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January 2021

GPS MODERNIZATION

DOD Continuing to Develop New Jam-Resistant Capability, But Widespread Use Remains Years Away

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GAO@100 Highlights

Highlights of GAO-21-145, a report to congressional committees

January 2021

GPS MODERNIZATION

DOD Continuing to Develop New Jam-Resistant Capability, But Widespread Use Remains Years Away

Why GAO Did This Study

DOD has been developing the capability to use its more jam-resistant military-specific GPS signal for 2 decades. The Air Force launched the first GPS satellite capable of broadcasting the M-code signal in 2005, but is only now completing development of the software and other equipment needed to use it. The GPS modernization effort spans DOD and the military services, but an Air Force program office is developing M-code cards for eventual production and integration into weapon systems.

The National Defense Authorization Act for Fiscal Year 2016 included a provision that the Air Force provide quarterly reports to GAO on next-generation GPS acquisition programs, and that GAO brief congressional defense committees. Since 2016, GAO has provided briefings and reported on various aspects of GPS. This report discusses DOD's progress and challenges (1) developing M-code receiver cards, and (2) developing receivers and taking other steps to make M-code-capable receivers available for fielding.

GAO reviewed schedules and cost estimates for the Air Force's MGUE programs; military service and DOD M-code implementation data; and test and integration plans for aircraft, ships, and ground vehicles. GAO also reviewed strategies for continued access to microelectronics and interviewed officials from the MGUE programs, military services, and DOD, and representatives from microelectronics developers.

View GAO-21-145. For more information, contact Jon Ludwigson at (202) 512-4841 or ludwigsonj@gao.gov.

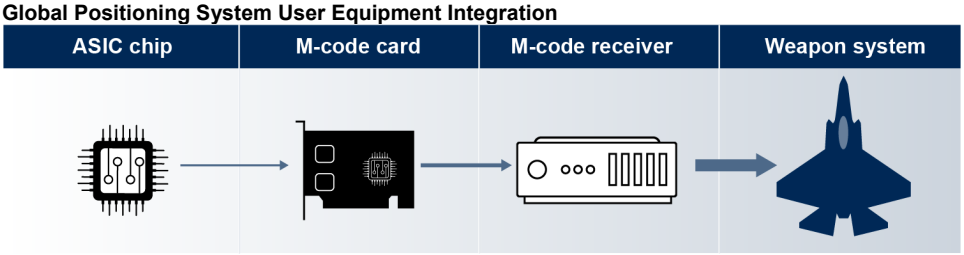
What GAO Found

The Department of Defense (DOD) is closer to being able to use military code (M-code)—a stronger, more secure signal for the Global Positioning System (GPS) designed to meet military needs. However, due to the complexity of the technology, M-code remains years away from being widely fielded across DOD. M-code-capable receiver equipment includes different components, and the development and manufacture of each is key to the modernization effort. These include:

- special M-code application-specific integrated circuit chips,
- special M-code receiver cards, being developed under the Air Force Military GPS User Equipment (MGUE) programs, and
- the next generation of GPS receivers capable of using M-code signals from GPS satellites.

DOD will need to integrate all of these components into different types of weapon systems (see figure for notional depiction of integration for one system). Integration across DOD will be a considerable effort involving hundreds of different weapon systems, including some with complex and unique integration needs or configurations.

Global Positioning System User Equipment Integration



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

Source: GAO analysis and representation of Department of Defense documentation. | GAO-21-145

The Air Force is almost finished—approximately one year behind schedule—developing and testing one M-code card for testing on the Marine Corps Joint Light Tactical Vehicle and the Army Stryker vehicle. However, one card intended for use in aircraft and ships is significantly delayed and missed key program deadlines. The Air Force is revising its schedule for testing this card.

The M-code card development delays have had ripple effects on GPS receiver modernization efforts and the weapon systems that intend to use them. For example, an Air Force receiver modernization effort that depends on the new technology will likely breach its schedule and incur additional costs because of the delay. In turn, DOD planned to incorporate that receiver into its F/A-18 fighter aircraft, AV-8B strike aircraft, and the MH-53E helicopter, but it no longer plans to do so because of the delay. DOD has not yet determined the full extent of the development effort to widely integrate and field M-code receivers across the department. The amount of additional development and integration work is expected to vary for each weapon system and could range from a few weeks to several years. DOD is taking steps to enable fielding modernized receivers that use M-code cards by working to identify integration and production challenges.

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Abbreviations

AECA	Arms Export Control Act
ASIC	application-specific integrated circuit
B-2	B-2 Spirit bomber
COps	Contingency Operations
CSDU	Commander Smart Display Unit
DAGR	Defense Advanced GPS Receiver
DDG 51 class	USS *Arleigh Burke* Class Destroyer
DMEA	Defense Microelectronics Activity
DOD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
ECDU	Enhanced Control Display Unit
ED3M	Enhanced DAGR Distributed Device M-code
EGI	Embedded GPS Inertial Navigation System
EGI-M	Embedded GPS Inertial Navigation System – Modernized
GPNTS	GPS-based PNT Service
GPS	Global Positioning System
GPS III	Global Positioning System III
GPS IIIF	Global Positioning System III Follow-On
ITAR	International Traffic in Arms Regulations
JLTV	Joint Light Tactical Vehicle
MAGR-2K	Miniature Airborne GPS Receiver 2000
MAGR-2K-M	Miniature Airborne GPS Receiver 2000 – Modernized
MAPS	Mounted Assured PNT System
MCEU	M-code Early Use
MGUE	Military GPS User Equipment
M-code	Military code
OCS	Operational Control Segment
OCX	Next Generation Operational Control System
OT&E	Operational Test and Evaluation
PGK	Precision Guidance Kit
PNT	Positioning, Navigation, and Timing
R-EGI	Resilient Embedded GPS Inertial Navigation System

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Congressional Committees

The U.S. military's Global Positioning System (GPS) is critical to national security, and a broad range of military assets—from vehicles to munitions—relies on it. Given the broad range of GPS applications that supports U.S. military operations, the military services need to have unimpeded access to GPS. Since the late 1990s, the Department of Defense (DOD) has been developing a new, more robust, jam-resistant GPS capability known as military code or M-code. To use M-code, DOD needs M-code-capable satellites in place to broadcast the signal, a ground system to control the satellites, and equipment—also known as user equipment—to receive it for military operations. The Air Force launched the first GPS satellite capable of broadcasting the M-code signal in 2005, but is about two years away from completing development of GPS ground control software upgrades, and DOD still lacks the equipment needed to receive the signal for military operations. The Air Force's two Military GPS User Equipment (MGUE) programs are developing and testing M-code user equipment for eventual production and integration into weapon systems by the military services.

Efforts to develop M-code user equipment have been underway for more than a decade. These efforts include the development of specific equipment, called M-code cards, which will be integrated into specialized radio receivers for use in military aircraft, ships, vehicles, and other weapon systems. Together, these cards and receivers will be capable of receiving and using the M-code signals broadcast by the GPS satellites. In 2006, the Assistant Secretary of Defense for Networks and Information Integration directed the Air Force to begin developing M-code cards for the military services, and the Air Force initiated development of M-code card prototypes for aviation and ground use under the Modernized User Equipment program. Technical difficulties resulted in significant cost and schedule growth to that program, which ended in 2013. The first MGUE program started in 2011 and began development in January 2017 to develop, but not produce, M-code cards. Under the first MGUE increment, the Air Force is developing ground and aviation/maritime M-code user equipment test articles and funding integration and testing on four lead weapon systems, one for each military service. The military services will then determine whether to procure the M-code user equipment as tested, or to pursue additional development and testing before making a procurement decision.

The National Defense Authorization Act for Fiscal Year 2016 included a provision that the Air Force provide quarterly reports to GAO on next-generation GPS acquisition programs.[1] The Act also included a provision that GAO brief congressional defense committees on the first report, and at GAO's discretion, on subsequent quarterly reports. We addressed the first quarterly report provision in 2016 and have continued to brief congressional defense committees on GPS acquisition progress. We published reports on the overall GPS enterprise and on schedule risks to the ground control segment of the GPS mission, referred to as the Next Generation Operational Control System (OCX) in December 2017 and May 2019, respectively.[2] This report assesses DOD's progress and challenges (1) developing M-code receiver cards, and (2) developing receivers using the M-code cards and taking other steps needed to make them available for fielding across DOD weapon systems.

To conduct our work, we reviewed and analyzed past and current schedules, cost estimates, key milestones, and risk assessments for each MGUE program, as well as military service and DOD M-code implementation data. We also analyzed M-code card test and integration plans for the MGUE Increment 1 lead weapon systems—the B-2 Spirit bomber (B-2), the USS *Arleigh Burke* Class (DDG 51 class) Destroyer, the Stryker, and the Joint Light Tactical Vehicle (JLTV). In addition, we reviewed applicable program documentation from five selected program executive offices overseeing non-lead weapon systems integrating M-code receivers outside the MGUE Increment 1 program of record. We also reviewed DOD's strategies and plans for continued access to trusted and export-compliant microelectronics, and documentation related to integrated circuit production risks faced by the MGUE Increment 1 and 2 programs.[3] We interviewed officials from the Air Force MGUE program offices and military service program executive offices for selected non-lead weapon systems; officials from the offices of the DOD Chief

[1]Pub. L. No. 114-92, § 1, 1621(a) (2015).

[2]GAO, *Global Positioning System: Updated Schedule Assessment Could Help Decision Makers Address Likely Delays Related to New Ground Control System*, GAO-19-250 (Washington, D.C.: May 21, 2019); and *Global Positioning System: Better Planning and Coordination Needed to Improve Prospects for Fielding Modernized Capability*, GAO-18-74 (Washington, D.C.: Dec. 12, 2017).

[3]Microelectronics includes various micro devices, commonly referred to as "integrated circuits," that form the basis of all electronic products. A trusted environment is required to secure national security systems by assessing the integrity of the people and processes used to design, generate, manufacture, and distribute national security critical components, and includes fabrication of classified designs.

Information Officer and the Under Secretaries of Defense for Acquisition and Sustainment, and Research and Engineering; the Defense Microelectronics Activity (DMEA); and service offices overseeing positioning, navigation, and timing modernization efforts. We also interviewed representatives from microelectronics developers/manufacturers about the production plans for, and development of advanced microelectronics for the MGUE Increment 1 and 2 programs. See appendix I for additional information on our objectives, scope, and methodology.

We conducted this performance audit from April 2019 to January 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

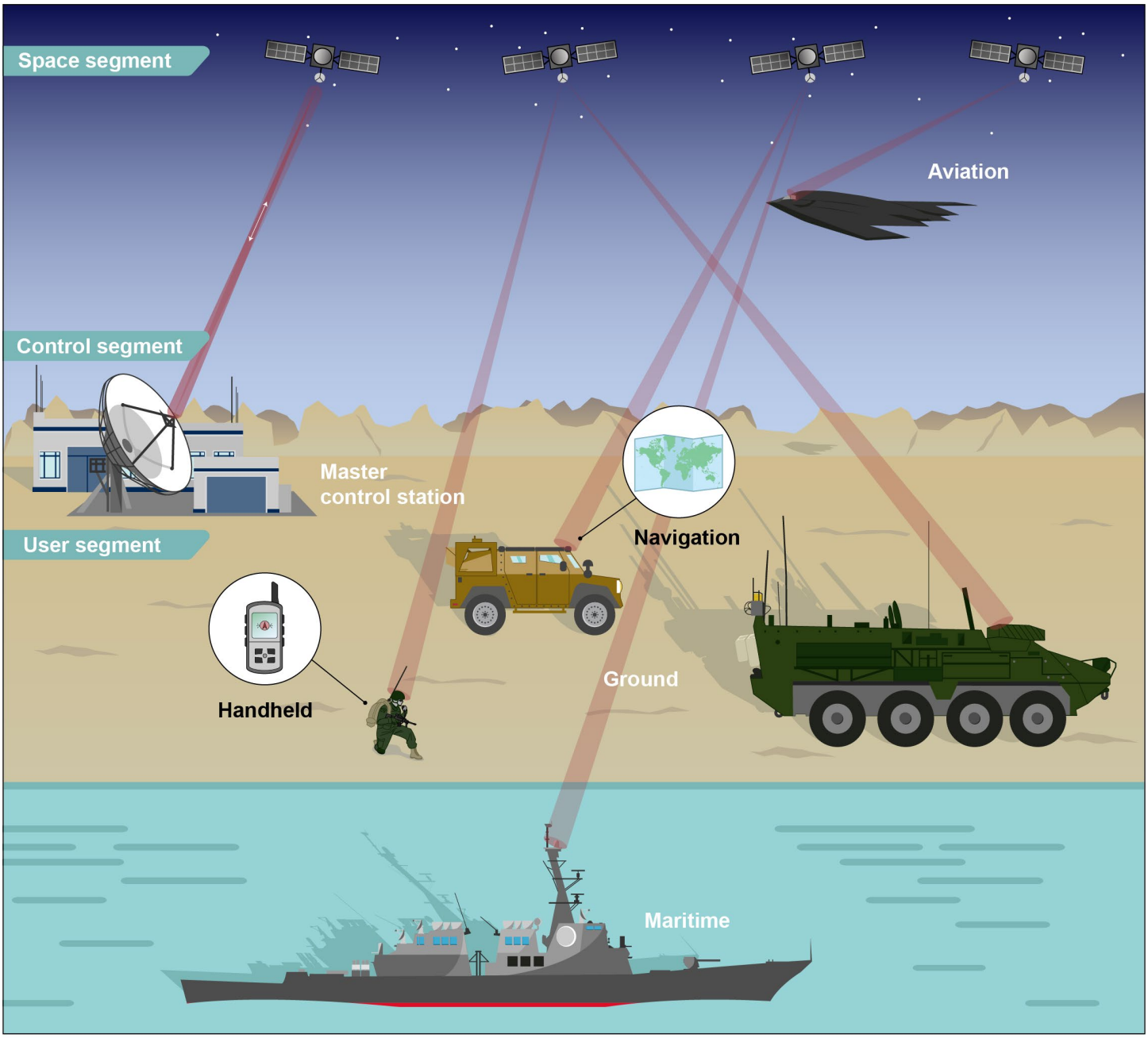
GPS consists of three segments: a constellation of orbiting satellites—known as the space segment—that continuously broadcast position and time data; a ground control segment for commanding and controlling the satellites; and a user segment, which is comprised of receivers used by civilians and the military in aircraft, ships, land vehicles, munitions, and handheld devices. Since 2000, the Air Force has been pursuing a multi-billion dollar effort to modernize GPS by providing new civilian and military signals, enhancing cybersecurity, and countering known threats.

GPS Modernization

Collectively, the ongoing GPS acquisition efforts aim to (1) modernize and sustain the existing GPS capability, and (2) enhance the current GPS system by adding an anti-jam, anti-spoof cybersecure M-code GPS capability.[4] Figure 1 shows the GPS satellite, ground control, and user equipment—in the form of receivers embedded in systems—segments that 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: Global Positioning System Operational System



Source: GAO analysis and representation of Department of Defense documentation. | GAO-21-145

M-code is a stronger, encrypted, military-specific GPS signal designed to meet military positioning, navigation, and timing (PNT) needs. M-code will help military users overcome GPS signal jamming by using a more powerful signal and protect against false GPS signals, known as spoofing, by encrypting the signal. Previous generations of satellites have been able to transmit the M-code signal since 2005, but DOD lacked the ground control capability to use M-code operationally. GPS III (GPS III) satellites, first launched in 2018, transmit a more powerful M-code signal than prior M-code transmitting satellites.

Modernization of GPS M-code Broadcast Capability

Modernizing and sustaining the current GPS broadcast capability requires launching new satellites to replace 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 broadcast modernization effort comprises two major acquisition efforts: (1) the space segment with the GPS III and GPS III Follow-On (GPS IIIF) satellite programs, and (2) the ground segment with the GPS Next Generation Operational Control System (OCX) to control the satellites. See table 1 for a description of these programs.

Table 1: Current Global Positioning System (GPS) Satellite and Ground Control Modernization Programs (fiscal year 2020 dollars)

Program	Description
	Space Segment
GPS III / Follow-On (GPS IIIF)	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. Lockheed Martin is the prime contractor to build the first 10 GPS III satellites as well as up to 22 subsequent GPS IIIF satellites. The Air Force accepted the first GPS III satellite for operations in January of 2020. The total program cost to complete the GPS III program is $5.8 billion and the estimated cost to complete the GPS IIIF program is $9.6 billion.
	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 military code (M-code) and some new civilian signals. Raytheon Technologies is the prime contractor for OCX. OCX is being developed in a series of blocks, with operational testing projected to be complete in September 2022. The estimated cost for Blocks 0-2 is $6.6 billion. 1. Block 0—provides 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 modern cybersecurity capabilities, a key advancement in securing the system. The Air Force took possession of Block 0 in October 2017.[a] 2. Blocks 1 and 2—will provide command and control for previous generations of satellites and GPS III satellites, monitoring and control for both current and modernized signals, and full M-code broadcast capability. The planned operational date for Blocks 1 and 2 is no later than April 2023, according to program documentation. 3. Block 3F—will upgrade OCX with new capabilities to control and use the GPS IIIF space segment and Military GPS User Equipment Increment 2 capabilities. The Space Force plans to award a development contract for OCX Block 3F by March 2021. The estimated cost to complete OCX 3F is $223 million.

Source: GAO analysis of Department of Defense data. | GAO-21-145

[a]The Air Force took possession after inspection by signing a Certificate of Conformance and will finally accept Block 0 at a later date after OCX Block 1 is delivered.

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 for all currently available GPS signals and provide a limited M-code broadcast capability. With the addition of these two programs, GPS operators can monitor and operationally control the M-code signal broadcast from on-orbit M-code-capable satellites, allowing the warfighter use of core M-code capabilities prior to the OCX program's delivery of full M-code control. Table 2 provides a description of the two additional programs.

Table 2: Modifications to Current Operational Control Segment (fiscal year 2020 dollars)

Program	Description
Contingency Operations (COps)	COps is a software modification to the existing Operational Control Segment (OCS) started in 2016 to sustain the Global Positioning System (GPS) constellation's capabilities. COps enables operational control of GPS III satellites and the legacy signals they broadcast, while OCS continues to control GPS II satellites and their signals. COps is a capability needed to fill in the gap created by Next Generation Operational Control System (OCX) development delays. Lockheed Martin is the prime contractor for this work and also built and maintains OCS. The Air Force operationally accepted the COps software upgrade in March 2020. The total program cost for COps is $165 million.
Military Code (M-code) Early Use (MCEU)	MCEU is an additional software modification to OCS after COps. It provides some operational control of specific M-code broadcast signals, but lacks the cybersecurity of OCX, among other features. This is another capability needed to fill in the gap created by the OCX development delays. Lockheed Martin is the prime contractor. Operational acceptance of MCEU occurred in November 2020. The total program cost for MCEU is $122 million.

Source: GAO analysis of Department of Defense data. | GAO-21-145

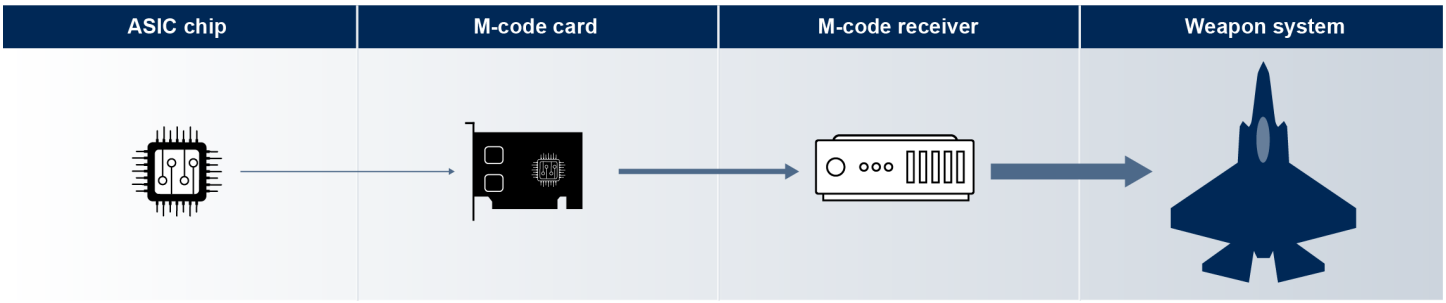
Modernization of GPS M-code User Equipment

Modernizing the GPS user segment involves developing a new M-code card and integrating it into modernized GPS receivers that will be embedded in DOD weapon systems. As we have previously reported, about 700 different types of weapon systems will ultimately require M-code cards and M-code-capable receivers, including ships, aircraft, ground vehicles, munitions, and handheld devices, among others, across DOD.[5]

GPS receivers are made up of different components, and the development and manufacture of each is a key part of the overall modernization effort. Modernizing the receivers involves development of an application-specific integrated circuit (ASIC), a type of microelectronic component on which specific M-code receiver functionalities are encoded. This chip is integrated into an M-code card that processes M-code and other GPS signals to provide positioning, navigation, and timing information. Each specialized M-code card is then integrated into a receiver that provides an interface with the host weapon system. See figure 2 for a simplified depiction of GPS user equipment integration for one system.

[5]GAO-18-74.

Figure 2: Global Positioning System User Equipment Integration



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

Source: GAO analysis and representation of Department of Defense documentation. | GAO-21-145

The Air Force Military GPS User Equipment (MGUE) program is developing initial M-code cards. These cards go through a security certification and approval process in order to complete developmental and operational testing. In order to use M-code and address other operational needs, the military services are also developing modernized receivers for air, sea, and land-based systems that will integrate M-code cards. Some of these receiver development efforts are dependent, in part, on the Air Force providing fully functional, certified M-code cards in order to conduct developmental and operational testing. The military services and DOD components determine whether to procure the M-code cards directly from the contractor or pursue additional development at their own expense to meet their requirements.

MGUE is expected to deliver improved capabilities to counter current and emerging threats to positioning, navigation, and timing data from U.S. adversaries and to better enable military operations in environments where those adversaries may deny or limit access to traditional GPS resources, referred to as navigation warfare environments.[6] MGUE is intended to address threats that deny or limit access, which include signal jamming and false signals (adversary spoofing). Military service officials noted that a capability gap exists and, while weapon systems are

[6]Navigation warfare is defined as deliberate defensive and offensive action to ensure that friendly use of positioning, navigation, and timing information is unimpeded while simultaneously denying an adversary's use of such information through coordinated employment of space, cyberspace, and electronic warfare operations.

attempting to address these threats through other means, they expressed an urgent need for M-code capability based on persistent threats to GPS.

The Ike Skelton National Defense Authorization Act for Fiscal Year 2011, enacted in January 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.[7] Under certain circumstances, this requirement to purchase M-code capable receiving equipment may be waived or certain exceptions may apply. Concurrent with M-code card development delays, DOD has issued waivers for this requirement for the hundreds of types of weapon systems that will eventually integrate M-code cards. DOD is currently operating under a blanket waiver the Office of the Under Secretary of Defense for Acquisition and Sustainment issued to cover all GPS user equipment purchases until March 31, 2021. The Under Secretary expects to issue long-term policy for M-code implementation and waiver requests by the time the waiver expires.

MGUE Increment 1

In January 2017, DOD approved the MGUE Increment 1 program, the first of two increments, to formally begin development of M-code cards and to eventually conduct operational testing of those cards on four military service-nominated systems.[8] The lead weapon systems for the ground-embedded card are the Army Stryker ground combat vehicle and the Marine Corps JLTV. The lead weapon systems for the

[7]Pub. L. No. 111-383, § 913 (the Act). This 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 after fiscal year 2017 unless the equipment is capable of receiving M-code. The Secretary of Defense may waive this limitation under certain circumstances or certain exceptions may apply.

[8]At development start, the MGUE Increment 1 program planned for operational test and evaluation events for MGUE Increment 1 technology on each of the four lead weapon systems. However, according to program officials, in August 2020, the Air Force revised the program's culminating test events to field testing after DOD's Office of the Director, Operational Test and Evaluation assessed that two of the tested configurations would not be operationally representative and therefore the final testing on those systems should not be considered operational testing. This indicated that operational test and evaluation events will be carried out for lead systems that will be testing production representative user equipment in operational configurations, and field user evaluations (or similar user tests) will be carried out for lead systems testing user equipment configurations not expected to be fielded. According to Army Positioning, Navigation, and Timing program officials, the key distinction between the two types of evaluations is that the Office of the Director, Operational Test and Evaluation will oversee the operational test and evaluation events, but will not oversee the field user evaluations.

aviation/maritime card are the Air Force B-2 and the Navy DDG 51 class destroyer.

DOD defined the criteria to complete the program as (1) verifying technical requirements on all types of final M-code test cards; (2) certifying readiness for operational testing by the Air Force Program Executive Officer; (3) completing operational testing for the four lead weapon systems for, at a minimum, the first card available; and (4) completing manufacturing readiness assessments for all Increment 1 card contractors.

To develop M-code cards that will meet the program's technical requirements, the MGUE Increment 1 program is working on two card types—one for the ground domain, which we refer to as the ground card, and one for the aviation and maritime domains, which we refer to as the aviation/maritime card. The MGUE Increment 1 acquisition strategy calls for the integration of the M-code cards into four lead weapon systems. The program provides some of its funding to the Air Force, Navy, Marine Corps, and Army so they can acquire, integrate, and operationally test the M-code cards on the four systems. The Air Force will fund operational testing on only two M-code cards—the first M-code cards available for each domain. The first ground card will be tested on the JTLV and the Stryker, while the first aviation/maritime card will be tested on the B-2 and the DDG 51 class.[9] The MGUE Increment 1 program, expected to cost about $1.5 billion, is developing five cards through the efforts of three contractors:[10]

- L3Harris, which is developing a ground card;
- Raytheon Technologies, which is developing both a ground and an aviation/maritime card; and
- BAE Systems, which is also developing both a ground and an aviation/maritime card.

[9]The first ground card available for operational testing is the L3Harris card; the first aviation/maritime card expected to be available is the Raytheon Technologies card.

[10]The contract for the card being developed by BAE Systems was originally awarded to Rockwell Collins, which later became Collins Aerospace after acquisition by United Technologies. Subsequent to the April 2020 completion of the merger of United Technologies and Raytheon, BAE Systems in July 2020 announced its acquisition of the Collins Aerospace business that develops military GPS technology.

The military services will integrate MGUE Increment 1 cards into the GPS receiver equipment aboard the lead weapon systems. The M-code-capable receivers are being developed through efforts outside of the MGUE Increment 1 program. The ground card is being integrated into

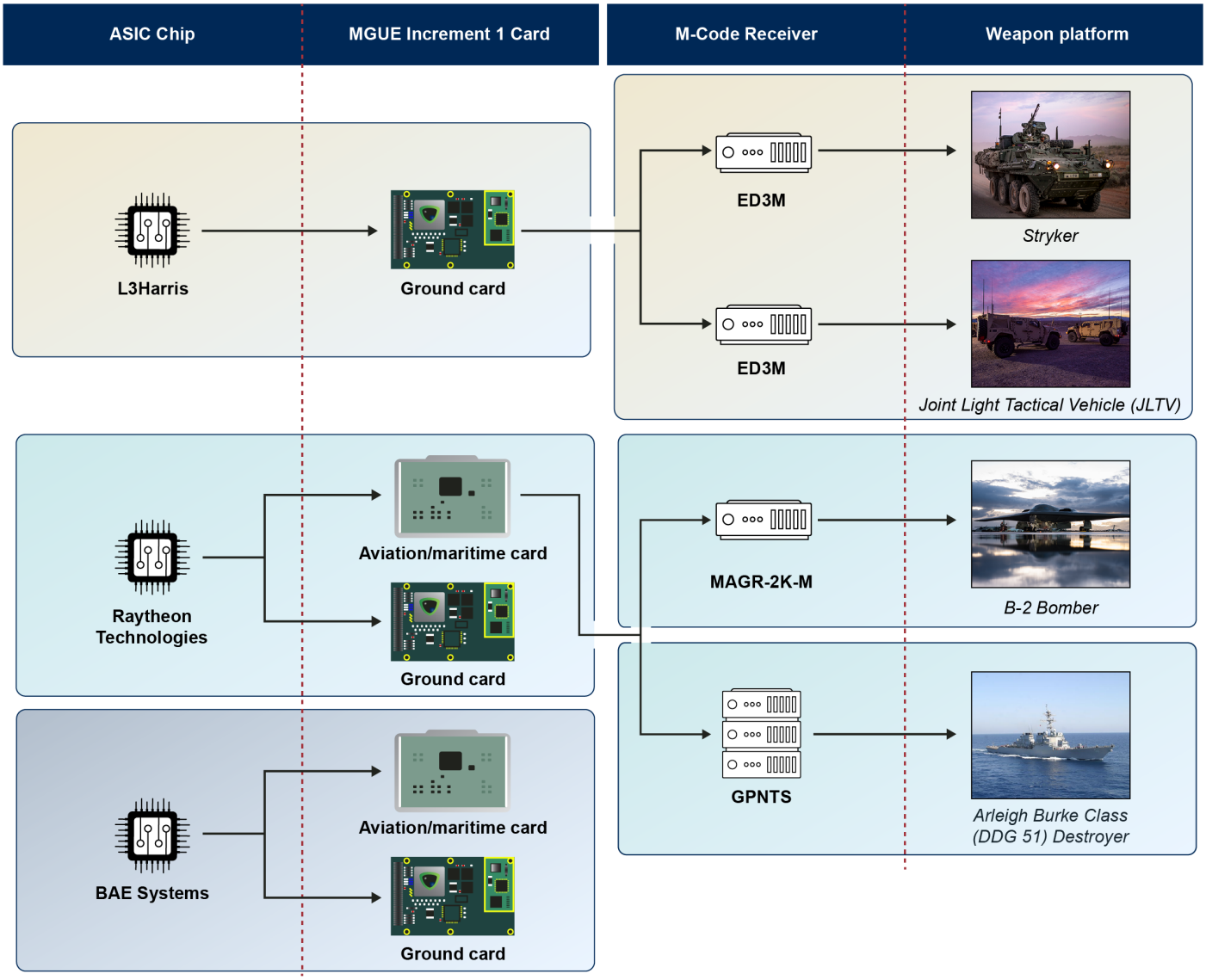
- the Enhanced Defense Advanced GPS Receiver (DAGR) Distributed Device M-code (ED3M) that will be used in the Stryker, and
- The JLTV's ED3M receiver.

The aviation/maritime card is being integrated into

- The Navy's GPS-based Positioning, Navigation, and Timing Service (GPNTS) system that is used in the DDG 51 class, and
- The Miniature Airborne GPS Receiver 2000 – Modernized (MAGR-2K-M) that will be used in the B-2 bomber.

Figure 3 illustrates the various constituent elements of MGUE Increment 1 development and integration for each lead weapon system.

Figure 3: Military Global Positioning System User Equipment Program Contractors, Increment 1 Elements, and Lead Weapon Systems



ASIC = Application-Specific Integrated Circuit
DAGR = Defense Advanced GPS Receiver
ED3M = Enhanced DAGR Distributed Device M-code
GPNTS = GPS-based PNT Service
GPS = Global Positioning System
MAGR-2K-M = Miniature Airborne GPS Receiver 2000 – Modernized
MGUE = Military GPS User Equipment
M-code = Military code
PNT = Positioning, Navigation, and Timing

Source: GAO analysis and representation of Department of Defense (DOD) information (data); GAO adaptation of DOD documentation (Aviation/maritime card and Ground card graphics); Air Force (B-2 image); Army (Stryker image); Marine Corps (Joint Light Tactical Vehicle image); Navy (DDG 51 image). | GAO-21-145

According to the Air Force's GPS test plans, each service's lead weapon system contractor conducts testing to verify that a given lead weapon system's receiving equipment is ready for the integration of the MGUE Increment 1 cards.

The MGUE increment 1 program is expected to end with the integration and operational testing of two of the five M-code cards—the first available for ground and aviation/maritime systems, respectively. In order for the hundreds of additional types of weapon systems to modernize their GPS reception capability, the military services and other DOD components will need to choose from among MGUE increment 1 cards or additional cards the contractors are developing outside of the MGUE program.

MGUE Increment 2

The MGUE Increment 2 program builds on Increment 1 technology and is developing smaller M-code cards to use in equipment for which Increment 1 cards were not developed and where they do not meet required needs, such as the size and power requirements of some weapon systems. The Increment 2 program specifically addresses requirements for handheld receivers, munitions, and space-based receivers.[11]

The Air Force approved the acquisition strategy for MGUE Increment 2 in November 2018. The program's acquisition strategy is to pursue two Middle Tier Acquisition rapid prototyping efforts.[12] The first effort involves developing a more compact M-code card with a smaller, more advanced Next-Generation ASIC. The second effort will develop a modernized handheld receiver for use by all of the military services.[13]

[11]While MGUE Increment 2 program documentation includes requirements for space-based receivers, these receivers are being developed under a separate Air Force program.

[12]Section 804 of the National Defense Authorization Act for Fiscal Year 2016 required DOD to issue guidance establishing two new streamlined acquisition pathways for DOD—rapid prototyping and rapid fielding—under the broader term "middle tier of acquisitions." Pub. L. No. 114-92 (2015). The objective of a rapid prototyping program is to field a prototype that can be demonstrated in an operational environment and provide for a residual operational capability within 5 years of the program start date. These acquisition pathways are distinct from the traditional acquisition system for major defense acquisition programs in that they allow for programs to be exempted from the acquisition and requirements processes normally followed for such acquisitions. GAO, *DOD Acquisition Reform: Leadership Attention Needed to Effectively Implement Changes to Acquisition Oversight*, GAO-19-439 (Washington, D.C.: June 5, 2019).

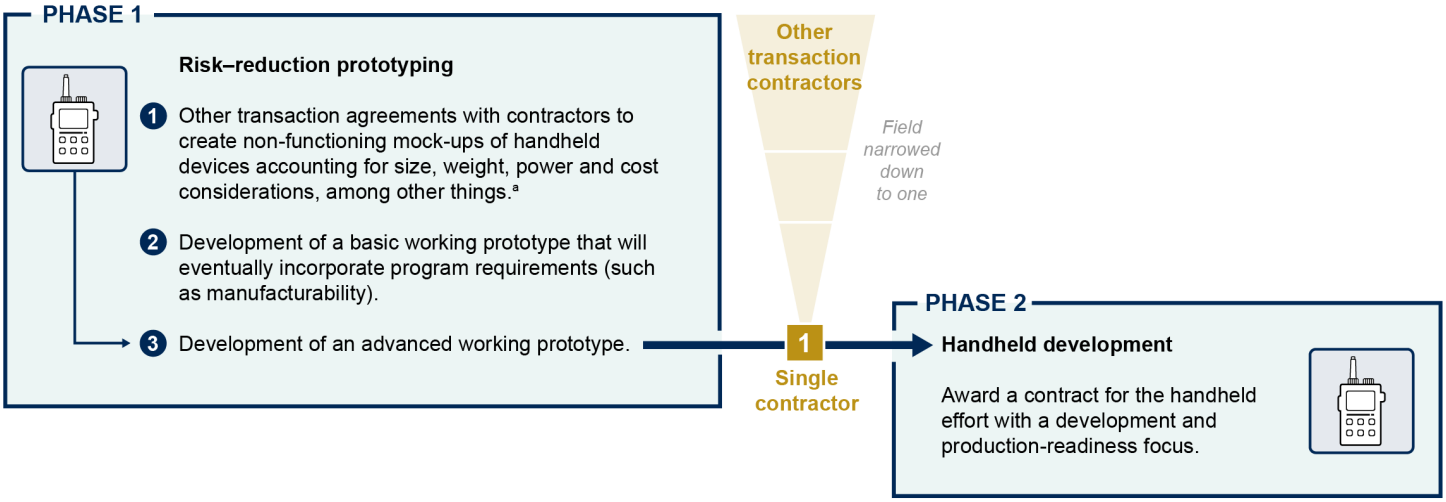
[13]The more compact card, called a miniature serial interface, is intended to take advantage of a smaller ASIC that consumes less power and that supports both MGUE Increment 1 and Increment 2 requirements.

The Air Force has been working with MGUE Increment 1 contractors BAE Systems, L3Harris, and Raytheon Technologies on initial designs for the Next-Generation ASIC, and this work will culminate in a preliminary design review for this key component. The Air Force issued a request for proposals for the Increment 2 card and Next-Generation ASIC development in December 2019, and competitively awarded contracts to Rockwell Collins, Inc., Interstate Electronics Corporation, and Raytheon Company in November 2020. Program officials said the 5-year development time frame for completing this Middle Tier Acquisition effort started when the first funds were obligated at contract award. The approved service cost estimate for the program is $1.9 billion.

According to the Increment 2 program schedule, the Next-Generation ASIC is expected to be available in fiscal year 2024 at the earliest, at which point programs adopting the technology will still have to conduct M-code card integration and testing, as needed. The program anticipates an M-code card demonstration in the fourth quarter of fiscal year 2025. Officials said that to mitigate risk, the program set its delivery date in fiscal year 2026 to allow time—if needed—for a second ASIC development phase, which is often needed for complex ASICs. Once the card is available, integration and testing will still be needed for specific receiver applications.

The handheld development Middle Tier Acquisition is split into two phases, with Phase 1 involving risk-reduction prototyping and Phase 2 consisting of handheld receiver development. The first phase, which was initiated in 2019, comprises three objectives illustrated in figure 4.

Figure 4: Military Global Positioning System User Equipment Increment 2 Handheld Development Phases and Objectives



Source: GAO analysis and representation of Department of Defense documentation. | GAO-21-145

[a]Other Transactions are legally binding instruments that may be used to engage industry and academia for a broad range of research and prototyping activities. Other Transactions are typically defined by what they are not: they are not standard procurement contracts, grants, or cooperative agreements. As such, they are generally not subject to the federal acquisition laws and regulations that apply to federal procurement contracts.

According to program officials, the final objective of Phase 1 requires a functional Increment 2 card from the first Middle Tier Acquisition effort and marks the beginning of the 5-year timeframe for the second Middle Tier Acquisition effort. Phase 2 is expected to begin in mid-fiscal-year 2025 and be completed toward the end of fiscal year 2026.

Coordination among Programs and Military Services

All of the military services have roles in the integration and testing of MGUE technology. The multi-service and multi-program nature of MGUE Increment 1 integration and testing necessitates coordination among the MGUE Increment 1 program, the four military service lead weapon system program offices, the service-level offices with positioning, navigation, and timing modernization and GPS receiver development roles, and service-level operational test organizations. Corresponding roles of these organizations include the following:

- **The MGUE Increment 1 program office** funds and manages M-code card development activities. It also supports both the card- and weapon system-level developmental and operational testing on the lead weapon systems.

- **The lead weapon system program** offices conduct weapon system integration and developmental testing with test cards provided by the Increment 1 program, to verify weapon system-level requirements and to support the process to certify that the cards are ready for operational testing. As the MGUE Increment 1 cards require modernized or updated GPS receivers, the lead weapon system program offices also integrate new receivers being developed in parallel with the M-code cards.
- **Service-level offices** overseeing GPS receiver and other positioning, navigation, and timing modernization efforts are developing modernized receivers for the lead weapon systems. These offices manage and fund receiver-level development efforts and are dependent on the MGUE Increment 1 program for the provision of the M-code cards that enable completion of their respective development programs. See figure 5.

Figure 5: Military Service-level Office Roles for Military Code Receiver Development and Integration

Lead weapon system	B-2 Bomber	*Arleigh Burke* Class (DDG 51) Destroyer	Stryker	Joint Light Tactical Vehicle (JLTV)
				
Assisting office	**Air Force Life Cycle Management Center's Agile Combat Support Directorate**	**Navy Communications and GPS Navigation Program Office**	**Army Positioning, Navigation and Timing Program Office**	**Marine Corps Systems Command's Portfolio Management Office, Command Element Systems**
Office role in integrating MGUE Increment 1 on service lead weapon system	Develops the MAGR-2K-M receiver, which will support the MGUE Increment 1 aviation/maritime card on the B-2 and eventually on certain other Air Force and Navy aircraft	Develops the GPNTS receiver, which will support the MGUE Increment 1 aviation/maritime card on the *Arleigh Burke* Class (DDG 51) Destroyer and eventually on other Navy surface vessels	Develops modernized positioning, navigation, and timing technologies to support the MGUE Increment 1 ground card on the Stryker vehicle	Develops the architecture supporting the integration of the MGUE Increment 1 ground card into the JLTV

DAGR = Defense Advanced GPS Receiver
ED3M = Enhanced DAGR Distributed Device M-code
GPNTS = GPS-based PNT Service
GPS = Global Positioning System
MAGR-2K-M = Miniature Airborne GPS Receiver 2000 – Modernized
MGUE = Military GPS User Equipment
PNT = Positioning, Navigation, and Timing

Source: GAO analysis of Department of Defense information (data); Air Force (B-2 image); Army (Stryker image); Marine Corps (Joint Light Tactical Vehicle image); Navy (DDG 51 image). | GAO-21-145

- **Service-level operational test organizations** are to conduct operational testing on the MGUE lead weapon systems. These service operational test organizations coordinate to ensure that service-specific objectives are assessed in the testing and to manage their respective service's participation in MGUE operational test events. This coordination is particularly important for services that intend to use the lead weapon system operational testing to assess broader GPS receiver integration objectives alongside the MGUE Increment 1 program's operational testing of the M-code cards.

In addition to integration and testing on lead systems, the military services are expected to procure, integrate, and test M-code cards on other systems, which we refer to as non-lead weapon systems. The military services plan to solicit from contractors either MGUE-developed cards or variants of those cards.

Trust Requirements and Export Control Regulations

Current DOD policy for protection of mission critical functions requires that, in applicable systems, integrated circuit-related products (generally referred to as ASICs) and services be procured from a trusted supplier using trusted processes accredited by the DMEA when they are custom-designed, custom-manufactured, or tailored for a specific military end use.[14] This accreditation process for trust provides for production facilities to maintain a chain of custody that ensures: (1) threats related to intentional or unintentional modification or tampering are addressed to the extent possible; and (2) protection from unauthorized attempts at reverse engineering, exposure of functionality, or evaluation of possible vulnerabilities. According to a MGUE Increment 1 requirements document, ASICs for this program will go through trusted design and production. Each MGUE Increment 1 contractor utilizes a different GlobalFoundries technology, and for each of these technologies, GlobalFoundries is currently the only company that has gone through the procedures to be designated a trusted manufacturer for these devices. With the sale of the GlobalFoundries ASIC development business to Marvell Government Solutions in 2019, Marvell now handles orders for the Raytheon Technologies and L3Harris Increment 1 ASICs, and contracts with GlobalFoundries for their production at the company's

[14]DOD Instruction No. 5200.44, *Protection of Mission Critical Functions to Achieve Trusted Systems and Networks (TSN),* (Nov. 5, 2012, Incorporating Change 3, Oct. 15, 2018).

facility in East Fishkill, NY.[15] A GlobalFoundries official noted that BAE Systems places orders with GlobalFoundries directly for its Increment 1 ASICs.

ASICs currently used for development and production of Increment 1 M-code cards are also subject to export controls in the International Traffic in Arms Regulations administered by the Department of State.[16] As with the trusted manufacturer accreditation, according to DOD officials, GlobalFoundries is the only supplier that has processes addressing export control regulations. These regulations apply to development and production of the Increment 1 ASICs, and restrict the design and production of export-controlled data for the ASIC from access by foreign persons whether in the U.S. or abroad.

One M-Code Card Nearly Complete Though Late, With Continuing Development Challenges Leading to Key Program Changes

The MGUE Increment 1 program is nearing completion—approximately 1 year later than planned—of development and testing for one M-code card of the five in development. In June 2020, the Program Executive Officer for Space Production certified the card as ready for final testing, but development work for the remaining four cards was not complete. The difficulties maturing the Increment 1 cards have caused significant development delays. As a result of these delays and their associated costs, the Air Force revised the exit criteria for Increment 1 and reduced the scope of the program. In 2018, the Air Force started efforts to develop and manufacture smaller M-code cards under the MGUE Increment 2 program, but this program is experiencing delays as well. There are currently no trusted suppliers for design and production of state-of-the-art technologies needed for the Next-Generation ASIC, but DOD is pursuing an alternative approach expected to meet security and export requirements.

[15]ON Semiconductor will take ownership of the GlobalFoundries East Fishkill, NY facility that manufactures the BAE Systems Increment 1 ASIC in January 2023 and, according to DOD and GlobalFoundries officials, ON Semiconductor has communicated its intent to pursue trust accreditation for that facility, though the company has not formally made that decision.

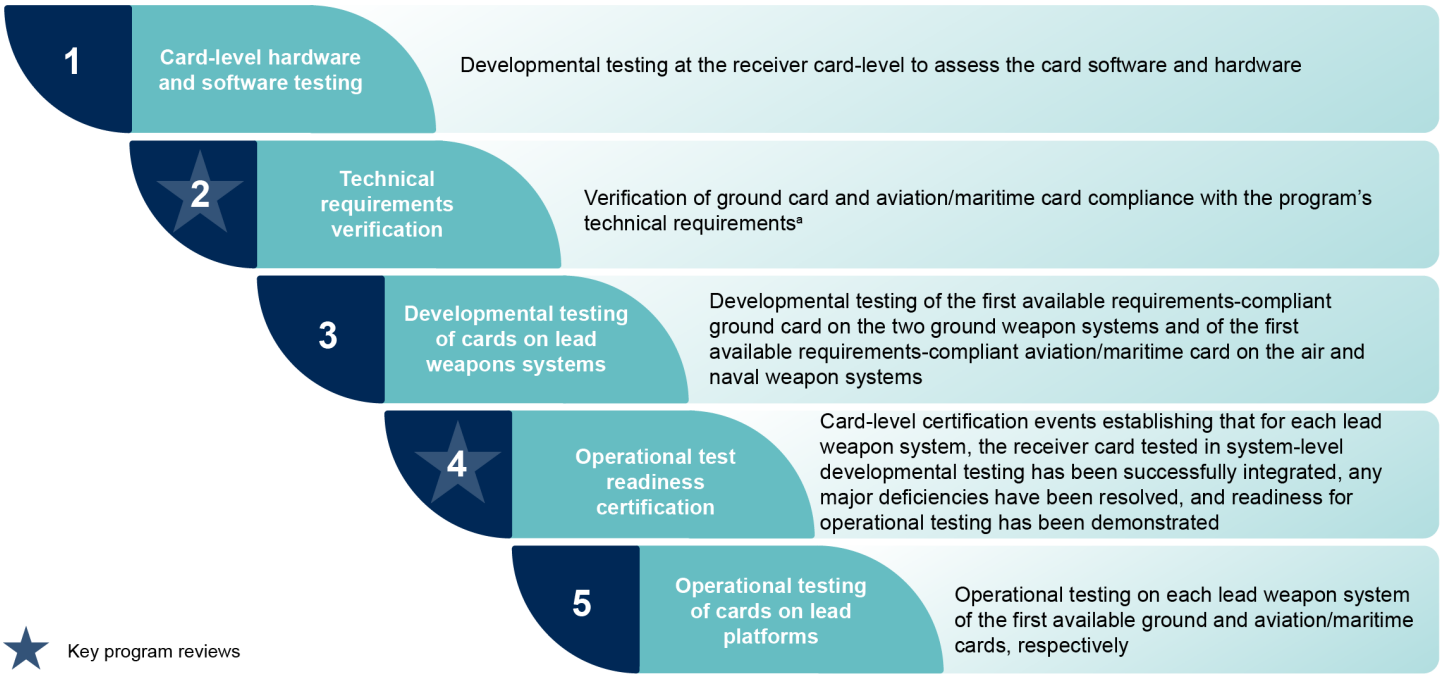
[16]International Traffic in Arms Regulations (ITAR, 22 C.F.R. §§ 120-130) implement the Arms Export Control Act (AECA), as amended, 22 U.S.C. § 2751 et seq. The AECA provides the President authority to control the export of defense articles and services, which the President has designated to the Secretary of State. For electronic equipment specifically designed, modified, or configured for military application, the ITAR generally restrict disclosing or transferring technical data to a foreign person.

One of Five M-Code Increment 1 Cards Ready for Operational Testing

The MGUE Increment 1 program has made some progress in software and hardware testing since development began in 2017. Most significantly, for the L3Harris ground card, the program (1) successfully completed technical requirements verification, (2) conducted integrated developmental testing on the JLTV and Stryker lead weapon systems, and (3) certified in June 2020 that the card is ready for final testing on the JLTV.

The MGUE Increment 1 program began the process of testing card software against program technical requirements in November 2016. The program's baseline schedule and Air Force test plans have a series of test events and review processes, depicted in figure 6, which would culminate in the operational testing of production-representative cards on lead weapon systems.

Figure 6: Military Global Positioning System User Equipment Increment 1 Test Phases and Key Reviews Established at the Start of Development



Source: GAO analysis of Department of Defense documentation. | GAO-21-145

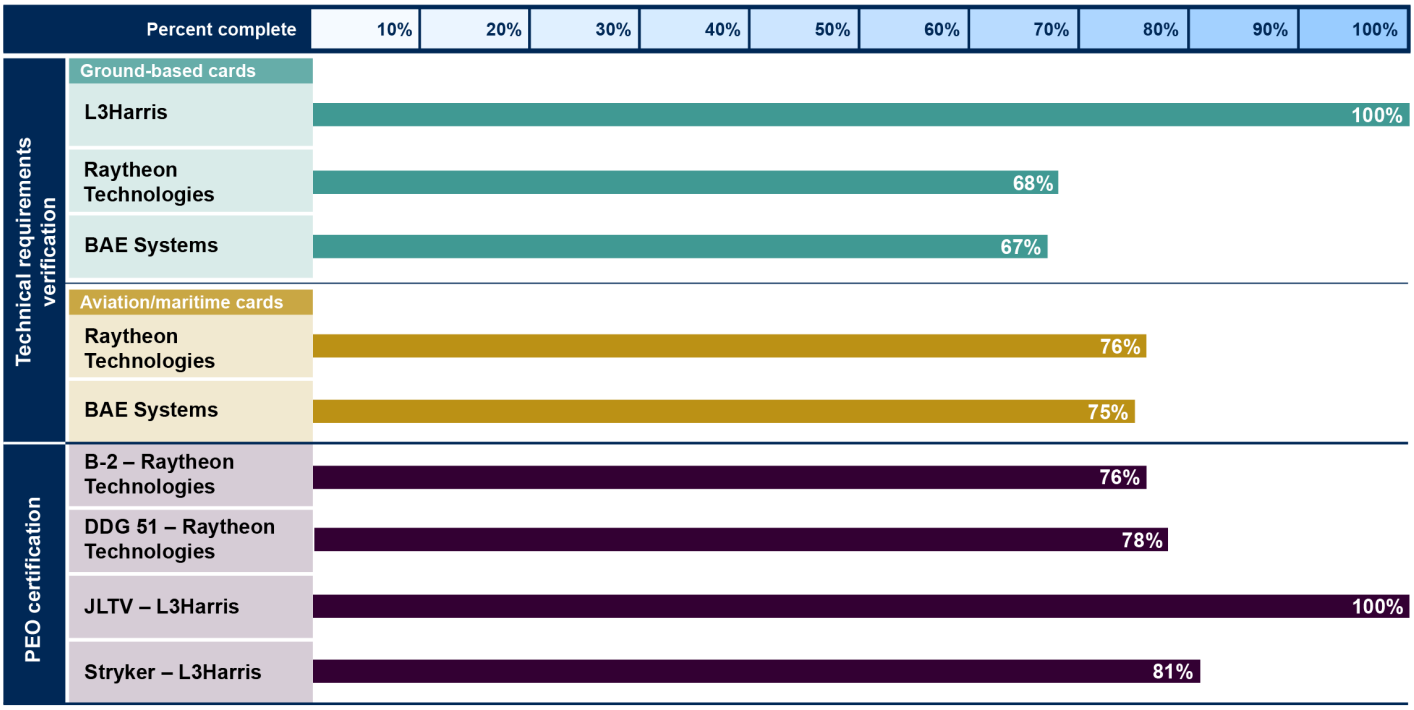
Note: To proceed to the weapon system-level testing that follows the technical requirements verification event, the program is to conduct verification for the first ground card made available by one of the program's three ground card contractors and for the first aviation/maritime card made available by one of the program's two aviation/maritime card contractors. Subsequent testing and certification is for only the first available card type for each weapon system (i.e., the first ground card

available for Stryker and Joint Light Tactical Vehicle and the first available aviation/maritime card for the B-2 and DDG 51 class).

As of August 2020, all five cards had made progress toward satisfying the technical requirements that are to be verified before the start of integrated testing on the lead weapon systems. According to Air Force data, the completion of development work supporting technical requirements verification ranged from 67 percent for the BAE Systems ground card to 100 percent for the L3Harris ground card.[17] Figure 7 shows each Increment 1 contractor's progress toward completion of two key program schedule events.

[17]According to MGUE program officials, Rockwell Collins—the original contractor for the MGUE increment 1 cards currently being developed by BAE Systems—was to deliver both ground and aviation/maritime cards only to 80 percent of the technical requirements. According to program officials, the ground card's contractor was awarded a contract action in August 2019 to develop its ground card to full technical requirements but the program no longer plans to conduct a formal verification of technical requirements.

Figure 7: Military Global Positioning System User Equipment Increment 1 Card Progress toward Two Key Program Events, as of August 2020



B-2 = B-2 Bomber
DDG 51 = Arleigh Burke Class Destroyer
JLTV = Joint Light Tactical Vehicle
PEO = Program Executive Office

Source: GAO representation of Department of Defense data. | GAO-21-145

Note: The MGUE program provided this progress report in August 2020. That same month, an Acquisition Decision Memorandum revised program exit criteria and scope, eliminating the need to verify technical requirements on cards for which contractors do not have production plans, including both BAE Systems cards and the Raytheon ground card.

After the L3Harris ground card successfully completed technical requirements verification, the Air Force and the Marine Corps conducted integrated developmental testing on the L3Harris ground card in the JLTV from February 2020 through May 2020. In this test event, the Air Force verified the card met 15 of 16 test parameters without issue. There were, however, two deficiencies assessed against the card's ability to reject invalid signals. Based on the test results, the Air Force Program Executive Office for Space Production certified in late June 2020—the threshold, or latest acceptable date for certification on the JLTV—that the program can proceed with final testing of the card on the JLTV once five

additional actions are complete. Specifically, final testing can begin once the program (1) delivers new card software; (2) tests software fixes for previously identified issues during August 2020 developmental testing on the Stryker; (3) delivers new card hardware; (4) conducts card-level regression testing to confirm that rework to the card has not resulted in any unintended effects to its functionality; and (5) conducts integration and regression testing of the updated card on the JLTV. The MGUE Increment 1 program reported that L3Harris delivered new software in advance of the August 2020 ground testing of the card on the Army's Stryker vehicle. The program further reported that L3Harris plans to deliver the updated hardware in October 2020, after which the remaining regression testing and JLTV integration and testing will be conducted. The MGUE Increment 1 program manager projected final testing of the ground card on the Stryker would occur no later than the end of June 2021, and program officials reported that final testing would begin in August 2021 on the JLTV.

Although the Increment 1 program has not yet verified that the other four cards have met technical requirements, the military services have conducted some early risk-reduction activities to prepare for integration of the cards on their respective lead weapon systems. As part of these activities, for example, the B-2 program integrated a pre-production Raytheon Technologies aviation/maritime test card into the B-2 for four flight tests in June and July of 2017, demonstrating the ability of the B-2 flight software to control the MGUE-equipped MAGR-2K-M receiver. Air Force officials stated that the B-2 program plans to continue such risk-reduction activities during ongoing B-2 modernization efforts, while the program awaits mature cards that have successfully met the Technical Requirements Verification milestone.

Similarly, Navy officials noted their ongoing development efforts with the GPNTS receiver, which will eventually host the MGUE Increment 1 Raytheon Technologies aviation/maritime card. They stated that the GPNTS receiver completed developmental testing and is in low-rate production for fielding with currently available GPS cards on Navy destroyers. Fall 2019 testing indicated that the Raytheon Technologies aviation/maritime card is not yet mature enough for integration into the GPNTS, but Navy Communications and GPS Navigation program officials said the Navy continued to conduct Increment 1 card testing in the GPNTS in a laboratory setting to reduce risk prior to integrated testing on the DDG 51 class.

Air Force Made Key Program Changes in Response to Program Delays and Rising Costs

The MGUE Increment 1 program encountered a number of development delays and the program recently missed key development deadlines after the Air Force was unable to certify receipt of a technically compliant aviation/maritime M-code card. Additionally, the delays contributed to rising program costs and an August 2020 Air Force decision to revise Increment 1 exit criteria and reduce program scope.

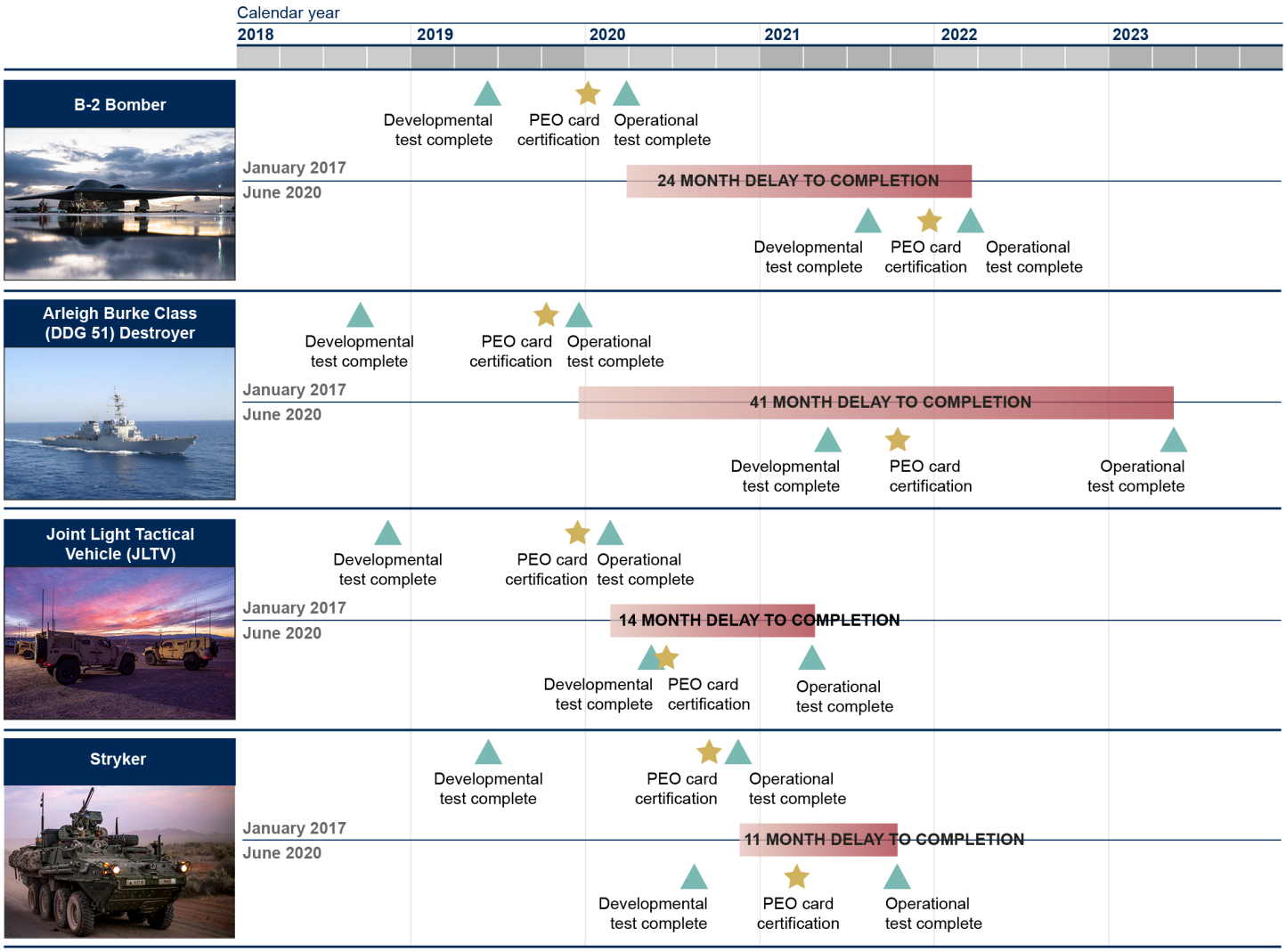
Four of the five M-code cards have not yet verified technical requirements because of challenges encountered developing and maturing both software and hardware. The Raytheon Technologies aviation/maritime card—the designated lead card for the planned B-2 and DDG 51 class operational tests—experienced developmental setbacks and schedule delays that led the program to miss a key deadline in its baseline schedule. Specifically, Raytheon Technologies was unable to produce a technical requirements-compliant card by January 2020, which the program's baseline schedule set as the latest acceptable date for completion of technical requirements verification. The Raytheon Technologies aviation/maritime card had critical technical deficiencies and was therefore unable to demonstrate its compliance with requirements. According to a program official, as of December 2020, the Raytheon Technologies aviation/maritime card had completed 87 percent of work supporting technical requirements verification. Additionally, the BAE Systems cards experienced early development difficulties, according to Air Force officials. In June 2020, MGUE program officials said they did not expect the BAE Systems ground and aviation/maritime cards to complete verification of requirements until May 2021 and July 2021, respectively. The Raytheon Technologies ground card was expected to complete verification of requirements in September 2021, according to MGUE Increment 1 program officials.

As of June 2020, the cumulative development delays had disrupted the MGUE Increment 1 program's developmental and operational test schedules, delaying the completion of operational testing. Because the Air Force is developing a new schedule for the aviation/maritime card, it does not yet know the full extent of the delays to the B-2 and DDG 51 class operational testing. As of June 2020, the planned program culminating event—operational testing—had been postponed for all four lead weapon systems. From January 2017 to June 2020, delays to the projected completion of operational testing had varied from 11 months in

the case of the Stryker, to 41 months in the case of the DDG 51 class.[18] As of June 2020, the GPS test and evaluation schedule projected that the DDG 51 class would complete operational testing in spring 2023, but further changes are possible. A revised schedule, initially expected in March 2020, is now anticipated by the end of December 2020. Figure 8 depicts the extent of schedule delays the Air Force projected for each Increment 1 lead weapon system as of June 2020.

[18]Operational testing is not a program milestone, as Air Force officials explained that the baseline schedule events are structured solely around events within the control of the MGUE Increment 1 program. The program does not control the lead weapon system operational test events or the timing thereof. As such, the projected delay in completion of operational testing will not result in a breach of the program's acquisition baseline.

Figure 8: Military Global Positioning System User Equipment Program Increment 1 Developmental and Operational Test Delays as of June 2020



GPS = Global Positioning System
PEO = Program Executive Office

Source: GAO analysis of Department of Defense information (data); Air Force (B-2 image); Army (Stryker image); Marine Corps (Joint Light Tactical Vehicle image); Navy (DDG 51 image). | GAO-21-145

Note: The June 2020 MGUE Increment 1 timelines above reflect the Air Force's June update to the GPS Enterprise Master Schedule, which is regularly updated to track the interrelated lines of efforts in modernizing the satellite, ground control, and user equipment segments of GPS. A program official said that, as of January 2021, expected test completion dates for the B-2 and DDG 51 class are yet to be determined; test completion dates for the Stryker and JLTV are the second and third quarter of calendar year 2021, respectively.

Prior to the Increment 1 program breaching its schedule for the aviation/maritime card, total estimated program costs remained below the roughly $1.5 billion estimate reported at development start in 2017. However, program officials reported that the schedule delays will result in an increase to the costs reflected in the program baseline. An Air Force draft estimate suggest costs could grow by about $216 million over the next five years.

In August 2020, the Air Force revised the Increment 1 exit criteria, citing growing costs associated with M-code card development delays and engineering changes previously added to the program baseline as reasons for the revisions. In addition, a program official said some Increment 1 contractors' market strategies and production plans for MGUE cards have changed since the program began development in 2017 and, in some cases, the contractors do not have production plans for those cards. According to the Air Force, the revisions are intended to focus resources on critical activities and align program efforts with only MGUE cards that have a production plan. Specifically, the Air Force changed the exit criteria to reduce the number of cards requiring technical requirements verification from all five to just two—the first available ground card and the first available aviation/maritime card. Since the L3Harris ground card completed technical verification and the Raytheon aviation/maritime card is planned as the first available aviation/maritime card, the exit criteria change relieves the Increment 1 program from having to formally verify technical requirements on the Raytheon ground card and the BAE Systems ground and aviation/maritime cards. Program officials confirmed that there are no production plans for these three cards. The full ramifications of these recent changes are yet to be determined. Some contractors are making other M-code cards available for military purchase. Verification that any M-code cards developed outside of the MGUE program meet requirements would be the responsibility of the military services choosing to purchase these cards.

The revised program exit criteria also reduces the level of oversight required for the MGUE Increment 1 final testing on some lead weapon systems. Program officials explained that the type of test oversight now required is dependent on whether there are plans to field the system configuration to be tested. At the program's development start, DOD expected that at the conclusion of testing the M-code cards would be available for each military service to procure and use. DOD guidance notes that operational test and evaluation events will be conducted using production or production-representative test articles. The revised exit criteria require the Increment 1 program to conduct operational test and

evaluation only on equipment that is planned to be fielded. Such operational test events will be conducted with the oversight of the office of DOD's Director, Operational Test and Evaluation (DOT&E), according to MGUE Increment 1 program officials. For other systems not planned to be fielded in the configuration expected to be tested for the MGUE Increment 1 program, the program plans to conduct field user evaluations to gather input on functionality.[19] While the testing objectives remain unchanged, according to program officials, the field user evaluation events will not be conducted with the DOT&E oversight planned for those systems testing configurations planned for fielding. As a result, plans currently provide for operational test and evaluation of aviation/maritime cards on the B-2 and DDG 51 class, and field user evaluations of ground cards on the Stryker and JLTV, according to officials with the Army's Positioning, Navigation, and Timing program. This approach is consistent with DOD testing guidance on equipment that is to be used for operational testing.

Additionally, the original criteria for completion of the Increment 1 program required the Air Force to conduct manufacturing readiness assessments for each contractor. However, the Air Force's revisions to the Increment 1 program relieve the program of the requirement to complete manufacturing readiness assessments for contractors that do not have production plans for cards in the Increment 1 configuration.[20] This is consistent with DOD acquisition guidance, since manufacturing readiness assessments are to provide the basis for managing manufacturing maturation and risk. With no production plans for some cards, manufacturing readiness assessments would likely provide only limited benefits.

[19]Operational test and evaluation evaluates a system's effectiveness and suitability under realistic combat conditions before full-rate production or deployment occurs. 10 U.S.C § 2399; 10 U.S.C. § 139(a)(2)(A).

[20]This change applies to the BAE Systems Increment 1 cards and the Raytheon Increment 1 ground card, for which there are no production plans. According to the MGUE Increment 1 program manager, the Raytheon ground card effort is being terminated. However, the Air Force directed the Increment 1 program to continue development work on the BAE Systems ground card because the software applies to other M-code cards the military services may procure.

Increment 2 Program Began Efforts to Develop and Manufacture Smaller M-code Cards and DOD is Developing Workarounds for Lack of Trusted Microelectronics Suppliers

In December 2019, the Air Force issued a request for proposals to design, develop, integrate, test, and deliver a smaller M-code card with a Next-Generation ASIC. The Air Force competitively awarded M-code card development contracts to Rockwell Collins, Inc., Interstate Electronics Corporation, and Raytheon Company in November 2020. Additionally, Increment 2 program officials said they began work in June 2019 with five other transaction agreement contractors to develop handheld receiver mockups for the first stage of phase 1 under the Increment 2 program. The goal of this phase is to reduce development risk and mature handheld receiver technology, as well as solicit iterative, early user feedback through prototype demonstrations. For example, program officials said they conducted user demonstrations of the mockups with the Marine Corps and Army, which resulted in feedback from users regarding fit, weight, and feel. These contractors can use this feedback to modify their designs as needed. In early 2020, the Air Force solicited proposals for the second stage of phase 1, involving the development of a basic working handheld receiver prototype. The Air Force awarded prototyping other transaction agreements to three contractors in June 2020. Program officials expect the effort to continue for 3 years.

In July 2020, DOD approved a new plan for ensuring manufacturing security that will reduce program risk by addressing trust requirements and export control regulations associated with Next-Generation ASIC microelectronic components for MGUE Increment 2. These components are to meet low power-usage and other performance requirements that can be achieved only with state-of-the-art technologies for which trust-accredited design and manufacturing are not currently available. DOD expects this approach to address information security during design and manufacturing, as well as compliance with export controls. Specifically, while DOD policy requires trusted custody—that is, procurement from a trusted supplier using trusted processes accredited by the DMEA, for microelectronics that are custom-designed or manufactured for military use—there are currently no suppliers for the advanced microelectronics technologies needed for the Increment 2 program that meet DOD's standards for trust. Additionally, DOD officials said implementing trust at existing supplier facilities is costly and that, given other options, such an approach is not needed to protect program information.

Instead of a trusted manufacturing approach, the MGUE Increment 2 program is shifting its efforts to a new approach. In particular, instead of planning to protect all the military functionality through trusted design and manufacturing, DOD is pursuing an approach that will utilize commercial, "system-on-a-chip" technologies wherein all the military functionality will

be programmed into the devices after production with the expectation of complying with export controls.[21] As an alternative to trust, DOD expects this new approach to take advantage of key attributes associated with state-of-the-art microelectronics technologies to evaluate and mitigate security risks. Because current DOD policy does not account for programmable system-on-a-chip designs, DOD's Office of the Under Secretary of Defense for Research and Engineering is revising that policy to facilitate a risk-based approach to protection of critical program information. A program official said the revised policy is expected to be finalized in December 2020.

DOD's plan for manufacturing and deploying the system-on-a-chip for MGUE Increment 2 is expected to comply with International Traffic in Arms Regulations (ITAR). While the ITAR does not currently specifically address programmable systems on a chip, the Department of State clarified that such designs are not subject to ITAR export controls if "all of the non-programmable elements are common to an integrated circuit used in an item that is not a defense article."[22] As a result, according to a program official, Increment 1 contractors performing early design work have all received formal determinations of export control classifications from the Department of State—known as Commodity Jurisdictions—that their Increment 2 designs are not ITAR controlled. The official said the Commodity Jurisdiction determinations also apply to the Increment 2 contract awards. Obtaining these determinations will enable manufacturing of ASICs in compliance with ITAR. The Office of the Under Secretary of Defense for Research and Engineering approved this approach in July 2020.

Based on this approach for addressing information security and export compliance, DOD officials said they are planning to work with GlobalFoundries to develop and eventually manufacture the Increment 2 microelectronic components at the company's Malta, New York fabrication facility. This facility is not accredited for trust, although GlobalFoundries indicated that with DOD funding, it could implement controls and achieve trust accreditation for the facility. GlobalFoundries

[21]A system-on-a-chip is an integrated circuit chip that contains a broad range of system components and includes extensive programmability, distinguishing it from ASICs, which are custom-built for a specific use.

[22]U.S. Dept. of State, Directorate of Defense Trade Controls, ITAR/USML Updates FAQs, response dated Aug. 16, 2020 at https://www.pmddtc.state.gov/ddtc_public?id=ddtc_public_portal_faq_detail&sys_id=8215c8a9db9bb3807ede365e7c9619d5.

also announced in May 2020 that it is implementing compliance with ITAR standards by the end of 2020, although an official from the DMEA said this would entail additional cost. Additionally, DOD officials said they are conducting technology demonstrations to eventually qualify another potential supplier. These demonstrations support microelectronics modernization activities that enable defense systems to keep pace with commercial microelectronics technological advances, reduce reliance on obsolete microelectronics, and mitigate DOD's reliance on sole-source foundries for assured state-of-the-art microelectronics.

Increment 2 Program Is Already Experiencing Development Delays

Development of the integrated circuit for Increment 2 cards is already approximately a year behind schedule based on design steps initially scheduled in mid-2018. Two development challenges for Increment 2 cards are (1) the time needed to design a smaller, advanced microelectronic integrated circuit as initially planned, and (2) developing memory that can be programmed more than once, also referred to as reprogrammable memory.

Representatives from Marvell Government Solutions—which acquired GlobalFoundries's ASIC business and is working with some Increment 1 contractors to develop Next-Generation ASIC designs for Increment 2—described the integrated circuit design process as iterative phases that turn customer-defined functionality and requirements into hardware-producing data. They noted that the various design steps yield prototypes for customers to evaluate against their requirements, at which point flaws or discrepancies can be identified and addressed. Progression through these design steps can take up to 2 years for some designs, according to Marvell representatives. Air Force officials said that, although the initial schedule for achieving these design steps was established in mid-2018, the program did not award modifications to the MGUE Increment 1 other transaction agreement contractors for Next-Generation ASIC studies and risk reduction work until mid-2019. The overall program is also behind schedule. The Air Force initially planned to award contracts for the Next-Generation ASIC and Increment 2 M-code cards in mid-fiscal year 2020, but the service did not award the contracts until November 2020.

The capability to write integrated circuit memory is needed in order for the chip to be developed as a primarily commercial item and later programmed with defense-specific functionality in a post-production environment. The Air Force funded development of programmable memory for the Increment 2 integrated circuit, which a program official also described as a security requirement. A GlobalFoundries official indicated that the company completed development work for one-time

programmable memory and that it is now available to the Increment 2 program.

However, the Increment 2 program has also been working with GlobalFoundries to develop memory that can be reprogrammed multiple times. GlobalFoundries officials indicated that initial efforts to develop the reprogrammable memory resulted in an Increment 2 circuit design that was not viable and that, according to the 2018 schedule, this capability was needed by November 2020 to support a key design step during which the integrated circuit design is nearly finalized. A GlobalFoundries official said the company updated its research and development schedule to reflect a validated reprogrammable design planned for the end of fiscal year 2022. An Increment 2 program official indicated that, although completion of the previously noted design step shifted from November 2020 to late fiscal year 2021, the GlobalFoundries schedule does not align with this timeline. It is therefore unlikely, given the GlobalFoundries projections, that the capability will be available in time for incorporation into Increment 2 cards. Increment 2 program officials also noted that one-time programmable memory was previously considered a fallback solution. However, the schedule and technical challenges with the multiple-time programmable memory have led the program office to focus on the one-time programmable memory solution.

Delays in Completing M-Code Cards Have Created Challenges and Uncertainties for Receiver Modernization Efforts

Delays in developing M-code cards are contributing to delays in—and increasing costs for—receiver modernization efforts that are dependent on the Increment 1 program. DOD has not yet determined the full extent of the development effort, the time frames, and costs associated with widely integrating and fielding M-code receivers across the department. DOD is taking steps to enable fielding modernized receivers that use Increment 1 M-code cards—or other cards based on Increment 1 technologies—by working to identify integration and production challenges.

M-code Card Problems are Delaying Receiver Development and Increasing Costs

GPS receiver modernization efforts—including those for some MGUE Increment 1 lead weapon systems—are ongoing and are tightly coupled to M-code card development. This linkage means delays in M-code card development have led to delays in receiver development. Air Force receiver program officials said that MGUE is the biggest risk for multiple receiver modernization efforts because those efforts rely on the underlying technologies—the M-code cards—MGUE provides. Specifically, delays in the Raytheon Technologies aviation/maritime M-code card development, and the resulting schedule breach, are contributing to schedule delays and cost increases for receiver

development efforts that depend on those cards. For example, recent schedule slips in the MGUE Increment 1 aviation/maritime card are directly affecting MAGR-2K-M receiver development. Until the Raytheon Technologies aviation/maritime M-code card development effort is rescheduled, the Air Force will not know the extent of delay in the MAGR-2K-M developmental effort. As a result of the aviation/maritime M-code card delay, according to MAGR-2K-M program officials, the receiver program is also expected to breach its acquisition program baseline schedule. That delay is likely to grow with any additional delays in Raytheon Technologies M-code card development. Program officials anticipate that the cost of the MGUE Increment 1 delays will be about $20 million.

Air Force receiver development officials noted that, while the Embedded GPS Inertial Navigation System—Modernized (EGI-M) program has not yet been affected by MGUE Increment 1 delays, they expect to see the effects of those delays beginning in fiscal year 2021. They anticipate a 9-month delay in the delivery of production-representative EGI-M units, from February 2022 to November 2022. Officials also noted that the estimated cost effect of the MGUE delays will be about $14 million.

Additionally, delays to dependent receiver development programs, in turn, are having ripple effects on weapon programs that will use those receivers. Some programs that plan to integrate new MAGR-2K-M or EGI-M receivers into their weapon systems are facing integration delays and changing acquisition plans as a result of MGUE and corresponding receiver development delays.

- Navy officials explained that no MAGR-2K-M receiver integration is taking place on Navy aircraft because they do not have receiver hardware mature enough for further testing. According to Air Force officials, the MGUE program office is providing updated M-code test cards to facilitate delivery of MAGR-2K-M prototype units to the Navy integration laboratories to enable early integration and test. Navy officials added that mature hardware for MAGR-2K-M is not expected until fiscal year 2022 or 2023. Similarly, Navy officials said that, currently, no M-code card integration with EGI-M receivers was taking place because the service lacks mature MGUE Increment 1 cards required for further testing.
- Navy officials noted that F/A-18 fighter aircraft will no longer be fitted with the MAGR-2K-M receiver as initially planned because, given delays on the MGUE Increment 1 and MAGR-2K-M programs, the Navy determined that decommissioning plans for these aging aircraft

do not justify the GPS receiver upgrade. According to DOD officials, other weapon systems that will no longer be fitted with modernized M-code receivers due to decommissioning plans include the AV-8B strike aircraft and the MH-53E helicopter.

Successive delays to DDG 51 class integration also affect M-code integration on Navy surface vessels. According to receiver modernization program officials, the Navy does not plan to transition GPNTS units on its surface fleet to M-code until MGUE Increment 1 operational testing is successfully completed on the DDG 51 class. Without a revised schedule for the aviation/maritime card, Navy officials said they did not have a definitive schedule for weapon system-level developmental testing and operational testing on the DDG 51 class. They noted that, once operational testing is complete, the Navy can begin integrating M-code cards into GPNTS units installed on other surface vessels. Navy officials also told us they are planning for a full MGUE operational capability on surface vessels in 2028, which will comprise 251 receivers on 131 vessels.[23]

MGUE Increment 1 delays are also hindering development of a timely M-code solution for weapon systems—such as the Patriot system—that are adapting Increment 1 technologies to their specific needs but not using receivers tested as part of the MGUE Increment 1 program. According to Army officials, as MGUE development continues to be delayed, funding to support M-code integration into the Patriot system has also been delayed. Officials said that this near-term funding and integration schedule uncertainty may affect the Patriot's ability to defeat existing threats. They added that they are mitigating this risk in part by planning an extended user evaluation of the M-code-capable Patriot system in 2021, to validate functionality before making additional card procurements.

Similar to the Increment 1 program, the MGUE Increment 2 program is developing a card capable of processing M-code signals for specific applications, but the program is only developing receiver equipment that will integrate that card for handheld applications and munitions. The Increment 2 program is still in early development, but the program strategy notes that development of other Increment 2 compatible receivers will follow a process similar to that employed for Increment 1. That receiver development process will include integration work with

[23]Some vessels are expected to receive more than one receiver.

security-certified Increment 2 cards that have undergone developmental testing to validate receiver requirements.

Once receiver development delays are resolved, DOD expects that integrating M-code capability into additional, non-lead weapon systems may be expedited because some non-lead weapon systems will use the same receivers tested in the MGUE program. For example:

- Navy officials said the Naval Air Warfare Center will integrate M-code receivers, including the MAGR-2K-M receivers, into aircraft. According to Navy officials, the Air Force's testing of the MAGR-2K-M receiver on the B-2 as a lead weapon system for M-code cards will help other aircraft employing that same modernized receiver, such as the MV-22B multi-role aircraft, with their own integration and testing. According to a Raytheon representative, the existing Miniature Airborne GPS Receiver 2000 (MAGR-2K) is currently used on multiple aircraft. Air Force receiver development officials described the modernized MAGR-2K-M receiver as a replacement for these older MAGR-2K receivers. As a result, testing of the M-code capability on the lead-system B-2 aircraft will verify many of the same functions and requirements that are common to those other aircraft and should expedite eventual integration into those aircraft.
- According to Navy receiver modernization program officials, the DDG 51 class lead weapon systems team for MGUE Increment 1 is integrating and testing the MGUE Increment 1 card within the GPNTS receiver system. Navy officials said the GPNTS configured with legacy GPS cards is currently installed on two DDG 51 class vessels for testing and will eventually be deployed on all major surface vessels (destroyers, cruisers, littoral combat ships, and others). According to Navy officials, when the aviation/maritime M-code card is operationally tested and proven, it will be considered ready to replace the existing GPS cards in all those receivers. They expect replacement of the existing GPS cards with M-code cards to be straightforward, including a 2-week software installation period for GPNTS to function with the new cards. Table 3 identifies systems that will be integrating the MAGR-2K-M and other modernized M-code capable receivers.

Table 3: Modernized Military Code (M-code) Receiver Integration Plans

Modernized M-code Receiver	Weapon System Integrating M-code Receiver	Anticipated Procurement Quantities (approximate)
MAGR-2K-M[a] (aviation)	B-2, E6-B, MV-22B, and others	3,000
EGI-M or R-EGI[b] (aviation)	B-1B, KC-130J, F/A-18E/F, F-15, F-22, E-2D, and others	10,000
MAPS[c] (ground)	M1 Abrams, M2 Bradley, JLTV[e], Stryker, M109, M1064, and others	20,000+
GPNTS (maritime)[d]	Navy surface vessels - destroyers, cruisers, aircraft carriers, amphibious craft, and others	251

Source: GAO analysis of Department of Defense information. | GAO-21-145

[a]MAGR-2K-M = Miniature Airborne Global Positioning System Receiver 2000 – Modernized.
[b]EGI-M = Embedded Global Positioning System Inertial Navigation System – Modernized. The Resilient Embedded Global Positioning System Inertial Navigation System (R-EGI) program is developing an aircraft receiver based on a modular, open-architecture design for which, according to program officials, the government will obtain the necessary technical data rights.
[c]MAPS = Mounted Assured Positioning, Navigation, and Timing System.
[d]GPNTS = Global Positioning System-Based Positioning, Navigation, and Timing Service.
[e]JLTV = Joint Light Tactical Vehicle.

DOD Uncertain of the Full Extent of Effort Needed to Widely Field M-code Receivers, but is Taking Steps to Prepare for Broader Integration and Production

DOD is uncertain of the timeframes, extent, and cost of the effort needed to widely integrate and field M-code receivers. Integrating M-code cards into some lead and non-lead weapon systems across DOD will require that each military service determine the level of work needed to adapt the cards to the receiver and mission equipment specific to each of the hundreds of different types of weapon systems. As a result, the amount of additional development and integration work is expected to vary for each weapon system and could range from a few weeks to several years. In addition, some of the MGUE lead systems will likely require additional developmental and operational testing. According to DOD, it is taking steps to address integration and production challenges and enable fielding modernized receivers through 2028.

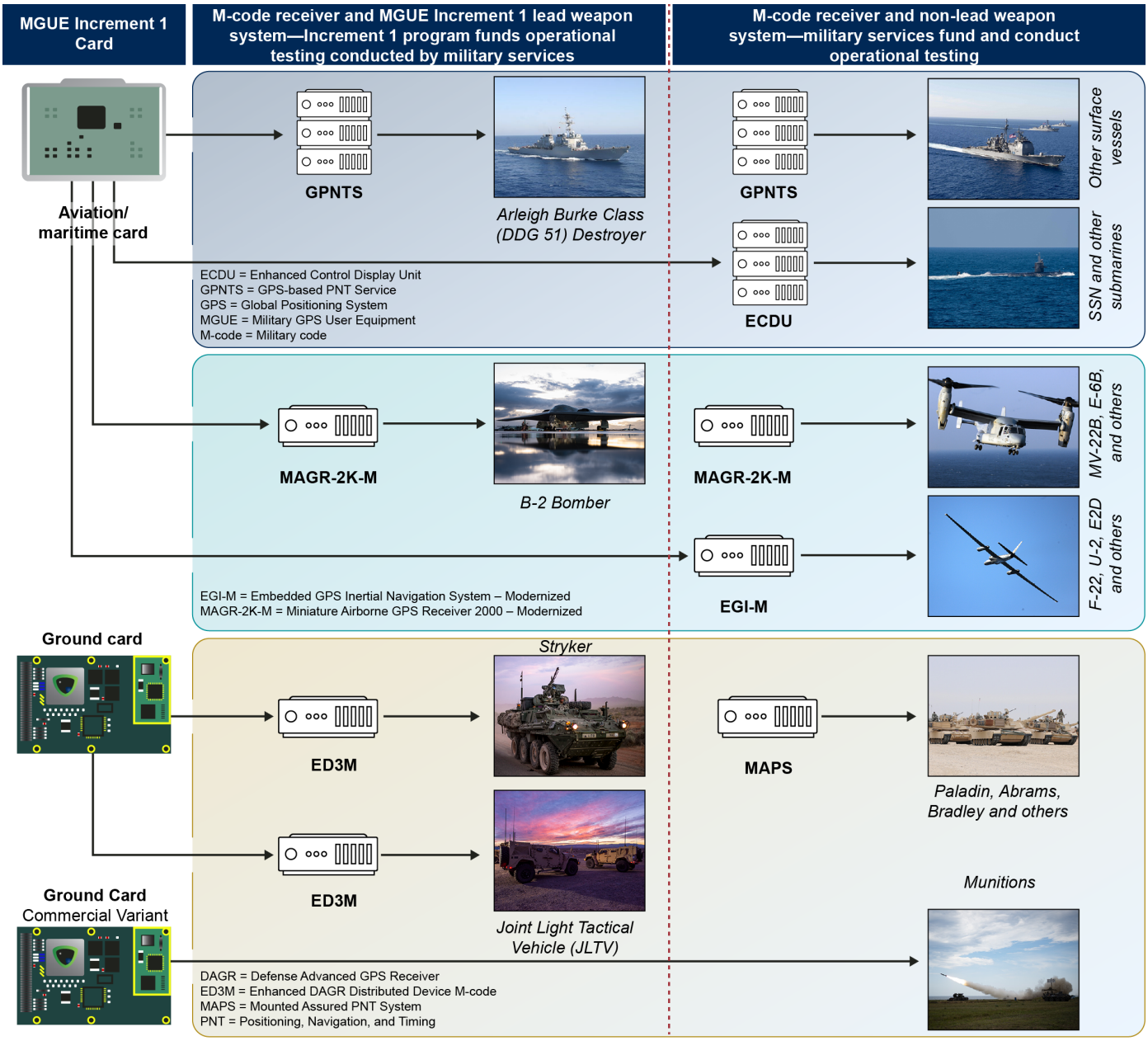
DOD Uncertain of the Full Extent of Effort for DOD-wide M-code Development, Testing, and Integration

DOD has not yet determined how long it will take to complete development and operational testing for the various weapon systems once M-code cards and receivers are broadly available. MGUE officials stated that it is up to each program office to conduct whatever operational testing is required to ensure the new integrations meet their mission-specific requirements. For multiple non-lead weapon systems, particularly those with performance requirements or receiver configurations that differ from the lead weapon systems, the services will need to conduct their own additional development and operational testing outside of the MGUE program of record. The amount of additional development and testing is expected to vary widely, requiring just a few weeks to integrate

aviation/maritime cards into GPNTS on naval surface vessels, to as long as 3 years of additional work to integrate the M-code capable EGI-M receiver into the CH-53K helicopter, Navy officials explained.

Figure 9 provides a notional representation of how some weapon systems will require integration or adaptation of MGUE technologies, along with who will fund and conduct operational testing, beyond the Increment 1 program.

Figure 9: M-code Receiver Integration and Operational Testing beyond Increment 1 Program



Source: GAO analysis and representation of Department of Defense (DOD) information (data); GAO adaptation of DOD documentation (Aviation/maritime card and Ground card graphics); Air Force (B-2 and F-22, U-2, E2D and others images); Army (Stryker and Paladin, Abrams, Bradley and others images); Marine Corps (Joint Light Tactical Vehicle image); Navy (DDG 51; SSN and other submarines; Other surface vessels; and MV-22B, E-6B, and others images). | GAO-21-145

Significantly more development and testing will be necessary if programs select M-code cards that have not been field tested in the MGUE program. Although there are two aviation/maritime cards and three ground cards in the MGUE Increment 1 program, the program is structured so that weapon system-level developmental testing and final testing—by either field user evaluation or operational test and evaluation, as applicable—is only conducted on the first available card of each of the two card types. MGUE program officials do not plan formal weapon system-level developmental or field testing of the Raytheon Technologies ground card or the BAE Systems aviation/maritime card. They noted that field testing on the JLTV and Stryker will include the BAE Systems ground card to facilitate service procurement decisions.[24]

Additional development and operational testing is particularly necessary where the performance requirements and operating conditions differ from those of the lead weapon systems. For example, Army officials said there is no MGUE Increment 1 lead weapon system for munitions, and the Army's MGUE operational testing on the Stryker will not be applicable to munitions because those tests will not evaluate system attributes unique to munitions. According to Army officials, weapon system-specific performance requirements and environmental effects would be expected to be evaluated in both the laboratory and live-fire environments to qualify each munition, and each munition will undergo operational testing to verify requirements are met.

In December 2017, we reported that DOD had developed preliminary—but incomplete—plans to fully develop and field M-code cards across the more than 700 weapon systems that will need to make the transition from the current technology.[25] We noted that DOD prepared initial cost estimates for department-wide fielding of a fraction of these weapon systems. At that time, DOD estimated a cost of $2.5 billion to integrate and procure M-code cards, including the 28 weapon systems that were funded through fiscal year 2021. This represented less than 4 percent of the 716 weapon systems identified at that time for transitioning to M-code. Since then, DOD has continued collecting information from the services and in April 2019, provided a classified report to Congress indicating

[24]While the BAE Systems ground card is not expected to undergo final testing as part of the MGUE Increment 1 program, MGUE program officials indicated that the both the Army and the Marine Corps can, at their discretion, include the BAE Systems card in their lead platform final testing, provided such testing does not interfere with the testing of the program-certified L3Harris ground card.

[25]GAO-18-74.

projected costs over the 5-year Future Years Defense Plan, as well as through 2029. In an unclassified portion of that report, DOD indicated that the estimates may be continuously revised. Additionally, a senior official in DOD's Office of the Chief Information Officer indicated that budget planning and M-code user equipment prioritization activities are ongoing, with updated information likely to be available in early 2021.

Additional M-code Integration Likely Necessary for Two Lead Weapon Systems

The Army and the Marine Corps are planning to acquire M-Code receiver solutions for the Stryker and the JLTV for operational use that are different from the MGUE Increment 1 receiver configurations. While this GPS receiver equipment will incorporate MGUE-derived card technology, these M-Code capable receiver solutions will likely require additional developmental and operational testing.

- According to Army officials, delays to the MGUE Increment 1 program resulted in the MGUE program's schedule lagging behind the Army's GPS user equipment modernization requirements. According to Army officials, this is a contributing factor in the Army's decision to pursue other card options as part of its strategy to integrate, test, and field a common M-code-capable GPS receiver—known as the Mounted Assured PNT System (MAPS)—on the Stryker vehicle and other Army ground vehicles (e.g., M2 Bradley Infantry Fighting Vehicle and the M109 Paladin howitzer). The MAPS program aims to acquire user equipment that draws from GPS as well as alternative positioning, navigation, and timing sources, and that distributes corresponding data to various pieces of mission equipment aboard a given weapon system. For the MAPS program, Army officials stated that they are considering two contractor solutions, each of which incorporates cards using MGUE Increment 1-derived technology. As part of the MAPS effort, the Army has tested an ED3M paired with an anti-jam antenna that houses the M-code card, according to Army officials. They stated that this configuration differs from the ED3M configuration tested in the MGUE Increment 1 program, where the MGUE card is installed within the ED3M device. The Army plans an initial production decision for the M-code-capable MAPS solution in early 2022, with fielding to continue until at least 2028, according to Army officials.
- Marine Corps officials stated that for the Corps' JLTVs, they are seeking to field a single card configuration and are monitoring the GPS receiver results for the Army's MAPS program to potentially use that system. For MGUE Increment 1 testing on the JLTV, the testing configuration uses two ground cards, one in the Commander Smart Display Unit (CSDU), and one in an ED3M. The Marine Corps began its MGUE lead weapon system efforts with the CSDU, but decided not

to procure it for fielding since, among other reasons, the CSDU does not support the JLTV's needs for GPS signal distribution to various on-board systems. In 2019, the JLTV contractor replaced the DAGR Distributed Device being used in the vehicle with an ED3M as a stand-alone positioning, navigation, and timing device. The Marine Corps incorporated the ED3 equipped with an Increment 1 card into MGUE testing, along with the CSDU. This change permitted required signal distribution and a second receiver enabled more robust data collection during test events. As with the MGUE Increment 1 program's efforts with the Stryker vehicle, the M-code card is installed within the ED3M receiver. Therefore, if the Marine Corps selects the ED3M configuration under consideration for the Army's MAPS program, it will be a different receiver configuration from that tested on the JLTV for the MGUE Increment 1 program.

DOD is Taking Steps to Identify Integration Challenges in Non-Lead Weapon Systems

The military services are pursuing their own various efforts to integrate MGUE-derived M-code card technologies in non-lead weapon systems. These efforts make use of pre-production M-code test cards to identify integration challenges.

- Despite some challenges resulting from Increment 1 delays, officials from the Army's Patriot program, for example, told us they are making progress integrating and testing a BAE Systems ground card that is similar to the M-code card the contractor is developing under the Increment 1 program. According to program officials, sometime in late 2016 or early 2017 the Patriot program received prototype M-code cards integrated into an ED3M receiver. The program tested these cards through an iterative development and testing process, finding some issues that were resolved and shared with the Increment 1 program. Program officials further explained that, as of February 2020, the Patriot program completed integration testing and plans to begin an extended user evaluation within the Indo-Pacific Command by early 2021 using production cards. Even though the Patriot is not a lead weapon system, it is functioning as a pathfinder for development and testing on missile programs.
- The Army has also undertaken efforts to adapt MGUE technology to munitions using a GPS receiver card that L3Harris modified for munitions based on its Increment 1 ground card. Army officials told us that the modified L3Harris card is being employed in the Army's

Precision Guidance Kit (PGK).[26] Officials explained that, while PGK is compatible with the MGUE Increment 1 ASIC, they described the card configuration for this application—where space is very limited—as being a custom design for both the M-code card, as well as the GPS receiver software. Army officials added that PGK configured with an M-code card is expected to complete qualification testing in fiscal year 2021, with production to start the following fiscal year.

- According to Navy officials, the Conventional Prompt Strike program conducted flight tests in 2019 and 2020 with a BAE Systems prototype Navstrike-M receiver. The Navstrike-M employs an M-code card and is based on the legacy Navstrike receiver that BAE Systems developed for use in guided munitions. The Conventional Prompt Strike program conducted tests with the Navstrike-M to reduce integration risk, but neither test employed the receiver for actual navigation in flight.
- The Air Force is also modernizing Embedded GPS Inertial Navigation System (EGI) receivers to utilize M-code technology, with the modernized receiver to be called the EGI-M. EGI receivers are widely used in aviation systems including the F-22, E-2D, B-1, and KC-130J, among others. There are currently more than 260 EGI configurations in operation. Part of the modernization effort, in addition to adding M-code capability, is to reduce the different configurations of the new EGI-M to 16. These will include small, medium, and large receiver sizes needed for the different aircraft, according to Air Force officials. Air Force officials added that they have been working to integrate an Increment 1 aviation/maritime card into a legacy EGI receiver to help reduce development challenges.

DOD Is Taking Steps to Address Production Challenges Through 2028

ASIC designs for each of the Increment 1 contractor's cards are mature and in production, and DOD is taking steps to enable fielding modernized receivers by purchasing these ASICs in bulk to mitigate the effect of losing its sole manufacturing source for these components. Specifically, the bulk purchases will help ensure sufficient supplies of Increment 1 ASICs are on hand for future integration into M-code cards and modernized receiver equipment, based on estimated need through 2028. This, in turn, will enable the services to field modernized receiver equipment more widely across DOD weapon systems. The Increment 1 ASICs are all fabricated by GlobalFoundries in trust-accredited facilities,

[26]The Army describes the PGK for artillery munitions as containing a GPS guidance kit with fuze functions and an integrated GPS receiver to correct for errors in targeting, reducing the number of artillery projectiles required to attack targets.

but each ASIC is facing the end of production as the company transitions away from these technologies. Specifically, final orders of the L3Harris Increment 1 ASIC were due by the end of June 2020, and final orders for the Raytheon Technologies ASIC can be made no later than the end of 2022. Orders for the BAE Systems Increment 1 ASIC will continue to be placed with GlobalFoundries, with delivery between January 2023 and the end of December 2024 dependent upon funding and successful trust accreditation for ON Semiconductor.

DOD officials indicated they asked the services and other components in 2019 to determine MGUE Increment 1 operational and sustainment needs—as well as projected foreign military sales—through 2028, and requested $405 million in the fiscal year 2021 President's Budget to begin a bulk buy of nearly 900,000 Increment 1 ASICs.[27] Budget estimates are for the ASICs only—there will be additional costs for procurement of the full M-code cards. Funding will also be needed in fiscal year 2022 to complete the ASIC bulk buy. This total does not include any of the L3Harris ASICs, as they will be out of production by the time DOD conducts the bulk buy. However, according to Army officials, the service procured approximately 200,000 of the L3Harris ASICs to support both ground system and precision munition M-code cards ahead of GlobalFoundries' pending sale of the facility that produces the L3Harris ASIC.

Agency Comments

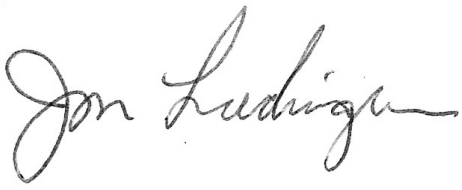
We provided a draft of this report to DOD for review and comment. DOD provided an official comment letter (reproduced in appendix II) which did not disagree with our findings. They also provided additional comments highlighting progress the program has made, as well as technical comments which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Acting 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 ludwigsonj@gao.gov. Contact points for our Offices of Congressional Relations and Public

[27]A DOD official indicated that $405 million would cover the cost of approximately 400,000 ASICs.

Affairs may be found on the last page of this report. Key contributors to this report are listed in appendix III.



Jon Ludwigson
Director, Contracting and National Security Acquisitions

List of Committees

Chair
Ranking Member
Committee on Armed Services
United States Senate

Chair
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

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

Chair
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

Appendix I: Objectives, Scope, and Methodology

The National Defense Authorization Act for Fiscal Year 2016 included a provision that the Air Force provide quarterly reports to GAO on next-generation Global Positioning System (GPS) acquisition programs. The Act also included a provision that GAO brief congressional defense committees on the first report, and at GAO's discretion, on subsequent quarterly reports.[1] We published reports on the overall GPS enterprise and on schedule risks to the ground control segment of the GPS mission, referred to as the Next Generation Operational Control System (OCX), in December 2017 and May 2019, respectively.[2] This report assesses the Department of Defense's (DOD) progress and challenges (1) developing military code (M-code) receiver cards, and (2) developing receivers using the M-code cards and taking other steps needed to make them available for fielding across DOD weapon systems.

To assess progress and challenges associated with developing M-code receiver cards, we reviewed past and current schedules, cost estimates, key milestones, and risk assessments for the Military GPS User Equipment (MGUE) Increment 1 and 2 programs. This included integration and test data for the various contractors' M-code cards. To determine the extent of any schedule delays we compared original and current test and integration schedules. We also reviewed service and DOD M-code implementation data, and positioning, navigation, and timing (PNT) strategy documents. We analyzed M-code receiver card test and integration plans and data for the MGUE Increment 1 lead weapon systems (B-2, DDG 51 class, Stryker, and Joint Light Tactical Vehicle) to assess progress against those plans and identify any areas of risk. We interviewed MGUE Increment 1 and 2 Air Force program officials, as well as military service officials overseeing M-code integration on Increment 1 lead weapon systems and military service officials who conduct PNT planning.

We reviewed strategies and plans for ensuring DOD's continued access to trusted, secure, and export-compliant microelectronics, and documentation related to integrated circuit production risks facing both MGUE program increments. We interviewed officials from the offices of the DOD Chief Information Officer and the Under Secretaries of Defense

[1]Pub. L. No. 114-92, § 1621 (2015).

[2]GAO, *Global Positioning System: Updated Schedule Assessment Could Help Decision Makers Address Likely Delays Related to New Ground Control System*, GAO-19-250 (Washington, D.C.: May 21, 2019); and *Global Positioning System: Better Planning and Coordination Needed to Improve Prospects for Fielding Modernized Capability*, GAO-18-74 (Washington, D.C.: Dec. 12, 2017).

for Acquisition and Sustainment, and Research and Engineering; the Defense Microelectronics Activity; and representatives from GlobalFoundries and Marvell Government Solutions about the production plans and development of advanced microelectronics for the MGUE Increment 1 and 2 programs.

To assess progress and challenges associated with developing receivers using M-code cards and taking other steps needed to make M-code capable receivers available for fielding across DOD weapon systems, we reviewed applicable documentation for the Miniature Airborne GPS Receiver 2000 – Modernized; the GPS-based Position, Navigation, and Timing Service; the Enhanced Defense Advanced GPS Receiver Distributed Device M-code; and the Embedded GPS Inertial Navigation System – Modernized. In addition, we reviewed applicable program documentation and interviewed program officials for non-lead weapon systems integrating M-code cards and receivers outside the MGUE program of record. Specifically, we judgmentally selected five program executive or other offices overseeing non-lead weapon systems integrating M-code cards—along with their respective receivers—including:

- Army Joint Program Executive Office Armaments and Ammunition,
- Army Program Executive Office Missiles and Space, Lower Tier Project Office,
- Navy Program Executive Office Command, Control, Communications, Computers, Intelligence and Space Systems, Communications and GPS Navigation Program Office,
- Navy Program Executive Office Submarines, and
- Navy Strategic Systems Programs.

We selected these offices based on budget data from the military services and compiled by the DOD Office of the Chief Information Officer, which identified projected funding through 2023 for M-code receiver programs that will be integrating M-code cards. We also based our selection on information from the MGUE Increment 1 program office that identified programs conducting integration and test activities with prototype M-code cards. We tailored our selection of weapon systems to ensure that a breadth of weapons system types was included, such as munitions and submarines, in addition to those represented by the lead weapon systems. We reviewed budget data associated with DOD's plans to purchase Increment 1 microelectronics in bulk, and interviewed officials

from DOD's Offices of Cost Assessment and Program Evaluation and the Under Secretary of Defense for Acquisition and Sustainment, as well as Army officials, regarding these plans.

We conducted this performance audit from April 2019 to January 2021 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

DEPARTMENT OF THE AIR FORCE
WASHINGTON, DC

OFFICE OF THE ASSISTANT SECRETARY

MEMORANDUM FOR GOVERNMENT ACCOUNTABILITY OFFICE

FROM: SAF/AQ
1060 Air Force Pentagon
Washington, DC 20330-1060

SUBJECT: Air Force Response to GAO Draft Report, "GPS MODERNIZATION: DOD Is Closer to a New Jam-Resistant Capability, But Widespread Use Remains Years Away" (Project Code 103484)

This is the DoD response to the GAO Draft Report 21-145, "GPS MODERNIZATION: DOD Is Closer to a New Jam-Resistant Capability, But Widespread Use Remains Years Away (Project Code 103484)."

The Department reviewed the report and has several administrative and technical comments. We provided these comments directly to your action officer to correct factual inaccuracies. The SAF/AQ point of contact is Maj Patrick DuVall, SAF/AQSS, (703) 695-3462, DSN 225, or via email at patrick.duvall@us.af.mil.

12/28/2020

X Duke Richardson

Signed by: RICHARDSON.DUKE.Z.1156456663
DUKE Z. RICHARDSON, Lt Gen, USAF
Military Deputy, Office of the Assistant Secretary of the Air Force (Acquisition, Technology & Logistics)

cc:
SAF/AQS
SAF/AQX

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact named above, the following staff members made key contributions to this report: David Best (Assistant Director), Andrew H. Redd (Analyst-in-Charge), Marie P. Ahearn, Pete Anderson, Susan Ditto, Ruben Gzirian, Matthew Metz, Jonathan Mulcare, and Roxanna Sun.