

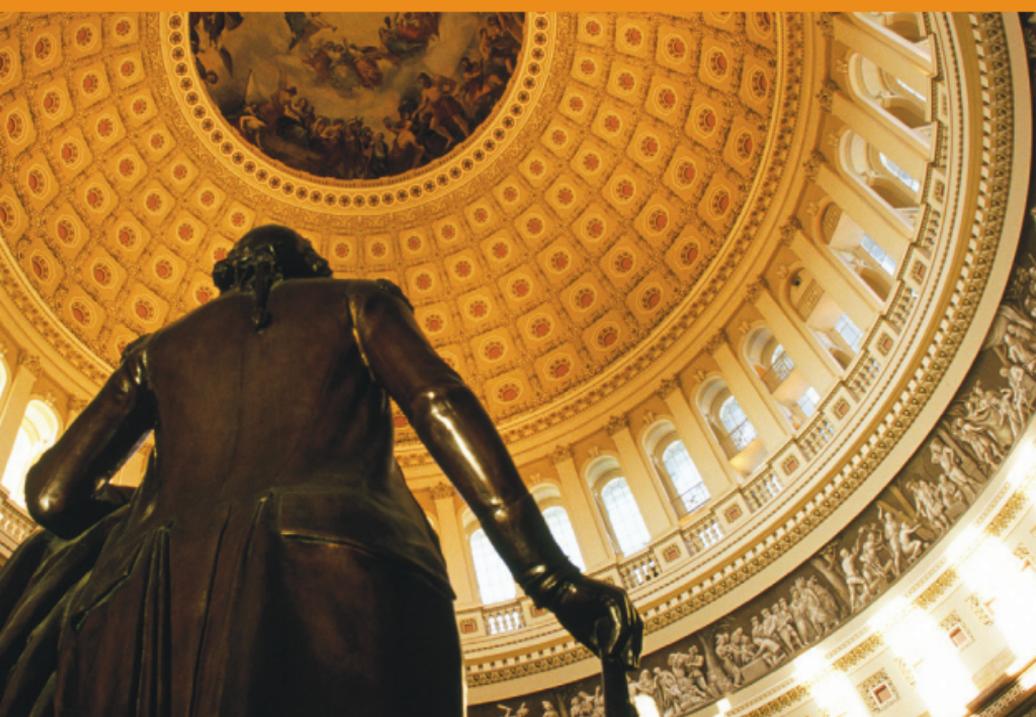
The Future of Space Tourism

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Alyssa K. King
Analyst in Transportation
Policy

The Future of Space Tourism

Several private companies are developing plans to take paying customers to space on a regular basis. Federal oversight of space tourism has been deliberately light, consistent with the Commercial Space Launch Amendments Act of 2004 (P.L. 108-492), in which Congress mandated a “learning period” for companies to develop business models, establish safety standards, and design spaceflight vehicles prior to establishment of federal regulations.

In that law, Congress directed the Federal Aviation Administration (FAA) to develop indicators showing when the space tourism industry has matured to the point that it can accommodate a stricter safety regulatory regime. In a 2019 report to Congress, FAA found that the sector was not yet ready for stricter regulation. It is to provide another assessment of the industry in 2022. The “learning period” during which the agency must forbear from regulation is currently set to expire in 2023.

At present, the U.S. government has no procedures for certifying the safety of launch vehicles for tourist passengers. Launch providers must receive a license for their rockets from FAA, but this licensing process addresses propulsion and trajectory aspects of spaceflight missions and public safety on the ground rather than passenger safety. For flights with passengers aboard, FAA requires crew and pilots of commercial spaceflight vehicles to meet certain training and medical standards, but it has no standards applicable to passengers.

Before boarding a rocket to space, or even just to the edge of space, passengers are required by FAA to sign a waiver acknowledging known risks of spaceflight. However, aerospace medical experts recognize many health risks associated with spaceflight are still not well understood, and very little research has been done on medical consequences of such flights on the health of untrained participants. Known medical risks vary based on many factors, including spaceflight profile, vehicle configuration, destination, and duration, as well as preexisting medical conditions in passengers. Participants enduring microgravity, high speeds, and intense gravitational forces could experience vision loss, motion sickness, balance issues, loss of consciousness, and cardiovascular complications. FAA and the National Aeronautics and Space Administration (NASA) recommended medical screening standards for tourist spaceflight participants in 2012, but these guidelines are not binding on companies that provide launch or accommodation for space travelers.

In the event of an accident involving a commercial spaceflight vehicle and passengers, FAA’s requirement for passengers to sign waivers absolves the government and launch operator of any liability for loss of life. However, families of spaceflight participants are not required to sign a waiver and could sue the launch operator after such an accident. To date, no such action has been tested in court. Responsibility for official accident investigations involving commercial space vehicles is shared between FAA and the National Transportation Safety Board (NTSB).

In 2018, the Department of Commerce proposed designating its Office of Commercial Space as an independent bureau with responsibility for commercial space traffic management, in addition to other functions. Since then, several bills have been introduced to create such a bureau and give it principal responsibility for regulating commercial spaceflight. None of those bills has been enacted.

As the congressionally mandated learning period approaches its expiration date, Congress may consider whether the development of the industry has progressed enough to impose a stricter governance regime for space tourism activities. Legislators could hold hearings, direct studies, or examine expert and industry views on whether the law restricting FAA’s authority to regulate the safety of commercial spacecraft for tourist use should be extended again or allowed to expire entirely or in phases. Congress also has supported the development of voluntary safety standards by industry, interagency working groups, and the aerospace medical community, and may want to consider whether the federal government should use such standards to create a regulatory framework.

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Introduction

Companies in the United States are advancing plans to offer paying customers rides into space on a regular basis. This development has been encouraged by Congress, which passed legislation in 2004 meant to enable commercial space transportation companies to develop business models under relatively light regulation.¹ While this approach has contributed to rapid growth in commercial launches of private satellites and of government cargoes, it has created uncertainty with respect to passenger transportation, as a nascent industry awaits guidance about what measures the government will require to keep paying passengers safe not only in space but on the way there and back to Earth.

A space tourism boom has been forecast for more than a decade,² but the current regulatory landscape is designed for a fledgling industry that is yet to fully emerge.³ Companies proposing to offer space tourism, which have stayed afloat financially with the help of investors who foresee long-term opportunities, will at least initially be dependent on a limited pool of exceptionally wealthy customers.⁴ When and to what extent it should be regulated by the government remain undecided.

This report provides an overview of the commercial space tourism industry and examines current federal safety standards for human spaceflight, opportunities for development of oversight frameworks, industry recommendations, medical considerations for space travelers, and other regulatory issues Congress may face as space transportation companies begin flying and accommodating paying customers.

History and Development of a Space Tourism Sector

The concept of a space tourist is fairly new. In 1998, U.S. billionaire video game developer Richard Garriott founded Space Adventures, the only private company to send paying customers to orbital space so far.⁵ For about a decade, the company functioned as a sort of space travel agency that brokered rides for paying customers aboard the Russian space program's Soyuz rockets when seats were available. In April 2001, its customer, 60-year-old Dennis Tito, became the first tourist to visit space.⁶ The National Aeronautics and Space Administration (NASA) objected to Tito's flight, citing training deficiencies, and declined requests from the company to offer seats to tourists aboard NASA's shuttles. Space Adventures sent a total of seven paying customers to space between 2001 and 2009, including Garriott, who spent 12 days in orbit in

¹ CRS Report R45416, *Commercial Space: Federal Regulation, Oversight, and Utilization*, by Daniel Morgan.

² Testimony of NASA Deputy Associate Administrator of Space Station Michael Hawes in U.S. Congress, House Committee on Science, Space, and Technology, *Space Tourism*, 107th Cong., 1st sess., June 26, 2001 (Washington, DC: GPO, 2001).

³ U.S. Congress, House Committee on Transportation and Infrastructure, Subcommittee on Aviation, *Commercial Space Transportation*, 111th Cong., 1st sess., December 2, 2009 (Washington, DC: GPO, 2009).

⁴ Northern Sky Research, "Space Tourism Market About to Take Off," December 17, 2019, at <https://www.nsr.com/nsr-report-space-tourism-market-ready-to-take-off/>.

⁵ The first private astronaut to fly beyond the Karman Line, the widely recognized edge of space, was test pilot Mike Melville in a SpaceShipOne built by aerospace engineering company Scaled Composites in 2004. Melville was not a paying customer, and as such is classified as a private astronaut and not a tourist for purposes of this report.

⁶ Catherine Clifford, "What it's Like to Travel to Space, from a Tourist who spent \$30 Million to Live there for 12 Days," *CNBC*, October 18, 2019 at <https://www.cnn.com/2018/10/19/what-its-like-in-space-from-a-tourist-who-spent-30-million-to-go.html>.

2008. Tourist visits to space came to a halt when NASA's shuttle program ended in 2011. Thereafter, American astronauts bound for the International Space Station (ISS) were allocated seats aboard Soyuz rockets pursuant to a U.S. diplomatic agreement with Russia, leaving no extra seats to accommodate tourist passengers.

While it is not currently possible for commercial travelers to fly into orbit with Space Adventures, they can come close. Space Adventures operates a modified Boeing aircraft that takes off from a runway, reaches a certain altitude, and performs a maneuver in the shape of an arc that allows passengers aboard to feel intense pressure almost twice that of normal gravity on the way up followed quickly by less than a minute of weightlessness near the top of the arc. The feeling of weightlessness is similar to what astronauts feel in the microgravity environment of the ISS. The aircraft performs this maneuver several times within airspace designated by the Federal Aviation Administration (FAA). The experience costs about \$5,400 per passenger.⁷

New Entrants

Several newer companies have begun selling tickets or advertising future dates for tourist flights to space:

Virgin Galactic, a publicly traded company founded by British entrepreneur Richard Branson, had reportedly received more than 8,000 reservation requests for travel aboard its rocket as of February 2020.⁸ The company says it has received down payments from 600 of those customers. Its planned flight profile consists of an aircraft and a second-stage vehicle that detaches once the main craft reaches a certain altitude and uses a rocket to propel it to suborbital space, an altitude at which passengers will temporarily experience weightlessness without entering orbit. To date, no paying customer has flown aboard a suborbital spacecraft.⁹ Prior to the COVID-19 pandemic, the company had publicly announced plans to begin flying tourists by 2022 from its spaceport in New Mexico, but its operations have been delayed by the virus, according to securities filings.¹⁰

Blue Origin, a privately held company controlled by Amazon.com chief executive Jeff Bezos, is building a passenger rocket and capsule to send a crew of up to six tourists to space for several minutes from a launch site in West Texas. The company has tested the rocket, New Shepherd, a dozen times with a dummy onboard covered in sensors to determine how trips might affect future human customers.¹¹ Blue Origin has not released information about when tourists might be able to fly on the rocket, what tourist training might be required, or the anticipated price of a flight.

Space Exploration Technologies (SpaceX), a private company controlled by Tesla Motors founder Elon Musk that is known for launching satellites aboard reusable rockets, announced in March 2020 that it would fly three tourists on a 10-day trip to the International Space Station in 2021. The price of the single trip is reportedly \$55 million.¹² SpaceX intends to fly these tourists on its Crew Dragon spacecraft, the same craft that transported two NASA astronauts to the ISS in

⁷ Space Adventures, "G Force One Ready for Takeoff" at <http://www.gozerog.com/>.

⁸ Catherine Thorbecke, "Virgin Galactic to Resume Selling Tickets to Space, Reports Skyrocketing Demand," *ABC News*, February 26, 2020.

⁹ Ken Davidian, "Space Tourism Industry Emergence: Description and Data," *New Space*, vol. 8, issue 2 (June 2020).

¹⁰ Virgin Galactic Holdings, Inc., SEC Form 10-Q for the Quarterly Period Ended June 30, 2020, p. 44, August 3, 2020.

¹¹ Jonathan O'Callaghan, "Blue Origin Launches its First Tourism Rocket in Seven Months – And Hopes to Take Humans to Space in 2020," *Forbes*, December 11, 2019.

¹² Sean O'Kane, "SpaceX Will Send Three Tourists to the International Space Station Next Year," *The Verge*, March 5, 2020, at <https://www.theverge.com/2020/3/5/21166657/spacex-tourists-iss-international-space-station-orbit-falcon-9-dragon>.

May 2020 from American soil for the first time since the U.S. space shuttle program ended. Unlike other spacecraft that are in design and production for tourist transport, the Crew Dragon will be rated and certified against NASA criteria that will formally deem it safe for human flight.¹³ SpaceX is also working with Space Adventures to send up to four private citizens into orbit around Earth with a projected date of late 2021. In 2018, a billionaire from Japan placed a down payment with SpaceX for a privately chartered tourist flight around the moon in a small vehicle that would be launched by a SpaceX rocket.¹⁴ SpaceX has said it hopes to launch the excursion in 2023.

Space Perspective, a private company created in June 2020, proposes to use high-altitude balloons to transport tourists to the edge of space.¹⁵ Space Perspective plans to launch a football-field-sized balloon with an attached pressurized capsule, initially from a base in Florida, to float passengers to altitudes of nearly 19 miles. During the balloon flights, passengers will not experience weightlessness but can expect to view the curve of the Earth and blackness of outer space from far above the altitudes at which commercial airplanes normally fly.¹⁶ The company envisions the balloons will descend to Earth after a several-hour journey by gradually releasing gas, like traditional hot air balloons. The company has said it plans to launch its first uncrewed test flight in 2021.¹⁷

Accommodations in Orbit

Prospective space tourists may have several destinations to choose from. The providers of accommodations in space may not be the same entities that provide space transportation.

One early destination is likely to be the ISS, which is controlled by NASA. In June 2019, NASA changed a long-standing policy when it announced plans to allow private citizens to fly to the ISS for short visits.¹⁸ It did not, however, offer to provide transportation. It is unclear whether NASA will insist that private astronauts and space tourists visiting the ISS meet the same medical and training requirements as NASA astronauts aboard the ISS.

Axiom Space, a private company that has several agreements with NASA, will provide training to private astronauts and plans to send the first fully private human spaceflight mission to the ISS. This mission is expected to include three astronauts launched aboard a SpaceX rocket in 2021.¹⁹ According to Axiom, private astronauts will go through initial physical and medical checks, and training modules will include 15 weeks of “expert training” in robotics, suborbital spaceflights,

¹³ National Aeronautics and Space Administration, “NASA Astronauts Launch from America in Historic Test Flight of SpaceX Crew Dragon,” press release, May 30, 2020.

¹⁴ Jackie Wattles, “SpaceX Will Take a Japanese Billionaire on a Trip Around the Moon,” *CNN Business*, September 18, 2018.

¹⁵ Loren Grush, “New Company Space Perspective Wants to Take You to the Stratosphere via High-Altitude Balloon,” *The Verge*, June 18, 2020.

¹⁶ Valerie Stimac, “New Tourism Company Space Perspective Aims to Make Space Accessible to as Many People as Possible,” *Forbes*, June 18, 2020.

¹⁷ Stefanie Waldek, “This New Company Wants to Send You to the Edge of Space in a High-Tech Balloon,” *Travel and Leisure*, July 7, 2020 at <https://www.travelandleisure.com/trip-ideas/space-astronomy/new-spaceflight-company-space-perspective-balloon-ship>.

¹⁸ National Aeronautics and Space Administration, “NASA Opens International Space Station to New Commercial Opportunities, Private Astronauts,” press release, June 7, 2019, at <https://www.nasa.gov/press-release/nasa-opens-international-space-station-to-new-commercial-opportunities-private>.

¹⁹ William Harwood, “Axiom Plans First Private Flight to Space Station, with Crew Launching Aboard SpaceX Capsule,” *CBS News*, March 5, 2020.

preparation for extreme environments, and high performance jet flights.²⁰ The crew scheduled to launch in 2021 will perform research in support of developing modules for a new, privately funded space station Axiom plans to construct and deploy to replace the ISS after its expected retirement in 2024.²¹ The new station is intended to be open to visitors from space agencies and the paying public. Under an agreement with NASA, the company plans to build the craft in stages as a modular attachment to the ISS that will be released as a free-floating station in orbit once complete.

Gateway Foundation, a California organization, announced design plans last year for a space hotel that could accommodate hundreds of passengers. The Von Braun Station design plans look like a giant wheel rotating in space that could provide Earth-like gravity to passengers on board. Construction is yet to start, but the company says it expects to complete the orbiting hotel by 2027 with the support of space construction company Orbital Assembly. Gateway’s website states that individuals can increase their chances of winning a free trip to its spaceport and will have priority right to purchase shares in an eventual public offering by becoming “crew members.”²²

Orion Span has announced a plan to build a luxury hotel in orbit. The hotel, Aurora Station, would be able to accommodate four passengers and two crew for 12-day stays.²³ The company has been plagued by financial difficulties but claimed in February 2019 to have a seven-month waitlist.²⁴

Regulating Space Tourism

The U.S. government currently has no procedures for certifying the safety of launch vehicles or space travel for tourists. An exhaustive certification process exists for commercial spacecraft transporting NASA astronauts, but the same standards have not been formally required of space vehicles for tourist use.²⁵

Federal law defines a spaceflight participant as “an individual, who is not crew or a government astronaut, carried within a launch vehicle or reentry vehicle.”²⁶ The few existing regulations pertaining to commercial spaceflight participant safety address the responsibility of a launch provider to inform a spaceflight passenger of certain risks and of the vehicle’s safety track record.²⁷ There are currently no federal rules related to suborbital operations or to the operation of

²⁰ Axiom Space, “Preparing for Your Journey,” at <https://www.axiomspace.com/private-astronauts-missions>. “Private astronauts” are distinct from spaceflight “participants” who are not trained to pilot a spacecraft. The Federal Aviation Administration (FAA) has not issued guidance for training of private astronauts or certified them. However, it will award astronaut wings to private astronauts aboard FAA-licensed launches who meet FAA requirements for flight crew qualifications and training under 14 C.F.R. Part 460 and who fly higher than 50 miles above Earth’s surface.

²¹ NASA, “NASA Selects First Commercial Destination Module for International Space Station,” press release, January 27, 2020.

²² <https://gateway.spaceport.com>.

²³ Orion Span, Aurora Station at <https://www.orionspan.com/>.

²⁴ Jeff Foust, “Orion Span Falls Far Short of Funding Goal to Support its Commercial Space Station Ambitions,” *Space News*, February 1, 2019, at <https://spacenews.com/orion-span-falls-far-short-of-funding-goal-to-support-its-commercial-space-station-ambitions/>.

²⁵ Daniel Oberhaus, “How NASA Certifies New Spacecraft Safe Enough for Humans,” *Wired*, May 13, 2020, at <https://www.wired.com/story/how-nasa-certifies-new-spacecraft-safe-enough-for-humans>.

²⁶ 51 U.S.C. §50902(20).

²⁷ Federal Aviation Administration, “Guidance on Informing Crew and Spaceflight Participants of Risk,” *FAA Office of Commercial Space Transportation*, April 4, 2017, at https://www.faa.gov/space/licensing_process/regulations/media/

privately owned space stations and private vehicles in space. Federal regulations related to space vehicle reentry pertain principally to the safety of people on the ground, not to the safety of passengers or crew members aboard commercial spaceflights.

Federal Aviation Administration Oversight Responsibilities

The Commercial Space Launch Amendments Act of 2004 (CSLAA; P.L. 108-492) designated FAA as the regulatory authority for oversight and licensing of commercial space launch activities. FAA's Office of Commercial Space Transportation issued rules in 2006 setting requirements for crew and participants aboard commercial flights.²⁸ Unless FAA has issued paying spaceflight participants their own licenses to launch and operate a spacecraft, an FAA-licensed crew is required on board any vehicle launched from the United States that is carrying passengers in space.

Under the human spaceflight requirements, the crew aboard a commercial space vehicle must be trained to carry out duties on the ground or onboard so the space vehicle does not harm the public. This training includes abort scenarios and emergency operations. Additionally, the crew must demonstrate an ability to withstand the stressors of spaceflight. Each crew member with a safety-critical role must possess a current FAA second-class airman medical certificate.²⁹

FAA requires that a space vehicle operator must inform any spaceflight participant in writing of the risks associated with launch and reentry and provide the safety record of the launch vehicle prior to accepting compensation or making an agreement to fly a paying customer.³⁰

During the informed consent process, an operator must present the risks in a "manner that can be readily understood" by spaceflight participants without specialized education or training. The vehicle operator must obtain a consent letter from each flight participant accepting the risks after the operator provides the following in writing:

- each known hazard that could result in serious injury or death;
- acknowledgement that there are unknown hazards;
- a disclaimer that participation in spaceflight may result in death, serious injury, or total or partial loss of physical or mental function;
- a disclaimer that the U.S. government has not certified the launch vehicle as safe for carrying crew or passengers; and
- a description of the vehicle's safety record, to include any accidents or mishaps and corrective actions.³¹

While the Office of Commercial Space Transportation is responsible for enforcing these informed consent requirements, it is prohibited by CSLAA from imposing any further safety requirements on launch companies flying commercial spaceflight participants.³² In particular, it is restricted from imposing new regulations, such as issuing design requirements for seatbelts or escape

Guidance_on_Informing_Crew_and_Space_Flight_Participants_of_Risk.pdf.

²⁸ Federal Aviation Administration, "Human Space Flight Requirements for Crew and Space Flight Participants," 71 *Federal Register* 75615, December 15, 2006.

²⁹ *Ibid.*

³⁰ 14 C.F.R. §460.45.

³¹ *Ibid.*

³² P.L. 114-90, §111(5).

hatches, which could affect the ability of commercial entities to innovate freely in areas of spacecraft design and development. This prohibition, which was originally set to expire in 2012, was extended to 2015 under the FAA Modernization and Reform Act of 2012³³ and then to October 2023 under the Commercial Space Launch Competitiveness Act of 2015.³⁴ According to 2016 testimony by the Government Accountability Office, experts believed that determining whether and when to regulate the safety of crew and spaceflight participants was one of FAA's most significant challenges.³⁵

This Commercial Space Launch Competitiveness Act required FAA to submit an initial report to Congress in March 2018 and a follow-on report in 2022 on the commercial space industry's progress in developing voluntary safety standards for human spaceflight. These reports must be prepared in coordination with an industry advisory group and include observable metrics that would indicate readiness of the commercial space sector to transition to a more regulated safety regime without undermining the growth of the industry. The reports are also to include a framework for transitioning to a new regulatory regime.

FAA submitted its first report, "Evaluation of Commercial Human Space Flight Safety Frameworks and Key Indicators," to Congress in 2017. The report identified four types of metrics FAA proposes to use in determining whether greater federal regulation is appropriate:³⁶

- Indicators of changes in the purpose of commercial space travel, such as moving beyond adventure travel to providing regular transportation to orbital space stations.
- Indicators of the size and complexity of the commercial spaceflight industry, such as the number of suppliers of orbital and suborbital commercial services and the existence of multiple suppliers of similar vehicles.
- Indicators of the industry's progress in developing voluntary safety standards, such as consensus safety standards and voluntary reporting.
- Indicators of FAA's readiness to provide expertise in human spaceflight safety and legal authorities to develop and implement a regulatory safety framework.

In February 2019, the Secretary of Transportation submitted a report to Congress recommending activities and regulatory action that would support establishment of a new safety framework and a proposed transition plan for the industry. The report found that, based on the readiness indicators, as of 2019, no commercial human spaceflight activities were ready to transition to a new safety framework that would involve regulatory action. This finding was based on the fact that, since the 2017 report identifying indicators of readiness, there had only been three FAA-licensed commercial launches carrying trained crew and no commercial launches with tourists aboard.³⁷

³³ P.L. 112-95, §827.

³⁴ P.L. 114-90 §111(9).

³⁵ U.S. Government Accountability Office, "Commercial Space: Industry Developments and FAA Challenges," Testimony before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, House of Representatives, June 22, 2016.

³⁶ Federal Aviation Administration, *Report to Congress: FAA Evaluation of Commercial Human Space Flight Safety Frameworks and Key Industry Indicators*, October 2017, at https://www.faa.gov/about/plans_reports/congress/media/CSLCA_Sec111_Report_to_Congress.pdf.

³⁷ Department of Transportation, "Report to Congress: U.S. Department of Transportation Evaluation of Commercial Human Space Flight Activities Most Appropriate for a New Safety Framework," February 26, 2019, at https://www.faa.gov/about/office_org/headquarters_offices/ast/advisory_committee/meeting_news/media/2019/may/Section_111_Report_Summary_v3.pdf.

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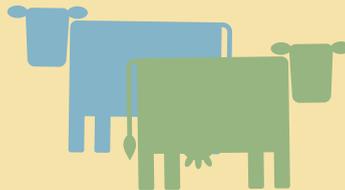
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Interagency Medical Standard Recommendations

Though federal law requires commercial spaceflight companies to inform passengers and crew of mission-related risks, certain medical conditions associated with spaceflight are still unknown or poorly understood. In 2012, FAA's Center of Excellence for Commercial Space Transportation issued a recommended set of comprehensive guidelines for medically screening crew and spaceflight participants ahead of tourist flights. The "Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight" was an attempt by FAA, NASA, and medical experts to provide a consolidated guide to medical screening practices that could be employed voluntarily by commercial operators and FAA.³⁸ The guidelines include a consensus set of passenger acceptance recommendations that could also serve as advice to commercial operators developing their own medical programs.

Recommended guidelines for suborbital flights included requiring commercial spaceflight participants to fill out a comprehensive medical questionnaire and undergo a physical examination by a physician with knowledge of the spaceflight environment. The guidelines recommended that the aerospace physician and vehicle operator develop, when possible, mitigation strategies and training regimens for any spaceflight participant who does not meet medical standards.

For orbital spaceflight, the guidelines recommend an additional mental health screening, as orbital spaceflight is associated with significant psychological stressors that underlying psychiatric or behavioral problems may exacerbate. Additionally, for orbital flights, the guidelines recommended chest X-rays, pregnancy tests, drug tests, pulmonary function testing, and exercise cardiovascular testing. Finally, the guidelines recommended post-flight medical evaluations and debriefings for spaceflight participants aboard orbital flights.³⁹

Medical Concerns for Spaceflight Participants

Spaceflight participants will face myriad health risks beyond the obvious perils of the initial rocket launch. Medical data on the effects of spaceflight on the human body have largely been provided by professional astronauts. Little research exists into the medical consequences of spaceflight on the health of untrained participants. Health risks of spaceflight will vary based on a number of factors, including spaceflight profile, vehicle configuration, destination, and duration, as well as preexisting medical conditions in passengers. Orbital and suborbital flights will pose different risks, as will the duration of time a participant endures microgravity, high speeds, and increased gravitational forces.

"G" Forces

To get to space, commercial space companies use two methods: vertical and horizontal launch. A vertical launch is one in which a rocket blasts off from a launchpad and carries its occupants directly to space using propulsion. NASA's space shuttle program and the May 2020 NASA/SpaceX launch of astronauts to orbit used this method. A horizontal launch, usually used for suborbital flight, entails a traditional airliner-like vehicle that takes off from a runway and

³⁸ Federal Aviation Administration, Center of Excellence for Commercial Space Transportation, "Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight," June 30, 2012, at <http://coe-cst.org/flight-crew-medical-standards-and-spaceflight-participant-medical-acceptance-guidelines-for-commercial-space-flight>.

³⁹ Ibid.

gradually builds elevation with a spaceflight vehicle attached. At a certain altitude, the spaceflight vehicle detaches from the airplane and its engines generate additional thrust to propel it into space. Virgin Galactic's tourist spacecraft uses this method.⁴⁰

During both a rapid ascent to space from a vertical launch and a parabolic flight profile flown by suborbital flights, crew and participants will encounter forces several times that of normal gravity to get through Earth's atmosphere. These are commonly referred to as "G" forces. An untrained flight participant can sometimes withstand about five times the force of normal gravity, or 5G, but others may lose consciousness at 3G.⁴¹ During a launch and a reentry through Earth's atmosphere, spaceflight participants are likely to experience forces from 3G to 6G or higher.⁴² Under high G forces, humans can experience tunnel vision, loss of vision, motion sickness, or loss of consciousness, as the heart must pump harder to circulate blood to the brain.⁴³ Individuals who smoke have diminished tolerance of high-altitude travel and G forces. Dehydration, fatigue, alcohol, a sedentary lifestyle, and illnesses such as cardiovascular disease can also reduce a person's tolerance of G forces.⁴⁴

FAA offers physiological training programs for pilots and one-day classes for prospective spaceflight participants that include altitude chambers and vertigo demonstrations to simulate human physiological responses to high-altitude travel. Additionally, a centrifuge could be used to test a spaceflight participant's tolerance of increased gravitational pressure, or G forces, and could assist in resistance training on Earth, but a commercial spaceflight operator would need to make arrangements for participants to gain access to one.⁴⁵

Oxygen Deprivation and Effects of Fluid Redistribution

At higher altitudes where oxygen is in short supply, such as those at the edge of space, spaceflight participants could be at risk of experiencing altitude sickness or other complications if oxygen supply is not carefully controlled within the spaceflight vehicle. During hypoxia, which occurs in humans at high altitudes without requisite oxygen supply, the body's tissues are deprived of oxygen, causing numbness, confusion, nausea, hallucinations, breathing problems, irregular heartbeat, and, if left untreated, heart failure, brain damage, and death.

Federal regulations applicable to any pressurized aircraft operating above 25,000 feet require commercial space transportation vehicles to be equipped with oxygen supply systems, but participants in suborbital and longer-duration spaceflight need to be aware of signs and symptoms

⁴⁰ Adam F. Dissel, Ajay P. Kothari, and Mark J. Lewis, "Comparison of Horizontally and Vertically Launched Airbreathing and Rocket Vehicles," *Journal of Spacecraft and Rockets*, Vol. 43, No. 1, pp. 161-163, January-February 2006.

⁴¹ Federal Aviation Administration, "Acceleration in Aviation: GForce," FAA Civil Aerospace Medical Institute.

⁴² Rebecca S. Blue, Jon M. Riccitello, Julia Tizard, Richard J. Hamilton, and James M. Vanderploeg, "Commercial Spaceflight Participant G-Force Tolerance During Centrifuge Simulated Suborbital Flight," *Aviation Space and Environmental Medicine*, October 2012, at <https://pubmed.ncbi.nlm.nih.gov/23066613/>.

⁴³ Marck HTM Haerkens, Ries Simons, and Andre Kuipers, "Doctor, May I Travel in Space? Aeromedical Considerations Regarding Commercial Suborbital Space Flights," National Institutes of Health, National Library of Medicine, 2011.

⁴⁴ Pierre Bienaime, "Here's How U.S. Fighter Pilots Learn to Survive Under Inhuman Levels of G Force," *Business Insider*, November 3, 2014.

⁴⁵ National Aeronautics and Space Administration, "Learning Launchers, a Spin on Things: Centrifuge," press release, November 26, 2019, at https://www.nasa.gov/audience/foreducators/stem-on-station/learning_launchers_centrifuge. A centrifuge used to prepare for spaceflight is a large chamber on the end of an arm that spins it at high speeds in a secured room. The faster it spins, the more pressure the human body experiences.

of oxygen deprivation in order to request supplemental oxygen if needed.⁴⁶ Oxygen starvation first affects the brain; judgment is impaired, so a participant may not realize the dangerous situation. Within five minutes of being deprived of oxygen, brain cells begin to die and significant, life-threatening brain damage occurs.⁴⁷

The human body is made up of more than 60% water; in microgravity where humans are weightless, these fluids redistribute themselves throughout the body.⁴⁸ Flow of blood through vessels changes, and the position and shape of organs change absent the gravitational forces pulling them toward Earth.⁴⁹ For example, the heart and eyeballs both change shape in microgravity; without gravity, the back of the eyeball flattens and has caused vision problems in astronauts who have stayed in space for extended periods. The heart becomes rounder and slightly less elongated than on Earth, as it does not have to work against gravity and blood no longer pools in the lower extremities.⁵⁰ Changes like these can cause cardiovascular complications for healthy individuals as well as those with certain preexisting conditions.⁵¹

Vestibular Complications

The vestibular system is contained in the inner ear and enables the human body to sense and respond to changes in internal and external environments. These functions are used to determine the body's orientation, sense body movement changes in velocity and direction, and maintain balance. When there is no visual reference, as is often the case during gravitational conditions in spaceflight or weightlessness aboard spacecraft in orbit, vestibular systems often have difficulty determining spatial orientation, and even short-term weightlessness can cause complications such as motion sickness, vomiting, vertigo, headaches, and lethargy.⁵² Disruptions to the vestibular system in space often result in symptoms similar to seasickness on Earth, where the combination of a boat's forward motion, speed, and rocking caused by swells incapacitate the vestibular system's ability to determine orientation and balance.⁵³

Spaceflight participants who spend several days in space could also experience health complications upon return to Earth. Vestibular disturbances and balance issues can occur in individuals transitioning from living and sleeping in a microgravity environment back to a G1 environment on Earth.⁵⁴ Additionally, medical research indicates travelers may be more

⁴⁶ 14 C.F.R. §135.157 requires any pressurized aircraft operating above 25,000 feet be equipped with at least a 10-minute supply of supplemental oxygen for each occupant.

⁴⁷ Federal Aviation Administration, "Hypoxia: The Higher You Fly, the Less Air in the Sky," *FAA Civil Aerospace Medical Institute*, April 29, 2020.

⁴⁸ Department of the Interior, U.S. Geological Survey, "The Water in You: Water and the Human Body," at https://www.usgs.gov/special-topic/water-science-school/science/water-you-water-and-human-body?qt-science_center_objects=0#qt-science_center_objects.

⁴⁹ Arnauld E. Nicogossian et al., "Chapter 13: Musculoskeletal Adaptations to Space Flight," *Space Physiology and Medicine: From Evidence to Practice*, 4th Edition (New York: Springer, 2016).

⁵⁰ Seema Yasmin, "Preparing Bodies for Liftoff: NASA Doctors Studying Travel that Can Take Toll on Organs, Skin, Bones," *Dallas Morning News*, June 26, 2015, at <http://interactives.dallasnews.com/2015/spacebody/>.

⁵¹ Naomi Brooks, "Five Things that Happen to Your Body in Space," *The Conversation*, January 15, 2016, at <https://theconversation.com/five-things-that-happen-to-your-body-in-space-52940>.

⁵² National Aeronautics and Space Administration, "Human Vestibular System in Space," *NASA Education in the Spotlight*, April 10, 2009.

⁵³ A.L. Elo, "Health and Stress of Seafarers," *Scandinavian Journal of Work, Environment, and Health*, Vol. 11, No. 6, pp. 427-432, December 1985.

⁵⁴ Michael Johnson, "New Ways to Assess Neurovestibular System Health in Space Also Benefits Those on Earth," *National Aeronautics and Space Administration*, March 28, 2019.

susceptible to infection and illness due to a suppressed immune system caused by changes in cellular function during even short trips to space.⁵⁵

Training Guidelines

Commercial crew and private astronaut pilots licensed by FAA to fly to space—or the edge of it—must meet certain training and medical standards, but those standards do not currently extend to spaceflight participants paying for a trip. Often, private astronauts that serve as pilots on space launch vehicles such as those flown by Virgin Galactic have significant NASA or military test pilot experience and thousands of flight hours. However, some private astronauts may need additional specialized training for certain missions such as docking with the ISS or using specific technologies. This year, NASA signed an agreement to partner with a private contracting firm to train such private astronauts at federal facilities⁵⁶ and provide aeromedical services prior to, during, and after private astronaut spaceflight missions.⁵⁷ While NASA works with private contractors on many mission support activities, this is the first NASA-sponsored contract for private astronaut training.

Insurance and Liability Issues

International governance regimes are in place to provide guidance about liability for space-related accidents. The United Nations Convention on International Liability Caused by Space Objects entered into force in 1972.⁵⁸ This agreement, which elaborates on Article VII of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (the Outer Space Treaty), stipulates that a state that launches an object to space shall be liable to pay compensation for damage caused by that object on the surface of Earth or to aircraft—but not for damage to a satellite in orbit.⁵⁹ According to the Outer Space Treaty, a nation is responsible for anything launched from its soil, including commercial spacecraft and payloads not owned or operated by the government. The treaty defines “damage” as loss of life, personal injury, or other impairment of health.⁶⁰

Article VII of the Liability Convention would likely apply to an accident involving a vehicle launched from U.S. soil with foreign spaceflight participants aboard. However, the article stipulates that the provisions of the treaty do not apply to damage caused by a space object of a launching state to nationals of that state. In other words, compensation for injury to U.S. citizens

⁵⁵ University of Arizona, “Prolonged Spaceflight Could Weaken Astronauts’ Immune Systems,” *ScienceDaily*, January 23, 2019, at <http://www.sciencedaily.com/releases/2019/01/190123174405.htm>.

⁵⁶ Andrea Leinfelder, “Houston Company to Train Private Astronauts at NASA Facilities,” *Houston Chronicle*, January 30, 2020, at <https://www.houstonchronicle.com/business/bizfeed/article/Houston-company-to-train-private-astronauts-at-15016337.php>.

⁵⁷ KBR, “In a Space Industry First, NASA Grants KBR the Right to Train Private Astronauts at NASA Facilities,” press release, January 30, 2020.

⁵⁸ United Nations Office for Outer Space Affairs, “Convention on International Liability for Damage Caused by Space Objects,” *Committee on the Peaceful Uses of Outer Space*, September 1972.

⁵⁹ United Nations, “Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, Article VII,” *Committee on the Peaceful Uses of Outer Space*, October 1967.

⁶⁰ Carl Christol, “International Liability for Damage Caused by Space Objects,” *American Journal of International Law*, vol. 74, no. 2, February 27, 2017, pp. 346-371.

and damage to property in the United States caused by a spacecraft launched from the United States would be entirely a matter of U.S. law and is not subject to the Outer Space Treaty.

In order to launch a rocket in the United States, a commercial launch operator must receive a license from FAA. One of the requirements for approval of a license is carriage of third-party liability insurance.⁶¹ FAA requires an assessment of maximum probable financial loss (MPL) from any accident claim and proof that the operator either has financial reserves equal to the MPL estimate or has purchased that amount of liability insurance. Federal law places a statutory cap of \$500 million on third-party liability.⁶² The original Space Launch Amendments Act, passed in 1988, makes the U.S. government responsible for covering damage beyond the \$500 million cap.⁶³

It is not clear whether that government coverage would extend to families of individuals aboard a commercial space vehicle that experiences an accident. Under informed consent agreements required by FAA, space tourists effectively waive the right to hold the launch operator liable for loss of life or injury. However, the families of spaceflight participants are not required to sign any such form and in theory could still sue the launch operator in the event of a catastrophic accident. Whether the informed consent waiver would preclude the award of damages in such a case has not been tested in court.⁶⁴

Accident Investigation

There are no current federal guidelines delineating accident investigation jurisdiction should a commercial spaceflight accident occur with passengers on board. According to a nonbinding 2004 memorandum of understanding between FAA, the National Transportation Safety Board (NTSB), and the U.S. Air Force, the U.S. military will investigate any accident that occurs during a space launch aboard its rockets, and FAA and the NTSB will be responsible for investigating commercial accidents.⁶⁵

FAA's Office of Space Transportation is responsible for overseeing investigations of all accidents associated with FAA-licensed space operations. However, by statute, the NTSB, an independent agency, could also have jurisdiction to investigate a commercial space accident when the board determines an accident related to the transportation of individuals is "catastrophic."⁶⁶ For example, the NTSB conducted the investigation into the crash of SpaceShipTwo, a Virgin Galactic-operated spacecraft that broke up in the air during a test flight, resulting in the death of the craft's copilot in 2014.⁶⁷ That spacecraft was insured under an aviation hull and liability

⁶¹ 51 U.S.C. §50914.

⁶² Federal Aviation Administration, "Risk-Sharing Regime for U.S. Commercial Space Transportation," April 2002 at https://www.faa.gov/about/office_org/headquarters_offices/ast/media/FAALiabilityRiskSharing4-02.pdf.

⁶³ Commercial Space Launch Act Amendments of 1988 (P.L. 100-657).

⁶⁴ Jackie Wattles, "Why on Earth Would a Company Offer Insurance for Space Travel?," *CNN Business*, September 15, 2018, at <https://money.cnn.com/2018/09/15/technology/business/space-insurance-industry/index.html>.

⁶⁵ Federal Aviation Administration, "Memorandum of Understanding Between the National Transportation Safety Board, Department of the Air Force, and Federal Aviation Administration Regarding Space Launch Accidents," September 2004, at https://www.faa.gov/about/office_org/headquarters_offices/ast/media/mou_space_launch_accidents.pdf.

⁶⁶ 49 U.S.C. §1131.

⁶⁷ Alwyn Scott, "Spacesuit? Helmet? Life Insurance? Space Tourist Loophole May End," *Reuters*, November 5, 2014, at <https://www.reuters.com/article/us-space-crash-virgin-insurance-analysis/spacesuit-helmet-life-insurance-space-tourist-loophole-may-end-idUSKBN01P2XO20141106>.

policy by AIG for losses of \$40 million to \$50 million.⁶⁸ There has been debate in Congress since that time about whether the NTSB's authority over commercial spaceflight accident investigations needs to be more clearly codified in law and how jurisdiction should be shared between FAA and the NTSB.

Considerations for Congress

Congress most recently addressed subjects with implications for space tourism in the Commercial Space Launch Competitiveness Act of 2015. In that law, Congress determined that the nascent commercial space transportation industry should go through a “learning period” lasting until at least 2023 before it receives closer regulation by the federal government.⁶⁹ Given the development of the industry since that time, Congress may want to consider whether the law restricting FAA's authority to regulate the safety of commercial spacecraft with humans onboard should be extended, lifted, or allowed to expire in phases. Congress also has supported the development of voluntary safety standards by industry, interagency working groups, and the aerospace medical community, and may want to consider whether the federal government should adopt such standards as regulations.

The Department of Commerce's Office of Space Commerce has a regulatory role in commercial human spaceflight activities, pursuant to the department's statutory responsibility to “foster the conditions for the economic growth and technological advancement of the United States space commerce industry” (51 U.S.C. §50702(c)(1)). Likewise, the National Institute of Standards and Technology (NIST), a part of the department, has the authority to issue voluntary standards. To date, the department has not authored any such standards related to commercial space activities but has convened stakeholder workshops and issued best practice frameworks and standards in areas such as cybersecurity, genetic testing technologies, and other challenging technology sectors as roadmaps for industry development and self-governance.

The National Space Council operates as part of the Executive Office of the President to provide advice on civil, commercial, and military space issues and coordinate implementation of the President's space policies and strategies. The council is chaired by the Vice President and includes the Secretaries of State, Defense, Transportation, and Commerce, among other members.⁷⁰ In 2018, the council directed the Department of Commerce to generate a legislative proposal to establish an entity within the department for administering regulation of commercial spaceflight activities not overseen by FAA.⁷¹ Such activities could potentially include asteroid mining, on-orbit satellite servicing, space traffic management, and other commercial endeavors. In 2018, the Department of Commerce proposed designating its Office of Commercial Space as an independent bureau with responsibility for commercial space traffic management, in addition to other functions. A bill to create such a bureau and assign it responsibility for regulating commercial spaceflight was introduced in the 115th Congress (H.R. 2809), but it did not advance. The bill was reintroduced in the 116th Congress (H.R. 3610), with no further action to date. A

⁶⁸ Carolyn Cohn and Richa Naidu, “Virgin Galactic Spaceship Insured for \$40 - \$50 million, lead underwriter, AIG: Sources” *Reuters*, November 3, 2014, at <https://www.reuters.com/article/us-space-crash-virgin-insurance/virgin-galactic-spaceship-insured-for-40-50-million-lead-underwriter-aig-sources-idUSKBN0IN0SP20141103>.

⁶⁹ P.L. 114-90, §111(5).

⁷⁰ Executive Order 13803, “Reviving the National Space Council,” 82 *Federal Register* 31429, July 7, 2017.

⁷¹ White House, Office of the Press Secretary, “Space Policy Directive – 2, Streamlining Regulations on Commercial Use of Space,” presidential memorandum, May 24, 2018 at <https://www.whitehouse.gov/presidential-actions/space-policy-directive-2-streamlining-regulations-commercial-use-space/>.

September 2019 Senate Appropriations Committee report expressed concern that an independent space commerce bureau might not be equipped to fully replace the military's space traffic management role, and the committee recommended an independent review by the National Academy of Public Administration.⁷²

Congress may at some point judge that the industry's progress is sufficient to justify a formal safety standard regime. In that circumstance, it could direct FAA to establish a licensing process for launch vehicles carrying human occupants.

Another option for congressional action would be hearings to examine expert or industry views on the need for closer government oversight of space tourism activities, to include launch and reentry as well as accommodations in orbit, if other than the ISS. Congress could also direct additional studies on some of these topics by organizations such as the National Academy of Public Administration, the National Academy of Sciences, or NIST.

Author Information

Alyssa K. King
Analyst in Transportation Policy

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⁷² S.Rept. 116-127.

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