind. These non-punitive reports help industry and regulators proactively identify problems in aviation. Such a program should be encouraged and applied to the space industry.

As casual travel to space becomes more common in the coming decades, it becomes ever more important to research the effect of space on the human body. It would also be essential to obtain medical information for future space passengers who would not have the same health status as NASA astronauts. Such medical information should also be made available in a shared database to better inform all parties on the impact of space travel on different types of human physiology. The opportunity to gather aggregate data is critical to determining the criteria for reliability in human spaceflight.

The Translational Research Institute for Space Health (TRISH) has developed a medical research program for commercial space passengers. To enable research, the goal is to host human and vehicle data from all commercial spaceflight missions. This program was first deployed on the 2021 Inspiration 4 SpaceX flight which lasted three days, and continued data collecting with the Axiom 1 missions. In partnership with NASA's Human Research Program, TRISH funds research to reduce health risks to passengers.[5] The TRISH model may inform how much medical and human research data can be gathered and de-identified.

Funding for a centralized database could be provided by the government, industry, or both. Nevertheless, each option has its obstacles. It may be politically questionable to use taxpayer dollars for what many in the public consider a billionaire's venture. Private enterprise may be reluctant to share data it feels proprietary information. A hybrid system where government invites companies to provide information voluntarily would seem best but would only work if larger companies also commit. However, such a program could also be seen as disproportionally beneficial to smaller and new firms which lack safety and reliability experience. With this in mind, it may be difficult to guarantee the participation of larger firms in such a program.

III Regulations & Government

The role of government in the future of space exploration is drastically changing. NASA has been a designer, developer, owner, and operator of space systems, giving it a leading role in U.S. space exploration. It is also a focal point for spaceflight and contracts organizations to perform specific tasks such as design.

Since the shuttle program's retirement, the commercial space sector has flourished, especially under the public-private partnership model. As more private space providers (commercial & human) enter the market in the coming decades, taking a ride on commercial rockets will likely become safer, more economically viable, and more reliable. Further, as the industry develops its space systems, such as in-space habitats, repair, and servicing missions, NASA will be economically encouraged to hand over the responsibility of significant space developments to the private sector.

Nevertheless, NASA will still have a significant role to play in space exploration. NASA has specialized in projects that are fascinating but not necessarily marketable. Projects such as the James Webb Telescope, deep space probes, and Mars rovers have captured the public's attention. However, these scientific activities are not profitable ventures that the industry would take over. In a commercially active space future, these awe-inspiring large-scale, one-off undertakings will likely remain under the purview of government agencies.

When the Human Landing System contract was awarded to SpaceX, it demonstrated confidence in the private space industry to carry on the legacy of human space exploration. NASA still de-risks and is an excellent validator of space development and technologies. By flying NASA missions that rely on commercial space providers, the agency lends credibility to that private sector service provider. This endorsement can serve to bolster confidence in new space systems.

NASA's role will still be significant in the decades to come. In partnership with industry, it will assist with developing appropriate standards for space conduct, especially regarding international interactions in the space domain. These standards should not reflect a prescriptive government solution but guide the stated intent of new systems, to encourage the development of innovative designs. The Artemis Accords, signed by 20 space-faring countries, is a start for the government and industry to pursue frameworks that will serve the greater goal of establishing international norms and rules of conduct for space activities.

The FAA is the primary governing body that regulates commercial launches and reentries. However, a regulation moratorium from 2004 has prevented the FAA from issuing new regulations intended to ensure the safety of crew or space flight participants. This constraint is currently scheduled to end in October 2023. Once the FAA promulgates rules governing crewed commercial space missions (should they do so), the conversation will revolve around what risks the government should allow and how risk assessments are performed and communicated.

One of the most critical factors in ensuring safety and reliability is the risk of debris impact and microparticle damages. This danger with space travel and prolonged exposure to space vehicles help inform safety standards, including the Loss of Crew (LOC) ratings. With 60 years' worth of derelict rocket parts and dead satellites continuing to orbit the Earth, the chance for space hazards has increased and is at the forefront of sustainable space policy. The long-term dangers of space debris is triggering the Kessler Syndrome, a chain reaction of collisions that destroys low earth orbit's usability. The U.S. tracks 25,000 pieces of debris in space larger than 10 cm in diameter and estimates that there are 900,000 pieces of debris less than 10 cm.[6] The dangers of space debris have manifested in an increased need for satellite and satellite and space station collision avoidance maneuvers.

1 Elizabeth Howell, "Axiom Space AX-1 Mission: The First All-Private Crew to the International Space Station," Space.com (Space, March 9, 2022), https://www.space.com/ax-1-axiom-space-station-mission.

2 Andrew Bisharat, "Why Are so Many Base Jumpers Dying?," Adventure (National Geographic, May 3, 2021), https://www.nationalgeographic.com/adventure/article/why-are-so-many-base-jumpers-dying.

3 Kris Annapurna, "Wingsuiting: A 1 in 500 Chance of Death ," Explorersweb, June 6, 2022, https://explorersweb.com/wingsuiting-dance-with-death/#:~:text=Since%201981%2C%20more%20than%20400,1%20death%20per%20500%20jumps.

4 National Business Aviation Association, "Sharing Aviation Safety Data Is a Good Thing: NBAA - National Business Aviation Association," NBAA, June 5, 2017, https://nbaa.org/aircraft-operations/safety/statistics/sharing-aviation-safety-data-good-thing/.

5 Kaylee Dusang, "Space Health Institute Launches First Commercial Spaceflight Medical Research Program," Baylor College of Medicine, September 7, 2021, https://www.bcm.edu/news/space-health-institute-launches-first-commercial-spaceflight-medical-research-program.

6 Secure World Foundation, "SPACE POLICY AND SUSTAINABILITY" (Secure World Foundation, December 2020), https://swfound.org/media/207084/swf_space_policy_issue_briefing_2020_web.pdf.

NASA has led the development of technical standards through the Inter-Agency Orbital Debris Coordination Committee and implemented them through the Orbital Debris Mitigation Standard Practices.[1]* These standards outline quantitative limits on debris released per flight, probability limits on explosions, and reliability thresholds for post-mission disposal. Each U.S. Agency must apply these standards for their missions and commercial launches. While these standards have been recently updated, there is a distinct lack of motivation from both industry and government to invest in debris cleanup.

The current framework for authorizing, licensing, and managing space has been criticized as inconsistent, raising concerns about ensuring long-term safety and reliability. The U.S. Government entity charged with granting frequency licensing for communications satellites and regulating space debris mitigation is the Federal Communications Commission (FCC).[2] In the absence of action by other regulatory agencies, they have also issued requirements relating to satellite disposal and space debris.

A significant challenge is ensuring consistent rules overseeing orbital debris among the various federal agencies responsible for different parts of the space domain. For example, in addition to the FCC and its role in licensing communications satellites, the US Department of Commerce licenses imagery satellites and thus reviews potential debris issues associated with these satellites, the Office of Space Commerce has been proposed as the lead agency for Space Traffic Management (a role that is still undergoing debate in Congress). As noted above, the FAA licenses commercial launches and reentries, while NASA and DoD oversee their respective spacecraft. In 2018 Swarm Technologies launched four CubeSats via an Indian launch provider, despite not having been granted a frequency by the FCC. This unauthorized launch highlighted growing concerns with current launch practices.[3] It showed that foreign launch providers had no obligations to enforce or adhere to U.S. policies and regulations, precisely the guidelines on debris mitigation. That said, the FCC ultimately fined SWARM owners $900,000 for failing to comply with the FCC rules.

Currently, there is a lack of clarity on which government entity is responsible for overseeing non-government activities in space. This leads to confusion and problems such as the Swarm Technologies incident, which may hinder future commercial investments in space. Ideally, a regulatory framework that centralizes debris mitigation and space traffic would benefit commercial space and space sustainability. Without a solid regulatory framework, these issues will impact the development of safety and reliability. The centralization of regulations and government oversight should provide common guardrails and create a stable environment for industry to flourish. Standardizing space regulations across civil, military, and commercial sectors will further enhance reliability and safety.

IV Building Infrastructure

Throughout history, governments have spearheaded the development of new inventions, often paving the way and building the fundamental technologies for such industries. In the 1800s, the U.S. government funded railway construction across the country, allowing cross-continent commerce and settlement. Computers and the internet are such examples of technology borne from government funding. In the context of the space age, government-funded infrastructure could develop and maintain spaceports, ensure space situational awareness, and manage space traffic. The United States should continue this tradition of critical infrastructure support and development.

It should be a top priority for the U.S. to form an overarching policy for space infrastructure maintenance and development. Ensuring continued maintenance of critical space infrastructure will be crucial for developing a burgeoning commercial space sector. These critical infrastructures include spaceports, securing the cyberspace domain, spectrum access, and supply chains crucial for the industrial base.[4]

V International Space Governance

Space diplomacy is crucial to ensuring safety and reliability in human space flight. The United States, through multilateral and bilateral efforts in concert with foreign partners, is attempting to establish what constitutes responsible norms of behavior in space. With countries joining the space-faring club, the United States should utilize its leadership in space to continue fostering international policies that improve space safety and reliability.

In a time of renewed geo-political competition with China and a resurgence of a hostile Russia, America's role in space takes on renewed importance. American leadership in space means leading by example in commercial, civil and military space affairs.[5] The Artemis missions will not only build a cislunar station but also build a coalition of nations. If the United States does not maintain its leadership role, competitive powers like China will set space policy and international standards. The Artemis Accords will also continue the tradition of international space cooperation, as exemplified by the International Space Station over the past two decades.

There are still many safety policy areas that would benefit all parties. The Liability Conventions and Rescue Agreement have governed space activities for the past half-century. The 1968 Rescue Agreement binds all signatories to provide all necessary aid to astronauts in need. This duty-to-rescue principle is also well established in maritime law.[6] Cooperation on this issue is crucial for saving lives and creating a viable commercial environment. China's adoption of the International Docking Standard signals a good direction for this principle.

The growing congestion and competition in space will inevitably lead to more near-collision incidents. It is prudent for the United States, China, and all other spacefaring (or aspiring spacefaring nations) to cooperate on the sustainable use of orbital space. Ensuring that U.S. tracking agencies and companies can rapidly communicate dangers to international partners is crucial to keeping orbit safe and sustainable.

Such efforts to ensure space sustainability and common infrastructure will serve to benefit all parties in the development of future human spaceflight.

VI Conclusion

Safety and reliability in human spaceflight is a priority issue for humanity's future in space. There are countless technical and policy hurdles to making space safe. It is incumbent on the United States Government and industry to formulate the right policies in concert, ensuring sustainability and reliability in human spaceflight. The United States must lead the world in developing policies for a safer and more reliable future in human space exploration.

Space has always been fraught with challenges, but it is also the inherent desire of humanity to go beyond the current possibilities. That will to try, and sometimes fail, is what drives the groundswell of support, and capital for private space developments. The issue of safety and reliability will always be a cause for concern in space flight, as it is for any other activity, but this emerging space sector must be allowed to flourish without undue burden. Finding balance in achieving safety and reliability in human spaceflight is the key to humanity's successful future Beyond Earth.

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1 Orbital Debris Mitigation Standard Practices (2019).

2 "TRESPASSING ON THE FINAL FRONTIER: REGULATORY CHALLENGES FOR NEW SPACE ENTRANTS," TRESPASSING ON THE FINAL FRONTIER: REGULATORY CHALLENGES FOR NEW SPACE ENTRANTS (Center for Space Policy and Strategy, n.d.).

3 Mark Harris, "Swarm Seeks Fresh FCC Satellite Launch Clearance While Still in Penalty Box," IEEE Spectrum (IEEE Spectrum, June 24, 2021), https://spectrum.ieee.org/company-behind-illegal-satellite-launch-seeks-fresh-orbit-clearance-before-fcc-hands-down-penalties.

4 White House, "United States Space Priorities Framework - White House," UNITED STATES SPACE PRIORITIES FRAMEWORK (whitehouse.gov, December 2021), https://www.whitehouse.gov/wp-content/uploads/2021/12/United-States-Space-Priorities-Framework-_-December-1-2021.pdf.

5 Secure World Foundation, "SPACE POLICY AND SUSTAINABILITY" (Secure World Foundation, December 2020), https://swfound.org/media/207084/swf_space_policy_issue_briefing_2020_web.pdf.

6 Irini Papanicolopulu, "The Duty to Rescue at Sea, in Peacetime and in War: A General Overview," International Review of the Red Cross, August 1, 2016, https://international-review.icrc.org/articles/duty-rescue-sea-peacetime-and-war-general-overview.