

# U.S. Space Policymaking in a New Era of Commercialization

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From Launch to Lunar Operations

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Over the last decade, the U.S. space industry has seen rapid commercialization and an emphasis for the U.S. government to "buy what you can, build what you must". Since 2015, one new launch provider has nearly taken over the U.S. market from the previous monopoly of United Launch Alliance and has disrupted traditional geostationary satellite communications with low-latency broadband from Low Earth Orbit, three U.S. commercial companies have launched commercial astronauts into space, and two U.S. commercial companies have landed, one successfully and one partially successfully, on the Moon. As the government seeks to enable new commercial space capabilities, new oversight functions will be needed to monitor safety, security, and economic stability of these services. This dissertation is split into three parts:

The first paper in this dissertation utilizes a historical comparative analysis to study twenty different measures of organizational culture throughout the history of U.S. aviation regulation, from the founding of the Aeronautics Branch to present. It explores the efficacy of the FAA and its predecessors in creating a safety culture, and makes recommendations for the creation of a new commercial human spaceflight aviation regulatory regime in FAA's Office of Commercial Space Transportation upon the expiration of the current "learning period".

The second paper utilizes case studies of historical critical infrastructure monopolies and vertical integration in resource, transportation, utility, information technology, and defense sectors, and their impacts on pricing and innovation, and examines the increasing role of SpaceX across the space supply chain in this context. It makes recommendations regarding the monitoring of economic indicators, ensuring competition, and enforcing antitrust laws.

The final paper explores mechanisms for mitigating interference in lunar operations. It surveys the international lunar community to determine types of interference of concern for lunar operations and information about its known spatiotemporal extent. To inform mitigation mechanisms, the paper looks at existing standards and best practices, and gaps, in interference mitigation, as well as existing data, measurements, and models of interference and gaps in that data. It additionally makes recommendations regarding improved data sharing during mission development.

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## Abbreviations

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|         |                                                                 |
|---------|-----------------------------------------------------------------|
| 3GPP    | 3 <sup>rd</sup> Generation Partnership Project                  |
| AST     | Office of Commercial Space Transportation (within FAA)          |
| CAA     | Civil Aeronautics Administration                                |
| CAB     | Civil Aeronautics Board                                         |
| CETEX   | Committee on Contamination by Extra-terrestrial Exploration     |
| CHS     | Commercial Human Spaceflight                                    |
| CLD     | Commercial LEO Destinations                                     |
| CLPS    | Commercial Lunar Payload Services                               |
| COMSTAC | Commercial Space Transportation Advisory Committee              |
| CONFERS | Consortium for Execution of Rendezvous and Servicing Operations |
| CONOPS  | Concept of Operations                                           |
| COPUOS  | Committee on the Peaceful Uses of Outer Space                   |
| COSPAR  | Committee on Space Research                                     |
| DoC     | Department of Commerce                                          |
| DoD     | Department of Defense                                           |
| DoJ     | Department of Justice                                           |
| EELV    | Evolved Expendable Launch Vehicle                               |
| EMI     | Electromagnetic Interference                                    |
| ERCOT   | Electric Reliability Council of Texas                           |
| FASAP   | Foreign Aviation Safety Assessment Program                      |
| FAA     | Federal Aviation Administration                                 |
| FCC     | Federal Communications Commission                               |
| FERC    | Federal Energy Regulatory Commission                            |
| FTC     | Federal Trade Commission                                        |
| GAO     | Government Accountability Office                                |
| GEGSLA  | Global Expert Group on Sustainable Lunar Activities             |
| GEO     | Geostationary Earth Orbit                                       |
| HLS     | Human Landing Systems                                           |
| HRO     | High Reliability Organization                                   |
| ICAO    | International Civil Aviation Organization                       |
| IATA    | International Air Transport Association                         |
| ISO     | International Standards Organization                            |
| ISO     | Independent System Operator                                     |
| ISS     | International Space Station                                     |
| ITU     | International Telecommunication Union                           |

|        |                                                                 |
|--------|-----------------------------------------------------------------|
| KARI   | Korean Aerospace Research Institute                             |
| LEO    | Low Earth Orbit                                                 |
| LOGIC  | Lunar Operating Guidelines for Infrastructure Consortium        |
| MADCAP | Multimission Automated Deepspace Conjunction Assessment Process |
| MEO    | Medium Earth Orbit                                              |
| NAS    | National Academy of Sciences                                    |
| NASA   | National Aeronautics and Space Administration                   |
| NTSB   | National Transportation Safety Board                            |
| NTIA   | National Telecommunications and Information Administration      |
| OS     | Operating System                                                |
| OSC    | Office of Space Commerce (within the Department of Commerce)    |
| OST    | Outer Space Treaty                                              |
| PNT    | Position, Navigation, and Timing                                |
| PSI    | Plume Surface Interaction                                       |
| PSR    | Permanently Shadowed Region                                     |
| RFI    | Radiofrequency Interference                                     |
| SCADTA | Sociedad Colombo-Alemana de Transportes Aeroes                  |
| SoPs   | Standard Operating Procedures                                   |
| STD    | Standard                                                        |
| SZM    | Shielded Zone of the Moon                                       |
| ULA    | United Launch Alliance                                          |
| U.N.   | United Nations                                                  |
| U.S.   | United States                                                   |
| WRC    | World Radiocommunications Conference                            |
| WWI    | World War I                                                     |

# 1. Introduction

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Since the mid-2010s, the U.S. space industry has experienced a rapid commercial transformation, migrating from primarily purpose-built systems for government use, to one in which the U.S. government has attempted to stimulate a thriving commercial space economy through the purchase of space as a service, with government acquisitions policies to “buy what you can, build what you must.”<sup>1</sup>

In the early 2010s, the U.S. government was reliant on one large launch provider, the United Launch Alliance (ULA), which was formed as a conglomerate in 2006 between Lockheed Martin and Boeing. The merger was a result of a 1994 decision by the Air Force to procure an Evolved Expendable Launch Vehicle; Lockheed Martin and Boeing developed Atlas and Delta rockets, respectively, but found themselves unable to compete with Russian and European launch prices, and struggling to stay afloat on Air Force contracts; to ensure the stability of the launch supply chain, the Air Force brokered the merger and requested that ULA maintain both Delta and Atlas launch vehicles. However, SpaceX, then still a start-up, sued to stop this merger in 2005.<sup>2</sup> The Federal Trade Commission (FTC) allowed the merger to continue, working with DoD due to national security interests, with three conditions: “(1) ULA must cooperate on equivalent terms with all providers of government space vehicles; (2) Boeing and Lockheed’s space vehicle businesses must provide equal consideration and support to all launch services providers when seeking any U.S. government delivery in orbit contract; and (3) Boeing, Lockheed, and ULA must safeguard competitively sensitive information obtained from other space vehicle and launch services provider.”<sup>3</sup>

For the next 7 years, the U.S. government had two contracts with ULA, a firm-fixed price contract for each launch, as well as a launch capability contract to maintain essential launch capabilities. The costs ballooned without competition, triggering a Nunn-McCurdy certification in 2012 due to the program’s ballooning costs. In 2014, the Air Force attempted to fix its procurement program with a 36-launch block buy agreement for \$4.4B with ULA through the end of the decade. SpaceX was not allowed to compete for any of these missions, despite having launched the Falcon 9 seven times with 100% success rate through 2013. After a Senate

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<sup>1</sup> “Race to Resilience”, U.S. Space Force, Space Systems Command, 18 May 2025, <https://www.ssc.spaceforce.mil/about-us/race-to-resilience>

<sup>2</sup> Berger, Eric, “How America’s two greatest rocket companies battled from the beginning”, Ars Technica, 2 Aug 2017, <https://arstechnica.com/science/2017/08/how-americas-two-greatest-rocket-companies-battled-from-the-beginning/>

<sup>3</sup> “FTC Intervenes in Formation of ULA Joint Venture by Boeing and Lockheed Martin”, Federal Trade Commission, 3 Oct 2006 <https://www.ftc.gov/news-events/news/press-releases/2006/10/ftc-intervenes-formation-ula-joint-venture-boeing-lockheed-martin>

Appropriations hearing on launch costs and subsequent SpaceX lawsuit, SpaceX and the Air Force entered mediation, resulting in the certification of the Falcon 9 for national security missions and opening up block buys for competition, with first SpaceX launch on May 1, 2014.<sup>4</sup>

The 2014 Russian invasion of Ukraine placed new pressure on the U.S. launch sector, with a Congressional mandate to phase out the Russian RD-180 engine by 2019; the RD-180 engine was used in Atlas V rockets, requiring ULA to develop a new rocket, the Vulcan, which also replaced the Delta IV. SpaceX was already using its own rocket engine, and did not have to modify its launch vehicle as a result.<sup>5</sup> Since 2014, ULA has launched on average 7.9 vehicles per year, with more on average from 2014-2016, and a drop off as it developed the Vulcan. SpaceX, in contrast, has steadily increased from low double digit launch numbers from 2017-2020 to 134 Falcon 9 launches in 2024.<sup>6</sup>

Launch has not only undergone a dramatic shift for payloads, but also for both government-funded and commercial human spaceflight. In 2003, the Space Shuttle Columbia disaster led to a push for NASA to abandon the shuttle program; after abandoning the Constellation program, it solicited commercial crew bids in 2010, and subsequently retired the space shuttle in 2011.<sup>7</sup> At the same time, a burgeoning commercial human spaceflight industry was beginning to take hold. In 2004, SpaceShipOne won the Ansari X Prize for launching the first nongovernmental vehicle to space twice within two weeks, resulting in the creation of Virgin Galactic.<sup>8</sup> Although many timelines for the first commercial human spaceflight launches came and went, 2021 was a year of many firsts, including the first fully crewed space launch by Virgin Galactic, first crewed suborbital launch by Blue Origin, and the launch of SpaceX's crewed Inspiration4 commercial mission.<sup>9</sup>

After the retirement of the space shuttle, the U.S. was reliant upon Russian launch vehicles for transportation to the International Space Station, until SpaceX launched its first crewed Dragon mission in 2020. Boeing's Starliner did not launch its first crewed mission until 2024, which famously resulted in a no-go decision to return to Earth after a zero-fault tolerant

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<sup>4</sup> Berger, 2017.

<sup>5</sup> Easley, Mikayla. "U.S. Kicking Russian Rocket Engines to the Curb", National Defense, 5 Aug 2022, <https://www.nationaldefensemagazine.org/articles/2022/8/5/us-kicking-russian-rocket-engines-to-the-curb>

<sup>6</sup> Krebs, Gunter D., "Chronology of Space Launches", Gunter's Space Page, 18 May 2025 <https://space.skyrocket.de/directories/chronology.htm>

<sup>7</sup> Gebhardt, Chris, "The Growing Importance of NASA's Commercial Crew Program", NASASpaceFlight, 11 April, 2014, <https://www.nasaspaceflight.com/2014/04/growing-importance-nasas-commercial-crew-program/>

<sup>8</sup> Dinner, Josh, "Who is Virgin Galactic and what do they do?", Space.com, 30 May 2023, <https://www.space.com/18993-virgin-galactic.html>

<sup>9</sup> Stimac, Valerie. "Space Tourism Took Off in 2021, Here's How it Happened", Forbes, 31 Dec 2021, <https://www.forbes.com/sites/valeriestimac/2021/12/31/space-tourism-took-of-in-2021-heres-how-it-happened/>

situation with the loss of four of twenty-eight thrusters, resulting in astronauts Suni Williams and Butch Wilmore spending 286 instead of 12 days in space.<sup>10</sup>

NASA's migration toward commercial crew and cargo missions is part of a larger push for the agency to move toward commercial; it expects to move toward Commercial LEO Destinations (CLDs) after the retirement of the International Space Station,<sup>11</sup> and is funding U.S. cislunar architecture primarily through commercial systems, via contracts such as Commercial Lunar Payload Services (CLPS), which has already had one successful and one partially successful commercial lunar landing,<sup>12</sup> and the Human Landing Systems (HLS) contracts awarded to SpaceX and Blue Origin,<sup>13</sup> among other infrastructure contracts.

Alongside drastic changes in launch in the past decade have been drastic changes in satellite services, migrating from custom-built solutions for primarily U.S. government customers, to space as a service, with broadband and remote sensing constellations providing communications or data analytics to customers both in the U.S. government and in the private sector. Cubesats, with 10x10x10 cm stackable forms, first began commercialization with the launch of 33 Planet remote sensing satellites from the International Space Station in 2014<sup>14</sup> and initial commercial satellites for remote sensing company Spire in 2015.<sup>15</sup> Around this time, new satellite communications companies began forming and announcing constellations in Low and Medium Earth Orbits, which would reduce latency but require more satellites for full-sky coverage (while advantageously providing the polar coverage geostationary satellites lack); SpaceX's Starlink launched its first operational satellites in 2019,<sup>16</sup> as did O3b, and OneWeb.<sup>17</sup> Starlink currently has over 7000 satellites on-orbit providing broadband access today,<sup>18</sup> OneWeb

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<sup>10</sup> Berger, Eric, "Starliner's flight to the space station was far wilder than most of us thought", Ars Technica, 1 April 2025, <https://arstechnica.com/space/2025/04/the-harrowing-story-of-what-flying-starliner-was-like-when-its-thrusters-failed/>

<sup>11</sup> "Commercial Space Stations", NASA, 18 May 2025, <https://www.nasa.gov/humans-in-space/commercial-space/commercial-space-stations/>

<sup>12</sup> "Commercial Lunar Payload Services", NASA, 13 June 2023, <https://www.nasa.gov/reference/commercial-lunar-payload-services/>

<sup>13</sup> "About Human Landing Systems Development", NASA, 18 May 2025, <https://www.nasa.gov/reference/human-landing-systems/>

<sup>14</sup> Wall, Mike "First 'Cubesats' in Record-Breaking Fleet Launched from International Space Station", Space.com, 11 Feb 2014, <https://www.space.com/24651-cubesats-launch-space-station-planet-labs.html>

<sup>15</sup> De Selding, Peter, "PSLV Launches India's First Astronomy Satellite, 4 Spire Cubesats, 28 Sept 2015, <https://spacenews.com/pslv-rocket-launches-indias-1st-astronomy-satellite/>

<sup>16</sup> Pultarova, Teresa, "Starlink satellites: Facts, tracking and impact on astronomy" <https://www.space.com/spacex-starlink-satellites.html>

<sup>17</sup> Holmes, Mark, "The Top 12 Satellite Events of 2019", Via Satellite, 19 Dec 2019, <https://interactive.satellitetoday.com/via/january-2020/the-top-12-satellite-events-of-2019>

<sup>18</sup> Wall, Mike, SpaceX launches 26 Starlink satellites to orbit from California (video), Space.com, 16 May 2025, <https://www.space.com/space-exploration/launches-spacecraft/spacex-launches-26-starlink-satellites-to-orbit-from-california-video>

has more than 630,<sup>19</sup> Amazon Kuiper has just launched its first 27 satellites,<sup>20</sup> while O3b has 8 in MEO.<sup>21</sup> As a result of Starlink's first-mover LEO advantage, industry mergers and acquisitions with traditional GEO operators have occurred (Eutelsat/OneWeb, SES/O3b and now Intelsat, Viasat/Inmarsat).

With these vast changes in the sector, comes a question of what oversight is needed to ensure space services are safe, secure, and reliable for both the U.S. government and the general public, while allowing for rapid innovation in the sector. The U.S. space licensing regime is fractured; the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) licenses launches and reentries, the Department of Commerce Office of Space Commerce (OSC) licenses remote sensing, the Federal Communications Commission (FCC) licenses commercial spectrum use while the National Telecommunications and Information Administration (NTIA) licenses government spectrum use, the Department of State and Department of Commerce are responsible for export controls, and the National Aeronautics and Space Administration (NASA) and Department of Defense (DoD) are not regulators but set contractual requirements which become de facto industry standards for most U.S. space systems due to the government's predominance as a customer.

This dissertation, accordingly, explores three oversight themes as a series of three papers for this rapidly changing U.S. commercial space sector. Due to the commercialization of the space sector, the U.S. government is in a new situation, needing to provide oversight of space technologies that were previously government owned and operated. This oversight extends from human safety, to ensuring the reliability and security of its space-dependent critical infrastructure sectors, to extending oversight into domains where no regulatory structure exists to ensure safe and sustainable space operations. In this dissertation, we look at three burgeoning fields in the space sector, and make recommendations regarding government intervention to ensure safe and sustainable space operations in commercial human spaceflight, for space-reliant critical infrastructure, and for lunar operations. Specifically, we seek to answer the following questions in a series of three papers:

1. Based on the history of U.S. aviation regulation, how can the U.S. create a safety culture in the burgeoning commercial human spaceflight industry?
2. How do monopolistic behaviors and vertical integration in critical infrastructure sectors historically impact pricing, innovation, and security, and what might this mean for the U.S. government's dependence on SpaceX?

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<sup>19</sup> "Connect With Confidence", eutelsat OneWeb, 18 May 2025, <https://oneweb.net/our-network>

<sup>20</sup> Foust, Jeff, 29 April 2025, "Atlas launches first operational Project Kuiper satellites" <https://spacenews.com/atlas-launches-first-operational-project-kuiper-satellites/>

<sup>21</sup> Rainbow, Jason, "SpaceX launches redesigned O3b mPower satellites", SpaceNews, 19 Dec 2024, <https://spacenews.com/spacex-launches-redesigned-o3b-mpower-satellites/>

3. What types of interference are of concern to lunar operations, and where do technical guidelines or requirements exist which may help mitigate interference either through coordination during mission development or during concurrent lunar operations? Are there existing data, measurements, or models that can inform additional guidelines, and where do gaps exist?

In the first paper, which was written and published for the 2016 International Astronautical Congress, we explore through case studies the history of U.S. aviation regulation from the beginning of aviation to present to make recommendations for the creation of a commercial human spaceflight safety culture. In this work, we explore twenty measures of organizational culture as a means of correlating administrative practices (e.g., critical experience of the workforce, horizontal and vertical communication, coordination with major stakeholders, autonomy of the agency) with outcomes (e.g., safety record, ability to enforce regulations). Despite publication of the research three years prior to the first commercial human spaceflight in 2019, the research remains timely, as the regulatory moratorium, or “learning period,” on commercial human spaceflight safety has been extended by Congress yet again until 1 Jan 2027.<sup>22</sup> The FAA 2023 “Report to Congress: U.S. Department of Transportation Evaluation of Commercial Human Space Flight Activities Most Appropriate for New Safety Framework” examined readiness indicators to transition to a human spaceflight safety framework, suggesting that it would be ready to end the moratorium with a five-year period for rulemaking, with rules in effect in 2028. The FAA particularly noted its participation with the standards group ASTM 47 Committee on Commercial Spaceflight, and updates to its 2014 Recommended Practices for Human Spaceflight Occupant Safety as starting points.<sup>23</sup> However, the FAA’s Commercial Space Transportation Advisory Committee (COMSTAC), reported that the industry disagreed with the FAA’s readiness, particularly due to a lack of flight heritage and only three different spaceship designs, and criticize the FAA for a lack of metrics or methodology to determine its readiness. They also noted the FAA’s inability to keep up with the increase in launch licensing, let alone take on a new mandate as time-consuming as human spaceflight safety.<sup>24</sup> Based on the history of U.S. safety regulations, the moratorium is most likely to expire under Congressional scrutiny after a fatal accident; this work is intended to serve as a guideline for the potential structure and possible shortfalls of a burgeoning regulatory agency.

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<sup>22</sup> Foust, Jeff, “NDAA extends commercial spaceflight learning period and launch indemnification”, SpaceNews, 7 Dec 2024, <https://spacenews.com/ndaa-extends-commercial-spaceflight-learning-period-and-launch-indemnification/>

<sup>23</sup> 51 U.S.C. §50905(c)(7); FAA, *U.S. Department of Transportation Evaluation of Commercial Human Space Flight Activities Most Appropriate for New Safety Framework*

<sup>24</sup> “COMSTAC Response To FAA Human Spaceflight Report to Congress”, FAA, 11 July 2023 <https://www.faa.gov/media/68011>

In the second paper, we use a comparative historical analysis to look at the history of monopolistic behavior and vertical integration in critical infrastructure sectors from the late 1800s to today, and determine the impact of this behavior on pricing, innovation, and security as an indicator for the impact of SpaceX's increasing share of the space infrastructure market. SpaceX, the world's largest launch and satellite communications provider, and the only U.S. commercial crew vehicle provider, plays an essential role for U.S. military, civil, and commercial space, and is growingly influential in U.S. policy decisions with the role of Elon Musk in the second Trump Administration. SpaceX's dominance raises questions in the U.S. and abroad regarding market oversight, competition policy, and national security implications. This analysis examines historical monopolies to provide actionable insights before SpaceX's market position becomes entrenched.

Finally, in the third paper, we look to another domain in which minimal governance structures exist: lunar operations. Lunar operations in the U.S. largely fall in a regulatory vacuum not covered by any specific agency; efforts have been made to try to fill this gap through mission authorization and supervision proposals, none of which have passed in Congress. While the FCC regulates communications and FAA launch and reentry on Earth, minimal legal guidelines exist to ensure safe and sustainable operations on the lunar surface. Until recent commercial missions, there was not an oversight gap, as NASA has de facto oversight over its own contracts. However, with a growing commercial lunar sector, dozens of nations interested in supporting lunar operations, and missions largely concentrated at the lunar south pole, it is necessary to develop an understanding of the interference that may occur during lunar operations. This paper surveyed over 50 individuals in government, non-profit, academic, and commercial sectors to determine the types of interference of concern and their spatiotemporal extent, and determine what existing technical guidelines, data, measurements, and models that exist or may be needed to help mitigate interference. This work is intended to spearhead public information-sharing prior to launch, encourage bilateral information-sharing during operations, and encourage model/data-sharing and lessons learned post-mission, and determine what further work is needed to improve our understanding of interference during lunar operations.

All three papers focus on emerging space technologies, without substantial direct precedent to inform their governance. As such, it was not possible to analyze past performance of governance structures in these specific domains. For the first paper, a focus on historical methods was chosen after interviewing multiple FAA AST staff, and learning that there was no primer on how to create effective regulations for U.S. civil servants at regulatory agencies; many of the difficulties in aviation regulatory history were cyclical, and potentially preventable for commercial human spaceflight. For the second paper, although space monopolies have existed historically, the transformation toward buying space as a service and increasing reliance of the U.S. government and private sector on space services, suggests that increasing scrutiny should be placed on vulnerable sole-source contracts. Since the de facto position of the DoD has been to allow mergers that would normally be blocked by the Federal Trade Commission as monopolies

when in the interest of national security, to mitigate vulnerabilities the DoD should determine how to monitor the impact of monopolization on the space sector and ensure competition. We similarly look to a comparative historical analysis in critical infrastructure sector monopolies due to a dearth of existing data on interventions regarding space monopolies, and due to the growing influence on SpaceX in close parallel to the magnitude of turn of the 20<sup>th</sup> century monopolies in resource and transportation sectors. Finally, we look to a new domain of lunar governance. While we look at historical uses of interference and contamination in the space industry for context about their meaning, a dearth of existing data and models regarding lunar interference suggests that interference mitigation will need to be an iterative effort, focused on information-sharing and gathering additional data. In this work, we survey the international lunar community to help build consensus on the meaning of interference, its extent, and further technical and coordination work needed to establish a safe, sustained, and sustainable lunar future, with the intent of continuously updating this information as further lunar operations ensue.

## 2. Creating A Safety Culture In Commercial Human Spaceflight

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*Note: This paper was published for the 2016 International Astronautical Congress and reflects the state of commercial human spaceflight regulation at that time. As the “learning period” has been extended until at least Jan 1, 2028, we have not updated this paper, as its conclusions remain relevant.*

### Abstract

The establishment of a culture of safety for commercial human spaceflight requires not only regulations, but an objective administrative regime capable of identifying, prioritizing, and responding to safety concerns, even in the face of economic loss. As countries begin to create commercial human spaceflight regulatory regimes, it is vital that they look to the lessons of history to avoid stifling innovation and mitigate catastrophe.

While limited data on human spaceflight safety exists, the history of aviation regulation is much more expansive. In this paper, we perform a case study of aviation regulatory administrations in the U.S. (the Federal Aviation Administration and its predecessors), and utilize roughly twenty measures of organizational culture as a means of correlating administrative practices (e.g., critical experience of the workforce, horizontal and vertical communication, coordination with major stakeholders, autonomy of the agency) with outcomes (e.g., safety record, ability to enforce regulations). Throughout the history of the FAA, the organization has been accused by the Government Accountability Office and Congress of preventing upward communication, failing to communicate laterally, setting unrealistic cost/schedule estimates, and operating as a branch of the aviation industry rather than a regulator. We examine the validity and evolution of these statements as a function of time, and connect the impact of elements of organizational culture and the FAA’s functionality.

We compare the results of the FAA study with the extensive body of work on the Challenger and Columbia disasters and the organizational culture of NASA, to determine which aspects of a safety culture are the same/different with a separate regulatory agency and manufacturer vs. a self-policing system. While many of the criticisms of the organizational culture of the FAA and NASA are similar, economic incentives on behalf of the commercial space sector may incentivize safety to an extent that overcomes any lapses in regulation.

We use these results to inform a discussion of the structure of a new U.S. commercial human spaceflight regulatory regime, what aspects of the FAA and NASA experience should carry over to this new domain, and in what capacity businesses are capable of self-regulating as the industry grows. With a Congressional moratorium on regulation of commercial human spaceflight until 2023, it is vital for the U.S. to begin laying the groundwork for an effective regulatory agency and collaborate with industry leaders to establish the critical experience necessary for the creation/enforcement of safety regulations.

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## Introduction

As the Federal Aviation Agency (FAA) Office of Commercial Space Transportation (AST) awaits the expiration of the Congressionally-mandated moratorium on commercial human spaceflight (CHS) safety standards until 2023, it should continue to lay the groundwork for industry cooperation and begin to look toward possibilities for future regulation and necessary areas for government intervention. While it is difficult to determine exactly what obstacles industry will face during this "learning period", it is possible to determine what factors may shape both the behavior of the industry and the ability of AST to coordinate (and eventually regulate) by looking at historical precedent. We therefore set out to elaborate: what creates a high reliability organization and what are common causes of failure in safety culture, as well as how aviation regulatory agencies have succeeded/failed at their dual mission of safety and promotion. We then synthesize this information, along with NASA's historical safety record, to make recommendations about the future function of a CHS regulatory agency in the U.S. and discuss its probable limitations.

## Developing a Framework to Evaluate Spaceflight and Aviation Regulatory Agencies

In this section, we explore a framework for how a regulatory agency evolves from its infancy to a mature state. We explore the characteristics necessary for an organization to mitigate safety failures, and discuss the tradeoffs between safety and other external pressures. Determining the appropriate balance between safety and promotion is critical in any new regulatory regime, and understanding the causality of safety violations may enable the prioritization of government oversight.

### *High Reliability Organizations*

Rochlin et al. (1987)<sup>25</sup> and the work of an interdisciplinary group from the University of California at Berkeley in the 1980s gave rise to the theory of High Reliability Organizations (HROs). HROs are distinct in their ability to operate highly complex, costly, and hazardous technologies with very high operational reliability. Examples include the operation of nuclear power plants, air traffic control, and assuring the safety of bridges and dams. Such organizations are unique from error-tolerant organizations in several ways (LaPorte and Consolini 1991):<sup>26</sup>

1. Failure will almost certainly result in costly and unacceptable outcomes
2. The physical technologies of an HRO are interdependent, such that if any element fails, the organization's core function is threatened

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<sup>25</sup> Rochlin, Gene I.; La Porte, Todd R.; and Roberts, Karlene H. "The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea," *Naval War College Review*: Vol. 40 : No. 4 , Article 7, 1987. <https://digital-commons.usnwc.edu/nwc-review/vol40/iss4/7>

<sup>26</sup> LaPorte, T.R., and P.M. Consolini. "Working in Practice but Not in Theory: Theoretical Challenges of High-Reliability Organizations." *Journal of Public Administration Research and Theory*, vol. 1, no. 1, 1991, pp. 19–47.

3. Operational failures are observable by the public, and feared
4. HROs often receive abundant funding to support error reduction

In order to understand how to mitigate failure, it is necessary to classify how failures come into existence. The Human Factors Analysis and Classification System, developed by the FAA's Civil Aeromedical Institute by Scott Shappell and Douglas Wiegmann, explores how humans may induce failure.<sup>27</sup> These failures may take place at either the operator level or organizational level. Operator error may be caused by sources such as: inadequate skill or resources to carry out the job, inadequate training, use of the wrong technique, intentional rule violation, forced rule violation due to circumstance, adverse mental/physical/environmental states, miscommunication, and technological failures. Inadequate supervision may also be a source of failure; inadequate supervision may include: failure to monitor performance, failure to ensure adequate training, excessive workload, and failure to enforce rules or correct problems. Finally, the organizational structure and function itself may contribute to failure. The organization may promote ineffective resource allocation (hiring, retention, equipment/infrastructure, staffing), condone rule violation, fail to allow for clear communication or formal accountability, create competing goals, or fail to adapt to new technology. External influences, such as poorly defined laws/regulations or pressure from outside bodies may also affect safety. For a more thorough checklist of contributing factors, see Appendix E of Federal Railroad Administration Office of Railroad Safety (2014).<sup>28</sup>

In order to mitigate human-induced failures, HROs have developed certain characteristics to improve accountability, increase redundancy, standardize practices, and adopt to new technology. As identified by an HRO literature review in O'Neil and Krane (2012),<sup>29</sup> high reliability can be fostered in the following ways:

1. Access to senior policy-makers in legislative, executive, or other governing bodies
2. External oversight to monitor performance
3. Adequate budget, if not overfunding
4. Safety prioritization via redundant systems.

O'Neil and Krane (2012)<sup>30</sup> also notes HROs at agency-level have the following attributes:

1. A redundant organizational structure, with uniform rules and clear lines of authority.
2. Mandated, standardized training
3. Formal system improvement programs
4. Specialized personnel requirements
5. An authoritative, centralized structure

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<sup>27</sup> Wiegmann, D., and S. Shappell. *A Human Error Approach to Aviation Accident Analysis*. Ashgate Publishing, 2003.

<sup>28</sup> Federal Railroad Administration Office of Railroad Safety. *Collaborative Incident Analysis and Human Performance Handbook*. May 2014.

<sup>29</sup> O'Neil, P.D., and D. Krane. "Policy and Organizational Change in the Federal Aviation Administration: The Ontogenesis of a High Reliability Organization." *Public Administration Review*, vol. 72, no. 1, 2012, pp. 98–111.

<sup>30</sup> Id.

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6. Prioritization of safety over cost
  7. Training and recertification standards rather than trial-and-error teaching

### *Tradeoff between Safety and Promotion*

Rasmussen argues that work conditions on one side are bounded by economic failure and unacceptable workload, and on the other by a boundary of acceptable performance. Pressures of efficiency and the gradient toward least effort push performance toward the boundary of acceptable performance, while a counter campaign for safety culture acts to reverse this trend (see Figure 3 of Rasmussen).<sup>31</sup> Pressure for cost-effectiveness tends to dominate this process for most systems, though the magnitude to which cost-effectiveness outweighs safety is typically proportional to the magnitude of the potential failure (e.g., a Chernobyl-type meltdown vs. confronting typical occupational hazards). We will address the mandate of the FAA in balancing the two in Sec 3.2, but the understanding of the framework for these competing priorities is vital to determining the function of any regulatory agency.

## Evaluation of Regulatory Agencies: Measuring Safety and Promotion Functions

### *Metrics*

Based on the studies of High Reliability Organizations as well as the Human Factors Analysis Classification Scheme discussed in Section 2, we utilize the following metrics in our evaluation of the safety and promotional functions of aviation and space regulatory agencies:

*Horizontal Communication:* Ease of communication across the agency's branches

*Vertical Communication:* Ease of communication between low, mid, and high-level workers

*Training:* The creation of standards and operating procedures within the institution

*Autonomy of Workers:* Autonomy of workers to perform tasks without oversight from senior-level management

*Decentralization of Tasks:* Outsourcing of tasks to improve agency efficiency

*Critical Experience:* Experience of new hires in the field, turnover rate at all levels in the agency, retention of previous organizational knowledge

*Safety Record:* Accident rates, reports of plane malfunctions

*Preventative Safety Measures:* Certification or inspection requirements to ensure competence of pilots, aviation instructors, mechanics, and airworthiness of aircraft/parts.

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<sup>31</sup> Rasmussen, J. Risk Management in a Dynamic Society: A Modeling Problem, Safety Science Vol. 27, no. 2/3 (1997), 183-213

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*Ability to fulfill tasks:* Ability of the agency to accomplish critical tasks

*Accountability:* Mechanisms for ensuring agency is accomplishing its critical tasks

*Ability to enforce regulations:* Follow-through on federal regulations and ensuring applicable punishment is given to regulation violators

*Ability to adapt to new tasks:* The ability of the agency to adjust to technological changes and new tasks assigned to the agency.

*Leadership:* effectiveness of administrator at getting agency to accomplish critical tasks

*Public Approval:* Public's perception of agency's successes and failures

*Coordination with industry stakeholders:* Communication with industry.

*Congressional relations:* Congressional approval of agency's performance

*Executive Branch relations:* Access to the President and respective Executive Branch Department

*Coordination with external government agencies:* Coordination with government agencies with stakes in aviation

*Autonomy of Agency:* Autonomy of agency to perform tasks and decide on its strategic direction without interference from other government branches

*Budge:* Budget allocation by Congress and ability to fund internal projects based on budget

*Foreign Relations:* Impact of organizational decisions on foreign relations

### *Aviation Regulatory Agencies in the U.S.*

While many think of the FAA as a regulatory agency, the 1926 Air Commerce Act established the Aeronautics Branch (the first U.S. aviation regulatory agency) as both a promotional and regulatory agency, functions that would later come into conflict. The Act established the Branch under the Secretary of Commerce, and specified the following promotional functions:<sup>32</sup>

1. 'The establishment of airports, civil airways, and other air navigation facilities '
2. Determine necessary meteorological service
3. Research and development, and dissemination of this information
4. Advise Bureau of Standards on how to improve air navigation facilities
5. Investigate accidents and make results public
6. Exchange relevant information with foreign governments

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<sup>32</sup> *Air Commerce Act* Amendment, 45 Stat. 11404, 17 Apr. 1929.

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As well as the following regulatory ones:

1. Provide registration of aircraft
2. Rate aircraft in terms of airworthiness
3. Examine airmen
4. Examine and rate air navigation facilities
5. Establish air traffic rules
6. Provide for issuance, expiration, suspension, and revocation of registration, aircraft and airman certificates

### Critical Experience

The task of establishing the Aeronautics Branch fell to then Secretary of Commerce, Herbert Hoover. Instead of giving the Branch full autonomy, Hoover opted to distribute the functions of the Branch across existing government agencies; he placed airway development and maintenance in the Bureau of Lighthouses, aeronautical research in the Bureau of Standards, and airway mapping in the Coast and Geodetic Survey, leaving only the separate establishment of Air Regulations and Information Divisions. This at first allowed existing government expertise to guide the piecemeal expansion of existing services, though would later lead to problems in communication and delegation of tasks.<sup>33</sup>

World War I (WWI) equipped the Aeronautics Branch with no shortage of military fliers from which to choose. The first Assistant Secretary of Commerce for Aeronautics, William MacCracken, was a WWI pilot and lawyer with a specialization in aviation law; he subsequently established a Director of Aeronautics to which he appointed attorney and former combat pilot Clarence Young.<sup>34</sup> MacCracken's insistence that all employees be fliers likely enabled the organization to function based on the shared experience and training of combat pilots, when no formal training mechanism within the institution existed.

However, the ability to recruit and retain such skilled personnel would not last. The federal pay scale has proven a constant obstacle in recruiting and retaining talent in aviation agencies. In the early days of the Aeronautics Branch, there became a gentleman's agreement that one year of service was required upon acceptance of a Branch position, after which personnel were typically snatched up by industry; the Chief of the Engineer Section asserted 100% turnover annually within his section. The salary at the time was also considered particularly low for inspection personnel, at \$3500-\$4400 per year, given a high fatality rate for the occupation.<sup>35</sup> This trend in salaries below industry standards for overworked personnel would continue throughout the lifetime of the agency.

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<sup>33</sup> Komons, N.A. *Bonfires to Beacons: Federal Civil Aviation Policy Under the Air Commerce Act, 1926–1938*. U.S. Department of Transportation, Federal Aviation Administration, 1978.

<sup>34</sup> Osborn, Michael, William P. MacCracken, and Joseph Howard Riggs. *Mr. Mac: William P. MacCracken, Jr. on Aviation, Law, Optometry*. Southern College of Optometry, Memphis, 1970.

<sup>35</sup> Rohlfsing, Charles C. *National Regulation of Aeronautics*. University of Pennsylvania Press, Philadelphia, PA, 1931.

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## Leadership

As an Executive Branch agency, the FAA and its predecessors have been subject to politicized appointments, particularly at leadership levels. MacCracken was well-qualified for the position as a former WWI pilot and lawyer, and proved a great communicator. He liaised frequently with industry members, and hired Charles Lindbergh to serve as one of aviation's greatest promoters of all time, via a cross-country tour and a campaign to take Congressmen and their families on flights around Washington, D.C.<sup>36</sup> However, he established a precedent of questionable ethics which would continue to plague the agency, in which officials used government planes for personal travel and accepted deals or free passes from airlines.<sup>37,38</sup> This system of utilizing the FAA and its predecessors to obtain favors from industry is one that seemingly has not evolved in a more ethical direction over time. Mary Schiavo, in *Flying Blind, Flying Safe*, a discussion of her perspective on the FAA as former Inspector General in the 1990s, asserts that "Candidates for administrator knew the FAA was essentially a flying club," and commanded their own fleet of aircraft.<sup>39</sup> She cites one Deputy Administrator who spent \$108,185 over a fourteen-month period on personal plane trips that would have cost \$11,225 on a regular airline. She notes, like many political appointees in the Executive Branch, "the Administrator generally displayed little knowledge about the inner workings of the FAA, anyway, and the Deputy Administrator even less".<sup>40</sup> The duties were thus taken on by career officials, who felt no need to defer to the administrator in decision-making.

In addition to unethical behavior, house-cleaning by new administrations has had a very turbulent effect on aviation regulatory agencies in the U.S., particularly in their early days, due to the purging of critical experience in the industry. Nearly all Presidents have appointed new administrators at the beginning of their terms; in all, there have been 36 administrators since the founding of the Aeronautics Branch in 1926. With administrative turnover every 2.5 years on average, it is unsurprising that the FAA has learned to effectively function without input from its administrator.

## Executive Branch Relations

The Aeronautics Branch received high levels of presidential support. Coolidge, president at the Branch's founding, witnessed the utility of aviation in WWI and felt aviation investment was vital to the country. In a speech at the International Civil Aeronautics Conference, he lauded the Branch, stating "The Aeronautics Branch of our Department of Commerce is vigilant, resourceful, and progressive. It has inaugurated a comprehensive system of regulation and control of aircraft manufacture as well as operation. Airways are laid out over the best flying country, and aids to flying, such as beacons and weather reports are furnished".<sup>41</sup> He also noted that the value of the aeronautic industry in the U.S. was less than \$5 million before the Air Commerce Act, booming to over \$150 million at the end of 1928.

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<sup>36</sup> Osborn, et al., 1970.

<sup>37</sup> Komons, 1978

<sup>38</sup> Mitchell, E.Y. *Kicked In and Kicked Out of the President's Little Cabinet*. Andrew Jackson Press, 1936

<sup>39</sup> Schiavo, Mary. *Flying Blind, Flying Safe*. Avon Books, New York, 1996, p. 59

<sup>40</sup> Id., p. 62

<sup>41</sup> Coolidge, Calvin, *Speech before the International Civil Aeronautics Conference*, Washington, DC, 12 Dec. 1928.

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With great fortune to the industry, Hoover became president after Coolidge. The *New York Times* lauded Hoover's oversight of the Department of Commerce as Secretary, praising his eventual appointment of Charles Young to lead the Branch during his presidency as 'in pursuance of the policy of promotion on merit first put into effect in the department when [he] was Secretary of Commerce'.<sup>42</sup> He saw the government's role of fostering the aviation industry as imperative to national defense and government expenditure on transportation;<sup>43</sup> his son was even a member of the aviation industry and lauded the industry for ushering in a new economic era.<sup>44</sup> Many hoped that Roosevelt would continue administrative support of aviation, as he was a regular air transport user.<sup>45</sup> However, this hope was soon vanquished by his appointment of Ewing Mitchell to the position of Assistant Secretary of Transportation, despite Mitchell's own assertions that he was unqualified and had no interest in transportation. Additionally, Roosevelt opted to purge nearly all high- and mid-level staff in the Branch as soon as he took office, in order to fill the agency with democrats, wiping away nearly all of the critical experience in the Branch. In a moment of indecision about how to select the next Branch leader, he appointed three men to split the post of Director of Aeronautics in the interim. This tripartite agreement, though short-lived, led to a vacuum of leadership, as upon Eugene Vidal's appointment as director, the other two men, Rex Martin and Carol Cone, attempted to retain their previous authority in their new positions of Assistant Directors. Internal politics would prove to be the focus of the Branch's/eventual Bureau of Air Commerce's attention.<sup>46</sup>

Eventually during Roosevelt's tenure, a series of accidents and the increasing impact of aviation would force the restructuring of aviation regulation via the Civil Aeronautics Act, which would reorganize the Bureau of Air Commerce as a quasi-independent Civil Aeronautics Administration (CAA). The Act also sought to make safety investigation independent of the Agency, which took the form of the Civil Aeronautics Board that would later evolve into the National Transportation Safety Advisory Board (NTSB). The direction of the CAA and FAA in years to come would be based upon numerous restructurings (nearly as many as administrators), the necessity of maintaining aviation operations in warfare, (in)accessibility of the president to the agency, presidential austerity in budgeting, and the competence of individuals appointed.

#### Congressional Relations, Public Approval, and Budget

One factor must not be overlooked in the emergence of the aviation industry in the US: overwhelming support by members of Congress and state governors. Lindbergh drummed up support on request of MacCracken after his transatlantic flight, offering free flights over Washington for government officials in 1928, an offer which saw droves of officials and family members line up to ride with Lindbergh. As Lindbergh noted, "the Washington flights' were for the purpose of bringing political attention to aviation, and demonstrating its potentialities to men and women who were in a position to exert great effect on its development," an effect which

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<sup>42</sup> "Young Third Yale Man in Cabinet Air Posts." *New York Times*. 23 Aug. 1929, p. 10.

<sup>43</sup> Speers, L.C. "Hoover Foresees A Greater Air Service." *New York Times*, 26 June 1927, p. 187.

<sup>44</sup> "Airplane Users in New Economic Era." *New York Times*. 4 May 1930, p. 208.

<sup>45</sup> Lyman, Lauren D. "Air Leaders Are Hopeful." *New York Times*, 19 Feb. 1933, p. 150.

<sup>46</sup> Komons, 1978

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likely had a correlation with the ease of aviation appropriations.<sup>47</sup> Similar enthusiasm was seen during an air survey by the Michigan Chamber of Commerce in 1930. In the survey, 26 state capitals were visited, and a total of 24 out of 26 governors in said state capitals joined the representatives of the Chamber for a flight.<sup>48</sup> Many Congressmen and governors were also aviators. Senator Hiram Bingham, a champion of aviation legislation, was also president of the National Aeronautical Association,<sup>49</sup> while flying governors included the father-in-law of President Coolidge's son, John Trumbull.<sup>50</sup> Officials largely recognized the necessity of aviation in times of war, and then quickly adopted it as a preferred mode of transportation to ferry themselves from their home states to the capital.

While the everyday workings of aviation regulation in the US have largely been overlooked, over the course of history intense Congressional and public scrutiny has been applied almost entirely in one circumstance: post major accident. One of the most notable accidents in the early days of American aviation was the downing of a Fokker F-10 in 1931, killing 8 people, including famed Notre Dame football coach Knute Rockne. The Aeronautics Branch received strong backlash as a result, with accusations that the Branch knew of safety issues with the F-10, but failed to act. In fact, the Navy Department had already found faults in the F-10, suggesting the Branch should have applied further scrutiny to the plane's licensing and maintenance. As a result of the accident and Congressional and public outrage, the Branch banned the aircraft.<sup>51</sup> Until this point, there was nearly zero transparency in accident investigations within the Branch, with only a summary of accidents and broadly categorized causes published. After the Rockne crash, this practice came under great scrutiny by Congress, who demanded full transparency in the investigation. While the Branch would subsequently publish more details of their accident investigation, a fundamental flaw remained: the Branch was in short evaluating its own efficacy. The death of New Mexico Senator Bronson Cutting in a 1935 TWA DC-2 accident once again highlighted the lack of ability of the then Bureau of Air Commerce to provide an objective accident evaluation; the Bureau blamed TWA, while an independent senate investigation deemed the Bureau's failure to provide adequate navigation aids a primary cause of the accident (Komons 1978). This conflict of interest between regulation and accident investigation would remain for decades.

Table 1 shows the Congressional and Regulatory reactions to a number of high-profile accidents from the 1940s-present. As shown, Congressionally mandated safety measures have historically been reactionary rather than preventative. The corresponding budget for aviation regulation has also been reactionary, with increases in funding to fix lapsed safety measures post-accident. While Depression-era budget cuts that left the Aeronautics Branch/Bureau of Air Commerce/CAA struggling to maintain any form of functionality may have been understandable, post-World War II (WWII) efforts by the CAA and FAA faced a series of austerity measures even in the face of an uptick in commercial and general aviation. Theodore Wright, administrator of the CAA immediately following the war, drastically cut administrative waste within the agency, but was then faced with a minimalist budget from Congress to create and maintain

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<sup>47</sup> Sperling, Zach. Letter to MacCracken. 26 Mar. 1928. RG 237, 805.1.

<sup>48</sup> *Aeronautics: Our Flying Governors*. May 1930.

<sup>49</sup> *New York Times*. "Young Third Yale Man in Cabinet Air Posts." 23 Aug. 1929, p. 10.

<sup>50</sup> *Aeronautics: Our Flying Governors*. May 1930

<sup>51</sup> "Government Bans Fokker Planes." *New York Times*. 5 May 1931, p. 1.

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airways.<sup>52</sup> Under President Johnson, the agency's 1967 budget allocation was \$100M less than that in 1964, despite a growth of over 30% in aviation activity during that time period. These austerity measures forced the stalling of ATC accommodation of the increase in growth; in 1967, faced with delays of up to 6 hours in New York airports due to overloading of the ATC system.<sup>53</sup> In effect, a negative feedback mechanism had been instated, such that efficiency and the economization of the agency would be met with lower budget allocations, and poor safety records would induce higher allocations.

### Coordination with External Government Agencies

The ACA was established with input from the twelve-person National Advisory Committee of Aeronautics, composed with representatives of the Departments of War, Navy, and Commerce. The Branch was established explicitly to regulate civil aviation, so as to be seen by foreign powers as a separate entity from military aviation.<sup>54</sup> While this separation from military aviation was explicit in the founding of the Aeronautics Branch, subsequent aviation regulatory agencies would find themselves operating alongside branches of the military, a process which often produced substantial friction. Roosevelt omitted CAA representation from his WWII aviation war board containing the Secretaries of State, War, and Navy, and the CAA was under constant threat of being taken over by military intervention.<sup>55</sup> The agency would also find itself at odds with the Department of Defense (DoD) in the delegation of ATC tasks and flight inspection service for military air navigation installations in the 1960s, with FAA air traffic controllers largely objecting to the militarization of their tasks. Faced with a deadlock, eventually the FAA was given authority to set ATC rules and set to become an arm of the DoD in the event of war.<sup>56</sup>

Repeatedly, the FAA and predecessor agencies have also allowed the commercial operation of airlines/planes that are deemed unsafe by other government agencies. As mentioned above, the Fokker F-10 in 1931 and the ValuJet tragedy of 1996 were both instances of the DoD information regarding potential safety lapses that were transmitted to the agency but ignored.

### Coordination with Industry

Throughout the history of aviation regulation in the U.S., the agency has largely been regarded as being within the pocket of the industry. In the Branch's infancy, according to Hoover "it has always been the policy of this department... to carry on such regulatory functions as it has in cooperation with the industry itself",<sup>57</sup> which resulted in a statement by Charles L. Lawrance, president of the Aeronautical Chamber of Commerce, claiming "the industry to a large degree

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<sup>52</sup> Wilson, John R.M. *Turbulence Aloft: The Civil Aeronautics Administration Amidst Wars and Rumors of Wars, 1938–1953*. U.S. Department of Transportation, Federal Aviation Administration, Washington, DC, 1979.

<sup>53</sup> Kent Jr., Richard J. *Safe Separated and Soaring: A History of Federal Civil Aviation Policy, 1961–1972*. U.S. Department of Transportation, Federal Aviation Administration, 1980.

<sup>54</sup> Komons, 1978

<sup>55</sup> Wilson, 1979

<sup>56</sup> Kent, 1980

<sup>57</sup> *Transcript of Aeronautical Conference*. U.S. Department of Commerce, December 5–9, 1927, p. 25.

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has had the privilege of self-regulation”.<sup>58</sup> This standard was set by MacCracken as soon as he took office, as he entertained airline officials at his home, in addition to providing an annual aeronautical conference for major industry stakeholders to voice their concerns about the industry.<sup>59</sup>

Technical progress and industry growth in excess of the agency’s ability to coordinate inspections forced safety functions to be turned over to industry starting with the Aeronautics Branch, and continuing through the lifespan of the agency. The impact of this dependence is discussed later in Sec 3.2.8, but suggests to this day the industry largely remains unchecked by the FAA except in the aftermath of major incidents. Technically, the FAA lost its promotional role with the Federal Aviation Administration Reauthorization Act of 1996, but arguably because of its new mandate to “encourage aviation”, did not change significantly. Programs such as the FAA’s 2003 “Customer Service Initiative” have continued to be criticized for the ability of the industry to cut deals with regulators.<sup>60</sup>

### Autonomy of the Agency and Ability to Fulfill Tasks

As discussed above, the many external pressures faced by the agency limited its autonomy greatly. Congress determines the agency’s mandate and budget, while the President determines the agency’s leader (and by proxy organization). The agency’s ability to fulfill its safety function has almost always been hindered by budgetary constraints, with clear prioritization of tasks necessary in order to maintain any semblance of regulatory power. The agency has historically had the ability to prioritize said tasks with almost complete autonomy from other government agencies, except in the event of accident investigations. However, the resulting budget cuts and task-prioritization have forced a focus on day-to-day operations, rather than the expansion of services or investment in new technologies, which have created long-term safety hazards that are not mitigated except in the event of accidents. Table 1 shows a sample of issues previously identified by the agency that were unable to be addressed prior to a major accident.

Additionally, due to the prioritization of licensing and inspection activities of the agency, many other agency safety-related tasks have gone ignored. In the 1950s, it was found that physical examination standards for aviators had not been modified for decades,<sup>61</sup> emergency procedures were not seriously evaluated until a 1965 accident in which a fire broke out and many perished upon landing, and airport regulation would have to wait until the Nixon Administration.<sup>62</sup>

### Safety Record, Preventative Safety Measures, Enforcement, and Accountability

While as Table 1 shows that there were a number of egregious accidents in aviation, it is difficult to attribute changes in safety record to the efficacy of one administration due to both small number statistics and the short timescales on which administrative turnover occurred,

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<sup>58</sup> Lawrance, Charles L. “The Opportunity of the States.” *Aviation*, Oct. 1931, p. 579.

<sup>59</sup> Osborn, et al., 1970

<sup>60</sup> Public Broadcasting Services. *Flying Cheap*. 2010, <http://www.pbs.org/wgbh/pages/frontline/flyingcheap/etc/cronfaa.html>. Accessed 7 Sept. 2016.

<sup>61</sup> Rochester, 1976

<sup>62</sup> Kent, 1980

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suggesting that predecessor policies often may have been the cause of accidents. However, it is possible to evaluate whether or not preventative safety measures were properly implemented and effective by examining the causes of accidents.

The early days of the Aeronautics Branch, were fraught with the need to pass students and aircraft on licensing/certification exams due to both a backlog of applicants and a desire to stimulate innovation in the industry, as license exams were performed with a very small pool of inspectors nationally. At the end of 1927, a backlog of 1700 pilots', 1500 mechanics' and 1000 plane license applications remained, as, only 15 inspectors nationally were able to provide pilot/mechanic licenses, and inspect aircraft given the minimal budget allocation to the Branch. MacCracken thus established a policy that with "funds so short and our staff so small [we] stipulated that everyone who applied for a license could fly until we had the opportunity to pass on him".<sup>63</sup> After three years of accident statistics to back the creation of further regulation, the Branch began rating flying schools, in order to standardize pilot training Air Commerce Act Amendment 1929. Prior to this point schools existed that had one plane and an instructor who had a limited license;<sup>64</sup> school operators often skimped on instruction in order to optimize profit.<sup>65</sup> While this system assured that high ratings were only given to schools run by accomplished flight instructors, instruction would not be standardized until WWII, when the Civilian Pilot Training Program implemented national instruction.<sup>66</sup>

Regardless of the stringency of national regulation, the Aeronautics Branch could not assure the competency of all pilots, due to the mandate of the Branch which prevented it from regulating intrastate commerce. Many states did not require licenses at all until the 1930s, while the Department of Commerce noted that unlicensed pilots had an appreciably higher rate of accidents than licensed ones, due to policy lapses that allowed a nearly blind woman to fly, those

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<sup>63</sup> U.S. House of Representatives. *Commerce Appropriation Hearings for FY 1928*.

<sup>64</sup> "Flying Schools May Soon Get Ratings." *New York Times*. 3 Feb. 1929, p. 145.

<sup>65</sup> Komons, 1978

<sup>66</sup> Wilson, 1979

with suspended federal licenses to continue to fly in-state, and of course those with minimal

Table 1: Accidents and Regulatory/Congressional Reactions<sup>67,68,69,70,71</sup>

| Accident                                                                                                                                                                  | Reaction                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1946: Christmas season accidents—Western Airlines, 12 deaths; American Airlines, 2 deaths; TWA, 13 deaths; 91 international deaths and 54 domestic in previous two months | Investigation in both houses of Congress. Controversy over allowing older planes to fly. Suggested airlines appoint full-time safety directors. Further accusation the Civil Aeronautics Authority (CAA) and Civil Aeronautics Board (CAB) were investigating themselves. Proposal for a new independent Air Safety Board, which failed.                                                                                                                                                                                                                                        |
| 1951-1952: 5 accidents in vicinity of Newark airport                                                                                                                      | Newark airport shuts down over concerns by local citizens for their own safety. New focus of accident investigation committee on ground safety. Introduction of positive air traffic control in all weather at major terminals                                                                                                                                                                                                                                                                                                                                                  |
| 1956: Super Constellation and DC-7 collide over Grand Canyon, killing 128                                                                                                 | Air Traffic Control had not been monitoring uncontrolled airspace due to other demands. Senators expressed lack of knowledge that pilots could fly visually/sans ATC. Funding for modernization of ATC dramatically increased, project compressed from 5 years to 3. Further accidents from 1959-1961 would put ATC under more scrutiny.                                                                                                                                                                                                                                        |
| 1961: President Airlines DC-6 in Ireland, kills 83; Imperial Airlines crash kills 74 army recruits and 3 crew in Richmond                                                 | Recognition for need for coordination between CAB and FAA between financial management and operating safety. Both airlines were non-scheduled, and subject to lesser safety standards. Imperial's certificate was revoked, and Congress allowed for the increase of fines for nonscheduled flights and clarified the duties of the CAB and FAA.                                                                                                                                                                                                                                 |
| 1974: Turkish Airlines DC-10 loses cargo door, 346 deaths                                                                                                                 | Previous safety concerns regarding the door had been disregarded. A similar accident had occurred in 1972 over Windsor, Ontario, but no deaths occurred. FAA did not ensure safety modifications were made on pre-existing aircraft (such as the DC-10 purchased by Turkish Airlines). As a result, Congressional pressure forced mandatory Airworthiness Directives be issued when a safety-related modification was necessary                                                                                                                                                 |
| 1974: TWA Flight 514 crashes into hill on approach to Dulles, 92 dead                                                                                                     | Deaths included many across government, including FBI, military officers, Congressional aides, creating high public scrutiny. Miscommunication between crew and ATC was cited as the cause, with an urge for technical solutions to ATC problems proposed by the FAA as a result. This combined with the DC-10 accident forced the assembly of the Staggers Congressional subcommittee, which attacked the dual safety/promotion functions of the FAA. A simultaneous TV documentary on the crash and others like it resulted in massive public distrust of the FAA and flying. |
| 1988: Aloha Airlines Flight 243 undergoes explosive decompression. Only 1 fatality occurs                                                                                 | It was determined the inspection and maintenance programs were faulty, and serious fatigue from the plane's age/use were a contributing factor. This mirrored a Far Eastern Air Transport crash in 1981, whose fuselage peeled back almost identically after many usage cycles. Tighter safety and maintenance inspections became required for high-use aircraft.                                                                                                                                                                                                               |
| 1996: ValuJet 592 downed by fire in cargo hold caused by hazardous material, 110 dead                                                                                     | Smoke detectors and fire extinguishers were previously proposed safety measures, but airlines fought back due to the expense of retrofitting all aircraft. They were mandated post-accident, and stricter standards regarding the transportation of hazardous materials were put in place. ValuJet was additionally shut down.                                                                                                                                                                                                                                                  |
| 2009, 2011: Southwest 2294, 812 fuselage failure, no deaths                                                                                                               | FAA issues emergency Airworthiness Directive, requiring more frequent inspections for Boeing 737 aircraft with over 30,000 cycles                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 2013: Asiana Flight 214 crashes short of the San Francisco runway; 2 deaths                                                                                               | Crew mismanaged approach, were too slow. Accident blamed on pilot overreliance on automation and lack of systems understanding. Legislation was passed to transfer \$500,000 from the Next Generation Air Transportation System for a low speed verbal warning system.                                                                                                                                                                                                                                                                                                          |

training to take flight.<sup>72</sup>

<sup>67</sup> Transportation, Housing and Urban Development, and Related Agencies Appropriations Act, H. Amdt.240 to H.R.2610, 113th Congress, 2013-2014

<sup>68</sup> Kent, 1980

<sup>69</sup> Molnar, Matt. "Southwest Airlines Scare: How the 737's Fuselage Weakness Went Undetected." *Popular Mechanics*, 6 Apr. 2011, <http://www.popularmechanics.com/flight/a6614/how-southwest-airlines-flight-812-737s-fuselage-weakness-went-undetected-5519864/>. Accessed 7 Sept. 2016.

<sup>70</sup> Rochester, Stuart I. *Takeoff at Mid-century: Federal Civil Aviation Policy in the Eisenhower Years, 1953-1961*. U.S. Department of Transportation, Federal Aviation Administration, Washington, DC, 1976.

<sup>71</sup> Wilson, 1979

<sup>72</sup> Komons, 1978

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While the ability to standardize licensing procedures for private pilots developed over the first several decades of the agency's existence, airlines have been more than willing to overlook incompetent pilots in the name of profit. After a series of Pan Am accidents in 1974, it was found that commanding pilots were rated by lower ranking officers who succumbed to institutional pressure to ignore any failings in competency, which resulted in crew members doing their best to avoid flying with pilots with incompetent reputations.<sup>73</sup> Similar failures in recent times have been identified particularly on economy carriers and commuter flights; the Colgan Air Crash of 2009 was operated by a pilot who repeatedly failed examinations. Prior to his time at Colgan, he failed three FAA proficiency checks on general aviation aircraft; at Colgan, he failed his initial co-pilot examination for the Beech 1900 aircraft, and repeatedly failed check-rides. Additionally, he only had 109 hours on the aircraft he captained that fatal day, a very limited time by industry standards.<sup>74</sup> Even without explicit negligence on behalf of the airline, an over-reliance on aviation systems is often a contributing factor to accidents. The pilot training failure of Asiana Flight 214, along with a subsequent FAA analysis that found manual flying error contributed to 60% of studied accidents from 2001-2009 worldwide, suggests that a reliance on automation is another common failure in pilot training.<sup>75</sup>

Flaws in aviation safety do not end in pilot certification; mechanic training and inspections have also played a major role in aviation accidents throughout history. While mechanics were licensed at the beginning of the Aeronautics Branch, a move for efficiency allowed for high passing rates and low technical competence. Complaints by the industry then forced the Branch to reverse course, creating exams so tough that mechanics had a tough time passing. The examinations during this period were uniform and not tailored to type of aircraft/engine serviced, requiring excessive knowledge of mechanics who only operated on certain aircraft; however, the Branch did not have the capacity to self-correct, hoping that the industry would resolve the issue in time. Though the agency would decentralize and outsource its inspection capacity to the industry over time, by allowing for type-certification of aircraft,<sup>76</sup> the influence of the industry over inspections would create a conflict of interest. As Schiavo notes, this decentralization was critically flawed; Designated Mechanics Examiners (non-government employees permitted to examine other mechanics) were incredibly inconsistent in their methods, and frequently lowered standards. She cites an instance where an applicant was unable to calculate the area of a rectangle, who was then coached by the examiner to give the correct answer on that question and multiple other questions during the 22-question exam. Most examiners were unaware of questions they were required to ask for a passing grade, and also did not have access to the airplanes on which they were examining mechanics. Similar outsourcing allowed plane manufacturers to investigate themselves; Boeing 777 engineers both conducted inspections of the plane as well as wrote the exam questions and set the standards for the aircraft. The FAA surrogate program ensured that the FAA only reviewed 5% of the work of surrogates, suggesting that pressure on the manufacturer could corrupt safety checks and balances. In the case of the 777, this meant an FAA certification to fly with zero passengers onboard, to salvage

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<sup>73</sup>Norris, William. *Willful Misconduct*. Norton Press, New York, 1984.

<sup>74</sup> Pasztor, Andy. "Captain's Training Faulted in Air Crash That Killed 50." *Wall Street Journal*, 11 May 2009.

<sup>75</sup> Federal Aviation Administration. *Fact Sheet: Report on the Operational Use of Flight Path Management Systems*, 21 Nov. 2013.

<sup>76</sup> Komons, 1978

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Boeing's economic performance. In the case of the 767, the FAA suggested an in-flight thrust reverser deployment, a suggestion that was written off by Boeing surrogates as unnecessary, an assertion not double-checked by the FAA when paperwork was submitted. The absence of this system would later be the cause of a 1991 Lauda Airlines 767 accident.<sup>77</sup>

While the accident investigation function did eventually migrate outside of the agency itself as part of NTSB, NTSB is only capable of making recommendations to the FAA, and is not capable of enforcing any recommendations. This limits the level of accountability of the agency; beyond being subject to the reaction of Congress in the wake of major accidents, the day-to-day activities of the agency go largely unchecked.

#### Horizontal and Vertical Communication, Decentralization, Autonomy of Workers, Training

The Agency has undergone nearly as many restructurings as it has administrators, with complete reorganization occurring every several years. These restructurings were motivated by multiple factors: changes in the prioritization of the agency within the Executive Branch, the need to adopt new tasks, and the need to keep up with increasing demand. Restructuring was often resisted by personnel, who tried to maintain their old levels of authority. One of the early attempts at decentralization during WWII, where regional offices were built up to cope with increases in activity in the field, saw regional program heads side-stepping management at their offices and reporting directly to Washington. This decentralization would last through the 1940s, where it became clear that there were vast regional differences in implementation in national policy.<sup>78</sup> The process of recentralization and decentralization would become a pattern nearly as frequent as the changing of administrators, ensuring that there was little consistency in lines of communication amongst personnel and between personnel and supervisors.<sup>79,80</sup>

As previously mentioned, decentralization also led to the designation of tasks to individuals outside of the government in order to cope with increasing demand. This designation process began with the Aeronautics Branch, where type-certification of parts, flying schools, and private medical examiners allowed the agency to function with minimal resources.<sup>81</sup> While this process led to greater efficiency, it also led to a conflict of interest in the industry, which has historically favored economization and the ability to meet scheduling demands over safety.

The FAA has undergone continuous criticism regarding its vertical lines of communication and the role of supervisors in creating environments that hinder safety. One 1996 GAO report on acquisitions suggests, "program officials did not perform mission needs analyses; set unrealistic program cost and schedule estimates; suppressed bad news; and began system production before completing development, testing, and evaluation". Employees additionally feared retaliation for discussing controversial issues, and program officials were discouraged from reporting cost overruns, delays, and performance problems. A rigid hierarchy also hindered accountability, by preventing empowerment of employees, and preventing upward communication. These same stovepipes also made coordination ineffective, as divisions were distinct without lateral lines of

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<sup>77</sup> Schiavo, 1996

<sup>78</sup> Wilson, 1979

<sup>79</sup> Kent, 1980

<sup>80</sup> Rochester, 1976

<sup>81</sup> Komons, 1978

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communication and authority.<sup>82</sup> Though this detailed report is nearly two decades old, the GAO has continued to cite similar issues (though in less detail) in reports on different FAA programs.

### Foreign Relations

Post-WWII, the U.S. has continually set international aviation precedent where aviation law has failed act. The International Civil Aviation Organization, the first standard in international aviation law, did not exist until the 1944 Chicago Convention, organized by the U.S. with participation by 53 countries. Though the Chicago Convention established international safety standards through the establishment of ICAO, the vision of an international aviation economic regulatory institution largely dissipated. Airlines themselves established the International Air Transport Association (IATA) in 1945, hoping to create consensus on fare and rate structure.<sup>83</sup> The standard for economic agreements was set by the U.S.-British Bermuda Agreement, which represented "not merely a bilateral agreement between two major air transport nations, but a general philosophy on the way in which the economic regulation of the industry should be achieved."<sup>84</sup> The principles outlined in the agreement suggested that fares should be negotiated within the IATA framework, and should be the same on identical routes to avoid price and subsidy wars. Individual governments designated carriers to operate routes, while capacity and frequency of said routes were left up to the decision of the operator.<sup>85</sup>

The 1950s and 1960s were dominated by carriers under national control, with a handful of multinational carriers. The recession of the 1970s led to overcapacity, and prompted U.S. policy change. Despite the creation of new actors in the commercial aviation space during this period, "the most conspicuous change in interaction patterns has, however, occurred among governments, where acute conflict has been triggered off by American policy changes".<sup>86</sup> Gerald Ford prompted the deregulation of the domestic aviation industry with a new Aviation Act of 1975, which was extended to the international regime by Jimmy Carter. "This new policy amounts to a fervent call for international deregulation, emphasizing competition, liberalization of charter options, no capacity restraints, and 'marketplace' pricing with minimal government involvement? an open challenge to the IATA fare-setting framework."<sup>87</sup>

The United States has also acted as a global enforcer of air accords, "since ICAO has been, and for the foreseeable future probably will be, silent in the area of enforcement."<sup>88</sup> The U.S. has not only used its power to enforce its laissez-faire aviation economic policy, but has used its position for political leverage. As part of its anti-Soviet Cold War policies, it imposed air sanctions against Poland in 1981 in response to the imposition of martial law by the Jaruzelski

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<sup>82</sup> *Aviation Acquisition: A Comprehensive Strategy Is Needed for Cultural Change at the FAA*. U.S. Government Accountability Office. Aug. 1996.

<sup>83</sup> Jönsson, Christer. "Sphere of Flying: The Politics of International Aviation." *International Organization*, vol. 35, no. 2, Spring 1981, pp. 273–302.

<sup>84</sup> Wheatcroft, Stephen. *Air Transport Policy*. Michael Joseph, London, 1964.

<sup>85</sup> Jönsson, 1981

<sup>86</sup> *Ibid.*

<sup>87</sup> *Ibid.*

<sup>88</sup> Stanleigh, Shadrach A. "Excess Baggage at the FAA: Analyzing the Tension Between Open Skies and Safety Policing in U.S. International Civil Aviation Policy." *Brooklyn Journal of International Law*, vol. 23, 1997–98, pp. 965–1006.

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government on its citizens. The Soviet invasion of Afghanistan in 1979 also prompted the U.S. to crack down on Aeroflot flights.<sup>89</sup>

The U.S. has also imposed ICAO's safety standards via the 1992 Foreign Aviation Safety Assessment Program (FASAP). This authorized the FAA to conduct inspections of foreign aircraft, and sorted the carriers into three categories: 1. Acceptable in the U.S., 2. Subject to sanctions, 3. Denied access. This program was subject to controversy, as it was accused of discriminating against countries with less substantial aviation, infrastructure; in Latin America and the Caribbean seventeen countries were categorized as Category 2/3.<sup>90,91</sup>

Budget considerations have also ensured that training on new technologies within the FAA is more or less ad hoc, with the industry able to pay qualified personnel far more than the agency, and the inability to train personnel on new technologies due to short-staffing; in the 1990s many personnel asserted they were at least 3-5 years behind new technology.<sup>92</sup> Without the ability to properly train new personnel on the latest technology, it is incredibly difficult to create a regulatory agency where the industry is not subject to self-regulation.

## NASA

The case of the Apollo 1 fire shows that NASA accident investigations were not always focused on organizational sources of failure. Causes were solely attributed to faulty engineering, inadequate escape mechanisms, and inadequate rescue mechanisms.<sup>93</sup> However, the Apollo 1 fire became the source of a Congressional mandate to separate safety and reliability offices at NASA from its Human Space Flight Centers. While this allowed for more independent oversight, NASA safety remained financially tied to the Human Space Flight Program.<sup>94</sup>

The Challenger disaster brought to light the organizational failures of NASA in establishing clear lines of communication in its hierarchy. The Rogers Commission found that Thiokol engineers were aware of potential O-ring failure, and expressed concern at the low-temperature launch. They were given little time to prepare an analysis the night before launch, which had to prove operational failure rather than prove doubt of success. It is commonly believed that organizational pressure to launch on schedule prevented any further investigation, as Reagan had intended to recognize the launch in his State of the Union address that night. Regardless of pressure in the Challenger scenario alone, the Rogers commission also cites a lack of willingness to adjust flight rates to accommodate problems, and the addition of late payloads without proper training. This escalated level of risk was tolerated because of a previous lack of failure; in fact, previous NASA data on O-ring erosion should have prompted maintenance prior to the fatal Challenger flight.<sup>95</sup>

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<sup>89</sup>Ibid.

<sup>90</sup> Ibid.

<sup>91</sup> Fidler, Stephen. "Air Travel Safety Gap Widens in Latin America." *Financial Post*, 8 May 1996.

<sup>92</sup> Schiavo, 1996

<sup>93</sup> National Aeronautics and Space Administration. *Apollo 1: The Fire*, 27 Jan. 1967, 10 Sept. 2015, [http://history.nasa.gov/SP-4029/Apollo\\_01a\\_Summary.htm](http://history.nasa.gov/SP-4029/Apollo_01a_Summary.htm). Accessed 7 Sept. 2016.

<sup>94</sup> *Columbia Accident Investigation Board. Volume 1*, NASA, Aug. 2003.

<sup>95</sup> *Rogers Commission Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident*. 6 June 1986.

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Post-Challenger, a new Headquarters Office of Safety, Reliability, and Quality Assurance was created, but did not allow for direct authority over programs and remained dependent on other programs and Centers for funding. Studies by the GAO and independent agencies criticized this practice, particularly after the Space Flight Operations Contract of 1996, which outsourced technical capabilities to the private sector. The desire to reduce costs was huge, and previous government-mandated safety checkpoints disappeared. The Columbia accident would prove no different in communication challenges, as the Columbia Accident Investigation Board found that the incidents were historically virtually identical, in that the political environment, organization, and managers' and engineers' decision-making all contributed to the crash. Foam loss had been normalized just as O-ring erosion had. Headquarters-level personnel were not responsible directly for safety execution, like the Rogers Commission had suggested, but instead safety policy and advice, creating a conflict of interest within Centers who were charged with developing both technical capabilities and executing safety-related initiatives. Foam strike data was also poorly analyzed and prioritized once a potential problem was identified, with low-level contractors responsible for data analysis and failures of management in following proper channels for data acquisition. Managers, when confronted with unclear data, opted to assume the most positive outcome, to assure schedule adherence and keep costs down. Engineers, who were forced to prove failure rather than prove safe operations were silenced by managers due to a strict hierarchy amongst contractors and NASA employees, as well as across NASA Centers. Past operational successes, despite abnormal technical incidents, were perceived as indicative of future operational success.<sup>96</sup>

## The Future of A Commercial Human Spaceflight Regulatory Agency

FAA AST is in its infancy. Though it has existed since 1984, its role is likely to dramatically change in the coming decade with the projected exponential increase in the number of launches into space. Like the FAA as a whole, the mandate of AST is similarly strained between promotion and regulation, as it was established to:<sup>97</sup>

- Regulate the U.S. commercial space transportation industry, to ensure compliance with international obligations of the United States, and to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States;
- Encourage, facilitate, and promote commercial space launches and reentries by the private sector;

- Recommend appropriate changes in Federal statutes, treaties, regulations, policies, plans, and procedures; and Facilitate the strengthening and expansion of the United States space transportation infrastructure.

### *What AST Can Do Now*

At the moment, national commercial space regulatory authorities are spread out over several government agencies, much like the founding of the Aeronautics Branch, with communications licensing within the Federal Communications Commission (FCC), remote sensing licensing with the National Oceanic and Atmospheric Agency, and the State Department assigned to review

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<sup>96</sup> *Columbia Accident Investigation Board. Volume 1, 2003*

<sup>97</sup> Federal Aviation Administration, Office of Commercial Space Transportation. *About the Office*, 2 Oct. 2014, [https://www.faa.gov/about/office\\_org/headquarters\\_offices/ast/about/](https://www.faa.gov/about/office_org/headquarters_offices/ast/about/). Accessed 7 Sept. 2016.

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cases which are ambiguous in terms of abiding by U.S. obligations under the United Nations space treaties. As exceptions to present regulatory infrastructure grow, in both mission and technology, it will be necessary to streamline this coordination, perhaps under the umbrella of one agency. Congressman James Bridenstine (R-OK) has already proposed to make FAA AST the 'FAA of space' through his American Space Renaissance Act. Bridenstine admits the bill is unlikely to pass in present form, but hopes it will become a platform for addressing space coordination issues.<sup>98</sup> Without mechanisms for streamlining the certification/licensing of new space applications and determining whether they meet international legal obligations, FAA AST and other agencies involved in space regulation will find themselves bogged down by exemptions to the current regulatory framework as the number of actors in space rapidly increases. The possible lag in approval may severely hinder the speed of industry, as it did in the early days of the Aeronautics Branch; the FCC has already seen strong industry dissatisfaction with its spectrum filing process for satellites, with companies claiming an inability to outpace foreign competitors in filing with the International Telecommunications Union due to the FCC's gatekeeping role (e.g., de Selding 2015<sup>99</sup>).

An institution-long history of ignoring aviation safety issues characterizes the FAA and its predecessors; promotion of the industry has unilaterally been favored over safety until the occurrence of a major accident. While it is commonly accepted that 'space is hard', and the error tolerance of the public, Congress, and industry are uncertain, it seems certain that public outcry or pressure by external government groups responsible for the accountability of FAA AST will be negligible regarding safety practices until an accident does occur, and even then, may be attributed to technological complexity over institutional failures. Similarly, individual deaths due to poor medical standards or test failures are unlikely to invoke outrage, as aviation history has shown that public outrage grew dramatically with the number of passenger deaths involved in single accidents.

Operator pressure to meet deadlines is a common stressor that has affected a number of NASA missions, and may impact the commercial industry even more because of the potential loss of contracts due to delays. Time pressure is a key factor in determining whether or not operators will report abnormal system behavior, and whether or not supervisors will react to potential reports or write them off prematurely as inconsequential. Having a set of SOPs, ensuring open lines of communication in an organization both horizontally and vertically, and training for non-ideal scenarios should aid in increasing the reliability of CHS. Both the Challenger and Columbia disasters faced barriers in communication, which ultimately led to a severe downgrading of perceived risk. FAA AST was also accused of ignoring warnings by its personnel in the SpaceShipTwo accident, and allowing a waiver of compliance from software and human error requirements without consulting Scaled Composites technical staff or asking for comments on areas of non-compliance.<sup>100</sup>

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<sup>98</sup> Bridenstine, J. *Bridenstine Introduces American Space Renaissance Act*, 13 Apr. 2016, <http://bridenstine.house.gov/space/?postid=710>. Accessed 7 Sept. 2016.

<sup>99</sup> de Selding, P. "U.S. Satellite Group: Simplify Regulatory Procedure, Create New Regime for Smallsats." *Space News*, 3 Feb. 2015, <http://spacenews.com/u-s-satellite-group-simplify-regulatory-procedure-create-new-regime-for-smallsats>. Accessed 7 Sept. 2016.

<sup>100</sup> National Transportation Safety Board. *In-Flight Breakup During Test Flight, Scaled Composites SpaceShipTwo, N339SS Near Koehn Dry Lake, California, October 31, 2014*. Aerospace Accident Report NTSB/AAR-15/02 PB 2015-105454, 28 July 2015.

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As highlighted by Rasmussen (1997), economic pressure will always counteract the pressure for a safety culture. Both NASA and the FAA have a history of conflict of interest in ensuring economic success of programs while maintaining their safety. NASA programs both became more dependent on cost reduction and reduced safety oversight with their outsourcing of capabilities via the 1996 Space Flight Operations Contract. Businesslike operations at NASA, rather than a safety culture, forced schedules, production demands, deadlines, and cost efficiency goals to be prioritized at the level of innovation and safety goals.<sup>101</sup> The acceptability of technical abnormalities as flukes rather than potential accident sources is not isolated to NASA. The need to outsource inspection effectively allowed aviation companies to inspect their own aircraft, which resulted in high failure rates, and economics of large-scale production created industry resistance to even the simplest safety devices on aircraft, such as smoke detectors. The separation of economic and safety functions is necessary in order to decrease incentives to bypass critical testing procedures and ignore abnormal results.

A further problem in ensuring system reliability that historically has plagued the FAA, though did not have as large an impact on NASA prior to its outsourcing days, is the inability to hire and retain qualified personnel. The government pay scale will never be able to keep up with that in industry, and has drawn the most talented minds in the aviation industry away from regulatory work. The lack of institutional memory amongst personnel will be critical to AST, who will presumably face similar recruiting and turnover challenges. The SpaceShipTwo NTSB report explicitly criticized the lack of familiarity of inspectors with Scaled Composites; while they focused on assigning personnel to specific commercial space operators in their recommendations, this does not alleviate personnel turnover or the level of training needed by new inspectors.<sup>102</sup> The standardization of this training becomes incredibly difficult in the CHS regime, because, as opposed to aviation, the operation and structure of said vehicles vastly differs from company to company. Historically, the FAA has also had a research-oriented branch; given the scarcity of qualified personnel, research efforts are likely best focused on safety issues that can be addressed universally across CHS companies. Additionally, AST is likely to face a severe resource constraint in the near future. An agency on the order of hundreds of members will have difficulty fulfilling the requirements of a drastically increasing pool of commercial operators. While AST has asserted that forecasts call for a massive increase in the number of launches, Congress and the GAO have largely cited continuing launch delays and lack of an increase in activity thus far as reasons to marginally increase funding annually. While AST claims that the uptick in licensing/certification activities will predate this launch boom and require extreme strain on staff, it is unlikely based on historical precedent that funding will drastically increase prior to the increase in launch activities, unless a transformative event occurs (e.g., an accident, a renewed interest in space accessibility for national security purposes).

Given the aforementioned constraints and historical pretext, what can AST do now? AST has already been given a mandate, and established its initial infrastructure from previously existing organizations and knowledge within the federal government. Given the moratorium on safety regulation until 2023, Congress has indicated that it would like AST to consider its critical task to be promotion. Regardless of the importance AST places on safety, the office must decide what the minimum acceptable threshold for reliability is in CHS, if they can measure reliability and error in reliability themselves, what the failure tolerance is of the industry/consumers/Congress,

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<sup>101</sup> *Columbia Accident Investigation Board. Volume 1, 2003*

<sup>102</sup> *National Transportation Safety Board, 2014*

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whether non-regulatory measures may increase reliability, and what promotional activities are appropriate in the office. The office should also immediately work on the implementation of emergency procedures for any newly licensed technologies that would require a significant deviation in protocol from historical functions. This may involve creating some form of checklist for CHS companies and AST in the event of an accident/emergency, working with companies to simulate an accident/emergency, or the creation of a "Tiger Team" of individuals across the industry who may be consulted in the event of an emergency where a proactive response may prevent further catastrophe (e.g., an event similar to the Columbia tile loss).

As AST determines its prioritization of its allocated duties and establishes channels by which to incorporate CHS and new space activities, it must also come up with SOPs and training to ensure consistency across the organization. SOPs, training, and the prioritization of and outsourcing of tasks may aid in dealing with the anticipated explosion in launches prior to proportional budgetary increases.

### *How does NASA fit into CHS?*

As NASA transitions to the Commercial Crew Program, it places even higher dependence on contractors to achieve CHS. The Columbia Accident Investigation Board found that NASA assumed that its reduction in safety personnel post-outsourcing would be countered by a greater responsibility toward safety by contractors. History has indicated that contractors, through a variety of pressures including the pressure of pleasing NASA (who is in turn attempting to please Congress and the White House), migrate toward the minimally acceptable operational safety standard. Without strong independent safety oversight, with a directive to interpret abnormal data as a potential failure and ignore scheduling/budgetary concerns, it is unlikely that NASA's safety culture will change.

However, NASA and other government agencies have the potential to shape the safety standards used by contractors. NASA or potential military contractors can demand more rigorous safety standards than those required for commercial carriers; if demand from government agencies meets a certain percentage of CHS companies' incomes, they are much more likely to strive to implement higher safety standards than if left to the free market. This could also create a competitive advantage for these companies while selling commercial services, as the government will have effectively have subsidized safety for consumers.

Another advantage of NASA's presence in the process of CHS regulation is the critical experience within NASA in developing CHS technology. While AST inspectors may have high turnover rates or little field experience with CHS technologies, decades of NASA work in these areas could provide the ability for NASA personnel to work alongside private companies to identify and mitigate safety problems. These lessons could be more broadly incorporated into future AST directives or recommended practices.

While the answer to the question, "Does AST need to promote high reliability?" may be no, it is unlikely that NASA will intentionally deviate from a model which prioritizes economizing over astronaut safety.

### *What Will the Future of AST Look Like?*

We use AST as a notional term in this section; as we point out above there may be a point in the future where all commercial space functions are consolidated under one agency, or spaceflight regulation is otherwise restructured.

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AST will likely be heavily reliant on industry to self-police for the near future, due to the Congressional moratorium, dearth of qualified staff, budget constraints, and the sheer magnitude of differences in launch vehicles. However, demand for regulation came from the industry in aviation at key points where commercial entities would develop an economic advantage from regulation, including broad regulation of the industry to encourage a drop in insurance rates, and once aviation became normalized, as a mechanism of indicating which carriers were safe. Similar incentives might cause CHS companies to begin to ask for regulation in certain domains as CHS becomes less experimental.

While the structure of AST is not particularly complex at the moment due to small numbers of staff, AST will need to move to decentralize and further specialize in order to adopt new tasks and incorporate the emergence of new technologies. Creating open lines of communication both across specializations and vertically will be vital during this period; as seen in the instance of NASA, a lack of open communication channels alone can lead to organizational failure. Further standardization of training and emergency preparedness will be vital as the organization becomes more complex, to ensure that SOPs are largely observed, anomalies are noticed and reported, and proper protocol in high-risk low-frequency events is followed. If AST ever wishes to see CHS behave as a high reliability system, a safety culture must be emphasized during on-boarding and all subsequent training, with budgetary setbacks impacting only non-critical tasks.

There are several fields in which industry has consistently performed poorly in which AST intervention may have dramatic impact at relatively low cost. Independently evaluating non-technical failures and ensuring economics does not override safety is a function that AST may perform in consultation with NTSB, NASA, and other federal agencies. Companies have historically stressed failures in engineering over failures in organization, leadership, and external pressures. Companies have also traditionally been averse to implementing safety measures for high-risk low-frequency events due to the high economic costs of implementation; it is possible that research and development funding on behalf of AST may be able to make safety-related technologies more economically viable, and may even be in the economic interest of the government given the 3rd party indemnification for launch activities between \$500M and roughly \$3B (\$1.5B in 1988 dollars)<sup>103</sup>. Along similar lines in preparation for high-risk, low-frequency events, AST may want to become more involved in emergency and contingency planning. Investment in non-vehicle infrastructure may also provide both economic and safety benefits for the entire industry, such as investment in spaceports and the integration of space traffic into the national airspace.

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<sup>103</sup> *Commercial Space Launch Act*, Pub. L. No. 98-575, 98 Stat. 3055, 1984.

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Finally, AST needs to evaluate its place in the international sphere. U.S. space does not exist in a bubble; it may be that other space regulatory infrastructures have a better safety culture than the U.S., and that lessons may be learned from them— an examination of the success of the Soyuz program, and once European human spaceflights occur, their successes in subsidization and standardization could be immensely helpful in determining how to prevent accidents. AST may also find that as the industry expands, companies will choose to adopt “flags of convenience”, and migrate their activities to other nations with fewer regulatory hurdles; it will be constantly necessary to reevaluate the restrictions placed on companies operating under a U.S. flag, to avoid situations like the SpaceX satellite constellation filing under Norway in order to side-step the delay created by FCC filings. AST must also contemplate, in coordination with the State Department and Department of Defense, what role it wishes to play in the creation of international standards and best practices in commercial human spaceflight. The U.S. led the international aviation regulatory community with the Chicago Convention; should it play a similar role in space? Are there bilateral treaties or cooperation that may aid in coordination before the establishment of international law? What are the threats of non-cooperative actors?

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### 3. Critical Infrastructure Monopolies: Historical Lessons for the Rise of SpaceX

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#### Executive Summary

In this comparative historical analysis, we look across the history of monopolistic behavior and vertical integration in critical infrastructure sectors from the late 1800s to today, and determine the impact of this behavior on pricing, innovation, and security as an indicator for the impact of SpaceX's increasing share of the space infrastructure market.

SpaceX is currently diversifying and vertically integrating downstream in the space sector, having migrated from launch to satellite communications to human spaceflight to payload integration to satellite bus manufacturing (including for remote sensing), with the presumable goal of being a primary provider of space-based services both on and off-Earth. The growing market power of SpaceX, as both the world's largest launch and satellite communications provider, and the only U.S. commercial crew vehicle provider, raises urgent questions for policymakers in the U.S. and abroad regarding market oversight, competition policy, and national security implications. This analysis examines historical monopolies to provide actionable insights before SpaceX's market position becomes entrenched.

The rapid diversification of SpaceX is similar to early 1900s resource monopolies such as Standard Oil, U.S. Steel, and Alcoa, and innovation in launch is comparable to very early process improvements at those companies that enabled rapid growth. Many monopolies used predatory pricing to oust competitors, such as the use of geographic pricing by U.S. Steel to eliminate local competition, before raising consumer prices. When Starlink first sold terminals, they charged \$599 to consumers, but were manufacturing at a cost of \$3000; although terminals remain at the same price today with a much lower manufacturing cost, monthly service costs have greatly increased for consumers, with one user complaining about a 300% price increase.

After establishing initial monopolies through innovation, the pace of innovation in the resource sector was not maintained, as shown by studies of patents in their respective fields. Anti-innovation policies have long predominated at monopolistic companies, as innovation would require self-cannibalization; this held at AT&T, Xerox, and IBM as well, while more patents were filed post-Microsoft antitrust action in 2002. However, in specific fields where there are imperfect substitutes for downstream products, monopolies have been selectively innovative; this held at Alcoa in attempting to utilize aluminum particularly in areas where steel had been the primary material, and at AT&T in developing undersea fiber optic cable to compete with telecommunications satellites (which it had initially tried to invest in, before the U.S. government gave Intelsat a monopoly).

If SpaceX's goal is to be the lead purveyor of space services on Earth, and to integrate with 5G, IoT, and analytics applications, while terrestrial applications may not be perfect substitutes, the complementary nature of space and ground-based applications in these domains may continue to drive a desire for innovation and cost-cutting at SpaceX for downstream applications. However, upstream, they may not be incentivized to further cut costs for consumers unless facing direct pricing competition from either domestic or international (potentially subsidized)

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competitors. With a current at least temporary monopoly on non-Chinese launch vehicles, SpaceX serves as a bottleneck to a wide variety of space applications in a similar way the railroad industry did in the 1800s/early 1900s (and to some extent, to present), with the ability to provide different cost and scheduling options preferentially to non-competitors. They may also have an incentive to, as has happened across the IT sector, bundle services offered such that competitors selling one individual component of SpaceX's services cannot competitively provide a service.

Regardless of the level of pricing or innovation maintained across SpaceX, especially given the influence of the company's CEO in the current U.S. Administration and need to maintain assured access to space, it is critical that the U.S. government invest in multi-source contracts and determine how to ensure competition across space infrastructure sectors.

Particularly, we recommend that the U.S. government should:

**Monitor Economic Indicators:**

1. The U.S. government should track global launch prices and contracts, to determine changes in prices, launch provider selection, and impact of launch timing on the industry.
2. The U.S. government should conduct a study on the prices of space acquisitions and how those have evolved through mergers and sole-source vs. competed contracts, to determine the impact of space merger activity and monopoly activity on pricing.
3. The U.S. government should be aware of incentives to collude on prices or underinvest in the provision of space infrastructure projects

**Ensure Competition:**

4. The U.S. government should continue to compete multi-source contracts for high-cost space technologies. The U.S. government should also continue investing in smaller contracts that could serve as a bridge to the creation of high-cost space technologies.
5. The U.S. should reduce bundling where possible to enable new entrants, and work toward standards development to enable smaller-scale contracts that are interoperable with other technologies.
6. The U.S. government may wish to leverage existing technology partnerships with non-traditional space industry players to drive down the pricing of downstream space services/analytics.

**Enforce antitrust laws in the defense sector where practicable:**

7. The U.S. government should establish triggers for action against anticompetitive behavior in the space industry, whether that be the capture of a certain percentage of market share in certain sectors, consolidation/market failure in certain sectors, or pricing,

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and outline in advance strategies with which to ensure a diverse and resilient space architecture (e.g., contracts, direct investment, antitrust action).

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## Introduction

### *SpaceX: Is a Rising Market Share Good for Industry?*

In the past decade, the U.S. space industry has transformed from one where the government was reliant on a single-source supplier of heavy launches (ULA), reliant on a handful of major geostationary (GEO) operators for commercial satellite communications, dependent largely on a single source for optical commercial satellite imagery (Maxar), and reliant on major defense primes for satellite buses, to one in which SpaceX dominates the launch market and also controls launch integration for secondary payloads, is the current sole provider of human launches to the International Space Station, is one of two crewed lunar lander awardees, is quickly pushing out GEO operators in the satcom business with customer limitations largely driven by current capacity, is aiming to provide global remote sensing coverage, is looking to provide hosted payloads as a service, and is vertically integrated, controlling manufacturing to launch to operations for its systems.

While U.S. government agencies have largely shied away from sole-source contracts in the space sector, the impact of having a dominant supplier may still produce monopolistic effects and vulnerabilities in contracted services. SpaceX already dominates a launch market which has quickly become oversaturated with medium to heavy launch demand due to the rise in proliferated low Earth orbit (LEO) constellations and is the lowest cost per kg provider. SpaceX has been the sole provider of human launch services in the U.S. the past three years, aside from the 2024 Boeing Starliner flight which was deemed not safe enough to return astronauts after a failure of nearly all of its thrusters upon docking,<sup>104</sup> suggesting that even with multi-source contracts, the U.S. government may not be able to avoid predominance of a single service provider for extended periods of time. SpaceX likely decimated Spaceflight Inc., a launch services company which made waves in the secondary payload market by optimizing secondary payload launch opportunities, by absorbing those services into their own offerings.<sup>105</sup> SpaceX drove the adoption of Starlink among personal consumers through not only a combination of perceived superior service and company branding, but through a user terminal that was initially sold for less than cost,<sup>106</sup> followed by a substantial monthly service cost increase of up to 300% for some users.<sup>107,108</sup> SpaceX, while initially touting its Starlink support of Ukraine, withdrew its military services abruptly in 2022, certainly causing a massive impact on satcom capacity in the conflict; while Ukraine currently pays for its own Starlink services, Elon Musk has threatened to

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<sup>104</sup> Berger, Eric, “Starliner’s flight to the space station was far wilder than most of us thought”, 1 April 2025, Ars Technica, <https://arstechnica.com/space/2025/04/the-harrowing-story-of-what-flying-starliner-was-like-when-its-thrusters-failed/>

<sup>105</sup> Werner, Debra, “SpaceX severs ties with longtime partner Spaceflight Inc.”, SpaceNews, 21 March 2022, <https://spacenews.com/spacex-severs-ties-with-spaceflight/>

<sup>106</sup> Sheetz, Michael, “SpaceX no longer taking losses to produce satellite Starlink antennas, a key step to increasing profitability”, CNBC, 13 Sept 2023, <https://www.cnbc.com/2023/09/13/spacex-no-longer-taking-losses-to-produce-starlink-satellite-antennas.html>

<sup>107</sup> Paisley, Jody, “Starlink announces major pricing and service changes”, YachtingPages Media Group, 10 Feb 2025 <https://www.yachting-pages.com/articles/starlink-major-pricing-and-service-changes-news.html>

<sup>108</sup> “Starlink Bait and Switch for Public IP Users: 300% Price Increase—Abandon It For Home Use?”, Mac Performance Guide, 18 March 2025 [https://macperformanceguide.com/blog/2025/20250318\\_1304-Starlink-price-soars.html](https://macperformanceguide.com/blog/2025/20250318_1304-Starlink-price-soars.html)

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revoke access unless the country signs a mineral rights deal with the U.S.<sup>109</sup> Starlink, with its Starshield hosted payload options, including its interest in providing remote sensing services, should be able to rapidly exceed the collection capabilities of proliferated LEO remote sensing providers who counted on high revisit rates for their market dominance.<sup>110</sup>

All technical, pricing, and service considerations aside, with a CEO that wields extensive influence over the U.S. Executive Branch—we must ask ourselves whether multi-source contracting alone can shield the U.S. government from vulnerabilities, provide services at competitive rates, and promote innovation in an increasingly sector-wide monopoly.

### *A Brief Legal History of Monopolies*

The Sherman Anti-Trust Act of 1890,<sup>111</sup> has served as the basis for antitrust litigation in the United States, by authorizing the U.S. government to dissolve trusts. While used as legal precedent to dissolve trusts, undefined concepts in the Act have often left trust-busting up to the discretion of the court, with terms such as “monopoly”, “trust”, “combination”, and “conspiracy” up to interpretation. In 1895, The Supreme Court found that the American Sugar Refining Company was not a monopoly despite controlling 98% of domestic sugar refining, ruling that control of manufacturing did not directly imply control of trade.<sup>112</sup> While it was clear that firms that firms who attained market dominance by acquisition violated the Anti-Trust Act, a broader question of whether or not companies that acquired market dominance through innovative measures were still in violation of the law. The follow-on Clayton Anti-Trust Act of 1914 identified four additional measures of anticompetitive practices—1. Price discrimination between purchasers that lessens competition, 2. Exclusive dealings preventing buyers from deals with competitors, 3. Mergers and acquisitions that substantially lessened competition, and 4. A person heading two or more companies if they would violate antitrust criteria through merging.<sup>113</sup>

While the enactment of Clayton was succeeded by the dissolution of major monopolies, firms quickly leveraged non-pricing strategies to maintain dominance, from vertical integration to building brand loyalty.<sup>114,115</sup> In comparing the 100 largest firms pre-Clayton (1903) and post-Clayton (1919), Edwards (1975) found that while two-thirds of the pre-Clayton firms either dissolved or lost substantial value, post-Clayton 90% of firms maintained their assets half a century later, suggesting that first movers became entrenched.<sup>116</sup> In the late 30s, this dominance began to take hold in the form of patent portfolios to achieve monopoly control, which resulted

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<sup>109</sup> Shalal, Andrea, and Roulette, Joey, “Exclusive: US could cut Ukraine's access to Starlink internet services over minerals, say sources,” Reuters, 22 Feb 2025, <https://www.reuters.com/business/us-could-cut-ukraines-access-starlink-internet-services-over-minerals-say-2025-02-22/>

<sup>110</sup> Foust, Jeff, “Earth observation companies wary of starshield”, SpaceNews, 19 Sept 2024, <https://spacenews.com/earth-observation-companies-wary-of-starshield/>

<sup>111</sup> 26 Stat. 209, 15 U.S.C. §§ 1–7

<sup>112</sup> United States Court of Appeals for the Third Circuit. 156 US 1 (1895). Argued. Oct 24, 1894. Decided. Jan 21, 1895.

<sup>113</sup> 15 U.S.C. §§ 12–27, 29 U.S.C. §§ 52–53

<sup>114</sup> Chandler, Alfred D. Jr. 1977. *The Visible Hand: The Managerial Revolution in American Business*. Cambridge, MA: Harvard University Press.

<sup>115</sup> Lamoreaux, Naomi R. 1985. *The Great Merger Movement in American Business, 1895–1904*. Cambridge: Cambridge University Press.

<sup>116</sup> Edwards, Richard C. 1975. “Stages in Corporate Stability and the Risks of Corporate Failure.” *Journal of Economic History* 35(2): 428–57.

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in a series of compulsory licensing orders over the following decades. The economic downturn of the late 1970s started to shift the view of both the Federal Trade Commission (FTC) and the courts to favor large employers in the hope of promoting innovation. As a result, today, antitrust rulings are more focused on gains to consumers than breaking big business, with the hope that big companies, such as the tech giants, will drive innovation.<sup>117</sup>

While exploring the legal history of monopolies may provide insight into whether or not the government will sanction companies with large market shares, the legal debate surrounding the definition of a monopoly is not the sole definer of economic impact or supply chain security. Alfred Chandler (1990) famously argued that first-movers have substantial competitive advantage, especially in “industries producing new or greatly improved products and using new or greatly improved processes”, and would have to find a way to take customers away from first movers.<sup>118</sup> Patents help cement the lead of the first movers, and later movers faced larger upfront capital costs due to the need to immediately compete against the first mover’s strength, whether that be in services, facilities, or human capital. Large integrated firms therefore do not typically have to compete on price, but set price based on demand relative to its plant capacity. Horizontal integration helps firms if they maintain a centralized structure upon acquisition, while vertical integration primarily seeks to assure the stability of their own supply chain and cost, providing insurance against variation in production and risk that suppliers would fail to carry out contracts.<sup>119</sup> Firms with large market shares may have an impact on broader sector innovation, or become the sole determiner of pricing or schedule, opening up supply chain vulnerabilities and encouraging waste in government contracting.

## Methodology

Over the last decade and a half, space applications have shifted from largely isolated government use cases, often for defense applications, to one in which everyday citizens rely heavily on space infrastructure, with GPS-dependent smartphone apps, smart agricultural applications with remote sensing data and connected sensors, hyperlocal weather data, rural satellite broadband, and more. As such, the 2021 United States Space Priorities Framework noted “Space systems are an essential component of U.S. critical infrastructure – by directly providing important services and by enabling other critical infrastructure sectors and industries.”<sup>120</sup> Critical infrastructure is defined in the Patriot Act as “namely systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.”<sup>121</sup> While the commercial space sector has historically been full of government-backed sole source providers, the

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<sup>117</sup> Lamoreaux, Naomi R. 2019. “The Problem of Bigness: From Standard Oil to Google.” *Journal of Economic Perspectives*, 33 (3): 94-117.

<sup>118</sup> Chandler, Alfred. *Scale and Scope, The Dynamics of Industrial Capitalism*, Belknap Press, Cambridge, Massachusetts, 1990, p. 34

<sup>119</sup> Id., p. 34-38

<sup>120</sup> “United States Space Priorities Framework”, White House, 1 Dec 2021, <https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2021/12/01/united-states-space-priorities-framework/>

<sup>121</sup> 42 U.S.C. 5195c(e)), Section 1016 (e)

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increasing reliance of both the U.S. government and private citizens on space services, bottlenecked by SpaceX as a launch provider, suggests an examination of historical critical infrastructure monopolies, rather than a space sector-specific examination, is warranted.

We explore in this paper historical monopolies across multiple critical infrastructure sectors<sup>122</sup> to evaluate impact of market dominance on pricing, innovation, and security. While space itself is not currently designated a critical infrastructure sector, most of the services offered—and thus most of SpaceX’s interests -- fall under one of the critical infrastructure sectors.

We specifically look at historical monopolies in the following sectors:

**Resources:** Spanning several critical infrastructure sectors (critical manufacturing, chemical, energy, defense industrial base), we look at the control of resources and the processing thereof as a proxy for the current reliance of the U.S. space sector on SpaceX launch capabilities for nearly all space services. Resource monopolies were additionally the earliest tests for Antitrust law in the United States in the late 19<sup>th</sup>/early 20<sup>th</sup> centuries.

**Infrastructure:** Spanning several critical infrastructure sectors (transportation, energy, water and wastewater, communications), with high upfront costs, infrastructure has long been viewed as a source of “natural monopolies”. The launch market is critical transportation for satellites and for crew, while satellite communications serve as a backbone for rural parts of the globe, and remote sensing provides weather forecasting, disaster monitoring, and agricultural services among other applications, upon which multiple critical infrastructure sectors rely.

Because of infrastructure’s critical role in meeting basic population needs, infrastructure is often provided via governmental funding as a public good, although debate over the economic efficiency of privatization has led some governments to pursue private infrastructure systems. As such, we look at the regulation and provision of transportation and utilities to explore the impact of monopolization on highly regulated critical infrastructure sectors.

**Information Technology:** A critical infrastructure sector, information technology integrates all other critical infrastructure sectors. Many antitrust cases over the past several decades focus on the dominance and vertical integration of big tech; today, Alphabet, Amazon, Apple, Meta, and Microsoft are cited as the big five, controlling everything from email services to software to social media to ecommerce to data analytics . As SpaceX is looking to downstream applications of space technologies for market growth, information technology antitrust cases form an important basis for comparison.

**Defense:** Lastly, we look at the defense industrial base critical infrastructure sector, a domain in which the Department of Defense is able to sanction monopolies in favor of U.S. national interests. Payload estimates in 2024 that SpaceX received \$1.68B from launch and

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<sup>122</sup> Presidential Policy Directive 21 (PPD-21): Critical Infrastructure Security and Resilience advances a national policy to strengthen and maintain secure, functioning, and resilient critical infrastructure

\$2B from Starlink/Starshield defense contracts,<sup>123</sup> suggesting that DoD is heavily reliant on SpaceX capabilities.

We rely largely on court cases, government reports, and secondary sources (books, journal articles) for events through the mid-twentieth century, and contemporaneous news articles where possible in addition to court cases, government reports, and secondary sources for more recent monopolies. For information regarding SpaceX, we rely on news sources, as well as personal correspondence with current/former SpaceX employees and buyers of SpaceX services.

In our analysis, we particularly look at trends in pricing, innovation, bundling, vertical integration, and competition (including from products that are imperfect substitutes). We note that the small sample size of cases in each sector may limit the overall conclusions that can be drawn from this work, but hope that by more closely monitoring market behavior, parallels to historical examples can be identified before there are detrimental effects to the U.S. space supply chain.

## Resources

In this section we look at historical government litigation of Standard Oil, U.S. Steel, and Alcoa as monopolies, and their characteristics which allowed them to establish market dominance. We summarize these characteristics in *Table 2* below.

Table 2: Resource Monopoly Summary

| Company | Standard Oil              | U.S. Steel                                                                                                                                                                                                                                                                                                                                                                                                                                | Alcoa                                                                                                                                                                                                                                                                                                                                                                                  |
|---------|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pricing | Secret railroad discounts | <p>Carnegie Steel drove prices down by 79% in 27 years. Carnegie also employed predatory pricing, with eastern manufacturers selling at or below cost to push out western manufacturers.</p> <p>U.S. Steel employed “Pittsburgh plus” pricing—steel was always priced at a standard cost plus freight cost from Pittsburgh to its final destination, regardless of where in the country the steel manufacturing facility was located.</p> | <p>Colluded internationally in the 1910s, and then during WWII with a spinoff Canadian company joining an international cartel which set production quotas, and set price floors through purchase of surplus aluminum.</p> <p>Truman Committee “noted: “Alcoa had long followed a policy of maintaining high prices and building new capacity only when certain that it could sell</p> |

<sup>123</sup> Kuhr, Jack, “Estimating SpaceX’s 2024 Revenue”, Payload, 29 Jan 2025  
<https://payloadspace.com/estimating-spacexs-2024-revenue/>

|                      |                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                  |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                      |                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                  | at its fixed prices all that would be produced”                                                                                                                                                                                                                  |
| Innovation           | <p>Rapid growth in patents across the petroleum sector pre-merger, no growth in patents post-merger pre-breakup, and new growth/increase in patents post-breakup</p> <p>Almost missed two revolutions (electric illumination, automobiles)</p>                                                                  | <p>Carnegie Steel (which eventually merged with Federal Steel company to form U.S. Steel), created Bessemer process, increasing efficiency 10x.</p> <p>Charles Schwab testified in Supreme Court case the steel industry had maximally innovated, but U.S. Steel policy was “no inventions, no innovations”, and other companies were innovating (e.g., Bethlehem Steel’s manufacturing of structural steel)</p> | <p>Smelting halved the cost of aluminum.</p> <p>Aluminum Research Laboratory--did not only try to improve current aluminum products, but investigated possible futuristic alternative materials as market research to ensure the dominance of their products</p> |
| Bundling             | N/A                                                                                                                                                                                                                                                                                                             | N/A                                                                                                                                                                                                                                                                                                                                                                                                              | N/A                                                                                                                                                                                                                                                              |
| Vertical Integration | <p>Many companies post-dissolution rapidly grew via vertical integration, expanding into gasoline, lubricant, or fuel-oil, expanding their businesses to cover refining, transportation, and distribution, while some moved backward into crude oil; those who didn’t vertically integrate generally folded</p> | <p>Carnegie began vertically integrating, buying everything from mining land to shipping vessels that was needed to manufacture and distribute steel.</p>                                                                                                                                                                                                                                                        | <p>Alcoa moved upstream into mining, refining, power generation, and transportation, mimicking the steel industry</p>                                                                                                                                            |
| Competition          | <p>Owned 90% of market share; electric illumination eventually threatened profit</p>                                                                                                                                                                                                                            | <p>Controlled 60% of U.S. steel capacity.</p>                                                                                                                                                                                                                                                                                                                                                                    | <p>Controlled 90% of aluminum market by 1945.</p>                                                                                                                                                                                                                |

|                                     |                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Other anti-competitive behaviors    | Campaign contributions, bribes to halt prosecution                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Court ruling or legal status change | <p>Monopoly.</p> <p><i>Standard Oil Company v. United States</i> (1911). Supreme Court ruled with the “Rule of Reason”, which asserted that mere size could not prove antitrust violation, but mergers with the intent of restraining trade and centralizing power were violations</p> | <p>Not a monopoly, but price discrimination.</p> <p><i>United States v. United States Steel Corporation</i> (1920). Supreme Court ruled that size alone could not constitute a monopoly, noting a lack of predatory practices on behalf of U.S. Steel, and that consolidation was a natural consequence of the "the metallurgical method of making steel and the physical method of handling it", and in fact improved both the quantity and consistency of trade.</p> <p>FTC ruled against Pittsburgh-plus pricing as price discrimination in 1924.</p> | <p>Monopoly. Prior to ruling, consent decree regarding collusion.</p> <p>1912 consent decree forbidding Alcoa from entering into territorial exclusivity agreements on U.S. soil</p> <p><i>United States v. Alcoa</i>, 148 F.2d 416 (2d Cir. 1945). Ruling against Alcoa due to size (90% of aluminum market), despite Alcoa argument that they were not due to a 33% share of the secondary aluminum market. Ruling that Alcoa had indirect control over the amount of aluminum that reentered the market. Disagreed with Alcoa on their attempt to exclude themselves from monopoly designation due to profit, with profit of 10% annually, holding that it was not for the courts to decide what profit margin was legal under antitrust law. Ruling that Limited and Alcoa were also both liable for an illegal price fixing agreement, though only Limited was liable for the cartel.</p> |

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## Standard Oil

Standard Oil formed the basis of the beginning of anti-trust case law in the United States after the adoption of the Sherman and then Clayton Antitrust Acts. In the 1870s, Standard Oil went from 4% U.S. petroleum market share to 90%, putting its practices under the microscope of lawmakers looking to break up monopolies. However, antitrust action regarding Standard Oil's monopoly was not driven by consumer protection concerns, as the cost of oil had dropped from 25 cents per gallon to 10 cents in the 1870s, and remained a steady price into the 1900s. Concerns were driven primarily by Standard Oil's business tactics, including secret railroad discounts, which led it to buy out competitors, and potential influence over politics. At the time, Rockefeller looked to railroad attempts to create a cartel to create parallel incentives for refiners to guarantee a share of business to railroads, and railroads would in turn give discounts on shipments—while the plan did not succeed, the period of uncertainty that ensued allowed Rockefeller to snatch up Cleveland refineries at below market rates and merge with other refineries. With such a large market share, Rockefeller was then able to demand railroad rebates and acquire further refineries.<sup>124</sup>

Standard Oil additionally made campaign contributions and supposedly offered bribes to try to halt prosecution post-Sherman. Despite threats to the Attorney General's future, the State won a case against Standard Oil, but the court only ruled to dissolve the trust rather than revoke its charter, and thus Standard Oil dissolved the trust and relocated to New Jersey. It took until 1911, in *Standard Oil Company v. United States*, for the Supreme Court to rule against Standard Oil, with the "Rule of Reason", which asserted that mere size could not prove antitrust violation, but mergers with the intent of restraining trade and centralizing power were violations.<sup>125</sup> Standard Oil was broken up into 34 different companies as a result.<sup>126</sup>

In assessing whether Standard Oil's pricing drop was due to internal innovation or external market forces, Scherer (2011) reviews patents before Standard Oil's rapid period of acquisitions, after its rapid growth, and post-breakup, finding rapid growth in patents across the petroleum sector pre-merger, no growth in patents post-growth pre-breakup, and new growth/increase in patents post-breakup. Additionally, only 9.4% of all patents from 1880-1900 were from Standard Oil and its subsidiaries, in stark contrast to its market share. Its primary innovations came in the form of patents it acquired from Hermann Frasch, particularly one that desulphurized oil. This suggests that Standard Oil benefitted from previous innovations in its pricing drop rather than innovating internally. Additionally, Scherer points out that the company nearly missed two technological revolutions—electric illumination, which threatened the demand for the kerosene oil that was Standard's principal initial product, and the automobile, which used gasoline, previously unwanted byproduct of refining. In fact, William Burton, head of production of Standard Oil Company of Indiana, requested authorization to develop and install thermal crackers, which would produce much higher returns of gasoline from crude oil, and was summarily declined the funding due to perceived risk. Once Standard Oil Company of Indiana

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<sup>124</sup> Lamoreaux, 96-98

<sup>125</sup> Id. 98-99

<sup>126</sup> Desjardens, Jeff, "Chart: The Evolution of Standard Oil", Visual Capitalist, 24 Nov 2017, <https://www.visualcapitalist.com/chart-evolution-standard-oil/>

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was broken off from its parent post Supreme Court ruling, the Burton process was broadly licensed and used.<sup>127</sup>

After Standard Oil was dissolved, many of the new companies rapidly grew via vertical integration, expanding into gasoline, lubricant, or fuel-oil, expanding their businesses to cover refining, transportation, and distribution, while some moved backward into crude oil. Those who were less integrated largely were acquired by existing integrated firms.<sup>128</sup>

### *U.S. Steel*

Andrew Carnegie revolutionized the domestic steel sector, after hiring Alexander Holley to implement the Bessemer process at U.S. Steel, becoming the first to widely adopt this process domestically, and applied additional operational modifications that increased output by nearly ten-fold at some furnaces. As a result, Carnegie Steel drove prices down by 79% in 27 years. Carnegie began vertically integrating his company, buying everything from mining land to shipping vessels that was needed to manufacture and distribute steel. To mitigate the threat of competition, he would employ predatory pricing to drive other companies out of business, before raising it after they folded.<sup>129</sup>

In 1901 J.P. Morgan sought to unify the steel industry and cut costs merger between Carnegie Steel and Federal Steel Company, creating U.S. Steel, which controlled 60% of the nation's steel capacity, resulting in the first billion-dollar corporation. Reback (2007) sums up its size: "U.S. Steel was capitalized at \$1.4 billion at a time when the total capitalization of American manufacturing was \$9 billion. This \$1.4 billion was larger than the national debt and over three times the size of the federal budget."<sup>130</sup>

*United States v. United States Steel Corporation* in 1920 was a landmark case in which the Supreme Court ruled that size alone could not constitute a monopoly, noting a lack of predatory practices on behalf of U.S. Steel, and that consolidation was a natural consequence of the "the metallurgical method of making steel and the physical method of handling it", and in fact improved both the quantity and consistency of trade.<sup>131</sup>

Although the Court ruled in favor of U.S. Steel, the opinion was not without controversy. Charles Schwab highlighted innovation and development in the steel industry, and how the processes and products revolutionized downstream industries. Maseritz (2012) noted that this innovation, and particularly the creation of H beams by Bethlehem Steel (technology in which U.S. Steel was disinterested), contributed greatly to a revolution in construction, and eventually revolutionized the automotive industry. Maseritz claims this contribution to innovation was glossed over in the court case by U.S. Steel and in related Congressional hearings. He noted that while U.S. Steel claimed to the federal government that they were revolutionizing the

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<sup>127</sup> Scherer, F.M. Standard Oil as a Technological Innovator. *Rev Ind Organ* 38, 225–233 (2011). <https://doi.org/10.1007/s11151-011-9283-y>

<sup>128</sup> Chandler, 97-98

<sup>129</sup> Adams, Sean, "Carnegie Steel and Creative Destruction", University of Florida, <https://ufl.pb.unizin.org/imos/chapter/steel/>

<sup>130</sup> Reback, Charles, *Merger for Monopoly: The Creation of U.S. Steel*, Essays in Economic & Business History, Vol. 25, p. 105 (2007)

<sup>131</sup> *United States v. United States Steel Corp.*, 251 U.S. 417 (1920)

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manufacturing process, in a *Fortune Magazine* profile their actual R&D policy was cited as “no inventions, no innovations.”<sup>132,133</sup>

In addition to eschewing technological innovation, U.S. Steel established an anticompetitive pricing system, the “Pittsburgh plus” pricing—steel was always priced at a standard cost plus freight cost from Pittsburgh to its final destination, regardless of where in the country the steel manufacturing facility was located, to preserve price competition for orders regardless of geographic location of the steel mill. This allowed producers to absorb a “phantom rate” when the buyer was closer to the steel mill than it was to Pittsburgh (for instance, if both the buyer and mill were in Chicago, the mill would profit from the entire phantom freight charge from Pittsburgh to Chicago), and prevented downstream manufacturers’ sales in closer proximity to Pittsburgh due to the abundance of lower-priced steel in those areas. This practice was not unlike the “running full” or predatory pricing tactic Andrew Carnegie used in his mills prior to acquisition, where eastern manufacturers sell at or below cost to push out western competition, and then reap the cost benefits of mass manufacturing with this long-term increase in orders.<sup>134</sup> The FTC ruled against Pittsburgh-plus pricing as anti-competitive in 1924.<sup>135</sup>

Masteritz argues a first mover advantage did not hold in the case of U.S. Steel, because of its aversion to innovation in manufacturing and focus on large-scale production gains, resulting in more innovative companies such as Bethlehem Steel and Armco being able to take advantage by innovating lower-cost, stronger structural steel and sheet steel for the automotive industry, respectively.<sup>136</sup>

## Alcoa

An 1888 patent by Charles Martin Hall for inexpensive smelting of aluminum began the Pittsburgh Reduction Company, renamed in 1907 as the Aluminum Company of America, or Alcoa. This smelting process halved the cost of aluminum, and transformed it from a seldom used material to one ubiquitous in applications from utensils to sheeting, wires, and automobiles. The company boomed as a result, going from \$2.3M in 1900 to \$90M by 1914.<sup>137</sup> At the same time, Alcoa moved upstream into mining, refining, power generation, and transportation, mimicking the steel industry.<sup>138</sup> While other companies attempted to compete with Alcoa, barriers to entry proved too steep—Cowles Company won a patent lawsuit of \$3 million against

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<sup>132</sup> Guy B. Maseritz, “No Inventions, No Innovations”: Reassessing the Government’s Antitrust Case Against United States Steel Corporation, 7 J. Bus. & Tech. L. 247 (2012) Available at: <https://digitalcommons.law.umaryland.edu/jbtl/vol7/iss2/1>

<sup>133</sup> *U.S. Steel Corporation*, *Fortune Magazine*, Mar. 1936, p. 173

<sup>134</sup> Maseritz, 2012

<sup>135</sup> “ANNUAL REPORT OF THE OF THE FEDERAL TRADE COMMISSION FOR THE FISCAL YEAR ENDED JUNE 30, 1924”, Federal Trade Commission, 30 June 1924, [https://www.ftc.gov/sites/default/files/documents/reports\\_annual/annual-report-1924/ar1924\\_0.pdf](https://www.ftc.gov/sites/default/files/documents/reports_annual/annual-report-1924/ar1924_0.pdf)

<sup>136</sup> Masteritz, 2012

<sup>137</sup> Laura Phillips-Sawyer, *Jurisdiction Beyond Our Borders: United States v. Alcoa and the Extraterritorial Reach of American Antitrust, 1909–1945*, The Tobin Project, 2023 <https://tobinproject.org/sites/default/files/assets/AAD%20Ch%208%20-%20Phillips-Sawyer%20-%20Jurisdiction%20Beyond%20Our%20Borders-United%20States%20v.%20Alcoa.pdf>

<sup>138</sup> David Smith, George. *From Monopoly to Competition: The Transformations of Alcoa, 1888-1986*, Cambridge University Press, Cambridge, MA, 1988, p. 53

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Alcoa in 1903, but without further funding, skills, or organization it could not become a challenger.<sup>139</sup>

Alcoa had pursued assertive tactics during this time to retain market dominance, including abroad, where it faced competition from France, Switzerland, and Brazil. It subsequently colluded to create agreements for territorial exclusivity, which led to a consent decree in 1912 forbidding Alcoa from entering such agreements on U.S. soil.<sup>140</sup>

Its dominance was further amplified by WWI, in which 90% of Alcoa's product went to wartime applications. After the failure of the Southern Aluminum Company, its assets were acquired by Alcoa, transforming it into a monopoly. Its uses only grew in the 1920s and 1930s as it became a ubiquitous household material. Additionally, Alcoa developed the Aluminum Research Laboratory in 1930, which did not only try to improve current aluminum products, but investigated possible futuristic alternative materials as market research to ensure the dominance of their products.<sup>141</sup>

Alcoa finally became a target of a U.S. antitrust lawsuit filed in 1937, a case that would not be resolved until post-WWII. Alcoa faced charges of international collusion, with a spin-off Canadian company, Limited, participating in a cartel, *L'Alliance Aluminum Compagnie*, with French, Swiss, British, and German counterparts which sought to recoup losses from the Depression. They set production quotas, and set price floors through purchase of surplus aluminum. The Department of Justice (DOJ) alleged Limited was a proxy for Alcoa in this cartel, as the management and ownership of the companies was intertwined. The initial ruling in 1941 dismissed the case, citing no intent to monopolize, a ruling which was quickly appealed by Assistant Attorney General Thurman Arnold.<sup>142</sup>

Even pre-war, there were reports of acute aluminum shortages. Although Alcoa asserted they could meet U.S. and U.K. wartime needs, its production ran far short of what the Truman Committee believed it needed in the ramp up to the war effort. It was clear that this effort would be needed to supply the airplanes requested by Roosevelt, as aluminum made up 54-80% of the weight of the airplanes.<sup>143</sup> The Committee noted: "Alcoa had long followed a policy of maintaining high prices and building new capacity only when certain that it could sell at its fixed prices all that would be produced;"<sup>144</sup> it was already at full capacity at 300 million pounds in 1939, and was reluctant to grow without government assistance, with the Senior Vice President acknowledging at a Committee hearing that they wouldn't be prepared to produce one-third of the aluminum necessary for the war effort. The Committee thus opted to finance the creation of new plants (60% of the total plants) but left Alcoa to operate all of them. There was not great incentive for an increase in private investment in factory production, both due to the vulnerability of companies who produced in excess capacity, and the typical clause that forced the government to sell-off wartime facilities at low rates post war when they became excess capacity. Investment by the private sector during the war for expansion was minimal, and remained aligned with normal non-war growth, in large part likely driven by the experiences of

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<sup>139</sup> Chandler, 1990, p. 124

<sup>140</sup> Phillips-Sawyer, 2003

<sup>141</sup> Sean Adams, *Aluminum: Alcoa and Anti-Trust*, Impact of Materials on Society, University of Florida, 28 July 2023 <https://ufl.pb.unizin.org/imos/chapter/aluminum/#footnote-46-8>

<sup>142</sup> Phillips-Sawyer, 2023

<sup>143</sup> George Argyrous, *Investment and the Capitalist Dynamic: The U.S. in World War II*, Journal of Australian Political Economy, 1990

<sup>144</sup> Truman Committee, Report 480, Part 1 :202

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companies after WWI which were forced to destroy much of their expansion in capacity.<sup>145</sup> While U.S. Steel was no longer a monopoly heading into WWII, the steel sector faced nearly an identical industry/government response, though new companies were not formed post-war during the selloff of government assets.<sup>146</sup>

The DOJ continued to pursue its case against Alcoa during the war, touting a free competition vs. Nazi cartel narrative.<sup>147</sup> In 1945, a Circuit Court judge, Learned Hand, ruled that Alcoa violated U.S. antitrust litigation by its sheer size, with 90% of the virgin aluminum market, even though it maintained only a 33% share of the secondary aluminum market, as he argued it had indirect control over the amount of aluminum that reentered the market. He deemed that 90% “is enough to constitute a monopoly; it is doubtful whether sixty or sixty-four percent would be enough; and certainly thirty-three per cent is not,” setting a legal precedent for what is large enough to be a monopoly.<sup>148</sup> Hand also disagreed with Alcoa on their attempt to exclude themselves from monopoly designation due to profit, with profit of 10% annually, holding that it was not for the courts to decide what profit margin was legal under antitrust law. He additionally ruled that Limited and Alcoa were also both liable for an illegal price fixing agreement, though only Limited was liable for the cartel.<sup>149</sup>

Post-war, the government divested its 60% share of plants to Reynolds Metal and Kaiser. Alcoa applied for a determination that it was no longer a monopoly, and the ruling was made solely for the divestiture of all major shareholders from either Alcoa or Limited stock.<sup>150</sup>

Although the Alcoa ruling set precedent for size as an indicator of an antitrust violation as well as extraterritorial jurisdiction, the size as a sole proxy for antitrust violations precedent has been questioned and largely discarded on its own, with courts generally also looking for increases in prices and limits to outputs to support their rulings.<sup>151</sup>

## Infrastructure

In this section we look at infrastructure monopolies in transportation (railroads, Pan Am), utilities (electric, water), and communications (AT&T/Bell, Intelsat). We specifically select infrastructure projects as they are often begin as government-owned or government-sanctioned “natural monopolies” due to infrastructure costs, though have experienced movements for deregulation. We summarize their characteristics in *Table 3*.

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<sup>145</sup> Argyrous, 1990

<sup>146</sup> Prechel, Harland. “Steel and the State: Industry Politics and Business Policy Formation, 1940-1989.” *American Sociological Review* 55, no. 5 (1990): 648–68. <https://doi.org/10.2307/2095862>.

<sup>147</sup> Phillips-Sawyer (2023)

<sup>148</sup> *United States v. Alcoa*, 148 F.2d 416 (2d Cir. 1945)

<sup>149</sup> Waller, Spencer Weber, *The Story of Alcoa: The Enduring Questions of Market Power, Conduct, and Remedy in Monopolization Cases*. Antitrust Stories, 2007, Available at SSRN: <https://ssrn.com/abstract=949925>

<sup>150</sup> Id.

<sup>151</sup> Id.

Table 3: Infrastructure Monopoly Summary

| Company or Sector | Railroads                                                                                                                                                                                                                                        | Pan Am                                            | Electric                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Water                                                                                                                                                                                                                                                                                                                                        | AT&T/Bell                                                                                                                                                                                                                                                                                        | Intelsat                            |
|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| Pricing           | <p>Collusion in 1840s/1850s (legal); after Interstate Commerce Act cartels fixed rates.</p> <p>Today, major U.S. freight disruptions have not had an impact on railroad stock prices, with nearly all increasing faster than the S&amp;P 500</p> | Pricing was set by Civil Aeronautics Board (CAB). | <p>Deregulation in 1970s and 80s caused many states to move to a deregulated wholesale market that allows for competition through independent operators and regional transmission organizations</p> <p>From 2012-2021, residential rates in deregulated states increased by 2.5 cents per kWh vs. 1.4 cents in regulated states.</p> <p>In CA, wholesale prices exceeded rates set by the state, which led utilities to default on payments to the power</p> | <p>Average of \$144/year more spent by consumers on private water bills than public. In communities with private providers, low-income households spent 1.55% more of income on water bills.</p> <p>Common for large multinational water corporations to take control of systems for short-term profit and pass high rates onto consumer</p> | <p>Entire telecommunications industry nationalized by WWII. By the 1970s, Bell System provided 85% of local telephone service, while AT&amp;T Long Lines provided 85% long-distance service, and Western Electric maintained an 82% market share on telecommunications equipment in the U.S.</p> | Rates regulated by FCC through 1999 |

|            |     |                                                                     |                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                    |                                                                                                                                                                          |     |
|------------|-----|---------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
|            |     |                                                                     | exchange. Companies created artificial congestion in order to receive payment for decreasing congestion, costing Californians \$4.6-\$7M in one trade experiment. Misrepresented demand for electricity in day-ahead markets to give them excess generation to sell in pricier real-time markets, and colluded with traders to turn units on and off. | (e.g., United Water in Atlanta, Veolia in Flint and Pittsburgh not investing in infrastructure).                   |                                                                                                                                                                          |     |
| Innovation | N/A | Invested in transoceanic-capable passenger plane, DC-8 jet aircraft | No incentive to innovate or create redundant infrastructure.                                                                                                                                                                                                                                                                                          | No incentive to innovate or maintain infrastructure. Towns are having to buy back private utilities at great loss. | FCC report in 1939 stated AT&T was slow at introducing technological innovations<br><br>Patents by inventors related to telecommunications increased 19% post-breakup by | N/A |

|                      |                                                                                   |                                                                                  |                                                                                   |     |                                                                                                                                                                                                                                                                                                        |     |
|----------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
|                      |                                                                                   |                                                                                  |                                                                                   |     | companies unrelated to Bell                                                                                                                                                                                                                                                                            |     |
| Bundling             | N/A                                                                               | Air mail contracts helped enable passenger service/construction of new airports. | N/A                                                                               | N/A | 1960s and 70s, allegations from competitors argued that Bell blocked other long-distance providers from connecting to local networks, and also refused to connect non-Western Electric equipment. They additionally directed Bell Operating Companies to produce primarily Western Electric equipment. | N/A |
| Vertical Integration | Important for other sectors; for instance, railroads were bought up by U.S. Steel | N/A                                                                              | Operators are independent but organized into regional transmission organizations. | N/A | AT&T served as the parent company presiding over Bell Labs (research), Western Electric (manufacturing), AT&T Long Lines (long-distance service; federally                                                                                                                                             | N/A |

|             |                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                        |                                |                                                          |                                                                                                                                                                                            |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|             |                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                        |                                | regulated), and Bell operating companies (local service) |                                                                                                                                                                                            |
| Competition | <p>Consolidated markets after the beginning of the enforcement of Sherman, through mergers, adding competing railroad officers on each other's boards, and purchasing interests or leasing land used for tracks by their competitor.</p> <p>Today, seven companies in total (four of which make up 83-90% of the market, running in effect two coastal duopolies. 78% of train stations served only by one railroad</p> | <p>Received exclusive landing rights in Cuba and became U.S. counter to Sociedad Colombo-Alemana de Transportes Aeroes (SCADTA) and merged with Atlantic, Gulf, Caribbean airline company to serve South America.</p> <p>WWII growth made Pan Am larger than all European carriers combined. One CIA official noted, "Pan Am was the American flag, for all practical purposes, an extension of the United States</p> | Multiple competing suppliers rather than regulated wholesale market with independent operators and regional transmission organizations | Single supplier at lowest bid. | U.S. government-sanctioned monopoly.                     | <p>FCC authorized domestic competition with "open skies" DOMSAT I order in 1970, and international in 1986</p> <p>Undersea fiber indirect substitute competition in 1988 from AT&amp;T</p> |

|                                  |                                                                                                   |                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                   |                                                           |                                                                                                          |                                             |
|----------------------------------|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|----------------------------------------------------------------------------------------------------------|---------------------------------------------|
|                                  |                                                                                                   | Government. In many places, it was the only symbol of America besides the embassy. Even before there was Coca-Cola in some places, there was Pan Am.”                                                                                                                                          |                                                                                                                                                                                                                                   |                                                           |                                                                                                          |                                             |
| Other anti-competitive behaviors | Enabled other monopolies via rebates to the largest shippers (e.g., major impact to Standard Oil) | Used Charles Lindbergh for lobbying and securing Foreign Airmail Act, which secured all U.S. airmail routes to South America.<br><br>Later requested U.S. government build airports at Guam, Midway, Wake Island, and acquired Chinese National Aviation Corporation to secure Pacific routes. | Failure to invest in long-term infrastructure: For ERCOT: failure of to perform in extreme freeze scenario, natural gas companies signing up for interruptible power contracts, failure to connect to other grids for redundancy. | General disregard for environmental and safety guidelines | Swapping of territory between operators to establish geographic control (encouraged by U.S. government). | N/A                                         |
| Court ruling or legal            | Initial cases in the late 1800s found price-fixing.                                               | Supreme Court ruling in Pan Am World Airways v. United States, 371,                                                                                                                                                                                                                            | ERCOT entitled to sovereign immunity as “arm of the state”, in CPS Energy v.                                                                                                                                                      | Often protracted legal battles to take eminent            | Decision that AT&T should no longer be allowed to have a natural                                         | Given non-dominant carrier status by FCC in |

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|                  |                                                                                                                                                                                                                                                                  |                                                                                                                                                                            |                                               |                                                                                                          |                                                                   |                                                |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|------------------------------------------------|
| status<br>change | <p>Interstate Commerce Act of 1887 made pooling and secret price cutting illegal.</p> <p>Supreme Court ruled in two separate cases that the Trans-Missouri Freight Association and Joint Traffic Association violated the Act, and made price-fixing illegal</p> | <p>U.S. 296 (1963) remanded decision and left in hands of CAB. Flights were already price-regulated by the CAB and it was deregulation which eventually killed Pan Am.</p> | <p>Electric Reliability Council of Texas.</p> | <p>domain after neglect and revert to public utility, with tens of millions in infrastructure costs.</p> | <p>monopoly United States v. AT&amp;T, 552 F.Supp. 131 (1982)</p> | <p>1998 and privatized by Congress in 2001</p> |
|------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|------------------------------------------------|

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## Transportation

### Railroads

Railroads domestically colluded by the 1840s and 1850s, which was not illegal prior to Sherman. Regulators tried pooling, in which either traffic would be divided under an established percentage, or total money would be with fixed traffic percentages, with fines for those not adhering to the pool agreement. This process largely worked, with few violations, and only short-term issues involving new entrants or economic downturn. The Interstate Commerce Act of 1887 made pooling and secret price cutting illegal, resulting in cartels reacting by fixing rates, which were different based on road, in an attempt to control traffic. Arguably, the ICA did little to impact railroad collusion, with many historians arguing the Interstate Commerce Committee actually strengthened collusion. Shortly after Sherman was enacted, and the Supreme Court ruled in two separate cases that the Trans-Missouri Freight Association and Joint Traffic Association violated the Act, and made price-fixing illegal.<sup>152</sup>

Although overt price-fixing was made illegal, the railroads quickly fixed prices in secret, with informal understandings or “independent” though publicly published rates. They began to consolidate their markets after the beginning of the enforcement of Sherman, through a great wave of mergers, adding competing railroad officers on each other’s boards, and purchasing interests or leasing land used for tracks by their competitor. Binder (1988) examined stock prices before and after Sherman to determine if the Act economically impacted railroads, finding it was not possible to reject the null hypothesis that the impact was zero, and also found no long-term effect on rates, implying there were at most minor effects of the legislation.<sup>153</sup>

Not only were the railroads effective regional monopolies even post-Sherman, they enabled other monopolies through rebates to the largest shippers, as discussed above with Standard Oil. Granitz and Klein (1996) argue that Standard’s rise to dominance was in fact driven by its collusion on transportation rather than petroleum itself, an easy feat given a mere three railroads transported petroleum. This resulted in, for instance, Standard receiving a rate for crude shipments to New York in 1878 of \$1.06/barrel vs its competitors with rate of \$1.70.<sup>154</sup> Standard had such a strong grip on the railroads that others found themselves unable to secure transportation; H.D. Lloyd noted in his 1881 article in *The Atlantic* that Erie shipped only ten cars for another company in an entire year—by accident, and one shipper was promised a shipment of 10,000 barrels by Erie, then had it transported down to the station, and promptly blocked by a Standard representative. Standard forced the hands of both producers and refiners, forcing them to sell their supply or their refineries at or below cost or risk recouping nothing. The refineries were bought by Standard and then largely dismantled.<sup>155</sup> U.S. Steel also looked to the railroads as a means of competitive advantage, buying up railroads in the Great Lakes region,

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<sup>152</sup> Binder, John J. “The Sherman Antitrust Act and the Railroad Cartels.” *The Journal of Law & Economics* 31, no. 2 (1988): 443–68. <http://www.jstor.org/stable/725339> and references therein

<sup>153</sup> Id.

<sup>154</sup> Granitz, Elizabeth, and Benjamin Klein. “Monopolization by ‘Raising Rivals’ Costs’: The Standard Oil Case.” *The Journal of Law & Economics* 39, no. 1 (1996): 1–47. <http://www.jstor.org/stable/725768>.

<sup>155</sup> Lloyd, H.D., “The Story of a Great Monopoly” *The Atlantic*, March 1881 <https://www.theatlantic.com/magazine/archive/1881/03/the-story-of-a-great-monopoly/306019/>

which cost its competitors \$2-\$3/ton over an average haul.<sup>156</sup> Railroad rates also played a role in the transformation of the meat market, as in the late 1800s, refrigerated cars invented by Gustavus Swift of Chicago threatened an entire industry that relied on shipping cattle for local slaughter rather than shipping “dressed meat” – at one point the cattle industry held a 40 cents per 100 pounds to 70 cents per 100 pound shipping price advantage, but still could not compete with dressed meat. A rate war ensued, and dressed meat eventually won out as prices could drop no further.<sup>157</sup>

Fast forward to today, regional monopolies of freight still dominate railroad transportation, with seven companies in total (four of which make up 83-90% of the market, running in effect two coastal duopolies) and 78% of train stations served only by one railroad.<sup>158</sup> The American Fuel and Petrochemical Society in 2022 cited transportation and distribution costs as 11% of total gas prices at the pump, made worse by being a captive customer of a singular freight company. The National Grain and Feed Association also cited freight disruptions as a source of \$100M in lost revenue in Q1 of 2022.<sup>159</sup> Despite the impact to U.S. supply chain, their performance has not impacted their own financial performance, as the “stock price and total return of every publicly traded Class I railroad from the end of 2011 to the end of 2021, except for Canadian National, grew faster than the S&P 500.”<sup>160</sup> While trucking and pipelines compete with rail today, rail as of 2019 still made up 27.9% of all shipping by ton-miles (with trucking at 39.6%, pipelines 17.5%), 52% of which was bulk commodities and 48% consumer products.<sup>161</sup> U.S. commodities are in essence still captive in an impenetrable monopoly for freight transportation, which continues to have massive impact on the domestic supply chain without any penalty on freight company profits.

## Pan Am

Pan Am cornered the U.S. international airline market for the better part of the 20<sup>th</sup> century. Much of this was due to the strategic planning, acquisitions and investment in technology by eventual President and CEO Juan Trippe. After several experiences starting aviation companies providing both transportation and air mail services, taking advantage of the publicity and investment surrounding Charles Lindbergh’s transatlantic flight, Trippe founded Aviation Corporation of America, with aspirations of not only securing air mail routes, but connecting locations across the globe.<sup>162</sup>

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<sup>156</sup> United States House of Representatives, *The Investigation of the United States Steel Corporation, 1911* (Washington, D.C.: GPO, 1913), 7.

<sup>157</sup> Kujovich, Mary Yeager. “The Refrigerator Car and the Growth of the American Dressed Beef Industry.” *The Business History Review* 44, no. 4 (1970): 460–82. <https://doi.org/10.2307/3112669>.

<sup>158</sup> Jinoo Buck, Matthew, “How America’s Supply Chain Got Railroaded”, *The American Prospect*, 4 February 2022, <https://prospect.org/economy/how-americas-supply-chains-got-railroaded/>

<sup>159</sup> Evers-Hillstrom, Karl, “Freight Rail Slowdowns Under Microscope Amid Supply Crunch”, *The Hill*, 25 May 2022, <https://thehill.com/lobbying/3500399-freight-railroad-slowdowns-under-microscope-amid-supply-crunch/>

<sup>160</sup> Jinoo Buck, 2022

<sup>161</sup> “Freight Rail Overview”, U.S. Department of Transportation Federal Railroad Administration, 30 July 2023, <https://railroads.dot.gov/rail-network-development/freight-rail-overview>

<sup>162</sup> Mayo, Anthony J., Nohria, Nitin, and Renella, Mark, “Entrepreneurs, Managers, and Leaders: What the Airline Industry Can Teach Us About Leadership”, Palgrave MacMillan, New York, 2009, p. 42-50

Trippe fell into fortuitous geopolitical circumstances, as the U.S. government grew concerned about the founding of the airline Sociedad Colombo-Alemana de Transportes Aeroes (SCADTA), founded by Colombians of German origin—its access to the Panama Canal Zone and U.S. route plans for both mail and passenger service threatened U.S. autonomy as well as the Monroe Doctrine. As the owner of SCADTA attempted to lobby the U.S. government for these routes, Major Hap Arnold (who eventually became Commander of the U.S. Army Air Force in WWII) proposed an American airline to ward off the German threat, Pan American Airways. With exclusive landing rights to Cuba in hand, Trippe leveraged his hand into a three-way merger with Pan Am and the Atlantic, Gulf, and Caribbean airline company, and announced plans to serve the South American coasts.<sup>163</sup>

To make this dream a financial reality, Trippe quickly found himself lobbying for legislation which became the Foreign Air Mail Act of 1928, and employed Charles Lindbergh to do an aviation tour with Trippe in South America shortly after President-elect Herbert Hoover was engaged on a steamship tour of the Americas. He secured a mail contract through Panama into Chile and Argentina, and quickly acquired a competitor, the New York, Rio, & Buenos Aires Line, to control all U.S. airmail routes to South America. Trippe immediately looked to trans-Atlantic and trans-Pacific flights to further build out his empire. Polar routes proved too treacherous, and more tropical routes were sought; a Pacific route eventually proved easier due to British diplomatic hurdles in acquiring trans-Atlantic landing rights. In 1934 Trippe declared to the Navy and Postmaster General that he needed access to (non-existent) airports at Guam, Wake, and Midway, which happened to support growing U.S. concern about the growth of the Japanese empire while also avoiding perception of infrastructure growth as military aggression, and within a year he secured authorization from the Navy to fly to the Philippines. He then acquired China National Aviation Corporation, and leveraged a landing agreement with the Portuguese government in Macau as a way to gain access to Hong Kong.<sup>164</sup>

Although securing a trans-oceanic monopoly was a huge step to Pan Am's growth, Trippe also needed to invest in the technology to make such long flights viable. He placed bids for planes at Sikorsky and a company run by Glenn Martin, asking for a ship that could cruise 4800 miles with 8000 lbs of cargo and 50 passengers. Martin's design was too expensive with too few passengers, and Sikorsky's four-year development time was deemed too long, so Trippe looked to a design submitted by Boeing for a plane with maximum weight of 82,500 pounds, which could hold 21 passengers and 8 crew for distances of up to 2500 miles. In 1939, Pan Am also succeeded at landing its first transatlantic flight from New York to France, for \$375 per passenger each way.<sup>165</sup>

WWII grew Pan Am to a global route of 98,582 miles, larger than all European carriers combined, and the company was commissioned to build 50 airports in the Pacific, resulting in a 76% increase in earnings. One CIA official noted "Pan Am was the American flag, for all practical purposes, an extension of the United States Government. In many places, it was the only symbol of America besides the embassy. Even before there was Coca-Cola in some places, there was Pan Am."<sup>166</sup> Pan Am in effect had a legal monopoly in the U.S. on international routes, as Congress had given the Civil Aeronautics Board authority to regulate rates and routes

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<sup>163</sup> Id., p. 52-54

<sup>164</sup> Id., p. 55-60, 86-90

<sup>165</sup> Id., p. 91-93

<sup>166</sup> Bender and Altschul, *The Chosen Instrument*, p. 365, 477

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(the Supreme Court upheld the CAB's oversight of this monopoly in the 1963 ruling *Pan Am World Airways v. United States*, 371, U.S. 296<sup>167</sup>).

Post-War Pan Am faced competition from several other U.S. airlines: Panagra (partially owned by Pan Am), American Export, and eventually TWA. He also faced competition from European airlines, which were largely subsidized by their governments. Trippe pushed to out-innovate as a result—he bought 100 Pratt and Whitney J-75 engines before an airplane even existed to host the engine—Boeing refused to incorporate them into their aircraft, but Douglas opted to utilize them in the DC-8. With 45 new jet aircraft orders in 1955 (25 from Douglas, 20 Boeing 707s with the inferior J-57 engine), Trippe set a new standard for other airlines to follow or face demise with propeller-driven aircraft. Trippe repeated his innovation bet in the 1960s, first ordering 15 Concorde, and then signing a \$500M contract with Boeing to build what became wide-body 747s, the largest ever by a commercial company.<sup>168</sup>

Although the 747 eventually revolutionized aviation, the circumstances did not benefit Pan Am—the 747 could not fly the long-haul distances expected, and the oil crisis of the 1970s precipitated its eventual demise. Previously, Pan Am had been denied the ability to expand domestically, but the 1978 Airline Deregulation Act opened up all routes for competition and deregulated fares. Pan Am purchased National Airlines in an attempt to stay afloat and continue to compete, but hemorrhaged money due to the lack of compatible fleets and needing to equalize pay across the company; the final nail in the coffin for the company was the Lockerbie bombing in 1988, in which Pan Am was found legally culpable for having ignored a security warning about a planned attack.<sup>169</sup>

## *Utilities*

### *Electric*

Although electricity had long been thought of as a public utility to be provided by the state, with vertically integrated companies providing service at set rates to consumers, the deregulatory movement of the 70s and 80s led some states to move from utilizing a regulated wholesale market, to a restructured (deregulated wholesale) market that allows for competition through independent operators and regional transmission organizations.<sup>170</sup>

While intuitively, multiple competing suppliers should decrease costs, evidence shows that deregulated markets actually increase downstream pricing. MacKay and Mercadal (2023) compare the cost of generation and utility pricing across both regulated and deregulated electricity markets from 1994-2016. They find that although generation costs go down after deregulation, wholesale prices increase.<sup>171</sup> This finding is supported by a report by the American Public Power Association and data from the U.S. Department of Energy's Energy Information

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<sup>167</sup> *Pan American World Airways v. United States*, 371 U.S. 296 (1963)

<sup>168</sup> Mayo, Nitin, and Renella, 2009, p. 101-104

<sup>169</sup> Gellene, Denise, and Dallos, Robert E., "Pan Am's Dive Began After the Government Axed Its Near-Monopoly: Airlines: The carrier had operated without competition for decades. When the floodgates opened in 1978, it couldn't cope.", *Los Angeles Times*, 9 Jan. 1991, <https://www.latimes.com/archives/la-xpm-1991-01-09-fi-7339-story.html>

<sup>170</sup> MacKay, Alexander, and Mercadal, Ignancia, "Do Markets Reduce Prices? Evidence from the U.S. Electricity Sector", Harvard Business School, Working Paper 21-095, 2023, [https://www.hbs.edu/ris/Publication%20Files/21-095\\_5398d456-f1de-432d-9a0b-cc7a58b51145.pdf](https://www.hbs.edu/ris/Publication%20Files/21-095_5398d456-f1de-432d-9a0b-cc7a58b51145.pdf)

<sup>171</sup> *Id.*

Administration, which found that from 2012-2021, residential rates in deregulated states increased by 2.5 cents per kWh vs. 1.4 cents in regulated states.<sup>172</sup> These effects were not immediate, largely because states passed measures such as price caps and long-term contracts to ease the transition to consumers; however, once these expired, power generators could sell at market rate to power marketers, and prices increased. MacKay and Mercadal note that this may be due to limited competition amongst generators, the inability to store/transport electricity efficiently, infrastructure cost, and long-term risk, factors which were unchanged by deregulation. They do note, however, that vertically integrated wholesale markets have less incentive to mark up prices, and that the results do not necessarily promote a regulated approach, but rather that oversight of deregulated markets is key in ensuring downstream consumer benefit.<sup>173</sup>

Deregulated wholesale markets in the U.S. have been the subject of great scrutiny in recent years, not just due to pricing, but multiple high-profile failures of electrical grids. One of the most prominent is the February 2021 power outage in Texas that left 10 Million people without heat and electricity for days, killed at least 246 people, and cost \$130B in damages, repeating a 2011 event that took out 75% of power generation units.<sup>174,175</sup> Texas's electric utilities are run by the Electric Reliability Council of Texas (ERCOT), with a variety of companies generating electricity from various sources, and retail electric providers selling it to consumers; 60% of Texas electricity customers buy from an open market with dozens of sellers; Texas prides itself in its largely self-contained electric grid and independence from the rest of the country for power.<sup>176,177</sup> Using a 2020 Ercot seasonal assessment<sup>178</sup>, energy economics professor Blake Shaffer found that all fuel sources severely underperformed in an extreme freeze scenario, with gas responsible for 2/3 of the overall deficit and underperforming by 37% in comparison to its expected output.<sup>179</sup> Unsurprisingly, during the February 2021 outage, natural gas producers were unable to keep up with demand, and were not subject to weatherization standards that could have helped meet demand. Additionally, natural gas suppliers rely on electricity to continue to produce power—many natural gas companies signed up for interruptible power contracts to minimize costs, and did not flag themselves as critical infrastructure, forcing their capacity offline; a similar series of events happened in 2011 but was not rectified. Although ERCOT tried to utilize scarcity pricing mechanisms to bring additional energy suppliers online, there was not nearly enough available supply, in large part due to a lack of weatherization. The lack of

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<sup>172</sup> “Retail Electric Rates in Deregulated and Regulated States: 2021 Update”, American Public Power Association, <https://www.publicpower.org/system/files/documents/2022%20Retail%20Electric%20Rates%20In%20Regulated%20Utilities%20Report.pdf>

<sup>173</sup> MacKay and Mercadal, 2023

<sup>174</sup> Busby, Joshua, et al., “Cascading Risks: Understanding the 2021 winter blackout in Texas”, Energy Research & Social Science, Volume 77, July 2021, 102106

<sup>175</sup> Hall, Katie, “In final tally, state officials say 246 Texans died in February from freeze and power loss”, Austin American-Statesman, 4 Jan 2022 <https://www.statesman.com/story/news/2022/01/04/246-texans-died-february-freeze-and-power-loss-officials-say/9080688002/>

<sup>176</sup> Busby, et al., 2021

<sup>177</sup> Cai, Mandi, Douglas, Erin, and Ferman, Mitchell, “How Texas’ power grid failed in 2021—and who’s responsible for preventing a repeat”, The Texas Tribune, 15 February 2022 <https://www.texastribune.org/2022/02/15/texas-power-grid-winter-storm-2021/>

<sup>178</sup> ERCOT, “Seasonal assessments show sufficient generation for winter and spring,” Nov. 05, 2020. <http://www.ercot.com/news/releases/show/216844> (accessed Mar. 17, 2021).

<sup>179</sup> Blake Shaffer, “Tweet”, Feb. 24, 2021. <https://twitter.com/bcshaffer/status/1364635625907912705>

connection to other electrical grids, while unlikely to solve the full crisis, likely would have provided some cushion to allow for rolling outages. Notably, several cities who were not connected to ERCOT but instead connected to other grids suffered minimal or no outages, including El Paso which had winterized their equipment.<sup>180</sup> As those impacted tried to hold ERCOT liable for the outage, the Texas Supreme Court ruled 5-4 that the organization qualified for sovereign immunity, despite being a purely private entity, as the Chief Justice noted in the majority opinion that state law intended for ERCOT to be an “arm of the State government”.<sup>181</sup>

California has also been plagued by similar problems. In the early 1990s, 70% of Californians received power from one of the state’s three vertically integrated investor-owned utilities, which functioned as regional monopolies, with retail rates set by the state, and wholesale prices set by the Federal Energy Regulatory Commission (FERC). The private utilities were generating excess capacity, encouraged to do so because they could recoup costs through higher pricing—the pricing of CA power was 75% higher than its neighbors, though that was in part due to hydroelectric power generation available in other states.

California deregulated its grid in 1996, a deal that was lauded as an example for other states. The three utilities were required to divest from at least 50% of their fossil fuel plants, and were required to buy all additional power from the Power Exchange which ran wholesale auctions, and required them to transfer control but not ownership of transmission to another nonprofit Independent System Operator (ISO). Retail prices were additionally frozen until 2002. The utilities moved fully to hydropower and nuclear plants to meet base requirements, and shifted to the exchange to buy power (mostly natural gas) for peak loads. Strong demand, limited capacity growth and a drop in hydropower, old infrastructure, and a heat wave led to continuous rolling blackouts across California in summer 2000. The problem was exacerbated by wholesale prices exceeding rates set by the state, which led utilities to default on payments to the power exchange.<sup>182</sup> California’s system also allowed companies to exploit loopholes in the power exchange—Enron notably took advantage of this, and created artificial congestion in order to receive payment for decreasing congestion, costing Californians \$4.6-\$7M in one trade experiment. They also misrepresented demand for electricity in day-ahead markets to give them excess generation to sell in pricier real-time markets, and colluded with traders to turn units on and off.<sup>183</sup> Rolling blackouts resumed in 2020—Loretta Lynch, president of the CA Public Utilities Commission during the 2000 crisis, cited power mechanisms that enabled electricity suppliers to withhold energy, and non-ISO utilities that did not have blackouts.<sup>184</sup> Faults in the

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<sup>180</sup> Busby, et al. 2021

<sup>181</sup> Foxhill, Emily, 23 June 2023, ERCOT can’t be sued over power grid failures during 2021 winter storm, Texas Supreme Court rules, Texas Tribune, 23 June 2023  
<https://www.texastribune.org/2023/06/23/ercot-lawsuits-winter-storms/>

<sup>182</sup> “Causes and Lessons of the California Electricity Crisis”, Congressional Budget Office, September 2001 <https://www.cbo.gov/sites/default/files/107th-congress-2001-2002/reports/californiaenergy.pdf>

<sup>183</sup> Nix, Adam, Decker, Stephanie, and Wolf, Carola, “Enron and the California Energy Crisis: The Role of Networks in Enabling Organizational Corruption”, *Business History Review*, 95(4), 765-802.  
doi:10.1017/S0007680521001008

<https://www.cambridge.org/core/journals/business-history-review/article/enron-and-the-california-energy-crisis-the-role-of-networks-in-enabling-organizational-corruption/457B1E245C6E6DE8903F531DD768D3F4#en156>

<sup>184</sup> Kasler, Dale, and Heeter, Maria, “California avoided rolling blackouts for two decades. What went wrong on the grid?”, Sacramento Bee, 17 August 2020  
<https://www.sacbee.com/news/local/article244988455.html>

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system continued to be balance of supply and demand in stressed conditions, inaccurate day-ahead scheduling, prioritization of schedules, and performance incentives/penalties.<sup>185</sup>

## Water

Water privatization, though not as common as electric privatization, is taking hold in the U.S.—out of the largest 500 community water systems, 321 are government-owned, 121 are cooperative, and 58 are private.<sup>186</sup> Crumbling infrastructure has motivated a lot of cash-strapped towns to privatize for what is seen as a way to fix their ailing utilities sectors; the U.S. water system is estimated to need \$1T in investment to close the gap, while federal funding for water infrastructure has dropped by 74% since 1977.<sup>187</sup> Although major cities can generally float infrastructure costs, small to mid-sized communities often cannot; the majority of the privatization occurs in communities of up to 45,000 people.<sup>188</sup>

Zhang et al. (2022) found that in these systems, after controlling for water system characteristics, water supply, and water demand, that private ownership has the largest impact on water bill, with an average of \$144/year more spent by consumers on private water bills than public. In communities with private providers, low-income households spent 1.55% more of their income on their water bills. They also note that in NJ and PA, with more favorable regulations for private owners, face higher rates.

Although the privatization of water services can be a short-term solution for cash-strapped cities, the large multinational water corporations which typically take control of these systems generally aim for short-term profit and pass high rates onto consumers. Numerous cases of failed privatization exist; one of the largest cases, Atlanta's 20-year contract with United Water, signed in 1999, found that United Water drastically underbid the contract, but blamed the city for failing to disclose its infrastructure woes. Water was unsafe to drink and ran orange or brown for many customers, and United Water failed basic system maintenance such as letting broken water mains run for days. Atlanta terminated the contract after a mere four years. In Laredo, Texas, United Water tried to terminate a ten-year contract at year five, citing unexpectedly higher operating costs; the city force United Water to pay a \$3M fine for termination, but was left with the repair bills.<sup>189</sup> A private water company, Veolia was not only involved in the Flint crisis, and, after having been contracted upon detection of contamination, determined that the water met drinking requirements and increased corrosion in the system by requesting the introduction of

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<sup>185</sup> CAISO, CPUC, CEC Issue Final Report on Causes of August 2020 Rotating Outages, California Energy Commission, 13 Jan 2021 <https://www.energy.ca.gov/news/2021-01/caiso-cpuc-cec-issue-final-report-causes-august-2020-rotating-outages>

<sup>186</sup> X. Zhang, M. González Rivas, M. Grant, M. E. Warner; Water pricing and affordability in the US: public vs. private ownership. *Water Policy* 1 March 2022; 24 (3): 500–516 <https://doi.org/10.2166/wp.2022.283>

<sup>187</sup> Douglass, Elizabeth, “Towns sell their public water systems—and come to regret it”, The Washington Post, 8 July 2017 [https://www.washingtonpost.com/national/health-science/towns-sell-their-public-water-systems--and-come-to-regret-it/2017/07/07/6ec5b8d6-4bc6-11e7-bc1b-fddbd8359dee\\_story.html](https://www.washingtonpost.com/national/health-science/towns-sell-their-public-water-systems--and-come-to-regret-it/2017/07/07/6ec5b8d6-4bc6-11e7-bc1b-fddbd8359dee_story.html)

<sup>188</sup> Smith, Catharine, “Amid Water Crisis, Majority-Black Town Faces Higher Utility Bills”, Pulitzer Center, 19 September 2022 <https://pulitzercenter.org/stories/amid-water-crisis-majority-black-town-faces-higher-utility-bills>

<sup>189</sup> Craig Anthony (Tony) Arnold, Water Privatization Trends in the United States: Human Rights, National Security, and Public Stewardship, 33 Wm. & Mary Env'tl. L. & Pol'y Rev. 785 (2009), <https://scholarship.law.wm.edu/wmelp/vol33/iss3/4>

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ferric chloride to offset discoloration, but in Pittsburgh also managed the water system when lead levels shot up. Upon taking control of the Pittsburgh water system, they fired many of the safety and water quality inspectors, and switched to lower-cost corrosion chemicals without informing the state's Department of Environmental protection, illegally.<sup>190</sup> For cities which try to regain control of private water utilities, they generally face lengthy and expensive eminent domain battles against companies unwilling to give up their profitable monopolies. In Mooresville Indiana, which tried to buy back its system from American Water for \$9M, found itself facing a \$20.3M price tag from the court, more than the town of 10,000 could afford. Fort Wayne, Indiana, found itself paying \$67M over 13 years and two court cases. Missoula, Montana, also faced a protracted legal battle, and in 2017 was left with an \$88.6M bill and millions in additional expenses, despite facing a privatized water system where half of all water flowing through its pipes was lost.<sup>191</sup>

## Communications

### *AT&T/Bell*

Bell Telephone company was founded by Alexander Graham Bell shortly after his 1875 invention of the telephone. The first several decades saw slow growth, primarily amongst business users; when their patents expired in 1893-94, they faced fast-growing competition, and by 1907 non-Bell firms made up 51% of the market, up from 5% in 1894. In 1907, with new president Theodore Newton Vail, AT&T (the new parent company of Bell) turned to consolidation. While the government raised antitrust concerns, they struck a deal in which AT&T sold off \$30M in Western Union stock, agreed not to acquire further independent companies, and allowed other competitors to connect to the Bell System. The deal in fact incentivized monopolies, with the swapping of territory between operators to establish geographic control. Interconnection also eliminated the desire of independent operators' incentive to compete with a long-distance system. Legislators began openly supporting a unified system, noting that "telephoning is a natural monopoly" in a 1921 Senate Commerce Committee hearing, and labeling competing infrastructure as duplicative and wasteful. State regulatory agencies encouraged swapping and consolidation for what was perceived as efficient service. During WWI, the government opted to nationalize the entire telecommunications industry, which resulted in post-war benefits to AT&T in the amount of rate increases of \$42M from the postmaster general, or 84% of the total approved during nationalization. The final nail in the coffin for other competitors was the decision to set standard long-distances rates based on average costs, and required universal service, meaning a true monopoly was needed to average out the costs of provision to rural areas.<sup>192</sup>

AT&T served as the parent company to a long-running telephone monopoly in the U.S., presiding over Bell Labs (research), Western Electric (manufacturing), AT&T Long Lines (long-distance service; federally regulated), and Bell operating companies (local service). Bell System

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<sup>190</sup> Hosea, Leana, and Lerner, Sharon, "From Pittsburgh to Flint, The Dire Consequences of Giving Private Companies Responsibility for Ailing Public Water Systems", The Intercept, 20 May 2018 <https://theintercept.com/2018/05/20/pittsburgh-flint-veolia-privatization-public-water-systems-lead/>

<sup>191</sup> Douglass, 2017

<sup>192</sup> Thierer, Adam, "Unnatural Monopoly: Critical Moments in the Development of the Bell System Monopoly", Cato Journal, Vol 14, No. 2, Fall 1994 <https://www.cato.org/sites/cato.org/files/serials/files/cato-journal/1994/11/cj14n2-6.pdf>

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had one million employees and revenue equaling 1.7% of the U.S. GDP by the 1970s, exceeding even that of the greatest tech companies in the U.S. today. Bell System provided 85% of local telephone service, while AT&T Long Lines provided 85% long-distance service, and Western Electric maintained an 82% market share on telecommunications equipment in the U.S.

In the 1960s and 70s, allegations from competitors argued that Bell blocked other long-distance providers from connecting to local networks, and also refused to connect non-Western Electric equipment. They additionally directed Bell Operating Companies to produce primarily Western Electric equipment. After a 1982 antitrust ruling, Bell was broken up into 7 separate companies in 1984, required to allow equal long-distance access to local networks, and banned from manufacturing telecommunications equipment. Watzinger and Schnitzer (2022) find that total patenting by inventors related to telecommunications increased 19% post-breakup by companies unrelated to Bell, while its successor companies dropped in patent rate, though influential patents as a percentage of all Bell patents was higher. They suggest that this is due to the Arrow replacement effect, giving little incentive to innovate and cannibalize their own revenue with new products, pointing to an example of the answering machine being developed in 1934 at Bell but kept secret by management out of fear that customer paranoia about being recorded would drop demand for services.<sup>193</sup> According to a 1939 FCC staff report, AT&T was “slow in introducing such technological innovations as automatic dialing, monolithic handsets, anti-sidetone circuitry, and office switchboards with enhanced features”.<sup>194,195</sup> Post-breakup, Bell won four Nobel Prizes and three Turing awards for work done from 1982-1990.<sup>196</sup>

### *Intelsat*

In 1961, President Kennedy announced an international effort to develop the first global satellite communications system, and sought private investment to back the system, to ensure that risk was not transferred onto taxpayers.<sup>197</sup> AT&T had already studied the technical requirements for space-based communication at Bell Labs and developed plans for a ground system in cooperation with JPL and build the full system without government investment, but it lacked launch capability. NASA supported the launch of two AT&T Telstar satellites launched in 1962-63. NASA also supported Hughes in launching three Syncom systems from 1963-1964, a program which was later transferred to DoD.<sup>198</sup> Concern over AT&T’s monopoly in the communications field and growing interest in satellites, Congress enacted the Communications Satellite Act of 1962, which authorized the formation of COMSAT to own and operate the U.S. portion of the global satellite system, and ensured non-discriminatory equitable rate access to

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<sup>193</sup> Watzinger, Martin, and Schnitzer, Monika, “The Breakup of the Bell System and its Impact on US Innovation”, 5 September 2022 [https://www.martin-watzinger.com/uploads/4/9/4/1/49415675/watzinger\\_schnitzer\\_breakup\\_of\\_bell.pdf](https://www.martin-watzinger.com/uploads/4/9/4/1/49415675/watzinger_schnitzer_breakup_of_bell.pdf)

<sup>194</sup> U.S. Federal Communications Commission, staff report, Report on Telephone Investigation (two volumes, mimeo, 1939), vol. I, pp. 323-398 and 404-405

<sup>195</sup> Scherer, F.M., “Technological Innovation and Monopolization” Department of Justice, March 2006 <https://www.justice.gov/sites/default/files/atr/legacy/2006/10/30/218697.pdf>

<sup>196</sup> Watzinger and Schnitzer, 2022

<sup>197</sup> Katkin, Kenneth, “Cable Open Access and Direct Access to INTELSAT”, Case Western Reserve Law review, Volume 53, Issue 1, 2002, <https://scholarlycommons.law.case.edu/cgi/viewcontent.cgi?article=1475&context=caselrev>, and references therein

<sup>198</sup> Launius, Roger D., and McCurdy, Howard E. “NASA SPACEFLIGHT: History of Innovation”, 17 October 2017 [https://link.springer.com/chapter/10.1007/978-3-319-60113-7\\_3](https://link.springer.com/chapter/10.1007/978-3-319-60113-7_3)

consumers.<sup>199</sup> COMSAT had an initial public offering in 1964, raising \$200M, and in 1965, as an international partnership of 44 countries, it launched its first geostationary commercial communications satellite. After several additional satellites were launched, 85 nations created Intelsat to formalize the partnership; similarly, COMSAT was the signatory to the International Maritime Satellite Organization (Inmarsat) which formed in 1978.

Until 1999, Intelsat was not required to provide unbundled service on a nondiscriminatory basis to non-COMSAT entities in the U.S., and instead rates were regulated by the FCC. Although the U.S. permitted Intelsat's international monopoly to last more than four decades, it did allow for the provision of non-Intelsat domestic service through the FCC's 1970 "open skies" DOMSAT I order,<sup>200</sup> and the FCC authorized competition on U.S.-international routes in 1986.<sup>201</sup> As a result, in 1988 PanAmSat became the first U.S. private sector international service, and by 1999, there were 73 commercial U.S. geostationary satellites out of 200 across the globe. Intelsat additionally faced intermodal competition from AT&T, as it completed the first transoceanic fiber-optic cable in 1988. As a result, Intelsat was given non-dominant carrier status by the FCC in 1998, and was privatized by Congress in 2001.<sup>202</sup>

### *Information Technology*

In this section, we look at the cases of Xerox, IBM, and Microsoft to determine how increasing tech consolidation impacts pricing and innovation. We summarize their characteristics in *Table 4*.

Table 4: Information Technology Monopoly Summary

| Company    | <b>Xerox</b>                                                                                                                                   | <b>IBM</b>                                                                                                                                                                                        | <b>Microsoft</b>                                                                                                                                                    |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pricing    | Set very high prices for machines such that leasing was generally more practical than ownership.                                               | Predatory pricing on peripherals                                                                                                                                                                  | N/A                                                                                                                                                                 |
| Innovation | By the 1970s had 1000 patents. After others created copiers, tried to diversify into personal computers (priced too high for most consumers at | After 1956 consent decree requiring it to lease or sell computers, IBM slowed the cannibalization of its business by halting the rollout of newer machines until a rival threatened its dominance | Blocked installation of non-Microsoft products, made Microsoft products incompatible with other OS. Innovation increased in the sector after 2002 antitrust decree. |

<sup>199</sup> Communications Satellite Act of 1962, Pub. L. No. 87-624, 76 Stat. 425, codified as amended at 47 U.S.C. §§ 701-769 (2000) [hereinafter Satellite Act].

<sup>200</sup> Establishment of Domestic Communications-Satellite Facilities by NonGovernmental Entities, First Report and Order, 22 F.C.C.2d 86, 19 (1970) [hereinafter DOMSAT I Order].

<sup>201</sup> Establishment of Satellite Systems Providing International Communications, 101 F.C.C.2d 1046 (1985) [hereinafter Separate Systems Order], modified on recon., 61 Rad. Reg. 2d (P&F) 649 (1986), further recon. denied, 1 F.C.C.R. 439 (1986).

<sup>202</sup> Katkin, 2002, and references therein

|                                     |                                                                                                                                                                                                |                                                                                                                                          |                                                                                                                                                                                                                                                                                             |
|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                     | \$16,000), and financial services.                                                                                                                                                             |                                                                                                                                          |                                                                                                                                                                                                                                                                                             |
| Bundling                            | Sale of very high-priced toner (while not the exclusive toner so as not to trigger antitrust cases, but highly recommended by salespeople for quality). Service bundled with lease of machine. | Locked customers into IBM software through backward compatibility and repair service bundled with contracts.                             | Microsoft gave manufacturers discounts if they paid for licenses for each computer sold, regardless if it contained the OS. Also bundling of Internet Explorer, Teams, Windows Media Player, instant messaging. Refused to port MS Office products to non-Windows or Apple systems.         |
| Vertical Integration                | N/A                                                                                                                                                                                            | Hardware, software, peripherals                                                                                                          | Hardware, software                                                                                                                                                                                                                                                                          |
| Competition                         | Held 95% of market in 1975. Charged less for high-volume jobs, as competitors existed with multilith and mimeograph machines at high volume, but none existed at low                           | 75% of market share by 1955.                                                                                                             | 85-90% of desktop market share by 1990.                                                                                                                                                                                                                                                     |
| Other anti-competitive behaviors    |                                                                                                                                                                                                | Changed hardware or delayed release of interface information to disadvantage competitors. Announced then delayed release of new systems. | Microsoft restrictions on installing rival software, lack of transparency in interface specifications, communications protocols                                                                                                                                                             |
| Court ruling or legal status change | Negotiated in antitrust case with FTC, consent decree signed in 1975. Assumed monopoly would hold, but other copiers quickly took hold of the market.                                          | U.S. government abandoned case started in 1969 in 1982, in part because other mini-computers had taken hold of the market.               | 1994 consent decree barring discounts to manufacturers for each computer sold. 2002 remedial order requiring non-discriminatory licensing, barred restrictions on rival software, required more transparent specification information. Many past and ongoing lawsuits in U.S. and abroad on |

|  |  |  |                                                                                      |
|--|--|--|--------------------------------------------------------------------------------------|
|  |  |  | bundling, and similar lawsuits against other companies who are part of the Big Five. |
|--|--|--|--------------------------------------------------------------------------------------|

## Xerox

Xerox began as several basic patents filed by physicist Chester Carlson in the 1930s. Finding that he did not have the ability to develop the technology en masse, he transferred the patents to a non-profit R&D firm, Battelle Memorial Institute, which then sold the patents to Haloid, eventually renamed Xerox.<sup>203</sup> They increased sales by 25 fold from 1959 to 1968, the first company to reach \$1B in sales.<sup>204</sup> By the 1970s, they had 1000 patents; they licensed patents on Xerox copying on coated paper to others, but maintained the licensing for much cheaper plain paper copying. They devised a number of ways to maintain their monopoly, including the sale of very high-priced toner (while not the exclusive toner so as not to trigger antitrust cases, but highly recommended by salespeople for quality), and set very high prices for machines such that leasing was generally more practical than ownership. They also charged less for high-volume jobs, as competitors existed with multilith and mimeograph machines at high volume, but none existed at low.<sup>205</sup>

IBM and Litton Industries both unleashed plain paper copiers in 1970 and 1972, respectively, and were promptly sued by Xerox.<sup>206</sup> After an antitrust case was brought against it in 1973, Xerox opted to negotiate in 1975, believing they would face lengthy legal battles, and assuming that their monopoly would hold.<sup>207</sup> Afterward, Japanese firms quickly dominated the market, increasing their number of patents and cornering the market of small desktop copiers.<sup>208</sup> Xerox had a joint venture in Japan with Fujifilm at the time, Fuji Xerox, which quickly grew in the 1970s as it started manufacturing its own devices and supplying them to Xerox. Although Fuji Xerox offered to help Xerox compete with the up-and-coming Japanese firms, Xerox declined its help. As a result, Fujifilm tried to acquire Fuji Xerox in 2018, which failed.<sup>209,210</sup>

<sup>203</sup> Scherer, 2006

<sup>204</sup> Jacobson, Gary and Hillkirk, John, *Xerox: American Samurai*, 1986, Macmillan

<sup>205</sup> Scherer, 2006

<sup>206</sup> Mamrak, Robin, Antitrust and (Foreign) Innovation: Evidence from the Xerox Case, Rationality & Competition CRC TRR 190, 12 May 2023

<sup>207</sup> Scherer, 2006

<sup>208</sup> Mamrak, 2023

<sup>209</sup> “Out On its own, Japanese Xerox partner tries to duplicate success”, The Asahi Shimbun, 20 April 2021, <https://www.asahi.com/ajw/articles/14326490>

<sup>210</sup> Yamazaki, Makiko, “Fujifilm wins appeal in battle with Xerox over aborted merger”, Reuters, 16 October 2018 <https://www.reuters.com/article/us-xerox-fujifilm/fujifilm-wins-appeal-in-battle-with-xerox-over-aborted-merger-idUSKCN1MR09F>

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Although Xerox tried to reinvent itself after the antitrust suit, including by investing in the Xerox Palo Alto Research Center. They attempted to make a prototype personal computer, which later inspired Steve Jobs, but when it was released in 1981 it was priced too high for the average consumer at \$16,000, and flopped. The same year, IBM came out with a computer for \$1600, and the Apple MacIntosh launched for \$2500 in 1984. It briefly dabbled—and failed at—financial services, then moving to business services. While it maintained some high-profile contracts (such as E-ZPass), it could not make up for the copier loss in sales. In contrast, Fujifilm has branched out greatly in chemical and imaging technology, investing in products from cosmetics to medical equipment.<sup>211</sup>

#### Tech giants from IBM-today

IBM was the target of multiple antitrust lawsuits, paving the way for further standards set on the tech giants of today. IBM locked in 75% of digital computer contracts by 1955, and retained its dominance through 1980. IBM locked customers into IBM software through backward compatibility and repair service bundled with contracts. While required to lease or sell computers under a 1956 consent decree, IBM slowed the cannibalization of its business (customers preferring to lease and upgrade to the newest models) by halting the rollout of newer machines until a rival threatened its dominance. It even announced new products well before their existence, including System 360/90, which not only slipped significantly in delivery, but required expensive peripherals; when other companies came up with cheaper versions, IBM undercut them until they were unprofitable and changed their hardware or delayed release of interface information to disadvantage competitors. The U.S. government filed an antitrust lawsuit in 1969, which was abandoned eventually in 1982 due to perceived obsolescence of IBM products in the time it took the case to play out.<sup>212</sup>

Microsoft was next; in 1994 they signed a consent decree which banned a practice where Microsoft had given manufacturers discounts on Microsoft operating systems (OS) if they paid for licenses for each computer sold, regardless of if it contained the OS. In 1998, the DOJ sued Microsoft for bundling Internet Explorer with Windows 98, but failed initially due to language in the consent decree allowing Microsoft to develop integrated products. The DOJ filed a broader antitrust suit immediately thereafter; in 2002 a final remedial order required non-discriminatory licensing of Windows, barred restrictions on installation of rival software, and required transparency about Windows interface specifications and communications protocols for the benefit of other software providers.<sup>213</sup> After the antitrust decree, Thatchenkery and Katila found that innovation, as measured by patents, increased but profitability decreased—they attribute this to innovative companies with low market segment share that rush to pursue offerings without due diligence.<sup>214</sup> They have had to fight additional antitrust suits over the past two decades both

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<sup>211</sup> Lohr, Steve, and Tejada, Carlos, “After Era That Made It a Verb, Xerox in a Sale, Is Past Tense”, The New York Times, 31 Jan 2018, <https://www.nytimes.com/2018/01/31/business/dealbook/xerox-fujifilm.html>

<sup>212</sup> Scherer, 2006

<sup>213</sup> Id.

<sup>214</sup> Thatchenkery, Sruthi, and Katila, Riita, “Innovation and Profitability Following Antitrust Intervention Against a Dominant Platform: The Wild, Wild West?”, Strategic Management Journal, Volume 44, Issue 4, April 2023, <https://doi.org/10.1002/smj.3470>

in the U.S. and abroad, with fines by the EU for bundling Windows Media Player,<sup>215</sup> for withholding information needed for interoperability,<sup>216</sup> and is currently undergoing a Teams bundling case,<sup>217</sup> from South Korea for bundling instant messaging,<sup>218</sup> from Japan for bundling Microsoft Word<sup>219</sup> and difficulty for Japanese manufactures to obtain Windows OEM licenses<sup>220</sup>, and recently globally for its proposed Activision merger.<sup>221</sup>

In the past several years there has been intense scrutiny of the monopolies of major tech firms; in 2020 the FTC issued Special Orders to Alphabet, Amazon, Apple, Facebook, and Microsoft to provide information on all acquisitions not previously reported from 2010-2019.<sup>222</sup> Numerous lawsuits have been filed against all of the major tech companies by the Department of Justice, state and international governments alleging both monopolies and anticompetitive behavior favoring their own platforms over access from competition.<sup>223</sup> However, the lawsuits are unlikely to be able to address several issues surrounding anticompetitive issues in vertical integration: although leveraging monopoly power in a secondary market to obtain a new monopoly is illegal, leveraging it to gain secondary access is not;<sup>224</sup> similarly self-preferencing is not illegal as long as there is not refusal of access.<sup>225</sup> While further legislation could clarify

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<sup>215</sup> Commission Decision 2007/53/EC of 24 March 2004 relating to a proceeding pursuant to Article 82 EC and Article 54 of the EEA Agreement against Microsoft Corp. (Case COMP/C-3/37.792 – Microsoft)

<sup>216</sup>“Antitrust: Commission imposes € 899 million penalty on Microsoft for non-compliance with March 2004 Decision”, European Commission, IP/08/318, 27 February 2008  
[https://ec.europa.eu/commission/presscorner/detail/en/IP\\_08\\_318](https://ec.europa.eu/commission/presscorner/detail/en/IP_08_318)

<sup>217</sup>“Antitrust: Commission opens investigation into possible anticompetitive practices by Microsoft regarding Teams”, European Commission, 27 July 2023,  
[https://ec.europa.eu/commission/presscorner/detail/en/ip\\_23\\_3991](https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3991)

<sup>218</sup> “South Korea fines Microsoft \$32 m”. BBC News. 2005-12-07.

<sup>219</sup> “Japan finds Microsoft Antitrust Violation”, Tech Monitor, 22 November 1998,  
[https://techmonitor.ai/technology/japan\\_finds\\_microsoft\\_antitrust\\_violation](https://techmonitor.ai/technology/japan_finds_microsoft_antitrust_violation)

<sup>220</sup> “Microsoft Japan raided on suspicion of anti-trust violation”, The Sydney Morning Herald, 27 February 2004, <https://www.smh.com.au/world/microsoft-japan-raided-on-suspicion-of-anti-trust-violation-20040227-gdifnf.html>

<sup>221</sup> “Microsoft-Activision deal back in hands of UK regulator after court pauses appeal” Reuters, 21 July 2023, <https://www.reuters.com/markets/deals/britains-competition-appeal-tribunal-grants-adjournment-microsoft-activision-2023-07-21/>

<sup>222</sup>Lunden, Ingrid, “FTC to examine every acquisition by Alphabet, Amazon, Apple, Facebook, and Microsoft in 2010-2019 over antitrust issues”, TechCrunch, 11 February 2020  
<https://techcrunch.com/2020/02/11/ftc-to-examine-every-acquisition-by-alphabet-amazon-apple-facebook-and-microsoft-in-2010-2019-over-antitrust-issues/>

<sup>223</sup> See concerns outlined in more detail in *Antitrust Reform and Big Tech Firms*, Congressional Research Service, R46875, 22 March 2023 <https://sgp.fas.org/crs/misc/R46875.pdf>

<sup>224</sup> Verizon Commc’ns Inc. v. L. Offs. of Curtis V. Trinko, LLP, 540 U.S. 398, 410 n.4 (2004); *see also* Levinton, *supra* note 432.

<sup>225</sup> *Trinko*, 540 U.S. at 409. Refusal-to-deal doctrine is discussed in greater detail in *supra* “Refusals to Deal.” The essential-facilities doctrine is also unlikely to preclude many forms of platform self-preferencing for a variety of reasons, even if that doctrine remains good law. For an overview of the difficulties facing an essential-facilities challenge to “search bias,” for example, see Marina Lao, *Search, Essential Facilities, and the Antitrust Duty to Deal*, 11 NW. J. TECH. & INTELL. PROP. 275, 298-304 (2013).

stricter boundaries to this anticompetitive behavior, it is unlikely to pass with a Republican Congress.<sup>226</sup>

## Defense

In this section, we look at defense monopolies and the specific case of ULA as a launch provider. We summarize the findings in Table 4.

Table 5: Defense Monopoly Summary

|                                     | <b>Defense sector trends post-1993</b>                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pricing                             | Mixed results on cost-savings, but many expensive sole-source contracts highlighted in reporting                                                                                                                                                                                                                                                                                           |
| Innovation                          | DoD noted “growing concentration can reduce the availability of key supplies and equipment, diminish vendors’ incentives for innovation and performance in government contracts, and lead to supply chain vulnerabilities”                                                                                                                                                                 |
| Bundling                            | Highly proprietary interfaces, particularly in the space sector, making system integration difficult unless U.S. government provides standards                                                                                                                                                                                                                                             |
| Vertical Integration                | Increasing vertical integration in space sector                                                                                                                                                                                                                                                                                                                                            |
| Competition                         | Often sole-source contracts, difficult to encourage new entrants to compete with longstanding monopolies                                                                                                                                                                                                                                                                                   |
| Other anti-competitive behaviors    | N/A                                                                                                                                                                                                                                                                                                                                                                                        |
| Court ruling or legal status change | Antitrust concerns may be overridden by DoD in favor of national security interests. Over concern about ULA, FTC “received spoken assurances from the DOD and the National Aeronautics and Space Administration... that these government customers would use best efforts to facilitate new market entries—most notably, by SpaceX—to compete with the US government with launch services” |

A pivotal moment in the treatment of monopolies in the defense sector occurred at the “Last Supper” in 1993, when Deputy Secretary of Defense William Perry, concerned about plummeting defense funding post-Cold War, noted the budget could no longer support the multitude of defense contractors in existence. While he did not prescribe consolidation, the

<sup>226</sup> Klar, Rebecca, and Evars-Hillstrom, Karl, “How Big Tech fought antitrust reform—and won”, The Hill, 23 Dec 2022, <https://thehill.com/policy/technology/3785894-how-big-tech-fought-antitrust-reform-and-won/>

defense contractor CEOs in the room were left to determine how best to reorganize.<sup>227</sup> As a result, DoD authorized repayment for merger expenses or “defense restructuring costs”,<sup>228</sup> and in 1994 the Defense Science Board advocated for a role of DoD in adjudicating mergers, giving weight to national security interests even if mergers induced monopolies,<sup>229</sup> permanently shifting the landscape of the defense industrial base. Industry representatives, such as CEO of Martin Marietta, Norman Augustine, testified that they would not have paid \$208M for General Dynamics Space Systems otherwise, but that the government would receive a cost savings of \$500M by consolidating Atlas V and Titan IV launch programs,<sup>230</sup> but the overall cost savings ended up being less than half of what was projected.<sup>231</sup> As a result, the Pentagon was accused of giving out “payoffs for layoffs”<sup>232</sup>. The 1997 DoD Appropriations Act shifted this policy, requiring a two to one cost savings for reimbursement.<sup>233</sup> Although the DoD policy change had an impact on the antitrust treatment of defense mergers, arguably the mergers were part of a broader merger trend across the entire economy.<sup>234</sup>

Due to this change in policy, there are now five major defense primes (Lockheed, Boeing, Raytheon, General Dynamics, and Northrop Grumman). A 2022 DoD Report, *State of Competition within the Defense Industrial Base*, highlights concern about consolidation and its impact on cost, performance, schedule, innovation, mission risk, and national security risk<sup>235</sup>. Economic studies of the mergers have shown mixed results on cost,<sup>236,237</sup> though several high-profile price increases from sole-source contracting were recently featured in 60 Minutes—an oil switch that was once \$328 and is now \$10,000; a shoulder fired missile that was \$25,000 in 1991 and now \$400,000; and a predatory acquisition company initially increasing an Apache

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<sup>227</sup> Chang, Jonathan, and Chakrabati, Megan, “The last supper’: How a 1993 Pentagon dinner reshaped the defense industry”, wbur, 1 March 2023 <https://www.wbur.org/onpoint/2023/03/01/the-last-supper-how-a-1993-pentagon-dinner-reshaped-the-defense-industry>

<sup>228</sup> Sanders, Bernie, “Payoffs for Layoffs Have to Stop”, Los Angeles Times, 11 July 1996 <https://www.latimes.com/archives/la-xpm-1996-07-11-me-23009-story.html>

<sup>229</sup> Robert Pitofsky et al., Defense Science Board, Antitrust Aspects of Defense Industrial Consolidation, 1994

<sup>230</sup> Jane’s Defence Weekly. 1994. “Recouping the Cost of Defence,” (August 27)

<sup>231</sup> Cooper, David E. 1997. “Statement of David E. Cooper, Associate Director, Defense Acquisitions Issues, National Security and International Affairs Division on Defense Industry Restructuring: Cost and Savings Issues,” Testimony before the Subcommittee on Acquisition and Technology, Committee on Armed Services, United States Senate, General Accounting Office, April 15.

<sup>232</sup> Sanders, 1996

<sup>233</sup> Cooper, 1997

<sup>234</sup> Hensel, Nayantara, “Can Industry Consolidation Lead to Greater Efficiencies? Evidence from the U.S. Defense Industry”, Business Economics, Vol. 45, No.3, July 2010, <https://www.jstor.org/stable/23490992>

<sup>235</sup> “State of Competition within the Defense Industrial Base”, Department of Defense, Office of the Undersecretary of Defense for Acquisition and Sustainment, February 2022 <https://media.defense.gov/2022/feb/15/2002939087/-1/-1/1/state-of-competition-within-the-defense-industrial-base.pdf>

<sup>236</sup> Caril, Rodrigo, and Duggan, Mark, “The Impact of Consolidation on Government Procurement: Department of Defense Contracting”, National Bureau of Economic Research, Working Paper 25160, October 2018 [https://www.nber.org/system/files/working\\_papers/w25160/w25160.pdf](https://www.nber.org/system/files/working_papers/w25160/w25160.pdf)

<sup>237</sup> Hunter, Andrew P., Sanders, Gregory, Huitink, Zach, “Evaluating the Consolidation and the Threat of Monopolies within Industrial Sectors”, Center for Strategic and International Studies, August 2018, <https://www.dair.nps.edu/bitstream/123456789/2733/1/CSIS-AM-18-230.pdf>

helicopter valve 40% to \$747, now to \$12000; and the F-35 debacle that may eventually cost over a trillion dollars.<sup>238</sup> DoD noted that even if there was not a clear cost correlation in consolidation, “growing concentration can reduce the availability of key supplies and equipment, diminish vendors’ incentives for innovation and performance in government contracts, and lead to supply chain vulnerabilities.” They recommend the following steps: 1. Strengthening Merger Oversight, 2. Addressing IP limitations that might prevent competition, 3. Increasing new entrants and reducing barriers to entry, 4. Increasing small business opportunities, and 5. Implementing Sector-specific Supply Chain Resiliency Plan.<sup>239</sup> We note that IP limitations in particular have impacted the space sector, with proprietary interfaces limiting the ability to utilize space systems from different companies (e.g., satcom receiver incompatibility,<sup>240</sup> satellite servicing incompatibility,<sup>241</sup> integration of Space Situational Awareness data<sup>242</sup>). These incompatibilities in government-procured space systems are often driven through a desire to spur innovation without adding additional systems requirements, but eventually require standards development for efficient systems integration.

Hensel (2010) examined the impact of consolidation on costs at defense primes from 1981-2006, finding that 17.54% had a positive total cost change and 26.32% negative change, 18.37% positive cost per-unit change and 20.41% negative change. However, the four of the five major defense firms (Lockheed, Boeing, Raytheon, and General Dynamics) did become more cost-efficient post-acquisition (Northrop Grumman data was limited). These efficiencies were particularly pronounced in strategic electronics, rotary aircraft, tactical missiles, and surface ships; however, satellites had higher per unit costs post-merger (potentially an artifact of limited data). Hensel suggests that a driver may have been efficiencies in the pooling of knowledge sets and rationalization of plant capacity.<sup>243</sup> Carril and Duggan (2018) find no change in defense contract pricing post-merger, though note an 18% drop in competitive contracts and 36% increase of dollars in cost-plus contracts as a result.<sup>244</sup> A deep dive into consolidation by Hunter, Sanders, and Huitink (2018) similarly found mixed benefits to monopolies, noting higher risk of termination and ceiling breaches with competition vs. single source contracts, even if lower prices were achieved.<sup>245</sup> Despite broad economic trends, a recent 60 Minutes episode highlighted several examples of extreme price increases as a result of mergers/sole suppliers—an oil switch that was once \$328 and is now \$10,000; a shoulder fired missile that was \$25,000 in

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<sup>238</sup> Whitaker, Bill, “Weapons contractors hitting Department of Defense with inflated prices for planes, submarines, missiles”, 60 Minutes, 21 May 2023 <https://www.cbsnews.com/news/weapons-contractors-price-gouging-pentagon-60-minutes-transcript-2023-05-21/>

<sup>239</sup> “State of Competition within the Defense Industrial Base”

<sup>240</sup> Hitchens, Theresa “Is It Terminal? Mess Threatens DoD SATCOM & Multidomain”, 30 Dec 2019, <https://breakingdefense.com/2019/12/is-it-terminal-mess-threatens-dod-satcom-multi-domain/>

<sup>241</sup> Erwin, Sandra, “Space Force eager to harness satellite-servicing technology”, SpaceNews, 13 June 2023, <https://spacenews.com/space-force-eager-to-harness-satellite-servicing-technologies/>

<sup>242</sup> “SPACE SITUATIONAL AWARENESS: DOD Should Evaluate How It Can Use Commercial Data”, GAO, April 2023 <https://www.gao.gov/assets/gao-23-105565.pdf>

<sup>243</sup> Id.

<sup>244</sup> Caril, Rodrigo, and Duggan, Mark, “The Impact of Consolidation on Government Procurement: Department of Defense Contracting”, National Bureau of Economic Research, Working Paper 25160, October 2018 [https://www.nber.org/system/files/working\\_papers/w25160/w25160.pdf](https://www.nber.org/system/files/working_papers/w25160/w25160.pdf)

<sup>245</sup> Hunter, Andrew P., Sanders, Gregory, Huitink, Zach, “Evaluating the Consolidation and the Threat of Monopolies within Industrial Sectors”, Center for Strategic and International Studies, August 2018, <https://www.dair.nps.edu/bitstream/123456789/2733/1/CSIS-AM-18-230.pdf>

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1991 and now \$400,000 when supplied by Raytheon to Ukraine; TransDigm with a market strategy of buying up companies the military is reliant on, and initially marking up a Apache helicopter valve 40% to \$747, now to \$12000; and the F-35 debacle that may eventually cost over a trillion dollars.<sup>246</sup>

#### ULA and the rise of SpaceX as a launch provider

In the Analysis of Agreement Containing Consent Order to Aid Public Comment, which enabled the creation of the United Launch Alliance (ULA) as a joint Lockheed Martin-Boeing effort, the FTC noted the high cost of launch vehicle development, in excess of \$1B, as well as the costs of failure to national security and scientific services.<sup>247</sup> Boeing and Lockheed claimed the merger would translate to hundreds of millions in cost reduction from redundancy and integration, as well as allowed for economy of scale with more regular launches and decrease the number of launch failures.<sup>248</sup>

The FTC noted that “despite the absence of current price competition... significant anticompetitive effects, including the loss of competition and loss of potential future price competition, are likely to occur if the proposed transaction is consummated”, noting that at the time, under the Buy III program, each company was incentivized to improve the capability and reliability of its services and gives the government the capability to down-select. National security benefits, however, overrode the FTC’s concerns. They noted three primary concerns from DoD: 1. ULA would favor its parents’ space vehicles over other manufacturers, e.g., Northrop (whereas at the time it cooperated with other vehicle suppliers), 2. Boeing and Lockheed would raise barriers to entry in the government medium-to-heavy launch services market as DoD often bundled launch and vehicle buys, and therefore could refuse to consider other competitors on equal terms such as SpaceX, and 3. Competitively sensitive information could be disclosed internally amongst ULA/Boeing/Lockheed that harmed competitors. In the consent decree, they required all space vehicle suppliers to receive equal access to resources and information from ULA, introduced a compliance officer to ensure fair competition of contracts, and required ULA, Boeing, and Lockheed Martin to safeguard competitively sensitive information.<sup>249</sup>

Elon Musk did not protest the merger, but advocated for a system that would allow SpaceX to receive future government contracts, asserting that he could drive the cost of launch down substantially, although SpaceX had not yet had a successful test of the Falcon rocket. As a

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<sup>246</sup> Whitaker, Bill, “Weapons contractors hitting Department of Defense with inflated prices for planes, submarines, missiles”, 60 Minutes, 21 May 2023 <https://www.cbsnews.com/news/weapons-contractors-price-gouging-pentagon-60-minutes-transcript-2023-05-21/>

<sup>247</sup> “Analysis of Agreement Containing Consent Order to Aid Public Comment: *In the Matter of The Boeing Company, Lockheed Martin Corporation, and United Launch Alliance File No. 051-0165*”, Federal Trade Commission <https://www.ftc.gov/sites/default/files/documents/cases/2006/10/0510165analysis.pdf>

<sup>248</sup> William E. Kovacic, “Competition Policy Retrospective: The Formation of the United Launch Alliance and the Ascent of SpaceX,” *George Mason Law Review* 27, no. 3 (Summer 2020): 863-904, and references therein

<sup>249</sup> Analysis of Agreement Containing Consent Order to Aid Public Comment: *In the Matter of The Boeing Company, Lockheed Martin Corporation, and United Launch Alliance File No. 051-0165*”, Federal Trade Commission <https://www.ftc.gov/sites/default/files/documents/cases/2006/10/0510165analysis.pdf>

condition of the approval of the merger, the FTC “received spoken assurances from the DOD and the National Aeronautics and Space Administration... that these government customers would use best efforts to facilitate new market entries—most notably, by SpaceX—to compete with the US government with launch services.”<sup>250</sup>

Kovacic, part of the FTC team who evaluated the merger, notes the success of ULA of becoming a reliable launch provider without any failures,<sup>251</sup> although the merger did not produce the organizational harmony it claimed, with a 2018 profile of Tory Bruno noting Under the joint ULA roof, the two clans remained separate, if not hostile, duplicating management functions and costs from top to bottom. “The staffs from the two product lines didn’t really mix all that much.”<sup>252</sup>

SpaceX, looking to compete for future Evolved Expendable Launch Vehicle (EELV) contracts, signed an agreement with the Air Force in 2013, which required it to demonstrate three successful Falcon 9 launches before becoming eligible to compete. When SpaceX had completed two of the three launches in 2013, the Air Force signed a contract with ULA for 36 rocket cores. SpaceX sued arguing the contract should have been competitively bid, a matter which was settled, and SpaceX was deemed eligible to compete in 2015. SpaceX has continued to dominate the launch market, driven in part due to ULA’s choice to utilize the RD-180 engine in its vehicles, a Russian-made engine, which was banned by the Fiscal Year 2017 National Defense Authorization Act with effective date of December 31, 2022.<sup>253</sup> Although this provided ULA considerable time to find an alternative engine (the Blue Origin BE-4), Vulcan did not launch until January 2024, only just qualifying for the National Security Space Launch Phase 3, a multi-billion Air Force procurement solicitation for 2025-2029.<sup>254</sup>

### *Additional Studies on Vertical Integration*

This section examines several economic studies on the impact of vertical integration on innovation; *Table 6* summarizes these studies.

Table 6: Economic Studies on the Impact of Vertical Integration on Innovation

| Study                      | Impact                                                                                                  |
|----------------------------|---------------------------------------------------------------------------------------------------------|
| Chen and Sappington (2010) | Cournot competition (companies compete on amount of output), vertical integration increases innovation  |
|                            | Bertrand competition (companies compete on price), upstream innovation may cannibalize overall profits. |

<sup>250</sup> Kovacic, 2020

<sup>251</sup> Id.

<sup>252</sup> Craig Mellow, *Tory Bruno, The Other Rocket Man*, Air & Space Magazine, June 2018, p. 67

<sup>253</sup> Harrison, Todd, Hunter, Andrew, Johnson, Kaitlyn, Linck, Evan, Roberts, Thomas, “Beyond the RD-180”, Center for Strategic and International Studies, 21 March 2017, <https://www.csis.org/analysis/beyond-rd-180> and references therein

<sup>254</sup> Klotz, Irene, “Debrief: Vulcan on Deck”, Aviation Week Network, 2 April 2025, <https://aviationweek.com/space/launch-vehicles-propulsion/debrief-vulcan-deck>

|                                   |                                                                                                                                                                                       |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Allain, Chambolle, and Rey (2015) | Vertical integration decreases investment in downstream innovation if another downstream competitor may benefit, unless competitor reinvests upstream                                 |
| Acemouglu, et al. (2010)          | Low likelihood of vertical integration for technology intensive suppliers and low technology intensity producers                                                                      |
| Liu (2016)                        | In pharmaceutical industry, when all stages of investment are risky, vertical integration is beneficial; when most innovation is upstream, easier to outsource less-complex processes |

At times, regulators have forced separation of different segments of a market in order to prevent the suppliers of bottleneck services from adversely impacting competition. Chen and Sappington (2010) find that the impact of vertical integration on innovation depends on the competition type—in Cournot competition, where companies compete on amount of output, vertical integration generally increases innovation. Under Bertrand competition, where companies compete in price, innovation can decrease, depending on direct incentives for innovation, as upstream cost reduction impacts the pricing of both an internal downstream producer and an external downstream rival dependent on the upstream product.<sup>255</sup> In other words, price wars at the downstream level caused by Bertrand competition erode gains from upstream efficiency/innovation. Allain, Chambolle, and Rey (2015) conclude that vertical integration also decreases investment in innovation from downstream companies if information exchange to a vertically integrated upstream supplier may be leaked to a downstream competitor (where one downstream company is integrated with the upstream company and the other is not);<sup>256</sup> if there is an ability to reinvest the non-integrated downstream product into the upstream company, however, this changes the R&D incentive to a positive one.<sup>257</sup>

Acemouglu, et al. (2010) examine trends in vertical integration across British manufacturing plants, finding that the “technology intensity” of downstream and upstream industries have opposite effects on vertical integration, with low likelihood of vertical integration for technology intensive suppliers and low technology intensity producers, an effect which is more pronounced when the supplier price is a large fraction of the producer cost.<sup>258</sup> Consistently, Liu (2016) finds two opposing trends in the pharmaceutical industry regarding vertical integration vs. outsourcing. Liu notes that in the most innovative sector, the biotech segment, requiring risky investments in every stage of the industry, vertical integration benefits the sector by incentivizing

<sup>255</sup> Chen, Youngmin, and Sappington, Davide E.M., “Innovation in Vertically Related Markets”, *The Journal of Industrial Economics*, June 2010, Vol. 58, No. 2, pp. 373-401, <https://www.jstor.org/stable/40662188>

<sup>256</sup> Marie-Laure Allain and Chambolle, Claire, and Rey, Patrick, Vertical Integration as a Source of Hold-up, *The Review of Economic Studies*, Volume 83, Issue 1, January 2016, Pages 1–25, <https://doi.org/10.1093/restud/rdv035>

<sup>257</sup> Lin, Ping, Zhang, Tianle, Zhou, Wen, “Vertical Integration and Disruptive-Cross Market RD”, *Journal of Economics & Management Strategy*, 9 Aug 2019, <https://doi.org/10.1111/jems.12328>

<sup>258</sup> Daron Acemoglu and others, Vertical Integration and Technology: Theory and Evidence, *Journal of the European Economic Association*, Volume 8, Issue 5, 1 September 2010, Pages 989–1033, <https://doi.org/10.1111/j.1542-4774.2010.tb00546.x>

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better coordination and decreasing the hold-up, plus forcing the company to strategically invest across the entire sector in ways that optimize output. In contrast, in the more traditional segment, chemistry-based processes require investments mostly in the discovery stage, and other less complex processes can be outsourced. Liu notes that this mirrors the tech sector, where e.g., companies have invested in their own smartphones to provide services.<sup>259</sup>

## Discussion

In this section, we summarize the lessons learned from monopolies and discuss their applicability to SpaceX.

### Lessons Learned from Monopolies

#### Monopolies often achieve their pre-monopoly growth through innovation.

First-movers with new technology are often able to establish an initial monopoly, e.g., Carnegie Steel (eventually part of U.S. Steel) through the Bessemer process,<sup>260</sup> Alcoa (aluminum) through smelting,<sup>261</sup> Bell through the telephone,<sup>262</sup> Xerox through copiers,<sup>263</sup> and Amazon through online shopping.<sup>264</sup>

#### Monopolies have a disincentive to innovate, except where imperfect substitutes may drive competition.

The Arrow Replacement effect suggests monopolists won't cannibalize their own revenue by innovating. This historically holds at many monopolies: patents dropped after Standard Oil rapidly grew, U.S. Steel's policy was "no inventions, no innovations",<sup>265,266</sup> the FCC labeled AT&T in 1939 as slow in introducing technological innovations and it actively blocked

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<sup>259</sup> Liu, Xingyi, "Vertical Integration and Innovation", *International Journal of Industrial Organization* (2016), <https://doi.org/10.1016/j.ijindorg.2016.02.002>

<sup>260</sup> Adams, Sean, "Carnegie Steel and Creative Destruction", University of Florida, <https://ufl.pb.unizin.org/imos/chapter/steel/>

<sup>261</sup> David Smith, George. *From Monopoly to Competition: The Transformations of Alcoa, 1888-1986*, Cambridge University Press, Cambridge, MA, 1988, p. 53

<sup>262</sup> Thierer, Adam, "Unnatural Monopoly: Critical Moments in the Development of the Bell System Monopoly", *Cato Journal*, Vol 14, No. 2, Fall 1994  
<https://www.cato.org/sites/cato.org/files/serials/files/cato-journal/1994/11/cj14n2-6.pdf>

<sup>263</sup> Scherer, F.M., "Technological Innovation and Monopolization" Department of Justice, March 2006  
<https://www.justice.gov/sites/default/files/atr/legacy/2006/10/30/218697.pdf>

<sup>264</sup> Khan, Lina, "Amazon's Antitrust Paradox", *Yale Law Journal*,  
[https://www.yalelawjournal.org/pdf/e.710.Khan.805\\_zuvfyeh.pdf](https://www.yalelawjournal.org/pdf/e.710.Khan.805_zuvfyeh.pdf)

<sup>265</sup> Maseritz, Guy, B. "No Inventions, No Innovations": Reassessing the Government's Antitrust Case Against United States Steel Corporation, 7 *J. Bus. & Tech. L.* 247, 2012,  
<https://digitalcommons.law.umaryland.edu/jbtl/vol7/iss2/1>

<sup>266</sup> *U.S. Steel Corporation*, *Fortune Magazine*, Mar. 1936, p. 173

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technology such as the answering machine,<sup>267,268</sup> Xerox rapidly declined after its antitrust suit,<sup>269</sup> and patents rose after Microsoft's 2002 antitrust decree.<sup>270</sup> However, imperfect substitutes can drive competition—for instance, Alcoa maintained a research laboratory largely to ensure aluminum would be used in manufacturing items where it could compete with steel,<sup>271</sup> and AT&T/Bell built early communications satellites before Intelsat was given a satcom monopoly, then eventually built transoceanic fiber to compete with satcom.<sup>272,273</sup>

Monopolies often achieve their dominance by implementing predatory pricing and driving out competitors.

U.S. Steel used a geographic pricing system to eliminate competition,<sup>274</sup> private electric and water utilities have consistently underbid to achieve long-term contracts which they are not able

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<sup>267</sup> U.S. Federal Communications Commission, staff report, Report on Telephone Investigation (two volumes, mimeo, 1939), vol. I, pp. 323-398 and 404-405

<sup>268</sup> Scherer, F.M., "Technological Innovation and Monopolization" Department of Justice, March 2006 <https://www.justice.gov/sites/default/files/atr/legacy/2006/10/30/218697.pdf>

<sup>269</sup> Id.

<sup>270</sup> Thatchenkery, Sruthi, and Katila, Riita, "Innovation and Profitability Following Antitrust Intervention Against a Dominant Platform: The Wild, Wild West?", Strategic Management Journal, Volume 44, Issue 4, April 2023, <https://doi.org/10.1002/smj.3470>

<sup>271</sup> Adams, Sean, *Aluminum: Alcoa and Anti-Trust*, Impact of Materials on Society, University of Florida, 28 July 2023 <https://ufl.pb.unizin.org/imos/chapter/aluminum/#footnote-46-8>

<sup>272</sup> Launius, Roger D., and McCurdy, Howard E. "NASA SPACEFLIGHT: History of Innovation", 17 October 2017 [https://link.springer.com/chapter/10.1007/978-3-319-60113-7\\_3](https://link.springer.com/chapter/10.1007/978-3-319-60113-7_3)

<sup>273</sup> Communications Satellite Act of 1962, Pub. L. No. 87-624, 76 Stat. 425, codified as amended at 47 U.S.C. §§ 701-769 (2000) [hereinafter Satellite Act].

<sup>274</sup> Masteritz, 2012

to fulfill without additional cashflows,<sup>275,276,277,278,279,280,281</sup> and IBM regularly undercut rivals who were independently selling peripherals.<sup>282</sup> Companies including Walmart,<sup>283</sup> Uber,<sup>284</sup> Amazon,<sup>285,286</sup> have been targets of antitrust investigations and lawsuits where they have undercut competitors to drive them from the market. However, the bar for predatory pricing antitrust lawsuits to succeed is very high, as proof is required that the company has intentionally undercut a competitor to force them out of the market; while this has been a subject of concern for both the FTC<sup>287</sup> and Congress, cases against the big five tech companies (Microsoft,

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<sup>275</sup> Busby, Joshua, et al., “Cascading Risks: Understanding the 2021 winter blackout in Texas”, *Energy Research & Social Science*, Volume 77, July 2021, 102106

<sup>276</sup> Causes and Lessons of the California Electricity Crisis”, Congressional Budget Office, September 2001 <https://www.cbo.gov/sites/default/files/107th-congress-2001-2002/reports/californiaenergy.pdf>

<sup>277</sup> Nix, Adam, Decker, Stephanie, and Wolf, Carola, “Enron and the California Energy Crisis: The Role of Networks in Enabling Organizational Corruption”, *Business History Review*, 95(4), 765-802. doi:10.1017/S0007680521001008

<https://www.cambridge.org/core/journals/business-history-review/article/enron-and-the-california-energy-crisis-the-role-of-networks-in-enabling-organizational-corruption/457B1E245C6E6DE8903F531DD768D3F4#en156>

<sup>278</sup> Kasler, Dale, and Heeter, Maria, “California avoided rolling blackouts for two decades. What went wrong on the grid?”, *Sacramento Bee*, 17 August 2020

<https://www.sacbee.com/news/local/article244988455.html>

<sup>279</sup> Hosea, Leana, and Lerner, Sharon, “From Pittsburgh to Flint, The Dire Consequences of Giving Private Companies Responsibility for Ailing Public Water Systems”, *The Intercept*, 20 May 2018 <https://theintercept.com/2018/05/20/pittsburgh-flint-veolia-privatization-public-water-systems-lead/>

<sup>280</sup> Craig Anthony (Tony) Arnold, *Water Privatization Trends in the United States: Human Rights, National Security, and Public Stewardship*, 33 *Wm. & Mary Env'tl. L. & Pol'y Rev.* 785 (2009), <https://scholarship.law.wm.edu/wmelp/vol33/iss3/4>

<sup>281</sup> Douglass, Elizabeth, “Towns sell their public water systems—and come to regret it”, *The Washington Post*, 8 July 2017 [https://www.washingtonpost.com/national/health-science/towns-sell-their-public-water-systems--and-come-to-regret-it/2017/07/07/6ec5b8d6-4bc6-11e7-bc1b-fddbd8359dee\\_story.html](https://www.washingtonpost.com/national/health-science/towns-sell-their-public-water-systems--and-come-to-regret-it/2017/07/07/6ec5b8d6-4bc6-11e7-bc1b-fddbd8359dee_story.html)

<sup>282</sup> Scherer, 2006

<sup>283</sup> Bordreaux, Donald, “Predatory Pricing in The Retail Trade: *The Wal-Mart Case*”, *The Economics of the Antitrust Process*, 1996, [https://link.springer.com/chapter/10.1007/978-1-4613-1397-7\\_10](https://link.springer.com/chapter/10.1007/978-1-4613-1397-7_10)

<sup>284</sup> Stempel, Jonathan, “Uber must face lawsuit claiming it stifled competition, drove out rival Sidecar”, *Reuters*, 1 May 2020, <https://www.reuters.com/article/us-uber-sidecar/uber-must-face-lawsuit-claiming-it-stifled-competition-drove-out-rival-sidecar-idUSKBN22D6AT>

<sup>285</sup> Khan, 2019

<sup>286</sup> Lee, Timothy B., “Emails Detail Amazon’s Plans to crush a startup rival with price cuts”, *Ars Technica*, 30 July 2020, <https://arstechnica.com/tech-policy/2020/07/emails-detail-amazons-plan-to-crush-a-startup-rival-with-price-cuts/>

<sup>287</sup> Papsun, Dan, “FTC’s Competition Policy Shift Paves Enforcement ‘Shortcuts’”, *Bloomberg Law*, 11 Nov 2022, <https://news.bloomberglaw.com/antitrust/ftcs-competition-policy-shift-paves-enforcement-shortcuts>

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Amazon, Alphabet, Facebook, Apple) are still pending litigation,<sup>288,289</sup> and new legislation is not likely to pass a Republican House.<sup>290</sup>

Monopolies are often able to prevent competition through bundling of services, incompatibility of technology, and patents.

Patents help cement the lead of the first movers, and later movers face larger upfront capital costs due to the need to immediately compete against the first mover's strength, whether that be in services, facilities, or human capital.<sup>291</sup> Alcoa kept competition away until a 1903 patent lawsuit, which was able to stave off growth of other companies long enough for it to keep its monopoly.<sup>292</sup> Bell grew rapidly in its first 20 years due to its patents, then eventually blocked long-distance providers from connecting to its local networks and would not connect competitors' equipment. Xerox grew quickly through patents, and eventually licensed Xerox paper copying but maintained licensing control over cheaper paper, and developed its own exclusive expensive toner. IBM locked customers into IBM software through backward compatibility and repair service bundled with contracts, and changed hardware to make competitors' peripherals incompatible. Microsoft gave manufacturers discounts on Microsoft operating systems (OS) if they paid for licenses for each computer sold, regardless of if it contained the OS,<sup>293</sup> and bundled services like Internet Explorer, Windows Media, and Teams

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<sup>288</sup> Lunden, Ingrid, "FTC to examine every acquisition by Alphabet, Amazon, Apple, Facebook, and Microsoft in 2010-2019 over antitrust issues", TechCrunch, 11 February 2020 <https://techcrunch.com/2020/02/11/ftc-to-examine-every-acquisition-by-alphabet-amazon-apple-facebook-and-microsoft-in-2010-2019-over-antitrust-issues/>

<sup>289</sup> See concerns outlined in more detail in *Antitrust Reform and Big Tech Firms*, Congressional Research Service, R46875, 22 March 2023 <https://sgp.fas.org/crs/misc/R46875.pdf>

<sup>290</sup> Klar, Rebecca, and Evars-Hillstrom, Karl, "How Big Tech fought antitrust reform—and won", The Hill, 23 Dec 2022, <https://thehill.com/policy/technology/3785894-how-big-tech-fought-antitrust-reform-and-won/>

<sup>291</sup> Chandler, Alfred. *Scale and Scope, The Dynamics of Industrial Capitalism*, Belknap Press, Cambridge, Massachusetts, 1990, p. 34-38

<sup>292</sup> Id., p. 124

<sup>293</sup> Scherer, 2006

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for free to ward off competitors.<sup>294,295,296,297,298</sup> Apple is infamous for having incompatible technology and for requiring all apps to be sold through the app store.<sup>299</sup>

Many monopolies vertically integrate, as it is beneficial upstream for supply chain reliability, and downstream for innovative sectors.

Vertical integration primarily seeks to assure the stability of their own supply chain and cost, providing insurance against variation in production and risk that suppliers would fail to carry out contracts.<sup>300</sup> U.S. Steel owned everything from mining land to shipping vessels needed to manufacture and distribute steel,<sup>301</sup> Alcoa mimicked this structure.<sup>302</sup> AT&T had branches covering manufacturing, research, long-distance, and local service.<sup>303</sup> IBM vertically integrated from semi-conductors to hardware to software,<sup>304</sup> Apple is similarly vertically integrated.<sup>305</sup> Amazon runs its own logistics and IT with AWS, has its own delivery service, and provides Amazon-branded products. Several studies have shown that it is beneficial to vertically integrate

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<sup>294</sup> Commission Decision 2007/53/EC of 24 March 2004 relating to a proceeding pursuant to Article 82 EC and Article 54 of the EEA Agreement against Microsoft Corp. (Case COMP/C-3/37.792 – Microsoft)

“Antitrust: Commission imposes € 899 million penalty on Microsoft for non-compliance with March 2004 Decision”, European Commission, IP/08/318, 27 February 2008  
[https://ec.europa.eu/commission/presscorner/detail/en/IP\\_08\\_318](https://ec.europa.eu/commission/presscorner/detail/en/IP_08_318)

<sup>295</sup> Antitrust: Commission opens investigation into possible anticompetitive practices by Microsoft regarding Teams”, European Commission, 27 July 2023,  
[https://ec.europa.eu/commission/presscorner/detail/en/ip\\_23\\_3991](https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3991)

<sup>296</sup> “South Korea fines Microsoft \$32 m”. BBC News. 2005-12-07.

<sup>297</sup> “Japan finds Microsoft Antitrust Violation”, Tech Monitor, 22 November 1998,  
[https://techmonitor.ai/technology/japan\\_finds\\_microsoft\\_antitrust\\_violation](https://techmonitor.ai/technology/japan_finds_microsoft_antitrust_violation)

<sup>298</sup> “Microsoft Japan raided on suspicion of anti-trust violation”, The Sydney Morning Herald, 27 February 2004, <https://www.smh.com.au/world/microsoft-japan-raided-on-suspicion-of-anti-trust-violation-20040227-gdifnf.html>

<sup>299</sup> Leswing, Kif, CNBC, 6 Oct 2020, “Apple’s ‘monopoly power’ over iPhone app distribution gives it outsized profits, antitrust committee says” <https://www.cnbc.com/2020/10/06/house-antitrust-subcommittee-apple-has-monopoly-power.html>

<sup>300</sup> Chandler, p. 34-38

<sup>301</sup> Adams, Sean, “Carnegie Steel and Creative Destruction”, University of Florida,  
<https://ufl.pb.unizin.org/imos/chapter/steel/>

<sup>302</sup> David Smith, 1988

<sup>303</sup> Thierer, 1994

<sup>304</sup> Hutcheson, Dan G, “The Three Business Integration Models: Horizontal, Vertical, and Matrix”, The Chip History Center, <https://www.chiphistory.org/883-the-3-business-integration-models-horizontal-vertical-and-matrix?frm=1>

<sup>305</sup> Levinthal, Daniel, Hsu, David, Hrebiniak, Lawrence, “Vertical Integration Works for Apple, But it Won’t Work for Everyone”, Knowledge at Wharton, 14 March 2012,  
<https://knowledge.wharton.upenn.edu/article/vertical-integration-works-for-apple-but-it-wont-for-everyone/>

when the downstream products are highly technology intensive.<sup>306,307</sup> Large integrated firms do not typically have to compete on price, but set price based on demand relative to its plant capacity.<sup>308</sup>

Transportation sector monopolies can make or break other businesses.

Standard Oil's rise to dominance was driven by its collusion on transportation rather than petroleum itself, an easy feat given a mere three railroads transported petroleum.<sup>309</sup> Standard had such a strong grip on the railroads that others found themselves unable to secure transportation, and were forced to sell to Standard well below market rate.<sup>310,311</sup> U.S. Steel also looked to the railroads as a means of competitive advantage, buying up railroads in the Great Lakes region, which cost its competitors \$2-\$3/ton over an average haul.<sup>312</sup> Railroad rates also played a role in the transformation of the meat market, as in the late 1800s, refrigerated cars threatened an entire industry that relied on shipping cattle for local slaughter rather than shipping "dressed meat". A rate war ensued, and dressed meat eventually won out as prices could drop no further.<sup>313</sup> Regional monopolies of freight still dominate railroad transportation. and the threat of recent rail strikes would have cost companies' \$1B per week in losses<sup>314,315,316</sup> Despite the impact to U.S. supply chain, their performance has not impacted their own financial performance, as the "stock price and total return of every publicly traded Class I railroad from the end of 2011 to the end of 2021, except for Canadian National, grew faster than the S&P 500."<sup>317</sup>

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<sup>306</sup> Daron Acemoglu and others, Vertical Integration and Technology: Theory and Evidence, *Journal of the European Economic Association*, Volume 8, Issue 5, 1 September 2010, Pages 989–1033, <https://doi.org/10.1111/j.1542-4774.2010.tb00546.x>

<sup>307</sup> Liu, Xingyi, "Vertical Integration and Innovation", *International Journal of Industrial Organization* (2016), <https://doi.org/10.1016/j.ijindorg.2016.02.002>

<sup>308</sup> Chandler, 1990, p. 34-38

<sup>309</sup> Granitz, Elizabeth, and Benjamin Klein. "Monopolization by 'Raising Rivals' Costs': The Standard Oil Case." *The Journal of Law & Economics* 39, no. 1 (1996): 1–47. <http://www.jstor.org/stable/725768>.

<sup>310</sup> Lloyd, H.D., "The Story of a Great Monopoly" *The Atlantic*, March 1881 <https://www.theatlantic.com/magazine/archive/1881/03/the-story-of-a-great-monopoly/306019/>

<sup>311</sup> Lloyd, H.D., "The Story of a Great Monopoly" *The Atlantic*, March 1881 <https://www.theatlantic.com/magazine/archive/1881/03/the-story-of-a-great-monopoly/306019/>

<sup>312</sup> United States House of Representatives, *The Investigation of the United States Steel Corporation, 1911* (Washington, D.C.: GPO, 1913), 7.

<sup>313</sup> Kujovich, Mary Yeager. "The Refrigerator Car and the Growth of the American Dressed Beef Industry." *The Business History Review* 44, no. 4 (1970): 460–82. <https://doi.org/10.2307/3112669>.

<sup>314</sup> Jinoo Buck, Matthew, "How America's Supply Chain Got Railroaded", *The American Prospect*, 4 February 2022, <https://prospect.org/economy/how-americas-supply-chains-got-railroaded/>

<sup>315</sup> Evers-Hillstrom, Karl, "Freight Rail Slowdowns Under Microscope Amid Supply Crunch", *The Hill*, 25 May 2022, <https://thehill.com/lobbying/3500399-freight-railroad-slowdowns-under-microscope-amid-supply-crunch/>

<sup>316</sup> Yurkevich, Vanessa, "U.S. Freight rail strike could cost US economy \$1 billion in first week", 23 Nov, 2023, <https://www.cnn.com/2022/11/23/economy/us-freight-railroad-strike-costs/index.html>

<sup>317</sup> Jinoo Buck, 2022

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The Aerospace and Defense Industry has drastically consolidated since the 1990s, and has received antitrust exemptions for national security. The data on the impact of consolidation on pricing is incomplete.

Defense companies are exempt from normal antitrust regulations, resulting in the dominance of five defense primes. There is not extensive data on the impact of consolidation on pricing, although DoD has expressed concern about vulnerabilities due to consolidation and the need to diversify and encourage new entrants. Closer monitoring of economic impact is needed.

### SpaceX as a Monopoly

Prior to the 2024 U.S. presidential election, most concern about use of U.S. government use of SpaceX launch, satellite, and commercial cargo and crew services was centered around sole-source or nearly sole-source contracting. In this section we primarily discuss current U.S. government SpaceX contracts from an economic and national security risk perspective assuming competitive contracting procedures are applied within the U.S. government, noting overall risk posture is higher when anticompetitive practices are adopted.

#### *SpaceX innovation and pricing*

SpaceX has gained a reputation for being the most innovative commercial space company, both inside the space industry and with the general public. The above analysis of previous monopolies has shown strong advantages to innovate in order to establish an initial monopoly in a sector.

SpaceX has clearly undergone a similar process revolution with launch, dramatically dropping launch costs in part due to its investment in reusability. Current prices are ~\$3500/kg or 50% more for rideshare customers (with actual cost priced at \$857-\$1600/kg),<sup>318</sup> while the new ULA Vulcan rocket has caught up years later at ~\$4000/kg.<sup>319</sup> However, this launch cost has not necessarily translated into U.S. government savings; A 2025 NASA publication revealed an increase to NASA launch costs in excess of inflation, including after the 2016 entrance of SpaceX as a new provider, countering the common industry notion that competition has decreased launch costs.<sup>320</sup> Although this publication masks launch costs as proprietary, anecdotally, SpaceX has been flagged for a FY 2022 NRO launch contract that was much higher than historically expected, at \$316M vs. \$337M awarded to ULA for two launches, or similar NASA contract for \$117M (with note that launch pricing is highly variable based on payload, timing, and other integration factors; SpaceX argued the price difference was due to

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<sup>318</sup> Fuhr, Jack, “Underutilized Capacity on Dedicated Customer Falcon 9 Rides: Payload Research”, Payload Space, 8 Jan 2025 <https://payloadspace.com/underutilized-capacity-on-dedicated-customer-falcon-9-rides-payload-research/>

<sup>319</sup> ULA vs SpaceX – A Detailed Comparison in 2024”, Space Insider, 31 July 2024, <https://spaceinsider.tech/2024/07/31/ula-vs-spacex/>

<sup>320</sup> Kim, Moon J., Counting stars and costs: An empirical examination of space launch cost trend at NASA, Acta Astronautica, Volume 232, 2025  
Acta Astronautica, Volume 232, 2025

infrastructure costs).<sup>321</sup> SpaceX has additionally been accused of predatory pricing on rideshares push out competition,<sup>322</sup> an accusation supported by one former SpaceX launch sales employee in private conversation.

As Vulcan is fully expendable, it is unlikely that they can beat SpaceX purely in cost, but a shortfall in capacity for launch may keep them as an alternative in the market (Cournot competition). One could expect that if the competition changes to be focused on price instead of schedule (Bertrand competition), SpaceX would further drop prices and become less likely to push innovation. A successful Starship vehicle will further lower actual SpaceX launch costs. Payload estimates that the cost per kg for Starship will be \$200/kg, but prices may remain high to cover development costs<sup>323</sup> (and due to lack of incentives to drop prices below those that would force out competition).

SpaceX has also arguably begun a process revolution in satellite communications. Starlink is a clearly superior substitute for terrestrial services provided in many rural areas, with download speeds of 25-250 Mbps and no infrastructure buildout cost to areas not currently served by FCC-defined broadband of 25 Mbps download 3 Mbps upload speeds. Many rural customers previously utilized GEO satcom service, but have shifted to Starlink for faster speeds. Satcom is also presently capacity constrained,<sup>324</sup> with both GEO and NGSO operators attempting to ramp up capacity by increasing the number of satellites on-orbit providing high-speed internet and IoT services; the overall capacity is not only constrained by manufacturing output, but by the cadence of the launch market, hit by the delay of the Vulcan and Ariane 6, the abandonment of Russian launches by most nations, and the hesitancy of most companies to use Chinese launch vehicles.<sup>325</sup> Similar to launch, satcom capacity constraints suggest Cournot competition will keep SpaceX innovating to maintain the highest quality satcom capabilities.

#### *SpaceX: anticompetitive behavior?*

Arguably, SpaceX is in a position to control the trajectory of much of the space sector through its current near-monopoly on launches outside of China, similar to the railroad industry which held (and to some extent still holds) a strong grasp on a wide range of sectors with ability to cut pricing and shipment quantity deals, and to favor Starlink launches over launches of competitors. As noted above, self-preferencing has been found to be legal as long as it doesn't

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<sup>321</sup> Erwin, Sandra, "SpaceX Explains Why the U.S. Space Force is Paying \$316 million for a Single Launch", SpaceNews, 9 Nov 2020 <https://spacenews.com/spacex-explains-why-the-u-s-space-force-is-paying-316-million-for-a-single-launch/#:~:text=The%20%24316%20million%20contract%20was,the%20one%20awarded%20to%20SpaceX.>

<sup>322</sup> Foust, Jeff "Smallsat launch and the real world", The Space Review, 21 February 2022, [thespacereview.com/article/4334/1](https://thespacereview.com/article/4334/1)

<sup>323</sup> "The Starship Report", Payload Research, January 2024, <https://docsend.com/view/fi9wuazzeex57iig>

<sup>324</sup> Brodtkin, Jon, "A year after ditching waitlist, Starlink says it is "sold-out" in parts of US", Ars Technica, 19 Nov 2024, <https://arstechnica.com/tech-policy/2024/11/starlink-brings-back-waitlist-in-parts-of-us-says-service-is-sold-out/?ref=broadbandbreakfast.com>

<sup>325</sup> Edwards, Brooke, "I literally have a stockpile": ULA CEO says of rocket backlog awaiting next launch", Florida Today, 17 March 2025, <https://www.floridatoday.com/story/tech/science/space/2025/03/17/ula-vulcan-rocket-fly-later-this-year-after-atlas-v-launch-spacex-united-launch-alliance-florida/82311083007/>

exclude others from the market, and SpaceX could easily institute preferential pricing for various companies to alter the market, but until this point, they have touted their transparency in listing their pricing online<sup>326,327</sup> in comparison to other launch companies. However, reports indicate SpaceX has exclusionary launch contracts with customers requiring they receive first right of refusal for future launches.<sup>328</sup> Such exclusive dealing contracts are not prima facie illegal in the U.S. under Sherman; one law firm asserts that you must prove you are in the same market, the restraint substantially foreclosed you from competing in the market, there was harm to competition, duration of the contract was long (generally > 1 year), there was anticompetitive intent, and there was anticompetitive injury in order to win such an antitrust case.<sup>329</sup>

Even if SpaceX retains a domestic monopoly on launch, similar to PanAm, it may face international competition, including by subsidized international competitors, which may drive continued innovation. The same holds for Starlink—while SpaceX has a substantial advantage in constellation deployment by both being the first mover and being vertically integrated to cut costs, it will likely face international competition from subsidized competitors including the European Commission’s IRIS<sup>2</sup><sup>330</sup> and Chinese constellation Guowang. Although SpaceX’s remote sensing aspirations are currently close-held, the strategic importance of remote sensing is widely recognized by international governments, and one would expect continued international subsidization of these capabilities even if SpaceX becomes the dominant U.S. market source of any specific phenomenology; SpaceX’s innovative capabilities on this front may also be limited by the U.S. commercial remote sensing regulatory regime which has been slow to adapt to new technology.

#### *SpaceX and vertical integration*

As long as the downstream industry remains highly technology intensive and innovative, vertical integration can be expected throughout the space sector including with SpaceX, as seen in both pharmaceutical and tech sectors. Starlink is looking to integrate into the 5G sector, with an existing T-Mobile contract,<sup>331,332</sup> and will likely become further integrated into 5G and IoT applications, after SpaceX announcing its Starshield service which will allow for hosted payloads on Starlink,<sup>333</sup> which has raised alarm at proliferated remote sensing operators concerned about future competition. With IoT and 5G applications, SpaceX may become even more embedded in downstream applications such as the finance sector, which is thought to be a

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<sup>326</sup> “Capabilities & Services”, SpaceX, <https://www.spacex.com/media/Capabilities&Services.pdf>

<sup>327</sup> “Smallsat Rideshare Program”, SpaceX, <https://www.spacex.com/rideshare/>

<sup>328</sup> Lipton, Eric, “Elon Musk Dominates Space Launch. Rivals are Crying Foul”, New York Times, 28 May 2024, <https://www.nytimes.com/2024/05/28/us/politics/elon-musk-space-launch-competition.html>

<sup>329</sup> Bona, Jared, “Does an Exclusive-Dealing Agreement Violate Antitrust Laws?”, Bona Law PC, 29 December 2022 <https://www.theantitrustattorney.com/exclusive-dealing-agreement-violate-antitrust-laws/>

<sup>330</sup> “Space: Commission invites the industry to submit proposals to deploy the new EU secure connectivity satellite constellation, IRIS<sup>2</sup>”, European Commission, 24 March 2023, [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_23\\_1882](https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1882)

<sup>331</sup> “T-Mobile Takes Coverage Above and Beyond With SpaceX”, T-Mobile, 25 Aug 2022 <https://www.t-mobile.com/news/un-carrier/t-mobile-takes-coverage-above-and-beyond-with-spacex>

<sup>332</sup> “T-Mobile Takes Coverage Above and Beyond With SpaceX”, T-Mobile, 25 Aug 2022 <https://www.t-mobile.com/news/un-carrier/t-mobile-takes-coverage-above-and-beyond-with-spacex>

<sup>333</sup> Erwin, Sandra, “With Starshield, SpaceX Readies for Battle”, 19 January 2023, <https://spacenews.com/with-starshield-spacex-readies-for-battle/>

primary beneficiary of low latency satellite internet at long circumglobal distances,<sup>334</sup> as well as near-instantaneous analytics provided by both Earth-based sensors connected by satellite and space-based sensors. One can assume that similar motivations have pushed Jeff Bezos's investment in this sector, as Amazon/Blue have invested in similar streams with different trajectories—Amazon Web Services is already critical to analytics on Earth with a plurality, one-third, of the cloud computing market share,<sup>335</sup> and Project Kuiper's launch strategy initially was dependent on vertical integration with Blue Origin (though it has diversified due to the delay of New Glenn); Blue also shares the Artemis lander award with SpaceX.

Much of the literature on vertical integration and monopolization focuses on a monopoly held over a downstream product without substitutes. At present, in many areas, Starlink has no terrestrial competition, allowing it to alter prices once consumer are locked into expensive equipment (which it initially sold well-below cost to drive subscriptions); while there are technically other satellite providers, the perception of inferior service has allowed SpaceX to capture much of the market.<sup>336,337</sup> However, in examining the likelihood of a space monopoly via vertical integration of SpaceX having a negative impact on pricing and innovation, it is necessary to ask—are the long-term downstream services SpaceX will be providing influenced by the demand for terrestrial offerings? As shown by the fiber optic transatlantic cable investment by AT&T,<sup>338</sup> and its previous desire to invest in satellite communications, then monopolized by Intelsat, simultaneous development of imperfect substitutes can drive innovation even in monopolists. While space-based satcom and remote sensing are often viewed as complementary to terrestrial infrastructure (for instance, SpaceX's T-Mobile contract<sup>339</sup> or the use of satellite remote sensing data to cue drone remote sensing), innovation on the terrestrial

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<sup>334</sup> Osipovich, Alexander, "High-Frequency Traders Eye Satellites for Ultimate Speed Boost", 1 April 2021, <https://www.wsj.com/articles/high-frequency-traders-eye-satellites-for-ultimate-speed-boost-11617289217>

<sup>335</sup> Miller, Ron, "Even as cloud infrastructure market grows, Microsoft continues to gain on Amazon, 6 February 2023, [https://techcrunch.com/2023/02/06/even-as-cloud-infrastructure-market-growth-slows-microsoft-continues-to-gain-on-amazon/?guccounter=1&guce\\_referrer=aHR0cHM6Ly93d3cuZ29vZ2x1LmNvbS8&guce\\_referrer\\_sig=AQAAAdM-vCmyjI8yu8OiJRD0iCTCsx5VTZ3KlwzYkDIbZfshOtmef2x15Vo79h2psqm3miWO67hX78gXjQg14KJybasxL3-TS60MSWSipRJp2PW6B2\\_tLpGuoQg9FzLDy4f4xO0zrtXqunAsT9eTnUlZQGDPtSYZp4YxW\\_Elieol](https://techcrunch.com/2023/02/06/even-as-cloud-infrastructure-market-growth-slows-microsoft-continues-to-gain-on-amazon/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2x1LmNvbS8&guce_referrer_sig=AQAAAdM-vCmyjI8yu8OiJRD0iCTCsx5VTZ3KlwzYkDIbZfshOtmef2x15Vo79h2psqm3miWO67hX78gXjQg14KJybasxL3-TS60MSWSipRJp2PW6B2_tLpGuoQg9FzLDy4f4xO0zrtXqunAsT9eTnUlZQGDPtSYZp4YxW_Elieol)

<sup>336</sup> Brodtkin, Jon, "Starlink to charge users in 'limited capacity' areas \$30 more than others", 22 Feb 2023, <https://arstechnica.com/tech-policy/2023/02/starlink-to-charge-users-in-limited-capacity-areas-30-more-than-others/>

<sup>337</sup> Kan, Michael, SpaceX Has Been Selling Starlink Dishes at a Huge Loss Despite \$499 Price Tag, 6 April 2021 <https://www.pcmag.com/news/spacex-has-been-selling-starlink-dishes-at-a-huge-loss-despite-499-price>

<sup>338</sup> Although not functional until 1988, after AT&T was broken up, Bell Labs began development of fiber optic cables for undersea deployment to compete with satellites in the late 1970s. See: Hecht, Jeff, "City of Light: The Story of Fiber Optics", Oxford University Press, 1999, <http://image.sciencenet.cn/olddata/kexue.com.cn/upload/blog/file/2010/10/201010311703539253.pdf>

<sup>339</sup> "T-Mobile Takes Coverage Above and Beyond With SpaceX", T-Mobile, 25 Aug 2022 <https://www.t-mobile.com/news/un-carrier/t-mobile-takes-coverage-above-and-beyond-with-spacex>

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side that contribute to IoT and advanced analytics may still drive innovation in a monopolistic space market. If SpaceX were split, however, there could be less interest in investing in innovation in segments where they maintained a monopoly.

#### *SpaceX as a transportation monopoly*

As discussed above, the launch market is severely capacity-constrained, with most companies eschewing Russian and Chinese launch vehicles, and Vulcan and Ariane 6 both experiencing delays in first launch, with two years of backlog on Vulcan. Payload notes that 66% of the 134 SpaceX launches in 2024 were Starlink; there were 144 U.S. launches total with an additional 14 U.S./New Zealand small vehicle launches from Rocket Lab.<sup>340</sup> Although 2024 commercial launches were heavily weighted toward SpaceX due to the delay in Vulcan and Ariane 6, Vulcan only anticipates a launch cadence of 20/year in 2025,<sup>341</sup> suggesting SpaceX will still maintain commercial launch market dominance, especially if Starship adds substantial capacity. With SpaceX's vertical integration and capture of the space transportation market, similar to that of Standard Oil and U.S. Steel, it will be able to sell satellite services at far lower costs than competitors while maintaining the ability to charge much higher launch costs for non-SpaceX payloads.

#### *SpaceX as a government supplier*

Regardless of the overall economic interests of innovation at SpaceX across its vertically integrated components, the criticality of its functions to national security cannot be overlooked in determining the impact of government contracting. Quilty Analytics estimates \$3B in revenue for Starlink U.S. government contracts in 2025.<sup>342</sup> SpaceX President Gwynne Shotwell has estimated overall SpaceX government contracts amount to \$22B, \$15B of which are NASA.<sup>343</sup>

There have been accusations of impropriety in government contracting that have favored SpaceX, with nominee for Secretary of the Air Force Troy Meink under scrutiny for writing requirements in a multi-billion dollar NRO contract that were only compatible with SpaceX capabilities,<sup>344</sup> and an effort to transfer a \$2.4B contract supporting FAA air traffic control from Verizon to SpaceX.<sup>345</sup> Even for contracts which are properly competed, new entrants as well as

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<sup>340</sup> Kuhr, Jack, "Estimating SpaceX's 2024 Revenue", Payload Space, 29 Jan 2025  
<https://payloadspace.com/estimating-spacexs-2024-revenue/>

<sup>341</sup> Jewett, Rachel, "ULA Prepares for Second Vulcan Launch and Ramps Up for 2025", Via Satellite, 2 Oct 2024 <https://www.satellitetoday.com/launch/2024/10/02/ula-prepares-for-second-vulcan-launch-and-ramps-up-for-2025/>

<sup>342</sup> Erwin, Sandra, "Starlink set to hit \$11.8 billion revenue in 2025, boosted by military contracts" Space News, 16 Dec 2024 <https://spacenews.com/starlink-set-to-hit-11-8-billion-revenue-in-2025-boosted-by-military-contracts/>

<sup>343</sup> "Elon Musk's US Department of Defense Contracts", Reuters, 11 Feb 2025,  
<https://www.reuters.com/world/us/elon-musks-us-department-defense-contracts-2025-02-11/>

<sup>344</sup> Irwin, Sandra, "Two Senators Question Air Force Nominee's SpaceX Connections", 28 Feb 2025,  
<https://spacenews.com/two-senators-question-air-force-nominees-spacex-connections/>

<sup>345</sup> Duncan, Ian, et al., "FAA targeting Verizon contract in favor of Musk's Starlink, sources say", Washington Post, 26 Feb 2025, <https://www.washingtonpost.com/business/2025/02/26/musk-starlink-doge-faa-verizon/>

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old entrants without access to nearly unlimited capital have found substantial barriers to competing; reporter Eric Berger found that the source selection for a US deorbit vehicle for the International Space Station could only drum up one other competitor (Northrop Grumman), who didn't even come close to SpaceX in qualifications for price, mission suitability, and past performance.<sup>346</sup> Boeing has additionally stated, after the Starliner debacle, that it will not be competing for fixed price contracts.<sup>347</sup> This suggests that a focus on anticompetitive behavior by SpaceX alone will not fix competition for USG contracts.

## CONCLUSION AND RECOMMENDATIONS

In the above analysis of historical monopolies in U.S. resource, infrastructure, IT, and defense sectors, we note that companies can establish monopolies legally, through a combination of innovation, patents, hard-to-prove predatory pricing, incompatibility of technology, bundling of services, and vertical integration. A monopoly by itself does not preclude innovation or guarantee disadvantageous consumer prices, particularly if production is capacity-constrained, if imperfect substitutes exist as external competition, or if large overhead costs for innovation prevent the entry of cost-effective substitutes.

SpaceX is in an early stage of monopolizing the space sector through vertical integration, and has utilized a combination of innovation, likely predatory pricing, financing, and geopolitical circumstances to its advantage. Today, SpaceX is capacity-constrained on both launch and satcom services, which allows for the participation of other companies in the market, but with the additional capacity of Starship and increased launch cadence of Starlink plus other customers, many of these other companies will likely be priced out of the launch and satcom sectors. Although SpaceX is likely to face long-term downstream incentives from complementary services to innovate across its functional subsidiaries with regard to its IoT and analytics aspirations, it has already begun to react to steer pricing of its upstream products to be more aligned with its competitors or trap existing users in higher-priced contracts. These price hikes may be partly mitigated by subsidized international competition, though likely not in full for U.S. government customers where U.S. is the flag of choice. SpaceX, while likely motivated to keep innovating, should also be considered an unstable supplier due to the unreliable behavior of its CEO.

In order to determine whether pricing, innovation, and reliability of services to the U.S. government are impacted by SpaceX's growing hold on the U.S. government, the U.S. government should track key economic indicators in the space sector and encourage new entrants to the sector that have on-roads to developing technology for highly complex contracts, particularly as the DoD can override Department of Justice antitrust concerns.

As such, we recommend that the U.S. government take the following actions:

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<sup>346</sup> Berger, Eric, "SpaceX just stomped the competition for a new contract-- that's not great", Ars Technica, 23 July 2024, <https://arstechnica.com/space/2024/07/spacex-just-stomped-the-competition-for-a-new-contract-thats-not-great/>

<sup>347</sup> Koenig, David, "NASA decision against using a Boeing capsule to bring astronauts back adds to company's problems", 24 Aug 2024, <https://apnews.com/article/boeing-starliner-space-defense-business-nasa-8e5f6414629efcc0a78d43fb9c778333#:~:text=%E2%80%9CWe%20have%20a%20couple%20of,%E2%80%9CNever%20do%20them%20again.%E2%80%9D>

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## Monitor Economic Indicators:

1. The U.S. government should track global launch prices and contracts, to determine changes in prices, launch provider selection, and impact of launch timing on the industry.

While launch providers are capacity-constrained, SpaceX has an incentive to price comparably to other launch providers. However, when competition switches from Cournot (capacity-driven) to Bertrand (price-driven), SpaceX will have an incentive to implement predatory pricing to drive out competition, as seen in resource monopolies at the turn of the 20<sup>th</sup> century and recent tech company tactics such as those used by Amazon and Uber. If Starship begins a cadence of successful orbital launches, this is likely to be triggered quickly.

Additional study of secondary payloads may help elucidate the dependence of launch timing and pricing on selection of launch provider. Secondary payloads are at the will of the schedule of the primary payload, and may become involuntarily very delayed. There may be substantial incentive for more predictable launch windows (as also demonstrated by the procurement of small launch vehicles), but also due to potential failures of hardware with integration delays; engineers in private conversations have expressed that the loss of recent lunar secondary payloads may have been due to the payloads sitting for a year plus in the conditions at Cape Canaveral while waiting to launch.

Although SpaceX is currently the largest international launch provider, increasing global anti-U.S. sentiment may drive non-U.S. customers to other vehicles.

2. The U.S. government should conduct a study on the prices of space acquisitions and how those have evolved through mergers and sole-source vs. competed contracts, to determine the impact of space merger activity and monopoly activity on pricing.

The shift in the 1990s toward DoD-review of defense mergers has led to major consolidation, with five major defense primes. A 2010 analysis on pricing of those primes post-merger does not clearly elucidate a cost impact of those mergers for the space sector, but the author noted the data was incomplete. Although SpaceX is not one of those primes and in fact had to overcome a ULA monopoly on launch, they have become the sole bidder or one of only a handful of bidders, usually by far the lowest price, on numerous NASA and DoD contracts. Although the overall costs of space technologies drop over time, it may be illustrative to perform a space acquisitions study looking at sole-source vs. competed contracts and impacts of mergers on pricing, particularly by doing econometric analyses of functional shocks to acquisitions.

3. The U.S. government should be aware of incentives to collude on prices or underinvest in the provision of space infrastructure projects

As long as launch and satcom are capacity-constrained, providers have an incentive to collude on prices, similar to railroads in the 1800s. Contracts which are awarded to the

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lowest cost bidder are likely to incentivize underinvestment in long-lasting infrastructure, similar to privatized electric and water utilities. Although some government acquisitions programs are moving from lowest cost contracts to contracts that also evaluate past performance, it can be difficult to evaluate performance metrics for innovative technologies (as seen in NASA's Commercial Lunar Payload Services contracting). Projects may wish to establish short-term milestones, which if not met, can trigger a recompetes of contracts.

### **Ensure Competition:**

4. The U.S. government should continue to compete multi-source contracts for high-cost space technologies. The U.S. government should also continue investing in smaller contracts that could serve as a bridge to the creation of high-cost space technologies.

Given historical predatory pricing followed by market takeover and price-gouging from historical monopolies in resources and tech sectors, as well as the reliance of U.S. national security on access to space technologies, the U.S. government should continue its efforts to compete multi-source contracts for high-cost space technologies, and invest in smaller contracts that could enable technology development at smaller companies which could then compete at larger scales. This report concurs with the DoD's 2022 *State of Competition within the Defense Industrial Base*, which recommends increasing new entrants and reducing barriers to entry, and increasing small business opportunities.

5. The U.S. should reduce bundling where possible to enable new entrants, and work toward standards development to enable smaller-scale contracts that are interoperable with other technologies.

Numerous monopolies, including U.S. Steel, Alcoa, AT&T, IBM, Apple, and Amazon have vertically integrated to control the supply chain and minimize overhead costs. While vertical integration does not in itself negatively distort innovation when downstream products are technologically intensive, forced bundling can prevent entrants at all levels of the supply chain. Bell, Xerox, IBM, Microsoft, and Apple all bundled services or made services incompatible with competitors to ensure a monopoly. The space sector is full of incompatible technologies, with proprietary satcom receivers, to space infrastructure with proprietary docking or other integration equipment. Standards should be pursued to the extent possible to ensure plug and play systems enabling smaller contracts. The 3<sup>rd</sup> Generation Partnership Project (3GPP) is already assisting in ensuring satcom is compatible with 5G cellular services, but other consortia such as the Lunar Operating Guidelines for Infrastructure Consortium (LOGIC) and the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) will be critical to enabling competition and interoperability.

6. The U.S. government may wish to leverage existing technology partnerships with non-traditional space industry players to drive down the pricing of downstream space services/analytics.

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Companies such as Standard Oil, U.S. Steel, AT&T, and Xerox showed a failure to innovate once a monopoly was established. However, competition from imperfect substitutes, such as Alcoa's desire to compete with steel and AT&T/Bell's eventual desire to compete with satcom, led to further innovation in those sectors. The government should leverage existing technology partnerships with non-traditional space companies to increase competition in space-based services and analytics.

**Enforce antitrust laws in the defense sector where practicable:**

7. The U.S. government should establish triggers for action against anticompetitive behavior in the space industry, whether that be the capture of a certain percentage of market share in certain sectors, consolidation/market failure in certain sectors, or pricing, and outline in advance strategies with which to ensure a diverse and resilient space architecture (e.g., contracts, direct investment, antitrust action).

Given the DoD's propensity to allow for mergers that would otherwise be blocked as anticompetitive, it is in the government's interest to more closely monitor anticompetitive behavior and pricing, and to develop potential policy or programmatic actions when these anticompetitive behavior indicators are triggered. Given the timeline to develop space technologies is often years, waiting until contract bids have one competitive applicant is too late to ensure the resiliency of the U.S. space architecture. Exemptions for anticompetitive behavior may still be necessary for national security interests, but a range of options including early warning triggers for the diversification of contracting or subcontracting should be included to ensure multiple competitors for space services.

We expect that the implementation of these recommendations will be an interagency effort, and should be coordinated across the National Space Council with support of the FCC, FTC, and DOJ.

The DoD should work with the FTC and DoJ to determine what anticompetitive indicators should be monitored after exempting monopolistic mergers for national security interests. The DoD should additionally work closely with NASA to track launch prices and disentangle specific program requirements from base-level government launch pricing. DoD and the FCC (particularly in its provision of rural broadband) may benefit from comparing satcom pricing and service quality.

The U.S. government has pursued a number of recent investment mechanisms which deviate from traditional contracting; programs DARPA, AFWERKS, IN-Q-TEL, DIU, and NASA programs such as CLPS should collectively identify sole-source vulnerabilities in space infrastructure and develop smaller contracting mechanisms to enable new competitors. They should also monitor the success of such programs in creating stable markets at all infrastructure levels, from subcomponent to launch vehicle or satellite. We anticipate that the development of additional space standards will be critical to increasing competition, and will require coordination between the Department of Commerce and its National Institute of Standards and Technology and acquisitions organizations, as well as standards bodies such as the International Standards Organizations, American Institute of Aeronautics and Astronautics, 3GPP, LOGIC, and CONFERS.

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We expect an increasing push for independent space capabilities from Europe, as well as strong subsidies from China, the UAE, and Saudi Arabia for new space technologies; it would be wise for the Department of Commerce to monitor the impact of these new entrants on the global market to determine impact to the U.S. space sector.

In order to support the recommendations above, we suggest the following future studies:

- Expansion of the work of Kim (2025) to include pricing for DoD as well as the commercial sector, and the inclusion of additional variables which are used to set launch prices
- A comparable launch pricing study for secondary payloads
- A comparable satcom services pricing study
- Difference-in-difference economic analyses of major policy or technological changes to the space sector (e.g., changes in contracting policy, commercial launches of Starship, etc.)
- A space industry wide supply chain vulnerability follow-on to the existing DoD National Defense Industrial Strategy Implementation Plan, which targets sole-source space industry vulnerabilities
- A determination of quantitative economic indicators that may trigger further oversight for space monopolies

## 4. Non-Interference of Lunar Activities

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### Executive Summary

As dozens of countries and private sector companies have expressed interest in establishing lunar operations by the end of the decade, including many in the South Pole region, it will be critical to determine how to minimize interference in lunar activities. Today, cislunar collision avoidance requires extensive international coordination, while crash landings and fuel leaks have permanently altered the lunar surface. As the density of cislunar actors increases, it will be vital to understand how lunar missions may temporarily or permanently impact other actors from both operational and scientific perspectives.

Although lunar interference concerns have been broadly identified, and deconfliction has been identified as an area of further work in Section 11 of the Artemis Accords, there is not broad consensus in the lunar scientific or technical community on key questions such as standards and best practices for non-interference or mechanisms for mitigation. This paper sought feedback from the scientific and technical community to determine the breadth of interference concerns, with feedback from roughly 50 international participants. We used this feedback, as well as consultations with NASA subject matter experts, to determine where technical guidelines or requirements exist which may help mitigate interference, either through coordination during mission development or during concurrent lunar operations. We also determined where existing data, measurements, models exist that can inform additional guidelines, and gaps in this data.

The interference concerns received fell into five primary categories: physical, thermal or optical disturbance, EMI/RFI, contamination (biological, chemical, mechanical), seismic/vibration from movement. In each of these categories, participants highlighted the spatiotemporal nature of these concerns (geographic of interference range, if known, and temporary or permanent nature of interference).

Physical interference included concerns both in cislunar orbit and on the lunar surface. The potential for cislunar conjunctions or occupation of highly desired orbits, as well as potential ejecta getting kicked up into cislunar space were of concern. On the surface, plume surface interactions or general movement of dust/soil were of great concern, with little current modeling information or in situ data, and impacts reaching tens of kilometers if not into cislunar space. There was additional concern about operations blocking solar power or comms, or active physical contact, including due to uncertainty of position.

Thermal and optical disturbances were also cited as an issue for both operational and scientific interference. Concerns included heating dissipating volatiles, reflection of sunlight onto another element or permanently shadowed region, glint for subsequent missions, and alteration of the thermal environment from shadowing.

RFI and EMI were of greatest concern to the astronomical community, with RFI from satellites, RFI/EMI from unshielded electronics, and energy deposited into surface dust increasing charged particles in lunar plasma causing charged particle-antenna interactions cited.

Contamination, and the existence of minimal protocols beyond planetary protection guidelines, was of high concern, including disposal of biological, mechanical, and radioactive waste materials, unplanned disposal of materials, astrobiological contamination, contamination

of cold traps from exhaust, exospheric contamination, and topographic changes impacting lunar processes.

Seismic/vibration concerns were also highlighted, particularly with regard to impact on gravitational wave astronomy and seismic stations.

Existing technical and standards work largely focuses on RFI/EMI, orbital debris mitigation, and planetary protection. COSPAR standards provide guidance for RFI/EMI, ITU and U.S. military standards provide guidance for RFI/EMI, and NASA's Orbital Debris Assessment Report provides both guidance for debris mitigation and basic spacecraft descriptions that may be useful in helping mitigate interference. The Artemis Accords signatories have also agreed to provide basic parameters during spacecraft registration at the United Nations. After consultation with subject matter experts, we note the following substantial gaps in mission development information-sharing best practices: temporal element of activities, knowledge of soil disturbance, size/mass/temporal locations of objects, anticipated landing accuracy with enough detail to be useful in deconfliction, models of heat dissipation, information about optical/thermal reflectivity of objects, planned frequency use (combined with all other lunar registration information, not only at the ITU), applicable EMI/RFI standards used, location of hazardous/organic materials and disposal plans, extended capability plans and availability of assets for reuse, mitigating impacts for surface disposal, information about overflight of potential scientific sites, details on rocket design, list of devices that might cause vibrational impact.

Finally, we look at existing measurements and models of interference, and gaps in this data. For cislunar conjunctions, while JPL MADCAP coordinates cislunar collision avoidance, there is no formal international consultative mechanism, tracking is difficult for inactive objects, and highly desired orbits are likely to increase congestion. Although some plume surface interaction models and in-situ data exist, very little is known about overall impact of terrain or engine size, or different sizes of materials. For heating of volatiles, although several models exist, the impact of heating varies highly on type/location/duration of mission. Several studies on the impact of electrostatic charge in permanently shadowed regions have shown the electrostatic hazard from rovers and astronauts moving is non-negligible, but the understanding of the change in charge due to operations and due to natural conditions is not well-understood. For contamination, NASA is working to model different types of contaminants and their longevity/migration on the lunar surface, and is working to expand molecular contamination understanding and develop a comprehensive organic inventory strategy and framework that included more sources than just outgassing. Topographic changes are not well-understood, and minimal data exists for seismic/vibrational impacts.

International prioritization of information-sharing and gathering of better data is needed short-term to avoid lunar interference, and eventually enable standards development for sustained lunar operations. Of most immediate concern on the lunar surface are the impacts of plume surface interactions on lunar infrastructure. Lunar missions should prioritize the inclusion of payloads that monitor PSIs, and this data should be taken into account in bilateral coordination.

Substantial concern from the international scientific community has been raised regarding better coordination on disposal of hazardous materials, and the prioritization of technical experiments at locations which do not disturb sites of high scientific value. This prioritization is likely to happen at the level of national space agencies, as there is no current international legal precedent for coordination, however bilateral coordination is encouraged where possible to align operational and scientific interests in lunar development.

While we acknowledge that operational coordination is most likely to occur on a bilateral level in real-time, it is critical to share technical information and best practices/lessons learned in forums such as the Artemis Accords, within the COPUOS Action Team on Lunar Activities Consultation, in GEGSLA, , and in other existing standards bodies.

## Introduction

The U.S., Russia, China, India, and Japan have all landed robotic missions on the lunar surface, while South Korea, Pakistan, and Italy have launched spacecraft orbiting the Moon.<sup>348</sup> International interest in lunar missions is booming, with fifty-two Artemis Accords signatories as of the end of 2024,<sup>349</sup> while thirteen nations have joined the China and Russia-led International Lunar Research Station (ILRS), with Thailand as a joint signatory of both ventures. Commercial lunar interest is also growing, with two Commercial Lunar Payload Services (CLPS) launches in 2024, one in 2025, and eight upcoming CLPS missions under contract,<sup>350</sup> plus work underway at SpaceX and Blue Origin for Artemis crew and cargo vehicles<sup>351</sup> and three lunar terrain vehicle phase one awards under contract.<sup>352</sup>

Despite the low number of lunar missions to date, there is pressing need for lunar coordination. In an eighteen-month period from 2023-2024, the Korean Aerospace Research Institute (KARI) noted it had received 40 “red alarms” for potential collisions between its Korea Pathfinder Lunar Orbiter, NASA’s Lunar Reconnaissance Orbiter, and India’s Chandrayaan-2.<sup>353</sup> Astrobotic’s Peregrine-1 suffered a fuel leak and was faced with a question of uncontrolled disposal on the lunar surface or disposal through Earth atmospheric reentry; via (unrequired) consultation with NASA it chose the latter. Tardigrades were unknowingly present onboard the failed Beresheet lander as it crashed onto the Moon in 2019, calling into question regulatory coordination and authorization and supervision of novel space activities as they pertain to planetary protection.<sup>354</sup> Intuitive Machine’s first lunar landing site was shifted from its original location, in part due to concern about propellant leaks during overflight of a site of scientific interest. Increasing interest and activity on the lunar south pole has called into question how to select sites for nascent operations vs. preserving sites for future operations or scientific research.<sup>355</sup>

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<sup>348</sup> “List of Missions to the Moon”, Wikipedia, 15 May 2025  
[https://en.wikipedia.org/wiki/List\\_of\\_missions\\_to\\_the\\_Moon](https://en.wikipedia.org/wiki/List_of_missions_to_the_Moon)

<sup>349</sup> “Artemis Accords”, Department of State, 20 Dec 2024, <https://2021-2025.state.gov/artemis-accords/>

<sup>350</sup> “Commercial Lunar Payload Services”, NASA, 15 June 2023,  
<https://www.nasa.gov/reference/commercial-lunar-payload-services/>

<sup>351</sup> O’Shea, C. “NASA Selects Blue Origin as Second Artemis Lunar Lander”, NASA, 19 May 2023,  
<https://www.nasa.gov/news-release/nasa-selects-blue-origin-as-second-artemis-lunar-lander-provider/>

<sup>352</sup> Donaldson, A. “NASA Selects Companies to Advance Moon Mobility for Artemis Missions”, NASA, 3 April 2024, <https://www.nasa.gov/news-release/nasa-selects-companies-to-advance-moon-mobility-for-artemis-missions/>

<sup>353</sup> Foust, J. “Lunar Spacecraft Receive Dozens of Collision Warnings”, SpaceNews, 11 July 2024  
<https://spacenews.com/lunar-spacecraft-receive-dozens-of-collision-warnings/#:~:text=Since%20KPLO%20entered%20orbit%20around,no%20risk%20of%20a%20collision>

<sup>354</sup> Johnson, C.D., et al., “The curious case of the transgressing tardigrades”, The Space Review, 26 Aug 2019, <https://www.thespacereview.com/article/3783/1>

<sup>355</sup> E.g., “The need for the designation and preservation of Sites of Special Scientific Interest (SSSI) on the Moon”, Conference Room Paper by the Committee on Space Research, the International Academy of

Unlike historic lunar operations which have operated in locations largely isolated from other missions, in order to achieve scientific and operational objectives, future operators will need to share information, consult, and potentially coordinate to mitigate interference for simultaneous and planned missions in proximity to one another, especially in the lunar south pole region. In order to determine what level of coordination could be needed, and what information should be shared, we explore historical and modern uses of the terms “contamination” and “interference”, the extent of contamination and interference concerns, and existing or proposed mitigation mechanisms (both policy and technical).

### *A history of international and U.S. domestic use of “contamination” and “interference”*

#### Interference in Telecommunications

The International Telecommunication Union (ITU) has acted as the primary international venue for regulations, guidelines, and arbitration surrounding radiofrequency allocation and interference, both terrestrially and in space. The international regulatory principle of non-interference in telecommunications can be traced back to the 1903 International Radio Conference, over concern of disturbing wireless stations. The concept of “harmful interference” was introduced at the International Radio Conference of 1947. Interference as defined in today’s ITU radio regulations was defined at the 1979 World Administrative Radio Conference<sup>356,357</sup>:

*1.166 Interference: The effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.*

*1.167 permissible interference: Observed or predicted interference which complies with quantitative interference and sharing criteria contained in these Regulations or in ITU-R Recommendations or in special agreements as provided in these Regulations.*

*1.68 accepted interference: Interference at a higher level than defined as permissible interference and has been agreed upon between two or more administrations without prejudice to other administrations.*

*1.169 harmful interference: Interference which endangers the functioning of a radionavigation service or other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with Radio Regulations (CS)*

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Astronautics, the International Astronomical Union and the Moon Village Association, Committee on the Peaceful Uses of Outer Space, 3 Feb 2025  
[https://www.unoosa.org/res/oosadoc/data/documents/2025/aac\\_105c\\_12025crp/aac\\_105c\\_12025crp\\_18\\_0.html/AC105\\_C1\\_2025\\_CRP18E.pdf](https://www.unoosa.org/res/oosadoc/data/documents/2025/aac_105c_12025crp/aac_105c_12025crp_18_0.html/AC105_C1_2025_CRP18E.pdf)

<sup>356</sup>Tenhula, P.A., and Frank, C.R., “The Untold History of Harmful Interference”, NSMA 38th Annual Conference: Spectrum 2023, [https://www.nsma.org/wp-content/uploads/12.-The-Untold-History-of-Spectrum-Interference\\_Peter-Tenhula.pdf](https://www.nsma.org/wp-content/uploads/12.-The-Untold-History-of-Spectrum-Interference_Peter-Tenhula.pdf)

<sup>357</sup> International Telecommunications Union, Radio Regulations, edition of 2024  
<https://www.itu.int/pub/R-REG-RR>

These interference categories delineate the level of impact to another party and recognize that some level of interference may be permissible either pursuant to regulatory guidance or after appropriate agreement with the affected party. This framework is applicable to radiofrequency interference on the Moon, and may be a useful framework for understanding the impacts of, and responding to, other forms of interference.

#### The Launch of Sputnik: Defining [Harmful] Contamination and Interference in Space

Shortly after the launch of Sputnik, international concern was raised regarding contamination of celestial bodies. On February 8, 1958, the National Academy of Sciences (NAS) of the United States adopted a resolution urging that “scientists plan lunar and planetary studies with great care and deep concern so that initial operations do not compromise and make impossible forever after critical scientific experiments,” citing examples of possible biological or radioactive contamination.<sup>358</sup> Upon the urging of the NAS, the International Council of Scientific Unions established an ad-hoc Committee on Contamination by Extra-terrestrial Exploration (CETEX). CETEX explicitly noted impacts to the Moon’s atmosphere, Moon dust, and biological contamination as potential areas of contamination concern. Contamination by lunar dust was incorrectly deemed to be unproblematic except in the instance of nuclear explosions, and a lack of understanding of the presence of lunar volatiles and water ice led to initial dismissal of impacts to the ability to study lunar geological history or biological contamination. CETEX noted in their recommendations that “there is a real danger that exploration attempts made within the next few years which would complicate or render impossible more detailed studies, when the technological problems of landing sensitive scientific instruments on the moon and planets have been solved,” noting that “an experiment essential for one purpose may make it impossible for other types of studies to be made subsequently (e.g., the explosion of a nuclear device to provide seismic data on the interior of the moon or of the planets might make subsequent radiochemical analysis meaningless)”.<sup>359</sup>

CETEX was formalized in 1958 through the founding of the Committee on Space Research (COSPAR). COSPAR provided contamination recommendations to the U.N. Committee on the Peaceful Uses of Outer Space (COPUOS) in 1964, focused on “upper atmospheric pollution by rocket exhaust and chemical injection experiments,” “belts of orbiting dipoles”, and “contamination of planets” with particular focus on further work regarding space probe sterilization.<sup>360</sup> The upper atmospheric group split impacts into four categories, noting an emphasis on long-term impact in their discussion of severity:<sup>361</sup>

- (a) A harmless, short-term and localized alteration of the upper atmosphere that can be readily observed at the ground;
- (b) A long-term and world-wide alteration of the observable characteristics of the upper atmosphere, but one which causes no identifiable interference or harmful effect;

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<sup>358</sup> *Science*, “News of Science: Development of International Efforts to Avoid Contamination of Extraterrestrial Bodies”, 17 October 1958, pp. 887-889.

<sup>359</sup> *Id.*

<sup>360</sup> *Id.*

<sup>361</sup> A/5785, Report of the Committee on the Peaceful Uses of Outer Space, 1964

- (c) An extensive alteration of the upper atmosphere that interferes with scientific experiments or other human activities
- (d) An atmospheric alteration that affects man's environment.

The discussion of the meaning of contamination continued through the drafting and negotiation of the Outer Space Treaty (OST). According to Gabrynowicz and Langston in "A Chronological Development of Article IX of the Outer Space Treaty"<sup>362</sup>, the inclusion of "harmful contamination" was widely understood by negotiators to be concerned about biological contamination (as well as nuclear weapons per Article IV), while the provisions related to "harmful interference" and consultation were developed based on a U.S.S.R. proposal designed to address U.S.S.R. concerns with U.S. Project West Ford, an experiment that put 480 million dipoles 0.7 inches in length in Medium Earth Orbit.<sup>363</sup> The U.S.S.R. sought to make advanced international coordination for all space missions mandatory, but the United States was concerned that such required coordination could result in a veto. The full text of Article IX reads:<sup>364</sup>

In the exploration and use of outer space, including the Moon and other celestial bodies, States Parties to the Treaty shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty. States Parties to the Treaty shall pursue studies of outer space, including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose. If a State Party to the Treaty has reason to believe that an activity or experiment planned by it or its nationals in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities of other States Parties in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, it shall undertake appropriate international consultations before proceeding with any such activity or experiment. A State Party to the Treaty which has reason to believe that an activity or experiment planned by another State Party in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, may request consultation concerning the activity or experiment

Since the entry into force of the Outer Space Treaty, COSPAR has continued to provide guidance on planetary protection and avoidance of "harmful contamination". Harmful

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<sup>362</sup> Gabrynowicz, J.I. and Langston, S.M., A Chronological Development of Article IX of the Outer Space Treaty, The University of Mississippi School of Law, Special Topics in Aerospace Law Series no. 3, 2010 <https://airandspace.law.olemiss.edu/pdfs/article-ix.pdf>

<sup>363</sup> "Project West Ford," *Harvard Crimson*, 24 May 1963, <https://dev.thecrimson.com/article/1963/5/24/project-west-ford-pfour-hundred-million/>

<sup>364</sup> Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), U.S., U.K., U.S.S.R., January 27, 1967, art. i, 18 U.S.T. 2410, <https://www.unoosa.org>

interference is not explicitly defined in Article IX, and is open to interpretation by the consultative parties.

Presidential Directive/National Security Council Directive-37, *National Space Policy* (1978), provides further domestic guidance on “interference,” noting that “[t]he space systems of any nation are national property and have the right of passage through and operations in space without interference. Purposeful interference with operational space systems shall be viewed as an infringement upon sovereign rights.”<sup>365</sup> This guidance has consistently remained in subsequent U.S. National Space Policies.

### Recent interest in contamination and interference

The 2011 “NASA’s Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts” provides guidance regarding the protection and preservation of lunar sites, noting that many Apollo sites are still active science sites. The recommendations define contamination as “the act of depositing chemical, biological or physical material onto artifacts at the heritage site such that the deposition reduces its historical, engineering, or scientific value. Contamination can take on several forms, including surface particulate, non-volatile residue, volatile hydrocarbons, and microbial”.<sup>366</sup> The recommendations specifically address physical contact, dust, un-burned/residual propellants, planetary protection, and residual biological contamination from past missions. It recommended a 2.0 km exclusion radius for heritage lander sites and 0.5 km exclusion radius for heritage impact sites to minimize the possibility of plume impingement and propellant deposition during overflight, exhaust-blown dust during near-overflight, or system failure. It additionally recommended the use of “natural lunar terrain barriers such as hills, crater rims, ridges, or terrain slopes to block spray of the landing spacecraft”.<sup>367</sup>

NASA, with particular mindfulness to the increase in lunar missions, updated its contamination guidance in Standard 8719.27 in 2022<sup>368,369</sup>, differentiating between contamination and harmful contamination as shown in Figure 1: Contamination vs. harmful contamination in NASA Standard 8719.27 (\* denotes definition in STD), courtesy of NASA Office of Planetary Protection, Office of Safety and Mission Assurance. Notably, harmful contamination, according to NASA Standard 8719.27, damages the integrity of the study of chemical evolution and the origin of life at another solar system body and focuses on biological/molecular contamination,

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<sup>365</sup> “Interim Agreement Between the United States and the Union of Soviet Socialist Republics on Certain Measures With Respect to the Limitation of Offensive Arms”, 3 Oct 1972, <https://2009-2017.state.gov/t/isn/4795.htm>

<sup>366</sup> NASA’s Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts, NASA, 20 July 2011, [https://www.nasa.gov/wp-content/uploads/2017/10/617743main\\_nasa-usg\\_lunar\\_historic\\_sites\\_reva-508.pdf?emrc=44e0c8](https://www.nasa.gov/wp-content/uploads/2017/10/617743main_nasa-usg_lunar_historic_sites_reva-508.pdf?emrc=44e0c8)

<sup>367</sup> Carter, Jimmy. PD/NSC-37. “National Space Policy.” Jimmy Carter Library and Museum. 22 May 1978. <http://www.jimmycarterlibrary.org/documents/pddirectives/pd37.pdf>

<sup>368</sup> NASA’s Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts, NASA, 20 July 2011, [https://www.nasa.gov/wp-content/uploads/2017/10/617743main\\_nasa-usg\\_lunar\\_historic\\_sites\\_reva-508.pdf?emrc=44e0c8](https://www.nasa.gov/wp-content/uploads/2017/10/617743main_nasa-usg_lunar_historic_sites_reva-508.pdf?emrc=44e0c8)

<sup>369</sup> Seasly, E. and Benardini, J.N. “NASA Planetary Protection: Technical Oversight in Practice”, NASEM CoPP Space Sciences Week 2024, 20 March 2024 <https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE3053A6A9B/file/D4100FD76735A49F83FD70E04D0AA5B3F34917FCB537?noSaveAs=1>

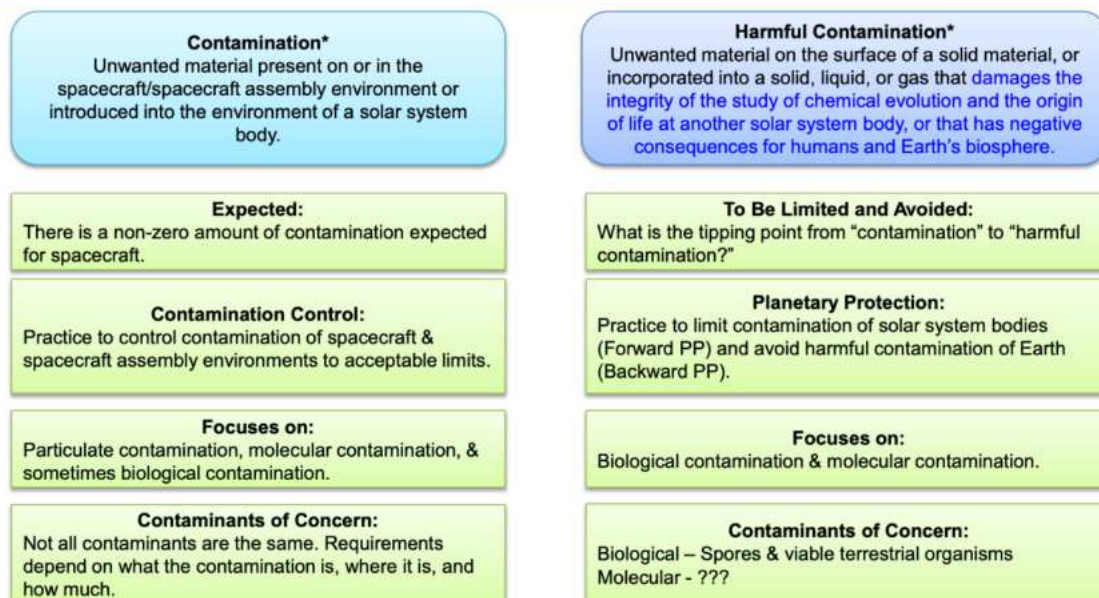
while contamination is unwanted material on the spacecraft or introduced to the environment of a solar system body, and may also include particulate contamination.

While there is no authoritative definition of “harmful interference” as that term is used in the Outer Space Treaty, Section 11 of the Artemis Accords details the notification and coordination measures to which Accords signatories have committed to avoid harmful interference, stating “[t]he area wherein this notification and coordination will be implemented to avoid harmful interference is referred to as a ‘safety zone’ . A safety zone should be the area in which nominal operations of a relevant activity or an anomalous event could reasonably cause harmful interference.”<sup>370</sup> Section 11 notes the size and scope of safety zones is dependent on activity, and should change over time to reflect the nature of operations.

### *Non-governmental interest in interference and contamination*

In addition to international law and governmental policies related to interference and contamination, several non-governmental groups have outlined interest in further work to mitigate impact of lunar interference and contamination.

A 2010 International Academy of Astronautics Cosmic Study, *Protecting the Environment of Celestial Bodies*, looked to go beyond planetary protection to the geophysical, industrial, and cultural realms, finding present space environment protection mechanisms insufficient. In particular, they note threat to geomorphological features from space exploration, increased use of lunar and planetary orbits, and cultural and historic sites as major gaps for lunar policy.<sup>371</sup>



<sup>370</sup> NASA Standard 8719.27, “Implementing Planetary Protection Requirements For Space Flight”, <https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/0/NASA-STD-871927-Baseline.pdf>

<sup>371</sup> “The Artemis Accords: Principles for Cooperation in the Civil Exploration and Use of the Moon, Mars, Comets, and Asteroids For Peaceful Purposes.” 13 Oct 2020 <https://www.nasa.gov/wp-content/uploads/2022/11/Artemis-Accords-signed-13Oct2020.pdf>

Figure 1: Contamination vs. harmful contamination in NASA Standard 8719.27 (\* denotes definition in STD), courtesy of NASA Office of Planetary Protection, Office of Safety and Mission Assurance

The Lunar Exploration Analysis Group, established in 2004 by NASA to bring together academia, industry, government, and the commercial sector to discuss lunar scientific, technical, commercial, and operational issues, developed a 2016 Lunar Exploration Roadmap. This roadmap outlines scientific and technical priorities for lunar exploration. It in particular outlines the need to measure certain scientific characteristics such as the lunar exosphere before extensive contamination by lunar activity, and notes that dust will have an immediate impact on lunar surface activities. It notes that site selection may not always be optimal to meet both scientific and exploration objectives, suggesting these parties “may have differing objectives for its collaborative use suggesting both a need for balanced negotiations and the best obtainable data from the candidate locations,” and suggests that in addition to getting feedback from across the lunar stakeholder community, operational considerations may drive site selection.<sup>372</sup>

In 2020, the Moon Village Association established the Global Expert Group on Sustainable Lunar Activities (GEGSLA), including representatives from academia, industry, government, and non-governmental organizations. They released a reference framework in 2022, which defined “harmful interference” as “the result of any activity with a significant adverse effect on the lunar activity of other actors, which prevents them from carrying out their legitimate lunar activities or gaining access to an area.” They additionally note that “lunar stakeholders should adopt appropriate measures to avoid harmful contamination to the environment of the Moon or adverse changes in the environment of Earth resulting from the introduction of extraterrestrial matter,” including “a) Internationally agreed planetary protection policies, b) Adverse changes to designated and internationally endorsed lunar natural or cultural heritage sites, c) Adverse changes to designated and internationally endorsed lunar sites of scientific, commercial or another interest.”<sup>373</sup> In their 2024 report to the COPUOS Scientific and Technical Subcommittee, the Moon Village Association noted that GEGSLA working group 1 seeks to offer clarification of “harmful contamination... and consider the extent to which this concept needs to be developed to include other forms of harmful interference,” and “assess aspects and locations of the lunar environment which merit protection from harmful contamination and other interference in order to preserve scientific, cultural and/or aesthetic value”, in addition to making recommendations to protect these environments. They note that interpretations of Article IX generally include planetary protection but do not explicitly include physical, chemical, and radiological contamination.<sup>374</sup>

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<sup>372</sup> *Protecting the Environment of Celestial Bodies*, International Academy of Astronautics Cosmic Study, 2010, <https://iaaspace.org/wp-content/uploads/iaa/Scientific%20Activity/Study%20Groups/SG%20Commission%205/sg56/sg56finaldraftreport.pdf>

<sup>373</sup> “The Lunar Exploration Roadmap: Exploring the Moon in the 21st Century: Themes, Goals, Objectives, Investigations, and Priorities, 2016.” Lunar Exploration Analysis Group. 2016. <https://www.lpi.usra.edu/leag/LER-2016.pdf>

<sup>374</sup> “Recommended Framework and Key Elements for Peaceful and Sustainable Lunar Activities”, GEGSLA, 2022. <https://moonvillageassociation.org/download/recommended-framework-and-key-elements-for-peaceful-and-sustainable-lunar-activities/>

In February 2025, COPUOS formally created an Action Team on Lunar Activities Coordination, which is expected to take up further work in this domain.<sup>375</sup>

## Methods

In order to receive public feedback on the scope of interference and contamination concerns, and potential mitigation measures, OTPS developed a questionnaire on lunar interference and contamination concerns, understanding site value, and mitigation mechanisms (full questionnaire in Appendix A). OTPS held two breakout sessions at the April 2024 Lunar Surface Innovation Consortium meeting in Laurel, MD, to get feedback from in-person and virtual participants on the questionnaire. The Lunar Surface Innovation Consortium is led by NASA’s Space Technology Mission Directorate and Johns Hopkins Applied Physics Laboratory and brings together lunar stakeholders across academia, industry, and government. Participants were asked to break out into groups and determine their definitions of interference and contamination, ways they measured site value, and potential impacts to site value.

OTPS simultaneously released the questionnaire publicly on the NASA website, social media, and relevant list-servs. Input was received from roughly 50 individuals or organizations between the workshop and questionnaire, representing both scientific and technical interests, including academia and industry. Responses to each question were qualitatively analyzed using an open coding model, which thematically grouped responses as they were digested. We selected a qualitative survey due to the lack of existing data on the definition of interference or its extent, with the intent of repeating the survey as a “user needs” survey, similar to other NASA user needs surveys (e.g., for the long-running Landsat program), on a roughly annual basis to determine the evolution of the needs of the sector and gauge the accuracy of previous results.

Participants in the workshop and on the survey were largely U.S.-centric, representing dozens of academic institutions, non-profits, and government agencies, though several international organizations responded. In order to get a more international perspective, we presented initial results to Artemis Accords signatories and received feedback via a draft discussion paper, as well as presented the results at the International Astronautical Congress in 2024, with the intent of holding a follow-on workshop at IAC 2025 to ensure comprehensive guidelines applicable to all lunar actors.

## Survey Results

Respondents largely focused on potential impacts to mission in their discussion of interference, and the alteration of materials or the environment in their discussions of contamination. Many noted that interference could be intentional or unintentional, permanent or temporary. For the purposes of the analysis below, we consider the amalgamated definition of interference from the questionnaire to be an activity that may impact the ability of another actor to carry out a mission or objective. We include contamination as a type of interference in this analysis, and adopt the NASA STD 8719.27 definition of contamination— “Unwanted material present on or in the spacecraft/spacecraft assembly environment introduced into the environment

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<sup>375</sup> “Action Team on Lunar Activities Coordination”, U.N. Office of Outer Space Affairs, 15 May 2025, <https://www.unoosa.org/oosa/en/ourwork/copuos/atlac/index.html>

of a solar system body” to aid in the categorization of responses. However, we note that there were a wide variety of definitions received from the questionnaire, which included non-physical materials/resources (e.g., RFI, orbits), the alteration from a natural or pristine state, and the alteration of safety or economic value.

### *Interference concerns*

Table 7 (summary) and Table 8 (full version, appendix) delineate respondents’ interference concerns. We break up their concerns into operational phases: orbital; entry, descent, and landing/ascent; static surface operations, and dynamic surface operations, and highlight by color which types of interference were flagged as scientific and/or operational concerns. In Table 9, we break up these interference concerns into scientific vs. operational concerns, and their spatiotemporal extent. While we do not define the delineation between short and long-term, or hyperlocal vs. regional, we hope further work will help refine the extent of these concerns.

Table 7: Summary of respondent interference concerns

| Interference Concern        | Examples                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical                    | <ul style="list-style-type: none"> <li>• Cislunar Conjunctions</li> <li>• Occupation of highly desired orbits</li> <li>• Movement and compression of lunar soil, dust</li> <li>• Ejection of debris into cislunar space</li> <li>• Operations blocking desired path/location</li> <li>• Operations blocking solar power or comms</li> <li>• Threat of active physical contact, including due to uncertainty of positioning</li> </ul> |
| Thermal/optical disturbance | <ul style="list-style-type: none"> <li>• Heating resulting in dissipation of volatiles</li> <li>• Reflection of sunlight into another element or PSRs</li> <li>• Glint for cameras on subsequent missions</li> <li>• Alteration of thermal environment from shadowing</li> </ul>                                                                                                                                                      |
| EMI/RFI                     | <ul style="list-style-type: none"> <li>• RFI from satellites</li> <li>• RFI/EMI at astronomical sites including from unshielded electronics (ion propulsion engines flagged)</li> <li>• Energy deposited into surface dust increasing charged particles in lunar plasma causing charged particle-antenna interactions</li> </ul>                                                                                                      |

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                         |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Contamination      | <ul style="list-style-type: none"> <li>• Improper disposal of hazardous materials</li> <li>• Unplanned disposal of materials</li> <li>• Biological/mechanical waste</li> <li>• Astrobiological contamination</li> <li>• Topographic changes impacting processes (e.g., water transport, particle flow, temperatures)</li> <li>• Contamination of cold traps from exhaust</li> <li>• Exospheric contamination</li> </ul> |
| Seismic/ Vibration | <ul style="list-style-type: none"> <li>• Seismic/vibrational impacts to experiments (e.g., gravitational wave astronomy)</li> <li>• Solar panels in proximity to seismic station</li> </ul>                                                                                                                                                                                                                             |

### Physical contact

Plume surface interactions and movement of dust were highly cited as both scientific and operational concerns, from coating solar panels/scientific instruments/habitats, to impacting geological samples. Movement or compression of lunar soil was also identified as a concern for operations and for geological sampling. The movement of soil and dust can have long-term scientific impact to lunar sites (hyperlocal for soil, regional for dust).

Additional concerns were raised about direct physical contact, both the potential for physical contact especially between crewed and uncrewed missions, and for the blocking of heavily desired corridors/locations. While the physical imprint of an object blocking a heavily utilized corridor may be small, infrastructure or other operational/scientific considerations may force a large diversion for other missions and thus have regional impact. Orbital conjunctions and occupation of highly desired lunar orbits/physical crowding in these orbits were highlighted as long-term concerns.

### Thermal disturbance

Respondents indicated scientific concern in the potential heating and dissipation of volatiles in PSRs. Reflection of sunlight onto other elements or PSRs could additionally impact operational objectives for thermally sensitive operations. While the reflection of sunlight primarily impacts concurrent hyperlocal operations, the impact to volatiles can be regional and long-term. Additionally, any thermal instability could impact gravitational wave detectors at a hyperlocal scale.

### EMI/RFI

Respondents expressed concern regarding the impact of radiofrequency interference (RFI) and electromagnetic interference (EMI) on astronomical observations from both orbital and surface assets. RFI was of particular concern for astronomers in the 0.1-110 MHz range with a power spectral density above 228 dBm/Hz, due to high scientific value of observations for fundamental physics, cosmology, astrophysics (cosmic origins, exoplanet habitability), heliophysics, space physics, and plasma physics. The band is inaccessible and/or compromised from the surface of the Earth due to Earth's ionosphere, Earth's auroral kilometric radiation, and terrestrial human transmissions. EMI concerns included unshielded/ insufficiently shielded

assets not only on the surface but ion propulsion engines during entry, descent, and landing/ascent. There was also concern about energy deposition into surface dust increasing charged particles on the lunar plasma and charged particle-antenna interactions, degrading passive use of radio band.

#### Contamination (biological, mechanical, chemical)

Many respondents highlighted concerns regarding the contamination by biological, mechanical, chemical and hazardous materials, especially during disposal. Improper disposal of hazardous materials, accidental disposal of material (e.g., crash landing), and astrobiological contamination including human health hazards were highlighted. Contamination of polar ice traps from water and from rocket exhaust was flagged as a contaminant that could add 20% to polar ice trap mass long-term.<sup>376</sup> Exospheric contamination was also flagged as a concern given the low density of the atmosphere and impact of high cadences of lunar operations, though some of this impact is likely temporary. One respondent noted that topographical changes could impact lunar processes such as water transport, energetic particle flow, and temperatures.

#### Shadowing from large structures

Respondents noted that shadowing from large structures may impact operations, particularly solar power and communications (visibility of Earth, of other lunar sites). These impacts, while hyperlocal, could have long-term effects in highly utilized corridors if there is not a disposal protocol for the structure.

#### Seismic/vibration from movement

Seismic impacts/vibrations from movement were highlighted as a particular concern for gravitational wave astronomy. Solar panel proximity to a seismic station was also flagged as a potential disturbance.

#### Aesthetic degradation

One respondent highlighted concerns regarding the visibility of lunar objects or structures from Earth with the naked eye or through small telescopes.

#### *Mitigation mechanisms*

Table 10 summarizes interference mitigation responses and existing technical or standards work on these mechanisms. Many respondents focused on broad coordination and communication to mitigate interference of lunar activities. This included the development of recommended concept of operations (CONOPS), to include information such as the activities an actor wishes to perform and their location, planned spectrum use, information to support dust ejecta predictions, and waste generation information. Astronomer respondents emphasized the need to maintain a database of transmitter frequencies used by all lunar assets, and encouragement of coordination between active/passive users during early stages of technology development. Pre-coordination of lunar trajectories, as well as a schedule of activities for long-term surface operations were also highlighted.

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<sup>376</sup> Farrell, W. et al., Possible Anthropogenic Contributions to the LAMP-observed Surficial Icy Regolith within Lunar Polar Craters: A Comparison of Apollo and Starship Landings, Planet. Sci. J. 5 105 (2024)

Multiple respondents suggested NASA or international technical bodies could provide guidance on sites of scientific interest and how to preserve their value, or even designating certain zones for specific purposes. One respondent suggested adding environmental impact guidance during procurement. Several respondents suggested defining minimum distances from gravitational wave detectors or from passive radio operations. One respondent highlighting an existing EMI standard, MIL-STD-461, which could be adopted to minimize impact of EMI on passive radio operations. Respondents also highlighted the desire for guidance on disposal of lunar waste, and how sites might be restored, if possible, after operations.

Several respondents noted that collective investments on infrastructure and data could help mitigate interference. Development of infrastructure such as roads and railways, landing pads, and regolith walls could help mitigate dust. Monitoring data and predictive tools could help assess and rectify impacts of lunar interference. Many respondents highlighted specific technologies or technological development initiatives that could help mitigate dust, provide guidance on reuse, minimize chemical contamination, improve energy efficiency, improve shielding, and more.

Respondents emphasized the need to share data on interference (e.g., plume surface interaction (PSI) data) and lessons learned publicly, and to coordinate on developing best practices to avoid interference.

## Improving Lunar Coordination

### *Expanding data parameter sharing*

Today, Artemis Accords signatories have agreed to submit to the United Nations Office of Outer Space Affairs a set of data parameters as part of registration; thus far this information been submitted both as a note verbale or via technical presentation.

The mission parameters shared are (e.g., in the 2025 note verbale on Intuitive Machines and Firefly lunar landings<sup>377</sup>):

- State of registry
- Launch date
- Landing date
- Duration of activities
- Landing location(s)
- Anticipated landing accuracy (meters/kilometers)
- Spacecraft mass at landing
- Item(s) being deployed
- Location(s) of activity/activities, if different from landing location(s)
- Information related to scientific aspects or special considerations of activities
- Plans for end of mission disposal

We note that these parameters are submitted by the state of registry. Due to a lack of U.S. mission authorization and supervision regime for commercial space activities, the obligation to

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<sup>377</sup>“Information furnished in conformity with the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies”, U.N. Office of Outer Space Affairs, A/AC.105/1353  
[https://www.unoosa.org/oosa/oosadoc/data/documents/2025/aac.105/aac.1051353\\_0.html](https://www.unoosa.org/oosa/oosadoc/data/documents/2025/aac.105/aac.1051353_0.html)

share mission parameters is not directly conveyed upon U.S. commercial companies, and only NASA payload information has been shared as a result, with “defer to commercial provider” for all other data.

While these very high-level parameters help ensure transparency surrounding lunar activities, they do not provide the level of detail needed (and are not currently provided in a timely enough fashion, being transmitted shortly before or after landing), to determine if deconfliction is needed during mission development, let alone to deconflict operational missions on the lunar surface. We note that many data parameters are considered mission-sensitive, whether due to proprietary hardware concerns, or due to concerns about competition for specific technologically or scientifically interesting landing sites. However, it is likely beneficial to publicly share a broader set of data parameters prior to launch, which may encourage bilateral deconfliction (which may be at more sensitive levels). As such, we summarize initial communication with subject matter experts on potential information to share to help mitigate each category of interference in Table 11. Further community buy-in with stakeholder meetings (e.g., previous work with Artemis Accords signatories and the Lunar Surface Innovation Consortium) is needed to come to consensus on a list of information to share, but initial parameters include:

Physical/temporal data parameters:

- Schedule of activity if location different from landing
- Structure locations, sizes, mass
- Location and timing of operations
- Orbital trajectory information (insertion, entry, ascent orbit entry)
- Controlled or uncontrolled soil disturbance and any knowledge of impact (e.g., PSI models)
- Proximity to PSR

Thermal/optical data parameters:

- How much heat is dissipated and how far
- Panels that might reflect sunlight or affect local thermal conditions

Radiofrequency parameters:

- Planned frequency use (ground, ground to space, space to ground, space to space)
- EMI standards used

Parameters related to mission disposal or off-nominal performance:

- Hazardous material list, including quantity and location
- Level of spillage mitigation that exists and reliability
- Disposal and extended capability plan (including surrendered, exhausted assets, what kind are there long-term that change environment or those available for reuse)
- Risk of accidental explosion, potential impacts, mitigations to prevent explosion and exposure
- Overflight information (where, when)
- Propellant type

Other:

- Operational strategy for ascent/descent (rocket design, number/orientation/size/position of firing nozzles)
- Other devices that might cause vibrational impacts (e.g., rovers)

## *Existing standards and best practices for interference mitigation*

In this section we look at standards and best practices, which primarily exist in three domains relevant to lunar activity: orbital debris mitigation, RFI/EMI, and contamination. We summarize this section in Table 12. We note that information-sharing as discussed in this section is focused on information-sharing during mission development; bilateral coordination at a technical, real-time level will likely be needed during mission operations to mitigate interference.

NASA STD-8719.14, “Process for limiting orbital debris”,<sup>378</sup> currently requires an Orbital Debris Assessment Report (ODAR);<sup>379</sup> material required a NASA ODAR is also included in the FCC’s Orbital Debris Mitigation plan for commercial actors. Of particular relevance to lunar operations are the following ODAR sections:

### Section 1: Program Management and Mission Overview

- g. Identification of the proposed launch date and mission duration
- h. Description of the launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination
- i. Description of the spacecraft’s maneuver capability, including both attitude and orbit control. Give the time period during which the capabilities will be exercised.
- k. Identification of any interaction or potential physical interference with other operational spacecraft

### Section 2: Spacecraft Description

- a. Physical description of the spacecraft, including spacecraft bus, payload instrumentation, and all appendages, such as solar arrays, antennas, and instrument or attitude control booms
- c. Total spacecraft mass at launch, including all propellants and fluids
- d. Dry mass of spacecraft at launch (minus all consumables and propellants),
- e. Identification, including type, mass and pressure, of all fluids (liquids and gases) planned to be on board (including any planned future in-space transfers), excluding fluids in sealed heat pipes.
- f. Description of all propulsion systems (e.g.: cold gas, mono-propellant, bi-propellant, solid propellant, electric, nuclear)
- h. Description of any range safety or other pyrotechnic devices
- i. Description of the electrical generation and storage system
- j. Identification of any other sources of stored energy not noted above
- k. Identification of any radioactive materials on board or an explicit statement that there are no radioactive materials onboard
- l. Description of any planned proximity operations or docking with other spacecraft, including the controls that will be used to mitigate the risk of a collision that could generate debris or prevent planned later passivation or disposal activities for either spacecraft.

### Section 3: Assessment of Spacecraft Debris Released during Normal Operations

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<sup>378</sup> “NASA STD 8719.14: Process for Limiting Orbital Debris”, NASA,

<https://standards.nasa.gov/sites/default/files/standards/NASA/C/0/nasa-std-871914c.pdf>

<sup>379</sup> “Small Spacecraft Technology Program Orbital Debris Assessment Report & End of Mission Plan Instructional Guide”, NASA, <https://www.nasa.gov/wp-content/uploads/2023/06/5.-odar-032123.docx>

- a. Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material
- c. Time of release of each object, relative to launch time
- d. Release velocity of each object with respect to spacecraft
- e. Expected orbital parameters (apogee, perigee, and inclination) of each object after release
- f. Calculated orbital lifetime of each object, including time spent in LEO

#### Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions

- a. Identification of all potential causes of spacecraft breakup during deployment and mission operations
- b. Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion
- c. Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions
- d. List of components which are passivated at EOM. List includes method of passivation and amount which cannot be passivated.

#### Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

- a. Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft, assuming no collision avoidance capability.
- b. Calculation of spacecraft probability of collision with space objects, including orbital debris and meteoroids, of sufficient size to prevent postmission disposal.
- d. Detailed description and assessment of the efficacy of any planned debris avoidance capability intended to help in meeting requirement 4.5-1, including any plans to move to less congested altitudes, as well as any tracking enhancements (e.g., GPS, laser retroreflector) that may assist in reducing the covariance of collision estimates. [...]

#### Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

- a. Description of spacecraft disposal option selected
- b. [...] Plan for any spacecraft maneuvers required to accomplish postmission disposal

Although numerous ISO standards on orbital debris mitigation exist, they are not particularly designed for lunar missions. The Jet Propulsion Laboratory (JPL)'s Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) is responsible for screening ephemerides for NASA spacecraft not orbiting Earth, and external spacecraft operators may opt into their conjunction assessment process; a short overview of the process can be found in "Conjunction Assessment Process for Lunar Orbiters".<sup>380</sup>

Mitigation of RFI and EMI is already highly standardized via regulation at the International Telecommunications Union and at the national-level. The ITU does not currently have lunar-specific radio frequency allocations, with current missions operating under experimental licenses. Lunar communications are a future agenda item for World Radiocommunications Conference 2027, where further recommendations on radio frequency allocations will be sought. However,

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<sup>380</sup> Barry, D. "Conjunction Assessment Process for Lunar Orbiters," Jet Propulsion Laboratory, California Institute of Technology, March 2022, [https://www.nasa.gov/wp-content/uploads/2022/08/moon\\_conjunction\\_assess\\_process-urs309081.pdf](https://www.nasa.gov/wp-content/uploads/2022/08/moon_conjunction_assess_process-urs309081.pdf)

ITU Radio Regulation Articles 22.22-22.25 on the Shielded Zone of the Moon (SZM) seek to protect the lunar far-side (of particular importance to radio astronomy) from interference.<sup>381</sup> The Space Frequency Coordination Group's (a consortium of space agencies from Australia, France, China, Canada, Australia, Germany, Europe, India, Japan, South Korea, UAE, U.S., Nigeria, Russia, and U.K.) Lunar Martian Spectrum Group maintains recommended spectrum agreed by member agencies for use at the Moon.<sup>382</sup> WRC-23 issued resolutions on lunar spectrum to:<sup>383</sup>

- Complete studies in time for WRC-27 on the spectrum needs of systems in the Space Research Service (SRS) which may operate on the lunar surface, or systems in lunar orbit communicating with systems on the lunar surface, in the frequency ranges 390-406.1 MHz, 420-430 MHz and 440-450 MHz, limited to outside the SZM and frequency ranges 2 400-2 690 MHz, 3 500-3 800 MHz, 5 150-5 570 MHz, 5 570-5 725 MHz, 5 775-5 925 MHz, 7 190-7 235 MHz, 8 450-8 500 MHz and 25.25-28.35 GHz;
- Complete studies in time for WRC-27 on propagation considerations for lunar surface systems and lunar-orbiting systems;
- Complete studies in time for WRC-27 on sharing and compatibility related to systems in the SRS to ensure protection of radiocommunication services and the Radio Astronomy Service (RAS) on the Earth and in the SZM in the same, adjacent or nearby bands; and
- Complete studies in time for WRC-27 on potential new or modified frequency allocations and/or identifications to the SRS with appropriate regulatory provisions, for communications on the lunar surface or in lunar orbit communicating with systems on the lunar surface

A further overview of lunar spectrum issues is provided in J. Schier et al. (2024) "INTERNATIONAL COORDINATION AND COOPERATION ON LUNANET SPECTRUM", which notes that in addition to the WRC-27 items above, these transmissions only account for spectrum "in which spacecraft or other objects in space are used for scientific or other technical research purposes," and not for instance data transmission used by astronauts for long-term lunar stays. They also note that optical communications may be used in point-to-point communications and optometrics for PNT with unlimited frequency reuse in the future.<sup>384</sup>

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<sup>381</sup> "Lunar and Martian in-situ PNT frequency bands, and guard bands", CNES, 16 Oct 2023, <https://www.unoosa.org/documents/pdf/icg/2023/ICG-17/icg17.02.09.rev1.pdf>

<sup>382</sup> Recommendation SFCG 32-2R5, "Communication And Positioning, Navigation, And Timing Frequency Allocations And Sharing In The Lunar Region," 7 June 2023, [https://www.sfcgonline.org/Recommendations/REC%20SFCG%20322R5%20\(Freqs%20for%20Lunar%20Region\).pdf](https://www.sfcgonline.org/Recommendations/REC%20SFCG%20322R5%20(Freqs%20for%20Lunar%20Region).pdf).

<sup>383</sup> "Resolution 680 (WRC-23) Studies on frequency-related matters, including possible new or modified space research service (space-to-space) allocations, for future development of communications on the lunar surface and between lunar orbit and the lunar surface." [https://www.itu.int/dms\\_pub/itu-r/oth/0c/0a/R0C0A0000100015PDFE.pdf](https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A0000100015PDFE.pdf)

<sup>384</sup> Schier, J. et al. (2024) "INTERNATIONAL COORDINATION AND COOPERATION ON LUNANET SPECTRUM", 29th Ka and Broadband Communications Conference, Seattle, WA, USA, 24-27 September 2024

GSFC-STD-7000<sup>385</sup> details Goddard-required electromagnetic compatibility requirements, which are largely based on MIL-STD-461G,<sup>386</sup> and cites three NASA Standards, 4003A,<sup>387</sup> 7002 rev B,<sup>388</sup> and HDBK-4002B,<sup>389</sup> which further detail requirements for electrical bonding, payload tests, and minimizing effects from spacecraft charging, respectively. MIL-STD-464 addresses EMI mitigation at a system-level, while AIAA S-121 combines MIL-STD-461G and 464 and tailors for space systems.<sup>390</sup>

In addition to contamination items covered in the ODAR above, and GSFC-STD-7000,<sup>391</sup> which addresses contamination control, NASA outlines planetary protection guidelines in NASA-STD-8719.27<sup>392</sup> and its Planetary Protection Handbook.<sup>393</sup> Lunar missions fall under planetary protection category II; IIa and IIb cover the lunar surface, where “Category IIa includes all missions to the surface of the Moon whose nominal mission profile does not access areas defined in Category IIb. The material inventory required for Category IIa is limited to organic products that may be released into the lunar environment by the spacecraft propulsion system. Category IIb includes all missions to the surface of the Moon whose nominal mission profile accesses PSRs and the lunar poles, in particular latitudes south of 79 °S and north of 86 °N. A Category IIb mission requires a full organic inventory, including solids and volatiles” [sample organic inventory in Appendix 3].<sup>394</sup> An organics inventory is only required if organic material exceeds 1 kg, but this requirement only addresses one contamination vector (outgassing), not

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<sup>385</sup> General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects, Goddard Space Flight Center, 28 April 2021, [https://standards.nasa.gov/sites/default/files/standards/GSFC/B/0/gsfsc-std-7000b\\_signature\\_cycle\\_04\\_28\\_2021\\_fixed\\_links.pdf](https://standards.nasa.gov/sites/default/files/standards/GSFC/B/0/gsfsc-std-7000b_signature_cycle_04_28_2021_fixed_links.pdf)

<sup>386</sup> MIL-STD-461G, Quick Search Assist, 11 Dec 2015, [https://quicksearch.dla.mil/qsdocdetails.aspx?ident\\_number=35789](https://quicksearch.dla.mil/qsdocdetails.aspx?ident_number=35789)

<sup>387</sup> “Standard: Electromagnetic Compatibility Requirements for Space Equipment and Systems (AIAA S-121A-2017)”, American Institute of Aeronautics and Astronautics, 2017, <https://arc.aiaa.org/doi/book/10.2514/4.105203>

<sup>388</sup> ELECTRICAL BONDING FOR NASA LAUNCH VEHICLES, SPACECRAFT, PAYLOADS, AND FLIGHT EQUIPMENT, NASA, 19 Jan 2019, [https://standards.nasa.gov/sites/default/files/standards/NASA/w/CHANGE-1/1/NASA-STD-4003A\\_w-Change-1-Revalidated.pdf](https://standards.nasa.gov/sites/default/files/standards/NASA/w/CHANGE-1/1/NASA-STD-4003A_w-Change-1-Revalidated.pdf)

<sup>389</sup> PAYLOAD TEST REQUIREMENTS, NASA, 24 March 2023 <https://standards.nasa.gov/sites/default/files/standards/NASA/B/1/NASA-STD-7002B-w-Change-1.pdf>

<sup>390</sup> MITIGATING IN-SPACE CHARGING EFFECTS—A GUIDELINE, NASA, 07 June 2022, <https://standards.nasa.gov/sites/default/files/standards/NASA/B/0/2022-06-07-NASA-HDBK-4002B-Approved.pdf>

<sup>391</sup> General Environmental Verification Standard (GEVS) for GSFC Flight Programs and Projects, Goddard Space Flight Center, 28 April 2021, [https://standards.nasa.gov/sites/default/files/standards/GSFC/B/0/gsfsc-std-7000b\\_signature\\_cycle\\_04\\_28\\_2021\\_fixed\\_links.pdf](https://standards.nasa.gov/sites/default/files/standards/GSFC/B/0/gsfsc-std-7000b_signature_cycle_04_28_2021_fixed_links.pdf)

<sup>392</sup> IMPLEMENTING PLANETARY PROTECTION REQUIREMENTS FOR SPACE FLIGHT, NASA, 30 Aug 2022, <https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/0/NASA-STD-871927-Baseline.pdf>

<sup>393</sup> NASA Planetary Protection Handbook, Dec 2024, [https://ntrs.nasa.gov/api/citations/20240016475/downloads/PlanetaryProtection\\_Hdbk\\_2024\\_Final\\_For508ing\\_comp.pdf](https://ntrs.nasa.gov/api/citations/20240016475/downloads/PlanetaryProtection_Hdbk_2024_Final_For508ing_comp.pdf)

<sup>394</sup> Id.

contamination from thruster plumes, vacuum venting, or leakage; as a result, the Jet Propulsion Laboratory is working to create a Comprehensive Organic Inventory strategy and framework.<sup>395</sup>

One other primary area of concern for contamination is radioactive material; NASA has “Information and Best Practices Related to NASA Nuclear Flight Safety for Space Flights Involving Space Nuclear Systems”<sup>396</sup> related to potential interaction with Earth’s biosphere. No comparable U.S. lunar guidance exists, beyond a requirement from “Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems” (NSPM-20) for the organization sponsoring a mission with nuclear material to provide a safety analysis report (with three tiers of approval scrutiny based on quantity/type of radioactive material).<sup>397</sup> A high-level U.N. Office of Outer Space Affairs and International Atomic Energy Agency report, “Safety Framework for Nuclear Power Source Applications in Outer Space”, emphasizes safety in design and recommends risk assessments and accident consequence mitigation efforts are undertaken.<sup>398</sup>

### *Existing measurements and models for interference mitigation*

In this section we detail existing measurements and models in published literature which may help inform best practices for the mitigation of interference. These measurements and models are briefly summarized in Table 13.

We note that for modeling many of these types of interference, the reference “CROSS-PROGRAM DESIGN SPECIFICATION FOR NATURAL ENVIRONMENTS (DSNE)”<sup>399</sup> will be a useful reference for lunar surface properties.

## Physical Interference

### *Cislunar conjunctions*

The JPL MADCAP team published “Deep-space Conjunction Assessment: Recent Developments and Future Evolution”<sup>400</sup> detailing experiences from 2016-2024 in cislunar

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<sup>395</sup> Sores, C. et al., “Characterization of Organic Footprint from Moon, Mars and Ocean World Landing Systems for Robotic and Crewed Missions”, 14 Oct 2024, <https://ntrs.nasa.gov/citations/16406207255693>

<sup>396</sup> “Information and Best Practices Related to NASA Nuclear Flight Safety for Space Flights Involving Space Nuclear Systems,” NASA-HDBK-8715.26, 30 Jun 2023  
<https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/0/NASA-HDBK-871526.pdf>

<sup>397</sup> “Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems”, White House, 20 Aug, 2019, <https://trumpwhitehouse.archives.gov/presidential-actions/presidential-memorandum-launch-spacecraft-containing-space-nuclear-systems/>

<sup>398</sup> “Safety Framework for Nuclear Power Source Applications in Outer Space”, U.N. Office of Outer Space Affairs and International Atomic Energy Agency, 2009,  
<https://www.unoosa.org/pdf/publications/iaea-nps-sfrmwrkE.pdf>

<sup>399</sup> CROSS-PROGRAM DESIGN SPECIFICATION FOR NATURAL ENVIRONMENTS (DSNE), SLS-SPEC-159 Rev. 1, NASA, 27 Oct 2021 [https://ntrs.nasa.gov/api/citations/20210024522/downloads/SLS-SPEC-159%20Cross-Program%20Design%20Specification%20for%20Natural%20Environments%20\(DSNE\)%20REVISION%20I.pdf](https://ntrs.nasa.gov/api/citations/20210024522/downloads/SLS-SPEC-159%20Cross-Program%20Design%20Specification%20for%20Natural%20Environments%20(DSNE)%20REVISION%20I.pdf)

<sup>400</sup> Tarzi, Z., et al., “Deep-space Conjunction Assessment: Recent Developments and Future Evolution”, 29th International Symposium on Space Flight Dynamics , 22-26 April 2024, <https://www.nasa.gov/wp->

conjunction assessment and deconfliction. They note that the number of conjunctions sharply rose in 2023 with three spacecraft in Low Lunar Orbit (Lunar Reconnaissance Orbiter, Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment, Korea Pathfinder Lunar Orbiter); as of July 2024 South Korea noted 40 conjunction warnings received, with three maneuvers taking place.<sup>401</sup> MADCAP noted an interest in incorporating Chinese lunar ephemerides into the MADCAP process.<sup>402</sup>

As Soyoung Chung, senior researcher at the Korea Aerospace Research Institute's (KARI's) strategy and planning directorate noted at the July 2024 Secure World Foundation Summit for Space Sustainability, "there's no mutually agreed-upon international consultation mechanism or protocol to resolve such collision risks" and also no formal mechanism to determine which spacecraft maneuvers if required.<sup>403</sup> Although no further formal coordination mechanism or protocol exists at this time, the MADCAP data indicates that coordination on lunar collision avoidance is necessary, particularly for missions in low lunar orbit.

#### *Movement and compression of lunar soil and dust*

The 2021 Planetary Science Decadal Survey white paper "Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars" gives an overview of knowledge of PSIs.<sup>404</sup> Although this information is being supplemented by recent lunar lander data, it importantly notes that for the Apollo modules, dust to sand-sized particles were blown several kilometers away, with plumes able to lift rocks up to 10 cm.<sup>405</sup> Blast zone scales quadratically with lander mass, with Apollo landings blasting up to 35,000 m<sup>2</sup>.<sup>406</sup> In addition to the University of Central Florida's Center for Lunar & Asteroid Surface Science's overview of the science of plume effects<sup>407</sup> Cuesta et al. 2025<sup>408</sup> give an overview of PSI experimental work and gaps, looking at the five erosion mechanisms: viscous erosion (VE), bearing capacity failure (BCF), diffusion-driven flow (DDF), diffused gas eruption (DGE), and diffusive gas explosive eruption (DGGE). Watkins et al. note that launch/landing pads may be one of the best ways to mitigate dust, but that much still needs to be learned about PSIs, particularly for physical impacts:

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content/uploads/2024/10/deep-space-conjunction-assessment-recent-developments-future-evolution.pdf?emrc=f57c9d

<sup>401</sup> Foust, J. "Lunar Spacecraft Receive Dozens of Collision Warnings", SpaceNews, 11 July 2024 <https://spacenews.com/lunar-spacecraft-receive-dozens-of-collision-warnings/#:~:text=Since%20KPLO%20entered%20orbit%20around,no%20risk%20of%20a%20collision.>

<sup>402</sup> Tarzi, Z. et al., "Deep-space Conjunction Assessment: Recent Developments and Future Evolution", 29th International Symposium on Space Flight Dynamics, 22-26 April 2024, <https://www.nasa.gov/wp-content/uploads/2024/10/deep-space-conjunction-assessment-recent-developments-future-evolution.pdf?emrc=f57c9d>

<sup>403</sup> Foust, J. "Lunar Spacecraft Receive Dozens of Collision Warnings", SpaceNews, 11 July 2024 <https://spacenews.com/lunar-spacecraft-receive-dozens-of-collision-warnings/#:~:text=Since%20KPLO%20entered%20orbit%20around,no%20risk%20of%20a%20collision.>

<sup>404</sup> Watkins, R. et al. "Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars," Planetary Science Institute, 2021 <https://arxiv.org/abs/2102.12312>

<sup>405</sup> Metzger, P. et al., 2011. J. Geophys. Res., 116, E06005, 1-22.

<sup>406</sup> Clegg-Watkins, R., et al., 2016. *Icarus*, 273, 84-95.

<sup>407</sup> "The Science of Plume Effects", Center for Lunar & Asteroid Surface Science, University of Central Florida, <https://sciences.ucf.edu/class/landing-team/the-science-of-plume-effects/>

<sup>408</sup> Cuesta, C. et al., 2025, *Ad Astronautica*, Volume 226, Part 1, January 2025, Pages 892-912

- What are the size distributions, volumes, and velocities of particles lofted by exhaust plumes? How far do they travel?
- How much dust (mass, particle size) remains lofted after engine shut-down, at what altitude and distribution, and for how long?
- What physical changes occur to the surface in the landing zone?
- How does PSI differ in different landing terrains?
- What effects do lander size and engine configuration have on PSI?
- How does the mass/volume/size/velocity/flux of dust particles lofted in the exhaust plume evolve through repeated landings/launches within a zone of interest? Are hazards mitigated or increased with repeated landings/launches?
- How far away from nearby hardware must a landing take place to ensure the safety of the emplaced infrastructure?
- How important will landing pads / prepared surfaces be for repeat missions to an area, and how effective will they be over time?<sup>409</sup>

J. Kim et al. (2024) present “A survey of research on lunar dust dispersal due to rocket plume impingement”. In addition to giving an overview of PSI dynamics, lunar dust properties, and PSI in-situ measurements, experiments, and models, they also given an overview of mitigation strategies. They note that in addition to landing pads, various landing strategies, materials that mitigate dust adhesion, management using electrostatic and electromagnetic fields, mechanical, and fluidal methods can help mitigate dust.<sup>410</sup>

#### *Threat of active physical contact*

Maps of past U.S. lunar sites, including still-active experiments from the Apollo era, are included in “NASA’s Recommendations to Space-Faring Entities.”<sup>411</sup> A centralized repository of mission sites, dates active, and infrastructure, would be useful to prevent direct physical contact.

#### Thermal Interference

For the now-canceled VIPER mission, which was intended to sample lunar volatiles, Ivarson et al. (2023) performed a study “The Effect of VIPER Headlights on Lunar Surface and Subsurface Temperatures”, finding that VIPER’s navlights would have minimal heating effects on the lunar surface and subsurface. They note that low lighting duration and other operational mitigations would minimize impact to science activities, but periods of extended illumination in future missions would likely impact stability of surface volatiles. They note for a notional

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<sup>409</sup> Watkins, R. et al. “Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars,” Planetary Science Institute, 2021 <https://arxiv.org/abs/2102.12312>

<sup>410</sup> Kim, J. et al. “A survey of research on lunar dust dispersal due to rocket plume impingement”, *Acta Astronautica* 227 (2025) 67–95

<sup>411</sup> NASA’s Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts, NASA, 20 July 2011, [https://www.nasa.gov/wp-content/uploads/2017/10/617743main\\_nasa-usg\\_lunar\\_historic\\_sites\\_reva-508.pdf?emrc=44e0c8](https://www.nasa.gov/wp-content/uploads/2017/10/617743main_nasa-usg_lunar_historic_sites_reva-508.pdf?emrc=44e0c8)

VIPER mission with 5-hour lighting duration, surface and subsurface temperatures down to 2cm could reach 140K and above.<sup>412</sup>

Olthoff, et al. (2023) performed a study on “Dynamic Thermal Interactions Between Spacesuits and Lunar Regolith in Permanently Shaded Regions on the Moon”, finding that spacesuits can cause a temperature change when moving slowly or standing large enough to dissipate volatiles in PSRs. Although they note that the dissipation is not enough to recommend a change in spacesuit design, they note that this dissipation may impact scientific sample extraction, and that further studies should be undertaken to determine the temperatures of which various types of volatiles are released from the lunar regolith.<sup>413</sup>

Any missions that wish to study the composition and extent of lunar volatiles should undertake similar analyses. In contrast, numerous notional ISRU architectures have sought to use thermal heating to extract volatiles (e.g., Zhang, et al., 2023 and references therein<sup>414</sup>), suggesting that any desired scientific volatile measurements of a region should be taken prior to extraction; in the questionnaire, one ISRU company did suggest incentivization to collect cryogenic samples stored on the lunar surface.

## EMI/RFI

With existing standards for EMI, we do not focus on typical EMI sources in this section. However, one rarely cited source of EMI is electrostatic discharge from human systems charged by contact with regolith. Farrell, et al. (2008) calculated that cold shadowed regions on the lunar surface had no pathway to dissipate charges created from e.g., astronauts and rovers, creating electrostatic hazard, with the charge lasting 100s of seconds in shadowed regions but less than one millisecond in the weakly sunlit terminator region.<sup>415</sup> There may also be substantial natural sources of EMI; C. Zhao, et al., (2023) found that in the Shackleton crater, surface potential could be -175 V on the leeward crater wall, suggesting that a number of charged dust grains can be emitted from this wall thus creating a dust cloud with density  $10^4$ - $10^5$  m<sup>3</sup>.<sup>416</sup>

As ITU and SFCG guidance on lunar RFI exists, and numerous WRC-27 studies are underway as noted in Section 4.2, we do not focus on other RFI models in this section.

## Contamination

Outgassing, venting, pluming, and leakage are all primary contamination mechanisms for spacecraft. In 2024, NASA hosted a Planetary Protection Organic Inventory and Archiving workshop which particularly sought to expand molecular contamination understanding and develop a comprehensive organic inventory strategy and framework that included more sources

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<sup>412</sup> Iverson, J. et al. “The Effect of VIPER Headlights on Lunar Surface and Subsurface Temperatures”. 54th Lunar and Planetary Science Conference 2023 (LPI Contrib. No. 2806)

<sup>413</sup> Olthoff, C., Kashubek, D., and Killian, M. “Dynamic Thermal Interactions Between Spacesuits and Lunar Regolith in Permanently Shaded Regions on the Moon”, *Acta Astronautica*, 203, 351-369, 2023.

<sup>414</sup> Zhang, P. et al. “Overview of the Lunar In Situ Resource Utilization Techniques for Future Lunar Missions”. *Space Sci Technol.* 2023;3:0037.

<sup>415</sup> Farrell, W. et al. “Concerning the dissipation of electrically charged objects in the shadowed lunar polar regions”, *Geophysical Research Letters*, Space Sciences, Vol 35, Issue 19, Oct 2008

<sup>416</sup> Zhao, C. et al. “Theoretical analysis of the electric potential and the electrostatic dust transport around the Shackleton crater in the Lunar south pole region”, *Science China Press* 2023, <https://www.sciengine.com/doi/pdf/B43498E302C24415989CAA043B1D633A>

than just outgassing. Dispersion models for microorganisms borne on spacecraft are also needed to determine overall contamination.<sup>417</sup> JPL is currently working on modeling contaminants based on mass, finding that regardless of mass contaminants will stick on night side. Mid-mass contaminants will stick permanently at high/low latitudes even during the day, and high mass will stick permanently at all latitudes regardless of day/night.<sup>418</sup>

Plumes are the primary source of exospheric and polar cold trap contamination. Farrell et al., (2022) modeled a mid-latitude CLPS landing, finding that outgassing produced a local exosphere for 10s of hours after landing.<sup>419</sup> Plumes also have the potential to substantially increase the amount of ice cold trapped in polar craters. Farrell, et al (2024) found that while Apollo mid-latitude landings contributed no more than 0.36 T of ice to PSRs, Starship has the potential to deliver >10 T of water to PSRs over the course of two lunar days even with landings at mid-latitudes, potentially increasing the intrinsic surficial water mass by 20%.<sup>420</sup>

Killen et al. (2024), “Temporary atmospheres produced by human activities on the Moon” detailed the impact of outgassing of materials on the lunar surface and exosphere. They note that for a notional starship mission, while the biggest source of anthropogenic gas to the exosphere is the plume, the airlocks, backpacks, and Starship, plus any trash and mining operations, combined produce half as much gas as the rocket plume. Water outgassing will dominate the exospheric environment near the lander, making detection of exospheric water very difficult.<sup>421</sup>

#### Seismic/Vibration from movement

A 2024 COPUOS submission from on the Protection of Astronomy and Science on the Moon notes that gravitational wave detectors on the lunar surface would need to be far removed from landings or mining sites, noting logging and trains impact the Laser Interferometer Gravitational-wave Observatory (LIGO) at 3 km.<sup>422</sup>

## Conclusions and Further Work

This work established through international scientific and technical community consensus, five main categories of interference in lunar activities: physical, thermal or optical disturbance, EMI/RFI, contamination, and seismic (aesthetic degradation of sites was also noted by one respondent). These categories, and the specific types of interference highlighted within,

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<sup>417</sup>Hoey, W et al., “The Footprint of Landed Spacecraft in Near-Vacuum: Contamination Sources and Transport Terms, 33rd International Symposium on Rarefied Gas Dynamics, 15-19 July 2024, <https://dataverse.jpl.nasa.gov/dataset.xhtml?persistentId=doi:10.48577/jpl.QCQ9TL>

<sup>418</sup> Soares, C. et al., “Characterization of Organic Footprint from Moon, Mars, and Ocean World Landing Systems for Robotic and Crewed Missions.” 75<sup>th</sup> International Astronautical Congress, Oct 14-18, 2024. <https://dataverse.jpl.nasa.gov/dataset.xhtml?persistentId=doi:10.48577/jpl.SBXCXY>

<sup>419</sup> Farrell, W. et al. “A lingering local exosphere created by a gas plume of a lunar lander”, *Icarus*, Vol. 376, April 2022, 114857 <https://www.sciencedirect.com/science/article/pii/S0019103521004966#ab0005>

<sup>420</sup>Farrell, W. et al., Possible Anthropogenic Contributions to the LAMP-observed Surficial Icy Regolith within Lunar Polar Craters: A Comparison of Apollo and Starship Landings, *Planet. Sci. J.* 5 105 (2024)

<sup>421</sup> Killen, R. et al. “Temporary atmospheres produced by human activities on the Moon “. 19 March 2024, *Advances in Space Research*, <https://doi.org/10.1016/j.asr.2024.08.042>

<sup>422</sup> “Protection of Astronomy and Science on the Moon”, Committee on the Peaceful Uses of Outer Space, Scientific and Technical Subcommittee, Sixty-First Session, Vienna, 29 Jan-9 Feb 2024 [https://www.unoosa.org/res/oosadoc/data/documents/2024/aac\\_105c\\_12024crp/aac\\_105c\\_12024crp\\_14\\_0\\_html/AC105\\_C1\\_2024\\_CRP14E.pdf](https://www.unoosa.org/res/oosadoc/data/documents/2024/aac_105c_12024crp/aac_105c_12024crp_14_0_html/AC105_C1_2024_CRP14E.pdf)

will be critical to understand as the cadence of lunar activity increases. Some of these types of interference are already highly studied and have existing standards (e.g., orbital debris mitigation, EMI/RFI, contamination), though these standards largely need to be supplemented once lunar activity increases, to account for increased spatiotemporal density and long-term impacts of to the lunar environment. Many types of lunar interference have only baseline in-situ measurements, experiments, and models, and will need further study as lunar activity increases. Of particular concern is the impact of PSIs on lunar infrastructure; plumes also have a substantial impact to scientific studies not only the local lunar environment, but also the overall polar volatile content, as even mid-latitude landings result in migration of volatiles over several lunar days to polar cold traps. Numerous entities have suggested international designation of lunar sites of scientific interest; while there is no clear legal or policy mechanism for such designation, it is wise for national space agencies or authorizing agencies for commercial space exploration to encourage technical experiments at sites which do not disturb sites with high scientific value.

This work was originally undertaken to support the eventual creation of safety zones for lunar activities. Identifying the types of interference of concern for lunar activities was one step toward achieving this goal; further work on data collection, models and experiments, and eventual standards creation is needed for sustained lunar activity, particularly at the lunar south pole. Prioritization of technology development to mitigate interference will also be necessary. Further research might develop a risk-based framework for prioritizing interference mitigation efforts, particularly for the lunar south pole region where mission density is projected to be highest. This framework should consider both temporal urgency (addressing interferences that could permanently impact scientific value) and operational criticality (preventing mission-threatening interference).

We note that the work in sections 1-3 was greatly supported by input from the international scientific and technical community who responded to the questionnaire, participated in Artemis Accords discussions, and joined our workshop at the Lunar Surface Innovation Consortium meeting, as well as through input within NASA. While a proposal for a more formalized section 4 was supported both internal to NASA and amongst Artemis Accords signatories, NASA decided to eliminate the Office of Technology, Policy, and Strategy, which ended its formal support of a comprehensive international scientific and technical approach to coordination of the types of interference described in this paper. Section 4 represents a very preliminary overview based on initial discussions and literature reviews of important sources of scientific and technical data, but initial presentation of this information to the international scientific and technical community for feedback is necessary to ascertain its completeness.

While acknowledge that operational coordination is most likely to occur on a bilateral level in real-time, it is critical to share technical information and best practices/lessons learned in forums such as the Artemis Accords, within the COPUOS Action Team on Lunar Activities Consultation, in GEGSLA, and in other existing standards bodies.

## Appendix A

### *Lunar Non-Interference Questionnaire*

- How do you define these terms?
  - Interference
  - Contamination
  - Deconfliction
- Understanding the Potential Value of a Site
  - What attributes/characteristics are relevant to site selection in consideration of science objectives? Attributes may include time-sensitive or physical characteristics, holds awaiting technology or science advancements, or other perspectives. Example scenarios are encouraged.
- Impacting the Potential Value of a Site
  - What human or robotic actions/events may negatively impact the value of a lunar site? Such as chemical contamination, physical contact, hardware proximity (for example Apollo hardware causing localized ‘moon quakes’ due to heating and cooling differences vs surroundings), waste hazards, etc.
    - How do the impacts of those actions/events alter the value of a site (e.g., unusable for certain missions, usable for certain missions but not others)?
    - What detrimental impacts are permanent, temporary, or still unknown?
  - What data, models, or information is needed to inform the value? Such as how to understand where contaminants are going, what they are doing that impacts science, computational models validated with ground and flight data, etc.
- Mitigation Mechanisms
  - What types of mitigation mechanisms exist to preserve the value of a site?
  - During what phases of operations are mitigation mechanisms needed? Examples include ascent/descent, overflight, traverse, contingency, experimental or construction phase, etc.
  - What technologies/capabilities need to be developed?
  - What types of communication and coordination efforts minimize concerns? Such as development/planned activity timelines for pre-coordination, operational timelines with time-critical communication mechanisms, list of materials, transparency, etc.

Table 8: Summarized public lunar interference questionnaire responses regarding interference concerns during phases of operations. Red are operational interference concerns, blue scientific interference concerns, black both operational and scientific interfere

| Interference Concern           | Orbital Operations                                                                                                       | Entry, Descent, and Landing; Ascent                                                                                                                                                                                                                                                                                            | Static Surface Operations                                                                                                                                                                                                                                                 | Dynamic Surface Operations                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical                       | <ul style="list-style-type: none"> <li>• Cislunar conjunctions</li> <li>• Occupation of highly desired orbits</li> </ul> | <ul style="list-style-type: none"> <li>• Movement and compression of lunar soil, movement of dust (e.g., PSIs), which may impact geological samples or impede physical movement</li> <li>• Dust coating scientific instruments, solar panels, or habitat surfaces</li> <li>• Ejection of debris into cislunar space</li> </ul> | <ul style="list-style-type: none"> <li>• Operations blocking desired path/location</li> <li>• Operations blocking solar power</li> <li>• Alteration of thermal environment</li> <li>• Operations blocking communications (visibility to Earth, lunar-to lunar)</li> </ul> | <ul style="list-style-type: none"> <li>• Movement and compression of lunar soil, movement of dust (e.g., PSIs), which may impact geological samples or impede physical movement</li> <li>• Dust coating scientific instruments, solar panels, or habitat surfaces</li> <li>• Operations blocking desired path/location</li> <li>• Threat of active physical contact, including due to uncertainty of positioning, especially between crewed and uncrewed operations</li> <li>• Operations blocking solar power</li> <li>• Alteration of thermal environment</li> <li>• Operations blocking communications (visibility to Earth, lunar-to lunar)</li> </ul> |
| Thermal or optical disturbance |                                                                                                                          | <ul style="list-style-type: none"> <li>• Heating resulting in dissipation of volatiles (e.g., in PSRs)</li> </ul>                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>• Reflection of sunlight into another element or into PSRs</li> <li>• Glint from structure</li> </ul>                                                                                                                              | <ul style="list-style-type: none"> <li>• Heating resulting in dissipation of volatiles (e.g., in PSRs)</li> <li>• Reflection of sunlight into another element or into PSRs</li> <li>• Glint from structure</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                      |

|               |                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EMI/RFI       | <ul style="list-style-type: none"> <li>• RFI from satellites, with particularly sensitive impacts to lunar astronomical observatories</li> </ul> | <ul style="list-style-type: none"> <li>• RFI and EMI with particular concern for proximity to astronomical sites; unshielded electronics from ion propulsion engines flagged for EDL/Ascent</li> <li>• Energy deposited into surface dust increasing charged particles on the lunar plasma and charged particle-antenna interactions, degrading passive use of radio band</li> </ul>                                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>• RFI and EMI with particular concern for proximity to astronomical sites</li> </ul>                                                                                                                                                                                                                                                                | <ul style="list-style-type: none"> <li>• RFI and EMI with particular concern for proximity to astronomical sites</li> <li>• Energy deposited into surface dust increasing charged particles on the lunar plasma and charged particle-antenna interactions, degrading passive use of radio band</li> </ul>                                                                                                                                                                                               |
| Contamination |                                                                                                                                                  | <ul style="list-style-type: none"> <li>• Improper disposal of hazardous materials (e.g., batteries, lubricants)</li> <li>• Unplanned disposal of materials (e.g., crash landing)</li> <li>• Biological/mechanical waste</li> <li>• Astrobiological contamination including human health hazards</li> <li>• Topographic changes (e.g., drilling, structures) that impact processes such as water transport, energetic particle flow, temperatures</li> <li>• <a href="#">Contamination of polar cold traps from exhaust</a></li> <li>• <a href="#">Exospheric contamination</a></li> </ul> | <ul style="list-style-type: none"> <li>• Improper disposal of hazardous materials (e.g., batteries, lubricants)</li> <li>• Biological/mechanical waste</li> <li>• Astrobiological contamination including human health hazards</li> <li>• Topographic changes (e.g., drilling, structures) that impact processes such as water transport, energetic particle flow, temperatures</li> </ul> | <ul style="list-style-type: none"> <li>• Improper disposal of hazardous materials (e.g., batteries, lubricants)</li> <li>• Unplanned disposal of materials (e.g., crash)</li> <li>• Biological/mechanical waste</li> <li>• Astrobiological contamination including human health hazards</li> <li>• Topographic changes (e.g., drilling, structures) that impact processes such as water transport, energetic particle flow, temperatures</li> <li>• <a href="#">Exospheric contamination</a></li> </ul> |

|         |  |                                                                                                                                                       |                                                                                                  |                                                                                                                                                                                                               |
|---------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Seismic |  | <ul style="list-style-type: none"> <li>• Seismic/vibrational impacts from operations of particular concern to gravitational wave astronomy</li> </ul> | <ul style="list-style-type: none"> <li>• Solar panels in proximity to seismic station</li> </ul> | <ul style="list-style-type: none"> <li>• Seismic/vibrational impacts from operations of particular concern to gravitational wave astronomy</li> <li>• Solar panels in proximity to seismic station</li> </ul> |
|---------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 9: Summarized public lunar interference questionnaire responses regarding spatiotemporal extent of interference concerns

| Interference Concern        | Scientific Impact: Concurrent, short, or long-term?                                                                                                                                                | Scientific Impact: Hyperlocal, regional, global?                                                                                                                                                                                                                                                                  | Operational Impact: Concurrent, short, or long-term?                                                                         | Operational Impact: Hyperlocal, regional, global?                                                                                                              |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical                    | Can be long-term for movement of soil/dust                                                                                                                                                         | Hyperlocal: Soil disturbance, blocking of transit corridors<br><br>Regional: dust                                                                                                                                                                                                                                 | Primarily concurrent for surface operations unless physically blocking highly utilized path; orbital debris can be long-term | Dust is regional for surface operations, global for orbital debris. Physical blocking of activity is largely hyperlocal unless blocking a highly utilized path |
| Thermal Disturbance/Optical | Long-term; thermal disturbance itself is concurrent but volatile disturbance could be permanent.                                                                                                   | Regional for volatiles; for gravitational wave detectors hyperlocal thermal instabilities are of concern                                                                                                                                                                                                          | Concurrent for sunlight reflected onto other elements unless structure is in-place long-term                                 | Hyperlocal                                                                                                                                                     |
| EMI/RFI                     | Concurrent                                                                                                                                                                                         | RFI: Global for cislunar satellites<br>EMI: hyperlocal                                                                                                                                                                                                                                                            | Concurrent                                                                                                                   | RFI: Global for cislunar satellites<br>EMI: hyperlocal                                                                                                         |
| Contamination               | Long-term for some hazardous materials and for contamination of polar ice traps from exhaust; some exospheric impact temporary. Localized changes to surface likely permanent on human-timescales. | Can be global for exosphere short-term, long-term gases can be permanently trapped near lunar poles. Changes to surface will affect multiple processes (water transport, particle flow, temperature variation, illumination). Estimated that Starship could dump 70 T of water in the polar region and possibly a | Could be long-term for chemical contaminant health hazards                                                                   | Hyperlocal                                                                                                                                                     |

|                       |                                                         |                                                                                         |            |                        |
|-----------------------|---------------------------------------------------------|-----------------------------------------------------------------------------------------|------------|------------------------|
|                       |                                                         | similar amount of CO <sub>2</sub> ; <sup>423</sup> water may migrate into polar craters |            |                        |
| Seismic/Vibration     | Concurrent                                              | Can be hyperlocal for some disturbances, global for others                              | Concurrent | Hyperlocal to regional |
| Aesthetic Degradation | Potentially long-term if structures are not disposed of | Depends on the extent of visible structures                                             | N/A        | N/A                    |

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<sup>423</sup> Farrell et al., 2024

Table 10: Summarized public lunar interference questionnaire responses regarding mitigation mechanisms and existing technical/standards guidance

| Interference Concern        | Mitigation Mechanisms?                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Existing Technical or Standards work?                                                                                                                                      |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical                    | <ul style="list-style-type: none"> <li>• Infrastructure to minimize dust (roads/railways, landing pads, regolith walls)</li> <li>• Pre-mission CONOPS reporting requirements to include dust ejecta predictions</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                            |
| Thermal/Optical disturbance | <ul style="list-style-type: none"> <li>• See contamination</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                            |
| EMI/RFI                     | <ul style="list-style-type: none"> <li>• Pre-mission CONOPS to include planned spectrum use, characterization of EMI/EMC</li> <li>• Maintaining a database of transmitter frequencies used by all lunar assets regardless of country of origin</li> <li>• Coordination between active/passive users during early stages of tech development</li> <li>• Minimizing active band spectrum to allow for more science (particularly at bands blocked by Earth's ionosphere)</li> <li>• Locating missions at geographically dispersed areas away from passive users</li> </ul>                                                                                                                                                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>• MIL-STD-461 for EMI</li> <li>• ITU working groups 7a/7d</li> <li>• Space Frequency Coordination Group</li> <li>• CITEL</li> </ul> |
| Contamination               | <ul style="list-style-type: none"> <li>• Designate (temporarily or indefinitely) certain regions for certain purposes.</li> <li>• Studies of if and how sites may be 'restored' after (say) in situ resource utilization may also be worthwhile.</li> <li>• Add environmental impact requirements to the NextSTEP Appendices used to procure HLS services.</li> <li>• NASA provide explicit guidelines on (1) what these sites are with respect to science and exploration, and (2) how lunar actors should conduct operations in their vicinity without compromising their value. These guidelines may include recommended landing site keepaway distance, recommended rover keep-away distance, discouraging certain activities in certain areas, etc.</li> <li>• industry best practices and standards,</li> <li>• Economic incentives for companies to sell NASA in situ data prior to site compromise</li> </ul> | <ul style="list-style-type: none"> <li>• COSPAR</li> </ul>                                                                                                                 |

|                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |  |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
|                          | <ul style="list-style-type: none"> <li>• Expanding ITU framework and Interagency Operations Advisory Group work to consider preservation for scientific community</li> <li>• Cryogenic sample collection and storage prior to executing surface activities that may impact future science in that area.</li> </ul>                                                                                                                                                                                                                                                                                                        |  |
| Seismic/<br>Vibration    | <ul style="list-style-type: none"> <li>• Defining minimum distances between machines and a gravitational-wave detector (dependent on machine)</li> <li>• Correct detector data with environmental monitoring systems measuring seismic disturbance</li> </ul>                                                                                                                                                                                                                                                                                                                                                             |  |
| Aesthetic<br>Degradation | <ul style="list-style-type: none"> <li>• Significant alteration of the Moon's surface must be prohibited to preserve its integrity as seen by Earth's inhabitants, i.e., any area of material concentration or in-situ processing must be strictly limited to a size smaller than 1 arcsecond from the Earth surface, equivalent to a disc with a radius of 2 km at the Moon's equatorial location. This ensures it remains unnoticeable to the naked eye and through amateur telescopes. Additionally, each of these areas must be at least 30 arcseconds apart to prevent the formation of visible clusters.</li> </ul> |  |

Table 11: Interference concerns and potential additional information-sharing parameters

| Interference Concern        | Examples                                                                                                                                                                                                                                                                                                                                                                                                                              | Potential additional useful information                                                                                                                                                                                                                                                                                                        |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical                    | <ul style="list-style-type: none"> <li>• Cislunar Conjunctions</li> <li>• Occupation of highly desired orbits</li> <li>• Movement and compression of lunar soil, dust</li> <li>• Ejection of debris into cislunar space</li> <li>• Operations blocking desired path/location</li> <li>• Operations blocking solar power or comms</li> <li>• Threat of active physical contact, including due to uncertainty of positioning</li> </ul> | <ul style="list-style-type: none"> <li>• Schedule of activity if location different from landing</li> <li>• Controlled or uncontrolled soil disturbance and any knowledge of impact (e.g., PSI models)</li> <li>• Structure locations, sizes, mass</li> <li>• Orbital trajectory information (insertion, entry, ascent orbit entry)</li> </ul> |
| Thermal/optical disturbance | <ul style="list-style-type: none"> <li>• Heating resulting in dissipation of volatiles</li> <li>• Reflection of sunlight into another element or PSRs</li> <li>• Glint for cameras on subsequent missions</li> <li>• Alteration of thermal environment from shadowing</li> </ul>                                                                                                                                                      | <ul style="list-style-type: none"> <li>• Proximity to PSR</li> <li>• How much heat you are dissipating and how far</li> <li>• Panels that might reflect sunlight or affect local thermal conditions?</li> <li>• Structure locations, sizes, mass</li> </ul>                                                                                    |
| EMI/RFI                     | <ul style="list-style-type: none"> <li>• RFI from satellites</li> <li>• RFI/EMI at astronomical sites including from unshielded electronics (ion propulsion engines flagged)</li> <li>• Energy deposited into surface dust increasing charged particles in lunar plasma causing charged particle-antenna interactions</li> </ul>                                                                                                      | <ul style="list-style-type: none"> <li>• Location of operations</li> <li>• Planned frequency use (ground, ground to space, space to ground, space to space)</li> <li>• EMI standards used</li> </ul>                                                                                                                                           |

|                    |                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Contamination      | <ul style="list-style-type: none"> <li>• Improper disposal of hazardous materials</li> <li>• Unplanned disposal of materials</li> <li>• Biological/mechanical waste</li> <li>• Astrobiological contamination</li> <li>• Topographic changes impacting processes (e.g., water transport, particle flow, temperatures)</li> <li>• Contamination of cold traps from exhaust</li> <li>• Exospheric contamination</li> </ul> | <ul style="list-style-type: none"> <li>• Hazardous material list, including quantity and location</li> <li>• Level of spillage mitigation that exists and reliability</li> <li>• Disposal and extended capability plan (including surrendered, exhausted assets, what kind are there for long-haul that change environment or those available for reuse)</li> <li>• Risk of accidental explosion, potential impacts, mitigations to prevent explosion and exposure</li> <li>• Overflight information (where, when)</li> <li>• Propellant type</li> <li>• Operational strategy for ascent/descent (rocket design, number/orientation/position of firing nozzles)</li> </ul> |
| Seismic/ Vibration | <ul style="list-style-type: none"> <li>• Seismic/vibrational impacts to experiments (e.g., gravitational wave astronomy)</li> <li>• Solar panels in proximity to seismic station</li> </ul>                                                                                                                                                                                                                             | <ul style="list-style-type: none"> <li>• Engine size, number</li> <li>• Location/timing of activity</li> <li>• Other devices that might cause vibrational impacts (e.g., rovers)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

Table 12: Interference Concerns: Mission Development Information-Sharing Best Practices and Gaps

| <b>Interference Concern</b> | <b>Potential useful additional information</b>                                             | <b>Existing standard/best practice?</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Gaps?</b>                                                                                                                 |
|-----------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| Physical                    | Schedule of activity if location different from landing                                    | Artemis Accords: Location(s) of activity/activities, if different from landing location(s)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Temporal element of activities                                                                                               |
|                             | Controlled or uncontrolled soil disturbance and any knowledge of impact (e.g., PSI models) | Artemis Accords: Location(s) of activity/activities, if different from landing location(s); information related to scientific aspects or special considerations of activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Knowledge of soil disturbance, if controlled or uncontrolled, including models                                               |
|                             | Structure locations, sizes, mass                                                           | Artemis Accords: Landing location(s), Location(s) of activity/activities, if different from landing location(s),<br>Spacecraft mass at landing<br><br>ODAR:<br>Section 2: Spacecraft Description <ul style="list-style-type: none"> <li>a. Physical description of the spacecraft, including spacecraft bus, payload instrumentation, and all appendages, such as solar arrays, antennas, and instrument or attitude control booms</li> <li>c. Total spacecraft mass at launch, including all propellants and fluids</li> <li>d. Dry mass of spacecraft at launch (minus all consumables and propellants),</li> </ul> Section 3: Assessment of Spacecraft Debris Released during Normal Operations | Size and masses of all physically separate objects and their locations, including any objects on the lunar surface long-term |

|                             |                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                  |
|-----------------------------|-----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
|                             |                                                                       | <p>a. Identification of any object (&gt;1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material</p> <p>c. Time of release of each object, relative to launch time</p> <p>d. Release velocity of each object with respect to spacecraft</p> <p>e. Expected orbital parameters (apogee, perigee, and inclination) of each object after release</p> <p>f. Calculated orbital lifetime of each object, including time spent in LEO</p>                                                                                                         |                                                                                                                                                  |
|                             | Orbital trajectory information (insertion, entry, ascent orbit entry) | <p>ODAR:</p> <p>Section 1: Program Management and Mission Overview</p> <p>g. Identification of the proposed launch date and mission duration</p> <p>h. Description of the launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination</p> <p>i. Description of the spacecraft's maneuver capability, including both attitude and orbit control. Give the time period during which the capabilities will be exercised.</p> <p>k. Identification of any interaction or potential physical interference with other operational spacecraft</p> | None                                                                                                                                             |
| Thermal/optical disturbance | Proximity to PSR                                                      | Artemis Accords: Landing location(s), Anticipated landing accuracy (meters/kilometers)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Anticipated landing accuracy not always given and does not directly address proximity to PSR, including for operations distant from landing site |

|               |                                                                                  |                                                                                                                                                                         |                                                                                                                                                                                                |
|---------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               | How much heat you are dissipating and how far                                    | None                                                                                                                                                                    | Models of heat dissipation                                                                                                                                                                     |
|               | Panels that might reflect sunlight or affect local thermal conditions?           | None                                                                                                                                                                    | Information about optical and thermal reflectivity of objects, especially those permanently on the lunar surface. Locations/sizes will also help understand thermal conditions from shadowing. |
|               | Structure locations, sizes, mass                                                 | See above                                                                                                                                                               | See above                                                                                                                                                                                      |
| EMI/RFI       | Location of operations                                                           | See above                                                                                                                                                               | See above                                                                                                                                                                                      |
|               | Planned frequency use (ground, ground to space, space to ground, space to space) | Part of ITU filings                                                                                                                                                     | Would be helpful if submitted as part of registration in addition to location information                                                                                                      |
|               | EMI standards used                                                               | EMI standards exist; MIL-STD-461G and 464 in particular used in U.S.                                                                                                    | Disclosure of applicable standards used                                                                                                                                                        |
| Contamination | Hazardous material list, including quantity and location                         | ODAR:<br>Section 2: Spacecraft Description<br>e. Identification, including type, mass and pressure, of all fluids (liquids and gases) planned to be on board (including | Location of materials, organic material inventory not required for orbital assets, which                                                                                                       |

|  |                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                          |
|--|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  |                                                          | <p>any planned future in-space transfers), excluding fluids in sealed heat pipes.</p> <p>f. Description of all propulsion systems (e.g.: cold gas, mono-propellant, bi-propellant, solid propellant, electric, nuclear)</p> <p>h. Description of any range safety or other pyrotechnic devices</p> <p>i. Description of the electrical generation and storage system</p> <p>j. Identification of any other sources of stored energy not noted above</p> <p>k. Identification of any radioactive materials on board or an explicit statement that there are no radioactive materials onboard</p> <p>COSPAR planetary protection: organic material inventory</p>             | may become surface assets upon disposal.                                                                                                                                                 |
|  | Level of spillage mitigation that exists and reliability | <p>ODAR:</p> <p>Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions</p> <p>a. Identification of all potential causes of spacecraft breakup during deployment and mission operations</p> <p>b. Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion</p> <p>c. Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions</p> <p>d. List of components which are passivated at EOM. List includes method of passivation and amount which cannot be passivated.</p> <p>COSPAR planetary protection: organic material inventory</p> | ODAR section focused on orbital assets rather than spillage on lunar surface; organic material inventory not required for orbital assets, which may become surface assets upon disposal. |
|  | Disposal and extended capability plan (including         | <p>Artemis Accords: Plans for end of mission disposal</p> <p>ODAR:</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Extended capability plans, whether or not assets are on the surface                                                                                                                      |

|  |                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                           |
|--|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | surrendered, exhausted assets, what kind are there for long-haul that change environment or those available for reuse) | <p>Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures</p> <ul style="list-style-type: none"> <li>a. Description of spacecraft disposal option selected</li> <li>b.[...] Plan for any spacecraft maneuvers required to accomplish postmission disposal</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | long-term (and when safety zone might expire), availability of assets for reuse. Further guidance on disposal of radioactive materials, other hazardous materials on lunar surface needed |
|  | Risk of accidental explosion, potential impacts, mitigations to prevent explosion and exposure                         | <p>ODAR:</p> <p>Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions</p> <ul style="list-style-type: none"> <li>a. Identification of all potential causes of spacecraft breakup during deployment and mission operations</li> <li>b. Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion</li> <li>c. Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions</li> <li>d. List of components which are passivated at EOM. List includes method of passivation and amount which cannot be passivated.</li> </ul> <p>Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions</p> <ul style="list-style-type: none"> <li>a. Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft, assuming no collision avoidance capability.</li> <li>b. Calculation of spacecraft probability of collision with space objects, including orbital debris and meteoroids, of sufficient size to prevent postmission disposal.</li> </ul> | ODAR is focused on orbital assets, mitigation mechanisms may be different for lunar surface (including for mitigating impacts of disposal of orbital assets on lunar surface).            |

|  |                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                              |
|--|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
|  |                                                                                                        | d. Detailed description and assessment of the efficacy of any planned debris avoidance capability intended to help in meeting requirement 4.5-1, including any plans to move to less congested altitudes, as well as any tracking enhancements (e.g., GPS, laser retroreflector) that may assist in reducing the covariance of collision estimates. [...]                                |                                                                                                                                              |
|  | Overflight information (where, when)                                                                   | ODAR:<br>Section 1: Program Management and Mission Overview<br>h. Description of the launch and deployment profile, including all parking, transfer, and operational orbits with apogee, perigee, and inclination                                                                                                                                                                        | Detailed information about overflight of potential sites of scientific interest due to potential propellant deposition                       |
|  | Propellant type                                                                                        | ODAR:<br>Section 2: Spacecraft Description<br>e. Identification, including type, mass and pressure, of all fluids (liquids and gases) planned to be on board (including any planned future in-space transfers), excluding fluids in sealed heat pipes.<br>f. Description of all propulsion systems (e.g.: cold gas, mono-propellant, bi-propellant, solid propellant, electric, nuclear) | None                                                                                                                                         |
|  | Operational strategy for ascent/descent (rocket design, number/orientation/position of firing nozzles) | ODAR:<br>Section 2: Spacecraft Description<br>f. Description of all propulsion systems (e.g.: cold gas, mono-propellant, bi-propellant, solid propellant, electric, nuclear)                                                                                                                                                                                                             | Details on rocket design, number/orientation/position of firing nozzles and any models of impact to lunar surface relevant to ascent/descent |

|                       |                                                                   |                                         |                                                            |
|-----------------------|-------------------------------------------------------------------|-----------------------------------------|------------------------------------------------------------|
| Seismic/<br>Vibration | Engine size, number                                               | See above                               | See above                                                  |
|                       | Location/timing of activity                                       | See above                               | See above                                                  |
|                       | Other devices that might cause vibrational impacts (e.g., rovers) | Artemis Accords: Item(s) being deployed | List of other devices that might cause vibrational impacts |

Table 13: Interference concerns: measurements and models, gaps

| Interference Concern | Concern                                                                              | Measurements and models                                                                                                                                      | Gaps                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Physical             | Cislunar conjunctions                                                                | JPL MADCAP coordinates cislunar conjunction assessment and deconfliction <sup>424</sup>                                                                      | <p>MADCAP is opt-in for non-U.S.; no formal international consultation mechanism</p> <p>Tracking difficult for inactive objects</p> <p>Highly desired orbits may increase congestion</p>                                                                                                                                                                                                                                                                                                                                                                                                            |
|                      | Movement and compression of lunar soil, dust; ejection of debris into cislunar space | Apollo blasted dust to sand-sized particles several kilometers away; PSI impacts not well-understood and dependent on engine type/orientation <sup>425</sup> | <p>Many; from Watkins et al 2021:<sup>426</sup></p> <ul style="list-style-type: none"> <li>▪ What is are the size distributions, volumes, and velocities of particles lofted by exhaust plumes? How far do they travel?</li> <li>▪ How much dust (mass, particle size) remains lofted after engine shut-down, at what altitude and distribution, and for how long?</li> <li>▪ What physical changes occur to the surface in the landing zone?</li> <li>▪ How does PSI differ in different landing terrains?</li> <li>• What effects do lander size and engine configuration have on PSI?</li> </ul> |

<sup>424</sup> Z. Tarzi et al., “Deep-space Conjunction Assessment: Recent Developments and Future Evolution”, 29th International Symposium on Space Flight Dynamics , 22-26 April 2024, <https://www.nasa.gov/wp-content/uploads/2024/10/deep-space-conjunction-assessment-recent-developments-future-evolution.pdf?emrc=f57c9d>

<sup>425</sup> R. Watkins et al. “Understanding and Mitigating Plume Effects During Powered Descents on the Moon and Mars, ” Planetary Science Institute, 2021 <https://arxiv.org/abs/2102.12312>

<sup>426</sup> Id.

|                             |                                               |                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                             |                                               |                                                                                                                                                                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>• How does the mass/volume/size/velocity/flux of dust particles lofted in the exhaust plume evolve through repeated landings/launches within a zone of interest? Are hazards mitigated or increased with repeated landings/launches?</li> <li>• How far away from nearby hardware must a landing take place to ensure the safety of the emplaced infrastructure?</li> <li>• How important will landing pads / prepared surfaces be for repeat missions to an area, and how effective will they be over time?<sup>i</sup></li> </ul> |
| Thermal/optical disturbance | Heating resulting in dissipation of volatiles | <p>VIPER mission lighting would have minimal impact to volatiles, but missions with 5-hour lighting would substantially heat surface<sup>427</sup></p> <p>Spacesuits also can cause temperature change high enough to dissipate volatiles if static or slow-moving<sup>428</sup></p> <p>Many ISRU models seek to use heating to extract volatiles</p> | Heating very dependent on mission type/location and duration.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

<sup>427</sup> J. Ivarson, et al. “The Effect of VIPER Headlights on Lunar Surface and Subsurface Temperatures”. 54th Lunar and Planetary Science Conference 2023 (LPI Contrib. No. 2806)

<sup>428</sup> C. Olthoff, D. Kashubek, and M. Killian. “Dynamic Thermal Interactions Between Spacesuits and Lunar Regolith in Permanently Shaded Regions on the Moon”, *Acta Astronautica*, 203, 351-369, 2023.

|               |                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                              |
|---------------|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EMI/RFI       | Energy deposited into surface         | Electrostatic hazard from movement of rovers and astronauts in PSRs, with the charge lasting 100s of seconds in shadowed regions but less than one millisecond in the weakly sunlit terminator region. <sup>429</sup> Also naturally occurring EMI; e.g. at Shackleton crater where leeward wall has -175V potential <sup>430</sup>                                                                                                                                                                                                        | Understanding of electrostatic charge due to operations as well as during natural conditions                                                                                                 |
| Contamination | Volatile and exospheric contamination | <p>Regardless of mass, contaminants will stick on night side. Mid-mass contaminants will stick permanently at high/low latitudes even during the day, and high mass will stick permanently at all latitudes regardless of day/night<sup>431</sup></p> <p>Plumes can substantially impact amount of ice and CO<sub>2</sub> cold trapped at poles even for mid-latitude landing; increase in lunar surface water at south pole 20% for one starship landing. Exospheric contamination can last 10s of hours after landing.<sup>432</sup></p> | NASA currently working to expand molecular contamination understanding and develop a comprehensive organic inventory strategy and framework that included more sources than just outgassing. |

<sup>429</sup> W. Farrell, et al. “Concerning the dissipation of electrically charged objects in the shadowed lunar polar regions”, Geophysical Research Letters, Space Sciences, Vol 35, Issue 19, Oct 2008

<sup>430</sup> C. Zhao, et al. “Theoretical analysis of the electric potential and the electrostatic dust transport around the Shackleton crater in the Lunar south pole region”, Science China Press 2023, <https://www.sciengine.com/doi/pdf/B43498E302C24415989CAA043B1D633A>

<sup>431</sup> C. Soares et al., “Characterization of Organic Footprint from Moon, Mars, and Ocean World Landing Systems for Robotic and Crewed Missions.” 75<sup>th</sup> International Astronautical Congress, Oct 14-18, 2024. <https://dataverse.jpl.nasa.gov/dataset.xhtml?persistentId=doi:10.48577/jpl.SBXCXY>

<sup>432</sup> W. Farrell, et al., 2024

|                       |                                                                                              |                                                                                                                                                                                              |                                                                               |
|-----------------------|----------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
|                       |                                                                                              | Additional anthropogenic sources of exospheric contamination include airlocks, backpacks, and lander, plus any trash and mining operations, making exospheric studies near lander difficult. |                                                                               |
|                       | Topographic changes impacting processes (e.g., water transport, particle flow, temperatures) |                                                                                                                                                                                              | Poorly understood impact                                                      |
| Seismic/<br>Vibration | Seismic/vibrational impacts to experiments (e.g., gravitational wave astronomy)              | Known disturbance from trains on Earth at 3km <sup>433</sup>                                                                                                                                 | International Astronomical Union currently working on further recommendations |

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<sup>433</sup> A/AC.105/C.1/2024/CRP.11, Reports of the Moon Village Association, Committee on the Peaceful Uses of Outer Space Scientific and Technical Subcommittee, 29 Jan-9 Feb 2024  
[https://www.unoosa.org/res/oosadoc/data/documents/2024/aac\\_105c\\_12024crp/aac\\_105c\\_12024crp\\_11\\_0\\_html/AC105\\_C1\\_2024\\_CRP11E.pdf](https://www.unoosa.org/res/oosadoc/data/documents/2024/aac_105c_12024crp/aac_105c_12024crp_11_0_html/AC105_C1_2024_CRP11E.pdf)

## Conclusions

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This dissertation examines oversight needs for the transformation of the U.S. space sector from one dominated by government owned and operated systems, to one in which commercial services are procured by both the federal government and private sector. Historic oversight of the U.S. space sector has been driven by this government demand, with DoD and NASA developing space system safety requirements for novel technologies through contracts rather than regulation, and economic considerations focused on immediate national security needs instead of enabling long-term competition and a commercial marketplace. As such, the U.S. government is struggling to keep up with the exponential increase in launch and satellite licensing, let alone provide meaningful oversight of new technologies, or track economic metrics that determine the competitiveness of space subsectors and viability of commercial markets independent of government customers.

For the space industry at large, those in charge of oversight should always be prepared to answer “if it explodes, what happens?” In the case of commercial human spaceflight, rippling economic repercussions could impact not only a company with an accident, but also impact other companies in the sector; what happens if NASA is reliant on the same service for ISS transport? If the U.S. lost SpaceX launch capabilities, or at least launch capabilities at one launch facility, what would this mean for U.S. space infrastructure with launches on other vehicles booked out for years? For lunar operations, how do you coordinate and respond to a robotic lunar landing if there are humans nearby on the surface, and how do you take into account the risk of an uncontrolled or crash landing?

Trends in U.S. oversight writ large are reactionary to major negative events, as discussed in aviation regulatory history in Section 2. Although there are substantial advantages to light oversight from both a requirements and regulatory perspective before a new technology is standardized or well-understood by government authorities, it may be possible to improve communication, coordination, and sharing of data and lessons learned in ways that may encourage safe operations and form the building blocks of requirements or regulations. As an example of a new industry with minimal regulatory oversight, the lunar community has largely been proactive in encouraging cooperation and information-sharing to ensure safe operations. Commercial lunar stakeholders in their survey responses were positive about sharing basic CONOPS information prior to launch to help mitigate potential interference amongst actors, in contrast to some government stakeholders who initially were wary at the concept of information-sharing due to the need to protect sensitive information. There was also largely an acknowledgement of needing to work together across scientific and technical communities to determine optimal usage of different sites, and share data and lessons learned from operations. Operators are currently working to start to create standards for lunar infrastructure, much in the same way the commercial human spaceflight community is beginning to create its own standards.

Internal, rather than government, oversight for more established technologies creates its own perverse economic incentives as Section 2 and 3 have shown. The aviation industry has largely self-certified, which has led to fatal accidents especially under economic pressure or decentralized reporting structures (whether on the regulatory side or oversight of outsourcing);

this was a known factor in the two 737 Max 8 crashes.<sup>434</sup> In Section 3, we show that even the most innovative critical infrastructure monopolies typically stopped innovating once achieving their monopolistic market shares as innovation would come at a cost to their profits, and that private sector utility monopolies typically underinvest on infrastructure to maximize earnings.

Although industry has often expressed concern about early government interventions during the release of new technology, such interventions can provide regulatory, economic, or technical certainty. The aviation industry demanded initial regulation as they were unable to procure insurance without it; there are numerous U.S. industry proponents of a mission authorization and supervision regime to ensure that licensing results in a yes, rather than a legal gray area which results in extensive interagency review, particularly for technologies which might be flagged as national security concerns (for instance, space nuclear power). Similarly, industry is actively working on studies for the ITU future agenda item on lunar communications, to ensure that long-term lunar infrastructure whose technological development often begins five or more years before its launch, is able to operate without interference. For technologies in which the U.S. government is the primary customer, it may be possible to build in safety requirements which can be later adopted by regulatory authorities; one example of this is the U.S. Orbital Debris Mitigation Standard Practices, for which NASA is the lead agency, but have been adopted by the FCC and FAA in their licensing regimes and have become an international standard which other countries adopt.

Better interagency coordination is needed particularly for early-stage policy interventions. Due to the complex space regulatory structure in the U.S., the authorizing agency is often not the technical expert on the technology being licensed; requests for technical assistance from other agencies (particularly NASA and DoD) are often complex and unfunded, resulting in low prioritization. Although the creation of the Space Force has sought to better align DoD space acquisitions, fractured U.S. government acquisitions of space systems have not aligned overall investment strategies to ensure competition or ensure expedient and efficient licensing, with investments across a variety of DoD agencies, the intelligence community, NASA, Department of Commerce, and occasionally other agencies for specialized programs. A 2024 GAO report found that the DoD pushed programs forward without sufficient knowledge about technical design, and lacked sufficient data on the effect of acquisitions pathways on technical capabilities;<sup>435</sup> alignment with interagency technical needs adds yet another layer of complexity. Nascent efforts in some domains, such as the White House-led 2024 National Cislunar Science and Technology Action Plan, have sought to bring together interagency stakeholders and identify specific technical and policy actions which each agency should undertake to enable a technology in a specific domain.<sup>436</sup> Often missing from these interagency plans is a study of economic impact or effectiveness of government interventions. The White House should include the National Economic Council in such plans, and work with interagency

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<sup>434</sup> Davis, Aaron C., and Lopes, Marina, “How the FAA allows jetmakers to ‘self certify’ that planes meet U.S. safety requirements”, Washington Post, 15 March 2019 [https://www.washingtonpost.com/investigations/how-the-faa-allows-jetmakers-to-self-certify-that-planes-meet-us-safety-requirements/2019/03/15/96d24d4a-46e6-11e9-90f0-0ccfeec87a61\\_story.html](https://www.washingtonpost.com/investigations/how-the-faa-allows-jetmakers-to-self-certify-that-planes-meet-us-safety-requirements/2019/03/15/96d24d4a-46e6-11e9-90f0-0ccfeec87a61_story.html)

<sup>435</sup> “Space Acquisitions: Analysis of Two DOD Reports to Congress”, GAO-24-106984, GAO, 26 March 2024 <https://www.gao.gov/products/gao-24-106984>

<sup>436</sup> “National Cislunar Science and Technology Action Plan”, Executive Office of the President, December 2024, <https://bidenwhitehouse.archives.gov/wp-content/uploads/2024/12/Cislunar-Implementation-Plan-Final.pdf>

economic experts, such as those in the Department of Commerce’s Bureau of Economic Analysis or experts at the Federal Trade Commission monitoring anticompetitive behavior, to determine the success of acquisitions programs and monitor economic indicators as discussed in Section 4. Such interagency task forces may also help align regulatory or standards efforts; the National Cislunar Science and Technology Action Plan acknowledges the need for cislunar coordination and consultation, as well as the need to identify harmful impacts that might limit future use,<sup>437</sup> but further interagency and international lunar consultation is needed to identify coordination best practices, data, and technology needs per Section 4.

For more developed technologies, particularly those upon which the U.S. government or general public is heavily reliant, monitoring of market conditions to ensure a price-competitive, innovative, and resilient climate is needed per Section 3. Although monopolies may remain innovative during Cournot competition where firms compete on the amount of output (which is currently the case for the space industry for both launch and satcom, which are capacity constrained), disruptions which add excess capacity are likely to entrench a monopoly and halt innovation. Starship is eventually expected to be such a disruption. Interagency coordination is needed today to ensure competitive entry points to all segments of the space supply chain and ensure resilience. War games and tabletop exercises may help elucidate the overall impact to the disruption of any element of the space supply chain.

Not explored in this work is the impact of first-mover regulatory advantage; this has particularly been a subject of FCC proceedings which favor incumbent licensees in interference mitigation, but also may be of eventual concern for lunar landings and the designation of safety zones or heritage sites, which may be nefariously used to try to create keep-out zones to prevent others from accessing certain lunar sites.

As we enter a new era of heavy U.S. government reliance on commercial space services, we must transform oversight mechanisms for commercial space. Given the nascency of many space technologies, it is critical to look to historical parallels, such as the history of aviation regulation or the behaviors of critical infrastructure monopolies in Sections 2 and 3, to determine best oversight mechanisms and determine when policy interventions are needed. For sectors which are largely too nascent for regulatory oversight, such as lunar operations in Section 4, it is critical to work across the international governmental, non-profit, academic, and commercial community to determine potential technical, scientific, logistical, or communications barriers to achieving safe, sustained, and sustainable operations. While industry standards will form the backbone of eventual regulations for many nascent technologies, equally important are creating transparent mechanisms for communicating safety concerns or data which may help improve safe operations. We hope that although the current Administration is likely to be light touch on regulation, a strong National Space Council may help better align interagency technology development and information-sharing efforts in critical space technology domains.

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<sup>437</sup> Ibid.

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