EVALUATING AND COMMUNICATING ACCEPTABLE LEVELS OF RISK IN SPACE TOURISM

Chris Beauregard

Space Policy Institute | 1957 E St. NW Washington, DC 20008 | beauregard@gwu.edu

ABSTRACT

In the advent of commercial human spaceflight, there exist a number of ventures that aim to serve the public sector through government contracts, as well as some that seek to provide human spaceflight capabilities to paying private customers. A human presence in space is inherently complicated, dangerous and relatively novel compared to the human existence on Earth and, accordingly, risks must be properly calculated for such missions. Such risks, including those of the technical, safety and business sense, must be properly communicated between organizations in the spaceflight sector and regulators, policymakers, customers and general public. However, the risk tolerance acceptable to different parties, such as government entities and the private sector, can vary quite widely. As new technologies are developed and demonstrated, an increasing amount of excitement surrounds the fledgling industry, which has already experienced a series of accidents. There will be will almost certainly be more mission failures in commercial human spaceflight, but through observation of precautions, communication of risk and creation of effective policies, such incidents can be limited, as will potential stagnation of an industry where acceptance of risk is a requirement to participate.

Keywords: Risk Management, Human Spaceflight, Space Tourism

1. INDUSTRY OVERVIEW

The remarkable era of human spaceflight is wrought with the excitement of exploration, scientific discovery, and challenges to the limits of the human body and engineering prowess. In terms of national pride and global impact, there is something about human exploration that robotics and imagery of deep space cannot quite match. Humans were first launched into orbit within sixty years of first achievement of manned flight and to the moon and back within another decade. In the present day, a near-permanent human presence in low Earth orbit has been established and it is important to recognize just how much has been accomplished. Such feats, however, do not come easily or inexpensively, in terms of financial capital and human life. In the pursuit of extending the human presence, over five hundred individuals have risked their lives by venturing to space, including nearly two dozen who made the ultimate sacrifice, not to mention scores of non-participant losses, due to accidents, such as engineers and members of the public. The lessons learned thanks to their expeditions, much like those from the deep sea, high altitude, and uncharted wilderness, will not soon be forgotten and have been used to improve the odds of success in future missions. The risks for these explorers, however, were understood and accepted, as a space program's ability to communicate risk and mission expectations is no accident. It is through decades of careful research, design, and precaution that organizations are able to limit and express risk within complex mission profiles to those who willingly accept them. In this advent of commercial human spaceflight, which includes orbital and suborbital private tourism, there are a new set of policy and safety concerns that must be addressed.

Historically, human access to space has been reserved for national space programs and a select few high-net-worth individuals that have paid sums over $20 million for orbital access aboard the International Space Station. Before the age of paying tourists, several other private individuals had flown for business purposes and as payload specialists in the United States Shuttle Program, including scientists, politicians, journalists, teachers, and civilians. For those with the financial means and willingness to accept the risk, private spaceflight is perhaps the most exciting venture accessible. Space tourism is a market often compared to climbing Mount Everest or trekking to the South Pole, as it is generally reserved for deep-pocketed risk-takers who will likely experience it once in a

lifetime to challenge themselves, check it off of a bucket list or impress peers. With the added novelty of the adventure, more comfortable accommodations and lower activity requirement than that of a long-distance or high-altitude excursion, commercial spaceflight is poised to become a viable market thanks to successful technology demonstrations and a strong indication by willing participants. There currently exist several private ventures that aim to create the market for widely accessible space tourism for suborbital flights, orbital adventures and beyond. In fact, it is estimated that the space tourism may swell to a billion dollar industry by 2022 [1].

Suborbital trips are expected to cost between $15,000 and $300,000 and would bring tourists to the edge of space by means of several different launch vehicles, most of which would include a period of weightlessness and a view of the Earth's curvature. At the lowest levels of complexity, cost and risk, Worldview and Zero2infinity, among others, aim to provide balloon-based experiences for passengers, which would provide experiences at the edge of Earth's atmosphere. At the suborbital level, companies are seeking to provide short-duration trips via spacecraft such as Blue Origin's New Shepard rocket and Virgin Galactic's SpaceShipTwo spaceplane. Orbital flights, due to higher velocity and altitude, will continue to be vastly more expensive and carry a greater number of qualifications for passengers. There are, however, several companies pursuing orbital excursions for private passengers, including Boeing's CST-100 Starliner and Bigelow Aerospace through their inflatable habitats. With their vision set beyond earth orbit, SpaceX, Space Adventures and several others seek to provide voyages to the Moon, with price tags in the tens of millions of dollars.

"Space transportation is inherently risky and the future of the commercial human spaceflight industry will depend on its ability to continually improve its safety performance.

- Commercial Space Launch Amendments Act

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2. RISK INVOLVED

Earth is a risk-filled environment, though most risks that comprise daily life are accounted for and effectively mitigated. Travel via motor vehicles and aircraft, consumption of substances and medications, failure to observe warnings and lack of exercise all contribute to an individual's everyday health risk profile, but a number of other activities fall outside of such risk accounting. For travel, entertainment, and sporting, the following activities give a perspective of the approximate mortality risk undertaken by willing participants:

Activity	**Fatality rate**
Commercial air travel	1 in 7,000,000 [2]
Skydiving	1 in 101,083 [3]
Travel by motor vehicle	1 in 48,000 [4]
Scuba diving	1 in 34,000 [5]
Base jumping	1 in 2,317 [6]
Hang gliding	1 in 560 [7]
Human spaceflight	1 in 91 [8]
Climbing above 6000m in the Himalayas	1 in 10 [9]

Given the hype surrounding the next-generation thrill ride industry, such excitement should be somewhat tempered with the realization that the ventures still have some obstacles to overcome in their varied stages of development. Not the least of these concerns is the risk profiles that will be undertaken by the commercial space tourists, the companies providing flights and the regulatory entities certifying their missions. Human spaceflight subjects the body to a number of forces, and a lack thereof, that would otherwise not be experienced on earth. The launch of objects into space is an extremely accelerative process that imparts significant G-forces on the human body. A typical launch will subject upon a passenger three times the force of Earth's gravity, which is typically compensated for through reorientation of the human body to a reclined position to best tolerate the force, though the effects are only partially mitigated. The noise and vibration can also affect passengers and create a stress-inducing experience that may impair communication and awareness. For missions that include the experience of microgravity, passengers should anticipate some spatial disorientation with a possible onset of space-induced motion sickness [10]. For flights that allow passengers to leave their seats, the environment may also be conducive to personal injury, especially if the passenger is unable to re-fasten themselves in their seat before reentry. In orbital flights

and high-altitude suborbital flights, the human body will also experience an increased exposure to radiation which, while not an immediate concern, is also a factor worth noting. Finally, during the reentry period, passengers will once again be exposed to high G-forces and a significant amount of noise and vibration. In addition to relatively minor health complications, participants in human spaceflight expose themselves to more catastrophic risks that could occur at any time, including decompression of a capsule, resulting in deprivation of breathable oxygen and exposure of the cabin to environmental conditions intolerable to life. During launch and reentry especially, atmospheric pressure and extreme heat on the craft can also create a risk of catastrophic loss of vehicle and crew should the structural integrity of the craft be compromised.

3. REGULATORY LANDSCAPE

With these risks in mind, mitigation of them can be partially achieved through observation of precautions such as the establishment of flight requirements for hopeful tourists. While US government entities such as the Federal Aviation Administration (FAA) have been developing their own guidelines for space tourism, health requirements have not yet been established, leaving many to believe the companies will self-regulate astronaut health guidelines [11]. Though FAA's Office of Commercial Space Transportation (FAA AST) currently oversees the licensing process for all US-based launches, including tourism, their focus is generally limited to public safety, property damage and supervision of the training processes for crew members [12]. FAA's ability to regulate human spaceflight was prohibited in the Commercial Space Launch Amendments Act of 2004 in order to encourage the growth of the industry. Thus, FAA AST is only able to regulate minor facets of commercial human flights, such as informing passengers of risks and training of participants "to respond to emergency situations, including smoke, fire, loss of cabin pressure, and emergency exit." In fact, the Federal Aviation Administration Office of Commercial Space Transportation *Recommended Practices for Human Space Flight Occupant Safety* lists "Medical Limits for Space Flight Participants" as a "Notable Omission." [13] In the case of non-US passengers, the case becomes slightly complicated, as foreign participants must be informed in the same way as us citizens, but discrepancies exist between US export control regulations and FAA informed consent regulations [14].

The criteria for astronauts as public servants have historically been very scrutinizing, often requiring high aptitude and fitness levels, advanced degrees, countless flight hours, extensive personal and family health history and strict personality requirements, but future commercial passengers will not be expected to meet many of those requirements. With regard to medical certification, Space Shuttle pilots were required to meet FAA Class I guidelines, while mission specialists adhered to slightly less restrictive Class II guidelines and payload specialists, Class III. From a risk perspective, the government tends to adhere to more restrictive standards of assurance, as organizations such as NASA under federal oversight cannot, in good faith, certify public servants to fly a mission with a high likelihood of failure. The initial risk profile target for the Shuttle program, for example, was a 1 in 1,000, while engineers estimated 1 in 100 and some management estimates cited a 1 in 100,000 chance of catastrophic loss of crew. Realistically, however, the chances of mission failure were far greater, as some experts cited retrospective statistics as grave as 1 in 9 [15].

Similarly, the current regulations state that commercial pilots are required to obtain an FAA pilot certificate with instrument rating, possess the necessary knowledge, experience and skills to control the vehicle and demonstrate an ability to withstand the stresses of spaceflight. Additionally, any safety-critical members of the flight crew must obtain an FAA Class II medical certificate. Finally, participants are required to agree to accept the risks involved by providing informed consent in writing. The FAA also encourages operators to comply with the "Recommended Practices for Human Space Flight Occupant Safety," though adherence is not required [16]. The FAA is currently most interested in maintaining public safety and prevention of third party harm and are relying on commercial spaceflight operators to create safe operating environment for its participants. However, as the industry matures, the scope of FAA AST may include occupant safety and mission assurance.

Some of the appropriate risks for spaceflight tourism are outlined in "Acceptable reusable launch vehicle mission risk," which specifies that the maximum risk level, which is measured in expected average number of casualties, to the general public shall be no more than 1x10-4 and those to any individual shall be no more than a 1x10-6 probability of casualty per mission [17]. However, these requirements only provide guidance for the general public. Spaceflight participants must also be properly informed, in writing, of the safety record of the individual vehicle, of the historical record of human spaceflight, that the vehicle has not been certified by the government, and of all

hazards, with the understanding that some are unknown. Consent must then be issued in writing in addition to a waiver of claims against the US government [18]. To facilitate industry growth, a moratorium on additional space tourism-related regulations was established and has since been extended to 2023, providing a "learning period for operators." [19]

4. COMMUNICATION OF RISK

The risks associated with human spaceflight, as with other high-stakes, complex systems, are a complicated concept to effectively communicate with the general population and cannot always be accurately simplified to numbers. It is simple enough to emphasize that missions are risky, and reminders of what can happen when things go awry are everpresent. Normalization of risk, though inherent in human nature, can lead the population to believe that there are never close calls and can create a perception of over-simplification. However, NASA, as an organization, has always appeared to operate as risk-averse and overly cautious, especially with the lives of its personnel. The risk profiles with crew versus cargo payloads differ quite a bit, as separate rating criteria are used to evaluate the two mission profiles. Similarly, the risk that the government is willing to take with taxpayer dollars and lives of public servants differs from the risk that commercial entities and private individuals are willing to take. Some risk is understood as a prerequisite for success, especially in business ventures, but with highly-publicized proceedings and human lives in the balance, how much risk are private ventures willing to take and how much *should* they be allowed to take? Communicating such a concept to the public is no easy task. According to NASA Associate Administrator for Human Exploration and Operations, Bill Gerstenmaier, the topic of risk "is one that we spend a lot of time and energy on within NASA, but we probably do not spend as much time with the public." [20] With so many emerging spaceflight systems born from companies with varying degrees of successful track records, it is important to recognize that the public must understand and accept the risk of failure- organizational, operational, mechanical and catastrophic.

While risk can never be completely removed from a system, it can be mitigated. However, even through careful reduction and use of statistical modeling, a simple figure, though easy for a consumer to understand, will never tell the full story. Soft data is a universal truth, especially with a limited data set from which to draw conclusions. Unfortunately, it may require some missteps to uncover insights and concrete statistics, though the hope is for miraculous near misses that allow for adjustments to systems and processes to ensure safer flights in the future. With the added complication of communication such concepts to policy makers holding pens by which entire industries live and die, such risks need to be accurately, simply, and carefully communicated. The intricate balance in this principle is one that must be struck correctly, and the outcome will determine jobs, bottom lines, human lives, and chances of reelection.

5. POLICY RECOMMENDATIONS

As there currently exist few industry standards for paying customers, there is a case to be made for additional regulations, as long as they do not excessively prohibit further growth of the industry. As with any effective legislation, it should be created in anticipation of industry developments and occurrences to foster growth without inhibiting progress in the best interest of the public. Preemptive legislation, if correctly formulated and instituted, can prove vital to an industry's survival after mishaps, which are a near certainty in spaceflight. For example, in a 2011 hearing before the US House Subcommittee on Space and Aeronautics, Bill Gerstenmaier reminded policymakers that failure was a fact of life in spaceflight and it would be a major step backward to significantly pause the Commercial Orbital Transportation Services missions in light of accidents, or to over-regulate in response to them [21] In a similar fashion, it would be shortsighted to place unnecessary restraints on a budding commercial tourism industry due to accidents, unless of course, they are frequent, catastrophic and immutable. Industry survivability could ultimately rest in the hands of consumers and their willingness to follow through with their ticketed flights after such incidents. It could also be argued that, even after an accident, the industry would recover, based on ongoing non-tourism-based commercial missions that would reinforce the reliability of launch vehicles.

With that said, it is worth examining prudent policies that could be instituted to better ensure the safety and success of commercial space tourism. From a passenger and crew health perspective, it would be unwise to allow companies to institute subjective health requirements for their passengers without standards being set by an advisory body and the playing field should be relatively even for companies performing similar services. An example of such regulation should include medical certification of passengers via screened medical history for presence of disqualifying conditions, such as pulmonary, cardiovascular, vestibular or central nervous system

risks, certain medications, mental illness, previous surgeries, and injuries. Prospective passengers should also be subjected to basic flight training and acclimated to the experience through means of simulations, centrifuge testing and other flight testing, specifically for orbital trajectories and beyond. Additionally, the certifying flight surgeon should be an employee of an entity other than the one with which the passenger will be flying to ensure an accurate evaluation with independent recommendations. A potential solution would be use of FAA designates, as currently employed by the aviation industry, to certify flightworthiness of participants and personnel. Such qualifications could ensure fewer adverse responses in flight, unfortunately, at additional cost and risk of self-deselection from their ticketed flight. Crew certification should be much more substantial and equivalent to an FAA Class I medical certificate, as well as advanced training in emergency situations, anti-g suits, medical response and other personal safety measures for themselves and passengers. An additional measure that has been advocated by the Office of Commercial Space Transportation to ensure participant readiness is the use of military support vehicles by commercial companies. The use of such test vehicles are not currently permitted, but could potentially be useful for training and familiarization of personnel and participants alike.

Such programs could potentially be overseen by FAA AST, NASA's Office of the Chief Health and Medical Officer, or a similar entity. To support this endeavor, as well as compensate for other shortcomings, funding must be increased for FAA AST, as the office will require additional resources to perform its workload and is not sufficiently equipped to expand its role [22]. In the same breath, it is also worth considering whether or not it is appropriate to have a single entity concurrently promoting and scrutinizing companies for commercial spaceflight undertakings. The Federal Aviation Administration's Office of Commercial Space Transportation's mission is "to ensure protection of the public, property, and the national security and foreign policy interests of the United States during commercial launch or reentry activities, and to encourage, facilitate, and promote U.S. commercial space transportation." Though not inherently counterproductive or a conflict of interest, the two missions may, at times, contradict one another.

Rather than creating new jurisdictional authority and in addition to an increased budget, the Office of Commercial Space Transportation could also be promoted to a higher level as an office under the Secretary of Transportation, perhaps in parallel with the Federal Aviation Administration or as a standalone entity. The present hierarchy does not delegate the appropriate authority or funding to AST and entangles space transportation within the same realm as traditional aviation. This restructuring would be beneficial for industry and the government, as it would assist in enabling transparent certification processes, consolidation of authority, better planning within the industry and government and simplification of development efforts [23]. In the interest of addressing several of these concerns, a review of domain definition should be conducted by the International Civil Aviation Organization with the intention of redefining space as a domain separate from aviation. This is a logical step for many reasons, especially considering the difference in environment, velocity and vehicle design. Additionally, space tourism should not fall under the profile of a common carrier as the present intention of space tourism is not to transport participants between locations. The outcome of this determination may also impact the entity tasked with investigation of any accidents that occur.

6. FUTURE CONSIDERATIONS

While it may be impossible to anticipate the nuances of an industry that hasn't quite taken shape, there are a number of considerations that might need to be addressed in the near future. Acknowledging that the opportunity of spaceflight might be used for purposes other than personal enjoyment, it should be asked what participant activities should be permitted and which should be banned. Could potential participants seek other tangible benefits during their flight, such as promotion of a brand or themselves? Will smartphones, cameras or other handheld technology be allowed? With the anticipation that participants could potentially have their vitals monitored, it may also be worth exploring what can be done with the data, especially considering the relatively small number of human spaceflight datasets. How would the sharing of that data take place, how would it benefit future studies of human health in space and how would participants be protected? When considering the context in which space tourism is marketed to consumers, is spaceflight likened more to a thrill ride like a roller coaster, an extreme sport like skydiving, an extraordinary tourist destination like summiting Mount Everest? The image portrayed may determine how the industry will be regulated and operators must carefully consider the perception of regulators and the public.

The industry is still in its infancy, but, as it develops, how should regulators stratify the different industry segments? Identifying orbital versus suborbital

segments and piloted versus unpiloted craft is a logical starting point, but other unique identifiers will become apparent as the market matures and each will deserve specific attention and regulation, or lack thereof. Would a passenger flight half-way across the planet in an orbital-class vehicle be considered a tourism venture or a common carrier? When considering the differences between providers and lack of industry-wide standards, it should also be explored how these gaps in standards should be addressed. For example, because Blue Origin does not have a pilot to alter the trajectory of the vehicle, they do not need to abide by the same FAA regulations as a craft that is piloted.

The establishment of industry standards can be expected to occur as the market further develops, but there are a multitude of important considerations that should be posed in the process and examined in advance. In environments where actors are rushing to bring a product to market, there may be left with gaps in standards, which are established, in part, to create duties for providers to their customers. These standards could potentially be set up through working groups within a standards body and in conjunction with the FAA's Commercial Space Transportation Advisory Committee. It's far more advantageous to have a coalition of operators determine standards than imposition of rules from a federal level.

7. CONCLUSION

Within the next decade, a new era of tourism in space is set to begin and a delicate regulatory balance must be struck to allow the market to flourish. Organizations such as FAA AST have been instrumental in encouraging innovation and championing an initial hands-off approach to many facets of the industry that could have otherwise be strictly regulated, though they continue to operate in the best interest of public safety and have established a realistic and effective informed consent regime and licensing process.

As the industry develops, coordination among actors, regulators and standards bodies is necessary to ensure cooperation in safety issues and sharing of information regarding mishaps. These mishaps, while they may affect public perception of the industry, should be anticipated and abated to ensure increases in flight frequency. Regulations that are instituted should be done so with the understanding of their temporality to compensate for changes in the industry, technology maturation and evolution of other interrelated markets and business practices.

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