CENTER FOR SPACE POLICY AND STRATEGY

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POLICY COMPLIANCE ROADMAP FOR SMALL SATELLITES

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AEROSPACE

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Summary

This paper explores U.S. space policies and how they apply to satellite missions that may not fit the typical satellite mission mold. It presents a policy compliance "roadmap" for satellites from diverse agencies and identifies areas where further work is underway to address the challenges posed by the evolution of the space industry. Also, it lays out a coherent way forward for all small satellites navigating the approval quagmire and for mission managers of multi-payload rideshares who wish to smooth the path to launch approval.

Introduction

In the early days of satellite development and launch, only governments or government contractors built satellites and rockets, and, generally, each launch carried only a single payload (typically a satellite) to orbit. Today, the space enterprise encompasses many players and stakeholders, including small businesses, universities, affinity organizations, and even primary schools. In addition, the proliferation of small satellites (or "smallsats") has led to large numbers of new entrants into the space business. This has increased the number of rideshares and a paradigm where a single launch carrying a single mission or payload to space is no longer the norm.

The Aerospace Corporation supports a diverse customer base and has insight into policy issues across multiple agencies and departments, allowing us to understand policy applicability and identify policy "boundaries" that exist. This paper explores U.S. space policies and how they apply to satellite missions that may not fit the "typical" mold on launch missions that may not have a single responsible agency. Where applicable, we have outlined the processes and approvals involved in getting to space. In addition, we have identified where further work is required to fill in policy gaps and "gray areas" in the overall policy picture.

Like the space industry itself, policy is constantly evolving. While we have tried to capture the current "policy roadmap" as accurately as possible, we welcome corrections and updates from the community as the picture comes into better focus.

This paper does not cover U.S. export control regulations. For more information on this subject, we recommend reviewing the *Introduction to U.S. Export Controls for the Commercial Space Industry*, 2nd Edition, prepared by the U.S. Department of Commerce's Office of Space Commerce and the Federal Aviation Administration's Office of Commercial Space Transportation.*

*The document can be found at https://www.space.commerce.gov/wp-content/uploads/2017-export-controls-guidebook.pdf.

International Treaties and U.S. National Policy and Regulations

The Outer Space Treaty of 1967 forms the basis of international space law and stipulates that the signatories "shall be responsible for national space activities whether carried out by governmental or non-governmental agencies."[1,2] It places the responsibility for operations in space on the government of the nations that fly in space and requires "authorization and continuing supervision" by that government. In the Outer Space Treaty, a nation "on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object…." This implies that the U.S. government has responsibility for U.S.-owned objects in space, regardless of whether that object is launched by the United States or by a foreign launch provider. Similarly, foreign satellites remain the property of foreign entities, even if launched from a U.S. rocket. While the Outer Space Treaty places joint liability for damage on the country "from whose territory or facility a space object is launched" as well as the country that procured the launch. This liability is only absolute for damages on Earth and to aircraft in flight. For damages in space, the launching country shall be liable "only if damage is due to its fault or the fault of persons for whom it is responsible"; in other words, only if the damage is due to the launching country's negligence or malicious intent.

The *National Space Policy of the United States of America*[3] also directs safe and responsible operations in space. Specific sections discuss protection of the space environment (including debris mitigation) and protection of the electromagnetic spectrum. The National Space Policy also discusses cybersecurity for U.S. space systems, which flows into lower-level guidance on cryptographic protection of space systems. Similarly, the National Space Transportation Policy[4] outlines the military, civil, and commercial launch oversight authorities. Military oversight is provided by the Department of Defense (DOD), while civil oversight is provided by the National Aeronautics and Space Administration (NASA). Commercial space transportation oversight is under the Secretary of Transportation; thus, commercial launches are licensed by the Federal Aviation Administration (FAA). These policies are often subject to change and reinterpretation based on current U.S. political leadership. The Federal Communication Commission (FCC) adopts regulations and authorizes almost all commercial space operations, including launches, space exploration, and proximity operations. It also regulates services and market access.

The Responsibilities of the Launch Provider Versus Satellite Owner

The *National Space Transportation Policy* is a document that, true to its name, mainly discusses access to space in the form of launches rather than operations in space once satellites have separated from the launch vehicle. Similarly, most of the lower-level policies (those derived from the document) demarcate the responsibilities of the launch provider and the responsibility of the spacecraft owner/operator at the point where the spacecraft separates from the launch vehicle or its upper stage.

In other words, the launching agency is responsible for launch policy and is generally not the policy gatekeeper for the satellites it launches. Without the ability or authority to enforce policy throughout the satellite's orbital lifetime, the launching agency cannot ensure compliance. Instead, compliance must be enforced through the parent agency of the satellite owner/operator. Thus, a NASA satellite launched on a DOD rocket must comply with NASA policy, not DOD policy. Similarly, a DOD satellite on a commercial launch must still demonstrate compliance with DOD policy, not commercial policy.

Figure 1 illustrates the general responsibilities of mission partners on a launch mission, and Figure 2 illustrates in more detail how these policy responsibilities break down for a sample multi-payload mission.

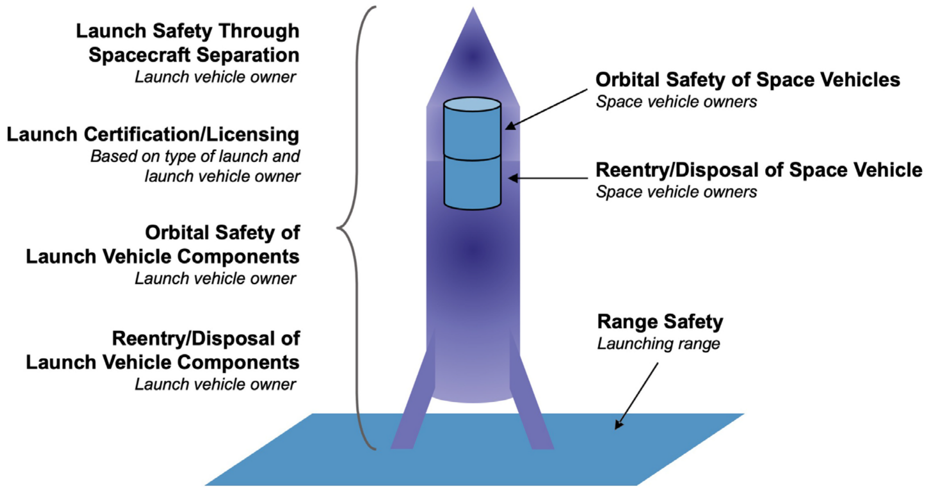

Figure 1: Policy Compliance and Safety Responsibilities for Launch Missions.

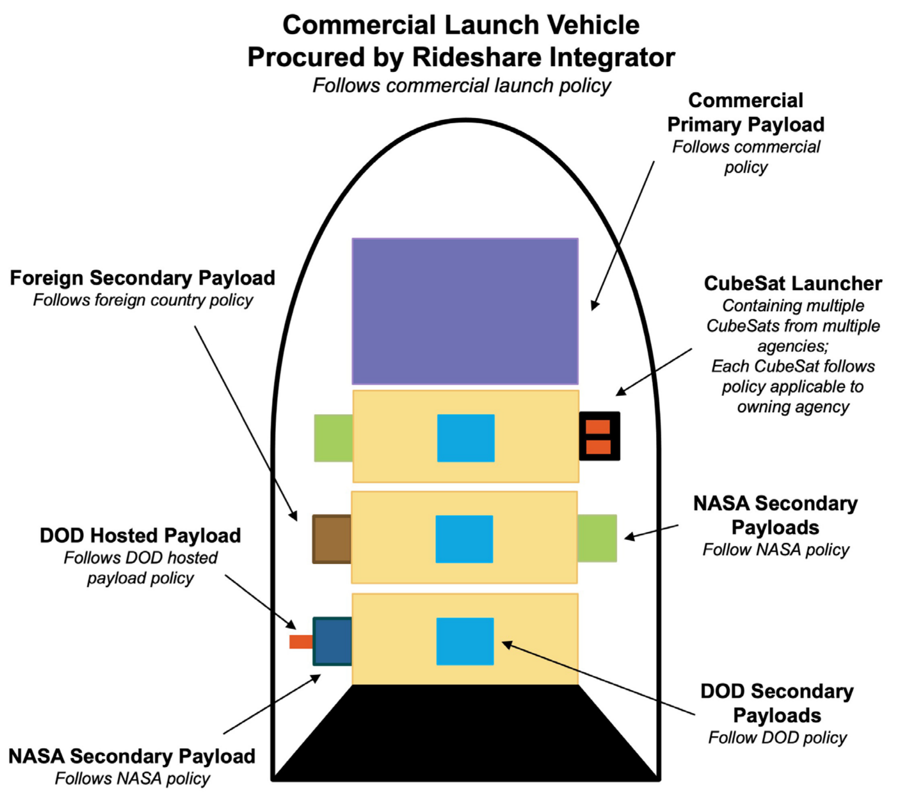

Figure 2: Rideshare Policy Compliance for Multiple Payloads.

While this demarcation provides a convenient boundary for separating the responsibility of the launching agency from the responsibility of the satellite provider, in practice, the line is less clear-cut. Recent events[5] illustrate the hazards of a launch provider, leaving regulatory compliance entirely up to the satellite provider. Even though these satellites are no longer necessarily under the authority or direction of the launching agency once launched, U.S. launch providers have a strong incentive to ensure all pre-launch approvals are in place. Most launch providers now require documentation of satellite policy compliance before satellites are integrated for launch. At the beginning of a mission, it is essential to clarify this demarcation and the proper policy compliance responsibilities for all satellite provider partners. The launching agency may still "refuse service" for a satellite that does not meet specific requirements, even if those stipulations are not required by any policy outlined by any government entity.

Special Consideration for Foreign Launch of U.S. Government Small Satellites

The emergence of new commercial companies that provide launch services for small satellites has led to questions about the suitability of these launch providers for U.S. government missions. Many of these launch providers are subsidiaries of foreign companies or maintain launch sites in foreign countries. Because a body of policy and law requires U.S. government satellites to be launched on U.S. launch providers, a determination specifically for these companies is required. This is a significant requirement that spacecraft operators must plan for far in advance to comply with them.

Several U.S. laws and policies require launch vehicles for U.S. government satellites to be manufactured in the United States.[3,4,6,7,8] These laws and policy statements establish a two-part test to determine if a launch vehicle is manufactured in the United States and, thus, allowed to launch U.S. government satellites. The two tests are:

1. Is the launch vehicle company more than 50 percent owned by U.S. nationals? (Required by Title 51 of U.S. Code and Department of Defense Instruction 3100.12)

2. Are 50 percent or more of the launch vehicle components, by cost, manufactured in the United States? (Required by Title 41 of U.S. Code and the National Space Transportation Policy)

Most government launch agreements are also subject to the Federal Acquisition Regulations. Part 52.225-18 of the Federal Acquisition Regulations also defines the "place of manufacture" as "the place where an end product is assembled out of components." This language appears to establish a third test to determine if a launch vehicle is manufactured in the United States; namely, is the product assembled out of components in the United States? However, in August 2018, the Deputy Secretary of Defense issued a memo confirming that the two-part test was sufficient. The government typically buys a launch service (the delivery to orbit), not the launch vehicle itself. In these cases, the government does not take possession of the launch vehicle, and, therefore, the launch vehicle is not an "end product" as defined by the Federal Acquisition Regulations. The launch itself is the end product. Recently, the DOD has launched several small satellites from new commercial providers using non-U.S. launch sites, as a new normal.[5] This was done showing that some of the emerging providers meet the two-part test.

The recently released 2020 National Space Policy does appear to give new direction on government technology demonstrations or scientific payloads being allowed to fly on foreign launches,[3] possibly allowing these payloads to bypass the two-part test, but it is too early to see how this change will be implemented.

What Constitutes Ownership?

Determining the parent agency of the satellite is critical to understanding the applicability of U.S. space policy. The flowchart shown in Figure 3, developed in partnership with the DOD Space Test Program (STP) and Air Force Research Laboratory (AFRL), illustrates a method for determining satellite ownership. The key consideration is "Who will have control authority over the satellite (or payload) once it launches?" Another, more direct, way to ask the question is "Who has the authority to decide when to execute the satellite's end-of-life or deorbit procedure?" If the DOD makes the decisions for all critical spacecraft activities after launch (commonly referred to as *Satellite Control Authority*), it is a DOD satellite, regardless of whether it is built or operated by a private company. Similar rules apply to NASA satellites, with the additional stipulation that NASA contracts and NASA grant recipients are also considered NASA satellites.

When using Figure 3, often the most reliable determinator of who "owns" a component or instrument is by looking to the source that provided funds to include the device or system on the spacecraft. Often, the funding body will be considered the liable owner or specify in its funding contracts who the owner of or otherwise responsible party for said device or system is.

However, some satellites, systems, components, instruments, and other payloads still fall into gray areas. For example, STP frequently arranges to launch private university or small business satellites sponsored by military sponsoring agencies to the DOD Space Experiments Review Board (SERB). Some of these university or small business satellites also receive small grants from the DOD. Although sponsored by the DOD, ownership of the vehicle and Satellite Control Authority remain with the universities. These organizations are private entities, and, therefore, such payloads currently follow a commercial path to comply with policy regulations, not a DOD path.

Other "special cases," include civil government satellites that are non-DOD, non-NASA satellites such as those belonging to National Oceanic and Atmospheric Administration (NOAA). Later sections also discuss the special case of DOD satellites that are not national security space satellites, as these highlight other policy gray areas that require further clarification. However, sometimes gray areas exist to provide policy and decisionmakers with sufficient option space to accommodate new types of missions.

Once the owning organization is identified, the appropriate policies can also be identified. For example, the DOD, National Telecommunications and Information Administration (NTIA), NOAA, NASA, the FAA, and the FCC all have broad policy directives or regulations that flow down from the National Space Policy; these are discussed in more detail in the applicable sections of this paper.

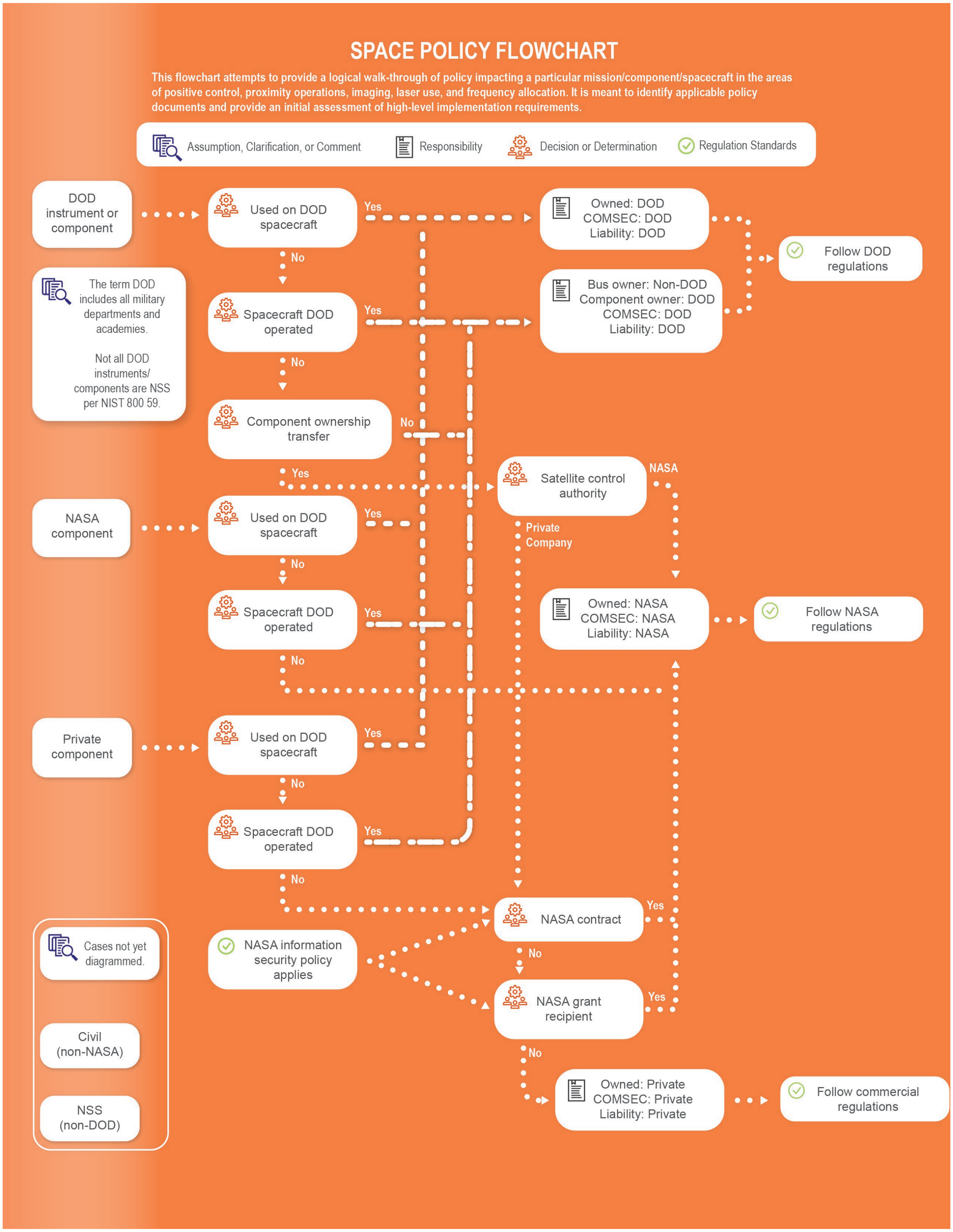

Figure 3: Flowchart for Determining Space Vehicle Ownership.

Orbital Debris Policy

National Policy

As described above, the U.S. National Space Policy calls for protecting the space environment from orbital debris. Specifically, one of the *Cross-sector Guidelines* directs compliance with U.S. Orbital Debris Mitigation Standard Practices (ODMSP)[9] and requires "the head of the sponsoring department or agency" for space missions to approve exceptions.

The ODMSP is outlined in a document of the same name last updated in November 2019. The updated document begins with a preamble that provides an overview of the updates and discusses the motivation behind them. The first four technical sections govern debris generation, accidental explosion, minimizing the risk of collision with other objects, and disposal of space objects at the end of mission life. A new fifth section discusses special cases of space operations, including large constellations, small satellites, rendezvous and proximity operations, active debris removal, and tether systems.

The ODMSP is the source of most of the debris requirements familiar to experienced satellite developers: disposal within 25 years of the end of the mission for low Earth orbit (LEO) satellites; reentering space objects will not cause casualties on Earth; and a limit on the potential for in-space collision, debris generation, and accidental explosion. The 2019 update adds several numerical guidelines to the general recommendations, including a 1-in-1000 limit on the probability of accidental explosions, a 1-in-1000 limit on the lifetime probability of collisions with objects greater than 1 cm, and a 1-in-100 limit on the lifetime probability of collisions with objects less than 1 cm that could interfere with post-mission disposal. The new ODMSP also provides extensive guidance on post-mission disposal options and orbits and stipulates that any post-mission disposal maneuvers have at least a 90 percent chance of success. The 25-year time limit on atmospheric reentry is unchanged, but the new ODMSP encourages small satellites to have orbital lifetimes "as short as practicable." The new fifth section of the ODMSP calls attention to constellations and small satellites (as well as tether systems, rendezvous and proximity operations, and active debris removal) but does not levy any additional requirements beyond those levied in the previous four sections.

Because these guidelines are national, they apply to all U.S. missions. Exceptions and waivers to the ODMSP typically require approval at high levels and are increasingly difficult to obtain.

NASA Policy

NASA documents its orbital debris mitigation requirements in NPR 8715.6B*, NASA Procedural Requirements for Limiting Orbital Debrisk*[10], and NASA-STD-8719.14A*, Process for Limiting Orbital Debri*s[11]. In this last document, we find specific numeric limits to the probability of in-space collision, which mirror those included in the 2019 ODMSP. The document lists other detailed requirements for compliance with ODMSP and requires documentation of compliance in an orbital debris assessment report (ODAR) and an end-of-mission plan (EOMP). The report and plan are approved through NASA channels, and exceptions flowed up through the NASA Office of Safety and Mission Assurance (OSMA). It is worth noting that the NOAA satellites also follow NASA debris mitigation requirements.[12]

NASA has also recently issued two documents governing conjunction assessment and collision avoidance. NASA Interim Directive 7120.132, *Collision Avoidance for Space Environment Protection*[13], outlines procedures for assessing and responding to the conjunction risk posed by debris and other space objects. It asks missions to document their collision avoidance practices in an orbital collision avoidance plan and, for the first time, provides guidance on thresholds for collision avoidance, suggesting teams maneuver at a probability of collision threshold of 1×10^{-4} (one in ten thousand). NASA has also released the *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook*[14], providing high-level guidance to missions.

DOD Policy

DOD Directive 3100.10, *Space Policy,* states that the "DoD will promote the responsible, peaceful, and safe use of space, including following the U.S. Government (USG) Orbital Debris Mitigation Standard Practices."[15] Department of Defense Instruction 3100.12, *Space Support,* requires that DOD missions comply with debris mitigation practices that echo the ODMSP.[7] The Air Force has implemented these two directives in several Air Force instructions, including Air Force Instruction 91-202, *The US Air Force Mishap Prevention Program*[16]. The 2020 version of Air Force Instruction 91-202 incorporates the space safety requirements formerly captured in the now-obsolete Air Force Instruction 91-217. The space safety requirements in Air Force Instruction 91-202 are similar to those in the NASA *Process for Limiting Orbital Debris*. In addition, the Air Force and Space Force record their compliance in two documents: the space debris assessment report for launch vehicles and the combined space debris assessment report/end-of-life plan for space vehicles. The format of these documents is essentially the same as the NASA orbital debris assessment report/end-of-mission plan. The Army and the Navy have relatively informal coordination processes for implementing DOD Directive 3100.10. At this time, the U.S. Space Force reports through the U.S. Air Force on policy matters related to space, and compliance processes have not yet changed to reflect the standup of the new service.

FCC Policy

Commercial satellites, defined in this case as any satellite not owned or operated by the U.S. federal government, do not fall under any of the NASA and DOD policies but must still comply with national orbital debris mitigation guidelines. The FCC currently enforces this compliance through its regulation of the nonfederal use of the radio spectrum. Title 47 of the *Code of Federal Regulations*[17] requires applicants for frequency licenses to provide information on their orbits and their plans for orbital debris mitigation. FCC regulations also require the use of disposal options and the safe management of pressure vessels at the end of life. Many commercial satellite operators use NASA's orbital debris assessment report format to document their orbital debris mitigation compliance when applying to the FCC.[18,19,20]

In October 2018, the FCC issued a Notice of Proposed Rulemaking to update and expand its orbital debris regulations, outlining several potential changes to the FCC's regulations.[21] Although many of the proposed rules were compatible with the new ODMSP, many differed from it. In addition, the FCC proposed rules required maneuverability above a certain altitude in LEO, a new performance bond requirement for successful disposal post-mission, and a new indemnification requirement. Following a comment and review period, the FCC published a final set of rules on August 25, 2020, and deferred some of the more contentious issues into a Further Notice of Proposed Rulemaking.[22] The topics being tabled for further review include maneuverability above a certain altitude in LEO, post-mission orbital lifetime, indemnification, and the requirement for a performance bond for successful disposal. At the time of this paper's writing, the FCC is reviewing comments from the Further Notice of Proposed Rulemaking.

FAA Policy

The FAA licenses launch and reentry operations for nongovernment launches from U.S. soil or conducted by U.S. companies or citizens. Contrary to popular belief, it does not currently oversee or regulate satellites or activities in space. FAA regulations levy safety requirements on nongovernment launch vehicles, including limiting the potential for debris generation and accidental explosions and, for reentry vehicles, limiting the potential for human casualties on the ground. The FAA, however, does not regulate the disposal of orbiting upper stages unless they plan to land on or impact Earth.[23]

Policy Compliance Process

Once the owning/operating agency for a satellite is known (see Figure 3), that agency must demonstrate compliance with its parent agency's orbital debris mitigation policy. For NASA, this involves the preparation and submittal of an orbital debris assessment report (ODAR) and end-of-mission plan (EMP) per the NASA *Process for Limiting Orbital Debris*. The process is similar for Air Force and Space Force missions, which require completion of a space debris assessment report (SDAR) and end-of-life plan per Air Force Instruction 91-202. Missions without defined processes or formats for debris compliance should consider using the NASA ODAR as the template for demonstrating compliance with the higher policy. This seems to be the practice for private satellites when requesting licenses from the FCC. Launch vehicles should follow the FAA process through the "end of launch," defined by the FAA as the last exercise of control over the launch vehicle. It is important to note that exceptions to *Orbital Debris Mitigation Standard Practice* guidelines require approval at high levels, typically the head of the sponsoring department or agency. Such waivers are increasingly difficult and time-consuming to obtain, suggesting that satellite missions should conduct the

Ambiguity, Open Questions, and Recommendations

Orbital Debris Policy

The guidelines in the ODMSP represent one of the more well-known and universally accepted aspects of space policy, but policy gaps still exist. One of the biggest open questions is whether the FCC should be the agency to enforce orbital debris mitigation policy on the burgeoning commercial and private satellite business. The exponential growth and danger in this area may call for new authorities with greater focus to take responsibility for orbital debris mitigation.

Several items in the FCC's recent *Further Notice of Proposed Rulemaking* are concerning to many of the different types of small satellite developers (commercial, academic, etc.). Most of the small satellites and CubeSats to date have lacked significant propulsion capabilities; requiring all missions above 400 km to be capable of collision avoidance maneuvers would drive significant design changes, cost increases, and, perhaps, other unforeseen consequences. One of those concerns is linked to small satellites also lacking robust security and command authentication systems. The proliferation of smallsats with propulsion but no encryption could pose a security concern. From a research and innovation perspective, requiring satellites to provide insurance, indemnification, or bonds against successful disposal will add an additional barrier to entry for new commercial ventures and academic programs that do not have the budget to do so.

The lack of specific requirements for orbiting upper stages for non-DOD or NASA launches is a gap that policymakers must ultimately address. Currently, the FCC's proposed rules in this area differ from several elements of the ODMSP without substantial documented justification. The industry is seeking a "whole of government approach" and is pushing back on the FCC's more subjective approaches.[24]

required analyses early to allow time for design changes or waiver approvals, as needed.

Spectrum Usage

Summary of Applicable Policy

Public law and regulations, rather than policy, provide all guidance for the assignment and usage of spectrum for satellites. The NTIA regulates frequency usage for federal agencies such as NASA and the DOD. The NTIA documents its rules and procedures in the *Manual of Regulations and Procedures for Federal Radio Frequency Management*[25].

Through Title 47, the FCC licenses frequency use for "non-federal agencies," including private and commercial satellites. Part 25 contains commercial and remote-sensing satellite communication regulations, Part 5 covers experimental licensing, and Part 97 covers amateur communications.[25] In 2019, the FCC adopted new streamlined regulations, *Licensing Procedures for Small Satellites (Report and Order) IB Docket 18-86*, to better support the small satellite industry.[26]

The FCC also serves as the United States' "notifying administration" to the International Telecommunication Union (ITU). As such, it acts as the "mailbox" for all coordination and registration correspondence to the ITU, including for federal systems. The ITU is the United Nations' "specialized agency" for telecommunications, including the international management of radiofrequency spectrum and orbital resources. The ITU has limited enforcement authority, but its 193 Member States may participate in World Radiocommunication Conferences (WRCs), a treaty conference convened every three-to-four years to revise the ITU's *Radio Regulations*[27]. Following each WRC, Member States integrate the new provisions of the *Radio Regulations* into their domestic regulations.

Policy Compliance Process

The NTIA is located within the Department of Commerce (DOC) and is the agency responsible for managing the "federal use" of the spectrum. Instructions for filing are laid out in the *Manual of Regulations and Procedures for Federal Radio Frequency Management*. The NTIA does not grant a frequency license but instead grants the authority to use a frequency. The Frequency Assignment Subcommittee within the NTIA coordinates and assigns radio frequencies. NASA programs work their submission through the individual center's spectrum management office and then through the NASA spectrum management office. The NASA spectrum management office then submits paperwork to the NTIA. DOD-owned missions submit through service-level spectrum management offices, which submit to the NTIA.

There are four filing stages for federal programs: (1) conceptual, (2) experimental, (3) developmental, and (4) operational. Each is explained in detail in section 10.4.1 of the NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management*[25]. Most small satellites performing science and technology, or research and development, missions will obtain a Stage 2 experimental license. As the name indicates, operational satellites will obtain a Stage 4 operational license. Unlike the FCC, there is no requirement to conduct debris or lifetime analysis when applying to the NTIA.

The FCC is an independent U.S. government agency (overseen by Congress) that regulates interstate and international communications by radio, television, wire, satellite, and cable. Part 25 of Title 47, *Telecommunications*, in the *Code of Federal Regulations* outlines the application and filing process.[17] Most noncommercial small satellite missions will submit applications under the amateur (Part 97) or experimental (Part 5) rules. These options provide access to different frequency bands and have different requirements and limitations.

Note that authority under Part 97 is not a license for a smallsats but, rather, a permit that allows a licensed amateur radio operator (a "ham") to operate a space station (defined as being more than 50 km above Earth's surface). There are neither application nor ITU recovery fees for this type of authorization.[26] Access to frequencies allocated to the amateur satellite service is limited to amateur-related services and may not include communications in which the licensee or operator has a pecuniary interest, including communications on behalf of an employer. Additionally, for any use of amateur frequencies, missions must coordinate with the International Amateur Radio Union (IARU) and include that information in the package to the FCC. Experimental license applicants may select from a broad range of frequencies, but they are limited to noncommercial missions, receive no regulatory status, and are typically limited to two-year license terms. In both instances, the FCC suggests that missions file no later than 30 days after the launch has been identified.

Eligibility for a Part 5 experimental license is limited to "experimentation under contractual agreement with the United States Government, and [for] communications essential to a research project."[26] Note that Part 5 specifies that spectrum is not limited to satellite use and is shared with many other experimental users. Experimental licenses are granted on a noninterference basis, and they may neither cause interference nor claim protection from interference.[26]

Missions filing with the FCC must demonstrate compliance with the debris mitigation guidelines (CFR 47 25.114d(14)),[17] as described in the orbital

Ambiguity, Open Questions, and Recommendations

Spectrum Usage

There is strict protection of the amateur frequencies from use by experimental or federal programs. This has led to some confusion in the community as to the ability to use amateur bands, particularly since, until recently, experimental or federally connected programs regularly used amateur bands. Determination has to be made whether missions that have previously used amateur bands now need to go through the FCC for an experimental frequency or through the NTIA, especially those missions run by service academies.

Additionally, there is often confusion for programs that fall into "gray areas." For example, a university-owned and -operated satellite that receives funding from the DOD and launches on a DOD launch vehicle remains a private satellite but is sometimes directed to the NTIA for frequency approval. Occasionally, missions get different answers from the FCC and the NTIA. The future will probably bring more of these "gray area" missions, so it might be advantageous to stand up a single office at some point in time for frequency submittals. That office could then route the approvals to either the FCC or the NTIA, as appropriate to each mission.

Since the FCC updated its rules, the FCC does not specifically refer to ODMSP, though FCC rules still partially follow the ODMSP. Theoretically, there could be a regulatory mismatch between the ODMSP and the FCC rules, which could lead to loopholes or gray areas in debris mitigation requirements. If a satellite also must obtain a NOAA imaging license, which still requires compliance with ODMSP, there could be further confusion as to what debris mitigation requirements apply and who provides approval.

debris section of this paper and with other requirements specified by the FCC that go beyond the ODMSP. In addition, missions must show that they adhere to debris generation guidelines, deorbit within 25 years of end of life or move to a disposal orbit, and expect zero casualties when reentering. If missions cannot demonstrate this satisfactorily to the FCC, they may be required to carry insurance or risk not being approved to broadcast.

When frequency usage and the international coordination process are concluded as required by the ITU's *Radio Regulations*, the operator submits its frequency assignments to the FCC liaison who files the United States' assignments to the ITU for recording in the Master International Frequency Register. Getting a license or approval to use a frequency through either agency and completing the ITU's coordination process takes from months to years, so missions should start working on the application and submittal as early as possible. The regulatory changes for small satellites by WRC-15 are contained in the *Final Acts of the Conference* and the *Radio Regulations*[27].

Optical Communication (LASERCOM)

Summary of Applicable Policy

Free-space optical (FSO) communication refers to the transmission of modulated light pulses through free space (vacuum or the atmosphere) to wirelessly transmit data for telecommunications or computer networking. The use of lasers for communication is often referred to as *lasercom*. Communication may be entirely in space (an intersatellite link) or be a ground-to-satellite or satellite-to-ground link. The technology has been increasing in popularity both due to the potential for high bandwidth and due to the limited availability of radiofrequency spectrum allocation.[28]

FSO as a form of communication in the optical spectrum (typically considered greater than 3 THz) is not heavily regulated. The rationale is that emitters in the optical and near-infrared band have extremely narrow beamwidth and that space is vast, so the potential for harm is low. Nevertheless, to reduce the possibility of DOD laser projects accidentally damaging satellites, the Laser Clearinghouse (LCH) was established to ensure lasers do not negatively impact orbital assets. The LCH is tasked with providing predictive avoidance analysis and deconfliction with U.S., allied satellites, and operations for projects that utilize lasers.

Additionally, visible and infrared lasers have great potential for damage to the human eye. In the United States, the FAA regulates commercial terrestrial FSO links to prevent distraction or damage to the eyesight of airline pilots.

Policy Compliance Process

The FAA regulates terrestrial laser communications in the United States for commercial applications. Therefore, any FSO link transmitting through "navigable airspace" requires coordination with the FAA. The laser operator must submit a "Notice of Proposed Outdoor Laser Operation(s)" form found in FAA Advisory Circular (AC) 70-1B, *Outdoor Laser Operations*, along with any supporting documents. Based on that information, the FAA will issue a "Letter of Non-Objection" if it is determined that the laser system in question either poses no hazard to aircraft or that all hazards have been adequately mitigated. Otherwise, a "Letter of Objection" will be issued. This means the laser will not be allowed to operate as described, and more mitigation methods may be required before a Letter of Non-Objection is provided.

Chapter 29 of FAA Order Job Order (JO) 7400.2M, *Procedures for Handling Airspace Matters,"* contains policy, responsibilities, and guidelines for processing the notice and determining the potential effect of outdoor laser activities.[29] Compliance practices are based on standards ANSI Z136.1, *American National Standard for Safe Use of*

Lasers[30] and ANSI Z136.6, *American National Standard for Safe Use of Lasers Outdoors*[31].

For non-DOD users, ANSI Z136.6 advises that lasers with a divergence less than 10 µrad or exceed a peak irradiance greater than 1 W/cm^2 above 18 km (60,000 ft) in altitude above sea level should contact LCH for screening. This screening is not required by law but still has a very high likelihood of being required by the FAA to obtain a Letter of Non-Objection.[32]

DOD/The Laser Clearinghouse

All DOD-run or funded laser programs operating to, in, though, or from space or which are aimed above the horizon are required to conform its operations to DOD Instruction 3100.11, *Management of Laser Illumination of Objects in Space*[33], and CJCSI 3225.01, *Procedures for Management of Illumination of Objects in Space*[32]. These specify that all DOD and DOD-funded missions must coordinate with the LCH. The LCH is operated under the U.S. Space Command but coordinates with the FAA regularly.

The first step in initiating the LCH's laser registration process is for the laser operator to submit the Laser Registration Form found on the LCH website (www.space-track.org), alongside Instruction 3100.11 and CJCSI 3225.01, which outlines all relevant laser requirements and processes. Next, laser operators will be required to submit their planned laser sources, targets, and planned times of operation using LCH-provided document templates found on space-track.org. Depending on the results of the LCH's risk assessments, each laser program will be assigned a laser activity category based on criteria defined in CJCSI 3225.01. The LCH might request that the laser operator proceed with a "normalization" process prior to categorization, including changing the operating plans and system parameters.

For the next step, LCH reviews the form and provides a deterministic risk analysis, which indicates whether the laser's operation poses a threat to any space objects of interest. If the laser system is found not capable of posing a threat, it will be

Ambiguity, Open Questions, and Recommendations

Optical Communication (LASERCOM)

Laser communications are becoming increasingly popular for space-to-ground and space-to-space communications links, and many proliferated LEO constellations are implementing or considering laser communications links. The paradigm where each laser shot is individually coordinated and cleared with either the FAA or the LCH is unlikely to be scalable to proliferated laser communications. Owners may need to ensure their lasers are low enough power to be exempt or the coordination process may need to be automated. Future satellite systems may also need to ensure they are unlikely to be damaged by lasers beneath a certain power, as deconfliction will be cumbersome.

Policy guidelines may need to be negotiated between the FAA and LCH as space-to-ground communications systems become more common. The FAA traditionally deconflicts laser use only with airlines, and commercial providers are not required to coordinate with the LCH. In the future, the FAA may need to take on more responsibility for commercial laser communications to space. Alternatively, the FCC might ultimately decide to regulate the optical spectrum as it does the radiofrequency spectrum—though the regulation of the optical spectrum is likely to focus on the prevention of damage, rather than the deconfliction of frequencies. Although it is important to note that the FCC does not "currently" have jurisdiction over lasers and the legality of them claiming authority is not settled.

assigned as a "Category I: No Risk Result" and be found exempt from LCH oversight. In this case, no further coordination with LCH is required, and the owner/operator of the laser communication system can operate freely without communication with the LCH but must re-register with the LCH annually.

However, if a project's laser has the "potential" to damage a space object of interest to the LCH, it will not be given a Category I designation, and the LCH will then conduct a probabilistic risk assessment to determine whether the laser system will pose a risk to space objects of interest during its nominal operation. If it is determined that the laser's activities, when conducted from its specified location, are found to pose no greater risk to space activities than other nominal risks, as defined by the LCH, it will be assigned as a "Category II: Nominal Risk Result." In this case, the laser operator is only required to notify the LCH (through a method LCH determines) when it is in use. The LCH will not require any further coordination for this category unless the operator will be deliberately targeting a space object of interest. Note that if a system operates within the constraints of a "Special Use Space Range" as defined by the U.S. Space Command, it will be assigned a Category II.

If the LCH's probabilistic analysis finds a laser system of risk higher than normal safety of flight risks, it will be designated a "Category III: Significant Risk Result." In this case, the system will require coordination and notification with the LCH for every use. Coordination may include using LCH-provided templates and software to develop a deconfliction plan. Control measures for deconfliction may include test plans, certification memos, aircraft spotters, radar systems, automated laser shutters, and laser pointing restrictions. Plan approval may be contingent on a site visit and end-to-end demonstration. Once approved, the LCH provides an authorization letter to the mission.

In rare circumstances, a waiver can be granted by the U.S. Space Command where a laser owner is authorized to conduct a specific laser activity without the need for further coordination, notification, or risk mitigation measures for a specific period. This waiver must go through and be documented by the LCH and will only be considered after initiating the laser registration process.

The process of coordinating with the LCH can be quite lengthy and may take months. Laser operators should establish contact with the LCH as early as possible to understand the process. It may be possible to reduce the negative impact of LCH restrictions by making smart decisions early in the design and use planning of the system.

Cybersecurity/Information Assurance

Summary of Applicable Policy

Cybersecurity policy for small spacecraft is defined in a complex collection of policy documents published by the DOD, the Committee on National Security Systems, the National Institute of Standards and Technology, and other organizations. For all spacecraft used by the DOD, a key document is DOD Instruction (DODI) 8581.01, *Information Assurance (IA) Policy for Space Systems Used by the Department of Defense*[34]. This instruction implements Committee on National Security Systems Policy No. 12, *Cybersecurity Policy for Space Systems Used to Support National Security Missions*[35]. To determine if an information system is considered national security space, refer to National Institute of Standards and Technology Special Publication 800-59, *Guideline for Identifying an Information System as a National Security System*[36].

Policy Compliance Process

Two primary areas of compliance are associated with spacecraft cybersecurity policy (although this is not exhaustive). The first concerns protection of spacecraft uplink and downlink (i.e., the requirement for encryption). The second concerns certification and accreditation requirements of the spacecraft as an information system (i.e., the requirement to receive an Authority to Operate). These are covered below.

Encryption

For DOD-owned or -controlled spacecraft, DODI 8581.01, requires encryption of uplink and downlink. This applies to all DOD satellites, including research and development spacecraft built by DOD laboratories or academic institutions. The selection and implementation of the cryptography used to meet requirements should be coordinated with the National Security Agency (NSA) early in the design phase of every spacecraft program.

Encryption is not strictly required for non-DOD federal spacecraft (i.e., NASA). However, the *National Institute of Standards and Technology Special Publication 800-53* does apply, and the criticality and sensitivity of information transmitted may lead to the selection of security controls that include encryption.[37] Organizational policies may also apply; for example, NASA Procedural Requirements 2810.1A, *Security of Information Technology*, defines information technology security requirements for NASA.[38]

For commercial or private spacecraft, encryption is not typically required. However, if the DOD is "using" a commercial, private, non-DOD federal or foreign space system, DODI 8581.01 contains requirements pertaining to encryption. Depending on the criticality and sensitivity of the DOD information being transmitted, uplink and/or downlink cryptography may be required ranging from NSA-approved to commercial best practices.

In addition, some NOAA private remote sensing licenses may include cybersecurity conditions that incorporate safeguards to ensure the integrity of system operations and security of data. Early coordination with NSA NOAA is recommended.

Certification and Accreditation

DODI 8581.01 requires that all DOD-owned systems undergo cybersecurity accreditation following the *Risk Management Framework for Department of Defense Information Technology*[39]. A complete discussion of the risk management framework process is beyond the scope of this paper. However, it is worth mentioning that each DOD spacecraft program should determine who their cybersecurity Authorizing Official is early in the program. The Authorizing Official will ultimately issue the "Authority to Operate" for the spacecraft.

NASA NPR 7120.5*, NASA Space Flight Program and Project Management Requirements*, requires a project protection plan be written based on threat summaries for NASA missions.[40] NASA-STD-1006, *Space System Protection Standard*, outlines baseline standards to improve space system protection from well-understood threats.[41] NASA maintains a list of candidate protection strategies that outlines best practices for programs. Programs each develop a project protection plan that incorporates the results of the candidate protection strategy analysis, including any requisite requirement tailoring. NASA has a standard project protection plan template available.

Commercial spacecraft have no requirements to undertake a formal cybersecurity accreditation. However, when the DOD is using non-DOD systems, DODI 8581.01 states that the Authorizing Official for the DOD organization using the system is required to perform a review of the space system's ability to meet cybersecurity requirements and accept the risk for any areas of noncompliance.

Ambiguity, Open Questions, and Recommendations

Cybersecurity/Information Assurance

The first ambiguity has to do with whether a spacecraft should be considered DOD and therefore subject to DOD cybersecurity policy. Differing interpretations have been received, with the most stringent classifying any spacecraft receiving DOD sponsorship or funding of any nature as DOD spacecraft and subject to following all DOD policy requirements. This interpretation might have far-reaching implications. As described in the section on satellite ownership, satellites should be classified unambiguously and based on who is the owner/operator of the spacecraft. Cybersecurity policy compliance could be based on the requirements of the owner/operator organization.

A second ambiguity has to do with whether a satellite system is considered a national security space system. Not all DOD spacecraft are necessarily national security space systems. The National Institute of Standards and Technology Special Publication 800-59 has a checklist consisting of six questions to determine if an information system is a national security space system. Based on this checklist, many DOD research and development spacecraft developed and operated by military laboratories and academic institutions are not national security space systems. As such, Committee on National Security Systems Special Publication No. 12 is not applicable. However, DODI 8581.01 (which implements Committee on National Security Systems Special Publication No. 12) does not provide any provisions for non-national security space DOD spacecraft, which drives costly compliance requirements on these programs out of proportion to overall program cost and risk. DODI 8581.01 could be revised to either explicitly exclude non-national security space DOD spacecraft or to provide streamlined compliance procedures for this class of spacecraft

DODI 8581.01 provides procedures for implementing cybersecurity when the DOD uses non-DOD spacecraft. However, “use” is not well defined and subject to interpretation. It would be beneficial to expand this section of the policy to include different cases of “use” (such as hosted payloads, commercial imagery, and DOD sponsorship). Additionally, as hosting DOD payloads on non-DOD spacecraft becomes more common, cybersecurity requirements and responsibilities need to be better defined in memoranda of agreement up front.

Finally, no policy exists requiring the protection of non-DOD spacecraft command and control capability (particularly uplink encryption). This is of particular concern when the spacecraft has propulsion, or the ability to maneuver, because of the possibility of a “bad actor” gaining control of the vehicle and using it to interfere with another spacecraft. This is a significant policy hole that will become more pronounced with the increasing capabilities of small satellites and CubeSats, and especially if future FCC debris mitigation policy requires propulsion on satellites going to altitudes higher than 400 km. Policy should be established requiring uplink security on all spacecraft with significant maneuver capability. This could be incorporated into the established process for securing an FCC frequency license. Federal organizations entering into agreements with foreign spacecraft should establish this requirement, particularly when the United States is providing launch services for foreign spacecraft.

Imaging

Summary of Applicable Policy

Regulations governing remote sensing from a space platform fall into two distinct categories in the United States: Earth-imaging and non-Earth imaging. There are also two types of satellites considered: commercial (civilian) satellites and satellites owned and operated by the U.S. government. Satellites owned by DOD academic institutions are considered a subtype of government-owned satellites and fall into their own unique policy bucket. This section explores the various policies that apply to each type of satellite in each regulatory category and provides a basic understanding of how to navigate the policy compliance process.

Satellites owned and operated by commercial entities and civilian academic institutions are governed by the National Commercial and Space Programs Act.[42] This law governs Earth-imaging and assigns authority to NOAA for licensing of the same. NOAA will ensure all imagers comply with DOD and intelligence community requirements for non-Earth imaging for satellites owned by commercial and civilian academic institutions.

Government agencies currently have no requirement to obtain licensing for Earth imaging, although it is highly recommended that DOD agencies seek internal guidance. The Defense Remote Sensing Working Group manages non-Earth imaging for operational DOD systems. Experimental DOD satellites are governed by interim guidance issued by the Principal DOD Space Advisor staff.[43] This interim guidance, issued in 2015, requires DOD experimental satellites with remote sensing capability to submit test plans, data protection plans, and technical specifications of their system and payloads through the secretary of the Air Force Space Programs (SAF/AQS) office. If it is determined that a concern exists concerning an experimental DOD satellite, the issue is automatically referred to the Defense Remote Sensing Working Group. Since this interim guidance was issued in 2015, there has been no effort to establish permanent policy or guidance. As a result, imaging approval for DOD experimental satellites remains a gray area.

In researching this topic, the authors were unable to identify any NASA guidance or documentation with respect to imaging approval. All imaging devices aboard NASA satellites and missions are handled on a case-by-case basis by NASA.

Policy Compliance Process

The compliance process for commercial and civilian entities is outlined on the NOAA Commercial Remote Sensing Regulatory Affairs (CRSRA) website. NOAA recommends beginning the process with informal, nonbinding meetings between the applicant and NOAA to help inform the process and prevent rework. Interested parties can submit a licensing query using the *Initial Contact Form* found on the NOAA/CRSRA website (https://www.nesdis.noaa.gov/commercial-space/regulatory-affairs/licensing).

When an organization is prepared to begin the application process, Title 15 of the Code of Federal Regulations (CFR), Part 960, amended in 2020, establishes the rules and procedures to be followed, and NOAA provides support to ensure all the required documentation is provided.[44.]All license determinations are required to be made within 60 days of receipt of a completed application unless written guidance is provided on issues that exist with the application. All licenses are valid for the system's operational lifetime unless voided through the action of the owner or operator.

Under the revised definitions in 15 CFR Part 960, remote sensing now applies only to imaging conducted when in orbit around Earth (rather than in orbit of any celestial body) and to the collecting of data that can be processed into imagery of Earth's surface features. NOAA licenses are not necessary for "instruments used primarily for mission assurance or other technical purposes, including but not limited to navigation, attitude control, monitoring spacecraft health, separation events, or payload deployments, such as traditional star trackers, sun sensors, and horizon sensors." Additionally, if a spacecraft only has instruments incapable of producing data that can be processed into Earth-surface imagery, they are not required to obtain a license.

Private entities should never take it upon themselves to determine if they need a license. All private entities must reach out to the CRSRA office at NOAA if there is a theoretical capability to image Earth with devices onboard their spacecraft. NOAA/CRSRA encourages consultation meetings with potential applicants before submitting a license application. These meetings will be informal and are not considered part of the agency record of an application.

Per the amended 15 CFR 960.6, the CRSRA office categorizes each private space-based remote sensing system it licenses into one of three tiers based on an analysis of whether the system can produce unenhanced data already available from other entities, foreign or domestic.

- Tier 1 is for systems capable of producing unenhanced data that is substantially the same as data available from other sources *not* regulated by the DOC (e.g., foreign sources) and will receive minimal license conditions.

- Tier 2 is for systems that can produce unenhanced data that is substantially the same as data available from U.S. sources that *are* regulated by the DOC (e.g., U.S.-based sources) and licensed by CRSRA.

- Tier 3 is for systems that produce data that is not directly comparable to existing systems (e.g., unenhanced data not substantially the same as unenhanced data already available), foreign or domestic. This tier may receive the most stringent license conditions.

Applicants and licensees are encouraged to provide CRSRA with new information and examples of available data using the Data Availability Notification Form. CRSRA will, as evidence becomes available, update tiering thresholds and reassess tiering of applicable licenses as necessary.[55] Tiering thresholds are found in the *Tiering Threshold Document* found on the NOAA/ CRSRA website, which is updated quarterly:

Note that the law known as the Kyl–Bingaman Amendment (Public Law 104-201, Section 1064) prohibits NOAA from granting a license for a system capable of collecting or disseminating satellite imagery of the country of Israel at a higher resolution than is available from other commercial sources; that is, from companies outside of the United States. In a decision published in the *Federal Register* on July 21, 2020, NOAA set the current image resolution limit of 0.4 meter ground sampling distance. Most licensees abide by this requirement by onboard removal of relevant imagery (via image processing) before downloading it to the ground.

Ambiguity, Open Questions, and Recommendations

Imaging

Additional or clarifying guidance related to military academic institutions, satellites that receive DOD funding, and experimental satellites has not been established since the original publication of *Policy Compliance Roadmap* in 2017 and remains an area open to interpretation.

Rendezvous and Proximity Operations

Summary of Applicable Policy

Rendezvous and proximity operations is a broad term used to describe any operations that intentionally take one satellite into the vicinity of another. Current proximity operations policy is a patchwork of policy and guidance documents across the space community. The 2019 update to the ODMSP for the first time references rendezvous, proximity operations, and satellite servicing in its new Objective 5-3; programs are encouraged to limit the probability of accidental collision and limit the probability of accidental explosion resulting from the operations. However, specific numeric thresholds for these guidelines and definitions of what constitutes *proximity operations* have not yet appeared in lower-level guidance.

As the capability of small satellite systems increases, the desire for missions to perform proximity operations becomes more of a reality. Spacecraft designers must balance the need to perform mission objectives with the safety-of-flight concerns—because of its debris-generating potential, a collision between two satellites is a concern for the entire space environment, not just the two satellites involved. Although not necessarily considered proximity operations, space safety concerns extend to formation flying missions that intend to maintain a constant relative distance to each other. NASA currently has no policy guidance concerning proximity operations. There is a policy in the DOD for the review of proximity operations missions, but this policy is not widely available. Neither the FCC nor the FAA has any policy

Ambiguity, Open Questions, and Recommendations

Rendezvous and Proximity Operations

With the growth in capability of small satellites, there has been a surge in formation flying, rendezvous, proximity operations, and docking missions. Due to the technical challenges of performing these missions and the inherent safety of flight concerns, clarification on processes for civil and commercial entities would be beneficial. The policy should distinguish between formation flying and proximity operations and define policy guidance for each class. One possible definition for proximity operations might define proximity operations as satellites that deliberately operate within the typical screening volumes used for conjunction assessment, continuously for long periods of time. These vary but are on the order of 20 km in the along-track direction, and 1 km in the cross-track and radial directions. Missions that intend to approach other satellites or cooperatively fly within these distances might be required to develop proximity operations safety plans. For both formation and proximity operations missions, mission designers are encouraged to comply with National Institute of Standards and Technology Special Publication 800-53 and implement commercial best practice encryption on the uplink and downlink.

There are no FCC spectrum allocations for rendezvous and proximity operations, and operators must apply for Special Temporary Authority or for an experimental license, which is also temporary in nature. With the trend toward regular operations of this type of dedicated frequency allocations, long-term licensing options need to be considered.

A related issue that needs to be captured (possibly in this policy) involves cybersecurity requirements for vehicles with propulsion, regardless of their intention to conduct proximity operations. Key to this guidance might be directives based off the amount of propulsion (or “delta-V) that a space vehicle intends to carry. This should inform the cybersecurity posture of the vehicle and ground system. Care should be taken to separate policy requirements for significant translational propulsion systems from those required for simple attitude control propulsive systems.

compliance requirements for on-orbit proximity operations.

Policy Compliance Process

DOD missions intending to perform proximity operations missions must comply with DOD processes. Civil and commercial entities are currently not required to comply with any process specific to proximity operations objectives, although missions will naturally need to comply with all frequency and imaging requirements discussed above.

Operations Beyond Earth Orbit/ Cislunar Space

Summary of Applicable Policy

The number of launch opportunities for missions beyond Earth orbit is expected to grow in the coming years, given NASA's renewed commitment to lunar exploration with the Artemis program and a new generation of heavy and superheavy launch vehicles. Additionally, the proliferation of public and private exploration partnerships, such as NASA's Commercial Lunar Payload Services program, have the potential to involve commercial and private organizations that have never operated in this region of space before. Small satellites, traditionally confined to low Earth orbit, are increasingly being considered and used for missions beyond geosynchronous orbit.[45] This section briefly addresses policy related to operations beyond Earth orbit.

Article VI of the Outer Space Treaty requires that "[t]he activities of non-governmental entities in outer space, including the Moon and other celestial bodies, shall require authorization and continuing supervision by the appropriate State Party to the Treaty." While the FAA has not released explicit guidelines for handling beyond Earth orbit space missions, two private lunar missions can provide insight into FAA processes for this mission type. On July 20, 2016, the FAA made a favorable payload determination for the Moon Express MX-1E mission. The FAA had determined that the launch of the payload did not jeopardize public health and safety, the safety of property, U.S. national security or foreign policy interests, or international obligations of the United States. For the mission, the FAA concluded, in concurrence with the Department of State, that the enforcement of regulations in Chapter 509 of Title 51 and other FAA regulations constitutes compliance with Article VI of the Outer Space Treaty. However, the FAA explicitly stated that these determinations did not extend to any future missions and that any future requests for a payload determination will be evaluated on a case-by-case basis. In July 2018, the FAA made another favorable payload determination for the SpaceIL Lunar Lander mission using a similar rationale.

Spectrum Usage

As part of the new FCC regulations, small spacecraft with planned non-Earth orbiting missions, such as commercial lunar missions, can file under the new streamlined process for frequency allocation and approval. Note that all spacecraft leaving Earth orbit must still receive assignment licensing with the ITU. Getting a license or approval to use a frequency through either the FCC or other agencies hinges on successfully completing the ITU's coordination process. This process can take months to years. (One cislunar operating X-band CubeSat took four years to get approval.) So, missions should start working on the application and submittal as early as possible. The regulatory changes for small satellites are contained in the *Final Acts WRC-15, World Radiocommunication Conference*[54] and the *Radio Regulations*[27].

Imaging Policy

In the newly amended CFR Title 15 Part 960, NOAA-regulated spacecraft orbiting celestial bodies other than Earth are not required to obtain a license even if carrying instruments theoretically capable of producing Earth-surface imagery.[44] Nongovernment missions must still reach out to the CRSRA to get a license determination.

Planetary Protection Policy Compliance Process

Article IX of the *Outer Space Treaty* states: "...parties to the Treaty shall … conduct exploration of [the moon and other celestial bodies] so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter."[1] The United Nations Committee on Space Research (COSPAR) maintains and promulgates the internationally accepted approaches to planetary protection on behalf of Article IX. COSPAR's *Planetary Protection Policy*, last updated in March 2011, lays out five categories of missions according to the destination involved and the type of mission (i.e., orbiter, lander, and return-to-Earth mission). NASA's planetary protection requirements are founded upon COSPAR policy and fall under the Office of Planetary Protection.[46] All NASA launched or funded missions which might intentionally or unintentionally carry Earth organisms and organic constituents to other solar system bodies, or any mission employing spacecraft which are intended to return to Earth and/or its biosphere from extraterrestrial targets of exploration, must be compliant with NPD 8020.7, *Biological Contamination Control for Outbound and Inbound Planetary Spacecraft*[47].

Protection requirements are specific to the type of mission and planetary bodies visited. As described in NPR 8020.12, *Planetary Protection Provisions for Robotic Extraterrestrial Missions*, missions must meet a specific set of forward contamination (bringing something to the planetary body from Earth) and backward contamination (bringing something from the planetary body to Earth) criteria that prevents unintended encounters with solar system objects and limits the probability of contamination if encounters are unavoidable. Missions to objects of interest for origins of life (including Earth's moon) require documentation of mission trajectory and disposition of hardware.[48] The NID 8715.128, *Planetary Protection Categorization for Robotic and Crewed Missions to the Earth's Moon,* addresses the control of forward biological contamination associated with all NASA and NASA-affiliated missions intended to land, orbit, or otherwise encounter the moon.[49] Additionally, NID 8715.129, *Biological Planetary Protection for Human Missions to Mars*, and NPD 8020.7, *Biological Contamination Control for Outbound and Inbound Planetary Spacecraft,* outlines requirements to avoid harmful forward and backward biological contamination to comply with Article IX.[47]

Careful mission design and planning are essential elements when considering planetary protection requirements, and consultations with the planetary protection officer (PPO) during mission development are critical in ensuring compliance with NASA policy.

Debris Mitigation Policy Compliance Process

The current ODMSP does not explicitly address debris mitigation requirements in cislunar or interplanetary space. However, NASA has required the first generation of interplanetary CubeSats on Artemis I to follow standard policies (as laid out in this paper) for debris mitigation. Although the focus of NPR 8715.6 and NS 8719.14 is on orbital debris mitigation in the near-Earth space environment, several requirements are applicable to interplanetary missions.

The requirements in NPR 8715.6 that are directly applicable for interplanetary missions include:

- Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions.

- Requirement 4.4-2: Design for passivation after completion of mission operations; i.e., limit or depletion of energy sources on spacecraft at the end of life.

- Requirements 4.4-3 and 4.4-4: Limiting the long-term risk to other space systems from planned breakups.

- Requirement 4.5-2: Limiting debris generated by collisions with objects when operating in Earth or lunar orbit.

- Requirement 4.6-1: Spacecraft disposal for lunar and Mars missions is coordinated with the NASA PPO to meet the applicable planetary protection requirements per NID 8715.129, NPD 8020.7 and NPR 8020.12.

- Requirement 4.8-1: Mitigate the collision hazards of space tethers in Earth or lunar orbits.

It is worth repeating that the current OSMA position is that CubeSats 3U or smaller are automatically considered compliant with requirements 4.4-1 and 4.4-2 due to their small size and low risk of debris generation.

Note that there are Planetary Protection considerations in NPR 8715.6A. In the event of conflicts between NPR 8715.6 and Planetary Protection requirements, the Planetary Protection requirements will take precedence. Paragraph 1.3.14 of NPR 8715.6A states that NASA's Planetary Protection Officer shall "review and concur in the final ODAR and EOMP for disposition of spacecraft on a solar system body other than the Earth." Also, Paragraph 2.2.2.4 states, "For missions traveling beyond geosynchronous Earth orbit (GEO) disposal orbits, the MDAA shall submit each draft EOMP to the NASA PPO for review, subject to NPR 8020.12."

Preservation of Historic Sites Policy Compliance Process

In 2011, NASA published voluntary guidelines entitled Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts. The One Small Step to Protect Human Heritage in Space Act, passed in December 2020, directs any federal agency that issues licenses to conduct activities in outer space (including the Department of Transportation (DOT), the DOC, FAA, and FCC) to require that all lunar activities they oversee must agree to abide by NASA's guidelines (or subsequent updates from NASA) and authorizes fines of any licensee who breaks the license terms. The law allows for exemptions (with consultation from NASA) from this requirement and calls for an international treaty consistent with this bill. So far, NASA has complied with the law through requirement 4.6-1 in NPR 8715.6.

The Artemis Accords

Drafted by NASA and the U.S. Department of State, The Artemis Accords is an international agreement that establishes a framework for cooperation in the civil exploration and peaceful use of the moon, Mars, and other astronomical objects. The agreement is meant to be "grounded in the Outer Space Treaty of 1967" to create a safe and transparent environment that facilitates exploration, science, and commercial activities for all of humanity to benefit. As of March 8, 2021, 21 countries have signed the Artemis Accords: Australia, Bahrain, Brazil, Canada, Colombia, France, Isle of Man, Israel, Italy, Japan, South Korea, Luxembourg, Mexico, New Zealand, Poland, Romania, Ukraine, the United Arab Emirates, the United Kingdom, and the United States.[51]

To date, extensive regulations and policy documents outlining how NASA and other U.S. agencies and commercial entities will implement the tenants of the Accords have not been released. Note that the Artemis Accords explicitly state that they only apply to signatory nations' civil space activities. Meaning the activities of the DOD (and the militaries of the other signatory nations) are not explicitly bound by the Artemis.

Ambiguity, Open Questions, and Recommendations

Operations Beyond Earth Orbit/Cislunar Space

For the oversight of non-NASA-run or -funded missions, the U.S. process is not yet well established. Due to the volume of upcoming missions, it will soon become vital to determine who will be the lead organizations for space traffic management, space domain awareness, and orbital debris mitigation for beyond-Earth orbit space activities. To date, NASA is the only U.S. agency with any significant planetary protection knowledge and expertise, but it does not regulate commercial activity. Agencies such as the FCC, FAA or the DOC may ultimately need to regulate planetary protection for commercial missions.

As missions beyond Earth become more accessible to small satellites, policymakers will need to start regulating debris, particularly in lunar orbit and high-value areas such as Lagrange points. Orbits around or near Lagrange points may ultimately need to be subject to similar regulations as satellites in geosynchronous orbit, with specific slots assigned to ensure lack of dangerous interference.

Orbits in the cislunar regime are subject to high perturbations, so further study is needed to determine how disposal and operations with significantly more active missions can be done safely.[52]

In September 2020, NASA and the U.S. Space Force signed a memorandum of understanding on space cooperation that more firmly pins the U.S. military to future missions in the vast region of space beyond Earth's orbit. The agreement expands long-standing NASA-DOD / Air Force space cooperation on space exploration, including cooperation on situational awareness, communications, and precision navigation. Additionally, it includes efforts to establish "norms of behavior" for activities such as moon and asteroid mining. The fruits of these efforts have yet to be widely disseminated.[53]

To date, the DOD, FAA, and FCC have issued no guidance on how they intend to comply with the One Small Step to Protect Human Heritage in Space Act, Article IX of the Outer Space Treaty, or the Artemis Accords. NASA has not issued explicit guidelines on how it intends to comply with the Artemis Accords.

With its approval of the Moon Express Mission, the FAA noted, "Future missions may require additional authority to be provided to the FAA to ensure conformity with the Outer Space Treaty. Suggested language for legislative relief and the relative merits and needs has been transmitted to Congress in compliance with Section 108 of the Commercial Space Launch Competitiveness Act (Public Law 114-90). In the absence of legislative relief, the FAA will continue to work with the commercial space industry to provide support for non-traditional missions on a case-by-case basis when the law permits."[54]

Use of Nuclear Material

Summary of Applicable Policy

As more performance is demanded, regulatory implications of using nuclear systems pose new considerations for smallsats. Nuclear systems include radioisotope thermoelectric generators, radioisotope heater units, and fission reactors. To date, nongovernment entities have been contracted to fabricate parts of past launches. For example, United Launch Alliance (ULA) constructed the Atlas V rocket for the 2011 Mars Science Laboratory (MSL) NASA mission. The power source for MSL is a multi-mission radioisotope thermoelectric generator (MMRTG) with 4.8 kg of plutonium dioxide. But now companies such as BWX Technologies, Atomos, and Ultra Safe Nuclear Company are actively pursuing the development of commercial nuclear fission systems for commercial customers.[55]

The policies and regulations of using and acquiring nuclear material for spacecraft are complex and lengthy. As a result, this paper does not explore the process in depth, and only the high-level compliance processes are discussed. Policies on any given mission may require coordination between and compliance to requirements from the U.S. Department of Energy (DOE), DOT, Department of Homeland Security (DHS), Nuclear Regulatory Commission (NRC) Atomic Energy Commission, NASA, and the DOD. It should also be noted that all U.S. launches of spacecraft containing space nuclear systems to date have included technology developed and manufactured by the DOE and its contractors.[56]

The U.S.'s nuclear flight safety program has existed since the early 1960s with continual evaluation from national laws, interagency declarations and international agreements and treaties like the 2019 *NSPM-20 Presidential Memorandum on Launch of Spacecraft Containing Space Nuclear Systems*, the 2020 *Pace Policy Directive 6*, *Memorandum on the National Strategy for Space Nuclear Power and Propulsion*, the 1992 UN's *Principles Relevant to the Use of Nuclear Power Sources in Outer Space,* and the 2018 International Atomic Energy Agency's *Regulations for the Safe Transport of Radioactive Material*."[57]

The Atomic Energy Act of 1954 stipulates that a "person" may not own, possess, use, or have the facilities to produce or utilize nuclear material without a license either from the DOE or NRC. The Act gives NRC the authority to license and regulate the possession, use, transfer, and transport (in conjunction with the DOT) of commercial nuclear facilities and materials (i.e., those not owned by the DOE).

Policy Compliance Process

DOD programs that use radioactive material and nuclear power systems in space shall follow AFMAN 91-110*, Nuclear Safety Review and Launch Approval for Space or Missile Use of Radioactive Material and Nuclear Systems* for all safety requirements, review processes, and approval processes.

For NASA-led or sponsored programs, NPR 8715.3 *NASA General Safety Program Requirements,* Chapter 6, "General Safety Program Requirements, Nuclear Safety for Launching of Radioactive Materials," describes the requirements for characterizing and reporting potential risks associated with a planned launch of radioactive materials into space.

All government missions involving space nuclear material require presidential approval through the Office of Science and Technology Policy (OSTP). The current launch approval process is governed at a high level by the 1996 NSC-25, *Presidential Directive/National Security Council Memorandum No. 25*, the 2010 *National Space Policy of the United States of America*, and the National Environmental Protection Act (NEPA).[57]

Ambiguity, Open Questions, and Recommendations

Use of Nuclear Material

Specific regulatory guidance for launch of space nuclear systems is under development by the FAA, to be covered under Title 14, Code of Federal Regulations for FAA-licensed launches. PD/NSC-25 states that "[t]he head of the sponsoring agency will request the President's approval for the flight through the Office of Science and Technology Policy [OSTP]." It is uncertain if and how this could apply to commercial launches. The sponsoring agency cannot be the licensing authority; i.e., the FAA for the commercial mission. Therefore, PD/NSC-25 could only apply in the commercial context if there is some other government agency willing to act as the sponsor of the mission.

The paper titled *Evolution of NASA's Nuclear Flight Safety Program to Meet Changing Needs* was presented in November 2021 at the 11th International Association for the Advancement of Space Safety Conference. It discusses NASA's plans to update its nuclear material usage and safety policies to maintain consistency with changes to U.S. government-issued national policies that fundamentally changed the approach to nuclear flight safety for aerospace applications. As part of this evolution, NASA is factoring in an objectives-driven and assurance case mindset to develop a risk-informed and performance-based program. It also declares NASA's desire to "harmonize" its nuclear flight safety practices among the DOT, the DOD, the DOE, and the NRC, to the greatest extent practicable. These changes have yet to be implemented.[56]

The launch approval process for government missions with nuclear material involves three separate and somewhat concurrent reviews:

1. The mission owner prepares an environmental impact statement (EIS), or environmental assessment (EA) mandated by the NEPA.

2. The DOE performs the safety analysis and prepares a safety analysis review (SAR)

3. The Interagency Nuclear Safety Review Panel (INSRP) reviews the SAR and prepares a safety evaluation report (SER).

Based on these inputs, either the director of OSTP or the president renders approval for a launch. The process has taken an average of six years and costs over $40 million for recent missions.

The current launch approval process for any space nuclear system has only been used for government-owned and operated missions, but commercial entities have increasingly been interested in using space nuclear systems. Under 14 CFR § 415.115, FAA also has the authority to evaluate the launch of any nuclear material on a launch vehicle or payload on a case-by-case basis and issue an approval if the FAA determines the launch is consistent with public health and safety.

Policy Flowchart and Sample Walkthrough

Figures 3 through 6 summarize the policy pathways described in this paper to the extent that the authors understand the existing policy framework. Starting with Figure 3, missions must first determine who "owns" the satellite to determine what policy applies. Typically, the ultimate satellite owner/operator — whoever will have satellite control authority once the satellite is operational—is the agency whose policy the mission must follow. Once mission ownership is understood, the remaining figures (Figures 4 through 6) describe the applicable policy.

For example, if AFRL builds a satellite intending to conduct unclassified proximity operations, the Air Force is the owner/operator, and the DOD policy flowchart should be followed. DOD satellites are required to abide by information assurance requirements as documented in DODI 8581.01, and even if the mission is unclassified, they must use NSA-approved encryption. Such a satellite would apply to the NTIA for frequency assignment. Since the satellite will perform proximity operations, DOD proximity operations regulations must be followed.

As another example, assume that a university builds a satellite capable of Tier 1 imaging and plans to do rendezvous proximity operations. They get a government organization to sponsor it to the DOD Space Experiments Review Board (SERB) for launch consideration. Even with government involvement, the satellite is still considered private and will follow the policy for privately owned satellites. The university will apply for a frequency license through the FCC and apply to NOAA for imaging approval. As part of its FCC filing, it will demonstrate its compliance with one of the respective debris mitigation regulations. As long as their imagery product does not need protecting, there are no existing regulations requiring such a satellite to encrypt its uplink or downlink, and no specific approvals are needed relating to rendezvous proximity operations.

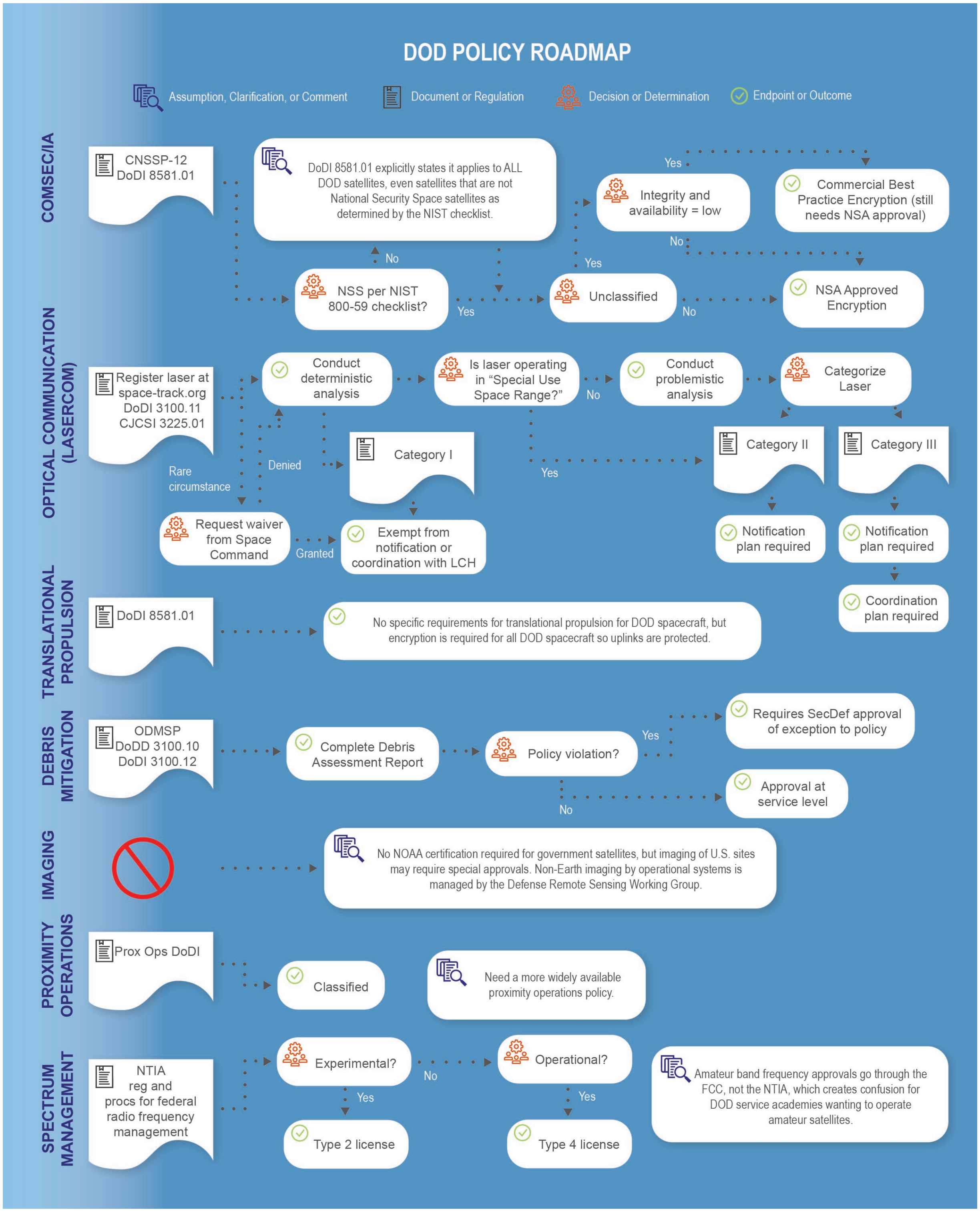

Figure 4: Policy Roadmap for DOD Satellites.

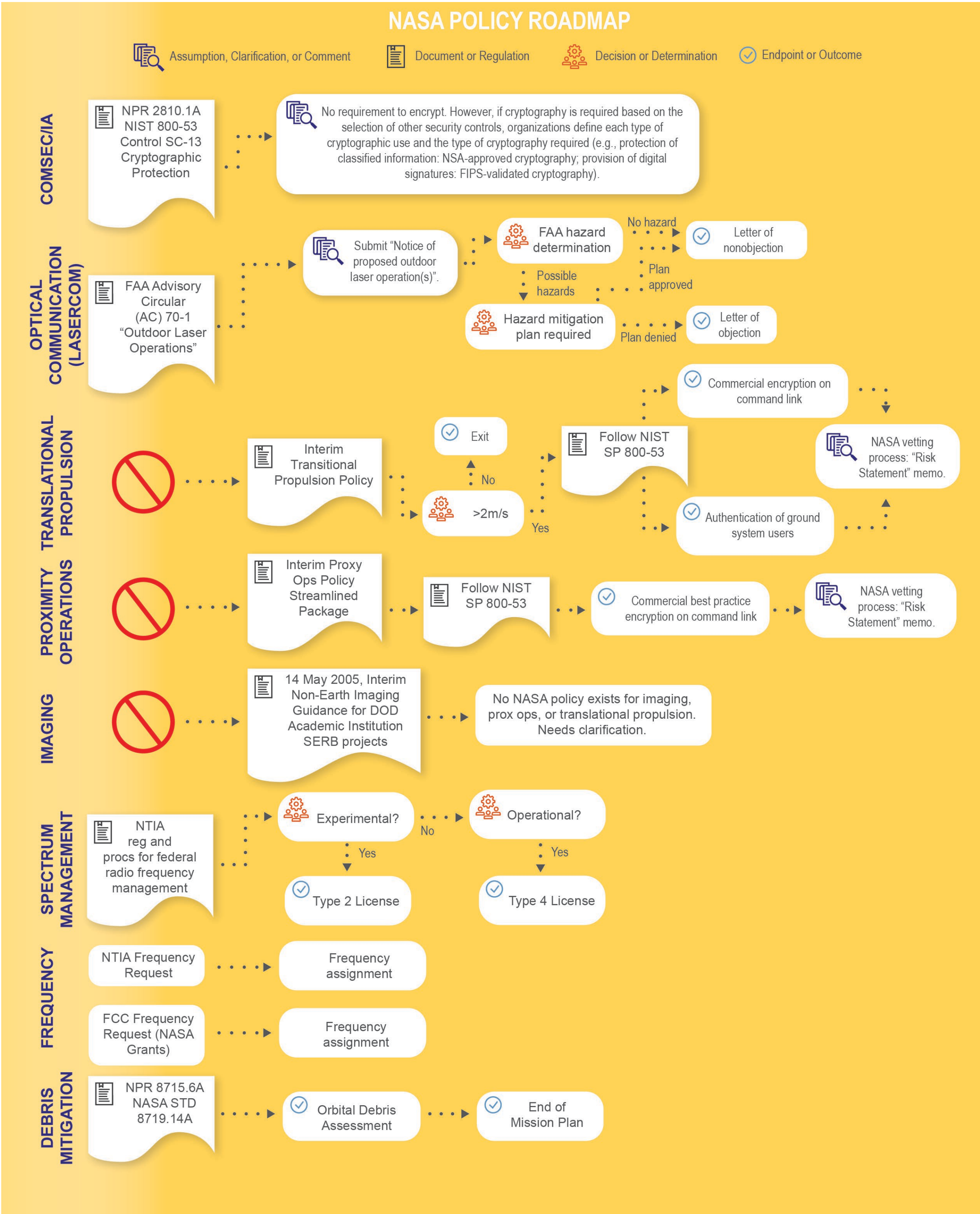

Figure 5: Policy Roadmap for NASA Satellites.

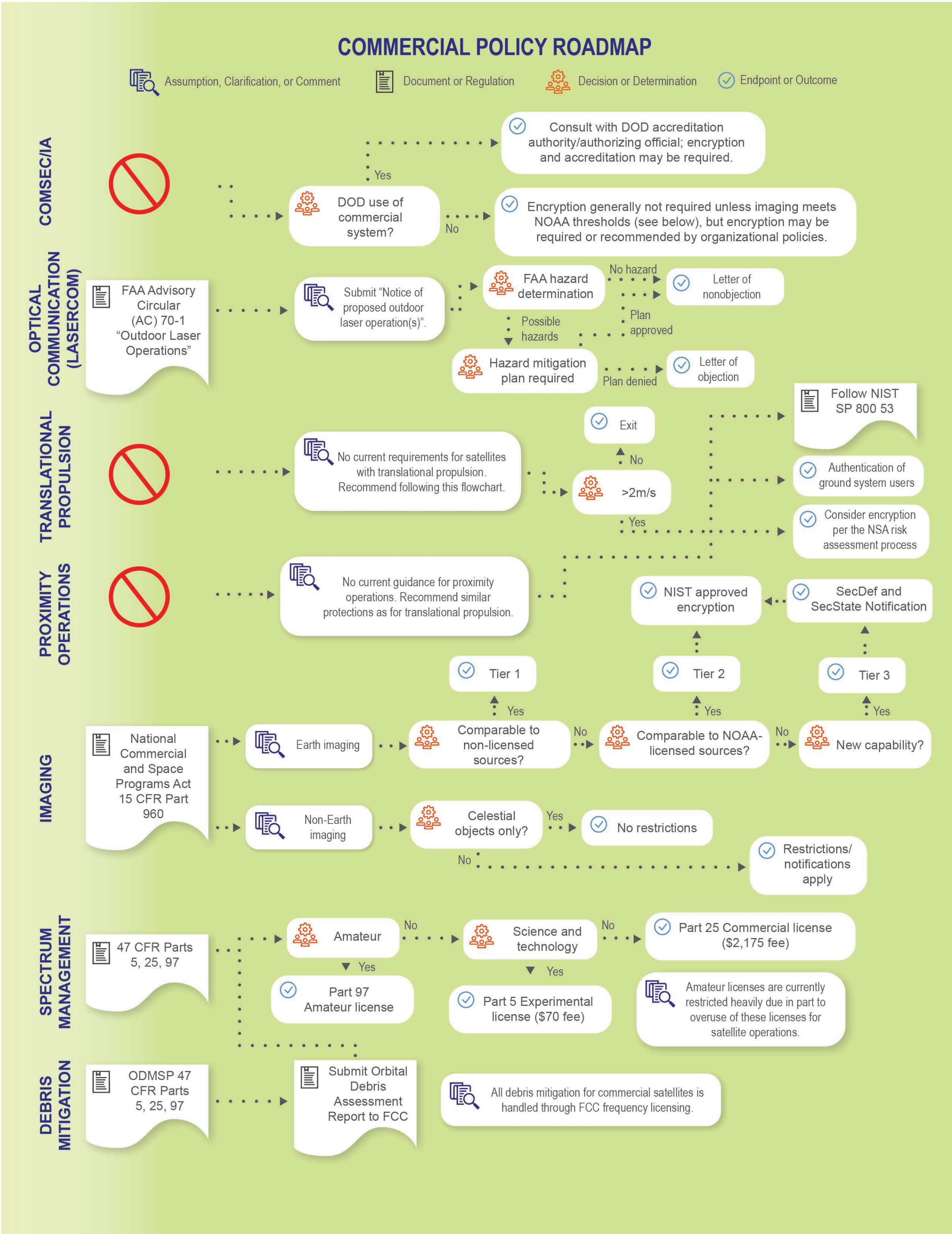

Figure 6: Policy Roadmap for Commercial Satellites.

Recent/Near Future Developments

The Small Satellite Coordination Activity (SSCA) is a DOD-level effort initiated by the Under Secretary of Defense for Acquisition and Sustainment, Ms. Ellen Lord, in 2018. The effort was started to better understand what was being done across the department in small satellites. Since 2018, a group of representatives from across the DOD and NASA have met quarterly to better understand DOD small satellite efforts and where the challenges lie. So far, there have been three phases to the SSCA. The first phase (February 2018 to July 2018) focused on data collection, the second phase (August 2018 to February 2020) focused on roadmapping, and the third phase (February 2020 to September 2020) convened eight focus groups to study challenges and make recommendations. The eight focus groups were launch, satellite vehicles, space operations and infrastructure, security, communications, remote sensing, navigation, and policy.

The policy focus group recommended including those with smallsat experience in space policy development and coordination to inform how policy affects smallsat programs. Often, policy is written with large operational programs in mind and without insight into how certain decisions (or processes) affect smallsat programs. An additional recommendation was to develop training materials to help the smallsat program managers navigate policy processes. As discussed at length in this paper, it is often hard for program managers to understand what policies they must follow and how to comply. A final recommendation was the formation of a single office at the DOD level to act as an advocate for smallsat programs and assist with policy navigation. As of the writing of this paper, these recommendations are being coordinated through the department.

On September 9, 2020, NASA and the U.S. Space Force (USSF) signed a memorandum of understanding to affirm the long-standing partnerships started under the U.S. Air Force. It also contained areas of interest for new cooperation that are relevant to smallsats. These include new rideshare opportunities, space domain awareness data sharing, and interoperability of communication systems for Earth orbit and beyond.

The Small Payload Ride Share Association (SPRSA) will be leading the development of a small payload Multi-manifest Design Specification (MMDS) in support of the USSF SSC/ECL Mission Manifest Office (MMO). The ultimate objective of this effort is to create an open-source document that clearly defines the small satellite vehicle design criteria that will allow efficient integration on multi-manifested missions, including the ability to be readily moved between different launch opportunities and different launch vehicles.

Conclusion

The policy picture for today’s rapidly evolving space enterprise is complex and confusing, particularly to non-traditional entrants and missions that occupy policy “gray areas.” In this paper, we have attempted to clarify the applicability of existing policy and outline a process for missions to follow to ensure compliance. We have also attempted to highlight areas where policy is absent or unclear. It is, however, important to remember that the policy roadmap is always “under construction” and that future changes are certainly expected. For example, with the standing of a new military service—the United States Space Force—policy roles and responsibilities are going to evolve in ways that have still not been determined. Transformation and reengineering processes will require time, broad participation, and cooperation. However, the tempo of space launches is expected to increase with several large, new constellations on the horizon. Now is a propitious time to prepare for a more crowded and busy space environment. As the space enterprise evolves, we hope that U.S. policy will be agile enough to evolve with it to ensure access to space for all and safety in space for all.

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References

[1] "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies," October 10, 1967, United Nations, New York, New York.

[2] "The Outer Space Treaty: Assessing Its Relevance at the 50-Year Mark," July 2017, James A. Vedda, The Aerospace Corporation (http://www.aerospace.org/publications/white-papers/the-outer-space-treaty-assessing-its-relevance-at-the-50-year-mark/).

[3] "National Space Policy of the United States of America," December 16, 2020, White House, Washington, D.C.

[4] "National Space Transportation Policy," November 21, 2013, White House, Washington, D.C.

[5] Braun, B., and Sims. E, "Trespassing on the Final Frontier: Regulatory Challenges for New Space Entrants," The Aerospace Corporation, June 2018

[6] Title 51, U.S. Code, National and Commercial Space Programs, December 18th, 2010 (http://uscode.house.gov/view.xhtml?path=/prelim@title51&edition=prelim).

[7] "Department of Defense Instruction 3100.12: Space Support." The Department of Defense, the U.S. government, September 14, 2000 (http://www.au.af.mil/au/awc/awcgate/dod-spc/i310012p.pdf).

[8] Title 41, U.S. Code, Public Contracts, January 4, 2011 (http://uscode.house.gov/view.xhtml?path=/prelim@title41&edition=prelim)

[9] "U.S. Government Orbital Debris Mitigation Standard Practices, November 2019 Update," November 2019, the U.S. government, Washington D.C., (https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf).

[10] "NASA Procedural Requirements for Limiting Orbital Debris (NPR 8715.6A)," May 14, 2009, National Aeronautics and Space Administration, Washington, D.C.

[11] "NASA Process for Limiting Orbital Debris (NASA STD 8719.14A)," May 25, 2012, National Aeronautics and Space Administration, Washington, DC.

[12] "Compendium of Space Debris Mitigation Standards Adopted by States and International Organizations," March 25, 2014, Committee on the Peaceful Uses of Outer Space, Vienna, Austria.

[13] "NASA Interim Directive 7120.132, *Collision Avoidance for Space Environment Protection*," November 2020, (https://nodis3.gsfc.nasa.gov/OPD_docs/NID_7120_132_.pdf).

[14] NASA *Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook,* December 2020 (https://nodis3.gsfc.nasa.gov/OCE_docs/OCE_50.pdf).

[15] "Department of Defense Directive 3100.10: Space Policy," October 18, 2012, Department of Defense, Washington, D.C.

[16] "Air Force Instruction 91-202: The US Air Force Mishap Prevention Program," June 24, 2015, Air Force, Washington, D.C.

[17] "Code of Federal Regulations Title 47: Telecommunications," April 19, 2016, Federal Communications Commission, Washington, DC.

[18] "Dove 3 Orbital Debris Assessment Report," October 9, 2012, Cosmogia, San Francisco, California.

[19] "Flock 1 Orbital Debris Assessment Report," June 20, 2013, Planet Labs, San Francisco, California.

[20] "TechEdSat Formal Orbital Debris Assessment Report," April 2, 2012, NASA Ames, Moffett Field, California.

[21] "Mitigation of Orbital Debris in the New Space Age," October 25, 2018, Notice of Proposed Rulemaking and Order on Reconsideration, IB Docket No. 18-313, Federal Communications Commission, Washington, D.C.

[22] "Mitigation of Orbital Debris in the New Space Age," April 24, 2020, Report and Order and Further Notice of Proposed Rulemaking, IB Docket No. 18-313, Federal Communications Commission, Washington, D.C.

[23] "Space Debris Mitigation Policy," Fall 2015, Crosslink Magazine, The Aerospace Corporation, El Segundo, CA.

[24] Sorge, Marlon, "US Space Debris Mitigation Regulatory Structure," The Aerospace Corporation, September 2017.

[25] *Manual of Regulations and Procedures for Federal Radio Frequency Management*, National Telecommunications and Information Administration, Washington, D.C. (https://www.ntia.gov/page/2011/manual-regulations-and-procedures-federal-radio-frequency-management-redbook) September 2017.

[26] Skinner. M., "CubeSat Confusion: Technical and Regulatory Considerations" The Aerospace Corporation's Center for Space Policy and Strategy. January 2021

[27] "Radio Regulations," World Radiocommunication Conferences, International Telecommunication Union, 2020, Geneva, Switzerland. https://www.itu.int/pub/R-REG-RR/en

[28] Sadiku, Matthew NO, Sarhan M. Musa, and Sudarshan R. Nelatury, "Free space optical communications: an overview," European scientific journal 12.9 (2016).

[29] "Procedures for Handling Airspace Matters," Job Order #7400.2M, Federal Aviation Administration, February 28, 2019 (https://www.faa.gov/documentLibrary/media/Order/7400.2M_Bsc_dtd_2-28-19.pdf).

[30] "American National Standard for Safe Use of Lasers," American National Standards Institute A136.1, 2014.

[31] "American National Standard for Safe Use of Lasers Outdoors," American National Standards Institute A136.6, 2015.

[32] Lafon, Robert, et al. "Regulatory Considerations: Laser Safety and the Emerging Technology of Laser Communication," American Institute of Aeronautics and Astronautics, *Space Operations: Experience, Mission Systems, and Advanced Concepts*, 2017.

[33] "Department of Defense Instruction 3100.11: "Management of Laser Illumination of Objects in Space," October 24, 2016, Department of Defense, Washington, D.C.

[34] "Department of Defense Instruction 8581.01: Information Assurance Policy for Space Systems," June 8, 2010, Department of Defense, Washington, D.C.

[35] "Committee on National Security Space Policy No. 12: Cybersecurity Policy for Space Systems Used to Support National Security Missions," February 2018, Committee on National Security Systems, Fort Meade, Maryland.

[36] "National Institute of Standards and Technology Special Publication 800-59: Guideline for Identifying an Information System as a National Security System," August 2003, Department of Commerce, Washington, D.C.

[37] "National Institute of Standards and Technology Special Publication 800-53, Security and Privacy Controls for Federal Information Systems and Organizations," April 2013, Department of Commerce, Washington, D.C.

[38] "NASA Procedural Requirements for Security of Information Technology (NPR 2810.1A)," May 16, 2006, National Aeronautics and Space Administration, Washington, D.C.

[39] "Risk Management Framework for Department of Defense Information Technology," March 12, 2014, Department of Defense, Washington, D.C.

[40] "NASA Space Flight Program and Project Management Requirements," NPR 7120.5, August 14, 2012, National Aeronautics and Space Administration, Washington, D.C.

[41] "Space System Protection Standard," NASA-STD-1006, November 5, 2020, National Aeronautics and Space Administration, Washington, D.C.

[42] "US Code Title 51: National Commercial and Space Programs," December 18, 2010, U.S. Government Printing Office, Washington, D.C.

[43] "Interim Non-Earth Imaging Guidance for DoD Academic Institution SERB Projects," November 3, 2015, Department of Defense, Washington, D.C.

[44] "Code of Federal Regulations Title 15 Part 960," May 20, 2020, Department of Commerce, Washington, D.C.

[45] Freeman, A., "Exploring our solar system with CubeSats and SmallSats: the dawn of a new era," *CEAS Space Journal*, pp.1-12, 2020.

[46] Krage, J., "An Overview of NASA Space Protection" Presented to the Small Spacecraft Systems Virtual Institute (S3VI), February 2020.

[47] "Biological Contamination Control for Outbound and Inbound Planetary Spacecraft," NPD 8020.7G, February 9, 1999, National Aeronautics and Space Administration, Washington, D.C. (https://nodis3.gsfc.nasa.gov/npg_img/N_PD_8020_007G_/N_PD_8020_007G__main.pdf).

[48] "Planetary Protection Provisions for Robotic Extraterrestrial Missions," NPR 8020.12D, April 20, 2011, National Aeronautics and Space Administration, Washington, D.C. (https://nodis3.gsfc.nasa.gov/npg_img/N_PR_8020_012D_/N_PR_8020_012D__Preface.pdf).

[49] "Planetary Protection Categorization for Robotic and Crewed Missions to the Earth's Moon," NID 8715.128, July 9, 2020, National Aeronautics and Space Administration, Washington, D.C. (https://nodis3.gsfc.nasa.gov/OPD_docs/NID_8715_128_.pdf).

[50] "Biological Planetary Protection for Human Missions to Mars," NID 8715.129, July 9, 2020, National Aeronautics and Space Administration, Washington, D.C., (https://nodis3.gsfc.nasa.gov/OPD_docs/NID_8715_129_.pdf).

[51] "NASA: Artemis Accords." NASA. https://www.nasa.gov/specials/artemis-accords/index.html

[52] Cheney, Thomas, et al. "Planetary Protection in the New Space Era: Science and Governance." Frontiers in Astronomy and Space Sciences 7 (2020): 90.

[53] "Memorandum of Understanding between Air Force Space. Command and the National Aeronautics and Space Administration" NASA https://www.nasa.gov/sites/default/files/atoms/files/nasa_ussf_mou_21_sep_20.pdf

[54] "Moon Express Payload Review Determination," FAA. https://www.faa.gov/newsroom/moon-express-payload-review-determination?newsId=20595

[55] Forsbacka, M. J., and D. M. Helton. Evolution of NASA's Nuclear Flight Safety Program to Meet Changing Needs. In *11th IAASS Conference*.

[56] Howieson, Susannah V., Jonathan R. Behrens, and Katherine M. Kowal. "Potential launch approval process for commercial space nuclear systems." *Proc. Nuclear and Emerging Technologies for Space, American Nuclear Society Topl. Mtg* (2019): 25-28.

[57] Howieson, S. V., R. Buenconsejo, B. Lal, and J. Behrens. "Legal Requirements of Nuclear Launch Approval," *ANS NETS 2018 – Nuclear and Emerging Technologies for Space*, Las Vegas, Nevada, February 26 to March 1, 2018 (2018).