



December 2022

MILITARY READINESS

Actions Needed to Further Implement Predictive Maintenance on Weapon Systems

Accessible Version

Highlights of [GAO-23-105556](#), a report to the Committee on Armed Services, House of Representatives

Why GAO Did This Study

DOD is continually challenged to provide battle-ready ground combat systems, ships and submarines, and aircraft to its warfighters, spending nearly \$90 billion each year on weapon systems maintenance. To improve availability of weapon systems, DOD is implementing predictive maintenance. Often used in the private sector, predictive maintenance relies on personnel to use condition-monitoring technology and data analytics to schedule maintenance based on evidence of need.

House Report 117-118, which accompanied a bill for the National Defense Authorization Act for Fiscal Year 2022, included a provision for GAO to examine the use of predictive maintenance for the sustainment of ground combat systems, ships and submarines, and aircraft. GAO examined the extent to which the military services have (1) implemented and (2) assessed the performance of predictive maintenance, and described (3) challenges and efforts to address challenges with implementing predictive maintenance. GAO reviewed DOD guidance and budget materials for predictive maintenance, interviewed maintenance officials, and visited units implementing predictive maintenance.

What GAO Recommends

GAO is making 16 recommendations to the Army, Marine Corps, Navy, and Air Force to develop plans to implement predictive maintenance and assess its performance. DOD generally concurred with the recommendations.

View [GAO-23-105556](#). For more information, contact Diana Maurer at (202) 512-9627 or maurerd@gao.gov.

MILITARY READINESS

Actions Needed to Further Implement Predictive Maintenance on Weapon Systems

What GAO Found

The Department of Defense (DOD) issued an interim predictive maintenance policy in 2002, but the military services made limited progress implementing it until recently. In 2007, DOD instructed the military services to designate a single focal point for predictive maintenance, provide funding, and begin implementing predictive maintenance to achieve readiness at the best cost where it is technically feasible and beneficial. While the military services have begun piloting predictive maintenance programs on some weapon systems, they do not replace parts or components regularly based on predictive maintenance forecasts. GAO found that the military services have not consistently adopted and tracked implementation of predictive maintenance. By developing plans to implement predictive maintenance, including action plans and milestones for weapon systems, the military services would be better positioned to determine where, when, and how to effectively adopt predictive maintenance.

The military services have reported examples of how predictive maintenance has improved maintenance outcomes. According to military service officials, unplanned maintenance—which adversely affects costs and operations—can be reduced through greater use of predictive maintenance. Army and Navy officials also provided examples of predictive maintenance possibly preventing accidents on aircraft such as the AH-64 Apache and the F/A-18 Super Hornet.

Predictive Maintenance Has Been Used for AH-64 and F/A-18 Aircraft



Source: U.S. Army/Sergeant S. Galimore (AH-64); U.S. Marine Corps/Corporal D. J. Bjorndal (F/A-18). | GAO-23-105556

Military service officials acknowledge that, while they have examples of improvements they attribute to predictive maintenance implementation, the examples are from limited experience, and the military services generally lack metrics to evaluate the results of predictive maintenance. By developing plans with goals and metrics, and establishing procedures to monitor predictive maintenance, the military services will be better able to determine whether predictive maintenance achieves expected results and improves military readiness.

The military services identified personnel, parts, and technology resource challenges to implementing predictive maintenance and have taken some actions to address challenges. For example, temporary policy exemptions allow personnel hours saved using predictive maintenance to be used to address maintenance backlogs in other systems. The military services have also begun efforts to allow units to order parts ahead of need rather than waiting for the part to break. The military services also recognize that shifting to predictive maintenance is a cultural challenge that requires sustained leadership focus.

Contents

GAO Highlights	ii
Why GAO Did This Study	ii
What GAO Recommends	ii
What GAO Found	ii
Letter	1
Background	3
Military Service Implementation of Predictive Maintenance Was Limited From 2002 to 2022	11
Predictive Maintenance Can Work, but Military Services Lack Performance Evaluation	26
Military Services Have Identified and Begun Taking Steps to Address Challenges to Predictive Maintenance	33
Conclusions	44
Recommendations for Executive Action	46
Agency Comments and Our Evaluation	48
Appendix I: Objectives, Scope, and Methodology	50
Appendix II: Comments from the Department of Defense	57
Accessible Text for Appendix II: Comments from the Department of Defense	63
Appendix III: GAO Contact and Staff Acknowledgments	68
Related GAO Products	69
Figures	
Figure 1: DOD Approaches to Weapon System Maintenance	4
Figure 2: Theoretical Approaches to Maintenance Used on a Notional Weapon System	5
Figure 3: DOD and Military Service Organizations Involved in Predictive Maintenance	9
Figure 4: DOD and Military Service Predictive Maintenance Implementation Progress, 2002–2022	12
Figure 5: DOD Weapon Systems with Predictive Maintenance Capabilities as of June 2022	13
Figure 6: The USS Mason Is a Navy Ship Implementing Predictive Maintenance	17

Figure 7: Navy Predictive Maintenance Metrics and Goals for One Aircraft and One Ship Class	31
Accessible Data for Figure 7: Navy Predictive Maintenance Metrics and Goals for One Aircraft and One Ship Class	31

Abbreviations

DOD	Department of Defense
DODIG	DOD Inspector General

This is a work of the U.S. government and is not subject to copyright protection in the United States. The published product may be reproduced and distributed in its entirety without further permission from GAO. However, because this work may contain copyrighted images or other material, permission from the copyright holder may be necessary if you wish to reproduce this material separately.



December 8, 2022

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

The Department of Defense (DOD) is continually challenged to provide battle-ready ground combat systems, ships and submarines, and aircraft to its warfighters, spending nearly \$90 billion each year on weapon systems maintenance. To improve operational availability of these weapon systems, DOD has begun implementing predictive maintenance—a practice that relies on knowledgeable personnel to use condition-monitoring technology such as sensors, data analytics, algorithms, and artificial intelligence to schedule maintenance based on evidence of need.¹ If implemented correctly, predictive maintenance can reform the military services’ approach to weapon systems readiness by reducing unplanned and unneeded maintenance, reducing maintenance delays, and reducing sustainment costs, according to DOD officials.²

In 2021, the House Armed Services Committee noted that the military services have begun developing predictive maintenance programs, and if performed effectively, predictive maintenance can reduce downtime of weapon systems, ensure adequate supply of needed parts, and decrease costs. House Report 117-118, accompanying a bill for the National Defense Authorization Act for Fiscal Year 2022, included a provision for us to examine the incorporation of predictive maintenance into the military services’ weapon system sustainment of ground combat systems, ships

¹Predictive maintenance does not always require the use of artificial intelligence and machine learning. For more information on human roles in designing, developing, deploying and monitoring the use of artificial intelligence and machine learning in achieving objectives, see GAO, *Artificial Intelligence: An Accountability Framework for Federal Agencies and Other Entities*, [GAO-21-519SP](#) (Washington, D.C.: June 2021).

²DOD defines “readiness” as the ability of the U.S. military forces to fight and meet the demands of assigned missions. We previously found that DOD (including operational units and maintenance depots) struggled to achieve readiness goals by addressing sustainment challenges. For more information, see the Related GAO Products pages at the end of this report.

and submarines, and aircraft.³ Our review examines the extent to which the military services (1) implemented predictive maintenance, and (2) assessed the performance of predictive maintenance; and describes (3) challenges to implementing predictive maintenance identified by the military services and efforts to address those challenges.

To address our objectives, we reviewed DOD, Army, Marine Corps, Navy, and Air Force guidance for predictive maintenance, reviewed written responses to questions we sent to the military services along with supporting documents, interviewed knowledgeable officials, and completed site visits.⁴ For our first objective, we reviewed documents detailing predictive maintenance implementation and discussed progress with military service officials. For our second objective, we reviewed assessments of predictive maintenance provided by the military services and discussed them with officials. For our third objective, we asked the military services to identify the primary challenges to predictive maintenance and collected information on their efforts to address those challenges. We focused our review on current systems. We excluded weapon systems undergoing the acquisition process and uncrewed weapon systems from the scope of this review.⁵ The F-35 Joint Strike Fighter is also beyond the scope of this review as we have separately

³H.R. Rep. No. 117-118, at 94 (2021). This report will refer to ground systems, as it includes details related to ground support systems not identified as combat systems, according to Army officials.

⁴Our review included the Army, Marine Corps, Navy and Air Force. For the Army we visited an Infantry Division and a Combat Aviation Brigade. For the Marine Corps we spoke with two logistics groups and an Air Test and Evaluation Squadrons. For Navy ships, we spoke with a Naval Surface Warfare Center. For Naval and Marine Corps aircraft, we visited aircraft test squadrons. For the Air Force, we visited a refueling wing and a bomber wing. Our review included ground combat systems, ships and submarines, and aircraft. The Coast Guard and Space Force were not within the scope of our review. For more information on our scope and the units we visited, see Appendix I.

⁵During the course of our review, we coordinated with the DOD Inspector General, who was also conducting a review of DOD Predictive Maintenance. See DOD Inspector General, *Audit of the Department of Defense's Implementation of Predictive Maintenance Strategies to Support Weapon System Sustainment*, DODIG-2022-103 (Alexandria, VA: June 13, 2022). Our objectives, scope, methodology, and audit work was independent of that of the DOD Inspector General.

reported on that weapon system.⁶ For more information on our scope and methodology, see appendix I.

We conducted this performance audit from November 2021 to December 2022, 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 the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

DOD Approaches to Weapon Systems Maintenance

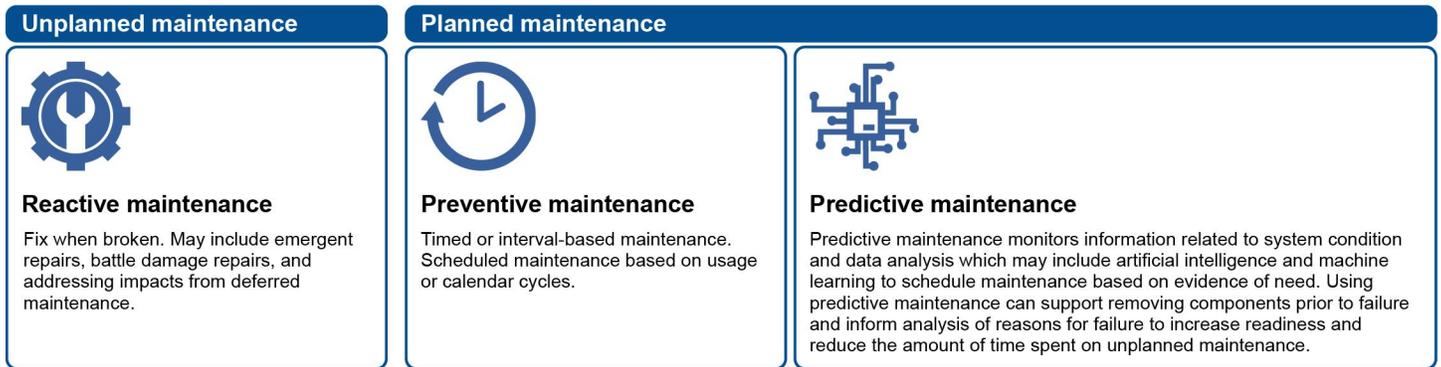
DOD provides maintenance on major weapon systems such as ground combat systems, ships and submarines, and aircraft.⁷ A recent DOD Inspector General (DODIG) report on DOD's implementation of predictive maintenance strategies identifies two main categories of maintenance—reactive and proactive.⁸ Unplanned maintenance is reactive; planned maintenance is proactive, using preventive and predictive maintenance techniques. (See figure 1.)

⁶For examples see GAO, *F-35 Sustainment: DOD Faces Several Uncertainties and Has Not Met Key Objectives*, [GAO-22-105995](#) (Washington, D.C.: Apr. 28, 2022), and GAO, *F-35 Joint Strike Fighter: Cost Growth and Schedule Delays Continue*, [GAO-22-105128](#) (Washington, D.C.: Apr. 25, 2022), along with the related reports section of that report.

⁷We define major weapon systems as systems acquired through major defense acquisition programs. A major defense acquisition program is an acquisition program that is designated by the Secretary of Defense as such or that is estimated to require a total research, development, test, and evaluation expenditure of more than \$300 million or an eventual total procurement expenditure of more than \$1.8 billion (based on fiscal year 1990 constant dollars).

⁸DODIG-2022-103.

Figure 1: DOD Approaches to Weapon System Maintenance



Source: GAO analysis of Department of Defense information. | GAO-23-105556

Note: We define predictive maintenance as any effort that uses condition-monitoring technology or analysis of historical data to anticipate maintenance needs in a manner that reduces unscheduled reactive maintenance or overly prescriptive preventive maintenance. The military services use multiple terms for predictive maintenance or predictive maintenance enablers, including Condition-Based Maintenance (CBM), Condition-Based Maintenance Plus (CBM+), Prognostic and Predictive Maintenance (PPMx), Enhanced Reliability-Centered Maintenance (eRCM), and Predictive Maintenance. Our definition of predictive maintenance includes any efforts described by the terms used by DOD and the military services previously listed. Other data-collection efforts may support predictive maintenance and improve maintenance planning.

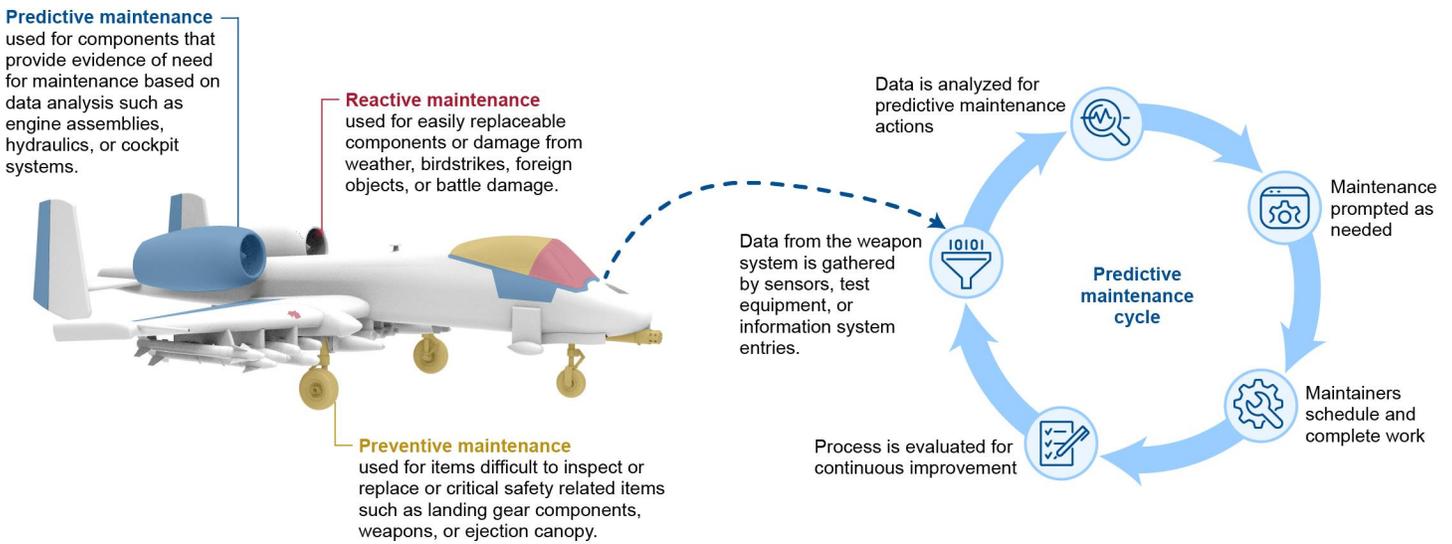
Unplanned reactive maintenance often requires more materials and a higher level of effort than planned maintenance, according to DOD and military service officials. Preventive maintenance is scheduled, or routine maintenance based on timed intervals. Predictive maintenance relies on the military services' ability to use a continuous feedback loop including the use of historical data, and information on the current condition of weapon systems. Predictive maintenance also relies on the ability to effectively store and transfer data, effective data analysis, the willingness of maintainers to act on predictive maintenance prompts, and evaluation of effectiveness, according to the DODIG report.⁹

Each approach to maintenance entails benefits and risks. For example, preventive maintenance may provide greater control over schedule and planned costs, but may occur more or less frequently than necessary. Meanwhile, predictive maintenance could reduce the amount of reactive and preventive maintenance and prevent weapon system failures, but may require up-front investments to incorporate condition-monitoring functions, train maintainers in new skills, and support data analysis,

⁹DODIG-2022-103.

transfer and storage.¹⁰ Reactive maintenance can be the most expensive type of maintenance, according to military service officials. A single weapon system may use all three types of maintenance for different situations, subsystems, or components based on the relative costs and benefits of each maintenance approach. (See figure 2.)

Figure 2: Theoretical Approaches to Maintenance Used on a Notional Weapon System



Source: GAO analysis of Department of Defense information; Sepia100/stock.adobe.com (plane rendering); FourLeafLover/stock.adobe.com (icons). | GAO-23-105556

Note: We selected the weapon system in this figure for ease of illustration only, and may or may not reflect specific practices for the aircraft depicted. We prepared the illustration to demonstrate the use of multiple approaches to maintenance on a single theoretical weapon system and its components, and not to represent actual practices for this aircraft.

The military services sometimes refer to reactive maintenance as “fly to fail” or “run to failure” and state that this approach often results in additional effort and expense. As an example, reactive maintenance may occur if a vehicle tire failed at speed, resulting in additional damage to suspension components and other parts and possible injuries to people. Using reactive maintenance can involve additional expense due to remote locations and unplanned damages. For example, if a weapon system with specialized parts fails in a remote location, the military service may have to pay to deliver parts and personnel with the expertise needed to replace it and perform the repairs at that location.

¹⁰Predictive maintenance may leverage existing condition monitoring capabilities and data produced by the weapon systems, and does not necessarily require adding sensors.

Commercial Transportation Uses Predictive Maintenance for Safety and Savings

The transportation industry uses predictive maintenance to reduce delays, minimize downtime, and save money.

A Tractor-Trailer Offloading Cargo



Trucking. According to industry sources, predictive maintenance decreased roadside breakdowns by 20 percent, reduced maintenance costs by \$2,000-\$12,500 per truck per year, and improved operations.

Rail. Railroads use wayside sensors to support predictive maintenance based on wheel and bearing temperatures and wheel geometry as trains pass to prevent derailments, and avoid down time and repair costs, and may reduce annual maintenance costs by 8-10 percent.

Aviation. Airlines use predictive maintenance to increase operational availability and reduce costs. One airline claims predictive maintenance prompts are valid more than 95 percent of the time. Another company estimates predictive maintenance reduced operation disruptions by 30-50 percent.

Source: GAO analysis of industry data, interviews with industry officials, and Department of Defense data. Photo Source: Greg L. Davis, 436th Airlift Wing Public Affairs, Dover Air Force Base. | GAO-23-105556

Preventive maintenance can also involve additional expenses when requirements are more frequent than necessary. For example, preventive maintenance may require replacing a tire every 30,000 miles or 3 years regardless of use or condition. Predictive maintenance may use data from electronic sensors combined with known historical data to anticipate the optimal time to replace the tire—not too early as to waste money, but also not too late as to let that tire fail unexpectedly. This approach could allow maintenance personnel and vehicle users to perform maintenance when needed and ensure that technicians are available to do the work at the preferred location.

Predictive Maintenance as a Private Sector Best Practice and Effort to Improve DOD Readiness

The use of data-driven methods such as predictive maintenance are increasingly becoming a norm in the transportation industry, according to DOD information and various trade publications.¹¹ Private-sector fleet managers use predictive maintenance to minimize maintenance expense, increase the availability of vehicles to meet customer demand, and increase profits. (See sidebar on previous page.) For example:

- The automotive and trucking industry uses increasingly complex data-rich vehicle systems to predict problems caused by performance deficiencies, provide technical solutions for vehicle safety and reliability, and save money for customers that act on predictions.
- The rail industry uses data algorithms to monitor for predictive maintenance and to help identify defects before derailments occur.¹²
- The airline industry uses predictive maintenance to improve maintenance planning to avoid unexpected failures, flight delays, and cancellations, and reduce the impact of aircraft groundings.¹³

Like the private sector, the military services can use predictive maintenance to improve supply chain and logistics planning and reduce unscheduled downtime. In addition, the military services expect to use predictive maintenance to increase weapon system readiness, according to DOD officials. As we have previously reported, the military services are frequently unable to complete maintenance on time or to achieve military

¹¹DOD issued the first *Condition-Based Maintenance Plus* policy memorandum in 2002 to set the path to establish broad-based capabilities—which include the use of predictive maintenance—for current weapon systems when technically feasible and beneficial. Deputy Under Secretary of Defense (Logistics and Materiel Readiness) (DUSD (L&MR)) Memorandum, *Condition Based Maintenance Plus* (Nov. 25, 2002). See also Theissler, Andreas; Pérez-Velázquez, Judith; Kettelgerdes, Marcel; and Elger, Gordon. “Predictive Maintenance Enabled by Machine Learning: Use Cases and Challenges in the Automotive Industry”, *Journal of Reliability Engineering and Systems Safety*, vol. 215 (2021).

¹²GAO, *Rail Safety: Improved Human Capital Planning Could Address Emerging Safety Oversight Challenges*, [GAO-14-85](#) (Washington, D.C.: Dec. 9, 2013).

¹³See International Air Transport Association, *Best Practices for Component Maintenance Cost Management*, 2nd Edition (Montreal, Quebec, Canada, December 2015). See also Verhagen, Wim J.C., and DeBoer, Lennaert W.M. “Predictive maintenance for Aircraft Components Using Proportional Hazard Models”, *Journal of Information Integration*, vol. 12 (Dec. 2018).

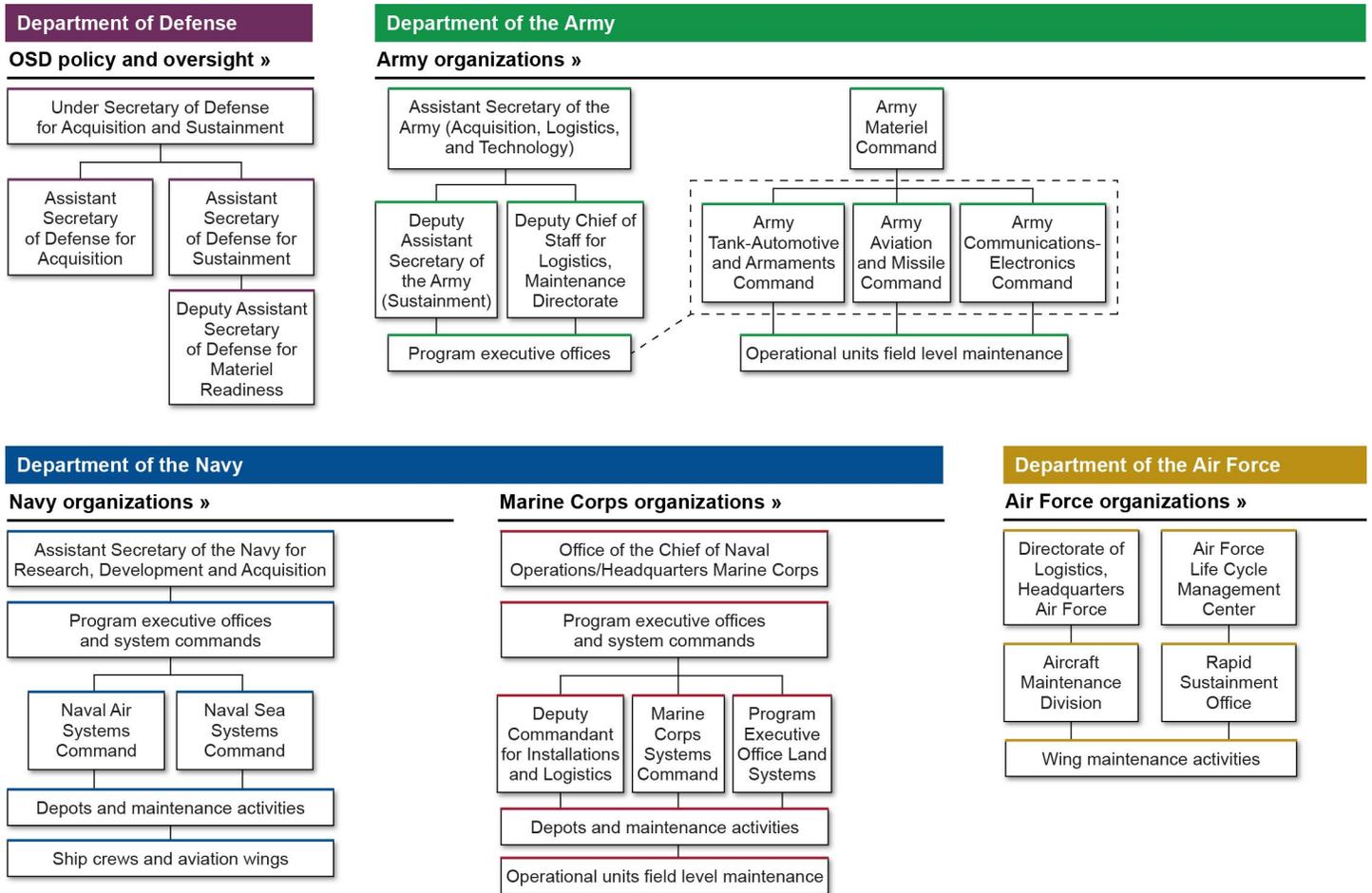
readiness goals.¹⁴ Army, Marine Corps, Navy, and Air Force officials agree that overreliance on reactive maintenance for the last several decades has contributed to readiness challenges. These military service leaders state that predictive maintenance requires a shift in paradigms but has the opportunity to improve readiness and may result in efficiencies.

Roles and Responsibilities

The Assistant Secretary of Defense for Sustainment develops policy, provides guidance, monitors and reviews implementation, and oversees effectiveness of predictive maintenance in DOD under the authority, direction, and control of the Under Secretary of Defense for Acquisition and Sustainment. The military services are responsible for developing service-wide requirements for implementing predictive maintenance and providing resources for those requirements at the service and weapon system levels. (See figure 3.)

¹⁴Delayed maintenance reduces the amount of time weapon systems are available for operations and training, which hinders military readiness, according to DOD and our prior reports. See GAO, *Military Readiness: Department of Defense Domain Readiness Varied from Fiscal Years 2017 through 2019*, [GAO-21-279](#) (Washington, D.C.: Apr. 7, 2021). We previously reported that DOD (including operational units and maintenance depots) struggled to achieve readiness goals by addressing sustainment challenges. For additional reports, see the Related GAO Products pages at the end of this report.

Figure 3: DOD and Military Service Organizations Involved in Predictive Maintenance



Source: GAO analysis of Department of Defense (DOD) and military service information. | GAO-23-105556

Note: The Chief of Naval Operations coordinates with the Commandant of the Marine Corps in sustainment support, acquisition or modernization programs, and maintenance.

Under Secretary of Defense for Acquisition and Sustainment. The offices reporting to the Under Secretary of Defense for Acquisition and Sustainment are responsible for matters related to acquisition, logistics, and materiel readiness. In particular, the Deputy Assistant Secretary of Defense for Materiel Readiness supports policy and management oversight for weapon systems and military equipment maintenance programs.

Military departments. The Secretaries of the military departments are responsible for incorporating predictive maintenance in appropriate guidance and policy for the military services. The military services are

responsible for implementing predictive maintenance, establishing military service-wide maintenance requirements, and providing weapon systems with resources for predictive maintenance. Program managers are required to implement predictive maintenance for current weapon systems where the benefits outweigh the costs, and to reduce down time by minimizing unscheduled repairs and unnecessary scheduled maintenance to enhance operational mission success, among other things.¹⁵

Predictive Maintenance Guidance

DOD established an interim policy on predictive maintenance 20 years ago. A 2002 memorandum outlined policy and directed the military services and other DOD components to evaluate, develop, and implement predictive maintenance technologies and process improvements to reduce unscheduled maintenance and increase operational availability, among other things.¹⁶ In 2007, DOD issued an instruction stating that the military departments and defense agencies shall incorporate predictive maintenance in policy.¹⁷ The instruction also directed program managers to design, develop, demonstrate, deploy, and sustain equipment in accordance with predictive maintenance guidance and procedures to achieve readiness at the best cost.

The 2007 guidance directed predictive maintenance implementation for current weapon systems where technically feasible and beneficial. Further, each military service was to designate a focal point for predictive maintenance efforts and monitor outcomes, among other actions. In 2020, updated guidance required the military services to provide resources for predictive maintenance requirements developed at the service and weapon systems levels.¹⁸

¹⁵DOD Instruction (DODI) 4151.22, *Condition-Based Maintenance Plus (CBM+) for Materiel Maintenance* (August 14, 2020). In addition, the DOD Guidebook, *Condition Based Maintenance Plus* (May 1, 2008) stated the principal objective of predictive maintenance is improved maintenance performance across a broad range of benefits, including greater productivity, shorter maintenance cycles, lower costs, increased quality of the process, better availability, and enhanced reliability of materiel resources.

¹⁶DUSD (L&MR) Memorandum.

¹⁷DODI 4151.22, *Condition Based Maintenance Plus (CBM+) for Materiel Maintenance* (Dec. 2, 2007).

¹⁸DODI 4151.22 (Aug. 14, 2020).

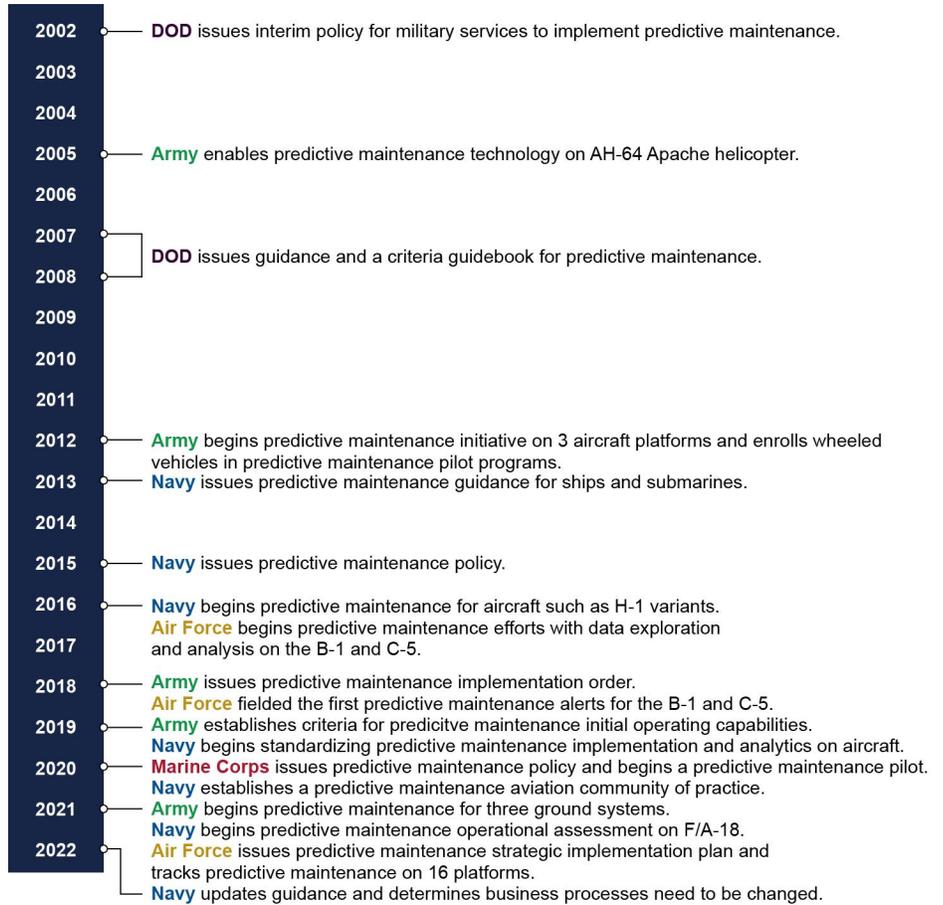
Military Service Implementation of Predictive Maintenance Was Limited From 2002 to 2022

The military services have made limited progress implementing predictive maintenance. Military services lack governance structures sufficient to implement predictive maintenance. In addition, the military services have not consistently adopted and tracked implementation of predictive maintenance.

DOD Issued Predictive Maintenance Policy 20 Years Ago, but the Military Services Made Limited Progress Implementing It Until Recently

Most actions taken to adopt predictive maintenance occurred during the last few years. (See figure 4.)

Figure 4: DOD and Military Service Predictive Maintenance Implementation Progress, 2002–2022

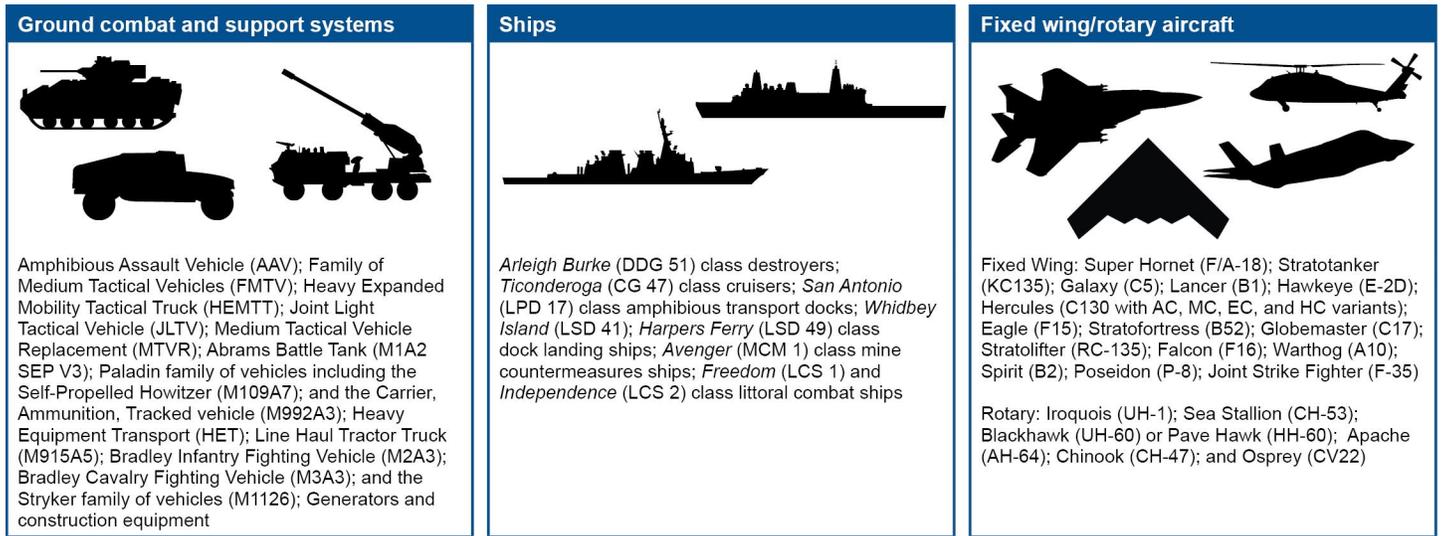


Source: GAO analysis of Department of Defense (DOD) and military services information. | GAO-23-105556

All four military services achieved relatively more progress implementing predictive maintenance on aircraft than on other weapon systems. This progress is in part because sensor technology has been available to enable predictive maintenance on some aircraft as early as 2002—when DOD issued interim predictive maintenance guidance—according to military service officials. The military services have also taken steps to implement predictive maintenance on a variety of other weapon systems as part of testing or pilot programs. However, as of June 2022, the military services have taken limited action to implement predictive maintenance for its weapon systems. For example, the DODIG report found that the military services do not replace parts or components

regularly based on predictive maintenance forecasts.¹⁹ Figure 5 depicts the weapon systems for which the military services have incorporated some limited predictive maintenance capabilities.

Figure 5: DOD Weapon Systems with Predictive Maintenance Capabilities as of June 2022



Source: GAO analysis of Department of Defense (DOD) and military services information. | GAO-23-105556

Note: The military services reported that these weapon systems have technologies that could enable the use of predictive maintenance. As of June 2022, the military services have not fully implemented predictive maintenance on any of its weapon systems, but may periodically replace parts based on forecasts or use software and condition-monitoring tools to improve continuous maintenance. Weapon systems undergoing the acquisition process, uncrewed weapon systems, and the F-35 are not within the scope of this review.

Army. The Army initiated efforts to enable predictive maintenance technology as early as 2005, when the Army began installing sensors on the AH-64 Apache helicopter. The Army took further action to implement predictive maintenance on aircraft in 2012, and has since equipped all of its AH-64 Apache and UH-60 Blackhawk helicopters with predictive maintenance technology. In addition, the Army has installed sensors on at least 65 percent of CH-47 Chinook aircraft as of February 2022, according to Army officials. The Army has been continuing to improve predictive maintenance for aircraft by installing sensors, and developing analysis and maintenance dashboards that allow personnel to see specific maintenance prompts. However, no Army aircraft regularly uses predictive maintenance to defer preventive maintenance or replace parts,

¹⁹DODIG-2022-103.

and some Army officials still consider predictive maintenance as somewhat experimental.

In 2012, the Army began pilot projects for wheeled vehicles, installing sensor technology and developing predictive maintenance concepts. The Army also established guidance to begin implementing predictive maintenance in 2018 and redirected the focus of predictive maintenance to emphasize artificial intelligence, according to the DODIG.²⁰

In addition, the Army issued an implementation plan for predictive maintenance in 2020. However, according to Army officials the Army did not field weapon systems with predictive maintenance capabilities in its most recent variants until 2021. According to Army documents, the Army is conducting pilot projects to use predictive maintenance on those systems. As of June 2022, the Army continues to have pilot projects to develop capabilities for these ground combat systems. For example, during our site visits officials demonstrated data transfers from Abrams tanks equipped with sensors to provide diagnosis and alerts about the operational status, and maintenance needs of the tanks.

The Army is evaluating predictive maintenance capabilities through technology demonstrations and experiments, according to Army documents. For example, the Army conducted a large-scale modernization experiment to transfer data from ground combat systems to command and control networks in 2020. According to Army officials, this end-to-end data transfer capability will allow ground combat systems to send alerts about operational status and maintenance needs for resource planning and logistics management. The Army agreed with a

²⁰Army Headquarters Execution Order (HQEXORD) 032-19, *Army Implementation and Execution of Condition Based Maintenance Plus (CBM+)* (November 2018). Army HQEXORD 032-19 directs that the establishment of CBM+ achieve full operational capability not later than Sept. 30, 2022. According to DOD, the Army's implementing policy for maintenance, Army Regulation (AR) 750-1, *Army Materiel Maintenance Policy* (Oct. 28, 2019), includes basic or general requirements to execute CBM+, but it does not provide comprehensive execution procedures in accordance with DODI 4151.22 (Aug. 14, 2020). See also DODIG-22-103.

DODIG recommendation published in June 2022 to scale predictive maintenance across the enterprise of Army weapon systems.²¹

Marine Corps ground combat systems. The Marine Corps is in the early stages of implementing predictive maintenance and started a predictive maintenance pilot project for wheeled systems in 2020, using 10 each of the Joint Light Tactical Vehicle and the Medium Tactical Vehicle Replacement as proof of concept platforms.²² The Marine Corps and the Army are working together to develop predictive maintenance for ground combat systems that they have in common, such as the Joint Light Tactical Vehicle, and are benefitting from collaboration on wireless data transfer technology for systems such as the Family of Medium Tactical Vehicles, according to Marine Corps officials. The Marine Corps planned to add predictive maintenance capabilities to up to 300 Joint Light Tactical Vehicles and Medium Tactical Vehicle Replacements across the Marine Corps during fiscal year 2022. The Marine Corps plans to use lessons learned from these efforts to expand predictive maintenance throughout the Marine Corps, according to Marine Corps officials.

Navy and Marine Corps aircraft. The Navy and Marine Corps maintain rotary and fixed-wing aircraft in collaboration with each other, have several aircraft with condition-monitoring technology, and are making progress toward fuller implementation of predictive maintenance, according to Navy and Marine Corps officials. The Navy issued its predictive maintenance policy in 2015, and the Marine Corps issued its predictive maintenance policy in 2020.²³ The Navy policy requires the

²¹See DODIG-2022-103. The DODIG report recommended the Army develop and implement a clear and comprehensive plan for scaling predictive maintenance across the enterprise. According to the DODIG report, the Army agreed to implement the recommendation.

²²A proof of concept or prototype may support later developments by focusing on the features that are most critical to customer needs, allowing new capabilities to be produced more quickly than if programs were bogged down with less critical requirements. For more information see GAO, *Leading Practices: Agency Acquisition Policies Could Better Implement Key Product Development Principles*, [GAO-22-104513](#) (Washington, D.C.: March 10, 2022).

²³Office of the Chief of Naval Operations Instruction (OPNAVINST) 4790.16B, *Condition Based Maintenance and Condition-Based Maintenance Plus Policy* (October 1, 2015), and Commandant of the Marine Corps, Marine Corps Order (MCO) 4151.22, *Condition-Based Maintenance Plus (CBM+) Order* (January 17, 2020).

implementation of predictive maintenance for all new and legacy Navy and Marine Corps aircraft.²⁴

Many of the aircraft currently used by the Marine Corps and the Navy have some form of condition monitoring system, according to Navy and Marine Corps officials. For example, the CH-53 Sea Stallion had electronic sensors installed as early as 2002, according to Navy officials. Weapon systems such as H-1 and F/A-18 variants are actively using predictive maintenance to increase flight safety and reduce the likelihood of physiological episodes among flight crews, according to Navy documents and officials. According to officials, other aircraft such as the E2-C Hawkeye are not using predictive maintenance. In short, there are varying degrees of implementation. According to officials, no Navy and Marine Corps aircraft have used predictive maintenance as fully as they would like. In addition, no Navy and Marine Corps aircraft regularly use predictive maintenance to defer preventive maintenance or replace parts, according to the DODIG.²⁵

Navy ships. The Navy has predictive maintenance pilot projects for surface ships. The Navy began a predictive maintenance pilot project on the USS Mason (DDG-87) in 2020, and added the USS McCampbell (DDG-85) and USS Bulkeley (DDG-84) in 2022, according to Navy officials. The Navy is using pilot projects to prove predictive maintenance concepts, further develop analysis techniques, and determine how best to provide predictive maintenance prompts to uniformed maintenance personnel aboard ships. As of June 2022, the USS Mason is the only vessel in the Navy that has tested predictive maintenance concepts and evaluated responses of ship's crew to maintenance prompts generated using predictive maintenance techniques, according to Navy officials. (See figure 6.)

²⁴OPNAVINST 4790.16B. According to officials, the Naval Aviation Maintenance Plan covers all Navy and Marine Corps aircraft, with Naval Air Systems Command serving as the contracting authority for all Navy and Marine Corps aircraft and leading predictive maintenance implementation efforts.

²⁵DODIG-2022-103.

Figure 6: The USS Mason Is a Navy Ship Implementing Predictive Maintenance



Source: U.S. Navy/Seaman A. Wade. | GAO-23-105556

In 2019, the Navy updated guidance to include consideration of predictive maintenance for the Common Maintenance Planning Working Group to use in reviewing maintenance plans for aircraft carriers, submarines, and surface ships.²⁶ In 2022, the Navy issued guidance requiring the use of predictive maintenance on all new and existing surface ships, submarines and aircraft carriers where technically feasible, cost-effective, and beneficial.²⁷ Aircraft carriers and submarines have pilot efforts related to data gathering and analysis to support predictive maintenance, but are not developing predictive maintenance in a manner comparable to surface ships, according to Navy officials.

Air Force. The Air Force began predictive maintenance efforts in 2016, according to an Air Force official, and the Air Force is implementing predictive maintenance in phases for a small number of components

²⁶Naval Sea Systems Command Instruction (NAVSEAINST) 4790.26A, *Common Maintenance Planning Working Group* (Mar. 6, 2019). The common maintenance planning working group is tasked with developing, issuing, and sustaining core processes for effectively reviewing aircraft carrier, submarine, and surface ship class maintenance plans and associated requirements. Class maintenance plans are all tasks required to maintain components, equipment, subsystems, and systems of a class of weapon systems throughout their useful service life.

²⁷Naval Sea Systems Command Instruction 4790.27B, *Condition-Based Maintenance Plus and Reliability-Centered Maintenance Policy for Ships, Ship Systems, and Equipment* (Jan. 21, 2022). The instructions allows exclusions for nuclear propulsion and ballistic missile systems, among other things.

across individual weapon systems. For example, the Air Force began predictive maintenance on a limited number of KC-135 Stratotanker components in 2019, and expanded the effort for that aircraft in an “All-in” Initiative in 2021. According to Air Force officials, the KC-135 “All-in” Initiative will help identify and address predictive maintenance challenges and share lessons learned in support of predictive maintenance implementation for other Air Force aircraft. In April 2021, the Air Force published a strategic implementation plan for predictive maintenance to support implementation to address degraded mission capable rates and aircraft availability issues across the fleet of Air Force aircraft.²⁸ In addition, according to officials the Air Force Rapid Sustainment Office established a Predictive Maintenance Enterprise Integration Governance Council in April 2021 to provide support and direction for predictive maintenance. Taken together, these steps may allow the Air Force to identify future requirements for the expansion of predictive maintenance, according to officials.

Military Services Lack Governance Structures Sufficient to Implement Predictive Maintenance

The military services have different methods of managing predictive maintenance implementation, both in terms of offices involved and resources used. Multiple organizations coordinate efforts to implement predictive maintenance for weapon systems, according to military service officials. For example, there are multiple organizations responsible for coordinating efforts to develop and/or procure condition-monitoring capabilities; supporting data collection, transmission, and analysis; transmitting maintenance prompts; providing parts and materials; scheduling and performing maintenance; evaluating the use of predictive maintenance; and using the information generated to increase operational effectiveness. These coordination efforts involve all of the organizations depicted in figure 3 above, as well as other DOD and joint organizations, as described below. DOD guidance requires the military departments to provide resources for predictive maintenance requirements at the military service and weapon systems levels, and to designate a single focal point to coordinate military service-level execution of predictive maintenance plans and programs, among other things.²⁹

²⁸Air Force, *CBM+ Strategic Implementation Plan* (April 2021).

²⁹DODI 4151.22 (Aug. 14, 2020).

Army. The Army identified three focal points for predictive maintenance implementation—the Deputy Assistant Secretary of the Army (Sustainment); the Deputy Chief of Staff for Logistics, Maintenance Directorate; and Army Materiel Command. According to Army officials, the Army’s Prognostics/Predictive Maintenance General Officers Steering Committee is responsible for developing the Army’s predictive maintenance strategy. According to Army officials, the Army organizational structure for Predictive Maintenance includes weekly Integrated Product Team meetings that report to a monthly Council of Colonels meeting, which then reports to a monthly General Officer Steering Committee meeting for decisions. However, a number of Army commands and program management offices are attempting to implement predictive maintenance without a comprehensive strategy, or a single entity responsible for the effort.

According to Army officials, the enterprise-wide effort is fragmented, under-resourced, and not suited to implementing predictive maintenance across the wide variety of Army weapon systems. Specifically, Army officials said the focal points have generally served as subject matter experts, without sufficient authority and staffing to coordinate predictive maintenance implementation Army-wide, and it is up to program management offices to plan and budget for predictive maintenance, and make decisions on whether to procure predictive maintenance enabling technologies.

Marine Corps. The Marine Corps also identified three predictive maintenance focal points—the Deputy Commandant for Installations and Logistics, the Marine Corps Systems Command, and the Program Executive Office Land Systems, according to DOD. However, according to Marine Corps officials, the Marine Corps does not have a single, specific designated entity with sufficient authority, staffing, and resources necessary to support the implementation of predictive maintenance. Marine Corps officials said the relatively small size of their maintenance community allowed them to be more agile. In addition, the Marine Corps also collaborated with the Army to support predictive maintenance implementation for ground combat systems, according to Army and Marine Corps officials. Similarly, the Marine Corps supports predictive maintenance implementation for aircraft collaboratively with the Navy. The Marine Corps is considering establishing a program office to support predictive maintenance implementation, according to Marine Corps officials.

Navy. Navy officials acknowledged that they did not identify a single, specific entity to lead the implementation of predictive maintenance. According to the DODIG report, the Navy stated the Deputy Assistant Secretary of the Navy (Sustainment) would lead the effort until the conclusion of the pilot programs.³⁰ The pilot programs cover the DDG ship class and the F/A-18. The DODIG recommended, and the Navy agreed, to develop and implement a clear and comprehensive strategic plan for scaling predictive maintenance across the Navy enterprise, and designate a predictive maintenance focal point. The Navy identified two focal points for predictive maintenance implementation—Naval Air Systems Command and the Naval Sea Systems Command. Both organizations rely on a small cadre of knowledgeable individuals to implement predictive maintenance, according to Navy officials. However, Navy officials characterized the current effort to implement predictive maintenance as fragmented, and stated that additional authority and staffing will be necessary to implement predictive maintenance across the fleet of Navy aircraft and ships.

Air Force. The Air Force identified two focal points to oversee predictive maintenance implementation across the Air Force—the Aircraft Maintenance Division for the Directorate of Logistics, Headquarters Air Force; and the Air Force Life Cycle Management Center’s Rapid Sustainment Office. However, the Rapid Sustainment Office has some ability to procure items for predictive maintenance, but does not have the authority to increase supplies of spare parts for predictive maintenance, according to Air Force officials.

In addition to different methods of managing predictive maintenance implementation in terms of offices involved, the military services also used different methods to request dollar amounts for predictive maintenance efforts. The military services plan to scale predictive maintenance across weapon systems to the extent feasible and have included funds to do so in Future Years Defense Spending Program plans, according to military service officials.

The military services have generally requested dollar amounts to support basic research related to predictive maintenance in research,

³⁰DODIG-2022-103.

development, test, and evaluation (RDT&E) appropriations.³¹ In addition, the military services have included dollar amounts for procurement of predictive maintenance capabilities in budget requests. For example, the Army requested \$15 million in procurement amounts for fiscal year 2022, in part to provide predictive maintenance kits for the Family of Heavy Tactical Vehicles. The Marine Corps requested \$14.2 million for the acquisition of repair test equipment for predictive maintenance to improve operational readiness, among other things, for fiscal year 2023. The Navy requested \$4.6 million in procurement amounts to support predictive maintenance for aviation logistics and support equipment for fiscal year 2023.³² The Navy also requested \$87 million to modernize the Littoral Combat Ship in fiscal year 2022, which included predictive maintenance capabilities for critical components, among other things.³³ The Air Force did not request specific dollar amounts for predictive maintenance as part of its procurement or operations and maintenance budget requests, according to our analysis.

In addition to specifically requested amounts for predictive maintenance, the military services use existing dollar amounts to further predictive maintenance implementation activities that are not broken out separately in procurement or operations and maintenance budget requests, according to military service officials. For example, program management offices and a variety of Army commands provide personnel resources to implement predictive maintenance on Army ground combat systems in dollar amounts too small to detail in budget documents, according to Army officials. Similarly, the military services provide personnel for predictive maintenance activities as corollary duties using dollar amounts small enough to be subsumed in other budget requests, according to military service officials. In September 2022, DOD requested additional information from the military services as part of the annual budget process for fiscal year 2024, and plans to update guidance to provide

³¹We reviewed budget military department budget request supporting documents for fiscal years 2022 and 2023, and inquired of the military services regarding the inclusion of funds for predictive maintenance in the Future Years Defense Spending Program plans.

³²The F-35 Joint Strike Fighter is beyond the scope of this review and any funds associated with that platform were not included.

³³For more information see GAO, *Littoral Combat Ship: Actions Needed to Address Significant Operational Challenges and Implement Planned Sustainment Approach*, [GAO-22-105387](#) (Washington, D.C.: Feb. 24, 2022). Ships not yet delivered to the Navy and commissioned are beyond the scope of this review.

additional transparency for predictive maintenance implementation resources in the future, according to DOD officials.

Echoing the 2002 memorandum, DOD's 2007 predictive maintenance guidance required the military services to designate a single focal point for predictive maintenance efforts. Subsequent revisions retained that requirement, and added the requirement that a governance structure that includes all relevant stakeholders be established to coordinate military-service level execution of predictive maintenance.³⁴ According to DOD, it is imperative that individuals and organizations charged with implementing predictive maintenance and overseeing such an effort have a comprehensive and understandable picture of their strategy.

According to the military services, they intend to scale predictive maintenance across their suite of weapon systems where it is feasible and beneficial to do so. In addition, the military services may make changes to facilitate more rapid implementation by establishing program management offices that can submit budget planning documents and funding requests, and have the authority needed to drive change across the variety of organizations involved. However, each of the military services acknowledge they have not established a single entity with the authority, staffing, and funding necessary to manage service-wide efforts to implement predictive maintenance, instead attempting to implement predictive maintenance using existing organizational structures.

The military services acknowledge that limited progress made toward implementing predictive maintenance results in part from the organization responsible not having a single entity designated with sufficient authority, staffing, and resources to support fuller implementation. Without designating a single entity with the authority, staffing, and visibility over resources necessary to implement predictive maintenance, the military services may have difficulty achieving their respective objectives.

Military Services Have Not Consistently Adopted and Tracked Implementation of Predictive Maintenance

The military services used a variety of pilot programs and ad-hoc approaches to support predictive maintenance implementation from 2002

³⁴DUSD (L&MR) Memorandum; DODI 4151.22 (Dec. 2, 2007); and DODI 4151.22 (Aug. 14, 2020).

through 2022, rather than a department-wide systematic approach applied to all current systems based on a business-case analysis, as required in DOD guidance.³⁵ Additionally, according to DODIG, the military services do not consistently, or effectively, track implementation progress.³⁶ DOD guidance also states that the services should prepare action plans and milestones for the integration and implementation of predictive maintenance capabilities on current weapon systems including outcome-related goals and objectives, a process for evaluating progress, and framework to develop and track implementation milestones.

Army. The Army does not have a current, comprehensive service-wide approach to implementing predictive maintenance, and it does not currently track its implementation progress. The Army has an implementation plan to support predictive maintenance across all Army weapon systems that an Army official said was approved in August 2020.³⁷ However, the Army implementation plan has estimated completion dates for a variety of tasks that have since elapsed, and is supported by a 2018 order that the Army plans to update, according to an Army official.³⁸

Further, the Army does not require specific milestones for individual weapon systems until after approval for implementation based on a cost-benefit analysis, according to an Army official. Army aircraft officials are supporting further implementation of predictive maintenance with draft

³⁵DODI 4151.22 (Aug. 14, 2020). The current guidance mirrors similar requirements included in the 2002 interim guidance (DUSD(L&MR) Memorandum). To achieve predictive maintenance goals, DOD guidance states that from the earliest acquisition phases the services will require program managers to integrate and incorporate capabilities that improve readiness, optimize sustainment resources, and reduce support costs over the equipment's life cycle through a variety of measures. These include the development of action plans and milestones that support the established policies, strategies, and objectives of the services' predictive maintenance vision. For the integration and implementation of predictive maintenance capabilities on current weapon systems including outcome-related goals and objectives, a process for evaluating progress, and framework to develop and track implementation milestones (for military service-wide implementation). With respect to existing systems, life cycle managers will consider implementing predictive maintenance where cost-benefit analyses indicate improved equipment availability or sustainment cost reduction, and develop action plans and milestones where predictive maintenance integration is supported by the analyses (for specific weapon systems).

³⁶DODIG-2022-103.

³⁷*Army Prognostics/Predictive Maintenance Implementation Plan* (August 2020).

³⁸Army HQDA EXORD 032-19.

plans of actions and milestones, but have not developed a current service-wide implementation plans according to officials. In addition, Army officials said they plan to expand implementation of predictive maintenance during fiscal year 2023. However, the Army has not developed firm, detailed plans with milestones to do so across all systems, according to Army officials.

Marine Corps. The Marine Corps has not developed a strategic plan for predictive maintenance implementation, even though they plan to adopt predictive maintenance more widely, according to Marine Corps officials. The Marine Corps did not have a service-wide approach to identifying weapon systems for predictive maintenance implementation. Rather, Marine Corps officials said they chose Joint Light Tactical Vehicles to pilot predictive maintenance based in part on available funding, the use of capabilities that can be scaled across other types of equipment, and its status as a new system being fielded with embedded diagnostic capabilities. Marine Corps ground combat officials said they plan to expand implementation of predictive maintenance during fiscal year 2023, but have not provided milestones or detailed plans to do so across all ground combat systems. Implementation of predictive maintenance for Marine Corps Aircraft is subject to coordination with Naval Air Systems Command, according to Marine Corps and Navy documents.

Navy. The Navy has not developed a strategic plan for predictive maintenance implementation, even though they plan to adopt predictive maintenance more widely, according to DOD. The Navy did not have a service-wide approach to identifying aircraft for predictive maintenance implementation, according to Navy officials. Instead, the Navy expedited predictive maintenance implementation in part to address an increasing number of crashes resulting from physiological episodes on aircraft such as the F/A-18 Super Hornet.³⁹ The Navy has since expanded the effort to other fixed wing and rotary aircraft, according to Navy officials. Navy and Marine Corps aircraft officials are supporting further implementation of predictive maintenance with draft plans of actions and milestones, but have not developed service-wide implementation plans according to officials.

For its ships, Navy officials said they chose the Arleigh Burke (DDG-51) ship class of destroyers because they had more reliable historic data than

³⁹For more information see DOD Inspector General, *Audit of the Department of the Navy Actions Taken to Improve Safety and Reduce Physiological Events*, DODIG-2021-004 (Alexandria, VA: Nov. 4, 2020).

other vessels to support an organically developed suite of predictive maintenance analytics. The Navy chose the USS Mason (DDG-84) from among other ships in that class because the USS Mason had a planned overhaul that would facilitate the installation of sensors and other equipment. The Navy does not have firm plans to implement predictive maintenance across all ships, aircraft carriers, and submarines, according to Navy officials.

Air Force. The Air Force has taken some steps to systematically plan for predictive maintenance, but it does not have a comprehensive service-wide approach to implementing predictive maintenance that includes dated milestones, and it does not currently track its implementation progress. The DOD IG reported that the Air Force has developed a predictive maintenance strategic implementation plan that provides direction, a structure for action, goals and objectives, roles and responsibilities, and a framework for implementation.⁴⁰ In addition, the Air Force's strategic plan includes descriptions of processes and responsibilities (including plans of actions and milestones), along with a list of weapon systems planned for predictive maintenance implementation.⁴¹

Like the other military services, Air Force aircraft officials are supporting further implementation of predictive maintenance service-wide, but have not developed service-wide implementation plans that include due dates for the milestones and a firm approach to determine where and how to implement predictive maintenance for all of its weapon systems, according to Air Force officials. Officials stated that they determine which components to use for predictive maintenance based on top degraders, data collection considerations, and the availability of parts.

Further, the Air Force Strategic Implementation plan states that the Air Force needs to take an incremental approach to adopting predictive maintenance while tracking improvements and return on investment to support continued innovation. The plan includes a decision tree for expanding predictive maintenance to weapon system components, and discusses data, supply chain, and cultural considerations, which affect the likelihood of successful implementation. For example, the Air Force selected aircraft such as the B-1 and KC-135 for more in-depth predictive maintenance implementation in part because officers or program offices

⁴⁰DODIG-2022-103.

⁴¹Air Force, *CBM+ Strategic Implementation Plan*.

responsible for maintenance on those airframes advocated for maintenance reform using predictive maintenance, according to Air Force officials. However, the Air Force's strategic implementation plan does not state when the milestones are required to be complete or detail a timeline for broader predictive maintenance implementation.

The military services acknowledge that they have not developed a service-wide, systematic approach to predictive maintenance implementation, including action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and framework to develop and track implementation milestones. Until the military services develop comprehensive implementation plans with specific milestones, deliverables, and tracking of predictive maintenance implementation, they may be unable to effectively determine how, when, and where to adopt predictive maintenance, or to inform decision-makers about the status of predictive maintenance implementation.

Predictive Maintenance Can Work, but Military Services Lack Performance Evaluation

The military services have identified specific examples of how predictive maintenance has contributed to reduced costs and improved maintenance outcomes. However, these examples are from limited experience and the military services generally lack established measures to evaluate the results of predictive maintenance. Military maintenance professionals based their conclusions attributing performance improvements to predictive maintenance by using their knowledge of how predictive maintenance has affected existing metrics, according to military service officials.

Military Services Have Some Examples of Predictive Maintenance Successes

The military services have reported some examples of how the use of predictive maintenance resulted in positive outcomes. For example, according to military service officials and documents, predictive maintenance has enabled pilots to avoid helicopter aircraft accidents and identify failures that were undetected by mechanics, avoid maintenance costs, and redirect maintenance personnel to other work creating cost efficiencies. As discussed below, these examples are the result of the

military services' limited use of predictive maintenance on specific weapon systems or weapon system components.

Army. According to the Army, the use of predictive maintenance helped the Army avoid four serious aircraft accidents.⁴² Army officials also told us about an incident when the use of predictive maintenance prevented loss of life. Specifically, health monitor sensors on an AH-64 Apache helicopter detected a nose gearbox malfunction that may have failed within a few hours. The Commander, Army Aviation and Missile Command said that the early detection prior to failure may have prevented an accident, saved the lives of two personnel, and prevented the loss of the aircraft.

Separately, the Army reported that using predictive maintenance reduced costs. For example, aviation battalions with CH-47 Chinook helicopters avoided costs of \$24 million and realigned 6,237 maintenance hours to higher priorities. Similarly, the Army reported avoiding costs of \$215 million and realigning 5,324 maintenance hours to higher priorities after using predictive maintenance on UH-60 Blackhawk helicopters over a six-year period. The Army also reported that using predictive maintenance helped the Army reduce costs for parts by 12 percent for the AH-64 Apache, 23 percent for the CH-47 Chinook, and 16 percent for the UH-60 Blackhawk over the same period. According to the Army, using predictive maintenance for about 2,500 tactical wheeled vehicles resulted in a cost avoidance of \$24 million over a six-year period, informed safety and mishap reviews, and helped the Army identify maintenance trends.

Marine Corps. The Marine Corps has seen success with its proof of concept and prototype efforts, according to Marine Corps officials. For example, after 18 months of predictive maintenance the Marine Corps reported reduced down time for Amphibious Assault Vehicles by 32 percent, reduced maintenance hours for those ground combat systems by 69 percent, increased weapon system availability by 6 percent, and reduced redundant preventive maintenance tasks. In addition, Marine Corps officials reported that the use of condition monitoring technology on a Medium Tactical Vehicle Replacement allowed them to discover a fault

⁴²We are using the phrase "serious accidents" to refer to "Class A" accidents, where the total cost of property damage of \$2,000,000 or more; an aircraft is destroyed, missing or abandoned; or an injury and/or occupational illness results in a fatality or permanent total disability.

critical enough to merit a dashboard warning light, even though the warning light failed to alert maintenance personnel of the problem.

Navy. In fiscal year 2016, the Navy and Marine Corps began using predictive maintenance on rotary aircraft such as the H-1 helicopters. This allowed the Navy and Marine Corps to identify and replace faulty components including contaminated or cracked bearings and replace them before failure to avoid an estimated 29 emergency landings. In addition, the Navy used predictive maintenance principles to adjust maintenance intervals for H-1 components such as main rotor gearboxes and other components for estimated cost avoidances of \$100 million over five fiscal years. The Navy also used predictive maintenance for fixed-wing aircraft to help reduce the number of physiological episodes during flight (an event when a pilot experiences loss in performance related to insufficient oxygen, depressurization, or other factors), according to the Navy.

According to a DODIG report, the number of physiological episodes across different types of aircraft (including F/A-18 Hornets, F/A-18 Super Hornets, and E/A-18 Growlers) increased from 13 in fiscal year 2010 to 165 in fiscal year 2017.⁴³ After the Navy implemented a predictive maintenance approach in 2019 known as the Hornet Health Assessment and Readiness Tool, the Navy reduced physiological episodes by about 80 percent, according to the Navy. In addition, the Navy estimates the use of predictive maintenance has since resulted in cost avoidances of \$110 million from about 400 of these aircraft, according to a Navy official.

Air Force. According to Air Force officials, the Air Force eliminated 84 hours of unscheduled maintenance for a cost avoidance of \$1.2 million in less than 2 years on eight C-5 cargo aircraft. Air Force officials also reported estimated savings from predictive maintenance of \$5 million in two years by reducing unscheduled maintenance on ten B-1 bombers, and said predictive maintenance helped resolve difficult maintenance issues that may have interfered with mission completion. For example, predictive maintenance analysis allowed a contractor to pinpoint the location of a shorted wire that maintenance personnel had not been able to locate in the airframe of a B-1 bomber, perhaps allowing maintenance personnel to avoid as many as hundreds of hours of additional effort, according to Air Force officials.

⁴³DODIG-2021-004.

Military Services Generally Do Not Have Measures for Evaluating Predictive Maintenance

The military services generally do not have stand-alone measures to evaluate the performance of predictive maintenance with the exception of the Navy, which developed specific metrics to demonstrate the results of predictive maintenance. Generally, the military services have used existing life-cycle sustainment metrics and professional judgement to determine whether the use of predictive maintenance on weapon systems has positive, negative, or negligible effects on sustainment outcomes. These include a range of metrics that measure maintenance performance, including how long it takes to perform maintenance, how often parts need to be taken from one weapon system in order to maintain another weapon system, and weapon system mission capable rates or not mission capable rates (due to supply or maintenance), among other things. Knowledgeable officials may continue to use existing metrics to demonstrate probable effects from predictive maintenance, but metrics developed specifically for predictive maintenance will help demonstrate its impact more directly.

Army. According to Army officials, the Army intends to use existing life-cycle sustainment metrics to measure and assess predictive maintenance results indirectly for its aircraft and ground systems while considering specific metrics specific to predictive maintenance. Army aircraft officials said that they can attest to the benefits of predictive maintenance for their weapon systems, and show examples of success, but they do not have a specific metric and historical data sufficient to demonstrate a cause-and-effect relationship between predictive maintenance and any improvements to readiness or increased operational availability. Further, Army officials do not have a standardized plan for monitoring the results of predictive maintenance across all of its weapon systems.

The Army has multiple cost-benefit analyses that support probable predictive maintenance outcomes, and according to Army officials, they are confident that predictive maintenance provides operational and cost-avoidance benefits. According to Army officials, that is why the Army is developing new checklists incorporating predictive maintenance on a variety of ground combat systems, including systems with similar

characteristics such as the Family of Medium Tactical Vehicles.⁴⁴ However, Army officials stated that they do not have enough historical data from ground systems equipped with predictive maintenance to assess whether any changes are a direct result of predictive maintenance alone.

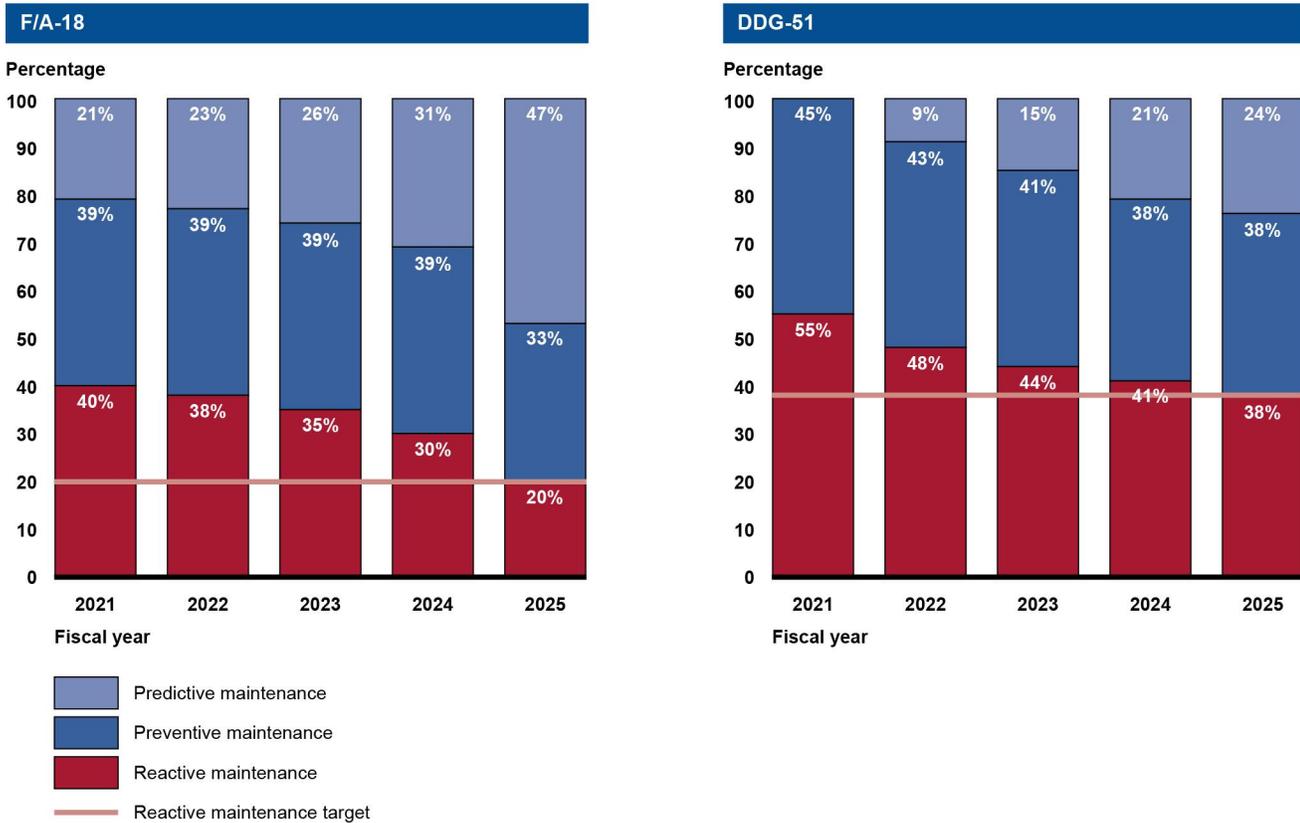
Marine Corps. According to the Marine Corps, they are developing predictive maintenance performance measures and has identified metrics to measure effectiveness of its ground system pilot projects. However, the Marine Corps officials say they are not effectively tracking and managing metrics for predictive maintenance. Marine Corps officials said that the relative newness of predictive maintenance and funding limitations have prevented the development of specific goals and metrics for predictive maintenance on ground combat systems. The Marine Corps manages aircraft collaboratively with naval aircraft, and any metrics applied to aircraft by the Navy will apply to Marine Corps aircraft, according to Navy and Marine Corps officials.

Navy. The Navy has developed specific predictive maintenance metrics and applied them to pilot projects on the F/A-18 Super Hornet and the DDG 51 class of ships to demonstrate how the use of predictive maintenance can change the ratio of planned maintenance to unplanned maintenance. According to Navy officials, they developed the metrics with the underlying premise that unplanned maintenance is more expensive and results in adverse impacts to operations.

The Navy set goals to increase predictive maintenance and decrease reactive maintenance as part of their pilot projects. Specifically, the Navy set a goal to reduce reactive maintenance to 20 percent for the F/A-18, and increase the amount of predictive maintenance by 26 percent. Similarly, the Navy set a goal to reduce reactive maintenance to 38 percent aboard DDG-51 class ships, and increase the amount of predictive maintenance by 24 percent. The Navy plans to include metrics for relative amounts of reactive, preventive, and predictive maintenance into its routine work processes, according to Navy officials. See figure 7 for the Navy's metrics and goals applied to pilot projects.

⁴⁴Fragmentary Order (FRAGO) 4 TO HQDA EXORD 169-19, *Optimizing Maintenance Requirements* (Oct. 29, 2021). Other systems listed include the Heavy Expanded Mobility Tactical Truck and the Palletized Load System.

Figure 7: Navy Predictive Maintenance Metrics and Goals for One Aircraft and One Ship Class



Source: GAO analysis of Navy data. | GAO-23-105556

Accessible Data for Figure 7: Navy Predictive Maintenance Metrics and Goals for One Aircraft and One Ship Class

Category	Fiscal year	Reactive maintenance	Preventive maintenance	Predictive maintenance	Reactive maintenance target
F/A-18	2021	40	39	21	20
F/A-18	2022	38	39	23	20
F/A-18	2023	35	39	26	20
F/A-18	2024	30	39	31	20
F/A-18	2025	20	33	47	20
DDG-51	2021	55	45	0	38
DDG-51	2022	48	43	9	38
DDG-51	2023	44	41	15	38
DDG-51	2024	41	38	21	38
DDG-51	2025	38	38	24	38

Note: Reactive maintenance is unscheduled, and often requires more materials and a higher level of effort than scheduled maintenance, according to DOD and military service officials. Preventive maintenance is scheduled, or routine maintenance based on timed intervals. Predictive maintenance relies on the military services' ability to leverage a continuous feedback loop including the use of historical data, information on the current condition of weapon systems, the ability to effectively store and transfer data, effective data analysis, the willingness of maintainers to act on predictive maintenance prompts, and evaluation of effectiveness, according to DOD documents.

The Navy is making progress in demonstrating predictive maintenance effectiveness metrics by using its pilot projects, and is developing additional metrics that focus on affordability and availability of weapon systems for use in training and operations, according to Navy officials. In addition, Navy officials said they are in the process of developing policies and capabilities to more accurately report the three categories of maintenance, reported in Figure 7. However, like the other military services, the Navy does not have a defined and repeatable predictive maintenance evaluation plan.

Air Force. The Air Force has not implemented any specific measuring tool or metric for predictive maintenance. According to Air Force officials, the Air Force initiated an assessment of how predictive maintenance efforts may result in changes to existing readiness metrics for specific aircraft, including the KC-135 Stratotanker, B-1 Lancer, and C-5 Galaxy. In addition, the Air Force developed proposed predictive maintenance metrics for its Strategic Implementation Plan. If adopted, the proposed metrics will track historical maintenance information and data analysis to predict component failure, and provide insights into component usage and removals based on predictive maintenance prompts. However, the Air Force has not developed stand-alone metrics to demonstrate the efficacy of predictive maintenance or standardized an approach for monitoring results from predictive maintenance for Air Force weapon systems.

DOD guidance requires the military services to review and monitor results from predictive maintenance, including changes in weapon system availability, safety, sustainment cost, and the amount of unscheduled maintenance.⁴⁵ DOD guidance also requires the military services to use effective metrics management, and to report on predictive maintenance execution on a routine basis. Additional DOD guidance states that a plan for evaluating predictive maintenance initiatives through quantifiable

⁴⁵DODI 4151.22 (Aug. 14, 2020).

metrics will help measure results.⁴⁶ However, the military services have not developed plans with specific quantifiable metrics and goals for evaluating predictive maintenance. In addition, the military services have not established procedures to conduct ongoing monitoring and reporting of program performance and accomplishments from predictive maintenance for major weapon systems, according to military service officials.

Without developing a systematic plan with specific metrics for evaluating predictive maintenance, the military services may be unable to determine its effectiveness or identify areas for improvement. Further, by establishing procedures, conducting ongoing monitoring, and reporting on results from predictive maintenance, the military services may be able to determine whether predictive maintenance achieves expected results and supports continuous improvement. The military services acknowledge that they generally have not evaluated the results of predictive maintenance, but are taking steps to establish metrics and measures to evaluate its effects.

Military Services Have Identified and Begun Taking Steps to Address Challenges to Predictive Maintenance

Military Services Identified Challenges to Predictive Maintenance

The military services identified key challenges to implementing predictive maintenance, which include (1) resource challenges and (2) organizational culture challenges.

Resource Challenges

Resource challenges associated with personnel, parts, and technology affect the implementation of predictive maintenance. The performance of maintenance depends on having a sufficient number of skilled personnel available to perform the work, parts available to use in maintenance, and a sufficient understanding of technology and the technological resources

⁴⁶DOD Guidebook, *Condition Based Maintenance Plus*.

to complete maintenance, according to our prior reports.⁴⁷ Conducting more predictive maintenance may help to mitigate these long-standing issues, according to military service officials. However, military service officials acknowledge that in order to implement predictive maintenance more broadly, changes will be necessary to mainstream business processes to address resource challenges from personnel, parts, and technology.⁴⁸

Personnel. The military services state that their maintenance personnel are overburdened and sometimes reluctant to use predictive maintenance.⁴⁹ For example, Air Force personnel stated there are not enough maintenance personnel available to complete the existing work. In addition, maintenance personnel at one of the locations we visited said that documenting predictive maintenance separately is time-consuming and takes away resources from more urgent maintenance work. In the short term, the burden on maintenance personnel may increase as personnel with critical skills acquire an understanding of predictive maintenance and provide on-the-job training to newer personnel, according to military service officials. The DODIG report noted implementing predictive maintenance would require the military services to provide additional training before obtaining efficiencies from predictive maintenance.⁵⁰ In the long term, however, implementing predictive maintenance may help to relieve overburdened maintenance personnel by reducing the amount of reactive maintenance and by allowing appropriate adjustments to preventive maintenance schedules, according to military service officials.

Parts. According to military service officials, parts are sometimes not available for predictive maintenance due to practices that establish spare

⁴⁷See Related GAO Products at the end of this report.

⁴⁸DODIG-2022-103. In response to the report, the military services agreed to scale the implementation of predictive maintenance enterprise-wide.

⁴⁹The number of uniformed maintenance personnel across the four military services decreased by about 29,000 from fiscal years 2007 through 2021, according to DOD data. This occurred in an era characterized by increasing operational demands, aging weapon systems in use beyond their expected service life, and the acquisition of newer, increasingly complex weapon systems.

⁵⁰DODIG-2022-103. The DOD Inspector General recommended that the military services develop and tailor training to the appropriate levels necessary to achieve effective condition-based maintenance plus and predictive maintenance implementation.

parts supply at lower levels than may be required.⁵¹ Specifically, maintenance officials said using predictive maintenance might increase short-term demands for parts until they can meet readiness goals. In addition, the military services manage spare parts that are generally more cost-effective to repair and reuse than to dispose of and replace, and predictive maintenance can increase demands for spare parts in the supply chain because units request spare parts before they can supply carcasses for overhaul by DOD depots.⁵²

Proactive and accurate planning is necessary to ensure the timely availability of spare parts for the maintenance process, especially since the acquisition lead-time for spare parts can range from days to years. For example, at the time of our site visit, Air Force officials stated that there were no additional spare parts available to support predictive maintenance for the KC-135. Similarly, Air Force officials stated that the lack of spare parts has limited the ability to conduct more predictive maintenance on the B-1 Bomber. We recently reported on parts challenges for unit-level maintenance.⁵³ For example, parts shortages and delays contributed to poor mission-capable rates for a wide variety of military aircraft. Similarly, long delays getting parts, cannibalizing parts (using parts from one weapon system or piece of equipment to make another weapon system or piece of equipment operable), and obsolete

⁵¹DODI 4140.01, *DOD Supply Chain Materiel Management Policy* (Mar. 6, 2019) states that DOD departments are responsible for conducting demand and supply planning to address demand forecasting, requirements definition, and inventory level setting through the life cycle of an item of supply, starting with its initial sparing during provisioning, among other things.

⁵²As we have previously reported, the military services and the Defense Logistics Agency manage the storage and distribution functions of spare parts, and the military services have retained some functions, such as determining the level of items to be stored. Supply levels for spare parts are based on a number of key planning factors, including the number of items planned for maintenance, the maintenance schedule, and the estimated frequency of replacement based on historical trends and engineering estimates, among other things. A “carcass” is a depot-level reparable item (e.g., a ship blade propeller, brake assembly) removed from a weapon system and returned to the supply system for overhaul or repair at the military maintenance depots. See GAO, *Defense Inventory: Further Analysis and Enhanced Metrics Could Improve Service Supply and Depot Operations*, [GAO-16-450](#) (Washington, D.C.: June 9, 2016).

⁵³GAO, *Air Force and Navy Aviation: Actions Needed to Address Persistent Sustainment Risks*, [GAO-22-104533](#) (Washington, D.C.: June 15, 2022).

parts being unavailable has had an adverse impact on ship maintenance performed by uniformed personnel.⁵⁴

Technology. The military services acknowledge they are facing significant technology challenges such as data transfer limitations, maintenance manual digitization, or problems with older information systems needed to plan and conduct predictive maintenance.⁵⁵ According to Army and Marine Corps officials, they do not have adequate resources for applying sensor technology to all ground combat systems, and it is important that the military services are selective about doing so. In addition, Army ground combat systems officials said their ability to conduct predictive maintenance is limited by the number of portable notebooks available for offloading data and transferring information for analysis and storage. According to Army aircraft maintenance officials, some of their weapon systems are more likely to have portable notebooks for offloading data, but they did not have a sufficient number of portable notebooks to support data transfers. Aircraft officials also stated they did not have technological solutions for obsolete memory cards that facilitate data offloading from aircraft sensors, and stated this may limit the amount of information the sensors can collect.

Navy maintenance officials stated that data transfer, storage, and analysis issues affect the ability to provide predictive maintenance to ships. Specifically, according to Navy officials, data transfer aboard ships is possible, but limited bandwidth exists for transferring data back and forth from ship to shore to support data analysis, feedback and data storage. Navy officials said this is particularly true when considering exponential increases to information collected by sensors to enable predictive maintenance. For example, according to Navy officials, they have increased the amount of information collected by increasing the frequency of readings from sensors from once per hour to once per second, with corresponding increased requirements for data storage.

⁵⁴GAO, *Navy Ship Maintenance: Actions Needed to Monitor and Address the Performance of Intermediate Ship Maintenance Periods*, [GAO-22-104510](#) (Washington, D.C.: Feb. 8, 2022).

⁵⁵For more information see Headquarters Department of the Army, *Report to Congress on Ground Combat Vehicle Maintenance Modernization* (March 30, 2022) in response to H.R. Rep. No. 117-118, at 92, accompanying a bill for the National Defense Authorization Act for Fiscal Year 2022.

Organizational Culture Challenges

In addition to resource challenges, the military services identified organizational culture as a challenge affecting the implementation of predictive maintenance. Shifting away from decades of performing reactive and preventive maintenance to a more proactive posture with greater reliance on predictive maintenance requires reviewing established business processes involves to identify changes necessary to support predictive maintenance, new approaches to maintenance for uniformed personnel, and adjustments to other aspects of weapon system sustainment, including acquisition, supply, and combat operations. For example, Army officials said that they have to train weapon system operators, uniformed maintenance personnel, supply chain participants, and even operational commanders about how to use predictive maintenance anywhere in the world. According to Army and Marine Corps officials, using predictive maintenance may decrease operational risks for commanders and increase the likelihood of completing maintenance successfully in the field. However, doing maintenance in new ways will require operational leaders and units to think and act differently, according to military service officials.

Sustained leadership and focus is necessary to implement predictive maintenance, and complicated terminology, skepticism among maintenance personnel, and organizational tendencies to adhere to long-standing practices have challenged predictive maintenance implementation. Army, Marine Corps, Navy and Air Force officials attributed recent progress implementing predictive maintenance to increased leadership understanding and focus on the potential results from predictive maintenance. However, key stakeholders in the military services may be unfamiliar with the multiple terms used for predictive maintenance, according to military service officials. For example, according to Army officials the Army uses multiple terms for predictive maintenance in addition to the terms codified in DOD guidance, such as predictive prognostic maintenance, and continues to introduce new terms such as predictive logistics. Army officials said the low number of personnel currently involved in early predictive maintenance efforts has limited confusion, but using terms not established in Army policy or used by the other military services will impede their ability to share lessons learned as the number of people participating in predictive maintenance grows.

Officials from all four military services stated that maintenance personnel are sometimes reluctant to complete predictive maintenance due in part

to skepticism about the validity of predictions. For example, according to Navy officials, during the Navy's first demonstration of predictive maintenance aboard a ship, ship's crew did not take action to address predictive maintenance prompts due to a variety of issues that caused skepticism among end users, such as incorrect algorithms. Officials stated a second demonstration aboard the same ship combined corrections to algorithms with coaching on predictive maintenance that resulted in a higher rate of action as the ship's crew began to understand the validity of the concept. Army, Marine Corps, Navy, and Air Force officials also said that overburdened personnel are hesitant to conduct maintenance on something that is not broken yet, or to change parameters of preventive maintenance without understanding why. Military service officials agreed predictive maintenance pilot projects revealed initial resistance to predictive maintenance prompts when maintenance personnel were unfamiliar with the concept. According to officials, it was especially important to ensure safety-critical preventive maintenance was not set aside, and if preventive maintenance intervals were extended personnel must be sure of the analysis.

Military Services Are Taking Some Steps to Address Challenges to Predictive Maintenance

Steps to Address Personnel Challenges

An Army Transportation Company Saved 6,100 Maintenance Hours in a Year Family of Medium Tactical Vehicles



In 2018, an Army unit responsible for maintaining Medium Tactical Vehicles in Hawaii used predictive maintenance techniques to adjust preventive maintenance for tasks such as oil changes to save 6,100

hours of labor. The Army exempted the unit from personnel reductions to allow maintenance personnel to address other needs, according to Army officials.

Source: GAO analysis of Army data. Photo Source: Capt. Joseph Warran, U.S. Army. | GAO-23-105556

The military services have taken some steps to address resource challenges to predictive maintenance implementation from personnel, according to our analysis. In particular, the military services have generally focused on providing a sufficient number of personnel and providing training on completing predictive maintenance.

Military service officials agree that if they increase the usage of predictive maintenance the resulting cost savings benefits might allow for the reduction of maintainers in the long term. Military service policies set up the possibility of a reduction in maintainers by connecting the number of maintenance hours to personnel requirements.⁵⁶ However, in the near term, the initial benefits of predictive maintenance could prematurely reduce the number of maintainers. According to military service officials, maintenance personnel need to address backlogs before efficiencies from predictive maintenance can justify personnel reductions. As a result, the military services have taken some temporary action to prevent personnel reductions in the near term.

For example, in 2018 the Army reported using predictive maintenance principles to reduce requirements for preventive maintenance that saved one transportation company 6,100 hours of work in one year. (See sidebar.) The Army used a temporary measure to prevent planners from using the hours saved to justify personnel reductions, according to Army officials. Personnel responsible for maintenance can use hours saved to address other maintenance demands in order to prevent accidents or improve the availability of other systems for operations.⁵⁷ Similarly, the Navy is drafting a policy to allow Marine Corps and Navy aircraft maintainers to use time saved from implementing predictive maintenance to perform other aircraft maintenance tasks, rather than justifying personnel reductions, according to Navy officials. However, military service officials acknowledge that temporary exemptions from personnel

⁵⁶The military services consider the number of maintenance hours expended over time to develop personnel requirements. See AR 71-32, *Force Development and Documentation Consolidated Policies* (March 20, 2019); MCO 5311.1E, *Total Force Structure Process* (Nov. 18, 2015); OPNAVINST 1000.16L, *Navy Total Force Manpower Policies and Procedures* (June 24, 2015) (incorporating Change 3, July 2, 2021); and AFI 38-101, *Manpower and Organization* (August 29, 2019).

⁵⁷We previously reported that improper maintenance contributed to 49 percent of serious tactical vehicle accidents for fiscal years 2010 through 2019. For more information see GAO, *Military Vehicles: Army and Marine Corps Should Take Additional Actions to Mitigate and Prevent Training Accidents*, [GAO-21-361](#) (Washington, D.C.: July 7, 2021).

reductions and draft policy documents do not represent a permanent solution.

In addition, the military services are developing, or have developed, training to support service-wide implementation of predictive maintenance, according to the 2022 DODIG report that included recommendations for the military services to provide predictive maintenance training.⁵⁸ The military services acknowledged the need for required training at the appropriate levels necessary to achieve effective predictive maintenance execution. For example, the Army agreed with the DODIG's recommendation, stating that training requirements and implications will be considered during the requirements development process. We observed early training efforts among operational maintenance units for Army ground combat systems and aircraft during site visits in April 2022, including basic instructions on how to transfer data from ground combat systems and aircraft and how to use predictive maintenance dashboards.

The Marine Corps and Navy have varying levels and comprehensiveness of predictive maintenance training developed and offered to their sustainment workforces. However, Marine Corps officials we met with acknowledged that they are still developing comprehensive predictive maintenance training curriculums and that currently available training is not always required. According to Navy officials, they use existing training resources related to predictive maintenance that are already required for predictive maintenance practitioners, such as Reliability and Engineering technical support communities. The Air Force is also making efforts to provide predictive maintenance training as appropriate, according to the DODIG's 2022 report.

Steps to Address Parts Challenges

The military services have identified some steps to address resource challenges to predictive maintenance implementation from parts, according to our analysis. For example, the military services are exploring how to provide a sufficient number of parts to perform predictive maintenance as well as how to adjust planning for parts management.

⁵⁸DODIG-2022-103.

KC-135 Stratotanker

The Air Force chose KC-135 components for predictive maintenance based on the sufficient availability of supply. However, after 3 years of predictive maintenance, replacement parts for the components chosen are no longer available. As a result, there are significant parts challenges affecting predictive maintenance implementation.

Source: GAO analysis of Air Force data. Photo source: U.S. Air Force photo by Senior Airman Ryan Gomez. | GAO-23-105556

While parts management problems are a longstanding issue for the military services, officials stated that they are planning to work on improving parts data during the next phase of predictive maintenance implementation. For example, the Air Force uses parts availability, among other things, to determine which aircraft components are viable candidates for predictive maintenance, according to Air Force officials. However, even when adequate supplies may seem to exist when the military service selects an aircraft component for predictive maintenance, the parts available may rapidly diminish if predictive maintenance outpaces available supplies. (See sidebar.)

Additionally, the military services have used a variety of temporary steps to address supply chain policy and process challenges to predictive maintenance. For example, maintenance units generally turn in broken parts before getting a replacement, but Air Force and Navy officials said they arranged exceptions for predictive maintenance pilot projects with DOD depots and the Defense Logistics Agency.⁵⁹ In doing so, the maintenance units could turn in parts that predictive maintenance sensors and analytics indicated would soon fail, although they were not yet broken. In addition, the Air Force is working with the other military services to develop new policies and processes to allow maintenance units to order parts for predictive maintenance in advance of need.

Shifting to predictive maintenance may decrease or increase demand for specific parts depending on the circumstances, according to military service officials. Predictive maintenance calculations may determine that maintenance was too frequent for some components. For example, preventive maintenance performed on ground combat vehicles based on the passage of time rather than actual usage or condition may artificially increase the demand for parts. Shifting to a predictive maintenance strategy may reduce the demand for parts in these cases. In other cases, military service officials noted demand for parts may increase in the short term, as discussed in the example for the KC-135 above. We have previously reported on the need for improved demand planning for parts.⁶⁰ As the military services adopt predictive maintenance more

⁵⁹Predictive maintenance identifies problems with parts before they break, allowing the military services to replace parts that otherwise appear to be working. DOD has many different weapon systems with a limited supply of parts (or components) that may be expensive. The military services manage depots that refurbish spare parts rather than buying new ones, and require units to turn in broken parts for refurbishment by the depots before issuing a replacement.

⁶⁰[GAO-16-450](#).

widely, flexible responses to fluctuations in demand for parts may benefit maintainers seeking to improve weapon system readiness, according to DOD.

Steps to Address Technology Challenges

The military services have identified some steps to address resource challenges to predictive maintenance implementation from technology, according to our analysis. Specifically, the military services are taking steps to adapt sensors and analytics to current weapon systems and plan to integrate predictive maintenance with preventive maintenance.

The military services use a wide variety of approaches to overcome technology challenges for current weapon systems using predictive maintenance. For example, during our site visits officials showed us sensor technology for ground systems to support wireless data transmission in a manner similar to systems available on private sector consumer vehicles that the Army and Marine Corps have worked together to adapt to military vehicles, but with limited range. The Air Force is overcoming challenges associated with a limited number of sensors on older aircraft by supplementing sensor data with historical data to enable predictive maintenance. The Air Force overcomes data analysis challenges for aircraft supported by large numbers of sensors, such as the B-1 bomber, by contracting with the private sector to provide data analysis services.

Further, Army, Marine Corps, Navy, and Air Force officials discussed the use of predictive maintenance principles to adjust the thresholds required for preventive maintenance. During our site visits, we observed changes made to preventive maintenance schedules based on the condition of aircraft rather than the number of flight hours. Additionally, the Army is trying to improve the use of sensory data from aircraft for predictive maintenance to more accurately track flight hours, and improve the accuracy of preventive maintenance intervals. Specifically, aircraft pilots often round up the number of flight hours they record in order to meet standards required for maintaining proficiency and unit readiness, according to Army officials.⁶¹ However, when pilots round hours up to

⁶¹AR 95-1, *Flight Regulations* (Mar. 22, 2018) establishes requirements for aviation training and prescribes requirements for the aviation standardization program. Individuals use prescribed forms to record flying hours necessary to maintain flight proficiency and unit readiness. See also, Army, *Commander's Aviation Training and Standardization Program* (April 2022).

meet training requirements it may artificially increase the frequency of preventive maintenance, according to Army maintenance officials.

Marine Corps and Navy aircraft maintenance personnel expressed similar concerns as those noted by the Army regarding the tendency of aircrew to round up the number of flight hours. According to aircraft maintenance officials, the Army, Marine Corps, Navy, and Air Force have changed predictive maintenance intervals for some aircraft components based on actual usage and conditions, but not others. Military service officials stated in some instances this is due to an abundance of caution for safety critical systems, but in others, maintenance personnel were hesitant to change longstanding preventive maintenance intervals due to policy constraints or a general discomfort with changes to long-standing practices, according to military service officials.

Steps to Address Organizational Culture Challenges

The military services have identified some steps to address challenges from organizational culture. These include sustaining leadership focus, participating in joint implementation efforts, and improving commonality among similar systems.

Leadership focus and attention to implementing predictive maintenance has improved among the military services in the last few years, according to military service officials. Army and Marine Corps officials responsible for implementing predictive maintenance pilot programs on ground combat systems said predictive maintenance activity since 2018 resulted from increased leadership attention. Marine Corps and Navy officials responsible for aircraft maintenance said that current senior officers support predictive maintenance, but prior leadership did not provide as much focus and attention to predictive maintenance. The presence of a champion among maintenance leadership for a weapon system was the principal reason specific program offices began emphasizing predictive maintenance, according to Air Force officials. However, sustaining leadership focus and attention remains a concern, according to military service officials. Army, Marine Corps, Navy, and Air Force officials stated that it is important to ensure future leaders are aware of efforts to implement predictive maintenance and know how best to use it as an option for improving readiness in a cost-effective manner.

In addition, the military services have participated in some joint implementation predictive maintenance efforts. Specifically, the Army and Marine Corps have collaborated to implement predictive maintenance for

ground systems. For example, Army and Marine Corps officials said they participated in joint projects at Yuma Proving Ground and in Project Convergence during fiscal year 2020 to develop predictive maintenance capabilities for ground combat systems.⁶² During a site visit to Fort Stewart Georgia, Army officials demonstrated the use of systems they collaborated on with Marine Corps officials and confirmed that Marine Corps maintenance personnel had assisted in the installation of sensors for older wheeled weapon systems. In addition, all of the military services have participated in various predictive maintenance efforts, such as the Condition-Based Maintenance Plus Working Group, and specific joint efforts related to ground systems and aircraft described above. Joint implementation of predictive maintenance is likely to continue along the lines established over the last few years, according to military service officials.

Furthermore, the military services have taken steps to maximize commonality of predictive maintenance processes in support of similar weapon systems and components. For example, during our site visits we observed Army ground systems implementing predictive maintenance are using similar electronic processes to store data and display the results of predictive maintenance analysis. Army aircraft implementing predictive maintenance are also sharing innovative dashboards for maintenance planning. Similarly, Marine Corps aircraft and Navy aircraft share approaches to predictive maintenance processes across related types of fixed-wing and rotary aircraft, such as the F/A- 18 Hornet, F/A-18 Super Hornet, and the E/A-18 growler and across similar variants of fixed and rotary-wing aircraft. Air Force officials share approaches to predictive maintenance across similar weapon systems to some extent, but differences persist among aircraft depending on the type and age of aircraft, according to Air Force officials.

Conclusions

DOD's decades-old approach to maintaining its ground combat systems, ships and submarines, and aircraft has contributed to delays completing necessary maintenance, which in turn can detract from military readiness. DOD issued interim predictive maintenance policy 20 years ago followed

⁶²The Army also held *Project Convergence* in 2021 as a large-scale modernization experiment that brought together roughly 1,500 joint participants to field-test future warfighting capabilities, including predictive maintenance.

by formal policy issuances to improve operational availability of these weapon systems, but the military services have made limited progress implementing it until recently.⁶³ The military services report that they intend to scale the use of predictive maintenance across their weapon systems where it is beneficial and feasible to do so, but current governance structures have been fragmented and unsuited to implementing predictive maintenance.

In addition, the military services have not consistently adopted and tracked implementation of predictive maintenance. By designating an entity with the authority, staffing, and funding necessary to support predictive maintenance, and developing implementation plans with action plans and milestones for current weapon systems, the military services will be better positioned to determine how, when, and where to adopt predictive maintenance. In addition, by establishing outcome-related objectives for predictive maintenance, a process for evaluating progress, and a framework to develop and track milestones of implementation the military services will be better positioned to gauge progress and results to inform decision makers about the changes being made to support increased readiness.

The military services have demonstrated, in some limited examples, that predictive maintenance could yield better results, but they lack performance metrics to demonstrate the results of predictive maintenance. The use of predictive maintenance may increase readiness and reduce costs in some cases, but without developing a plan with specific metrics for evaluating predictive maintenance, the military services may be unable to assess its effectiveness or identify areas for improvement. In addition, as DOD begins to implement predictive maintenance more broadly, developing stand-alone metrics for predictive maintenance, and conducting ongoing monitoring procedures and reporting of the results of predictive maintenance will better position the military services to decide how and where to apply predictive maintenance to additional weapon systems.

⁶³DUSD (L&MR) Memorandum (Nov. 25, 2002); DODI 4151.22 (Dec. 2, 2007); and DODI 4151.22 (Aug. 14, 2020).

Recommendations for Executive Action

We are making a total of 16 recommendations, including four to the Secretary of the Army, eight to the Secretary of the Navy, and four to the Secretary of the Air Force.

The Secretary of the Army should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Army. (Recommendation 1)

The Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Marine Corps. (Recommendation 2)

The Secretary of the Navy should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Navy. (Recommendation 3)

The Secretary of the Air Force should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Air Force. (Recommendation 4)

The Secretary of the Army should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones. (Recommendation 5)

The Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones. (Recommendation 6)

The Secretary of the Navy should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones. (Recommendation 7)

The Secretary of the Air Force should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones. (Recommendation 8)

The Secretary of the Army should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance. (Recommendation 9)

The Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance. (Recommendation 10)

The Secretary of the Navy should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance. (Recommendation 11)

The Secretary of the Air Force should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance. (Recommendation 12)

The Secretary of the Army should establish procedures and conduct ongoing monitoring and reporting of the results from predictive maintenance for major weapon systems. (Recommendation 13)

The Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems. (Recommendation 14)

The Secretary of the Navy should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems. (Recommendation 15)

The Secretary of the Air Force should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems. (Recommendation 16)

Agency Comments and Our Evaluation

We provided a draft of this report to DOD for review and comment. In its written comments, reproduced in appendix II, DOD concurred with 14 of our recommendations and partially concurred with the other two recommendations.

Specifically, the Department of the Navy, on behalf of the Navy and Marine Corps, partially concurred with recommendations six and seven that that the Secretary of the Navy should develop a comprehensive implementation plan for predictive maintenance. The Department of the Navy agreed that a comprehensive strategic implementation plan is necessary, but stated it does not believe that all weapon systems are suitable candidates for predictive maintenance. The Department of the Navy's position is that deliberate study and analysis is required to determine which weapon systems should implement predictive maintenance, and the degree to which such implementation is necessary and beneficial.

We agree that not all weapon systems may be suitable candidates for predictive maintenance, and that deliberate study and analysis will help determine which weapon systems should implement predictive maintenance. However, as we stated in our report, developing a comprehensive implementation plan would help the Department of the Navy effectively determine how, when, and where to adopt predictive maintenance. As we stated, DOD guidance requires that life cycle managers will consider implementing predictive maintenance where cost-benefit analyses indicate improved equipment availability or sustainment cost reduction, and develop action plans and milestones where predictive maintenance integration is supported by the analyses for specific weapon systems. We believe that implementation of our recommendations for the Navy and the Marine Corps to develop comprehensive implementation plans for predictive maintenance would entail analysis and decisions about the suitability of predictive maintenance for specific weapons systems.

DOD also provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Defense, the Secretary of the Army, the Commandant of the Marine Corps, the Secretary of the Navy, and the Secretary of the Air Force. In addition, the report is available at no charge on the GAO website at <http://www.gao.gov>.

If you or your staff has any questions about this report, please contact me at (202) 512-9627 or maurerd@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of published GAO reports. GAO staff that made key contributions to this report are listed in appendix III.

A handwritten signature in black ink that reads "Diana Maurer". The signature is written in a cursive style with a large, sweeping initial "D".

Diana Maurer
Director, Defense Capabilities and Management

Appendix I: Objectives, Scope, and Methodology

Our objectives were to assess the extent to which the military services have (1) implemented predictive maintenance, (2) assessed the performance of predictive maintenance, and described (3) challenges to predictive maintenance identified by the military services, and efforts to address those challenges.¹ We focused on current weapon systems used by the Army, Marine Corps, Navy and Air Force, but excluded weapon systems in acquisition, and uncrewed weapon systems from the scope of this review. The F-35 Joint Strike Fighter is also beyond the scope of this review as we have separately reported on the weapon system.²

For our first objective, we reviewed DOD, Army, Marine Corps, Navy, and Air Force guidance and documents detailing predictive maintenance

¹The military services use multiple terms for predictive maintenance or predictive maintenance enablers, including Condition-Based Maintenance (CBM), Condition-Based Maintenance Plus (CBM+), Prognostic and Predictive Maintenance (PPMx), Enhanced Reliability-Centered Maintenance (eRCM), and Predictive Maintenance. For the purposes of our review, we define predictive maintenance as any effort that uses analysis of historical data or sensor-generated data to anticipate maintenance needs in a manner that reduces unscheduled reactive maintenance or overly prescriptive preventive maintenance. This definition includes any efforts described by the terms used by DOD and the military services previously listed.

²For examples, see GAO, *F-35 Sustainment: DOD Faces Several Uncertainties and Has Not Met Key Objectives*, [GAO-22-105995](#) (Washington, D.C.: Apr. 28, 2022), and GAO, *F-35 Joint Strike Fighter: Cost Growth and Schedule Delays Continue*, [GAO-22-105128](#) (Washington, D.C.: Apr. 25, 2022), along with the Related GAO Products section of that report.

implementation and discussed progress with military service officials.³ Specifically, we reviewed DOD and military service documentation and plans for predictive maintenance, as well as our previous reports related to readiness efforts associated with ground combat systems, ships and submarines, and aircraft. We also obtained the views of officials from the Office of the Secretary of Defense, the military services, and officials participating in the implementation of predictive maintenance. We reviewed the DOD Inspector General's report on predictive maintenance implementation, and obtained views from military service officials and related commands on predictive maintenance implementation efforts and progress.⁴ We compiled a list of weapon systems with predictive maintenance capabilities provided by the military services, reviewed responses, and verified the status of weapon systems undergoing active pilot projects during interviews with agency officials and site visits. We did not validate the list of weapon systems as the DOD Inspector General had determined that officials did not have full visibility of predictive maintenance projects and tools.⁵ We reviewed the President's budget request for the Department of Defense for fiscal years 2022 and 2023 and defense budget materials presented by the military services, and requested information from the military services regarding future years' defense plans. In addition, we requested status updates on

³For example see DOD Instruction (DODI) 4151.22, *Condition-Based Maintenance Plus for Materiel Maintenance* (August 14, 2020); DOD Guidebook, *Condition Based Maintenance Plus* (May 1, 2008); Army Headquarters (HQDA) Execution Order (EXORD) 032-19, *Army Implementation and Execution of Condition Based Maintenance Plus (CBM+)* (November 2018); Marine Corps Order (MCO) 4151.22, *Condition Based Maintenance Plus Order* (Jan. 17, 2020); Navy Chief of Naval Operations Instruction (NAVSEAINST) 4790.27B, *Condition-Based Maintenance Plus and Reliability-Centered Maintenance Policy For Ships, Ship Systems, And Equipment* (Jan. 21, 2022); and Air Force, *CBM+ Strategic Implementation Plan* (Apr. 2021). In addition, we considered applicable portions of GAO, *Government Reorganization: Key Questions to Assess Agency Reform Efforts*, [GAO-18-427](#) (Washington, D.C.: June 13, 2018) and applicable portions of GAO, *Standards for Internal Control in the Federal Government*, [GAO-14-704G](#) (Washington, D.C.: Sept. 10, 2014).

⁴DOD Inspector General, *Audit of the Department of Defense's Implementation of Predictive Maintenance Strategies to Support Weapon System Sustainment*, DODIG-2022-103 (Alexandria, VA: June 13, 2022). During the course of our review, we coordinated with the DOD Inspector General, who was also conducting a review of DOD Predictive Maintenance. Our objectives, scope, methodology, and audit work was independent of that of the DOD Inspector General.

⁵DODIG-2022-103. The DOD IG Recommended that the Deputy Assistant Secretary of Defense (Materiel Readiness), in coordination with the CBM+ focal points for the Services and other relevant stakeholders, develop and execute a mechanism to report and provide visibility of CBM+ and predictive maintenance projects and tools, among other things.

implementation progress, along with plans of action and milestones for specific weapon systems, and any plans for scaling the implementation of predictive maintenance across each of the military services within the scope of our review.

For our second objective, we reviewed DOD and military service guidance related to evaluating predictive maintenance outcomes, and conducted interviews with military service officials to discuss whether predictive maintenance has improved outcomes such as mission capability, readiness, asset availability, and life cycle costs.⁶ We requested copies of predictive maintenance performance metrics, tools, and program evaluations used to measure performance for the weapon systems identified by the military services as part of our first objective. If developed by the military services, we reviewed performance assessments and briefings to determine whether the military services attributed trends associated with increasing operational availability, equipment reliability, and reducing operating costs to predictive maintenance. We discussed the use of performance measures as management tools with military service officials, and performed analysis to determine whether military service officials could clearly identify results from predictive maintenance separately from the effects of other changes or maintenance performance drivers.

For our third objective, we asked the military services to identify the principle reasons for implementing predictive maintenance through a series of semi-structured questionnaires. We reviewed responses provided by the military services and followed up with additional written questions as needed to identify the primary challenges to predictive maintenance, and discussed these with military service officials responsible for implementing predictive maintenance. When military services identified specific challenges, we corroborated their assertions in written document and prior reports. Specifically, we reviewed and analyzed documentation and written responses from knowledgeable Army, Marine Corps, Navy, and Air Force officials. The officials we met and corresponded with include command officials, program officials, and unit officials from units we selected to identify challenges that are affecting the implementation and performance of predictive maintenance, and efforts made to overcome those challenges. Specifically, we selected

⁶ For example see, DODI 4151.22; DOD Guidebook; HQDA EXORD 032-19; MCO 4151.22; NAVSEAINST 4790.27B; Air Force Plan; and applicable portions of GAO, *Performance Measurement and Evaluation*, [GAO-11-646SP](#) (Washington, D.C.: May 2, 2011).

units operating current weapon systems implementing predictive maintenance from among the list of systems identified by the military services, and identified by the military services as being available for visits during our review.

We selected operational units from a list of weapon systems within the scope of our review—ground combat systems, ships and submarines, and aircraft—provided by the military services in response to our first two objectives for further review. We used additional information provided by military service officials related to other weapon systems for illustrative examples as needed. Based on this information, we selected a non-generalizable list of specific weapon systems and operational units that perform maintenance on these weapon systems in collaboration with the military services identified as most relevant to our objectives, or as having made the most progress implementing predictive maintenance, as follows:

Ground combat systems. For Army ground combat systems, we selected the M1A2 Abrams Main Battle Tank (SEP V3), the M109A7 Paladin Self-Propelled Howitzer, and its companion, the M992A3 Carrier, Ammunition, Tracked vehicle. For Marine Corps ground combat systems, we selected the Joint Light Tactical Vehicle and the Medium Tactical Vehicle Replacement. We used information provided by military service officials related to other ground combat systems for illustrative examples as needed.

Ships and submarines. For the Navy, we selected the USS Arleigh Burke (DDG-51) class of destroyers, and the USS Mason (DDG-87) specifically, as the only example of predictive maintenance implementation available among Navy ships and submarines. We considered Navy submarines, aircraft carriers, and Army watercraft to be beyond the scope of our review, as military service officials did not identify predictive maintenance implementation efforts for those vessel types.

Aircraft. For the Army, we selected the AH-64 Apache, the UH-60 Blackhawk, and the CH-47 Chinook rotary aircraft. For the Marine Corps and Navy, we selected the CH-53 Sea Stallion, and UH-1 Viper rotary aircraft, the F/A-18 Super Hornet and the E/A-18 Growler fixed wing aircraft. For the Air Force, we selected the KC-135 Stratotanker, and the B-1 Lancer Bomber fixed wing aircraft.

In the course of our performance audit, we interviewed officials from organizations listed below.

- Office of the Assistant Secretary of Defense for Sustainment
 - Deputy Assistant Secretary of Defense for Materiel Readiness
- Department of the Army
 - Army Deputy Chief of Staff, G-4 Logistics
 - Army Materiel Command
 - Army Tank-automotive and Armaments Command
 - Army Aviation and Missile Command
 - Army Forces Command
 - Army Futures Command
 - Program Executive Office, Ground Combat Systems
 - Program Executive Office, Aviation
 - Program Executive Office, Combat Support and Combat Service Support
- Department of the Navy
 - Deputy Assistant Secretary of the Navy - Sustainment
 - Commander, Naval Air Systems Command
 - Commander, Fleet Readiness Centers
 - F/A-18 and EA-18G Program Office (PMA-265)
 - H-53 Heavy Lift Helicopters Program (PMA-261)
 - Program Executive Office, Tactical Aircraft Programs
 - Commander, Naval Sea Systems Command
 - Surface Ship Sustainment Office (PMS 443)
 - Program Executive Office, Integrated Warfare Systems
 - Headquarters Marine Corps, The Deputy Commandant, Installations and Logistics
 - Commander, Marine Corps Systems Command

- Program Executive Officer, Land Systems
- Department of the Air Force
 - Deputy Chief of Staff for Logistics, Engineering and Force Protection
 - Air Force Materiel Command
 - Air Force Sustainment Center
 - Air Force Rapid Sustainment Office

In addition to the offices listed above, we visited or spoke with operational units responsible for adapting predictive maintenance to existing weapon systems.

- Department of the Army
 - Army 3rd Infantry Division at Fort Stewart-Hunter Army Airfield, Georgia
 - Army 3rd Combat Aviation Brigade at Hunter Army Airfield, Georgia.
- Department of the Navy
 - Marine Corps
 - 3rd Marine Logistics Group, Okinawa, Japan
 - 2nd Marine Logistics Group, Camp Lejeune, North Carolina,
 - Air Test and Evaluation Squadron Twenty One (HX-21), Patuxent River, Maryland
 - Naval Air Systems Command
 - Air Test and Evaluation Squadron Twenty Three (VX-23) , Patuxent River, Maryland
 - Naval Sea Systems Command
 - Naval Surface Warfare Center, Philadelphia, Pennsylvania
- Department of the Air Force
 - 92nd Air Refueling Wing at Fairchild Air Force Base, Washington
 - 7th Bomb Wing, Dyess Air Force Base, Texas

**Appendix I: Objectives, Scope, and
Methodology**

We conducted this performance audit from November 2021 to December 2022, 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 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

Appendix II: Comments from the Department of Defense



SUSTAINMENT

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3500 DEFENSE PENTAGON
WASHINGTON, DC 20301-3500

November 22, 2022

Ms. Diana Maurer
Director, Defense Capabilities Management
U.S. Government Accountability Office
441 G Street, NW
Washington DC 20548

Dear Ms. Maurer,

This is the Department of Defense (DoD) response to the Government Accountability Office (GAO) Draft Report GAO-23-105556, "MILITARY READINESS: Actions Needed to Further Implement Predictive Maintenance on Weapon Systems," dated October 27, 2022 (GAO Code 105556).

Attached is the DoD's response to the subject report. My point of contact is Mr. Steve McKee, who may be reached at stephen.e.mckee.civ@mail.mil and by phone at 571-969-0662.

Sincerely,

RAMDASS.VICKY .
SHASHINDERAJ.10
19209780

Digitally signed by
RAMDASS.VICKY.SHASHINDER
AJ.1019209780
Date: 2022.11.22 12:09:49 -0500

Vic S. Ramdass, Ph.D
Deputy Assistant Secretary of Defense
(Materiel Readiness)

Enclosure:
As stated

**GAO DRAFT REPORT DATED OCTOBER 27, 2022
GAO-23-105556 (GAO CODE 105556)**

**“MILITARY READINESS: ACTIONS NEEDED TO FURTHER IMPLEMENT
PREDICTIVE MAINTENANCE ON WEAPON SYSTEMS”**

**DEPARTMENT OF DEFENSE COMMENTS
TO THE GAO RECOMMENDATION**

RECOMMENDATION 1: The GAO recommends that the Secretary of the Army should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Army.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 2: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Marine Corps.

DoD RESPONSE: The Deputy Assistant Secretary of the Navy for Sustainment (DASN-S), on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the response to GAO recommendation number 3 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 2.

RECOMMENDATION 3: The GAO recommends that the Secretary of the Navy should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Navy.

DoD RESPONSE: The Department of the Navy concurs with this recommendation. The Assistant Secretary of the Navy for Research, Development, and Acquisition is the executive agent for Department oversight of sustainment activity to include maintenance as defined in section 915 of the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2019.

RECOMMENDATION 4: The GAO recommends that the Secretary of the Air Force should designate a single entity with sufficient authority and funding necessary to support the implementation of predictive maintenance across the Air Force.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation. The Air Force Life Cycle Management Center’s Rapid Sustainment Office serves as the center of excellence to support implementation of predictive maintenance.

RECOMMENDATION 5: The GAO recommends that the Secretary of the Army should develop a comprehensive implementation plan for predictive maintenance, which includes action

plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 6: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The DASN-S, on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the response to GAO recommendation number 7 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 6.

RECOMMENDATION 7: The GAO recommends that the Secretary of the Navy should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The Department of the Navy partially concurs with this recommendation. The Department of the Navy concurs that a comprehensive strategic implementation plan is necessary, but does not believe that all weapon systems are suitable candidates for predictive maintenance. The Department of the Navy's position is that deliberate study and analysis is required to determine which weapon systems should implement predictive maintenance and to what degree such implementation should be deemed necessary and beneficial.

RECOMMENDATION 8: The GAO recommends that the Secretary of the Air Force should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation. The Air Force's Condition-Based Maintenance Plus (CBM+) Strategic Implementation Plan provides a predictive maintenance implementation approach, execution processes, and milestones for progress.

RECOMMENDATION 9: The GAO recommends that the Secretary of the Army should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 10: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The DASN-S, on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the responses to GAO recommendation number 11 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 10.

RECOMMENDATION 11: The GAO recommends that the Secretary of the Navy should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The Department of the Navy concurs with this recommendation. The Navy and Marine Corps are currently executing pilot studies on various aviation, maritime, and ground combat systems to expand implementation and adoption of predictive maintenance to Navy and Marine Corps weapon systems. Part of these pilot studies is to assess how to measure predictive maintenance and how to determine the correct metrics for tracking and accountability at the correct echelons of oversight and governance. The Navy and Marine Corps pilot programs are scheduled to conclude in FY 2024.

RECOMMENDATION 12: The GAO recommends that the Secretary of the Air Force should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation.

RECOMMENDATION 13: The GAO recommends that the Secretary of the Army should establish procedures and conduct ongoing monitoring and reporting of the results from predictive maintenance for major weapon systems.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 14: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems.

DoD RESPONSE: The DASN-S, on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the responses to GAO recommendation number 15 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 14.

RECOMMENDATION 15: The GAO recommends that the Secretary of the Navy should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems.

**Appendix II: Comments from the Department
of Defense**

4

DoD RESPONSE: The Department of the Navy concurs with this recommendation. The Department of the Navy is aligned to the Office of the Secretary of Defense's initiatives to develop and implement mechanisms for tracking and understanding sustainment data. Examples include the Deputy Secretary of Defense's Memoranda to establish data driven approaches to containing sustainment costs and detailed guidance on sustainment performance and cost metrics.

RECOMMENDATION 16: The GAO recommends that the Secretary of the Air Force should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation.

Accessible Text for Appendix II: Comments from the Department of Defense

November 22, 2022

Ms. Diana Maurer
Director, Defense Capabilities Management
U.S. Government Accountability Office
441 G Street, NW
Washington DC 20548

Dear Ms. Maurer,

This is the Department of Defense (DoD) response to the Government Accountability Office (GAO) Draft Report GAO-23-105556, "MILITARY READINESS: Actions Needed to Further Implement Predictive Maintenance on Weapon Systems," dated October 27, 2022 (GAO Code 105556).

Attached is the DoD's response to the subject report. My point of contact is Mr. Steve McKee, who may be reached at stephen.e.mckee.civ@mail.mil and by phone at 571-969-0662.

Sincerely,

Vic S. Ramdass, Ph.D
Deputy Assistant Secretary of Defense
(Materiel Readiness)

Enclosure:
As stated

GAO DRAFT REPORT DATED OCTOBER 27, 2022 GAO-23-105556 (GAO CODE 105556)

"MILITARY READINESS: ACTIONS NEEDED TO FURTHER IMPLEMENT
PREDICTIVE MAINTENANCE ON WEAPON SYSTEMS"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATION

RECOMMENDATION 1: The GAO recommends that the Secretary of the Army should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Army.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 2: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Marine Corps.

DoD RESPONSE: The Deputy Assistant Secretary of the Navy for Sustainment (DASN-S), on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the response to GAO recommendation number 3 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 2.

RECOMMENDATION 3: The GAO recommends that the Secretary of the Navy should designate a single entity with sufficient authority and resources necessary to support the implementation of predictive maintenance across the Navy.

DoD RESPONSE: The Department of the Navy concurs with this recommendation. The Assistant Secretary of the Navy for Research, Development, and Acquisition is the executive agent for Department oversight of sustainment activity to include maintenance as defined in section 915 of the National Defense Authorization Act (NDAA) for Fiscal Year (FY) 2019.

RECOMMENDATION 4: The GAO recommends that the Secretary of the Air Force should designate a single entity with sufficient authority and funding necessary to support the implementation of predictive maintenance across the Air Force.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation. The Air Force Life Cycle Management Center's Rapid Sustainment Office serves as the center of excellence to support implementation of predictive maintenance.

RECOMMENDATION 5: The GAO recommends that the Secretary of the Army should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 6: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The DASN-S, on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the response to GAO recommendation number 7 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 6.

RECOMMENDATION 7: The GAO recommends that the Secretary of the Navy should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The Department of the Navy partially concurs with this recommendation. The Department of the Navy concurs that a comprehensive strategic implementation plan is necessary, but does not believe that all weapon systems are suitable candidates for predictive maintenance. The Department of the Navy's position is that deliberate study and analysis is required to determine which weapon systems should implement predictive maintenance and to what degree such implementation should be deemed necessary and beneficial.

RECOMMENDATION 8: The GAO recommends that the Secretary of the Air Force should develop a comprehensive implementation plan for predictive maintenance, which includes action plans and milestones for current weapon systems, outcome-related goals and objectives, a process for evaluating progress, and a framework to develop and track milestones.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation. The Air Force's Condition-Based Maintenance Plus (CBM+) Strategic Implementation Plan provides a predictive maintenance implementation approach, execution processes, and milestones for progress.

RECOMMENDATION 9: The GAO recommends that the Secretary of the Army should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 10: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The DASN-S, on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the responses to GAO recommendation number 11 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 10.

RECOMMENDATION 11: The GAO recommends that the Secretary of the Navy should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The Department of the Navy concurs with this recommendation. The Navy and Marine Corps are currently executing pilot studies on various aviation, maritime, and ground combat systems to expand implementation and adoption of predictive maintenance to Navy and Marine Corps weapon systems. Part of these pilot studies is to assess how to measure predictive maintenance and how to determine the correct metrics for tracking and accountability at the correct echelons of oversight and governance. The Navy and Marine Corps pilot programs are scheduled to conclude in FY 2024.

RECOMMENDATION 12: The GAO recommends that the Secretary of the Air Force should develop a plan with specific quantifiable metrics and goals for evaluating predictive maintenance.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation.

RECOMMENDATION 13: The GAO recommends that the Secretary of the Army should establish procedures and conduct ongoing monitoring and reporting of the results from predictive maintenance for major weapon systems.

DoD RESPONSE: The Department of the Army concurs with this recommendation.

RECOMMENDATION 14: The GAO recommends that the Secretary of the Navy, in coordination with the Commandant of the Marine Corps, should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems.

DoD RESPONSE: The DASN-S, on behalf of the Navy Secretariat, coordinated the following responses across the Department of the Navy and determined the

responses to GAO recommendation number 15 is sufficient for the purpose of addressing Navy and Marine Corps equities otherwise directed in recommendation 14.

RECOMMENDATION 15: The GAO recommends that the Secretary of the Navy should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems.

DoD RESPONSE: The Department of the Navy concurs with this recommendation. The Department of the Navy is aligned to the Office of the Secretary of Defense's initiatives to develop and implement mechanisms for tracking and understanding sustainment data. Examples include the Deputy Secretary of Defense's Memoranda to establish data driven approaches to containing sustainment costs and detailed guidance on sustainment performance and cost metrics.

RECOMMENDATION 16: The GAO recommends that the Secretary of the Air Force should establish procedures and conduct ongoing monitoring and reporting of program performance and results from predictive maintenance for major weapon systems.

DoD RESPONSE: The Department of the Air Force concurs with this recommendation.

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

Diana Maurer, 202-512-9627 or maurerd@gao.gov

Staff Acknowledgments

In addition to the contact listed above, Jodie Sandel (Assistant Director), John E. “Jet” Trubey (Analyst-in-Charge), Simon Chan, Nathan Hanks, David L. Jones, Felicia Lopez, Keith E. McDaniel, Michael L. Perkins, Clarice Ransom, and Terry Richardson made key contributions to this report.

Related GAO Products

Weapon System Sustainment: Aircraft Mission Capable Goals Were Generally Not Met and Sustainment Costs Varied by Aircraft. [GAO-23-106217](#). Washington, D.C.: Nov. 10, 2022.

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

Air Force and Navy Aviation: Actions Needed to Address Persistent Sustainment Risks. [GAO-22-104533](#). Washington, D.C.: June 15, 2022.

Navy Ships: Applying Leading Practices and Transparent Reporting Could Help Reduce Risks Posed by Nearly \$1.8 Billion Maintenance Backlog. [GAO-22-105032](#). Washington, D.C.: May 9, 2022.

Artificial Intelligence: Status of Developing and Acquiring Capabilities for Weapon Systems. [GAO-22-104765](#). Washington, D.C.: Feb. 17, 2022.

Defense Acquisitions: DOD Should Take Additional Actions to Improve How It Approaches Intellectual Property. [GAO-22-104752](#). Washington, D.C.: Nov. 30, 2021.

Littoral Combat Ship: Actions Needed to Address Significant Operational Challenges and Implement Planned Sustainment Approach. [GAO-22-105387](#). Washington, D.C.: Feb. 24, 2022.

Navy Ship Maintenance: Actions Needed to Monitor and Address the Performance of Intermediate Maintenance Periods. [GAO-22-104510](#). Washington, D.C.: Feb. 8, 2022.

Military Vehicles: Army and Marine Corps Should Take Additional Actions to Mitigate and Prevent Training Accidents. [GAO-21-361](#). Washington, D.C.: July 7, 2021.

Artificial Intelligence: An Accountability Framework for Federal Agencies and Other Entities. [GAO-21-519SP](#). Washington, D.C.: June, 2021.

Military Readiness: Department of Defense Domain Readiness Varied from Fiscal Year 2017 through fiscal year 2019. [GAO-21-279](#). Washington, D.C.: Apr. 7, 2021.

Navy and Marine Corps: Services Continue Efforts to Rebuild Readiness, but Recovery Will Take Years and Sustained Management Attention. [GAO-21-225T](#). Washington, D.C.: Dec. 2, 2020.

Weapon System Sustainment: Aircraft Mission Capable Rates Generally Did Not Meet Goals and Cost of Sustaining Selected Weapon Systems Varied Widely. [GAO-21-101SP](#). Washington, D.C.: Nov. 19, 2020.

Navy Maintenance: Navy Report Did Not Fully Address Causes of Delays or Results-Oriented Elements. [GAO-21-66](#). Washington, D.C.: Oct. 29, 2020.

Navy Shipyards: Actions Needed to Address the Main Factors Causing Maintenance Delays for Aircraft Carriers and Submarines. [GAO-20-588](#). Washington, D.C.: Aug. 20, 2020.

Military Depots: Army and Marine Corps Need to Improve Efforts to Address Challenges in Measuring Performance and Planning Maintenance Work. [GAO-20-401](#). Washington, D.C.: July 16, 2020.

Army Readiness: Progress and Challenges in Rebuilding Personnel, Equipping, and Training. [GAO-19-367T](#). Washington, D.C.: Feb. 6, 2019.

Military Personnel: Strategy Needed to Improve Retention of Experienced Air Force Aircraft Maintainers. [GAO-19-160](#). Washington, D.C.: Feb. 5, 2019.

Air Force Readiness: Actions Needed to Rebuild Readiness and Prepare for the Future. [GAO-19-120T](#). Washington, D.C.: Oct. 10, 2018.

Government Reorganization: Key Questions to Assess Agency Reform Efforts. [GAO-18-427](#). Washington, D.C.: June 13, 2018

Military Readiness: DOD's Readiness Rebuilding Efforts May Be at Risk without a Comprehensive Plan. [GAO-16-841](#). Washington, D.C.: Sept. 7, 2016.

Defense Inventory: Further Analysis and Enhanced Metrics Could Improve Service Supply and Depot Operations. [GAO-16-450](#). Washington, D.C.: June 9, 2016.

Related GAO Products

Defense Logistics: Improvements Needed to Enhance DOD's Management Approach and Implementation of Item Unique Identification Technology. [GAO-12-482](#). Washington, D.C.: May 3, 2012.

GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through our website. Each weekday afternoon, GAO posts on its [website](#) newly released reports, testimony, and correspondence. You can also [subscribe](#) to GAO's email updates to receive notification of newly posted products.

Order by Phone

The price of each GAO publication reflects GAO's actual cost of production and distribution and depends on the number of pages in the publication and whether the publication is printed in color or black and white. Pricing and ordering information is posted on GAO's website, <https://www.gao.gov/ordering.htm>.

Place orders by calling (202) 512-6000, toll free (866) 801-7077, or TDD (202) 512-2537.

Orders may be paid for using American Express, Discover Card, MasterCard, Visa, check, or money order. Call for additional information.

Connect with GAO

Connect with GAO on [Facebook](#), [Flickr](#), [Twitter](#), and [YouTube](#).
Subscribe to our [RSS Feeds](#) or [Email Updates](#). Listen to our [Podcasts](#).
Visit GAO on the web at <https://www.gao.gov>.

To Report Fraud, Waste, and Abuse in Federal Programs

Contact FraudNet:

Website: <https://www.gao.gov/about/what-gao-does/fraudnet>

Automated answering system: (800) 424-5454 or (202) 512-7700

Congressional Relations

A. Nicole Clowers, Managing Director, ClowersA@gao.gov, (202) 512-4400, U.S. Government Accountability Office, 441 G Street NW, Room 7125, Washington, DC 20548

Public Affairs

Chuck Young, Managing Director, youngc1@gao.gov, (202) 512-4800
U.S. Government Accountability Office, 441 G Street NW, Room 7149
Washington, DC 20548

Strategic Planning and External Liaison

Stephen J. Sanford, Managing Director, spel@gao.gov, (202) 512-4707
U.S. Government Accountability Office, 441 G Street NW, Room 7814,
Washington, DC 20548



Please Print on Recycled Paper.