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Report to Congressional Committees

December 2017

GLOBAL POSITIONING SYSTEM

Better Planning and Coordination Needed to Improve Prospects for Fielding Modernized Capability

GAO-18-74

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GAO Highlights

Highlights of GAO-18-74, a report to congressional committees

Why GAO Did This Study

GPS provides positioning, navigation, and timing data to civilian and military users who depend on this satellite-based system. Since 2000, DOD—led by the Air Force—has been working to modernize GPS and to keep the current system of satellites—known as the GPS constellation—operational, although these efforts have experienced cost and schedule growth.

The National Defense Authorization Act for Fiscal Year 2016 contained a provision that the Air Force provide reports to GAO on GPS acquisition programs and that GAO brief the congressional defense committees. GAO briefed the committees in 2016 and 2017. This report summarizes and expands on information presented in those briefings.

This report assesses the extent to which DOD faces acquisition challenges (1) sustaining the GPS constellation; (2) developing a new ground control system; and (3) developing and fielding modernized receivers. GAO analyzed GPS quarterly acquisition reports and data, acquisition strategies, software and test plans, and other documents, and interviewed DOD and contractor officials.

What GAO Recommends

DOD should assign responsibility to an organization to collect test data, lessons learned, and design solutions so they may be shared. DOD concurred with the recommendation.

View GAO-18-74. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

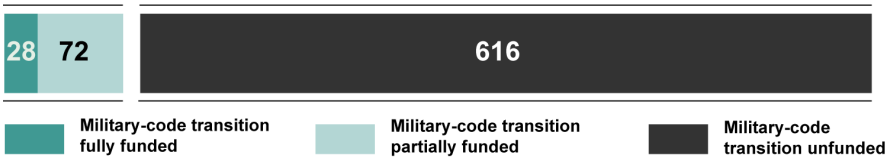
What GAO Found

The Department of Defense's (DOD) acquisition of the next generation Global Positioning System (GPS) satellites, known as GPS III, faces a number of acquisition challenges, but these challenges do not threaten DOD's ability to continue operating the current GPS system, which DOD refers to as the constellation, in the near term. Projections for how long the current constellation will be fully capable have increased by nearly 2 years to June 2021, affording some buffer to offset any additional satellite delays. While the first GPS III satellite has a known parts problem, six follow-on satellites—which do not—are currently scheduled to be launched by June 2021.

DOD is relying on a high-risk acquisition schedule to develop a new ground system, known as OCX, to control the broadcast of a modernized military GPS signal. OCX remains at risk for further delays and cost growth. To mitigate continuing delays to the new ground control system, the Air Force has begun a second new program—Military-code (M-code) Early Use—to deliver an interim, limited broadcast encrypted GPS signal for military use by modifying the current ground system. GAO will continue to monitor OCX progress.

DOD has made some progress on initial testing of the receiver cards needed to utilize the M-code signal. However, additional development is necessary to make M-code work with over 700 weapon systems that require it. DOD has begun initial planning for some weapon systems, but more remains to be done to understand the cost and schedule needed to transition to M-code receivers. The preliminary estimate for integrating and testing a fraction of the weapon systems that need the receiver cards is over $2.5 billion through fiscal year 2021 with only 28 fully and 72 partially funded (see figure). The cost will increase by billions when as yet unfunded weapon systems are included.

Status of Weapon Systems That Have Determined the Cost Needed to Transition to M-code Receivers through Fiscal Year 2021, as of February 2017



Source: GAO analysis of Department of Defense data. | GAO-18-74

The level of development and procurement effort beyond the initial receiver cards is significant and will require close coordination across DOD. After the Air Force develops initial cards, the breadth and complexity of this acquisition will multiply, as the offices responsible for upgrading hundreds of weapon systems begin their own individual efforts to further develop and test the cards. However, DOD does not have an organization assigned to collect test data, lessons learned, and design solutions so that common design solutions are employed to avoid duplication of effort as multiple entities separately mature receiver cards. DOD therefore risks paying to repeatedly find design solutions to solve common problems because each program office is likely to undertake its own uncoordinated development effort.

Contents

Abbreviations

COps	Contingency Operations
DOD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
GPS	Global Positioning System
IBR	integrated baseline review
JLTV	Joint Light Tactical Vehicle
MCEU	M-code Early Use
M-code	military code
MGUE	military GPS user equipment
OCS	operational control system
OCX	next generation operational control system
PNT	positioning, navigation, and timing
SAASM	Selective Availability/Anti-Spoofing Module
SMC	Space and Missile System's Center
USD AT&L	Under Secretary of Defense for Acquisition, Technology, and Logistics

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U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
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December 12, 2017

Congressional Committees

For more than two decades, the satellite-based Global Positioning System (GPS) has provided positioning, navigation, and timing (PNT) data to civilian and military users worldwide. Given its ubiquity throughout the world, failure, malfunction, or jamming of GPS can severely disrupt day-to-day civilian and military activities across the globe. The Department of Defense (DOD) maintains and operates GPS, which consists of three segments: orbiting satellites that continuously broadcast position and time data; a ground control system that operates the satellites and monitors and corrects signal data; and receivers used by civilians and the military in aircraft, ships, land vehicles, munitions, and hand-held units. Since 2000, the Air Force has led the multi-billion dollar effort to modernize GPS to sustain the satellite constellation—currently comprised of 31 satellites—by providing new civilian and military signals, enhancing cybersecurity, developing modernized military receivers, and countering known threats.

The National Defense Authorization Act for Fiscal Year 2016 contained a provision that the Air Force provide quarterly reports to GAO on the next generation GPS acquisition programs.[1] The Act also contained a provision that GAO brief congressional defense committees on the first report, and at GAO's discretion, on subsequent quarterly reports. The Air Force delivered the first quarterly report to us on April 22, 2016. We assessed the report, briefed congressional committees in June 2016, and issued a report on that briefing.[2] During fiscal years 2016 and 2017, we briefed the congressional defense committees several additional times regarding the ongoing work. This report summarizes and expands on those briefings. This report assesses the extent to which DOD faces acquisition challenges (1) sustaining the GPS constellation; (2) developing a new ground system to control the broadcast of a modernized military GPS signal called military-code, or M-code; and (3)

[1]Pub. L. No. 114-92, § 1621 (2015).

[2]GAO, *Global Positioning System: Observations on Quarterly Reports from the Air Force*, GAO-17-162R (Washington, D.C.: Oct. 17, 2016).

developing and fielding modernized receiver cards across the department.[3]

To conduct our work, we reviewed Air Force GPS fiscal year 2016 and 2017 quarterly acquisition reports, program acquisition baselines, integrated master schedules, acquisition strategies, software development plans, test plans, and other documents for five programs:

- GPS III,
- Next generation operational control system (OCX),
- Military GPS user equipment (MGUE),
- Contingency Operations (COps), and
- M-code Early Use (MCEU) programs.

We also interviewed officials from the GPS III, OCX, MGUE, COps, and MCEU programs; the prime contractors from all five programs; the Defense Contract Management Agency; and, where applicable, officials from DOD's Office of Cost Assessment and Program Evaluation; the Office of the Director, Operational Test and Evaluation (DOT&E); Under Secretary of Defense for Acquisition, Technology, and Logistics (USD AT&L); Joint Staff / J-6 Space Branch; Air Force Space Command; and each of the military services involved with the planning and procurement of the MGUE program. Appendix I contains a more detailed description of our scope and methodology.

We conducted this performance audit from February 2016 to December 2017 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

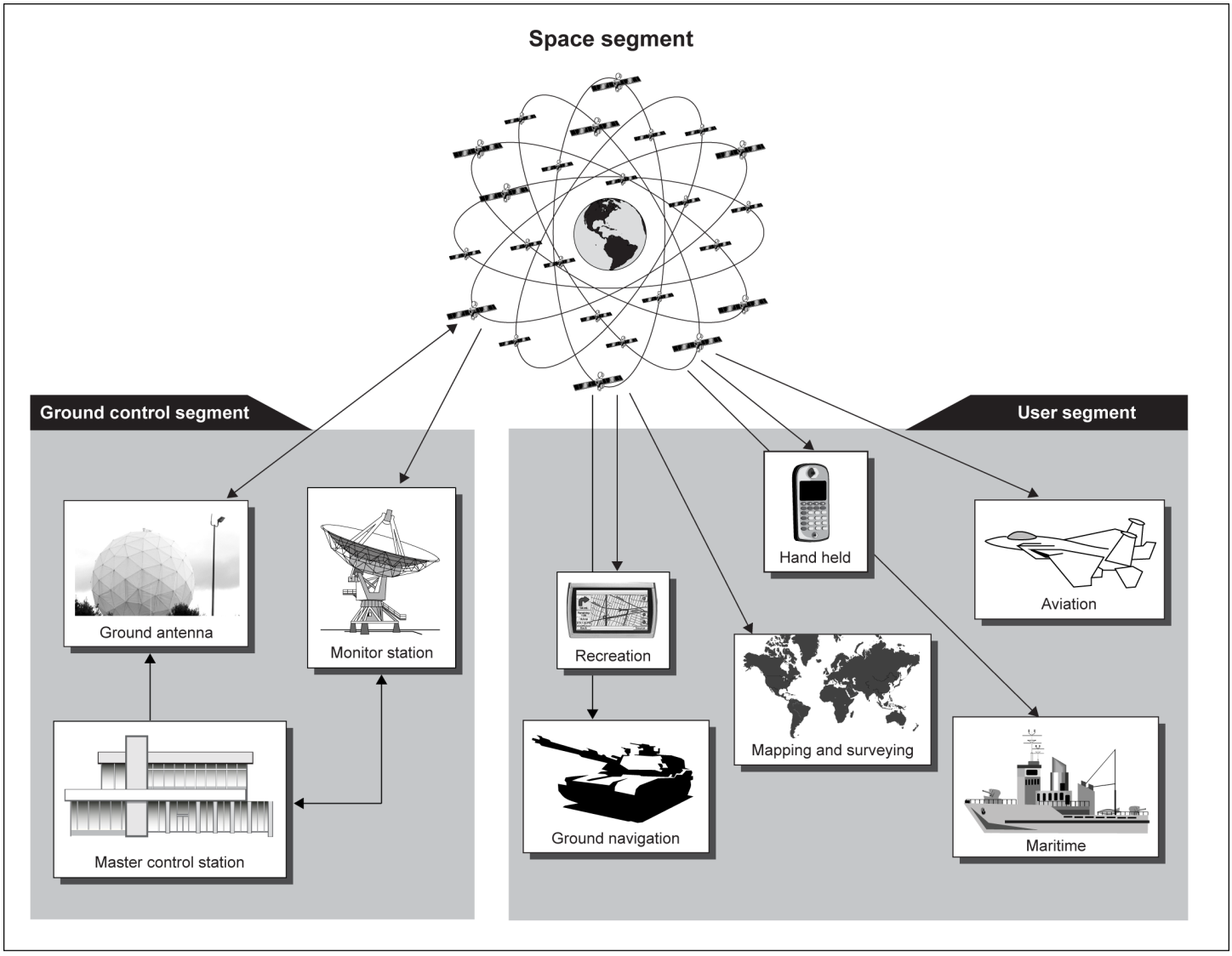
Collectively, the ongoing GPS acquisition effort aims to (1) modernize and sustain the existing GPS capability and (2) enhance the current GPS

[3]M-code is a stronger, encrypted, military-specific GPS signal designed to meet military PNT needs.

system by adding an anti-jam, anti-spoof cybersecure M-code capability.[4] Figure 1 below shows how GPS satellites, ground control, and user equipment—in the form of receiver cards embedded in systems—function together as an operational system.

[4]Anti-jam capability blocks signal interference (jamming). Anti-spoof capability protects users against false signals that adversaries may employ to imitate friendly GPS systems (spoofing).

Figure 1: GPS Operational System



Source: Copyright © Corel Corp. all rights reserved (map); Art Explosion (images); GAO analysis of Department of Defense data. | GAO-18-74

Modernizing and sustaining the current GPS broadcast capability requires launching new satellites to replace the existing satellites that are near the end of their intended operational life as well as developing a ground control system that can launch and control both existing and new satellites. Sustaining the current GPS broadcast capability is necessary to ensure the quality and availability of the existing broadcast signals for

civilian and military GPS receivers. The ongoing modernization of GPS began with three programs: (1) GPS III satellites; (2) OCX to control the satellites; and (3) MGUE increment 1 (which develops initial receiver test cards for military ships, ground vehicles, or aircraft).[5] Table 1 describes these programs.

Table 1: Current Global Positioning System Modernization Programs

Program	Description
	Space Segment
Global Positioning System (GPS) III	GPS III satellites will supplement and eventually replace the constellation of GPS satellites now in orbit, sustaining current capabilities and providing new signals. The GPS constellation currently consists of multiple satellite generations. Previous generations of satellites have been transmitting the military code—or M-code—signal for more than 11 years. GPS III satellites will provide a stronger M-code signal. Lockheed Martin was awarded the contract to build the first 10 GPS III satellites. The Air Force plans to competitively award satellites 11 through 32 in fiscal year 2018.
	Ground Control Segment
Next Generation Operational Control System (OCX)	OCX will replace the current ground control system, known as the operational control segment (OCS). OCS lacks modern cybersecurity protections and cannot control–or enable–modernized features of the two latest generations of GPS satellites now in orbit, including M-code and some new civilian signals. Raytheon is the prime contractor. OCX is being developed in a series of blocks: 1. Block 0—will provide the launch and checkout system and supports initial testing of GPS III satellites. GPS III satellites cannot be launched without OCX block 0. It also provides most of the modern cybersecurity—a key advancement in securing the system. 2. Blocks 1 and 2—will provide command and control for previous generations of satellites and GPS III satellites, as well as monitoring and control for both current and modernized signals. Block 2 will provide the full M-code broadcast capability. The planned operational date for block 2 is January 2022.
	User Segment
Military GPS User Equipment (MGUE)	MGUE is developing the M-code capable receiver cards with enhanced positioning, navigation, and timing (PNT) capabilities and improved resistance to existing and emerging threats, such as jamming. The Air Force is developing MGUE in two increments: 1. Increment 1—will provide initial ground, maritime, and aviation security-certified receiver cards. It entered system development in January 2017 and is scheduled to conduct operational testing on four military service-nominated lead platforms by April 2021. Three contractors—L3 Technologies, Raytheon, and Rockwell Collins—are building initial receiver cards. The cards consist of hardware—the physical card itself—and software—the coding within the card—that must be developed, tested, and integrated. 2. Increment 2—will provide more compact receiver cards to be used when size, weight, and power must be minimized, such as on handheld receivers, space receivers, and precision munitions. The Air Force plans to deliver the acquisition strategy for increment 2 in March 2018.

Source: GAO analysis of Department of Defense data. | GAO-18-74

[5]The MGUE increment 1 program is developing two receiver card types for (1) ground and (2) aviation/maritime applications on four military service-nominated “lead platforms,” which serve as initial representatives for all platforms’ integration.

Delays to OCX of more than 5 years led the Air Force to create two additional programs in 2016 and 2017 to modify the current GPS ground system to control GPS III satellites and provide a limited M-code broadcast. As a result, there are currently five total GPS modernization programs. Table 2 provides a description of the two new programs.

Table 2: Modifications to Current Operational Control Segment

Program	Description
Contingency Operations (COps)	COps will be a software modification to the existing operational control segment (OCS) started in 2016 to sustain the GPS constellation's capabilities. COps is planned to enable operational control of GPS III satellites and the legacy signals they will broadcast, while OCS will continue to control GPS II satellites and their signals. COps is a bridge capability needed to fill in the gap created by OCX development delays. Lockheed Martin is the prime contractor for this work and also built and maintains OCS.
M-code Early Use (MCEU)	MCEU will be an additional software modification to OCS after COps is completed. It will provide some operational control of specific M-code broadcast signals, but will lack the cybersecurity of OCX, among other features. This is a bridge capability needed to fill in the gap created by the OCX development delays. Lockheed Martin is the prime contractor.

Source: GAO analysis of Department of Defense data. | GAO-18-74

All of the original GPS modernization programs—GPS III, OCX, and MGUE—have experienced significant schedule growth during development. Table 3 outlines several schedule challenges in the modernized GPS programs.

Table 3: Schedule Challenges in Modernized GPS Programs

Program	Challenges
Global Positioning System (GPS) III	Since the program's original 2008 baseline, the first GPS III satellite's planned launch date has been delayed by four years—from April 2014 to May 2018. The Air Force and Lockheed Martin had repeated delays due to technical challenges with the navigation payload, resulting in a January 2016 cost and schedule rebaseline—or a recalculation by the program of new costs based on the new schedule.
Next Generation Operational Control System (OCX)	Since the program's original 2012 baseline: OCX block 1 ready to transition to operations date has been delayed by 63 months—from October 2016 to January 2022. The program's cost increases prompted a cost and schedule rebaseline in 2015 and declaration of a critical Nunn-McCurdy unit cost breach in 2016.[a] The Air Force and Raytheon have struggled with OCX development hurdles and unrealistic schedules with numerous root causes.
Military GPS User Equipment (MGUE) Increment 1	The Air Force began MGUE technology development in April 2012, but the cost and schedule baseline for the program was not approved until January 2017, over a year later than originally planned. The Air Force and the MGUE contractors—L3 Technologies, Raytheon, and Rockwell Collins—have experienced varying degrees of schedule delays, in part, due to lack of software engineering rigor and technology readiness shortcomings. The Air Force pursued an accelerated MGUE development and eliminated a key milestone based on early optimistic assessments of technology maturity. However, independent reviews highlighted concerns over development maturity and the characterization of demonstration test results.

Source: GAO analysis of Department of Defense data. | GAO-18-74

[a]10 U.S.C. § 2433, commonly referred to as Nunn-McCurdy, requires the Department of Defense to notify Congress whenever a major defense acquisition program's unit cost experiences cost growth that exceeds certain thresholds.

We found in 2015 that unrealistic cost and schedule estimates of the new ground control system and receiver card development delays could pose significant risks to sustaining the GPS constellation and delivering M-code.[6] At that time, we also made five recommendations so that DOD would have the information necessary to make decisions on how best to improve GPS modernization and to mitigate risks to sustaining the GPS constellation. We made four OCX-specific recommendations targeted to identify underlying problems, establish a high confidence schedule and

[6]GAO, *GPS: Actions Needed to Address Ground System Development Problems and User Equipment Production Readiness*, GAO-15-657 (Washington, D.C.: Sept. 9, 2015).

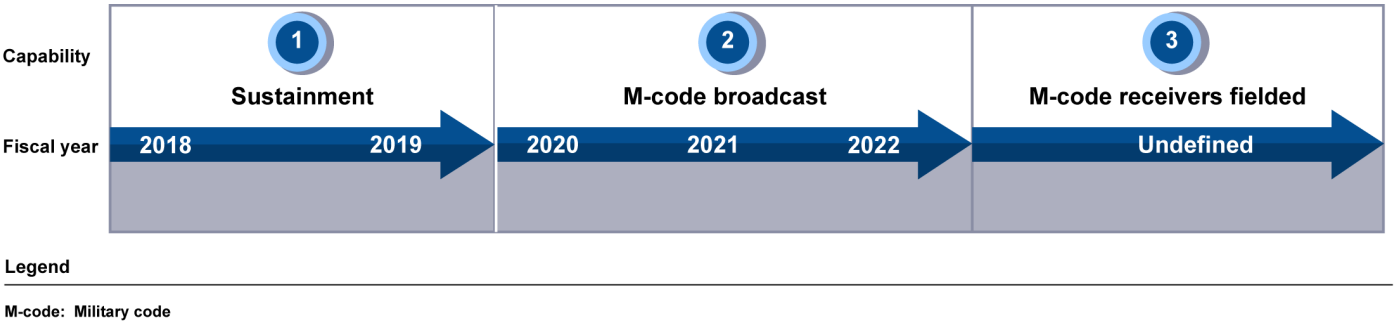
cost estimate, and improve management and oversight. For MGUE, we recommended the Air Force add a critical design review before committing resources to allow the military services to fully assess the maturity of the MGUE design before committing test and procurement resources. DOD concurred with the four recommendations on OCX and partially concurred on the MGUE recommendation. Since 2015, our annual assessment of DOD weapon systems has shown that some of the original GPS programs have continued to face cost or schedule challenges, increasing the collective cost to modernize GPS by billions of dollars.[7] Appendix III outlines the cost increases that have resulted.

Key GPS Modernization Points

According to our analysis, over the next decade or more, DOD plans to achieve three key GPS modernization points: (1) constellation sustainment, (2) M-code broadcast, and (3) M-code receivers fielded.

Figure 2 shows the current sequencing of the three points and the intervals when they are planned to be achieved, if known.

Figure 2: Current Key Global Positioning System Modernization Points



Source: GAO analysis of Department of Defense data. | GAO-18-74

Note: This depiction reflects the current plan after numerous delays, not the original planned dates for all capabilities.

Throughout this report, we will use figures based on this one to highlight the separately-managed programs DOD plans to synchronize to achieve each of the three identified modernization points. Some GPS capabilities

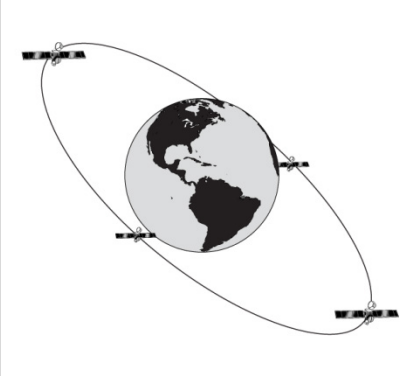
[7]GAO, *Defense Acquisitions: Assessment of Selected Weapon Programs*, GAO-17-333SP (Washington, D.C.: Mar. 30, 2017); *Defense Acquisitions: Assessment of Selected Weapon Programs*, GAO-16-329SP (Washington, D.C.: Mar. 31, 2016).

require the delivery of more than one program, which must compete for limited resources, such as testing simulators. The Air Force coordinates the interdependent activities of the different programs and contractors in order to achieve each modernization point.

GPS Satellite Constellation

The satellites in the GPS constellation broadcast encrypted military signals and unencrypted civilian signals and move in six orbital planes approximately 12,500 miles above the earth.

What is a Global Positioning System (GPS) satellite orbital plane and how many are there?



An orbital plane is an imaginary flat disc containing an Earth satellite's orbit. One orbital plane, as is shown above, represents the trajectory a GPS satellite follows as it circles the Earth in space.

The GPS constellation has six orbital planes. Each contains at least 4 satellites that allow the constellation to meet the minimum requirement of 24 satellites.

Source: Department of Defense (data); Art explosion (images). | GAO-18-74

The GPS constellation availability performance standards commit the U.S. government to at least a 95 percent probability of maintaining a constellation of 24 operational GPS satellites to sustain the positioning services provided to both civilian and military GPS users. Therefore, while the minimum constellation consists of satellites occupying 24 orbital slots—4 slots in each of the six orbital planes—the constellation actually has 31 total satellites, generally with more than four in each plane to meet the 95 percent probability standard. These additional satellites are needed to provide uninterrupted availability in case a satellite fails. The constellation includes three generations of satellites with varying capabilities and design lives.

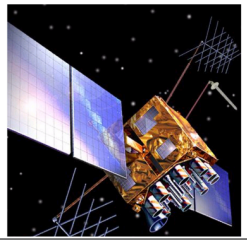
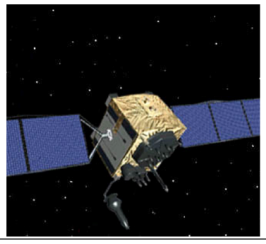
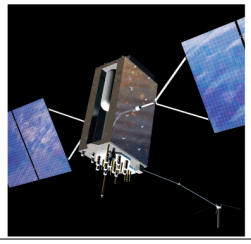
We found in 2010 and 2015 that GPS satellites have proven more reliable than expected, greatly exceeding their initially predicted life expectancies.[8] Nevertheless, the Air Force must regularly replace satellites to meet the availability standard, since operational satellites have a finite lifespan. Excluding random failures, the operational life of a GPS satellite tends to be limited by the amount of power that its solar arrays can produce.[9] This power level declines over time as the solar arrays degrade in the space environment until eventually they cannot produce enough power to maintain all of the satellite's subsystems. Consequently, the Air Force monitors the performance of operational satellites in order to calculate when new satellites need to be ready to join the constellation.

[8]GAO, *Global Positioning System: Challenges in Sustaining and Upgrading Capabilities Persist*, GAO-10-636 (Washington, D.C.: Sept. 15, 2010); GAO-15-657.

[9]The solar array is the component of the satellite's power subsystem upon which the solar cells are mounted.

The 10 GPS III satellites currently under contract and in production with Lockheed Martin will provide a range of performance enhancements over prior GPS satellite generations. The GPS III satellites were designed to provide a longer life than previous generations, greater signal accuracy, and improved signal integrity—meaning that the user has greater assurance that the broadcast signal is correct. When they are eventually controlled through the OCX ground control system, the satellites will also offer a stronger M-code signal strength than prior GPS satellite generations. They will also include an additional civilian signal known as L1C, which will permit interoperability with European, Japanese, and other global navigation satellite systems for civilian users. Figure 3 describes the evolution of GPS satellite generations, including capabilities and life-span estimates.

Figure 3: Active and Future GPS Satellite Generations

	GPS IIR	GPS IIR-M	GPS IIF	GPS III
				
Number	12 operational	7 operational	12 operational	10 under contract; additional 22 planned
Design life[a]	7.5 years	7.5 years	12 years	15 years
Mean life estimate[b]	26.2 years	18.9 years	12.5 years	16.3 years
Launched	1997 - 2004	2005 - 2009	2010 - 2016	First planned for May 2018
Capabilities	• Civilian and military signal broadcasts as provided by prior IIA generation satellites • Improved time keeping with on board clock monitoring	**IIR capabilities, plus:** • 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

GPS **Global Positioning System**

Source: GAO analysis of Department of Defense information (data); U.S. government (images). | GAO-18-74

[a]Design life is the period of time 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.

Ground Control Segment

The current GPS ground control segment, OCS, primarily consists of software deployed at a master control station at Schriever Air Force Base, Colorado, and at an alternate master control station at Vandenberg Air Force Base, California. The ground control software is supported by 6 Air Force and 11 National Geospatial-Intelligence Agency monitoring stations located around the globe along with four ground antennas that communicate with the moving satellites. Information from the monitoring stations is processed at the master control station to determine satellite clock and orbit status. As each of the three ground control segment

programs—COps, MCEU, and OCX—is completed or partially completed, they will each introduce new capabilities, eventually culminating in the delivery of the full M-code broadcast planned for January 2022.

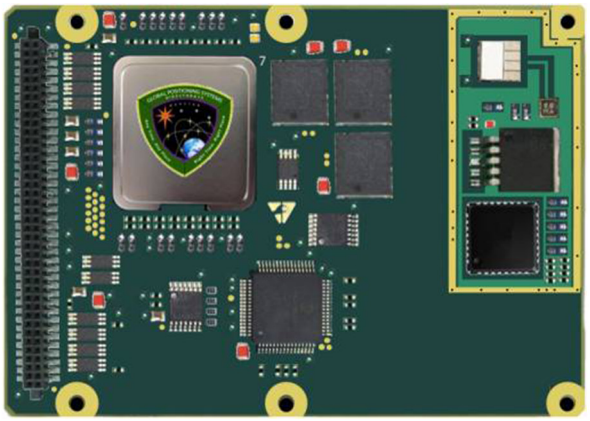
Receiver Cards

GPS receiver cards determine a user's position and time by calculating the distance from four or more satellites using the navigation signals on the satellites to determine the card's location. All warfighters currently acquire, train with, and use GPS receivers. Until MGUE receiver cards are developed and available for production, all DOD weapon systems that use GPS will continue to use the current GPS Selective Availability/Anti-Spoofing Module (SAASM) receiver card or an older version.[10] The Ike Skelton National Defense Authorization Act for Fiscal Year 2011 generally prohibits DOD from obligating or expending funds to procure GPS user equipment after fiscal year 2017 unless that equipment is capable of receiving M-code.[11] Under certain circumstances this requirement may be waived or certain exceptions may apply. The increment 1 receiver cards range in size from approximately 2 inches by 3 inches for the ground card up to 6 inches by 6 inches for the aviation/maritime card. Figure 4 below shows an illustration of a MGUE receiver card.

[10]For the purposes of this report, weapon systems include all DOD programs, platform systems, and subsystems that incorporate GPS.

[11]Pub. L. No. 111-383, § 913 (the Act) 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 during the fiscal years after fiscal year 2017 unless the equipment is capable of receiving M-code. This limitation does not apply to purchases of passenger or commercial vehicles in which GPS equipment is installed. Additionally, the Secretary of Defense may waive this limitation under certain circumstances.

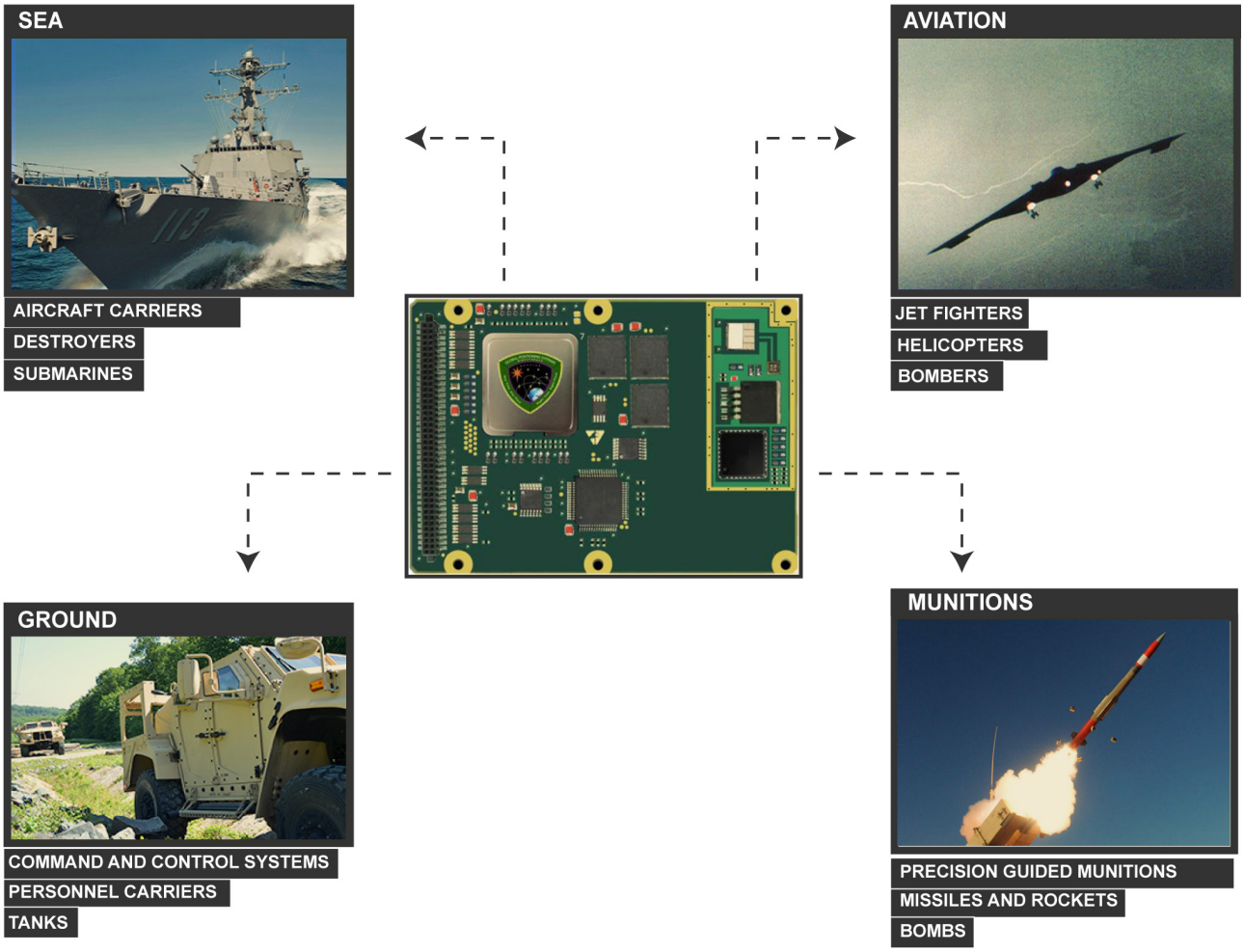
Figure 4: MGUE Receiver Card



Source: Air Force. | GAO-18-74

DOD has previously transitioned its weapon systems gradually from one generation of GPS receivers to the next. For example, some weapon systems have either upgraded or are still in the process of upgrading to the current SAASM receivers that were introduced in 2003, while others are still equipped with older cards. DOD anticipates that the length of time necessary to transition to MGUE will require users to operate with a mix of receiver cards. Hundreds of different types of weapon systems require GPS receiver cards, including ships, aircraft, ground vehicles, missiles, munitions, and hand-held devices, among others, across all military services. The Air Force funds the MGUE program, providing funding to the military services so they can acquire, integrate, and operationally test the receiver cards on four service-specific lead platforms. These platforms are intended to test the card in the military services' ground, aviation, and maritime environments: (1) Army—Stryker ground combat vehicle; (2) Air Force—B-2 Spirit bomber; (3) Marine Corps—Joint Light Tactical Vehicle (JLTV); and (4) Navy—DDG-51 Arleigh Burke destroyer. Figure 5 depicts selected weapon systems that will need to install M-code capable receiver cards.

Figure 5: Selected Weapon Systems That Require Military Code Receiver Cards

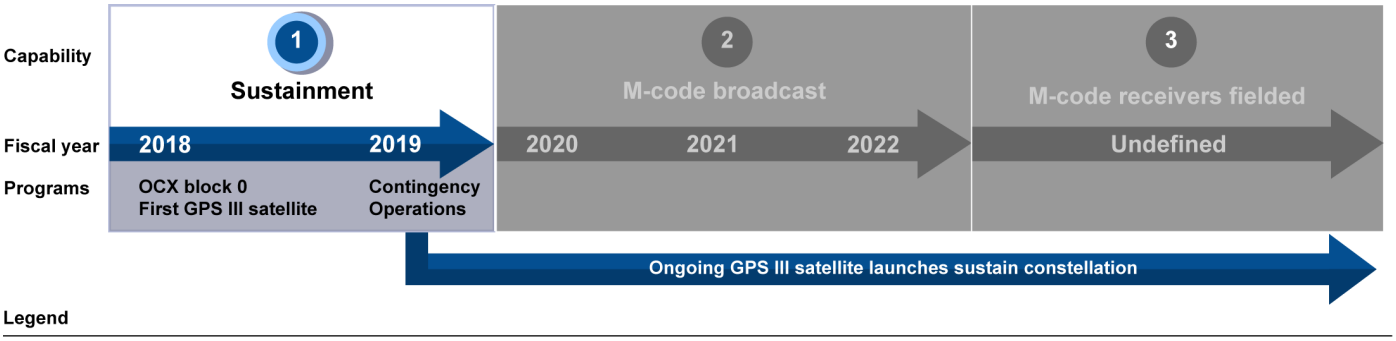


Source: Huntington Ingalls Industries, Pascagoula, MS (top left image); Air Force (center and top right image); Army (bottom left and right image). | GAO-18-74

Acquisition Risks Persist on GPS III Satellites but Do Not Threaten Sustainment of the Constellation in the Short Term

The Air Force has made some progress toward ensuring continued constellation sustainment since our September 2015 report and should be able to sustain the current service because of the length of life of the current satellites. The current GPS constellation is now projected to meet its availability performance standard (in the absence of operational GPS III satellites) into June 2021—an increase of nearly 2 years over previous projections. This increase will give the Air Force more schedule buffer in the event of any additional delays to the GPS III satellite program. However, the Air Force still faces technical risks and schedule pressures in both the short and long term. In the short term, schedule compression with the first GPS III satellite is placing the satellite's launch and operation at risk of further delays. In the long term, most of the satellites under contract will have been launched before operational testing is completed, limiting Air Force corrective options if issues are discovered. Figure 6 shows the schedule for programs that need to be delivered to modernize and sustain the GPS satellite constellation.

Figure 6: Schedule to Modernize and Sustain the GPS Satellite Constellation



GPS: Global Positioning System | M-code: Military code | OCX: Next Generation Operational Control System

Source: GAO analysis of Department of Defense data. | GAO-18-74

Progress: Programs Advancing to Support Constellation Sustainment Requirements

The Air Force has made progress since our last report in September 2015 on the three programs (GPS III, OCX, and COps) needed to support GPS constellation sustainment, readying both ground control and the satellite for the first GPS III satellite's launch, testing, and eventual operation. Raytheon delivered OCX block 0, the launch and checkout system for GPS III satellites, in September 2017. The Air Force took possession of

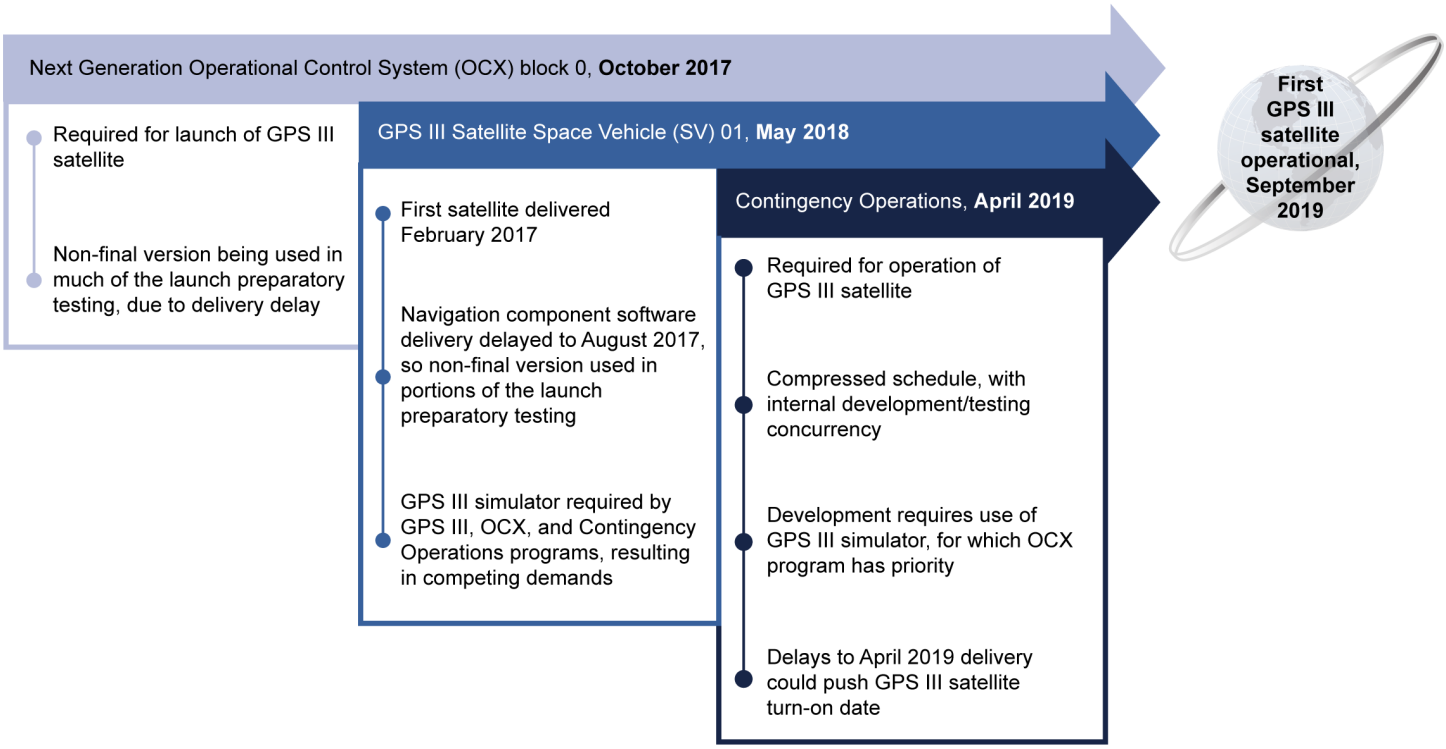
OCX block 0 in October 2017 and will finally accept it at a later date after OCX block 1 is delivered.[12] Lockheed Martin completed the assembly, integration, and testing for the first GPS III satellite and in February 2017 the Air Force accepted delivery in advance of its currently scheduled May 2018 launch. As noted earlier, because of delays to OCX block 1, the Air Force initiated the COps program to ensure an interim means to control GPS III satellites. Without COps, no GPS III satellites can join the constellation to sustain it until OCX block 1 is operational in fiscal year 2022. In September 2016, COps formally started development, establishing a cost baseline of approximately $162 million to meet an April 2019 delivery. The COps program began software coding in November 2016, after a design review established that the product design would meet the Air Force's intended needs.

Short-Term Challenges: Compressed and Concurrent Schedules, Component Issues with the First GPS III Satellite

The Air Force continues to struggle with keeping multiple, highly compressed, interdependent, and concurrent program schedules synchronized in order to sustain and modernize the GPS constellation. Figure 7 shows some of the schedule challenges of the three programs needed for constellation sustainment and modernization.

[12]The Air Force took possession after inspection by signing a Certificate of Conformance.

Figure 7: Global Positioning System (GPS) Challenges and Deliveries Needed to Launch the First GPS III Satellite



GPS III **Global Positioning System III**

Source: GAO analysis of Department of Defense data. | GAO-18-74

Launching and operating the new GPS III satellite is a highly complex effort, since it requires synchronizing the development and testing schedules of OCX block 0, the first GPS III satellite, and the COps programs. For the Air Force to achieve its objective of making the first GPS III satellite operational by September 2019, numerous challenges (discussed below) must be addressed in the next 18 months on all three programs. If any of the three programs cannot resolve their challenges, the operation of the first GPS III satellite—and constellation sustainment—may be delayed.

OCX Block 0 and Pre-Launch Testing Schedules

With the goal of launching the first GPS III satellite in March 2018, the Air Force restructured its pre-launch integrated satellite and ground system testing in the summer of 2016, compressing the overall testing timeframe

from 52 weeks to 42 weeks.[13] More OCX block 0 delays in early fiscal year 2017 complicated Air Force test plans, resulting in changes to the sequence and timing of events, the introduction of concurrency at various points throughout the testing, the use of incomplete software in early testing, and an increase in the likelihood of discovering issues later in pre-launch integrated testing. Air Force officials stated that some pre-launch testing revisions streamlined the overall test plan since the merging of certain test events allowed multiple objectives to be met by the same event. Raytheon delivered OCX block 0, the launch and checkout system for GPS III satellites, in September 2017. The Air Force took possession of OCX block 0 in October 2017 and will finally accept it at a later date after OCX block 1 is delivered. However, if issues requiring corrective work are discovered during subsequent integrated testing, the GPS III launch schedule may be delayed further since there is minimal schedule margin on OCX block 0 for correcting any additional problems that may be found.

First GPS III Satellite Capacitors

There are hundreds of capacitors—devices used to store energy and release it as electrical power—installed in each GPS III satellite. In 2016, while investigating capacitor failures, the Air Force discovered that the subcontractor, then known as Exelis (now Harris Corporation), had not conducted required qualification testing for the capacitor's operational use in GPS III satellites. The Air Force conducted a review of the components over many months, delaying program progress while a subcontractor qualified the capacitor design as suitable for use on the GPS III satellite. However, the Air Force concluded that Harris Corporation failed to properly conduct a separate reliability test of the particular production lot from which the questionable capacitors originated. The Air Force directed the contractor to remove and replace the capacitors from that production lot from the second and third GPS III satellites. After weighing the technical data and cost and schedule considerations, the Air Force decided to accept the first satellite and launch it "as is" with the questionable capacitors installed.

[13]Independent of OCX development, the Air Force moved the first GPS III target launch date from March to May 2018 in the spring of 2017. According to Air Force officials, the change was the result of a decision to launch the first GPS III satellite on a Falcon 9 rocket, rather than a Delta IV.

Contingency Operations Schedule

The COps program is also pursuing a compressed and concurrent development and testing schedule to be operational as planned in September 2019. The COps acquisition strategy document acknowledges that the program's timeline is aggressive. DOT&E has highlighted the compressed COps schedule as a risk, since the limited time between the developmental and operational testing permits little time for the evaluation of test results and resolution of any deficiencies found. The COps program has already begun drawing from its 60-day schedule margin, with a quarter of this margin used within the first 5 months after development started. According to Air Force officials, this margin use was the result of unplanned delays certifying a software coding lab. Additionally, the program schedule has concurrent development and testing, which in our previous work we have noted is often a high risk approach but is sometimes appropriate for software development.[14]

COps faces further schedule risk from its need for shared test assets, particularly the GPS III satellite simulator, a hardware- and software-based ground system that simulates GPS III function, which is also required by the GPS III and OCX programs. According to a DOT&E official, the OCX program receives priority over COps for the use of the GPS III satellite simulator, since the testing asset is heavily needed in the development of the ground control system. Because of the competing demands for this resource, which Air Force and DOT&E officials maintain requires lengthy and complex software reconfigurations to repurpose the simulator from one test event to the next, the Air Force is using a less realistic and purely software-based simulator for the testing of COps, where possible.

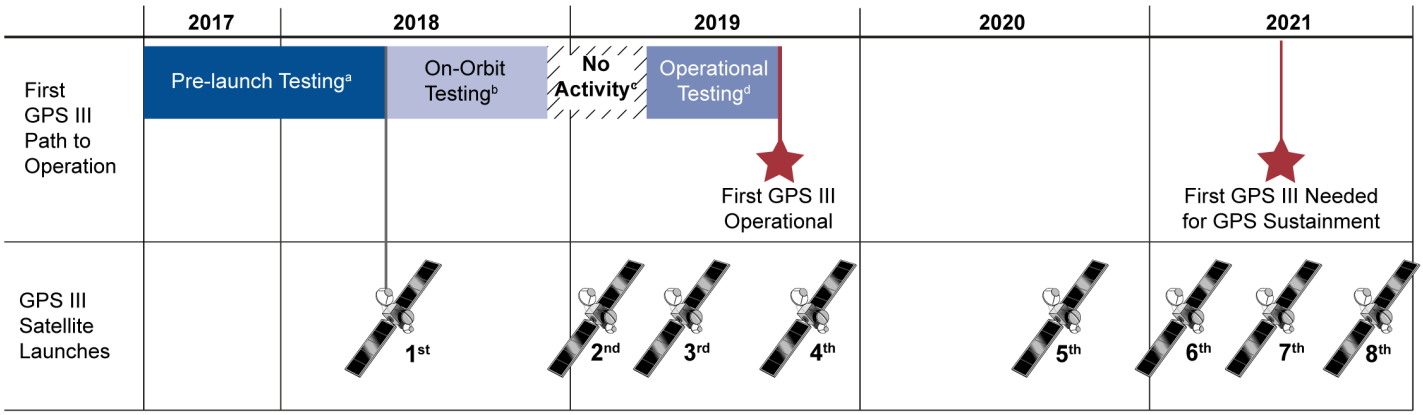
Short-Term Risk Mitigation: Nearly 2 Years of Schedule Buffer to When First GPS III Satellite Needed

Recent data show that the current satellites in the GPS constellation are expected to remain operational longer than previously projected, creating an additional, nearly 2-year schedule buffer before the first GPS III satellite needs to be operational to sustain the current GPS constellation capability. The Air Force projected that the first GPS III satellite needed to be operational by September 2019 based on 2014 satellite performance data. However, our analysis of the Air Force's more recent May 2016 GPS constellation performance data indicates that, in order to continue

[14]GAO, *Missile Defense: Opportunity Exists to Strengthen Acquisitions by Reducing Concurrency*, GAO-12-486 (Washington, D.C.: Apr. 20, 2012); GAO-16-329SP.

meeting the constellation availability performance standard without interruption, the operational need for the first GPS satellite is now June 2021. This projection incorporates updated Air Force data from the current satellites that take into account an increase in solar array longevity expected for IIR and IIR-M satellites, according to Air Force officials. The Air Force is likely to meet the constellation's June 2021 operational requirement because there are seven GPS III satellites planned to be launched by June 2021. Figure 8 shows the events leading to the launch and operation of the first GPS III satellite, achieving constellation sustainment once the first GPS III is operational, and subsequent GPS III launches that continue to support sustainment.

Figure 8: Path to Global Positioning System (GPS) Constellation Sustainment



Source: GAO analysis of Department of Defense data. | GAO-18-74

[a]Pre-launch testing entails operational-like testing of the OCX block 0 launch and checkout system and the GPS III satellite to demonstrate launch and satellite checkout capabilities prior to the May 2018 launch.

[b]On-orbit testing is the post-launch checkout testing of the GPS III satellite with OCX block 0 to provide early verification of some satellite subsystem functions.

[c]After completion of on-orbit testing, the GPS III satellite will orbit in a non-operational state until operational testing begins.

[d]Operational testing entails the testing of both the Contingency Operations (COps) ground control and the GPS III satellite to support an operational acceptance decision for both systems for non-modernized navigation signal capabilities.

The nearly 2-year buffer between planned operation and actual need for the first GPS III satellite permits the Air Force additional time to resolve any development issues. Because of this additional 2-year schedule buffer, we are not making a recommendation at this time to address the short term challenges we have identified but will continue to assess the progress of each of the programs and risks to constellation sustainment in our future work.

Long-Term Challenge: Most GPS III Satellites Under Contract Will Have Launched before Operational Testing Confirms Satellite Performance

The Air Force risks additional cost increases, schedule delays, and performance shortfalls because operational testing to confirm that GPS III satellites work as intended with OCX blocks 1 and 2 will not be completed until after the planned launch of 8 of the 10 GPS III satellites currently under contract. Due to delays to the OCX final delivery, the new ground control system will not be completed in time to control the GPS III satellites for the first few years they are in orbit (approximately 3.5 years). Consequently, GPS III operational testing will now occur in three phases—

1. in late fiscal year 2019 to confirm the satellites can perform similarly to the existing GPS satellites with COps;
2. in fiscal year 2020 to confirm the GPS III satellites can perform some of the new M-code capabilities with MCEU; and
3. in fiscal year 2022 to confirm the GPS III satellites can perform all of the new M-code capabilities with OCX blocks 1 and 2.

The first GPS III satellite is projected to complete operational testing of legacy signal capabilities in September 2019. By that point, the Air Force plans to have launched 3 of the 10 GPS III satellites, the fourth satellite is expected to be delivered, and major integration work will be underway on satellites 5 through 8. Therefore, if satellite shortcomings are discovered during any phase of the operational testing, the Air Force will be limited to addressing such issues through software corrections to satellites already on orbit. If any of the three phases of operational testing reveals issues, the Air Force may face the need for potentially costly contract modifications and delivery delays for satellites not yet launched. To offset this risk, the Air Force has obtained performance knowledge of GPS III satellites through ground testing of the first satellite, and findings from this testing have driven modifications to all ten satellites. Because of the rigor of the ground testing of the first satellite, Air Force officials maintain that the knowledge that might be obtained through on-orbit operational testing of the first GPS satellite would be minimal. However, a DOT&E official said that ground testing is limited to assessing system responses that are induced through the testing process and therefore may omit phenomena that might be experienced in actual system operation on orbit. We will continue to track the progress of operational testing in our future work.

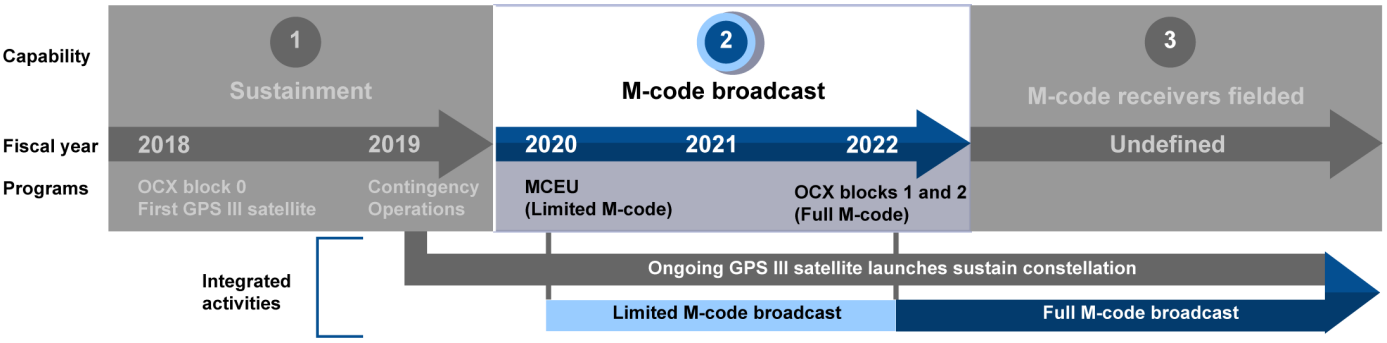
Modernizing GPS Military Broadcast Challenged by High-Risk Development Schedules

DOD has established high-risk schedules for modernizing the GPS broadcast, or M-code signal, produced by GPS satellites. These risks are manifest in different ways. In the near term, the Air Force plans to provide a limited M-code broadcast—one that does not have all of the capabilities of OCX—in the MCEU program in fiscal year 2020. However, the MCEU schedule is high risk for its dependency on the timely completion of the COps program, for its aggressive schedule, and because of competition for limited test resources. Further, the full M-code broadcast capability, planned for fiscal year 2022, is at high risk of additional delays because (1) it is dependent on unproven efficiencies in software coding, (2) the program has not yet completed a baseline review, which may identify additional time needed to complete currently contracted work, and (3) there are known changes to the program that must be done that are not included in the proposed schedule.

High-Risk Programs Underlie Strategy to Deliver M-code Broadcast Capability

As noted above, the Air Force's plans for delivering the M-code broadcast involve two separate high-risk programs—MCEU and OCX blocks 1 and 2—delivered at separate times to make an operational M-code signal available to the warfighter. Figure 9 highlights the current forecasted operational schedules to deliver limited M-code broadcast capabilities with MCEU and full M-code broadcast with OCX.

Figure 9: Schedule to Achieve Limited and Full M-code Broadcast



Legend

GPS: Global Positioning System | M-code: Military code | MCEU: M-code Early Use | OCX: Next Generation Operational Control System

Source: GAO analysis of Department of Defense data. | GAO-18-74

MCEU

The MCEU program, created because of multiple delays to OCX and to partially address that program's remaining schedule risk, is itself a high-risk program that is dependent on the timely development of COps. Estimated to cost approximately $120 million, MCEU formally entered the acquisition process in January 2017 as a software-specific program to modify OCS. To develop MCEU, Lockheed Martin officials stated they will leverage personnel with expertise maintaining and upgrading OCS as well as utilize the staff working on COps. With a planned December 2019 delivery for testing and a September 2020 target to begin operations, the MCEU program faces several schedule risks. The Air Force's proposed plan anticipates a compressed software development effort, which the Air Force describes as aggressive. The Air Force has also identified potential risks to the MCEU schedule from competing demands by GPS III, OCX, COps, and MCEU for shared test resources. Air Force officials specifically noted competing demands for the GPS III simulator test resource. If development or testing issues arise in these other programs, those issues could delay the availability of the satellite simulator and thereby disrupt the planned MCEU development effort. According to program officials, the Air Force is working to mitigate this threat to the MCEU program through the use of a software-based simulator, when possible. Additionally, MCEU software development work is dependent on the timely conclusion of the COps effort—which, as previously mentioned, itself has an aggressive schedule and faces competition for a limited test resource. Air Force program officials have said that some Lockheed Martin staff planned to support MCEU will need to transfer from the COps effort. However, after reviewing the staffing plans at the MCEU contractor kickoff, Air Force officials said this is no longer viewed as a significant risk.

OCX blocks 1 and 2

Raytheon has made some progress starting coding for OCX block 1 and taken the first steps toward implementing and demonstrating initial software development efficiencies that may benefit development for OCX blocks 1 and 2. The software efficiencies are built up in seven phases and need to be completed before the development process reaches each of the phases to take full advantage of the efficiencies they will create. Once ready, the efficiencies are inserted at different points in the software development schedule. For example, as of August 2017, the first of seven phases implementing the software development improvements was nearly complete, while the second phase was approximately two-thirds

complete. Both are needed in place for insertion when the next phase of coding begins.

Further, the Air Force proposed a new rebaselined schedule in June 2017 as the final step to getting the program back on track after declaring a critical Nunn-McCurdy unit cost breach in 2016 when the program exceeded the original baseline by more than 50 percent. A Nunn-McCurdy unit cost breach classified as critical is the most serious type of breach and requires a program to be terminated unless the Secretary of Defense submits a written certification to Congress that, among other things, the new estimate of the program's cost is reasonable and takes other actions, including restructuring the program. In October 2016, DOD recertified the program, with a 24-month schedule extension. Under this newer proposed schedule Raytheon forecasts delivering blocks 1 and 2 in December 2020 with 6 months of extra schedule—a 30-month schedule extension—to account for unknown technical issues before OCX blocks 1 and 2 are due to the Air Force in June 2021. The Air Force projects operating OCX in fiscal year 2022 after completing 7 months of operational testing post-delivery.

Three factors place delivery of OCX blocks 1 and 2 in June 2021 at high risk for additional schedule delays and cost increases:

- First, the newly proposed June 2017 rebaselined schedule assumes significant improvements in the speed of software coding and testing that have not yet been proven, but will be introduced at various periods as software development proceeds. Whether Raytheon can achieve the majority of these efficiencies will not be known until the end of fiscal year 2018. However, the Defense Contract Management Agency, which independently oversees Raytheon's work developing OCX, noted in July 2017 a number of risks to the schedule, including that some initial assumed efficiencies had not been demonstrated. Specifically, they noted for initial coding on block 1 that Raytheon had achieved only 60 percent of the software integration maturity planned to that point in time in conjunction with greater numbers of software deficiencies that will require more time than planned to resolve.
- Second, the proposed rebaseline schedule has not yet undergone an integrated baseline review (IBR) to verify all of the work that needs to be done is incorporated into that schedule. The IBR is a best practice required by the Office of Management and Budget on programs with

earned value management.[15] An IBR ensures a mutual understanding between the government and the contractor of the technical scope, schedule, and resources needed to complete the work. We have found that too often, programs overrun costs and schedule because estimates fail to account for the full technical definition, unexpected changes, and risks.[16] According to prior plans, the IBR would have taken place in early 2017, but it has been delayed multiple times for a number of reasons. A significant and recurring root cause of delays on the OCX program has been a lack of mutual understanding of the work between the Air Force and Raytheon.

The IBR start was scheduled for November 2017 with completion in February 2018. Once conducted, the review may identify additional work not in the proposed schedule that needs to be completed before delivery. For example, Raytheon is conducting a review of hardware and software obsolescence. If significant additional obsolescence issues are found that need to be resolved before OCX blocks 1 and 2 are delivered, the projected delivery date may need to be delayed further at additional cost.

- Third, the OCX contract will likely be modified because the Air Force needs to incorporate into its contract with Raytheon a number of changes that are not currently a part of the proposed schedule. According to Air Force and contractor officials, negotiations are under way to determine which of these changes will be incorporated before OCX blocks 1 and 2 are delivered and which may be added after delivery. Air Force officials said that the incorporation of changes should be completed by February 2018.

Schedule risk assessments for OCX blocks 1 and 2 delivery vary, making it unclear when the full M-code broadcast will finally be operational. Government assessments of Raytheon's performance continue to

[15]Earned value management is a project management tool that integrates the technical scope of work with schedule and cost elements for investment planning and control. It compares the value of work accomplished in a given period with the value of the work expected in that period. Differences in expectations are measured in both cost and schedule variances. The Office of Management and Budget requires agencies to use earned value management in their performance-based management systems for major acquisitions with developmental effort. Office of Management and Budget, *Capital Programming Guide* v. 3.0, Supplement to Office of Management and Budget Circular No. A-11, *Preparation, Submission, and Execution of the Budget*, para. I.5.5.4 & I.5.5.5 (July 2017).

[16]GAO, *Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs,* GAO-09-3SP (Washington, D.C.: Mar. 2009).

indicate more schedule delays are likely. Table 4 shows the varying assessments of potential schedule delays by the Defense Contract Management Agency and the Air Force to the proposed June 2021 delivery date and the subsequent operational date that occurs 7 months later.

Table 4: Forecasts for the Next Generation Operation Control System (OCX) Blocks 1 and 2 Delivery with Subsequent Operational Date, as of July 2017

Forecaster	Schedule risk to current delivery of June 2021	Forecast delivery with schedule risk included	Operational date[a]
Defense Contract Management Agency	14 months	August 2022	March 2023
Air Force	6-7 months	January/February 2022	August/September 2022

Source: GAO analysis of Department of Defense data. | GAO-18-74

[a]Air Force estimates that after delivery from Raytheon, the government will need an additional 7 months to test and prepare OCX to be operational.

In 2015, we made four recommendations to the Secretary of Defense, one of which was to use outside experts to help identify all underlying problems on OCX and develop high confidence cost and schedule estimates, among others, in order to provide information necessary to make decisions and improve the likelihood of success.[17] To date, none of these recommendations have been fully implemented but DOD has taken steps to address some of them. Further, because the Air Force has undertaken the COps and MCEU programs to provide interim capabilities to mitigate OCX delays for the full broadcast capability, we are not making additional recommendations at this time but will continue to monitor progress and risks to the acquisition of OCX.

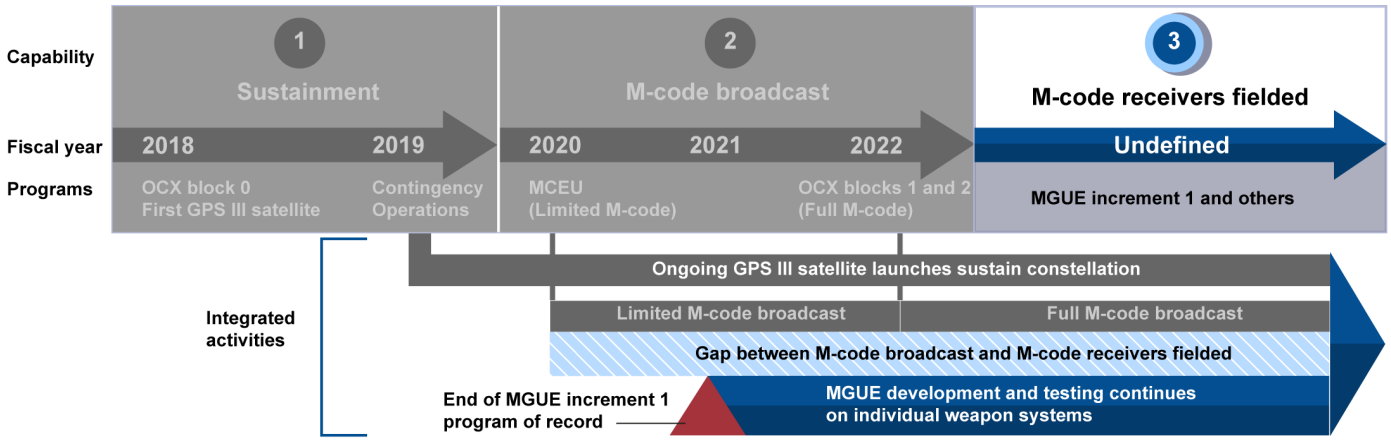
Greater Coordination Needed to Prevent Duplication of Effort Developing and Fielding M-code Receivers

While technology development for the M-code receiver cards is underway, DOD has developed preliminary—but incomplete—plans to fully develop and field M-code receiver cards across the more than 700 weapon systems that will need to make the transition from the current technology. DOD has prepared initial cost and schedule estimates for department-wide fielding for a fraction of these weapon systems. While the full cost remains unknown, it is likely to be many billions of dollars greater than the $2.5 billion identified through fiscal year 2021 because there is significant work remaining to verify the initial cards work as planned and to develop them further after the MGUE increment 1 program ends. Without greater coordination of integration test results, lessons learned, and design solutions DOD is at risk of duplicated development work as multiple weapon system programs separately

[17]GAO-15-657.

mature and field similar technologies on their own. Further, with the full M-code broadcast available in fiscal year 2022, a gap—the extent of which is unknown—between operationally broadcasting and receiving M-code exists. Figure 10 highlights the gap between the time the M-code signal will be operational and the undefined time M-code can be used by the military services.

Figure 10: Schedule for Fielding Military Code Receiver Cards



Legend

GPS: Global Positioning System | M-code: Military code | MCEU: M-code Early Use | MGUE: Military GPS User Equipment

OCX: Next Generation Operational Control System

Source: GAO analysis of Department of Defense data. | GAO-18-74

DOD Has Made Some Progress in Developing Technology for New M-code Receiver Cards

The Air Force program to develop initial M-code receiver test cards has made progress by establishing an acquisition strategy for this effort and maturing receiver test cards. In January 2017, DOD approved the MGUE increment 1 program to formally begin development, and it defined the criteria to end the program as (1) verifying technical requirements on all types of final receiver test cards; (2) certifying readiness for operational testing by the Air Force Program Executive Officer; (3) completing operational testing for the four lead platforms for, at a minimum, at least the first card available; and (4) completing manufacturing readiness assessments for all three contractors.

Within the MGUE increment 1 program, contractors are making progress toward delivering final hardware test cards and incremental software capabilities. For example, one contractor has achieved its initial security certification from the Air Force, which is a key step toward making the MGUE increment 1 receiver test card available for continued development and eventual procurement. Further, the MGUE increment 1 program is also conducting risk reduction testing in preparation for formal developmental verification testing, an important step that ensures the receiver cards meet technical requirements. Programs throughout DOD

can make risk-based decisions to develop and test the receiver test cards after technical verification of the card's hardware and software. According to MGUE program officials, this is significant because it allows non-lead platforms to obtain and work with the cards sooner than the end date of operational testing on lead platforms.

Significant Development Work Remains to Eventually Field M-code Receiver Cards

Although the Air Force has made progress in maturing receiver test cards, significant development work remains to reach the point where the cards can ultimately be fielded on over 700 different weapon systems. For example, for MGUE increment 1, the Air Force must define additional technical requirements in order for the M-code receiver cards to be compatible and communicate with existing weapon systems. The Air Force will also need to conduct operational tests for each of the lead platforms—the Stryker ground combat vehicle; B-2 Spirit bomber; JLTV; and DDG-51 Arleigh Burke destroyer—before the full M-code signal is available with OCX. Because these tests will instead be conducted with the limited signal provided by MCEU, DOD risks discovering issues several years later once full operational testing is conducted. Further, according to military service officials and assessments by DOT&E, this operational testing will only be minimally applicable to other weapon systems because those other weapon systems have different operational requirements and integration challenges than the four lead platforms. As a result, additional development and testing will be necessary on an undetermined number of the remaining weapon systems to ensure the receiver cards address each system's unique interfaces and requirements. In 2018, DOD will also formally begin development for MGUE increment 2. Increment 2 will provide more compact receiver cards to be used when size, weight, and power must be minimized, such as on handheld receivers, space receivers, and munitions where increment 1 receiver cards are too large to work.

The military services are working to mitigate some of these development challenges. For example, Army officials told us they do not plan to field MGUE receiver cards on its lead platform, the Stryker, due to ongoing gaps in technical requirements. In addition, there is not a lead platform to demonstrate increment 1 on munitions since munition requirements were planned to be addressed in increment 2. However, to address its needs, the Army has initiated efforts to modify the MGUE increment 1 receiver card for some munitions that would otherwise need to wait for MGUE increment 2 technologies. Individual munition program offices within other military services have begun to do so as well. According to military service officials from the Army, Navy, and Marine Corps, it is essential

that user needs are met by increment 2, or they will have to conduct additional development and testing. The Army previously identified gaps in increment 1 that the Air Force has either addressed in increment 1, has deferred to increment 2, or will need to be addressed outside of the MGUE increment 1 and 2 programs. Army and Navy officials also stated that they were concerned that any disagreements in requirements for increment 2 could lead to further fielding delays.

Finally, the transition from existing GPS receiver cards to M-code receiver cards is likely to take many years. We recently reported that transitioning all DOD platforms to the next generation of receiver cards will likely take more than a decade.[18] A lengthy transition has happened before, as previous efforts to modernize GPS to the current receiver cards, begun in 2003, are still underway and the older receiver cards are still being used. As a result, DOD anticipates that warfighters will have to operate with a mix of older and newer receiver cards.

DOD Has Begun Cost and Schedule Planning; Full Cost Is Unknown but Likely to be Many Billions of Dollars

DOD has begun collecting preliminary information on M-code requirements for individual weapon systems. In December 2016, the USD AT&L directed the military services, the Missile Defense Agency (MDA), and Special Operations Command (SOCOM) to submit implementation plans with M-code investment priorities across weapon systems and munitions, including projected costs and schedules.[19] According to DOD, these M-code implementation plans are intended to provide DOD with a management and oversight tool for the fielding effort. In February 2017, each organization submitted its own implementation plan to USD AT&L.

[18]GAO, *Space Acquisitions: DOD Continues to Face Challenges of Delayed Delivery of Critical Space Capabilities and Fragmented Leadership*, GAO-17-619T (Washington, D.C.: May 17, 2017).

[19]The National Defense Authorization Act for Fiscal Year 2017 eliminated the position of USD AT&L effective February 1, 2018. The position will be divided into the Under Secretary of Defense for Research and Engineering and the Under Secretary for Defense for Acquisition and Sustainment. Pub. L. No. 114-328, § 901(a) and (b) (2016) (codified at 10 U.S.C. §§ 133a and 133b).

These plans were then briefed to the PNT Executive Management Board and PNT Oversight Council in February and March, respectively.[20]

However, these implementation plans are preliminary and based on assumptions about the Air Force's ability to achieve MGUE increment 1 and 2 technical requirements, the timeline required to do so, and the amount of development and test work that will remain for the receiver cards to be ready for production and fielding after the programs end. Since the MGUE increment 2 program has not started development, it has not yet finalized requirements. Once approved, the increment 2 program office will produce an acquisition strategy, schedule, and cost estimate. However, after the MGUE increment 2 program ends there is no detailed plan for completing development, testing, and fielding of M-code receiver cards for weapon systems across the department.

DOD has preliminary cost and schedule estimates for some weapon programs, but lacks a total cost at this point because the department does not include all efforts initiated by programs to meet specific needs, including those outside the MGUE increment 1 and 2 programs. The initial M-code implementation plans responded to what was requested but do not individually identify what the total cost will be for each organization to develop and field M-code receiver cards, so a total cost can be determined across DOD. Because USD AT&L required that the implementation plans include funding and schedule estimates for 2 to 3 years while directing that plans be resubmitted, at a minimum, every 2 years, weapon systems that will need M-code but were not considered an immediate priority were not included in the initial submissions. In addition, the military services, MDA, and SOCOM provided only initial cost estimates.[21] According to military service officials, these estimates were based on the current MGUE increment 1 program schedule and technical development and include risk-based decisions to partially fund specific

[20]The PNT Executive Management Board is chaired by the DOD Chief Information Officer and oversees the governance process in support of the PNT Oversight Council, including developing topics and recommendations for PNT Oversight Council actions. The PNT Oversight Council is co-chaired by USD AT&L and the Vice Chairman Joint Staff. The Council serves as the principal unified and integrated DOD governance body that ensures the DOD PNT Enterprise functions meet national objectives, is consistent with national policy and guidance, and that the mutually supporting systems continue to evolve to address emerging threats.

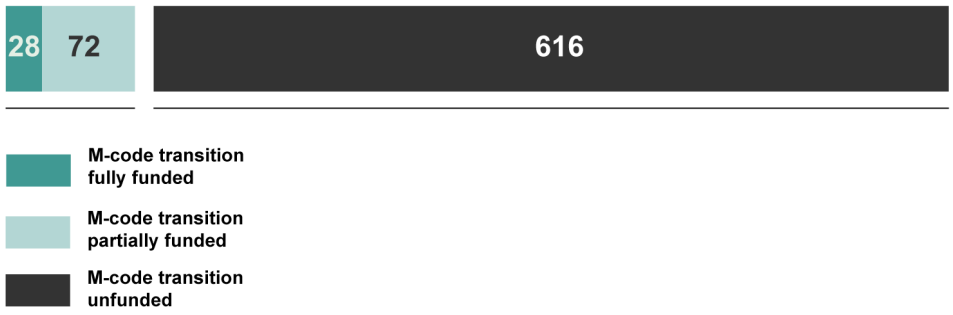
[21]When we refer to "funded" or "partially funded" programs, we mean programs which DOD has planned—in full or in part—to fund in DOD's future years budget projections through fiscal year 2021, as reflected in the implementation plans.

programs until the MGUE increment 1 program matures. According to a USD AT&L official, the plans would both facilitate M-code implementation planning for the department and inform the issuance of waivers. [22] The official stated that as the acquisition programs critical to providing M-code capability mature, future implementations plans should provide more comprehensive estimates of cost and schedule to achieve M-code implementation for the department.

Our analysis of the M-code receiver card implementation plans found that initial funding estimates indicate a cost of over $2.5 billion to integrate and procure M-code receiver cards on only a small number of weapon systems out of the hundreds of types that need M-code receiver cards. The full cost will be much larger—likely many billions of dollars because the majority of the weapon systems that need M-code receiver cards are not funded yet or are only partially funded, according to the M-code implementation plans. Specifically, the military services, MDA, and SOCOM identified 716 types of weapon systems in their February 2017 implementation plans that require almost a million M-code receiver cards. For example, the JLTV fleet—which provides protection for passengers against current and future battlefield threats for multiple military services—is one type of weapon system that will eventually need almost 25,000 receiver cards. Of the 716 types of weapon systems that will need M-code receiver cards, only 28—or less than 4 percent—are fully funded through fiscal year 2021. The remainder have either partially funded M-code development and integration efforts (72 weapon systems), or do not yet have funding planned (616 weapon systems). Additionally, the preliminary estimates to develop and procure M-code receivers on selected weapon systems do not all include funding beyond fiscal year 2021 that will be needed for further development, integration, and procurement. This means that DOD and Congress do not have visibility into how much additional funding could be needed to fully fund the remaining 96 percent of all weapon systems that need M-code receivers. Figure 11 shows the M-code development and integration efforts that are funded, partially funded, or unfunded through fiscal year 2021 across DOD weapon systems that will need M-code receiver cards.

[22]Pub. L. No. 111-383, § 913 (the Act) 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 during the fiscal years after fiscal year 2017 unless the equipment is capable of receiving M-code. This limitation does not apply to purchases of passenger or commercial vehicles in which GPS equipment is installed. Additionally, the Secretary of Defense may waive this limitation under certain circumstances.

Figure 11: Status of Weapon Systems That Have Determined the Cost Needed to Transition to M-code Receivers through Fiscal Year 2021, as of February 2017



M-code: Military code

Source: GAO analysis of Department of Defense data. | GAO-18-74

Note: Weapon systems include all Department of Defense programs, platform systems, and subsystems that incorporate the Global Positioning System.

Because the implementation plans are a first step toward providing DOD leadership insight on this large set of acquisitions and they will be updated at least every 2 years by the different organizations within DOD, we are not making a recommendation at this time. However, we will continue to monitor DOD's cost and schedule planning.

DOD Risks Duplication of Effort Integrating and Testing M-code Receiver Cards

The level of development and procurement effort beyond MGUE increments 1 and 2 is significant and will require close coordination among the military services, MDA, and SOCOM. While Joint Staff officials stated that the DOD Chief Information Officer is working with the military services and Joint Staff to produce a user equipment roadmap to help guide that coordination, they said that these efforts are not yet complete. DOD has designated the Air Force to lead initial development of both larger and smaller test cards that other organizations will need to develop further to meet their individual needs. After the Air Force develops initial cards for both sizes, the breadth and complexity of this acquisition will multiply, as the offices responsible for upgrading hundreds of weapon systems begin their own individual efforts to further develop and test the cards so they work for the unique needs of their specific system. While some common solutions are being developed, Air Force officials said the military services and individual weapon systems will have the freedom to go to the contractors and begin their own development efforts.

DOD does not have a developed plan in place to help ensure that common design solutions are employed and that DOD avoids duplication of effort as multiple entities separately mature receiver cards. We previously found that duplication occurs when two or more agencies or programs are engaged in the same activities.[23] In this case, because the individual organizations and program offices are likely to be pursuing individual and uncoordinated receiver card programs at different times with different contractors, DOD is at risk for significant duplication of effort. We previously found that establishing formal mechanisms for coordination and information sharing across DOD programs reduces the risk of gaps and results in more efficient and more effective use of resources.[24] Internal control standards also state that establishing clear responsibilities and roles in achieving objectives is key for effective management.[25] Further, DOD previously reported clear leadership ensures that programs and stakeholders are aligned with common goals.[26]

According to MGUE program officials, the MGUE increment 1 program is already capturing all issues observed in receiver test card risk reduction testing and sharing this information through a joint reporting system. However, while non-lead platforms may also report deficiencies in this system, there is no requirement that they do so, nor is there an entity responsible for ensuring data from testing, design, and development is shared between programs. We previously found that the absence of a formal process for coordination results in the potential for duplication, overlap, and fragmentation.[27] DOD therefore risks paying to repeatedly find design solutions to solve common problems because each program office is likely to undertake its own uncoordinated development effort. Some duplicated effort may already be occurring. Air Force officials have expressed concern that work is already being duplicated across the military services in developing embedded GPS systems to be integrated

[23]GAO, *2017 Annual Report: Additional Opportunities to Reduce Fragmentation, Overlap, and Duplication and Achieve Other Financial Benefits,* GAO-17-491SP, (Washington, D.C.: Apr. 26, 2017).

[24]GAO-17-491SP.

[25]GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G, (Washington, D.C.: Sept. 2014).

[26]Defense Science Board, *Creating a DOD Strategic Acquisition Platform,* April 2009.

[27]GAO-17-491SP.

into aircraft. According to multiple DOT&E assessments, the absence of a plan across the wide variety of intended interfaces leaves significant risk in integrating the receiver cards, and therefore fielding cost and schedule risk for DOD.

Conclusions

GPS is a national asset for civilians and the military service members who depend upon it each day. Any disruption to the system would have severe economic and military consequences. In keeping the system sustained and modernizing it with additional capabilities, DOD has spent billions of dollars more than planned developing five interdependent GPS programs. Developing these technologies is complex work with the collective effort already years behind initial estimates to provide the warfighter with a means to counter known threats, such as jamming, to the current system. It will be many years before M-code receiver cards are fielded at a cost that remains unknown but that will be substantially higher than the estimated $2.5 billion already identified through fiscal year 2021. In the short term, it is unclear when there will be a receiver card ready for production after the end of operational testing, and in the long term DOD risks wasting resources duplicating development efforts on weapon systems with similar requirements. Without better coordination of this effort, DOD risks unnecessary cost increases and schedule delays because there is no established process or place for collecting and sharing development and integration practices and solutions between programs.

Recommendations for Executive Action

We are making the following recommendation to DOD:

The Secretary of Defense should ensure that the Under Secretary of Defense for Acquisition, Technology, and Logistics, as part of M-code receiver card acquisition planning, assign an organization with responsibility for systematically collecting integration test data, lessons learned, and design solutions and making them available to all programs expected to integrate M-code receiver cards.

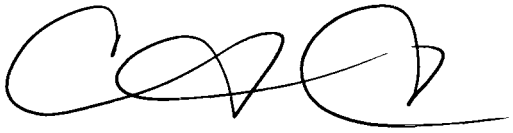
(Recommendation 1)

Agency Comments and Our Evaluation

We provided a draft of this report to the Department of Defense for review and comment. In its written comments, reproduced in appendix II, DOD concurred with the recommendation. DOD also provided technical comments, which we incorporated as appropriate.

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

If you or your staff have any questions concerning this report, please contact me at (202) 512-4841 or by email at chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Key contributors to this report are listed in appendix IV.



Cristina T. Chaplain
Director, Acquisition and Sourcing Management

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Appendix I: Objectives, Scope, and Methodology

To determine the extent to which there are acquisition risks to sustaining the Global Positioning System (GPS) satellite constellation, we reviewed the Air Force GPS quarterly reports, program acquisition baselines, integrated master schedules, acquisition strategies, software development plans, test plans, and other documents to the extent they existed for GPS III, Next Generation Operational Control System (OCX), and Contingency Operations (COps) programs. We also interviewed officials from the GPS III, OCX, and COps programs; the Air Force Space and Missile Systems Center's (SMC) GPS Enterprise Integrator office; the prime contractors from all three programs; the Defense Contract Management Agency; the Office of Cost Assessment and Program Evaluation; and the Office of the Director, Operational Test and Evaluation (DOT&E). We also reviewed briefings and other documents from each to evaluate program progress in development. We assessed the status of the currently operational GPS satellite constellation, interviewing officials from the Air Force SMC GPS program office and Air Force Space Command.

To assess the risks that a delay in the acquisition and fielding of GPS III satellites could result in the GPS constellation falling below the 24 satellites required by the standard positioning service and precise positioning service performance standards, we employed a methodology very similar to the one we had used to assess constellation performance in 2009, 2010, and 2015.[1] We obtained information dated May 2016 from the Air Force predicting the reliability for 63 GPS satellites—each of the 31 current (on-orbit as of July 2017) and 32 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. It 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 each of the 63 satellites, we obtained the two parameters defining the cumulative normal distribution, and the two parameters defining the

[1]GAO, *Global Positioning System: Significant Challenges in Sustaining and Upgrading Widely Used Capabilities*, GAO-09-325 (Washington, D.C.: Apr. 30, 2009); *Global Positioning System: Challenges in Sustaining and Upgrading Capabilities Persist*, GAO-10-636 (Washington, D.C.: Sept. 15, 2010); and *GPS: Actions Needed to Address Ground System Development Problems and User Equipment Production Readiness*, GAO-15-657 (Washington, D.C.: Sept. 9, 2015).

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

cumulative Weibull distribution. For each of the 32 unlaunched satellites we included in our model, we also obtained a parameter defining its probability of successful launch, and its current scheduled launch date. The 32 unlaunched satellites include 10 GPS III satellites currently under contract and 22 GPS III satellites planned for contract award in late 2018; launch of the final GPS III satellite we included in our model is scheduled for October 2031. Using this information, we generated overall reliability curves for each of the 63 GPS satellites. We discussed with Air Force 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 Air Force provided parameters.

Using the reliability curves for each of the 63 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 2016. We conducted several runs of our simulation—each run consisting of 10,000 trials—and generated "sawtoothed" curves depicting the probability that at least 24 satellites would still be operational as a function of time.[3] 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/year delay scenarios, calculating new probabilities that at least 24 satellites would still be operational as a function of time, determining in terms of month/year the point at which a satellite would be required to enter operations to maintain an uninterrupted maintenance of the 95 percent probability of 24 satellites in operation. The Air Force satellite parameters we used for the Monte Carlo simulation pre-dated the Air Force investigation into navigation payload capacitors and the subsequent decision to launch the first satellite "as is" with questionable parts. Therefore, the reliability parameters for this satellite were not informed by any possible subsequent Air Force consideration of the decision to launch the first GPS III satellite "as is" with these parts.

[3]Monte Carlo simulation refers to a computer-based analysis that uses probability distributions for key variables, selects random values from each of the distributions simultaneously, and repeats the random selection over and over. Rather than presenting a single outcome—such as the mostly likely or average scenario—Monte Carlo simulations produce a distribution of outcomes that reflect the probability distributions of modeled uncertain variables.

To determine the extent to which the Department of Defense (DOD) faces acquisition challenges developing a new ground system to control the broadcast of a modernized GPS signal, we reviewed Air Force program plans and documentation related to cost, schedule, acquisition strategies, technology development, and major challenges to delivering M-code Early Use (MCEU) and OCX blocks 1 and 2. We interviewed officials from the MCEU and OCX program offices, SMC GPS Enterprise Integrator office, DOT&E, and the prime contractors for the two programs. For OCX, we also reviewed quarterly reviews, monthly program assessments, and slides provided by Raytheon on topics of our request. We also interviewed Office of Performance Assessments and Root Cause Analyses officials regarding root causes of the OCX program's cost and schedule baseline breach and Defense Contract Management Agency officials charged with oversight of the OCX contractor regarding cost and schedule issues facing the program's development efforts, major program risks, and technical challenges.

To determine the extent to which DOD faces acquisition challenges developing and fielding modernized receiver cards across the department, we reviewed Air Force program plans and documentation related to M-code GPS User Equipment (MGUE) increment 1 cost, schedule, acquisition strategy, and technology development. We interviewed officials at the Air Force SMC GPS program office, MGUE program office, DOT&E, and the three MGUE increment 1 contractors—L3 Technologies, Raytheon, and Rockwell Collins. To identify the military services' respective development efforts and challenges in integrating MGUE with their lead platforms, we interviewed officials from the lead program offices for the Army's Defense Advanced GPS Receiver Distributed Device/Stryker, Air Force's B-2 aircraft, Navy's DDG-51 Arleigh Burke class destroyer, and Marine Corps Joint Light Tactical Vehicle. Additionally, to understand the extent to which DOD has a plan for implementing M-code for the warfighter, we analyzed DOD Positioning, Navigation, and Timing (PNT) plans and other DOD memorandum on GPS receiver cards. We also held discussions with and received information from officials at Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics; Joint Staff / J-6 Space Branch; and military service officials from the offices responsible for developing M-code receiver card implementation plans.

We conducted this performance audit from February 2016 to December 2017 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: Comments from the Department of Defense

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3600 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

NOV 30 2017

Ms. Cristina Chaplain
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G Street, NW
Washington DC 20548

Dear Ms. Chaplain,

This is the Department of Defense (DoD) response to the Draft Government Accountability Office (GAO) Final Report, GAO-18-74, Global Positioning System (GPS): Better Planning and Coordination Needed to Improve Prospects for Fielding Modernized Capability, dated October 2017 (GAO Code 100643).

DoD acknowledges receipt of the draft final report and concurs as written.

My point of contact is Dr. Charles (Chuck) Frizzelle at 571-372-4408 or via email at charles.d.frizzelle.civ@mail.mil.

Sincerely,

James A. MacStravic
Acting Assistant Secretary of Defense
for Acquisition

GAO Draft Report Dated September 20, 2017
GAO-18-74 (GAO CODE 100643)

"GLOBAL POSITIONING SYSTEM: BETTER PLANNING AND COORDINATION NEEDED TO IMPROVE PROSPECTS FOR FIELDING MODERNIZED CAPABILITY"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATION

RECOMMENDATION 1: The Government Accountability Office (GAO) recommends the Under Secretary of Defense for Acquisition, Technology, and Logistics should, as part of M-code receiver card acquisition planning, assign an organization with responsibility for systematically collecting integration test data, lessons learned, and design solutions and making them available to all programs expected to integrate M-code receiver cards.

DoD RESPONSE: Concur as written.

Appendix III: GPS Modernization Cost Increases, Original Baseline vs. Current Estimate

Table 5: GPS Modernization Costs

Program	Original Baseline[a] (fiscal year 2017 dollars, in millions)	Current Estimate (fiscal year 2017 dollars, in millions)	Percentage Increase
GPS III[b]	4,275.2	5,834.1	36
Next Generation Operational Control System (OCX)	3,591.8	5,498.4	53
Military GPS User Equipment (MGUE) Increment 1	1,505.7	1,505.7	0
Contingency Operations (COps)	0.0	161.7	N/A
M-Code Early Use (MCEU)	0.0	119.5	N/A
Total[c]	**9,372.7**	**13,119.4**	**40**

Source: GAO analysis of Department of Defense data. | GAO-18-74

[a]Dates for original baselines are: GPS III–May 2008, OCX–November 2012, and MGUE–January 2017.

[b]The original GPS III baseline was for eight satellites. The current baseline is for 10 satellites. The cost per satellite has increased from $534 million to $583 million, or approximately 9 percent.

[c]The total cost does not include the cost for the GPS Enterprise Integrator which integrates, synchronizes, tests, and verifies the GPS programs but is not a baselined program of record. The fiscal year 2018 budget request projects total GPS Enterprise Integrator expenditures across numerous fiscal years as $801.9 million. The table also omits future potential development for GPS III satellites or their procurement (up to 22 in total), the planned MGUE increment 2 program, or the costs to operationally test, integrate, and procure receiver cards across the Department of Defense. The table also does not include costs to operate and maintain any of the programs once operational.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Cristina T. Chaplain (202) 512-4841 or chaplainc@gao.gov

Staff Acknowledgments

In addition to the contact named above, David Best, Assistant Director; Jay Tallon, Assistant Director; Karen Richey, Assistant Director; Pete Anderson; Andrew Berglund; Brandon Booth; Brian Bothwell; Patrick Breiding; Erin Carson; Connor Kincaid; Jonathan Mulcare; Sean Sannwaldt; Alyssa Weir; Robin Wilson and Marie P. Ahearn made key contributions to this report.

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