GPS MODERNIZATION

Delays Continue in Delivering More Secure Capability for the Warfighter

Report to Congressional Committees

September 2024
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GAO Highlights

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Highlights of GAO-24-106841, a report to congressional committees
September 2024

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Delays Continue in Delivering More Secure Capability for the Warfighter

Why GAO Did This Study

GPS is the principal source of positioning, navigation, and timing information for the U.S. military and its partners. The Air Force launched the first GPS satellite capable of broadcasting the more jam-resistant M-code signal in 2005. Continued delays to the ground and user equipment segments, however, prevent widespread use of the technology. Integration of the user equipment with ground, air, and maritime weapon systems by the military departments is critical to delivering this capability to the warfighter. GAO has reported on challenges DOD experienced developing these systems since 2009 and made many recommendations to improve those efforts. For example, DOD has implemented eight of nine recommendations since 2022.

Congress included a provision for GAO to assess the cost, schedule, and performance of GPS acquisition programs. This report assesses (1) the progress the Space Force has made in modernizing GPS space and ground control segments; (2) the extent to which the Space Force has identified and managed risks in developing and demonstrating user equipment; and (3) the extent to which the military departments have identified and managed risks in acquiring, testing, and fielding M-code-capable user equipment.

GAO reviewed pertinent documentation, such as contract performance reports, and interviewed relevant officials from DOD and the military departments. DOD provided technical comments, which we incorporated as appropriate.

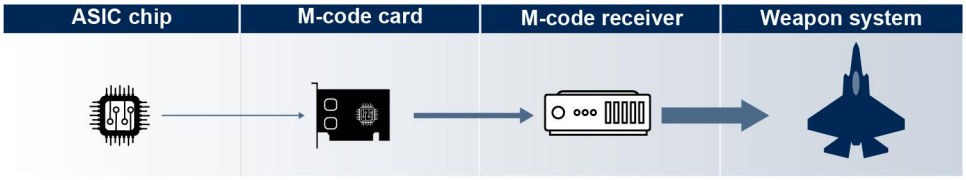
What GAO Found

The Department of Defense (DOD) has worked for more than 2 decades to modernize its GPS with a more secure, jam-resistant, military-specific signal known as M-code. The Space Force, part of the Department of the Air Force, is responsible for GPS modernization. The GPS system consists of three segments that cooperate to provide M-code: a space segment, a ground control segment, and user equipment.

After multiple delays, the Space Force has continued its GPS modernization efforts, but significant work and challenges remain for each segment:

- The space segment has mitigated some technical and manufacturing challenges. But in doing so, the Space Force has consumed schedule margin, resulting in potential delays to delivering the satellites. Further delays could risk DOD's goal to have 24 M-code-capable satellites in continuous operation through the 2030s.
- After multiple delays, ground segment modernization has completed some key testing, but further testing and demonstration is needed before the military departments can accept the system. This is projected to occur by December 2025.
- While the Space Force has made progress in developing user equipment, significant risks remain to delivering capabilities to the warfighter. After years of delay, the first increment of user equipment—microchips and cards that process M-code signals—is approaching its final series of tests. However, discovery of additional deficiencies threatens the program's schedule. Meanwhile, DOD is addressing potential shortages of GPS chips and cards.

GPS User Equipment Integration



ASIC Application-Specific Integrated Circuit **M-code** Military code

Source: GAO analysis and representation of Department of Defense documentation; GAO (icons). | GAO-24-106841

The military uses receivers in vehicles, munitions, and handheld devices to receive and process GPS data. The Air Force has been delayed in integrating M-code with its receivers. But the other departments are making progress.

- To mitigate some of these delays, the Navy and Air Force are planning an interim solution that could provide limited M-code capability for aircraft.
- The Army plans to field receivers in its platforms in fiscal years 2024 and 2025.
- The Navy plans to complete operational testing of its maritime receiver in fiscal year 2025.

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Abbreviations

ASIC	application-specific integrated circuit
DAPS	Dismounted Assured Positioning, Navigation, and Timing System

DOD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
EAGLE-M	Embedded GPS/Inertial Navigation System/Enhanced Aviation Global Air Traffic Management Localizer Performance Vertical Guidance Embedded GPS Inertial Navigation System M-code
EGI-M	Embedded GPS Inertial Navigation System – Modernized
GPNTS	GPS-based Positioning, Navigation, and Timing Service
GPS	Global Positioning System
GPS III	Global Positioning System III
GPS IIIF	Global Positioning System III Follow-on
MAGR-2K-M	Miniature Airborne GPS Receiver 2000 – Modernized
MAPS	Mounted Assured Positioning, Navigation, and Timing System
M-code	military code
MGUE	Military GPS User Equipment
OCX	Next Generation Operational Control System
PNT	positioning, navigation, and timing
R-EGI	Resilient-Embedded GPS/Inertial Navigation System
SSC	Space Systems Command

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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September 9, 2024

Congressional Committees

The Department of Defense's (DOD) Global Positioning System (GPS) remains the principal source of positioning, navigation, and timing information for the U.S. military and North Atlantic Treaty Organization partners. DOD has been working for more than 2 decades to modernize its use of GPS with a more jam-resistant, encrypted, military-specific signal, referred to as military code (M-code), which is critical to maintaining the system's effectiveness in the face of adversary threats. The Air Force launched the first GPS satellite capable of broadcasting the M-code signal in 2005. The U.S. Space Force, part of the Department of the Air Force, is currently developing modernized elements of GPS to use M-code.

The Space Force's GPS efforts include the development of a modernized ground control system, upgraded satellites, and user equipment that the military departments will integrate with platforms such as ground vehicles to receive the M-code signal. Many of the programs that are part of the GPS modernization effort had significant development challenges that resulted in cost overruns and years of delays to implementing M-code capability. These delays increase risk to the warfighter as adversaries continue to develop and field technology that can compromise GPS signals. Since 2009, we have reported on the challenges DOD has experienced developing these systems and recommended actions for improvement.[1] For example, DOD has implemented eight of nine recommendations since 2022.

Section 1621 of the National Defense Authorization Act for Fiscal Year 2016 includes a provision for us to report on, among other things, the cost, schedule, and performance of the GPS acquisition programs until they reach initial operational capability.[2] This report assesses (1) the progress the Space Force has made in achieving operational capability for the modernized GPS ground control and space segments; (2) the extent to which the Space Force has identified and managed risks in developing and demonstrating user equipment; and (3) the extent to which the military departments have identified and managed risks in acquiring, testing, and fielding M-code-capable user equipment and integrating that equipment into platforms.

For all our objectives we reviewed pertinent documentation, such contract performance reports, and conducted interviews with relevant officials from DOD, the Army, Navy, Marine Corps, Air Force, and the Space Force. Specific to the satellite analysis in the second objective, we analyzed the GPS satellite constellation based on

[1]GAO, *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices*, GAO-23-106018 (Washington, D.C.: June 5, 2023); *GPS Modernization: Better Information and Detailed Test Plans Needed for Timely Fielding of Military User Equipment*, GAO-22-105086 (Washington, D.C.: May 9, 2022); *GPS Modernization: DOD Continuing to Develop New Jam-Resistant Capability, but Widespread Use Remains Years Away*, GAO-21-145 (Washington, D.C.: Jan. 19, 2021); *Global Positioning System: Better Planning and Coordination Needed to Improve Prospects for Fielding Modernized Capability*, GAO-18-74 (Washington, D.C.: Dec. 12, 2017); *GPS: Actions Needed to Address Ground System Development Problems and User Equipment Production Readiness*, GAO-15-657 (Washington, D.C.: Sept. 9, 2015); *Global Positioning System: Challenges in Sustaining and Upgrading Capabilities Persist*, GAO-10-636 (Washington, D.C.: Sept. 15, 2010); and *Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities*, GAO-09-325 (Washington, D.C.: Apr. 30, 2009).

[2]National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114-92, § 1621 (10 U.S.C. § 2281 note).

GPS data provided by the Space Force. We determined these data to be reliable for the purpose of the analysis.[3] For additional details on our scope and methodology, see appendix I.

We conducted this performance audit from May 2023 to September 2024 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 a 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.

Background

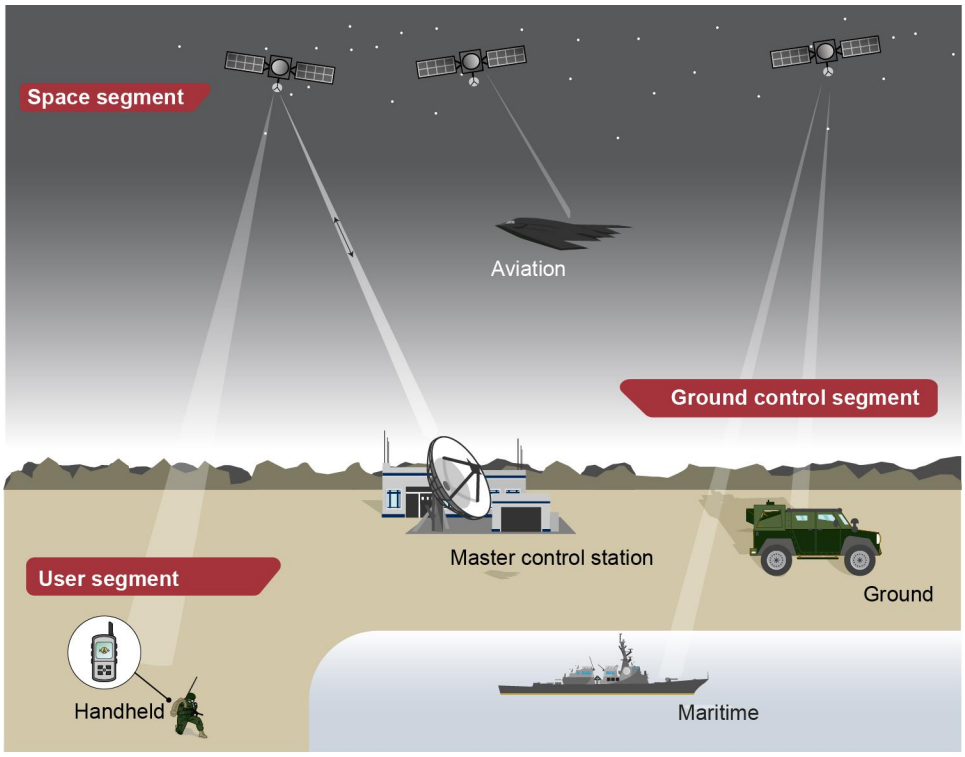
GPS consists of three segments—ground control, space, and user equipment. The ground control segment commands and controls the satellites that make up the space segment. The space segment is a constellation of orbiting satellites that continuously broadcast the GPS signal. The user equipment segment includes cards and receivers used by the military in aircraft, ships, land vehicles, munitions, and handheld devices that derive positioning, navigation, and timing (PNT) data from the satellite signals. Since 2000, the Air Force (and later the Space Force) has pursued a multi-billion-dollar effort to modernize the three segments of GPS to provide new signals, enhance cybersecurity, and counter known threats. In August 2021, day-to-day responsibility for modernizing and sustaining GPS transitioned from the Air Force to the Space Force's Space Systems Command (SSC).

GPS Modernization

Collectively, the ongoing GPS acquisition efforts intend to enhance the current system by adding M-code capability. M-code is a stronger, encrypted, military-specific GPS signal designed to meet military PNT information needs. M-code will help military users overcome adversaries' attempts to block the GPS signal, known as jamming, by using a more powerful signal with a broader radio frequency range. It will also protect against false GPS signals, known as spoofing, by providing enhanced encryption for the signal. Figure 1 shows the GPS satellite, ground control, and user equipment segments that function together as an operational system.

[3]GAO-23-106018.

Figure 1: GPS Segments



Source: GAO analysis and representation of Department of Defense documentation; GAO illustration. | GAO-24-106841

M-code Ground Segment

Modernizing GPS with M-code requires the development of a ground control system that can enable the launch and control of existing and new, more powerful satellites. DOD has been working to develop the modernized ground control segment since 2010. In 2020, SSC provided two modifications to the current GPS ground control system. This enabled, among other things, some operational control of a subset of M-code capabilities, and the testing and fielding of M-code user equipment. SSC continues to develop the system it expects to eventually provide the full M-code capability.

The effort to modernize the ground segment is managed through the GPS Next Generation Operational Control System (OCX) program, which plans to enable full M-code capabilities, as well as provide improved cybersecurity. SSC's OCX efforts are structured through a series of block upgrades and are primarily software-based, but they also include new hardware and upgrades to monitoring stations throughout the world. Raytheon Technologies, the prime contractor for OCX, is developing these blocks. See table 1 for a description of the GPS ground control modernization program.

Table 1: Current GPS Ground Control Modernization Program

Program	Description	Total program costs as of November 2023
Next Generation Operational Control System (OCX) Blocks 0, 1, and 2	Block 0—provides the launch and checkout system and supports initial testing of GPS III satellites. GPS III satellites cannot launch without OCX Block 0. It also provides modern cybersecurity capabilities, a key advancement in securing the system. The contractor delivered Block 0 in October 2017. The Space Force has used Block 0 to launch six GPS III satellites as of January 2023. Blocks 1 and 2—will provide command and control for GPS III as well as previous generations of satellites, monitoring and control for both modernized and current signals, and full M-code broadcast capability.	$7.6 billion
OCX Block 3F	Block 3F—will build on OCX Blocks 1 and 2 software to add capabilities to control and use the GPS IIIF space segment and future user equipment capabilities. The Space Force awarded a development contract for OCX Block 3F to Raytheon in April 2021.	$433 million

Source: GAO analysis of Department of Defense data. | GAO-24-106841

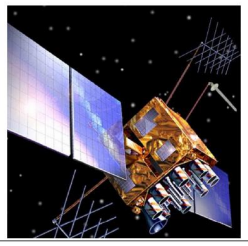
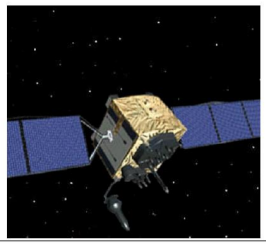
The users of OCX are satellite operators from the Space Force's 2nd and 19th Space Operations Squadrons. The operators will assist with developmental testing of OCX after receiving training from Raytheon. The operators are also responsible for transitioning the GPS satellite constellation from the current ground system to OCX.

M-code Space Segment

The GPS satellite constellation is controlled by the ground segment and is composed of four generations of satellites with varying capabilities and design lives, or the time during which a satellite is expected to meet its mission objectives. The first satellite able to transmit the M-code signal entered orbit in 2005, and 24 of the 31 satellites in the GPS constellation were M-code-capable as of May 2024.

Ensuring that the constellation maintains and expands this M-code capability requires launching additional M-code-capable satellites. SSC currently manages the acquisition of the space segment portion of this effort through two programs known as the GPS III and GPS III Follow-On (GPS IIIF) satellite programs. These programs are replacing existing satellites (including GPS IIR-M and GPS IIF) as they near the end of their intended operational life. Figure 2 describes the evolution of M-code-capable GPS satellite generations, including capabilities and lifespan estimates.

Figure 2: Active and Future Military (M)-code GPS Satellites

	GPS IIR-M	GPS IIF	GPS III	GPS IIIF
				
Quantity	7 operational	11 operational	6 operational; 4 not yet launched	10 on contract; additional 12 planned
Design life[a]	7.5 years	12 years	15 years	15 years
Mean life estimate[b]	22.1 years	25.6 years	16.9 years	16.2 years
Launch	2005 - 2009	2010 - 2016	2018 - 2025	Planned to begin from mid - 2027
Capabilities	• Second civilian signal • Second military signal (M-code) for enhanced jam resistance • Ability to increase signal power to improve resistance to jamming	**IIR-M capabilities, plus:** • Third civilian signal for transportation safety requirements • Improved accuracy, signal strength, and quality • Advanced atomic clocks	**IIF capabilities, plus:** • Fourth civilian signal to enable GPS interoperability with foreign satellite navigation systems • Enhanced signal reliability, accuracy, and integrity • Stronger military signal to improve jamming resistance	**III capabilities, plus:** • Steerable, high power M-code signal, known as Regional Military Protection • Search and rescue capability for detection and location of emergency beacons

Source: GAO analysis of Department of Defense information (data); U.S. government (images). | GAO-24-106841

Note: In addition to the M-code-capable satellites depicted in this figure, the space segment also contains six non-M-code-capable GPS IIR satellites.

[a]Design life is the period during which the satellite is expected to meet its mission objectives.

[b]Mean life estimate figures reflect the average of the predicted lifespans for the satellites of a given GPS satellite generation.

M-code User Equipment Segment

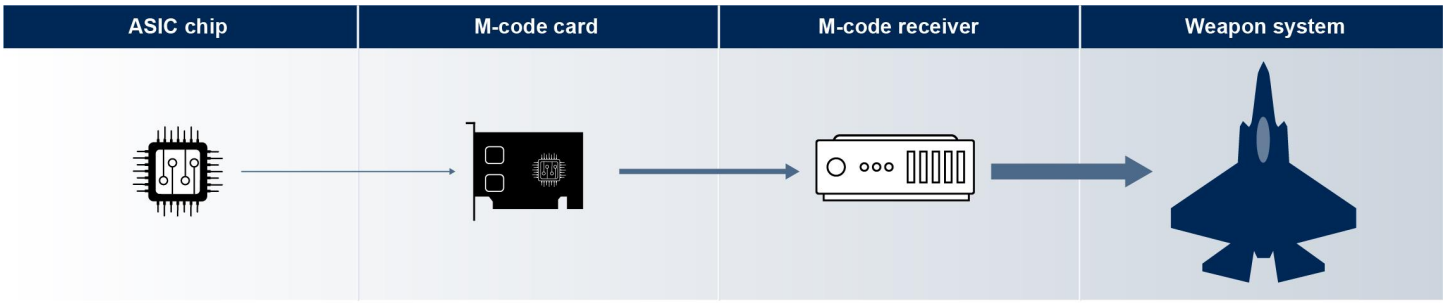
For warfighters to use the M-code signal controlled by the ground segment and transmitted by the space segment, the military departments will need to upgrade existing weapon systems and platforms with M-code-capable user equipment. As we previously reported, approximately 700 different types of weapon systems—such as aircraft, ground vehicles, and ships—will ultimately require M-code-capable user equipment.[4] The

[4]GAO-22-105086.

military departments will outfit these systems with modernized, M-code-capable GPS receivers. Eventually, the total number of GPS receivers purchased by DOD could number over 1 million.[5]

GPS user equipment consists of three key components: a microelectronic circuit chip, a card that integrates the chip along with other microelectronics, and a receiver that provides the ability to use the card. The development and manufacture of each component is critical to the overall modernization effort. The first element in GPS modernization has been the development of an application-specific integrated circuit (ASIC), a microelectronic component specifically designed to process and execute M-code functions. These chips are then integrated into a card that processes M-code signals to provide PNT information. The military departments then integrate each specialized M-code card into a receiver that provides an interface with the host weapon system. See figure 3 for a simplified depiction of GPS user equipment integration for one system.

Figure 3: GPS User Equipment Integration



ASIC Application-Specific Integrated Circuit
M-code Military code
Source: GAO analysis and representation of Department of Defense documentation; GAO (icons). | GAO-24-106841

Military GPS User Equipment Increment 1

The Space Force's Military GPS User Equipment (MGUE) program is developing the first generation of M-code-capable user equipment. In January 2017, DOD approved the MGUE Increment 1 program to begin development of an ASIC chip and receiver cards for the military departments. SSC initially awarded contracts to three contractors—L3Harris, Raytheon, and Rockwell Collins (later BAE Systems)—to develop Increment 1 M-code cards.

Critical to the development of MGUE Increment 1 is the production of the ASIC. GlobalFoundries, the sole manufacturer of these chips, is in the process of phasing out production of chips because more advanced technologies now dominate the commercial microelectronics market. M-code cards developed under the MGUE Increment 1 program, as well as derivative versions of these cards, all require increment 1 ASICs specially designed for them, with no potential for an off-the-shelf replacement. Beginning in 2019, the Defense Logistics Agency and officials from the Office of the Under Secretary of Defense for Acquisition and Sustainment developed plans for a bulk buy of nearly 1 million chips. They estimated that this would provide

[5]The Ike Skelton National Defense Authorization Act for Fiscal Year 2011, Pub. L. No. 111-383, § 913 (10 U.S.C. § 2281 note) provides that none of the funds authorized to be appropriated or otherwise made available under the act or any other act for DOD may be obligated or expended to purchase GPS user equipment after fiscal year 2017 unless the equipment is capable of receiving M-code. The Secretary of Defense may waive this limitation under certain circumstances or certain exceptions may apply. Concurrent with M-code card development delays, DOD has issued waivers for this requirement for the hundreds of types of weapon systems that will eventually integrate M-code cards.

for DOD's needs through approximately 2028, which DOD revised in August 2024 to 2030. DOD awarded contracts to Raytheon and BAE for bulk orders of their ASICs from GlobalFoundries in 2021-2022.

The MGUE Increment 1 program is developing two card types. One will be used in ground-based weapon systems such as combat vehicles, which we refer to as the ground card. The other will be used in aviation and maritime weapon systems, which we refer to as the aviation/maritime card. Currently, the program consists of the L3Harris-designed ground card and the Raytheon-designed aviation/maritime card.

Each of the initial contractors for the MGUE Increment 1 program is also developing derivative cards. Derivative cards use the same ASIC as L3Harris and Raytheon cards, as well as much of the same software. Contractors' derivative cards can vary in size and technical capability, however, allowing them to meet the specific needs of different receivers and users. As these derivative cards and software were designed for specific applications, they are not interchangeable. Derivative cards must have their designs certified and authorized by the Space Force.

As a result of the various types of cards that have been developed within the MGUE program and as derivatives, the military departments have options as they proceed with receiver development. For each weapon system, when the military departments upgrade to M-code, they can select an Increment 1 card, select a derivative card based on one of the Increment 1 cards, or pursue additional development of a different ASIC or card at their own expense.

MGUE Increment 1 program officials have made multiple adjustments to program plans due to development delays, rising program costs, and changes to the contractors' marketing and production plans. In June 2023, we reported on developments for the program.[6]

- The Marine Corps Operational Test and Evaluation Activity completed the MGUE Increment 1 field user evaluation in September 2021 to demonstrate the exit criteria for the program. During the evaluation, multiple ground cards, including the L3Harris card and derivatives, were integrated with a receiver for the Marine Corps' lead ground platform, the Joint Light Tactical Vehicle. During the evaluation, the L3Harris ground card did not process an M-code signal. Following the evaluation, SSC officials stated that subsequent updates to the ground card software had corrected the issue. As a result of these updates, the Space Force determined that the program's exit criteria were satisfied, allowing potential users to purchase the ground card.
- In December 2022, the Space Force determined that issues with software provided by Raytheon to support its aviation/maritime card required further modifications before final integration could begin. Once the corrected version is received, the Air Force plans to conduct a combined developmental and operational test with the Air Force's receiver for its lead platform, the B-2 Spirit. The Navy will integrate the card with a receiver and conduct testing on its lead platform, an *Arleigh Burke* class destroyer.

Military GPS User Equipment Increment 2

The Space Force is executing the MGUE Increment 2 effort to develop a smaller, more power-efficient ASIC based on a manufacturing process that will have sufficient commercial interest to avoid the scarcity issues that

[6]GAO-23-106018.

led to the Increment 1 bulk buy. As we previously reported, the Increment 2 ASIC combines a series of commercial off-the-shelf designs with sensitive military functions to be added to the programming later.[7] SSC plans to use these size and power advantages to develop a card specifically for the challenging requirements posed by handheld devices and precision-guided munitions. The effort's acquisition strategy is to pursue two 5-year middle tier of acquisition rapid prototyping efforts, with plans to complete development by the first quarter of fiscal year 2026.[8]

The first effort, estimated to cost approximately $1.4 billion at the start of the program in 2020, involves developing the Next-Generation ASIC and integrating it with a smaller chip and card assembly. Raytheon, BAE, and L3Harris were selected by the Space Force to develop an Increment 2 card. However, since the time these were awarded in 2020, two of the three contractors have stated they are unable to meet several of the effort's requirements. This prompted Space Force officials to request that the Joint Requirements Oversight Council lower these requirements to more achievable levels. This issue is discussed in more detail later in this report.

The second effort, estimated at $149.2 million in 2020, will use the Increment 2 chip and card to develop a handheld, M-code-capable receiver. The Space Force reported that a contract for the handheld receiver effort was awarded to Technology Advancement Group in July 2023.

In 2023, we reported that the Army, the largest potential customer of the handheld receiver, had no plans to procure it.[9] Another potential buyer, the Marine Corps, worked closely with SSC to develop requirements for the handheld receiver. However, one Marine Corps official stated that the Marine Corps did not intend to commit to the handheld receiver prior to a full and open competition that evaluated available options. We noted that the limited market poses a significant threat to the program's business case. In response to the lack of potential customers, we recommended that SSC produce a sound business case for the MGUE Increment 2 handheld receiver program prior to initiating the rapid prototyping phase of the middle tier of acquisition, or else not initiate the acquisition due to the absence of a sound business case. DOD agreed with this recommendation but reported an award for the handheld receiver in July 2023 without having first established a sufficient business case. We therefore closed the recommendation as being no longer valid.

M-code Receiver Development

The military departments are procuring or developing several different models of M-code-capable receivers for use with either Increment 1 cards or a derivative card. They are developing these receivers to meet the needs of systems in the ground, aviation, and maritime domains. In addition, the military departments have developed

[7]GAO-21-145.

[8]Pursuant to section 804 of the National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114-92 (2015) (10 U.S.C. § 2302 note), DOD issued guidance establishing a streamlined acquisition pathway for middle tier of acquisition with two paths—rapid prototyping and rapid fielding. Department of Defense, *Operation of the Middle Tier of Acquisition (MTA)*, DOD Instruction 5000.80 (Dec. 30, 2019). The objective of a rapid prototyping effort is to field a prototype that can be demonstrated in an operational environment and provide for a residual operational capability within 5 years of the program start date. Programs following the middle tier of acquisition are generally exempted from certain acquisition and requirements processes normally followed by programs using other pathways in DOD's Adaptive Acquisition Framework. DOD, *Operation of the Adaptive Acquisition Framework*, DOD Instruction 5000.02 (Jan. 23, 2020) (incorporating change 1, June 8, 2022). Also see GAO, *Middle-Tier Defense Acquisitions: Rapid Prototyping and Fielding Requires Changes to Oversight and Development Approaches*, GAO-23-105008 (Washington, D.C.: Feb. 7, 2023).

[9]GAO-23-106018.

some receivers to process both M-code and alternate sources of PNT information derived from other sensors or equipment, which we refer to as multi-PNT receivers.[10] Some examples of alternative PNT sources include (1) an inertial sensor that detects acceleration and rotation changes to measure position, and (2) receivers for signals from systems operated by commercial companies or foreign allies. To better facilitate this capability, the military departments are developing some receivers using a modular open system approach, which incorporates modular design and open standards for key interfaces to readily accept equipment from a variety of suppliers and data from alternative PNT sources.

We previously reported on the development of alternate PNT systems and receivers. In 2022, we determined that four Navy PNT efforts did not have a complete business case and recommended that the Navy ensure that they are complete.[11] DOD has partially addressed the recommendation by providing sufficient additional documentation for three of the four efforts. We also reported that the PNT Oversight Council—which is responsible for oversight of DOD's PNT enterprise—had no strategic objectives or metrics to measure progress on the alternate PNT efforts and recommended that the council develop such metrics.[12] The recommendation remains open.

Table 2 provides information that we previously reported about the various receivers the military departments are developing and producing.[13]

Table 2: GPS Military-code Receivers Developed by the Military Departments as of June 2023

Military branch	Receiver	Platform type	Chip card type	Notes
Army	Mounted Assured Positioning, Navigation, and Timing System (MAPS)	Ground Vehicle	BAE derivative from MGUE Increment 1 ground card	Split into two separate phases, MAPS Generation I was tested and fielded using the urgent capability acquisition pathway. MAPS Generation II introduces M-code capability and will replace the existing GPS receivers and antennas in most of the Army's ground vehicle variants. Multi-PNT using modular open systems approach

[10]It is possible to deliver this capability at the card level as well, as some derivative cards do and the Increment 2 card also plans to do.

[11]GAO, *GPS Alternatives: DOD Is Developing Navigation Systems but Is Not Measuring Overall Progress*, GAO-22-106010 (Washington, D.C.: Aug. 5, 2022).

[12]DOD established the PNT Oversight Council in 2016 in response to a section in a 2015 statute. The section required the PNT Oversight Council to be responsible for oversight of DOD's PNT enterprise and pointed to several specific responsibilities including vulnerability identification and mitigation, oversight of performance, and resource prioritization. Pub. L. No. 114-92, § 1603(a) (2015) (codified, as amended, at 10 U.S.C. § 2279b).

[13]GAO-23-106018; and GAO-22-106010.

Military branch	Receiver	Platform type	Chip card type	Notes
Army	Dismounted Assured Positioning, Navigation, and Timing System (DAPS)	Handheld	BAE derivative from MGUE Increment 1 ground card	Split into separate phases, DAPS Generation I has been tested and fielded using the urgent capability acquisition pathway. Operates with the existing Nett Warrior system, a suite of communications and sensor equipment currently deployed with Army soldiers. The second variant of Generation I introduces M-code capability and can operate independently from Nett Warrior with its own battery. DAPS Generation II has additional capabilities, including hardening against chemical, biological, and nuclear environments, and reduced energy consumption. Multi-PNT using modular open systems approach
Army	Embedded GPS/Inertial Navigation System/Enhanced Aviation Global Air Traffic Management Localizer Performance Vertical Guidance Embedded GPS Inertial Navigation System M-code (EAGLE-M)	Air	Raytheon derivative of MGUE Inc 1 aviation/maritime card	Developed for Army air platforms.
Air Force	Resilient-Embedded GPS/Inertial Navigation System (R-EGI)	Air	Raytheon MGUE Increment 1 Aviation/Maritime Card	Multi-PNT using modular open system approach Lead platform is F-16 and Air Force is developing plans to include F-15 and F-15EX

Military branch	Receiver	Platform type	Chip card type	Notes
Air Force	Embedded GPS Inertial Navigation System – Modernized (EGI-M)	Air	Raytheon MGUE Increment 1 Aviation/Maritime Card	Two contractors were developing replacements for their current respective hardware. In addition to the Air Force platforms, the receivers will support multiple Naval air platforms. Provides M-code capability for multiple platforms including the Air Force's F-22 and the Navy's KC-130J and F/A-18
Air Force	Miniature Airborne GPS Receiver 2000 – Modernized (MAGR-2K-M)	Air	Raytheon MGUE Increment 1 Aviation/Maritime Card	Receiver for lead air platform (B-2) supporting the Space Force's MGUE Increment 1 program
Navy	GPS-based Positioning, Navigation, and Timing Service (GPNTS)	Maritime	Raytheon MGUE Increment 1 Aviation/Maritime Card	Receiver for the lead maritime platform (Arleigh Burke class destroyer) supporting the Space Force's MGUE Increment 1 program and will be used for other surface vessels Multi-PNT using modular open system approach

Source: GAO analysis of Department of Defense data. | GAO-24-106841

We previously reported that data regarding the development, integration, and fielding of M-code for all relevant platforms are not complete, consistent, or up to date to support planning and budgeting across DOD. In addition, we reported that operational test plans for multiple platforms were not fully developed, due in part to development delays with user equipment. In 2022, we made seven recommendations to DOD and the military departments related to implementation of M-code capability for their respective platforms.[14] Four of the recommendations were to improve the sufficiency of internal data DOD collects from the military services that are used for planning and tracking the progress of M-code implementation for weapon platforms across DOD. The other three recommendations were for the military departments to finalize operational test plans for priority weapon systems to ensure operational testing can occur once cards become available and that the services can field equipment in time to meet future operational scenarios. All seven recommendations have been closed as implemented.

[14]GAO-22-105086.

The Space Force Has Made Progress Developing Ground and Space Segments but Significant Work Remains

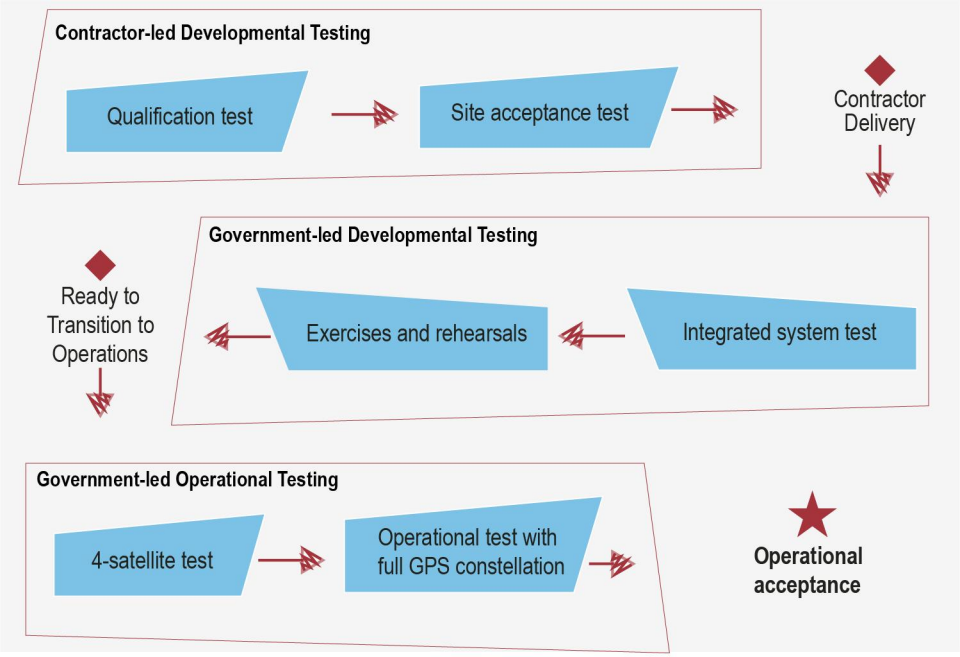
The Space Force has continued its GPS ground and space segment modernization efforts, but significant work and challenges remain. After multiple delays, the Space Force's OCX program completed a qualification test for Blocks 1 and 2 in December 2023. More test events must be completed before the projected December 2025 operational acceptance of the system. The related OCX Block 3F program has progressed in software development, but factors such as the ongoing delays with Blocks 1 and 2 have complicated efforts. The GPS IIIF satellite program has progressed in addressing technical and manufacturing challenges. But in doing so, the program consumed schedule margin, resulting in delays to projected GPS IIIF satellite deliveries. Further delays could create risk to the GPS satellite constellation's ability to provide the required 24 operational M-code-capable satellites at a high confidence level into the 2030s.

Despite Progress, Schedule Risk Remains for the Ground Segment

OCX Blocks 1 and 2

The OCX program completed a significant testing milestone in 2023. However, development challenges pose risk to the program's projected December 2025 acceptance for operational use. To achieve this final acceptance, OCX must complete a sequence of test events and program decision points. First, Raytheon must complete demonstration of OCX system specifications to permit government acceptance of the system's delivery. Secondly, OCX must complete government-led developmental testing to demonstrate readiness for the transition of the GPS satellite constellation to OCX control. Lastly, OCX must complete operational testing to achieve government acceptance of the system for operational use. Figure 4 summarizes the order of events for the OCX program toward final operational acceptance.

Figure 4: Next Generation GPS Operational Control System (OCX) Events Toward Operational Acceptance

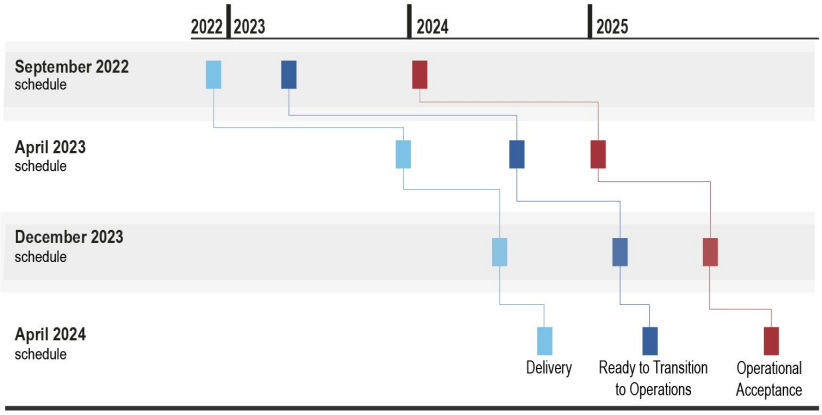


Source: GAO analysis of Department of Defense information. | GAO-24-106841

The Space Force reported that Raytheon had successfully completed its system-level qualification testing for OCX Blocks 1 and 2 in December 2023. The purpose of this contractor-led testing is to ensure the system works as intended and meets the requirements before proceeding to government-led developmental testing. Raytheon conducted this system-level qualification testing in two phases. First, Raytheon carried out “dry run” testing to demonstrate readiness for final qualification testing while identifying any remaining issues. Second, Raytheon conducted a “run for record” test to demonstrate the ability of OCX Blocks 1 and 2 to execute the system’s required functions at contractor and operational facilities.

Though the program completed the dry run and run for record, OCX system-level qualification testing was marked by significant challenges that drove delays to the program’s schedule. The program expected the system-level dry run qualification testing in August 2022 to last a month and a half. The testing was not completed until October 2023, 14 months later. According to program officials, this delay was due to deficiencies that prevented uninterrupted execution of the testing. The program encountered software deficiencies in multiple areas. These included the integration of the navigation system with other OCX subsystems and instability in the GPS System Simulator—a resource that Raytheon uses to test OCX functionality. As result of such shortcomings, the OCX program halted the dry run testing for 5 months. When testing resumed in spring 2023, software deficiencies continued to impede progress, resulting in the program restructuring the dry run testing to allow Raytheon to address deficiencies incrementally throughout testing. These challenges contributed to the program pushing forthcoming milestones further into the future. Figure 5 illustrates the schedule changes the OCX program has experienced over time.

Figure 5: Next Generation GPS Operational Control System Schedule Comparison as of April 2024



Source: GAO analysis of Department of Defense information. | GAO-24-106841

In December 2023, the program completed the second portion of the system-level qualification testing—the run for record—with an acceptable pass rate, although follow-up testing is planned. The program carried out the qualification test run for record from October to December of 2023. The program reported an 82 percent pass rate against requirements derived from OCX system specifications. For a retest event in March 2024, the program reported an 88 percent pass rate. The program plans to carry out an additional retest in June 2024, according to Space Force officials, with the intent to achieve a 100 percent pass rate on all of these requirements.

To achieve readiness for delivery of OCX to the government, which Space Force officials currently project for October 2024, Raytheon must meet multiple additional criteria, including:

- completing installation of the Alternate Master Control Station at Vandenberg Space Force Base—a deployment that had been deferred while Raytheon was using the station as an environment for testing OCX software and further delayed by facility problems during the installation;
- ensuring that OCX passes remaining testing for critical requirements in qualification testing;
- ensuring OCX successfully completes Site Acceptance Testing—a test event to validate OCX functionality in its intended operational sites, including its ability connect with external systems; and
- finalizing OCX technical orders, which function as operators' manuals, prior to contractor delivery of OCX.

In bringing OCX to a readiness for delivery, the program faces challenges from product deficiencies. In February 2024, the Defense Contract Management Agency noted that these product deficiencies create a risk of further delays.[15] As of April 2024, program officials reported a backlog of 292 critical deficiencies. Of these, 69 are software deficiencies. The remaining 223 pertain to what the program characterizes as platform requirements, which affect areas such as hardware and network configuration, according to contractor

[15]The Defense Contract Management Agency provides contract administration services for DOD buying activities and works with defense contractors to help them deliver goods and services on time, at projected costs, and in accordance with performance requirements. The agency works to identify quality deficiencies at all points throughout the production process. It oversees production by inspecting and testing the contractor's completed work and issuing requests for the contractor to correct any identified deficiencies.

representatives. By comparison, in December 2022, the program reported a backlog of 116 software-related critical deficiencies and 192 platform-related critical deficiencies.

Program officials stated that the program's backlog of deficiencies is within expectations since an uptick in deficiencies was anticipated during qualification testing. They further stated that the number of new identified deficiencies is stabilizing. The Defense Contract Management Agency, however, expressed concern about the number of deficiencies and the program's lack of consistency in documenting and addressing these deficiencies. Additionally, the Defense Contract Management Agency noted that deficiency discovery has continued to occur at a higher-than-expected rate. As of February 2024, the agency was predicting that Raytheon would deliver OCX to the government no sooner than December 2024—2 months later than Space Force officials' estimate, due in part to deficiencies.

After Raytheon's delivery of OCX, the Space Force will begin government-led developmental testing to determine if OCX is ready to transition to operations. As of April 2024, the program office projected that the determination decision will occur in April 2025. The testing will involve all three GPS segments and external interfaces executing in an operationally realistic manner. According to a Space Force official, this testing will finalize the process and deepen the knowledge of how to transfer the GPS constellation to OCX control. The Space Force will also carry out cybersecurity and navigation warfare testing as part of this testing. Concurrent with this testing, the Space Force will continue training GPS satellite operators on OCX. It will also execute operational readiness exercises and rehearsals to prepare for the transition of the GPS constellation operations to OCX.

As of May 2024, Space Force officials' projections indicate that OCX's readiness to transition to operations will occur 6 months after government acceptance of OCX, which could prove a difficult schedule to maintain. Space Force officials stated that there is no margin in the schedule and they will be conducting activities concurrently in order to meet the schedule. The Space Force is concerned that the compressed time frame and concurrent scheduling of events may prove unworkable, due to operator availability constraints. This could result in delays to testing, as well as to subsequent program decision points. In response, the Space Force program office is working with operators and the contractor to address conflicts for resources.

After OCX is ready to transition from testing to operations, the Space Force will conduct transition and operational testing to facilitate the final acceptance of OCX, which Space Force officials project for December 2025. The first test is a limited "dress rehearsal" in which four on-orbit GPS satellites will be transferred to OCX control to demonstrate command and control capability over the satellites, according to a Space Force official. This test will inform a Space Force decision to transition the full operational GPS satellite constellation to OCX control. Following additional testing, the Space Force's 4th Test and Evaluation Squadron will conduct the Initial Operational Test and Evaluation of OCX with the full constellation to inform a final acceptance decision for OCX by Space Operations Command.

OCX 3F

The OCX Block 3F program has made progress developing software but continues to face risks. As of April 2024, the program reported that it had completed development on 11 of 17 OCX Block 3F software increments. According to Defense Contract Management Agency estimates from February 2024, Raytheon's work under the OCX Block 3F contract was 65 percent complete. The program also made progress in demonstrating the system's compatibility with the OCX Block 1 and 2 software. In December 2023, the program completed an integration readiness review, which qualified a recent OCX Block 3F version in

preparation for integration with OCX Block 1 and 2 subsystems, according to program officials. The review also confirmed that recent qualification test-prompted changes to the OCX Block 1 and 2 baseline have had no adverse effect on OCX Block 3F development, according to program officials. However, modifications to the OCX Block 1 and 2 software remain ongoing, so the Block 1 and 2 baseline remains subject to change.

Since 2023, the OCX Block 3F program delayed some events to later dates than previously projected but continued to execute within its formal baseline schedule. Since March 2023, the program has reported an average 5-month delay in the projected deliveries of the OCX Block 3F's three capability releases. The first of these capability releases—the launch and checkout capability, which is expected to enable pre-launch preparations and exercises for GPS IIIF satellites—is scheduled for delivery by Raytheon in August 2024. This represents a 6-month shift from the February 2024 delivery projected in March 2023. During the same period, there has been a 6-month delay, from August 2025 to February 2026, to the projected date for the program's System Integration Test—the final test event before the contractor delivery of OCX Block 3F. Despite this delay, the System Integration Test remains scheduled for 4 months ahead of the latest acceptable date on the program's formal schedule.

The OCX Block 3F program continues to face challenges that pose risk to its schedule. Because OCX Block 3F builds onto the OCX Block 1 and 2 software, the ongoing modifications of these blocks creates an integration risk. Furthermore, the continued delays to the OCX Block 1 and 2 program have prevented Raytheon from transitioning personnel and other resources to the OCX Block 3F effort at the pace that was previously expected. The Defense Contract Management Agency anticipates that these challenges will continue to pose risk to the OCX Block 3F program schedule at least until the contractor delivery of OCX Blocks 1 and 2. Additionally, significant portions of the OCX Block 3F program's technical orders and training activities depend upon on the OCX Block 1 and 2 program completing related product support deliverables.

The OCX Block 3F program is also tracking a risk to the GPS System Simulator, which is required to test mission capabilities. To test OCX Block 3F's ability to command and control GPS IIIF satellites, this simulator must be able to replicate GPS IIIF satellite functionality. For this reason, the OCX Block 3F program must integrate into the simulator the software from the GPS IIIF satellite's mission data unit—the brain of the satellite's navigation mission. The subcontractor for this unit is scheduled to deliver a version of the software at a date that is later than the OCX Block 3F program expected. As result, Raytheon has expressed concern about its ability to test OCX Block 3F capabilities against simulated GPS IIIF satellites within the program's schedule. The government plans to mitigate the software delivery challenge by working to ensure delivery of early engineering versions of the software to Raytheon.

Space Segment Schedule Could Compromise Constellation Health

The program's schedule as established in September 2018 may not meet Space Force's requirement for keeping 24 operational M-code-capable satellites on orbit. This baseline schedule established the earliest delivery date for the first GPS IIIF satellite as January 2028, while the latest delivery date for the satellite was established as July 2028 (this schedule was then accelerated, as discussed below). Using Space Force data, we found that if GPS IIIF satellites deliver at even the earliest date and each satellite launches 6 months after delivery, the constellation's probability of providing 24 operational M-code-capable satellites will fall short of a

95 percent confidence level from early 2028 through late 2032.[16] If satellite deliveries begin at the tail end of the range in July 2028 and each satellite launches 6 months after delivery, the constellation's probability of providing 24 operational M-code-capable satellites will fall short of a 95 percent confidence level from early 2028 through early 2033.[17]

The Space Force forecasts project high confidence—a 95 percent minimum probability—of the constellation maintaining the required 24 M-code satellites because the GPS IIIF program aims to deliver satellites ahead of the established schedule. When the program began development in September 2018, it pursued an accelerated schedule aimed at delivering the first GPS IIIF satellite in February 2026. As result, the schedule contained nearly 30 months of schedule margin, or additional time to achieve delivery, relative to the latest acceptable date for the first satellite delivery. Based on the accelerated schedule, the Space Force projected in May 2023 that it could achieve a greater than 95 percent probability of 24 operational M-code-capable satellites into the late 2030s.

During 2023, the GPS IIIF program consumed a portion of this schedule margin as it worked to address technical challenges. As of April 2024, the program reported it was investigating four mission data unit technical issues. The program's efforts to resolve these technical challenges resulted in revisions to the program's projected satellite deliveries. These revisions delayed the first two satellites by an average of 10 months and the remaining eight satellites under contract by an average of 17 months. The first delivery of a GPS IIIF satellite, previously projected for February 2026, is now slated for November 2026.

The GPS IIIF program also faces schedule challenges from manufacturing difficulties with a major component. Lockheed Martin is working to mitigate manufacturing challenges for the Linearized Traveling Wave Tube Amplifier. This is a component needed to enable a high-powered, steerable M-code signal from the GPS IIIF satellite. To mitigate the manufacturing challenges, program officials noted that Lockheed Martin is subcontracting the construction of the amplifiers from the third GPS IIIF satellite onward. The program reported that after multiple delays, Lockheed Martin completed construction of all developmental traveling wave tube amplifiers needed for testing in May 2023. The developmental amplifiers have been incorporated, along with other key GPS IIIF subsystems and components, into a non-flight satellite test bed. The program successfully began testing with the test bed in August 2023. The completion date for this testing is projected for July 2024—a 6-month delay from the program's projections in January 2023.

As a result of the GPS IIIF program's use of schedule margin and the resulting changes to satellite delivery dates, the GPS constellation could face challenges maintaining its current high probability of 24 operational M-code satellites. In February 2024, the Space Force approved a new launch schedule for the 10 GPS IIIF satellites currently under contract. The revised delivery dates associated with this launch plan still reflect an

[16]Since the GPS IIIF program baseline formalizes delivery dates only for satellites 1, 2, 3, 6, and 12, GAO used notional delivery dates for satellites 4 and 5 that are evenly spaced between 3 and 6, and used notional delivery dates for satellites 7, 8, 9, 10, and 11 that are evenly spaced between 6 and 12. Our prior reporting on GPS constellation availability assessed the constellation against a 95 percent probability of 24 GPS satellites, because this is DOD-established standard to which the U.S. government is committed for the operational availability of 24 satellites for the civilian and pre-M-code military positioning service. However, DOD has not established a probability standard for the GPS space segment's full operational capability of 24 M-code-capable satellites. It remains a useful benchmark for a reasonably high level of confidence in achieving a particular level of performance. See GAO-23-106018; GAO-18-74; GAO-15-657; GAO-10-636; and GAO-09-325.

[17]The Space Force data used for this analysis take into account the planned launches of the four previously delivered GPS III satellites and use the Space Force's May 2023 operational GPS satellite reliability estimates, which project satellite lifespans that exceed contractor design life.

accelerated GPS IIIF schedule compared to the program's formal baseline schedule, with projected satellite deliveries averaging 17.5 months ahead of the early baseline schedule delivery dates. Despite this accelerated schedule, our analysis using this launch schedule and Space Force GPS constellation data indicates that the GPS constellation will fall slightly below a 95 percent probability of 24 M-code-capable satellites for a 3-month span in early 2028. If further delays to projected satellite deliveries occur, the dip below the 95 percent probability of 24 M-code satellites would last longer and grow more pronounced. Such shortfalls could be mitigated by ongoing Space Force efforts to extend the service life of certain currently operational GPS satellites. As we reported previously, the Space Force is exploring new power management techniques to derive additional service life from the IIR-M and, potentially, from the IIF satellites.[18]

DOD Is Managing Risks in Developing User Equipment Including Potential Capability Gaps

While the Space Force has made progress in developing user equipment, significant risks remain to delivery of capability to the military departments. After years of delays, the Space Force's MGUE Increment 1 program is approaching its final series of tests. However, discovery of additional deficiencies could add further risk to the program's schedule. While two of the MGUE Increment 2 contractors have started critical design review for their receiver cards, the program is at risk of exceeding the 5-year time frame associated with programs using the middle tier of acquisition pathway. In addition, the PNT Oversight Council, the Office of the Chief Information Officer, and the military departments have discovered, and are addressing, potential shortages of GPS chips and cards.

Increment 1 Completed Ground Card Development but Aviation/Maritime Card Development Faces Schedule Risk

The MGUE Increment 1 program office considers the ground card development effort complete after years of delays. As we previously reported, a field user evaluation completed in September 2021, followed by further testing, satisfied the program's exit criteria.[19] In January 2023, the program conducted an additional test of the L3Harris card at the Naval Information Warfare Center in coordination with the Director, Operational Test and Evaluation (DOT&E). According to program officials, the Navy and Marine Corps wanted follow-up testing done to confirm that the card was suitable for use in the field. The test determined that the ground card performed as required and that it achieved expected outcomes for all executed test cases. A DOT&E official noted that while the testing demonstrated the performance of the card, it was not conducted with an operationally representative test. Further, the officials stated that if a military department should decide to field the L3Harris ground card, the program office should repeat testing in an operationally relevant environment.

The Space Force also completed a critical program milestone in the development of the aviation/maritime card and has two more remaining. In April 2023, the program completed the technical requirements verification. This event documented compliance with the program's technical requirements and allowed the program to deliver the card to the Air Force and Navy to support integration and development testing with their lead platforms: the B-2 Spirit and the *Arleigh Burke* class destroyer. The Space Force's remaining milestones are

[18]GAO-23-106018.

[19]GAO-23-106018.

card-level program executive office certifications for each of the two lead platforms. Successful completion of the certifications will clear the card for operational testing.

According to Air Force PNT program officials, the certifications represent the MGUE Increment 1 program's hand-off of the aviation/maritime card to the Air Force and Navy. The military departments will then complete their own certifications to support operational testing and fielding with their respective lead platforms. The Air Force and Navy have started conducting integration testing of the card with the lead platforms' respective receivers, while Space Force's MGUE Increment 1 program continues additional software development for the card.

After the Space Force confirmed the aviation/maritime card met technical requirements, additional testing uncovered issues that increase the risk of further delays with the Air Force's lead platform. According to program documents and discussions with officials, an independent test identified a deficiency that causes the card to receive encrypted information in only one of two channels, which could reduce a platform's ability to initiate an M-code connection with a satellite. According to the Space Force, the next software build, expected for delivery in June 2024, will correct this issue and provide some additional capabilities to address software security and potential vulnerabilities.

As a result of the deficiency, the Air Force has been adjusting program plans for testing with the B-2. According to Air Force officials, Air Force Global Strike Command directed the program to move forward with the current software build for the B-2s for testing and initial fielding instead of waiting for the next build to address the deficiency. However, according to program documents, Air Force testers have since experienced additional anomalies during integration testing. Air Force officials noted that, as of May 2024, they did not know what effect these issues will have on the schedule for operational testing and fielding. According to officials at the Office of Developmental, Test, Evaluation, and Assessments, the Navy was confident that it can progress with platform testing with the *Arleigh Burke* class destroyer using the current software build.

After delays, the MGUE Increment 1 card-level certifications for the Air Force and Navy lead platforms are each now estimated to take place in the last month of their schedules as established in January 2021. The program office estimates that the military departments' certification that the aviation/maritime card will function as intended in the Navy's *Arleigh Burke* class destroyer and the Air Force's B-2 Spirit will occur by September 2024 and January 2025, respectively. This timing leaves little to no margin to avoid a breach of the program's schedule baseline. Additional delays would result in another breach and risk further delaying the fielding of M-code capability on these lead platforms.

Increment 2 Is Managing Risks in Requirements and Contractor Performance

In August 2023, the Joint Requirements Oversight Council approved the request submitted by the MGUE Increment 2 program office to adjust its requirements in response to concerns by two of the contractors. The contractors were seeking relief on requirements related to several issues including: the time necessary to determine the user's location when a device is first powered on, and the overall battery life. As we previously reported, the contractors' inability to meet these requirements was due to the chip consuming more power than the vendors originally expected.[20]

[20]GAO-23-106018.

As the contractors worked to meet the program's technical requirements, the critical design review for the MGUE Increment 2 chip and card were delayed. One of the three contractors closed the final tasks identified in its review in October 2023, 1 month after the deadline originally established by the program. A second contractor also held its design review in October 2023, but, as of January 2024, was still working to address identified deficiencies. Program officials estimate completion of these tasks by June 2024, 9 months past the original deadline. The third contractor, Raytheon, decided to end its participation in the MGUE Increment 2 program, and the program reported that it issued a stop work order in October 2023. In November 2023, the government and the contractor negotiated an agreement modification that ended the contractor's period of performance.

Program officials noted that the two remaining contractors are making progress but that maintaining the current schedule is critical. For example, they noted that one contractor released its design to GlobalFoundries to manufacture a prototype for testing in February 2024 while the other submitted its design in May 2024. Program officials stated that one of their top priorities is to minimize the chance that the prototype chip will need to be rebuilt, which could introduce significant schedule delays. Because MGUE Increment 2 began in 2020 as a middle tier of acquisition prototyping effort, it is expected to complete the effort within 5 years of the program start. Any extension of the effort's schedule beyond those 5 years requires a waiver by the Defense Acquisition Executive or a restructuring of the effort.

Potential Lack of Chips and Cards for User Equipment Could Create Capability Gaps

While the MGUE programs in the Space Force are making progress, DOD has identified potential gaps in providing user equipment to the military departments that it is working to address:

- DOD is facing a potential gap in the availability of GPS receiver cards as some of the current cards can no longer be produced and the M-code-capable replacements have been delayed. In addition, Army officials stated that foreign military sales of GPS-enabled equipment to allies and foreign partners are also depleting the stock of cards. DOD is also experiencing delays in fielding M-code-capable receiver cards, as previously discussed. In November 2022, DOD's Chief Information Officer established a working group to focus on this issue. According to senior PNT officials, the PNT Oversight Council is addressing the projected shortfall and options to mitigate the problem. In the meantime, the military departments have also been harvesting the current cards from decommissioned platforms and are considering other methods to reserve current cards and store them for future use.
- DOD is concerned that the supply of MGUE Increment 1 ASIC chips procured in the bulk buy will not last as long as previously estimated, creating a second cause for a potential gap. The Defense Logistics Agency ordered the bulk buy, in 2021 and 2022, based on estimates provided by the military services. As discussed above, the supply was originally estimated to meet DOD's need through approximately 2028. In August 2024, DOD revised this estimate to 2030. However, according to senior PNT officials, increased demand, due in part to global conflicts such as those in Ukraine and the Middle East, may contribute the supply expiring earlier than estimated. DOD is working to address this issue. For example, according to the Defense Logistics Agency and officials from the PNT Oversight Council, while production for the bulk buy is complete, the Defense Logistics Agency is working to acquire additional chips from GlobalFoundries, the sole vendor. This is possible as the vendor was able to produce more chips than those originally required by the bulk buy.
- The potential gap due to the limited number of Increment 1 chips is further exacerbated by the fact that the Space Force has no plans to develop MGUE Increment 2 cards for platforms other than munitions and

handheld receivers. The current requirements for the MGUE Increment 2 program support development only of handheld and munitions platforms and cannot be extended to other platforms without revisions to the requirements. Without an MGUE Increment 2 card that works with other platforms, DOD aircraft, maritime, and ground systems will be vulnerable to potential MGUE Increment 1 chip shortages. In addition, these platforms would not be able to capitalize on additional MGUE 2 capabilities. According to senior PNT officials, the PNT Oversight Council has acknowledged this issue and is working with the military departments to address this concern. One option being considered is to leverage alternative PNT technologies that are already in development to augment GPS signals.

The Air Force is starting to develop a new receiver card that could partially address the gaps for aviation platforms, but the card's availability to deploy it on platforms is still years away. Instead of using an ASIC chip, the new receiver card and associated antenna system, termed the Software Defined User Equipment, uses a commercial off-the-shelf integrated circuit that can be custom programmed to receive an M-code GPS signal as well as other PNT signals, according to Air Force officials. The effort would provide aircraft with more PNT capabilities and long-term protection from obsolescence issues associated with the ASIC chip. According to Air Force officials, a primary challenge for the program will be to acquire a security certification for protecting sensitive technical information in the card if it is acquired by an adversary. In addition, according to Air Force officials, the program must ensure that aircraft can provide enough power for a receiver card that will use significantly more power than ASIC-enabled MGUE Increment 1 cards. Air Force documents indicate that the Air Force will pursue a middle tier of acquisition rapid prototyping pathway for the Software Defined User Equipment, with an initial award planned by the end of fiscal year 2024. The program is estimated to cost $673 million and the Air Force plans to start initial production at the end of fiscal year 2027.

The Air Force is Experiencing Delays in Fielding M-code-Capable Receivers While Other Military Departments Are Making Progress

The Air Force continues to face delays in the development of its M-code GPS receivers while the Army and Navy are making progress toward fielding theirs. Due to development issues, the Air Force's M-code GPS receivers are significantly delayed, pushing back fielding of M-code capability for multiple Air Force and Navy aviation platforms. To mitigate some of these delays, the Navy and Air Force are planning an interim solution that would provide M-code capability with some of their current receivers. The Army is making progress with its ground vehicle, handheld, and aviation receivers, with plans to field them in platforms in fiscal years 2024 and 2025. The Navy is reliant on the Air Force to develop its air platform receivers, while its maritime receiver plans to complete operational testing in fiscal year 2025. Finally, the Marine Corps plans to leverage the Army's M-code receiver for its ground vehicles and has not yet chosen an option for its new handheld GPS systems.

Schedule Delays Continue for M-code-Capable Air Force Receivers

The Air Force continues to face development and integration challenges with three receivers. These challenges have contributed to the delay in fielding M-code-capable air platforms for the Air Force and Navy. Officials from the Office of the DOD Chief Information Officer noted that air platforms represent the most challenging platforms to integrate with M-code due to the complexity of integration with flight software and obtaining airworthiness certification.

The following is a discussion of the challenges with the three receivers:

- **Resilient Embedded GPS/Inertial Navigation (R-EGI):** The Air Force's multi-PNT R-EGI receiver program continues to mitigate risks after reporting cost and schedule breaches in October 2022. Previous cost and schedule overruns were due in part to supply chain issues and parts availability. According to program documents, the delays R-EGI experienced were due to challenges that a subcontractor, Honeywell, had in developing and integrating critical systems. According to program officials, the use of a modular open system and preservation of Air Force intellectual property rights allowed the program's design agent, Integrated Solutions for Systems—which is responsible for managing development of R-EGI—to replace Honeywell with a new subcontractor, Kearfott, in November 2023. While the program was delayed, replacing the subcontractor allowed the design agent to move forward while developing a new schedule and cost estimate.

  According to program documents, R-EGI is to complete a design review and conduct its initial flight demonstration by the end of fiscal year 2024. The program then plans to deliver production-representative prototypes starting in fiscal year 2026 and complete prototype flight testing in the second quarter of fiscal year 2026. According to program officials, R-EGI will transition from the middle tier of acquisition rapid prototyping pathway to the major capability acquisition pathway later in 2024. R-EGI is being developed to support alternative PNT technologies, such as inertial sensors, through its open systems approach.

- **Embedded GPS Inertial Navigation System – Modernized (EGI-M):** The Air Force has been working with two contractors to replan development of the EGI-M receiver program. In addition to providing advanced GPS capability, the EGI-M program is intended to increase commonality among air platforms by decreasing the number of configurations in use from over 260 to 16. Both Northrop Grumman and Honeywell are developing replacements for their specific receivers, and both have reported significant delays.

  - **Northrop Grumman:** The EGI-M program approved an updated schedule for Northrop Grumman's EGI-M program that represents progress for the program, but places integration with aircraft years behind schedule. According to program documentation, the Air Force approved a new schedule submitted by Northrop Grumman in the fall of 2023. These documents indicate that the contractor had success keeping to the new schedule and delivered engineering development models in February 2024—3 months ahead of that schedule. However, the revised schedule represents a significant delay, with the production decision now estimated for fiscal year 2027, which is 5 years later than the previous estimate.

  - **Honeywell:** Air Force efforts to mitigate performance problems in Honeywell's EGI-M program were not successful. Program documents indicate that the Air Force initially requested that Honeywell replan the program in 2022. According to program documents, Honeywell did not provide "credible" or "executable" new schedules in response to this request with its schedule submissions in June and September of 2023. As a result, the Air Force allowed Honeywell's contract to expire in March 2024, after all options were exercised and the period of performance had ended. According to program documents, the program was 2 years behind schedule when the contract ended, only 30 percent complete, and would have required an additional $300 million to deliver a prototype receiver. According to Air Force officials, they are working with the Navy to explore other potential options for air platform receivers, including the Northrop Grumman EGI-M or R-EGI.

  - **Miniature Airborne GPS Receiver 2000 – Modernized (MAGR-2K-M):** The Air Force is moving forward with testing of the MAGR-2K-M receiver with the Space Force's MGUE Increment 1 card to support the lead air platform for the card, the B-2. The receiver completed development in 2019 and production-representative units have been delivered to the B-2 program and other priority air platforms. But integration testing was delayed due to schedule overruns associated with the MGUE

Increment 1 aviation/maritime card. According to Air Force officials, the receiver is undergoing integration testing with the current software version of the MGUE increment 1 card and it will then be integrated with the B-2 before testing with other aircraft. Program documents indicate that the Air Force's certification that the integrated card and receiver meets requirement will take place in the second quarter of fiscal year 2025 and fielding with the B-2 is estimated to start in fiscal year 2027. However, the program faces additional schedule risk due to issues raised during testing, as we noted above.

Army Has Begun Field Testing of M-code-Capable Ground and Aviation Receivers

The Army has continued to move forward with testing and fielding its M-code-capable, multi-PNT receiver programs for its ground vehicle and handheld systems. Both systems are based on a derivative M-code receiver card that was initially developed as part of the MGUE Increment 1 program. Originally authorized for rapid prototyping using the urgent capability acquisition pathway, the second generations of both programs—Dismounted Assured Positioning, Navigation, and Timing System (DAPS) GEN II and Mounted Assured Positioning, Navigation, and Timing System (MAPS) GEN II—are now using the major capability acquisition pathway, according to Army program documents. In addition to M-code GPS capability, the Army developed DAPS and MAPS GEN II with Alternative Navigation, a global navigation capability that leverages a commercial satellite system to provide platforms with PNT information if GPS is compromised or unavailable. To facilitate easier integration of additional and upgraded capabilities into the receivers, the programs have adopted a modular open systems approach.

- **DAPS GEN II:** According to program officials, testing for the handheld receiver program has remained on schedule since our 2023 report.[21] Initial operational testing started in November 2023. Officials added that the estimated start of fielding has been delayed about 6 months to the second quarter of fiscal year 2025 to adjust for the availability of fielding units. Program documents indicate that by October 2023 the Army had procured an initial 698 units to be delivered by April 2024. The Army plans to procure a total of 51,500 units for $960 million.
- **MAPS GEN II:** According to Army officials, the start of initial operational testing for MAPS GEN II was delayed by about 3 months since our last report due to a lack of soldiers available for testing, but the Army completed the testing in February 2024. Similar to DAPS Gen II, Army officials stated that the estimate for initial fielding was pushed back about 6 months from the first quarter to the third quarter of 2025 to adjust for the availability of units. The Army plans to procure 18,190 systems for $1.9 billion and integrate them with at least 20 platforms.

The Army's M-code-capable aviation receiver—Embedded GPS/Inertial Navigation System/Enhanced Aviation Global Air Traffic Management Localizer Performance Vertical Guidance Embedded GPS Inertial Navigation System M-code (EAGLE-M)—has completed development and is undergoing testing. According to program officials, the Army was able to field M-code capability on an earlier timeline with EAGLE-M than other receivers because of its development approach. Program officials noted that the Army EAGLE-M is a similar design as the receiver that it is replacing. They added that the Army used a backwards-compatibility approach, allowing it to swap out current GPS cards with a derivative of the MGUE Increment 1 card for M-code capability. In addition, production of the Army's EAGLE-M receivers includes a mix of both new receivers and refurbished

[21]GAO-23-106018.

receivers rebuilt to provide M-code capability. According to Army officials, this approach reduced program costs.

In January 2023, the Army announced that it had conducted successful test flights with the EAGLE-M on an uncrewed air platform, the MQ-1 Gray Eagle. During testing, the receiver maintained a successful M-code connection, making it the first aircraft to achieve M-code capability. According to Army program documents, other air platforms are scheduled to begin integration testing in fiscal year 2024 with plans for fielding later that same year and through fiscal year 2025.

Due to the simpler design approach for the EAGLE-M, it does not have alternative PNT capability like some multi-PNT receivers in development. According to program officials, the Army is planning to incorporate alternative PNT capability into its air fleet and is currently exploring multiple capabilities.

While Navy M-code-Capable Aviation Receivers Are Delayed, Its Maritime Receiver Is Progressing

The Navy's air platforms rely on the receivers developed by the Air Force, most critically the EGI-M. As a result, the Navy is facing the same delays as the Air Force in fielding M-code capability for its air platforms. To mitigate the delay in the delivery of a fully capable EGI-M, the Navy is coordinating with the Air Force to develop an interim solution for platforms awaiting EGI-Ms from both contractors. The Navy plans to refurbish its current receivers to accept new MGUE Increment 1 cards or derivative cards using the Air Force's indefinite delivery, indefinite quantity contracts with Northrop Grumman and Honeywell. According to Navy and Air Force officials, this approach for Honeywell is similar to how the contractor is providing M-code capability for Army air platforms with the EAGLE-M. According to program documents, Honeywell plans to conduct a design review in October 2024, produce a production representative unit by early 2026, and achieve initial operational capability in mid-2027. Air Force officials noted that they have not yet developed a schedule for Northrop Grumman's effort. The temporary solution will not provide platforms with the advanced capabilities of the EGI-M.

Development of the primary maritime platform receiver—GPS-based Positioning, Navigation, and Timing Service (GPNTS)—is also in progress. As noted above, the Navy received the MGUE Increment 1 card for integration testing with the maritime lead platform, the *Arleigh Burke* class destroyer. The Space Force plans to complete card-level certification in September 2024, and joint follow-on operational testing with the Navy is expected to be completed in August 2025. The Navy has already fielded GPNTS with the current GPS card. After the Space Force and the Navy complete integration of the MGUE Increment 1 card, the Navy will then integrate the M-code-capable card and receiver with other naval platforms.

The Marine Corps Is Purchasing the Army's M-Code-Capable Receivers Before Developing Its Own Ground Vehicle Receivers

The Marine Corps is continuing plans to use M-code-capable receivers developed by the other military departments. Program documents indicate that for its ground vehicles, the Marine Corps has started the Mounted Assurance Resilient Navigation program, which is divided into two blocks. For the first block, the program is purchasing the MAPS GEN II receiver developed by the Army to install in its own ground vehicle platforms. According to Marine Corps program officials, the Marine Corps purchased 357 MAPS GEN II systems from the Army's production contract in fiscal year 2023 and plans to purchase an additional 345 in fiscal year 2024. For the second block, the Marine Corps plans to develop its own ground vehicle receiver to

meet the department's specific requirements. According to Marine Corp officials, the program plans to approve requirements for the receiver in fiscal year 2025. The Marine Corps has not yet determined whether to pursue the Army's DAPS GEN II or the Space Force's MGUE Increment 2 handheld receivers. Program officials noted that the Marine Corps is continuing to monitor progress on DAPS GEN II as well as MGUE Increment 2 efforts by the Space Force.

Agency Comments

We provided a draft of this report to DOD for review and comment. DOD provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Defense, 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 may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.

Jon Ludwigson
Director, Contracting and National Security Acquisitions

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Appendix I: Objectives, Scope, and Methodology

Section 1621 of the National Defense Authorization Act for Fiscal Year 2016 includes a provision that the Secretary of the Air Force provide quarterly reports and supporting documentation to us on, among other things, next-generation GPS acquisition programs. The act also includes a provision that we brief congressional defense committees on the Air Force's first report and, at our discretion, on subsequent reports. We issued reports on the overall GPS enterprise, on schedule risks to the ground control segment of the GPS mission, and on progress and challenges delivering modernized GPS user equipment in December 2017, May 2019, January 2021, May 2022, and June 2023. This report examines:

1. the progress the Space Force has made in achieving operational capability for the modernized GPS ground control and space segments;

2. the extent to which the Space Force has identified and managed risks in developing and demonstrating user equipment; and

3. the extent to which the military departments have identified and managed risks in acquiring, testing, and fielding M-code-capable user equipment and integrating that equipment into platforms.

To assess the progress of the Space Force's efforts to develop components of ground control and space segments, as well as determine the extent the Space Force has identified and managed risks in developing and demonstrating user equipment, we reviewed program and contract performance documents, provided by Space Systems Command (SSC) and interviewed program officials for the following programs: the Global Positioning System III Follow-on (GPS IIIF) satellite, the Next Generation Operational Control System (OCX), the OCX Follow-on (OCX Block 3F), and the Military GPS User Equipment (MGUE Increment 1 and MGUE Increment 2). We also interviewed officials from SSC's Lead Development Test Organization and the Office of the Chief Engineer for Military Communications and Position, Navigation, and Timing (PNT). For information about the Department of Defense's (DOD) purchase of application-specific integrated circuits, we interviewed officials from the Defense Logistics Agency.

To assess the extent to which the military departments have identified and managed risks in acquiring, testing, and fielding M-code-capable user equipment, we reviewed materials and interviewed officials from the military departments responsible for the planning and implementation of M-code capability about the status of critical receiver programs that the services were responsible for developing, testing, and fielding. These included:

- the Air Force's PNT Program Office; and the Air Force Research Laboratory;
- the Army Cross-Functional Team for Assured PNT; the Army Program Manager for PNT; the Army Program Executive Office for Missiles and Space; and the Army Program Executive Office for Aviation;
- the Office of the Deputy Assistant for the Navy Chief of Naval Operations for Information Warfare and Enterprise Services; and Naval Air Systems Command's Air Navigation Warfare Program; and
- Marine Corps Systems Command.

To obtain further information about contract performance and testing for programs related to all three objectives, we also interviewed officials and reviewed contract performance reports from the Defense

Contracting Management Agency and interviewed officials at the DOD Office of Developmental Test, Evaluation, and Assessments and the DOD Office of the Director of Operational Test and Evaluation.

To obtain information about DOD's oversight and assessment of efforts to implement M-code capability across the military departments, we interviewed officials from the Office of the DOD Chief Information Officer and the Office of the Under Secretary of Defense for Acquisition and Sustainment. We also reviewed classified and unclassified briefing materials from the PNT Oversight Council.

To assess the projected health of the GPS constellation for full operational capability of 24 M-code-capable GPS, we employed a methodology very similar to the one we used to assess constellation performance in 2009, 2010, 2015, 2017, and 2023.[1] We obtained information dated May 2023 from the Space Force predicting the reliability for 61 GPS satellites—each of the then 35 on-orbit (31 in operational status, four in non-operational reserve status) and 26 future GPS satellites—as a function of time. Each satellite's total reliability curve defines the probability that the satellite will still be operational at a given time in the future. The probability is generated from the product of two reliability curves—a wear-out reliability curve defined by the cumulative normal distribution, and a random reliability curve defined by the cumulative Weibull distribution.[2]

For our analysis, we excluded the 10 non-M-code-capable GPS satellites and included in our model only the 25 operational and 26 future M-code-capable GPS satellites. For each of these 51 satellites, we obtained the two parameters defining the cumulative normal distribution, and the two parameters defining the cumulative Weibull distribution. For each of the 26 unlaunched satellites that we included in our model, we also obtained a parameter defining its probability of successful launch, and its current scheduled launch date. These 26 satellites include four GPS III satellites unlaunched as of May 2023 and 22 GPS IIIF satellites currently under contract or planned; launch of the final GPS IIIF satellite that we included in our model is scheduled for July 2037. Using this information, we generated overall reliability curves for each of the 51 M-code-capable GPS satellites. We discussed with Space Force officials and Aerospace Corporation representatives, in general terms, how each satellite's normal and Weibull parameters were calculated. However, we did not analyze any of the data used to calculate these Space Force-provided parameters. We found these data to be reliable for the purposes of supporting our analysis of the GPS constellation.

Using the reliability curves for each of the 51 M-code-capable GPS satellites, we developed a Monte Carlo simulation to predict the probability that at least a given number of satellites would be operational as a function of time, based on the GPS launch schedule as of May 2023. We conducted several runs of our simulation—each run consisting of 10,000 trials—and generated data representing the probability that at least 24 M-code-capable satellites would still be operational from May 2023 to December 2039.

[1]GAO, *GPS Modernization: Space Force Should Reassess Requirements for Satellites and Handheld Devices,* GAO-23-106018 (Washington, D.C.: June 5, 2023); *Global Positioning System: Better Planning and Coordination Needed to Improve Prospects for Fielding Modernized Capability*, GAO-18-74 (Washington, D.C.: Dec. 12, 2017); *GPS: Actions Needed to Address Ground System Development Problems and User Equipment Production Readiness*, GAO-15-657 (Washington, D.C.: Sept. 9, 2015); *Global Positioning System: Challenges in Sustaining and Upgrading Capabilities Persist*, GAO-10-636 (Washington, D.C.: Sept. 15, 2010); and *Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities*, GAO-09-325 (Washington, D.C.: Apr. 30, 2009).

[2]The Weibull distribution is a common two-parameter continuous probability distribution used to model the random failures of GPS satellites.

We then used our Monte Carlo simulation model to examine the effect of delays to the operational induction of the GPS III satellites into the constellation. We reran the model based on month and year delay scenarios, calculating new probabilities that at least 24 M-code-capable satellites would still be operational from May 2023 to December 2039.

We conducted this performance audit from May 2023 to September 2024 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 a 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.

Appendix II: GAO Contact and Staff Acknowledgments

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Staff Acknowledgments

In addition to the contact named above, J. Kristopher Keener (Assistant Director), Matt Shaffer (Analyst-in-Charge), Bonita Oden, Jonathan Mulcare, and Gary George were key contributors to this report. Other contributors included Laura Greifner, Sylvia Schatz, and Robin Wilson.

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