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Report to Congressional Addressees

March 2021

HYPERSONIC WEAPONS

DOD Should Clarify Roles and Responsibilities to Ensure Coordination across Development Efefforts

GAO-21-378

GAO@100 Highlights

Highlights of GAO-21-378, a report to congressional addressees

March 2021

HYPERSONIC WEAPONS

DOD Should Clarify Roles and Responsibilities to Ensure Coordination across Development Efforts

Why GAO Did This Study

Hypersonic missiles, which are an important part of building hypersonic weapon systems, move at least five times the speed of sound, have unpredictable flight paths, and are expected to be capable of evading today's defensive systems. DOD has begun multiple efforts to develop offensive hypersonic weapons as well as technologies to improve its ability to track and defend against them. NASA and DOE are also conducting research into hypersonic technologies. The investments for these efforts are significant.

This report identifies: (1) U.S. government efforts to develop hypersonic systems that are underway and their costs, (2) challenges these efforts face and what is being done to address them, and (3) the extent to which the U.S. government is effectively coordinating these efforts. This is a public version of a sensitive report that GAO issued in January 2021. Information that DOD deemed to be sensitive has been omitted.

GAO collected and reviewed information from DOD, DOE, and NASA to identify hypersonic weapons development efforts from fiscal years 2015 through 2024. GAO also analyzed agency documentation and interviewed agency officials.

What GAO Recommends

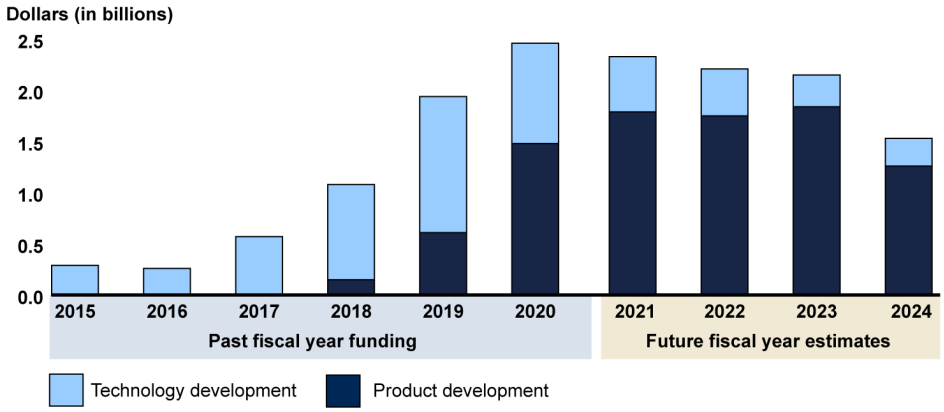
The Secretary of Defense should define and document the roles, responsibilities, and authorities of the leadership positions and organizations in DOD responsible for the development and acquisition of hypersonic weapons. DOD concurred with the recommendation.

View GAO-21-378. For more information, contact Jon Ludwigson at (202) 512-4841 or ludwigsonj@gao.gov.

What GAO Found

GAO identified 70 efforts to develop hypersonic weapons and related technologies that are estimated to cost almost $15 billion from fiscal years 2015 through 2024 (see figure). These efforts are widespread across the Department of Defense (DOD) in collaboration with the Department of Energy (DOE) and, in the case of hypersonic technology development, the National Aeronautics and Space Administration (NASA). DOD accounts for nearly all of this amount.

Hypersonic Weapon-related and Technology Development Total Reported Funding by Type of Effort from Fiscal Years 2015 through 2024, in Billions of Then-Year Dollars



Source: GAO analysis of Department of Defense, Department of Energy, and National Aeronautics and Space Administration data. | GAO-21-378

The majority of this funding is for product development and potential fielding of prototype offensive hypersonic weapons. Additionally, it includes substantial investments in developing technologies for next generation hypersonic weapons and a smaller proportion aimed at countering hypersonic threats.

Hypersonic weapon systems are technically complex, and DOD has taken several steps to mitigate some of the challenges to developing them. For example, DOD has attempted to address challenges posed by immature technologies and aggressive schedules by pursuing multiple potential technological solutions so that it has options. Other challenges DOD is addressing relate to industrial base and human capital workforce investments needed to support large-scale production and the availability of wind tunnels and open-air flight test ranges needed to test hypersonic weapons.

DOE and NASA have agreements with DOD on supporting roles, but DOD itself has not documented the roles, responsibilities, and authorities of the multitude of its organizations, including the military services, that are working on hypersonic weapon development. Such governing documentation would provide for a level of continuity when leadership and organizational priorities inevitably change, especially as hypersonic weapon development efforts are expected to continue over at least the next decade. Without clear leadership roles, responsibilities, and authorities, DOD is at risk of impeding its progress toward delivering hypersonic weapon capabilities and opening up the potential for conflict and wasted resources as decisions over larger investments are made in the future.

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Abbreviations

DARPA	Defense Advanced Research Projects Agency
DCMA	Defense Contract Management Agency
DOD	Department of Defense
DOE	Department of Energy
JHTO	Joint Hypersonics Transition Office
NASA	National Aeronautics and Space Administration
OSD	Office of the Secretary of Defense
OUSD (A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
OUSD (R&E)	Office of the Under Secretary of Defense for Research and Engineering
S&T	science and technology
T&E	test and evaluation
TRL	technology readiness level
TRMC	Test Resource Management Center

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Congressional Addressees

Hypersonic missiles, which move at least five times the speed of sound and have unpredictable flight paths, are expected to be capable of evading today's U.S. defensive systems.[1] For decades, multiple Department of Defense (DOD) organizations and other federal agencies have undertaken various science and technology efforts to develop hypersonic technologies. More recently, senior DOD officials have stated potential U.S. adversaries have made progress in developing hypersonic weapons. In light of the potential threats posed by these developments, DOD has led multiple efforts to further develop its own hypersonic weapons and technologies to provide an offensive capability and improve its ability to track and defend against adversaries. Additionally, other agencies such as the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE) have extensive experience and facilities applicable to developing or testing weapon systems and are either conducting research into hypersonic technologies or supporting DOD's hypersonic weapon-related development. The investments for these efforts are significant, with public reports of DOD spending billions of dollars.

We prepared this report on U.S. government hypersonic weapon development under the authority of the Comptroller General to assist Congress with its oversight responsibilities. This report identifies: (1) U.S. government efforts to develop hypersonic systems that are underway and their recent and estimated future costs, (2) challenges these efforts face to develop hypersonic weapon systems and what is being done to address them, and (3) the extent to which the U.S. government is effectively coordinating these efforts. For the purposes of this report, we consider hypersonic weapon-related and technology development broadly in that it can include any system, prototype, component, research, or

[1]Mach number is the ratio of travel speed relative to the speed of sound. Mach 1 refers to traveling at the speed of sound, and Mach 5 refers to traveling at five times the speed of sound. The speed of sound varies with temperature and the atmospheric temperature varies with altitude. At sea level, the speed of sound is approximately 761 miles per hour. At an example flight altitude for hypersonic weapons, the speed of sound is approximately 660 miles per hour.

technology being pursued by DOD to deliver an offensive hypersonic capability or to defend against an adversary's hypersonic weapons.

This report is a public version of a sensitive report that we issued on January 15, 2021.[2] DOD deemed some of the information in our January 2021 report to be sensitive, which must be protected from public disclosure. Therefore, this report omits sensitive information about critical technologies, human capital and industrial base investments, and hypersonic test resources. Although the information provided in this report is more limited, the report addresses the same objectives as the sensitive report and uses the same methodology.

To identify what U.S. government efforts to develop hypersonic systems are underway and their costs, we collected information via surveys on hypersonic weapon system development and related research from officials directly involved in planning or managing efforts at DOD, DOE, and NASA, which were identified by senior officials and hypersonic experts as the relevant agencies.[3] At our request, the surveys asked agencies to identify all efforts, classified and unclassified, across the government to develop hypersonic weapons and technologies over a 10-year period from fiscal years 2015 to 2024. The surveys included questions focused on a range of acquisition and science and technology topics related to the purpose, schedule, cost, challenges, and collaboration with the hypersonic community, among other topics. For more information on our surveys, see appendix I. Additionally, we gathered and analyzed agency documentation, interviewed agency officials, and analyzed available budget data.

To identify the challenges these efforts face to develop hypersonic systems, we used survey data, interviewed agency officials, and analyzed agency documentation.

[2]GAO, *Hypersonic Weapons: DOD Should Clarify Roles and Responsibilities to Ensure Coordination across Development Efforts,* GAO-21-75SU (Washington, D.C.: Jan. 15, 2021).

[3]For the purposes of this report, we defined a hypersonic system as one that: (1) flies at speeds of Mach 5 or higher, (2) uses aerodynamic lift for the majority of its flight path, (3) maneuvers while in flight, or (4) includes defensive, tracking, or sensing systems used to defeat an offensive hypersonic missile. This definition intentionally excludes other systems and technology that meet the Mach 5 velocity portion of the general hypersonic definition, such as intercontinental ballistic missiles, space vehicles, and some projectiles, but that are not part of the more recent effort to develop hypersonic weapon systems or technology.

To identify the extent to which the U.S. government is effectively coordinating hypersonic efforts, we used survey data, reviewed agency documentation, and interviewed agency officials. We assessed this information against GAO's leading practices for interagency collaboration, government standards for internal controls, and Office of Management and Budget guidance. Appendix I provides additional information on our scope and methodology.

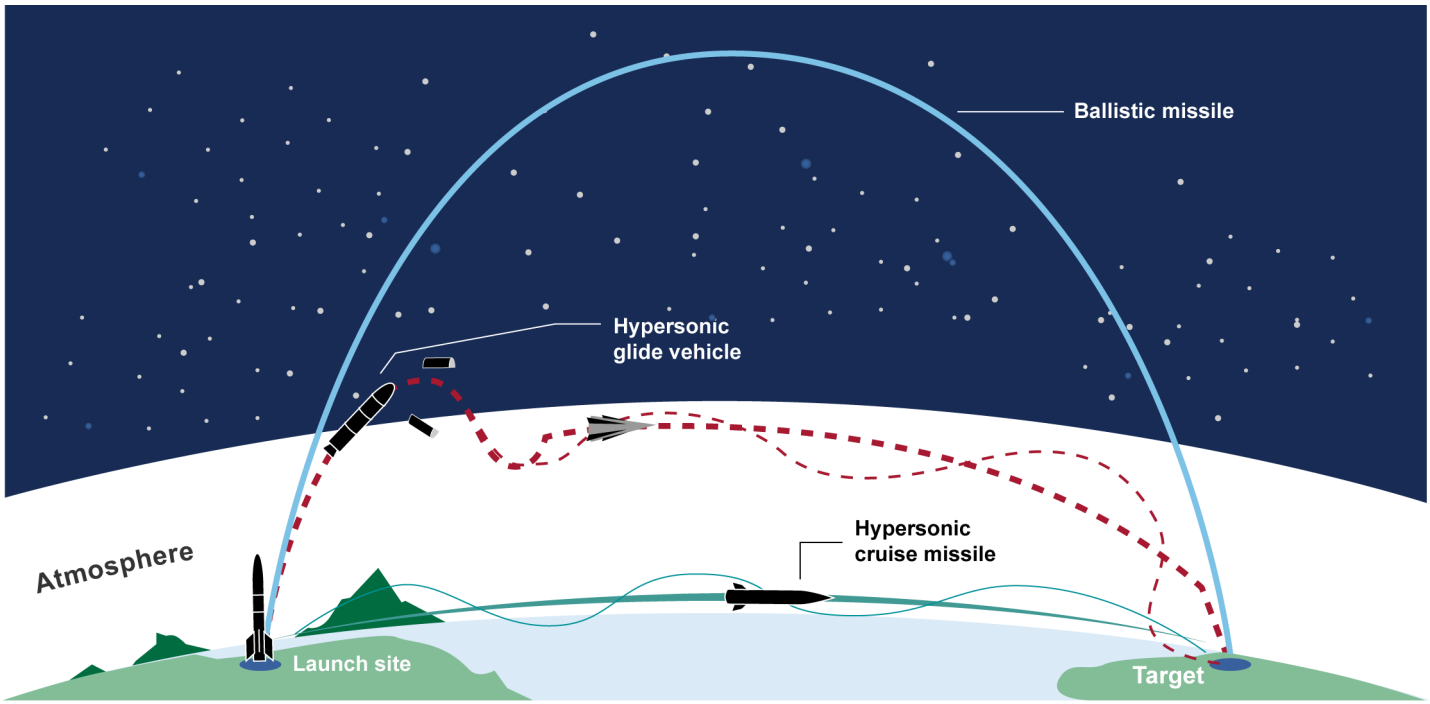
We conducted this performance audit from June 2019 to January 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. We subsequently worked with DOD, DOE, and NASA from January 2021 to March 2021 to prepare this public version of the sensitive report. This public version was also prepared in accordance with these standards.

Background

The U.S. government has invested in hypersonic technology since at least the 1950s but recently renewed its focus in an effort to develop offensive and defensive weapon systems. Hypersonic missiles fly at different altitudes and trajectories than traditional long-range missiles, such as ballistic missiles. As shown in figure 1, there are generally two variants of offensive hypersonic missiles in development:

1. Hypersonic glide vehicles are launched from booster rockets before gliding to their targets from higher altitudes in the atmosphere.
2. Hypersonic cruise missiles are powered by advanced engines that use oxygen in the atmosphere for propulsion during their flight after they are launched and accelerated by booster rockets. Consequently, hypersonic cruise missiles fly closer to the Earth than hypersonic glide vehicles.

Figure 1: Comparison of Ballistic and Hypersonic Flight Trajectories



Source: GAO analysis of Department of Defense data. Figure not drawn to scale. | GAO-21-378

Note: Air and sea-launched variants of hypersonic missiles are not pictured.

Weapon system development often includes science and technology (S&T) efforts aimed at developing and maturing key technologies. We have previously found that DOD prioritizes S&T investments based on near- and far-term adversarial threats, capability needs, and warfighter requirements.[4] Successful technology development is a progression from less mature S&T research to product development in the form of testable prototypes. First, technology development seeks to study or mature the

[4]GAO, *Defense Science and Technology: Adopting Best Practices Can Improve Innovation Investments and Management*, GAO-17-499 (Washington, D.C.: June 29, 2017).

most immature technology or determine its feasibility.[5] If successful, technology development may advance and include demonstrations that attempt to prove a concept or a technology. Next, product development, sometimes using prototypes, attempts to build a system which integrates various technologies to prove a system or subcomponent technology. If successful, this opens up the possibility the technology could be produced or inserted into an acquisition program where it could be further developed and produced on its own or as part of a larger system, sometimes in significant quantities.

The Office of the Under Secretary of Defense for Research and Engineering (OUSD (R&E)) is generally responsible for overseeing early-phase technology development, including establishing policies on and supervising all aspects of defense research and engineering, technology development, technology transition, prototyping, experimentation, and developmental testing activities and programs, including the allocation of resources for defense research and engineering. This organization also interacts with major defense acquisition programs throughout their life cycles with regard to technical risks.[6] For major defense acquisition programs, the staff in OUSD (R&E) conduct assessments in areas such as technology maturity, interoperability, and cybersecurity.

As technologies mature and efforts move toward developing integrated weapons systems, Office of the Secretary of Defense (OSD)-level oversight for them generally moves to the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD (A&S)). This organization is responsible for establishing policies on and overseeing all matters relating to acquisition—including (1) system design, development, and production; and (2) procurement of goods and services—and sustainment.

DOD made investments into hypersonic weapons prior to fiscal year 2015. For example, beginning in fiscal year 2008, OSD funded the

[5]Congress provided DOD's research labs with several authorities related to management and operations. One of those authorities, laboratory initiated research authority, as implemented, provides labs with a means to fund new science and technology projects that they consider a priority.

[6]Major defense acquisition programs generally are those designated by DOD as such or that have a dollar value for all increments estimated to require eventual total expenditure for research, development, test, and evaluation of more than $525 million, or for procurement of more than $3.065 billion, in fiscal year 2020 constant dollars.

Conventional Prompt Strike program for the purpose of maturing hypersonic glide vehicle technologies and research across DOD.[7] OSD's primary goal was to demonstrate relevant technologies through flight demonstrations. That program continued to be funded by OSD through fiscal year 2020, extending into the period we are covering in this report. The program also laid the groundwork for the current investments being made—especially in regard to hypersonic glide vehicle prototyping efforts. This work involved many projects that funded technology maturation test flights, technical support, booster technology development, and initial contractor work. In fiscal year 2020, most efforts derived from OSD's Conventional Prompt Strike program transitioned to the services for further investment and are now directly funded and overseen by service acquisition executives.[8] See figure 2 for a depiction of DOD's hypersonic weapon system acquisition phases.

Figure 2: Selected Department of Defense Hypersonic Weapon System Acquisition Phases

OUSD = Office of the Under Secretary of Defense

Source: GAO analysis of Department of Defense data. | GAO-21-378

[7]Before 2016, this effort was named the Conventional Prompt Global Strike program.

[8]The term "service acquisition executive" means the civilian official within a military department who is designated as the service acquisition executive for purposes of regulations and procedures providing for a service acquisition executive for that military department.

DOD Is Conducting Wide-Ranging Efforts to Develop Hypersonic Technologies, with Total Reported Funding of Almost $15 Billion from Fiscal Years 2015 through 2024

Hypersonic weapon-related and technology development is widespread across DOD and includes supporting efforts by DOE and NASA, such as basic hypersonic research and reimbursable testing.[9] Reported received and planned future funding substantially increased from fiscal years 2015 through 2024 and is currently estimated to total almost $15 billion over this period.[10] The majority of total funding in this period is directed to the product development of offensive hypersonic weapon prototypes. Each of the military services is developing its own limited operational capability before transitioning them to other acquisition programs. Additionally, there are substantial investments in S&T to develop additional technologies for next generation hypersonic weapons and acquisition programs. Efforts to counter hypersonic threats are also focused on maturing technologies, but those represent only a small portion of efforts and total funding for this period.

Number of Wide-Ranging Efforts Increased in the Last 3 Fiscal Years

We identified 70 total hypersonic weapon-related and technology development efforts reported by the U.S. government spread across DOD's military services, research laboratories, and defense agencies, as well as NASA and DOE in support of DOD. Over 60 percent of these efforts began after fiscal year 2017, with the remainder having started previously. Based on the 70 efforts we identified through our surveys, we assigned each to one of two of DOD's hypersonic weapon system acquisition phases based on the type and goals of the effort. Table 1 lists the number of efforts by acquisition phase and a general description of the efforts by increasing level of maturity.[11] For context, we included a third DOD phase to show that no effort has reached maturity for production. We further divided the technology development phase into two categories: initial and advanced.

[9]A DOE official reported DOE's work is funded by and supports DOD efforts except for DOE's Stockpile Responsiveness Program.

[10]For the purposes of this report, "received" or "received funding" refers to DOD, DOE, and NASA data that was provided in the surveys, and indicated past funding received for all sources. "Planned" or "Planned funding" refers to DOD, DOE, and NASA data that were provided in the surveys, indicating funding that has been planned for the out years. "Total funding" refers to both reported received and planned funding.

[11]For more information on the hypersonic weapon-related development prototypes, see appendix III.

Table 1: Phases of Hypersonic Weapon-related and Technology Development Efforts from Fiscal Years 2015 through 2024

Acquisition phase	Number of efforts	Description
Technology development	65	Initial technology development focuses on basic and applied research in key technologies for future hypersonic development and programs. There are 29 such efforts focusing on research in aerodynamics, materials, propulsion, chemistry, and simulations, among other areas. 25 of the efforts are led within research laboratories run by the military services or by research entities funded through the Office of the Under Secretary of Defense for Research and Engineering. The additional four are underway at the Defense Advanced Research Projects Agency (DARPA), Missile Defense Agency, and the National Aeronautics and Space Administration. Advanced technology development seeks to develop components and integrate subsystems into technology demonstrators for field experiments and/or tests in a simulated or operational environment. There are 36 such efforts focusing on propulsion, materials, guidance, control, and communication, among others. They include 15 efforts at DARPA and the Missile Defense Agency that are maturing technologies and incorporating them into testable systems. An additional 21 involve the Office of the Under Secretary of Defense for Research and Engineering, the military services, and DOE (on behalf of DOD) to develop technologies of varying maturities.
Product development	5	Product development includes developing offensive prototypes by the Air Force, Army, and Navy. Hypersonic glide vehicle and missile development efforts are in varying stages of maturity.
Production	0	Currently, no hypersonic efforts are in production. The Air Force's Air-launched Rapid Response Weapon is expected to be the first to achieve a residual operational capability where production decisions can be made after fielding at the end of fiscal year 2022.

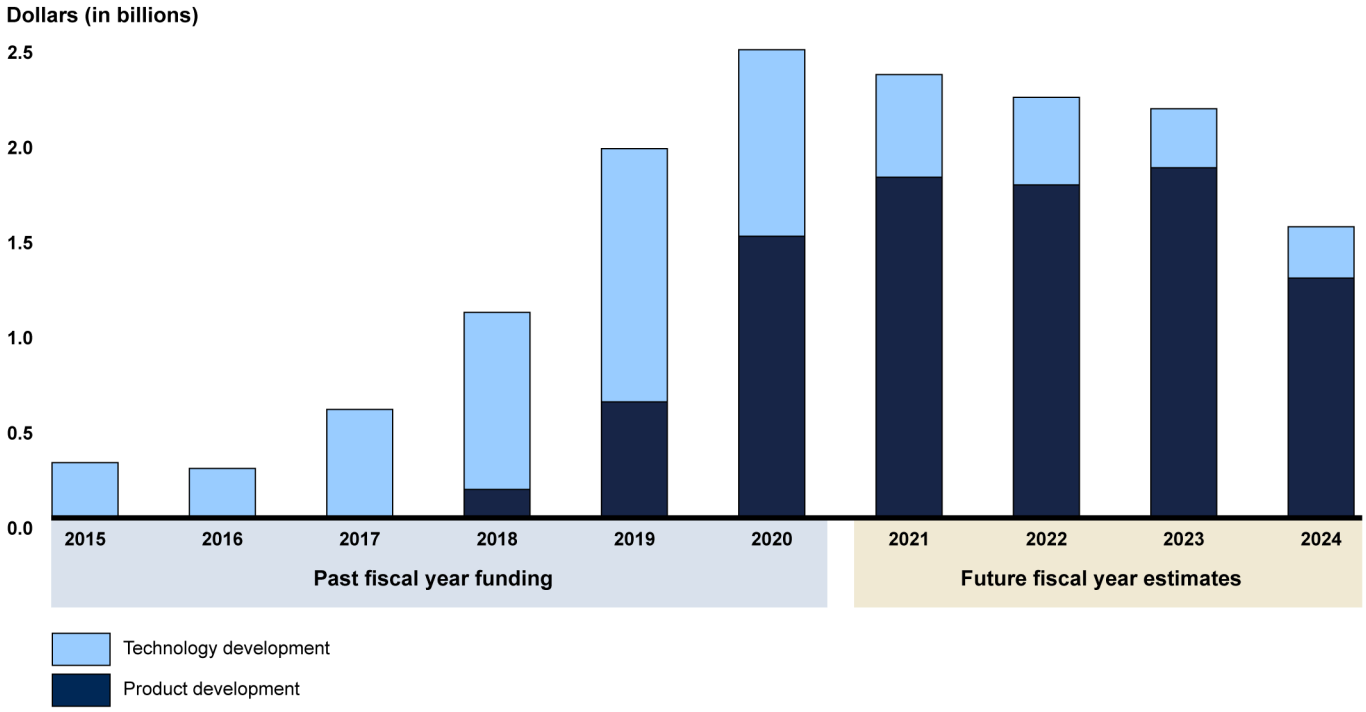
Source: GAO analysis of Department of Defense, Department of Energy, and National Aeronautics and Space Administration data. | GAO-21-378

Note: The Department of Energy also identified 10 additional efforts not counted separately because they are funded by the Department of Defense's product development efforts, such as flight tests, and are not unique efforts. One additional Department of Defense product development effort, the Hypersonic Conventional Strike Weapon, was cancelled in early 2020, leaving four ongoing. According to the Air Force, the effort had concluded because it reached critical design review, consistent with Air Force's original acquisition strategy to carry two programs to that point as a risk reduction effort.

Hypersonic Total Reported Funding is Estimated to Total Almost $15 Billion from Fiscal Years 2015 through 2024

Based on our analysis of survey responses, we found that total estimated funding for hypersonic weapon-related and technology development efforts increased substantially between fiscal years 2015 and 2024, including an increase of approximately 740 percent between fiscal years 2015 and 2020. Over the entire period, total funding is estimated to total almost $15 billion. These estimates do not include any costs related to production of hypersonic weapons because DOD has not yet budgeted for them. See figure 3.

Figure 3: Hypersonic Weapon-related and Technology Development Total Reported Funding by Type of Effort from Fiscal Years 2015 through 2024, in Billions of Then-Year Dollars



Source: GAO analysis of Department of Defense, Department of Energy, and National Aeronautics and Space Administration data. | GAO-21-378

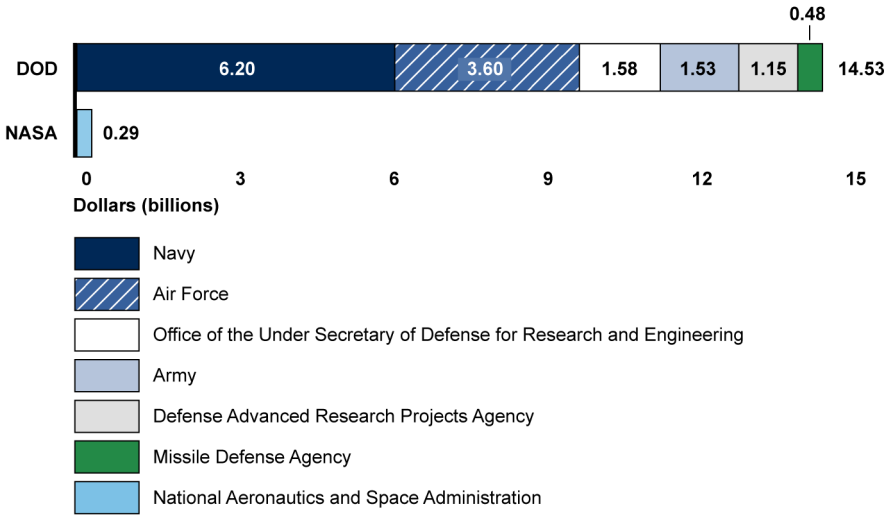
Note: The total funding does not include test and evaluation operations and modernization as these are outside of hypersonic weapon-related and technology development efforts. Future year funding is not yet authorized and subject to change. This information was collected in fiscal year 2020 before fiscal year 2021 budget requests had been considered. For the purposes of this report, fiscal years 2015 through 2020 include reported past funding received, and fiscal years 2021 through 2024 include reported future funding planned.

As shown in figure 3, the focus of the hypersonic efforts is expected to shift toward product development. Most funding prior to fiscal year 2020 was focused on technology development. However, product development efforts total almost $9 billion, representing 60 percent of the total funding during these 10 fiscal years, and for which most is planned for future years.

DOD accounts for nearly all, or 98 percent, of the total funding for hypersonic weapon-related and technology development efforts from fiscal years 2015 through 2024. Based on surveys, Navy efforts account for the most within DOD for this period—approximately 43 percent of total DOD hypersonic weapon and technology development funding. Figure 4

shows the total funding for hypersonic weapon-related and technology development efforts across DOD and NASA.

Figure 4: Hypersonic Weapon-related and Technology Development Efforts Total Reported Funding from Fiscal Years 2015 through 2024, in Billions of Then-Year Dollars



Source: GAO analysis of Department of Defense (DOD), and National Aeronautics and Space Administration (NASA) data. | GAO-21-378

Note: This information was collected in fiscal year 2020 before fiscal year 2021 budget requests had been considered. The Department of Energy (DOE) is not listed in the figure above. However, DOE reported that its hypersonic weapon-related and technology development total funding is comprised of approximately $8 million for a single effort from fiscal years 2015 through 2024. This effort focuses on initial studies of hypersonic system environmental conditions.

We also assessed reported funding related to U.S. government test and evaluation (T&E) resources, which we accounted for outside of the individual agency efforts in figure 4. DOD officials noted T&E resources include wind tunnels and open-air flight test ranges that support hypersonic weapon-related and technology development. The Test Resource Management Center (TRMC), which is organizationally within OUSD (R&E), acts as a coordinating body, directing resources to improve test infrastructure across DOD for hypersonic system testing along with service operated facilities and ranges. Our assessment of data provided by TRMC shows approximately $1 billion in total funding dedicated to hypersonic modernization for facilities from fiscal years 2015 through 2024.

However, the actual T&E costs for hypersonic weapon-related and technology development efforts government-wide are likely higher because (1) the $1 billion amount may not include all facility operational costs, (2) hypersonic development efforts are only one of many programs that use T&E facilities, and (3) some funding for hypersonic efforts cannot be separated from larger pools of funding. For example, in some cases, the military services reported they do not track data the same way as TRMC to reflect only hypersonic-related costs associated with operating these facilities, but can only aggregate the costs to operate them for all programs that use them. Additionally, NASA reported over $500 million dedicated to the operation, sustainment, and modernization of facilities that support hypersonic testing, along with other applications. DOE indicated it had no dedicated hypersonic T&E funding within our scope.

DOD Has Prioritized Fielding Offensive Hypersonic Weapons in the Near-Term

Our analysis shows that all four ongoing product development efforts in DOD are for offensive weapon systems and they represent 56 percent of total funding for hypersonic weapon-related and technology development from fiscal years 2015 through 2024.[12] Table 2 describes each of these efforts and appendix III provides additional details.

[12]This does not include the now cancelled Hypersonic Conventional Strike Weapon program. During the period of this review, the Air Force also funded a second hypersonic glide vehicle effort, known as the Hypersonic Conventional Strike Weapon, from fiscal year 2017 through fiscal year 2020. However, the Air Force stopped requesting funding for the Hypersonic Conventional Strike Weapon development in early 2020, concluding the effort with completion of the critical design review. If the Hypersonic Conventional Strike Weapon funding is added to the other four active efforts, they collectively represent 60 percent of hypersonic weapon-related and technology development from fiscal years 2015 through 2024.

Table 2: Department of Defense Offensive Hypersonic Weapons in Product Development, as of November 2020

Name	Organization	Description
Air-launched Rapid Response Weapon	Air Force	Seeks to develop a hypersonic glide vehicle carried on a B-52 bomber. The glide vehicle is being developed under the Tactical Boost Glide program in a partnership with the Defense Advanced Research Projects Agency.
Conventional Prompt Strike	Navy	Seeks to develop a hypersonic glide vehicle for underwater submarine launch using the Common Hypersonic Glide Body. The missile system is built jointly with the Army, with the Navy building the missile booster and integrating the missile system.
Long Range Hypersonic Weapon	Army	Seeks to develop a hypersonic glide vehicle for land launch using the Common Hypersonic Glide Body. The missile system is built jointly with the Navy, with the Army producing the Common Hypersonic Glide Body.
Standard Missile-6 IB	Navy	Seeks to modify an existing Navy missile, the Standard Missile-6 IA, by integrating a new rocket booster that a DOD official reported will allow it to fly at hypersonic speeds.

Source: GAO analysis of Department of Defense (DOD) data. | GAO-21-378

DOD has also been funding technology development to mature offensive hypersonic cruise missiles as another variant of offensive weapons. Hypersonic cruise missile efforts build off the joint Air Force and Defense Advanced Research Projects Agency (DARPA) effort called the Hypersonic Air-breathing Weapon Concept as well as other advanced technology weapon concepts that have been developed. Table 3 describes selected efforts to advance this technology.

Table 3: Selected Hypersonic Cruise Missile Technology Development Efforts

Name	Description
Southern Cross Integrated Flight Research Experiment	Funded by the Office of the Under Secretary of Defense for Research and Engineering (OUSD (R&E)) in collaboration with the Air Force, the effort seeks to reduce risk, mature, and demonstrate an operational hypersonic cruise missile through two to four flight tests. This effort seeks to act as a bridge between the Hypersonic Air-breathing Weapon Concept and a future Air Force hypersonic cruise missile acquisition program.
HyFly2	Funded by OUSD (R&E) in collaboration with the Navy, the effort seeks to reduce risk and mature a hypersonic air-launched cruise missile concept compatible with aircraft carrier operations.
Carrier compliant Hypersonic Air-breathing Weapons Concept	The Office of Naval Research seeks to demonstrate the performance of an aircraft carrier compliant hypersonic air-breathing missile integrated with a staged booster. The effort will be used to validate models developed to assess a proposed future hypersonic long range strike weapon.

Source: GAO analysis of Department of Defense data. | GAO-21-378

Other technology development efforts are working to demonstrate various future technologies to support next generation hypersonic weapon systems, to support acquisition programs, or to mature additional system or component technologies.

Defensive systems for detecting, tracking, and defeating adversary hypersonic missiles are in the early stages of planning and development. Based on our analysis of the surveys we collected, at least 12 of the 70 reported efforts were directly related to defending against offensive hypersonic missiles—almost all of which were research-focused—with none rising to the level of maturity seen in the offensive prototype efforts. Congress passed legislation directing DOD to accelerate the development of defensive systems and provided additional funding. For example, Congress appropriated over $100 million in additional funding—above what was requested in the President's Budget—for hypersonic defensive development in fiscal year 2020.

The Missile Defense Agency, with its Director as DOD's Executive Agent for developing solutions against adversarial hypersonic weapons, is considering a variety of ground and space-based technologies for

hypersonic missile defense.[13] Two of its efforts are conceptual studies for hypersonic weapon interceptors, one of which has been recently paused. Specifically, the Missile Defense Agency reported in July 2020 that it is pausing development of the Regional Hypersonic Glide Phase Weapon System to spend more time focusing on the S&T necessary to achieve the capability. Additionally, DOD officials reported that the Space Development Agency is seeking to design, build, and launch a new satellite constellation to detect, track, and help engage threats. A Space Development Agency official reported the Missile Defense Agency is contributing to the Space Development Agency's work by providing the Hypersonic and Ballistic Tracking Space Sensor.[14] This official also mentioned this space sensor will be integrated into the Space Development Agency's proliferated low earth orbit satellite architecture. A prototype of this system is scheduled to be demonstrated by mid fiscal year 2023.

The Principal Director for Hypersonics, who is responsible for leading the development of DOD's overarching hypersonic strategy within OUSD (R&E), told us there are other efforts outside the scope of this report that are critical for the integration of hypersonic weapons into DOD's existing systems and capabilities. Specifically, he said that efforts aimed at reducing the time it takes from identifying targets to striking them—known as the kill chain—are critical and involve a number of space-based components in development by the Space Development Agency and Missile Defense Agency.

[13]A DOD Executive Agent is the head of a DOD component to whom the Secretary of Defense or the Deputy Secretary of Defense has assigned specific responsibilities, functions, and authorities to provide defined levels of support for operational missions, among other things. Executive Agent's authority takes precedence over the authority of other DOD Component officials performing related or collateral joint or multi-component support responsibilities and functions. From DOD Directive 5101.1, *DOD Executive Agent* (Sept. 3, 2002) (certified current as of Nov. 21, 2003) (incorporating change 1, May 9, 2003). The Director of the Missile Defense Agency serves as the executive agent for the Department of Defense for the development of a capability by the U.S. to counter hypersonic boost-glide vehicle capabilities and conventional prompt strike capabilities. National Defense Authorization Act for Fiscal Year 2017, Pub. L. No. 114-328, § 1687 (2016).

[14]The Hypersonic and Ballistic Tracking Space Sensor is also known as the Space Sensor Layer.

Hypersonic Product Development Emphasizes Use of Middle-Tier Pathways

To expedite the development of hypersonic weapons, DOD is using middle-tier acquisition pathways for many of its hypersonic prototyping programs in the product development phase. Three of the four active offensive hypersonic weapons are using middle-tier acquisition pathways.[15] Section 804 of the National Defense Authorization Act for Fiscal Year 2016 required DOD to issue guidance establishing two new streamlined acquisition pathways—rapid prototyping and rapid fielding—collectively referred to as middle-tier acquisition pathways.[16] These middle-tier acquisition pathways allow expedited and streamlined acquisitions to be completed within 5 years. Middle-tier acquisition pathways are aimed at attempting to produce a capability, potentially operational, in a shorter period of time and are exempted from acquisition and requirement development policies and processes defined by DOD Directive 5000.01 and the *Manual for the Operation of the Joint Capabilities Integration and Development System*, unless required by DOD middle-tier acquisition pathways implementing guidance.[17] For rapid prototyping programs, the objective is to develop a prototype meeting defined requirements that can be demonstrated in an operational environment and provide for a residual operational capability within 5 years of the development of an approved requirement.[18] For rapid fielding programs, the objective is to begin production within 6 months and complete fielding within 5 years of the middle-tier acquisition start date. After completing either of the middle-tier acquisition pathways, a program has a number of options, including but not limited to transitioning into an existing program of record or its own acquisition program for further development.

[15]The Army's Long Range Hypersonic Weapon is using research and development funds but is not a middle-tier acquisition. However, the program is working to achieve fielding the weapon with a schedule of less than 5 years.

[16]National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114-92, § 804 (2016). For more information on middle-tier acquisitions, see GAO, *DOD Acquisition Reform: Leadership Attention Needed to Effectively Implement Changes to Acquisition Oversight*, GAO-19-439 (Washington, D.C.: June 5, 2019).

[17]National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114-92, § 804 (c) (2016); J-8, Joint Staff, Manual for the Operation of the Joint Capabilities Integration and Development System (Aug. 31, 2018); Department of Defense Directive 5000.01, The Defense Acquisition System (September 9, 2020).

[18]National Defense Authorization Act for Fiscal Year 2016, Pub. L. No. 114-92, § 804 (b)(1) (2015).

DOD Faces Challenges in Developing and Fielding Hypersonic Weapons, but Is Taking Several Steps to Address Them

DOD has initiated several programs which aim to develop and field a hypersonic weapon system in the coming years. Multiple DOD officials have said that, for these programs to achieve their development and fielding goals, they must overcome a number of challenges. To that end, DOD has taken several steps to mitigate these challenges, though others remain unaddressed. Many of these difficulties arise from the fact that these systems are technically complex and subjected to extreme conditions over the course of flight. These issues range from those posed by immature technologies and aggressive schedules to significant cost uncertainties and industrial base and human capital workforce challenges. Furthermore, wind tunnels are key support assets needed to test and evaluate hypersonic weapons, and their access must be closely managed to meet program schedules. Lastly, flight testing may also prove difficult given logistical constraints.

Some Critical Technologies for Hypersonic Weapons are Not Yet Mature, Posing Challenges to Developing Capabilities within Schedule Goals

Among programs that aim to provide a limited operational capability, we identified a number of critical technologies that were not fully mature at the time of program start, which could create challenges for meeting program objectives.[19] Table 4 describes this challenge and steps DOD has taken to mitigate it.

[19]Critical technologies are technology elements deemed as critical if they are new or novel, or used in a new or novel way, and are needed for a system to meet its operational performance requirements within defined cost and schedule parameters. GAO, *Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects*, GAO-20-48G (Washington, D.C.: Feb. 11, 2020).

Table 4: Technical Challenge to Developing and Fielding Prototype Hypersonic Weapon Systems and Associated Mitigation Efforts

Challenge area	Description of challenge	DOD mitigations
Technology immaturity	Hypersonic weapons programs rely on a number of immature technologies that need to be mature to be part of an operational system.	• According to DOD officials, the Air Force funded a more-mature hypersonic program to act as a hedge against a program that was less mature, but may have some operational advantages. • The Army and Navy have jointly adopted a previously tested design (though not technically fully mature). The two services agreed to harmonize requirements, which Army officials stated will reduce the program's complexity.

Source: GAO analysis of Department of Defense (DOD) data and interviews with program officials. | GAO-21-378

Our prior work has shown that programs that start product development before fully maturing critical technologies are more likely to encounter problems such as cost increases or schedule delays, or fail to achieve their objectives.[20] DOD major defense acquisition programs are generally required to commence product development with subsystems demonstrated in a relevant environment, that is, a technology readiness level (TRL) of 6. See appendix IV for more detailed descriptions of the nine TRLs. Based on our previous work identifying leading practices for product development and assessing technology readiness, we consider technologies that have been demonstrated on a system prototype in an operational environment (a TRL of 7) to be fully mature.[21]

Our review of these critical technologies provides some insight into the technical challenges facing prototype hypersonic weapon systems under development. For example, a number of technologies involve protecting against the extreme heat experienced by hypersonic missiles in flight. These technologies cover other missile components as well, such as adapting existing technologies like solid-fueled rockets to the unique flight requirements of a hypersonic weapon, effectively controlling and directing the weapon to the target, and ensuring that the weapon's payload is effective. This report omits additional, sensitive information about specific critical technologies.

[20]GAO, *Defense Acquisitions Annual Assessment: Drive to Deliver Capabilities Faster Increases Importance of Program Knowledge and Consistent Data for Oversight*, GAO-20-439 (Washington, D.C.: June 3, 2020); and GAO-20-48G.

[21]GAO-20-439; and GAO-20-48G.

DOD officials we spoke to described their development approach as acknowledging and accepting technology risk early in the program in order to achieve an operational hypersonic capability sooner, in line with DOD's modernization priorities and in accordance with senior leaders' guidance. These officials cited several strategies to mitigate technology maturity risks. Specifically, in some cases DOD officials stated they chose to invest in maturing multiple potential technological solutions, such as with the Air Force's Hypersonic Conventional Strike Weapon, which served as an alternative to the less technologically mature Air-launched Rapid Response Weapon. Alternatively, the Army and Navy programs sought to reduce their technological risk by choosing a relatively more developed design for their glide vehicle. In addition, Army and Navy officials reported agreeing to harmonize the environmental requirements for the booster associated with their programs. As a result, both programs will be able to use the same booster rather than having to develop two different designs for land- and sea-launched versions, which officials stated would save time and reduce program risk.

DOD did not identify any hypersonic cruise missile programs within our scope that seek to provide an operational capability at program conclusion, even in a limited capacity.[22] However, it has several technology risk reduction efforts underway that might lead to such a program in the future. According to DOD officials, while hypersonic cruise missiles cannot achieve the same speeds as hypersonic glide vehicles, they have potential cost and weight advantages that could prove operationally useful. DOD has identified several technologies which must be matured to achieve an operational capability for hypersonic cruise missiles. These include air inlet designs that can adjust airflow at high speeds, advanced combustion systems, and rocket boosters capable of getting a hypersonic cruise missile to the speed and altitude conditions necessary for the advanced engine to ignite and provide power to sustain hypersonic flight.

Several Hypersonic Weapon Programs Have Adopted Aggressive, Risk-Accepting Schedules That Will Be Difficult to Achieve

Programs that seek to produce an operational hypersonic weapon system have done so with schedules that the programs themselves have acknowledged will be difficult to achieve. Table 5 describes this challenge and provides DOD's explanation of the purpose these schedules serve.

[22]According to program officials, while the Standard Missile-6 Block IB differs from the traditional boost-glide design in important ways, its flight profile more closely resembles hypersonic glide vehicles than it does hypersonic cruise missiles.

Table 5: Schedule Challenges to Developing and Fielding Hypersonic Weapons and Associated Department of Defense Explanation

Challenge area	Description of challenge	DOD explanation
Aggressive schedules	Program officials and documents acknowledge that the schedules for achieving an operational hypersonic capability are ambitious, often dependent on other programs, and will be difficult to achieve. One program has already experienced significant delays.	• Officials have stated that schedules reflect the priority DOD has placed on achieving this capability.

Source: GAO analysis of Department of Defense (DOD) documentation and interviews with DOD officials. | GAO-21-378

Though the Army's Long Range Hypersonic Weapon and the Navy's Conventional Prompt Strike built on previous technology development efforts, they were formally initiated in fiscal year 2019 and fiscal year 2020, respectively. The Long Range Hypersonic Weapon schedule calls for the fielding of a battery of operational weapons no later than fiscal year 2023. The Conventional Prompt Strike schedule currently plans for fielding as early as fiscal year 2025, but the program, which is intended for submarines, has also examined even earlier fielding dates based on mating the system to surface ships. Additionally, the Air Force's Air-launched Rapid Response Weapon and the now-cancelled Hypersonic Conventional Strike Weapon programs both formally began in fiscal year 2018, and both planned to field an operational capability by fiscal year 2022.

We found in June 2020 that the Air-launched Rapid Response Weapon program experienced a cascading delay of all four of its planned flight tests, which put additional pressure on the program's plans to achieve an operational capability by the end of fiscal year 2022.[23] The delay came after the Tactical Boost Glide program, a DARPA risk-reduction effort on which the Air-launched Rapid Response Weapon program depends for its glide body technology, experienced a delay of almost 1 year. According to the Air Force, the Air-launched Rapid Response Weapon program has slipped its schedule by only 4 months since inception and is on-track to achieve an early operational capability by the end of fiscal year 2022.

The Army and Navy's hypersonic prototype schedules are somewhat different, despite being jointly developed as a single system. The Navy is using the streamlined acquisition approach available under the middle-tier

[23]GAO-20-439.

acquisition pathway in an effort to meet its aggressive schedule. Army program officials told us that, when crafting their schedule for the Long Range Hypersonic Weapon, they recognized that not even that particular streamlined approach could support their goal of achieving a limited operational capability by fiscal year 2023. Instead, Army officials stated they structured the program as an advanced technology or prototype effort, rather than a single major system development effort. These officials stated this approach provides the program with greater flexibility. The Navy's Conventional Prompt Strike program features later planned delivery dates for an operational capability, but its development and production schedules are tightly bound to the Long Range Hypersonic Weapon's development. As a result, delays or problems in the Army program could eventually impact the Navy's program. DOD hypersonic leadership and program officials acknowledged their programs' schedules present some risks, but that these risks were justified by the high priority DOD leadership places on developing a hypersonic capability at the earliest possible date.

Uncertainties Hinder Assessments of Future Costs and Affordability

Estimating the costs of developing hypersonic weapons and assessing their affordability have proven to be complicated by several factors, including the specific acquisition approaches that the military services have taken. Table 6 describes how these challenges complicate cost estimating and what steps, if any, DOD has taken to mitigate them.

Table 6: Cost Estimating Challenges to Developing and Fielding a Hypersonic Weapon and Associated Mitigation Efforts

Challenge area	Description of challenge	DOD mitigations
Near-term cost estimating	Two programs have experienced either formal cost increases or have submitted budget estimates that exceed their previous rough-order-of-magnitude estimates.	• None. In one case, program officials said that the cost increases were due to unique factors not likely to occur again. For both cases, DOD accepted this risk and continued development at the higher estimates.
Sustainment cost planning	Rapid prototyping programs may not focus on planning for sustainment costs in the development phase. Sustainment costs often outweigh development costs over the life cycle of a system.	• Army program officials said they have involved the office that will be responsible for operating and sustaining the Long Range Hypersonic Weapon, with the goal of giving sustainment issues a voice in the development process. • Navy program officials said that the Conventional Prompt Strike program has also embedded sustainment planning into the development process to ensure adequate planning and preparation for these issues.

Source: GAO analysis of Department of Defense (DOD) documentation and interviews with DOD officials. | GAO-21-378

The hypersonic weapon prototype programs we assessed have already experienced difficulty estimating development costs. The Air Force's Air-launched Rapid Response Weapon, for example, experienced a nearly 40 percent increase in its estimated total cost within its first year. The Navy's Conventional Prompt Strike program has also experienced budget growth. Between fiscal year 2019 and fiscal year 2020, program documents indicate the Navy's budget estimate almost doubled. In addition, a September 2019 Senate report expressed concerns about the Navy's contract strategy and its understanding of costs.[24] The report directed the Navy to submit a formal service cost position as well as certify full funding. The resulting Navy cost position showed that in less than a year, its budget estimate for fiscal years 2020 through 2024 had increased by an additional 7 percent. This revised figure was also reliant on the Navy accomplishing unspecified efficiencies that, if not achieved, would require a reduction in the program's scope.

The structure of these initial hypersonic weapon programs produces additional uncertainties in terms of expected costs of full production of the resulting weapons. The Air-launched Rapid Response Weapon, Conventional Prompt Strike, and Long Range Hypersonic Weapon are all structured with the goal of producing a limited number of units for testing, following which, a small number of units would be fielded as part of a limited operational capability. Program officials stated that, at this point,

[24]S. Rpt. No. 116-103 (Sept. 12, 2019).

the programs would then be transitioned into programs of record where the services will then need to make decisions about full production rates and production quantities. However, beyond those operational units that are first fielded, DOD officials told us that very few decisions have been made with respect to quantities or the mix of different hypersonic weapon options DOD plans to pursue. These uncertainties for a future production run would itself have a significant impact on both unit and total program costs of any subsequent programs to field these weapons, important metrics by which acquisition programs are often evaluated.

Finally, rapid prototyping programs for hypersonic weapons are focused on developing testable prototypes and not necessarily planning for sustainment costs. In general, the nature of rapid prototyping programs is to develop a residual operational capability within a relatively short timeframe. Characteristics such as maintainability and long-term affordability do not always align with these goals, unless programs choose to proactively prepare for them early in the acquisition process. GAO has identified a variety of factors that influence programs to prioritize factors such as performance and schedule over sustainment costs until late in the acquisition process.[25] This emphasis is reflected in DOD acquisition guidance, which does not require rapid prototyping programs to complete a full life-cycle cost estimate in advance, as it does for the rapid fielding pathway. Our previous work has shown that operations and sustainment costs are often responsible for the majority of total program costs, yet for these hypersonic programs, these costs may not become apparent until later phases of the acquisition process.

DOD hypersonic leadership and program officials we spoke to acknowledged many of these challenges and pointed to a number of steps taken to mitigate them, as noted in table 6. The main strategy that these officials identified was to give organizations that will be acquiring and sustaining these systems a voice early in the development process. For example, according to program officials, when the Long Range Hypersonic Weapon program achieves its operational capability, it will transition to the Army's program executive office for Missiles and Space. Despite not being this office's responsibility yet, Army officials told us that several members of that office are embedded within the Long Range

[25]GAO, *Navy Shipbuilding: Increasing Focus on Sustainment Early in the Acquisition Process Could Save Billions*, GAO-20-2 (Washington, D.C.: Mar. 24, 2020); and *Weapon Systems Management: Product Support Managers' Perspectives on Factors Critical to Influencing Sustainment-Related Decisions,* GAO-17-744R (Washington, D.C.: Sept. 12, 2017).

Hypersonic Weapon program to ensure that the transition goes smoothly and planning for sustainment operations can begin well in advance. Officials from the Navy's Conventional Prompt Strike program also emphasized that they sought to embed sustainment planning within the program's structure from the outset. Officials reported that this included inserting sustainment documentation requirements into the program's contracts, as well as conducting sustainability assessments of the design. These actions notwithstanding, Conventional Prompt Strike program documents show that the Navy does not plan to produce a complete life-cycle sustainment plan for this system until fiscal year 2023.

Workforce and Industrial Base Challenges to Development of Hypersonic Weapon Systems

According to DOD documentation, emerging hypersonic technologies are highly specialized, and robust industry and technical expertise are necessary to support them. Table 7 describes these dual challenges as well as steps DOD is taking to mitigate them.

Table 7: Human Capital and Industrial Base Challenges to Developing and Manufacturing Hypersonic Weapons and Associated Mitigation Efforts

Challenge area	Description of challenge	DOD mitigations
Human capital	Ensuring there is sufficient engineering talent capable of contributing to hypersonic programs.	• The Under Secretary of Defense for Research and Engineering is organizing a U.S. university research consortium that will provide research and professional opportunities in areas relating to hypersonics.
Industrial base	Ensuring that the industrial base is capable of supporting hypersonic weapon production.	• The Defense Contract Management Agency studied the hypersonic industrial base in 2019 to prepare for production. • The Office of the Under Secretary of Defense for Acquisition and Sustainment convened what it calls a war room to study production issues and prepare the industrial base.

Source: GAO analysis of Department of Defense (DOD) documentation and interviews with DOD officials. | GAO-21-378

Ensuring Availability of Specialized Engineering and Other Personnel for Research and Development Poses a Workforce Challenge

Officials within OUSD (R&E) stated that ensuring a human capital pipeline sufficient to meet the demand for hypersonic research and development is a key workforce challenge. According to these officials, universities wishing to conduct research or establish training programs in this area would face significant investments. The officials also said that hypersonic engineering problems are often multidisciplinary in nature and are

increasingly classified. Classification in particular can create problems with stove-piping research areas. This report omits additional, sensitive information about human capital resources.

OUSD (R&E) officials told us they were exploring ways to make the human capital pipeline more robust and sustainable. For example, OUSD (R&E) is organizing a university research consortium that would conduct government-sponsored research. According to DOD documentation, establishing the consortium will help to identify universities capable of supporting classified or restricted research, while also creating ways to share their research findings among themselves. Promoting research at U.S. universities in this way is intended to entice a steady stream of engineering talent to enter the field.

Ensuring Sufficient Resources to Support Development and Large-Scale Manufacturing Is a Key Industrial Base Challenge

In addition to human capital, the industrial base is also a critical factor for hypersonic systems development, particularly if systems progress toward full production. Multiple DOD officials we spoke to identified the industrial base as an ongoing concern. In November 2019, the Defense Contract Management Agency (DCMA), at the request of the Deputy Assistant Secretary of Defense for Industrial Policy and OUSD (R&E)'s Principal Director for Hypersonics, issued a report on the hypersonic industrial base and its ability to support a transition to full production. In its report, DCMA made recommendations to help bolster the industrial base. According to OUSD (A&S) officials, the hypersonic war room convened by that office is using the results of the DCMA study to help prepare the industrial base for production. This report omits additional, sensitive information about the DCMA study and related industrial base issues.

Test Facilities Require Management to Ensure Access

Both ground and flight tests are essential elements of delivering an operational hypersonic capability, but the facilities to support both are increasingly busy. Table 8 describes these challenges and steps DOD has taken to mitigate them.

Table 8: Flight and Ground Testing Challenges to Developing and Fielding Hypersonic Weapons and Associated Mitigation Efforts

Challenge area	Description of challenge	DOD mitigations
Availability of ground-test facilities, including wind tunnels	U.S. hypersonic wind tunnel infrastructure is aging and may be unable to meet demand.	• DOD's Test Resource Management Center (TRMC) plans to invest hundreds of millions of dollars to support and expand wind tunnel infrastructure. • TRMC also acts as a coordinating body to ensure that competing programs are given access to facilities according to DOD priorities.
Flight testing logistical challenges	Hypersonic flight testing is logistically difficult.	• TRMC is working to open up new corridors for flight testing. • DOD is developing aerial sensors that could relieve some of the burden on ground- and sea-based sensors, which are logistically difficult to arrange. • DOD is exploring international partnerships that could provide access to overland flight ranges.

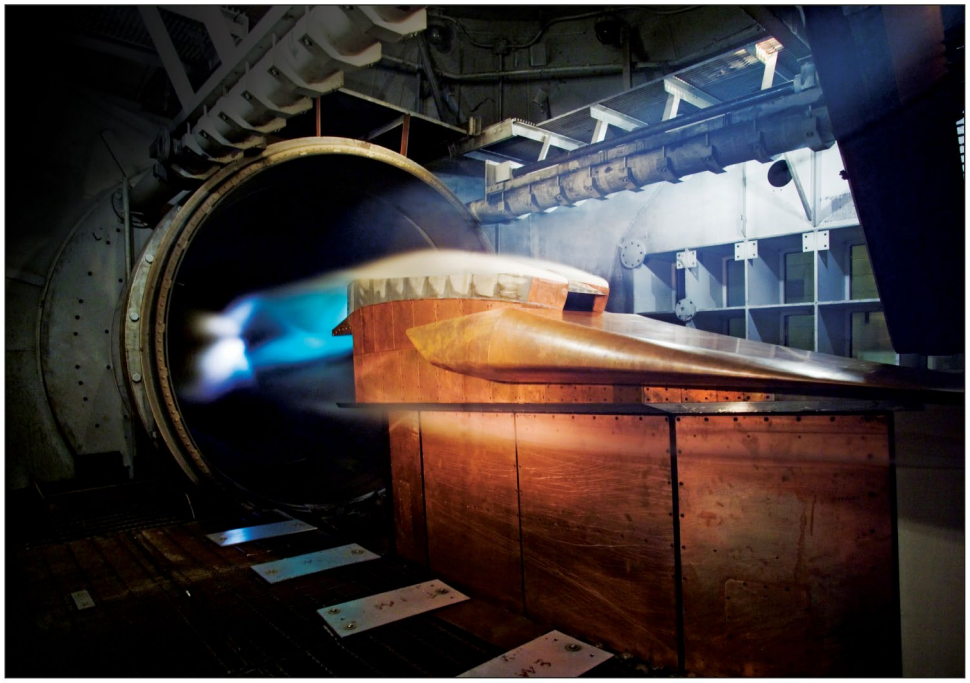
Source: GAO review of Department of Defense (DOD) documentation and the National Aeronautics and Space Administration-provided survey data. | GAO-21-378

Availability of Wind Tunnels Is a Scheduling Challenge

Gaining timely knowledge from ground tests is essential for hypersonic programs to meet their ambitious schedules. According to DOD hypersonic and testing officials, recreating the extreme conditions experienced by hypersonic missiles is difficult, and wind tunnels are essential for testing parts and components, as well as validating designs prior to flight testing. Specifically, because gaining full knowledge of a system's capabilities solely through flight testing can be logistically difficult and costly, flight testing is often supplemented with additional ground tests, models, and simulations. Ground tests are therefore important both for influencing design as well as reducing risk by validating performance.

As U.S. interest in hypersonic technology has increased in recent years, so has demand for time in these wind tunnels. According to NASA officials, this increased demand is not exclusive to hypersonic tunnels; they noted that lower-speed tunnels have also had a similar increase in demand. Hypersonic tunnels vary in size and configuration, but according to hypersonic experts the schedule challenges are most noticeable in the largest high-speed tunnels (see figures 5 and 6 for examples). If programs cannot get sufficient time in the correct tunnels, they may be forced to either wait or find other, less ideal means to complete their testing. These options include conducting more flight testing, adopting more conservative designs, or making expanded use of computer models.

Figure 5: NASA Langley's Hypersonic Model Test in the 8-Foot High Temperature Tunnel



Source: National Aeronautics and Space Administration (NASA). | GAO-21-378

Figure 6: NASA Langley's 8-Foot High Temperature Tunnel Testing a Large-scale Cone Aerothermodynamic Test Article

Source: National Aeronautics and Space Administration (NASA). | GAO-21-378

DOD reports we reviewed state that, of the 26 DOD, DOE, NASA, and private U.S. wind tunnel facilities capable of supporting hypersonic research, 14 were constructed prior to 1970.[26] According to DOD officials, investments for maintenance and refurbishment are necessary to maintain availability and must also be carefully managed as demand for time in the tunnels increases. The officials said that this is especially important as DOD documentation indicates that nearly every wind tunnel facility suitable for hypersonics testing is booked a year or more in

[26]Office of the Secretary of Defense, Test Resource Management Center, *Report on the Ability of the U.S. Test and Evaluation Infrastructure to Effectively and Efficiently Mature Hypersonic Technologies for Defense Systems Development and Plan for Proposed Improvements and Modernization* (Feb. 2015). Though the report was published by TRMC, the study was organized by the Office of Science and Technology Policy; Office of the Undersecretary of Defense for Research and Engineering, *Report to Congress: National Hypersonics Strategy and Joint Hypersonics Transition Office (JHTO)* (September 2020).

advance. This report omits additional, sensitive information about wind tunnels.

Open-Air Ranges Present Challenging Logistics for Flight Testing

Flight testing hypersonic weapons also poses logistical problems that will make achieving existing schedules difficult. Flight testing is essential for validating system performance, and to inform models and simulations that provide further insight into a new system's capabilities. According to DOD officials, current plans call for as many as 40 flight tests over the next 5 years. At present, DOD relies primarily on a single, long-range flight-test corridor, but it will not by itself be able to support this pace of testing. If programs are unable to conduct as many flight tests as they planned, they will be forced to either proceed to an operational capability with fewer tests (and thus less knowledge), or to accept the delay, with schedule and cost consequences.

Hypersonic weapons are useful in part because they are difficult to track, but this complicates efforts to flight test them. According to DOD officials, in order to conduct a flight test, programs must organize a suite of sensors to maintain coverage along the entire flight path. These officials stated that, at present, such flight tests can only be conducted over open ocean, meaning that the sensors must be stationed on boats which take weeks to reach their remote destinations. These ranges and these test assets are also in demand by other high-priority programs, including missile defense and intercontinental ballistic missile testing.

DOD Is Taking Steps to Increase Available Ground and Open-Air Ranges

DOD has spent the last several years attempting to mitigate these issues, and officials have cited future plans that they say will continue to alleviate scheduling challenges for wind tunnel and flight test facilities. Coordination between programs and agencies is another element of DOD's approach. According to DOD officials, much of this work is overseen by TRMC, which itself oversees much of DOD's physical test and evaluation infrastructure. According to these officials, TRMC, with the Principal Director for Hypersonics, has established a system for managing programs' access to test facilities when faced with schedule conflicts. In addition to TRMC's efforts, in June 2018, OSD, the Missile Defense Agency, and the military services signed an agreement that will prioritize among the signatories flight tests for prototype efforts based on the Common Hypersonic Glide Body design.

DOD is also taking steps to expand its wind tunnel and open-air flight test infrastructure. Here, too, TRMC has played an important role. According to a TRMC official, TRMC has directed several hundred million dollars in recent years to the refurbishment and expansion of ground and flight test

facilities. In addition, it is also developing new land and sea ranges that can be used for testing, to relieve pressure on existing corridors. Additionally, it is developing aerial sensors that could be mounted on drones, which would add additional flexibility to flight range logistics by taking some of the burden off ground and ship-based sensors.

Finally, DOD has pursued and is continuing to pursue international partnerships that could accelerate hypersonic research, and could provide it with additional test facilities.

Robust Collaboration Taking Place, but DOD Lacks Governing Documentation to Ensure Efforts are Effective, Efficient, and Enduring

Collaboration between Agencies and Within DOD Is Taking Place to Develop and Prototype Hypersonic Technologies

We found that the hypersonic weapon-related and technology development efforts are widespread across DOD with additional supporting activities occurring in DOE and NASA, some of which are funded by DOD. In particular, within DOD, DOE, and NASA, there are at least 78 organizations playing some role developing or researching hypersonic weapons, with the majority located in DOD. See table 9 for the number of organizations by agency.

Table 9: U.S. Government Organizations Participating in Hypersonic Weapon-related and Technology Development

Agency	Number of organizations
Department of Defense	70
Department of Energy	3
National Aeronautics and Space Administration	5

Source: GAO analysis of Department of Defense, Department of Energy, and National Aeronautics and Space Administration data. | GAO-21-378

Note: This does not include contractors, additional government agencies that are not developing hypersonic weapons or conducting research and development but were identified in surveys as having various roles, coordinating bodies, independent laboratories, and others. The National Aeronautics and Space Administration distributes funding from its headquarters to four different centers where the testing and activities are conducted.

DOD has a history of collaborating with other U.S. government agencies to develop and test hypersonic weapon-related technology, and we found that such collaboration is continuing. Both DOE and NASA have established agreements with DOD on their roles and responsibilities for hypersonic weapon-related development. Sandia National Laboratories, a federally funded research and development center and contractor for DOE's National Nuclear Security Administration, has played a critical role in the development of the first generation of hypersonic weapons.[27] It helped to develop and build the Common Hypersonic Glide Body with in-house expertise and testing facilities. Among the five product development efforts in our review, DOE supported three and, according to a NASA official, one made use of NASA's wind tunnels for testing. In some cases, according to NASA officials, DOD reimburses NASA for use of its wind tunnels. Officials also noted that in some instances NASA waives the reimbursement costs because it is able to acquire data from testing it would not be able to obtain on its own because it would be too expensive.

Within DOD, the military services and agencies are coordinating hypersonic weapon product development for versions of the hypersonic glide vehicle. The coordination is to leverage investments and take advantage of limited resources. For example, in June 2018, five DOD

[27]The National Nuclear Security Administration is a separately organized agency within DOE that is responsible for the management and security of DOE's nuclear weapons, nuclear nonproliferation, and naval reactor programs. Federally funded research and development centers are public-private partnerships which conduct research for the U.S. government. They are administered in accordance with U.S. Code of Federal Regulations by universities and other organizations. 48 C.F.R. § 2101, 35.017.

organizations signed the Common Hypersonic Glide Body memorandum of agreement for hypersonic glide vehicle development. This agreement established roles, responsibilities, and sharing mechanisms, including the prioritization of flight tests across hypersonic glide vehicle efforts, a board of directors, a DOD-wide account for hypersonic investments, a common data repository, and data sharing from flight tests. DARPA's Tactical Boost Glide effort reported collaborating with 19 different entities in government, including organizations involved in Air Force hypersonic prototypes efforts and DARPA projects, OUSD (R&E), NASA, DOE's Sandia National Laboratories, and DOD's combatant commands. The Principal Director for Hypersonics said that, consistent with all DOD modernization priorities, DOD established a position like his to lead the development of a strategy for the development of an offensive hypersonic capability and defense against adversary hypersonic systems. As a part of this work, he also said he works closely with the military services and other agencies to ensure that the efforts across DOD are being executed and integrated in accordance with that strategy.

DOD Uses Several Coordination Mechanisms to Facilitate Its Hypersonic Strategy and Development

Several coordinating bodies within DOD work to organize and coordinate hypersonic program and S&T investments, consider future procurement challenges as prototypes evolve into larger-scale acquisition programs, and develop future workforce talent. Some of these coordination mechanisms have existed for years, while others started more recently in response to the increased focus in DOD on hypersonic weapon development. Five key coordinating mechanisms leading hypersonic weapon-related and technology development within DOD are described in table 10.

Table 10: Key Selected DOD Hypersonic Development Coordination Mechanisms

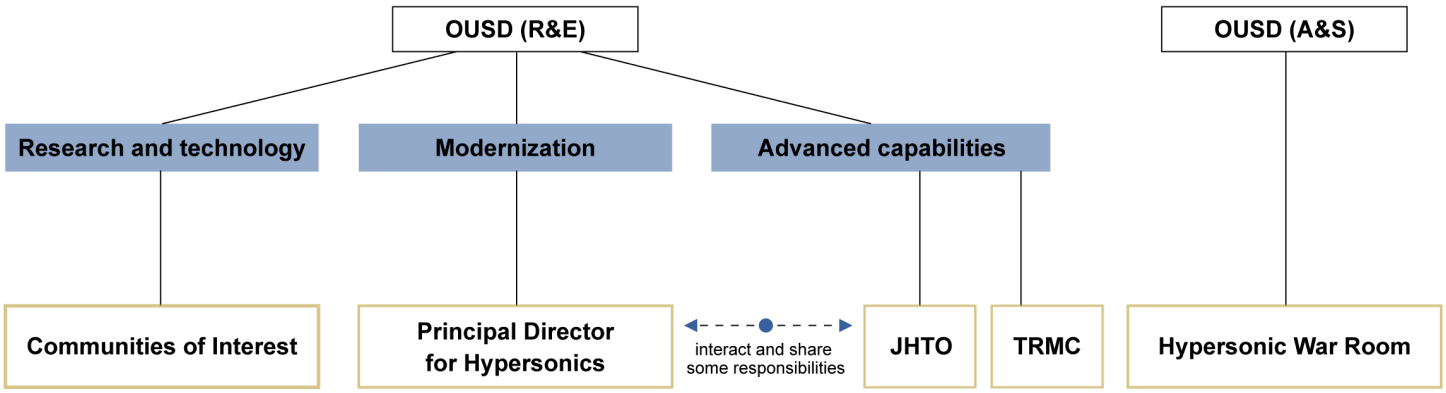
Organization/Position	Description of activities
Principal Director for Hypersonics	The Office of the Under Secretary of Defense for Research and Engineering (OUSD (R&E)) established the position of Principal Director for Hypersonics in October 2018 to develop the overarching hypersonic strategy and roadmaps. The roadmaps include integrating research, development, test, and evaluation efforts in the military services and the National Aeronautics and Space Administration (NASA). In 2019, the Principal Director for Hypersonics established a DOD-wide Hypersonics Working Group to develop a capability-based integrated science and technology (S&T) strategy. The Hypersonics Working Group includes scientists, engineers, planners, and operators from across DOD, including the combatant commands, the Defense Advanced Research Projects Agency, the Missile Defense Agency, and the military services. Additionally, the working group includes members from the Department of Energy and NASA to ensure coordination of activities across the U.S. government. The Principal Director for Hypersonics told us he shares responsibility for hypersonic weapon development with the director of the Joint Hypersonics Transition Office, which is charged with executing key elements of the S&T strategy.
Joint Hypersonics Transition Office	Located in OUSD (R&E), according to the current director, the Joint Hypersonics Transition Office was stood up in April 2020 in response to congressional direction. The office integrates the hypersonic S&T strategy and certifies budgets for hypersonic research, development, and demonstrations. The Transition Office also coordinates a university consortium on applied hypersonic research and hypersonic S&T investments within DOD. By funding research, the consortium is forming partnerships with universities to develop experts and enhance the hypersonic workforce. According to DOD officials, the director of the Transition Office shares responsibility for coordination of hypersonic weapon development efforts with the Principal Director for Hypersonics in OUSD (R&E).
Test Resource Management Center	Located in OUSD (R&E), the Test Resource Management Center (TRMC) acts as a coordinating body, directing resources to improve test infrastructure across DOD for hypersonic system testing along with service operated facilities and ranges. According to the Principal Director for Hypersonics, TRMC has developed an adjudication process to deconflict demand for ground and flight test resources. In this process, TRMC serves as data gatherer and mediator between program elements requiring test time and resources.
Communities of interest	Located within OUSD (R&E), communities of interest were established as a mechanism to encourage multi-agency coordination and collaboration in cross-cutting technology focus areas with investments by multiple DOD components. For example, the Air Platforms community of interest, which includes hypersonic missiles, provides a forum for coordinating S&T strategies so that different efforts can share new ideas and coordinate key technology investments to reduce unnecessary duplication. Communities of interest also provide advice to DOD S&T senior leadership.
Hypersonic war room	Located in the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD (A&S)), DOD officials said the hypersonic war room was stood up in February 2020. An official said the organization gathers data, conducts analysis, and provides recommendations on steps needed to ensure there is a sufficient industrial base for the transition of hypersonic weapons efforts into acquisition programs. This report omits additional, sensitive information about the war room.

Source: GAO analysis of Department of Defense (DOD) data and interviews with DOD officials. | GAO-21-378

Note: Section 214 of the National Defense Authorization Act for Fiscal Year 2018 redesignated the joint technology office on hypersonics in the Office of the Secretary of Defense to the "Joint Hypersonics Transition Office." Pub. L. No. 115-91, § 214 (2018).

Leadership for DOD's hypersonic weapons development is primarily centralized within different parts of OUSD (R&E) and OUSD (A&S) offices. The coordination bodies are spread across different OUSD (R&E) and OUSD (A&S) divisions. See figure 7.

Figure 7: Department of Defense Hypersonic Coordination Structure



OUSD (R&E) = Office of the Under Secretary of Defense for Research and Engineering
OUSD (A&S) = Office of the Under Secretary of Defense for Acquisition and Sustainment
JHTO = Joint Hypersonics Transition Office
TRMC = Test Resource Management Center

Director of Defense Research and Engineering level

Entities that coordinate hypersonic efforts

Source: GAO analysis of Department of Defense data. | GAO-21-378

DOD Lacks a Cohesive, Overarching Management and Oversight Structure with Clearly Defined Roles and Responsibilities

DOE and NASA have agreements with DOD on their roles supporting DOD. But DOD itself has not documented the roles, responsibilities, and authorities of all of the organizations within DOD that are working on hypersonic weapon-related and technology development. The Principal Director for Hypersonics told us that no governing documentation exists that defines the roles, responsibilities, and authorities for the different hypersonic organizations in DOD, including his position. The hypersonic enterprise is vast and scattered among many parts of DOD. To some extent, the lack of established roles, responsibilities, and authorities is a result of new hypersonic organizations being stood up and numerous hypersonic activities that have commenced in recent years. According to the Principal Director for Hypersonics, an informal draft governance guidance existed prior to his appointment in 2018 but was never formalized or approved.

Formally documenting government coordination is important. Our prior work on leading practices for collaboration emphasizes the importance of clarifying roles through policies, memoranda of understanding, and other

requirements.[28] Further, collaboration can benefit agencies pursing a common goal. To assist in achieving this goal, defining the roles, responsibilities, and coordination mechanisms can increase efficiency by clarifying things such as who will lead or participate in which activities, organizing joint activities and individual efforts, and facilitating decision making. We also found that documenting this information in written guidance is a best practice.

Documenting roles, responsibilities, and authorities also provides for a level of continuity when leadership or membership inevitably changes, which is especially important since hypersonic weapon development efforts are expected to continue over at least the next decade. As an example, the Under Secretary for Defense for Research and Engineering, who made hypersonics DOD's top modernization priority in 2018, has recently resigned from his position. The Principal Director for Hypersonics told us that interim OUSD (R&E) leadership continues to support hypersonic efforts within DOD.

During the course of our work, we observed robust collaboration across the hypersonic enterprise. In fact, DOD officials spoke of the relatively small group of people who work in the hypersonic field. According to the Principal Director for Hypersonics, this situation has benefits that make collaboration easier. DOD is hoping to expand the number of people with hypersonic expertise by increasing the workforce, as discussed above. Thus, additional changes and new personnel can be expected in senior leadership, program offices, and research laboratories throughout DOD, among other areas. In addition, senior leadership in DOD can and does change. For example, over recent decades, the average time a Secretary of Defense serves in that capacity has been less than 3 years and service secretaries have similar, or shorter, tenures. Further, changes at both top and mid-tier leadership may periodically occur as a result of normal rotations for military officers and other changes could occur as civilians change positions. Without clear roles, responsibilities, and authorities established and documented, DOD opens up the potential for conflict and wasted resources as decisions over larger investments into hypersonic weapon systems and production are made in the future. It also risks missing opportunities to appropriately leverage the various efforts underway to make progress to deliver integrated, hypersonic weapon capabilities.

[28]GAO, *Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

Conclusions

Developing and fielding offensive and defensive hypersonic weapon systems has emerged as one of DOD's highest modernization priorities, but it faces considerable technical and other challenges to fielding viable and operational weapons over the next few years. DOD has mitigations and plans in place to address most of the challenges or acknowledges the risks they pose. Because hypersonic weapon development efforts are ongoing across dozens of organizations within DOD, effective coordination among these efforts is particularly important for delivering capabilities efficiently and on the expedited schedule set out for achieving them. While OUSD (R&E) has established a position to help coordinate these efforts and the parties involved are working together, DOD lacks guidance that defines the roles, responsibilities, and authorities of this position, along with those of the other organizations developing hypersonic weapon systems or technology, raising the risk of breakdowns in coordination as leadership and key staff change over the next decade. Such formalization for hypersonics will (1) help to ensure effective coordination and continuity of effort over the next decade or more, especially as investments are expected to increase, and (2) enhance opportunities to leverage the various efforts to develop such weapons.

Recommendation for Executive Action

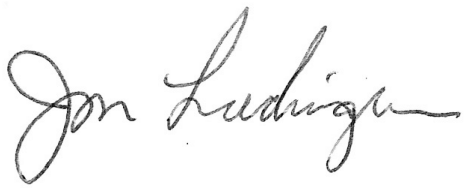
The Secretary of Defense should define and document the roles, responsibilities, and authorities of the leadership positions and organizations in the Department of Defense responsible for the development and acquisition of hypersonic weapons. (Recommendation 1)

Agency Comments and Our Evaluation

We provided a draft of this report to DOD, DOE, and NASA for review and comment. DOD concurred with the recommendation. We received written comments from DOD that are reprinted in appendix II. DOE and NASA told us that they had no comments on the draft report. DOD and NASA provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees and members, the Secretaries of Defense and Energy, and the Acting NASA Administrator. In addition, the report is available at no charge on our website at https://www.gao.gov.

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



Jon Ludwigson
Director, Contracting and National Security Acquisitions

List of Addressees

The Honorable Jack Reed
Chairman
Committee on Armed Services
United States Senate

The Honorable Maria Cantwell
Chairman
Committee on Commerce, Science, and Transportation
United States Senate

The Honorable Jon Tester
Chairman
Richard C. Shelby
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Dianne Feinstein
Chair
Subcommittee on Energy and Water Development
Committee on Appropriations
United States Senate

The Honorable Eddie Bernice Johnson
Chairwoman
The Honorable Frank Lucas
Ranking Member
Committee on Science, Space, and Technology
House of Representatives

The Honorable Robert Wittman
Ranking Member
Subcommittee on Seapower and Projection Forces
Committee on Armed Services
House of Representatives

The Honorable Don Beyer
Chairman
The Honorable Brian Babin
Ranking Member
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
House of Representatives

The Honorable Dick Durbin
United States Senate

The Honorable C.A. Dutch Ruppersberger, III
House of Representatives

Appendix I: Objectives, Scope, and Methodology

This report identifies: (1) what U.S. government efforts to develop hypersonic systems are underway and their recent or estimated future costs, (2) what challenges, if any, these efforts face to develop hypersonic weapon systems and what is being done to address them, and (3) the extent to which the U.S. government is effectively coordinating these efforts.[1]

This report is a public version of a sensitive report that we issued on January 15, 2021.[2] DOD deemed some of the information in our January 2021 report to be sensitive, which must be protected from public disclosure. Therefore, this report omits sensitive information about critical technologies, human capital and industrial base investments, and hypersonic test resources. Although the information provided in this report is more limited, the report addresses the same objectives as the sensitive report and uses the same methodology.

To inform all three objectives, we created two different surveys—one focused on hypersonic systems in development and a second to gather information about hypersonic science and technology (S&T) development in the 10-year period from fiscal year 2015 to fiscal year 2024—to send to different organizations within the Department of Defense (DOD), the National Aeronautics and Space Administration (NASA), and the Department of Energy (DOE). At our request, the surveys asked agencies to identify all efforts, classified and unclassified, across the government to develop hypersonic weapons and technologies. Survey questions included a range of acquisition and science and technology topics related to the purpose, schedule, cost, challenges, and collaboration within the hypersonic community, among other topics. Funding questions in the surveys were based on the President's Budget for fiscal year 2020, with funding reported from fiscal years 2015 to 2020 considered past funding, and fiscal years 2021 to 2024 considered planned future funding. Working with the Principal Director for Hypersonics within the Office of the Under

[1]For the purposes of this report, we defined a hypersonic system as one that: (1) flies at speeds of Mach 5 or higher, (2) uses aerodynamic lift for the majority of its flight path, (3) maneuvers while in flight, or (4) includes defensive, tracking, or sensing systems used to defeat an offensive hypersonic missile. This definition intentionally excludes other systems and technology that meet the Mach 5 velocity portion of the general hypersonic definition, such as intercontinental ballistic missiles, space vehicles, and some projectiles, but that are not part of the more recent effort to develop hypersonic weapon systems or technology.

[2]GAO, *Hypersonic Weapons: DOD Should Clarify Roles and Responsibilities to Ensure Coordination across Development Efforts,* GAO-21-75SU (Washington, D.C.: Jan. 15, 2021).

Secretary of Defense for Research and Engineering and each agency, we identified points of contact within DOD, NASA, and DOE to help us identify the hypersonic weapon-related and technology development activities within the U.S. government.

In developing the surveys, we pretested each with six different government organizations working on hypersonic weapons development or technology development and incorporated their feedback before sending them to be completed by the agencies. We then sent both surveys to the three agencies starting January 10, 2020. We originally collected most of our survey information in January and February 2020 via a classified system, but due to COVID-19, had to adjust our plans and recollect many of the unclassified surveys a second time which prolonged the data collection process. Overall, surveys were returned between January 23 and July 24, 2020. We received surveys from the following entities:

DOD

- Office of the Under Secretary of Defense Research and Engineering
  - Defense Advanced Research Projects Agency
  - Missile Defense Agency
  - Joint Hypersonics Transition Office
  - Principal Director for Hypersonics
- Department of the Air Force
  - Office of the Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics
- Department of the Army
  - Office of the U.S. Army Deputy Chief of Staff
- Department of the Navy
  - Strategic Systems Programs
  - Office of Naval Research
  - Naval Sea Systems Command

DOE

- Office of Science
- National Nuclear Security Administration

NASA

- Aeronautics Research Mission Directorate

In all, we collected 17 system surveys that identified five hypersonic systems under development by DOD and 67 S&T surveys identifying various hypersonic technology development underway or planned across the three agencies, for a total of 84 returned surveys. Two surveys were duplicative of other surveys returned and were omitted from analysis. An additional 10 surveys from DOE were omitted that supported DOD prototyping efforts, but were funded by DOD and were not separate hypersonic weapon-related and technology development efforts. Two additional surveys provided budgetary information as separate from their parent efforts and were not counted in the overall effort number. This left us with 70 efforts to report in our analysis.

1. We divided the surveys into two phases of hypersonic weapon-related and technology development for our report in the following manner.
2. Efforts were considered in the “product development” phase if they were prototype systems in development, for a total of five.

Efforts were considered in the “technology development” phase if their budget activity codes included basic research, applied research, advanced component development and prototypes funding, and advanced technology development, for a total of 65. For technology development, we separated efforts into two categories: initial—which includes applied and basic research—and advanced, which includes advanced component development and prototypes funding and advanced technology development.

To ensure our surveys depicted a comprehensive view of all U.S. government efforts related to hypersonic weapons, we took steps to confirm with officials from DOD, DOE, and NASA that all the surveys we received from their agency included all relevant efforts from fiscal years 2015 through 2024. In addition, we reviewed all efforts in the DOD hypersonic roadmaps, compared them with our data, and worked with DOD’s Principal Director for Hypersonics to review a listing of all efforts we collected. We took additional steps to clarify information, such as dollar amounts, with officials who either filled out the surveys or liaisons gathering the data for the agency or service on specific surveys as an additional data quality check.

To identify what U.S. government efforts to develop hypersonics systems are underway and their costs, we used survey data and analyzed them to identify historical and estimated future costs. We also reviewed program documentation and budget submissions to compare with survey data to ensure we had a comprehensive set of cost information and efforts. We interviewed officials from DOD, NASA, and DOE related to the efforts and their cost. Specifically, we interviewed officials from the following agencies to gain further insight into hypersonic efforts:

DOD

- Office of the Under Secretary of Defense for Research and Engineering
  - Defense Advanced Research Projects Agency
  - Missile Defense Agency
  - Joint Hypersonics Transition Office
  - Principal Director for Hypersonics
- Office of the Under Secretary of Defense for Acquisition and Sustainment
- Office of Cost Assessment and Program Evaluation
- Office of the Director of Operational Test and Evaluation
- Space Development Agency
- Test Resource Management Center
- Department of the Air Force
  - Office of the Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics
- Department of the Army
  - Office of the U.S. Army Deputy Chief of Staff
- Department of the Navy
  - Strategic Systems Programs
  - Office of Naval Research
  - Naval Air Warfare Center Weapons Division

DOE

- National Nuclear Security Administration

NASA

- Langley Research Center

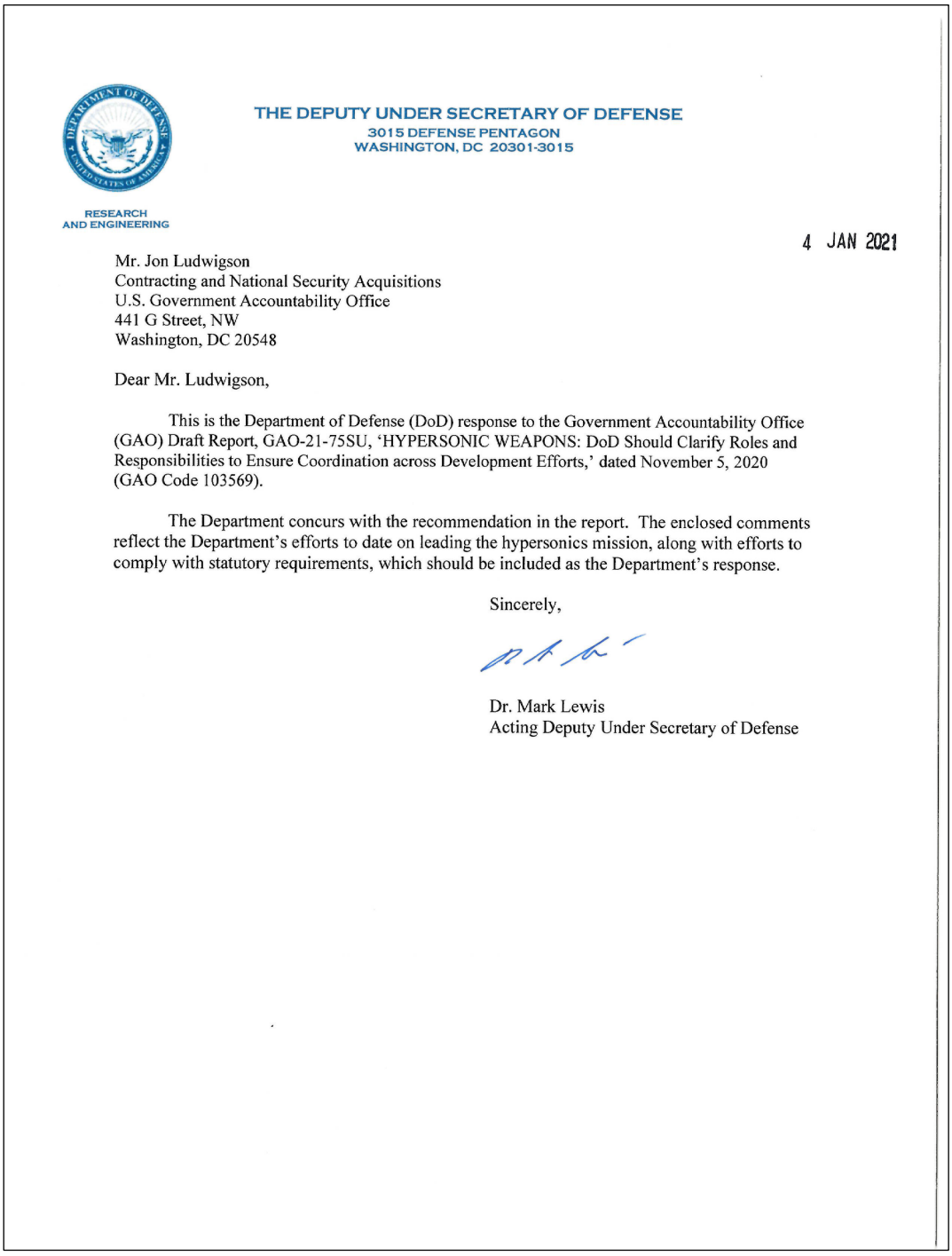
To identify the challenges these efforts face to develop hypersonic weapon systems and what is being done to address them, we reviewed agency documentation, analyzed the information provided from agencies in our surveys, and interviewed officials from organizations listed above. We also gathered documentation from DOD on other challenges outside of individual efforts including examining reviews on the industrial base, testing resources, and the hypersonic roadmap. To identify mitigations for challenges we identified, we interviewed agency officials and reviewed agency documentation.

To identify the extent to which the U.S. government is effectively coordinating hypersonic efforts, we analyzed the information provided from agencies in our surveys to determine the number of organizations involved and the frequency and nature of their coordination mechanisms. We also reviewed agency documentation and interviewed agency officials. We then compared this information to seven leading practices on interagency collaborative mechanisms, government standards for internal control, and guidance from the Office of Management and Budget Circular A-123.[3]

We conducted this performance audit from June 2019 to January 2021 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. We subsequently worked with DOD, DOE, and NASA from January 2021 to March 2021 to prepare this public version of a sensitive report. This public version was also prepared in accordance with these standards.

[3]*Managing for Results: Key Considerations for Implementing Interagency Collaborative Mechanisms*, GAO-12-1022 (Washington, D.C.: Sept. 27, 2012).

Appendix II: Comments from the Department of Defense



THE DEPUTY UNDER SECRETARY OF DEFENSE
3015 DEFENSE PENTAGON
WASHINGTON, DC 20301-3015

RESEARCH
AND ENGINEERING

4 JAN 2021

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

Dear Mr. Ludwigson,

This is the Department of Defense (DoD) response to the Government Accountability Office (GAO) Draft Report, GAO-21-75SU, 'HYPERSONIC WEAPONS: DoD Should Clarify Roles and Responsibilities to Ensure Coordination across Development Efforts,' dated November 5, 2020 (GAO Code 103569).

The Department concurs with the recommendation in the report. The enclosed comments reflect the Department's efforts to date on leading the hypersonics mission, along with efforts to comply with statutory requirements, which should be included as the Department's response.

Sincerely,

Dr. Mark Lewis
Acting Deputy Under Secretary of Defense

GAO DRAFT REPORT DATED NOVEMBER 5, 2020
GAO-21-75SU (GAO CODE 103569)

"HYPERSONIC WEAPONS: DOD SHOULD CLARIFY ROLES AND RESPONSIBILITIES TO ENSURE COORDINATION ACROSS DEVELOPMENT EFFORTS"
DEPARTMENT OF DEFENSE COMMENTS
TO THE GAO RECOMMENDATION

RECOMMENDATION 1: The GAO recommends that the Secretary of the Defense should define and document the roles, responsibilities, and authorities of the leadership positions and organizations in the Department of Defense responsible for the development and acquisition of hypersonic weapons. (Recommendation 1)

DOD RESPONSE: Concur. While the Department has already taken many actions to define and document an integrated hypersonics modernization strategy, we agree that a more formal documentation of the roles, responsibilities, and authorities of the leadership positions and organizations in the Department responsible for the development and acquisition of hypersonic weapons would add clarity, efficiency and robustness to our efforts.

The Principal Director for Hypersonics has already taken action to execute an integrated overarching vision and strategy for hypersonics development across all of DoD. The execution of this strategy is proceeding in a coherent and integrated fashion, with various organizations owning their appropriate key elements of the strategy. Additionally, section 218 of the National Defense Authorization Act for Fiscal Year 2007, as amended, established the Joint Hypersonics Transition Office (JHTO) to carry out key elements of our hypersonic strategy. Further, Section 217 of the National Defense Authorization Act for Fiscal Year 2021 formalizes the requirement for the Under Secretary of Defense for Research and Engineering (USD(R&E)) to appoint a senior official (Principal Director) responsible for each Modernization Priority, with duties and responsibilities enumerated. This will place into statute the leadership roles and responsibility of the Principal Director for Hypersonics, as the Acting USD(R&E) intends to appoint such an official for Hypersonics. Section 217 also requires that the Defense Advanced Research Projects Agency, the Service Acquisition Executives, and the intelligence organizations identify a senior official with whom the OUSD(R&E) senior official for hypersonics will coordinate. We believe that the requirements of section 217 align with this GAO recommendation, so that the Department's efforts to comply with this statute will also help provide the definition and documentation of leadership roles and responsibilities recommended by GAO.

The Department has already taken many steps in a collaborative unity of effort to advance the hypersonics mission. The Principal Director's overarching hypersonics development vision and strategy, along with the efforts to comply with statutory requirements, have provided the structure for the Department's efforts to date. However, the Department's implementation of the GAO recommendation will only strengthen the progress made to date, and will help ensure the future success of the hypersonic mission.

Appendix III: Hypersonic Prototyping Development Efforts

Table 11: Summary of U.S. Hypersonic Weapon Prototypes

Name of Effort	Type of weapon	Service	Planned fielding date (by fiscal year)	Acquisition approach
Air-launched Rapid Response Weapon	Hypersonic glide vehicle	Air Force	2022	Middle-tier acquisition
Conventional Prompt Strike	Hypersonic glide vehicle	Navy	2025, on nuclear-powered guided missile submarine 2028, on a nuclear-powered attack submarine	Middle-tier acquisition
Hypersonic Conventional Strike Weapon	Hypersonic glide vehicle	Air Force	Program cancelled after completing critical design review	Middle-tier acquisition
Long Range Hypersonic Weapon	Hypersonic glide vehicle	Army	2023	Research and development funds typically reserved for advanced technology or prototypes, rather than major system development
Standard Missile-6 Block IB	Rocket propelled missile	Navy	2024	Middle-tier acquisition

Source: GAO analysis of Department of Defense data. | GAO-21-378

Appendix IV: Technology Readiness Levels Numbers and Descriptions

Technology readiness level (TRL)		Description
1	Basic principles observed and reported	Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.
4	Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory.
5	Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components.
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.
7	System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space).
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.
9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.

Source: GAO analysis of agency documents. | GAO-21-378

Appendix V: GAO Contact and Staff Acknowledgments

GAO Contact

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

Staff Acknowledgments

In addition to the contact above, Rich Horiuchi (Assistant Director), Patrick Breiding (Analyst-in-Charge), Matthew Ambrose, Lori Fields, Laura Greifner, Laura Holliday, Jean Lee, Chi Mai, Matthew L. McKnight, Jean McSween, and Christine Pecora made significant contributions to this review.