National Security Space Launch

Research Thesis

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Introduction

The United States Air Force's National Security Space Launch (NSSL) program, formerly known as the Evolved Expendable Launch Vehicle (EELV) program, was first established in 1994 by President William J. Clinton's National Space Transportation Policy.[1] The policy assigned the responsibility for expendable launch vehicles to the Department of Defense (DoD), with the goals of lowering launch costs and ensuring national security access to space. As such, the United States Air Force Space and Missile Systems Center (SMC)[1] started the EELV program to acquire more affordable and reliable launch capability for valuable U.S. military satellites, such as national reconnaissance satellites that cost billions per satellite.[2] In March 2019, the program name was changed from EELV to NSSL, which reflected several important features: 1.) The emphasis on "assured access to space," 2.) transition from the Russian-made RD-180 rocket engine used on the Atlas V to a US-sourced engine (now scheduled to be complete by 2022), 3.) adaptation to manifest changes (such as enabling satellite swaps and return of manifest to normal operations both within 12 months of a need or an anomaly), and 4.) potential use of reusable launch vehicles.[3]

Currently, the performance requirements for the next generation of NSSL vehicles to be used until at least 2030 include three payload categories: Category A (fits within a 4m payload envelope), Category B (fits within a 5m payload envelope), and Category C (requires an extended 5m payload envelope). Performance requirements also specify particular orbits, consisting of LEO (lower Earth orbit), Polar orbit, MEO (medium Earth orbit), GTO (geostationary transfer orbit), Molniya orbit, and GEO (geostationary orbit). As of August 2019, Blue Origin, Northrop Grumman Innovation Systems, SpaceX, and United Launch Alliance (ULA) have all submitted proposals. From these, the U.S. Air Force will be selecting two companies to fulfill approximately 34 launches over a period of five years,[4] beginning in 2022.[5]

Additionally, there are still unresolved issues over how the contract acquisition model will function. The Air Force is trying to diversify the launch portfolio for the NSSL by picking two launch providers from a pool of four launch vehicles, but the process has not been entirely streamlined, such as Blue Origin's pre-award protest and SpaceX's lawsuit.[6] These gaps negatively impact how well the NSSL program can accomplish the goals outlined in National Presidential Directive Number 40, which emphasize the role of U.S. space access and transportation capabilities in maintaining U.S. security and capabilities in an increasingly competitive and global world.[7]

This paper will therefore first examine the objectives for the NSSL as presented in the 2017 National Security Strategy, Fiscal Year 2019, Fiscal Year 2020, and Fiscal Year 2021 National Defense Authorization Acts (NDAA), and National Presidential Directive No. 40. The paper will then identify areas of potential weakness and gaps that exist in space launch programs as a whole

[1] The Space and Missile Systems Center (SMC) is the U.S. Space Force's center of acquisition excellence for acquiring and developing military space systems. Its portfolio includes GPS, military satellite communications, defense meteorological satellites, space launch and range systems, satellite control networks, space based infrared systems and space situational awareness capabilities. See "Los Angeles Air Force Base," Los Angeles Air Force Base.

and explore the security implications that impact the NSSL specifically. Finally, the paper will examine how the trajectory of the NSSL program could be adjusted in order to facilitate a smooth transition into new launch vehicles, while maintaining mission success, minimizing national security vulnerabilities, and clarifying the defense acquisition process.

NSSL Program Background

i. History

The United States Air Force (USAF) implemented the Evolved Expendable Launch Vehicle (EELV) program in 1995 as a way to acquire launch services and ensure continued access to space for critical national security missions.[8] Prior to 1995, there were concerns within the USAF and space launch community "over increasing cost and decreasing confidence in the continued reliability of national access to space."[9] As such, the purpose of the EELV was to provide affordable, reliable, and assured access to space, as well as provide critical space lift capability to "support DoD and intelligence community satellites, together known as National Security Space (NSS) missions."[10]

a. 1990s-2011

In the FY1994 National Defense Authorization Act (NDAA), Congress directed the DoD to develop a Space Launch Modernization Plan (SLMP) to "establish and clearly define priorities, goals, and milestones regarding modernization of space launch capabilities for the Department of Defense or, if appropriate, for the Government as a whole."[11] Thus, the primary goal of the EELV program was to reduce costs by 25% and to ensure 98% launch vehicle design reliability and to standardize EELV system launch pads and the interface between satellites and their launch vehicles. These efforts were further sustained by the FY1995 NDAA, which provided a recommended "$30 million for a competitive reusable rocket technology program and $60 million for expendable launch vehicle development and acquisition."[12]

In the initial competition the USAF provided contracts to four launch providers, which comprised of Lockheed Martin, Boeing, McDonnell Douglas, and Alliant Techsystems, to develop launch vehicles. Lockheed Martin and McDonnell Douglas were selected, but after Boeing acquired McDonnell Douglas in 1997, Boeing took over the EELV launch vehicle development. Both launch providers were retained as the space launch market was deemed large enough to support two EELV providers, which also provided the DoD with "some confidence in its ability to maintain 'assured access to space'."[13]

In the late 1990s, however, the U.S. suffered "six space launch failures in less than a year. These failures included the loss of three national security satellites in 1998-1999, at a cost of over $3 billion. One, a critical national security communications satellite (MILSTAR – Military Strategic and Tactical Relay) was lost on a failed Titan IV launch in 1999… The other two losses were an NRO reconnaissance satellite and a DSP (Defense Support Program) satellite."[14] In addition to the payloads themselves, there were cost, schedule, and operational losses incurred by the failed missions. Changes brought on by President William Clinton and President George W. Bush's administrations led to increased oversight activities and fixed DoD launch costs, respectively, and the DoD "revised its EELV acquisition strategy because of the collapse of the commercial launch market and the ongoing erosion of the space industrial base."[15]

In December 2006, Boeing and Lockheed Martin consolidated their launch operations into a joint venture under the United Launch Alliance (ULA), which resulted in two launch vehicle families under one entity.

b. 2011-Current

In November 2011, the DoD adopted a new EELV acquisition strategy, following studies and internal evaluation of possible business model alternatives. The new acquisition strategy "advocated a steady launch vehicle production rate."[16] By doing so, the strategy sought to benefit the government by using block buys of launch vehicles to provide a predictable production schedule; this demand would then stabilize the space launch industrial base. In December 2013, the DoD implemented the strategy and signed a contract modification with ULA, committing the DoD to buy 35 launch vehicle booster cores over five years and the associated launch infrastructure capability. However, some members of Congress and external analysts disputed whether the DoD was actually saving costs with the new contract. Additionally, there were issues with the FY2015 budget request that raised questions over how many launches were actually open to competition.

According to the Congressional Research Service, the acquisition strategy has been adjusted to a three-phase approach:

i. Phase 1 (FY2013-FY2019): Sole-source block-buy awarded to ULA to procure up to 36 cores and to provide 7 years of NSS launch infrastructure capability.
    1. Phase 1A (FY2015-FY2019): Modification to Phase 1 that opened up competition for NSS launches to new launch providers, such as SpaceX; the Air Force could award up to 14 cores to a new entrant over 3 years if the new entrant became certified. Phase 1 and Phase 1A awards were made to ULA and SpaceX.

ii. Phase 2 (FY2018-FY2022): Full competition among all launch service providers. The operational requirements, budget, and potential for competition are currently being worked on.
    1. As of April 2020, the DoD is currently in the middle of Phase 2; the competitions are accomplished through either Launch Service

Agreements (LSA) or Launch Service Procurement (LSP) awards; according to the GAO:[2]

a. LSA awards are a set of three Air Force RDT&E awards intended to facilitate the development of three domestic launch system prototypes. The DoD awarded LSAs to ULA, NGIS, and Blue Origin in October 2018.
b. LSP is an ongoing procurement competition that is currently in Phase 2. The second phase is a 5-year procurement of approximately 34 launches starting in 2022. USAF plans to select two space launch providers in 2020 from ULA, NGIS, SpaceX, and Blue Origin, for the Vulcan, OmegA, Falcon, and New Glenn, respectively. Currently, ULA and SpaceX are the only launch providers that are certified to launch NSSL payloads.

iii. Phase 3 (FY2023-FY2030): Full competition with the award of any or all required launch services to any certified provider.

In March 2019, the FY2019 National Defense Authorization Act changed the program name from EELV to NSSL to reflect a "consideration of both reusable and expendable launch vehicle during future solicitations."[17] Additionally, the FY2020 NDAA created the United States Space Force[3] under the USAF, who now has jurisdiction over the NSSL program launches.

ii. Program Purpose and Current Launch Vehicles

As outlined earlier, the National Security Space Launch (NSSL) is a program under the United States Space Force (USSF) that aims to ensure access to space for the United States Department of Defense (DoD) and other U.S. government payloads. As of July 2019, the Air Force Space Command defines the NSSL program objectives to be 1.) procure affordable NSSL services, 2.) maintain assured access to space, and 3.) ensure mission success with viable domestic launch service providers. Additionally, the "program is driven to provide launch flexibility that meets warfighter needs while leveraging the robust U.S. commercial launch industry, which has grown significantly during the past five to seven years."[18] The program has launched over 70 national security space launches for the Air Force, National Reconnaissance Office (NRO) and the U.S. Navy, and has not suffered a launch failure since 1999; ULA's Delta IV and Atlas V launch vehicles (which are older than the NSSL program) have performed over 90 consecutive successful missions, whereas SpaceX has performed five successful NSS

[2] U.S. Government Accountability Office (GAO) is an independent, nonpartisan agency that works for Congress. It is often called the "congressional watchdog" as it examines how taxpayer dollars are sent and provides Congress and federal agencies with objective, reliable information to help the government save money and work more efficiently. See GAO, "About GAO," U.S. Government Accountability Office.

[3] The enactment of FY20 NDAA re-designated the Air Force Space Command (AFSPC) as the U.S. Space Force on Dec. 20, 2019, which granted Title 10 authorization to the USSF as a new armed service within the USAF.

launches. The program intends to continue its track record, while seeking also to lower launch costs and better incorporate private-sector innovations.

The current lineup of launch vehicles for the NSSL include four vehicles – United Launch Alliance's (ULA) Atlas V and Delta IV Heavy,[4] and SpaceX's Falcon 9 and Falcon Heavy.

a. United Launch Alliance – Atlas V

"The Atlas V consists of a common core booster powered by an RD-180 engine (liquid oxygen and kerosene), the high-energy Centaur upper stage powered by an RL10 engine (liquid oxygen and liquid hydrogen) and either a 4-meter (400 series) or a 5-meter-diameter (500 series) payload fairing. For additional power at liftoff, up to three solid rocket boosters (SRBs) can be added to the Atlas V 400 series while the 500 series can support up to five SRBs."[19]

Lift Capability to LEO:[5] 18,850 kg or 41,570 lb[20]

Lift Capability to GTO:[6] 8,900 kg or 19,620 lb[21]

b. United Launch Alliance – Delta IV Heavy

The Delta IV Heavy consists of three common booster cores, each powered by an RS-68A engine (liquid oxygen and liquid hydrogen), and the Delta Cryogenic Second Stage powered by an RL10 engine (liquid oxygen and liquid hydrogen). A 5.4-meter-diameter payload fairing completes the "stack."[22] One launch costs about $350 million, making it an extremely expensive option for commercial launches.[23] The Delta IV Heavy will be launching five final National Reconnaissance Office (NRO) missions between 2020 and 2023.[24]

Lift Capability to LEO: 28,370 kg or 62,540 lb[25]

Lift Capability to GTO: 14,210 kg or 31,330 lb[26]

c. SpaceX – Falcon 9

According to the SpaceX Falcon User's Guide, the Falcon 9 is a two-stage launch vehicle, with both stages powered by liquid oxygen (LOX) and rocket-grade kerosene (RP-1).[27] The vehicle is designed, built and operated by SpaceX. Falcon 9 can be flown with a fairing or with a SpaceX Dragon spacecraft, and the first-stage booster can be recovered for repeated space missions. In the First Stage, the Falcon 9 "incorporates nine Merlin engines and aluminum-lithium alloy tanks containing liquid oxygen and rocket-grade kerosene (RP-1) propellant."[28] Additionally, the "Falcon 9 is the only vehicle currently flying with engine out

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[4] For more details about Atlas V and Delta IV payload information and different configurations, refer to the User Guides provided at www.ulalaunch.com; guide is subject to change and revision.
[5] ULA defines LEO (Low Earth Orbit-Reference) as 200 km circular at 28.7 deg or 90 deg.
[6] ULA defines GTO (Geosynchronous Transfer Orbit) as 35,786 km x 185 km at 27.0 deg.

capability; Falcon 9 can lose up to two of its Merlin engines on the first stage and still complete its mission."[29]

Payload to LEO:[7] 22,800 kg or 50,625 lb

Payload to GTO: 8,300 kg or 18,300 lb

d. SpaceX – Falcon Heavy

The Falcon Heavy is a two-stage, heavy-lift launch vehicle powered by LOX and RP-1. It can transport more payload mass into LEO or GTO than any other launch vehicle currently in operation. Falcon Heavy is the most powerful launch vehicle in operation with more than 5.1 million pounds of thrust at liftoff. Falcon Heavy builds on the proven, highly reliable design of the Falcon 9. Falcon Heavy's first-stage is comprised of three Falcon 9 first stages with enhancements provided to strengthen the cores.[30]

Payload to LEO: 63,800 kg or 140,660 lb

Payload to GTO: 26,700 kg or 58,860 lb

iii. Progression of Next Generation Launch Vehicle Procurement

Next generation launch vehicle procurement is largely impacted by both the continued need for affordable and secure launch vehicles, as well as the need to phase out reliance on the Russian RD-180 rocket engine that powers the Atlas V, and the retirement of the Atlas V itself. As such, in October 2018[31] the USAF announced it was awarding three contracts totaling $2 billion to Blue Origin, Northrop Grumman Innovation Systems (NGIS), and ULA to develop launch system prototypes.

In March 2019, USAF's Launch Services Procurement (LSP) Phase 2 competition for launch missions from 2022 to 2026 moved onto soliciting bids for two awards, to be split 60/40 between two launch providers.[32] This phase was supposed to build off the OTAs[8] and Launch Service Agreements awarded in 2018 to Blue Origin, NGIS, and ULA. However, in August 2019 there were reportedly four proposals submitted - by Blue Origin, NGIS, SpaceX, and ULA - from which two companies will be awarded "up to 34 launches over a five-year period."[33]

a. Blue Origin – New Glenn

[7] SpaceX does not directly define LEO or GTO specifics on the website. See SpaceX, *Falcon User's* for more details.

[8] Other Transaction Authority (OTA) allows the use of Other Transaction Agreements (OTAs), which can come in a variety of different forms and is typically distinguished by whether its purpose is for a research or for a prototype project. OTAs are not standard procurement contracts, grants, or cooperative agreements, so they are not generally subject to federal laws and regulations that apply to government procurement contracts (e.g., FAR/DFARS). See U.S. Air Force, "Other Transaction," U.S. Air Force Office of Transformational Innovation.

According to Blue Origin, “New Glenn’s fully reusable first stage is designed for a minimum of 25 flights, making it competitive for a variety of launch markets… New Glenn is a reliable, cost-competitive system with high availability. The 7-meter fairing has two times the payload volume of any existing launch vehicle, which means more room for satellites and the freedom to build in more capacity. New Glenn is also able to launch and land in 95% of weather conditions.”[34] The New Glenn will be able to launch payloads of 13 metric tons to GTO and payloads of 45 metric tons to LEO.

According to Blue Origin’s information on all their engines, the “BE-4 is the most powerful liquefied natural gas (LNG) fueled rocket engine ever developed. Using an oxygen-rich staged combustion cycle, BE-4 is capable of producing 2,400 kN (550,000 lbf) thrust with deep throttle capability.”[35] The company chose LNG as their fuel source “because it is highly efficient, low cost, and widely available. Unlike kerosene, LNG can be used to self-pressurize its tank. Known as autogenous repressurization, this eliminates the need for costly and complex systems that draw on Earth’s scarce helium reserves. LNG also possesses clean combustion characteristics even at low throttle, simplifying engine reuse compared to kerosene fuels” (Blue Origin, 2019). Regarding engine use, “seven BE-4 engines will power New Glenn’s reusable booster, and two BE-4 engines will drive the first stage of ULA’s Vulcan launch vehicle. The BE-4 engine will not only be used on New Glenn, but also ULA’s Vulcan rocket.”[36]

Unlike many launch companies at Cape Canaveral, Blue Origin has decided to build their own, clean-sheet launch pad for New Glenn.”[37] The New Glenn will have comparable capability to ULA’s current Delta IV Heavy.

The New Glenn will be launching its first flight in late 2021.[38]

b. Northrop Grumman – OmegA

The OmegA is designed to use strap-on GEM-63XLT (solid-propellant) boosters (from 0 to 6 as needed) as part of a modular launch solution that can fly payloads to the various orbits that are needed for national security flights (ranging from 100km low Earth orbit to geostationary orbit at 35,786km, and everything in between, with polar inclinations and Molniya orbits included). The OmegA is designed to perform all national security missions, which can require a lift capability of up to 18,000 pounds for geostationary transfer orbit, or 37,000 pounds for polar-orbiting satellites.”[39]

“OmegA was designed around a solid rocket booster core derived from the Space Shuttle’s solid rocket motor. The design choice of using solids for the first two stages and a liquid stage for the third stage was driven by the capability of solids to quickly thrust through the atmosphere as well as by liquid stages’ capability to go from one high-velocity orbit to another.”[40]

"Another driver for this decision, according to NGC, was that since 1980 solid rocket systems have four times less risk of failure than liquid systems as per gathered statistics, and there have been no solid rocket motor failures for the last 18 years, resulting in an overall 99.7 percent success rate in the last 40 years, a greater success rate than liquid-fueled engines. As per gathered statistics, there are also fewer launch delays for solid engines (2 percent of delays for Delta and Shuttle caused by solid rocket boosters, compared to 22-24 percent of delays caused by liquid-fueled engines)."[41]

The first flight for OmegA will be in spring of 2021, when the OmegA rocket will be used to launch two Nationsats[9] for Saturn Satellite Networks (SSN)[10] into a GTO from NASA's Kennedy Space Center.[42] Additionally, Charlie Precourt, vice president, propulsion systems, of Northrop Grumman, states that "the first flight of OmegA is a key step in our certification process for the USAF NSSL program."[43]

c. United Launch Alliance – Vulcan Centaur

Vulcan Centaur is expected to reduce launch costs in comparison to Atlas V and Delta IV when it debuts, but future developments are intended to reduce costs even further. This includes evolving Centaur into the Advanced Cryogenic Evolved Stage (ACES), which will allow the upper stage to operate on orbit for weeks at a time to support multi-launch, distributed lift missions."[44]

"ULA also plans to recover and reuse the BE-4 first stage engines via Sensible Modular Autonomous Return Technology, or SMART Reuse… While the first stage fuel tanks will not be recovered, recovering the engines will allow reuse of the most expensive component of the stage."[45]

As of November 2019, ULA's Vulcan Centaur "consists of a single booster stage powered by a pair of BE-4 engines, the high-energy Centaur upper stage powered by two RL10 engines and a 5.4-meter-diameter payload fairing. For additional power at liftoff, up to six solid rocket boosters can be added to the Vulcan Centaur rocket."[46]

The Vulcan Centaur ranges from 0 solids to 6 solids, as well as the Vulcan Centaur Heavy. Performance values are as ranges:

GEO (Geosynchronous Earth Orbit): 35,786 km circular at 0 deg
GTO (Geosynchronous Transfer Orbit): 35,786 km x 185 km at 27.0 deg
LEO-Reference (Low Earth Orbit-Reference): 200 km circular at 28.7 deg

[9] Nationsat is a small 4kW GEO communications satellite system that can provide requirements for video and data communications applications. See "Introducing Saturn," Saturn Satellite Networks.
[10] Saturn Satellite Networks (SSN) Inc. was established in 2017 by former executives of satellite operator ABS to develop small geostationary satellites with digital payloads. Saturn has also expressed an interest in developing satellites for low and medium Earth orbit applications. See Foust and Erwin, "Saturn Satellite," SpaceNews.

LEO-ISS (Low Earth Orbit-International Space Station): 407 km circular at 51.6 deg
LEO-Polar (Low Earth Orbit-Polar): 200 km circular at 90 deg
MEO (Medium Earth Orbit): 20,368 km circular at 55 deg
TLI (Trans-lunar Interjection): C3: -2 km2/sec2

The first flight for the Vulcan Centaur is scheduled for 2021.[47] The Vulcan Centaur rocket will be used to launch Astrobotic's Peregrine lunar lander to the moon and will launch from Space Launch Complex-41 at Cape Canaveral Air Force Station in Florida.[48] ULA has stated that "the launch of this mission will serve as the first of two certification flights required for ULA's USAF certification process."[11]

d. SpaceX – Falcon 9

SpaceX is bidding its current Falcon 9, which has already been certified for NSSL missions.

NSSL Policy Objectives

To better understand the nature of the NSSL program, it is important to track how the program and its objectives have changed since its inception. Following how space policy changes along with U.S. foreign policy may help provide insight into how the NSSL should adapt in the upcoming years and what goals are the most critical to pursue.

i. Presidential Decision Directive 4 – 1994

The National Security Space Launch was originally established in 1994 by President William J. Clinton's Presidential Decision Directive (PDD)/National Science and Technology Council (NSTC)-4 on National Space Transportation Policy and called for changes to existing expendable launch vehicles (ELV). PDD/NSTC-4 delegated the modernization, evolution, and technological development of the ELVs to the Department of Defense (DoD) with the goals of "[reducing] costs while improving reliability, operability, responsiveness, and safety."[49] As outlined in the Office of Science and Technology Policy's Statement on National Space Transportation Policy, the policy "commits the nation to a two-track strategy of: (1) maintaining and improving the current fleet of expendable launch vehicles as necessary to meet civil, commercial, and national security requirements; and (2) investing R&D resources in developing and demonstrating next generation reusable space transportation systems with the potential to greatly reduce

[11] Astrobotic Technology, Inc. is a space robotics company; their lunar lander, Peregrine, delivers payloads to the Moon for companies, governments, universities, non-profits, and individuals. The company is also developing advanced space robotics capabilities such as terrain relative navigation, mobile robotics for lunar surface operations, and reliable computing systems for mission-critical applications. See "About Astrobotic," Astrobotic.

the cost of access to space." With this strategy in mind, the policy sought to accomplish four critical objectives:

> 1.) Establishes new national policy for federal space transportation spending, consistent with current budget constraints and the opportunities presented by emerging technologies.
>
> 2.) Establishes policy on federal agencies' use of foreign launch systems and components.
>
> 3.) Establishes policy on federal agencies' use of excess U.S. ballistic missile assets for space launch, to prevent adverse impacts on the U.S. commercial space launch industry.
>
> 4.) Provides for an expanded private sector role in the federal space transportation R&D decision making processes.

In contrast to today's stance on foreign technology, in the post-Cold War international climate, use of foreign technology, especially Russian rocket engines, was allowed as long as the U.S. avoided building a dependency on foreign assets.

ii. National Security Presidential Directive 40 – 2004

In 2004, President Bush's National Security Presidential Directive/NSPD-40 superseded all of PDD/NSTC-4 (1994) and portions of PDD/NSTC-49 (1996), providing new nuances to proposed policy and program objectives. Overall, the goal of NSPD-40 "is to ensure the capability to access and use space in support of national and homeland security, civil, scientific, and economic interests."[50]

Regarding the Evolved Expendable Launch Vehicle (EELV) program, "capabilities developed under the EELV program shall be the foundation for access to space for intermediate and larger payloads for national security, homeland security, and civil purposes to the maximum extent possible consistent with mission, performance, cost, and schedule requirements."[51] Private industry is included more explicitly as well, as "new U.S. commercial space transportation capabilities that demonstrate the ability to reliably launch intermediate or larger payloads will be allowed to compete on a level playing field for United States Government missions."[52] However, there is still much discussion currently on what constitutes a level playing field.

As is consistent with past policy, NSPD-40 allows for "the use of foreign components or technologies, and the participation of foreign governments and entities in current and future U.S. space transportation systems is permitted consistent with U.S. law and regulations, as well as nonproliferation, national security, and foreign policy goals and commitments and U.S. obligations under the Strategic Arms Reduction Treaty, Intermediate Nuclear Forces Treaty, and the Missile Technology Control Regime,"[53] with more elaboration on specific policy goals and legal agreements or limitations as compared to PDD/NSTC-4.

Overall, there is an emphasis on assuring U.S. access to space and decreasing the costs of launches. For implementation, the Secretaries of Defense, Commerce, and Transportation, the Director of the CIA, and Administrator of NASA were to jointly formulate a national space transportation strategy covering requirements, plans, schedules, and resources within 180 days following the release of NSPD-40. Specifically, for the EELV, the strategy "shall address how the Evolved Expendable Launch Vehicle program will be managed through 2009."[54]

iii. National Space Policy – 2010

The National Space Policy directive was issued on June 28th, 2010 by President Barack H. Obama to provide "comprehensive guidance for all government activities in space, including the commercial, civil, and national security space sectors."[55] Compared to prior space policies, the 2010 directive "leans farther forward in support of U.S. business interests."[56]

Of the goals outlined in the policy, there are two that are most relevant to the NSSL:

> a.) Energize competitive domestic industries to participate in global markets and advance the development of: satellite manufacturing; satellite-based services; space launch; terrestrial applications; and increased entrepreneurship.
>
> This clause covers space launches and thus includes the NSSL. Private industries have been tasked with fulfilling contracts and providing launch services, even in the earliest days of the EELV. However, given the growing shifts in different industry players today, there is question as to whether a monopoly or duopoly, such as ULA and SpaceX's joint control over current NSSL contracts, will continue to be the preferred system. The global market also needs to be considered when it comes to selecting providers for the NSSL, especially to mitigate possible threats or supply chain weaknesses that come with increased globalization in manufacturing.
>
> b.) Increase assurance and resilience of mission-essential functions enabled by commercial, civil, scientific, and national security spacecraft and supporting infrastructure against disruption, degradation, and destruction, whether from environmental, mechanical, electronic, or hostile causes.
>
> Since the NSSL is responsible for the launch of critical and expensive national security payloads, it is even more important to ensure that the launch vehicles and processes are capable of successfully placing infrastructure into the necessary orbits to achieve mission success.

Under Inter-sector Guidelines, there are several Foundational Activities and Capabilities that are relevant to the NSSL:

> a.) Enhance Capabilities for Assured Access to Space. United States access to space depends in the first instance on launch capabilities. United States

Government payloads shall be launched on vehicles manufactured in the United States unless exempted by the National Security Advisor and the Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy… departments and agencies shall:

> Work jointly to acquire space launch services and hosted payload arrangements that are reliable, responsive to United States Government needs, and cost-effective;
>
> Enhance operational efficiency, increase capacity, and reduce launch costs by investing in the modernization of space launch infrastructure; and
>
> Develop launch systems and technologies necessary to assure and sustain future reliable and efficient access to space, in cooperation with U.S. industry, when sufficient U.S. commercial capabilities and services do not exist.

b.) Improve Space System Development and Procurement. Departments and agencies shall:

> Improve timely acquisition and deployment of space systems through enhancements in estimating costs, technological risk and maturity, and industrial base capabilities;
>
> Reduce programmatic risk through improved management of requirements and by taking advantage of cost-effective opportunities to test high-risk components, payloads, and technologies in space or relevant environments;
>
> Embrace innovation to cultivate and sustain an entrepreneurial U.S. research and development environment; and
>
> Engage with industrial partners to improve processes and effectively manage the supply chains.

These inter-sector guidelines provide some insight into the necessity for interagency coordination and private-public sector collaboration for securing launch capabilities and procurement. To strengthen interagency partnerships, the policy further states that "departments and agencies shall improve their partnerships through cooperation, collaboration, information sharing, and/or alignment of common pursuits. Departments and agencies shall make their capabilities and expertise available to each other to strengthen our ability to achieve national goals, identify desired outcomes, leverage U.S. capabilities, and development implementation and response strategies."[57] However, the policy does not offer specific direction for how that process may be accomplished.

The 2018 National Defense Strategy offers a possible direction for approaching interagency partnerships in calling for DoD's cooperation and collaboration with other agencies, such as the Department of State, Treasury, Justice, Energy, Homeland Security, Commerce, USAID, and the Intelligence Community, etc. in order to "identify and build partnerships to address areas of economic, technological, and informational vulnerabilities."[58] A similar framework of communication and collaboration could be taken between private partners and public sector agencies to increase inter-sector coordination.

Specifically, regarding the policy's National Security Space Guidelines, clauses that are relevant to the NSSL are a.) Ensure cost-effective survivability of space capabilities, including supporting information systems and networks, commensurate with their planned use, the consequences of lost or degraded capability, the threat, and the availability of other means to perform the mission; and b.) Develop and implement plans, procedures, techniques, and capabilities necessary to assure critical national security space-enabled missions. Options for mission assurance may include rapid restoration of space assets and leveraging allied, foreign, and/or commercial space and non-space capabilities to help perform the mission.[59]

iv. National Security Space Strategy – 2011

Released in 2011, the National Security Space Strategy sought to provide direction for the next decade on responses to the space strategic environment. The DoD and the Intelligence Community (IC) was to coordinate with other departments and agencies to implement the strategy by "using it inform planning, programming, acquisition, operations, and analysis."[60] Sections that are most directly relevant to the NSSL are as listed:

Providing Improved U.S. Space Capabilities:

> "In cooperation with our industrial base partners, DoD and the IC will revalidate current measures and implement new measures, where practicable, to stabilize program acquisition more effectively and improve our space acquisition processes. We will reduce programmatic risk through improved management of requirements. We will use proven best practices of systems engineering, mission assurance, contracting, technology maturation, cost estimating and financial management to improve system acquisition, reduce the risk of mission failure, and increase successful launch and operation of our space systems."[61]
>
> "Mission permitting, we will synchronize the planning, programming, and execution of major acquisition programs with other DoD and IC processes to improve inefficiencies and overall performance of our acquisition system and industrial base. DoD and the IC will evaluate the requirements and analysis of alternatives processes to ensure a range of affordable solutions is considered and to identify requirements for possible adjustment."[62]

Streamlining the timelines and program scheduling of major acquisition programs across other DoD and IC activities could potentially help minimize some program inefficiencies with resource usage.

"To support the range of national security space activities, we will develop current and future national security space professions – our 'space cadre' – who can acquire capabilities, operate systems, analyze information, and succeed in a congested, contested, and competitive environment. We will build a more diverse and balanced workforce among military, civilian, and contractor components."[63]

Having a capable and diverse workforce for the NSSL program would help provide more dedicated resources. Creating a more cohesive network could also help better manage program needs with more efficiency and responsiveness.

Preventing and Deterring Aggression against Space Infrastructure that Supports U.S. National Security:

"Given the degree to which the United States relies on space systems and supporting infrastructure for national security, we must use a multi-layered approach to prevent and deter aggression. We seek to enhance our national capability to dissuade and deter the development, testing, and employment of counterspace systems and prevent and deter aggression against space systems and supporting infrastructure that support U.S. national security."[64]

"We will seek to deny adversaries meaningful benefits of attack by improving cost-effective protection and strengthening the resilience of our architectures. Partnerships with other nations, commercial firms, and international organizations, as well as alternative U.S. Government approaches such as cross-domain solutions, hosted payloads, responsive options, and other innovative solutions, can deliver capability, should our space systems be attacked. This will also enable our ability to operate in a degraded space environment."[65]

This section highlights a need for more flexibility with launch scheduling and adaptations to sudden changes or other changes.

v. Russian Annexation of Crimea

In March 2014, Russia annexed Crimea,[66] which raised concerns in Congress regarding the use of Russian rocket engines to launch critical U.S. national security payloads. In December 2014, Congress voted to approve a ban that barred the Pentagon from awarding future national security launch contracts to companies using Russian engines.[67] The ban impacted ULA, who had been launching all NSSL/EELV missions up until SpaceX was able to also secure national security launches. ULA and the Pentagon were able to weaken the bill enough so that ULA could continue using Russian engines already in inventory or previously ordered. In June 2015, the Pentagon continues to push for relaxing the ban, since the Russian RD-180 rocket engines would still be needed for a few more years while alternatives were sourced.[68]

In response to the demand to phase out RD-180 rocket engines entirely, the Air Force had solicited bids in March 2019 for Phase 2 Launch Procurement. In August 2019, four proposals for new launch vehicle were submitted by ULA, NGIS, SpaceX, and Blue Origin. USAF will be testing them within the next few years with the goal of picking two launch providers for launches starting in 2022.

vi. National Security Strategy – 2017

The National Security Strategy was published in December 2017 and focuses on four main pillars: 1.) Protect the American People, the Homeland, and the American Way of Life, 2.) Promote American Prosperity, 3.) Preserve Peace through Strength, and 4.) Advance American Influence.[69]

Under Pillar II, sections that are most directly applicable to the NSSL are:

Lead in Research, Technology, Invention and Innovation:

> a.) Understand worldwide science and technology (S&T) trends: To retain U.S. advantages over our competitors, U.S. Government agencies must improve their understanding of worldwide S&T trends and how they are likely to influence – or undermine – American strategies and programs.
>
> b.) Attract and retain inventors and innovators: The U.S. Government must improve our collaboration with industry and academia and our recruitment of technical talent. We will remove barriers to the full use of talent across Federal agencies and increase incentives for hiring and retaining Federal STEM employees.
>
> c.) Leverage private capital and expertise to build and innovate: The U.S. Government will use private sector technical expertise and R&D capabilities more effectively. Private industry owns many of the technologies that the government relies upon for critical national security missions. The Department of Defense and other agencies will establish strategic partnerships with U.S. companies to help align private sector R&D resources to priority national security applications.
>
> d.) Rapidly field inventions and innovations: The United States must regain the element of surprise and field new technologies at the pace of modern industry. Government agencies must shift from an archaic R&D process to an approach that rewards rapid fielding and risk taking.

Promote and Protect the U.S. National Security Innovation Base (NSIB):

The NSIB "is the American network of knowledge, capabilities, and people – including academia, National Laboratories, and the private sector – that turns ideas into innovations, transforms discoveries into successful commercial products and companies, and protects and enhances the American way of life… Protecting the NSIB requires a domestic and international response beyond the scope of any individual company, industry, university, or government agency. The landscape of innovation does not divide neatly into sectors. Technologies that are part of most weapon systems often originate in diverse businesses as well as in universities and colleges."[70] The NSSL is one such program that relies on innovation and technology to maintain reliable and affordable access to space and needs protections in order to maintain national security missions.

> a.) Protect intellectual property: The United States will reduce the illicit appropriation of U.S. public and private sector technology and technical knowledge by hostile foreign competitors. While maintaining an investor-friendly climate, this Administration will work with the Congress to strengthen the Committee on Foreign Investment in the United States (CFIUS) to ensure it addresses current and future national security risks. The United States will prioritize counterintelligence and law enforcement activities to curtail intellectual property theft by all sources and will explore new legal and regulatory mechanisms to prevent and prosecute violations.
>
> b.) Protect data and underlying infrastructure: The United States will expand our focus beyond protecting networks to protecting the data on those networks, so it remains secure – both at rest and in transit.
>
> These priority actions would help provide direction on maintaining security on areas such as communication, information, and operations, at all stages of the NSSL program and national security launches.

Under Pillar III, the Space section offers more targeted guidance for space programs; the strategy considers "unfettered access to and freedom to operate in space to be a vital interest,"[71] and is taking into consideration the increasing access that other actors have to space-based systems, whether domestically or internationally.

> a.) Advance space as a priority domain: America's newly re-established National Space Council, chaired by the Vice President, will review America's long-range space goals and develop a strategy that integrates all space sectors to support innovation and American leadership in space.
>
> b.) Promote space commerce: The United States will simplify and update regulations for commercial space activity to strengthen competitiveness. As the U.S. Government partners with U.S. commercial space capabilities to improve the resiliency of our space architecture, we will also consider extending national security protections to our private sector partners as needed.
>
> These priority actions outline possible extension of security measures to the private sector, which may be more critical currently due to increased information flow and transfer between multiple parties and across different platforms.

vii. John S. McCain National Defense Authorization Act 2019

The FY19 NDAA (H.R.5515)[72] was signed into law on August 13th, 2018:

Under Sec. 1603 (10 USC 2273) Rapid, Responsive, and Reliable Space Launch, the EELV was renamed as the National Security Space Launch (NSSL) Program, effective March 1st, 2019. Under Sec. 4101 Procurement, Space Procurement, Air Force, the NSSL was authorized $1.7 billion for Evolved Expendable Launch Capability and Evolved Expendable Launch Vehicles (p. 132 Stat. 2345 Line 013-014). Under Sec. 4201 Research, Development, Test, and Evaluation, the NSSL was authorized $245 million (p. 132 Stat. 2368 Line 130 Program Element 1206853F).

viii. National Defense Authorization Act 2020

The FY20 NDAA (S.1790)[73] was signed into law on December 20th, 2019:

The FY20 NDAA establishes the U.S. Space Force as the sixth branch of armed forces. The Space Force is "part of the Department of the Air Force, much as the U.S. Marine Corps is part of the Department of the Navy. The new branch will be stood up over the next 18 months."[74] According to the U.S. Space Force Fact Sheet, "USSF responsibilities include developing military space professionals, acquiring military space systems, maturing the military doctrine for space power, and organizing space forces to present to our Combatant Commands,"[75] and includes jurisdiction over the NSSL program launches.

Under Sec. 4101 Procurement, Space Procurement, Air Force, the NSSL was authorized $1.2 billion for Evolved Expendable Launch Vehicles (S.1790-831, Line 015). Under Sec. 4201 Research, Development, Test, and Evaluation, the NSSL was authorized $432 million (S.1790-856, Line 122 Program Element 1206853F). The total $1.7 billion will be used for four launches under the NSSL Program.

ix. Proposed Budget Request for 2021

On February 10th, 2020, President Donald J. Trump sent Congress the FY21 budget proposal, which requested $705.4 billion for the Department of Defense.[76] Within the Space Domain, the budget proposal requests $18.0 billion, of which $15.4 billion will go to the U.S. Space Force. Through the U.S. Space Force, the NSSL will receive $1.6 billion for three launches. Budget materials do not yet specify how that proposed $1.6 billion will be portioned across procurement and RDT&E.

NSSL Current Events

As of March 13th, 2020, the Space and Missile Systems Center is on track for the scheduled launches, with 10 NSSL missions scheduled for this year. Col. Robert Bongiovi, director of the SMC's Launch Enterprise, also mentioned that the U.S. Space Force "[expects] to award [the] Phase 2 launch contracts, heralding the next generation of launch vehicles, effectively ending our nation's reliance on Russian propulsion systems."[77] Though multiple government agencies and departments have been locking down or restricting activity due to recent COVID-19 issues, the NSSL does not appear to have suffered any delays or modifications to the schedule.

Another interesting development is the Space and Missile Systems Center's Launch Enterprise Mission Manifest Office's (MMO) integration of a multi-manifest small satellite vehicle, TDO-2, along with the March 26th AEHF-6 mission aboard ULA's Atlas V. The TDO-2 is "carrying multiple U.S. Government payloads that will provide optical calibration capabilities, which will support space domain awareness" through optical calibration and satellite laser ranging.[78] According to SMC "the payload is integrated on the aft-end of the Centaur upper stage, where it will deploy the TDO-2 multi-manifest satellite vehicle approximately 31 minutes after launch. TDO-2 will deploy after the second main engine cut off (MECO 2) and prior to the anchor AEHF satellite, which is only the second time this event has occurred during a NSSL mission."[79] Most critical is the MMO focus on "enabling the 'swap-out' capability of multi-manifest satellites late in integration process," which can be as late as one month prior to launch, which is significantly more flexible compared to the historical integration timeline for traditional satellites of approximately 24 months.[80] Other launch providers have been looking at similar multi-manifest/rideshare launch capabilities, such as SpaceX's Space Test Program-2 (STP2) demonstrations with the Falcon Heavy.[81] The goal of such multi-manifest launches suggests further possible affordability and mission flexibility.

On March 26th, 2020, ULA successfully launched the first NSSL mission for the USSF (Wall, 2020).[82] The Atlas V rocket was used to launch the final Advanced Extremely High Frequency satellite (AEHF-6), which completes the six-satellite AEHF-MILSTAR constellation; AEHF is "part of the protected communications network providing global, survivable, protected communications capabilities for national leaders and tactical warfighters operating across ground, sea and air platforms."[83] Atlas V rockets were also used to launch the first five AEHF satellites in August 2010, May 2012, September 2013, October 2018, and August 2019.[84]

To summarize, the National Security Space Launch (NSSL) Program is now operating under the U.S. Space Force (USSF) with the continued goals of providing affordable and reliable launch capabilities for critical national security space missions. The program will also be looking into reusable launch capabilities for next generation launch vehicles, as well as phasing out reliance on the Russian RD-180 engines. Policy trends also point towards the desire to foster better relationships between private industry and government, with the goals of capitalizing on the private industry's flexibility and innovation. All these goals continue to function within the context of a competitive space strategic environment that demands constant growth and innovation to keep pace with global technological developments and potential threats.

With these policy trends and goals in mind, the paper will now examine possible vulnerabilities and gaps that are present in the space industry as a whole and how those weaknesses might also be present in the NSSL program.

Potential Gaps and Vulnerabilities in the NSSL Program

i. Technological Limitations

Space launch vehicles are technologically complex and involve numerous components and parts that each play a critical role. Failure of any one of these parts can have consequences ranging from minor damage to catastrophic mission failure, and there have been multiple past incidents resulting from damaged equipment, faulty testing, and missed vulnerabilities.[85] Though the NSSL does not encompass launches with a human crew, vehicles in the program still deliver expensive and critical national security payloads to orbit. Therefore, it would be informative to examine vulnerabilities and gaps in other space launch programs and commercial space launches when considering issues that might face the NSSL. Technological weaknesses include malfunctions in the hardware or software, while limitations address issues of longevity and durability of launch vehicles, especially concerning reusability.

a. Software and Hardware Vulnerabilities

i. Case Study: Starliner Software Failure

In December 2019, Boeing's Starliner was launched on its "inaugural, uncrewed Orbital Flight Test mission to the International Space Station."[86] To get the Starliner to the ISS, ULA used the Atlas V rocket to launch the Starliner into the planned initial-orbit trajectory, where the Starliner was then supposed to finish placing itself into a stable and circular orbit. However, shortly after Atlas V successfully placed the Starliner, "a Mission Event Timer issue resulted in the Starliner burning a significantly larger amount of propellant than planned and forced Boeing and NASA to abort the planned rendezvous and docking with the International Space Station."[87] As a result of such an early major software issue, "instead of an eight-day mission that would have seen the return of biological science samples from the Station, Starliner will now come back to Earth after just 48 hours in orbit, without the performance of some of its critical test flight objectives such as rendezvous, proximity operations, and automated docking to the International Space Station."[88] Though software testing was done prior to launch, the Boeing teams had only run phases of the Starliner mission individually, rather than doing a full integrated test run from beginning to end.[89] Additionally, there were configuration issues with software and hardware for the Starliner, as well as communication outages that impacted the ground teams' ability to directly command and control the Starliner after the mission timing error happened. The Starliner was recovered successfully after it landed in New Mexico and "post-landing inspections show it can be flown again." Some of the system functions were successfully demonstrated.[90]

However, this test launch lays bare the risks that come with any new system or spacecraft being tested. Some of the errors could not be caught in simulation or testing on ground, and only manifested during the actual flight. Others could have been found through a more substantive and flight-like test program. It is important to note, especially given the context of this paper, that the launch vehicle chosen performed perfectly. However, when the payloads are worth significantly more than the launch itself, both in monetary value and national security mission value, these types of software errors become extremely costly. One question, therefore, is how much testing or how many test flights might be necessary until a system is deemed secure and safe for actual launches; for the NSSL, this is a standard that is not clearly defined since the only reference point is ULA's almost perfect (98.9% success rate as of March 26th, 2020) mission track record and history of launches.

ii. Case Study: Columbia – Equipment Failure and NASA Internal Safety Culture

On February 1st, 2003, the space shuttle Columbia disintegrated after re-entering the atmosphere, leading to the loss of its seven-member crew. However, "its fate had been all but sealed during ascent, when a 1.67-pound piece of insulating foam broke away from the external fuel tank and struck the leading edge of the craft's left wing. The foam punched a hole that would later allow superheated gases to cut through the wing's interior like a blowtorch."[91]

The Columbia launched on January 16th, 2003. According to the Report of Columbia Accident Investigation Board, "post-launch photographic analysis showed that one large piece and at least two smaller pieces of insulating foam separated from the external tank left-bipod (-Y) ramp area at 81.7 seconds after launch. Later analysis showed that the larger piece struck Columbia on the underside of the left wing."[92] The Intercenter Photo Working Group had discovered the debris strike after the launch film was processed overnight, and requested that "a high-resolution image of the Orbiter on-orbit be obtained by the Department of Defense," the first of three distinct requests to image the Columbia.[93] On January 21st, five days into the mission, the Debris Assessment Team held its first meeting, which ended with the highest-ranking NASA engineering bringing forth the team's request for imaging the wing on-orbit to the Johnson Space Center Engineering Management Directorate. However, the Space Shuttle Program managers declined to image Columbia, which meant the Debris Assessment Team would have to use mathematical modeling to assess damage, even though the modeling tool would not be adequate for modeling this specific type of impact. The team determined that there would be some amount of damage but could not definitively state what would happen. On January 24th, the Mission Management Team "declared the debris strike a 'turnaround' issue and did not pursue the request for imagery, thus limiting the investigation.[94] Ultimately, when Columbia descended on February 1st, it spun out of control and disintegrated.

The Columbia disaster highlights critical issues in both the technology and what has been referred to as NASA's "broken safety culture."[95] Debris-shedding of the foam was not a problem unique to the last Columbia mission. At one point the foam shedding was characterized as an "accepted risk," rather than a "not a safety-of-flight" issue. However, the two terms became blurred over time, and with each successful landing, NASA engineers and managers "increasingly regarded the foam-shedding as inevitable, and as either unlikely to jeopardize safety or simply an acceptable risk", a simple maintenance or "turnaround" issue.[96] As further noted by the Board, "assessments of foam-shedding and strikes were not thoroughly substantiated by engineering analysis, and the process for closing In-Flight Anomalies is not well-documented and appears to vary." Another issue of question was NASA's lack of understanding of foam properties, and "although tests were conducted to develop and qualify foam for use on the External Tank, it appears there were large gaps in NASA's knowledge about this complex and variable material."[97] All of these factors contributed to the oversight and denial of a significant technical weakness.

STS-27R Atlantis and STS-107 Columbia also showed a significant difference in how the two debris strike events were treated. As outlined Chapter 6 of the report:

"After the discovery of the debris strike on Flight Day Two of STS-27R, the crew was immediately directed to inspect the vehicle. More severe thermal damage – perhaps even a burn-through – may have occurred were it not for the aluminum plate at the site of the tile loss. Fourteen years later, when a debris strike was discovered on Flight Day Two of STS-107, Shuttle Program management declined to have the crew inspect the Orbiter for damage, declined to request on-orbit imaging, and ultimately discounted the possibility of a burn-through. In retrospect, the debris strike on STS-27R is a 'strong signal' of the threat debris posed that should have been considered by Shuttle management when STS-107 suffered a similar debris strike. The Board views the failure to do so as an illustration of the lack of institutional memory in the Space Shuttle Program that supports the Board's claim, discussed in Chapter 7, that NASA is not functioning as a learning organization."[98]

As further highlighted in Chapter 7, there are several central considerations that critical for understanding NASA's failures as an agency:

- Commitment to a Safety Culture
- Ability to Operate in Both a Centralized and Decentralized Manner
- Importance of Communication
- Avoiding Oversimplification
- Conditioned by Success
- Significance of Redundancy

The CAIB report goes into significant detail about how the NASA failed to accomplish these objectives, which ultimately contributed to an internal safety culture that was complacent and placed priority focus on the wrong issues. The Board noted how "cultural traits and organizational practices detrimental to safety were allowed to develop," with "reliance on past success as a substitute for sound engineering practices" and "organizational barriers that prevented effective communication of critical safety information."[99] Again, in the context of this paper, the USSF is the agency in charge of maintaining the NSSL, which means NASA's organizational culture and weakness, especially for that time frame, will not directly impact the NSSL. Even so, the gaps and vulnerabilities that NASA experienced should be noted so that the institutional memory can be used to better inform future decisions.

b. Reusable Launch Vehicles

In contrast to expendable launch systems or launch vehicles, which are used only once to carry a payload into space, reusable launch systems are intended to "allow for recovery of all or part of the system for later reuse. To date, several fully reusable sub-orbital systems and partially reusable orbital systems have been flown. However, the design issues are extremely challenging and no fully reusable orbital launch system has yet been demonstrated."[100] Despite the difficulties, companies such as SpaceX are still looking into developing reusable launch systems as a way to reduce the cost of space access and to better retain resources. Theoretically, "a reusable rocket could launch payloads much less expensively than existing expendable rockets, allowing the company to gain more market share and, perhaps, opening new markets."[101] Even so, there isn't a huge rush to develop a fully reusable launch vehicle, other than SpaceX's efforts,[102] due to some perceptions that the launch market will remain relatively consistent in its demands.[103] Market demands may change as technology advances, but different launch providers have taken different stances on the proposed launch vehicles for the NSSL Phase 2.

i. Blue Origin

According to Blue Origin, "New Glenn's full reusable first stage (powered by BE-4 rockets) is designed for a minimum of 25 flights."[104] After lifting off from Launch Complex 36 at Cape Canaveral and following stage separation, the "first stage flies back to Earth and lands nearly 1,000 km downrange on a moving ship, allowing the booster to land in heavy sea-states."[105]

Though it won't be used in the New Glenn, Blue Origin's BE-3PM engine has demonstrated reusability and has completed 11 successful flights with the New Shepard. According to a Blue Origin fact sheet, the "BE-3PM is designed for operational reusability with minimal maintenance between flights and uses high performing liquid oxygen and liquid hydrogen.[106] At full throttle, BE-3PM generates 490 kN (110,000 lbf) thrust at sea level. When returning to Earth, it uniquely throttles down to 90 kN (20,000 lbf), enabling a controlled and gentle vertical landing on the pad." Although the BE-3PM operates with liquid oxygen and liquid hydrogen, compared to the BE-4 liquefied natural gas (LNG) rocket engine, Blue Origin has demonstrated the ability to deliver on some form of reusable engine.

ii. SpaceX

In the Falcon 9's User Guide, reusability is highlighted as an integral element of the Falcon program; in 2018, SpaceX flew more missions with a flight-proven rocket than a first flight rocket. Falcon 9's Block 5 first stage boosters are "designed to fly 10 times with little refurbishment in between flights, and 100 times before the vehicle would be retired."[107] In the long run, SpaceX wants to make a fully reusable rocket, and is now pursuing attempts to "recover and reuse the payload fairings, the protective nose cone that shields the rocket's cargo as it travels through the atmosphere."[108] In March 2020, SpaceX launched the Starlink 5 mission, which marked the second time SpaceX has flown a full payload fairing. As such, the rocket's upper stage is now the remaining piece of hardware that is new for each launch.

iii. Northrop Grumman

OmegA is a fully expendable launch vehicle that was designed specifically to launch national security missions.[109]

iv. ULA

ULA chose to start the Vulcan Centaur as an expendable vehicle, though the ULA plans to later reuse Vulcan's first-stage engines; according to Tiphaine Louradour, ULA's president of global commercial sales, "ULA still believes reusability makes sense when saving the engine instead of the entire first-stage booster, as SpaceX does."[110] Currently, there is still no timeline as to when the Vulcan will be made reusable.

ii. Infrastructure Vulnerabilities

a. Cybersecurity

The GAO defines cybersecurity as "the defense against attacks on our information technology infrastructure."[111] The weaknesses with IT systems that support federal agencies and critical infrastructure is the complex, dynamic, technological diverse and geographically dispersed nature of these systems, which make it difficult to identify manage, and protect the numerous operating systems, applications, and devices that make up the IT systems.[112] The issue becomes even more complicated when factoring in the networks that connect internal and external systems, including the Internet. In FY2017 there were 35,277 total federal information security incidents, with different threat vector categories of multiple attack vectors, attrition, external/removable media, physical cause, web, loss or theft of equipment, email/phishing, improper usage, or other attack methods.[113] Breaches and attacks can result in loss of personal identifiable information (PII), money or resources, data theft, or damage to critical infrastructure.

b. Supply Chain Security

The GAO did a study on information security risks that are associated with the supply chains used by the federal government. As stated, "IT systems are essential to the operations of the federal government. The supply chain – the set of organizations, people, activities, and resources that create and move a product from suppliers to end users – for IT systems is complex and global in scope."[114] It makes for a rich target, since there are many points at which the supply chain can be compromised; on the cybersecurity end, experts have even described supply chain attacks as "worst-case scenarios, because they taint products or services at the time of their creation."[115]

i. Hardware Supply Chain Attack

Hardware supply chain attacks are primarily about gaining access to the system and allowing control without leaving behind traces. In a Bloomberg report on Supermicro and other major manufacturers that were compromised, officials discuss how hardware implants on a motherboard could allow them to a.) tell the infected device to communicate with other anonymous computers and networks and to b.) prepare the infected device's operating system to accept new code, which would allow perpetrators to gain open access to the infected devices.[116] Since the USG (U.S. Government) does not manufacture its own computers or processing systems in-house and buys them as do other companies, such hardware attacks can have severe implications for the security of classified systems. Even very small manipulations of hardware can create devasting gaps and vulnerabilities, with the added difficulty of being hard to detect.

ii. Software Supply Chain Attack

The Office of the Director of National Intelligence (DNI) and the National Counterintelligence and Security Center (NCSC) defines a software supply chain attack as "compromising software code through cyberattacks, insider threats, and other close access activities at any phase of the supply chain to infect an unsuspecting the customer."[117] They can be simple or complicated in nature and attack in many different ways. Due to the relative efficiency and low cost of these types of attacks, software supply chain attacks can bypass traditional cybersecurity defense and compromise a large number of computers and networks. The shift towards software as a means of infiltrating the supply chain may also be "due to improved security for consumers and companies cutting off some other easy route to infection," with the general public becoming more aware about general security measures.[118] Software supply chain vulnerability can affect any and all systems in any sector, so this should be considered a definitive vulnerability for the NSSL program and launch providers.

c. Insider Threat

The National Insider Threat Task Force (NITTF) defines an insider threat as a "threat posed to U.S. national security by someone who misuses or betrays, wittingly or unwittingly, their authorized access to any U.S. Government resource. This threat can include damage through espionage, terrorism, unauthorized disclosure of national security information, or through the loss or degradation of departmental resources or capabilities."[119] Insider threats don't always involve malicious intent, as people might not be aware of the implications of their action or might be exploited by adversaries. Regardless of intent, insider threat does affect the security of whatever system and information is being handled because the human link is often considered the weakest in any security system.[120] Additionally, insider threats can cause damage in many different ways, such as economic espionage[12] or compromising information and personnel. These actions are punishable by law.[13]

i. Case Study: Boeing Engineer Espionage Case

In July 2009, a former Rockwell and Boeing engineer, Dongfan "Greg" Chung, from Orange County, CA was convicted of "charges of economic espionage and acting as an agent of the People's Republic of China, for whom he stole restricted technology and Boeing trade secrets, including information related to the Space Shuttle program and Delta IV rocket."[121] According to the evidence presented, "individuals in the Chinese aviation industry began sending Chung 'tasking' letters as early as 1979. Over the years, the letters directed Chung to collect specific technological information, including data related to the Space Shuttle and various military and civilian aircraft."[122] FBI and NASA agents "found more than 250,000 pages of documents from Boeing, Rockwell and other defense contractors inside the house and in a crawl space…scores of binders containing decades' worth of stress analysis reports, test results and design information for the Space Shuttle."[123] It is not clear whether the information leaks on the Delta IV had any impact on the NSSL program directly, but ULA is currently launching NSSL missions and competing with the

[12] The FBI defines economic espionage as foreign power-sponsored or coordinated intelligence activity directed at the U.S. government or U.S. corporations, establishments, or persons, designed to unlawfully or clandestinely influence sensitive economic policy decisions or to unlawfully obtain sensitive financial, trade, or economic policy information; proprietary economic information; or critical technologies. This theft, through open and clandestine methods, can provide foreign entities with vital proprietary economic information at a fraction of the true cost of its research and development, causing significant economic losses. See "What is 'economic," FBI.

[13] See Economic Espionage, 18 U.S.C. § 1831 (2013). Accessed April 2020. https://www.law.cornell.edu/uscode/text/18/1831; and Disclosure of Classified Information, 18 U.S.C. § 798 (1996). Accessed April 2020. https://www.law.cornell.edu/uscode/text/18/798.

new Vulcan Centaur. Due to the nature of national security programs, the NSSL has many classified and restricted components that can be damaging or dangerous if leaked or lost. As such, this case study does point to vulnerabilities with program personnel, whether contractor or USG employee, and how a similar situation could occur with any launch provider or contractor.

iii. Defense Acquisition Weakness

a. Different Contract Types, Funding, and Agreements

i. EELV Original Contract Model vs. NSSL Current Acquisition Strategy

According to the GAO, the ULA was the primary provider of launch vehicles to the EELV from 2006 to 2013,[124] operating under a two-contract structure that unfortunately for Congress did not provide much insight into launch costs. The two-contract structure enabled the DoD to meet its needs for "unprecedented mission success and an at-the-ready launch capability" but "the scope of its cost-reimbursement contract limited the DoD's ability to identify the cost of an individual launch as direct launch costs were not separated from other costs." The two-contract structure operated as follows:

1. ELS firm-fixed-price contract to pay for hardware and;
2. ELC cost-plus-incentive-fee contract to fund infrastructure and engineering support

DoD officials have said the ELC contract was not transparent and there was a limited understanding of activities funded under this contract.[125] The DoD also had a minimal understanding of contractor cost and lack of pricing data, possibly impacting their ability to negotiate reasonable launch prices. As such, GAO concluded that "coupled with uncertainties and possible instability in the launch vehicle industrial base, EELV program costs were predicted to rise at an unsustainable rate."[126]

At the time of the GAO report in 2014, the DoD was looking to develop a methodology for proposal evaluation and new proposal structures. If the DoD maintained a similar two-contract structure as it did with the ULA monopoly, "there could be benefits to DoD and ULA, but potential burdens to new entrants. Alternatively, if DoD implements a fixed-price commercial approach to launch proposals, DoD could lose insight into contractor cost or pricing. DoD could also require a combination of elements from each of these approaches or develop new contract requirements for this competition."[127]

The original contract model also drew concerns from members of Congress in terms of "how much the U.S. Air Force pays for the [RD-180 rocket] engines, how much the Russians receive, and whether members of the elite in President Vladimir Putin's Russia are secretly profiting by inflating the price."[128]

However, the proposed ban of the Russian RD-180s in 2015 raised the question of whether SpaceX could recreate a monopoly over national security launches in the same way ULA did, since there would be no one else available to compete against SpaceX if ULA could not fly its Atlas V or Delta IV rockets.[129] Today, with so many different commercial launch providers and launch system capabilities, this isn't as critical a concern, with a variety of companies such as Blue Origin, FireFly, Rocket Lab, and others available to compete. The focus could be instead placed on national security certifications, such as the process that certified SpaceX's Falcon 9 and Falcon Heavy for NSSL launches.

The NSSL is currently in Phase 2 of adjusting its acquisition strategy and is transitioning away from the original EELV contract model. Phase 1 and Phase 1A consisted of the initial sole-source block-buy awarded to ULA, with cores later awarded to SpaceX after modifications were made, but Phase 2 seeks full competition among all launch service providers. As noted earlier, the operational requirements, budget, and potential for competition are currently being worked on. Though the objective is to gain more transparency into the contract costs and to provide more competition among providers, it is still too early to tell if the changes in Phase 2 will deliver on its promises of reducing costs while maintaining assured access to space.

ii. Challenges with USAF Phase 2 Procurement Efforts

Progression towards Phase 2 of the acquisition strategy has not been without issue; launch providers and USG have had disagreements over how the acquisition process is happening, which indicates gaps in the strategy.

1. SpaceX Lawsuit

In May 2019, SpaceX filed a lawsuit against U.S. government to challenge the USAF's October 2018 Launch Service Agreements (LSAs), which were awarded to Blue Origin, Northrop Grumman Innovation Systems, and ULA.[130] The LSAs were intended to "facilitate the development of three domestic launch system prototypes and enable the future competitive selection of two national security space launch service providers for future procurements."[131] Since SpaceX did not receive one, it would have to field the costs of research and development on its own. According to the bid protest filed in the U.S. Court of Federal Claims, SpaceX "does not seek any advantage, but only the opportunity to compete for national security missions on a fair and level playing field" and is only challenging the LSAs awarded, not the NSSL Phase 2 RFP.[132]

In response, Blue Origin, NGIS, and ULA have all filed motions to intervene in the lawsuit, which allows the Department of Justice to use these three companies for "documentation or data that could help win the case."[133]

In January 2019, SpaceX has requested the U.S. District Court of the Central District of California to hold a hearing on March 2nd, 2020.[134] SpaceX is arguing that not having LSA funds "has caused the company financial damage…and also 'irreparable harm' because not being an LSA recipient means SpaceX does not get direct insight into the Air Force's design priorities and technical requirements for the Phase 2 competition."[135] Additionally, SpaceX will be making the same case that "while we support the Air Force moving forward with its Phase 2 acquisition strategy for national security space launches as currently planned, we are formally challenge the Air Force's LSA decision to ensure a level playing field for competition."[136] It is uncertain how the case will turn out.

This lawsuit points towards a gap in the USAF's goal of achieving open competition between launch providers, and how there are discrepancies between what the USG and launch providers perceive of contract and funding opportunities.

2. Blue Origin Pre-award Protest

On August 12, 2019 Blue Origin filed a pre-award protest with the U.S. Government Accountability Office (GAO) over the structure of the USAF's Phase 2 Launch Service Provider (LSP) competition.[137] Blue Origin raised multiple challenges to the Phase 2 Request for Proposal (RFP) issued on May 3rd, 2019, which is an unrestricted competition.[138]

The protests are as follows:

a.) Protest challenging the solicitation's basis for award that will use a methodology predicated on the agency's determination of which combination of two independently developed proposals offers the best value to the government.[14]

b.) Protest alleging that the agency's acquisition strategy will unduly restrict competition and result in de-facto sole-source acquisition procedures.[15]

c.) Protest challenging the solicitation's price evaluation methodology as ambiguous.[16]

[14] Sustained, where the methodology does not provide an intelligible, common basis on which offerors will be expected to compete and have their proposals evaluated.
[15] Denied, where the record shows that the terms of the solicitation are reasonably necessary to meet the agency's needs, and the protestor's policy objections fail to state cognizable bases of protest within [GAO]'s bid protest jurisdiction.
[16] Denied, where the record shows that the terms of the solicitation provide sufficient information to allow offerors to intelligently prepare their proposals on a common basis.

d.) Protest challenging provisions in a commercial item solicitation as contrary to customary commercial practice.[17]

The GAO sustained in part, and denied in part, Blue Origin's protest. They found that "the RFP's anticipated 'when combined' best-value methodology fails to provide offerors with an intelligible and common basis for competition" and sustained the first protest. The recommendation is as follows: We recommend that the Air Force amend the solicitation consistent with our decision and the requirements of applicable procurement law and regulation.[139] The GAO then dismissed the rest of the protests.

At the time of the decision, the recommended change was "unlikely to seriously delay Air Force plans to contract next-generation launch services by June 2020, according to the Air Force."[140] However, a spokesperson for ULA voiced a slight concern regarding the potential for delay, as "we believe the timetable the Air Force has set for this procurement is critical to ensuring on-time launch of important missions," since it may take some time to rewrite the RFP.[141] In December 2019, the amendment to the NSSL Phase 2 LSP RFP was in final coordination, according to SMC Launch Enterprise Director Col. Robert Bongiovi.[142] Bongiovi also "insisted that the change in the evaluation criteria will not affect the overall program schedule," as the USAF plans to select two launch providers in the third quarter of FY20.[143] Updates were made on December 20th, 2019 to the official USG contract website and contract solicitation (Notice ID FA8811-19-R-0002),[144] which set the official offer due dates to February 5th, 2020. As such, Phase 2 procurement efforts appear to still be on track for selection later this year.

While the protest and amendment process have not dramatically affected the USAF's procurement timeline, having potential conflicts over acquisition processes can affect and create delays in scheduling. It also illustrates a potential gap in the United States Government's (USG) understanding of terminology or criteria that commercial providers are more accustomed to, or commercial practice versus government contract practices. If the USG wants to continue increasing private sector involvement, it may be worth exploring best practices that work well for both parties.

iii. Delays in Testing and Program Scheduling

[17] Denied, where the protestor does not show that the provisions are inconsistent with customary commercial practice.

1. Launch Delays

   Between 2002 and 2006, the NSSL program (then EELV) experienced significant delays when "the anticipated commercial launch market did not materialize in the early 2000s," with "the last of these originally awarded missions launched in 2016."[145] Similar issues with anticipating the future space environment and launch market is something to keep in mind when adjusting the acquisition structure to accommodate commercial launch providers.

   Sudden changes to launch manifests can cause significant delays, whether due to "mishaps, payload delays, sudden space threats, supply chain disruption, or natural disasters."[146] Thus, a potential gap to address would be the possibility of multi-manifest launches and flexible launch programming, and whether there are ways to provide more adaptable systems that can accommodate launch schedule changes more efficiently.

   Within recent years, the ULA has delayed launches in order to avoid suffering launch failure and to maintain their mission success rates for the Atlas V and Delta IV. Though ULA claims "to be the most on-time launch provider in the United States," other analysis of past few launches "shows a 42% scrub delay rate" and a willingness to delay "almost half their Atlas V launches in a two-year window."[147] Though mission success is crucial, it is also important to consider possible impacts of delayed launches and scheduling, especially when timing is just as critical for ensuring national security space access and capabilities.

2. COVID-19 and Impacts on Operations

   As of March 11th, 2020, the World Health Organization (WHO) has categorized the coronavirus disease 2019 (COVID-19) as a pandemic. According to the USAF COVID-19 Fact Sheet, the "Department of the Air Force is responding appropriately to protect the health of the force and maintain operational readiness."[148] As part of the DoD, the USAF also follows the health protection conditions (HPCONs) protocol for public health emergencies.[149] On March 25th, the Secretary of Defense "issued guidance to raise the HPCON level to Charlie at all DoD installations globally," which means there will likely be implementation of measures such as "maximum telework, cancellation of large-scale meetings, taking temperatures at certain access points within buildings," etc.[150] The specifics of these measures will vary depending on the installation. On April 1st, 2020, Air Force Chief of Staff Gen. David L. Goldfein said that the Air Force is assessing and adjusting practices in response to COVID-19 while also ensuring operations continue. Though there will likely be negative effects on readiness due to adjusted operations, Goldfein has also "been in contact with major defense contractors and to date the virus has not had a heavy impact on the supply chain or the Air Force's ability to get necessary material, parts and munitions."[151] As of 9 p.m., April 13th, 2020,[18] there are a total of 659 positive COVID-19 cases and one death in the USAF, including military, civilian, dependent, and contractor personnel.[152]

Additionally, as of March 29th, the SMC is still reviewing bids from launch providers for NSSL Phase 2, which are still targeted to be awarded mid-2020. Lt. Gen. John Thompson, commander of the SMS, has mentioned that the transition to telework has not delayed source selection work, and that none of the launch providers have indicated an inability to continue with the procurement process.[153]

In the future months, it is highly likely that some programs, including the NSSL, might be affected or delayed by a variety of issues brought on by COVID-19. On the USG end alone, installations and agencies must adjust operations to adapt to the decreased number of in-person employees, cancelled meetings, and surge in telework. Depending on classification levels and security needs, certain projects might not be able to transition to telework or at-home work. According to a senior acquisition executive for the USAF, "space and nuclear weapons programs have significant classified components which means that discussions on these projects have to be conducted in buildings like the Pentagon where there are sensitive compartmented information facilities (SCIFs)."[154] If employees are asked to shelter in place, then there is no way for them to work in the SCIFs.

Another key component to consider are the launch teams, who are also taking extra precautions. According to Brig. Gen. Doug Schiess, "several hundred people are needed to support a launch, and some missions, like AEHF-6, require more range support than others."[155] The SpaceX Falcon 9 rocket requires around 200 people, while the Atlas V or Delta IV need over 300 people to support launches, numbers that include operators, weather personnel, safety personnel, and others.[156] Though Schiess said that he believes "we have to have a significant population within the operations folks to be sick to have a situation where it would impact our launches," the COVID-19 pandemic is new and its trajectory and impacts are still largely unknown.

As such, it will be critical to plan for and expect potential delays as COVID-19 impacts continue to mount, despite USSF assurance that the

[18] These numbers are updated periodically on the Air Force's COVID-19 page in addition to other updates about USAF operations. The Department of Defense has an overall DoD response timeline page that is updated daily as well. See Department of Defense, "Coronavirus: DoD Response," U.S. Department of Defense.

> launch schedule and procurement efforts for the NSSL program will proceed with minimal issue.[157]

Summary of Potential Gaps and Vulnerabilities

Technological challenges will remain even as innovation continues to produce newer and better products, so it is critical to have a proper framework for addressing those challenges rather than to focus on specific technological weaknesses. Another key issue to address is security as it relates to supply chains, cybersecurity, and operations. Defense acquisition overall has many weaknesses, which might not immediately impact the NSSL, but does pose a long-term issue.[158]

NSSL Program Adjustments

Given that the Atlas and Delta launch vehicles are being phased out, and that new launch systems are being solicited for the NSSL, the priority of the NSSL should be to maintain program security in order to best ensure that critical government payloads will be placed successfully with the same, if not higher, launch success rate as was provided by the Atlas and Delta launch vehicles. Security protocol should be applied to physical and supply chain security, communications and operational security, information security, and insider threats. Secondary priorities for the program should focus on decreasing complexity and bureaucratic inefficiencies in the defense acquisition process so that the government can access the best technology suited to its needs.

The NSSL Phase 2 LSP Performance Work Statement (PWS) (FA8811-19-R-0002), amended most recently as of December 20th, 2019, should be referenced to assess existing requirements and program measures and areas of possible adjustment. As defined by the FY19 Federal Acquisition Regulation[159] (FAR):

> (a) A Performance work statement (PWS) may be prepared by the Government or result from a Statement of objectives (SOO) prepared by the Government where the offeror proposes the PWS.
>
> (b) Agencies shall, to the maximum extent practicable –
>
>> (1) Describe the work in terms of the required results rather than either “how” the work is to be accomplished or the number of hours to be provided;
>>
>> (2) Enable assessment of work performance against measurable performance standards;
>>
>> (3) Rely on the use of measurable performance standards and financial incentives in a competitive environment to encourage competitors to develop and institute innovative and cost-effective methods of performing the work.

The NSSL Phase 2 LSP PWS specifically “defines the launch services (LS), mission integration (MI), mission-unique (MU), and level of effort (LOE) work the Contractor will perform for

National Security Space (NSS) missions. This PWS also defines Launch Service Support (LSS) work that will be performed annually, and fleet surveillance (FS) work that the Contractor will perform for each non-NSS mission. The PWS includes the Program Management, Systems Engineering, Launch Vehicle (LV) Production, Mission Integration, Mission Operations, and Support to Government Space Flight Worthiness (SFW), LOE Activities, and Mission-Unique Options necessary to deliver healthy Payloads (PL) into their intended orbits managed by Air Force Space Command, Space and Missile Systems Center (AFSPC/SMC)."[160]

i. Supply Chain Risk Management (SCRM)

Ensuring the security of supply chains and lowering possible risks will better enable launch vehicle providers to meet the goals stated in the Performance Work Statement.

a. DNI National Counterintelligence and Security Center

The DNI National Counterintelligence and Security Center works to assess and mitigate the activities of foreign intelligence entities and other adversaries who attempt to compromise the supply chains of our government and industry.[161] There are several reports, briefings, and readings that provide information and awareness regarding supply chain risk management.

b. National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) put out a publication in 2015 on "Supply Chain Risk Management Practices for Federal Information Systems and Organizations," which seeks to "provide guidance to federal agencies on identifying, assessing, and mitigating ICT supply chain risks at all levels of their organizations."[162] In detail, the report provides frameworks for multitiered organization-wide risk management and applications. As such, it provides an in-depth coverage that may be of assistance when looking at launch supply security measures and government contracting.

c. SECURE Technology Act – H.R. 7327[163]

The SECURE Technology Act "requires the Secretary of Homeland Security to establish a security vulnerability disclosure policy, to establish a bug bounty program for the Department of Homeland Security, to amend title 41, United States Code, to provide for Federal acquisition supply chain security, and for other purposes."[164]

Title II of the SECURE Technology Act, the Federal Acquisition Supply Chain Security Act of 2018, creates the Federal Acquisition Security Council (FASC); the FASC will develop criteria to assist departments and agencies in "determining the risk to the ICT supply chain, disseminating supply chain risk information, and deciding what action to take to mitigate the risk."[165] Each department and agency, which includes the USSF, will be required to have a SCRM program that meets these criteria. The goal of the FASC legislation is "to arm departments and agencies with the knowledge to assess their own supply chain risk, make more informed decisions to acquire and protect critical ICT components necessary for mission success."[166] Such practices can also be applied to contractor practices, including launch providers for the NSSL.

d. 13 Elements of an Effective SCRM Program

The NCSC 13 Elements of an Effective SCRM Program[167] provides a simplified and concise outline of objectives to pursue when setting up a SCRM. The thirteen elements are listed:

1. Obtain executive-level commitment to establish a SCRM program.
2. Communicate with all organizational stakeholders – horizontally and vertically.
3. Identify, assess, and prioritize critical assets, systems, processes, and suppliers.
4. Implement integrated risk reduction: identify, assess, prioritize, and implement measures to reduce risks to items delineated in no.3 above.
5. Elevate security as a primary metric, just like cost, schedule, and performance, for assessing a vendor's ability to meet contract requirements.
6. Conduct due diligence on suppliers at least through the first tier.
7. Monitor suppliers' adherence to agreed-upon SCRM-related security requirements.
8. Identify critical data and information about organization and customers.
9. Establish processes to share information with suppliers about vulnerabilities and vice versa.
10. Manage security risks when terminating relationships with suppliers.
11. Monitor effectiveness of established risk mitigating strategies; update as needed.
12. Train employees about managing, mitigating, and responding to supply chain risks.
13. Plan for contingency operations; exercise plans regularly, update as needed.

In conjunction with NIST publications and other NCSC materials, this framework is recommended as a course of action to take to better protect the NSSL program when it comes to launch provider supply chains. Additionally, this helps provide a general framework that can be used to guide the finer details in the Performance Work Statement to ensure all elements are covered.

Something of interest to consider is the use of performance-based functional availability (PFA) tools, which can be used to evaluate satellite failure risk. PFA models "can address risks at the piece-part level, such as suspect microelectronics as a function of reduced performance and likelihood of occurrence."[168] By factoring in technical risks and schedule slips and adjusting for launch schedules and reliability or performance models, the PFA tools can be used to compute constellation impact, user impact, enterprise impact, and resilience impact. As such, "once a PFA tool is established for a constellation, regenerating impact plots is quickly accomplished for any given technical risk or schedule slips allowing for direct comparisons at multiple impact levels."[169] Such tools can provide a way to deduce proper responses and decisions in the event of a compromised supply chain or other possible security concern, allowing for adjustments to be made for not just a single mission but also constellations and operations as a whole.

ii. Cybersecurity

Based on the GAO's High-Risk Series Study on cybersecurity challenges, there are ten critical actions that the federal government and other entities need to take to address the four major cybersecurity challenges.[170] The recommendations are listed based on which challenge they address:

1. Challenge: Establishing a comprehensive cybersecurity strategy and performing effective oversight.
    a. Develop and execute a more comprehensive federal strategy for national cybersecurity and global cyberspace.
    b. Mitigate global supply chain risks (e.g., installation of malicious software or hardware).
    c. Address cybersecurity workforce management challenges.
    d. Ensure the security of emerging technologies (e.g., artificial intelligence and the Internet of Things).
2. Challenge: Securing federal systems and information
    a. Improve implementation of government-wide cybersecurity initiatives.
    b. Address weaknesses in federal agency information security programs.
    c. Enhance the federal response to cyber incidents.
3. Challenge: Protecting cyber critical infrastructure.
    a. Strengthen the federal role in protecting the cybersecurity of critical infrastructure (e.g., electricity grid and telecommunications network).
4. Challenge: Protecting privacy and sensitive data.
    a. Improve federal efforts to protect privacy and sensitive data.
    b. Appropriately limit the collection and use of personal information and ensure that it is obtained with appropriate knowledge or consent.

Based on one of GAO's cybersecurity framework from 2004,[171] the NSSL should also incorporate these five points in tandem with the more recent 2018 framework:

1. Determine the business requirements for security;
2. Perform risk assessments;
3. Establish a security policy;
4. Implement a cybersecurity solution that includes people, processes, and technologies to mitigate identified security risks; and

5. Continuously monitor and manage security.

Because cybersecurity is so critical to ensuring the functions of the nation's infrastructure, adopting stronger protections and reducing risks will help better minimize security vulnerabilities across all areas of government functions. The NSSL would benefit significantly from heightened cybersecurity measures, since it carries out critical and often classified national security space missions. With more complex launch systems and increased automation, there will be both current and new vulnerabilities that need to be addressed. Cybersecurity will also be important for contractors and launch providers, especially since there is a lot of sensitive information that is being transferred daily, as well as personnel and teams that work on these missions and operations.

iii. Models for Safety Programs

The following programs have been highlighted as successful independent safety programs that have strived for and achieved accident-free performance.[172] As noted, "the safety cultures and organizational structure of all three make them highly adept in dealing with inordinately high risk by designing hardware and management systems that prevent seemingly inconsequential failures from leading to major accidents. Although size, complexity, and missions in these organizations and NASA differ (in the context of this paper, the NSSL as well), the following comparisons yield valuable lessons for the space agency to consider when re-designing its organization to increase safety."[173] Though the frameworks were outlined over 17 years ago, similar practices can be adapted and incorporated; relevant sections have been taken directly from the report.

a. U.S. Navy Submarine Flooding Prevention and Recovery (SUBSAFE)

SUBSAFE serves to verify the readiness and safety of submarines. Practices that have factored into the success of the program include:

i. SUBSAFE requirements are clearly documented and achievable, with minimal "tailoring" or granting of waivers.
ii. A separate compliance verification organization independently assess program management.
iii. The submarine Navy has a strong safety culture that emphasizes understanding and learning from past failures.
iv. The Navy implements extensive safety training based on the *Thresher*[19] and *Scorpion*[20] accidents.
v. The SUBSAFE structure is enhanced by the clarity, uniformity, and consistency of submarine safety requirements and responsibilities.

[19] The USS *Thresher* (SSN-593) sank after a possible piping failure during deep submergence tests off the New England coast and was declared lost at sea on April 10th, 1963. See U.S. Navy, "US Navy," Naval History and Heritage Command.
[20] The USS *Scorpion* (SSN-589) loss was not ascertainable, though potentially due to inadvertent activation of battery of torpedo resulting in a possible "hot run" torpedo detonation off Azores. Declared lost May 27th, 1968. See U.S. Navy, "US Navy," Naval History and Heritage Command.

Program managers are not permitted to “tailor” requirements without approval from the organization with final authority for technical requirements and the organization that verifies SUBSAFE’s compliance with critical design and process requirements.

vi. The SUBSAFE Program and implementing organization are relatively immune to budget pressures.

vii. Compliance with critical SUBSAFE design and process requirements is independently verified by a highly capable centralized organization that also “owns” the processes and monitors the program for compliance.

viii. Quantitative safety assessments in the Navy submarine program are deterministic rather than probabilistic.

b. Naval Nuclear Propulsion (Naval Reactor) Programs

The Naval Reactor Program is a joint Navy/Department of Energy organization responsible for all aspects of Navy nuclear propulsion, including research, design, construction, testing, training, operation, maintenance, and the disposition of the nuclear propulsion plants onboard many Naval ships and submarines, as well as their radioactive materials.[174]

The U.S. nuclear Navy has more than 5,500 reactor- years of experience without a reactor accident. Put another way, nuclear-powered warships have steamed a cumulative total of over 127 million miles, which is roughly equivalent to over 265 lunar roundtrips. In contrast, the Space Shuttle Program has spent about three years on-orbit, although its spacecraft have traveled some 430 million miles.[175]

In 2020 the numbers are significantly different for the varying space programs, but the nuclear Navy remains steadfast in its safety. In a DoE/Navy report from November 2015, the naval reactors maintained “an outstanding record of over 157 million miles safely steamed on nuclear power. The Program currently operates 96 operators and has accumulated over 6,700 reactor- years of operation.[176] The absence of radiological incidents is testament to the program’s success.

Key elements of the program can be grouped into several categories:

Communication and Action:

Formal and informal practices ensure that relevant personnel at all levels are informed of technical decisions and actions that affect their area of responsibility. Contractor technical recommendations and government actions are documented in peer-reviewed formal written correspondence. Unlike NASA, PowerPoint briefings and papers for technical seminars are not substitutes for completed staff work. In addition, contractors strive to provide recommendations based on a technical need, uninfluenced by headquarters or its representatives. Accordingly, division of responsibilities between the contractor and the Government remain clear, and a system of checks and balances is therefore inherent.

Recurring Training and Learning from Mistakes

The Naval Reactor Program has yet to experience a reactor accident. This success is partially a testament to design, but also due to relentless and innovative training, grounded on lessons learned both inside and outside the program. For example, since 1996, Naval Reactors has educated more than 5,000 Naval Nuclear Propulsion Program personnel on the lessons learned from the Challenger accident.

Encouraging Minority Opinions

The Naval Reactor Program encourages minority opinions and "bad news." Leaders continually emphasize that when no minority opinions are present, the responsibility for a thorough and critical examination falls to management. Alternate perspectives and critical questions are always encouraged.

Retaining Knowledge

Naval Reactors uses many mechanisms to ensure knowledge is retained. The Director serves a minimum eight-year term, and the program documents the history of the rationale for every technical requirement. Key personnel in Headquarters routinely rotate into field positions to remain unfamiliar with every aspect of operations, training, maintenance, development and the workforce. Current and past issues are discussed in open forum with the Director and immediate staff at "all-hands" informational meetings under an in-house professional development program.

Worst-Case Event Failures

Naval Reactors hazard analyses evaluate potential damage to the reactor plant, potential impact on people, and potential environmental impact.

c. Aerospace Corporation's Launch Verification Process

"The Aerospace Corporation, created in 1960, operates as a Federal Funded Research and Development Center that supports the government in science and technology that is critical to national security."[177]

"Aerospace's primary product is a formal verification letter to the Air Force Systems Program Office stating a vehicle has been independently verified as ready for launch. The verification includes an independent General Systems Engineering and Integration review of launch preparations Aerospace staff, a review of launch system design and payload integration, and a review of the adequacy of flight and ground hardware, software, and interfaces."

"This 'concept-to-orbit' process begins in the design requirements phase, continues through the formal verification to countdown and launch, and concludes with a post-flight evaluation of events with findings for subsequent missions. Aerospace Corporation personnel cover the depth and breadth of space disciplines, and the organization has its own integrated engineering analysis, laboratory, and test matrix capability."

Today, Aerospace continues to offer Launch Assurance as one of their several focus areas.[178] Most recently, Aerospace used its comprehensive launch verification process to assist with ULA's Atlas V AEHF-6 mission, which was the first successful NSSL launch under the new USSF.[179] Aerospace also successfully accommodated COVID-19 challenges and developed and implemented a highly distributed launch support concept of operations.[180] Extensive preparation and pre-coordination were key to ensuring the mission success.

As noted earlier, "spacecraft and submarines both operate in hazardous environments, use complex and dangerous systems, and perform missions of critical national significance."[181] Thus, of all three safety programs that were mentioned in the Columbia Accident Investigation Board report, the Naval Nuclear Propulsion Program offers the best framework for a potential safety or accountability program for the NSSL. The stakeholders are similar, with both government and private sector components. The Naval Nuclear Propulsion Program highlights the importance of communication between all parties and the need for knowledge-based decision making, both of which are critical components to the NSSL program, especially during the procurement phases. For the NSSL specifically, having another component within the agency (here, the USSF) to provide oversight and accountability could potentially provide added benefits of better mediating launch provider-government relations, while also providing more in-depth insight into commercial practices and how to best translate them for government contracting. Being able to learn from other agencies and successful contract programs is also important and having a program for the NSSL could help better collect and communicate institutional knowledge and areas for improvement and innovation. To supplement the launch processes for the NSSL, Aerospace Corporation's launch assurance should continue to be applied, especially when evaluating new launch vehicles.

Recommendations

I. Heighten supply chain security to ensure launch providers can provide assured and reliable access to space.

II. Heighten cybersecurity measures to help minimize security risks with information, communications, and operations, when transitioning towards an increasingly networked system.

III. Consider the use of PFA tools and models to evaluate not only satellite failure risk but also NSSL mission risk at multiple levels, with the goal of increasing preparedness and flexibility when addressing possible challenges.[21]

IV. Implement an accountability and oversight program for the NSSL to provide increased communication between all parties involved, standardize safe and efficient practices, and increase industry and institutional knowledge for better sustaining national security space launches.
   a. For Phase 2 and future Phase 3 launch vehicle procurement, continue using additional individual launch verification processes to ensure safety and capabilities of new launch systems.

Future Work

The NSSL is still in the middle of the Phase 2 procurement process, and many changes are likely to happen rapidly within the next few years. This paper will only cover events leading up to the beginning of April 2020. Depending on how the procurement progresses, new problems may surface, and others might become irrelevant. One key issue that will likely have a significant yet unknown impact is the COVID-19 pandemic, which has affected global activities and will likely continue to do so.

A significant point of interest is the GAO's 2017 "Adopting Best Practices Can Improve Innovation Investments and Management" report, which recommended that the DoD "define a science and technology management framework that uses leading commercial practices."[182] Because the DoD's ability to innovate is limited by its funding policies and Congressional funding in general, which do not offer longer-term project funding, it is difficult for the DoD and all agencies within to capitalize on best commercial practices and to harness cutting edge technology. This paper did not explore management frameworks or investment portfolios for the NSSL, so while Phase 2 is largely underway and cannot be changed significantly, Phase 3 is still upcoming in the future. As such, it would be interesting to see what research could be done on investment models and portfolios to better bring the NSSL program longevity, flexibility, and adaptability when it comes to harnessing commercial launch providers.

More research on cybersecurity measures will also likely be necessary in the future; as launch vehicles and systems become increasingly more networked and automated, there will be an even higher demand for protecting those critical infrastructures. Cybersecurity covers a wide range of essential aspects, including classified information, missions, operations, proprietary hardware and software, etc. Once specific launch vehicles are selected for the NSSL, more directed cybersecurity measures could be considered for ensuring the continued success of national security space missions.

[21] See PFA tools mention under Supply Chain Security section.

Concluding Thoughts

The National Security Space Launch program, formerly known as the Evolved Expendable Launch Vehicle program, has undergone a number of changes in the past few years and will continue to witness developments as the NSSL Phase 2 Launch Procurement continues. Out of launch providers Blue Origin, SpaceX, Northrop Grumman, and United Launch Alliance, two will be selected to carry out the national security space missions starting from 2022. The goal is to maintain program security so that the NSSL can continue to deliver critical national security payloads to space at the same standards, if not higher, as that of the current NSSL fleet. Policy goals outline a general trend towards maintaining assured access to space as well as increasing space capabilities. There is also the desire to secure the United States' space presence at a time when more parties are becoming involved in the space sector, especially as orbits become increasingly crowded. As such, the recommendations are aimed at addressing key vulnerabilities that might weaken the NSSL program's ability to carry out missions. Prioritizing supply chain security and cybersecurity will best ensure the success of transitioning to new launch vehicles, though it is also critical to maintain existing safety protocols and mission operations. A secondary focus on streamlining defense acquisition seeks to address program flexibility and readiness in the long term but is more relevant to the future Phase 3 Procurement efforts. It therefore becomes even more critical to leverage institutional memory and knowledge in tandem with the industry's current practices in order to enable the NSSL to best fulfill its goals of procuring affordable NSSL services, maintain assured access to space, and ensure mission success with domestic launch service providers. Looking forward, defense acquisition as a whole will need to adjust and adapt to the pace of the modern world, and the NSSL too will continue to change.

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