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THESIS

IMPROVING NAVAL SPECIAL WARFARE INNOVATION: LESSONS FROM THE SPACE ECOSYSTEM

by

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December 2023

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**IMPROVING NAVAL SPECIAL WARFARE INNOVATION: LESSONS FROM
THE SPACE ECOSYSTEM**

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ABSTRACT

What factors influence technology adoption in the U.S. Space Force, NASA, and commercial space industry, and can these insights benefit technology innovation in Naval Special Warfare (NSW)? The growing space industry is rich with innovation lessons and offers insights to inform military modernization efforts with an emphasis on identifying their innovation philosophy and the challenges in realizing it. Military leaders face similar innovation obstacles to external, non-military organizations and can draw lessons from such organizations to improve their process for technology adoption. Based on current innovation frameworks, the research identified three factors influencing technology adoption: COMFORT, STAFF & SYSTEMS, and END-USER. Deploying these factors of influence, an analysis of several technology adoption cases reveals how each factor affects adoption outcomes. Key findings emphasize the importance of effective communication, understanding user needs, and organizational adaptability in technology adoption. The research suggests that managing risk perception, incentivizing innovation, engaging users, and equipping decision-makers with actionable information can enhance military innovation. This analysis provides insights for NSW and other military units to optimize technology adoption processes. Policy recommendations include increasing the shared understanding of technologies while overcoming organizational resistance to maintain a competitive edge in future conflicts.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASDS	Advanced SEAL Delivery System
COTS	Commercial-Off-the-Shelf
CTO	Chief Technology Officer
CTP	Commercial Technology Pipeline
DIO	Defense Innovation Organization
DIU	Defense Innovation Unit
DOD	Department of Defense
DOI	Diffusion of Innovation
GEO	Geosynchronous Earth Orbit
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
IRAD	Internal Research and Development
KSC	Kennedy Space Center
LEO	Low Earth Orbit
M-code	Military Code
NASA	National Aeronautics and Space Administration
NDS	National Defense Strategy
NSW	Naval Special Warfare
OCX	Next Generation Operational Control System
OTA	Other Transaction Authority
PLA	People's Liberation Army
PRC	People's Republic of China
RDT&E	Research, Development, Test, and Evaluation
RF	Radio Frequency
SATCOM	Satellite Communications
SDA	Space Domain Awareness
SDV	SEAL Delivery Vehicle

SEAL	Sea, Air, and Land Special Operator
SOCOM	Special Operations Command
SOF	Special Operations Forces
SpaceX	Space Exploration Technologies
SSA	Space Situational Awareness
SSC	Space Systems Command
STM	Space Traffic Management
SWAC	Space Warfighting Analysis Center
TAL	Technology Adoption Life cycle
TBIRD	Terabyte Infrared Delivery System
TEMPO	Technology Enterprise and Mission Pathfinder Office
TRL	Technology Readiness Level
USAF	United States Air Force
USSF	United States Space Force
VEO	Violent Extremist Organization

EXECUTIVE SUMMARY

Title: Improving Naval Special Warfare Innovation: Lessons from the Space Ecosystem.

Research Question: What factors influence technology adoption in the U.S. Space Force, NASA, and commercial space industry? Can these insights benefit technology innovation in NSW?

Findings: While all three variables identified in this study—COMFORT, STAFF & SYSTEMS and END-USER factors—can tip the adoption outcome towards success or failure, STAFF & SYSTEMS and END-USER factors were most impactful to government organizations that typically suffer from entrenched processes. STAFF & SYSTEMS refer to organizational influences such as the culture, various resistances, and staff processes. END-USER factors refer to the implementation of user input and user comprehension of risk and applicability of the innovation. These factors may be more critical for NSW to consider when adopting emerging technologies.

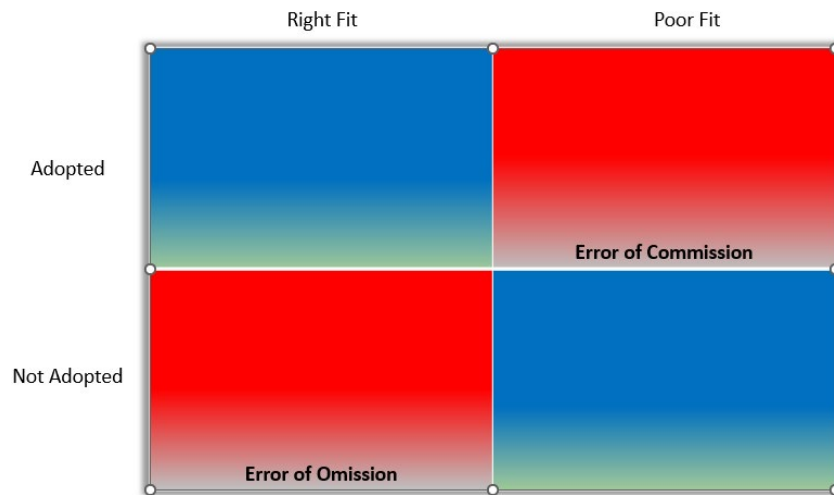
Additional takeaways are provided below:

1. **It is not just about the technology.** Entrenched processes typically stall or prevent a new technology from being successful. Leaders should question entrenched processes and their original purposes.
2. **It is mainly about the people.** Humans often serve as inhibitors to innovation. The good news is that these “regulators” of innovation can be converted to “enablers” by changing the incentive structure to support the organization’s innovation goals. Leaders can often start by answering the question: “What’s in it for them?”
3. **Communication is key.** Organizational members should communicate the benefits of the innovation up, down, and across the organization to achieve a successful outcome. Communication informs key decision-makers while

aligning end-users with innovation objectives to facilitate the development of new operational concepts.

4. **Reframe risk.** Two types of errors are involved in technology adoption: errors of omission (failing to adopt useful technologies) and errors of commission (adopting useless technologies). Government bureaucracies tend to favor maintaining the status quo because they are incentivized to avoid errors of commission at the cost of rewarding errors of omission. Leaders must reframe incentives for the staff to understand and balance both types of risks.
5. **Integrate the operators at every opportunity.** The end-user determines if an innovation is successful or not. There are many NSW operators and opportunities to get them involved early in implementation, demonstrations, TTP generation, and feedback loops that may inform future innovations.
6. **Education is the technology NSW needs most.** The organization needs to improve its comprehension and understanding of innovations before implementing emerging solutions skillfully. NSW must cross the “say-do” gap between what senior military leaders ask regarding technology and what the operators can deliver based on their limited understanding of these technologies. Solving this challenge may require innovating how we mass-deliver education to operators with little discretionary time.

The study simplified the concept of technology adoption and identified four possible outcomes: (1) adopting useful innovations, (2) passing on useless innovations, (3) errors of omission, and (4) errors of commission. The following figure illustrates these outcomes. The blue quadrants are desirable (outcomes 1 and 2), and the red quadrants are undesirable (outcomes 3 and 4).



Possible Outcomes of Technology Adoption.

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I. INTRODUCTION

A. BACKGROUND

The 2022 U.S. National Defense Strategy (NDS) highlights the People’s Republic of China (PRC) as “the most comprehensive and serious challenge to U.S. national security.”¹ The People’s Liberation Army (PLA) is continually advancing its technological competency and integration of several domains, including space, counter-space, cyber, electronic warfare, and information warfare.² This rapid technological advancement, assisted by national economic growth and substantial investments in national defense, has made the PLA a more capable and effective fighting force.³ These advancements have arguably enabled China to reach near-technological parity with the U.S. military.⁴

Guided by the NDS, the U.S. Department of Defense (DOD) is shifting its focus from counterterrorism to strategic competition and increasing readiness for state-based conflict.⁵ In lieu of this change in mission, the U.S. Department of Defense (DOD) is investing significantly in private partner collaboration and emergent technologies to outpace looming technological threats and sustain best-in-class capabilities.⁶ This realignment of priorities is evident in the \$123 billion expenditure in FY22 on research, development, test, and evaluation (RDT&E) accounts, a \$50 billion increase from just five years earlier.⁷ Naval Special Warfare (NSW) is no exception to this trend and “employs an

¹ U.S. Department of Defense, *2022 National Defense Strategy of The United States of America* (Washington, D.C.: U.S. Department of Defense, 2022), 4 <https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF>.

² U.S. Department of Defense, 4.

³ Joseph R. Biden Jr., *2022 National Security Strategy of the United States of America* (Washington, D.C.: The White House, 2022), 23–25.

⁴ Josh Rogin, “China’s Military Expansion Is Reaching a Dangerous Tipping Point,” *Washington Post*, June 17, 2022, para. 3, <https://www.washingtonpost.com/opinions/2022/06/16/china-expansion-indopacific-asia-taiwan-xi-aquilino/>.

⁵ U.S. Department of Defense, *2022 National Defense Strategy of The United States of America*.

⁶ U.S. Department of Defense, 9.

⁷ William Thomas, “DOD Budget: FY22 Outcomes and FY23 Request,” AIP, June 15, 2022, para. 1, <https://ww2.aip.org/fyi/2022/dod-budget-fy22-outcomes-and-fy23-request>.

aggressive approach to leveraging technology and data-driven means” that improve battlefield effects while mitigating risk and providing unique solutions to operational challenges.⁸ Specifically, NSW established an N9 directorate in 2020 to conceptualize and develop transformational technologies and operational concepts while identifying and purchasing commercially available disruptive technologies.⁹ Academia and the commercial industry significantly influence NSW’s innovation perspective and construct, aligning it with the NDS directives.

Aside from academia and industry, other viable sectors, such as the space ecosystem, provide unique value and insights into NSW’s mission to identify, develop, and adopt emerging technologies. The space ecosystem, defined as the diverse array of public and private space organizations, has rapidly expanded, reaching \$469B in global spending in 2021.¹⁰ For example, U.S. government spending accounted for \$59.6B of this total (a 12% global share).¹¹ Given the unforgiving nature of space operations, many organizations in the space ecosystem operate under the same risk-associated pressures as NSW. For instance, the National Aeronautics and Space Administration’s (NASA) first mission in a stepwise progression of returning humans to the Moon, Artemis-1, highlights these shared challenges.¹² Like NSW’s efforts in adopting new technologies, NASA pursued an ambitious (and successful) outcome while managing the substantial risks and uncertainties associated with a manned mission to the Moon. Additionally, with its last lunar mission over 50 years prior, NASA was forced to develop and adopt unproven innovations, introducing more uncertainty and magnifying the risk of a high-profile failure. The Artemis-1 mission required NASA to integrate many novel systems, including the Space

⁸ Scott Gourley, “NAVSPECWARCOM: Interview: Rear Adm. Collin P Green, Commander Naval Special Warfare Command,” *issuu*, n.d., para. 27, https://issuu.com/faircountmedia/docs/soo19a_issuu_prepped__2_/s/102037.

⁹ Scott Gourley, “Naval Special Warfare Command Modernization,” *Defense Media Network* (blog), n.d., para. 1, <https://www.defensemmedianetwork.com/stories/naval-special-warfare-command-modernization/>.

¹⁰ Carlie Porterfield, “Space Industry Grew to Record \$469 Billion Last Year, Report Finds,” *Forbes*, n.d., para. 1, <https://www.forbes.com/sites/carlieporterfield/2022/07/27/space-industry-grew-to-record-469-billion-last-year-report-finds/>.

¹¹ Porterfield, 5.

¹² NASA, “Artemis I,” NASA, n.d., <https://www.nasa.gov/mission/artemis-i/>.

Launch System and Orion spacecraft.¹³ Moreover, Artemis-1 required “all of NASA’s space communications and navigation networks to work in tandem” to ensure that future crewed missions to the Moon would have communications and tracking services through all phases of the mission.¹⁴ This complex orchestration of multiple unproven systems and processes underscores the similar challenges organizations like NSW faces when pushing technology frontiers.

B. RESEARCH QUESTION

This research analyzes different organizations within the space ecosystem to determine how each innovates through technology adoption. The organizations selected are comprised of: DOD, civil space, and commercial industry components of the space ecosystem. The findings will provide insights for NSW and other military units to modernize their organizations through optimized technology adoption and innovation strategies. Therefore, this thesis seeks to answer the following research question.

What factors influence technology adoption in the U.S. Space Force, NASA, and commercial space industry? Can these insights benefit technology innovation in NSW?

C. LITERATURE REVIEW

This literature review is sectioned into three relevant themes to explore technology adoption supporting the research question. The first section briefly discusses foundational technology diffusion principles led by the work of Everett Rogers and Geoffrey Moore. The second section discusses additional organizational-based factors that can promote or impede technological innovation. The last section discusses the DOD’s challenges in modernizing through integrating emerging technology. The gaps in the DOD’s technology innovation strategy will inform the research approach and analysis when evaluating the space ecosystem.

¹³ Rachel Kraft, “Analysis Confirms Successful Artemis I Moon Mission, Reviews Continue—NASA,” *NASA* (blog), March 7, 2023, para. 1, <https://www.nasa.gov/humans-in-space/analysis-confirms-successful-artemis-i-moon-mission-reviews-continue-2/>.

¹⁴ Danny Baird and Katherine Schauer, “Artemis I: Demonstrating the Capabilities of NASA’s United Networks—NASA,” *NASA* (blog), October 8, 2020, para. 2, <https://www.nasa.gov/missions/artemis/artemis-i-demonstrating-the-capabilities-of-nasas-united-networks/>.

1. Foundational Innovation Diffusion Principles

Many experts in the field of technology adoption agree that Everett Rogers' Diffusion of Innovation (DOI) theory is foundational to technology innovation and diffusion, shown by Rogers' book as the second most cited across the social sciences.¹⁵ The theory explains the rate at which an innovation (product, service, process, or idea) spreads through a population.¹⁶ In doing so, organizations may better understand the factors determining the rate at which customers adopt innovations. These factors are characteristic differences between the populations that adopt innovations early and those that adopt innovations late. In 1903, Gabriel Tarde developed the original S-shaped diffusion curve;¹⁷ however, Rogers later refined this model to create a normal distribution curve (or bell-shaped curve) to illustrate the five categories of adopters that characterize a market.¹⁸ These categories are the innovators, early adopters, early majority, late majority, and laggards. Figure 1 shows the DOI normal distribution curve, later known as the "Technology Adoption Life cycle" (TAL).¹⁹

¹⁵ Enablers of Change, "What Is the Diffusion of Innovations Theory?—Enablers of Change," Enablers of Change, May 24, 2021, para. 4, <https://www.enablersofchange.com.au/what-is-the-diffusion-of-innovations-theory/>.

¹⁶ Everett Rogers, *Diffusion of Innovations* (New York: Free Press of Glencoe, 1962).

¹⁷ Gabriel Tarde, *The Laws of Imitation* (New York: Holt and Company, 1903).

¹⁸ Everett Rogers, *Diffusion of Innovations*, 5th ed. (New York: Free Press, 1995), 247.

¹⁹ Geoffrey Moore, *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers*, 3rd ed. (Harper Business, 2014).

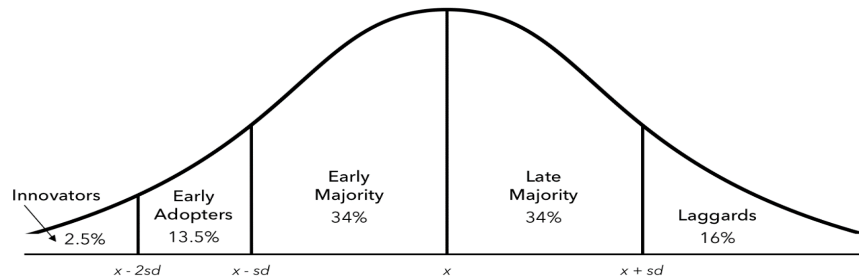


Figure 1. Rogers' Diffusion of Innovation Normal Distribution Curve with Five Adopter Categories.²⁰

Like Ryan and Gross (1943), who analyzed the diffusion of a corn seed innovation among Iowa farmers²¹ and influenced Rogers' claims that communication between adopter categories is critical to the diffusion process.²² Further, each population's unique social characteristics (social system or social capital) determine the diffusion rate. For example, the "innovators" typically accept more risk in innovation adoption and are generalized by their higher social status, higher disposable income, and deeper connections with other innovators and developers. Conversely, "laggards" adopt innovations late due to more risk-averse behavior, lower disposable income, and few social connections outside immediate family and close friends. As a result of differing characteristics between populations, viable marketing strategies can be formulated from a thorough understanding of behavior change, trends, and roles and responsibilities of key marketers or communicators. While Ryan & Gross (1943) identified broad characteristic differences between early and late adopter markets,²³ Rogers refined these market segments and distributed them along a bell curve.

Although much attention is given to population-specific differences in earlier editions of Rogers' work, he also emphasizes product-specific characteristics in later

²⁰ Source: Rogers, *Diffusion of Innovations*, 1995.

²¹ B. Ryan and N. Gross, "The Diffusion of Hybrid Seed Corn in Two Iowa Communities," *Rural Sociology* 8, no. 1 (1943): 15–24.

²² Rogers, *Diffusion of Innovations*, 1962.

²³ Ryan and Gross, "The Diffusion of Hybrid Seed Corn in Two Iowa Communities."

editions. He classifies these characteristics as “Attributes of Innovations.”²⁴ These innovation attributes include relative advantage, compatibility, complexity, trialability, and observability.²⁵ First, “relative advantage” refers to the benefits of the innovation compared to the incumbent technology, process, or idea.²⁶ Second, an innovation’s “compatibility” “is its congruence with the end-user’s existing behaviors, beliefs, and experiences.”²⁷ Next, “trialability” refers to the opportunities available for demonstrations and experimentation to witness first-hand the benefits of the innovation.²⁸ Then, the “complexity” of an innovation describes the degree to which end-users can understand its use.²⁹ Lastly, “observability” refers to the visibility of the innovation and its potential to influence others to adopt it.³⁰ While the success rate of new product innovation is low, when managed well, these five attributes can positively influence the diffusion rate associated with innovations.³¹ Rogers’ seminal “Attributes of Innovation” from his DOI theory formed the basis for later influential works, including those by Tidd and Bessant (1985), Moore (1991), and Goldenberg (2001).

Building off Rogers’ work, Geoffrey Moore (1991) provides equally foundational insights into innovation diffusion by identifying and focusing specifically on “The Chasm” within the TAL.³² Rogers did not identify this characteristic in his original work. “The Chasm” is a “gap between the early adopters and the early majority” (Figure 2), defined as the most significant challenge a product must overcome to reach the mainstream market successfully.³³ A chasm exists between these adopter groups due to differences in

²⁴ Rogers, *Diffusion of Innovations*, 1995, 210.

²⁵ Rogers, 211.

²⁶ Rogers, 217.

²⁷ Rogers, 223.

²⁸ Rogers, 231.

²⁹ Rogers, 230.

³⁰ Rogers, 232.

³¹ Rogers, 233.

³² Moore, *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers*.

³³ Moore, 25.

behavior, motivations, risk tolerance, and end-user needs.³⁴ The mainstream adopters are generally more pragmatic with their preferences, tolerate less risk, find significant behavior changes unappealing, and must observe the innovation being used successfully by others.³⁵ Informed by numerous case studies, including an examination of Apple, IBM, and Cisco, Moore offers several methods for crossing the chasm. The first is to target a very small market within the early majority (likened to securing a beachhead) so that this group can be referenceable and facilitate future diffusion.³⁶ Next, the innovation's characteristics should be deliberately refined to better match the selected niche market and provide a complete solution to this market's problems (whole product concept).³⁷ Finally, the innovation must be masterfully contrasted against existing alternatives to effectively message to end-users that the innovation is a safer option.³⁸ The philosophies of Everett Rogers and Geoffrey Moore have significantly influenced the widespread approach to product adoption by clearly identifying the challenges and providing proven strategies to overcome them.

³⁴ Moore, 25–31.

³⁵ Moore, 53.

³⁶ Moore, 75.

³⁷ Moore, 130.

³⁸ Moore, 164.

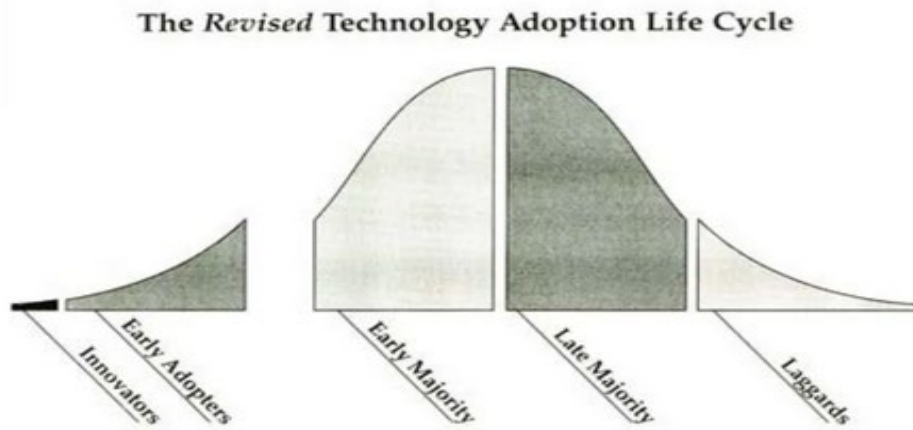


Figure 2. “The Chasm” Found in the Technology Adoption Life Cycle (TAL).³⁹

2. Organizational Factors of Technology Innovation

This section reviews several organizational factors that drive technology adoption apart from the product- and user-specific factors examined in the last section.

Though Rogers grounded his DOI theory across diverse empirical cases from agriculture to public health, later scholars focused on applying his framework specifically to technology innovation. The Stanford Innovation Project was a multi-phase study conducted in 1982 that assessed the U.S. electronics industry to determine organizational factors that affected new product innovation.⁴⁰ Researchers compared successful and unsuccessful innovations from 36 companies to determine critical factors that contributed to new product success.⁴¹ The research yielded several key communication-centric findings that support Rogers’ and Moore’s innovation theories. First, organizations engaged in frequent and intense customer interaction fully understood end-user needs,

³⁹ Source: Moore, *Crossing the Chasm*, 3rd ed., 2014, 21

⁴⁰ Modesto A. Maidique and Billie Jo Zirger, “A Study of Success and Failure in Product Innovation: The Case of the U.S. Electronics Industry,” *IEEE Transactions on Engineering Management* EM-31, no. 4 (November 1984): 192–203, <https://doi.org/10.1109/TEM.1984.6447537>.

⁴¹ Maidique and Zirger.

which correlated to new product success.⁴² Moreover, when the organizations fully met the identified needs of the end-user through product specification, it significantly boosted the positive outcome of the innovation. Another key finding is that product success was influenced more by marketing and promotional factors than the technological benefit of the innovation. This finding is consequential because Gourville states, “Many technologists believe that advantageous innovations will ‘sell themselves’ and diffuse rapidly.”⁴³ Other drivers of success encompass educating end-users, reducing risk by leveraging developer expertise, and sustaining managerial support through development and implementation to overcome impediments. This research made a significant contribution to the field through its large-scale validation of the drivers of new product success.

More recently, Leonard-Barton and Kraus argue that effective implementation of new technologies is just as important as developing them but poses several managerial challenges.⁴⁴ These challenges include understanding the implementation manager’s dual role, appropriately marketing without overhyping, and overcoming organizational resistance.⁴⁵ First, managers should balance the perspectives of the technology developers and the end-users.⁴⁶ The needs of both groups should be fulfilled to adopt innovations into the organization successfully. Secondly, marketing strategies should be multi-dimensional and target several constituencies, such as top management, middle managers, and end-users.⁴⁷ The different groups require different marketing strategies and arguments for successful persuasion. Moreover, managers should not “overhype” the innovation because the technology would likely not live up to expectations, leading to disillusionment. The allocation of marketing responsibilities across several roles, including sponsors, champions, project managers, integrators, and a single implementation executive authority,

⁴² Maidique and Zirger, 201–202.

⁴³ John Gourville, “Note on Innovation Diffusion: Rogers’ Five Factors” (Harvard Business School, April 2006), sec. 2.

⁴⁴ Dorothy Leonard-Barton and William A Kraus, “Implementing New Technology,” *Harvard Business Review*, 1985.

⁴⁵ Leonard-Barton and Kraus.

⁴⁶ Leonard-Barton and Kraus, sec. 2.

⁴⁷ Leonard-Barton and Kraus, sec. 3.

also leads to successful technology implementation.⁴⁸ Finally, the authors contend that organizational resistance arises from innovations that fail to demonstrate clear personal advantages or employees who fear the erosion of their skills, job security, or control.⁴⁹ As a result, Leonard-Barton and Kraus highlight that managerial skill is critical to successfully implementing and capturing the benefits of technological innovations.

3. Department of Defense Challenges

Experts widely acknowledge that the complex and hierarchical organizational structure of the DOD may pose challenges to its capacity for rapid innovation and the adoption of new technologies. In 2023, the RAND Corporation published the results of a DOD-wide study that identified shortcomings in how the DOD transitions commercial innovations to the military, named the commercial technology pipeline (CTP).⁵⁰ The study cited a long history of U.S. government-sponsored research and development (R&D) that provided a substantial technological superiority advantage relative to peers and adversaries. The U.S. military's technological superiority, once a critical strategic asset, is now eroding due to a booming commercial technology industry and rival nations' military modernization efforts.⁵¹ A few of the gaps identified in the CTP include a lack of a "DOD-wide strategy or policy guidance for innovation," misalignment between CTP stakeholders' actions and the mission of "pushing promising technology through the innovation life cycle," unclear roles and responsibilities, and a marked lack of incentives to encourage the improvement of the innovation process.⁵² Further, even though defense innovation groups (DIOs) are intended to expedite the military's incorporation of commercial technologies, the study found their efforts mainly concentrated on identifying emerging technologies and crafting preliminary integration frameworks rather than

⁴⁸ Leonard-Barton and Kraus, sec. 4.

⁴⁹ Leonard-Barton and Kraus, sec. 8.

⁵⁰ Brodi Kotila et al., "Fostering Innovation in Military Technology: Strengthening DOD's Commercial Technology Pipeline" (RAND Corporation, March 7, 2023), https://www.rand.org/pubs/research_briefs/RBA1352-1.html.

⁵¹ Kelley Saylor, *Emerging Military Technologies: Background and Issues for Congress*, CRS Report No. R46458 (Washington, D.C.: Congressional Research Service, 2022), para. 1.

⁵² Kotila et al., "Fostering Innovation in Military Technology," 5

facilitating widespread implementation.⁵³ Further analysis by the RAND authors showed that DIOs generally focus on the early phases of commercial technology adoption, limiting their ability to facilitate the adoption or transition of those technologies to military applications.⁵⁴ RAND also suggests that barriers such as cultural resistance, lack of incentives, or disconnects with acquisitions may be limiting the ability of DIOs to facilitate technology adoption and transition effectively.⁵⁵ The DOD can address several challenges identified in RAND's analysis by applying the foundational principles discussed previously. However, the analysis also highlights unique factors and differences unique to the military that necessitate tailored solutions.

National security experts agree that the military and private sectors experience similar innovation challenges, and an analysis of unrelated organizations may provide solutions.⁵⁶ Over time, the Department of Defense (DOD) has engaged in extensive collaborations with various private sector organizations, fostering significant advancements and innovative solutions across different operational processes.⁵⁷ However, few innovation studies have been conducted on the space industry, which is experiencing exponential economic growth due to an increasing number of commercial and international participants (over 90 countries are operating in space).⁵⁸ NASA is an example of an agency that has demonstrated significant technological progress over the last 60 years and is known for utilizing emergent technologies to achieve mission success. SpaceX is another example of a space organization that has transformed the future of space exploration by innovating reusable rocket technology. Unlike military organizations, many organizations within the space industry have successfully overcome unprecedented innovation challenges while a

⁵³ Kotila et al., 2.

⁵⁴ Kotila et al., 2.

⁵⁵ Kotila et al., 4.

⁵⁶ James Andrew Lewis, "National Security and the Innovation Ecosystem," October 1, 2021, <https://www.csis.org/analysis/national-security-and-innovation-ecosystem>.

⁵⁷ Defense Business Board, "Implementing Best Practices for Major Business Processes in the Department of Defense," 2014.

⁵⁸ Space Foundation Editorial Team, "Space Industry Growth: Where Are the Opportunities in 2022?," *Center for Innovation and Education* (blog), October 11, 2022, sec. 2, <https://cie.spacefoundation.org/space-industry-growth-where-are-the-opportunities-in-2022/>.

similar level of governmental oversight constrains them.⁵⁹ Despite these constraints, the space industry grew to \$469B in 2022 and may provide solutions to DOD innovation challenges.⁶⁰

4. Summary

In summary, the dynamic landscape of technological innovation and adoption—highlighted by the 2022 NDS—clearly shows that the DOD faces considerable opportunities and challenges. The People’s Republic of China is modernizing rapidly, especially in cyber and space domains, emphasizing how critical it is for the U.S. to maintain its technological lead. Given this imperative, the DOD has strategically decided to reprioritize from counterterrorism to defending against state-based threats. This reprioritization is apparent from the DOD’s increased investment in R&D and NSW’s proactive adoption of cutting-edge technologies. The space ecosystem provides the DOD with important insights due to its spectacular growth and pioneering innovations. The parallels between special operations and space operations in confronting extreme environments and continuous uncertainty highlight prospective approaches for NSW to drive innovation and integration amidst high-risk conditions. This chapter’s examination of organizational innovation factors, core diffusion principles, and the unique challenges the DOD faces builds a convincing case for leveraging insights across industries like space. This approach could enhance the DOD’s innovation ability and ensure its continued technological superiority in an increasingly competitive global arena. The next chapter will discuss the theoretical approach for this research.

5. Roadmap of Thesis

This thesis is organized into six chapters. The current chapter has provided an introduction describing the research question, background, and literature review of the

⁵⁹ James R. Kerr, “Congress and Space: Overview or Oversight?,” *Public Administration Review* 25, no. 3 (1965): 185–92, <https://doi.org/10.2307/973742>.

⁶⁰ Carlie Porterfield, “Space Industry Grew To Record \$469 Billion Last Year, Report Finds,” *Forbes*, n.d., <https://www.forbes.com/sites/carlieporterfield/2022/07/27/space-industry-grew-to-record-469-billion-last-year-report-finds/>.

research area. Chapter II explains the theoretical approach of the research and describes the independent variables used to assess the technology adoption cases throughout the project. Chapter III examines NASA, a space organization with a long history of innovation, and evaluates an optical communication innovation for the technology adoption case study. Chapter IV examines several commercial space industry organizations and case studies of successful and unsuccessful technology adoption. Chapter V analyzes the U.S. Space Force and how this relatively new organization was created to maintain technological superiority by modernizing its space systems. Finally, Chapter VI concludes by drawing out findings relevant to future work in this research area and provides recommendations for NSW leadership derived from Chapters III-V's analysis. This progression of chapters aims to provide context and build understanding, apply an analytical framework across the adoption methodology of various space organizations, and extract lessons to inform NSW's innovation pursuits.

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II. APPROACH

A. METHODOLOGY

This research examines several instances of successful and unsuccessful technology adoption performed by various organizations within the space ecosystem. Historical case studies and interviews with innovation experts are the primary means of data collection. Each technology adoption case study is selected based on the information provided by the interviewees of each organization. Additionally, each case study represents a successful or unsuccessful adoption outcome that inherently supplies information to inform NSW's innovation approach. First, it is essential to note that the organizational factors that lead to successful technology adoption are the focus of the study, not the innovations themselves. This chapter analyzes two examples of NSW technology adoption, one resulting in a negative outcome (failed adoption) and another resulting in a positive outcome (successful adoption). These brief technology adoption case studies will highlight the effect the variables used in this study have on the adoption outcome. Importantly, this research distinguishes between “adoption” and “success” since an adopted technology may prove ineffective when implemented. However, the standard for successful adoption is full integration into an organization's regular processes or demonstrable progress toward that goal. In other words, there are two pathways to failure: failing to adopt useful technology (an error of omission) and adopting useless technology (an error of commission). This thesis seeks to identify pathways to increase the likelihood of innovation: defined as the integration of new technologies that benefit the organization in its mission.

The analysis in this project shows that the dependent variable—an organization's capacity to innovate—is determined through the complex interplay of the three primary independent variables: COMFORT, STAFF & SYSTEMS, and END-USER factors (Figure 3) that are inductively identified through the case studies.⁶¹ In this work, these three variables are treated as being dichotomous, with only two qualitative values: **LOW** or **HIGH**. These binary

⁶¹ Alexander George and Andrew Bennett, *Case Studies and Theory Development in the Social Sciences* (Cambridge, Massachusetts: MIT Press, 2005), 75.

categorizations are based on the presence or absence of specific defining characteristics and conditions subcategorized under each primary variable. This research subcategorizes these characteristics under each variable based on Wittgenstein's "family resemblance logic,"⁶² later adapted by Goertz,⁶³ which groups concepts sharing overlapping traits rather than requiring all characteristics to be present (Figure 3). Similar to how some family members may share certain traits (like eye color or nose shape) without sharing all features, concepts grouped into a variable category using family resemblance logic does not need to possess one definitive characteristic but can exhibit overlapping similarities. As a result, this study argues that three families of characteristics determine successful or unsuccessful technology adoption.

Family resemblance logic is essential for this study because it is difficult to ascertain the exact traits that lead to adoption success or failure. For instance, if the COMFORT level of an innovation is determined to be **HIGH**, and the innovation is CREDIBLE, COMPATIBLE with existing capabilities, and provides significant IMPACT to the organization, which trait is responsible for its success? Therefore, it is logical to group a family of similar traits, as Goertz conceptualizes, to measure the presence or absence of the independent variables.⁶⁴ Figure 3 lists the three independent variables and supporting family of traits used to measure each technology adoption case study.

⁶² Michael Forster, "Wittgenstein on Family Resemblance Concepts," in *Wittgenstein's Philosophical Investigations: A Critical Guide* (Cambridge: Cambridge University Press, 2010), 66–87.

⁶³ Gary Goertz, *Social Science Concepts: A User's Guide* (New Jersey: Princeton University Press, 2006).

⁶⁴ Goertz.

Independent Variables of Study

- **(1) COMFORT**
 - Understand end-user preferences
 - Communication of scope and impact (marketing relative advantage)
 - Credibility and recognizability of innovation (buy-in)
 - Comprehension of risks (complexity)
 - Familiarity with technology
 - Uncertainty associated with technology (understanding)
 - Compatibility with existing capabilities and processes
 - Attractiveness of technology
- **(2) STAFF & SYSTEMS**
 - Access and communication between decision-makers, end-users, and developers
 - Tolerance to new types of risk and changes in behavior
 - Innovation incentives
 - Resistance to change
 - Decision-making authority level
 - Capacity to mitigate cost/schedule/performance repercussions
 - Decision-making with the necessary information
 - Relevant education pertaining to technology
 - Presence of internal advocacy
- **(3) END-USER**
 - Risk perception
 - Productivity potential of technology
 - End-user input informing decisions (feedback loops)
 - End-user willingness to adapt behaviors
 - Testability (trialability) of technology
 - Demonstrations prove concept
 - Demonstrations enhance end-user mental models
 - Implementation follow-through
 - Observability of technology facilitates networked diffusion
- **OUTPUT = ORGANIZATIONAL CAPACITY TO INNOVATE**
 - Elimination of type 1 and type 2 errors

Figure 3. The Independent Variables and Associated Family of Traits.

Throughout this thesis, certain concepts integral to technology adoption are represented in capitalized form (i.e., BUY-IN, COMFORT) when discussed in specific influential contexts. This differentiated formatting aims to underscore their impact as conceptual variables driving integration outcomes. While the exact terminology may appear uncapitalized elsewhere when not directly engaged, highlighting them as COMFORT or BUY-IN links to defined adoption factors. Additionally, the phrase “the innovation” is employed as a prototypical placeholder, not indicating any specific technology but as an archetype embodiment of an emerging technology requiring adoption. This generalized

construct allows “the innovation” to symbolize innovations in aggregate rather than a specific technology or process. The goal of these formatted distinctions is twofold: first, to synthesize the complex factors influencing adoption into clear representative variables, and second, to enable comprehensive studying of the full process of innovation adoption across various technologies by employing an archetypal framework.

This thesis will examine space technologies from each organization and measure the presence or absence of the identified variables listed in Figure 3. This data will give NSW leadership insights and recommendations regarding factors influencing innovation and technology adoption. As discussed previously, the space sector offers an optimal backdrop for comparative analysis, overflowing with technology adoption examples and sharing operational similarities with NSW across hazardous environments, crew survival imperatives, and communications hardships. This analysis will focus on technologies that are not only relevant and feasible but also offer valuable insights and future potential for NSW, whether through direct adoption or leveraging of critical space capabilities, while remaining within reasonable budget constraints. The goal is to provide both actionable and visionary recommendations for NSW leadership. Specific examples like optical communications and low-Earth orbit (LEO) proliferated satellites may be out of scope for near-term NSW adoption but provide critical lessons as emerging space technologies demonstrate relevant capabilities. Conversely, while developing a new launch vehicle may be an essential innovation for the space industry, analyzing the factors influencing its adoption would provide little value for NSW. A large-scale rocket system involves enormous costs and engineering challenges unrelated to NSW’s mission. Therefore, the organizational dynamics and constraints shaping the feasibility of adopting such capital-intensive technologies offer minimal applicable insights. By focusing this study only on innovations with clear relevance and budgetary alignment for NSW, the resulting findings can provide directly actionable recommendations to leadership.

B. ERRORS OF OMISSION AND ERRORS OF COMMISSION

When evaluating technology adoption overall, organizations seek to prevent two types of errors from occurring: adopting ineffective innovations and mistakenly rejecting

promising ones. On the one hand, errors of commission are false positives and occur when an organization adopts an innovation that it assumes will increase organizational performance. In other words, the organization mistakenly commissions an innovation as valuable when it is not. On the other hand, errors of omission represent false negatives and occur when an organization does not adopt an innovation that would have added value if implemented. In other words, the organization omits an innovation that should have been considered valuable.

Both errors are equally detrimental for military organizations like NSW and laden with significant liabilities. For example, errors of commission may jeopardize mission success or unknowingly increase risk-to-force if a failure occurs at a critical moment. Implementing innovations caused by errors of commission may also require unnecessary changes to doctrine, training, and operations, which needlessly consume resources. Moreover, acquiring, maintaining, and operating the ineffective technology feeds into the “sunk cost fallacy,” the tendency to continue investing in something simply because of how much has already been spent on it, even if future costs far outweigh any benefits.⁶⁵ The “sunk cost fallacy” is exacerbated when the technology is adopted across the force, and unreasonable costs and complexity impede the option to reverse the implementation. Likewise, errors of omission are also detrimental because they carry significant opportunity costs. Seizing these opportunities can strengthen an organization’s performance and ability to undertake further innovations, though the benefits of prospects not taken are challenging to quantify. Still, capitalizing on potential advantages may meaningfully curb risks to mission, risks to force, and adversary gains; thus, these opportunities are worth pursuing. As a result, preventing these two types of errors from occurring should be a priority for organizations like NSW, seeking to prevail against rapidly modernizing adversaries.

⁶⁵ David Ronayne, Daniel Sgroi, and Anthony Tuckwell, “How Susceptible Are You to the Sunk Cost Fallacy?,” *Harvard Business Review*, July 15, 2021, <https://hbr.org/2021/07/how-susceptible-are-you-to-the-sunk-cost-fallacy>.

C. BASELINING METHODOLOGY WITH NSW TECHNOLOGY EXAMPLES

This section will briefly examine two recent NSW technology adoption cases, demonstrating the methodology applied to assess space technologies in subsequent chapters. The independent variables will be measured and visualized through introduced figures to portray the adoption outcomes. Further, the NSW examples highlight an error of commission and an error of omission to emphasize the detrimental effect of committing these errors. This research project aims to optimize NSW's technology adoption practices to eliminate errors of commission and omission while enabling the successful adoption of advantageous emergent technologies.

In 1994, NSW awarded a contract to Northrup Grumman Corporation to develop a state-of-the-art, battery-powered, dry submersible: the Advanced SEAL Delivery System (ASDS).⁶⁶ The ASDS was designed to extend the combat radius of the original SEAL Delivery Vehicle (SDV) by increasing range, speed, and habitability in a dry (and warm) pressurized environment.⁶⁷ The ASDS was also designed to be compatible with modern submarines, enabling these platforms to transport the ASDS to intended operational areas of interest.⁶⁸ The tactical benefits the ASDS offered are commensurate with the substantial costs, as the platform represented one of the U.S. Special Operations Command's largest expenditures and most advanced technologies.⁶⁹

Unfortunately, the ASDS was wrought with several technical problems, schedule slips, and cost overruns. A major shortcoming was the contractor's and NSW's inadequate grasp of the still-developing lithium-ion battery technology for submarine applications.⁷⁰

⁶⁶ "Advanced SEAL Delivery System Program Needs Increased Oversight" (Government Accountability Office (GAO), March 2003).

⁶⁷ "Advanced SEAL Delivery System Program Needs Increased Oversight."

⁶⁸ "Advanced SEAL Delivery System Program Needs Increased Oversight."

⁶⁹ DDN, "USSOCOM Ends ASDS Effort, Requests Funds For New Submersible Effort," Defense Daily, July 27, 2009, <https://www.defensedaily.com/ussocom-ends-asds-effort-requests-funds-for-new-submersible-effort/navy-usmc/>.

⁷⁰ "Success of Advanced SEAL Delivery System Hinges on Establishing a Sound Contracting Strategy and Performance Criteria" (Government Accountability Office (GAO), May 2007).

The lithium-ion battery was considered “an immature energy storage technology” at the time.⁷¹ This limited understanding of advanced battery technology likely induced the fire that extensively damaged the ASDS while recharging at its home port in Pearl Harbor, Hawaii.⁷² This technical failure in the ASDS exemplifies an organization investing significant resources as the “first adopter” to get ahead of emerging but unfamiliar technology. The ASDS development also exposed deficiencies like inadequate consultation with future SEAL operators, poor communication between the contractor and NSW leadership, ineffective oversight and program management, insufficient testing and demonstrations, and unrealistic cost, schedule, and performance assessments.⁷³ These combined issues caused the DOD to cancel plans to procure the five pending ASDS platforms in 2006.⁷⁴

Using the methodology explained in a previous section, the values for the ASDS case study measured **LOW** for all three variables: COMFORT, STAFF & SYSTEMS, and END-USER. The ASDS demonstrates a failed adoption outcome where many family characteristics in Figure 3 are absent. For example, COMFORT scored **LOW** because the ASDS had issues with credibility due to immature technologies and lack of testing. The associated risks and complexity were poorly communicated and not well understood. Further, the limited end-user engagement exacerbated these issues and ultimately hurt adoption. The STAFF & SYSTEMS variable also scored **LOW** due to poor information sharing between the contractor and NSW, the customer organization. Both organizations insufficiently invested in education relevant to the innovation challenge. Moreover, the program management was deficient, causing significant cost, schedule, and performance slips. Finally, the END-USER factors ranked **LOW** because a valuable end-user feedback loop was not instituted, resulting in developers failing to incorporate critical operator insights. Most importantly, the implementation of the ASDS was poor, leaving many issues

⁷¹ GlobalData Thematic Intelligence, “Lithium-Ion Batteries (LIB): Opportunities and Threats,” *Naval Technology* (blog), June 12, 2020, <https://www.naval-technology.com/comment/lithium-ion-batteries-lib/>.

⁷² DDN, “USSOCOM Ends ASDS Effort, Requests Funds For New Submersible Effort.”

⁷³ “Success of Advanced SEAL Delivery System Hinges on Establishing a Sound Contracting Strategy and Performance Criteria.”

⁷⁴ DDN, “USSOCOM Ends ASDS Effort, Requests Funds For New Submersible Effort.”

unresolved after initial delivery. These variables combine to produce a failed adoption outcome, demonstrating an error of commission. Figures 4 and 5 illustrate the variable effects and adoption outcome, respectively, for the ASDS analysis.

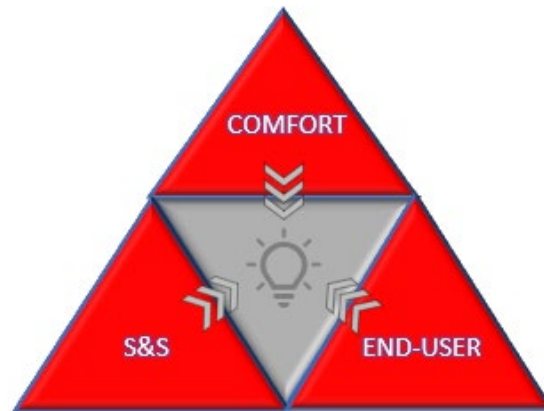


Figure 4. Measurement of the ASDS COMFORT (**LOW**), STAFF & SYSTEMS (**LOW**), and END-USER (**LOW**) Indices.

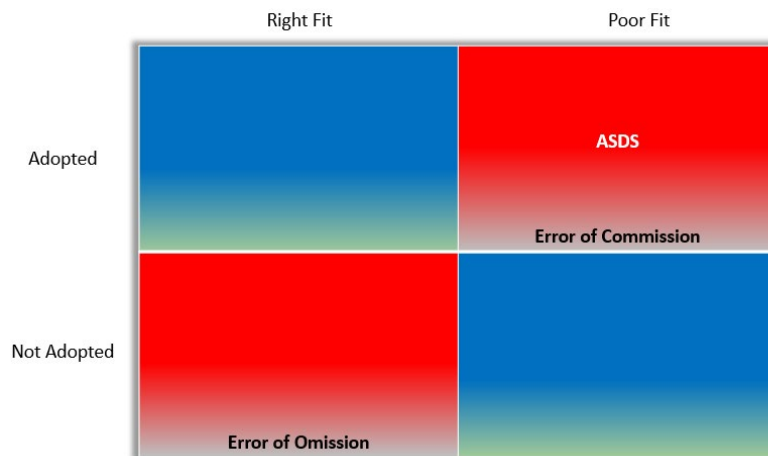


Figure 5. The ASDS Adoption Outcome.

A brief analysis of the Joint Multi-Mission Submersible (JMMS) program provides a counterexample to the preceding ASDS case study, epitomizing an error of omission rather than commission. Due to the classified nature of the JMMS program, this case study

will briefly cover the organizational factors that led to its failed adoption outcome. In 2010, SOCOM requested funding for the JMMS, proposed as the much-improved successor to the failed ASDS. Like the ASDS, the JMMS was envisioned as a clandestine infiltration vehicle capable of increased range, endurance, and protection for SEAL operators in its dry environment. This new platform would responsibly encourage the reuse of the ASDS's proven technologies while improving upon the deficiencies to mitigate technology risk. Incorporating hard-won insights from the ASDS's failure, JMMS seemed well-positioned to overcome previous pitfalls and achieve adoption success.

Despite inheriting ASDS enhancements for greater dependability, the ill-fated JMMS never came to fruition. The ASDS debacle cast such a blemish on the DOD's appetite for submersibles that decision-makers shied from investing in a follow-on program so soon after. Still, the JMMS is built upon proven submersible technology, improving its credibility, reducing uncertainty, and exhibiting clear scope and impact, resulting in a **HIGH** COMFORT score. While cutting-edge vehicles are always susceptible to cost and schedule overruns, the DOD planned to have increased program oversight and more efficient managers with greater familiarity and submersible expertise following the ASDS project. These factors contribute to the JMMS's **HIGH** STAFF & SYSTEMS score. Finally, the JMMS received a **HIGH** END-USER score, although the vehicle never made it into the hands of the SEAL operators. End-user concerns became the priority for JMMS planning when developers ignored these same concerns during ASDS development. The end-users were the drivers for the redesign effort because they understood and desired the operational advantages that a capable dry submersible would offer.

The JMMS program exemplifies an error of omission; the advantageous technology and significantly mitigated risks merited adoption, but decision-makers remained risk-averse after the ASDS failure. Furthermore, failing to adopt the JMMS inflicted sizable opportunity costs, forfeiting over a decade of potential operational use that could have provided NSW forces with sizable advantage over adversaries still lacking similar capabilities. Figures 6 and 7 illustrate the variable effects and adoption outcome for the JMMS analysis.

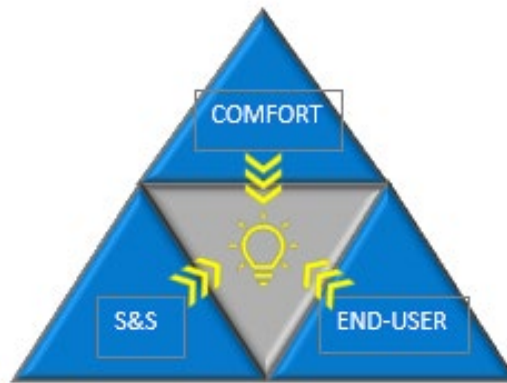


Figure 6. Measurement of the JMMS COMFORT (**HIGH**), STAFF & SYSTEMS (**HIGH**), and END-USER (**HIGH**) Indices.

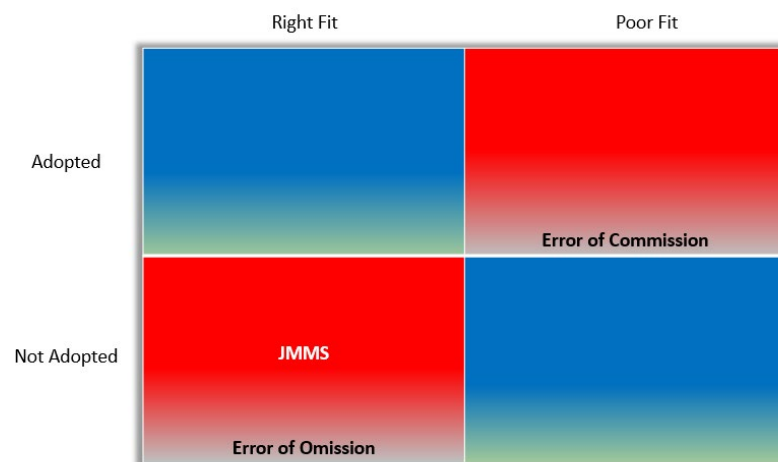


Figure 7. The JMMS Adoption Outcome.

In summary, this chapter established the methodology for assessing technology adoption across space organizations in subsequent chapters. Case studies are analyzed by measuring three independent variables—COMFORT, STAFF & SYSTEMS, and END-USER factors—and providing a value of **LOW** or **HIGH**. This framework, built upon foundational technology adoption concepts, enables evaluating factors driving successful or failed adoption outcomes. The next chapter will examine innovation and technology adoption within the National Aeronautics and Space Administration (NASA).

III. NASA

Failure is not an Option.

-Gene Kranz⁷⁵

A. INTRODUCTION

This chapter aims to analyze a civil space example of technology adoption and the factors that affected this process. This research theorizes that different combinations and values of the three measured variables influence civil space technology adoption when compared to a DOD or commercial space technology adoption example. This chapter focuses on one National Aeronautics and Space Administration (NASA) innovation department, the Technology Enterprise and Mission Pathfinder Office (TEMPO), which is routinely exposed to innovation barriers. The significant barriers to innovation and technology adoption at NASA are used to highlight their impact in the technology adoption case. The key takeaways will be used to inform NSW's innovation process in a subsequent chapter.

B. FRAMING NASA'S INNOVATION CHALLENGE

Like NSW, NASA is a high-performing organization with a rich history of operational successes built upon a constant stream of successful innovations. Douglas Terrier, NASA Chief Technologist from 2017–2021, communicates:

We've had a 60-years-long unbroken line of firsts. First landing on the Moon, the space shuttle, the International Space Station, robotic missions to every planet in the solar system, and then, of course, our incredible telescopes looking both at Earth and out into the solar system. All of that has been built on a solid foundation of NASA's innovation.⁷⁶

⁷⁵ Gene Kranz, *Failure Is Not An Option: Mission Control From Mercury to Apollo 13 And Beyond* (New York: Simon & Schuster, 2009).

⁷⁶ National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA's Innovation Ecosystem: Proceedings of a Workshop* (Washington, D.C.: National Academies Press, 2019), 5, <https://doi.org/10.17226/25505>.

Terrier added, “We’re at a fork in the road. Not because NASA has suddenly started to do something different, but because the world is doing something very different in technology and culture and everything else. . . And we’re really at a decision point about how we’re going to adapt to that.”⁷⁷ These comments suggest that, much like NSW, NASA must break from previously successful strategies and change its approach to solving future problems in a dynamic environment. Similarly, NSW must move away from successful strategies used to combat relatively “low-tech” violent extremist organizations (VEOs) and apply innovations to compete with relatively “high-tech” peer adversaries.

Success is an unrecognized factor that can inhibit innovation and catalyze the emergence of several additional resistances within an organization.⁷⁸ NASA must also contend with a culture consisting primarily of systems engineers, personnel who solve complex technical problems with strict process-based approaches. Newly-adopted innovations may induce changes to these “tried-and-true” processes closely associated with past mission success. Consequently, changes to these processes usually require varying degrees of behavioral changes that tend to make engineers uncomfortable and fearful of failing. Further, NASA is preconditioned to “stay the course” or maintain its organizational status quo because it has an excellent track record (with few exceptions) in high-risk human spaceflight operations and expensive scientific experiments, mission categories that have endured significant budget cuts in previous decades.⁷⁹ As a result, NASA is considered to be an organization that is risk-averse, afraid to fail, and perceives innovation as a threat due to a lack of trust and ORGANIZATIONAL INERTIA.⁸⁰ Figure 8 depicts that COMFORT and STAFF & SYSTEMS are the most significant innovation factors affecting NASA.

⁷⁷ National Academies of Sciences, Engineering, and Medicine, 5.

⁷⁸ Francesca Gino and Gary P. Pisano, “Why Leaders Don’t Learn from Success,” *Harvard Business Review*, April 1, 2011, para. 2, <https://hbr.org/2011/04/why-leaders-dont-learn-from-success>.

⁷⁹ “Your Guide to NASA’s Budget,” The Planetary Society, n.d., <https://www.planetary.org/space-policy/nasa-budget>.

⁸⁰ National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA’s Innovation Ecosystem*, 11.

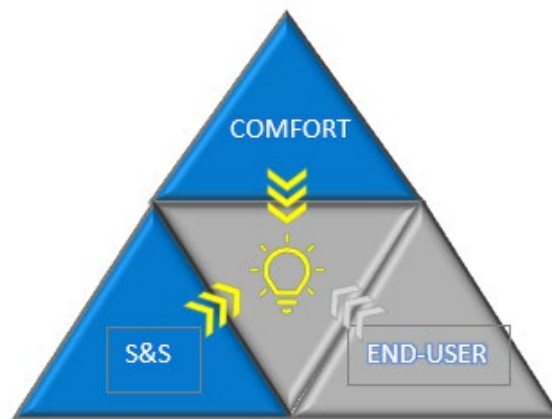


Figure 8. COMFORT and STAFF & SYSTEMS Are the Most Significant Factors Affecting NASA's Capacity to Innovate.

C. BARRIERS TO INNOVATION

In November 2016, the NASA Advisory Council (NAC) Technology, Innovation, and Engineering (TI&E) Committee and NASA's Office of the Chief Technologist (OCT) began an agency-wide study to explore how to promote innovations and overcome barriers to innovation within the organization.⁸¹ Terrier defined innovation as "turning ideas into value."⁸² The study identified seven critical barriers to innovation within the agency (Figure 9).⁸³ Unsurprisingly, other government organizations, including NSW, are challenged by many of these same factors.

⁸¹ Douglas Terrier, "NASA 's Barriers to Innovation and Chief Technologist Update."

⁸² National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA's Innovation Ecosystem*, 5.

⁸³ "NASA 's Barriers," 6.

Risk-averse culture	• Management/workforce conservatism and oversight bodies drive costs and create more incremental steps
Short-term focus	• Immediate mission needs (for example, meeting level 1 requirements) often must take priority over development of future capabilities
Instability	• Changes in decisions and direction set by external stakeholders as well as tactical decisions have dried the innovation pipeline and led to a cycle of technology start/stops
Lack of Opportunity	• Fewer flight opportunities have reduced available pathways for infusion of innovations. Technology demonstrations historically come and go, yet have spurred some of the revolutions in NASA history
Process Overload	• Excessive administrative burdens can stagnate innovators; process owners have become gatekeepers instead of enablers
Communication Challenges	• Organizational silos, 'not invented here' thinking, and lack of commonality in IT and communication technologies for linkage
Organizational Inertia	• Cultural tendency to stay the course and a lack of trust often portray innovation as a threat; need to balance the risk with reward

Figure 9. “Barriers to Innovation at NASA.”⁸⁴

David Miranda, Chief of Spaceport Technologies at NASA/Kennedy Space Center (KSC), expanded the definition of innovation: “Innovation should have an impact—either positive or negative, but aiming for positive.”⁸⁵ Miranda highlighted an essential point because ORGANIZATIONAL INERTIA (resistance to change) may contribute to a negative outcome for innovation, even when the intent is to improve the organization’s performance. These “dis-innovations” are synonymous with errors of commission in technology adoption cases discussed in Chapter II (took a risk, tried it out, but failed). The phrase “Failure is not an option” was initially used to emphasize the importance of perfect execution when human lives were on the line but has since broadened to mean that any failure within NASA is unacceptable, resulting in heightened fear of failure. Miranda adds, “Inherent to the innovation process is accepting the risk that the innovation might fail and not produce the

⁸⁴ Source: National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA’s Innovation Ecosystem*.

⁸⁵ Bradley Hill and David Miranda, personal communication, Microsoft Teams, August 18, 2023.

expected outcome, which is why successful organizations are threatened. A worse outcome, however, is not attempting to innovate at all.”⁸⁶

ORGANIZATIONAL INERTIA threatens innovation because organizations are constructed to “deliver predictable, reliable results,” a paradox where the processes that enable today’s success reinforce behaviors inconsistent with innovating tomorrow.⁸⁷ Jeff Bezos, Amazon Founder and CEO, describes “Day 2” organizations as static, resting on the laurels of success, and quickly followed by a slow, gradual, painful decline before death.⁸⁸ As a result, Bezos strives to keep “Day 1” energies within his organization, characterized by END-USER “obsession, a skeptical view of proxies, the eager adoption of external trends, and high-velocity decision-making.”⁸⁹ NASA also advocates for increasing decision-making velocity to improve the speed and ownership of decisions by minimizing bureaucratic steps and sign-offs.⁹⁰

ORGANIZATIONAL INERTIA inhibits innovation at many NASA Centers across the United States. TEMPO, a NASA/Goddard Space Flight Center (GSFC) department, was created in 2016 to manage the innovation pipeline for Goddard’s space communications and navigation capabilities.⁹¹ This task includes incubating and infusing concepts and technologies developed within NASA, academia, or commercial industry. TEMPO specifically aims to adopt technologies that directly support future missions to the Moon and Mars and innovate the processes associated with implementing the technology.⁹²

⁸⁶ Hill and Miranda.

⁸⁷ Scott D. Anthony et al., “Breaking Down the Barriers to Innovation,” *Harvard Business Review*, November 1, 2019, para. 8, <https://hbr.org/2019/11/breaking-down-the-barriers-to-innovation>.

⁸⁸ Jeff Bezos, “Day 1 Letter to Shareholders” (memorandum, Amazon.com, 1997), <https://www.sec.gov/Archives/edgar/data/1018724/000119312517120198/d373368dex991.htm#:~:text=Are%20you%20falling%20prey%20to%20proxies%2C%20or%20do,your%20hard%20work%2C%20your%20ingenuity%2C%20and%20your%20passion>.

⁸⁹ Bezos.

⁹⁰ National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA’s Innovation Ecosystem*.

⁹¹ “Technology Enterprise and Mission Pathfinder Office | ESC Public Site,” n.d., <https://tempo.gsfc.nasa.gov/projects/TEMPO?tab=overview>.

⁹² Bradley Hill, personal communication, Microsoft Teams, May 25, 2023.

Bradley Hill, a TEMPO Deputy Project Manager at NASA/GSFC, indicates that an essential characteristic of the TEMPO team’s innovation process is the long “runway” (approximately two years) provided to technologies to increase their technology readiness levels (TRLs).⁹³ This characteristic defines the entire incubation cycle, beginning with the Internal Research and Development (IRAD) phase. The technologies associated with this early phase are unproven (~TRL 2–3) and often originate from industry or academia. If possible, this phase aims to “break” the innovations by becoming intimately familiar with the projects for a long enough period to predict any potential long-term failure points. This type of failure is rarely observed in technology evaluation processes and differs significantly from the shorter-term “likely” failures that most organizations identify. Hill defines success in this phase as “identifying a technology with long-term reliability and functional characteristics or acquiring information from a failed project that can inform future approaches.”⁹⁴ This definition suggests that a successful outcome can be achieved in this phase if a long enough “runway” is provided for each technology in the evaluation process.

The projects that succeed in the IRAD phase will enter the second phase of the development cycle, officially named the Incubation phase, characterized by technologies from TRL 3–6.⁹⁵ The goal of this phase is to raise the projects to TRL 6, meaning these technologies must cross the “Chasm” or the “Valley of Death” (~TRL 5).⁹⁶ Like many technologies in the industry that must clear this critical milestone, several types of human-derived resistances are introduced in this incubation phase. For example, a promising innovation may eventually displace an inferior incumbent technology with substantial support in prior (and significant) investments, numerous stakeholders, or a history of success. Additionally, the processes associated with the incumbent technology would need to be revised to support the implementation of the innovation, thus introducing new forms

⁹³ Hill.

⁹⁴ Hill.

⁹⁵ Hill.

⁹⁶ Moore, *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers*, 25.

of risk and unwanted changes in behavior. The risks associated with this phase will be explored in greater detail in the following section.

Often, advantageous innovations can be killed by the BIASES of organizational “regulators,” people whose job is to say “no.”⁹⁷ Hill states, “It is acceptable if the project dies on the vine ‘naturally’ because it isn’t functional or it isn’t the right fit. Our goal is to not let the project die on the vine ‘artificially’ due to human factors such as risk misperception, resistance to change, or communication failures.”⁹⁸ As such, TEMPO aims to shield these projects from the many barriers to innovation identified in NASA’s 2016 study. Projects that are “enabled” rather than “regulated,” rise to TRL 6 and will be deemed mission-capable and transition to the Infusion phase of the development cycle. These projects can create new “operating paradigms” that can induce changes in mental models, perceptions, and behaviors. Typically, these projects will “spin out” of TEMPO and diffuse to other directorates within NASA for integration into various training and operational mission profiles.

One critical technology area upon which TEMPO focuses its infusion strategy on is optical communication systems.⁹⁹ Optical communications provide significant advantages over current architectures that consist of radio frequency (RF) systems. One example of an optical system that highlights these advantages is the Terabyte Infrared Delivery (TBIRD) system launched in May 2022 as a “hosted payload on the Pathfinder Technology Demonstrator 3 CubeSat.”¹⁰⁰ During the recent demonstration, this technology proved that optical communication is viable for near-Earth networks by demonstrating the highest space-to-ground data rates and throughputs ever recorded (4.8 TB error-free in under 5 minutes / 200GB per second).¹⁰¹ TBIRD also demonstrated the

⁹⁷ Joel Babbitt, *Half-Price Negotiating: Reframing Defense Acquisition Program Management to Achieve Extraordinary Results*, 2022, ch. 9, para. 3.

⁹⁸ Hill, personal communication, May 25, 2023.

⁹⁹ NASA, “Technology Enterprise and Mission Pathfinder Office,” NASA, n.d., <https://tempo.gsfc.nasa.gov/projects/TEMPO?tab=incubated%20projects>.

¹⁰⁰ NASA.

¹⁰¹ Hill and Miranda, personal communication.

highest downlink pointing accuracy by a CubeSat in LEO orbit (~ 30 μ rad RMS) and the first use of commercial-off-the-shelf (COTS) components for a NASA satellite communications system.¹⁰²

Although the TBIRD mission was incredibly successful and reduced many barriers to implementing optical systems into NASA's future architectures, the TEMPO team encountered several factors that impeded the adoption of their technology.¹⁰³ These factors are categorized by the indices below:

- **Comfort: LOW**¹⁰⁴

Several operational and cost-associated RISKS were linked to the adoption and implementation of TBIRD. In general, operating laser communications and navigation systems require new end-to-end hardware and software infrastructure, including integrating different supporting technologies and developing improved ground stations, factors that drive up cost. Further, to operate TBIRD, personnel require training specific to the new processes and equipment, and this requirement is amplified with the mass adoption of optical systems. Lastly, TEMPO incorporated COTS equipment developed for optical communications into the development of TBIRD to provide cost savings and improved schedule benefits. This milestone is significant because NASA's communications architectures have never integrated COTS equipment.

Although NASA has been exploring optical systems since the early 1960s, AWARENESS of optical communication's benefits, particularly in CubeSat-sized payloads, has been limited, except for the engineers typically involved with these technologies.¹⁰⁵ Likewise, the AWARENESS of "off-the-shelf" optical capabilities has been low. As a result, the advantages of optical communication technology were COMMUNICATED poorly to decision-makers for many years. Notably, engineers rarely make the best MARKETERS that can articulate the promise of lowering long-term operational costs if optical networks were to displace RF networks.

¹⁰² Kathleen Riesing et al., "Pointing, Acquisition, and Tracking for the TBIRD CubeSat Mission: System Design and Pre-Flight Results," *MIT Lincoln Laboratory*, 2022, 1.

¹⁰³ Hill and Miranda, personal communication.

¹⁰⁴ Hill and Miranda.

¹⁰⁵ W. Dan Williams et al., "RF and Optical Communications: A Comparison of High Data Rate Returns from Deep Space in the 2020 Timeframe" (NASA, January 2018).

- **Staff & Systems: LOW**¹⁰⁶

NASA experts state, “RF is the most widely used communication medium for space applications.”¹⁰⁷ The existing RF network is reliable and has successfully supported decades of NASA’s scientific and human space flight missions.¹⁰⁸ ORGANIZATIONAL INERTIA was a significant factor in TBIRD development and adoption (“If it isn’t broke, don’t fix it” mentality). Previous INVESTMENTS in the current RF network, supporting technologies, and existing processes also impeded TBIRD adoption. Subsequent impacts from shifting to a more efficient communication network might include lower operational costs and job and profit losses for companies dependent on maintaining the existing RF network. These factors combine to create an intra-ORGANIZATIONAL RESISTANCE and conservatism towards adopting optical systems.

- **End-user: HIGH**¹⁰⁹

The live DEMONSTRATION of TBIRD in the space environment proved the advantages of optical communications for improved “science data return and higher data transfer capacity.”¹¹⁰ The success of the TBIRD DEMONSTRATION exceeded anticipated downlink data rates: about 4.8 TB in 4.8 minutes. This improvement presents a viable solution to directly support the Vision of Space Exploration (VSE), including returning humans to the Moon, then onto Mars, along with data-intensive space science missions. This DEMONSTRATION likely catalyzed opportunities for additional COTS-enabled technology adoptions.

Figures 10 and 11 illustrate how COMFORT and STAFF & SYSTEMS variables affect the TBIRD adoption outcome.

¹⁰⁶ Hill and Miranda, personal communication.

¹⁰⁷ Williams et al., “RF and Optical Communications: A Comparison of High Data Rate Returns from Deep Space in the 2020 Timeframe,” 2

¹⁰⁸ Williams et al., 2.

¹⁰⁹ Hill and Miranda, personal communication.

¹¹⁰ Hill and Miranda.

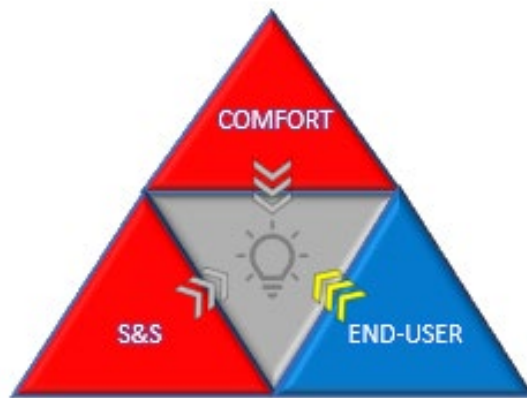


Figure 10. Measurement of the TBIRD COMFORT (**LOW**), STAFF & SYSTEMS (**LOW**), and END-USER (**HIGH**) Indices.

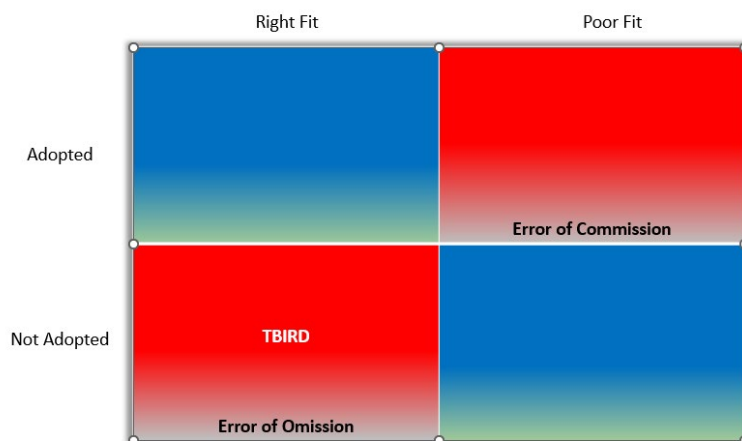


Figure 11. TBIRD Technology Adoption Outcome. (While Successfully Demonstrated, the Technology is Pending Utilization in Focused Mission Areas.)

The primary factors that inhibited the adoption of TBIRD were the LIMITED UNDERSTANDING of the innovation and flow of information, and the ORGANIZATIONAL INERTIA. This case study shows that COMMUNICATING the advantages of innovation throughout the organization (from earliest decision-makers to end-users) is a critical step in technology adoption. Hill observes, “It is common to assume that the technology’s performance can speak for itself, but we learned that effective MARKETING to decision-makers is important

too.”¹¹¹ Hill explains that during a budget cut window, the TEMPO team realized they had not adequately communicated the criticality of a key component for lunar-based optical communications infrastructure. While TEMPO advertised the performance of this specific component appropriately, TEMPO needed to communicate how the TBIRD component was also a critical enabler for six other NASA- and DOD-related projects (with a combined investment valued at nearly one billion dollars) to remain viable. In other words, select aspects of the innovation were marketed, but its most important characteristic—enabling other projects—was not emphasized, putting the innovation at risk of being cut. The Stanford Innovation Project (1984) conducted a long-term study of U.S. industrial innovation. The study identified successful examples where the innovation’s technological superiority was attenuated, and more emphasis was placed on the MARKETING of the innovation.¹¹² The TBIRD example demonstrates this finding and suggests that TEMPO may have benefitted from increased MARKETING effort.

Outside of increasing decision-maker BUY-IN, NASA is pushing to prioritize change within its risk-averse culture.¹¹³ This trend discouraged many at NASA from absorbing the risks of adopting optical communication systems. Although many organizations publicly advertise innovation, the underlying cultures actually may be risk-averse.¹¹⁴ A significant factor is that managers in large, hierarchical organizations are “actively discouraged” from taking risks due to INCENTIVES and control processes.¹¹⁵ Hill adds, “Middle managers follow the precise instructions of their superiors because that is what makes them good middle managers.”¹¹⁶ Whereas senior leaders in an organization are assessed based on their long-term achievements, managers at lower levels often stake their

¹¹¹ Bradley Hill, personal communication, Microsoft Teams, June 23, 2023.

¹¹² Maidique and Zirger, “A Study of Success and Failure in Product Innovation.”

¹¹³ National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA’s Innovation Ecosystem*, 11.

¹¹⁴ Ron Ashkenas and Lisa Bodell, “The Reason Your Team Won’t Take Risks,” *Harvard Business Review*, September 9, 2014, para. 2, <https://hbr.org/2014/09/the-reason-your-team-wont-take-risks>.

¹¹⁵ Dan Lovallo et al., “Your Company Is Too Risk-Averse,” *Harvard Business Review*, March 1, 2020, para. 8, <https://hbr.org/2020/03/your-company-is-too-risk-averse>.

¹¹⁶ Hill, personal communication, May 25, 2023.

careers on each decision they make. Thus, they are unincentivized to take risks due to varying degrees of PUNISHMENT or non-advancement.¹¹⁷ In practice, middle managers have the power and authority to approve or deny technology adoptions. They will generally say “no” after balancing the risk they are likely to incur with the technological advantages of certain innovations they may not fully understand.

Although risk aversion and lack of decision-maker BUY-IN were the causes of difficulty in initially adopting TBIRD, NASA actively works to mitigate these and other barriers in several ways.¹¹⁸ Janice Fraser of Bionic states, “In the best-case scenarios, buy-in should take place in four sequential steps, beginning with understanding and then moving on to belief, advocacy, and decisions.”¹¹⁹ She adds, “Leaders often have to make decisions before they fully understand what it is they are signing up for. A decision made without comprehension is a fragile form of buy-in, because when comprehension does occur, the decision-maker may not believe in it, resulting in the decision-maker reversing that decision.”¹²⁰ In practice, failure in this sequence of events can generate errors of omission or commission and can be quite visible and disastrous for the manager’s reputation.

Hill suggests that it is imperative to have an advocate in the higher-level managerial group who understands the innovation. That individual can clarify misperceptions and translate technical advantages to their peers if necessary, thus increasing COMPREHENSION.¹²¹ Additionally, Hill finds that constrained time slots limit the information provided in proposal presentations. These limitations make it challenging to tailor the presentation to the audience while including all the relevant information.¹²² In these situations, a high-level advocate could inform peer decision-makers pre- or post-presentation, if necessary,

¹¹⁷ Lovallo et al., “Your Company Is Too Risk-Averse,” 8.

¹¹⁸ National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA’s Innovation Ecosystem*, 11.

¹¹⁹ National Academies of Sciences, Engineering, and Medicine, 28.

¹²⁰ National Academies of Sciences, Engineering, and Medicine, 28.

¹²¹ Hill, personal communication, June 23, 2023.

¹²² Hill.

to get the development team’s project supported. Critical COMMUNICATION can also flow in reverse when the high-level advocate feeds the decision-maker’s vision to the development team and conveys which technologies are essential to realizing that vision.¹²³ Hill states, “These types of feedback loops are important to generate BUY-IN but require that high-level managers are accessible to the development team.”¹²⁴ While NASA’s organizational structure supports this communication flow, achieving this feedback loop within the DOD is likely more difficult.

NASA also explores making the working environment ‘safe to try’ something new.¹²⁵ For this approach to work, Fraser suggests that leaders who promote innovation “need to see their jobs differently and make it safe for people to accomplish their goals.”¹²⁶ She continues, “One question leaders should ask is ‘What can I unblock for you?’”—a question that allows leadership to gain AWARENESS of existing obstacles.¹²⁷ This approach to leadership focuses on discovering rather than oversight and knowing. Fraser concludes that leaders performing the key task of removing roadblocks allows others to “deliver maximum value from their ideas.”¹²⁸ Additionally, NASA is also increasing the isolation and autonomy of its innovation teams, an attempt to create a ‘safe space’ with different boundaries for them to conduct their work.¹²⁹ “If a team must work within the boundaries of existing processes used to maintain an organization, it will be very difficult for that team to innovate effectively,” says Tom Ingersoll, former CEO of Skybox Imaging.¹³⁰ This approach also suggests that leaders should incur more RISK and allow their innovators the independence to do things differently without repercussion.

¹²³ Hill.

¹²⁴ Hill.

¹²⁵ National Academies of Sciences, Engineering, and Medicine, *Continuous Improvement of NASA’s Innovation Ecosystem*, 29.

¹²⁶ National Academies of Sciences, Engineering, and Medicine, 29.

¹²⁷ National Academies of Sciences, Engineering, and Medicine, 29.

¹²⁸ National Academies of Sciences, Engineering, and Medicine, 29.

¹²⁹ National Academies of Sciences, Engineering, and Medicine, 54.

¹³⁰ National Academies of Sciences, Engineering, and Medicine, 55.

In summary, NASA and the TEMPO team had to overcome significant barriers to technology adoption to arrive at a successful demonstration of TBIRD. This technology will likely change NASA's future space exploration and approach to scientific missions. This case identified that creating COMFORT is an important step for adopting technologies because generating belief in the decision-making cohort can provide opportunities for a technology to prove its advantages. Unfortunately, ORGANIZATIONAL INERTIA and risk-averse practices can stifle these opportunities, so adjusting INCENTIVES and training for the 'gatekeepers' of technology adoption should also be prioritized. These adjustments can limit the volume of errors of omission and commission attributed to an organization's decision-making process. Although there is an inherent RISK in innovation, the real risk comes from doing nothing and committing an error of omission. Harding and Ghooroo highlight, "We need a new way of thinking about risk. When people suggest they won't do risky projects, they are transferring risk to the warfighter."¹³¹ The next chapter will analyze several commercial space organizations to determine how they behave differently, and which factors affect technology adoption most.

¹³¹ Emily Harding and Harshana Ghoorhoo, "Seven Critical Technologies for Winning the Next War," April 18, 2023, 22, <https://www.csis.org/analysis/seven-critical-technologies-winning-next-war>.

IV. COMMERCIAL SPACE INDUSTRY

Fail Fast, Iterate Rapidly.

-Silicon Valley innovation mantra

A. INTRODUCTION

The commercial space industry is at the forefront of technological innovation, boasting unprecedented investment, risk, and a burgeoning startup ecosystem. Companies such as SpaceX and Relativity Space exemplify the sector's potential and highlight the intricate balance between groundbreaking innovation and understanding END-USER requirements. While investment flows and startups flourish, the key to sustainable success goes beyond the technological aspects of innovation. Commercial innovation relies on adapting to changing environments, administrations, and budgets, preempting user needs, and ensuring consistent stakeholder BUY-IN. Additionally, the commercial industry is not bound by the same limitations of government-funded space technology development. This allows commercial organizations to focus on COMFORT and END-USER factors to accelerate the innovation process. This chapter analyzes the success and failure mechanisms within the commercial space sector, emphasizing the critical role of user-centric strategies in a world driven by rapid technological changes. The chapter will explore the criticality of COMFORT factors, END-USER input, and the effects of temporal and environmental shifts in industry product innovation. Figure 12 shows the logos of the various organizations that will be discussed in this chapter.



Figure 12. Logos of the Commercial Organizations that will be Assessed in Chapter IV.

B. FRAMING THE COMMERCIAL INNOVATION CHALLENGE

Like many companies that experience failure while developing emerging technologies, the commercial space industry finds success by learning to generate COMFORT and tailor their innovations to the END USER. This sector received an all-time high in venture capital and growth firm funding in 2021.¹³² Through approximately 450 deals, space tech funding totaled \$12.1 billion.¹³³ The profitability in this sector is due to the success of name-brand companies such as Space Exploration Technologies (SpaceX) and relatively newer startups like Relativity Space, Hawkeye 360, and Astranis.¹³⁴ As of August 2023, 487 new space tech startups aim to find success in a growing technology sector.¹³⁵ Rob Reis, President and Founder of Higher Ground L.L.C., a space tech startup, notes, “There are approximately 15,000 high-tech startups per year and only about 100 of those are significantly successful.”¹³⁶ Reis, who has over 50 years of experience working in Silicon Valley, adds, “Silicon Valley is a ‘laboratory of failures,’ and an important part of finding success in high-tech innovation is by learning from these failures, which doesn’t happen often.”¹³⁷

“Fail fast” is a common phrase in the startup culture, which generally motivates companies to iterate more rapidly or determine if “pivoting” to a different market is necessary. In most instances, “failing fast” can only lead to success if the organization “learns from the failure,” an equally important behavior.¹³⁸ Reis doesn’t apply the “fail fast” mentality to his business models to further emphasize this point. He states, “Failing fast is a flawed approach fueled by the seemingly infinite resources provided by venture capitalists that directly increases a company’s RISK tolerance. Instead of failing and pivoting,

¹³² Chris Metinko, “Space Tech Funding Comes Back Down To Earth,” Crunchbase News, July 20, 2023, para. 3, <https://news.crunchbase.com/venture/space-tech-funding-drops-spacex-relativity/>.

¹³³ Metinko, para. 3.

¹³⁴ Tracxn, “New Space Startups in the United States | Tracxn,” Tracxn, n.d., <https://tracxn.com/explore/NewSpace-Startups-in-United-States>.

¹³⁵ Tracxn.

¹³⁶ Rob Reis, personal communication, Phone, June 27, 2023.

¹³⁷ Reis.

¹³⁸ Reis.

learning from the failure and fixing the problem is a common pattern seen in successful companies.”¹³⁹ In other words, an organization needs to learn why it failed to understand the problem and will likely experience similar troubles finding success in the future. Additionally, it is difficult for government organizations to adopt the “fail fast” approach due to finite resources and higher RISK aversion.

To prevent failures, profit-motivated private companies must generate critical “COMFORT” to be successfully adopted by organizations and END-USERS with varying needs. The likely outcome is failure if COMFORT is not sufficiently generated to facilitate technology adoption. Regarding defense acquisitions, Joel Babbitt, author of *Half-Price Negotiating*, suggests that organizational credibility, scope, and impact of an innovation are components of a “common language of senior military officers” responsible for approving programs.¹⁴⁰ Babbitt adds that bureaucratic processes and the “regulators” that maintain them can significantly influence COMFORT.¹⁴¹ Additionally, END-USERS can also promote, discourage, or inhibit COMFORT, as the examples in the following sections describe. As a result, commercial organizations must prioritize strengthening their COMFORT and END-USER factors to facilitate successful technology adoption. Figure 13 illustrates that COMFORT and END-USER factors are significant variables related to commercial space technology adoption cases.

¹³⁹ Reis.

¹⁴⁰ Babbitt, *Half-Price Negotiating: Reframing Defense Acquisition Program Management to Achieve Extraordinary Results*, ch. 4, para. 18.

¹⁴¹ Babbitt, ch. 9, para. 3.

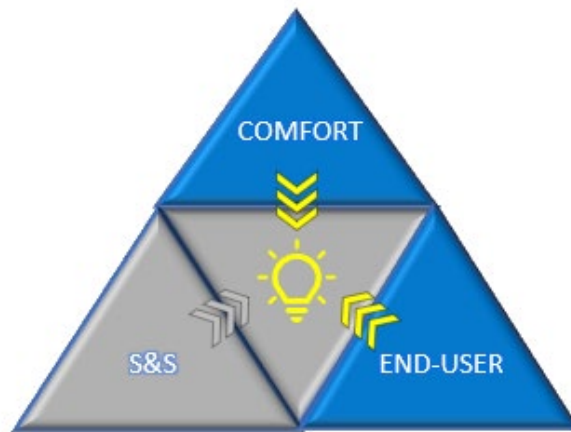


Figure 13. COMFORT and END-USER are the Most Significant Factors Affecting Commercial Industry Innovation Capacity.

C. END USER INPUT

In 1984, an extensive research project was conducted at Stanford (Stanford Innovation Project) to understand the difference between success and failure in high-tech product innovation.¹⁴² Modesto Maidique and Billie Zirger, experts in business management, led the study with 72 Stanford business students, including Rob Reis.¹⁴³ The study analyzed 36 companies through product surveys and personnel interviews. The study determined that product outcome (success or failure) was determined by how well the company understood end-user needs and whether it addressed them in the product specification.¹⁴⁴ Moreover, 70% of the failures analyzed in this study suggest that the company assumed it knew exactly what the end-users needed and did not effectively communicate with them.¹⁴⁵

Reis contributed to this study by analyzing Magnavox's Transit satellite receiver, a precursor to the global positioning system (GPS) integrated into ocean-going cargo ship

¹⁴² Maidique and Zirger, "A Study of Success and Failure in Product Innovation."

¹⁴³ Reis, personal communication.

¹⁴⁴ Maidique and Zirger, "A Study of Success and Failure in Product Innovation."

¹⁴⁵ Reis, personal communication.

navigation practices in 1973.¹⁴⁶ Reis learned that Magnavox was very successful in this endeavor because these large vessels could save time (and money) by navigating great circle routes with the assistance of the Transit satellite receiver.¹⁴⁷ Great circle routes allow a vessel to travel the shortest course between two points on the surface of a sphere, a practice that saved approximately \$300,000 per day in cargo operations in the 1970s.¹⁴⁸ Following this success, Magnavox confidently attempted to shift its market to the small vessel recreational boating community.¹⁴⁹ Unfortunately for Magnavox, it was unsuccessful in diffusing its innovation to the recreational boating market.

The Stanford Innovation Project concluded that this failure in technology adoption was caused by Magnavox's presumption of knowing better than the END-USERS regarding what they need.¹⁵⁰ As informed by Reis, Magnavox stated, in hindsight, that they provided approximately 95% of the optimal features; however, they forgot one critical element: a "sleep mode."¹⁵¹ While the overall purpose of the satellite receiver was to increase navigational efficiency, the overlooked inclusion of a "sleep mode" inefficiently drained the boat's battery, causing the END-USERS to be powerless out in the water, requiring a tow back onto shore. Consequently, boat operators did not take long to spread the word about the product, which affected future BUY-IN.¹⁵² This feature was overlooked because Magnavox did not integrate recreational boat operators into its development team and, as a result, did not have its finger on the "pulse" of the concerns of the boating community.¹⁵³

Moreover, the company entered "stealth mode" during the development cycle, a common business practice used to mitigate information leaks, prevent alerting competitors

¹⁴⁶ Reis.

¹⁴⁷ Reis.

¹⁴⁸ Reis.

¹⁴⁹ Reis.

¹⁵⁰ Reis.

¹⁵¹ Reis.

¹⁵² Reis.

¹⁵³ Reis.

to a product launch, and protect intellectual property.¹⁵⁴ Unfortunately, “stealth mode” also prevents the company from obtaining market information concerning the product by inhibiting COMMUNICATION with the END-USERS.¹⁵⁵ Reis adds that “stealth mode” is arrogant because it assumes a detailed market understanding without first talking to customers.¹⁵⁶ Further, Babbitt states, “If you can’t speak the language of the people who use your product, then you aren’t part of the culture. And if you aren’t part of the culture, you’ll make decisions and create products that are discordant with the users—like playing a violin out of tune in the midst of an orchestra.”¹⁵⁷ As a result, “stealth mode” is a practice that Reis does not endorse and a practice he attributes to many failed startups.¹⁵⁸

Reis informs that when most companies experience failures like Magnavox’s Transit satellite receiver, the management team typically removes team members and “pivots” to a new market.¹⁵⁹ Fortunately for Magnavox, they kept all team members onboard, prioritized learning from their mistakes, and worked quickly to remedy them.¹⁶⁰ This rapid remediation effort emphasized learning from failure, resulting in a successful outcome, and facilitated a mass adoption of their line of satellite receivers that eventually evolved into the GPS era of navigation systems.¹⁶¹ This technology adoption case highlights the significant importance of END-USER feedback loops and “lessons learned” concerning successful technology adoption. Figures 14 and 15 show the effects of COMFORT and END-USER factors in Magnavox’s first attempt at shifting to the recreational boating market.

¹⁵⁴ Bond Collective, “Stealth Mode Startups: What Are They And When To Launch One,” Bond Collective, n.d., sec. 2, <https://www.bondcollective.com/blog/stealth-mode-startup>.

¹⁵⁵ Bond Collective, sec. 3.

¹⁵⁶ Reis, personal communication.

¹⁵⁷ Babbitt, *Half-Price Negotiating: Reframing Defense Acquisition Program Management to Achieve Extraordinary Results*, ch. 3, para. 26.

¹⁵⁸ Reis, personal communication.

¹⁵⁹ Reis.

¹⁶⁰ Reis.

¹⁶¹ Reis.

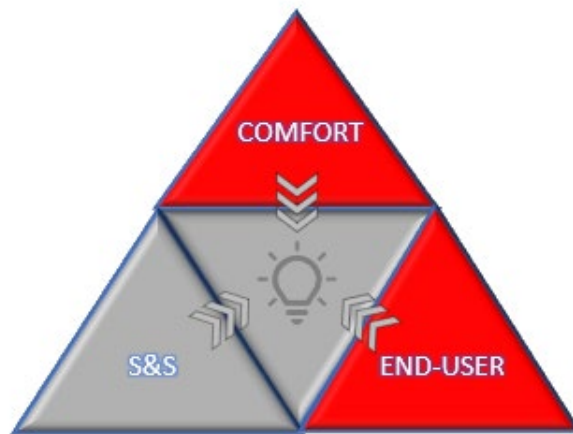


Figure 14. COMFORT and END-USER Factors Scored **LOW** in the Magnavox Case Study.



Figure 15. Magnavox Satellite Receiver Adoption Outcome.

D. TEMPORAL AND ENVIRONMENTAL SHIFT

The previous section highlights the importance of END-USER input. This section enhances the discussion by analyzing how temporal and environmental changes can drastically shift END-USER sentiment toward an innovation. Today, satellite-provided broadband communications are synonymous with SpaceX’s Starlink low-earth orbit (LEO) systems, and other companies are projected to offer this type of service in the near term,

including OneWeb, Amazon Kuiper, and Iridium.¹⁶² Surprisingly, these companies were not the first to attempt LEO broadband communications. Teledesic, a private company owned by telecommunications billionaire Craig McCaw and backed by Microsoft's Bill Gates in the early 1990s, was the first to attempt to provide a Starlink-like service.¹⁶³ Comparing Starlink to Teledesic allows for an apples-to-apples comparison of success and failure to determine the factors that differed between the innovations.

Teledesic sought to fill a market need between the fast but urban-limited terrestrial-based communications networks and the wider-ranging, slow, geosynchronous earth orbit (GEO) satellite services. The markets Teledesic targeted were underserved populations in rural areas of developed countries, underdeveloped countries, and other remote users associated with government and corporate activities.¹⁶⁴ Additionally, Teledesic identified that LEO-based services could greatly improve upon the existing geosynchronous earth orbit (GEO) satellite services regarding latency, signal strength, and service reliability at higher latitudes.¹⁶⁵ The proposed solution was to launch 840 satellites into an orbital altitude of 700 km using 21 orbital planes consisting of 40 satellites each, providing service to the entire Earth's surface, including polar regions.¹⁶⁶ The Teledesic system specifications were advertised as "fiber-like," and included 65 Mbps downlink, 2Mbps uplink, and a bit error rate better than 10^{-10} , an improvement over GEO satellite services and comparable to terrestrial networks at the time.¹⁶⁷

¹⁶² Kristin Cooke, "What Are the New Satellite Internet Providers?," *SatelliteInternet.com*, August 4, 2023, sec. 2, <https://www.satelliteinternet.com/resources/history-and-future-of-satellite-internet/>.

¹⁶³ Thomas Eisenmann, Doug Rogers, and Dan Green, "Teledesic" (Harvard Business School, March 22, 2004).

¹⁶⁴ Eisenmann, Rogers, and Green, 5.

¹⁶⁵ RF Wireless World, "Advantages and Disadvantages of GEO | Geosynchronous Orbit," RF Wireless World, n.d., sec. 2, <https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-GEO-Geosynchronous-orbit.html>.

¹⁶⁶ James Stewart, "Teledesic Global Wireless Broadband Network: Space Infrastructure Architecture, Design Features, and Technologies" (NASA, October 1995), 8.

¹⁶⁷ Stewart, 8.

Significant financial and logistical hardships led to the downfall of Teledesic even though it was backed by Saudi Prince Alwaleed bin Talal, Boeing, and Motorola.¹⁶⁸ Costs associated with training, manufacturing, launching, and constructing the necessary ground stations and user terminals were elevated.¹⁶⁹ For example, Teledesic could fit only eight of its 120-kilogram T1 satellites into the average launch vehicle, requiring 105 launches (> \$500 million per launch in 1995 dollars at \$26,884/kg) to get the entire constellation to orbit.¹⁷⁰ ¹⁷¹ The user terminals were also expensive (~\$1000 in 1995 dollars) with a large form factor that required roof installation.¹⁷² Further, mass-producing novel, high-end space technology in the 1990s was costly, as were the logistics to operate the technology, including distribution, installation, training, and remote field repairs.¹⁷³

Ultimately, the END-USER characteristics in the telecommunications market were the most significant factors associated with Teledesic's failure.¹⁷⁴ At the time, terrestrial broadband networks primarily served urban areas with moderate speeds and latency and, in contrast, were cost-prohibitive to rural or poor populations.¹⁷⁵ These trends rapidly changed in the mid-'90s with advancing terrestrial networks offering increased availability, speed, and data transmission (in addition to voice-only) and lower monthly prices.¹⁷⁶ Moreover, high-speed online gaming, shopping, and streaming television services were yet to be part of the customer lifestyle in the '90s. As a result, the financial and logistical

¹⁶⁸ Sharon Pian Chan, "The Birth and Demise of an Idea: Teledesic's 'Internet in the Sky' | The Seattle Times," Seattle Times, n.d., sec. 2, <https://archive.seattletimes.com/archive/?date=20021007&slug=teledesic070>.

¹⁶⁹ Eisenmann, Rogers, and Green, "Teledesic," 7.

¹⁷⁰ Mark G. Matossian, "A Teledesic Space Infrastructure Overview," in *Mission Design & Implementation of Satellite Constellations* (Dordrecht: Springer Netherlands, 1998), 153–56, https://doi.org/10.1007/978-94-011-5088-0_14.

¹⁷¹ Will Fox, "Launch Costs to Low Earth Orbit, 1980–2100," n.d., <https://futuretimeline.net/data-trends/6.htm>.

¹⁷² Eisenmann, Rogers, and Green, "Teledesic," 7.

¹⁷³ Eisenmann, Rogers, and Green, 8.

¹⁷⁴ Pian Chan, "The Birth and Demise of an Idea: Teledesic's 'Internet in the Sky' | The Seattle Times," sec. 5.

¹⁷⁵ Eisenmann, Rogers, and Green, "Teledesic," 3.

¹⁷⁶ Eisenmann, Rogers, and Green, 21.

hardships and the lack of END-USER need for expensive high-speed communications services caused Teledesic's failure, a classic case of the right technology introduced at the wrong time. In other words, the costs were too great relative to the perceived need. Figures 16 and 17 illustrate how unfavorable END-USER factors led to a negative adoption outcome for Teledesic's T1 satellite receiver.

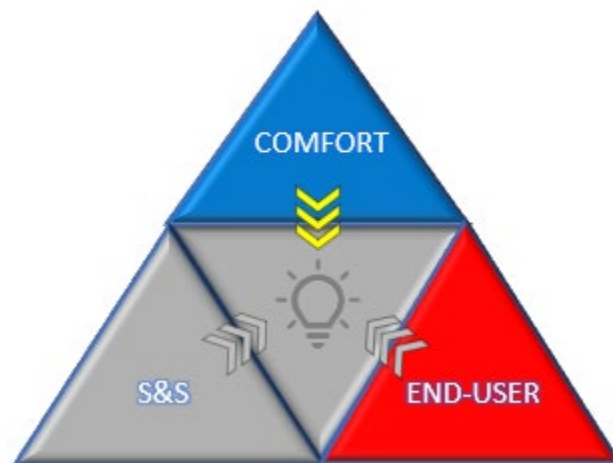


Figure 16. Measurement of Teledesic's COMFORT Index (**HIGH**) and END-USER Index (**LOW**).

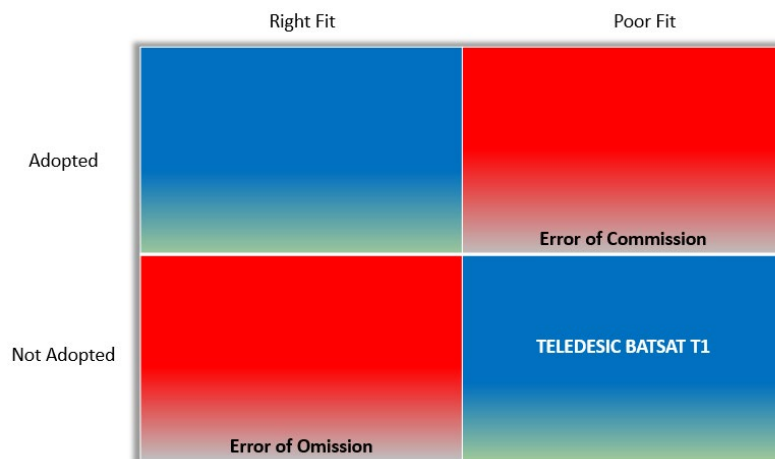


Figure 17. Teledesic's Adoption Outcome.

Three decades later, SpaceX revived the LEO-based broadband concept by introducing Starlink, a successful megaconstellation of over 4,500 satellites (and growing) providing broadband service to the same market that Teledesic targeted.¹⁷⁷ While the approach and business plan are remarkably similar to Teledesic's, Starlink benefits greatly from temporal and environmental changes to the market and its END-USERS. As of 2023, high-speed gaming, online shopping, streaming entertainment services, distance education, and teleconference capabilities are considered essential commodities.¹⁷⁸ Consequently, user demand for high-speed internet services is greater than ever, and users in underserved areas are no exception.¹⁷⁹ Modern terrestrial networks, including 5G, are still market competitors; however, LEO broadband has evolved to complement terrestrial competitors and can fill the gaps when 5G services suffer outages.¹⁸⁰

The costs of accessing space have also dramatically decreased over time, accelerating Starlink's success. SpaceX has spearheaded these cost reductions by inventing the reusable launch vehicle, the Falcon 9 and Falcon Heavy rockets.¹⁸¹ Not only have reusable launch vehicles reduced launch costs to \$62 million per launch (\$2,720/kg), but launch vehicles also accommodate 60 Starlink satellites per launch.¹⁸² Additionally, mass production of Starlink satellites is incredibly efficient, with SpaceX producing six per

¹⁷⁷ Pultarova, Tereza, Mann, Elizabeth, "Starlink Satellites: Everything You Need to Know about the Controversial Internet Megaconstellation," Space.com, April 14, 2022, sec. 2, <https://www.space.com/spacex-starlink-satellites.html>.

¹⁷⁸ Cheri Beranek, "Anything We Can Do, High-Speed Broadband Could Help Us Do Better," Forbes, March 7, 2022, <https://www.forbes.com/sites/forbestechcouncil/2022/03/07/anything-we-can-do-high-speed-broadband-could-help-us-do-better/>.

¹⁷⁹ Statista, "COVID-19—Daily in-Home Data Usage Change U.S. 2020," Statista, n.d., <https://www.statista.com/statistics/1106863/covid-19-daily-in-home-data-usage-change-us-2020/>.

¹⁸⁰ Arpita Agnihotri and Saurabh Bhattacharya, "SpaceX: Starlink's Uncertain Demand Trajectory" (Ivey Publishing, 2021), 4.

¹⁸¹ Rich Smith, "How Much Cheaper Are SpaceX Reusable Rockets? Now We Know," The Motley Fool, October 5, 2020, para. 1, <https://www.fool.com/investing/2020/10/05/how-much-cheaper-are-spacex-reusable-rockets-now-w/>.

¹⁸² Caleb Henry, "SpaceX Launches 60 Starlink Satellites, Begins Constellation Buildout," *SpaceNews* (blog), May 24, 2019, para. 1, <https://spacenews.com/spacex-launches-60-starlink-satellites-begins-constellation-buildout/>.

day.¹⁸³ Consequently, the U.S. is poised to proliferate satellite architectures due to cheaper launch and manufacturing costs, making Teledesic’s original vision achievable. More importantly, the market is much better aligned with LEO broadband, facilitating mass adoption and creating a viable business plan. Figures 18 and 19 illustrate the effect optimal levels of COMFORT and END-USER factors have on Starlink’s adoption outcome.

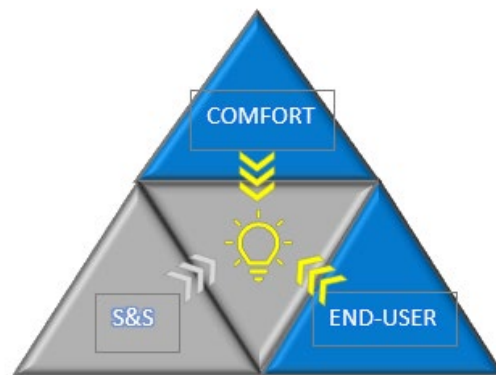


Figure 18. Measurement of Starlink’s COMFORT Index (**HIGH**) and END-USER Index (**HIGH**).

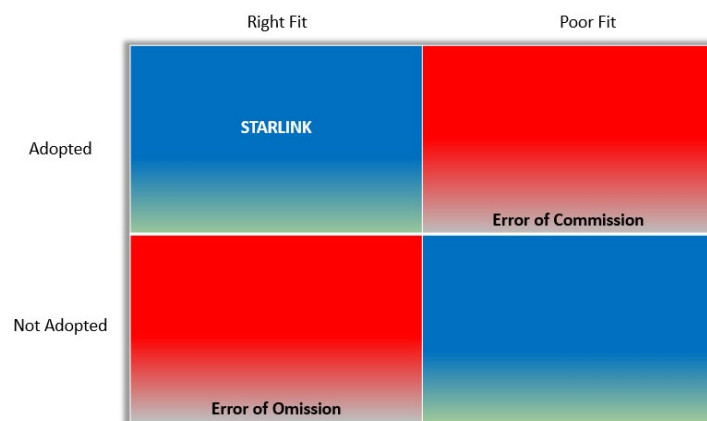


Figure 19. Starlink’s Adoption Outcome.

¹⁸³ Eric Ralph, “SpaceX Starlink Factory Building Satellites Four Times Faster than Closest Competitor,” *TESLARATI* (blog), March 12, 2020, para. 3, <https://www.teslarati.com/spacex-starlink-satellite-production-faster-than-competitors/>.

E. COMFORT

Generating COMFORT with an innovation is extremely important in producing successful outcomes in technology adoption. As defined earlier, a critical component of COMFORT is understanding the SCOPE AND IMPACT of the innovation. Ian Eishen, Global Public Sector Director at Aalyria, a space technology startup, suggests that education is instrumental to understanding the value that emerging technologies provide, and this increases COMFORT.¹⁸⁴ For example, education is a critical element that has factored into adopting one of Aalyria's developed technologies: Spacetime. Spacetime is a software-defined network orchestrating technology at TRL 9, designed to ensure reliable, secure communications by continuously optimizing data transmission pathways.¹⁸⁵ In other words, Spacetime provides a solution to the military's pursuit of Joint All-Domain Command and Control (JADC2) by linking all forms of communication nodes (space, air, maritime, ground, and cyber) to dynamically route communications through the path of least resistance, providing connectivity to areas previously thought unconnectable.¹⁸⁶ While the technology is groundbreaking and arguably necessary for the future of warfare, and because system communications across orbits are currently limited, this concept is difficult to grasp, and thus reduces COMFORT for many potential customers, including many military organizations that do not possess a critical mass of space systems expertise.

To reach its desired technology adoption outcome, Aalyria builds COMFORT by EDUCATING and COMMUNICATING complex ideas with simpler language. In the case of military customers, Eishen notes that it often takes multiple meetings to establish a "baseline" of UNDERSTANDING with an organization before the customer fully grasps the advantages and use cases for Spacetime.¹⁸⁷ Additionally, Eishen adds that UNDERSTANDING the total value of Spacetime is complex and requires a foundational understanding of networks,

¹⁸⁴ Ian Eishen, personal communication, Microsoft Teams, September 27, 2023.

¹⁸⁵ Aalyria, "Spacetime," Aalyria, n.d., <https://www.aalyria.com/spacetime>.

¹⁸⁶ Debra Werner, "Rivada Space Networks Selects Aalyria Spacetime," SpaceNews, March 13, 2023, para. 3, <https://spacenews.com/rivada-space-networks-selects-aalyria-spacetime/>.

¹⁸⁷ Eishen, personal communication.

frequencies, free space optics, and orbital regimes; however, Aalyria has found success when simplifying its concept to just a handful of elements, providing an entry-level UNDERSTANDING of the technology.¹⁸⁸ Still, front-end EDUCATION is needed to understand the array of emerging technologies changing warfare's nature.¹⁸⁹ Eishen observes that the benefits of advanced EDUCATION are evidenced by the engineers and space-oriented personnel who quickly realize the benefits and support Spacetime following briefings and DEMONSTRATIONS.¹⁹⁰ Conversely, military leaders are more hesitant to support Spacetime, likely due to a limited UNDERSTANDING of the challenge space. This deficiency directly affects trust and how decision-makers conceptualize the use cases for the technology.

Unfortunately, it is increasingly more common for many leaders in the DOD not to UNDERSTAND the fundamentals of emerging technologies, including space systems. This lack of understanding impairs the DOD's ability to envision what the technology can do, thereby delaying the integration of the technology into DOD strategies.¹⁹¹ Eishen reinforces these arguments by adding, "Education takes time and most military personnel don't have that kind of time when they are confronted with high operational tempos."¹⁹² As a result, one of the primary obstacles affecting the adoption of Spacetime is the knowledge gap pertaining to network orchestration that leads to decreased COMFORT levels with military decision-makers. An increasing trend for military organizations, including NSW, is to hire a civilian technology specialist or Chief Technology Officer (CTO) to mitigate these effects by validating emerging technologies and potentially recommending

¹⁸⁸ Eishen.

¹⁸⁹ Michael Freeman and Colonel Todd Lyons, "Education Is the Technology the Navy Needs Most," U.S. Naval Institute, July 30, 2020, <https://www.usni.org/magazines/proceedings/2020/july/education-technology-navy-needs-most>.

¹⁹⁰ Eishen, personal communication.

¹⁹¹ Herbert Williams, "A DOD Education Strategy for Artificial Intelligence" (Air University Press, April 2020), 1.

¹⁹² Eishen, personal communication.

their adoption.¹⁹³ While not a replacement for military strategists coming to the table with advanced technical EDUCATION, technology officers can help organizations invest in disruptive technologies; CTOs are also subject to BIASES and influences that may be incongruent with the military organization.

Other mechanisms are in place to assist Aalyria in generating COMFORT with potential customers, including utilizing proven government innovation-centric organizations such as the Defense Innovation Unit (DIU). The DIU seeks to identify relevant commercial market technologies and rapidly solve operational challenges by bringing potential capabilities to military organizations through unique contracting mechanisms.¹⁹⁴ DIU awarded Aalyria an Other Transaction Authority (OTA) contract in 2022 as a central component of its hybrid space architecture (HSA) that seeks to modernize military communications by converging information-age assets with space-age assets to provide secure and assured communications anywhere on and off Earth.¹⁹⁵ DIU has effectively bridged Aalyria's unique value proposition to military organizations that could benefit from these capabilities to solve current challenges. As a military organization, DIU shares a common language with potential military customers and understands the acquisition barriers that also encumber these customers. Moreover, another key to DIU's success is to embed active duty and retired military personnel with industry civilians to accelerate two-way learning. As a result, Aalyria's association with DIU has helped generate COMFORT for military decision-makers.¹⁹⁶ To revisit an earlier theme, technological advantages alone do not necessarily lead to adoption; tailored communication and using "CHAMPIONS," such as DIU, can increase UNDERSTANDING and

¹⁹³U.S. Central Command, "U.S. Central Command Hires Chief Technology Officer," U.S. Central Command, n.d., para. 1, <https://www.centcom.mil/MEDIA/PRESS-RELEASES/Press-Release-View/Article/3178494/us-central-command-hires-chief-technology-officer/>
<https%3A%2F%2Fwww.centcom.mil%2FMEDIA%2FPRESS-RELEASES%2FPress-Release-View%2FArticle%2F3178494%2Fus-central-command-hires-chief-technology-officer%2F>.

¹⁹⁴ Defense Innovation Unit, "Defense Innovation Unit," n.d., <https://www.diu.mil/>.

¹⁹⁵ Defense Innovation Unit, "Initial Contracts for Hybrid Space Architecture Program," Defense Innovation Unit, July 7, 2022, para. 2, <https://www.diu.mil/latest/developing-the-internet-of-space>.

¹⁹⁶ Courtney Albon, "Defense Innovation Unit Teams with Companies on Space-Based Internet," C4ISRNet, July 10, 2023, para. 5, <https://www.c4isrnet.com/battlefield-tech/space/2023/07/10/defense-innovation-unit-teams-with-companies-on-space-based-internet/>.

COMFORT, which is more impactful to adoption outcomes. Consequently, the U.S. Space Force's Space Development Agency (SDA) recently contracted Aalyria, along with SpaceX and Kuiper Government Solutions, to examine the prospects of integrating their commercial capabilities into the upcoming government-owned satellite constellation dubbed the Proliferated Warfighter Space Architecture (PWSA).¹⁹⁷ Figures 20 and 21 illustrate that inadequate COMFORT has slowed the adoption of Spacetime, a useful and disruptive technology.

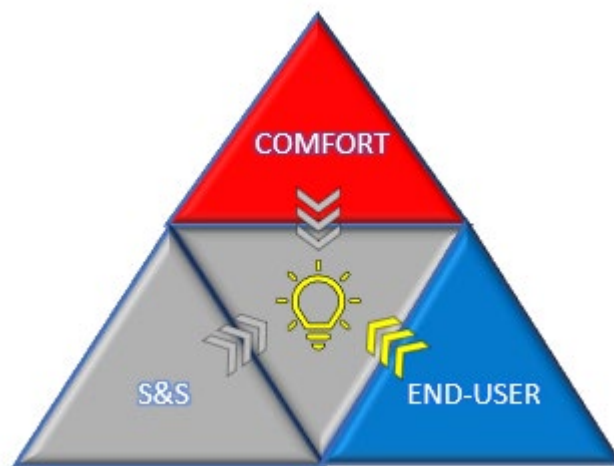


Figure 20. Measurement of Spacetime's COMFORT Index (**LOW**) and END-USER Index (**HIGH**).

¹⁹⁷ Evelyn Janeidy Arevalo, "U.S. Space Force Selects SpaceX Starlink, Kuiper Government Solutions, and Aalyria Technologies for Military Satellite Backhaul Studies," TESMANIAN, September 7, 2023, para. 5, <https://www.tesmanian.com/blogs/tesmanian-blog/pswa>.

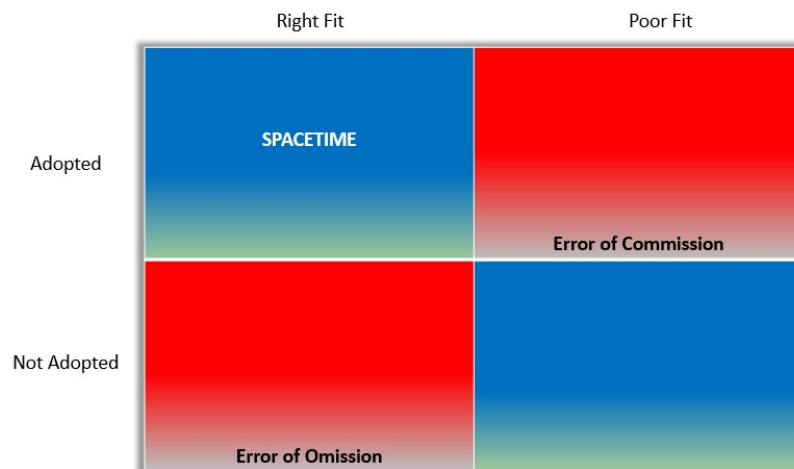


Figure 21. Spacetime’s Adoption Outcome.

Emergent technologies that are “evolutionary” rather than “disruptive” are more COMFORTABLE for military leaders. Thus, evolutionary innovations are more likely to accelerate adoption and integration into EXISTING OPERATIONAL CONCEPTS. Higher Ground’s SatPaq2, a compact satellite communicator, is an example of an evolutionary technology that uses existing Android devices (with millions of associated users) to provide complementary SATCOM capability.¹⁹⁸ SatPaq2 uses GEO satellites and the cell phone’s transmitting power to provide global C-Band, a mid-band spectrum offering a mix of performance and coverage advantages, for guaranteed text and data at any location worldwide. Additionally, C-Band allows for lower cost bandwidth using small user devices within the Size, Weight, and Power (SWaP) constraints that military END-USERS require. This capability, assisted by its small form factor, integrates seamlessly into current PACE (primary, alternate, contingency, emergency) plans, eliminating drastic behavior changes and increasing COMFORTABILITY.

Dave Perry, Vice President of Higher Ground L.L.C., utilized his experience in the special operations community to help tailor the SatPaq2 to solve specific END-USER problems.¹⁹⁹ He states, “When asked to explain what SatPaq2 is, I say that it is a SATCOM

¹⁹⁸ Higher Ground, “SatPaq,” Higher Ground, n.d., <https://satpaq.com/>.

¹⁹⁹ Dave Perry, personal communication, Microsoft Teams, June 30, 2023.

capability that would have saved Michael Murphy by allowing him to request help without exposing himself to deadly enemy fire.”²⁰⁰ Perry references a 2005 U.S. operation in Afghanistan (Operation Red Wings) that resulted in the death of three of four Navy SEALs, including LT Michael Murphy, who was unable to communicate back to headquarters during an engagement and was forced to knowingly expose himself to enemy fire to acquire a signal that led to the rescue of the last member of the team.²⁰¹ Higher Ground’s SatPaq2 may have conceivably provided a solution to this scenario. Military leaders easily UNDERSTAND this concept, as do special operations end-users who have experienced operational emergencies and would have benefitted from the new technology. These factors increase COMFORTABILITY and make it relatively more manageable for the SatPaq2 to penetrate military markets. Like Starlink, Figures 22 and 23 illustrate how SatPaq2’s positive COMFORT and END-USER factors led to a successful adoption outcome.

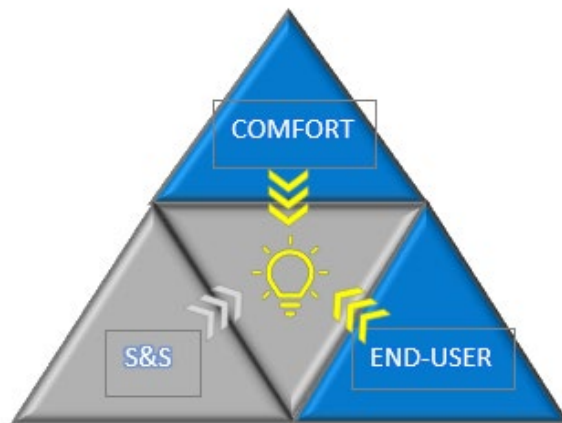


Figure 22. Measurement of SatPaq2’s COMFORT Index (**HIGH**) and END-USER Index (**HIGH**).

²⁰⁰ Perry.

²⁰¹ Marcus Luttrell, *Lone Survivor* (New York: Little, Brown & Company, 2007).



Figure 23. SatPac2's Adoption Outcome.

In summary, the growth of the commercial space sector highlights the delicate interplay between cutting-edge technological advances and the constantly changing needs and preferences of END-USERS. While the rise in venture capital funding and disruptive advancements from industry leaders like SpaceX demonstrate the enormous potential within the industry, they also highlight the critical necessity of COMPREHENDING and meeting END-USER needs for long-term success. Case studies from businesses like Magnavox and Teledesic shed light on the dangers of making assumptions without sufficient user feedback and the consequences of failing to know market needs. In contrast, the success stories of Aalyria and Higher Ground demonstrate the value of ADAPTABILITY, EDUCATION, and accurately assessing user sentiment toward new technologies. From these examples, military organizations, including NSW, should learn to have an acute UNDERSTANDING of their user base, adaptive learning from failures, and develop user-centric strategies to align with this period of rapid technological transformation. The next chapter will analyze the U.S. Space Force to determine its approach to innovating for strategic competition.

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V. U.S. SPACE FORCE

Exploit what we have, buy what we can, build what we must.

-General John W. Raymond (USAF, Ret.)²⁰²

A. INTRODUCTION

General John W. Raymond (USAF, Ret.) was the first member of the United States Space Force (USSF) and its first Chief of Space Operations. In the evolving landscape of space security, and in *The Guardian Ideal*, Raymond advocates for transformative cultural shifts within the newly-established USSF.²⁰³ The document highlights innovation and digital fluency as pivotal to rapid technology adoption, streamlining bureaucratic processes, and creating an agile talent management strategy tailored to modern challenges. To maintain a competitive advantage in space, Raymond's *Chief of Space Operations Planning Guidance* underscores the necessity of embracing calculated risks and breaking away from traditional paradigms.²⁰⁴ This ethos is echoed in Space System Command's (SSC)'s subsequent efforts, such as accelerating space technology acquisition, which aims to reduce acquisition complexity and timelines, and to optimize resource deployment.²⁰⁵ As the premiere space capability delivery organization, SSC has set ambitious resiliency goals for 2026, emphasizing collaboration with the commercial space industry to boost innovation.²⁰⁶ In 2021, the USSF also birthed the Space Warfighting Analysis Center (SWAC) to refine its approach toward space technology, guiding acquisition decisions

²⁰² "Gen Raymond Reflects on Highlights of Space Force's Achievements and Predicts 'great History Ahead'," United States Space Force, September 20, 2022, para. 23, <https://www.spaceforce.mil/News/Article/3164602/gen-raymond-reflects-on-highlights-of-space-forces-achievements-and-predicts-gr/http%3A%2F%2Fwww.spaceforce.mil%2FNews%2FArticle-Display%2FArticle%2F3164602%2Fgen-raymond-reflects-on-highlights-of-space-forces-achievements-and-predicts-gr%2F>.

²⁰³ General John W. Raymond, "The Guardian Ideal," September 2021.

²⁰⁴ General John W. Raymond, "Chief of Space Operations Planning Guidance," November 2020.

²⁰⁵ Frank Calvelli, "Memorandum for the Department of Air Force Space Acquisition Workforce." Official memorandum. Washington, D.C.: Department of the Air Force, April 5, 2023.

²⁰⁶ Linda Kane, "Space Systems Command Targets 2026 for Key Resilience Goals," Space Systems Command, April 6, 2023, para. 1, <https://www.ssc.spaceforce.mil/Newsroom/Article-Display/Article/3355729/https%3A%2F%2Fwww.ssc.spaceforce.mil%2FNewsroom%2FArticle-Display%2FArticle%2F3355729%2Fspace-systems-command-targets-2026-for-key-resilience-goals>.

based on rigorous analyses.²⁰⁷ The USSF's business fairs bridge the gap between classified government objectives and the commercial sector to foster enhanced cooperation and enable commercial partners to contribute more effectively to the strategic modernization of space. This chapter highlights the intricate challenges of integrating innovation within a massive organizational structure by using the Global Positioning System (GPS) as a case study, stressing its significance to military and civilian users. The GPS modernization effort is ongoing and is progressing slowly. The continual effort to modernize GPS underscores the complexities inherent in coordinating between multiple segments and dealing with unforeseen challenges. In essence, the USSF's approach illustrates the intricate dance of integrating innovation, managing risk, and navigating bureaucratic hurdles with the goal of remaining at the forefront of space security.

B. FRAMING THE USSF CHALLENGE

The USSF was established in December 2019 as a new branch of the U.S. Armed Services. Its primary objective is to sustain superiority in the space domain as a national security imperative.²⁰⁸ Erwin states, "The very existence of the USSF underscores the fiercely-contested nature of space" stemming from a proliferation of competitor space assets that place our national systems at risk.²⁰⁹ The DOD depends on the U.S. national security space architectures and considers them critical to communication, navigation, meteorology, situational awareness, and intelligence.²¹⁰ Adversaries such as China and Russia consider this dependency as a critical vulnerability to exploit during conflict with

²⁰⁷ Theresa Hitchens, "Exclusive: Space Warfighting Analysis Center Chief on Creating 'Something out of Nothing,'" *Breaking Defense* (blog), January 19, 2022, para. 1, <https://breakingdefense.sites.breakingmedia.com/2022/01/exclusive-space-warfighting-analysis-center-chief-on-creating-something-out-of-nothing/>.

²⁰⁸ United States Space Force, "About Space Force," United States Space Force, n.d., sec. 2, <https://www.spaceforce.mil/About-Us/About-Space-Force/>.

²⁰⁹ Sandra Erwin, "Tech Innovations Help Space Force Guardians Prepare for the Battlefield Above," *SpaceNews* (blog), October 11, 2023, para. 6, <https://spacenews.com/tech-innovations-help-space-force-guardians-prepare-for-the-battlefield-above/>.

²¹⁰ Brett Tingley, "What Is the U.S. Space Force and What Does It Do?," *Space.com*, February 14, 2023, para. 2, <https://www.space.com/us-space-force-history-mission-capabilities>.

the U.S.²¹¹ As a result, the USSF is purpose-built for operating and protecting these critical spaceborne assets and ensuring space superiority in the face of strategic competition.

The USSF must assess U.S. commercial satellite architectures and the implications they create for national security while they provide immense benefits supporting the USSF mission.²¹² On the one hand, proliferated commercial satellite systems, such as Starlink and OneWeb, significantly increase space congestion, which stresses existing space situational awareness (SSA) and space traffic management (STM) constructs.²¹³ Greater congestion increases the risk of collisions, which generate deadly orbital debris that can threaten the survival of national overhead assets.²¹⁴ On the other hand, increased commercial systems can provide incredible resiliency and asymmetric advantages to U.S. national space capabilities that are unlikely to be rivaled.²¹⁵ These competing dynamics highlight the immense responsibility the USSF has been given to increase capability, resiliency, and safety while ensuring the space environment remains accessible to allies and partners.

Therefore, the USSF must leverage commercial innovations to sustain capability, increase resiliency, and improve space domain awareness (SDA). Colonel Joseph Roth, Commander of Innovation and Prototyping Acquisitions Delta at the Space Force's Space Systems Command, states, "The Space Force is responsible for ensuring the joint warfighter has the capabilities it needs to deter conflict, whether that's in space and cyber,

²¹¹ Matthew Hallex and Travis Cottom, "Proliferated Commercial Satellite Constellations: Implications for National Security," *National Defense University Press Joint Force Quarterly*, no. 97 (March 31, 2020), sec. 5, <https://ndupress.ndu.edu/Media/News/News-Article-View/Article/2106495/proliferated-commercial-satellite-constellations-implications-for-national-secu/>
<https%3A%2F%2Fndupress.ndu.edu%2FMedia%2FNews%2FNews-Article-View%2FArticle%2F2106495%2Fproliferated-commercial-satellite-constellations-implications-for-national-secu%2F>.

²¹² Hallex and Cottom, sec. 1, para. 2.

²¹³ Hallex and Cottom, sec. 8, para. 2.

²¹⁴ Hallex and Cottom, sec. 8, para. 2.

²¹⁵ David Vergun, "Official Details Space-Based Threats and U.S. Countermeasures," U.S. Department of Defense, April 26, 2023, para. 9, <https://www.defense.gov/News/News-Stories/Article/Article/3375577/official-details-space-based-threats-and-us-countermeasures/>
<https%3A%2F%2Fwww.defense.gov%2FNews%2FNews-Stories%2FArticle%2F3375577%2Fofficial-details-space-based-threats-and-us-countermeasures%2F>.

on the ground, at sea, or on the land. It's a really important mission and I think the commercial industry plays a big part of that."²¹⁶ The current government system and its constraints fail to keep pace with fast-evolving threats and technologies, so the USSF must be prudent with those technologies it develops slowly and those it rapidly adopts.²¹⁷ Colonel Roth adds, "We don't want to be developing systems that we think commercial can develop better."²¹⁸ Traditionally, long acquisition timelines are inefficient when trying to remain ahead of adversaries. The resulting challenge is to diverge from "reliance on small numbers of highly capable, expensive satellites" and shift to a commercially-provided resiliency posture that is resistant to adversary attack and provides enhanced space capability to the warfighter.²¹⁹ Figure 24 depicts that STAFF & SYSTEMS and END-USER factors are the most significant innovation factors affecting the USSF's capacity to innovate.

²¹⁶ Aerospace, "Expanding Integration Across Government and Commercial Space for Speed and Resiliency | The Aerospace Corporation," Aerospace, August 29, 2023, sec. 4, para. 4, <https://aerospace.org/article/expanding-integration-across-government-and-commercial-space-speed-and-resiliency>.

²¹⁷ Department of Defense, *Department of Defense Cyber Strategy 2018* (Washington, D.C.: Department of Defense, 2018), 4, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwijaPs_-mCAxW8ie4BHThLBRcQFnoECBkQAQ&url=https%3A%2F%2Fmedia.defense.gov%2F2018%2FSep%2F18%2F2002041658%2F-1%2F-1%2F1%2FCYBER_STRATEGY_SUMMARY_FINAL.PDF&usg=AOvVaw3GLVob1pXJWhCeJIbNJ5Pd&opi=89978449.

²¹⁸ Aerospace, sec. 4, para. 4.

²¹⁹ Hitchens, "Exclusive," para. 3.

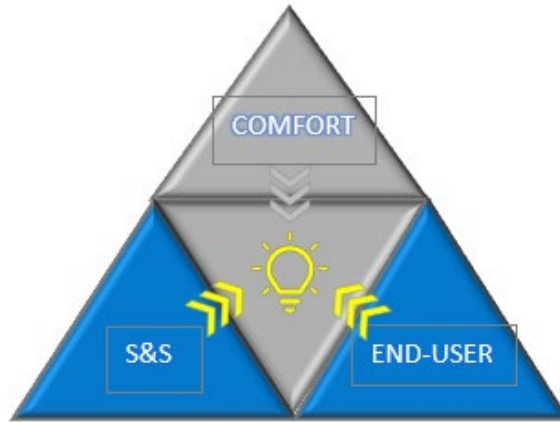


Figure 24. STAFF & SYSTEMS and END-USER are the Most Significant Factors Affecting USSF’s Capacity to Innovate.

C. ORGANIZATIONAL CULTURE AND PROCESSES

In 2021, the newly appointed Chief of Space Operations, Gen. Raymond, unveiled several formative documents, including his *Guardian Ideal*, to guide the new service’s mission to keep space secure, stable, and accessible.²²⁰ The *Guardian Ideal* highlights cultural changes that depart from standard military expectations.²²¹ The document states that innovation in operations, processes, and activities is necessary, and one avenue to achieve this goal is by increasing the digital fluency of its members.²²² These additional competencies include data analytics and cyber defense. These competencies are part of the USSF’s new talent management construct and will provide Guardians with the required skillsets to modernize effectively and harness emerging technologies.²²³ The talent management construct includes reducing administrative burdens and bureaucratic processes to eliminate stovepipes that hinder innovation, agility, and speed within the

²²⁰ Nathan Strout, “U.S. Space Force Chief Lays out His Priorities in New Guidance,” Defense News, November 9, 2020, <https://www.defensenews.com/space/2020/11/09/space-force-chief-lays-out-his-priorities-in-new-guidance/>.

²²¹ General John W. Raymond, “The Guardian Ideal.”

²²² General John W. Raymond, 4.

²²³ General John W. Raymond, 6–7.

USSF.²²⁴ Further, the USSF focuses on attracting new members with critical competencies and incentivizing current members to acquire these competencies. One unique example of how the USSF aims to recruit the right people is by exploring employment options that bring onboard critical talent temporarily, to work on a specific project.²²⁵ These and many other cultural changes have helped shape and orient the organization to provide rapid and effective solutions to emerging technical challenges.

General Raymond's *Chief of Space Operations Planning Guidance* (CPG) provides fundamental guidance to inform how the service should adopt innovation and technology.²²⁶ In the document, Raymond acknowledges that the success of the newly-established Space Force requires "productive disruption" and that adherence to "the ways and means of our past" is not a practical path to deliver new capabilities rapidly.²²⁷ General Raymond expects "commanders and program managers to accept moderate risk associated with innovation and experimentation to build an agile force that better ensures our long-term competitive advantage in space."²²⁸ He adds, "Failing to accept the risk that accompanies innovation and experimentation will slow capability development and ultimately transfer risk to Joint warfighters. I do not accept the imposition of risk on warfighters to protect bureaucratic processes."²²⁹ Raymond's intent is to challenge risk-aversion and legacy-oriented processes that typically stifle innovation by placing more emphasis on transformative force design. As a result, the USSF is established with ideal cultural and organizational guidance that set conditions for positive innovation and the adoption of technological advances.

General Raymond emphasizes the requirement for faster acquisition speeds needed to field more proliferated and resilient architectures.²³⁰ Therefore, hastening acquisition

²²⁴ General John W. Raymond, 6–7.

²²⁵ General John W. Raymond, 7.

²²⁶ General John W. Raymond, "Chief of Space Operations Planning Guidance."

²²⁷ General John W. Raymond, 2.

²²⁸ General John W. Raymond, 2.

²²⁹ General John W. Raymond, 2.

²³⁰ General John W. Raymond, 4.

processes would improve the standard years-long process between validating capability gaps and fielding new capabilities. For instance, Frank Calvelli, the Assistant Secretary of the Air Force for Space Acquisition and Integration, released a memorandum in April 2023 that details his “formula to go fast in space acquisition.”²³¹ These factors include building smaller systems to shorten development timelines, using existing technology to drive shorter development cycles further, driving contract length to three years or less from start to launch by capitalizing on government research and development and commercial investments, and using fixed-priced contracts.²³² Combined with Calvelli’s previous memorandum on the nine space acquisition tenets, these documents reinforce the rapid delivery of needed capabilities to the warfighter while building resiliency in space architecture.²³³

Space Systems Command (SSC), the Space Force’s space development, acquisition, launch, and logistics field command, has established 2026 as the target date for achieving key resiliency goals.²³⁴ The timeline is based on adversaries’ intent and projected capabilities, an evolving geopolitical landscape, and an assessment of current U.S. vulnerabilities.²³⁵ To achieve this goal, SSC employs the strategy “exploit what we have, buy what we can, build only what we must.”²³⁶ The creative optimization of current architectures allows the USSF to deliver more timely capability to support warfighters in the near term. Purchasing capability from commercial providers leverages the booming commercial space industry’s rapid innovation potential to deliver new capabilities sooner. A common example within the DOD is buying space-based capabilities as-a-service to

²³¹ Frank Calvelli, “Memorandum for the Department of Air Force Space Acquisition Workforce.” Official memorandum. Washington, D.C.: Department of the Air Force, April 5, 2023, para. 2.

²³² Frank Calvelli, Assistant Secretary of the Air Force for Space Acquisition and Integration, para. 2.

²³³ Frank Calvelli, “Space Acquisition Tenets Memorandum.” Official memorandum. Washington, D.C.: Department of the Air Force, October 31, 2022.

²³⁴ Kane, “Space Systems Command Targets 2026 for Key Resilience Goals,” para. 1.

²³⁵ Kane, para. 1.

²³⁶ Kane, para. 5.

augment existing capabilities.²³⁷ This business model allows the DOD to buy access to data, broadband, and services without investing significant sums and long development times into spacecraft or launch vehicles.²³⁸ Services often include remote sensing imagery, communications, navigation, and weather data.²³⁹ As a result, this judicious organizational strategy will keep the Space Force on pace to modernize and meet its resiliency goals.

D. SPACE WARFIGHTING ANALYSIS CENTER

In 2021, the USSF established the Space Warfighting Analysis Center (SWAC) to deliver critical force design guidance to organizational leadership.²⁴⁰ The SWAC informs service leadership of optimal force design pathways by creating operational concepts acquired from analysis, modeling, wargaming, and experimentation.²⁴¹ The USSF uses “force design” to determine the service’s approach to achieving its mission goals, such as appropriately organizing space technology for application. Consequently, the SWAC is a significant component in capabilities development with considerable influence on how the USSF conducts space acquisitions and tests and evaluates new technologies. Major Christopher Hare, USAF, Space Systems Command, states, “the SWAC is critical in determining what technologies the USSF needs to chase by helping to down-select options and prioritize technologies that will have the most impact on force design.”²⁴² In other words, organizations typically have long technology wish lists but require the correct information to evaluate and select the most viable and impactful options; the SWAC provides this guidance.

²³⁷ Sandra Erwin, “On National Security | Is Space-as-a-Service a Viable Option for the DOD?,” SpaceNews, April 30, 2021, <https://spacenews.com/on-national-security-is-space-as-a-service-a-viable-option-for-the-dod/>.

²³⁸ Erwin, para. 3.

²³⁹ Erwin, para. 5.

²⁴⁰ Lt Gen Nina Armagno, USSF, “Fortifying Stability in Space: Establishing the U.S. Space Force,” June 14, 2023, para. 5, <https://www.airuniversity.af.edu/JIPA/Display/Article/3428291/fortifying-stability-in-space-establishing-the-us-space-force/>.

²⁴¹ Lt Gen Nina Armagno, USSF, para. 5.

²⁴² Major Christopher Hare, personal communication, August 16, 2023.

The SWAC excels at enabling informed decision-making by employing various tools. In doing so, the SWAC directly affects service modernization by employing a systematic, model-based systems engineering (MBSE) approach to assess architectures, develop concept designs, and conduct affordability analyses that provide USSF decision-makers with crucial data needed for effective resource allocation.²⁴³ For example, the SWAC's space data transport force design inputs have identified what wideband and narrowband satellite communications would be needed to transfer high-volume data in a conflict with a strategic competitor.²⁴⁴ Subsequently, the SWAC walked the timeline backward to derive what assets would be required to provide resiliency to the proposed architecture to inform decision-makers of the optimal pathway for modernization. A critical element of the proposed space data transport force design is improving command and control by creating the "outernet," or the internet in space.²⁴⁵ This capability will require an interplay between secure military, allied, and unclassified commercial constellations.²⁴⁶ The integration of commercial systems will help accelerate resiliency as a critical effort; however, it requires the USSF to ensure few barriers prevent integrating commercial capabilities with military ones.

Another decision-enabling tool that the SWAC employs is holding business fairs to connect with industry partners and accelerate innovation and technology procurements for the USSF.²⁴⁷ The business fairs are unique opportunities for the USSF to surmount classification barriers by providing temporary security clearances to industry partners to share design ideas, threat intelligence, and USSF technology interests.²⁴⁸ Further, the

²⁴³ Lt Gen Nina Armagno, USSF, "Fortifying Stability in Space: Establishing the U.S. Space Force," 7.

²⁴⁴ Space Force Tech Connect, "Space Force Wraps Initial Plan for Building 'Hybrid' Commercial/Military 'outernet'," Space Force Tech Connect, May 9, 2023, para. 5, <https://spaceforcetechconnect.org/news/space-force-wraps-initial-plan-building-hybrid-commercialmilitary-outernet>.

²⁴⁵ Space Force Tech Connect, para. 1.

²⁴⁶ Space Force Tech Connect, para. 9.

²⁴⁷ Nichols Martin, "Gen. Nina Armagno: Space Force to Boost Tech Procurement Speed in 2022," December 16, 2021, para. 3, <https://executivegov.com/2021/12/gen-nina-armagno-space-force-to-boost-tech-procurement-speed-in-2022/>.

²⁴⁸ Martin, para. 3.

business fairs effectively disseminate classified information to industry partners to announce USSF interest areas that inform and guide commercial capability development. Space industry partners have previously highlighted the challenges of the military over-classifying space content, making the information inaccessible.²⁴⁹ Hence, opportunities to communicate with government customers with few classification restrictions resonate well with them.²⁵⁰ Ian Eishen, Global Public Sector Director at Aalyria, states, “the transparency associated with the USSF’s business fairs helps to build relationships with industry and provides commercial partners one-on-one time with the request for proposal (RFP) teams so that they can become more familiar with USSF needs.”²⁵¹ These interactions suggest that organizations seeking technological modernization should increase their time spent with commercial entities and bring them on as part of the team. This advantage does not require congressional approval or significant bureaucratic adjustments.

E. GPS AND END-USERS

Global Positioning System, a critical USSF-owned capability, is deeply integrated into the daily lives of military and civilian users and is used in this case study to describe END-USER complexity. With the inclusion of civilians, the USSF END-USER is unique compared to many of the organizations analyzed in this research. Additionally, GPS-supported applications are so broad that it is likely easier to identify unsupported use cases rather than the supported ones. Notably, the GPS constellation is highly sophisticated, few in number, and is a strategic target for adversaries.²⁵² The U.S. military, civilian users, and international allies are highly dependent on assured position, navigation, and timing (PNT) provided by the USSF, and this dependency is evidenced by the approximately 900 million

²⁴⁹ J. Olson et al., “State of the Space Industrial Base 2022: Winning the New Space Race for Sustainability, Prosperity, and the Planet,” August 2022, 56.

²⁵⁰ J. Olson et al., “State of the Space Industrial Base 2022: Winning the New Space Race for Sustainability, Prosperity, and the Planet,” August 2022, 56.

²⁵¹ Eishen, personal communication.

²⁵² Sandra Erwin, “U.S. Military Doubles down on GPS despite Vulnerabilities,” *SpaceNews* (blog), August 9, 2021, para. 6, <https://spacenews.com/u-s-military-doubles-down-on-gps-despite-vulnerabilities/>.

GPS receivers in use.²⁵³ Consequently, the USSF's goal is to create resiliency in the GPS constellation that will reliably provide location-aware capability to users around the globe under any circumstances.

The USSF is attempting to modernize the three segments of GPS: space, ground, and user segments.²⁵⁴ The cooperation between modernized segments will ensure the delivery of a military-specific signal (M-code), a requested capability that significantly increases security and counters existing threats. M-code was developed to help military customers overcome jamming and spoofing attempts that are common threats in contested environments. The first M-code-capable satellites were launched in 2005, and the aging GPS constellation has been consistently updated to include 24 on-orbit M-code GPS satellites.²⁵⁵ Space Systems Command currently manages the acquisition of new GPS satellites through two programs: GPS III and GPS III Follow-On (GPS IIIF).²⁵⁶ Like the space segment, SSC modernizes the ground control segment to support testing, fielding, and operational control of M-code user equipment. In addition to enabling full M-code capability, the modernized GPS ground segment, called the Next Generation Operational Control System (OCX), will also provide improved security through increased jamming resistance.²⁵⁷ Lastly, the user equipment consists of a microelectronic chip, an M-code card that uses the chip, and an M-code receiver that reads the card.²⁵⁸ The cards and receivers will allow customers to utilize the M-code signal broadcasted by modern GPS satellites.

Although the space segment is nearly complete and can support M-code, the adoption of the new capability is impeded by complications related to the ground and user

²⁵³ Diana Furchtgott-Roth, "America Needs GPS Backup," *Forbes*, March 10, 2022, para. 2, <https://www.forbes.com/sites/dianafurchtgott-roth/2022/03/10/america-needs-gps-backup/>.

²⁵⁴ Jon Ludwigson, *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices*, GAO-23-106018 (Washington, D.C.: Government Accountability Office, 2023).

²⁵⁵ Ludwigson, 19.

²⁵⁶ Ludwigson, 5.

²⁵⁷ Ludwigson, 6.

²⁵⁸ Ludwigson, 7.

segments.²⁵⁹ First, Raytheon Technologies, the prime contractor for OCX, is seven years behind schedule due to pandemic-related difficulties, software development challenges, and insufficient END-USER guidance for system use.²⁶⁰ The delay of the new ground segment is a limiting factor that impedes the DOD's transition to M-code and the timeline for USSF personnel to effectively train in operating the segment.²⁶¹ Next, the development and integration of the user equipment is complex. The microelectronic chip and the M-code card are USSF programs outsourced to prime contractors. Conversely, the M-code receiver is developed and integrated at the service level to ensure compatibility with the estimated 700 different types of aircraft, ground vehicles, ships, and weapon systems that require the capability.²⁶² Unsurprisingly, schedule slips are the primary cause of the receiver delays, affecting the M-code's operational testing and fielding.²⁶³ Lastly, the first iteration of the microelectronic chip (Increment 1) was a military-specific component that mated specifically with the M-code card.²⁶⁴ The M-code card-chip configuration is specialized, expensive, and specific to military applications and does not have a civilian customer base to help reduce the price. Hence, the USSF was obligated to award high-cost contracts to procure one million chips. These complications, including the schedule slips and bespoke systems, pressure M-code's success and increase the risk of adoption or performance failures.

The USSF is actively managing this risk in several ways, including developing a second increment of user equipment and a universal handheld receiver that can be shared

²⁵⁹ Ludwigson, 13–18.

²⁶⁰ Frank Wolfe, "GPS OCX Not Operationally Ready Until Next May, DOD Estimates," *Defense Daily*, October 4, 2023, para. 11, <https://www.defensedaily.com/13-month-delay-for-operational-readiness-of-gps-ocx-dod-estimates/space/>.

²⁶¹ Ludwigson, *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices*, 13.

²⁶² Jon Ludwigson, *GPS Modernization: Better Information and Detailed Test Plans Needed for Timely Fielding of Military User Equipment*, GAO-22-105086 (Washington, D.C.: Government Accountability Office, 2022), 6, <https://www.gao.gov/products/gao-22-105086>.

²⁶³ Ludwigson, *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices*, 27.

²⁶⁴ Ludwigson, 29.

across the services.²⁶⁵ The military GPS user equipment Increment 2 is developed to be smaller, more power efficient, and adapted to commercial interests to avoid the scarcity issues of the previous bespoke iterations that increased costs.²⁶⁶ Specifically, the design and manufacturing process is commercially informed, and the equipment is made military-peculiar later.²⁶⁷ These adaptations are anticipated to fix the problems with the Increment 1 user equipment by accelerating the process, increasing the customer base, and driving down total costs. Next, the USSF will utilize the Increment 2 equipment to develop M-code capable receivers for handheld devices and precision-guided munitions across the services.²⁶⁸ An issue that the USSF has encountered with developing the Increment 2 M-code receiver is that it must be military-specific, which limits potential customers and drives up costs.

In summary, the nearly 20-year development process to deliver M-code capability to the warfighter has been protracted, and the USSF has adapted to manage risk and accelerate the delivery of these systems. Even through these adaptations, the outcome of M-code is undetermined due to complex vehicle and platform requirements that induce the services to pursue their own receiver solutions. Without a major committed customer dependent on the USSF solution, the USSF risks expending significant resources without providing capability to the military END-USERS.²⁶⁹ As a result, the divergence of END-USER requirements and their unique associated processes have contributed to schedule delays and a lack of synergy in efforts that dampens M-code capability adoption. Figures 25 and 26 below summarize the current GPS M-code capability adoption outcome.

²⁶⁵ Jon Ludwigson, *GPS Modernization: DOD Continuing to Develop New Jam-Resistant Capability, But Widespread Use Remains Years Away*, GAO-21-145 (Washington, D.C.: Government Accountability Office, 2021), 13.

²⁶⁶ Ludwigson, 30.

²⁶⁷ Ludwigson, *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices*, 32.

²⁶⁸ Ludwigson, 32.

²⁶⁹ GlobalData, “GAO: U.S. Military Must Reassess GPS Modernisation,” *Airforce Technology* (blog), June 6, 2023, para. 9, <https://www.airforce-technology.com/news/gao-us-military-must-reassess-gps-development/>.

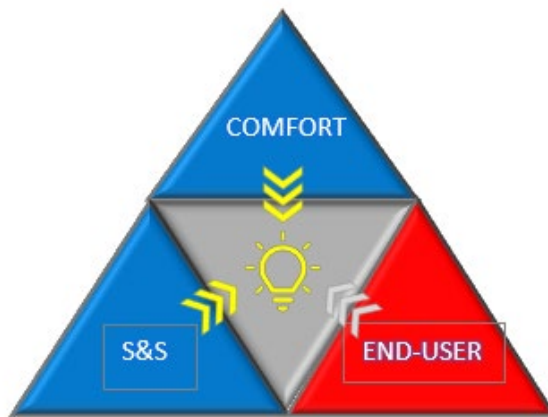


Figure 25. Measurement of GPS M-code COMFORT (**HIGH**), STAFF & SYSTEMS (**HIGH**), and END-USER (**LOW**) Indices.

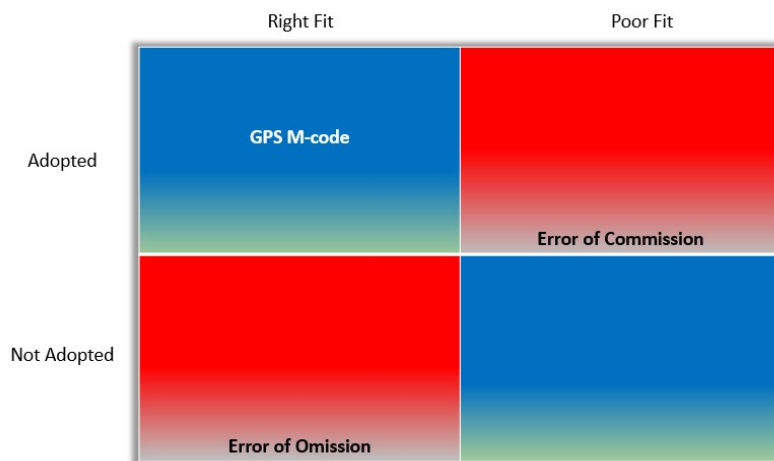


Figure 26. GPS M-Code Technology Adoption Outcome.

F. CONCLUSION

While the USSF matures as the guarantor of space security, its path, replete with innovation challenges and bureaucratic intricacies, provides invaluable lessons for other organizations seeking to modernize. The complex interplay of rapid technological adoption, collaboration with the commercial sector, and internal restructuring exemplify many of the challenges organizations face in the space domain. Understanding the nuances of the USSF’s strategies becomes paramount to sustaining superiority in the space domain.

The next chapter will draw upon lessons learned from the studied organizations and explore actionable strategies and suggestions that may guide organizations in adopting and developing emerging technologies.

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VI. CONCLUSIONS

A. THESIS CONCLUSIONS

The 2022 U.S. National Defense Strategy highlights the need for the DOD, including NSW, to prioritize adopting emergent technologies to maintain superiority against rapidly modernizing adversaries. Fueled by free enterprise, the U.S. private technology sector offers a prime strategic advantage, delivering capabilities at speeds unattainable to closed, state-run competitors. Thus, as emphasized in the NDS, increasing collaborative efforts between the DOD and private technology sector is critical to rapid modernization. NSW has been forward-leaning with these collaborative efforts, resulting in the adoption of various technologies, some successfully implemented and others resulting in failure. A significant challenge in NSW's modernization efforts is understanding the innovation factors unique to military organizations compared to commercial enterprises. Fortunately, additional unexplored opportunities exist to enhance NSW's technology adoption approach by learning from other domains like the space ecosystem.

The flourishing U.S. space sector offers insight into countless technology adoption examples across hundreds of new space organizations. The space sector also consists of forward-thinking U.S. government organizations facing similar innovation challenges, such as complex risk management, budget constraints, entrenched processes, and rapid personnel turnover. These organizations face unique barriers to innovation and provide valuable lessons learned, like the need to align incentives and increase top-down education on emerging technologies. Given the high-risk nature of space operations, natural parallels exist between the motivations, approach, and associated risk involved in adopting technologies for space systems and special operations. As a result, this research explored several space organizations' technology adoption and innovation approaches to provide insights beneficial to NSW.

This research identified the critical factors influencing innovation and technology adoption in NASA, the USSF, and several commercial space companies using foundational

technology diffusion literature as a starting framework. The study found that three key variable categories proved decisive in shaping the adoption outcome. These categories include COMFORT, STAFF & SYSTEMS, and END-USER factors listed in Figure 3. Several similar supporting variables were assigned to each of the three categories and were grouped together using Gary Goertz's adapted family resemblance logic for analysis.²⁷⁰ The analysis of technology adoption examples across the space organizations employed the three independent variables: COMFORT, STAFF & SYSTEMS, and END-USER factors.

The study revealed that optimal integration of COMFORT, STAFF & SYSTEMS, and END-USER factors were associated with the most successful examples of technology adoption and innovation. Successful application of these variables manifested as communicating with precision at all levels of the organization, increasing awareness of entrenched processes and human behavior, integrating personnel from all phases of the innovation process, and expanding the education of decision-makers and end-users. A common theme among these findings is that abundant and frequent communication is critical to educating relevant parties, building awareness, and overcoming most challenges associated with innovation. Further, the entrenched organizational processes and behaviors of the human "inhibitors" that typically stifle innovation can be substantially improved if these issues are effectively communicated and win-win solutions negotiated to advance the adoption process.

The study also found that STAFF & SYSTEMS and END-USER factors were the most influential to government organizations. For instance, NASA displayed substantial organizational inertia, contributing to resistance against unproven innovations. NASA's leadership is actively addressing this deficiency by integrating feedback and input from middle management and end-users across the organization. This feedback loop highlights the entrenched processes and attitudes that, once improved, should substantially improve NASA's innovation capacity. Likewise, the USSF was created to be innovative but is still impeded by the organizational inertia and processes carried over by the U.S. Air Force. The USSF is aware of these challenges and manages them in several ways. These

²⁷⁰ Goertz, *Social Science Concepts: A User's Guide*.

management efforts include novel recruiting solutions, expanding the education of its personnel, restructuring its organization to eliminate stovepipes and entrenched processes, and creating innovation-centric commands empowered by USSF leadership. NSW can apply these lessons and focus on STAFF & SYSTEMS and END-USER factors to refine its technology adoption approach.

This research also identified a general misalignment of incentive structures tailored to innovation goals and a lack of incentives for the innovators. Managers in the examined organizations lacked targeted incentives to approve emerging technology integration. The lack of an innovation-enabling incentive structure induces managers to be more risk-averse to adopting technologies. This phenomenon occurs because if the technology underperforms or the integration fails, the approving manager is held responsible and may be punished by losing credibility or not promoting. This “disincentive” produces a paradoxical “say-do” gap, where national directives and top leaders demand innovation. Yet, lower-level managers are unwilling to absorb new risks, displace incumbent technologies, or invest in solutions they do not fully comprehend. NSW can learn from these impediments and align incentive structures to innovation objectives.

Finally, this study identified that evolutionary technology was typically more successful than revolutionary technology. Intuitively, decision-makers and end-users are more familiar with evolutionary technologies that improve incrementally. Organizations do not require significant behavioral changes to integrate evolutionary technologies because they are compatible with existing operational concepts, and the return on investment is well understood. Moreover, organizations follow an evolutionary path when they learn from previous unsuccessful attempts to revolutionize technology; failures provide lessons to enable future successes. For instance, the study showed that Starlink exemplifies a successful proliferated LEO communications model constructed by applying lessons from comparable concepts that failed decades prior. While evolutionary innovations hold certain advantages, revolutionary technologies will likely provide more substantial gains if successfully adopted and implemented. This study identified that advanced education is critical to understanding and harnessing revolutionary innovations like Aalyria’s SpaceTime. Thus, NSW should prioritize increasing technological education

within the organization. Education tailored to trending technologies can equip leaders to make more informed adoption decisions and ready end-users to integrate these technologies seamlessly.

This research demonstrates the value of examining innovation factors and technology adoption approaches across domains like the space industry to reveal best practices. Naval Special Warfare can refine its methods to integrate emergent technologies, align incentives, increase education, and overcome organizational resistance by learning from other organizations facing similar challenges. While evolutionary technologies have advantages, revolutionary innovations promise immense opportunity. NSW can continue fulfilling its tremendous potential as a pioneering force harnessing the latest innovations to maintain superiority in future conflicts by improving organizational COMFORT, STAFF & SYSTEMS, and END-USER factors. NSW's operational expertise, combined with disruptive commercial technologies, can drive breakthrough capabilities that outpace determined adversaries.

B. RECOMMENDATIONS

This section provides recommendations to NSW leaders from innovation lessons learned across the space ecosystem. This research informs the recommendations and is structured to bolster each adoption factor.

1. Comfort

a. Technology assessment as a dedicated role or task

The creation of a role centered on technology assessment could substantially enrich the innovation insights and information available to the commander. Positioned to inform leadership's technology adoption decisions from N9's purview, this set of tasks could judiciously compile inputs from across NSW departments without bias. This role would generate comprehensive, multi-lens appraisals into a technology's viability and desirability by convening civilian experts, tactical specialists, and requirements generators to evaluate innovations on characteristics like feasibility and operational fit. The delivered product should be a report furnished in a standard DOTMLPF-P format (doctrine, organization,

training, materiel, leadership and education, personnel, facilities, and policy), which could arm decision-makers with the most comprehensive technology assessment when determining whether to pursue or pass on a given innovation. Ideally, the actor executing these tasks would hold the appropriate seniority and gravitas to convene stakeholders yet remain junior enough to stay close to relevant operational challenges. The execution of these duties may, to some degree, parallel an investigating officer (15-6 officer) in that this would involve the delegated authority to organize personnel and collect technology-related information from NSW departments as needed.

b. Establish a forum to foster debate and increase understanding

Current debates around the rapidly changing operational environment and the impact of emerging technology are being held in online, accessible outlets such as “War on the Rocks.” Outlets like this have changed the game by creating a focal point for real-time debate among national security professionals. Many U.S. Army-specific outlets have arisen in this space framed around the specific needs of their service, but an outlet focusing on the challenges of maritime irregular warfare remains a gap. The creation of such an online outlet, perhaps in a collaborative effort between NPS and NSW, could fill this gap. Debates in such an outlet could be shaped to identify trends, capability gaps, and unseen opportunities -and, in doing so, alleviate some of the research-intensive work traditionally performed by N9 and N5. An NPS-managed publication would, in addition, greatly enhance NSW’s connection to NPS and increase its understanding of future technologies.

2. Staff and Systems

a. Align incentives to innovation objectives

Incentives could be balanced to better align the risk appetite of actors with the organization’s innovation goals. To achieve this balance, NSW leadership could reward personnel involved with successful technology adoption or who achieved critical innovation with consideration for early promotion, increased recognition, or periodic cash prizes. Presently, more incentives exist to dismiss prospective technologies or continue investing in acceptable but inferior legacy solutions rather than integrate newer, more effective alternatives. Further, NSW leadership should incentivize innovation-related

positions to be more desirable with clear advantages for advancement if acquiring disruptive technologies is a goal for the organization. These positions would be more competitive and could consistently recruit highly motivated individuals if appropriate incentives were in place. Finally, realigning incentives could mitigate undesirable decision-making biases like the sunk cost fallacy, risk aversion, status quo adherence, and confirmation bias.

b. Lessons learned repository

Like operational after-action reviews (AARs), successful and unsuccessful innovation lessons should be captured and used to prepare new personnel filling these critical positions. This mechanism would enable the innovation-related departments to grow and remain aware of pitfalls that inhibited previous technology adoption attempts or highlight the factors that led to their success. Moreover, compiling collective lessons learned prevents critical information from being stove-piped within individual departments. Innovation is complex and requires the interplay of multiple directorates, and the lessons learned in one directorate may enable success in another. Finally, the lessons learned in this repository could serve as ideal material to fuel articles and debates in an online forum (see Recommendation “b” above) to elevate the shared understanding of the enterprise.

3. End-User

a. Goal-oriented innovation teams

Based on the findings of this research, end-users drive successful innovations when they frequently interact with the development team and the facilitating staff. Often, only two components of the innovation pathway will convene to discuss innovation matters shared between their departments. Rarely do all components, including developers, scouting elements, requirements generators, and end-users, meet to discuss matters in real-time. As is the case with organizations examined in this study, when the staff gets involved, innovation capacity typically decreases due to the introduction of various resistance factors. Thus, including a commander or critical decision-maker in these meetings is equally important to moderate and prevent inhibitory factors from taking hold. Bridging

commanders, developers, end-users, and intermediary staff in person closes crucial feedback loops, driving innovation and averting errors in real-time.

b. Platoon integration

This research revealed that using end-users optimally will lead to innovation and technology adoption success. These findings suggest that SEAL platoons could critically support NSW's modernization efforts. First, available platoons (such as deploy-for-purpose platoons) can support these efforts by testing and evaluating technologies considered for adoption. This effort would familiarize end-users with future capabilities and provide decision-makers with platoon-proposed operational concepts, tactics, techniques, and procedures (TTPs) developed during this process. Next, NSW leaders can use platoons to drive deck plate-up modernization improvements. For instance, Troop and Team schedules can be made more efficient by digitizing inventories and other time-consuming manual processes. As previously suggested, leaders can recoup the extra time produced by streamlined processes and direct those efficiency dividends toward end-user support for modernization efforts.

c. Technology roadmap

A visual roadmap of NSW's desired technologies is another way for commanders to communicate their vision to the organization. NASA's TechPort Strategic Framework (<https://techport.nasa.gov/framework>) is an online roadmap that organizes its technology domains to display desired strategic innovation outcomes, current innovation gaps, and areas NASA can use to validate and improve its technologies. Similarly, NSW could post its desired technology roadmap on its classified portal page to message technology interests, priorities, and gaps. As a result, a displayed roadmap informs end-users of the direction the organization is headed and increases opportunities for end-users to support NSW's innovation priorities.

C. LIMITATIONS/FUTURE RESEARCH

Future analyses should examine individually the variables grouped within each family to reveal which factors most powerfully shape COMFORT, STAFF & SYSTEMS, and

END-USER values. In such an analysis, the researcher can quantitatively analyze the grouped variables to determine which produces the greatest effect on the outcome. Further, the study could expand the values for COMFORT, STAFF & SYSTEMS, and END-USER factors beyond the dichotomous scale to provide additional context to the technology adoption outcome.

While the organizations examined in this study were diverse, future research could explore additional space-related government organizations. Such organizations should include the National Reconnaissance Office (NRO) and the Defense Advanced Research Projects Agency (DARPA). While the NRO and DARPA would offer rich adoption insights, their deeply classified nature precluded this analysis from addressing them; nevertheless, they remain strong candidates for future inquiry. Many related space technologies developed for the U.S. government are associated with higher classification levels. Consequently, a study performed at a higher classification could widen the aperture for future analysis, enabling the examination of a broader swath of space technologies.

LIST OF REFERENCES

- Aalyria. “Spacetime.” Aalyria, n.d. <https://www.aalyria.com/spacetime>.
- “Advanced SEAL Delivery System Program Needs Increased Oversight.” Government Accountability Office (GAO), March 2003.
- Aerospace. “Expanding Integration Across Government and Commercial Space for Speed and Resiliency | The Aerospace Corporation.” Aerospace, August 29, 2023. <https://aerospace.org/article/expanding-integration-across-government-and-commercial-space-speed-and-resiliency>.
- Agnihotri, Arpita, and Saurabh Bhattacharya. “SpaceX: Starlink’s Uncertain Demand Trajectory.” Ivey Publishing, 2021.
- Airforce Technology. “GAO: U.S. Military Must Reassess GPS Modernisation.” *Airforce Technology* (blog), June 6, 2023. <https://www.airforce-technology.com/news/gao-us-military-must-reassess-gps-development/>.
- Albon, Courtney. “Defense Innovation Unit Teams with Companies on Space-Based Internet.” C4ISRNet, July 10, 2023. <https://www.c4isrnet.com/battlefield-tech/space/2023/07/10/defense-innovation-unit-teams-with-companies-on-space-based-internet/>.
- Anthony, Scott D., Paul Cobban, Rahul Nair, and Natalie Painchaud. “Breaking Down the Barriers to Innovation.” *Harvard Business Review*, November 1, 2019. <https://hbr.org/2019/11/breaking-down-the-barriers-to-innovation>.
- Ashkenas, Ron, and Lisa Bodell. “The Reason Your Team Won’t Take Risks.” *Harvard Business Review*, September 9, 2014. <https://hbr.org/2014/09/the-reason-your-team-wont-take-risks>.
- Babbitt, Joel. *Half-Price Negotiating: Reframing Defense Acquisition Program Management to Achieve Extraordinary Results*, 2022.
- Baird, Danny, and Katherine Schauer. “Artemis I: Demonstrating the Capabilities of NASA’s United Networks—NASA.” *NASA* (blog), October 8, 2020. <https://www.nasa.gov/missions/artemis/artemis-i-demonstrating-the-capabilities-of-nasas-united-networks/>.
- Beranek, Cheri. “Anything We Can Do, High-Speed Broadband Could Help Us Do Better.” *Forbes*, March 7, 2022. <https://www.forbes.com/sites/forbestechcouncil/2022/03/07/anything-we-can-do-high-speed-broadband-could-help-us-do-better/>.

- Bezos, Jeff. “Day 1 Letter to Shareholders.” Memorandum, Amazon.com, 1997.
<https://www.sec.gov/Archives/edgar/data/1018724/000119312517120198/d373368dex991.htm#:~:text=Are%20you%20falling%20prey%20to%20proxies%2C%20or%20do,your%20hard%20work%2C%20your%20ingenuity%2C%20and%20your%20passion.>
- Biden Jr., Joseph R. *2022 National Security Strategy of the United States of America*. Washington, D.C.: The White House, 2022.
- Bond Collective. “Stealth Mode Startups: What Are They And When To Launch One.” Bond Collective, n.d. <https://www.bondcollective.com/blog/stealth-mode-startup>.
- Cooke, Kristin. “What Are the New Satellite Internet Providers?” *SatelliteInternet.com*, August 4, 2023. <https://www.satelliteinternet.com/resources/history-and-future-of-satellite-internet/>.
- DDN. “USSOCOM Ends ASDS Effort, Requests Funds For New Submersible Effort.” *Defense Daily*, July 27, 2009. <https://www.defensedaily.com/ussocom-ends-asds-effort-requests-funds-for-new-submersible-effort/navy-usmc/>.
- Defense Business Board. “Implementing Best Practices for Major Business Processes in the Department of Defense,” 2014.
- Defense Innovation Unit. “Defense Innovation Unit,” n.d. <https://www.diu.mil/>.
- . “Initial Contracts for Hybrid Space Architecture Program.” *Defense Innovation Unit*, July 7, 2022. <https://www.diu.mil/latest/developing-the-internet-of-space>.
- Defense Media Network. “Naval Special Warfare Command Modernization,” n.d. <https://www.defensemmedianetwork.com/stories/naval-special-warfare-command-modernization/>.
- Department of Defense. *Department of Defense Cyber Strategy 2018*. Washington, D.C.: Department of Defense, 2018. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwijaPs_-mCAxW8ie4BHThLBRcQFnoECBkQAQ&url=https%3A%2F%2Fmedia.defense.gov%2F2018%2FSep%2F18%2F2002041658%2F-1%2F-1%2F1%2FCYBER_STRATEGY_SUMMARY_FINAL.PDF&usg=AOvVaw3GLVob1pXJWhCeJbNJ5Pd&opi=89978449.
- Eisenmann, Thomas, Doug Rogers, and Dan Green. “Teledesic.” *Harvard Business School*, March 22, 2004.
- Enablers of Change. “What Is the Diffusion of Innovations Theory?—Enablers of Change.” *Enablers of Change*, May 24, 2021. <https://www.enablersofchange.com.au/what-is-the-diffusion-of-innovations-theory/>.

- Erwin, Sandra. "On National Security | Is Space-as-a-Service a Viable Option for the DOD?" *SpaceNews*, April 30, 2021. <https://spacenews.com/on-national-security-is-space-as-a-service-a-viable-option-for-the-dod/>.
- . "Tech Innovations Help Space Force Guardians Prepare for the Battlefield Above." *SpaceNews* (blog), October 11, 2023. <https://spacenews.com/tech-innovations-help-space-force-guardians-prepare-for-the-battlefield-above/>.
- . "U.S. Military Doubles down on GPS despite Vulnerabilities." *SpaceNews* (blog), August 9, 2021. <https://spacenews.com/u-s-military-doubles-down-on-gps-despite-vulnerabilities/>.
- Forster, Michael. "Wittgenstein on Family Resemblance Concepts." In *Wittgenstein's Philosophical Investigations: A Critical Guide*, 66–87. Cambridge: Cambridge University Press, 2010.
- Fox, Will. "Launch Costs to Low Earth Orbit, 1980–2100," n.d. <https://futuretimeline.net/data-trends/6.htm>.
- Frank Calvelli. "Memorandum for the Department of Air Force Space Acquisition Workforce." Washington, D.C.: Department of the Air Force, 2023.
- Frank Calvelli, Assistant Secretary of the Air Force for Space Acquisition and Integration. "Space Acquisition Tenets Memorandum." Department of the Air Force, October 31, 2022.
- Freeman, Michael, and Colonel Todd Lyons. "Education Is the Technology the Navy Needs Most." U.S. Naval Institute, July 30, 2020. <https://www.usni.org/magazines/proceedings/2020/july/education-technology-navy-needs-most>.
- Furchtgott-Roth, Diana. "America Needs GPS Backup." *Forbes*, March 10, 2022. <https://www.forbes.com/sites/dianafurchtgott-roth/2022/03/10/america-needs-gps-backup/>.
- General John W. Raymond. "Chief of Space Operations Planning Guidance," November 2020.
- . "The Guardian Ideal," September 2021.
- George, Alexander, and Andrew Bennett. *Case Studies and Theory Development in the Social Sciences*. Cambridge, Massachusetts: MIT Press, 2005.
- Gino, Francesca, and Gary P. Pisano. "Why Leaders Don't Learn from Success." *Harvard Business Review*, April 1, 2011. <https://hbr.org/2011/04/why-leaders-dont-learn-from-success>.

- Goertz, Gary. *Social Science Concepts: A User's Guide*. New Jersey: Princeton University Press, 2006.
- Gourley, Scott. "NAVSPECWARCOM: Interview: Rear Adm. Collin P Green, Commander Naval Special Warfare Command." issuu, n.d. https://issuu.com/faircountmedia/docs/soo19a_issuu_prepped__2_/s/102037.
- Gourville, John. "Note on Innovation Diffusion: Rogers' Five Factors." Harvard Business School, April 2006.
- Hallex, Matthew, and Travis Cottom. "Proliferated Commercial Satellite Constellations: Implications for National Security." *National Defense University Press Joint Force Quarterly*, no. 97 (March 31, 2020). <https://ndupress.ndu.edu/Media/News/News-Article-View/Article/2106495/proliferated-commercial-satellite-constellations-implications-for-national-secu/https%3A%2F%2Fndupress.ndu.edu%2FMedia%2FNews%2FNews-Article-View%2FArticle%2F2106495%2Fproliferated-commercial-satellite-constellations-implications-for-national-secu%2F>.
- Harding, Emily, and Harshana Ghoorhoo. "Seven Critical Technologies for Winning the Next War," April 18, 2023. <https://www.csis.org/analysis/seven-critical-technologies-winning-next-war>.
- Henry, Caleb. "SpaceX Launches 60 Starlink Satellites, Begins Constellation Buildout." *SpaceNews* (blog), May 24, 2019. <https://spacenews.com/spacex-launches-60-starlink-satellites-begins-constellation-buildout/>.
- Higher Ground. "SatPaq." Higher Ground, n.d. <https://satpaq.com/>.
- Hitchens, Theresa. "Exclusive: Space Warfighting Analysis Center Chief on Creating 'Something out of Nothing.'" *Breaking Defense* (blog), January 19, 2022. <https://breakingdefense.sites.breakingmedia.com/2022/01/exclusive-space-warfighting-analysis-center-chief-on-creating-something-out-of-nothing/>.
- Intelligence, GlobalData Thematic. "Lithium-Ion Batteries (LIB): Opportunities and Threats." *Naval Technology* (blog), June 12, 2020. <https://www.naval-technology.com/comment/lithium-ion-batteries-lib/>.
- Janeidy Arevalo, Evelyn. "U.S. Space Force Selects SpaceX Starlink, Kuiper Government Solutions, and Aalyria Technologies for Military Satellite Backhaul Studies." *TESMANIAN*, September 7, 2023. <https://www.tesmanian.com/blogs/tesmanian-blog/pswa>.

- Kane, Linda. “Space Systems Command Targets 2026 for Key Resilience Goals.” Space Systems Command, April 6, 2023. <https://www.ssc.spaceforce.mil/Newsroom/Article-Display/Article/3355729/https%3A%2F%2Fwww.ssc.spaceforce.mil%2FNewsroom%2FArticle-Display%2FArticle%2F3355729%2Fspace-systems-command-targets-2026-for-key-resilience-goals>.
- Kerr, James R. “Congress and Space: Overview or Oversight?” *Public Administration Review* 25, no. 3 (1965): 185–92. <https://doi.org/10.2307/973742>.
- Kotila, Brodi, Jeffrey A. Drezner, Elizabeth M. Bartels, Devon Hill, Quentin E. Hodgson, Shreya S. Huilgol, Shane Manuel, Michael Simpson, and Jonathan P. Wong. “Fostering Innovation in Military Technology: Strengthening DOD’s Commercial Technology Pipeline.” RAND Corporation, March 7, 2023. https://www.rand.org/pubs/research_briefs/RBA1352-1.html.
- Kraft, Rachel. “Analysis Confirms Successful Artemis I Moon Mission, Reviews Continue—NASA.” *NASA* (blog), March 7, 2023. <https://www.nasa.gov/humans-in-space/analysis-confirms-successful-artemis-i-moon-mission-reviews-continue-2/>.
- Kranz, Gene. *Failure Is Not An Option: Mission Control From Mercury to Apollo 13 And Beyond*. New York: Simon & Schuster, 2009.
- Leonard-Barton, Dorothy, and William A Kraus. “Implementing New Technology.” *Harvard Business Review*, 1985.
- Lewis, James Andrew. “National Security and the Innovation Ecosystem,” October 1, 2021. <https://www.csis.org/analysis/national-security-and-innovation-ecosystem>.
- Lovullo, Dan, Tim Koller, Robert Uhlener, and Daniel Kahneman. “Your Company Is Too Risk-Averse.” *Harvard Business Review*, March 1, 2020. <https://hbr.org/2020/03/your-company-is-too-risk-averse>.
- Lt Gen Nina Armagno, USSF. “Fortifying Stability in Space: Establishing the U.S. Space Force.” *Journal of Indo-Pacific Affairs*, June 14, 2023. <https://www.airuniversity.af.edu/JIPA/Display/Article/3428291/fortifying-stability-in-space-establishing-the-us-space-force/>.
- Ludwigson, Jon. *GPS Modernization: Better Information and Detailed Test Plans Needed for Timely Fielding of Military User Equipment*. GAO-22-105086. Washington, D.C.: Government Accountability Office, 2022. <https://www.gao.gov/products/gao-22-105086>.
- . *GPS Modernization: DOD Continuing to Develop New Jam-Resistant Capability, But Widespread Use Remains Years Away*. GAO-21-145. Washington, D.C.: Government Accountability Office, 2021.

- . *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices*. GAO-23-106018. Washington, D.C.: Government Accountability Office, 2023.
- Luttrell, Marcus. *Lone Survivor*. New York: Little, Brown & Company, 2007.
- Maidique, Modesto A., and Billie Jo Zirger. “A Study of Success and Failure in Product Innovation: The Case of the U.S. Electronics Industry.” *IEEE Transactions on Engineering Management* EM-31, no. 4 (November 1984): 192–203. <https://doi.org/10.1109/TEM.1984.6447537>.
- Martin, Nichols. “Gen. Nina Armagno: Space Force to Boost Tech Procurement Speed in 2022.” *ExecutiveGov* (blog), December 16, 2021. <https://executivegov.com/2021/12/gen-nina-armagno-space-force-to-boost-tech-procurement-speed-in-2022/>.
- Matossian, Mark G. “A Teledesic Space Infrastructure Overview.” In *Mission Design & Implementation of Satellite Constellations*, 153–56. Dordrecht: Springer Netherlands, 1998. https://doi.org/10.1007/978-94-011-5088-0_14.
- Metinko, Chris. “Space Tech Funding Comes Back Down To Earth.” *Crunchbase News*, July 20, 2023. <https://news.crunchbase.com/venture/space-tech-funding-drops-spacex-relativity/>.
- Moore, Geoffrey. *Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers*. 3rd ed. Harper Business, 2014.
- NASA. “Artemis I.” NASA, n.d. <https://www.nasa.gov/mission/artemis-i/>.
- . “Technology Enterprise and Mission Pathfinder Office.” NASA, n.d. <https://tempo.gsfc.nasa.gov/projects/TEMPO?tab=incubated%20projects>.
- National Academies of Sciences, Engineering, and Medicine. *Continuous Improvement of NASA’s Innovation Ecosystem: Proceedings of a Workshop*. Washington, D.C.: National Academies Press, 2019. <https://doi.org/10.17226/25505>.
- Olson, J., S. Butow, E. Felt, and T. Cooley. “State of the Space Industrial Base 2022: Winning the New Space Race for Sustainability, Prosperity, and the Planet,” August 2022.
- Pian Chan, Sharon. “The Birth and Demise of an Idea: Teledesic’s ‘Internet in the Sky’ | The Seattle Times.” *Seattle Times*, October 7, 2002. <https://archive.seattletimes.com/archive/?date=20021007&slug=teledesic070>.

- Pope, Charles. “Gen Raymond Reflects on Highlights of Space Force’s Achievements and Predicts ‘great History Ahead’.” United States Space Force, September 20, 2022. <https://www.spaceforce.mil/News/Article/3164602/gen-raymond-reflects-on-highlights-of-space-forces-achievements-and-predicts-gr/http%3A%2F%2Fwww.spaceforce.mil%2FNews%2FArticle-Display%2FArticle%2F3164602%2Fgen-raymond-reflects-on-highlights-of-space-forces-achievements-and-predicts-gr%2F>.
- Porterfield, Carlie. “Space Industry Grew To Record \$469 Billion Last Year, Report Finds.” *Forbes*, n.d. <https://www.forbes.com/sites/carlieporterfield/2022/07/27/space-industry-grew-to-record-469-billion-last-year-report-finds/>.
- . “Space Industry Grew To Record \$469 Billion Last Year, Report Finds.” *Forbes*, n.d. <https://www.forbes.com/sites/carlieporterfield/2022/07/27/space-industry-grew-to-record-469-billion-last-year-report-finds/>.
- Pultarova, Tereza, Elizabeth Howell Contributions from Daisy Dobrijevic, and Adam Mann last updated. “Starlink Satellites: Everything You Need to Know about the Controversial Internet Megaconstellation.” *Space.com*, April 14, 2022. <https://www.space.com/spacex-starlink-satellites.html>.
- Ralph, Eric. “SpaceX Starlink Factory Building Satellites Four Times Faster than Closest Competitor.” *TESLARATI* (blog), March 12, 2020. <https://www.teslarati.com/spacex-starlink-satellite-production-faster-than-competitors/>.
- RF Wireless World. “Advantages and Disadvantages of GEO | Geosynchronous Orbit.” RF Wireless World, n.d. <https://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-GEO-Geosynchronous-orbit.html>.
- Riesing, Kathleen, Curt Schieler, Joshua Brown, Jesse Chang, Noah Gilbert, Andrew Horvath, Lawrence Petrilli et al. “Pointing, Acquisition, and Tracking for the TBIRD CubeSat Mission: System Design and Pre-Flight Results.” *MIT Lincoln Laboratory*, 2022.
- Rogers, Everett. *Diffusion of Innovations*. New York: Free Press of Glencoe, 1962.
- . *Diffusion of Innovations*. 5th ed. New York: Free Press, 1995.
- Rogin, Josh. “Opinion | China’s Military Expansion Is Reaching a Dangerous Tipping Point.” *Washington Post*, June 17, 2022. <https://www.washingtonpost.com/opinions/2022/06/16/china-expansion-indopacific-asia-taiwan-xi-aquilino/>.
- Ronayne, David, Daniel Sgroi, and Anthony Tuckwell. “How Susceptible Are You to the Sunk Cost Fallacy?” *Harvard Business Review*, July 15, 2021. <https://hbr.org/2021/07/how-susceptible-are-you-to-the-sunk-cost-fallacy>.

- Ryan, B., and N. Gross. "The Diffusion of Hybrid Seed Corn in Two Iowa Communities." *Rural Sociology* 8, no. 1 (1943): 15–24.
- Sayler, Kelley. *Emerging Military Technologies: Background and Issues for Congress*. CRS Report No. R46458. Washington, D.C.: Congressional Research Service, 2022.
- Smith, Rich. "How Much Cheaper Are SpaceX Reusable Rockets? Now We Know." *The Motley Fool*, October 5, 2020. <https://www.fool.com/investing/2020/10/05/how-much-cheaper-are-spacex-reusable-rockets-now-w/>.
- Space Force Tech Connect. "Space Force Wraps Initial Plan for Building 'Hybrid' Commercial/Military 'outernet'." Space Force Tech Connect, May 9, 2023. <https://spaceforcetechconnect.org/news/space-force-wraps-initial-plan-building-hybrid-commercialmilitary-outernet>.
- Statista. "COVID-19—Daily in-Home Data Usage Change U.S. 2020." Statista, n.d. <https://www.statista.com/statistics/1106863/covid-19-daily-in-home-data-usage-change-us-2020/>.
- Stewart, James. "Teledesic Global Wireless Broadband Network: Space Infrastructure Architecture, Design Features, and Technologies." NASA, October 1995.
- Strout, Nathan. "US Space Force Chief Lays out His Priorities in New Guidance." *Defense News*, November 9, 2020. <https://www.defensenews.com/space/2020/11/09/space-force-chief-lays-out-his-priorities-in-new-guidance/>.
- "Success of Advanced SEAL Delivery System Hinges on Establishing a Sound Contracting Strategy and Performance Criteria." Government Accountability Office (GAO), May 2007.
- Tarde, Gabriel. *The Laws of Imitation*. New York: Holt and Company, 1903.
- Team, Space Foundation Editorial. "Space Industry Growth: Where Are the Opportunities in 2022?" *Center for Innovation and Education* (blog), October 11, 2022. <https://cie.spacefoundation.org/space-industry-growth-where-are-the-opportunities-in-2022/>.
- "Technology Enterprise and Mission Pathfinder Office | ESC Public Site," n.d. <https://tempo.gsfc.nasa.gov/projects/TEMPO?tab=overview>.
- Terrier, Douglas. "NASA 's Barriers to Innovation and Chief Technologist Update." March 2017.
- The Planetary Society. "Your Guide to NASA's Budget," n.d. <https://www.planetary.org/space-policy/nasa-budget>.

- Thomas, William. "DOD Budget: FY22 Outcomes and FY23 Request." AIP, June 15, 2022. <https://ww2.aip.org/fyi/2022/dod-budget-fy22-outcomes-and-fy23-request>.
- Tingley, Brett. "What Is the U.S. Space Force and What Does It Do?" Space.com, February 14, 2023. <https://www.space.com/us-space-force-history-mission-capabilities>.
- Tracxn. "New Space Startups in the United States | Tracxn." Tracxn, n.d. <https://tracxn.com/explore/NewSpace-Startups-in-United-States>.
- United States Space Force. "About Space Force." United States Space Force, n.d. <https://www.spaceforce.mil/About-Us/About-Space-Force/>.
- U.S. Central Command. "U.S. Central Command Hires Chief Technology Officer," n.d. <https://www.centcom.mil/MEDIA/PRESS-RELEASES/Press-Release-View/Article/3178494/us-central-command-hires-chief-technology-officer/https%3A%2F%2Fwww.centcom.mil%2FMEDIA%2FPRESS-RELEASES%2FPress-Release-View%2FArticle%2F3178494%2Fus-central-command-hires-chief-technology-officer%2F>.
- U.S. Department of Defense. *2022 National Defense Strategy of The United States of America*. Washington, D.C.: U.S. Department of Defense, 2022. <https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF>.
- Vergun, David. "Official Details Space-Based Threats and U.S. Countermeasures." U.S. Department of Defense, April 26, 2023. <https://www.defense.gov/News/News-Stories/Article/Article/3375577/official-details-space-based-threats-and-us-countermeasures/https%3A%2F%2Fwww.defense.gov%2FNews%2FNews-Stories%2FArticle%2FArticle%2F3375577%2Fofficial-details-space-based-threats-and-us-countermeasures%2F>.
- Werner, Debra. "Rivada Space Networks Selects Aalyria Spacetime." SpaceNews, March 13, 2023. <https://spacenews.com/rivada-space-networks-selects-aalyria-spacetime/>.
- Williams, Herbert. "A DOD Education Strategy for Artificial Intelligence." Air University Press, April 2020.
- Williams, W. Dan, Michael Collins, Don Boroson, James Lesh, Abihijit Biswas, Richard Orr, Leonard Schuchman, and O. Scott Sands. "RF and Optical Communications: A Comparison of High Data Rate Returns from Deep Space in the 2020 Timeframe." NASA, January 2018.
- Wolfe, Frank. "GPS OCX Not Operationally Ready Until Next May, DOD Estimates." Defense Daily, October 4, 2023. <https://www.defensedaily.com/13-month-delay-for-operational-readiness-of-gps-ocx-dod-estimates/space/>.

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