United States Government Accountability Office

Report to Congressional Committees

February 2025

LASER COMMUNICATIONS

Space Development Agency Should Create Links Between Development Phases

GAO-25-106838

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GAO Highlights

Highlights of GAO-25-106838, a report to congressional committees

Why GAO Did This Study

The Department of Defense (DOD) is developing space-based laser technology to support large constellations of satellites for missions, including missile warning and data transport. Laser communications could improve capabilities beyond traditional radio frequency communications that DOD has traditionally used, in part, because data can be transmitted faster. These constellations are expected to cost nearly $35 billion through fiscal year 2029.

A Senate report includes a provision for GAO to assess DOD's efforts to develop these capabilities. GAO's report (1) describes SDA's efforts to develop laser communications technology, and (2) evaluates the extent to which SDA is following leading product development practices for its laser communications efforts.

GAO reviewed relevant documents; assessed SDA's schedule and plans against leading acquisition practices; conducted site visits to Air Force Research Lab, Naval Research Lab, and contractor facilities; and interviewed DOD, SDA, and Space Force officials and contractor representatives.

What GAO Recommends

GAO is making four recommendations, including that SDA demonstrate laser communications capabilities before finalizing efforts in T0 and before making further investments in subsequent tranches. DOD concurred with our recommendations with comments.

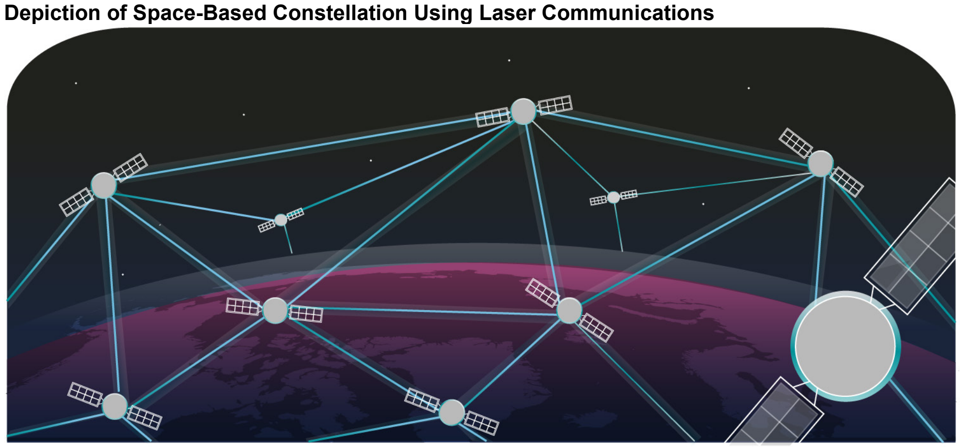
View GAO-25-106838. For more information, contact Jon Ludwigson at (202) 512-4841 or ludwigsonj@gao.gov.

What GAO Found

The Space Development Agency (SDA) has taken steps to develop laser communications technology but has not yet fully demonstrated it in space. SDA has planned for iterations of satellites and related systems to be launched every 2 years, referred to as tranches. SDA's demonstration tranche—referred to as Tranche 0 or T0—has faced development challenges and delays and has not fully demonstrated the capabilities expected from it. For example, SDA planned to launch the first T0 satellites in 2022 but launched them in 2023 and 2024. Further, this initial group of satellites has not yet fully demonstrated laser communications technology in space. Specifically, as of December 2024, SDA reported that one of its four prime contractors in T0 had demonstrated three of the eight planned laser communications capabilities while another contractor had demonstrated one of the eight capabilities. The remaining two contractors have not yet achieved any planned capabilities.

SDA's development approach thus far is inconsistent with the leading practices GAO identified. For example, although it has not yet achieved its requirements established for T0, SDA has now awarded contracts worth almost $10 billion for Tranche 1 and Tranche 2 (referred to as T1 and T2). Further, these two new tranches are expected to include increased technology complexity and significantly more satellites. While T0 was planned with 28 satellites, T1 and T2 are to have 165 and 264, respectively.

Depiction of Space-Based Constellation Using Laser Communications



Source: GAO analysis of Department of Defense information; illustration. | GAO-25-106838

According to GAO's leading practices for product development, iterative development depends on demonstrating necessary capability in each iteration. SDA has described its efforts as iterative and noted that tranches need to work together to create the laser-based constellations. However, SDA officials also said that tranches are independent and delays in one will not delay the development schedule of future tranches. This approach means that SDA is proceeding through tranches and increasing the complexity of its development based on designs that have not yet met initial capabilities. As a result, SDA is at risk of unnecessarily investing in new efforts without yet delivering on promised capabilities intended to support critical missions.

Contents

Abbreviations

AFRL	Air Force Research Laboratory
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
GPS	Global Positioning System
LEO	low Earth orbit
MTA	Middle Tier of Acquisition
MVC	minimum viable capability
MVP	minimum viable product
OCT	optical communications terminal
PAT	pointing, acquisition, and tracking
PWSA	Proliferated Warfighter Space Architecture
SDA	Space Development Agency
T(#)	tranche number

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441 G St. N.W.
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February 26, 2025

Congressional Committees

In response to the increasing threats to current satellites and emerging threats such as hypersonic missiles, the Department of Defense's (DOD) Space Development Agency (SDA) is developing a new space-based architecture comprised of a large constellation of satellites. This effort, known as the Proliferated Warfighter Space Architecture (PWSA), is a planned space-based design of at least 300-500 satellites in low Earth orbit (LEO). It is designed to include a Transport Layer with planned capabilities including transmitting data throughout the constellation and a Tracking Layer to provide critical missile warning and missile tracking capabilities. DOD has committed nearly $11 billion to this effort since 2020 and plans to spend a total of nearly $35 billion for it through fiscal year 2029.[1]

The PWSA is relying on successfully implementing new space-based optical communications—referred to in this report as laser communications—technology that would enable transmission of data within space and to the Earth. The commercial sector has been developing and using similar technology in recent years, and the Space Force hopes to leverage these commercial advancements to support its efforts.

Space-based laser communications are a significant change from traditionally used radio frequency-based communications technologies. It may mean advantages such as the ability to transmit at much higher data rates through significantly narrower transmission beams, which enables more secure communication between users.

However, this technology is much more complex, and the Space Force is working with multiple vendors to develop it. Nevertheless, the number of vendors involved adds further complexity to the overall effort. Among other things, the Space Force will need to ensure that different vendors' satellite optical communications terminals (OCT), devices used to

[1]These figures include current and planned funding for PWSA satellites and launch services, but do not include other critical elements such as ground stations.

establish laser data transmission links, are able to communicate with each other.

A report accompanying the James M. Inhofe National Defense Authorization Act for Fiscal Year 2023 directs us to assess DOD's efforts to develop laser communications capabilities.[2] DOD has a number of efforts to develop laser communications technology. Because SDA's acquisition of laser technology is relatively advanced compared to other DOD efforts, our report (1) describes SDA's efforts to develop and demonstrate laser communications technology; and (2) evaluates the extent to which SDA is following leading product development practices for incorporating space-based laser communications technology into its PWSA.

To answer these objectives, we reviewed relevant documentation such as SDA's OCT Standards and technical memorandums used by commercial vendors in developing OCTs for SDA's PWSA. We also reviewed planning documents, test strategies and reports, SDA's request for proposals, and contracts. We assessed SDA's schedule and plans against some of our criteria on leading acquisition practices. We also conducted site visits and interviewed officials from the Naval Research Laboratory, DOD testing agencies, Defense Advanced Research Projects Agency (DARPA), and Air Force Research Laboratory (AFRL) to better understand the development, testing, and some of the ways SDA is collaborating on developing laser communications technology. Additionally, we interviewed PWSA contractors and commercial vendors responsible for the design, development, manufacture, and supply of OCTs to the DOD contractors in support of SDA's PWSA. Appendix I includes more details about our objectives, scope, and methodology.

We conducted this performance audit from May 2023 to February 2025 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

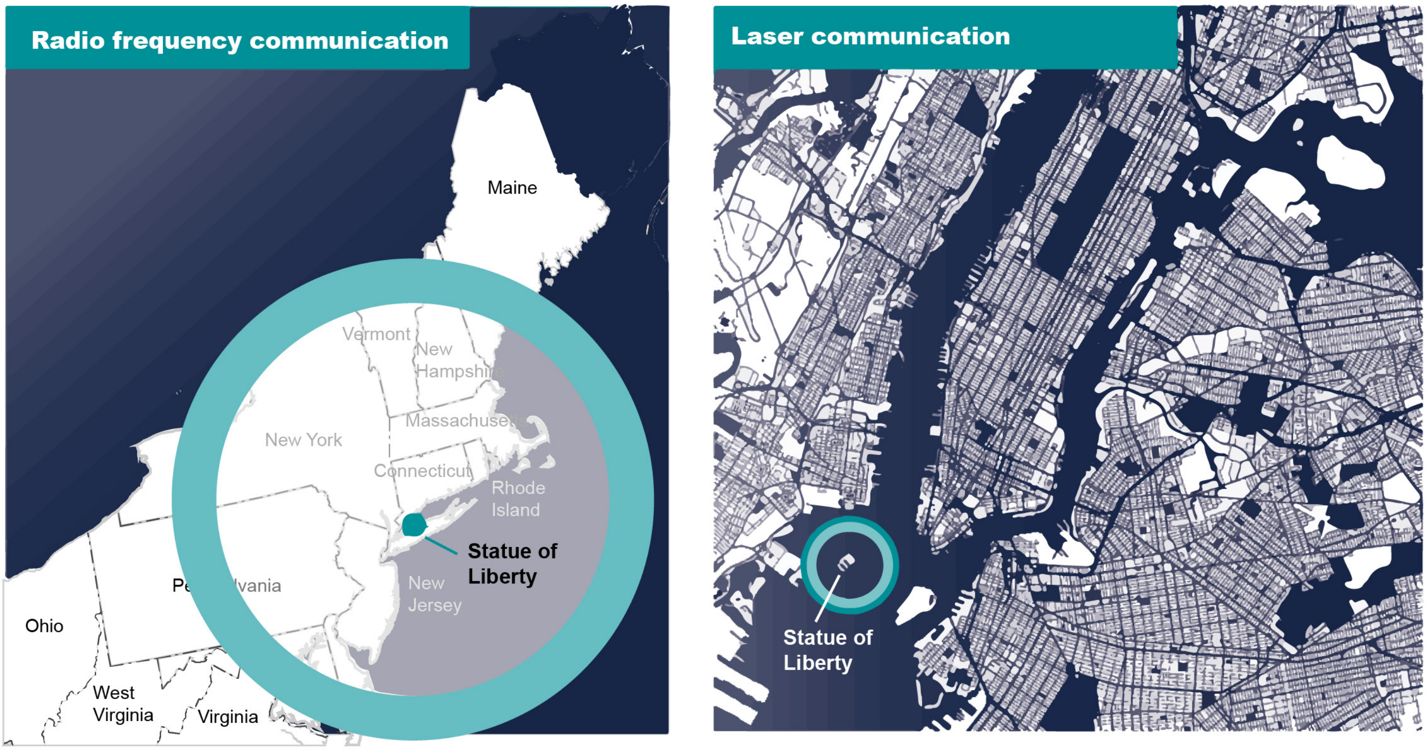
[2]S.Rep. No. 117-130, at 323 (2022).

Background

Laser Communications Technology in Space

DOD is in the early stages of developing a new way to communicate in space, using laser technology. According to department documents, DOD has traditionally relied on radio frequency—electromagnetic waves that transmit data over a specific frequency—to communicate between satellites and with receivers on the ground or sea or in the air. Specifically, like radio frequency, laser communications can be used to transmit data from space-to-space; space-to-ground, such as to ground stations or ships at sea; and space-to-air, such as to aircraft in flight. According to DOD documentation and laser communication technology developers, laser communications are an alternative to using radio frequency to transmit data in space and are capable of communicating at a rate 10 to 40 times higher than radio frequency data transmission rates, using a beam of light that is about 1,000 times narrower. As shown in figure 1, this narrower beam means that laser communications have a far smaller "footprint" or area in which a receiver can receive data. This limits the potential for adversaries or others to intercept the signal.

Figure 1: General Difference in the Area That Transmissions to the Statue of Liberty from Low Earth Orbit Could Be Received



not to scale

Source: GAO illustration based on multiple sources; (left) Map resources; (right) Knut Hebstreit /adobe.stock.com. | GAO-25-106838

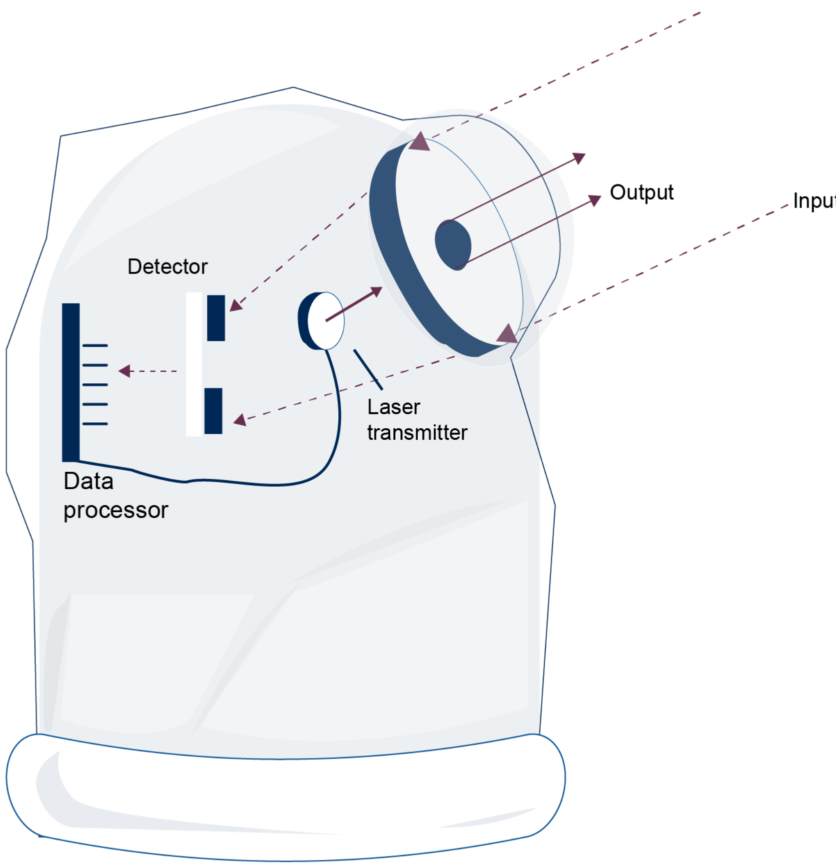
In laser communications, data are transferred using laser beams from one OCT to another.[3] In space-based laser communications, OCTs are affixed to a satellite and transmit data to other compatible OCTs or receivers. For two OCTs to transmit signals between one another, they must have compatible waveforms, unique characteristics of the laser beam that carry the data through space.

Figure 2 provides an overview of key components of an OCT. According to laser communications developers we interviewed, the amount of data transferred per unit of time is referred to as the data transmission rate. This rate is determined by several design features including those in the hardware and software. Hardware features include optical lenses that determine the amount and range of data transmitted from the OCT.

[3]For this report, we refer to receivers as OCTs, though there may be other types of optical receivers.

Generally, a larger optical lens can transmit more data over greater distances. A key software feature would likely support the signaling capability to distinguish between a laser beam from a friendly OCT and one from an adversary. See figure 2 for an overview depiction of a generic OCT.

Figure 2: Generic Depiction of an Optical Communications Terminal



Source: GAO illustration based on multiple sources. | GAO-25-106838

According to laser communications technology developers we spoke to, OCT designs balance three priorities: efficiency or the amount of power required to transmit data; range or the distance a set amount of data can travel through a laser link; and complexity of the components, such as the technologies used to transmit data to or receive data from the OCT.

Advantages and Challenges of Using Laser Communications

Based on our review of multiple DOD documents, interviews with DOD experts, and interviews with laser communications technology developers, we identified several key advantages and challenges in using laser communications systems on satellites.

Advantages of using laser communications in space include the following:

Higher data rates. Lasers can transmit data at higher rates than radio frequency. Higher data transmission rates are important for supporting selected new on-orbit technologies, such as new "high definition" instruments that collect larger volumes of data.

More secure. OCTs use highly focused and narrow laser beams, making them less susceptible to detection and interception compared to traditional radio frequency signals.

Lighter. OCTs are smaller, lighter, and require less power than traditional radio frequency communications equipment.[4] For example, unlike radio frequency communications, OCTs do not require a large antenna to transmit and receive data.

Not regulated. The use of radio frequencies is highly regulated to minimize interference among radio frequency applications. The US government does not regulate laser communications because the risk of interference is low.

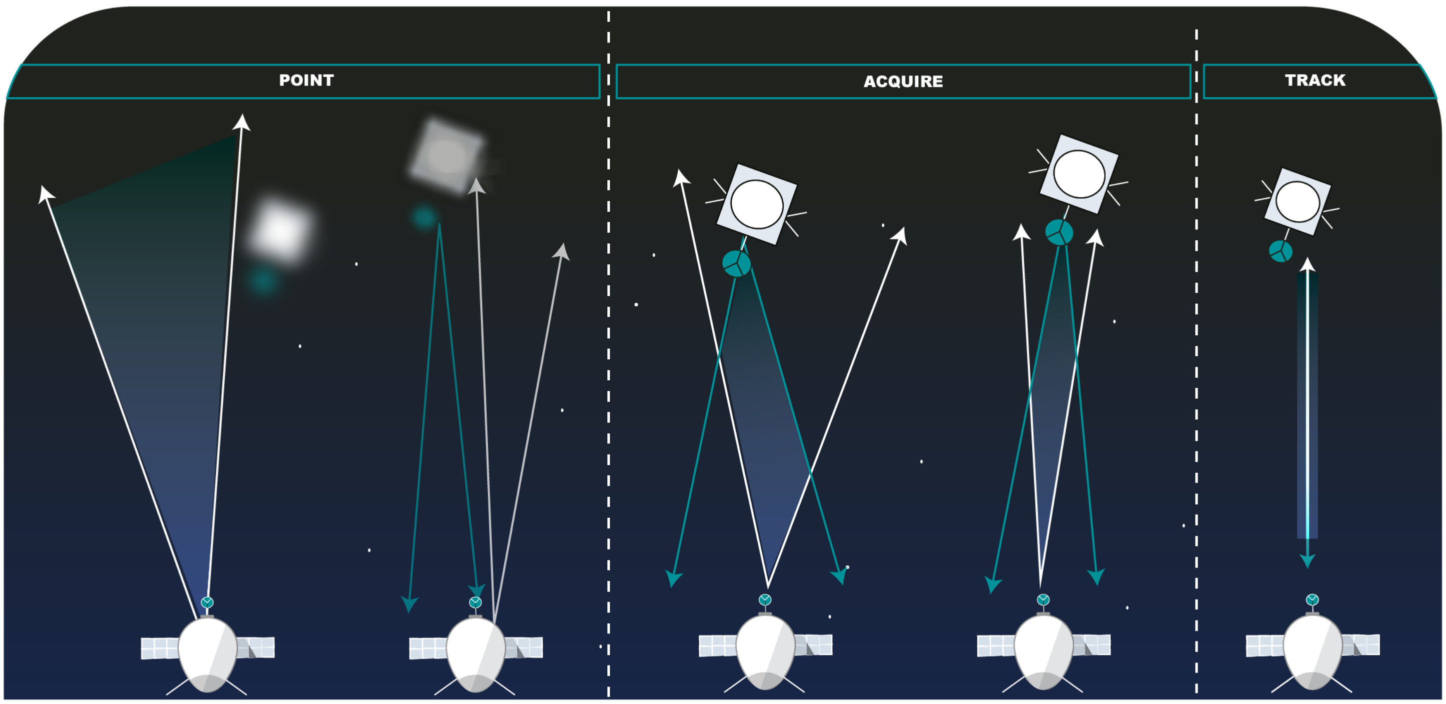
Challenges of using laser communications in space include the following:

Jitter. For laser communications to work, the transmitting and receiving systems need to minimize disturbance to the signal—referred to as jitter—caused by mechanical vibration and, in some cases, atmospheric turbulence. The amount of jitter in a signal affects the amount of data transmitted. If the jitter is significant, it may prevent the signal from being received and maintained. Because of the high level of precision required for laser communications, establishing a link is highly sensitive to disturbances that may cause jitter, including those that arise in the pointing, acquisition, and tracking (PAT) process and in the atmosphere.

[4]For more information on the advantages of laser communications, see National Aeronautics and Space Administration, "Optical Communications" (Sept. 20, 2023). Accessed on December 20, 2024, https://www.nasa.gov/technology/space-comms/optical-communications-overview.

Pointing, acquisition, and tracking. PAT is the process by which two OCTs point at one another to make initial contact, acquire a laser link, and track one another to maintain that link while data are transmitted.[5] The OCT programming used to establish PAT must be intentionally designed to “speak” to one another. Achieving PAT requires that the design of satellites and the integration of the OCTs onto the satellites factor in how any vibrations may affect the level of jitter and the ability of the laser beam to transmit data. Figure 3 shows high-level steps of achieving a laser link between two OCTs.

Figure 3: Three Primary Stages of Pointing, Acquisition, and Tracking in Space-Based Laser Communications

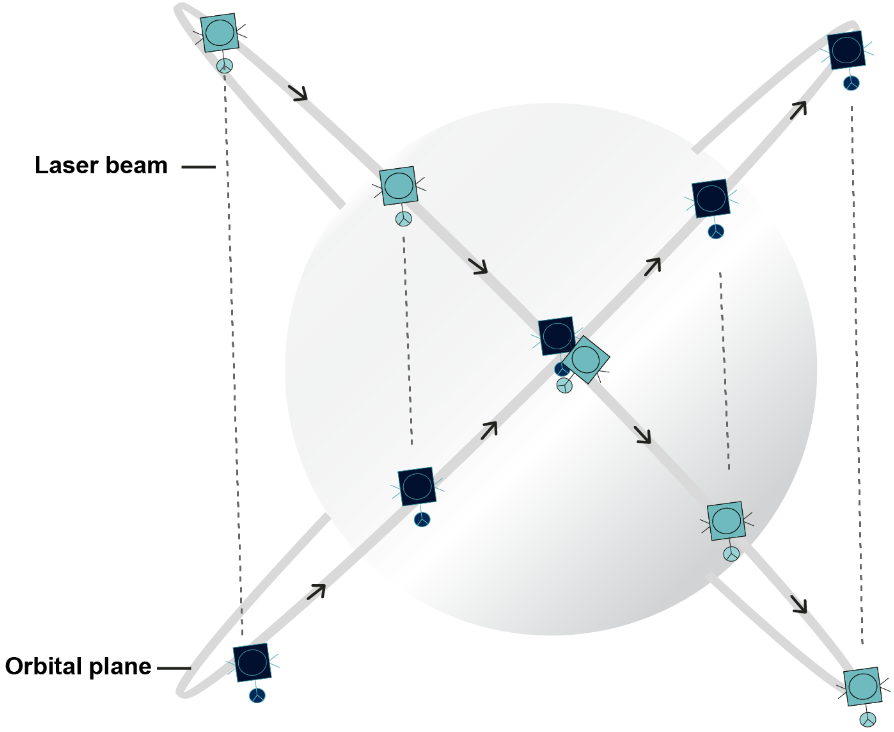


Source: GAO analysis of Department of Defense information. | GAO-25-106838

[5]Generally, pointing is achieved when an OCT initially aims a relatively wide laser beam toward its best estimate of the location of the other OCT. The other terminal must illuminate with sufficient power for the first OCT to detect it. Acquisition is a process that involves each OCT refining its estimate of the location of the other OCT by observing the incoming beam and adjusting its pointing accordingly. To track, the OCTs then narrow the width of their beams used to transmit data and track one another for the duration of the communication period.

Establishing laser communications between satellites often needs to be accomplished in a short period of time. Data transmission occurs between satellites moving together in the same orbital plane as well as satellites communicating across multiple orbital planes. For satellites moving together in the same plane—like train cars moving together along a track—they may only need to establish PAT once because their relative positions do not change. However, for satellites moving in separate orbital planes, establishing a link is highly complex as satellites move toward, adjacent to, and then away from one another. Once satellites are no longer able to “see” one another, each satellite must quickly connect to another satellite to continue transmitting data through the constellation. A given satellite could have multiple OCTs to accomplish simultaneous in- and cross-plane connections. Satellites orbiting at 1,000 kilometers above the Earth in LEO take about 90 minutes to circle Earth, and the amount of time OCTs in different planes may be within sight of one another varies depending on the orientation and altitude of their orbits. Figure 4 illustrates the dynamic environment in which OCTs must achieve PAT quickly when satellites are communicating across orbital planes.

Figure 4: Laser Communications of Two Satellites Across Multiple Orbital Planes



not to scale

Source: GAO analysis of Department of Defense information. | GAO-25-106838

Atmospheric effects. For laser communications to airborne platforms or to ground stations, the atmosphere may limit the amount of data transmitted through a laser communications signal. In the presence of atmospheric interference, such as clouds, laser communications may be less effective than radio frequencies, which are generally not significantly affected by atmosphere.[6]

[6]Because there are no atmospheric gases in space, there are less environmental disturbances in space-to-space laser communications compared to those in Earth's atmosphere.

Infrastructure Needed to Support Laser Communications Technologies

According to DOD documents and experts, beyond achieving laser links in space, transmitting data between satellites—and from satellites to ground and air—requires additional processes and technologies to be in place, including a network and ground stations.

Network. Satellite constellations need a network protocol to determine how and where data should be transmitted and routed. This protocol will, for example, tell the satellites in the constellation which satellites are available for data transmission and the best route to get information to the ground or air.

Ground and air receivers. Transmitting data from space to ground or air platforms requires OCTs on the ground or on aircraft that can receive laser signals from satellites. Receivers on the ground, or on an airplane, can then route those data to users.

Rapid Evolution of Commercial Space Sector

Over the past 10 years, commercial activities in space have grown considerably and the U.S. government expects continued growth in the future.[7] In September 2022, we reported that technological advancements have allowed for more affordable satellites and dramatic decreases in the cost to launch satellites, which can improve the potential to deploy large constellations of satellites that cover the entire globe. We also reported that some experts cited the potential for 58,000 additional active satellites to be launched by 2030, driven largely by commercial companies.[8]

DOD has benefitted from the increase in commercial space development, but commercial and government needs for laser communications technologies differ. DOD officials told us that the proliferation of commercial development has provided DOD with increased access to laser communications technologies. For example, some commercial companies have been developing space-based laser communications technologies over the last 5 years, and one company recently demonstrated lasers as part of a constellation. However, DOD officials say commercial and government needs differ in several key ways including security needs, data transmission rates, and laser beam ranges. Each of these differences in requirements could affect OCT designs. Because of these differences, designs and technologies that are mature for commercial uses may not be mature for government uses if they need

[7]GAO, *Space Situational Awareness: DOD Should Evaluate How It Can Use Commercial Data,* GAO-23-105565 (Washington, D.C.: Apr. 24, 2023).

[8]GAO, *Large Constellations of Satellites: Mitigating Environmental and Other Effects,* GAO-22-105166 (Washington, D.C.: Sept. 29, 2022).

modifications. DOD officials also said that the availability of laser communications technology in the defense industrial base is still nascent.

Evolving Threats to the Space Environment

DOD reported, in 2018, that China and Russia, the strategic competitors of the U.S., pose a threat to U.S. space capabilities during a time of conflict.[9] In 2024, DOD officials said that these adversarial threats to assets in space continue to evolve. Specifically, a DOD official said that China is developing directed energy weapons, electronic warfare, and anti-satellite capabilities.[10] In addition to the threat faced from China, DOD officials point out that Russia has also reinvigorated its space capabilities, and that Russia considers space a warfighting domain.

DOD has also expressed specific concerns about these adversaries targeting the traditionally large and expensive satellites in outer orbits that it has relied upon for missions such as missile warning and missile tracking. The department relies heavily on satellites for much of the work it does to defend the United States and expects that reliance to grow in coming years. DOD officials have described U.S. vulnerabilities in space as partly due to relying on large satellites in outer orbits for communications, with one official calling them “big, fat, juicy targets.”[11]

SDA Directed to Pursue Development of a LEO-based Architecture and Is Doing So Using Laser Communications Technology

In response to the changing threat environment, Congress established the SDA and instructed the head of the agency to, among other things, establish a proliferated space-based architecture in low Earth orbit (LEO)

[9]Department of Defense, Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military’s Competitive Edge (Jan. 19, 2018).

[10]Garamone, Jim. “Military Experts Highlight Space Opportunities, Threats at Aspen Conference,” *U.S. Space Command*, (July 18, 2024). Accessed December 20, 2024, www.spacecom.mil/Newsroom/News/Article-Display/Article/3844275/military-experts-highlight-space-opportunities-threats-at-aspen-conference/

[11]This report does not include analysis of what and how threats are addressed in various orbits.

to support critical sensing, tracking, and data transport missions.[12] To meet this requirement, SDA is building a large constellation of satellites in LEO to conduct missions typically conducted by larger, easier-to-target satellites in outer orbits.[13] Some DOD officials say this increase in the total number of satellites will also increase resilience.

In 2020, SDA initiated work on the PWSA—a LEO constellation that relies on laser communications technology to form a network—to address the issue of relying on the traditional satellites previously noted.[14] SDA is developing the PWSA to conduct a number of missions, including missile warning and missile tracking, as well as serve as an alternative to GPS to provide position, navigation, and timing services.[15]

Constellations in LEO. A large constellation of satellites in LEO has several advantages in meeting the warfighter needs that SDA was directed to address. According to SDA officials, a large constellation that leverages laser communications has the potential to transform the way certain threat information is gathered and communicated to the warfighter. Large constellations enable the ability to adapt quickly if connection to one of the satellites is lost due to attack or a natural event. The mission monitoring activity on the Earth or transmitting communications signals could be taken over by other satellites or rerouted through multiple alternate paths to bypass a disabled satellite.

[12]See William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021, Pub. L. No. 116-283, § 1601(a)(adding 10 U.S.C. § 9084 renumbered as § 9085). DOD established SDA in March 2019 to provide fast, responsive, and resilient solutions to national security space requirements, specifically a threat-driven space surveillance and communications architecture to provide low-latency global awareness, targeting, tracking, and fire control. SDA's requirements and function were transferred to the Space Force in 2022. Department of Defense Memorandum, Establishment of the Space Development Agency (May 12, 2019). National Defense Authorization Act for Fiscal Year 2022, Pub. L. No. 117-81, § 1081.

[13]A constellation is a group of satellites, ranging from a few to hundreds or more, that collectively perform a particular mission.

[14]The architecture was originally known as the National Defense Space Architecture; SDA renamed it the Proliferated Warfighter Space Architecture in January 2023.

[15]We have ongoing work looking at SDA's PWSA acquisition approach to developing and delivering missile warning and missile tracking capabilities.

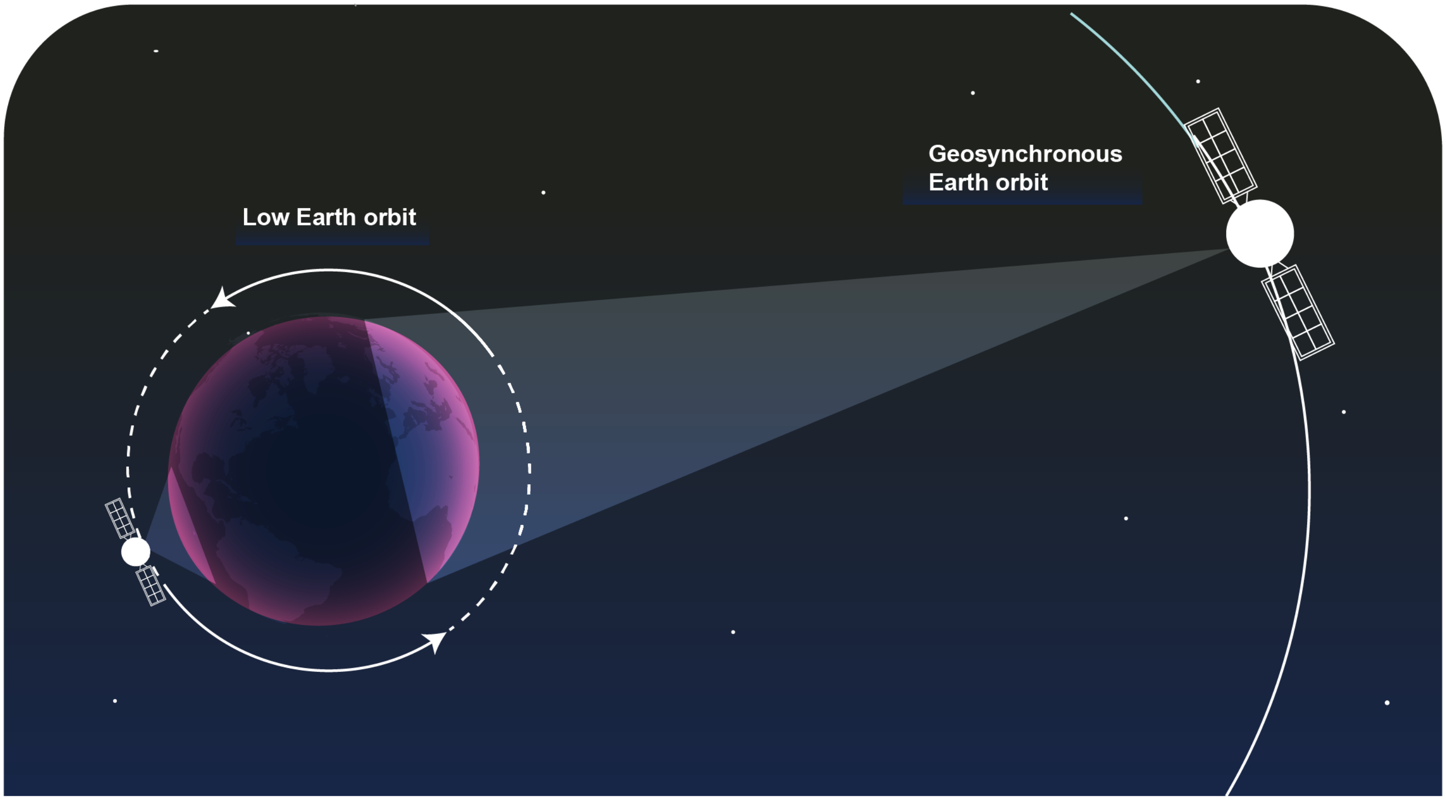
Satellites designed to operate in LEO are generally smaller and cost less than those at higher altitudes.[16]

However, in LEO, the environment also creates some difficulty. Satellites designed for LEO typically have shorter lifespans, so they need to be replaced more often to maintain the constellation. The Congressional Budget Office and DOD’s Cost Assessment and Program Evaluation office have reported that costs of maintaining LEO constellations for many years are potentially higher than medium Earth orbit or geosynchronous Earth orbit constellations with comparable coverage.[17] Additionally, more LEO satellites are generally needed to achieve coverage comparable to smaller constellations at higher altitudes. For example, because satellites in LEO are closer to Earth, their field of view is not as wide as that of a satellite that is farther away, so more satellites are required to ensure coverage of the Earth’s surface (see fig. 5).

[16]For more information about the trade-offs of LEO constellations, see Congressional Budget Office, *Large Constellations of Low Altitude Satellites: A Primer* (Washington, D.C.: May 2023).

[17]LEO costs could be reduced if mass production significantly decreases unit costs or if launch costs continue to decline.

Figure 5: Field of View from Satellites in Low Earth Orbit and Geosynchronous Earth Orbit



not to scale

Source: GAO analysis of Congressional Budget Office information. | GAO-25-106838

Note: Figure shows an image of the differences in the surface area that cameras with the same lens angle would be able to capture in each orbit.

Rapid Data Transmission in LEO. For LEO constellations to work, data must move quickly through a network of satellites. For example, according to SpaceX representatives, the company's Starlink constellation relies on laser communications technology to transmit data through its constellation of approximately 5,000 satellites. These representatives told us that initially establishing and maintaining laser links—both from space-to-space and space-to-ground—is very challenging. Satellites in LEO are moving so quickly—based on the altitude, this could be about 7.7 kilometers per second or more than

17,000 miles per hour—that performing missions here can be complex.[18] Additionally, satellites in LEO are only in view of a given ground station for about 10 minutes depending on altitude. This short period provides only a limited window for communication, which is why high data transmission rates, such as those enabled by laser communications, are needed.

SDA's PWSA LEO architecture. SDA's PWSA is a layered architecture within the LEO satellite constellation in which each layer supports a specific function, according to program documentation. Each relies upon laser communications. This report focuses on the two layers—the Tracking Layer and Transport Layer—that have satellites that require OCTs to deliver operational capability. The Tracking Layer will include sensors to collect data on, among other things, potential missile launches. The primary purpose of the Transport Layer will be to transmit data throughout the constellation. Satellites in this constellation rely on OCTs to communicate data between themselves and to ground and air platforms.

SDA identified laser communications technology as central to the success of its overall PWSA architecture because only laser communications can provide the data speed and throughput that the missile tracking and data transport missions require. In addition to laser communications technology, SDA plans to incorporate communications technologies such as radio frequency communication capabilities. However, SDA officials have said that, although these complementary communications technologies will be helpful, the laser communications must work across a network of hundreds of satellites to achieve planned mission capabilities.

To develop laser communications technology for PWSA, SDA is rapidly developing capabilities through a series of spiral, or iterative, development efforts, where technologies are developed and built upon through phases. These development efforts, which SDA refers to as tranches, are planned every 2 years, for both the Tracking and Transport Layers. Table 1 identifies the planned number of satellites and cost of the initial tranches.

[18]Satellites in LEO have altitudes of about 300km to 2,000km. The example provided here is the speed of the International Space Station, which has an altitude of 370 to 460km, or about 200 to 250 miles above Earth.

Table 1: Number of Satellites and Contract Value by SDA Proliferated Warfighter Space Architecture (PWSA) Tranche and Layer

SDA PWSA layer	Number of satellites in Tracking Tranche	Number of satellites in Transport Tranche	Year awarded	Approximate total cost by tranche (dollars in millions)
Tranche 0	8	20	2020	**$657**
Tranche 1	39	126	2022 and 2023	**$3,674**
Tranche 2	54	210	2023 and 2024	**$6,267**
				$10,598

Source: GAO analysis of Space Development Agency (SDA) information. | GAO-24-106838

Note: The table includes the original prototyped satellite capabilities in T0, T1 and T2 as reflected in the original contracts. SDA ultimately launched 27 Tranche 0 satellites and removed seven satellites from Tranche 1 (Tracking). Alpha, Beta, and Gamma refer to variants of the satellites introduced in the Tranche 2 Transport Layer.

Part of this iterative development process is identifying a capability for each tranche, then building a product that supports that capability. For each tranche, SDA has committed to demonstrating these products. PWSA spiral development starts with a demonstration tranche—Tranche 0—followed by a series of independent prototyping efforts. Starting with the tranche following T0, referred to as Tranche 1 (T1), each PWSA tranche within each constellation layer is an individual effort using the Middle Tier of Acquisition (MTA) Rapid Prototyping pathway. Each effort has its own requirements.[19] SDA awarded other transaction agreements

[19]The MTA pathway is one of six acquisition pathways in DOD's Adaptive Acquisition Framework (AAF). Department of Defense, *Operation of the Adaptive Acquisition Framework*, DOD Instruction 5000.02 (incorporating change 1, June 8, 2022). Each pathway in the AAF has its own processes, reviews, documentation requirements, and metrics matched to the characteristics and risk profile of the capability being acquired. Rapid Prototyping MTA programs have the objective to field a prototype that can be demonstrated in an operational environment within 5 years of MTA program start. Department of Defense, *Operation of the Middle Tier of Acquisition*, DOD Instruction 5000.80 (Dec. 30, 2019). SDA leadership has characterized its approach to PWSA development as spiral, iterative, and incremental.

for its tranches using a competitive process.[20]. Each tranche is expected to demonstrate increasing capability over the last while also interconnecting with earlier tranches to create an interconnected network spanning multiple tranches. Looking ahead, SDA plans to award contracts for Tranche 3 (T3) starting in 2025, for a total of approximately 200 satellites across the Tracking and Transport layers.

SDA intended to use the 28-satellite T0 constellation to demonstrate laser communications technology and reduce risk for its PWSA program. Like the larger PWSA effort, the T0 demonstration was designed with a tracking layer and transport layer, and SDA intends to demonstrate OCTs with the laser communications waveform needed to support PWSA mission and objectives. SDA identified a major objective for T0 as testing, evaluating, and assessing its capability to pass data through the constellation—including through space-to-space laser links—with minimal delay.

GAO's Leading Practices for Product Development

We have identified leading practices for product development that include using an iterative development approach focused on designing, validating, and delivering products in time to meet the users' needs.[21] Some of these practices include:

- creating and validating key capabilities—or a minimum viable product (MVP)—through prototyping where information gathered, such as

[20]DOD can use other transactions—which are not subject to the requirements of the Federal Acquisition Regulation—for prototype projects directly relevant to improving platforms, systems, components, or materials. 10 U.S.C. §§ 4021, 4022. DOD must meet at least one of the following conditions to enter an other transaction agreement for a prototype project using its authority under 10 U.S.C. §§ 4022: (1) at least one nontraditional defense contractor or nonprofit institution is participating, (2) all significant participants are small businesses or nontraditional defense contractors, (3) one-third of the total cost is paid by sources other than the federal government, or (4) DOD's senior procurement executive determines in writing an other transaction provides an innovative business arrangement or expands the defense supply base in ways not feasible under a contract. 10 U.S.C. §§ 4022(d)(A)-(D). For the purposes of this report, we use "contract" to mean both contracts that follow federal acquisition regulations and other transaction agreements entered into pursuant to 10 U.S.C. § 4022.

[21]GAO, *Leading Practices: Iterative Cycles Enable Rapid Delivery of Complex, Innovative Products,* GAO-23-106222 (Washington, D.C.: July 27, 2023).

lessons learned, based on the MVP is then used to inform subsequent iterations or new products;[22]

- ensuring funding is commensurate with the design and development progress of the product, rather than committing a substantial amount of funding at the start of development; and
- providing access and communicating real-time information to stakeholders.

Further, according to our Agile Assessment Guide, for systems that rely on software development, an MVP is valuable if the product is sufficiently developed to allow for customer interaction and to elicit feedback and learning.[23]

Past GAO Work on DOD's Challenges with Space Capability Development

We previously reported on DOD's challenges with developing space capabilities, including immature technologies, the slow pace of past DOD acquisitions, infrequent opportunities to insert new technology, and reliance on a limited number of contractors.

Reliance on immature technologies. We reported that traditional DOD acquisition programs have planned to develop immature technologies rather than use mature technologies and witnessed increases in cost and schedule. This is because programs may find themselves addressing problems related to technology immaturity that hamper other aspects of the acquisition process. We made several recommendations to DOD to address this issue. For example, we recommended and DOD implemented more closely tracking changes in technology development plans, including improving interim assessments. Further, we found that DOD's budgeting process, which usually targets investments at least 2 years in advance of their activation, makes it difficult for

[22]Our prior work found that to implement iterative development, organizations set development timelines based on factors specific to their product. Leading companies use prototyping results to help assess whether products will remain within the schedule parameters established in their business cases and adjust the parameters when more time is needed to develop features that are critical for most users. See GAO, *Leading Practices: Agency Acquisition Policies Could Better Implement Key Product Development Principles*, GAO-22-104513 (Washington, D.C.: Mar. 10, 2022).

[23]GAO, *Agile Assessment Guide: Best Practices for Adoption and Implementation*, GAO-24-105506 (Washington, D.C.: Nov. 28, 2023; reissued Dec. 15, 2023).

DOD to seize opportunities to introduce technological advances into acquisition programs.[24]

Slow pace of past acquisitions. We previously reported that some members of Congress and DOD had long-standing concerns that the defense acquisition process was too slow to deliver capabilities to the warfighter.[25] For DOD space programs, this has meant acquisition challenges including significant cost growth and schedule delays. For example, DOD's Space Based Infrared System, a missile warning satellite program, experienced cost growth of 261 percent from its original estimate and the first satellite launch was delayed by 9 years. Additionally, Wideband Global SATCOM, a wideband satellite communication program, experienced cost growth of 260 percent from its original estimate and schedule delays of 4 years.[26] DOD has attempted to address slow acquisitions, in part, by implementing the MTA pathway to offer a streamlined process for certain types of prototype efforts.[27] We have made multiple recommendations for implementing this pathway. For example, we recommended and DOD implemented establishing certain processes and policies and improving the reliability of program data.[28]

Infrequent opportunities to insert new technology. We reported that transitioning new technologies from the lab and commercial environment into operational use has been an ongoing, critical problem.[29] We further reported that the ability to spur and leverage technological advances is vital to sustaining DOD's ability to maintain its superiority over adversaries. Traditionally, however, DOD has had infrequent opportunities to

[24]GAO, *Defense Technology Development: Management Process Can Be Strengthened for New Technology Transition Programs*, GAO-05-480 (Washington, D.C..: June 17, 2005).

[25]GAO, *Middle-Tier Defense Acquisition: Rapid Proto*typing and Fielding Requires Changes to Oversight and Development Approaches, GAO-23-105008 (Washington, D.C..: Feb. 7, 2023).

[26]GAO, *Space Acquisitions: DOD Faces Challenges and Opportunities with Acquiring Space Systems in a Changing Environment*, GAO-21-520T (Washington, D.C..: May 24, 2021).

[27]Department of Defense, *Operation of the Middle Tier of Acquisition,* DOD Instruction 5000.80 (Dec. 30, 2019).

[28]GAO-23-105008.

[29]GAO-05-480.

introduce the latest technology in space systems. DOD space programs have typically been expensive, low-volume acquisitions expected to remain in service for a decade or longer. For example, satellites in geostationary orbit have an average expected lifespan of 14 years. One study highlights that, because satellites in orbit are largely unable to be modified or upgraded, users and acquirers have tended to overload requirements and be risk averse.[30] Long periods of planned service, coupled with the slow pace of developing space capabilities in the first place, can result in systems that warfighters rely upon being based on technologies that are 2 decades old or older.

Limited number of companies serving DOD. A healthy defense industrial base—including resilient and diverse supply chains—is critical to maintaining U.S. national security objectives.[31] We reported that DOD identified consolidation of its suppliers as a key risk that may reduce opportunities for competition and increase the risk of higher costs and reduced innovation. We recommended that DOD track the risks associated with certain mergers and acquisitions, but DOD has yet to implement this recommendation.[32] Further, DOD identified the need to reduce its reliance on a limited set of traditional defense contractors. Specifically, DOD has identified challenges with diversifying the number and types of contractors it relies on due to barriers such as overly bureaucratic government processes and complex regulations that small businesses consider burdensome.[33] We reported that one way DOD attempted to address some of these challenges is through the use of agreements known as other

[30]RAND Corporation, Strategies for Acquisition Agility: Approaches for Speeding Delivery of Defense Capabilities (Santa Monica, CA.: Aug. 27, 2020).

[31]GAO, *Defense Industrial Base: DOD Should Take Actions to Strengthen Its Risk Mitigation Approach,* GAO-22-104154 (Washington, D.C.: July 7, 2022).

[32]GAO, *Defense Industrial Base: DOD Needs Better Insight into Risks from Mergers and Acquisitions,* GAO-24-106129 (Washington, D.C.: Oct. 17, 2023).

[33]Department of Defense, *Small Business Strategy* (January 2023).

transactions, which can help DOD to attract companies or other entities that are not traditional defense contractors.[34]

SDA Has Taken Steps to Develop Laser Communications Technology, but Has Not Yet Fully Demonstrated It in Space

SDA Has Taken Steps to Advance Development of Laser Communications Technology

Efforts to develop laser communications technology include developing a new government OCT standard, conducting OCT laboratory testing, and maturing component technologies.

Developing an SDA OCT Standard

SDA developed a new government standard—the SDA OCT Standard—that defines technical specifications for PWSA OCTs intended to connect to one another in space. SDA's OCT Standard specifies unique features that SDA officials say support their unique government mission and needs as well as ensures interoperability among different commercial vendors. For example, SDA's identified data rate of 2.5 gigabits per second is relatively lower than some commercial technologies that transmit data at 100 gigabits per second. DOD officials stated that the lower rate was due, in part, to the need to conform to DOD data encryption requirements, which do not support the higher data rates.[35] SDA officials noted that their design also took several factors into

[34]Other transactions may be attractive to nontraditional defense contractors as other transactions are not subject to the requirements of the Federal Acquisition Regulation. See Department of Defense, Office of the Under Secretary for Acquisition and Sustainment, *Other Transactions Guide*, Version 2.0 (July 2023). See also GAO, *Defense Acquisitions: DOD's Use of Other Transactions for Prototype Projects Has Increased,* GAO-20-84 (Washington, D.C.: Nov. 22, 2019).

[35]In addition to SDA's new OCT standard, Space Systems Command is developing another government standard, the SIS-002 Standard that supports higher data rates—up to 20Gbs—to orbits beyond LEO. SIS-002 was developed with a consortium of government, industry, and contractors and supports the development of another Space Force OCT effort, the Enterprise Space Terminal.

consideration, including supporting development of more affordable OCTs that allow more vendors to participate. The standard also requires a specific waveform and is designed to support laser links from space to space, air, or ground.

To develop the standard, SDA solicited feedback from contractors, commercial vendors, and DOD organizations. SDA and its contractors have described this as a collaborative process. SDA has issued several updates to and continues to refine the standard based, in part, on feedback from developers and other stakeholders. This is discussed further later in this report.

SDA officials said that advancements in commercial OCT technologies give them confidence that OCT vendors can use mature components of these technologies to build the OCTs for PWSA.[36] Some vendor representatives stated they are able to leverage their commercial technology components to meet the SDA OCT Standard and have a dedicated OCT product line for PWSA. However, other vendor representatives said their commercial products are different designs from those that they produce for PWSA and required additional development to meet the SDA OCT Standard.

Conducting Laboratory Testing

SDA supports two types of testing for OCTs in development for PWSA—verification and interoperability. The verification test is designed to ensure that the OCT waveforms are compatible with SDA's OCT Standard and can transmit data to and receive data from test equipment provided by the Naval Research Laboratory. This test is conducted by PWSA contractors at their own facilities. According to officials, contractors are required to complete this testing before moving forward with the next level of testing, the OCT Interoperability Test.

SDA partnered with the Naval Research Laboratory to conduct the OCT Interoperability Test, which ensures that OCTs built by different developers can connect to one another in a lab. To support this effort, the laboratory developed a testbed that validates and certifies that the OCTs can connect to one another. The laboratory supported some interoperability testing for the T0 OCTs and provided additional testing capability in T1. Specifically, T0 OCTs were tested for waveform

[36]OCT vendors are companies that develop OCT Technology supporting SDA's PWSA. In some cases, they are prime contractors and in others they are subcontractors.

compatibility but not the pointing, acquisition, and tracking (PAT) process. The Naval Research Laboratory tested PAT during testing for T1.

SDA officials said that testing whether the OCTs can connect in a lab helps build confidence that those OCTs will be able to connect in space. However, there are limitations to the testing. Naval Research Laboratory testing officials and contractor representatives cautioned that several variables cannot be tested in a lab. OCTs, they said, must be tested in space to ensure that no critical design changes must be made to future OCTs or satellites. For example, testing officials said that some environmental conditions that may affect OCT performance in space cannot be tested in a lab. While SDA officials said contractors are required to test that systems operate in the full range of operational environments, some testing officials said the unpredictable effects of extreme temperature variations in space cannot be fully tested in a lab.

Maturing Component Technologies

SDA has several ongoing efforts to support the advancement of laser communications technologies. Specifically, SDA reported that it is working with multiple small businesses to develop and mature OCT capabilities, including improvements to technologies that support routing data through the constellation. SDA also reported that it is working with another small business to develop a technology that will help increase the laser link distance between two satellites in LEO.

Additionally, SDA has collaborated with other DOD science and technology organizations to advance laser communications technology. For example, in 2021 and 2022, SDA worked with the Defense Advanced Research Projects Agency (DARPA) and Air Force Research Lab (AFRL) on a laser communications demonstration. This demonstration was designed to demonstrate a laser communications waveform that officials characterized as similar to SDA's OCT Standard. SDA also partnered with AFRL to develop a ground terminal that could send laser signals to and receive laser signals from satellites in space.

SDA Attempted to Quickly Demonstrate Laser Communications in Space, but Efforts Have Not Progressed as Expected

In 2020, SDA initiated its demonstration tranche—T0—as the first step in its effort to rapidly develop laser communications in space. According to agency planning documents, SDA is implementing spiral development by establishing a minimum viable product (MVP) that SDA defines as a version of a product with just enough features to be usable by early customers who can then provide feedback for future product development. The MVP is based on each tranche's minimum viable capability (MVC)—a set of requirements established by SDA and stakeholders that SDA agrees to fulfill within that specific tranche's timeline. An example of an MVC is the amount of global coverage the constellation will have, and the related MVP is the number of PWSA satellites required to meet that capability.[37]

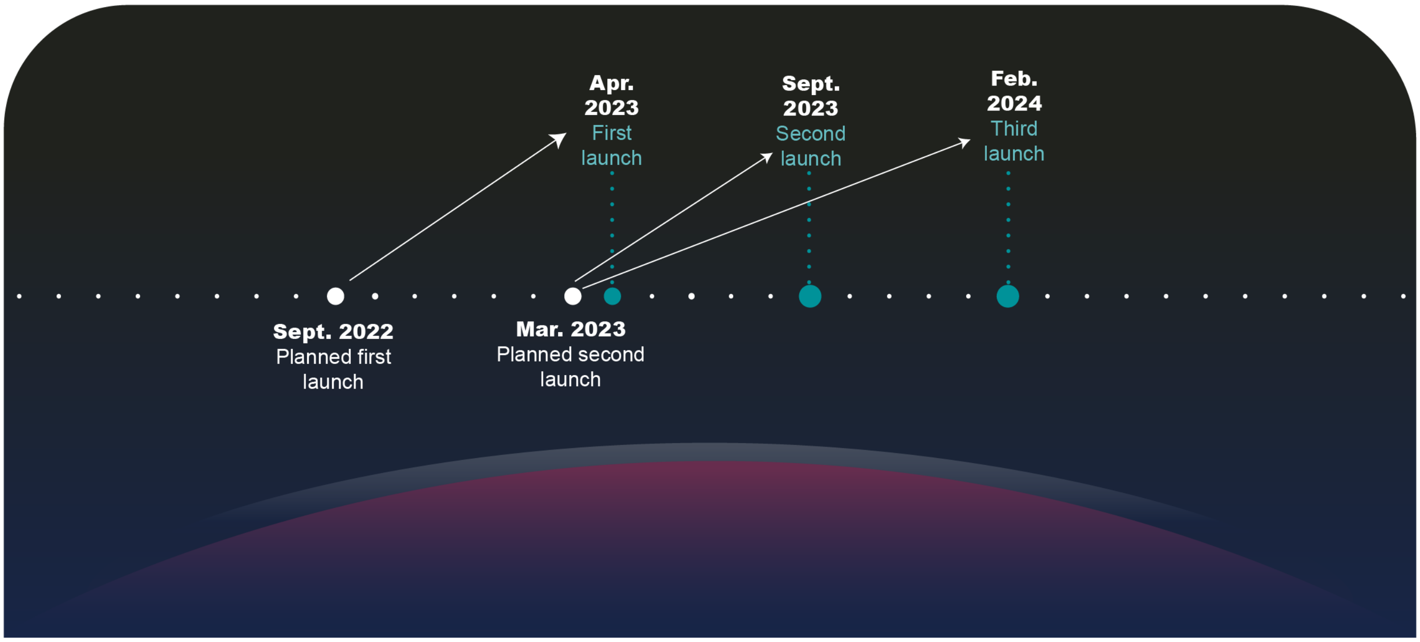
SDA officials said that their focus on delivering capabilities every 2 years has several advantages. For example, SDA officials said that compared to systems built under longer, traditional acquisition processes, PWSA is better able to adapt to threats as they evolve because SDA will be able to make changes to technology more quickly based on that new threat information. They also stated that using a 2-year cadence allows them to insert new technologies into the constellation more quickly and as they become available.

Additionally, SDA officials and some contractor representatives said that a predictable acquisition cycle, like the 2-year cycle SDA has put forward, may help diversify the defense industrial base by encouraging participation by companies not already working with DOD in this area. For example, some laser communications commercial vendors developing the OCTs used in PWSA have reported expanding manufacturing capacity in the United States to support SDA contractors in anticipation of continued involvement. Other contractor representatives cautioned that participation may be dependent on receiving contracts in each tranche.

However, T0 laser technology demonstration has not happened as quickly as expected. Although T0 is SDA's primary effort to demonstrate OCTs using its new OCT standard, SDA officials said the effort has not progressed as planned based, in part, on supply chain challenges. SDA planned to start launching the satellites in September 2022, but the initial launch was delayed until April 2023. The remaining launches took place over the following 10 months. Because of this, SDA did not have the full constellation on orbit until 2024. As a result, SDA has faced delays in on-orbit testing, including testing of laser communications technology. Figure 6 shows SDA's planned and actual launch dates for the PWSA T0 prototype demonstration effort from 2022 through 2024.

[37]In October 2024, the SDA Director said that SDA is no longer planning to develop an MVP, rather that the agency considers the MVP to be equivalent to the MVC. However, given that MVP and MVC have had distinct and different meanings in SDA's planning documents as described above, it is unclear how this change will be incorporated going forward.

Figure 6: Planned and Actual Launch Dates of Satellites for Proliferated Warfighter Space Architecture Tranche 0

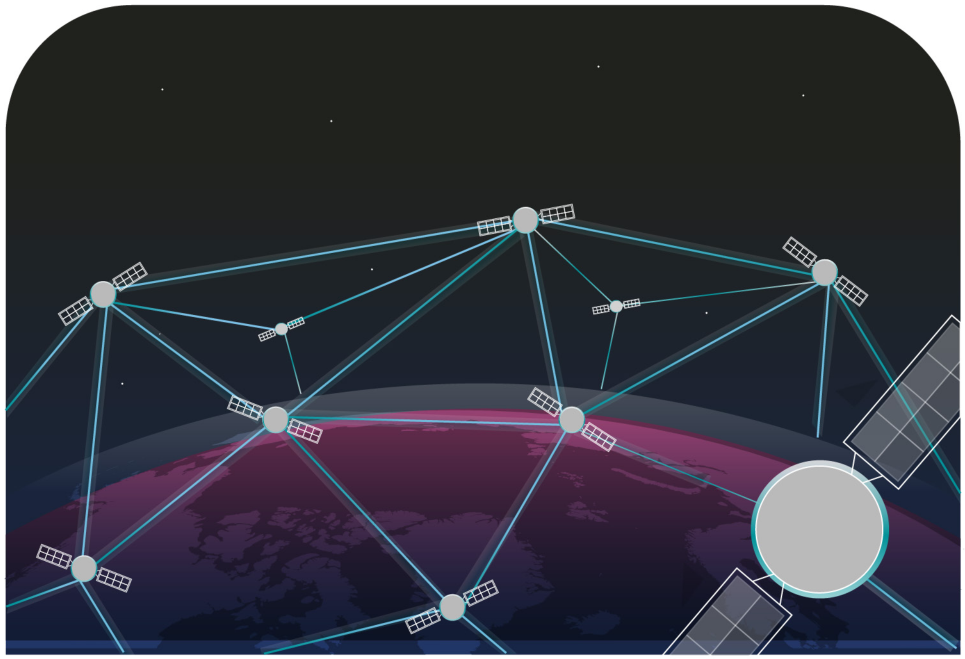


Source: GAO analysis of Department of Defense information. | GAO-25-106838

SDA Has Not Yet Demonstrated Minimum Capability of PWSA's Laser Communications Technology

In T0, SDA intended to demonstrate a mesh network—a decentralized type of network that automatically configures and adapts itself to route data most efficiently—as part of the MVP (see fig. 7 for a depiction of a mesh network). April 2022 DOD planning documents show that SDA planned to demonstrate in-orbit performance, including mesh networking and laser communications performance, 6 months after the initial T0 launches.

Figure 7: Depiction of Space-Based Mesh Network



Source: GAO analysis of Department of Defense information. | GAO-25-106838

However, SDA has not yet successfully demonstrated the full range of its laser communications technology in space using its new OCT standard. About one quarter into the 5-year design life of the first T0 satellites, limited capability has been demonstrated. We analyzed SDA's documentation and identified at least eight capabilities as central to demonstrating a mesh network with laser communications technology and could have been demonstrated in T0. SDA officials said that it is not required that all of the technologies below are demonstrated, but our analysis shows their contracts describe the intention to demonstrate each technology as part of the mesh network MVP. Although there were reports in September and December 2024 that SDA has demonstrated T0 lasers in space, SDA has demonstrated only a few of the capabilities. See table 2.

Table 2: Demonstrated Laser Communications Capabilities by Contractor in Tranche 0 as of December 2024

Intended OCT capability	Transport Layer contractors		Tracking Layer contractors	
	Lockheed Martin	York Space Systems	SpaceX	L3Harris
Space-to-space laser link with OCTs built by same vendor in the same orbital plane	—	✓	✓	—
Space-to-space laser data transmission with OCTs built by same vendor in the same orbital plane	—	—	✓	—
Space-to-space laser link with OCTs built by different vendors in the same orbital plane	—	—	—	—
Space-to-space laser data transmission with OCTs built by different vendors in the same orbital plane	—	—	—	—
Space-to-ground laser data links	—	—	✓	—
Space-to-ground laser data transmissions	—	—	—	—
Space-to-space laser data transmission across two orbital planes	—	—	—	—
Space-to-space laser data links across two orbital planes	—	—	—	—

Legend: ✓ = demonstrated capability; — = has not demonstrated capability

Source: GAO analysis of Space Development Agency information. | GAO-25-106838

Each of these individual capabilities in the T0 MVP represents a significant step forward in using laser communications to support a mesh network in PWSA but also an increase in difficulty. For example, achieving the space-to-space laser link is a critical first step and indicates that the satellites have sufficient pointing mechanisms to find one another and establish a link. Achieving data transmission indicates that the satellites' PAT systems can not only point to one another but can also sufficiently track one another and maintain contact while moving through space. Achieving an in-plane laser link means that two satellites moving at the same relative speed, one in front of the other, can connect. Demonstrating data transmission across two or more orbital planes is significantly more difficult because it introduces challenges such as changes in the relative speed and trajectories of the satellites.

According to SDA and contractor officials, several factors are contributing to SDA taking longer than expected to achieve the elements of demonstrating a mesh network. These include challenges with coordinating ground support and SDA prioritizing the demonstration of other technologies. For example, contractor representatives and SDA officials said that coordinating the timing of tests with the ground has been challenging because of limited time the satellites are in contact with the available ground stations. Additionally, the representatives from the first contractor to make the space-to-space link between its OCTs said that achieving this first step took approximately 11 months. This was considerably longer than they expected, in part, due to the time required to diagnose issues and transmit corrective software updates to the satellites. SDA officials also reported that they instructed the contractor to prioritize its support to demonstrating other technologies before continuing to test the laser communications technology.

In addition to T0, SDA has supported other laser communications technology initiatives to attempt to reduce risk, but those efforts did not perform as expected. This includes, for example, SDA's collaboration with DARPA and AFRL on the development of the previously mentioned laser communications waveform demonstration. While AFRL officials said the demonstration achieved a laser link and data transmission, due to propulsion issues on the spacecraft, the OCTs connected at 113 kilometers, which was about 1/20th of the planned demonstration distance of 2,400 kilometers. Officials said that the demonstration achieved all of its planned objectives, but not some of the "stretch goals". Specifically, when the satellites attempted to connect with the ground, they were unable to perform the tracking function.

SDA's PWSA contracts require contractors to develop OCTs that can connect at up to 6,500 kilometers, nearly three times greater than the distance planned in the demonstration and up to nearly 60 times greater than the distance realized in the demonstration. AFRL officials acknowledged that this performance, among other factors, limits the extent to which this demonstration can inform SDA's PWSA efforts.

DOD's Prototyping Guidebook says that prototype demonstrations can provide significant value to early technology development even if they do not demonstrate technology as planned. However, this is only true if developers can apply what they learned to future efforts and decisions. The guidebook describes the "Fail Fast, Fail Cheap" approach as a philosophy that seeks to use the simplest and least expensive representative model possible to quickly determine the value of an approach, concept, or technology through incremental development and evaluation.[38] Using prototype demonstrations, the prototype design can be modified and reevaluated—or decision-makers can pivot to a different approach—when testing reveals something is not working as expected or desired (in other words, a “failure”).

SDA’s Approach Does Not Follow Leading Practices Related to Learning, Investment, and Communication

SDA’s early development approach has not followed key leading practices for rapid delivery of complex products. Specifically, SDA has not ensured opportunities to learn between tranches, and the agency is moving forward with additional investments that are not commensurate with its development progress. Furthermore, SDA has not sufficiently communicated key T0 schedule or performance information to relevant stakeholders to inform future decisions.

SDA’s PWSA Development Approach Does Not Ensure Opportunities to Incorporate Lessons Between Tranches

Rapid Iterations Come at the Expense of Being Able to Incorporate Lessons

SDA efforts have focused on maintaining a 2-year preset schedule—based on what SDA officials described as an SDA-led informal analysis of industry capability—even with the previously noted challenges with achieving planned time frames. This focus is reducing the opportunity to incorporate lessons learned between tranches and poses challenges to capturing the benefits of iterative development.

Our leading practices emphasize that prioritizing schedule—as SDA has done—and using an iterative development approach can support delivering products with speed to users. However, our leading practices also note that speed cannot come at the cost of demonstrating critical capability. Specifically, our leading practices emphasize the importance of using the information gathered based on designing, testing, and deploying the MVP to inform subsequent iterations or new products.

As previously noted, SDA has not yet demonstrated the minimum capability of a laser-based mesh network MVP planned for T0. Nevertheless, SDA continued to adhere to its planned timelines for

[38]Department of Defense, Office of the Under Secretary of Defense for Research and Engineering, *Prototyping Guidebook*, Version 3.1 (October 2022).

awarding contracts for two subsequent tranches. This is inconsistent with the leading practice of demonstrating the MVP before moving to the next iteration. For example, at the time SDA awarded initial T1 and T2 contracts in 2022, 2023, and early 2024—worth about $9.5 billion—none of the T0 vendors had demonstrated the required OCT capabilities in space, which are part of the planned T0 MVP mesh network.[39] T0 launches were significantly delayed, and contractors said that on-orbit OCT testing has taken longer than expected. In some cases, it has taken months or more than a year to get through the steps necessary to establish a laser link. However, SDA continues to move forward with T1 where contractors have completed laser communications testing on the ground and started to deliver OCTs as they prepare for initial launch in early 2025.

SDA has lowered its expectations for T0 but has still faced challenges. For example, SDA originally planned to demonstrate OCTs built by different vendors, but SDA officials said they now plan to demonstrate space-to-space laser data transmission between OCTs in the same orbital plane that were built by the same vendors. However, in July 2024, SDA officials described changes to their plan for demonstrating a mesh network in T0 that, in effect, redefine the T0 MVP as it relates to demonstrating laser communications technology. SDA officials said they still plan to demonstrate a T0 mesh network prior to the first T1 launch, but they now only plan to demonstrate some of the original planned mesh network capabilities. As of December 2024, SDA contractors have demonstrated two of the planned OCT capabilities identified in table 2 in T0. SDA officials said contractors have also achieved a laser link between two satellite vendors, York Space Systems and SpaceX, but both of those companies are using the same OCT developer. This means SDA has yet to demonstrate a link between two OCT vendors in space as originally planned.

SDA has described PWSA development, starting with T0, as spiral development, meaning it intended to increase planned capability with each tranche based on the demonstrated capability. However, SDA's current approach means it no longer plans to fully demonstrate key capabilities in T0 that it had previously characterized as the MVP. Specifically, SDA's characterization of T0 has changed over time from the "first step in spiral development" that demonstrates a laser

[39]In addition to these initial awards, SDA made a fourth award in August 2024 for T2, putting the total amount over $10 billion for T0, T1, and T2.

communications-based mesh network in an operational environment to “a separate proof of concept effort that will inform future tranches,” which generally means a plan to demonstrate in T0 that laser communications are possible.

Even with this change in what SDA planned to demonstrate, it has not adjusted plans for demonstrating laser communications technology in T1 and T2. Furthermore, as described below, T1 has a more complex MVP because it has significantly more satellites and broader planned coverage and is scheduled to launch starting in 2025. Similarly, T2 will have an even greater number of satellites and more complex capabilities and MVP and is scheduled to launch starting in 2026.

Laser Communications Technology Underpins Space Development Agency’s Satellite Constellation Architecture Minimum Viable Capabilities

The Space Development Agency’s Proliferated Warfighter Space Architecture is defined by a space mesh network and optical communications terminals are critical for maintaining that network. A mesh network is a decentralized type of network that automatically configures and adapts itself to route data most efficiently. Below is a list of the original minimum viable capabilities and originally planned time frames for tranches 0, 1, and 2.

Tranche 0 “warfighter immersion” (fiscal year 2022) will demonstrate a laser-based mesh network. This includes demonstrating the feasibility of a proliferated architecture in cost, schedule, and scalability towards necessary performance for beyond-line-of-sight targeting and advanced missile detection and tracking.

Tranche 1 “initial warfighting capability” (fiscal year 2024) will deliver a resilient laser-based mesh network with regional coverage. This includes delivering data communications and connectivity on a persistent regional basis for Link 16, advanced missile detection, and beyond-line-of-sight targeting plus demonstration of other radio frequency-based—ultra high frequency and S-band—tactical satellite communications.

Tranche 2 “final warfighting capability” (fiscal year 2026) will deliver a resilient laser-based mesh network with global coverage. This tranche expands the capabilities delivered in Tranche 1 from a regional to global persistent basis and demonstrates advanced tactical data links and future proliferated missions.

Source: GAO analysis of Department of Defense information. | GAO-25-106838

Evolving OCT Standard Increases Risk to Achieving Capability

SDA’s OCT standard is evolving as SDA incorporates feedback from developers, but making these changes concurrent with OCT development across multiple contractors increases risk of achieving interoperability. Even with the central importance of the OCT standard to the success of implementing laser communications, SDA has made significant changes across tranches. In particular, SDA made revisions to the standard between T0 and T1, which developers characterized as substantial, and again between T1 and T2, which developers and SDA officials characterized as fairly minor. Experts and contractors told us that changes in the OCT standards could lead to difficulties in communicating across the satellites in each tranche and those built by different contractors. For additional details on the versions of the standard, see appendix II.

Looking ahead, SDA plans for T3 to include more significant changes to the standard. In June 2024, SDA issued SDA OCT Standard, version 4.0. SDA developed this standard to support laser links to orbits beyond LEO. Multiple contractors we spoke with said that the change to the standard this time is significant, and, rather than the evolutionary change in the earlier standards, they characterized this change as revolutionary. Specifically, some contractors said that meeting the requirements of the new standard could mean changes in hardware and software.

Multiple contractors reported that participating in a working group to discuss OCT development is critical to their success in meeting the evolving standard. These contractors meet weekly to discuss OCT development and said that being a part of this group is critical to understanding common design decisions not captured in the standard itself. Multiple contractor representatives said that it is important to be a part of this group to ensure they are developing an OCT that is interoperable with the other PWSA OCTs. Contractor representatives said this is because even for seemingly straightforward requirements in a standard, different people may interpret implementation differently, potentially resulting in incompatible designs.

New standards typically evolve as feedback from developers and users is gathered and incorporated, and new needs and capabilities are required. However, changing the SDA OCT Standard while each tranche is under development increases the risk that the OCTs may not be interoperable among different vendors, even if they meet the standard. It also risks some contractors not meeting the new standard at predicted costs and schedule. This increases the importance of fully testing and demonstrating capability in each tranche to ensure the OCTs can connect before the same design is used for future tranches.

SDA Does Not Currently Link Future Development to Demonstrated Capability

While SDA had taken steps to implement iterative development by establishing an MVP in each tranche, it is prioritizing rapid iteration of the tranches over iterative learning because it is starting new tranches before demonstrating earlier MVPs. The Director of SDA said that PWSA tranche development efforts are independent and delays in one tranche will not affect the development schedule of future tranches. The director said SDA does not link the efforts based on the status of the fully demonstrated MVPs or intend to revise the timeline for T1 based on whether the MVP is demonstrated in T0. Likewise, SDA does not intend to change the schedules of future tranches, including T2 or T3, based on demonstrating the MVP in prior tranches.

As a result, SDA cannot ensure that information gained from initial tranches or MVPs can be used to inform future tranches, and risks not developing sufficient capability to address user needs and mission capability. By not continuously evaluating schedule and performance parameters to confirm that the underlying business case is still sound, SDA risks continuing to launch satellites in subsequent tranches that do not deliver planned capability on the timeline it presented to stakeholders.

SDA Is Moving Forward with Increased Scale of and Investment in Future Tranches Without Commensurate Progress in Demonstrated Capability

SDA is moving forward with dramatic increases in the scale of future tranches even though it has made limited progress demonstrating laser communications—a central capability for PWSA. The added size and planned capabilities increase the complexity of transferring data successfully through laser communications technologies throughout the constellation. Additionally, SDA is planning significant continued investment. In March 2024, SDA announced plans for future spending, bringing the total planned investment in PWSA through fiscal year 2029 to nearly $35 billion.

Planned Increases in Constellation Size and Capability Precede Demonstrated Success

SDA plans to increase the constellation sizes considerably and has involved multiple vendors at each stage. For example, SDA contracted with nine unique prime contractors to develop the T0, T1, and T2 Tracking and Transport Layers. A total of at least four different OCT developers are subcontractors across the nine prime contractors. Table 3 shows the prime contractors involved in each tranche, as well as the cost and number of planned satellites.

Table 3: Number of Total Satellites by SDA Proliferated Warfighter Space Architecture (PWSA) Tranche and Layer, Including Prime Contractor and Contract Values

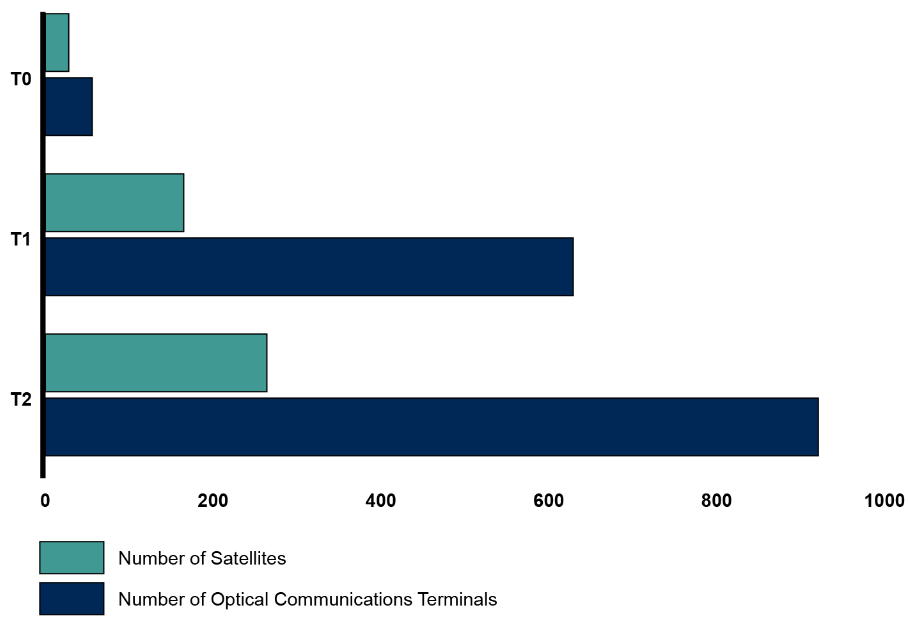
SDA PWSA layer	Tranche 0	Tranche 1	Tranche 2	Approximate total contract value by layer (dollars in millions)
Tracking	8	39	54	$4,707
	SpaceX	Northrop Grumman	Lockheed Martin	
	L3Harris	L3Harris	Sierra Space	
		Raytheon	L3Harris	
Transport	20	126		$2,074
	Lockheed Martin	Lockheed Martin		
	York Space Systems	Northrop Grumman		
		York Space Systems		
Transport (Alpha)			100	$1,328
			York Space Systems	
			Northrop Grumman	
Transport (Beta)			90	$2,064
			Northrop Grumman	
			Lockheed Martin	
			Rocket Lab	
Transport (Gamma)			20	$424
			York Space Systems	
			Tyvak Nano-Satellite Systems	
Approximate total cost by tranche (dollars in millions)	$657	$3,674	$6,267	**$10,598**
Total number of planned satellites by tranche	**28**	**165**	**264**	

Source: GAO analysis of Space Development Agency (SDA) information. | GAO-24-106838

Note: The table includes the original prototyped satellite capabilities in T0, T1 and T2 as reflected in the original contracts. SDA ultimately launched 27 Tranche 0 satellites and removed seven satellites from Tranche 1 (Tracking). Alpha, Beta, and Gamma refer to variants of the satellites introduced in the Tranche 2 Transport Layer. Due to rounding, the approximate total cost by layer does not add up to exactly $10,598 million.

Further, in T1, SDA's plans require approximately 10 times the number of OCTs developed for T0 to support the larger constellation. See figure 8.

Figure 8: Number of Planned Satellites and Laser Communications Terminals by Proliferated Warfighter Space Architecture Tranche



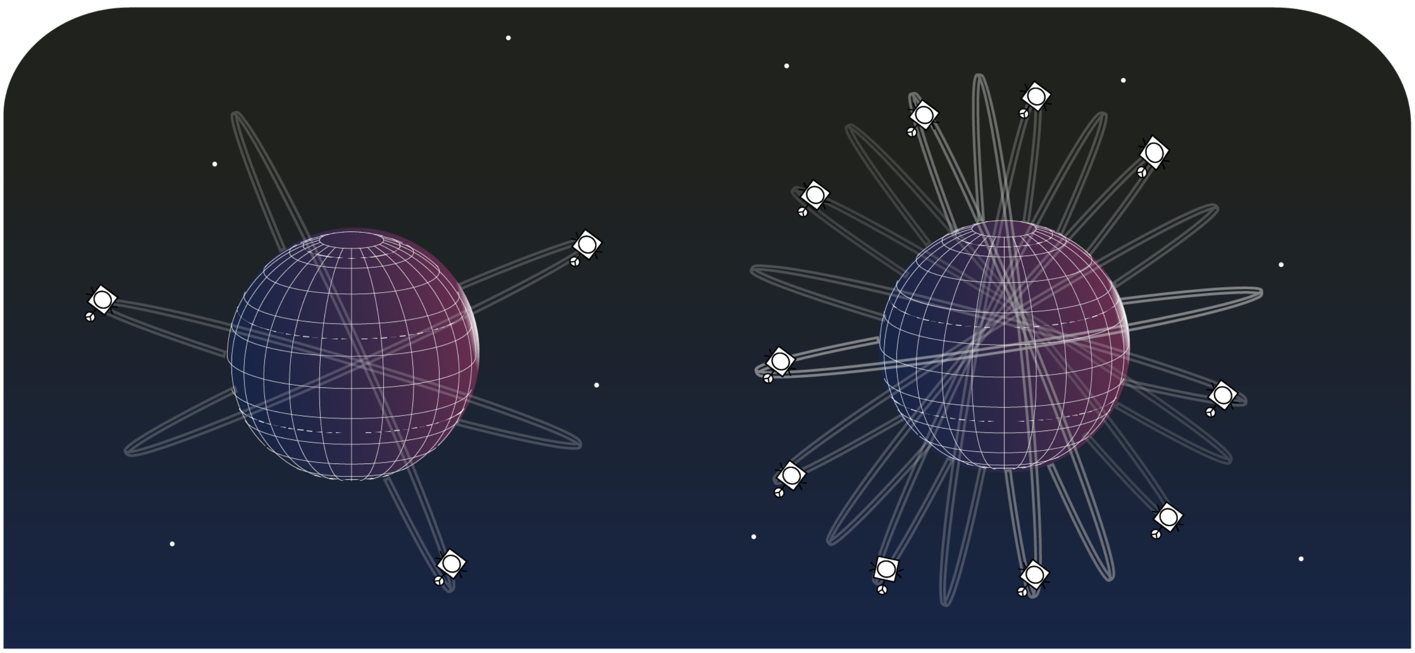
Source: GAO analysis of Department of Defense information. | GAO-25-106838

The T1 MVP will provide a more complex capability than the T0 MVP. SDA describes T1 as providing persistent regional access for some capabilities, such as low-latency data connectivity. To achieve this capability, SDA plans to add capability to the mesh network MVP they had planned to demonstrate in T0 and expand the network to increase the number of orbital planes that OCTs must transmit data across from three planes in T0 to 10 planes in T1.[40] T1 also includes a requirement that OCTs on Transport Layer satellites enable a minimum of four simultaneous laser communications links, and OCTs on Tracking Layer satellites support two or three simultaneous laser communications links, depending on the variant. These laser communications technology requirements support a mesh network that is far more complex than anything SDA has been able to demonstrate in T0, and the satellites for T1 are already in production.

[40]SDA descoped an agreement with one of its contractors, Raytheon, in early 2024, eliminating another planned T1 Tracking plane. Officials said this does not affect the MVP.

Similarly, SDA plans to add substantially more satellites and capability in T2 beyond what is planned for T1. In T2, SDA plans to improve T1 capabilities with persistent global access plus demonstration of additional capabilities. Specifically, SDA plans to further expand the network in T2, connecting OCTs across at least another 26 planes and including multiple satellite variants that require design changes. T2 also includes requirements for three or four simultaneous laser communications links, depending on the satellite variant. Plans for future tranches include added capability across the architecture. Figure 9 depicts an increase from three orbital planes to 10 orbital planes.

Figure 9: Image of Three Orbital Planes and Ten Orbital Planes



not to scale

Source: GAO analysis of Department of Defense information. | GAO-25-106838

As the number of satellites in each tranche increases, establishing functional and timely laser links becomes increasingly important. As noted previously, SDA's approach is contrary to our leading practices for development timelines. Without achieving the initial MVP in each tranche to inform design changes for future tranches, SDA is not taking advantage of an iterative approach and PWSA is at risk of not achieving full laser communications capability in space. For example, on-orbit T0 test results, once complete, may uncover problems that necessitate design changes to achieve connections between OCTs. Since T1 and T2 are already in development, SDA may have limited opportunities to incorporate required design changes into those designs. Incorporating design changes in those tranches could potentially delay capability, meaning that laser communications capability required to support multiple DOD missions may not be available for the warfighter as planned.

SDA Has Not Demonstrated Progress Commensurate with the Level of Planned Investment

According to our leading practices for product development, programs should ensure that funding is commensurate with a product's design and development progress, rather than giving a product development team a substantial amount of funding at development start. SDA officials said that schedule is a priority and delays in one tranche, such as those experienced in T0, will not affect the next tranche, including decisions to award contracts. However, SDA has not demonstrated a baseline laser communications capability or MVP for its current efforts in T0, nor does its plan require demonstrated capability in T1 and T2 before moving forward. Further, SDA plans to continue to commit to high levels of investment in future tranches. The agency plans to award contracts for T3 starting in 2025 for approximately 200 satellites. As a result, SDA's spending plans are not commensurate with its demonstrated capability, and SDA is at risk of investing substantial amounts of money without delivering promised capabilities to support critical missions.

SDA Has Not Sufficiently Communicated Key T0 Schedule or Performance Information to Stakeholders to Inform Future Decisions

Communication about test schedules and when stakeholders can expect to receive performance data on the MVP of each tranche is critical to ensuring effective design decisions. This is due to the sensitivity of laser communications technology, and the effect satellite and OCT designs can have on performance. In addition, DOD guidance and GAO's leading practices stress the importance of including stakeholders in critical phases of project development.

To SDA's credit, multiple contractors we spoke with said that SDA's approach to PWSA has facilitated unique levels of collaboration across vendors and across tranches. For example, one contractor described learning about a challenge with a specific OCT hardware component in one of the tranches and said that sharing that challenge with another contractor helped them identify a common solution.

Having multiple contractors involved in and across tranches increases the need for communication about testing results, including lessons learned and necessary design changes. SDA's strategy of competitively awarding contracts for each of the tranches means that different contractors may participate in each tranche. For T0, T1, and T2, this has meant differing configurations of contractors within and across each tranche, which increases the number of unique designs that must work together. Specifically,

- T0 includes four prime contractors.
- T1 includes five prime contractors, two of which did not participate in T0.
- T2 includes seven contractors, four of which participated in T1 and three of which are new.
- Nine total contractors are on contract through T2.[41]

Although essential to success, SDA has not sufficiently communicated key T0 test schedule or performance information to relevant stakeholders, such as testing officials and contractors working on T0, T1, and T2. Selected T0, T1, and T2 stakeholders, including contractors and test officials, told us that SDA has shared very little information about T0 testing timelines or performance information from on-orbit testing. Although T0 contractors developed individual test plans, we could not identify any overarching test or demonstration strategy that stakeholders could use to understand overall test plans. These stakeholders added that any lessons that emerge from T0 testing are important to communicate as early as possible.

In response, SDA officials said they do not have an overall schedule for T0 laser communications testing. Additionally, SDA officials and contractor representatives said that sharing performance information can be challenging because the need to protect proprietary information makes it difficult to share challenges and potential solutions for OCT technology development. The lack of an overall test schedule and plan is concerning.

Without knowledge of SDA's T0 testing schedule and performance data, stakeholders cannot synchronize key decisions with T0 information that could inform technical and programmatic risks in succeeding tranches.

Conclusions

Laser communications are essential to support DOD's desired pivot to a low-earth-orbit-based constellation that could provide significant advantages to DOD when facing new threats. SDA is taking important steps to develop laser communications technologies, including using an

[41]Multiple contractors are involved in both transport and tracking and may have multiple contracts within a tranche. This represents the unique number of contractors.

iterative approach that could allow it to move more quickly to develop a satellite constellation.

While SDA has taken considerable steps to prioritize speed, this has had consequences. In particular, contracting for the larger and more complex T1 and T2 before demonstrating the lowered expectations for T0 presumes that these future efforts will be successful even given what has been witnessed with initial prototyping. However, SDA does not yet fully understand what will and will not work in T0. SDA's schedule-driven focus impedes its ability to incorporate lessons from each tranche, a key feature of iterative development. As a result, it has not fully incorporated lessons learned and corrective updates into these follow-on efforts. Without demonstrating key laser communications technology capabilities, or MVPs, SDA is risking not being able to leverage past experiences into the investments either under contract or planned for in the future. These investments are substantial—nearly $35 billion. Finally, SDA has not ensured that stakeholders, such as contractors and testing officials, have received important information on test schedule plans and performance data.

The focus on seeking to use iterative development is important, but SDA's current approach does not provide sufficient opportunity to leverage past experiences. Adhering to the leading practices for product development that GAO has identified can improve SDA's likelihood of successfully delivering critical capabilities that meet the needs of the warfighter in a timely and cost-effective manner.

Recommendations for Agency Action

We are making the following four recommendations to the Air Force:

The Secretary of the Air Force should ensure that the Director of the Space Development Agency demonstrates the minimum viable product for laser communications capability in space in PWSA's T0 and incorporates relevant lessons learned and corrective updates before proceeding with launch decisions for satellites in T1. (Recommendation 1)

The Secretary of the Air Force should ensure that the Director of the Space Development Agency creates and documents a link between demonstrating the minimum viable product for laser communications capability in space in PWSA's T1 and incorporates relevant lessons learned and corrective updates before proceeding further with launch decisions for satellites in T2. (Recommendation 2)

The Secretary of the Air Force should direct the Director of the Space Development Agency to ensure investment in PWSA is commensurate with development progress by demonstrating the minimum viable product of laser communications in space and incorporating lessons learned and corrective updates in T1 and, to the extent practicable, T2 before proceeding with the T3 effort. (Recommendation 3)

The Secretary of the Air Force should direct that the Director of the Space Development Agency documents and communicates PWSA's T0, T1, T2 and future tranche on-orbit test plans, including timelines and results, to relevant stakeholders. (Recommendation 4)

Agency Comments

We provided a draft of this report to DOD in November 2024 for a 30-day review and opportunity to comment. DOD provided technical comments, which we incorporated as appropriate.

In the formal comments provided by DOD in February 2025 (reproduced in appendix III), the department formally concurred with our recommendations, with comments. However, in the content of these comments, DOD notes that it believes it is already implementing our recommendations. We disagree. The evidence presented throughout our draft and final report supports our view that SDA is not already taking the actions we recommend. We continue to believe SDA would benefit from taking steps aimed at implementing our recommendations.

In its comments, DOD's letter presents a revised statement of the T0 MVP—shifting from what we document as a mesh network, to demonstrating the feasibility of developing such a network. This approach to revise downward the minimum viable product, or capability, is at odds with the leading practices for iterative development. Similarly, the letter notes that lessons learned and test plans are being shared with stakeholders. While we are aware that some information is shared with certain stakeholders, other stakeholders we spoke with said that schedule and performance data were not available to them.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Defense, the Secretary of the Air Force, and other interested parties. In addition, the report is available at no charge on the GAO website at https://www.gao.gov.

If you or your staff have any questions about this report, please contact Jon Ludwigson at (202) 512-4841 or ludwigsonj@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs are on the last page of this report. GAO staff who made contributions to this report are listed in appendix IV.

Jon Ludwigson
Director, Contracting and National Security Acquisitions

List of Committees

The Honorable Roger Wicker
Chairman
The Honorable Jack Reed
Ranking Member
Committee on Armed Services
United States Senate

The Honorable Mitch McConnell
Chair
The Honorable Christopher Coons
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Mike Rogers
Chairman
The Honorable Adam Smith
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable Ken Calvert
Chairman
The Honorable Betsy McCollum
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

Appendix I: Objectives, Scope, and Methodology

This report (1) describes the Space Development Agency's (SDA) efforts to develop and demonstrate laser communications technology; and (2) evaluates the extent to which SDA is following leading product development practices for incorporating space-based laser communications technology into its Proliferated Warfighter Space Architecture (PWSA).

To conduct this work, we reviewed relevant Department of Defense (DOD) documents related to budgets and strategic planning, and reports such as DOD's Cost Assessment and Program Evaluation's evaluation of SDA's PWSA. We interviewed officials from offices throughout DOD to get a better understanding of the department's approach to developing laser communications technologies. These offices included the Defense Advanced Research Projects Agency; Office of Developmental Test, Evaluation, and Assessment; DOD's Principal Director of Space; Space Force's Space Warfighting Analysis Center; and others. We interviewed multiple officials in Space Systems Command doing similar development work, but whose efforts are in earlier stages of development than SDA.

To better understand the technical challenges of developing laser communications technologies, we conducted site visits to the Air Force Research Laboratory and the Massachusetts Institute of Technology's Lincoln Lab. We also toured contractor labs and viewed optical communications terminals (OCT) and satellite prototypes. We also visited the Naval Research Laboratory testbed, where OCTs built by different vendors and that are planned to be used for Tranche 1 (T1) have undergone OCT Interoperability Testing. We met multiple contractor representatives—including from prime contractors and subcontractors, and large and small contractors—and toured facilities doing OCT development. To better understand how data could be received and processed on the ground from laser technologies in space, we visited the Boulder Ground Innovation Facility. We also met with officials from the National Aeronautics and Space Administration to discuss their independent efforts to develop laser communications technologies in space.

To address our first objective to describe the status of SDA's development efforts and demonstration of laser communications technology, we reviewed documents such as SDA's OCT Standards and OCT technical memorandums used by commercial vendors in developing an OCT for SDA's PWSA; SDA's request for proposals, contracts, and agreements; planning documents such as the Concept of Operations and Life-Cycle Sustainment Plan; test strategies and outcomes; and SDA briefings to Congress. We also attended presentations where SDA officials spoke.

To address our second objective to evaluate whether SDA is following our leading practices for product development, we reviewed SDA's planning documents and conducted interviews with leadership to better understand SDA's approach to product development. We then compared those practices with some of our leading practices on product development relevant to the development of a space-based cyber-physical system technology.[1] We also reviewed relevant DOD guidance, such as the DOD Prototyping Guidebook and compared that guidance to SDA's efforts.

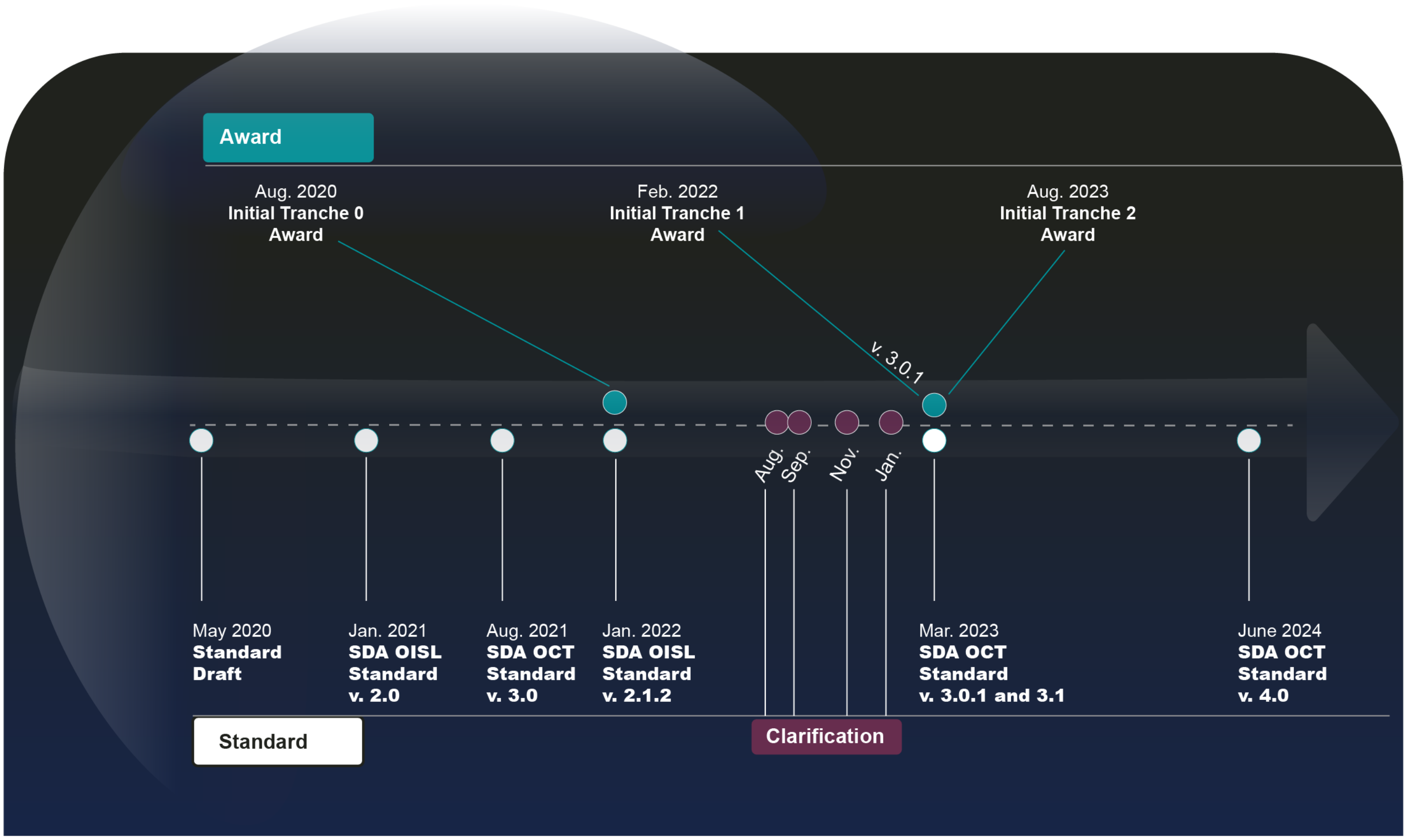
We conducted this performance audit from May 2023 to February 2025 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

[1]GAO, *Agile Assessment Guide: Best Practices for Adoption and Implementation*, GAO-24-105506 (Washington, D.C.: Nov. 28, 2023; reissued Dec. 15, 2023); and *Leading Practices: Iterative Cycles Enable Rapid Delivery of Complex, Innovative Products,* GAO-23-106222 (Washington, D.C.: July 27, 2023).

Appendix II: Space Development Agency Optical Communications Terminal Standard

Each of the Space Development Agency's (SDA) tranches so far is built to a different version of the SDA Optical Communications Terminal (OCT) Standard. This increases the complexity of achieving the desired capability. Figure 10 illustrates the changes in the OCT Standard across tranches.

Figure 10: Space Development Agency's Optical Communications Standard Development Timeline



SDA Space Development Agency

OCT Optical Communications Terminal

OISL Optical Intersatellite Link

Source: GAO analysis of Department of Defense information. | GAO-25-106838

SDA finalized the different versions of the standard during overlapping time periods. For example, the version of the standard used in Tranche 0 (T0) was finalized 5 months after the version included in the Tranche 1 (T1) Transport Layer and Tracking Layer program solicitations.

Additionally, standard versions 3.0.1 and 3.1 were finalized in the same month—March 2023.

Contractors told us that these versions of the standard are a significant improvement, but concerns continue about interoperability with OCTs made by other vendors because some specifications can be interpreted multiple ways. SDA initially communicated to potential contractors in the solicitations that the OCTs for T1 would be required to meet the SDA OCT Standard version 3.0 and used that version and another version of the standard in the awards. Additionally, following the T1 solicitations, SDA issued four technical clarifications in response to contractor questions related to the standard. For example, SDA issued a clarification on the modem implementation. The clarification notes that one of the OCT providers made certain implementation choices that, while consistent with the SDA OCT Standard, would lead to challenges with interoperability if interpreted differently by a different vendor. This clarification also notes that it is intended to address areas where the standard was ambiguous, incomplete, or contradictory.

Tranche 2 (T2) uses yet another version of the standard, SDA OCT Standard version 3.1, with changes that DOD officials and contractor representatives characterized as an evolution and clarification. SDA documents show that OCTs designed for T2 with this version of the standard are required to connect with T1 OCTs.

Appendix III: Comments from Department of Defense

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3030 DEFENSE PENTAGON
WASHINGTON, DC 20301-3030

MISSION CAPABILITIES

Mr. Jon Ludwigson
Director, GAO Contracting and National Security Acquisitions
U.S. Government Accountability Office
441 G Street, NW
Washington DC 20548

6 FEB 2025

Dear Mr. Ludwigson,

Enclosed is the Department of Defense response to the Government Accountability Office (GAO) Draft Report, GAO-25-106838, "LASER COMMUNICATIONS: Space Development Agency Should Demonstrate Capabilities Before Making Further Investments" dated November 8, 2024 (GAO Code 106838).

My point of contact is Dr. Paul Zablocky, who can be reached at paul.g.zablocky.civ@mail.mil and phone (703) 693-8554.

Sincerely,

Marcia B. Holmes
Performing the Duties of
Assistant Secretary of Defense
for Mission Capabilities

Enclosure:
As stated

GAO DRAFT REPORT DATED NOVEMBER 8, 2024
GAO-25-106838 (GAO CODE 106838)

"LASER COMMUNICATIONS: Space Development Agency Should Demonstrate Capabilities Before Making Further Investments"

DEPARTMENT OF DEFENSE COMMENTS
TO THE GAO RECOMMENDATIONS

RECOMMENDATION 1: The Secretary of the Air Force should ensure that the Director of the Space Development Agency (SDA) demonstrates the minimum viable product for laser communications capability in space in the Proliferated Warfighting Space Architecture's (PWSA's) Tranche 0 (T0) and incorporates relevant lessons learned and corrective updates before proceeding with launch decisions for satellites in Tranche 1 (Tl).

DOD RESPONSE: Concur with comments. The recommendation should read " ... continue to incorporate relevant lessons learned ... "

SDA has met the minimum viable product (MVP) for T0, which is to demonstrate the feasibility of the proliferated architecture in cost, schedule, and scalability towards necessary performance for beyond line of sight targeting and advanced missile detection and tracking. SDA's MVP for the T0 Transport Layer includes periodic regional access for low latency data connectivity, data directly to tactical elements, and data disseminated to theater targeting cells. T0 validates our approach and achieved stated objectives: Link-16 from space-to-ground, -air, and -sea; and forming an optical network in Low Earth Orbit (LEO) for both the Transport and Tracking Layers. Lessons learned with respect to optical communications have been documented in technical memos provided to GAO as well as used to update SDA's Optical Communication Standard for subsequent tranches. SDA continues to incorporate lessons from T0 into T1, Tranche 2 (T2), and future tranches.

RECOMMENDATION 2: The Secretary of the Air Force should ensure that the Director of the Space Development Agency creates and documents a link between demonstrating the minimum viable product for laser communications capability in space in PWSA's Tl and incorporates relevant lessons learned and corrective updates before proceeding further with launch decisions for satellites in T2.

DOD RESPONSE: Concur with comments. Recommendation should read " ... continue to incorporate relevant lessons learned ... "

SDA uses spiral development as it prioritizes early risk identification and mitigation through iterative cycles known as tranches, allowing for continuous stakeholder feedback and adjustments to the minimum viable capabilities throughout the development process, which is driving higher stakeholder satisfaction and a better final capability.

2

SDA has folded in lessons learned from T0 and will continue to do so as it obtains additional data. SDA successfully demonstrated the joint warfighter defined MVP then incorporated lessons learned with respect to data connectivity to the warfighter and missile tracking and is proceeding to T1 launch. Similar approaches to incorporating lessons learned, particularly from Critical Design Reviews, into subsequent tranches are part of the continuous development approach at SDA. Additionally, SDA has realigned its Chief Engineering Officer to ensure knowledge management of lessons learned for each capability set are applied across tranches.

RECOMMENDATION 3: The Secretary of the Air Force should direct the Director of the Space Development Agency to ensure investment in PWSA is commensurate with development progress by demonstrating the minimum viable product of laser communications in space and incorporating lessons learned and corrective updates in Tl and, to the extent practicable, T2 before proceeding with the Tranche 3 (T3) effort.

DOD RESPONSE: Concur with comments. Recommendation should read " ... continue to incorporate relevant lessons learned ... "

SDA is using spiral development as it prioritizes early risk identification and mitigation through iterative cycles known as tranches, allowing for continuous stakeholder feedback and adjustments to the minimum viable capabilities throughout the development process, which is driving higher stakeholder satisfaction and a better final capability for the joint warfighter.

SDA's continuous development process and Chief Engineering Officer are ensuring demonstration of the minimum viable product for laser communications and that lessons learned from all prior tranches with respect to all capability sets are incorporated into subsequent tranches on a continuous basis. SDA updated elements of its solicitations for T2 and T3 based on lessons learned from T0 and T1 solicitations and responses.

RECOMMENDATION 4: The Secretary of the Air Force should direct that the Director of the Space Development Agency documents and communicates PWSA's T0, Tl, T2 and future tranche on-orbit test plans, including timelines and results, to relevant stakeholders.

DOD RESPONSE: Concur with comments. SDA is providing and will continue to provide on-orbit test plans and timelines to Delta 12 and other relevant stakeholders.

Appendix IV: GAO Contacts and Staff Acknowledgments

GAO Contact

Jon Ludwigson at (202) 512-4841 or ludwigsonj@gao.gov

Staff Acknowledgments

In addition to the contact name above, the following staff members made key contributions to this report: Raj Chitikila (Assistant Director), Mary C. Diop (Analyst-in-Charge), Joseph Aubee, Breanne Cave, Edward Harmon, Albirio Madrid, Jean McSween, Christine Pecora, Mary Anne S. Sparks, Jay Tallon, Alyssa Weir, and Robin Wilson.

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