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Introduction to Cybersecurity for Commercial Satellite Operations

Matthew Scholl

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Introduction to Cybersecurity for Commercial Satellite Operations

Matthew Scholl
Computer Security Division
Information Technology Laboratory

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June 2021

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National Institute of Standards and Technology
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Public comment period: *June 30, 2021* through ~~*August 13*~~ *October 13, 2021*

National Institute of Standards and Technology
Attn: Computer Security Division, Information Technology Laboratory
100 Bureau Drive (Mail Stop 8930) Gaithersburg, MD 20899-8930
Email: DraftIR8270Comments@nist.gov

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Reports on Computer Systems Technology

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Abstract

Space is an emerging commercial critical infrastructure sector that is no longer the domain of only national government authorities. Space is an inherently risky environment in which to operate, so cybersecurity risks involving commercial space – including those affecting commercial satellite vehicles – need to be understood and managed alongside other types of risks to ensure safe and successful operations. This report provides a general introduction to cybersecurity risk management for the commercial satellite industry as they seek to start managing cybersecurity risk in space. This document is by no means comprehensive in terms of addressing all of the cybersecurity risks to commercial satellite infrastructure nor does it explore risks to satellite vehicles, which may be introduced by implementing cybersecurity controls. The intent is to introduce basic concepts, generate discussions, and provide sample references for additional information on pertinent cybersecurity risk management concepts.

Keywords

commercial space satellite operations; cybersecurity; cybersecurity risk management; risk management.

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Audience

The primary audience for this publication includes chief information officers (CIOs), chief technology officers (CTOs), and risk officers of organizations who are using or plan to use commercial satellite operations and are new to cybersecurity risk management for these operations.

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Executive Summary

As stated in the September 2018 United States National Cyber Strategy, the U.S. Government considers unfettered access to and freedom to operate in space vital to advancing the security, economic prosperity, and scientific knowledge of the Nation. However, cyber-related threats to space assets (e.g., commercial satellites) and supporting infrastructure pose increasing risk to this economic promise and commercial space emerging markets.

Commercial satellite operations occur in an inherently risky environment. Physical risks to these operations are generally quantifiable and have the most likely potential to adversely impact the businesses that operate commercial satellites, usually in low earth orbit. While this is the primary risk consideration to satellite operations, continued growth in this new commercial infrastructure allows for opportunities to address the cybersecurity risks along with the other risk elements.[1]

Methods for the creation, maintenance, and implementation of a cybersecurity program for many of the commercial and international markets include products in National and International Standard-Setting Organizations (SSOs), as well as the use risk management guidance from the National Institute of Standards and Technology (NIST). NIST risk management guidance includes specific technical references, cybersecurity control catalogues, the IT Risk Management Framework, and the Cybersecurity Framework (CSF).

The intent of this document is to introduce the CSF to commercial space businesses. This includes describing a specific method for applying the CSF to a small portion of commercial satellite operations (e.g., a small sensing satellite), creating an example CSF set of desired security outcomes based on missions and anticipated threats, and describing an abstracted set of cybersecurity outcomes, requirements, and suggested cybersecurity controls.

NIST asks the commercial satellite operations community to use this document as an informative reference to assist in managing cybersecurity risks and to consider how cybersecurity requirements might coexist within space vehicle system requirements. The example requirements listed in this document could be used to create an initial baseline. However, NIST recommends that organizations use this document in coordination with the set of NIST references and applicable SSOs material to create cybersecurity outcomes, requirements, and controls customized to support an organization's particular business needs and address its individual threat models.

This report focuses on crewless commercial space vehicles that will not dock with human-occupied spacecraft.

[1] These can include, but are not limited to, physical risks, EMI/EMC, financial risks, and supplier and customer risks.

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1 Introduction

The concept of a commercial space sector has been evolving for some time. In 2007, the U.S. Leadership in Space Commerce Strategic Plan stated,

> From television and data communications, to personal navigation, to internet-based satellite imagery, space commerce has enabled countless new economic benefits for our nation. In addition, the expansion of the global market for commercial space capabilities has generated robust worldwide competition. [3]

The White House National Space Policy stated this in 2010:

> The term 'commercial,' for the purposes of this policy, refers to space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential nongovernmental customers. [4]

Today, space continues to be an emerging commercial sector that is no longer the domain of only national government authorities. The commercial uses of space for research and development, material sciences, communication, and sensing are growing in size, scale, and importance for the future of the U.S. economy. Space is an inherently risky environment in which to operate, so cybersecurity risks involving commercial space need to be understood and managed alongside other types of risks to ensure safe and successful operations.

1.1 Purpose and Scope

This report provides a general introduction to cybersecurity risk management to the commercial space commerce industry. This document is by no means comprehensive in terms of addressing all cybersecurity risks to commercial space infrastructure, nor does it explore how cybersecurity solutions might introduce risk to a space vehicle. The intent is to introduce basic concepts, generate discussions, clear confusion, and provide references for additional information on pertinent cybersecurity risk management concepts. ***This report focuses on crewless commercial space vehicles that will not dock with human-occupied spacecraft.***

1.2 Report Structure

The rest of this report is organized into the following sections and appendices:

- Section 2 provides a notional, conceptual, high-level architectural view of commercial satellite operations.
- Section 3 describes the steps of the Cybersecurity Framework and provides a notional example of how a satellite organization might apply those steps.

- Appendix A provides examples of regulations that may be relevant for commercial satellite operations.
- Appendix B lists the acronyms used in the report.

2 Conceptual High-Level Architecture of Satellite Operations

This section provides a notional, conceptual, high-level architectural view of commercial, crewless space operations. This view can be helpful in understanding, assigning, and managing cybersecurity requirements and risks associated with different owners and operators of different parts of the architectures. This architecture can be under the sole control of one system owner or shared among numerous owners, including public, commercial, and private.

Once in operation, space vehicles share an ecosystem that has no national and few natural boundaries and where safety is a communal concern. For the purposes of this paper and to facilitate subsequent discussions in setting, expressing, or meeting cybersecurity requirements, NIST notionally defines the scope of a commercial space operations architecture to include the following:

Space Architecture Segments

Ground Segment: *Ground operations* are terrestrial-based activities that can be automated or conducted by human operators. They often include some or all of the space operations (i.e., station keeping and payload commanding) and can be co-located with launch facilities or at a separate set of facilities. Ground operations can be outsourced in whole or in part. Even at launch, the payload operator may not be collocated with the launch facility.

Link Segment: *Command and control* are the signaling operations sent to the satellite to conduct a mission function, perform diagnostics, reset the state of the equipment, and/or activate the propulsion systems of the vehicle. Command and control operations are generated on the ground and can be transmitted to the vehicle in several ways. The commands may be sent via a fiber link to a remote ground station, which then transmits the commands via a direct RF or optical link to the satellite from the ground. The second method uses a set of space relays, where the original commands are sent from the ground via RF or optical to a relay satellite and then transmitted via RF or optical to the target satellite. Finally, mobile devices and technologies not associated with a specific ground operations location, such as intra-vehicle communications, can be used to deliver commands to a satellite or its payload.

User Segment: These are consumers, such as GPS receivers, satellite phone users, or satellite TV receivers.

Space Segment: *The space vehicle consists of the satellite* (BUS) and one or more payloads. The BUS consists of the components of the vehicle associated with the "flying of the satellite," such as power, structure, attitude control system, processing and command control, and telemetry. The spacecraft can carry many specialized payloads to conduct missions, including remote sensing and communications. The BUS and the payload generally combine to form the satellite.

Inter-Vehicle Cybersecurity: *Inter-vehicle cybersecurity* refers to the cybersecurity capabilities of the satellite vehicle itself, including its ability to protect itself against cybersecurity threats, detect threat actions, respond to cybersecurity attacks, and recover when necessary. These capabilities should be designed as part of security development and integrated early in the system life cycle. Often, inter-vehicle cybersecurity is the primary responsibility of small commercial satellite owners and operators, and much of the rest of the architecture is outsourced to external suppliers and providers.

Intra-Vehicle Communications: Communications between operational satellites for mission functions – such as command and control, networking of compute capabilities, redundancy of operations and mission functions, tracking, and communications – are known as *intra-vehicle communications*. Therefore, the integrity and authenticity of these communications is critical.

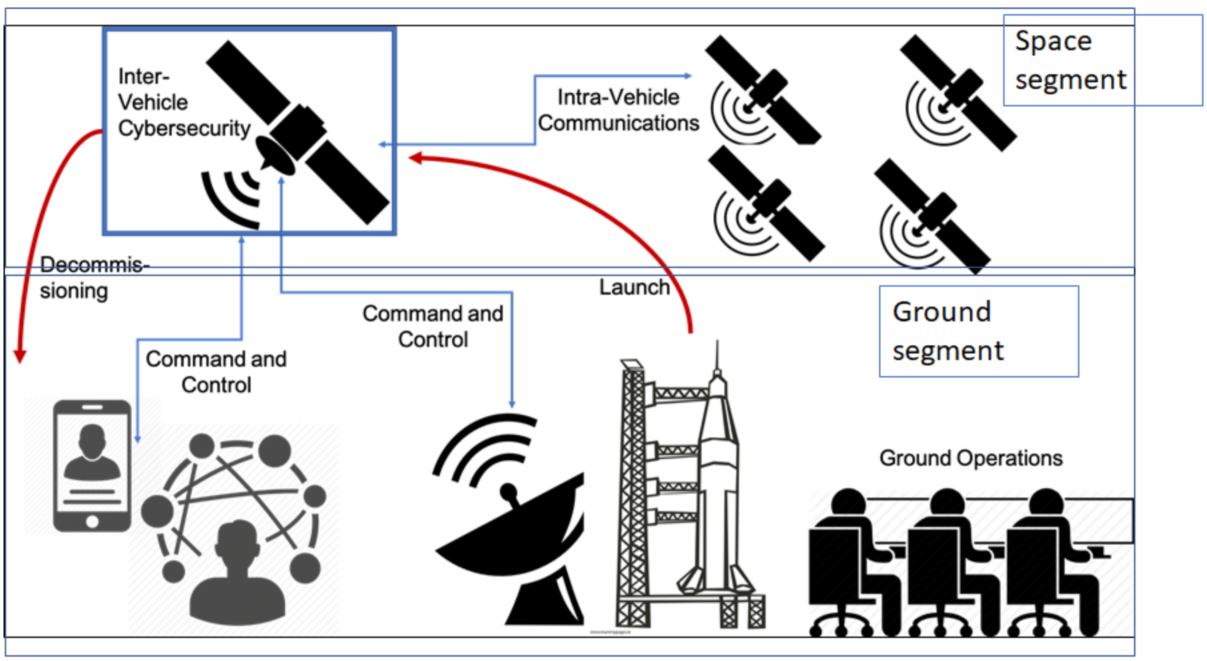

Figure 1. Major Parts of the Conceptual High-Level Architecture of Space Operations

Figure 1 reflects major parts of the conceptual, high-level architecture of satellite operations. This architecture is for crewless spacecraft and does not include cybersecurity requirements for human space systems, spacecraft, or systems that will dock with human systems and/or lunar landers.

Spacecraft Vehicle Life Cycle Phases

The space vehicle will experience different phases of operations, each of which may have unique risks that need to be addressed.

Assembly: Spacecraft components are procured from across the world and brought together to allow the spacecraft to perform various missions. Hardware and software supply chain is, therefore, a critical component of cybersecurity. Once vehicles are launched, the ability to modify hardware is limited, if not impossible. Hardware implants or vulnerabilities are difficult to mitigate and can have a foundational impact on cybersecurity. However, software on a space vehicle can often be patched or modified from the ground.

Prelaunch: This is a critical time for the vehicle, when operators will be testing RF links as well as the utilization of an umbilical cord to the launch vehicle for diagnostics and telemetry. It is important for operators to understand the connectivity and access that the various satellite health monitoring systems have during prelaunch.

Launch: *Launch* is the phase of space commerce that entails moving the space system to its operational environment – generally in low Earth orbit (LEO) – from a pad, rack, ramp, or other device or installation. Launch can include launch devices and installations, fuel operations and storage, and launch safety and destruct systems. Launch can have significant overlap with ground operations, and the two are often combined. However, due to the current cost, complexity, and safety concerns associated with launch, it is often outsourced to small commercial satellites.

On-orbit check out: Once the satellite is placed into orbit, the satellite must beacon and establish a link to the ground command and control system. The satellite typically undergoes several checks to make sure that the system has survived launch and that all systems are operational. Once this has occurred, the satellite will enter operational status.

Operations – Sensing, Information Processing, Data Acquisition, and Communication: The satellite conducts a mission operation that involves some function or combination of functions for sensing, information processing, data acquisition, and communication. These are functional requirements directly related to the business mission of the satellite and are conducted by the satellite and/or its payloads.

Decommissioning: Decommissioning of a commercial satellite is a high-risk endeavor with requirements for the post-mission disposition of satellites. General good practices include maintaining control of orbital debris released during normal operations, minimizing debris generated by accidental explosions, and ensuring the post-mission disposal of space structures. Decommissioning other areas of the space operations architecture can include the need to handle and dispose of sensitive materials, intellectual property, and hazardous materials. The cybersecurity risks of decommissioning should consider appropriate confidentiality, integrity, and availability considerations as well as related physical threats to commercial satellite systems once decommissioned.

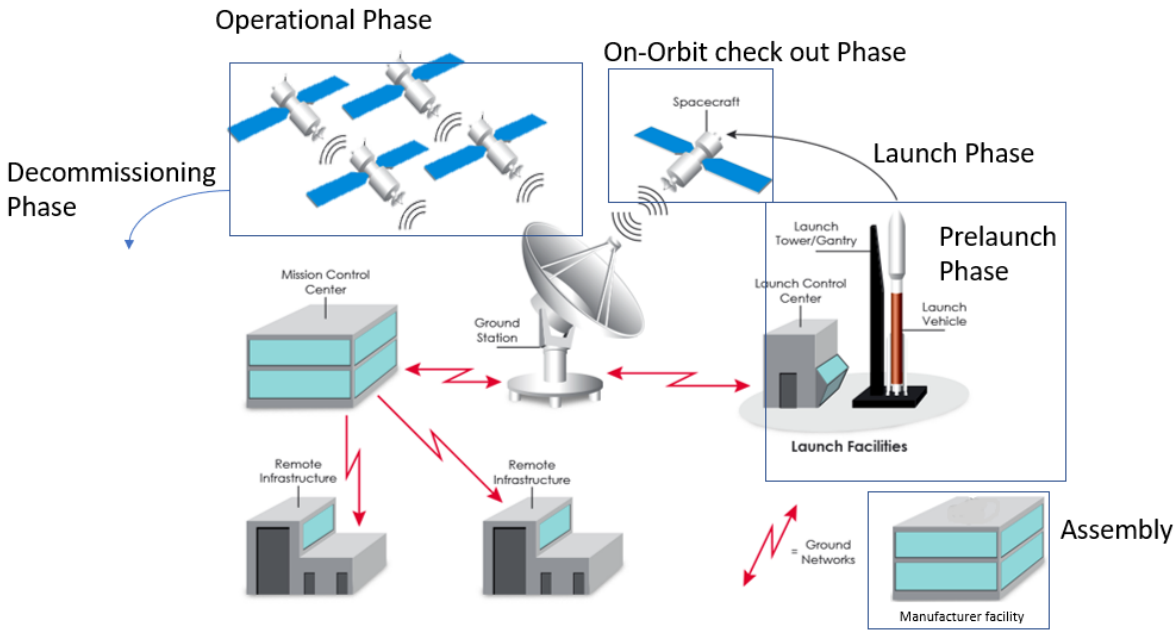

Figure 2. Phases of Operations

3 An introduction to the Cybersecurity Framework

The Cybersecurity Framework was developed in reponse to Executive Order 13636, *Improving Critical Infrastructure Cybersecurity*. The framework is based on a risk management approach to cybersecurity that can be tailored to various industries. It provides common terminology and a methodology that can be implemented by organizations based on their resources and business needs. The Cybersecurity Framework consists of five functions: identify, protect, detect, repond, and recover. The functions are shown in a circular format to communicate to the user that cybersecurty is a continuous process that enables an organization to navigate the changing landscape of cybersecurity risks.

Figure 3. The Cybersecurity Framework

In addition to the five primary functions of the Cybersecurity Framework, there are categories and subcategories that express cybersecurity outcomes and informative references to assist in the implementation of controls that can achieve those outcomes. A breakdown of the CSF can be visualized in Figure 4.

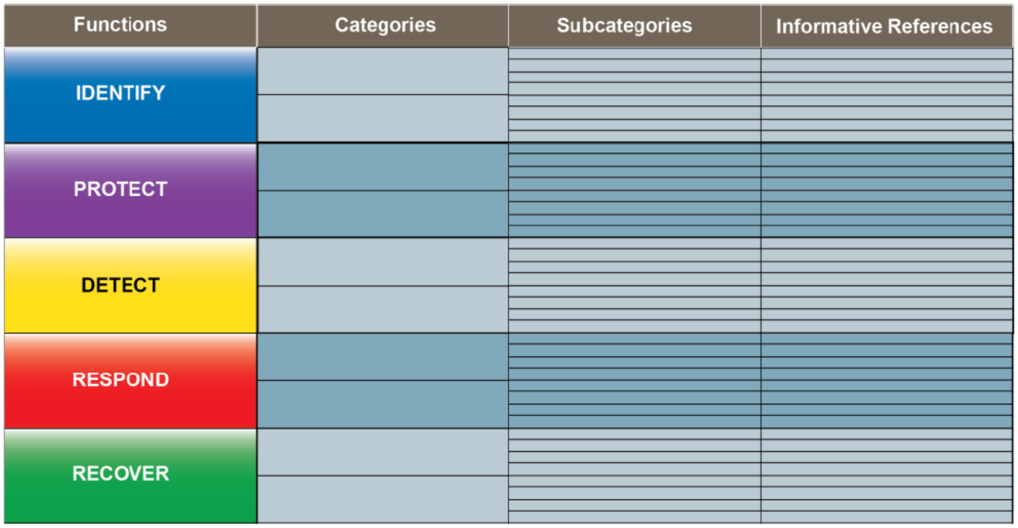

Figure 4. Framework Core Structure

To help explain the context of the categories, subcategories, and informative references, an example of the first row of *identify* with the category of identity and access management is provided in Figure 5. Each category has associated subcategories, which provide specific outcomes. The last column of information references provides references for that particular outcome that cite applicable NIST and SSO references.

Function	Category	Subcategory	Informative References
IDENTIFY (ID)	**Asset Management (ID.AM):** The data, personnel, devices, systems, and facilities that enable the organization to achieve business purposes are identified and managed consistent with their relative importance to business objectives and the organization's risk strategy.	**ID.AM-1**: Physical devices and systems within the organization are inventoried	· **CCS CSC** 1 · **COBIT 5** BAI09.01, BAI09.02 · **ISA 62443-2-1:2009** 4.2.3.4 · **ISA 62443-3-3:2013** SR 7.8 · **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2 · **NIST SP 800-53 Rev. 4** CM-8
		ID.AM-2: Software platforms and applications within the organization are inventoried	· **CCS CSC** 2 · **COBIT 5** BAI09.01, BAI09.02, BAI09.05 · **ISA 62443-2-1:2009** 4.2.3.4 · **ISA 62443-3-3:2013** SR 7.8 · **ISO/IEC 27001:2013** A.8.1.1, A.8.1.2 · **NIST SP 800-53 Rev. 4** CM-8
		ID.AM-3: Organizational communication and data flows are mapped	· **CCS CSC** 1 · **COBIT 5** DSS05.02 · **ISA 62443-2-1:2009** 4.2.3.4 · **ISO/IEC 27001:2013** A.13.2.1 · **NIST SP 800-53 Rev. 4** AC-4, CA-3, CA-9, PL-8
		ID.AM-4: External information systems are catalogued	· **COBIT 5** APO02.02 · **ISO/IEC 27001:2013** A.11.2.6 · **NIST SP 800-53 Rev. 4** AC-20, SA-9
		ID.AM-5: Resources (e.g., hardware, devices, data, and software) are prioritized based on their classification, criticality, and business value	· **COBIT 5** APO03.03, APO03.04, BAI09.02 · **ISA 62443-2-1:2009** 4.2.3.6 · **ISO/IEC 27001:2013** A.8.2.1 · **NIST SP 800-53 Rev. 4** CP-2, RA-2, SA-14
		ID.AM-6: Cybersecurity roles and responsibilities for the entire workforce and third-party stakeholders (e.g., suppliers, customers, partners) are established	· **COBIT 5** APO01.02, DSS06.03 · **ISA 62443-2-1:2009** 4.3.2.3.3 · **ISO/IEC 27001:2013** A.6.1.1 · **NIST SP 800-53 Rev. 4** CP-2, PS-7, PM-11

Figure 5. Example of the Identity Function showing the first category identity and access management, along with the subcategories and informative references

4 Creating a Cybersecurity Program for Space Operations

The application of high-level processes from the Cybersecurity Framework may help satellite operators with the creation and maintenance of a cybersecurity program. While the overall process is applicable to all parts of commercial space architectures and phases of operations, this document also provides a notional example of applying the CSF to generating cybersecurity requirements for the satellite during sensing, information processing, data acquisition, and communication to illustrate how these steps are used and to derive example cybersecurity outcomes, requirements, and controls for this specific use.

4.1 Using the Cybersecurity Framework

While only a few organizations will own or control all aspects of space operations, the Cybersecurity Framework helps with organizing and communicating about cybersecurity risks and activities. The Framework can be used to communicate cybersecurity requirements to suppliers and to manage how risk is mitigated, managed, transferred, or accepted when outsourcing one or more parts of space operations.

Commercial space operations can be hybrid modes with few organizations owning or controlling all parts of space operations. Therefore, communicating clear expectations, capabilities, and requirements across the different owners of the space operations scope is important for understanding and managing cybersecurity risks.

Step 1: Establish Scope and Priorities. It is most effective to address cybersecurity in the earliest stages of building the components of the space architecture and embedding risk-reducing measures that meet organizational mission and business objectives into the design and supply chain. However, many commercial satellite operators have already deployed several generations of their vehicles, and many parts of an architecture are in use.

For companies that have already begun deployment, a current cybersecurity profile should be created to describe what cybersecurity outcomes are being achieved. A target profile can be created to describe the outcomes needed to meet the cybersecurity risk management goals of the organization. A gap analysis of the differences between the current profile versus the target profile provides information that the organization can use to make decisions regarding cybersecurity.

Step 2: Orient. Once the scope of the cybersecurity program has been determined for mission and business needs, the organization identifies related systems, assets, regulatory requirements,[2] and its overall risk approach. The organization then works to identify threats and vulnerabilities applicable to those systems and assets.

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[2] Some examples of regulatory requirements can be found in Appendix A.

Step 3: Create a Current Profile. This step allows the organization to understand their current cybersecurity posture. An organization can assess how it is currently implementing the CSF functions by creating a Current Profile: a list of subcategory activities that are currently being implemented within the organization.

Step 4: Conduct a Risk Assessment. This assessment could be guided by the organization's overall risk management process or previous risk assessment activities. The organization analyzes the operational environment, identifies emerging risks, and uses cyber threat information from internal and external sources to discern the likelihood of a cybersecurity event and the impact that the event could have on the organization.

Step 5: Create a Target Profile. The organization creates a Target Profile by selecting the subcategories that support the organization's desired cybersecurity outcomes. Each organization will have a unique risk posture, which will result in a unique set of subcategories.

Step 6: Determine, Analyze, and Prioritize Gaps. The organization compares the Current Profile and the Target Profile to identify potential gaps. It then creates a prioritized action plan to address those gaps.

Step 7: Implement Action Plan. The organization determines which actions to take to address the gaps.

4.2 Case Study Example

This section provides a short example walk-through using the Cybersecurity Framework steps for a notional low Earth orbit (LEO) "small satellite vehicle," which represents only one portion of larger space operations. The same process[3] can be applied to the other areas of space operations, if needed. In this notional example, a Framework Profile is created to address the core cybersecurity areas below:

- **Identify** assets, threat models, and regulatory requirements.
- **Protect** assets using outcomes that are then traced to controls and standards.
- **Detect** cybersecurity issues and threats as they materialize.
- **Respond** to those threats.
- **Recover** from incidents.

For Step 1 – The notional use case is scoped to just the following aspects of Figure 1: the satellite vehicle itself, Inter-Vehicle Cybersecurity, Command and Control, and Sensing, Information Processing, and Data Acquisition. The notional company only owns and controls the satellite vehicle part of the operations. They will use its generated target profile to express

[3] It is important to note that the CSF is not prescriptive about how the steps should be applied, and this use case is intended for use as one of many possible methods.

cybersecurity requirements for their vehicle and to compare products and services offered for other areas of space operations that are hybrid and/or outsourced.

For Step 2 – The organization's business leaders identify relevant regulatory requirements and critical systems, and they model potential high-level threats (and their potential impacts). The organization defines its critical systems as those with a direct impact on the satellite itself, as well as their business model, which acquires "data over a geographic area." Organizational leadership determines that the business and mission-critical systems are:

- Communications technologies
- Guidance control
- Sensor systems

The organization then generates a high-level cybersecurity risk model that can be help identify its most severe cybersecurity vulnerabilities, the threat events that are most likely occur, and events that could have the highest negative impact on the business. This analysis is less rigid than the detailed risk evaluation that occurs in Step 4 and is intended to spur discussion regarding the types of risk events that might have some impact on the organization. The resulting risk understanding helps in shaping the Current State Profile described in Step 3.

A list of the events and the business impacts is then generated:

Cybersecurity Events	***Business Impacts***
Intentional jamming and spoofing of sensor data	loss of data assets for customers
Interception and theft of sensor data	loss of markets and customers
Intentional corruption of sensor systems	loss of satellite vehicle
Jamming of guidance control	loss of satellite vehicle
Hijacking and unauthorized commands to guidance control	loss of satellite vehicle
Malicious code injection	loss of satellite vehicle, data corruption, and data loss
Denial-of-service attack	loss of data and/or loss of guidance

To mitigate these high-impact, high-probability events, a set of needed cybersecurity outcomes is generated. These are, in effect, the inverse of the threat models to the critical systems and are placed in the terms used in the core of the CSF where they are most appropriate for the outcomes. An example is below:

- *Protect/Detect/Respond/Recover* from jamming, spoofing, and data interception of communication technologies;
- *Protect/Detect/Respond/Recover Guidance Control* from unauthorized access, unauthorized commands, and unauthorized jamming;
- *Protect/Detect/Respond/Recover* from spoofing, interception, and the corruption of sensor data;
- *Protect/Detect/Respond/Recover Satellite Operations* from malicious code attacks; and,
- *Protect/Detect/Respond/Recover* communication technologies, sensors, and guidance controls from denial-of-service attacks.

Regulations and other requirements for each component of operations, specifically for the sensing satellite vehicle, are identified and used to generate outcomes that are added to the above list when needed. These are then tagged to identify their sources as regulatory and to ensure that any needed records are generated and maintained on the implementation of these requirements.

Currently, many federal agencies hold oversight over and requirements in different elements of space operations. These are the primary inputs for identifying initial cybersecurity requirements for space commerce systems. Some examples of relevant regulations are described in Appendix A.

<u>*For Step 3*</u> – Assume that the only current cybersecurity implementation is that driven by regulatory requirements. In the example use case, these are the NOAA requirements for the licensing of Private Remote Sensing Space Systems. The organization will need to assure and state that:

> The methods applicant will use to ensure the integrity of its operations, including plans for: Positive control of the remote sensing space system and relevant operations centers and stations; denial of unauthorized access to data transmissions to or from the remote sensing space system; and restriction of collection and/or distribution of unenhanced data from specific areas at the request of the U.S. Government.[4]

The organization documents the policies, processes, and technology that are in place, especially those related to the high-level cybersecurity risk issues described in Step 2. The organization should walk through all of the subcategories outlined in the Cybersecurity Framework and select those that are currently in practice. The list of subcategories being addressed forms the "Current Profile." For the purposes of this example, the company has found that they are currently implementing the following, which will serve as their "Current Profile":

- PR.AC-1: Identities and credentials are issued, managed, verified, revoked, and audited for authorized devices, users, and processes.

[4] https://www.nesdis.noaa.gov/CRSRA/licenseHome.html

- PR.AC-4: Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties.
- PR.AC-7: Users, devices, and other assets are authenticated (e.g., single-factor, multi-factor) commensurate with the risk of the transaction (e.g., individuals' security and privacy risks and other organizational risks).
- PR.DS-1: Data at rest is protected.
- PR.DS-2: Data in transit is protected.
- PR.DS-4: Adequate capacity to ensure availability is maintained.
- PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity.
- PR.IP-12: A vulnerability management plan is developed and implemented.
- PR.PT-5: Mechanisms (e.g., fail-safe, load balancing, hot swap) are implemented to achieve resilience requirements in normal and adverse situations.
- DE.AE-3: Event data is collected and correlated from multiple sources and sensors.
- DE.CM-1: The network is monitored to detect potential cybersecurity events.
- DE.CM-4: Malicious code is detected.
- DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed.

For Step 4 – The organization prioritizes and validates the needed cybersecurity outcomes from Step 3 and uses them to inform the specific technical cybersecurity controls to be selected to meet those outcomes.

The organization considers the costs of cybersecurity mitigation and the potential risks addressed in light of each subcategory recorded in the Current State Profile. The team consults various authorities at the Department of Homeland Security and Department of Defense to better understand potential threats to space-based network operations. The organization joins a local Information Sharing and Analysis Center (ISAC) so that company representatives will have a venue for sharing and receiving prioritized information regarding known risks as the threat and technology landscapes evolve.

The organization applies the principles described in NIST SP 800-30, *Guide for Conducting Risk Assessments*, to set a scale for likelihood and impact and to prioritize outcomes and controls that can manage the risks with the most negative impacts and/or that are most cost-effective for their risk management results. Supported by this information, the organization is then prepared to determine the outcomes that will achieve the desired risk posture in a cost-effective way.

For Step 5 – The organization creates the following Target Profile to express its satellite vehicle Cybersecurity Requirements. Table 1 maps outcomes that address threats and associated technical controls. An ordinal count is made for the amount of individual outcome and threat-pairing that a control might address. This will further assist in establishing priorities and helping with investment decisions. For example, one cybersecurity control might be effective in achieving many of the outcomes sought. This information can assist in understanding priorities as well as mitigations that might need stronger monitoring, detection, and recovery capabilities.

The creation of these outcome/threat-pairings with mitigation techniques also builds a list of references that can be used to express the specific technical requirements of the control. These include NIST references and those from other sources, such as Standard Development Organizations (SDOs), the Committee on National Security Systems Instructions (CNSSI) 1200, and others that are relevant to the organization.

Table 1: Control Table for Addressing Outcomes Countering Threat Models

Outcome	Threat	Mitigation Technique	CSF Subcategory	Potential 800-53r4 Control Reference	Potential 800-53r5 Control Reference
Protect communication technologies	Denial of service (DOS)	Authenticated communications	PR.AC-7 PR.DS-4	IA-1, 2,3,5,8 SC-5, AU-4	IA-1, 2,3,5,8 SC-5, AU-4
		Allow listing	PR.IP-1	PS 2,3,4,5,6 CM-7	CM-7
		System resilience	PR.PT-5	CP-2,7 SA-14	CP-7
	Spoofing	Authenticated communications	PR.AC-7 PR.DS-4	IA-1, 2,3,5,8	IA-1, 2,3,5,8
		Allow listing	PR.IP-1	PS 2,3,4,5,6 CM-7	CM-7
		Access control	PR.AC-1 PR.AC-3 PR.PT-3 PR.AC-6 PR.AC-7	AC-3, 8, 9,19	AC-3
		Encryption of data in transit	PR.DS-2	SC-8/SC-17	SC-8
	Data interception	Encryption of data in transit	PR.DS-2 PR.DS-4	SC-5, SC-8	SC-5,8
Detect threats to communication technologies	DOS		DE.CM-1	SC-5	SC-5
	Spoofing	Audit logs of communication activity	ID.SC-4 DE.DP-4	AU-2	
	Data interception	Encryption of data in transit	PR.DS-2 PR.DS-4	SC-5, SC-8	SC-5,8
Respond to threats to communication technologies	DOS	Use of secondary/alternate channels; log, report, share	RS.MI-1 PR.DS-4 PR.PT-1	IR-4	IR-4
	Spoofing	Log, report, share	PR.PT-1	AU Family	AU-1,2,3,6,7,12,13,14, 16
	Data interception	Encryption of data in transit	PR.DS-2 PR.DS-4	SC-8, SC-11	SC-8,11

Outcome	Threat	Mitigation Technique	CSF Subcategory	Potential 800-53r4 Control Reference	Potential 800-53r5 Control Reference
Recover from Threats to Communications Technologies	DOS	Audit, Self/Health Testing	RC.IP-1	CP-10, IR-4, IR-8	CP-10, IR-4, IR-8
	Spoofing	Audit, Self/Health Testing	RC.IP-1	AU-2	
	Data Interception	Encryption of Data in Transit	RC.IP-1	SC-5, SC-8	SC-5, SC-8
Protect guidance control	Unauthorized access	Access control	PR.AC-4 PR.DS-1		
	Unauthorized commands	Authenticated communication	PR.AC-6 PR.AC-7	SC-8	SC-8
		Encryption of data in transit	PR.DS-2 PR.DS-4	SC-8	SC-8
	DOS	Authenticated communications	PR.AC-6 PR.AC-7	SC-8	SC-8
		Command signal allow listings	PR.IP-1	CM-7	CM-7
		System resilience/fail-safe	PR.PT-5		
Detect threat to guidance control	Unauthorized access	Access logging and audit	DE.CM-4 PR.PT-1 PR.AC-7	AU-2/AC-7	AU-2
	Unauthorized commands	Command logging and audit	DE.CM-4 DE.CM-7 PR.PT-4 PR.AC-7 PR.PT-1	AU-2/AC-7, SC-24	AU-2
	DOS	Drop unauthorized communications/fail-safe	PR.PT-5	AC-3, 8,9,19	AC-3
Respond to threats to guidance control	Unauthorized access	Forensic review of data and access areas; system lockout	RS.AN-3 RS.MI-1 PR.AC-7	AC-7	AC-7
	Unauthorized commands	Forensic review of command logs; system lockout	RS.AN-3 RS.MI-1 PR.AC-7 PR.PT-4	SC-24	
	DOS	Drop unauthorized communications/fail-safe	PR.AC-3, PR.AC-4 PR.PT-5	AC-3, 8,9,19	AC-3
Recover to threats to guidance control	Unauthorized access	Access credential rotation and refresh	PR.AC-1, PR.AC-6, PR.AC-7	AC-3, 8,9,19	AC-3

Outcome	Threat	Mitigation Technique	CSF Subcategory	Potential 800-53r4 Control Reference	Potential 800-53r5 Control Reference
	Unauthorized commands	Access credential rotation and refresh	PR.AC-1, PR.AC-6, PR.AC-7	AC-3, 8,9,19	AC-3
	DOS		PR.PT-4, PR.PT-5		
Protect sensor data	Spoofing	Encryption of data in transit	PR.DS-2	SC-8	SC-8
	Corruption	Message authentication	PR.AC-7	SC-8	SC-8
		Digital signature	PR.AC-6	SC-8	SC-8
	Interception	Encryption of data in transit	PR.DS-2	SC-8	SC-8
	DOS	Fail-safe/store and send	PR.PT-5 PR.DS-1 PR.DS-6	SI-7	SI-7
Detect threats to sensor data	Spoofing	Detect unauthorized access to data; encryption	DE.CM-1 DE.AE-3 DE.CM-7	SC-5	SC-5, CM-3, 8
	Corruption	Data reference checks	DE.AE-3	SC-5	SC-5, CM-3, 8
	DOS	Data type allowlistings	DE.CM-7	CM-7	SC-5, CM-3, 8
Respond to threats to sensor data	Spoofing	Data quality checks	RS.AN-1 RS.AN-3	AC-7	
	Corruption	Data quality checks	RS.AN-1 RS.AN-3	AC-7	AU-7, IR-4
	Interception	Encryption	PR.DS-2	SC-8	SC-8
	DOS	ReXmit/Data ACK, HMACs/CRCs	PR.PT-4, PR.PT-5	AC-4, AC-17, SC-7	
Recover from threats to sensor data	Spoofing	Restore systems or assets	RC.IP-1	CP-10, IR-4, IR-8	CP-10, IR-4, IR-8
	Corruption	Restore systems or assets	RC.IP-1	CP-10, IR-4, IR-8	CP-10, IR-4, IR-8
	Interception	Restore systems or assets	RC.IP-1	CP-10, IR-4, IR-8	CP-10, IR-4, IR-8
	DOS	Restore systems or assets	RC.IP-1	CP-10, IR-4, IR-8	CP-10, IR-4, IR-8
Protect satellite operations	Malicious code	Secure engineering	PR.IP-1 PR.IP-3	CM-3, 4, 10	CM-3, 4, 10

Outcome	Threat	Mitigation Technique	CSF Subcategory	Potential 800-53r4 Control Reference	Potential 800-53r5 Control Reference
		Independent bus design	PR.PT-5	CP-7	
		Malware detection	PR.DS-6	SI-7	SI-7
		Input constraints/allow listings	PR.PT-3	AC- 3	AC-3 , 7
		BIOS security	PR.DS-6, PR.DS-8	SI-7	SI-7
		Secure update	PR.DS-6 PR.IP-12	SI-7	SI-7
Detect threats to satellite operations	Malicious code	AV/Health checks	DE.CM-4, DE.CM-7	AU-2, AC-7	
Respond to threats to satellite operations	Malicious code	Alternate safety check methods	RS.AN-1 RS.AN-3 RS.MI-1	AC-7	
Recover to threats to satellite operations	Malicious code	Secure update/reinstall; verify data sets; self-testing	RC.IP-1	CP-10, IR-4, IR-8	CP-10, IR-4, IR-8

For Step 6 – The organization determines a new cybersecurity baseline, and each row in the Target Profile will be part of the new action plan. In subsequent iterations, this step will identify gaps between the current and target states and will provide an opportunity to add or update plans.

In light of the desired state, as described in the profile, the following action plans for protecting the cybersecurity of the satellite vehicle service is created.

To protect the satellite and its data from communications spoofing, interception, corruption, tampering, and denial of service:

1. Only allow authorized devices to communicate with the satellite, and employ the following requirements:
    a. Authenticate the claimed identity of any device attempting to communicate. CSF: PR.AC-1, PR.AC-6, PR.AC-7
    b. Drop all communication attempts for which the access authorization of the other device cannot be confirmed. CSF: PR.AC-3, PR.AC-4
    c. Check the integrity of communications and drop any communications where integrity appears to have been violated. CSF: PR.DS-2
2. Only allow authorized devices to access sensitive data within the satellite's communications.

   a. Use encryption to protect the contents of communications. CSF: PR.DS-2, PR.DS-4
   b. Require that the recipient of encrypted communications be authenticated before they can decrypt the communications and access their contents. (See 1a above.)
3. Make the satellite's communications resilient to adverse conditions.
   a. Use communication protocols that ensure delivery. CSF: PR.PT-5
   b. Have a secondary or alternate communications channel available at all times, and automatically fail over to it when the primary communications channel is not functioning properly. CSF: PR.PT-5
   c. When communications are unavailable, store any unsent sensor data and send it after communications are restored. CSF: PR.PT-5
4. Build protections into the satellite to thwart DDoS-related connection attempts. CSF: PR.PT-4, PR.PT-5

To protect the satellite and its data from unauthorized access, use, corruption, tampering, and denial of service:

1. Use secure device design and development practices for the satellite hardware, firmware, operating system, and applications.
   a. Isolate executing processes from each other. See the SSDF publication.
   b. Validate all input, including commands and data (e.g., allow listings, input constraints). See the SSDF publication.
   c. Satellites typically have multiple redundant paths to account for failures in orbit. For example, the MIL-STD-1553 data bus has multiple redundant paths. The standard also calls for an "A" side and a "B" side for space vehicles and associated redundant hardware that will allow the satellite to operate if any component fails. The isolation of the data bus is logical, not physical, and space operators should consider isolation as part of their design, understanding the SWAP (i.e., size, weight, and power) impacts that this may produce.
   d. Build protections into the device for DoS attacks.
2. Prevent and deter attacks against the satellite.
   a. Use a hardware root of trust to perform a secure boot, which will be the basis for verifying BIOS security and conducting system integrity checks and other health checks/self-tests. CSF: PR.DS-6, PR.DS-8
   b. Provide update, upgrade, and uninstall capabilities for firmware and software. (Also see items 1 and 2 above.) CSF: PR.IP-12
   c. Configure the satellite to avoid known security weaknesses. CSF: PR.IP-1, PR.IP-3

   d. Prevent unauthorized software from executing (e.g., anti-malware software, application allow listings software, code signing). CSF: DE.CM-4, DE.CM-7, PR.PT-3

3. Only allow authorized parties to access and alter sensor data stored on the satellite.
   a. Enforce the principle of least privilege. CSF: PR.AC-4, PR.DS-1
   b. Protect the integrity of all stored sensor data. CSF: PR.DS-1, PR.DS-6

To detect, respond to, and recover from attacks and incidents involving the satellite, its data, and its communications:

1. Log security-related events, and continuously review the logs. CSF: PR.PT-1, DE.AE-3, DE.CM-1
2. Investigate suspicious events. CSF: DE.DP-4, RS.AN-1, RS.AN-3
3. Prevent an incident from continuing or expanding (e.g., by failing safe). CSF: RS.MI-1
4. Recover from incidents by restoring data and software. RC.IP-1

For Step 7 – Security leaders present the action plan to key company stakeholders for approval. The business case and requests for appropriate resources are presented to the executives for approval of the plan. Processes to monitor and review the plan's implementation ensure that the activities sufficiently address cybersecurity risks to satellite operations, allow for future updates to the profiles, and maintain oversight over external service providers.

4.3 Conclusion

NIST has provided this example to show how an organization might apply the steps of the Cybersecurity Framework to evaluate and address possible security risks. NIST recommends that organizations apply the steps that best apply to their threat models, business cases, and risk tolerance. As the industry expands, NIST will continue to support the community through research products and risk management guidance.

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Appendix A—Examples of Relevant Regulations

This appendix provides examples of regulations that may be relevant to some but not all commercial satellite operations. It is important for each organization to identify the potential regulation and regulatory agency that applies to their specific operations and business.

DoD/IC/NGA

From the *National Information Assurance Policy for Space Systems Used to Support National Security Missions* by the Committee on National Security Systems Publication (CNSSP) No. 12:

> Presidential Policy Directive (PPD-4), *National Space Policy of the United States of America*…reiterates that United States national security is critically dependent upon space capabilities and this dependence will grow. Space activities are also closely linked to the operation of the United States Government's (USG) critical infrastructures and have increasingly been leveraged to satisfy national security requirements. Therefore, increased assurance and resilience are needed for the mission-essential functions of national security space systems, including their supporting infrastructure, to help protect against disruption, degradation, and destruction, whether from environmental, mechanical, electronic, or hostile means.

> The primary objective of this policy [CNSSP-12] is to help ensure the success of national security missions that use space systems, by fully integrating information assurance into the planning, development, design, launch, sustained operation, and deactivation of those space systems used to collect, generate, process, store, display, or transmit national security information, as well as any supporting or related national security systems. Fully addressing information assurance is especially important for the space platform portion of space systems, since any vulnerability in them normally cannot be eliminated once launched.

Federal Communications Commission (FCC)

Regarding the International Bureau Satellite Division, Federal Communications Commission (FCC):

> The primary mission of the Satellite Division is to serve U.S. consumers by promoting a competitive and innovative domestic and global telecommunications marketplace. The Division strives to achieve this goal by:

1. Authorizing as many satellite systems as possible and as quickly as possible to facilitate deployment of satellite services;
2. Minimizing regulation and maximizing flexibility for satellite telecommunications providers to meet customer needs;
3. Fostering efficient use of the radio frequency spectrum and orbital resources. The Division also provides expertise about the commercial satellite industry in the domestic

> spectrum management process and advocates U.S. satellite radiocommunication interests in international coordinations and negotiations.

Federal Aviation Administration (FAA)

Regarding the Office of Commercial Space Transportation:

> The Office of Commercial Space Transportation (AST) was established in 1984…as part of the Office of the Secretary of Transportation within the Department of Transportation (DOT). In November 1995, AST was transferred to the Federal Aviation Administration (FAA) as the FAA's only space-related line of business. AST was established to:

- Regulate the U.S. commercial space transportation industry, to ensure compliance with international obligations of the United States, and to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States;
- Encourage, facilitate, and promote commercial space launches and reentries by the private sector;
- Recommend appropriate changes in Federal statutes, treaties, regulations, policies, plans, and procedures; and
- Facilitate the strengthening and expansion of the United States space transportation infrastructure.

National Oceanic and Atmospheric Administration (NOAA)

Regarding the Commercial Remote Sensing Regulatory Affairs (CRSRA) Licensing Program:

> This web site is intended to provide U.S. laws, regulations, policies, and guidance pertaining to the operation of commercial remote sensing satellite systems. Pursuant to the National and Commercial Space Programs Act (NCSPA or Act), 51 U.S.C. § 60101, et seq, responsibilities have been delegated from the Secretary of Commerce to the Assistant Administrator for NOAA Satellite and Information Services (NOAA/NESDIS) for the licensing of the operations of private space-based remote sensing systems.
>
> In accordance with the Act, the regulations 15 CFR Part 960 concerning the licensing of private remote sensing space systems have been promulgated.

Appendix B—Acronyms

Selected acronyms and abbreviations used in this paper are defined below.

AST	Office of Commercial Space Transportation
CFR	Code of Federal Regulations
CIO	Chief Information Officer
CNSS	Committee on National Security Systems
CNSSP	Committee on National Security Systems Publication
CRSRA	Commercial Remote Sensing Regulatory Affairs
CTO	Chief Technology Officer
DOT	Department of Transportation
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FOIA	Freedom of Information Act
IR	Internal Report
ITL	Information Technology Laboratory
LEO	Low Earth Orbit
NCSPA	National and Commercial Space Programs Act
NESDIS	National Environmental Satellite, Data, and Information Service
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
OSC	Office of Space Commercialization
PPD	Presidential Policy Directive
SP	Special Publication
USG	United States Government

Appendix C—Glossary

Beacon	Initial signal by satellite conducted when first put into mission operation in order to establish communications with command and control and report initial operating status.
BUS	Consists of the components of the vehicle associated with the "flying of the satellite," such as power, structure, attitude control system, processing and command control, and telemetry. The spacecraft can carry many specialized payloads to conduct missions, including remote sensing and communications. The BUS and the payload generally combine to form the satellite.
Payload	Mission-specific items of the overall satellite that are not part of the overall operations or "flying" of the satellite.
Satellite	BUS and payload combined into one operational asset.
Space Structures	Term referring to "space debris" or "space junk" that is no longer in use for any business or mission need.
Umbilical Cord	Connective cabling to BUS, Satellite, Payload and/or Vehicle that can exchange data with the mission systems.
Vehicle	Space-operational items that include the launching items that are used to place the satellite, BUS and/or payload into orbit.