RAND CORPORATION

ASSESSING THE READINESS FOR

HUMAN COMMERCIAL SPACEFLIGHT SAFETY REGULATIONS

CHARTING A TRAJECTORY FROM REVOLUTIONARY TO ROUTINE TRAVEL

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Published by the RAND Corporation, Santa Monica, Calif.

Library of Congress Cataloging-in-Publication Data is available for this publication.

ISBN: 978-1-9774-1102-0

Cover image: Paopano/Adobe Stock

Cover design by Katherine Wu

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About This Report

Human spaceflight has evolved from a world that was once the purview of highly trained government astronauts to one in which a member of the public is able to purchase a ticket to space—albeit a very expensive one. Although space travel by private citizens is still revolutionary and headline-making, it could conceivably become more routine in the years ahead. Like the evolution of other industries, the question of how and when the spaceflight industry should be regulated at a federal level is receiving increasing attention—not only within the industry and federal agencies responsible but also from Congress.

In 2015, Congress directed the Secretary of Transportation to contract for an independent report that would provide an assessment of whether the commercial space industry was ready to transition to a safety framework that might include regulations. The RAND Corporation was asked to conduct this assessment, the results of which are contained in this report. The assessment primarily covers three topics: the progress the commercial space industry has made in adopting voluntary standards, the industry's progress in meeting key industry metrics set out by the Federal Aviation Administration in 2017, and whether the industry has reached a level of maturity such that certain areas identified in previous Federal Aviation Administration reports were ready for regulatory action. This research report reflects work conducted from May 2022 to December 2022. This report should be of interest to Congress, federal department and agency leaders and policymakers, the commercial space industry, professional standards organizations, the space commercial industry, and the general public.

This research was sponsored by the Federal Aviation Administration and was conducted within the Community Health and Environmental Policy Program within RAND's Social and Economic Well-Being division.

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This funding for this research was provided by the Federal Aviation Administration to RAND through RAND's National Defense Research Institute (NDRI), a federally funded research and development program sponsored by the Office of the Secretary of Defense, the

Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense intelligence enterprise. For more information on the RAND Acquisition and Technology Policy Program, see www.rand.org/nsrd/atp or contact the director (contact information is provided on the webpage).

Acknowledgments

We thank the leadership of the Federal Aviation Administration's Office of Strategic Management, Commercial Space Transportation—in particular, James Hatt, for his assistance at all phases of this project—for sharing their expertise, experience, and insights. We also thank the numerous stakeholders who participated in our interviews; their willingness to share their time, insights, data, and informational material greatly supported this study. As a matter of policy, we have not named these individuals or organizations, but they include representatives from industry, government, and many stakeholder organizations.

We also wish to thank George Nield and George Nacouzi for their careful peer review of the report. Finally, we would like to thank Rebecca Sepich for assisting with sponsor and interviewee interactions and for all of her administrative support throughout this project.

Summary

This report was produced in response to a call by Congress in the Commercial Space Launch Competitiveness Act (CSLCA) of 2015 for an independent review of the "readiness of the commercial space industry and the Federal Government to transition to a safety framework that may include regulations."[1] The Federal Aviation Administration (FAA) contracted with the RAND Corporation to conduct this independent review. Specifically, the CSLCA requires that the independent review evaluate three items: (1) the progress of the commercial space industry in adopting voluntary industry consensus standards for participant safety, (2) the progress of the commercial space industry toward meeting key metrics that would indicate readiness for regulation, and (3) whether areas identified in previous reports to Congress are appropriate for regulatory action or whether those areas should see further development of voluntary consensus standards without regulatory actions.

Currently, the CSLCA sets limitations on federal human safety regulation of the commercial space industry. Any such regulations apply only to launches in which humans are on board the spacecraft—i.e., crew, government astronauts, and "space flight participants."[2] Additionally, the law imposes a moratorium on these safety regulations until October 1, 2023, unless design features or operating practices result in serious or fatal injury or there is an "unplanned event or series of events . . . that posed a high risk of causing a serious or fatal injury."[3]

There is significant attention on this topic because of the increasing number of commercial spaceflights, and because decisions about whether to extend the moratorium have substantive implications for the commercial space launch industry, the FAA, flight participants, and other stakeholders. Even though the FAA will be authorized to propose and issue regulations upon expiration of the moratorium, the law requires the FAA to "encourage, facilitate, and promote commercial space launches and reentries, including those involving space flight participants," and "take actions to facilitate private sector involvement in commercial space

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1 Public Law 114-90, U.S. Commercial Space Launch Competitiveness Act, Section 111, Consensus Standards and Extension of Certain Safety Regulation Requirements, November 25, 2015.

2 See U.S. Code, Title 51, Section 50905, License Applications and Requirements, Subsection c, Safety Regulations. We note that the FAA has authority to regulate safety related to launch and reentry activities and operations and is not restricted to incidents in which there is a loss of life or serious injury during these phases of phases of activities and operations. See 51 U.S.C. § 50905(a) and (b). A "space flight participant" is defined as "an individual, who is not crew or a government astronaut, carried within a launch vehicle or reentry vehicle." See U.S. Code, Title 51, Section 50902, Definitions, Subsection 20.

Throughout this report, we refer to *spaceflight* as the activity conducted by the commercial space industry. However, the phrase *space flight* is also used where appropriate—i.e., with respect to quoted material or in reference to the federal statute, in which it is used to define "space flight participant." See 51 U.S.C. § 50902(20).

3 See 51 U.S.C. § 50905(c)(2)(C).

transportation activity."[4] Therefore, the FAA must seek to balance both participant safety and the growth of the industry when considering whether to regulate, and the FAA must incorporate industry input into its decisionmaking processes.

Our team took a holistic approach in its examination and analysis of the three study objectives. We conducted an in-depth review of the existing literature and the public data, information, and other documentation available on this topic. We also conducted detailed interviews of subject-matter experts and stakeholders across the space domain, including government, industry, and standards development organizations (SDOs). These sources informed our assessment of the current status of voluntary industry standards, the key metrics that have been developed and adopted so far, and the readiness of the industry for regulation. Our assessment of the industry's readiness for regulation adopts an analytic framework used in other sectors (specifically the energy sector). We also acknowledge a broad suite of normative and subjective concerns (ethically, morally, or otherwise value-based considerations) inherent in making judgments about the distribution of risks and responsibilities among public spaceflight participants, federal regulators, and the commercial industry. Finally, we discuss the suite of available options, their potential implications, and our recommendations about how to develop a safety framework that might include regulations.

As to the current state of voluntary industry consensus standards, we found that SDOs have developed standards related to commercial spaceflight safety that could impact participant safety, although the consensus is that significant work remains to be done. Some stakeholders expressed concern that the process is moving too slowly. We identified several challenges that are limiting the development of consensus standards, but we also found that the process of building consensus standards remains valuable, particularly because it provides a forum for collaboration and for industry members to provide input and feedback. Although no single set of consensus standards for participant safety has been adopted across the industry, commercial spaceflight companies have their own set of safety practices that may (or may not) incorporate SDO standards. Directly assessing the safety practices of individual companies was not possible because this information is treated as proprietary.

As to the current progress of meeting key metrics that support voluntary consensus safety standards and a transition to a safety framework, many of the same challenges and impediments exist. Like the standards, the data and information related to many key metrics are also unique to the individual companies and are deemed by the companies to be proprietary or otherwise not publicly releasable. Additionally, many of the current metrics do not have the characteristics (e.g., definition, specificity, measurability, or temporality) that would allow for an appropriate and scientifically valid assessment to be conducted such that progress of the industry toward meeting them could be determined with confidence. This fact inhibits the ability to operationalize the metrics, collect corresponding data and information, and determine benchmarks or targets that would signify readiness of the industry for regula-

[4] See U.S. Code, Title 51, Section 50903, General Authority, Subsection b, Facilitating Commercial Launches and Reentries.

tion. Interviewees were hard-pressed to identify bright lines based on these or other metrics that would signal readiness to end the moratorium and transition to a framework that might include regulations. Most did not believe that a binary view of whether regulations were appropriate was the right approach; rather, they believed that some aspects of industry operations might be ready for some forms of regulations while others might not be.

This view is reflected in our assessment that the readiness of the commercial space industry for regulation, or for further development of voluntary consensus standards, does not depend only on the progress of adopting voluntary consensus standards and meeting key metrics. An assessment of regulatory readiness depends also on five key factors: (1) access to, and understanding of, the regulatory process; (2) security of regulatory support (i.e., the level of certainty of future regulations); (3) the effectiveness of the regulatory support for the technology (i.e., that regulations could be issued that would support both public safety and technology development); (4) environmental effects, costs, and security issues related to the regulation; and (5) the ability to pass the regulation (or legislation) (i.e., political and social acceptability of the regulation). Additionally, normative and subjective judgments (e.g., how much risk or liability burden is appropriate for an individual versus a corporation to accept) must be made as these factors are applied to the unique particularities of the commercial space industry at this point in its development.

In sum, we find that regulatory action is appropriate in the following form: allowing the moratorium to expire as per current law, the continuation of development of voluntary consensus standards, and the institution of Space Aerospace Rulemaking Committees. Equally as important, we find that the foregoing regulatory actions should be accompanied by additional resourcing of the FAA. Although we also suggest options to consider for potential areas of regulation in this report (such as data-sharing), we do not recommend specific regulations, nor do we make any findings or judgments as to when it may be appropriate for such regulations to be issued. We find that further research, and further coordination and collaboration, will be required between the FAA, industry, and SDOs to address and answer these specific questions.

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CHAPTER 1

Introduction

When the transportation of humans into space began in the 1960s, it was an activity only conducted by the governments of major global powers.[1] The individuals transported into space were highly trained government employees who traveled aboard government-designed and government-owned rockets for the purpose of conducting scientific missions.[2] As time and (commercially available) technology have advanced, a commercial market for space travel has slowly begun to emerge. This market began with private citizens paying to travel on government rockets,[3] and it has more recently evolved into several private companies developing launch capabilities that they sell to both government and private customers.[4]

As of 2022, these services were prohibitively expensive for all but the wealthiest individuals.[5] Nonetheless, it is true that a member of the general public can now purchase a trip

[1] For the purposes of this report, we define *transportation of humans into space* in accordance with the Federal Aviation Administration's (FAA's) current definitions regarding launch and reentry of vehicles that carry spaceflight participants. The FAA defines a *space flight participant* as an individual "who is . . . carried within a launch vehicle or reentry vehicle" (U.S. Code, Title 51, Section 50902, Definitions, Subsection 20). We note that *space tourism* is currently not defined in the law.

Throughout this report, we refer to *spaceflight* as the activity conducted by the commercial space industry. However, the phrase *space flight* is also used where appropriate—i.e., with respect to quoted material or in reference to the federal statute, in which it is used to define "space flight participant." See 51 U.S.C. § 50902(20).

A *launch* is defined as "to place or try to place a . . . human being from Earth—(A) in a suborbital trajectory; (B) in Earth orbit in outer space; or (C) otherwise in outer space" (51 U.S.C. § 50902(7)).

A *reentry* is defined as "to return or attempt to return, purposefully . . . human beings . . . from Earth orbit or from outer space to Earth" (51 U.S.C. § 50902(16)).

[2] National Aeronautics and Space Administration (NASA), "Human Spaceflight," webpage, undated.

[3] In 2001, American engineer Dennis Tito became the first commercial space traveler, paying $20 million for an eight-day trip to the International Space Station, with transportation provided by the Russian Federal Space Agency (David Kipping, Christian Johnson, Sho Nakanose, Pete Worden, Ishii Yasuo, Bonnie L. Triezenberg, Chad J. R. Ohlandt, Ron Lopez, Isaac Arthur, and Scott W. Harold, *The Future of Space Cooperation Between the U.S. and Japan*, RAND Corporation, CF-A1556-2, 2022).

[4] Svetia Ben-Itzhak, "Companies are Commercializing Outer Space. Do Government Programs Still Matter?" *Washington Post*, January 11, 2022.

[5] Adam Mann, "Space Is All Yours—For a Hefty Price," *MIT Technology Review*, February 21, 2022.

to space. At present, the number of trips to space by the general public is small,[6] and the purposes are generally part tourism and part testing the capabilities of companies' systems. However, it is increasingly easy to imagine a world in which members of the general public travel to and from space with a high degree of regularity, and for purposes that could range from commercial ventures in space to transportation around the globe.

Travel to space is not safe compared with any other form of transportation or tourism.[7] The history of space travel has many unfortunate examples of how errors can quickly result in the death of participants.[8] Fortunately, there has not yet been a fatality among commercial travelers. Even so, there is widespread acknowledgment among participants, companies, federal agencies, and all stakeholders that travel to space remains a risky activity.[9] The question at hand, broadly speaking, comes down to whether, when, and to what extent the federal government should play a role in ensuring the safety of commercial passengers on space launches chartered by private companies.

The FAA currently regulates the commercial space launch industry with respect to launch health and safety. Specifically, 51 U.S.C. § 50905(c) grants the Secretary of Transportation permission to regulate the design and operation of launch vehicles. The language is as follows:

> **(1) In general.—**
>
> The Secretary may issue regulations governing the design or operation of a launch vehicle to protect the health and safety of crew, government astronauts, and space flight participants.
>
> **(2) Regulations.**—Regulations issued under this subsection shall—
>
> (A) describe how such regulations would be applied when the Secretary is determining whether to issue a license under this chapter;
>
> (B) apply only to launches in which a vehicle will be carrying a human being for compensation or hire;
>
> (C) be limited to restricting or prohibiting design features or operating practices that—
>
> (i) have resulted in a serious or fatal injury (as defined in 49 CFR [Code of Federal Regulations] 830, as in effect on November 10, 2004) to crew, government

[6] See Figure 3.1 and the corresponding discussion for additional details. Other sources report 16 commercial space travelers in the first half of 2022 (Douglas Messier, "Commercial Space Travelers Outnumbered Professional Astronauts in First Half of 2022," *Parabolic Arc*, July 25, 2022).

[7] See, generally, Andrew S. Freiberg and Shouhau Zhou, "Celestial Versus Terrestrial Travel—An Analysis of Spaceflight Fatalities and Comparison to Other Modes of Transportation," *American Journal of Medicine*, Vol. 133, No. 11, November 2020.

[8] NASA, JSC SMA Flight Safety Office, "Significant Incidents and Close Calls in Human Spaceflight," infographic, September 30, 2019a.

[9] David Klaus, "The Pursuit of Occupant Safety in Commercial Human Spaceflight," *New Space*, Vol. 6, No. 1, 2018, p. 48.

> astronauts, or space flight participants during a licensed or permitted commercial human space flight; or
>
> (ii) contributed to an unplanned event or series of events during a licensed or permitted commercial human space flight that posed a high risk of causing a serious or fatal injury (as defined in 49 CFR 830, as in effect on November 10, 2004) to crew, government astronauts, or space flight participants; and
>
> (D) be issued with a description of the instance or instances when the design feature or operating practice being restricted or prohibited contributed to a result or event described in subparagraph (C).[10]

However, as indicated in subsection (2)(C), the FAA is currently prohibited from issuing regulations regarding design or operations pursuant to the safety of commercial passengers unless that design feature or operating practice causes or nearly causes a serious or fatal injury. This prohibition, commonly referred to as "the moratorium," was first issued in the Commercial Space Launch Amendments Act of 2004 (see Appendix A for full legislative history). The 2004 act provided the Department of Transportation with the jurisdiction and authority to regulate human spaceflight (including participants), without limiting such regulations to issues that relate to serious or fatal injury, but it then imposed a moratorium on the issuance of any such regulation unless in response to operating practices that resulted in serious or fatal injury or an event or series of events that posed a high risk of causing a serious or fatal injury.[11] To date, a single 2014 accident involving the SpaceShipTwo reusable suborbital rocket, N339SS, which was developed and operated by Scaled Composites LLC for Virgin Galactic, has been the only event that met the criteria for imposing regulation.[12] The vehicle broke into multiple pieces during a test flight, killing the copilot and seriously injuring the pilot.

The National Transportation Safety Board issued eight safety recommendations to the FAA following this event.[13] At the time this report was published (April 2023), four of these

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[10] U.S. Code, Title 51, Section 50905, License Applications and Requirements, Subsection c, Safety Regulations. We note that although the moratorium applies to regulations under this section, it does not apply to 51 U.S.C. § 50905(b)(6)(B), which gives the Secretary the authority to issue regulations to set reasonable medical and training requirements for spaceflight participants. Additionally, the FAA has issued the following regulation at 14 CFR § 460.51 with respect to training: "An operator must train each space flight participant before flight on how to respond to emergency situations, including smoke, fire, loss of cabin pressure, and emergency exit."

[11] See Public Law 108-492, Commercial Space Launch Amendments Act of 2004, December 24, 2004, Section 2, subsection (13): "Beginning 8 years after the date of enactment . . . the Secretary may propose regulations under this section without regard to paragraph (2)(C) and (D)."

[12] National Transportation Safety Board, *In-Flight Breakup During Test Flight, Scaled Composites SpaceShipTwo, N339SS, Near Koehn Dry Lake, California, October 31, 2014*, NTSB/AAR-15/02, 2015a.

[13] The safety recommendation report on the SpaceShipTwo crash can be read in National Transportation Safety Board, Safety Recommendation, August 4, 2015b.

recommendations have remained open with an acceptable response, three were closed with an acceptable response, and one recommendation was closed with an unfavorable response from the FAA.[14] These recommendations led to (1) formation of the ASTM F47 Committee on Commercial Spaceflight,[15] (2) revisions to the Waiver Procedures and Expansion of the Equivalent Level of Safety Option Final Rule (83 FR 28528),[16] (3) revisions to the FAA Safety Inspection Processes and Procedures document (P-008),[17] (4) a revised version of the FAA's Office of Commercial Space Transportation (AST) Safety Management System manual,[18] and (5) the creation of the Reportable Safety Events Task Group by the Commercial Space Transportation Advisory Committee (COMSTAC).[19] However, the recommendations have not resulted in the issuance of any new space participant safety regulations.

The moratorium is not a permanent prohibition. Section 111 of the Commercial Space Launch Competitiveness Act (CSLCA), enacted on November 25, 2015, modified 51 U.S.C. § 50905(c) such that the moratorium expires on October 1, 2023.[20] Specifically, the CSLCA modified 51 U.S.C. § 50905(c)(9) as follows:

> **(9) Learning period.—**
>
> Beginning on October 1, 2023, the Secretary may propose regulations under this subsection without regard to subparagraphs (C) and (D) of paragraph (2). The development of any such regulations shall take into consideration the evolving standards of the commercial space flight industry as identified in the reports published under paragraphs (5), (6), and (7).

Drawing from our discussions with current and former congressional representatives involved in drafting the CSLCA, our understanding is that the moratorium and its eventual expiration were intentionally designed to provide industry with a window of time—known as the learning period, as indicated in the legislation—to explore and better understand the safety implications of different designs and operations. The concern was that a premature regulatory regime might restrict the development of industry in undesirable ways, such as limiting creativity in design and operations or creating requirements that limit the growth and development of the nascent industry. On this basis, the law enacted a temporary mora-

14 National Transportation Safety Board, 2015b.

15 National Transportation Safety Board, Safety Recommendation A-15-019, August 4, 2015c.

16 National Transportation Safety Board, Safety Recommendation A-15-021, August 4, 2015d.

17 National Transportation Safety Board, Safety Recommendation A-15-022, August 4, 2015e.

18 National Transportation Safety Board, Safety Recommendation A-15-025, August 4, 2015f.

19 National Transportation Safety Board, Safety Recommendation A-15-026, August 4, 2015g.

20 Public Law 114-90, U.S. Commercial Space Launch Competitiveness Act, November 25, 2015. (We subsequently refer to this law as CSLCA.)

torium to allow industry time to properly develop best practices and standards, such as those created via discussion and engagements with standards development organizations (SDOs).

It is in this context that Congress requested multiple reports, including this independent report, to assess various aspects of the commercial space launch industry's readiness for a transition to a regulatory framework, as might occur under the expiration of the moratorium. Stakeholder views on the moratorium diverge, with some urging Congress to allow the moratorium to expire, while others would prefer that Congress again extend it.

Congressional Mandate

This study was mandated by the CSLCA of 2015. In Section 111 of the CSLCA, Congress required the Secretary of Transportation to contract for an independent report to be submitted to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science, Space, and Technology of the House of Representatives, providing an "assessment of the readiness of the commercial space industry and the Federal Government to transition to a safety framework that may include regulations."[21] The CSLCA requires that, as part of the review, an independent organization

> shall evaluate—
>
> (A) the progress of the commercial space industry in adopting voluntary industry consensus standards as reported by the Secretary in the interim assessments included in the reports under paragraph (5);
>
> (B) the progress of the commercial space industry toward meeting the key industry metrics identified by the report under paragraph (6), including the knowledge and operational experience obtained by the commercial space industry while providing services for compensation or hire; and
>
> (C) whether the areas identified in the reports under paragraph (5) are appropriate for regulatory action, or further development of voluntary industry consensus standards, considering the progress evaluated in subparagraphs (A) and (B) of this paragraph.[22]

This CSLCA section references paragraphs (5) and (6), which delineate reports that the Secretary of Transportation was mandated to provide to Congress on various dates since 2015:

[21] CSLCA of 2015, § 111, amending 51 U.S.C. § 50905(c)(8).

[22] CSLCA of 2015, § 111, amending 51 U.S.C. § 50905(c)(8).

- Paragraph (5) refers to reports that the Secretary was required to submit in "consultation and coordination" with COMSTAC[23] on the development of interim voluntary industry consensus standards.[24]
- Paragraph (6) refers to reports that the Secretary was required to submit in "consultation and coordination" with COMSTAC on the development of "key industry metrics that might indicate readiness of the commercial space sector and the Department of Transportation to transition to a safety framework that may include regulations . . . ."[25]

Research Scope and Approach

To address the topics outlined by Congress, we began our research by conducting discussions with representatives of Congress responsible for mandating this report and with FAA leadership. During these discussions, it was determined that the scope of our research and assessment in the three areas prescribed should focus on spaceflight participants as that term is defined by Title 51 of the U.S. Code, which states that a spaceflight participant is "an individual, who is not crew or a government astronaut, carried aboard a launch vehicle or reentry vehicle."[26]

As defined by the statute, *crew* are employees of a licensee or transferee or of a contractor or subcontractor of a licensee or transferee, while a *government astronaut* is either an employee of the U.S. government or an international partner astronaut.[27] Crew safety and government astronaut safety are currently governed by 14 CFR Subpart A, § 460 et. seq., and NASA standards, respectively. [28] Therefore, both congressional and FAA representatives requested that we focus our research on the remaining population: commercial spaceflight

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[23] COMSTAC is a federal advisory committee established in 1984 pursuant to the Federal Advisory Committee Act of 1972 and by order to the Department of Transportation. See U.S. Department of Transportation, Federal Aviation Administration, "SUBJ: Commercial Space Transportation Advisory Committee," Order 1110.124E, September 21, 2006; see also FAA, *Commercial Space Transportation Advisory Committee Charter*, undated-d.

[24] CSLCA of 2015, § 111, amending 51 U.S.C. § 50905(c)(5).

[25] CSLCA of 2015, § 111, amending 51 U.S.C. § 50905(c)(6).

[26] 51 U.S.C. § 50902(2).

[27] See 51 U.S.C. § 50902(4), for the definition of *government astronaut*. Individuals that participate as part of a vehicle crew are "any employee or independent contractor of a licensee, transferee, or permittee, or of a contractor or subcontractor of a licensee, transferee, or permittee, who performs activities in the course of that employment or contract directly relating to the launch, reentry, or other operation of or in a launch vehicle or reentry vehicle that carries human beings. A crew consists of flight crew and any remote operator." See 51 U.S.C. § 50902(17).

[28] We note that requirements in 14 CFR Part 460, Subpart A, focus on issues related to how the crew can affect public safety in the performance of their duties. They do not specifically delineate requirements addressing the safety of crew members themselves.

participants and their safety, particularly in lieu of the statutory end of the moratorium on October 1, 2023.

Given this focus, we also scoped our definition of *commercial space industry* to commercial entities directly involved, or directly supporting, the business of participant spaceflight for compensation or hire, as referred to in the CSLCA of 2015.[29] Additionally, because the CSLCA does not define the term *safety framework*, we scoped this concept broadly in order to assess possible paths forward for Congress and stakeholders to consider. Thus, a *safety framework* for the purposes of this report means both an examination of the current state (moratorium) and a hypothesized future state that could result from either an extension or a sunset of the moratorium.

Our approach to conducting the study consisted of the following lines of effort:

- We reviewed and analyzed academic, scholarly, and industry literature related to spaceflight participant transportation, current industry safety standards and best practices, and the impact (if any) of the existing regulatory regime.[30] This review included reports and related documents produced to date, as directed by Congress in various sections contained within 51 U.S.C. § 50905.
- We conducted semistructured interviews with government officials, stakeholders, subject-matter experts, industry representatives, and practitioners.
- We analyzed and collected relevant documentation, data, information, metrics, evidence, and other materials related to commercial space transportation safety that we solicited from relevant government officials, industry stakeholders, SDOs, and other subject-matter experts.
- We developed a framework consisting of a set of evaluation criteria to assess the readiness of the commercial space transportation industry to transition to a safety framework. This framework was adapted from existing social science research and literature that address regulation readiness levels and the criteria applied to these assessments.[31]

The interviews we conducted represent a significant portion of the data and information that we collected. We have incorporated this material within and throughout each chapter to address each element of the congressional mandate. We emphasize that these data and information represent the experiences, insight, and judgments of the interviewees and do not represent RAND's position on the issues addressed. Our analysis is contained in Chapter 4, and recommendations are contained in Chapter 6. Synthesis of all the materials collected

[29] 51 U.S.C. §§ 50905(b)(2)(D), (c)(2)(B), and (c)(8)(B).

[30] See, generally, U.S. Code, Title 51, Chapter 509, Commercial Space Launch Activities, and 14 CFR Chapter III, Parts 400 to 460.

[31] See, generally, Peter H. Kobos, Leonard A. Malczynski, La Tonya N. Walker, David J. Borns, and Geoffrey T. Klise, "Timing Is Everything: A Technology Transition Framework for Regulatory and Market Readiness Levels," *Technological Forecasting and Social Change*, Vol. 137, December 2018.

informed these findings and recommendations and is found in in each of the chapters of this report.

Organization of This Report

The remainder of this report contains the results of our research. Chapters 2, 3, and 4 assess the three topics set out in the legislation—progress in adopting voluntary standards, progress toward meeting key industry metrics, and the status of the industry with respect to adopting a safety framework that might include regulations, respectively. Chapter 5 reflects on perspectives on passenger safety regulation from other transportation sectors that provide useful context for evaluating the current maturity of the commercial spaceflight industry and identifying important trade-offs. The report concludes in Chapter 6 with key findings and recommendations. Two appendixes provide a legislative history (Appendix A) and a list of the relevant standards collected during the research (Appendix B).

CHAPTER 2

Progress of the Commercial Space Industry in Adopting Voluntary Consensus Industry Standards

Voluntary consensus standards are commonly defined as standards that are "developed or adopted by voluntary consensus standards bodies" both in domestic and international settings.[1] Standards development bodies seek input from relevant stakeholders, which could include those applying the standards, manufacturers, buyers, government agencies, consumers and protection agencies, subject-matter experts, academics, and nongovernmental organizations.[2] Standards development bodies generate consensus standards by implementing a mutually agreed-on set of procedures to develop, form, and manage consensus standards that incorporate the viewpoints of participating representatives.[3]

Additionally, Public Law 104-113 and Office of Management and Budget Circular A-119 encourage the participation of government representatives in these bodies to increase the likelihood that consensus standards will meet both public- and private-sector needs.[4] Standards development bodies that have worked on spaceflight participant safety include ASTM International, the American Institute of Aeronautics and Astronautics (AIAA), the ISO, and SAE International (SAE; formerly the Society of Automotive Engineers). These organizations are more commonly referred to as SDOs.[5]

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1 Circular No. A-119, Federal Register (Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities), Office of Management and Budget, February 29, 1998. Note that a voluntary consensus standard may also be known as a *voluntary standard*, a *consensus standard*, or a *consensus technical standard*.

2 National Fire Protection Association, "Benefits of Standards Development Organizations," webpage, undated-a; and International Organization for Standardization (ISO), "Developing Standards," webpage, undated.

3 Circular No. A-119, 1998.

4 Public Law 104-113, National Technology Transfer and Advancement Act of 1995, 1996; and Circular No. A-119, 1988.

5 FAA, *Report to Congress: Interim Report on Voluntary Industry Consensus Standards Development—January 2022*, 2022a, pp. 6–7, 10–12.

In addition to SDOs, the FAA has worked with industry members on its own effort to develop industry consensus standards through COMSTAC. As described previously, COMSTAC is an advisory committee consisting of commercial space industry members, state and local officials, and subject-matter experts who assist and make recommendations to the FAA on relevant commercial space topics.[6] The 2015 CSLCA directed the FAA to work with COMSTAC on developing consensus standards to improve the safety of spaceflight participants.[7] These FAA-led efforts were the primary focus of our discussions with government and industry interviewees, described later in this chapter. Before turning to that discussion, we consider the status of standards development and adoption for spaceflight safety.[8]

Commercial Spaceflight SDO Standards

Commercial human spaceflight standards existed as early as 2002 with the creation of ISO performance-based standards for system safety requirements.[9] SDOs increased their standards and development efforts following the passage of the CSLCA in 2015. After the moratorium was extended to October 1, 2023, as discussed in the previous chapter, SDOs took additional steps toward developing standards for commercial spaceflight, such as ASTM's establishment of its F47 committee in 2016. The committee published its first standard in 2019, which addressed the "storage, use, and handling of liquid rocket propellants."[10] The majority of SDO standards related to commercial human spaceflight have been published or revised within the past four to five years, with many currently under development.[11] Since

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6 FAA, "Commercial Space Transportation Advisory Committee (COMSTAC)," webpage, January 12, 2023b.

7 Public Law 114-90, Section 111, 2015.

8 In the CSLCA of 2015, Congress requested an assessment of industry's progress in "adopting voluntary consensus standards." From our research, we learned of current efforts to first develop voluntary consensus standards that could then be adopted by industry members. Additionally, the most recently released FAA report on industry's progress focused on the development of industry standards related to commercial spaceflight as part of its assessment of the industry's progress in adopting consensus standards. Thus, we cover the progress that has been made by industry in both developing and adopting standards in this chapter. We understand *developing* to mean efforts by industry through such mechanisms as SDOs or other formal collaborative forums (i.e., COMSTAC) to seek stakeholder input, draft, and then publicly publish standards. We understand *adopting* to mean industry members applying published standards from SDOs or other formal consensus standard bodies within their safety practices, specifically referencing those standards within those practices, and publicly sharing such information to ensure transparent application. See Public Law 114-90, Section 111, 2015.

9 ISO 14620-1:2002, *Space System—Safety Requirements—Part 1: System Safety*, December 2002.

10 ASTM F3344-19, *Standard Guide for Storage, Use, and Handling of Liquid Rocket Propellants*, January 29, 2019.

11 Some of the SDO standards were developed in earlier years. See FAA, 2022a, pp. 6–7, 10–12. Appendix B contains a list of current standards, as of December 2022.

2015, COMSTAC and the FAA have also coordinated on standards development efforts. COMSTAC's mission is to provide the FAA with information, advice, and recommendations on important commercial space industry matters, standards development being one of those matters.[12] Thus, although COMSTAC itself does not develop standards, it provides facilitation and feedback support for both the FAA and private-sector bodies to help develop consensus standards for industry adoption.[13] As of the writing of this report in December 2022, we had identified 20 relevant standards that have been published by SDOs. Additionally, SDOs had a total of six relevant standards under development or revision.[14]

ASTM International published six standards related to commercial spaceflight under its F47 committee. These standards cover propellant handling, terminology, classification of safety events, training and qualification of operations personnel, and failure tolerance. ASTM has four standards under development or revision.[15] These standards cover the areas of crew safety, spacecraft vehicle types, flight controller training, space data exchange, and reportable safety events.

The ISO currently has 12 published standards that address participant safety under its 49.140 Space Systems and Operations working group. These standards cover life support systems, launch site safety, air quality, launch site operation plans, debris mitigation, launch complexes, and reentry risk management. Two other standards are under development that cover the topics of launch vehicle test requirements and general testing guidelines of sites and facilities.

SAE is currently working on a standard for commercial spaceflight seat restraints under its commercial space issuing committee.

The AIAA published two standards covering the design, manufacture, quality control, testing, and storage of moving mechanical assemblies to be used on space and launch vehicles and defining a human spaceflight spacecraft ontology. The organization also has two standards under development.

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12 FAA, undated-d; and CSLCA of 2015, § 111.

13 FAA, 2022a, p. 3.

Because we used the FAA's 2022 report as a starting point for developing a list of current standards, the standards include all that might impact commercial spaceflight safety in a broad sense, not just participant safety. See FAA, 2022a, p. 6.

14 The discussion on existing standards is derived from the FAA's 2022 report to Congress and information on each SDO's website. The resulting list of standards, published and under development as of late 2022, is contained in Appendix B. See FAA, 2022a, pp. 10–12.

15 A standard might cover multiple topic areas or overlapping topic areas, or it could simply clarify definitions and priorities for future standards. One industry official familiar with the F47 committee noted that they believed that ASTM had published six standards (confirming our findings) and currently had eight standards in development (twice the amount we had determined) (industry officials, interview with the authors, December 7, 2022).

Lastly, the International Association for the Advancement of Space Safety (IAASS) has one publication covering safety certification services within its standard on commercial human-rated systems safety.

Industry Voluntary Consensus Standards

As outlined in the previous section, third-party SDOs have thus far developed 20 standards related to commercial spaceflight, some of which impact participant safety. In a series of reports, beginning in 2017, the FAA documented industry's progress in adopting voluntary consensus standards. Because these FAA reviews served as a point of departure for our own assessment of industry progress, we begin with highlights of the FAA findings.

FAA's Assessment of Industry Progress: 2017–2022

As detailed in Appendix A, the CSLCA of 2015 required the FAA to report on "the progress of the commercial space transportation industry in developing voluntary industry consensus standards that promote best practices to improve industry safety."[16] Three reports published by the FAA to date in response to this requirement provide an assessment of the commercial space industry's progress in adopting consensus standards.

In its 2017 report to Congress, the FAA set the stage for industry's progress on adopting voluntary consensus standards. Overall, the FAA determined that no known consensus standards had been developed and/or adopted by the industry at that time.[17] The FAA tied the lack of standards to the fact that industry had not engaged in any formal road-mapping to guide standards development efforts. However, the report detailed the progress made by relevant stakeholder groups, such as COMSTAC and ASTM, in laying the groundwork for standards development.

This progress included the development of a Commercial Spaceflight Committee within ASTM, which the FAA highlighted as a significant step in forming consensus standards.[18] The FAA also noted that there had not yet been a spaceflight that included participants and that it anticipated that private space companies would continue to develop applicable consensus standards as more individuals participated in spaceflights.[19] Indeed, the FAA highlighted in the report's conclusion that, with industry-developed standards in place, government involvement might not be necessary.[20]

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16 Public Law 114-90, 2015.

17 FAA, *Report to Congress: FAA Evaluation of Commercial Human Space Flight Safety Frameworks and Key Industry Indicators*, October 20, 2017b, p. 28.

18 FAA, 2017b, pp. 24–27.

19 FAA, 2017b, pp. 28–29.

20 FAA, 2017b, p. 36.

The FAA issued a concise report in 2019, reflecting the limited changes in the spaceflight industry's progress toward developing a set of common standards for human spaceflight safety. The report emphasized that little progress in human spaceflight had been made since the previous report, because only three flights with human passengers had occurred during that period.[21] Those flights consisted of astronauts and crew, with no participants aboard. Consequently, progress on voluntary consensus standards remained preliminary, and "significant work" still remained.[22] With limited flight experience, the FAA noted the concern that any standards developed might stifle innovation as companies developed flight and vehicle plans. The FAA reiterated its commitment to working with and looking to industry to develop the standards that made the most sense as it continued to evolve.[23]

The FAA outlined the "moderate progress" seen within the commercial space transportation industry since 2019 in an interim report published in early 2022.[24] This report detailed a broader assessment of the commercial space industry than previous reports, as the agency stated that standards related to the "entire commercial space industry" might impact participant safety. The FAA assessed that industry had made "moderate progress in finalizing and proposing additional needed standards."[25] The level of acceptance of these standards, however, remained unclear to the FAA. Thus, the FAA directed COMSTAC to investigate the extent to which industry has adopted these standards, and the FAA plans to include that information in its final report to Congress.[26] To support this effort and at the request of COMSTAC, the FAA compiled a list of existing standards that it deemed relevant to commercial human spaceflight, a broader category than participant safety or even industry safety. This list is included as an appendix in the 2022 report.[27]

Our Assessment of Industry's Progress

Industry's Current Approach to Spaceflight Participant Safety Standards

According to the information garnered during our interviews, the commercial space industry has yet to develop and/or adopt a common set of voluntary consensus standards for spaceflight participant safety.[28] While some standards and guidance related to participant safety

[21] FAA, *Report to Congress: U.S. Department of Transportation Evaluation of Commercial Human Space Flight Activities Most Appropriate for New Safety Framework*, 2019a, p. 5.

[22] FAA, 2019a, Executive Summary.

[23] FAA, 2019a, p. 5.

[24] FAA, 2022a, p. 6. The FAA's final report to meet congressional requirements is still to be published.

[25] FAA, 2022a, pp. 6–7.

[26] FAA, 2022a, p. 7.

[27] FAA, 2022a, pp. 8, 10–12.

[28] Our assessment of industry's progress reflects a compilation and analysis of information collected during our interviews because they served as the primary source of data due to a lack of publicly available

exist, companies have yet to clearly or consistently adopt them in a manner that can be confirmed or verified publicly.

As of the writing of this report (February 2023), individual private space companies continued to apply their own independent safety practices for spaceflight participants. Companies essentially determine the types of training and preparation that spaceflight participants must complete and the level of transparency that the companies provide to potential participants.[29] These standards and practices have not been disclosed publicly in any documentation that can be independently assessed and analyzed. For example, one government official noted that some companies have "extensive training" for their participants, but, because the federal government does not yet regulate this area, they did not know what such training included.[30]

Even though each company currently implements its own set of practices, multiple interviewees emphasized that the companies are incentivized to maintain safety for the sake of their own reputation and sustainability and the industry as a whole. As one interviewee contended, "I think if there were incidents, the entire industry would falter."[31] Thus, while overarching standards are yet to be adopted, pressures to support and expand the nascent industry might shape current safety practices.

In developing their own sets of safety practices, commercial spaceflight companies may or may not use external, third-party guidance and standards. For instance, companies could use or refer to standards developed by SDOs to show that they are meeting those requirements. Companies might or might not also use materials developed by the FAA. To provide support to commercial spaceflight companies in this manner, the FAA issued guidance on participant safety in 2014 through a publicly available report entitled *Recommended Practices for Human Space Flight Occupant Safety*.[32] This guidance provided a reference for companies on spaceflight participant safety and a starting point for developing consensus standards and potential future regulations.[33] However, although companies can choose to incorporate or apply the FAA guidance as they see fit, the FAA cannot yet require companies to do so.[34] Participants in two interviews stated that companies use SDO standards and/or FAA guidance to

information. We summarize and present interview insights without judgment to ensure the inclusion of all perspectives of those we interviewed.

[29] Government officials, interviews with the authors, September 13, 2022, September 27, 2022, and October 4, 2022.

[30] Government officials, interview with the authors, October 4, 2022.

[31] Government officials, interview with the authors, September 1, 2022.

[32] One interviewee with whom we spoke noted that the FAA planned to expand the 2014 guidance but had not received the desired level of feedback from industry partners in order to do so. Thus, the 2014 guidance remains the most recent provided by the agency.

[33] FAA, *Recommended Practices for Human Space Flight Occupant Safety*, Version 1, August 27, 2014.

[34] Government officials, interview with the authors, October 13, 2022.

inform their own safety practices.[35] Although we found no indication that this is not the case, we also cannot confirm or validate the extent to which this incorporation occurs or whether standards and practices might be set aside based on certain circumstances or criteria, because of the lack of publicly available information.

Although our questions focused primarily on determining the extent of industry's progress summarized in this section, several interviewees also offered general assessments of that progress based on their unique perspectives. Some interviewees noted that the progress made thus far was reasonable for the number of flights and extent of experience by commercial spaceflight companies to date.[36] Others noted that they believed the progress did not reflect the pace of development by the industry and thus felt frustrated by, or disappointed in, what they deemed to be a lack of progress in developing consensus standards or practices.[37]

Industry's Progress on Developing Consensus Standards

While we determined that the commercial space industry has yet to develop or adopt a common, single set of spaceflight participant safety standards, we also inquired about progress that the industry has made in this endeavor during our interviews. In particular, three topics encapsulate where standards development currently stands: (1) where consensus among industry stakeholders exists, (2) the value provided by the consensus standards development process, and (3) the challenges to progress in developing and adopting consensus standards.

During our discussions with industry and government stakeholders, a few interviewees acknowledged that some level of consensus existed around the need for and benefit of a common set of participant safety standards. The acknowledged benefit stemmed in large part from the recognition that a single serious incident involving a spaceflight participant could lead to significant impacts on the industry's reputation and sustainability.[38] Consequently, multiple interviewees stated that the industry could coalesce around a set of broad, reasonable standards that outline basic principles.[39] In one interviewee's words, such standards need to be "broad enough to apply to everyone."[40]

Companies' current practices could potentially serve as a step in that direction as the basis for a potential set of standards. For instance, we heard in two interviews that private space companies apply similar methods for protecting participant safety at fundamental levels. The

[35] Government and industry officials, interview with the authors, November 30, 2022, and December 7, 2022.

[36] Government and industry officials, interviews with the authors, September 13, 2022, and December 7, 2022.

[37] Government and industry officials, interviews with the authors, September 1, 2022, October 6, 2022, November 8, 2022, and November 18, 2022.

[38] Industry and government officials, interviews with the authors, September 23, 2022, November 8, 2022, and November 30, 2022.

[39] Government officials, interviews with the authors, October 7, 2022, and October 13, 2022.

[40] Industry officials, interview with the authors, November 18, 2022.

interviewees iterated that companies' application of the FAA's 2014 guidance and of standards developed by SDOs, in conjunction with the incentive to protect the nascent space industry's reputation, leads to similar efforts. Essentially, while companies have not explicitly agreed on a common set of safety standards, their individual practices may reflect some level of coordination and informal information-sharing with one another when it comes to basic safety requirements.[41]

While no distinct common set of consensus standards have been developed and adopted across industry, several interviewees noted that the processes to inform and develop those standards still provided value because they brought government and private-sector representatives together to discuss potential safety standards and practices.[42] One interviewee stated that despite the challenges that the process may have faced over the years, involving industry stakeholders was "absolutely necessary because you do not want to inadvertently regulate them out of business."[43] Relatedly, another interviewee emphasized that the process helps ensure that any standards or regulations implemented based on stakeholder collaboration would be familiar to industry—i.e., their content would not come as a surprise.[44] Additionally, the process of bringing government and industry together to consider participant safety standards provided a forum and pathway for consensus.[45] It also offered the opportunity to bring people with relevant expertise and commitment to the same table. One interviewee specifically highlighted the "sincerity and earnestness" with which many stakeholders approached the consensus standards development process. Without such a process and forum in place, such investment and diversity of perspectives may be limited.[46]

Our interviewees from government and industry identified multiple challenges to developing consensus standards that have arisen over the past few years. The challenges relate to differences between the private space companies, the status of the human spaceflight industry, information sharing, and difficulties in ensuring the commitment of all stakeholders. Two main areas of differences between space companies arose during our discussions. The

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41 Government and industry officials, interviews with the authors, November 8, 2022, and November 30, 2022.

42 The process we spoke most about with interviewees is the COMSTAC effort led by the FAA, which provides a forum for collaboration on areas in need of standards and input and feedback on proposed or in-progress standards. We recognize that other efforts exist and spoke with interviewees about these processes when appropriate, such as the F47 committee within ASTM, which also includes a wide representation from industry for input and feedback. We specifically focused on the COMSTAC effort to provide the FAA with the most relevant information for the process where it has the most influence.

43 Government officials, interview with the authors, September 1, 2022.

44 Government officials, interview with the authors, October 6, 2022.

45 However, we note that it appears—from the lack of agreed-upon public standards—that consensus is difficult to obtain at this point. Interviewees did note that there is not always agreement during these collaborations. Industry officials, interview with the authors, October 19, 2022

46 Industry officials and other private and expert stakeholders, interviews with the authors, September 15, 2022, and September 27, 2022.

first focused on how some companies have been working in the space field for much longer than others and thus might be more comfortable with adhering to a set of common standards or even regulations. These companies are more likely to have the resources and capabilities to make necessary changes and ensure compliance with determined standards or regulations. Newer entrants into the human spaceflight arena may still be in a startup phase, however, and thus are less likely to have the resources and capabilities to meet externally set standards or regulations. These entities simply may not have the time or staff to dedicate to such tasks.[47] As one interviewee highlighted, a "large segment of the industry is just trying to survive."[48]

The second area related to space company differences centered on the variations in their operations, processes, vehicle construction, and respective customers. Interviewees stressed that finding standards to apply across the industry is difficult when all the companies feature so many different characteristics. Therefore, implementing higher-level and basic standards may be a helpful starting point compared with more-detailed and nuanced standards or regulations.[49] One interviewee captured this difficulty by saying, "We don't have commonality at all in our industry. They [private space companies] don't do the same things. A launch of a Falcon is entirely different than a launch of an Atlas."[50]

Relatedly, multiple interviewees noted that industry members hesitate to commit to a common set of standards due to the nascent nature of the commercial spaceflight field. They stated that companies may question how and why they need to come to an agreement on standards when the pace of human spaceflight missions remains slow, despite recent advances and increases in number of flights. Essentially, they contended that it is still too early in the development of the commercial human spaceflight industry to consider standards and regulations applicable across the board.[51] For instance, one interviewee noted how some companies are still in the design phase of their vehicles, and thus asking them about safety standards may require them to envision aspects of their vehicles that have yet to be developed or created.[52] One interviewee captured this hesitation by stating, "How do you regulate something that does not exist yet? It is impossible to regulate an industry that is this immature at this point."[53]

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47 Government officials, interviews with the authors, October 6, 2022, and November 11, 2022.

48 Government officials, interview with the authors, November 1, 2022.

49 Government officials, interviews with the authors, September 13, 2022, September 27, 2022, October 6, 2022, and October 7, 2022.

50 Government officials, interview with the authors, September 27, 2022.

51 Government officials, interviews with the authors, September 1, 2022, September 13, 2022, and October 18, 2022.

52 Government officials, interview with the authors, October 18, 2022.

53 Government officials, interview with the authors, September 13, 2022. We note that these statements make the presumption that safety standards cannot be developed concurrently with the development of devices, technologies, or processes. We also note that this presumption is not supported in at least some of the scientific literature regarding technology, equipment, and machine design and development. See Raid

Publicly sharing information, even if only among government and industry stakeholders, presents another challenge that has slowed progress toward developing and adopting a common set of safety standards. A couple of interviewees discussed how industry members could not always agree on the level and types of information that they would be willing to share in order to build consensus standards and/or meet future regulatory requirements. Many companies may view such information as proprietary and, therefore, feel concerned over who may access that information should they be required to divulge it.[54]

The last challenge to reaching consensus on a common set of voluntary safety standards relates to the primary governmental forum and process that has been used to build consensus, COMSTAC. While there are some benefits from that collaborative effort, some aspects of the COMSTAC process have presented challenges. According to our interviewees, one of those aspects is the varying levels of participation from different stakeholders, as well as their varying levels and types of expertise. Interviewees noted that different industry members had varied demands on their time and resources, leading to differing abilities and levels of time to devote to the effort. As a result, COMSTAC may not be hearing from a diverse set of stakeholders. Thus, any standards coming out of the effort may not fully represent the nuances within the commercial space industry.[55] Both of these challenges can slow down the standards development process, as meetings may not include the necessary stakeholders to take action. A few of our interviewees suggested that the COMSTAC process could be improved by using it more as a forum for feedback on a safety framework developed by the government or other appointed entity.[56] One interviewee even noted that COMSTAC might be better at validating the standards process, instead of weeding through specific standards.[57]

Hasan, Alain Bernard, Joseph Ciccotelli, and Patrick Martin, "Integrating Safety into the Design Process: Elements and Concepts Relative to the Working Situation," *Safety Science*, Vol. 41, Nos. 2–3, March 2003. The extent to which safety-integrated design is or should be applicable to the commercial space industry may be an open question that is ripe for additional research.

[54] Government and industry officials, interviews with the authors, September 26, 2022, October 6, 2022, and November 8, 2022.

[55] Government officials, interviews with the authors, September 23, 2022, and October 7, 2022.

[56] Government officials, interviews with the authors, September 13, 2022, September 27, 2022, and October 6, 2022.

[57] Government officials, interview with the authors, September 13, 2022. We note that any changes (such as those noted in this section) to the manner in which COMSTAC exercises its duties would need to be in compliance with its charter. See FAA, undated-d. The FAA and other government officials responsible for federal advisory committees at the Department of Transportation would be in the best position to make these determinations.

Summary

Our analysis has led to the following conclusions:

- SDOs have developed standards related to commercial spaceflight safety that could impact participant safety.
- While no single set of consensus standards for participant safety have been adopted across the industry, commercial spaceflight companies have their own set of safety practices that may (or may not) incorporate SDO standards.

Additionally, the FAA and industry members continue to work together through COMSTAC in high-level discussions on the efforts to develop consensus standards and best practices, and through ASTM F47 as a private/public consensus-based forum that includes both technical subcommittee standards development and conference-level standards and best practices development.

We also identified several challenges faced by those working on developing consensus standards:

- The commercial space industry is relatively immature, particularly in regard to human spaceflight experience, and commercial spaceflight companies differ in their stages of development. Thus:
  - Consensus on voluntary standards between companies remains elusive.
  - Broad standards covering basic safety principles could serve as starting points for consensus.
- Proprietary and other industry nondisclosure concerns create barriers to information sharing. Therefore:
  - These concerns impede the cross-industry learning and institutionalization of standards and best practices.
  - These concerns prevent an independent assessment and validation of the progress of voluntary consensus standards.
- Participation in consensus-building forums does not consistently reflect a diverse representation of industry stakeholders. Consequently:
  - Outputs of consensus-building forums might not incorporate all relevant perspectives.

Despite these challenges, there is value in the process of building consensus standards, particularly because it provides a forum for collaboration and for industry members to provide input and feedback.

CHAPTER 3

Progress Toward Meeting Key Industry Metrics

The CSLCA required the FAA to specify "key industry metrics that might indicate readiness of the commercial space sector and the Department of Transportation to transition to a safety framework that may include regulations."[1] The FAA delivered its report that included these metrics, prepared in consultation with COMSTAC, to Congress in October 2017.[2] The second of three topics we cover is "the progress of the commercial space industry toward meeting the key industry metrics."[3] We discuss these metrics and progress toward meeting them in this chapter.

We begin by describing the metrics themselves, alternatively known as *indicators* in FAA reporting, as well as several premises underlying them. We discuss how the metrics were selected and industry's role in developing them. We then analyze progress as measured by these metrics—as described in subsequent FAA reports and based on our independent review of available documents and data and stakeholder interviews. We conclude by describing the limitations of a metrics-based approach to gauging readiness to transition to a safety framework.

Key Industry Metrics

The CSLCA directed the FAA to consult with the commercial space sector to develop a report identifying key metrics of industry and government readiness to transition to a safety framework. The CSLCA did not define *key metric* or *safety framework*, nor did it specify which types of metrics might be in scope. Other notable ambiguities included that these metrics "might indicate" readiness for a safety framework that "may include regulations."[4] The FAA

1 Public Law 114-90, Section 111 (6), 2015.

2 FAA, 2017b.

3 Public Law 114-90, Section 111 (8) (B), 2015.

4 Public Law 114-90, Section 111 (6), 2015.

had considerable discretion to select the metrics and values for them that would indicate readiness.

Federal Aviation Administration 2017 Report to Congress

The FAA submitted a report to Congress in October 2017, entitled *FAA Evaluation of Commercial Human Space Flight Safety Frameworks and Key Industry Indicators*.[5] The report provided the FAA's view of what a safety framework entails; described several premises that in the FAA's view underlie the indicators it selected; and listed three sets of indicators on industry readiness, industry progress in developing a safety framework, and Department of Transportation readiness.

The FAA describes a safety framework as potentially including "a combination of standards, norms, best practices, regulations, codes of conduct, and guidance."[6] The three elements of a safety framework in the FAA's view are voluntary safety reporting (company-wide or industry-wide), standards covering the "design, manufacture, and operation of a human spaceflight system" (e.g., voluntary consensus standards), and mechanisms to document compliance with established standards.[7] According to the report, developing a safety framework does not necessarily imply government regulation; rather, "successful implementation of an industry-led framework could obviate the need for government involvement," at least to a point.[8]

The five premises that underlie its indicators shed light on the FAA's view, as of its 2017 report, of when government involvement would become necessary. These premises are as follows:

- The human space flight industry must continually improve its safety performance.
- As industry grows and matures, the depth and breadth of a safety framework should evolve.
- The public's expectation of safety will increase as the purpose of flying to space evolves from adventure, to occupation, to transportation.
- Once space travel becomes transportation, the Federal Government will likely need to have a regulatory role.
- Until space travel becomes transportation, industry may lead the development and implementation of a safety framework, with limited government involvement.[9]

5 FAA, 2017b.

6 FAA, 2017b.

7 FAA, 2017b.

8 FAA, 2017b.

9 FAA, 2017b.

TABLE 3.1
Key Industry Indicators

Indicator Set	Readiness Area	Readiness Indicators
Industry readiness	Purpose of people flying in space	• The extent to which people are flying for adventure purposes • The extent to which people are flying as part of their occupation • The extent to which people are flying as a mode of transportation
	Size and complexity of the industry	• The number of suppliers of orbital or suborbital spaceflight • The number of suppliers of similar spaceflight, types such as vertical suborbital, horizontal suborbital, and balloon • The extent to which there is a broad supplier network • The extent to which operations occur internationally
	Safety of the industry	• The extent to which there is evidence of unsafe operations • The extent to which the industry is having difficulty attracting new customers • The extent to which insurance companies are willing to insure human spaceflight operations
Industry's progress in developing a safety framework	Voluntary safety reporting	• The extent to which individual companies have an internal voluntary reporting system to identify and address potential precursors to accidents • The extent to which industry members share safety data with each other, with a common data format and taxonomy
	Voluntary consensus standards	• The extent to which industry has formed a consensus on top-level performance standards • The extent to which industry has developed and maintains voluntary consensus standards in high-priority areas • The extent to which industry has developed and maintains a robust set of voluntary consensus standards
	Compliance	• The extent to which individual companies self-verify compliance with voluntary consensus standards • The extent to which a third party verifies compliance with voluntary consensus standards
Department of Transportation readiness	FAA authority to transition to a safety framework	• Status of the "learning period"
	FAA expertise in human spaceflight safety	• The extent to which the FAA has helped create elements of a space safety framework • The extent to which the FAA has engaged with industry regarding standards development • The extent to which the FAA has published safety practices related to commercial human spaceflight • The extent to which the FAA has experience participating in a space safety framework

SOURCE: FAA, 2017b.

The FAA then outlines indicators (preferring this term over *metrics*) that could be used to gauge the readiness of industry and the Department of Transportation to transition to a safety framework that may include regulations. We list these indicators in Table 3.1.

Developing the Key Industry Metrics

The FAA's AST developed the key industry indicators in consultation with COMSTAC and in collaboration with the Institute for Defense Analyses Science and Technology Policy Institute (IDA-STPI), a federally funded research and development center. The 2017 report itself and COMSTAC meeting minutes and presentations document the iterative process that resulted in the metrics. In April 2016, one of the observations, findings, and recommendations from COMSTAC's Standards Working Group (SWG) was that "COMSTAC/SWG will provide FAA AST and IDA-STPI responses and proactive inputs on occupant safety industry standardization areas and also 'readiness metrics' to transition to an evolved oversight framework beyond the current moratorium/learning period."[10] At the October 2016 meeting, the SWG reported that it had met with IDA-STPI in July 2016 and "praise[d] AST and IDA-STPI for seeking industry response on occupant safety standardization and readiness metrics" through the group and additional individual meetings.[11]

Our stakeholder interviews confirmed that consultations over the 2016 to 2017 period occurred but that these were relatively informal and small-scale interactions involving a limited number of FAA staff and industry officials.[12] The goal was to identify metrics that would inform an understanding of industry maturity in carrying out commercial human spaceflight operations and developing a safety framework. However, most stakeholders seemed to have had little interest in pre-committing to specific metrics or targets that would signal readiness to transition to specific forms of government involvement.[13]

Assessing Readiness Using the Key Industry Metrics

The ability to use the key industry metrics, or indicators, as measures of readiness to transition to a safety framework depends in part on their strength as indicators. One basic definition of an indicator is a "quantitative or qualitative variable that provides reliable means to measure a particular phenomenon or attribute."[14] Program evaluators often seek out as measures of progress indicators that meet criteria abbreviated by the acronym SMART: specific,

[10] FAA, "Commercial Space Transportation Advisory Committee, Spring Meeting," April 28, 2016c.

[11] FAA, "Commercial Space Transportation Advisory Committee, Fall Meeting," October 26, 2016d.

[12] Government officials, interviews with the authors, September 1, 2022, and October 7, 2022.

[13] Government officials, interviews with the authors, September 3, 2022, October 5, 2022, and October 7, 2022.

[14] United States Agency for International Development, *Glossary of Evaluation Terms*, Office of the Director of U.S. Foreign Assistance, March 25, 2009.

measurable, actionable (or appropriate), reliable, and time-bound.[15] While some indicators included in the FAA report meet at least some of these SMART criteria, many do not. Often, key terms, specific measures, and how data would be collected (and by whom) are not specified. In no instances are targets provided for the indicators that would signify readiness to transition.

Several interviewees acknowledged that the indicators were vague, perhaps deliberately so.[16] The FAA wrote in its report that the indicators are not "pass/fail" but rather "provide a measure of industry's evolving safety framework," providing "maximum flexibility for Congress in determining the time and manner of a transition to a safety framework that may include regulations."[17] However, an aspect expressed in both the report and our interviews is that the indicators were designed as a package—and assessments of readiness to transition to a safety framework that may include regulation should take all three sets of indicators into consideration.[18] Notably, as industry marks progress according to indicators of industry readiness (e.g., the purpose and cadence of flights), it is expected that industry also should make strides toward developing consensus standards and creating industry-driven safety reporting and compliance systems; failing to develop standards in tandem with increased flight cadence could spur government regulation. According to the report, "The first two sets are related to the third in that if the safety framework developed by industry is not sufficient to support the state of the industry, then the FAA could increase its involvement with commensurate resources."[19]

Industry Progress on Key Metrics

Our review of the FAA's reports to Congress and stakeholder interviews suggest that neither the FAA nor industry has developed a systematic approach to operationalizing the key industry metrics identified by the FAA in its October 2017 report or to collecting and reporting data aligned with them. Targets for the metrics do not exist, and both government and industry stakeholders expressed to us that it might be impractical to establish specific, meaningful

[15] Benjamin K. Master, Shelly Culbertson, Brian Phillips, Elaine Lin Wang, Harold D. Green, Joe Francombe, Hamish Evans, and Susan Guthrie, *Transforming Global Education Through Evidence: An Evaluation System for the BHP Foundation's Education Equity Global Signature Program*, RAND Corporation, RR-A239-1, 2021; Shelly Culbertson, Gabriella C. Gonzalez, and Nupur Nanda, *The Appalachia Partnership Initiative's Investments in Education, Workforce Development, and the Community: Technical Appendixes*, RAND Corporation, RR-2017/1-CHC, 2017.

[16] Government officials, interviews with the authors, September 1, 2022, and October 4, 2022.

[17] FAA, 2017b.

[18] The three sets of indicators cover (1) industry readiness, (2) industry's progress in developing a safety framework, and (3) Department of Transportation readiness (FAA, 2017b).

[19] FAA, 2017b.

targets to signify readiness to transition.[20] It is, therefore, difficult to assess whether there has been progress toward meeting key industry metrics when there are not clear targets that could be met.

Despite not having prespecified benchmarks for the indicators that would signal readiness, in a 2019 report, the FAA concluded that, "based on these readiness indicators, there are no commercial human space flight activities that are ready for a new safety framework that may include regulatory action."[21] This conclusion likely flowed from the FAA's finding that there "has been little commercial human space flight activity" since the 2017 report, meaning that even if benchmarks for readiness had existed, they would not have been met.[22] The 2019 FAA report did, however, include a shift in the FAA's language from characterizing "successful implementation of an industry-led framework" as having the potential to "obviate" the need for government involvement to having the potential to "minimize" the need for government involvement.[23]

The January 2022 FAA report did not make the same blanket assertion of a lack of readiness, and, despite listing the indicators and including a discussion of several of them, it did not provide a conclusion about industry readiness.[24] Our interviews and analyses also revealed a more nuanced picture of progress, as measured by the key industry metrics, than the one offered in the FAA's 2019 report because the 2022 report reflects industry developments over the past three years, in which the pace of flights and development of voluntary consensus standards has accelerated. It also reflects the views of a range of stakeholders that some activities and portions of the industry might be ready to advance along a continuum toward a larger role for government, especially considering the extended runway that might be required to develop appropriate regulations, while other aspects of commercial human spaceflight might not yet be ready.[25]

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[20] The FAA's reports to Congress do not specify targets for the indicators that would indicate readiness for regulation. (See FAA, 2017b; FAA, 2019a; FAA, 2022a.) Interviewees typically were unable to identify what appropriate targets for the indicators might be (government and industry officials, interviews with the authors, September 1, 2022, September 23, 2022, November 8, 2022, and December 7, 2022).

[21] Elaine L. Chao, letter about the *U.S. Department of Transportation Evaluation of Commercial Human Space Flight Activities Most Appropriate for New Safety Framework* report to Roger F. Wicker, February 26, 2019.

[22] FAA, 2019a.

[23] FAA, 2019a.

[24] FAA, 2022a.

[25] For example, several interviewees viewed data-reporting requirements and performance-based standards in areas described in the FAA's 2014 *Recommended Practices for Human Space Flight Occupant Safety* document, such as fire suppression, emergency egress, and crew restraint, as reasonable starting points on a glidepath to a larger role for government. By contrast, stakeholders viewed prescriptive standards related to vehicle design as inappropriate given the range of vehicle types in existence and the potential for continued evolution of designs (government and industry officials, interviews with the authors, September 1, 2022, October 7, 2022, November 8, 2022, and December 7, 2022).

We now turn to a discussion of the three sets of industry indicators developed by the FAA: industry readiness indicators, industry's progress in developing a safety framework, and Department of Transportation readiness.

Industry Readiness Indicators

In this section, we discuss the first set of indicators, industry readiness indicators, which covers three readiness areas: the purpose of people flying in space, the size and complexity of the industry, and the safety of the industry.

Purpose of People Flying in Space

The three indicators in this readiness area are closely linked: the extent to which people are flying to space (1) for adventure purposes, (2) as part of their occupation, and (3) as a mode of transportation. These three indicators could be represented as proportions of the total number of people on commercial human spaceflights. In its 2017 report, the FAA suggested that the first two indicators might be in the offing—with hundreds of individuals signed up for a once-in-a-lifetime adventure and scientists eyeing experiments that might entail human travel to space—but that commercial human spaceflight as a means of transportation was "likely decades away."[26] Yet progress was slow to come, with the FAA writing in 2019 that only flight crew had been to space on a small number of commercial flights.[27] By early 2022, however, adventure-seekers had gone into orbit along with NASA astronauts who were ferried to the International Space Station.[28] This remains the state of play as of this writing in January 2023.

Figure 3.1 displays the number of commercial human spaceflights and number of people on those spaceflights, by year, starting with SpaceShipOne's five flights in 2004 (each with one crew member on board) through mid-October 2022. The chart reflects commercial flights listed in the U.S. Human Space Flight Safety Record, which includes licensed or permitted launches and reentries with a human on board,[29] with launch defined in CFR as

> to place or try to place a launch vehicle or reentry vehicle and any payload or human being from Earth in a suborbital trajectory, in Earth orbit in outer space, or otherwise in outer space, including activities involved in the preparation of a launch vehicle or payload for launch, when those activities take place at a launch site in the United States.[30]

[26] FAA, 2017b.

[27] FAA, 2019a.

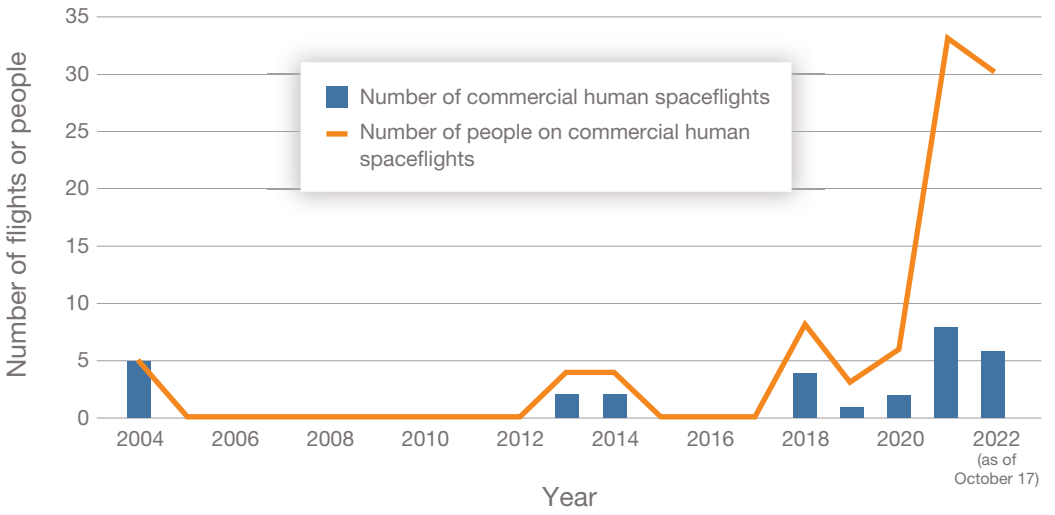
[28] FAA, 2022a.

[29] FAA, "U.S. Human Space Flight Safety Record," webpage, October 17, 2022e.

[30] 14 CFR § 401.7.

FIGURE 3.1

Number of Commercial Human Spaceflights and People Flying, 2004–October 2022



SOURCE: Total number of flights: FAA, 2022e. Number of people by flight by year: FAA, "Licensed Launches," webpage, undated-f, and FAA, "Permitted Launches," webpage, undated-h.

NOTE: The number of people includes crew, spaceflight participants, and government astronauts flying on commercial flights. The data do not distinguish between these categories.

The sharp increase in flight cadence and the number of people flying on commercial flights over the past two years is apparent. In 2021 and 2022, the types of people taking part in these spaceflights shifted from primarily commercial pilots and crew to adventure-seekers and government astronauts. It is not clear whether the FAA metric related to the "purpose of people flying to space" and the continuum from adventure to occupation intends for crew to be considered people with "flying as part of their occupation" or if the metric should be scoped to noncrew spaceflight participants flying as part of their occupation—for example, scientists sent to space to carry out experiments.

During interviews, two interviewees emphasized that the distinction between spaceflight for adventure and spaceflight for work or transportation is important for gauging the appropriateness of transitioning to a new safety framework.[31] It was noted that the level of risk aversion among spaceflight participants is likely to increase along the spectrum from adventure to work-related travel to transportation.[32] While early adopters would be more likely to accept a higher level of risk, a larger future customer base participating for work or transport rea-

[31] Government officials, interviews with the authors, October 6, 2022, and October 7, 2022.

[32] Government officials, interview with the authors, October 7, 2022.

sons would need to be reassured that spaceflight was safe, at which point adherence to safety standards would become an important measure of success.[33]

Although interviewees did not generally explicitly characterize industry progress from adventure to occupational or transportation purposes, relevant comments tended to echo an overall conclusion that, at present, industry remains oriented toward flying people to space for adventure.[34] Interviewees did suggest several nuances to the picture of an industry still at an early stage of readiness in terms of the purpose of travel. One interviewee noted that as commercial spaceflights for adventure and tourism increase, industry will gain in-flight experience and will be able to develop safer spacecraft, suggesting that adventure remaining the primary purpose of commercial spaceflight does not by itself mean that industry would not be ready to transition to a safety framework with a role for government regulation.[35] More broadly, interview comments emphasizing the quick pace of industry growth in recent years left open the possibility that the purpose of commercial spaceflight could shift in the future.[36] However, as of the publication of this report (April 2023), the commercial human spaceflight industry appears almost solely focused on adventure as the purpose of spaceflight participant (i.e., noncrew) travel, and this appears likely to remain the case for at least the next several years.

Size and Complexity of the Industry

This readiness area includes indicators on (1) the number of suppliers of orbital or suborbital spaceflight; (2) the number of suppliers of "similar" spaceflight types, such as vertical suborbital, horizontal suborbital, or balloon; (3) the extent to which there is a broad supplier network; and (4) the extent to which operations occur internationally. The number of active suppliers of commercial orbital or suborbital human spaceflight has gone from zero (in 2017) to one provider of suborbital flights (as of the FAA's 2019 report) to two suborbital providers and one orbital provider (as of the FAA's January 2022 report).[37] In its 2017 and 2022 reports, the FAA characterized the supplier network as "rapidly expanding."[38] We note that *supplier* is defined differently in indicator three, referring to "the industry supplier net-

[33] Government officials, interview with the authors, October 7, 2022.

[34] Government officials, interviews with the authors, September 13, 2022, October 6, 2022, and October 7, 2022.

[35] Government officials, interview with the authors, September 13, 2022.

[36] Government officials, interview with the authors, October 6, 2022.

[37] The FAA's October 2017 report stated that there "is no active commercial U.S. provider of orbital or suborbital human space flight" (FAA, 2017b, p. 17). The FAA's February 2019 report stated, "There have been only three FAA-licensed launches that carried humans onboard, and all three of those were conducted by one commercial space launch operator" (not named, but FAA licensed launch data confirm that it is Virgin Galactic) (FAA, 2019a, p. 5); for launch data, see FAA, undated-f. The FAA's January 2022 report describes orbital flights by SpaceX and suborbital flights by Virgin Galactic and Blue Origin (FAA, 2022a).

[38] FAA, 2017b; FAA, 2022a.

work that makes up the materials, subsystems, vehicles and equipment, and infrastructure that supports the human space flight industry," as opposed to the suppliers of the flight services themselves.[39] Even though, in the FAA's view, commercial human spaceflight is "inherently international,"[40] to date, U.S. operators' launches and landings have occurred only in the United States or just offshore. Uncrewed commercial launches, however, have occurred overseas.[41]

An array of data and public and private forecasts suggest that the commercial human spaceflight industry might be growing at an accelerating rate in size and complexity. Existing launch companies plan to ramp up operations over the coming years. SpaceX was awarded five more missions as part of NASA's Commercial Crew Program,[42] and it plans on its first commercial spacewalk in 2023.[43] Virgin Galactic is planning to start space tourism flights in the second quarter of 2023 after a series of delays.[44] Blue Origin is aiming to resume suborbital launches in 2023 following the conclusion of an investigation into a September 2022 uncrewed flight mishap and to begin orbital flights in the near future as well.[45] New companies are expected to begin launch operations, including Boeing's Starliner, expected to fly in April 2023,[46] and Space Perspective's stratospheric balloons.[47] Additionally, though not limited to crewed space travel and therefore only a proxy measure for the pace of that activity, FAA data show that licensed or permitted commercial space operations nearly doubled in fiscal year (FY) 2021 from 33 to 64 operations, increased by ten to 74 launches in FY 2022, and are forecasted to fall between 59 (low end) and 186 (high end) by FY 2025.[48]

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[39] FAA, 2017b.

[40] FAA, 2017b.

[41] FAA, *The Annual Compendium of Commercial Space Transportation: 2018*, January 2018.

[42] NASA, "NASA Awards SpaceX More Crew Flights to Space Station," August 31, 2022.

[43] Leonard David, "Polaris Dawn Crew Prepares for World's 1st Private Spacewalk with SpaceX," *Space Insider*, November 22, 2022.

[44] Loren Grush, "Virgin Galactic Says Commercial Space Flights on Track for Second Quarter," *Bloomberg*, November 3, 2022b; Virgin Galactic, "Virgin Galactic Announces Third Quarter 2022 Financial Results and Provides Business Update," press release, November 3, 2022.

[45] Loren Grush, "Jeff Bezos's Blue Origin Expects Launch in 2023 After Rocket Mishap Review," *Bloomberg*, November 9, 2022c; Emre Kelly, "Blue Origin Again Delays Upcoming New Glenn Rocket's First Launch from Florida," *Florida Today*, March 23, 2022.

[46] Loren Grush, "Boeing Starliner's First Crewed Flight Pushed Back to April 2023," *Bloomberg*, November 3, 2022a.

[47] Mike Wall, "Space Perspective Wants to Take Tourists on Balloon Rides to the Stratosphere," space.com, November 2, 2022a; Mike Wall, "World View to Start Flying Passengers on Stratospheric Balloon Rides in 2024," space.com, November 2, 2022b.

[48] FAA, "Licenses, Permits and Approvals," January 5, 2023a.

Private analyst forecasts of growth in the space tourism market over the coming decade vary based on market definitions and reference years but consistently expect strong growth.[49] Looking backward, U.S. Bureau of Economic Analysis (BEA) data on goods and services supply chains that support the space economy (though inclusive of numerous aspects of the space economy beyond human spaceflight) show that growth in the space economy, as measured by its real (inflation-adjusted) contribution to gross domestic product, outpaced overall economic growth over the 2012 to 2019 period, growing at a 2.7 percent annual rate, compared with 2.3 percent for the economy overall.[50] Space-related manufacturing grew at a brisk 7.8-percent annual pace, but much of this was driven by satellites and related equipment; the "other transportation equipment" category (inclusive of manufacturing of space vehicles and space weapons systems) grew by just 1.8 percent annually, though the data do not distinguish between the contribution from space vehicles and from weapons systems.[51]

As of 2019, according to BEA, employment in the private space economy totaled 354,000, with about one-third employed in space-related manufacturing (the employment estimates do not distinguish between satellites and related equipment and other transportation equipment).[52] These BEA data did not allow us to isolate the employment and economic contribution of the portions of this broader industry that supply goods and services to the commercial human spaceflight sector, and we were unable to determine how closely correlated growth in the broader industry is with growth in the networks that supply the human spaceflight sector. However, to the extent that there are shared supply chains across the broader industry, the data provide a way to characterize growth of these networks that supply materials to the launch companies—the third of the four indicators in the industry size and complexity readiness area.[53]

Despite these data and projections, history gives reason for caution. Launch companies have encountered obstacles and delays in developing their systems. Interviewees attributed some of these delays in part to self-regulation within the companies that empowers employees to "call 'stop'" at any point, including on launch day.[54] Both Blue Origin and Boeing have

[49] Northern Sky Research, "Flying Over 57,500 Passengers Toward Space by 2031—Orbital Travel Captures Majority of $20.3 Billion Space Travel Revenue," press release, January 5, 2022; Grand View Research, *Space Tourism Market Size & Growth Report, 2022–2030*, undated; Vantage Market Research, "Global Space Tourism Market Size to Hit USD 3622.5 Mn, with a CAGR of 36.4% | The Rapid Advancement of Technology to Drive the Market," press release, September 21, 2022.

[50] Tina Highfill, Annabel Jouard, and Connor Franks, *Updated and Revised Estimates of the U.S. Space Economy, 2012–2019*, U.S. Bureau of Economic Analysis, 2022.

[51] Highfill, Jouard, and Franks, 2022.

[52] Highfill, Jouard, and Franks, 2022.

[53] We note, additionally, that an industry group has referred to these BEA data in a similar context, as an imperfect gauge of the size of the space commerce industry that includes the commercial space tourism market. See Aerospace Industries Association, *2021 Facts & Figures U.S. Aerospace & Defense*, undated.

[54] Industry officials, interview with the authors, December 7, 2022.

pushed back their timelines for beginning orbital flights.[55] Meanwhile, Virgin Galactic had to put flights on hold for a period because of a 2021 mishap investigation,[56] and it has delayed its planned space tourism flights on several occasions already.[57] FAA operations data (inclusive of crewed and uncrewed launches) show that while actual operations fell short of the "high" projections up to FY 2020, they have exceeded FAA estimates since then.[58]

It appeared to be generally accepted by interviewees that the commercial human spaceflight industry is still small, at least in the terms of the number of flights carrying spaceflight participants into space, but that it is a dynamic and growing industry. When reflecting on the size and complexity of the industry, some interviewees emphasized the limited size of the industry currently, while others emphasized its growth trajectory. For example, one interviewee doubted whether it would be possible to regulate commercial spaceflight given how immature the sector still is.[59] In contrast, two other interviewees underlined that industry growth and technological advances had been pronounced in the past few years, with activity increasing especially since 2019.[60] Some interviewees also mentioned a feature of the industry that made it more complex and potentially difficult to regulate: the changing and nonuniform nature of vehicle designs as companies pursued different design and engineering strategies. One interviewee contrasted the commercial space industry in this regard with the aviation industry, where airplane design is generally stable and well understood.[61]

Interestingly, interviewees did not offer much in the way of data or observations specific to the FAA indicators in this readiness area.[62] Although the FAA readiness indicators equate industry size with the number of firms, interviewees often assessed industry size, in the context of readiness to transition to a safety framework, by reference to the number of flights or the number of participants—or they even used these data to more broadly assess the scale of spaceflight "activity."[63] Interviewees focused on the number of human spaceflights or participants as a primary indicator for increasing size and complexity of the industry because a larger number of flights increases the number of individuals at risk and has implications

55 Emre, 2022; Grush, 2022a.

56 David Shepardson, "U.S. Grounds Virgin Galactic Flights Pending Mishap Probe," Reuters, September 3, 2021.

57 Michael Sheetz, "Virgin Galactic Again Delays Space Tourism Flights, to Second Quarter 2023," *CNBC*, August 4, 2022b.

58 FAA, 2023a.

59 Government officials, interview with the authors, September 13, 2022.

60 Government officials, interviews with the authors, October 6, 2022, and October 7, 2022.

61 Industry officials, interview with the authors, November 8, 2022.

62 The FAA indicators are the number of suppliers of orbital or suborbital spaceflight; the number of suppliers of similar spaceflight types, such as vertical suborbital, horizontal suborbital, and balloon; the extent to which there is a broad supplier network; and the extent to which operations occur internationally.

63 Government officials, interviews with the authors, October 6, 2022, October 7, 2022, and October 13, 2022.

for the current informed consent regime. One interviewee pointed out that more participants increase the number of individuals needing to make informed decisions about their risk tolerance, which increases the chance of some participants not understanding the potential risks of spaceflight.[64]

In terms of the number of spaceflights or participants, interviewees noted that current levels are still low. One interviewee pointed out that the number of spaceflight participants is still small, especially in comparison with the number participating in other recreational activities that are also risky.[65] Another interviewee said that a regulator might be interested in whether there were a million individuals flying in space or just three individuals and cautioned that three was the closer figure to reality at present.[66] Nonetheless, interviewees also said that the industry had shown momentum in recent years. According to one interviewee, the number of spaceflight participants has increased dramatically since 2019, even if the baseline from that year was low.[67] Another interviewee said that the industry had been slower in reaching the tempo of flights that had been expected ten years ago but that it was on verge of breaking through to this higher, expected level of activity now.[68]

Safety of the Industry

This readiness area contains three indicators: the extent to which (1) there is evidence of unsafe operations, (2) the industry is having difficulty attracting new customers, and (3) insurance companies are willing to insure human spaceflight operations. The 2017 FAA report noted that one fatality of a flight crew member had occurred previously (the 2014 crash of Virgin Galactic's SpaceShipTwo) but that "it would be imprudent to assess the safety of future licensed vehicles on the test program of one vehicle operating under an experimental permit."[69] Further commentary on these indicators in the 2017 and subsequent FAA reports is sparse, likely reflecting a combination of a lack of evidence of unsafe operations to date coupled with limited experience on which to base an assessment of customer interest in flying and insurability.

The FAA tabulates the total number of human spaceflights, travelers on those flights, catastrophic failures, and deaths or serious injuries, including both government and commercial operations. Table 3.2 displays data as of October 2022 for commercial operations and documents that there has still just been one catastrophic failure of a commercial flight, entailing two deaths or serious injuries (one death and one serious injury).[70] The 3-percent catastrophic

[64] Government officials, interview with the authors, September 23, 2022.

[65] Government officials, interview with the authors, October 13, 2022.

[66] Government officials, interview with the authors, September 23, 2022.

[67] Government officials, interviews with the authors, October 18, 2022, and November 1, 2022.

[68] Industry officials, interview with the authors, November 8, 2022.

[69] FAA, 2017b.

[70] FAA, 2022e.

TABLE 3.2
Commercial Human Spaceflight Safety Record

Launch Type	Total Number of People on Commercial Human Spaceflights	Total Number of People Who Died or Were Seriously Injured	Percentage of People Who Died or Were Seriously Injured	Total Number of Commercial Human Spaceflights	Total Number of Catastrophic Failures	Percentage of Catastrophic Failures
Orbital	26	0	0%	7	0	0%
Suborbital	66	2	3%	23	1	4%
Total	92	2	2%	30	1	3%

SOURCE: FAA, 2022e.

failure rate is about half the failure rate for small-satellite mission launch vehicles of 6 percent from 2000 to 2016,[71] though it is far higher than the accident rate of less than 1 in 100,000 (or 0.001 percent) for scheduled commercial air service.[72] Furthermore, the catastrophic failure rate for commercial human spaceflight may evolve over time as technology matures.

A more-expansive tabulation of significant incidents in U.S. commercial human spaceflight compiled by NASA's Safety and Mission Assurance office documents just two incidents since 2014, neither of which resulted in any injuries to spaceflight participants: (1) a November 2021 waste management system leak on SpaceX's Crew Dragon Endeavor and (2) an August 2021 delay in an uncrewed test flight of Boeing's Starliner caused by failures of propulsion valves to close properly.[73] Although the September 2022 loss of an uncrewed Blue Origin New Shepard rocket and the successful recovery of the crew capsule is not currently included on the list, it likewise did not result in any injuries to spaceflight participants.[74]

Although the elevated level of risk associated with spaceflight was acknowledged, one common theme from the interviews was that industry has a major incentive to avoid deaths and injuries to spaceflight participants, from both an ethical perspective and a business perspective. Interviewees noted that safety incidents could have a twofold impact on the industry, both through direct negative economic impact and by triggering additional government regulation.[75] Interviewees emphasized that spaceflight companies themselves recognize how detrimental safety incidents could be to the industry and that this provided a large stimulus

[71] Stephen A. Jacklin, *Small-Satellite Mission Failure Rates*, National Aeronautics and Space Administration, NASA/TM-2018-220034, March 2019.

[72] National Transportation Safety Board, "Aviation Accident Rates, 2001–2020," spreadsheet, October 14, 2021h, Table 1.

[73] NASA, JSC SMA Flight Safety Office, "Significant Incidents," infographic, September 30, 2019b.

[74] Kenneth Chang, "Bezos' Rocket Crashes; No People Were Aboard," *New York Times*, September 12, 2022.

[75] Government officials, interviews with the authors, September 1, 2022, and September 15, 2022.

for safety efforts. On the other hand, several interviewees acknowledged that that they lacked visibility into the concrete efforts of private companies to ensure participant safety.[76] According to interviews, one way that companies work to ensure safety is by providing preflight training to participants, although the level and type of training may vary by company.[77] Two interviewees emphasized that, beyond regulation, developing organizational cultures that promoted and valued safety was important for ensuring participant safety.[78]

The interviews did not suggest that companies were having difficulty attracting new customers. Publicly available information confirms that, if anything, demand to travel to space vastly outstrips current supply of these services being offered by operators. For example, Virgin Galactic's most recent quarterly report to the Securities and Exchange Commission includes a section on "Customer Demand" that indicates that "as of September 30, 2022, we had reservations for space flights for approximately 800 future astronauts."[79] Blue Origin has cited "robust demand" from customers, with its chief executive officer stating in 2022 that "I think the challenge for Blue at this point is that we're actually supply limited."[80] SpaceX is developing a larger vehicle, Starship, with an eye toward serving what it believes is a growing market for space travel while lowering the costs of space travel to further expand the potential market for these services.[81]

Information on whether insurance companies are willing to insure spaceflight participants traveling into space is limited. Interviewees did not raise this as a concern. Several reports indicated that insurance companies have made space travel policies available and have even received some customer interest in them, but the reports provide no confirmation that these policies have been sold.[82] More likely, as several articles suggest, travelers rely on their personal life insurance policies, with these insurers not yet accounting for the possibil-

[76] Government officials and other private and expert stakeholders, interviews with the authors, September 13, 2022, October 6, 2022, October 7, 2022, and October 19, 2022.

[77] Government officials, interviews with the authors, September 13, 2022, and October 4, 2022. The National Transportation and Safety Board's investigation into the 2014 SpaceShipTwo accident determined that enhanced attention to "human factors" in flight crew simulator training could reduce the chances of a catastrophe in the future. See National Transportation Safety Board, 2015a, p. 47.

[78] Government and industry officials, interviews with the authors, October 7, 2022, and November 8, 2022.

[79] U.S. Securities and Exchange Commission, Virgin Galactic Holdings, Inc., Form 10-Q, September 30, 2022.

[80] Michael Sheetz, "Bezos' Blue Origin Is Building More Rockets to Meet 'Robust Demand' for Space Tourism, CEO Says," *CNBC*, February 17, 2022a.

[81] Emily Frolick, "Before the 'Trust' Settles," *Fast Company*, November 15, 2022; Bruno Venditti, "The Cost of Space Flight Before and After SpaceX," *Visual Capitalist*, January 27, 2022.

[82] Christopher Elliott, "What Are Your Passenger Rights in Space?" *Washington Post*, November 16, 2022; Sara Lewis Kallop, "Cover Me to the Moon: Will Insurers Provide Coverage for Space Tourism Travel?" *JDSupra*, September 1, 2021.

ity of human space travel when underwriting these policies given the very small number to date of individuals who have flown to space.[83]

Industry's Progress in Developing a Safety Framework

The second set of indicators pertains to industry's progress in developing a safety framework, encompassing the readiness areas of voluntary safety reporting, voluntary consensus standards, and compliance. As the FAA's 2017 report described, and interviewees confirmed, there is an underlying expectation that progress with respect to the first indicator set, industry readiness, would be paired with industry progress in developing a safety framework.[84] In short, the more flights, the more industry should be learning, the more data it should be collecting, and the more advanced its safety reporting, consensus standards, and compliance efforts should be.

In Chapter 2, we discussed in detail industry progress in developing voluntary consensus standards. Here, we summarize that discussion and consider its implications for readiness to transition to a safety framework that might include regulations. We also discuss industry progress with respect to voluntary safety reporting and compliance mechanisms.

Voluntary Safety Reporting

This readiness area includes indicators on (1) the extent to which individual companies have an internal voluntary reporting system to identify and address potential precursors to accidents and (2) the extent to which industry members share safety data with each other, with a common data format and taxonomy. As of 2017, the FAA had "limited insight into [the] extent" of internal company reporting systems and wrote that although there was no industry-wide data-sharing mechanism, it was embarking on a process to develop a framework, including by "conducting research to examine extending to commercial human space flight operations the tools developed for voluntary sharing and mining of aviation data."[85] The FAA's January 2022 report included a 2019 COMSTAC finding that, in its view, "industry is aligned and making progress related to the FAA's vision of safety framework elements such as standards and voluntary reporting systems," but neither the 2019 nor the 2022 FAA report discussed further FAA efforts to develop a reporting system.[86]

Several themes regarding industry voluntary safety reporting emerged from the interviews. Concerning internal voluntary reporting systems, several interviewees said that they

[83] Noor Zainab Hussain and Carolyn Cohn, "Bezos' 2021 Space Odyssey a Risk Too Far for Insurers," Reuters, June 24, 2021; Jason Metz, "Could Commercial Space Travel Affect Your Life Insurance?" *Forbes*, July 19, 2021.

[84] Government and industry officials, interviews with the authors, September 23, 2022, and November 8, 2022.

[85] FAA, 2017b.

[86] FAA, 2022a; FAA, 2019a.

had limited insight into the internal systems used for tracking safety incident data.[87] One interviewee said that it was their assumption that companies collect safety incident information.[88] Despite the lack of direct knowledge and details about internal safety reporting, interviewees did not raise concerns or indicate that they had reason to believe that companies were failing to track safety incidents internally. On the other hand, a major theme from interviews was that company concerns about safeguarding proprietary information and systems are limiting the voluntary sharing of safety information externally.[89]

Another theme was that the aviation industry's system for sharing safety information voluntarily and in a way that protects sensitive company information could be a useful model for the commercial space industry as a whole.[90] However, one interviewee noted that the limited number of companies in the commercial spaceflight industry, at least currently, makes it harder to share safety information anonymously than in the aviation industry.[91] There were differing views on the current level of information-sharing within the industry. One interviewee did not believe that any meaningful safety information-sharing was occurring at present.[92] In contrast, another interviewee thought that some level of safety information-sharing did occur, at least verbally, but felt that concerns about divulging proprietary information limited the sharing of detailed information.[93] A different interviewee said that some information-sharing occurs informally, as employees move from company to company within the industry.[94] One limitation of safety information-sharing noted in an interview is that vehicle design in the commercial spaceflight industry varies substantially from vehicle to vehicle, so that safety data or lessons learned for one vehicle type might not be relevant for other vehicle types.[95] Despite the differences in vehicle design, however, another interviewee noted the importance of sharing information and lessons learned among commercial spaceflight companies.[96]

Voluntary Consensus Standards

We discussed industry progress via SDOs in developing voluntary consensus standards in detail in Chapter 2. This progress has been documented in a series of FAA reports, most

[87] Government officials, interviews with the authors, September 1, 2022, and October 4, 2022.

[88] Government officials, interview with the authors, September 1, 2022.

[89] Government officials, interviews with the authors, September 13, 2022, October 6, 2022, October 7, 2022, and October 13, 2022.

[90] Government officials, interviews with the authors, October 6, 2022, and October 7, 2022.

[91] Government officials, interview with the authors, October 7, 2022.

[92] Government officials, interview with the authors, September 27, 2022.

[93] Government officials, interview with the authors, September 13, 2022.

[94] Government officials, interview with the authors, October 13, 2022.

[95] Government officials, interview with the authors, September 13, 2022.

[96] Industry officials, interview with the authors, December 7, 2022.

notably the January 2022 report, as well as through COMSTAC meetings and documents produced by SDOs, including ASTM, ISO, and others (see Appendix B for a list of standards). As we noted in Chapter 2, some standards related to participant safety have been developed, and companies might (or might not) reference these standards in their practices to some extent. However, we were not able to review company practices to assess which standards (or elements of standards) were being referenced or to confirm how companies decided which standards to reference, because this information was not publicly available.

Interviewees underscored the complex and sometimes conflicting incentives facing industry when it comes to developing and adopting voluntary consensus standards. On the one hand, industry might be incentivized to make progress on safety standards because this progress might help prevent safety incidents that could harm the sector's reputation and potential for future growth.[97] On the other hand, the development of some consensus standards might indicate to the FAA that the sector is ready for regulation, since it would indicate that industry has coalesced around a concrete set of safety requirements and principles that might serve as the basis for future regulation.[98]

Thus, to the extent that it triggers regulation that is viewed as potentially burdensome, there could exist a disincentive to demonstrating significant progress toward voluntary industry consensus standards. Therefore, assessing the significance of progress on voluntary consensus standards requires a determination of whether progress reduces the need for regulation or signals a readiness to transition to regulation. However, because industry has agreed on few standards that might contribute to a safety framework, it is not possible to make this assessment at this time.

Compliance

This readiness area includes indicators on (1) internal-to-company self-verification with voluntary consensus standards and (2) the extent of third-party verification of compliance. As of 2017, the FAA wrote that there were no voluntary standards with which to comply. By January 2022, some standards did exist, but the FAA reported a lack of visibility into "the extent to which industry is incorporating voluntary standards into commercial space transportation operations," which presumably included whether they verified compliance with those standards.[99]

Interviews provided little or no evidence concerning the commercial spaceflight industry's progress on either internal or third-party compliance with voluntary consensus standards. Interviewees did point out that companies participating in NASA's Commercial Crew Program must comply with NASA safety requirements, although these are distinct from vol-

[97] Government officials, interview with the authors, October 13, 2022.

[98] Government officials, interview with the authors, September 1, 2022.

[99] FAA, 2017b; FAA, 2022a.

untary industry consensus standards.[100] Consistent with the 2022 FAA report, several interviewees noted that they had limited insight or visibility into how individual companies were using safety standards or guidelines or recording information about safety incidents.[101]

Although a number of interviewees noted that the industry is incentivized to ensure occupant safety and has maintained a good safety record thus far, what contribution, if any, is made by internal compliance with voluntary consensus standards was not quantified or well characterized.[102] Interviewees did emphasize the importance of fostering strong safety cultures at commercial spaceflight companies as a complement to safety standards or regulations.[103]

As for external validation of compliance, multiple interviewees raised the point that companies are wary of sharing information externally out of concern about being put at a competitive disadvantage.[104] A third-party system of compliance verification that includes robust mechanisms for protecting sensitive information and maintaining anonymity as appropriate will likely be needed.

Department of Transportation Readiness

The final set of indicators pertains to the readiness of the Department of Transportation, and in particular FAA's AST, to transition to a safety framework that might include regulations. Though the CSLCA language that describes what this independent review shall evaluate does not explicitly state that indicators of government readiness are among those to be discussed, we include such a discussion in this section because government readiness indicators were included in the FAA report alongside indicators of industry readiness and because the report emphasized that the three sets of indicators were intertwined.[105] Moreover, we believe that government readiness is important to consider when assessing readiness to transition to a safety framework that could entail a larger regulatory role for the FAA. Readiness areas within this indicator set included the FAA's authority to regulate (i.e., the status of the learning period) and the FAA's expertise in human spaceflight safety. We address these two dimensions in this section.

[100] Government officials, interviews with the authors, September 23, 2022, and September 26, 2022.

[101] Government officials, interviews with the authors, September 1, 2022, October 4, 2022, and October 6, 2022.

[102] Government officials, interviews with the authors, September 1, 2022, September 15, 2022, and October 13, 2022.

[103] Government and industry officials, interviews with the authors, October 7, 2022, and November 8, 2022.

[104] Government officials, interviews with the authors, September 13, 2022, September 27, 2022, October 6, 2022, October 7, 2022, October 13, 2022, October 18, 2022, and November 1, 2022.

[105] FAA, 2017b.

Status of Learning Period/Moratorium

Under current law, the FAA remains prohibited from regulating to protect occupant safety apart from "design features or operating practices" that lead to or pose "a high risk of causing a serious or fatal injury," with this moratorium scheduled to expire on October 1, 2023.[106] Therefore, the FAA does not currently have the authority to transition to a safety framework that may include regulations. However, there is evidence to suggest that the agency is laying the groundwork for the possibility that this might soon change. Several interviewees indicated that the FAA was either considering or planning to convene a Space Aerospace Rulemaking Committee (SpARC) for human spaceflight in early 2023 that would include industry and government officials.[107] COMSTAC's SWG has provided inputs that might inform the scoping and guidance provided to this SpARC.[108] Meanwhile, the FAA's FY 2023 budget request included a plan to develop a human spaceflight program, with "pre-rulemaking activities for human space flight, including stakeholder engagement through [a SpARC]."[109] Appropriations legislation for FY 2023 enacted in December 2022 included a $5.4 million increase for commercial space operations (to $37.9 million),[110] with the explanatory statement indicating that this includes "up to 40 new positions for launch and reentry licensing activities and human spaceflight activities."[111] The appropriated amount reflected an increase over the House-passed and draft Senate appropriations bills for FY 2023 but fell short of the Department of Transportation's request for $42.8 million for commercial space.[112]

We learned from our interviews (most of which were conducted prior to the enactment of FY 2023 appropriations legislation) that ambiguities surrounding authorities and funding pose challenges for the FAA. One interviewee said that the FAA was shifting some resources to prepare for the end of the moratorium, although the extent of the shift was limited by resource constraints.[113] Another interviewee made the point that any continuing uncertainty

[106] 51 U.S.C. Chapter 509.

[107] Government officials, interviews with the authors, September 23, 2022, October 4, 2022, and October 7, 2022.

[108] FAA, *COMSTAC Safety Working Group Report*, May 2022b.

[109] U.S. Department of Transportation, Budget Estimates Fiscal Year 2023: Federal Aviation Administration, undated.

[110] U.S. House of Representatives, Consolidated Appropriations Act, 2023, Bill 2617, December 29, 2022b.

[111] U.S. Congress, *Division L—Transportation, Housing and Urban Development, and Related Agencies Appropriations Act*, conference committee joint explanatory statement, December 19, 2022.

[112] U.S. Senate, *Explanatory Statement for the Departments of Transportation, and Housing and Urban Development, and Related Agencies Appropriations Bill, 2023*, Committee on Appropriations, July 28, 2022; U.S. House of Representatives, Transportation, Housing and Urban Development, Agriculture, Rural Development, Energy and Water Development, Financial Services and General Government, Interior, Environment, Military Construction, and Veterans Affairs Appropriations Act, 2023, Bill 8294, July 26, 2022a; U.S. Department of Transportation, undated.

[113] Government officials, interviews with the authors, October 18, 2022, and November 1, 2022.

about whether there would be another extension beyond 2023 made it harder for the FAA to prioritize resources on human spaceflight rulemaking because there are competing demands for resources within the agency.[114]

Federal Aviation Administration Expertise in Human Spaceflight Safety

A second component of government readiness is whether the FAA has sufficient expertise to transition beyond engagement in an industry-led safety framework to taking on a regulatory role. Indicators in this readiness area are the extent to which the FAA (1) has helped create elements of a space safety framework, (2) has engaged with industry regarding standards development, (3) has published safety practices related to commercial human spaceflight, and (4) has experience participating in a space safety framework.

Since enactment of the CSLCA, the FAA has regularly participated in discussions related to a space safety framework and standards development, including via its engagement with COMSTAC and SDOs, such as ASTM's Committee F47 on Commercial Spaceflight, as our interviews confirmed.[115] It also is considering setting up a SpARC as an additional forum for discussions on what a safety framework might entail, as previously noted. Additionally, the agency is in the process of revising a 2014 publication, *Recommended Practices for Human Space Flight Occupant Safety*, describing recommended practices for human spaceflight safety that might form a starting point for future regulatory efforts.[116] However, information gained through our interviews suggested that the expertise developed and demonstrated by FAA officials and staff through these engagements has not yet prepared the agency to make an abrupt transition to an expansive regulatory role; rather, interviewees viewed a gradual transition, with increased staffing levels and further cultivation of expertise, as a more feasible path forward.

In particular, there was a consensus across interviewees that the FAA is currently underresourced to take on additional regulatory responsibilities related to human spaceflight safety. Several interviewees pointed out that AST lacks resources to carry out its current regulatory duties, especially given the growth of the space industry overall, let alone to take on a major new role writing and implementing spaceflight participant safety regulations.[117] NASA was offered up in several interviews as an illustrative point of comparison, as interviewees reported that the agency's Commercial Crew Program is much better resourced than AST.[118] Interviewees said that AST requires additional resources to fulfill its current responsibilities in a timely manner and would require even more resources to undertake additional

[114] Government officials, interview with the authors, October 7, 2022.

[115] Private and expert stakeholders, interview with the authors, October 19, 2022.

[116] Government officials, interviews with the authors, September 27, 2022, October 6, 2022, October 18, 2022, and November 1, 2022; FAA, 2014.

[117] Government officials, interviews with the authors, September 13, 2022, October 6, 2022, and October 13, 2022.

[118] Government and industry officials, interviews with the authors, October 7, 2022, and November 8, 2022.

duties related to human spaceflight regulation. Several interviewees noted at the time of the interviews that the FAA had requested additional resources from Congress.[119] The subsequent FY 2023 appropriations for the FAA provided $37.9 million for funding commercial spaceflight operations.[120] However, based on the general consensus of the interviewees, FAA AST would need a sustained increase in resources over time to facilitate effective regulatory processes.

Figure 3.2 displays appropriated amounts and full-time equivalent (FTE) staff for AST from FY 2015 to FY 2022.[121] It shows that appropriations increased markedly in FY 2022 and FY 2023 after changing little over several years prior to that when adjusted for inflation. FTE increased in FY 2021 and FY 2022 after hovering around 100 for a few years and is expected to increase further in FY 2023, in line with the FY 2023 appropriations bill language.

Interviewees had mixed views concerning FAA expertise and experience with human spaceflight safety. Some interviewees said that FAA staff currently possess substantial relevant knowledge and technical ability.[122] It was pointed out that the FAA could also draw from the technical expertise of the Aerospace Corporation, a federally funded research and development center for space issues, and its Space Safety Institute.[123] But a number of interviewees reported that the FAA faced expertise gaps in the area of human spaceflight safety. Interviewees argued that this is partly because the FAA's legislative mandate has been focused on launch and reentry operations and public safety, rather than participant safety, which is reflected in its staff's current expertise and skill sets.[124] The FAA would benefit from staff with more knowledge and technical skill sets relevant to human safety regulation, interviewees said, with one person suggesting that additional collaboration between NASA and the FAA might be helpful.[125] Industry representatives also have provided testimony to Congress

[119] Government officials, interviews with the authors, October 13, 2022, October 18, 2022, and November 1, 2022.

[120] U.S. House of Representatives, 2022b.

[121] Because final appropriations for FY 2022 matched the Department of Transportation's budget request (and exceeded the FY 2022 continuing resolution amounts included in the FY 2023 budget request), rising to $32.47 million, we assume that FTE also increased from the continuing resolution level of 108 FTE to the "restoration of FY 2022 request" level of 113 FTE. We did not include FTE for FY 2023. We anticipate that it will fall between 113 and the budget request of 140 FTE (because the appropriated amount of $37.854 million fell between the FY 2022 amount of $32.47 million and the FY 2023 requested amount of $42.777 million).

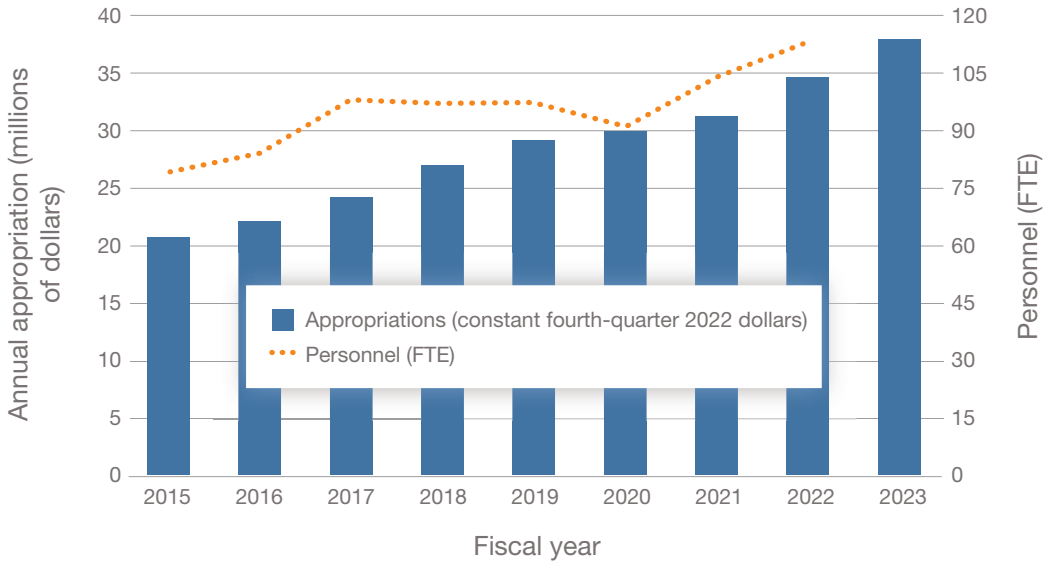
[122] Government officials, interviews with the authors, September 26, 2022, and September 27, 2022.

[123] Government officials and other private and expert stakeholders, interviews with the authors, September 15, 2022, and September 27, 2022.

[124] Government and industry officials, interviews with the authors, September 26, 2022, and November 8, 2022.

[125] Government officials, interviews with the authors, September 26, 2022, and October 4, 2022.

FIGURE 3.2
Federal Aviation Administration Office of Commercial Space Transportation Funding and Full-Time Equivalent Staff, FY 2015–FY 2023



SOURCE: FAA budget documents: FAA, "Budget," webpage, undated-c; Public Law 117-103, Consolidated Appropriations Act, 2022, March 15, 2022; Public Law 117-328, Consolidated Appropriations Act, 2023, December 20, 2022; BEA, Gross Domestic Product: Implicit Price Deflator [GDPDEF], retrieved from Federal Reserve Bank of St. Louis, FRED Economic Data, "Gross Domestic Product, Implicit Price Deflator," January 26, 2023.

NOTE: Appropriated amounts are in constant fourth-quarter 2022 dollars (the first quarter of FY 2023), adjusted for inflation using the Gross Domestic Product Implicit Price Deflator from BEA (based on the deflator for the first quarter of each FY). FY 2021 to FY 2023 amounts reflect enacted appropriations. Prior years reflect actual spending.

calling for increased funding for AST to support industry rotations for its employees so they can "better understand the state of the art and its continuing advancement."[126]

Summary

For the majority of indicators defined by the FAA, we found that key terms, specific measures, and how data would be collected (and by whom) are not described, specified, or otherwise delineated in a manner that would allow for us to properly assess progress in a valid manner. We found that adventure remains the principal reason why people are flying to space, that the industry shows signs of potentially accelerating growth in size and complexity despite remaining small at present, and that there have been very few safety incidents to date.

[126] U.S. House of Representatives, *Starships and Stripes Forever—An Examination of the FAA's Role in the Future of Spaceflight*, Remote Hearing Before the Subcommittee on Aviation, U.S. Government Printing Office, July 16, 2021.

Industry progress in developing a shared safety framework has improved in recent years, but, as discussed in Chapter 2, safety reporting, safety standards, and compliance with standards typically remains company-specific and internal to each company. For its part, the FAA has engaged with industry through COMSTAC and via participation in SDO meetings, developing greater expertise of human spaceflight safety in the process, but has lacked the budget and staff resources to develop a full slate of commercial human spaceflight regulations.

Although we were required under the CSLCA to assess progress toward meeting the key industry metrics as part of this independent review, we do not view the progress or lack thereof as gauged by these metrics as a precondition for readiness to transition to a safety framework that might include regulations. It is important to note that the FAA did not include specific targets for the indicators that would indicate degrees of readiness to transition to specific elements of a safety framework. Interviewees also were hard-pressed to identify bright lines based on these or other metrics that would signal readiness to end the moratorium and transition to a framework that might include regulations. Most did not believe that a binary view of whether regulations were appropriate was the right approach but, rather, that some aspects of industry operations might be ready for some forms of regulations, while others might not be. That said, as described in following chapters, we ultimately recommend allowing the moratorium to end. This will allow for a new phase of metrics development. Thus, in the next chapter, we move beyond these indicators to provide our framework and assessment of readiness for regulation.

CHAPTER 4

Next Steps: Further Standards Development and Regulation Readiness

The third question that Congress required this report to address is whether the areas identified in the previous reports[1] submitted by the FAA to Congress pursuant to the CSLCA are appropriate for regulatory action or further development of voluntary consensus standards.[2] This third question required us to determine whether the commercial space industry has made sufficient progress with respect to the two focal areas of the FAA's previous reports: (1) the adoption of voluntary consensus standards and (2) meeting key industry metrics that relate to the knowledge and operational experience obtained "by the commercial industry while providing services for compensation or hire."[3] The answer to this question also answers the question in the prefatory language of the congressional mandate for this study—i.e., the requirement for an "independent" reviewer to provide an "assessment of the readiness of the commercial space industry to transition to a safety framework that may include regulations."[4]

Using the foregoing analysis and the analysis presented in this chapter, we find that the commercial space industry should transition to a safety framework that includes the opportunity for federal regulations to be issued. This is to say that we recommend that the moratorium set to expire on October 1, 2023, should expire on that date, but it will be important to ensure that the FAA is appropriately resourced to engage in these activities (if determined to be necessary).[5] Accordingly, as prescribed by the CSLCA, the development of any regulations after that date "shall take into consideration the evolving standards of the commercial space

1 FAA reports submitted pursuant to CSLCA, Section 111; 51 U.S.C. § 50905(c)(5) ("Interim Voluntary Consensus Standards Reports") and § 50905(c)(6) ("a report specifying key industry metrics that might indicate readiness of the commercial space sector and the Department of Transportation to transition to a safety framework that may include regulations…"). These reports have been previously described and examined in Chapters 2 and 3 of this report.

2 CSLCA, Section 111; 51 U.S.C. § 50905(c)(8)(C).

3 CSLCA, Section 111; 51 U.S.C. § 50905(c)(8)(A) and (B).

4 CSLCA, Section 111; 51 U.S.C. § 50905(c)(8).

5 CSLCA, Section 111; 51 U.S.C. § 50905(c)(9).

flight industry as identified in the reports published under paragraphs (5), (6), and (7)."[6] To meet this statutory requirement, we further recommend that the FAA proceed to implement a SpARC.[7]

It is important to note that we are not suggesting or recommending that any particular regulations be issued at that time. As noted by some of our interviewees, the expiration of the moratorium merely enables both industry and the FAA to move forward on the development of a human spaceflight participant safety framework in a manner that may also develop actionable, effective, and transparent consensus-based safety standards and metrics.[8] By giving the FAA the authority and opportunity to issue regulations, both the agency and industry will be incentivized to engage actively and substantively in the pre-rulemaking SpARC processes. Additionally, as required or as the agency determines it to be helpful, the FAA will be able to engage the public rulemaking process pursuant to the Administrative Procedure Act.[9] This process can facilitate the FAA's collection of necessary data, information, evidence, viewpoints, and opinions through the issuances of Advance Notices of Proposed Rulemaking (ANPRMs) and/or Notices of Proposed Rulemaking (NPRMs).[10]

A Framework for Assessing Readiness

To assess whether the commercial space industry and the federal government are ready to transition to a safety framework that may include regulation, it was necessary to define *readiness* in the context of human spaceflight participant safety. The term is not defined by the CSLCA. Moreover, although the FAA reports delineate readiness indicators and areas, the reports also do not define *readiness*. The concept of *regulatory readiness* has been explored in the context of transformative technologies in the energy sector, which is an informative guide-

6 CSLCA, Section 111; 51 U.S.C. § 50905(c)(9). Note that the phrase "paragraphs (5), (6), and (7)" refer to the FAA's previous reports on the progress of the development of voluntary consensus standards, the progress of key metrics related to those standards, and the identification of activities most appropriate for a new safety framework that may include regulatory action.

7 As we understand the SpARC process from various interviewees, the FAA does not need the moratorium to sunset before implementing SpARCs. However, interviewees also noted that it was difficult for both the government and industry to plan for, prioritize, and set aside the necessary resources for SpARCs while the moratorium was in place. This is due to the tendency to prioritize other issues because the moratorium is also a basis to put off or delay rulemaking efforts. Government officials, interviews with the authors, October 6, 2022, and November 11, 2022

8 Government and industry officials, interviews with the authors, September 23, 2022, October 4, 2022, and November 8, 2022. The framework would also include crew and government astronauts in addition to commercial spaceflight participants.

9 See, generally, the Administrative Procedure Act, U.S. Code, Title 5, Government Organization and Employees, Section 553, Rulemaking. See also regulations delineating the FAA's specific rulemaking authorities, 14 CFR Chapter I, Subchapter B, Part 11 (General Rulemaking Procedures).

10 See, generally, 5 U.S.C. § 553; see also 14 CFR §§ 11.3 (ANPRMs) and 11.5 (NPRMs).

post for developing a working definition in the context of the commercial space industry.[11] In the energy sector, a *regulatory readiness level* for a particular technology is assessed based on the following factors: (1) access to, and understanding of, the regulatory process; (2) security of regulatory support (i.e., the level of certainty of future regulations); (3) the effectiveness of the regulatory support for the technology (i.e., that regulations could be issued that would support both public safety and technology development); (4) environmental effects, costs, and security issues related to the regulation ("do no harm");[12] and (5) the ability to pass the regulation (or legislation) (i.e., the political and social acceptability of the regulation).[13]

To assess readiness in the context of commercial spaceflight safety, we adapted these five factors to more closely relate to the readiness issues identified by our interviewees and the data and information they provided. In the following sections, we take each factor into consideration.

Access to, and Understanding of, the Regulatory Process

Subject-matter expert and stakeholder interviewees agreed nearly unanimously that commercial space stakeholders had appropriate access to, and an understanding of, the regulatory process with respect to human spaceflight.[14] Commercial stakeholders operating or investing in the space sector are generally well resourced (both in terms of capital and staff). The leadership, management, and staff are generally highly sophisticated, experienced, and familiar with operating in compliance with federal statutory and regulatory regimes. Most importantly, commercial stakeholders are well-represented, active participants in both COMSTAC[15] and ASTM F-47, which are the current standards and metrics development entities.[16] Commercial stakeholder interviews conveyed a high level of understanding of the SpARC and the formal Administrative Procedure Act Federal Register rulemaking processes.[17] Some interviewees, however, did point out that the sector includes small startup companies that may

[11] Kobos et al., 2018.

[12] For this criterion, we substitute human safety for the environment effects as described by Kobos et al., 2018, p. 215 ("Do No Harm" section).

[13] Kobos et al., 2018, pp. 213–215.

[14] Government and industry officials and other private and expert stakeholders, interviews with the authors, September 13, 2022, September 15, 2022, September 26, 2022, October 6, 2022, and November 8, 2022.

[15] COMSTAC members are listed at FAA, "Commercial Space Transportation Advisory Committee, January 2023 Membership," undated-e.

[16] F-47 representatives are listed at ASTM International, "Committee F47 Officers and Staff Support," webpage, undated-a.

[17] Industry officials, interviews with the authors, November 14, 2022, and November 15, 2022.

not have the resources and staff to fully engage in a SpARC or formal rulemaking process.[18] Notwithstanding this, the interview data demonstrate that the commercial space industry has both access to the regulatory process and a substantive understanding of it.

Security of Regulatory Support

Discussions with government officials, commercial stakeholders, industry group representatives, and SDOs demonstrated a common belief that formal regulations for human participant spaceflight were inevitable.[19] A majority of interviewees agreed that if a major mishap or accident occurred in which spaceflight participants were killed or seriously injured, Congress would be very likely to enact legislation requiring safety regulations immediately or very soon after such an incident.[20] However, interviewees also agreed that it should not be necessary, nor would it be preferrable, to wait to institute a regulatory regime until the aftermath of a catastrophic incident. Interviewee consensus demonstrated that a more thorough and thoughtful path to regulation would be through a SpARC and formal processes that take time to pursue, and that such a path would potentially reduce the likelihood of a catastrophic incident.[21]

Effectiveness of the Regulatory Support for the Technology

Numerous interviewees expressed a belief that the FAA, or other regulatory agency if designated, would likely be sensitive to the potential for regulations to be overly burdensome such that they would jeopardize sector growth and/or negatively impact certain companies inequitably (emergent startups, for example).[22] This is particularly so given that Title 51 itself requires that the Secretary "encourage, facilitate, and promote commercial space launches and reentries by the private sector, including those involving space flight participants."[23]

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[18] Government and industry officials, interviews with the authors, October 13, 2022, November 8, 2022, and December 7, 2022.

[19] Government and industry officials, and private and expert stakeholders, interviews with the authors, September 15, 2022, October 19, 2022, November 8, 2022, and December 7, 2022.

[20] Government and industry officials, and private and expert stakeholders, interviews with the authors, September 15, 2022, October 13, 2022, October 19, 2022, November 8, 2022, and December 7, 2022. We note that, as stated in Chapter 1, the FAA maintains authority (notwithstanding the moratorium) to regulate if incidents occur that result in "a serious or fatal injury . . . to crew, government astronauts, or space flight participants" pursuant to 51 U.S.C. § 50905(c)(2)(C)(i).

[21] Government and industry officials, and private and expert stakeholders, interviews with the authors, September 13, 2022, September 15, 2022, October 13, 2022, October 19, 2022, November 8, 2022, and November 22, 2022.

[22] Government and industry officials, interviews with the authors, October 13, 2022, November 18, 2022, and December 7, 2022.

[23] See U.S. Code, Title 51, Section 50903, General Authority, Subsection b, Facilitating Commercial Launches and Reentries, Subsection 1.

Interviewees noted that, based on the FAA's prior development and issuance launch and reentry regulations,[24] the agency had both expertise and a robust understanding of the impact of regulations (both positive and negative) on commercial space stakeholders.[25]

Additionally, interviewees generally agreed that the FAA SpARC and formal rulemaking processes—as demonstrated by the development of 14 CFR Part 450—enabled both industry and other private-sector stakeholders (e.g., the public, the insurance industry) to provide input and feedback such that the process as a whole was supportive of the growth of commercial spaceflight.[26] That said, there was consensus among a majority of interviewees that both the SpARC and the formal regulatory process could be lengthy and resource intensive for both the FAA and commercial industry.[27] Other interviewees noted that the SpARC and formal rulemaking could also be hampered by communication issues between industry and the government and by a lack of expertise if the right individuals were not selected or were not able to participate.[28]

Human Safety Effects, Costs, and Security Issues Related to the Regulation ("Do No Harm")

In general, most interviewees expressed the belief that participant safety regulations, if developed by the FAA in partnership with commercial and private stakeholders, would likely result in lower risks of death or injury to commercial spaceflight participants than if either group were solely responsible for safety.[29] Stakeholder interviewees, primarily commercial industry entities and industry representative entities, expressed concerns that formal rule-

[24] See, generally, 14 CFR Part 450.

[25] Government and industry officials, interviews with the authors, November 18, 2022, November 30, 2022, and December 7, 2022. We note, however, that some interviewees expressed concerns that 14 CFR Part 450 licensing regulations were already "burdensome enough" without the addition of new regulations regarding safety resulting in a licensing backlog. Thus, according to these stakeholders, resource constraints both at the FAA and across the industry should be taken into account if and when safety regulations are developed.

[26] Industry officials, interviews with the authors, November 18, 2022, and December 7, 2022. We note, however, that one interviewee expressed concern that the streamlining process employed to update 14 CFR Part 450 moved too quickly. The interviewee indicated that the streamlining process did not always include personnel with the necessary expertise, that feedback from industry was often too rushed, and that the goals and objectives of the update could have been scoped better. (See, generally, Wayne Monteith, Michelle Murray, Charles Huet, and John Sloan, "Update to Streamlining Commercial Space Transport Regulations," 72 International Astronautical Congress, D6.1.1, October 25–29, 2021.

[27] Government and industry officials, interviews with the authors, September 13, 2022, September 15, 2022, November 8, 2022, and December 7, 2022.

[28] Government and industry officials, interviews with the authors, September 26, 2022, November 8, 2022, and December 7, 2022.

[29] Government and industry officials, and private and expert stakeholders, interviews with the authors, September 13, 2022, October 13, 2022, October 19, 2022, and November 8, 2022.

making by the FAA or any government agency with respect to participant safety would result in financial and resource costs that would inhibit sector growth and/or negatively impact specific companies.[30]

However, when pressed on these concerns, no interviewee could provide quantifiable evidence to support the claim. The claims were all indeterminate in nature and appeared to stem from a generalized concern or fear that government regulations would result in increased costs that impede or damage the industry.[31] Likewise, industry stakeholders expressed concerns that regulations might force them to disclose sensitive proprietary information that could harm their firm's financial security.[32] Again, however, these fears were abstract and without any quantifiable measure.

This is not to say that both concerns are invalid. However, it is not possible to articulate, a priori, any economic or security harms to industry caused by regulations in absence of the regulations themselves. This fact does not argue for a continued moratorium of regulations given that, at no point since the moratorium was imposed in 2004, does it appear that the cost of any proposed regulations has been quantified in a manner that would allow for an informed decision to be made regarding the issuance of such regulations and their impact on industry (positive or negative). Instead, the speculative nature of these concerns argues for the lifting of the moratorium so that proposed regulations can be drafted for the purposes of conducting a benefit-cost analysis pursuant to Office of Management and Budget Circular A-4 and Executive Order 12866.[33] A cost analysis could occur during the SpARC or formal rulemaking processes. Moreover, rather than focusing on industry *readiness* for regulation, there could be opportunities to conduct a benefit-cost analysis of considered regulations. For certain safety standards, devices, or systems, there might be quantitative and qualitative data that can be collected to determine whether particular regulations themselves are appropriate or not. This removes some of the normativity and subjectivity inherent in the question of readiness (discussed in more detail later in this chapter).

[30] Industry officials and private and expert stakeholders, interviews with the authors, September 15, 2022, October 19, 2022, November 8, 2022, and December 7, 2022.

[31] See, generally, the discussion of corporate disposition to regulations in Peter M. Madsen, "Does Corporate Investment Drive a 'Race to the Bottom' in Environmental Protection? A Reexamination of the Effect of Environmental Regulation on Investment," *Academy of Management Journal*, Vol. 52, No. 6, December 1, 2009 (finding that environmental regulation and corporate investment growth need not be mutually exclusive, and that regulation does not harm corporate and economic growth of a sector [using the automobile industry as a sector of analysis]).

[32] Industry officials, interviews with the authors, November 8, 2022, and December 7, 2022.

[33] See Circular No. A-4, "Regulatory Analysis," U.S. Office of Management and Budget, September 17, 2003; Executive Order 12866, "Regulatory Planning and Review," Executive Office of the President, September 30, 1993.

Ability to Issue the Regulation—the Political and Social Acceptability of the Regulation

Although we did not specifically ask about social or political acceptability, interviewees did not organically express concerns that participant safety regulations would face political or social opposition. It is possible, of course, that specific regulations—depending on their substance—could face opposition for any number of political or social concerns. Concerns regarding the ability of the FAA to issue regulations focused primarily on the FAA's resource constraints.[34] The ability of the FAA to develop and manage both SpARCs and a formal rulemaking process requires both funding and personnel (particularly personnel with the appropriate space domain subject-matter expertise and the appropriate administrative and rulemaking expertise). Both government and nongovernment stakeholders agreed that the FAA is not currently resourced for either process and expressed concern that implementing these processes without sufficient resources would result in a failure to issue regulations in a timely manner (if at all) or the issuance of regulations that would not be effective (with respect to safety and/or industry growth).[35]

Normative and Subjective Issues

An assessment of the readiness of the commercial space industry and the federal government to transition to a safety framework that might include regulations also involves making normative and subjective judgments regarding participant safety. For example, does the fact that the spaceflight participant population is small mean that the industry need not be subject to formal rulemaking in this area? Similarly, does the fact that current spaceflight participants may be categorized as adventure travelers or adventure-seekers mean that they assume a greater level risk to their lives and safety than a participant who might join a spaceflight to conduct a scientific experiment as part of their employment? Does the fact that a participant signs an informed consent document shift the burden of risk of death or injury entirely to the participant (as is the case now)? Should the commercial spaceflight provider assume the burden of having to meet a regulatorily prescribed safety standard, thereby potentially lowering the risk assumed by the participant?

The answers to these and similar questions are primarily based on normative and subjective judgments, not quantitative or scientific determinations. These judgments can impact an assessment of whether sufficient progress has been made with respect to voluntary safety standards and key metrics. This congressionally mandated study did not specifically task us with conducting a normative, values-based analysis with regard to the three topics posed

[34] Government and industry officials, interviews with the authors, September 27, 2022, October 6, 2022, October 7, 2022, October 13, 2022, November 8, 2022, and December 7, 2022.

[35] Government and industry officials, interviews with the authors, September 27, 2022, October 6, 2022, October 7, 2022, October 13, 2022, November 8, 2022, and December 7, 2022.

in the legislation. Notwithstanding this, the assessment of whether progress has been made toward a standard, a key metric, or readiness in general is often open to normative and subjective opinion. The term *safety* itself involves preconceived notions that can differ significantly among individuals based on their own personal values and risk tolerances. In keeping with this fact, many interviewees expressed normative and subjective concerns and opinions that could be relevant to Congress's consideration and deliberation of these issues as they relate to spaceflight participant safety.

Participant Purpose or Intent of Travel in Space

Interviewees were split on the question of whether the purpose of the travel of the spaceflight participant was relevant to the question of imposing formal (binding) regulations on the industry.[36] Some interviewees did not believe that there should not be any distinction between a participant who is an adventure-seeker and a participant who is traveling for scientific, employment, transport, or other reasons that could be deemed less pleasure related or less voluntary in nature.[37] In other words, the same safety standards, including formal regulatory protections, should apply to all types of travelers regardless of the purpose of travel. In contrast, other interviewees asserted that adventure-seeking or pleasure-seeking participants should be deemed to have accepted an increased level of personal risk, thereby reducing the need to provide them with any formal regulatory safety rules related to their protection.[38]

Participant Population Size

Similarly, the number of flight operators, flights, and participants traveling into orbit or suborbit was another area about which interviewees expressed normative or subjective concerns. Some interviewees believed that, if the number of participants in space remained low, there would be less need to impose formal regulations on the industry.[39] Other interviewees expressed a belief that, as the number grew, there would be a greater need for formal rules to ensure a certain level of protection for the traveling population.[40] Essentially, interviewees associated varying levels of risk that participants should be in a position to accept with how many participants would be at risk of death or injury if a catastrophic event occurred. This

[36] Government and industry officials, interviews with the authors, October 6, 2022, October 13, 2022, November 8, 2022, and December 7, 2022.

[37] Government and industry officials, interviews with the authors, October 6, 2022, October 13, 2022, November 8, 2022, and December 7, 2022.

[38] Government and industry officials, interviews with the authors, October 6, 2022, October 13, 2022, November 8, 2022, and December 7, 2022.

[39] Government officials, interviews with the authors, October 6, 2022, October 7, 2022, and November 1, 2022.

[40] Government officials, interviews with the authors, September 23, 2022, September 26, 2022, and October 13, 2022.

factor gets into difficult ethical and potentially contentious questions concerning the value of one human life (or a small number of lives) versus the value of a group of lives. Notwithstanding the difficult ethical considerations, federal agencies—including the Department of Transportation—do have guidance regarding the valuation of the reduction of fatalities and injuries by regulations or investments.[41] This guidance could be applied to a spaceflight participant regulatory framework.

Participant Death or Injury

Interviewees also expressed concerns regarding whether the risk of death or injury to a participant warrants formal regulations based on the nature of space travel itself. Some interviewees noted that space travel, regardless of the purpose of travel (adventure-seeking, employment, transport, etc.) involves an exceptional level of inherent risk.[42] These interviewees stated, in varying articulations, that participants are placing themselves on the top of rockets to go to an environment that is extraordinarily dangerous to human life, so what can they reasonably expect in terms of safety protections and/or guarantees?[43] The implication of this line of reasoning is that the risks inherent in spaceflight are significant, obvious, and knowingly accepted by the participants, and that as such it is not reasonable to shift additional responsibility for their safety to industry in the form of formal regulations.[44]

A common articulation by interviewees on this point was to compare spaceflight with adventure (or extreme) sports, such as scuba diving, skiing, hang gliding, bungee jumping, sky diving, and rock climbing. A number of interviewees (government and industry stakeholders) asserted that these activities were generally not regulated and, because the inherent risk of death or injury is similar to that of spaceflight, participant safety should not be formally regulated by the FAA or another government agency. We found this assertion and comparison to be without support. Upon examination, it is evident that adventure sports are, in fact, regulated to a substantive degree. The form of this regulation, however, differs from activities or operations regulated by the issuance of federal statutes or codified regulations.

[41] See U.S. Department of Transportation, "Departmental Guidance on Valuation of a Statistical Life in Economic Analysis," webpage, March 23, 2021.

[42] Government and industry officials, interviews with the authors, September 23, 2022, September 27, 2022, October 6, 2022, November 18, 2022, and December 7, 2022.

[43] Government and industry officials, interviews with the authors, September 23, 2022, September 27, 2022, October 6, 2022, November 18, 2022, and December 7, 2022.

[44] This is not to imply that industry does not share any risk with respect to spaceflight safety generally. The current statutory and regulatory framework requires spaceflight providers to conduct safe launch and reentry operations. Notwithstanding this, if there is a wrongful death or injury to a participant, that individual, or the individual's estate, would have to pursue an individual legal claim against the provider to seek recompense, rather than a regulator intervening on their behalf. This places the burden of proof on the spaceflight participant in the case of wrongful death or serious injury.

The regulation of adventure sports occurs primarily through the state court systems, but also through state legislatures via sport safety statutes.[45] Decades of lawsuits filed against adventure sport providers have created an existing and enforceable body of case law that functions as a regulatory regime. As a general matter, courts impose a "duty of care" on adventure sports providers that even a signed informed consent form or waiver does not obviate.[46] Additionally, courts may invalidate informed consent forms or waivers that fail to provide appropriate notice or are otherwise inadequate.[47] Breaching a duty of care to a customer results in a finding of responsibility and liability on the part of the commercial provider.[48] To ensure against a finding of breach, commercial providers are required, as a matter of law, to take steps to eliminate (where reasonably possible), mitigate, or at least not increase the inherent risk of the activity and ensure that they themselves are not acting negligently as to the customers' safety.[49]

As a result of this regulatory regime imposed by the courts and state legislatures, commercial entities involved in providing adventure or extreme sport experiences apply numerous safety rules, standards, and precautions to meet these legal requirements, such as maintaining equipment and facilities, ensuring adequate supervision, employing qualified and trained staff (including first aid certifications), restricting access to areas or actions deemed dangerous, providing training and orientation information, and performing safety checks.[50] Thus, far from being unregulated in the manner that participant spaceflight is unregulated, adventure or extreme sports appear to be well regulated in a manner that has shifted a significant burden for customer and participant safety to the industry.

Although a normative judgment could be made to allow the court system to impose regulatory conditions on the commercial spaceflight industry as opposed to FAA formal rulemak-

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[45] See, generally, Amanda Greer, "Extreme Sports and Extreme Liability: The Effects of Waivers of Liability in Extreme Sports," *DePaul Journal of Sports Law*, Vol. 9, No. 1, Fall 2012; and David Horton, "Extreme Sports and Assumption of Risk: A Blueprint," *University of San Francisco Law Review*, Vol. 38, Summer 2004.

[46] Greer, 2012, pp. 88, 94–96. Note that, in some cases, the duty of care is enacted and imposed by states as part of the sport safety statutes. In these cases, comparing spaceflight participant safety to adventure sports is particularly erroneous—even more so than in instances where the regulation is in the form of court-issued precedent.

[47] Horton, 2004, p. 617.

[48] Greer, 2012, pp. 88, 91, 96–97, 101, and 103.

[49] Greer, 2012, pp. 93, 96–99. For example, courts have imposed a legal duty on commercial adventure sport providers in the following circumstances: failure to protect customers from injury negligently caused by the provider (Greer, 2012, p. 88); negligent facility design and operations (Horton, 2004, p. 621); failure to reasonably maintain a ski slope (Greer, 2012, pp. 95–96); failure to remove a stump from outside the course of a motocross track (Horton, 2004, p. 632); failure to provide flaggers or warning systems on a motocross track (Greer, 2012, p. 97; Horton, 2004, p. 630); and improper design of a BMX course (Greer, 2012, p. 98).

[50] See, generally, Rufus E. Brown, "Outdoor Law: Basic Risk Management Concepts for Outdoor Programs," OutdoorEd.com, October 4, 2010; WaiverForever, "Running an Adventure Tourism Business: Guide to Duty of Care and Liability," webpage, undated.

ing, this would necessarily require adversarial litigation resulting from death or injury. Additionally, this course assumes another normative position—i.e., that individual complainants (or their estates in the event of death) are in the best position to initiate the process that would impose legally binding and enforceable standards or rules on the commercial space entity. Depending on the ability of individual complainants to bring suit, the ability of individual commercial entities to defend themselves, and the potentially diverse (or random) holdings of various courts, this might not be the most systematic, efficient, or informed method of bringing regulation to the commercial space industry. If Congress believes that this alternative path would be unpredictable and undesirable, the expiration of the moratorium could be an opportunity for the FAA and industry to coordinate and collaborate via SpARCs and formal rulemaking processes to ensure the adoption of appropriate safety regulations in a systematic and predictable manner.

Finally, another common assertion among interviewees was that, because the death or injury of a participant would likely have a negative impact on a particular provider, and on the industry as a whole (because of the chilling effect it would have on future prospective customers), this fact was a sufficient incentive for industry self-policing of all participant safety issues. Correspondingly, said interviewees, this incentive nullifies the need for formal rulemaking in this area.[51] However, this assertion typically was presented as a self-proving argument on its face, without any additional quantitative or qualitative data, information, or evidence in support. Additionally, a major accident could involve many lives, which could have significant negative social, economic, and political impacts beyond a chilling business effect on the industry. We were not able to find case studies or analogues, or other empirical evidence, to support or contravene this contention. Although, as a general matter, Congress and stakeholders might assume that this is a powerful incentive to ensure safety, it is not a measurable one (in the absence of conducting further research). Therefore, we cannot say to what degree, and under what circumstances, this incentive may or may not ensure participant safety, or whether its existence in any way affects or obviates the need for a more formal regulatory framework.

Informed Consent

Currently, the only regulatory requirement related to participant safety that is binding on industry is to provide notice to participants via an informed consent process.[52] This regulation requires the commercial provider to notify the participant in writing as to certain aspects of risk associated with the flight, such as

- the safety record of the launch and reentry vehicles
- each known hazard that could result in injury, death, or disability

[51] Government and industry officials, and private and expert stakeholders, interviews with the authors, September 13, 2022, September 15, 2022, October 13, 2022, October 19, 2022, and November 8, 2022.

[52] See 14 CFR § 460.45.

- that there are hazards that are unknown
- that the launch and reentry vehicles are not certified as safe for carrying crew or participants
- the number of individuals who have been in orbital or suborbital flight and whether any have died or have been injured
- the number of catastrophic failures.[53]

The issue of informed consent creates several normative and subjective concerns and was a common point of contention among interviewees. Some stakeholders asserted that informed consent should negate the need for formal rulemaking because participants are knowingly and willingly subjecting themselves to (1) a dangerous and unpredictable environment, (2) the understanding that they have little or no recourse against the provider or the U.S. government if they are killed or injured, and (3) the understanding that the vehicles are not certified as safe by the U.S. government.[54] Other stakeholders asserted that the idea of informed consent is irrelevant with respect to whether the U.S. government should engage in pre-formal rulemaking (such as SpARCs) or formal rulemaking. They asserted that these documents are designed to protect the industry and, therefore, do nothing to ensure a safe environment for participants.[55]

Whether these consent documents fully present these risks and conditions was not possible for us to assess. Although we requested copies of these documents to review, no stakeholder was willing to provide the documents, generally on the basis that they contained or might contain proprietary or other sensitive information. Thus, it was not possible, for example, for us to determine whether these documents sufficiently convey (in a manner that a space novice or layperson may reasonably understand) the fact that any safety certifications or standards are entirely and voluntarily within the discretion of the commercial provider and that any recourse for death or injury would likely only be available through litigation (assuming that the commercial entity denied any responsibility or negligence).

As noted earlier (in the "Participant Death or Injury" section), in the context of other industries that use informed-consent notices or waivers (e.g., adventure and extreme sports), courts often find that those waivers are insufficient or are inapplicable as to negligent actions by the commercial provider (or actions that otherwise fail to meet a judicial or statutory duty of care standard). As a legal matter, the informed-consent regime protects only two groups: industry and the U.S. government.[56] Thus, leaving this regime in place without the possibility of additional regulation would continue to assign the burden of absorbing all risks to the par-

[53] See 14 CFR § 460.45.

[54] Government and industry officials, interviews with the authors, September 27, 2022, October 4, 2022, November 18, 2022, and December 7, 2022.

[55] Private and expert stakeholders, interviews with the authors, September 15, 2022, and October 19, 2022.

[56] Tracy Knutson, "What Is 'Informed Consent' for the Space-Flight Participants in the Soon-to-Launch Space Tourism Industry?" *Journal of Space Law*, Vol. 33, No. 1, Summer 2007, p. 107.

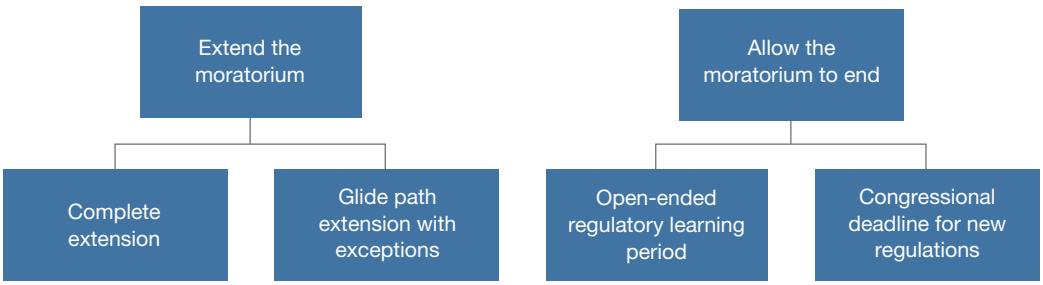
ticipant.[57] This would likely leave only litigation and the court system as a means to shift risk or liability to the provider or the government in the absence of lifting the moratorium and allowing SpARCs and formal rulemaking as an additional mechanism to potentially reassess and/or reassign risk and liability burdens.

We are not in a position to provide findings or recommendations on these normative and subjective issues as to whether to issue regulations. This is not within the scope of our statutory mandate and scope of inquiry. That said, we provide the above discussion and highlight particular areas of concern based on three considerations. First is the fact that these concerns were repeatedly expressed across interviews and stakeholder categories. Second, the research shows that normative and subjective concerns could inform Congress's deliberations and decisionmaking with respect to spaceflight participant safety generally. Third, analysis of the normative and subjective concerns is part of the analytic basis for our recommendation to allow the moratorium to expire.

Options and Implications

A wide array of nuanced options are available to Congress. As shown in Figure 4.1, we suggest that the array of options can be organized into two broad categories: (1) extend the moratorium beyond October 1, 2023, or (2) allow the moratorium to end on October 1, 2023. This section summarizes and contextualizes all options we identified, then considers the potential implications of these options through two different lenses. First, we consider, "How might this policy choice affect the stakeholders?" Second, we consider, "Who bears responsibility, and the associated costs, if something goes wrong?"

FIGURE 4.1
Potential Paths Forward



[57] Knutson, 2007, p. 108.

Extend the Moratorium

The first category, extending the moratorium beyond October 1, 2023, includes options that require congressional action. One would be to extend the moratorium in its current form. Congress could select a new date at which the moratorium would expire, extend the moratorium without an expiration date at all, or tie the end of the moratorium to specific industry metrics.

A more nuanced approach might be for Congress to extend the moratorium but include exceptions that allow the issuance of regulations covering a narrow list of topic areas. The list of topic areas could be expanded upon or otherwise revisited over time. This option can be colloquially referred to as a *glide path*. One glide path option, for example, could be to extend the moratorium but allow the FAA to issue rules related only to the collection and sharing of specific participant safety data and information from industry, which could then be used for further analysis and institutional expertise building.

On one hand, the glide path approach allows the FAA to begin the process of gaining the expertise necessary to effectively regulate the commercial space travel industry while limiting the risk of the FAA enacting controversial or harmful regulations. In that manner, this approach has some conceptual similarities to the regulatory learning period approach described next. On the other hand, this approach requires Congress to have detailed subject-matter understanding of the regulatory space to inform the selection of appropriate exceptions. Regulatory authority is delegated to agencies in part to allow such regulatory details to be shaped by subject-matter experts.

Potential Implications

Extending the moratorium, either in full or with topical exceptions, would affect some stakeholders in important ways while leaving other issues unchanged. The FAA would remain unable to pursue regulations pursuant to participant safety and, thus, would likely be unwilling or unable to invest in developing the capabilities necessary to do so. Our analysis left us with no reason to anticipate that an extension of the moratorium would cause changes to the pace of development of voluntary consensus standards at SDOs, and we expect that both industry and the FAA would likely choose to continue their current level of involvement in those processes.

If the moratorium is extended, industry would have a longer period over which it might expect to retain some level of independence over its designs and operations. However, an extension of the moratorium would not mean that those factors are completely without oversight, as the FAA would continue to regulate public safety under its authority in 51 U.S.C. § 50905(c). This oversight is not trivial. For example, one industry group with whom we spoke referenced having sent the FAA approximately 13,000 pages of information in support of existing regulations.

Drawing on our understanding of stakeholders' positions from interviews and reviews of documents, we have no reason to expect that an extension to the moratorium would result in meaningful changes to the activities that are and are not currently being conducted by

industry, SDOs, and the FAA. The current pace of development of voluntary industry consensus standards would likely continue at its current pace. The core uncertainties to reflect on when considering an extension to the moratorium are (1) whether voluntary consensus standards will be developed and adopted prior to a potentially preventable serious or fatal injury and (2) whether allowing the FAA to develop a regulatory regime might permit the industry to mitigate safety risks more quickly and without undue harm to the growth of the industry. The first question is largely unanswerable. Some interviewees suggested that the second could be resolved if properly resourced and thoughtfully approached, while others were worried that poorly designed regulations might harm industry development.

If a severe or fatal injury were to occur under the moratorium, the affected individual(s) and their heirs would likely have little scope for obtaining compensation for any damages if the event occurred in the context of an informed-consent regime, unless the event occurred due to gross negligence. Industry would still incur damages, likely in the form of reduced demand for services from cautious customers. Unless the event could arguably have been prevented by regulations governed under the FAA's authority to protect public safety, the FAA would be unlikely to bear responsibility for the event. It is not difficult to imagine that some groups would use the opportunity to assert that the moratorium should have been lifted earlier, making the argument that lifting the moratorium sooner would have prevented the event.

The severity of damages that would ensue from a severe or fatal injury is unknown and would likely depend on context. Still, stakeholders widely agreed that a severe or fatal injury occurring before a safety framework is in place could severely reduce demand for further space travel, potentially crippling the industry.[58] Notwithstanding this, there was also wide agreement and understanding that, given the inherently dangerous nature of space operations and activities, it is highly likely that such accidents will occur in the future. It is unclear whether such an event at one company would shift demand to its competitors or would reduce demand for space travel across the industry as a whole. In any case, any steps toward reducing the likelihood and frequency of such events are a clear consensus objective among all stakeholders.

End the Moratorium

No congressional action is required for the moratorium to expire on October 1, 2023,[59] although Congress's role in appropriating funds would significantly shape the FAA's choices

[58] Government and industry officials, interviews with the authors, September 27, 2022, October 4, 2022, November 18, 2022, and December 7, 2022.

[59] Congressional action would be required if Congress decided to end the moratorium earlier—for example, to quickly implement regulations following a high-profile accident. Although the views of interviewees (from both the government and industry) differed on how soon regulations should be implemented, there was broad agreement that the industry as a whole would be better off with a "controlled descent" into a regulatory framework, rather than a rush to immediately implement regulations following an accident. See

and capabilities. If the moratorium expires without further direction from Congress, the result would be what we refer to as an open-ended regulatory learning period. In this outcome, the FAA would have the authority to enact regulations, but the expiration of the moratorium would not require the FAA to immediately implement any regulations, nor would it specify what regulations the FAA should implement. As a result, subsequent choices would be mostly made by the FAA, although the FAA would need additional resources to successfully pursue the activities discussed in this section.

In an open-ended regulatory learning period, we both suggest and believe it is likely that the FAA would of its own volition approach the regulatory process slowly rather than rushing to enact regulations immediately. Interviewees widely agreed that the FAA does not currently possess the resources or expertise necessary to enact a new regulatory framework for commercial spaceflight participant safety. However, some interviewees contended that the current moratorium precludes (or at least impedes) the FAA from obtaining the budget and authority necessary to develop that expertise. There are many activities that the FAA could potentially pursue in this vein, including implementing a SpARC, issuing ANPRMs, or establishing mandatory data-sharing requirements that would inform future rulemaking and other safety efforts.

Another option is for Congress to mandate that the FAA implement regulations by a specific date or once a specific industry metric is reached. Depending on the immediacy of the mandate, the FAA may issue one or more ANPRMs and/or NPRMs. According to conversations with interviewees, immediate regulations would likely need to be drawn from existing material, such as the FAA's *Recommended Practices for Human Space Flight Occupant Safety*,[60] NASA's Human Spaceflight & Aviation Standards, or standards produced by the various SDOs.[61]

Although NASA's standards provide a ready source from which to craft regulations, particularly if there were a catastrophic event that lawmakers felt required immediate regulatory action, interviewees generally agreed that adopting the NASA standards in whole or in significant part would not be appropriate.[62] The applicability and stringency of many of the standards do not take into account the wide variance in vehicle design among provid-

51 U.S.C. § 50905(c)(2)(C) (limiting the ability of the FAA to issue regulations during the moratorium in absence of an event resulting in "serious or fatal injury").

60 See FAA, 2014.

61 See FAA, 2014. We note that interviewees stated that a revised version of this guidance document is being developed by the FAA (government officials, interview with the authors, September 23, 2022, and October 13, 2022). See also NASA, *NASA Space Flight Human-System Standard Volume 1*, NASA-STD-3001 Vol. 1, 2022a, and NASA, *NASA Space Flight Human-System Standard Volume 2*, NASA-STD-3001 Vol. 2, 2022b, as well as NASA, "ISS Crew Transportation and Services Requirements Document," NASA Commercial Crew Program, CCT-REQ-1130, Revision E-1, October 12, 2016. For SDO standards, see Appendix B.

62 Government and industry officials, interviews with the authors, September 13, 2022, September 27, 2022, October 4, 2022, November 30, 2022, and December 7, 2022.

ers. In other words, the standards would have to be customized to a substantive degree, and this process would necessarily take time. Additionally, the purpose of NASA missions (i.e., government-determined objectives) is significantly different from the commercial objectives (i.e., adventure-seeking and, perhaps in the future, transportation). These differences may lead to the development of different standards over time.[63] Given the broad agreement that the FAA currently lacks the necessary resources or expertise to enact a new regulatory framework for commercial participant safety, very few interviewees said that it would be appropriate for the FAA to seek to immediately enact binding regulations, particularly binding regulations based solely on the existing standards (such as those applied by NASA).

Potential Implications

Like extending the moratorium, allowing the moratorium to end would affect some stakeholders in important ways while leaving other issues unchanged. The FAA would gain the ability to pursue regulations pursuant to participant safety, although it is unlikely that changes would occur overnight unless mandated by Congress. The extent to which the FAA engages in regulatory actions over the subsequent months and years would likely depend on the resources Congress allocated to the FAA. The FAA would require funding, staffing, and facilities to evaluate these regulatory issues. Information shared during one interview suggested that supporting these regulatory responsibilities could require as many as 200 FTE staff, although we suggest that the FAA develop a more precise estimate of their funding requirements.[64]

It is possible that an expiration of the moratorium would accelerate the development of consensus standards. Some interviewees stated that the potential for regulatory action might incentivize stakeholders to focus on developing standards, if for no other reason than to obviate the need for formal rules. Such a change would be welcomed by the many stakeholders who felt that the development of consensus standards was moving too slowly. However, other interviewees argued that the current tempo of development for consensus standards is consistent with the rate of development of consensus standards in other settings.

For these reasons, if the moratorium is allowed to expire, it is unlikely that industry would see any immediate changes to the oversight of its designs and operations. The FAA would continue to regulate public safety under its authority in 51 U.S.C. § 50905(c) and would presumably begin exploring a potential regulatory framework with greater seriousness. Drawing from our interviews, we anticipate that a healthy and appropriate dialogue would occur—i.e., that the FAA would seek to engage with industry throughout that process, and that industry would be generally willing to communicate its needs and concerns to the FAA. Although

[63] Government and industry officials, interviews with the authors, September 13, 2022, September 27, 2022, October 4, 2022, November 30, 2022, and December 7, 2022.

[64] We could not validate whether this or any particular number of FTEs would be sufficient. This issue was not within the scope of this study. This estimate is shared as a matter of relevant context. Additional research would be necessary to determine what additional resourcing and manpower would be required.

such matters can always change over time, interviewees suggested that at present there is a healthy level of mutual trust and respect between the FAA and industry.[65] The widely cited concerns about the FAA's current capabilities were broadly understood as a function of resources, rather than reflecting any level of distrust or animosity. However, one interviewee suggested that there was a risk that the FAA's focus on aviation might overshadow efforts to regulate commercial space travel and that the industry might be better served if the FAA's space portfolio was spun out into a separate administration within the Department of Transportation devoted to matters of space.[66]

If a severe or fatal injury were to occur after the moratorium had expired but before any significant regulatory actions had been taken, the immediate outcomes would likely be the same as if the moratorium had been extended. The affected individual(s) and their heirs would likely have the same limited scope for obtaining compensation for any damages, and industry would still incur the same reduced demand. However, with the moratorium already lifted, it is not difficult to imagine that such an event would put pressure on the FAA to enact regulations sooner than it might otherwise.

Summary

There are many nuanced options available to Congress and the FAA between the bookends of fully extending the moratorium and immediately enacting new regulations. Our assessment is that a middle-of-the-road approach is likely to be most effective. A full extension of the moratorium would do little to help the FAA prepare for its inevitable role in regulation while also continuing the risk that a high-profile accident could lead to pressure to immediately implement a regulatory regime regardless of the readiness of the industry and the FAA. Immediate implementation of a regulatory regime, regardless of whether driven by an accident or simply a desire to regulate, could plausibly result in unintended consequences that harm the development of the industry.

For these reasons, we recommend that no changes be made to prevent the moratorium from expiring on October 1, 2023. This expiration, combined with sufficient funding, would provide a much-needed learning period for the FAA by allowing for more-serious consideration and development of well-informed regulations, including the potential implementation of regulations on widely agreed-upon issues, but this learning period should not require the FAA to rush into creating new regulations for their own sake.

[65] Government officials, interviews with the authors, September 15, 2022, and October 6, 2022.

[66] We do not take any position on this suggestion, as this issue was not within the scope of this study. This suggestion is shared as a matter of relevant context. Additional consideration would be necessary to determine the implications and requirements of such a change in the organization of the Department of Transportation.

While rushed regulations could potentially cause harm to the industry, carefully considered and crafted regulations are not necessarily harmful to the industry. Focusing on performance standards rather than prescriptive standards is important to avoid unnecessarily dissuading the future pursuit of creative designs and operations and to provide equal accommodation to the highly varied designs and operations that already exist. At the same time, some interviewees cautioned against standards based solely on high-level probabilistic models (e.g., requirements that the probability of passenger death be less than *X* out of 100), because, in their experience, the complex systems involved in space travel mean that there are too many sources of uncertainty for the models that calculate such probabilities to be of practical value.

Instead, regulations might focus on specific aspects of participant safety in a nonprescriptive manner (e.g., regulations that ensure that there are appropriate mechanisms in place for fire suppression, emergency egress, or fuel storage safety). Multiple interviewees suggested that some level of agreement on industry best practices did exist at these less-specific levels. Consensus standards developed by SDOs can help point toward key issues and areas where stakeholders have been able to reach agreement about best practices.

We suggest that the FAA explore two actions once the moratorium has expired and the FAA has sufficient funding in place. First, the FAA should consider implementing a SpARC and other formal rulemaking processes (i.e., ANPRMs or NPRMs) to gather information, viewpoints, and expert opinions from both industry and the public as to what a regulatory agenda for spaceflight participant safety should address. In addition to these formal mechanisms, the FAA should meet regularly with industry representatives to understand their needs and challenges as regulations are developed.

Second, the FAA should create a mechanism or regulation that would require industry to report and share initial data for participant safety, mishaps, accidents and other related data and information collected by commercial space providers during orbital and suborbital periods of flight. To protect proprietary information from public disclosure, these regulations could limit sharing to the FAA and/or a designated safety assessment and evaluation organization.

We acknowledge that stakeholders have different perspectives on the appropriateness of extending the moratorium. There was broad agreement that industry has a strong incentive to protect the safety of its customers. Some stakeholders felt that this market incentive was sufficient for industry to appropriately self-police at this time. However, there was also broad agreement that it is important to have some form of regulatory regime in place prior to any severe or fatal injury and that the hazardous nature of space travel means that such a severe or fatal injury is likely inevitable. The main argument in favor of the expiration of the moratorium was not the need for immediate regulation per se but, rather, the need to enable the FAA to prepare to regulate. Having a regulatory regime in place prior to a severe or fatal injury could shift some (but presumably not all) responsibility for the event from industry to government. Beyond simply shifting the distribution of responsibility, some interviewees said that external oversight of industry practices would also lead to safer outcomes.

CHAPTER 5

Perspectives on Passenger Safety Regulation from Other Transportation Modes

Although safety regulations are not specifically required by the language in the CSLCA mandating this report, we believe that the experiences of other transportation modes with safety regulations offer useful context in considering next steps for the spaceflight industry. Therefore, in this chapter, we describe some key features of passenger safety regulation for more-established transportation modes, specifically aviation, rail, motor carriers, maritime, public transit, and highway. Although not a comprehensive assessment, this discussion complements the readiness assessments in Chapters 2 and 3.

We found during our interviews that government officials and industry representatives sometimes compared the commercial space industry—both its level of development and its special characteristics—with more-established transportation modes, notably aviation, when discussing the readiness of the commercial space industry to transition to a new safety framework that would potentially include regulation. For example, one interviewee asserted that the commercial space industry should be viewed like the aviation sector in the 1930s, a new industry that had much to learn before it would be ready for regulation.[1] Two government interviewees noted that the level of safety regulation in the aviation sector was not uniform but depended on the purpose of flight, with commercial air transportation being more heavily regulated than general aviation, such as light sport aircraft.[2] Several interviewees mentioned that regulating commercial spaceflight was more challenging than commercial air transport because commercial spacecraft design is much less standardized.[3]

Other interviewees expressed concern that the space domain was so distinct from other modes of transportation that such comparisons provided limited value.[4] We include these examples both for the purpose of illustrating highlighted parallels and for illustrating the differences between these industries and commercial spaceflight.

1 Government officials, interview with the authors, September 13, 2022.

2 Government officials, interviews with the authors, October 6, 2022, and October 7, 2022.

3 Government and industry officials, interviews with the authors, September 27, 2022.

4 Government officials, interviews with the authors, September 1, 2022, and October 6, 2022.

Commercial Aviation

The commercial air transportation industry was born out of the need to transport mail in the post–World War I era. In 1925, Congress passed the Contract Air Mail Act, often known as the Kelly Air Mail Act, which allowed the federal government to contract the delivery of airmail to private carriers.[5] One year later, Congress passed the Air Commerce Act of 1926, which authorized federal regulation and oversight of aviation safety, including by licensing qualified pilots and by certifying that airplanes were airworthy.[6] Following the inception of this act, two significant incidents occurred that led to a focus on aviation safety at the executive level. The first incident was the loss of a popular sports figure, Notre Dame football coach Knute Rockne, in an airliner crash in 1931. The subsequent loss of U.S. Senator Bronson Cutting in the 1935 crash of TWA Flight 6 elicited public outcry for greater federal oversight within the aviation sector.[7] Incidents such as these were the catalyst for the 1938 passage of the Civil Aeronautics Act, which established an Air Safety Board that was tasked with conducting accident investigations and root cause analysis.[8] Despite such early efforts to improve flight safety, additional aviation accidents over the next 30 years led to the passage of the Federal Aviation Act in 1958 to further strengthen safety regulation of civil aviation, including the establishment of the Federal Aviation Agency.[9] In 1966, the Federal Aviation Agency was renamed the Federal Aviation Administration and moved to the newly created Department of Transportation.[10]

One of the major functions of the FAA is to promote the safety of civil aviation through regulation. Air carriers and operators who operate for compensation or for hire are currently regulated under Title 14 of the CFR. Carriers operating under an air carrier domestic, flag, and supplemental operation certificate and who are conducting scheduled passenger-carrying operations, commonly referred to as *commercial air carriers*, fall specifically under 14 CFR Part 121. The FAA oversees a robust set of passenger safety regulations for commercial air carriers who, on average, transport more than 600 million passengers annually.[11] The administration promotes air travel as one of the safest means of transportation and requires that all air carriers adhere to published regulations to ensure that passenger cabin safety is paramount.[12] These include the requirement for an oral passenger briefing, details on the location of survival equipment, details on the location and use of oxygen, provision of a visual

5 Public Law 68-359, Air Mail Act of 1925, February 2, 1925.

6 Public Law 69-254, Air Commerce Act of 1926, May 20, 1926.

7 FAA, "A Brief History of the FAA," webpage, undated-a.

8 Public Law 75-706, the Civil Aeronautics Act of 1938, June 23, 1938.

9 Public Law 85-726, the Federal Aviation Act of 1958, August 23, 1958.

10 FAA, undated-a.

11 Bureau of Transportation Statistics, "TranStats," webpage, undated.

12 FAA, "Cabin Safety," webpage, September 23, 2022d.

diagram of emergency exits with methods of operation, and the use of safety belts and shoulder harnesses.

Airframes are required to meet specific sets of airworthiness standards outlined in 14 CFR Part 121 Subpart H. These standards require certificate holders to have an airworthiness certificate for each airframe,[13] and they must be in a safe operating condition.[14] Airplane equipment is specifically regulated within 14 CFR Special Federal Aviation Regulation No. 109, Subsection 4. 14 CFR Chapter 1 Part 25, entitled "Airworthiness Standards: Transport Category Airplanes," contains detailed and extensive safety regulations. Emergency provisions, for example, are covered in Subpart D of Part 25. Located within this section are emergency exit standards, which define emergency exit types and require that the number and type of emergency exits be commensurate with an airplane's passenger seating capacity.[15] Locations of these exits are also based on the type of exit and passenger capacity. Another additional requirement, again based on the type of emergency exit installed, is that there be a means of assistance for passengers to reach the ground level. In addition, emergency lighting is required to be independent of the airplane's main lighting system and must illuminate emergency exit markings, signs, exit areas, and floor proximity path markings.[16] Emergency exit signage is standardized based on the passenger seating configuration of the airplane.[17] Passenger aisle width requirements are based on seating capacity of the airframe. Furthermore, floor proximity lighting must mark escape paths when all other illumination sources are totally obscured.

The materials used in aircraft design, such as fabrics and fasteners, along with specific design factors, such as bearings, fittings, castings, and the aeroelastic stability requirement (to be included all in airplane systems), are also regulated in 14 CFR Part 25 Subpart D. Subpart D also specifies dimensions for pilot compartments; locations of controls; windshield design requirements; and detailed design criteria and testing requirements for seats, berths, safety belts, and harnesses.[18] Crewmembers are required to be qualified in the airframe in which they operate, and each certificate holder is required to establish and implement a training program that ensures that all crewmembers are adequately trained. Training programs are required to be approved by the FAA before implementation. Additionally, the FAA requires certificate holders operating under 14 CFR Part 121 to have an administrator-approved Safety Management System in place that defines an organization's safety objectives. Furthermore, the FAA also requires that airplanes used by operators have flight data record-

13 14 CFR § 121.153(a).

14 FAA, "Condition for Safe Operation," webpage, June 29, 2022.

15 14 CFR § 25.807(a).

16 14 CFR § 25.812(a)(1).

17 14 CFR § 25.812(b).

18 14 CFR § 25.601.

ers installed to record flight parameters.[19] Lastly, flight crewmembers are required to follow strict flight time and crew rest requirements.[20]

Rail Industry

The commercial domestic rail industry developed significantly following the expansion of the country's rail system in the late 1860s. Public outcry for safety regulation followed years of rail accidents, and the amassing statistics showed that over a ten-year period between 1883 and 1892, an average of 562 individuals were killed via rail incidents,[21] which led to the passage of the Safety Appliance Act of 1893. This act "required the use of power brakes on all trains engaged in interstate commerce as well as requiring all railcars engaged in interstate commerce to be equipped with automatic couplers, drawbars, and handholds."[22]

The current regulating body stemmed from the 1966 Department of Transportation Act, which created the Federal Railroad Administration (FRA). The FRA is located within the Department of Transportation and is charged with regulating railroad safety.[23] The FRA's statutory authorization puts safety at the center of its mission, stating that the FRA should consider safety as its "the highest priority" and explicitly noting Congress' intent for the FRA to further "the highest degree of safety in railroad transportation."[24] The FRA regulates and imposes passenger safety regulations in such areas as passenger train equipment, including the design of car components and safety appliances; passenger train emergency preparedness; and safety training for railroad employees.[25]

Rail industry safety regulations are found within 49 CFR, Subtitle B, Chapter II. Regulations stipulate the placement and size of emergency exit access and rescue points.[26] Emergency lighting and standardized marking of egress points are also outlined.[27] A system safety plan is required to be submitted to the FRA for all operators. Like what is seen in the aviation sphere, event recorders are required for all trains traveling over 30 miles per hour. Operators engaged in commuter or intercity passenger transportation must adhere to duty-hour limita-

19 14 CFR § 121.343.

20 14 CFR § 121.471(a).

21 Charles W. McDonald, *The Federal Railroad Safety Program: 100 Years of Safer Railroads*, U.S. Department of Transportation, August 1993.

22 49 CFR § 231.

23 The FRA is authorized by U.S. Code, Title 49, Section 103, Federal Railroad Administration. Public Law 89-670, Department of Transportation Act, October 15, 1966.

24 49 U.S.C. § 103.

25 49 CFR § 221, 215, 209.

26 49 CFR § 238.441.

27 49 CFR § 238.115(a).

tions.[28] Operators are also required to have a written safety plan on file prior to commencing revenue service.

Motor Carriers

The Federal Motor Carrier Administration is part of the Department of Transportation and is authorized by 49 U.S.C § 113. The law makes clear that safety is a core responsibility of the Federal Motor Carrier Administration. The administration is directed to "consider the assignment and maintenance of safety as the highest priority, recognizing the clear intent, encouragement, and dedication of Congress to the furtherance of the highest degree of safety in motor carrier transportation."[29] The federal motor carrier safety regulations are located within 49 CFR Subtitle B, Chapter III.

By definition, a *motor carrier* is any for-hire carrier or private motor carrier.[30] These carriers operate commercial motor vehicles that transport property and passengers involved in commerce. Commercial motor vehicle operators must ensure that vehicles meet the specifications of Part 393 regarding the parts and accessories necessary for safe operations. Some items covered under this section are brakes and their required stopping power, lighting and lamps, reflectors, windshield standards, and the requirement for emergency exits on buses to include emergency exit identification. This section also covers the standards for seat design and locations for both buses and truck tractors.[31]

Drivers of commercial motor vehicles are also not permitted to operate said vehicles if they are unable to drive safely, whether due to sickness, fatigue, or other conditions, except under "grave emergency" circumstances.[32] Those operating under this section are subject to specific driving-time limitations imposed by regulation.[33] Special provisions are also made for drivers of vehicles that are equipped with sleeper berths and for those who are engaged in retail delivery operations. Lastly, Subpart H of 49 CFR Part 393 details the emergency equipment that is required for truck, truck tractors, and buses. Some of the required items include fire extinguishers, warning devices for stopped vehicles, and spare fuses.[34]

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28 49 CFR § 228.405.

29 U.S. Code, Title 49, Section 113(b), Federal Motor Carrier Safety Administration.

30 49 CFR § 390.5.

31 49 CFR § 393.93.

32 49 CFR § 392.3.

33 49 CFR § 395.5. The states of Alaska and Hawaii have specific provisions for duty period limitations.

34 49 CFR § 393.95.

Maritime

The Maritime Administration within the Department of Transportation has as its statutory mission to "foster, promote, and develop the merchant maritime industry."[35] Within the Maritime Administration, the Office of Safety addresses a range of maritime safety topics, including standards development.[36] The maritime industry is regulated under 46 CFR Chapter II. Regulatory and enforcement aspects of marine safety for passenger vessels are carried out by the United States Coast Guard.[37] Passenger vessels are required to be constructed under the Safety of Life at Seas standard,[38] and all interior spaces are to be constructed in a manner that addresses fire protection. Specific structural elements, such as ceilings and trim, are regulated to minimize the presence of combustible materials. Specifications for other design elements, such as stairways and ladders, are also addressed.[39] Working hours of credentialed officers and crew members are outlined in 46 U.S.C. 8104. Lifesaving equipment and arrangements to include distress items, life jackets, personal flotation devices, survival craft, and rescue boats are all required by the standard.[40]

Public Transit

The Federal Transit Administration (FTA) is a Department of Transportation agency that supports public transit around the nation through a number of programs and activities.[41] Public transit is regulated under 49 CFR, Subtitle B, Chapter VI. Transportation methods including charter services, school buses, and rail fixed guideway systems are regulated under this chapter. The FTA utilizes a Safety Management System approach to enhance public transportation safety, in part with the Public Transportation Safety Program. Transit agents or states are required to also have in place a Safety Management System plan.[42] The FTA also issues National Transportation Safety Plans that contain "safety performance criteria for all modes of public transportation," as well as other safety-oriented elements.[43] States are required to establish a State Safety Oversight Agency to oversee the safety of rail fixed-

[35] U.S. Code, Title 49, Section 109(a), Maritime Administration.

[36] Maritime Administration, "Office of Safety," webpage, undated.

[37] 46 CFR Chapter I.

[38] 46 CFR § 72.01-2(b)(1).

[39] 46 CFR § 72.05.

[40] 46 CFR § 117.15.

[41] U.S. Code, Title 49, Section 107, Federal Transit Administration; U.S. Code, Title 49, Chapter 53, Public Transportation.

[42] 49 CFR § 673.3.

[43] 49 CFR § 670.31.

guideway public transportation systems.[44] Additionally, the FTA also has in place a Public Transportation Safety Certification Training Program that requires designated State Safety Oversight Agency personnel to complete a standardized curriculum.[45] Furthermore, each transit agency or state must establish a Public Transportation Agency Safety Plan for each mode of service that is certified annually.[46]

Highway

The Department of Transportation Federal Highway Administration has statutory responsibilities related to the promotion of highway safety.[47] Highway safety is regulated under Title 23 CFR, Chapter I and Chapter II. Highways are also regulated by the National Highway Traffic Safety Administration (NHTSA) which is also located within the Department of Transportation.[48] NHTSA regulates under 23 CFR Chapter II, 23 CFR Chapter III, 47 CFR Chapter IV, and 49 CFR Chapter V. Federal Highway Administration regulations direct each state to develop highway safety improvement programs, including strategic highway safety plans, to "significantly reduce fatalities and serious injuries resulting from crashes on all public roads."[49]

Design standards and specifications for highways are also regulated by the Federal Highway Administration. Under Subpart B of 49 CFR Part 571, titled Federal Motor Vehicle Safety Standards, NHTSA regulates such vehicle features as controls, displays, illumination brightness and color, standardized markings and symbols for controls, windshield wiper dimensions and coverage areas, braking systems, seat belts (including buckles and webbing), child restraint systems, and ejection mitigation systems.[50] This section covers requirements for buses as well. NHTSA regulations incorporate by reference a wide range of motor vehicle safety standards developed by SDOs, including ASTM, ISO, and SAE.[51] Additionally, NHTSA regulates the design and performance of anthropomorphic test devices used in motor vehicle safety testing.[52]

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44 49 CFR § 674.27 (a).

45 49 CFR § Appendix A to Part 672 A.(1).

46 49 CFR § 673.11.

47 U.S. Code, Title 49, Section 104, Federal Highway Administration.

48 U.S. Code, Title 49, Section 105, National Highway Traffic Safety Administration.

49 23 CFR § 924.3 and § 924.5.

50 49 CFR, Part 571, Subpart B, Federal Motor Vehicle Safety Standards.

51 49 CFR § 571.5.

52 49 CFR, Part 572, Anthropomorphic Test Devices.

Summary

This review of regulatory experiences in other transportation sectors offers insights that can shed light on future pathways for a safety framework for the commercial space industry that might include regulation. First, safety regulation often followed in the wake of accidents that resulted in loss of life and injuries. It is worth considering the benefit of enacting regulations before any such incidents occur in the commercial space industry instead of reactively, after deaths and injuries occur. As was noted in an interview, there could be pressure to develop regulations quickly in the wake of a safety incident, when a deliberate process would be more helpful for developing more-thoughtful and efficacious regulations that benefit both industry and public safety.[53]

Second, our review highlighted some of the vehicle design features and procedures that are regularly subject to regulations to ensure passenger safety. We found that each transportation mode is subject to a set of passenger safety regulations that is configured to address the specific design characteristics, operating profile, and safety risks of that method of transportation. The regulatory structure for each transportation mode promotes passenger safety as one of its high-priority areas. The common areas that are regulated across all transportation modes include the designs and requirements of components, material testing, standardization of markings, passenger and occupant restraint or safety systems, and design features. Within all transportation methods that utilize operators, we found a requirement to document and enforce duty-period limitations. It is also commonplace for sectors to use some form of safety management system to provide guidance on policies. However, we did not find a standardized method of certification for personnel involved in safety-related duties. Professional organizations offer such certification, but the selection of a specific certification is not included in applicable regulations.

Lastly, we found that many standards were adopted through incorporation by reference within all transportation industries. For context, incorporation by reference allows federal agencies to comply with the requirement to publish rules in the Federal Register and the CFR by referring to material already published elsewhere. The legal effect of incorporation by reference is that the material is treated as if it were published in the Federal Register and CFR.[54] Furthermore, it should be noted that these materials are to be made "reasonably available" to those affected. [55] The term *reasonably available* was addressed by multiple commenters during the 2014 commenting period on the petition to revise 1 CFR Part 51.[56] The discussion also included costs of standards and access, because many of these standards are available only by purchasing them from the publisher.

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[53] Government officials, interview with the authors, October 6, 2022.

[54] 1 CFR § 51.1(a).

[55] 1 CFR § 51.7(a)(3).

[56] "Rules and Regulations," *Federal Register*, Vol. 79, No. 216, November 7, 2014.

CHAPTER 6

Recommendations

Protecting the growth and development of the commercial spaceflight industry is important because there are persuasive economic and national security arguments for ensuring U.S. leadership in the development of a commercial spaceflight industry. At the same time, human participant safety is also essential. Safety can only be ensured when industry, the government, and the public all have an opportunity to identify, measure, and assess the risks and burdens associated with space travel so that they may be appropriately balanced in accordance with the nation's values.

As many stakeholders we interviewed noted, industry has powerful market incentives to ensure participant safety even in the absence of regulatory oversight. There was wide agreement that catastrophic events, even if accidental, could have significant and long-lasting negative impacts on industry growth and sustainability. Some of these negative impacts could result from regulations being imposed too quickly after a high-profile incident—regulations that might be imprudent or not fully vetted and considered by key stakeholders. Industry representatives with whom we spoke emphasized the seriousness with which they approach the safety of their customers, their engagement in the voluntary development of industry standards and best practices, and their continued concern that ill-conceived regulations could harm their ability to conduct their business.

At the same time, other stakeholders expressed skepticism about the extent to which appropriately conceived regulations would truly hinder industry's creativity or development. They also acknowledged that regulations, if conceived properly and in partnership with the appropriate stakeholders, could ensure both participant safety and industry growth. Regardless of the differing views on industry's readiness for the learning period to conclude and the potential of formal rulemaking, there was broad agreement that the FAA is not currently sufficiently resourced to successfully develop appropriate regulations. Some stakeholders were concerned that the moratorium itself was effectively prohibiting the FAA from gaining the resources and experience necessary to develop appropriate regulations at whatever point in time they become necessary.

Recommendations

Drawing on these major themes that emerged during our research, and the detailed analysis of the current state of voluntary consensus standards, key metrics, and industry readiness for regulation articulated in the preceding chapters, we offer the following recommendations.

Allow the Moratorium to End as Per Current Law

Despite the moratorium being in place since 2004, we cannot find that the moratorium has supported, per se, the development of voluntary consensus standards, key metrics, or regulation readiness. Notwithstanding industry assertions that they have developed robust and proven internal safety standards, and notwithstanding industry's strong safety record writ large, we could not establish a causal link between these facts and the moratorium. In other words, based on the data, information, and evidence collected, we cannot reject the possibility that the absence of the moratorium may have resulted in the same current state. Indeed, some interviewees suggested that allowing the moratorium to lapse could result in both industry and the FAA further prioritizing the development of consensus safety standards, key metrics supporting those standards, and the consideration of regulations that could serve both industry and participant safety at this time and in the future.

Additionally, we did not find any evidence to suggest that the FAA will necessarily engage in formal rulemaking in a manner that is hasty, ill informed, or overly prescriptive when the moratorium expires. The absence of a moratorium does not equate to the fait accompli of formal rulemaking and regulation. Even if the FAA wanted to quickly impose regulations, the administrative procedures required to do so would take years in absence of an emergent situation (such as a catastrophic event). Although we agree that poorly conceived regulations could be harmful to industry growth and thus should be avoided, we are not aware of any data, information, or evidence to suggest that more-carefully conceived regulations would necessarily be an imminent threat to industry growth. It is possible that carefully conceived regulations and external oversight could be beneficial to both the safety and growth of the industry without being overly prescriptive.

We did not find sufficient evidence to support a recommendation that Congress extend the moratorium (or curtail it more quickly). Such concerns as the limited number of flights, the limited number of participants, the variance in spacecraft or technologies, and the adventure-seeking nature of current participants do not, in and of themselves, establish or substantiate a basis to deviate from the currently planned expiration of the moratorium.

Resource the FAA

Our recommendation to allow the moratorium to end is, however, caveated by our recommendation to concurrently resource the FAA appropriately to engage in additional actions and activities to meet its statutory responsibilities. These actions and activities would (ideally) continue to support the development of voluntary consensus standards and key metrics,

as well as lay the groundwork for informal and formal pre-rulemaking and rulemaking. Any pre-rulemaking or rulemaking measures should be initiated as needed, and in partnership with industry and the appropriate SDOs, to balance participant safety and industry growth.

Proceed with SpARCs

The development of a regulatory framework that successfully supports participant safety while avoiding harm to industry requires input from industry and other expert stakeholders. To obtain this input, the FAA should form a SpARC. Although some interview information suggests that SpARCs can be overly formalized in a manner that may not capture all stakeholder views equally, this was outweighed by the evidence suggesting that SpARCs—as a forum and a mechanism for pre-rule development—are much more likely to set the appropriate goals, objectives, and procedures for the identification and deliberation of regulatory issues. Additionally, SpARCs might find that certain areas should not be regulated or certain types of regulations (e.g., prescriptive regulations) should not be considered or issued. This flexibility would be beneficial to industry, the FAA, and other stakeholders.

Continue Voluntary Consensus Standards and Key Metric Development

Regardless of decisions regarding the moratorium, we recommend that all parties continue to engage in the development of voluntary consensus standards and key metrics that support those standards. The expiration of the moratorium in no way requires these activities and processes to slow or stop. Although there were differing views on whether the pace of development of voluntary consensus standards was too slow or was as expected, development of standards is, regardless, a beneficial process for the safety and development of the industry and is laying a foundation that supports the eventual development of a regulatory safety framework.

Consider Limited Informal Rulemaking

One key factor that emerged throughout the research was the importance of participant safety–related data. Interviewees overwhelmingly agreed that the identification, collection, and analysis of these data and information were essential to developing, for example, standards, key metrics, procedures, rules, and after-action reviews. Currently, however, these data and information are held by the commercial providers who are in the position to capture them. Limited data and information may be discussed or shared during COMSTAC and ASTM F47 proceedings, but this is not sufficient to allow for robust analysis.

Commercial industry interviewees expressed the concern that these data and information were often proprietary and that their release could potentially harm their company. Because we did not have access to this information, we cannot make an independent determination of this fact, but we nonetheless accept this reasoning given the emergent state of the indus-

try and the variance in craft and equipment design and deployment.[1] The tension between reporting and sharing data and information (and perhaps best practices as well) for analysis and protecting proprietary information is also difficult to manage when the number of providers is very small. The disclosure of certain data might, by its nature, identify the company that provided them.[2]

Notwithstanding this tension, we recommend that the FAA and industry explore a means to identify, collect, report, and analyze these data in a manner that prevents public release of sensitive or otherwise proprietary data and information. We recognize that this could require legislation from Congress and formal rulemaking by the FAA. Doing so would very likely increase the FAA's institutional expertise and understanding of key safety issues and would allow it to develop key insights and recommendations across the current stovepiped system. For industry, this would also be an opportunity to learn from other sources in a manner that might expose current blind spots (if they exist); enable the sharing of best practices that are developing dynamically; and potentially avoid anomalies, mishaps, and catastrophic events. In this way, participant safety could be increased with minimal risk to industry's proprietary data and information.[3]

More generally, we note that the Administrative Procedure Act allows both informal and formal rulemaking to occur. Once the moratorium has lapsed, tools such as ANPRMs, NPRMs, and notice and comment can take place that will allow for public discussion of whether or not, and how, the commercial space industry should (or should not) be regulated. Our research indicates that facilitating public discussion to identify potential areas of future informal rulemaking could benefit both the FAA and industry. Additionally, were the FAA to attempt to propose rules that stakeholders believed were harmful, the Administrative Procedure Act offers a clear judicial process to allow for the adjudication of these concerns and, if necessary, the enjoining of such rules.[4]

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[1] We requested data and information from interviewees regarding any current industry safety standards in place. Interviewees declined to provide this information for various reasons related to proprietary protections, security issues, or other legal concerns.

[2] At the same time, we note that many interviewees acknowledged that, because the industry is small and the number of providers sending participants into space is small, there is considerable personnel transfer among the companies. This often equates to a default sharing of data, information, and best practices.

[3] We also note that the sharing of these data and information with the FAA prior to any rulemaking could allow industry to put forth rules specific to its systems and business objectives. If such rules were eventually incorporated into regulations, the public could make more-informed choices about provider types based on individual risk tolerances.

[4] See, generally, 5 U.S.C. §§ 701 to 706 (U.S. Code, Title 5, Government Organization and Employees, Chapter 7, Judicial Review). For example, the federal courts are empowered (upon the complaint of a stakeholder with a sufficient interest in the rule) to declare rules null and void if they are deemed to be "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with the law; contrary to constitutional right, power, privilege, or immunity; in excess of statutory jurisdiction, authority, or limitations, or short of statutory right; without observance or procedure required by law; unsupported by substantial evidence in a case [subject to certain conditions as described further in the statute] or otherwise reviewed on the record

Other Issues Beyond the Scope of This Study

We emphasize, based on our analysis, that providing the FAA with sufficient resources is critical to the development of a beneficial and carefully conceived regulatory safety framework. However, this study did not formally explore or estimate the level of resourcing that would be required.

Final Thoughts

Overall, we recommend a measured approach whereby the systems and expertise necessary to regulate this nascent industry can be developed, but in a slow and systematic manner that does not unduly hamper innovation or industry's ability to continue engaging in appropriately safe launches.

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of an agency hearing provided by statute; or unwarranted by the facts to the extent that the facts are subject to trial de novo by the reviewing court." See U.S. Code, Title 5, Government Organization and Employees Section 706, Scope of Review.

APPENDIX A

Legislative History

The legislative history of the regulation of commercial human spaceflight in the United States is one of cumulative advances in response to changing technological conditions and the progress of the commercial space industry. The foundational legislation is recent—for instance, the Commercial Space Launch Act dates only from the 1980s—but successive legislation has expanded the government's regulatory reach over the commercial space industry. Through legislation, Congress has granted government agencies responsibility for different aspects of commercial space regulation, including the FAA, the National Oceanic and Atmospheric Administration, the Federal Communications Commission, the Department of State, and the Department of Commerce.[1] As the legislative history shows, the FAA has been delegated a primary role in the regulation of launch, reentry, and spaceflight safety, although its current powers in the latter area remain circumscribed. Five laws that are important for understanding the evolution of the FAA's regulatory powers are the Commercial Space Launch Act of 1984, the Commercial Space Launch Amendments Acts of 1988 and 2004, the Commercial Space Act of 1998, and the CSLCA of 2015.

The Commercial Space Launch Act of 1984 established an initial regulatory framework for FAA oversight of commercial space activities. The commercial space launch industry had begun to take shape in the 1980s, as the private sector's interest in satellite launches outpaced NASA's ability to deliver payloads into space, notably via the space shuttle program.[2] A major milestone for the nascent industry was achieved in 1982, when Space Services Inc. succeeded in delivering a rocket into space from a launch site in Texas.[3] The growth of the commercial space industry spurred action in both the executive and legislative branches. In 1984, President Reagan issued Executive Order 12465, Commercial Expendable Launch Vehicle Activities, which directed the Department of Transportation to serve as "lead agency" for "encouraging and facilitating commercial ELV [expendable launch vehicle] activities by the

1 Congressional Research Service, *Commercial Space: Federal Regulation, Oversight, and Utilization*, 2018.

2 Congressional Research Service, 2018.

3 FAA, "Origins of the Commercial Space Industry," undated-g; Dan Balz, "Privately Funded Rocket Launched," *Washington Post*, September 10, 1982.

United States private sector."[4] Both AST and COMSTAC were established that same year.[5] AST, which was originally located within the Office of the Secretary of Transportation rather than within the FAA, was designated as responsible for the Department of Transportation's commercial space launch regulatory activities.[6]

The Commercial Space Launch Act of 1984 set forth a statutory basis for the regulation of the commercial spaceflight industry, focused particularly on creating a regulatory system that facilitated commercial launches and encouraged the development of the new industry. The bill's language, especially in the findings and statements of purpose, emphasized the value and benefits of the commercial space industry and highlighted industry growth and competitiveness as goals. Congress noted that the commercial space industry could complement government space programs and provide national security as well as economic benefits. The industry could be encouraged by "stable, minimal, and appropriate regulatory guidelines that are fairly and expeditiously applied," Congress found.[7]

At this early stage of the industry's development, Congress found that the goals of regulation should be limited to the protection of a specified set of interests, which, notably, did not yet include participant safety. Commercial launches should be regulated "only to the extent necessary," Congress noted, to comply with "international obligations" and "protect the *public health and safety* [italics added], safety of property, and national security interests and foreign policy interests of the United States."[8] Similarly, the act's identified purposes included promotion of "economic growth and entrepreneurial activity" and commercial launch activities through the establishment of a simpler and faster licensing process for private-sector launches.[9] To help achieve these goals, the Department of Transportation was designated as the responsible agency for implementing the bill's provisions.

In addition, the Commercial Space Launch Act of 1984 established a licensing requirement for commercial space launches, stating that "[n]o person shall launch a launch vehicle or operate a launch site within the United States, unless authorized by a license issued or transferred under this Act."[10] The Secretary was authorized to grant licenses and to issue regulations specifying launch licensing requirements. The safety of spaceflight participants was not directly addressed in the law, with the government's regulatory authority instead based

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4 Executive Order 12465, "Commercial Expendable Launch Vehicle Activities," Executive Office of the President, February 24, 1984.

5 FAA, "About the Office of Commercial Space Transportation," webpage, undated-b; FAA, "Commercial Space Transportation Advisory Committee (COMSTAC)," webpage, January 12, 2023b.

6 Congressional Research Service, *Commercial Space: Federal Regulation, Oversight, and Utilization*, 2018; FAA, undated-b.

7 Public Law 98-575, Commercial Space Launch Act, Sec. 2(6), October 30, 1984.

8 Pub. L. 98-575, Sec. 2(7), 1984.

9 Pub. L. 98-575, Sec. (3)(1)(2), 1984.

10 Pub. L. 98-575, Sec. (6)(a)(1), 1984.

on the need to protect "public health and safety, safety of property, and national security interests and foreign policy interests."[11] The law allowed the Secretary to suspend or revoke licenses and to immediately terminate planned launches under certain specified conditions, which again included circumstances that might threaten public safety, though not spaceflight participant safety. License holders were required to allow government observers to monitor launch sites and other relevant sites or facilities to ensure that licensing requirements were being met. License holders were also required to obtain liability insurance, and the Secretary was authorized to determine the suitable level of insurance required.

Congress continued to amend the Commercial Space Launch Act of 1984 in the decades that followed, addressing commercial space indemnification, whereby the government may provide financial support and protection to commercial space entities facing liability claims above some certain specified threshold, and providing new authorities for the regulation of commercial space reentry operations.[12] In comparison, the Commercial Space Launch Act of 1984 had focused on launch operations. However, major legislative progress on commercial human spaceflight safety would wait until the early 21st century, with the passage of the Commercial Space Launch Amendments Act of 2004.[13]

The commercial space industry had continued to make progress in the two decades since the passage of the Commercial Space Launch Act of 1984. In June 2004, Mojave Aerospace Ventures' SpaceShipOne and its human pilot achieved suborbital flight, the first-ever commercial spaceflight with a human occupant.[14] SpaceShipOne would again reach suborbital altitudes with human pilots twice that same year.[15] Against this backdrop, the Commercial Space Launch Amendments Act was enacted into law on December 23, 2004.

The law provided the FAA with new authorities to regulate the safety of commercial human spaceflight, but it also enacted significant limitations on these same authorities. Congress' findings in the law regarding the future of commercial spaceflight safety regulation give insight into the law's regulatory approach. Congress recognized the progress of efforts to advance commercial human spaceflight, noting that the "the public interest is served by creating a clear legal, regulatory, and safety regime for commercial human space flight" and that the Department of Transportation would have an important safety role in the regulation of the industry as it grew.[16] However, Congress also drew attention to policy goals in the legislation that could, at least in part, be seen as in tension in terms of their implications

[11] See, for example, Pub. L. 98-575, Sec. (7), 1984.

[12] George C. Nield, Brooke Owens, and John Sloan, "The Origin and Practice of U.S. Commercial Human Space Flight Regulations," International Astronautical Congress, 2008; Public Law 105-303, Commercial Space Act of 1998, October 28, 1998.

[13] Pub. L. 105-303, 1998.

[14] Congressional Research Service, *Commercial Human Spaceflight*, October 1, 2021; Nield, Owens, and Sloan, 2008.

[15] Congressional Research Service, 2021; Nield, Owens, and Sloan, 2008.

[16] Pub. L. 108-492, 2004.

for regulation. One goal was to improve the safety of commercial space flight for spacecraft occupants. Congress emphasized that, for long-term success, the commercial spaceflight industry would need to "continually improve its safety performance."[17] Future safety regulations would need to be crafted in such a way that spaceflight occupants were protected against "avoidable risks."[18]

But a second goal was to continue to advance and mature the American commercial space industry. Congress noted that "the goal of safely opening space to the American people and their private commercial, scientific, and cultural enterprises should guide Federal space investments, policies, and regulations."[19] Furthermore, regulations should not "stifle technology development."[20] In addition, the law uses the term space flight "participant" rather than "passenger" to refer to "an individual, who is not crew, carried within a launch vehicle or reentry vehicle."[21] According to a later statement before Congress by the AST Associate Administrator at the time, the use of the term *participant* can "underscore the fact that private citizens making suborbital flights will encounter an elevated level of risk."[22]

This being the case, Congress might have sought to emphasize through its choice of terminology that individuals choosing to fly to space on private spacecraft were distinct from passengers on more-established transportation modes, as they were actively participating in a potentially risky activity. Congress appeared to seek to harmonize the two potentially conflicting goals of safety and industry progress by stating that safety regulations should be implemented and strengthened over time, as the industry developed and as safety expectations changed. "The regulatory standards governing human space flight must evolve as the industry matures," the law stated. For although transporting humans in space is "inherently risky," over time "the public . . . [will come] . . . to expect greater safety for crew and space flight participants from the industry."[23] Therefore, the law directed government regulators to pursue the "continuous improvement" of launch vehicle safety.[24]

Thus, the regulatory approach for commercial human spaceflight safety adopted in the Commercial Space Launch Amendments Act of 2004 included several key elements. First, the law provided authority to the government to regulate commercial human space flight safety but only under certain limited conditions. According to the law, "The Secretary may issue

17 Pub. L. 108-492, Sec. (2)(a)(5), 2004.

18 Pub. L. 108-492, Sec. (2)(a)(5), 2004.

19 Pub. L. 108-492, Sec. (2)(a)(5), 2004.

20 Pub. L. 108-492, Sec. (2)(a)(5), 2004.

21 Pub. L. 108-492, Sec. (2)(b)(9), 2004.

22 George C. Nield, "Statement on Commercial Space Transportation," testimony before the House of Representatives Committee on Transportation and Infrastructure, Subcommittee on Aviation, December 2, 2009.

23 Pub. L. 108-492, Sec. (2)(a)(5), 2004.

24 Pub. L. 108-492, Sec. (2)(c)(2), 2004.

regulations governing the design or operation of a launch vehicle to protect the health and safety of crew and space flight participants."[25] Notably, however, the government could only regulate launch vehicles in response to mishaps that had already occurred. Specifically, regulators could regulate "design features or operating practices" that had "resulted in a serious or fatal injury . . . to crew or space flight participants during a licensed or permitted commercial human space flight."[26] Alternatively, regulations could be promulgated when features or practices "contributed to an unplanned event or series of events during a licensed or permitted commercial human space flight that posed a high risk of causing a serious or fatal injury . . . to crew or space flight participants."[27] In order to issue regulations in response to safety mishaps in one of these two categories, regulators would need to explicitly connect the regulation to the triggering incident with an incident description.[28]

By design, this regulatory approach limited the scope of the FAA's power to regulate commercial human spaceflight to protect participant safety. For the time being, the government's regulatory power was retrospective in nature, focusing on past safety incidents, rather than prospective.[29] This approach meant that regulators could not work to prevent accidents by identifying and limiting potentially unsafe design elements in advance but were instead restricted to ensuring that elements that had already led to mishaps were not reproduced. They could not limit the use of a certain design feature, for instance, because of an assessment that such a feature was potentially unsafe; regulations could only restrict or set acceptable parameters for such a feature if it had played a role in a safety mishap.

But in keeping with Congress' apparent preference for a graduated approach to commercial human spaceflight safety regulation, the limitations on the government's regulatory powers were not envisioned in the law as permanent. Instead, the law contained a sunset provision indicating that in the future the government could regulate commercial human spaceflight safety more broadly and proactively. After eight years, the law directed, the government no longer had to limit itself to regulation in the wake of safety incidents and could implement the mandate to regulate launch vehicle safety to "protect the health and safety of crew and space flight participants" more broadly.[30] The eight-year suspension has been described as a "learning period" for the commercial spaceflight industry to innovate and generate information in the area of human spaceflight without major government regulations on participant safety.[31]

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[25] Pub. L. 108-492, Sec. (2)(c)(14), 2004.

[26] Pub. L. 108-492, Sec. (2)(c)(14), 2004.

[27] Pub. L. 108-492, Sec. (2)(c)(14), 2004.

[28] Pub. L. 108-492, Sec. (2)(c)(14), 2004.

[29] Congressional Research Service, 2018.

[30] Pub. L. 108-492, Sec. (2)(c)(14), 2004.

[31] See, e.g., FAA, 2017b; Christian Davenport; "Richard Branson and Jeff Bezos Will Fly to Space at Their Own Risk. Does That Make It Right for Everyone?" *Washington Post*, June 23, 2021.

A second key element of the law's approach to commercial human spaceflight safety regulation was the establishment of an informed consent requirement for spaceflight participants.[32] Participants would now need to receive a written notification before launch that the flight vehicle had not received a safety certification from the government. Such notification would need to be provided before a participant made a payment for the planned spaceflight. In addition, the law specified several categories of safety information that would need to be shared with prospective spaceflight participants. For one, space launches with human participants would be permitted only after "the holder of the license or permit has informed the space flight participant in writing about the risks of the launch and reentry, including the safety record of the launch or reentry vehicle type."[33]

The government would also be responsible for providing certain safety information to spaceflight participants. The law required the Secretary of Transportation to inform prospective participants "of any relevant information related to risk or probable loss during each phase of flight."[34] Moreover, the law authorized regulators to establish other "reasonable requirements" for spaceflight participants, which could include "medical and training" standards.[35] After being provided with the specified safety information, spaceflight participants would need to affirm in writing their informed consent to fly. In the case of crew members, the law did not include the same informed-consent requirement as for spaceflight participants. As with participants, however, the law did require the entity launching a vehicle into space to inform crew members that the vehicle had not received a safety certification from the government. Regulators were also authorized to establish training or other requirements that crew members would need to satisfy before taking part in a spaceflight.

Taken as a whole, the regulatory framework for commercial human spaceflight safety adopted in the Commercial Space Launch Amendments Act of 2004 provided notable but limited protections. Consistent with Congress' characterization of the industry as "inherently risky," the requirement to provide safety and risk information to prospective participants was a central element.[36] Regulators would also have some power to ensure that participants and crew were appropriately prepared for spaceflight. If a mishap or accident did occur, regulators would be able to take steps to prevent reoccurrence. But more-sweeping powers to

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[32] Pub. L. 108-492, Sec. (2)(c)(13), 2004.

[33] Pub. L. 108-492, Sec. (2)(c)(13), 2004.

[34] Pub. L. 108-492, Sec. (2)(c)(13), 2004. The FAA AST has been delegated the regulatory responsibilities of the Transportation Secretary concerning commercial human spaceflight. See, e.g., Order 8800.2, "FAA Commercial Space Astronaut Wings Program," Federal Aviation Administration, July 20, 2021. The order notes that "[t]he Commercial Space Launch Act of 1984, as amended and re-codified at 51 U.S.C. 50901 - 50923 (the Act), authorizes the Department of Transportation and, through delegations, the FAA AST, to oversee, authorize, and regulate both launches and reentries of commercial space vehicles, and the operation of launch and reentry sites when carried out by a U.S. citizen or entity within the United States."

[35] Pub. L. 108-492, Sec. (2)(c)(13), 2004.

[36] Pub. L. 108-492, Sec. (2)(a)(5), 2004.

protect spaceflight participants were expressly limited until the end of the eight-year learning period, which was initially set to expire in 2012.[37]

Despite this initial target, Congress postponed the end date of the learning period in 2012, when the FAA Modernization and Reform Act set the new end date as 2015.[38] Three years later, Congress passed the CSLCA of 2015, which again extended the learning period, this time until October 1, 2023.[39] For the period before the new 2023 end date of the learning period, Congress promoted another approach, short of regulation, for improving participant safety—the use of voluntary standards by the commercial space industry. In particular, the CSLCA of 2015 directed the Transportation Secretary to "continue to work with the commercial space sector, including the Commercial Space Transportation Advisory Committee, or its successor organization, to facilitate the development of voluntary industry consensus standards based on recommended best practices to improve the safety of crew, government astronauts, and space flight participants as the commercial space sector continues to mature."[40]

The law also mandated the completion of several reports related to commercial human spaceflight safety. For example, Congress directed the Transportation Secretary to issue periodic reports concerning "the progress of the commercial space transportation industry in developing voluntary industry consensus standards that promote best practices to improve industry safety."[41] It also required reports "specifying key industry metrics that might indicate readiness of the commercial space sector and the Department of Transportation to transition to a safety framework that may include regulations" and identifying "activities . . . most appropriate for a new safety framework that may include regulatory action, if any, and a proposed transition plan for such safety framework."[42] Finally, the law called for an independent "assessment of the readiness of the commercial space industry and the Federal Government to transition to a safety framework that may include regulations."[43] Together, these reports could help generate information and analysis for a potential transition to more-extensive commercial spaceflight participant safety regulations.

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37 Congressional Research Service, 2021.

38 Public Law 112-95, FAA Modernization and Reform Act of 2012, Sec. 827, February 14, 2012.

39 Pub. L. 114-90, 2015.

40 Pub. L. 114-90, Sec. 111(5), 2015.

41 Pub. L. 114-90, Sec. 111(5), 2015.

42 Pub. L. 114-90, Sec. 111(5), 2015.

43 Pub. L. 114-90, Sec. 111(5), 2015.

APPENDIX B

Referenced Standards

During the course of our research, we examined all relevant referenced standards that could be applied to the topics raised by Congress within the CSLCA. SDOs were found to be involved in creating industry consensus standards, but those interviewed noted that progress from these organizations was often slow from conception to implementation.[1] The processes that these organizations use to propagate standards vary based on their established guidelines. This appendix provides an overview of relevant SDOs and the relevant standards referred to in the report.

The following SDOs were involved in development of standards that are currently published and were included in the 2022 FAA report to Congress.[2] We provide a brief overview of each organization.

The American Society for Testing and Materials was formed in 1898 and subsequently changed its name to ASTM International. ASTM International is a "globally recognized leader in the development and delivery of voluntary consensus standards." Currently, it has more than 12,000 standards "in use around the world to improve product quality, enhance health and safety, strengthen market access, and trade, and build consumer confidence."[3]

IAASS, established in 2004, is "a non-profit organization dedicated to furthering international cooperation and scientific advancement in the field of space systems safety."[4] IAASS helps "shape and advance an international culture of space safety (technical, organizational, and socio-political), which would contribute to make space missions, vehicles, stations, extra-terrestrial habitats, equipment and payloads safer for the general public, ground personnel, crews and flight participants."[5]

ISO is an independent, nongovernment international organization founded in 1947 as a forum for experts from around the world to come together and discuss international standardization. "Through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market relevant International Standards that support

1 Government officials, interview with the authors, September 1, 2022, and October 13, 2022.

2 FAA, 2022a, pp. 18–20.

3 ASTM International, "Detailed Overview," webpage, undated-b.

4 IAASS, "Welcome to IAASS," webpage, undated.

5 IAASS, undated.

innovation and provide solutions to global challenges."[6] ISO currently provides more than 25,000 international standards covering nearly "all aspects of technology, management, and manufacturing."[7]

AIAA consists of nearly 30,000 engineers and scientists from 88 countries dedicated to the global aerospace profession. "AIAA convenes yearly forums, publishes books . . . [and] technical journals, hosts a collection of 160,000 technical papers, develops and maintains standards, and advocates on policy issues. AIAA serves aerospace professionals around the world by providing the tools, insights, and collaborative exchanges to advance the state of the art in engineering and science for aviation, space, and defense."[8]

SAE produces standards "used to advance mobility engineering throughout the world." Today's SAE standards include almost 10,000 documents created for mobility industries, including aerospace, automotive, and commercial vehicles.[9]

Table B.1 lists the standards relevant to this study.

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6 ISO, "About Us," webpage, undated.

7 ISO, undated.

8 AIAA, *Ascending to New Heights*, AIAA Institute Report, 2019–2020.

9 SAE, "SAE Standards Development," webpage, undated.

TABLE B.1

Standards Relevant to This Study, Published and Under Development

Standard ID Number	Standard Title	Publishing Organization and Standard Number (if available)	Status
ISO 16157:2018	Space Systems — Human-Life Activity Support Systems and Equipment Integration in Spaceflight — Techno-Medical Requirements for Space Vehicle Human Habitation Environments	ISO; 49.140 (Space Systems and Operations)	Published
ISO 17763:2018	Space Systems — Human-Life Activity Support Systems and Equipment Integration in Spaceflight	ISO; 49.140 (Space Systems and Operations)	Published
ISO 14620-2:2019	Space Systems — Safety Requirements — Part 2: Launch Site Operations	ISO; 49.140 (Space Systems and Operations)	Published
ISO 14620-3:2021	Space Systems — Safety Requirements — Part 3: Flight Safety Systems	ISO; 49.140 (Space Systems and Operations)	Published
ISO 16726:2018	Space Systems — Human-Life Activity Support Systems and Equipment Integration in Spaceflight — Techno-Medical Requirements for Space Vehicle Human Habitation Environments — Requirements for the Air Quality Affected By Harmful Chemical Contaminants	ISO; 49.140 (Space Systems and Operations)	Published
ISO 19971:2018	Space Systems — Spacecraft and Launch Vehicle Combined Operation Plan (COP) at Launch Site — General Format	ISO; 49.140 (Space Systems and Operations)	Published
ISO/TR 20590:2021	Space Systems — Space Debris Mitigation Design and Operation Manual for Launch Vehicle Orbital Stages	ISO; 49.140 (Space Systems and Operations)	Published
ISO 20892:2018	Space Systems — Launch Complexes Modernization Process — General Requirements	ISO; 49.140 (Space Systems and Operations)	Published
ISO 27875:2019	Space Systems — Re-Entry Risk Management for Unmanned Spacecraft and Launch Vehicle Orbital Stages	ISO; 49.140 (Space Systems and Operations)	Published
ISO 14620-1:2018	Space Systems — Safety Requirements — Part 1: System Safety	ISO; 49.140 (Space Systems and Operations)	Published

Table B.1—Continued

Standard ID Number	Standard Title	Publishing Organization and Standard Number (if available)	Status
ISO 24917:2020	Space Systems — General Test Requirements for Launch Vehicles	ISO; 49.140 (Space Systems and Operations)	Published
ISO/TR 17400:2021	Space Systems — Space Launch Complexes, Integration Sites and Other Facilities — General Testing Guidelines	ISO; 49.140 (Space Systems and Operations)	Published
ASTM F3550-22	Standard Guide for Classifying Safety-Related Events	ASTM International, Committee F47 on Commercial Spaceflight; F47.05 Cross-Cutting	Published
ASTM F3520-21	Standard Guide for Training and Qualification of Safety-Critical Space Operations Personnel	ASTM International, Committee F47 on Commercial Spaceflight; F47.03 Launch and Reentry Vehicles	Published
ASTM F3479-20	Standard Specification for Failure Tolerance for Occupant Safety of Suborbital Vehicles	ASTM International, Committee F47 on Commercial Spaceflight; F47.01 Occupant Safety	Published
ASTM F3344-19	Standard Guide for Storage, Use, and Handling of Liquid Rocket Propellants	ASTM International, Committee F47 on Commercial Spaceflight; F47.04 Spaceports	Published
ASTM F3377-20	Standard Terminology Relating to Commercial Spaceflight	ASTM International, Committee F47 on Commercial Spaceflight; F47.91 Terminology	Published
ASTM F3514-21	New Guide for Space Data Exchange to Support the Integration of Space Operations into Air Traffic Management	ASTM International, Committee F47 on Commercial Spaceflight; F47.05 Cross-Cutting	Published
ASTM WK59508	Guide for Fault Tolerance for Occupant Safety of Suborbital Vehicles	ASTM International, Committee F47 on Commercial Spaceflight; F47.01 Occupant Safety	Under development
ASTM WK70011	New Guide for Occupant Safety of Orbital Vehicles	ASTM International, Committee F47 on Commercial Spaceflight; F47.01 Occupant Safety	Under development
ASTM WK61254	New Classification for Spacecraft Vehicle Types	ASTM International, Committee F47 on Commercial Spaceflight; F47.03 Launch and Reentry Vehicles	Under development
ASTM WK64814	New Guide for Flight Controller Training	ASTM International, Committee F47 on Commercial Spaceflight; F47.03 Launch and Reentry Vehicles	Under development
ANSI/AIAA S-153-2021	Human Spaceflight – Spacecraft Architecture and Systems Engineering Ontology	ANSI/AIAA	Published

Table B.1—Continued

Standard ID Number	Standard Title	Publishing Organization and Standard Number (if available)	Status
AIAA S-114A-2020	Moving Mechanical Assemblies for Space and Launch Vehicles	ANSI/AIAA	Published
SAE AS6818	Commercial Spaceflight Seat Restraints	SAE	Under development
NFPA 461	Standard for Fire Protection of Spaceport Facilities	National Fire Protection Association	Under development
IAASS-SSI-1700	Commercial Human-Rated System	IAASS	Published

SOURCE: Standards referenced in this table were derived from FAA, 2022a, and cross-referenced for updated publication data. Additional standards were included because of their industry recognition. Standards currently listed as under development might not have publicly available information about their current development status.

Abbreviations

AIAA	American Institute of Aeronautics and Astronautics
ANPRM	Advance Notice of Proposed Rulemaking
AST	Office of Commercial Space Transportation
BEA	U.S. Bureau of Economic Analysis
CFR	Code of Federal Regulations
COMSTAC	Commercial Space Transportation Advisory Committee
CSLCA	Commercial Space Launch Competitiveness Act
FAA	Federal Aviation Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FTE	full-time equivalent
FY	fiscal year
IAASS	International Association for the Advancement of Space Safety
IDA-STPI	Institute for Defense Analyses Science and Technology Policy Institute
ISO	International Organization for Standardization
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
SAE	SAE International
SDO	standards development organization
SpARC	Space Aerospace Rulemaking Committee
SWG	Standards Working Group

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SOCIAL AND ECONOMIC WELL-BEING

At Congress's request, RAND researchers assessed the progress that the commercial spaceflight industry has made in adopting voluntary safety standards, the industry's progress in meeting key metrics set by the Federal Aviation Administration (FAA) in 2017, and whether the industry has matured such that areas identified in FAA reports are ready for regulatory action. The Commercial Space Launch Competitiveness Act of 2015 imposes a moratorium on safety regulations until October 1, 2023. The FAA will be authorized to propose and issue regulations upon expiration of the moratorium (if it is allowed to expire). The RAND team reviewed the existing literature and public data. They also conducted interviews with subject-matter experts and stakeholders across the space domain, including government, industry, and standards development organizations. In the authors' assessment, the readiness of the commercial space industry for regulation, or for further development of voluntary consensus standards, does not only depend on the progress of adopting standards and meeting metrics. Regulatory readiness depends also on five key factors: access to, and understanding of, the regulatory process; security of regulatory support; the effectiveness of the regulatory support for the technology; environmental effects, costs, and security issues related to the regulation; and the ability to pass the regulation. The authors found that regulatory action is appropriate in the following form: allowing the moratorium to expire as per current law, continuing the development of voluntary consensus standards, and instituting Space Aerospace Rulemaking Committees. These regulatory actions should be accompanied by additional resourcing of the FAA.

$28.00

ISBN-10 1-9774-1102-9
ISBN-13 978-1-9774-1102-0

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RR-A2466-1