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SUMMARY

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Hypersonic Weapons: Background and Issues for Congress

The United States has actively pursued the development of hypersonic weapons—maneuvering weapons that fly at speeds of at least Mach 5—as a part of its conventional prompt global strike program since the early 2000s. In recent years, the United States has focused such efforts on developing hypersonic glide vehicles, which are launched from a rocket before gliding to a target, and hypersonic cruise missiles, which are powered by high-speed, air-breathing engines during flight. As Vice Chairman of the Joint Chiefs of Staff and former Commander of U.S. Strategic Command General John Hyten has stated, these weapons could enable "responsive, long-range, strike options against distant, defended, and/or time-critical threats [such as road-mobile missiles] when other forces are unavailable, denied access, or not preferred." Critics, on the other hand, contend that hypersonic weapons lack defined mission requirements, contribute little to U.S. military capability, and are unnecessary for deterrence.

Funding for hypersonic weapons has been relatively restrained in the past; however, both the Pentagon and Congress have shown a growing interest in pursuing the development and near-term deployment of hypersonic systems. This is due, in part, to the growing interest in these technologies in Russia and China, both of which have a number of hypersonic weapons programs and are expected to field an operational hypersonic glide vehicle—potentially armed with nuclear warheads—as early as 2020. The United States, in contrast to Russia and China, is not currently considering or developing hypersonic weapons for use with a nuclear warhead. As a result, U.S. hypersonic weapons will likely require greater accuracy and will be more technically challenging to develop than nuclear-armed Chinese and Russian systems.

The Pentagon's FY2021 budget request for all hypersonic-related research is $3.2 billion—up from $2.6 billion in the FY2020 request—including $206.8 million for hypersonic defense programs. At present, the Department of Defense (DOD) has not established any programs of record for hypersonic weapons, suggesting that it may not have approved either requirements for the systems or long-term funding plans. Indeed, as Assistant Director for Hypersonics (Office of the Under Secretary of Defense for Research and Engineering) Mike White has stated, DOD has not yet made a decision to acquire hypersonic weapons and is instead developing prototypes to assist in the evaluation of potential weapon system concepts and mission sets.

As Congress reviews the Pentagon's plans for U.S. hypersonic weapons programs, it might consider questions about the rationale for hypersonic weapons, their expected costs, and their implications for strategic stability and arms control. Potential questions include the following:

- What mission(s) will hypersonic weapons be used for? Are hypersonic weapons the most cost-effective means of executing these potential missions? How will they be incorporated into joint operational doctrine and concepts?
- Given the lack of defined mission requirements for hypersonic weapons, how should Congress evaluate funding requests for hypersonic weapons programs or the balance of funding requests for hypersonic weapons programs, enabling technologies, and supporting test infrastructure? Is an acceleration of research on hypersonic weapons, enabling technologies, or hypersonic missile defense options both necessary and technologically feasible?
- How, if at all, will the fielding of hypersonic weapons affect strategic stability?
- Is there a need for risk-mitigation measures, such as expanding New START, negotiating new multilateral arms control agreements, or undertaking transparency and confidence-building activities?

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Introduction

The United States has actively pursued the development of hypersonic weapons as a part of its conventional prompt global strike (CPGS) program since the early 2000s.[1] In recent years, it has focused such efforts on hypersonic glide vehicles and hypersonic cruise missiles with shorter and intermediate ranges for use in regional conflicts. Although funding for these programs has been relatively restrained in the past, both the Pentagon and Congress have shown a growing interest in pursuing the development and near-term deployment of hypersonic systems. This is due, in part, to the growing interest in these technologies in Russia and China, leading to a heightened focus in the United States on the strategic threat posed by hypersonic flight. Open-source reporting indicates that both China and Russia have conducted numerous successful tests of hypersonic glide vehicles, and both are expected to field an operational capability as early as 2020.

Experts disagree on the potential impact of competitor hypersonic weapons on both strategic stability and the U.S. military's competitive advantage. Nevertheless, current Under Secretary of Defense for Research and Engineering (USD R&E) Michael Griffin has testified to Congress that the United States does not "have systems which can hold [China and Russia] at risk in a corresponding manner, and we don't have defenses against [their] systems."[2] Although the John S. McCain National Defense Authorization Act for Fiscal Year 2019 (FY2019 NDAA, P.L. 115-232) accelerated the development of hypersonic weapons, which USD R&E identifies as a priority research and development area, the United States is unlikely to field an operational system before 2023. However, the United States, in contrast to Russia and China, is not currently considering or developing hypersonic weapons for use with a nuclear warhead. As a result, U.S. hypersonic weapons will likely require greater accuracy and will be more technically challenging to develop than nuclear-armed Chinese and Russian systems.

In addition to accelerating development of hypersonic weapons, Section 247 of the FY2019 NDAA required that the Secretary of Defense, in coordination with the Director of the Defense Intelligence Agency, produce a classified assessment of U.S. and adversary hypersonic weapons programs, to include the following elements:

> (1) An evaluation of spending by the United States and adversaries on such technology.
>
> (2) An evaluation of the quantity and quality of research on such technology.
>
> (3) An evaluation of the test infrastructure and workforce supporting such technology.
>
> (4) An assessment of the technological progress of the United States and adversaries on such technology.
>
> (5) Descriptions of timelines for operational deployment of such technology.
>
> (6) An assessment of the intent or willingness of adversaries to use such technology.[3]

This report was delivered to Congress in July 2019. Similarly, Section 1689 of the FY2019 NDAA requires the Director of the Missile Defense Agency to produce a report on "how hypersonic missile defense can be accelerated to meet emerging hypersonic threats."[4] The

[1] For details, see CRS Report R41464, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, by Amy F. Woolf.

[2] U.S. Congress, Senate Committee on Armed Services, "Testimony of Michael Griffin," Hearing on New Technologies to Meet Emerging Threats, April 18, 2018, https://www.armed-services.senate.gov/imo/media/doc/18-40_04-18-18.pdf.

[3] P.L. 115-232, Section 2, Division A, Title II, §247.

[4] P.L. 115-232, Section 2, Division A, Title XVI, §1689.

findings of these reports could hold implications for congressional authorizations, appropriations, and oversight.

The following report reviews the hypersonic weapons programs in the United States, Russia, and China, providing information on the programs and infrastructure in each nation, based on unclassified sources. It also provides a brief summary of the state of global hypersonic weapons research development. It concludes with a discussion of the issues that Congress might address as it considers DOD's funding requests for U.S. hypersonic technology programs.

Background

Several countries are developing hypersonic weapons, which fly at speeds of at least Mach 5 (five times the speed of sound), but none have yet introduced them into their operational military forces.[5] There are two primary categories of hypersonic weapons

- **Hypersonic glide vehicles (HGV)** are launched from a rocket before gliding to a target.[6]
- **Hypersonic cruise missiles** are powered by high-speed, air-breathing engines, or "scramjets," after acquiring their target.

Unlike ballistic missiles, hypersonic weapons do not follow a ballistic trajectory and can maneuver en route to their destination. As Vice Chairman of the Joint Chiefs of Staff and former Commander of U.S. Strategic Command General John Hyten has stated, hypersonic weapons could enable "responsive, long-range, strike options against distant, defended, and/or time-critical threats [such as road-mobile missiles] when other forces are unavailable, denied access, or not preferred."[7] Conventional hypersonic weapons use only kinetic energy—energy derived from motion—to destroy unhardened targets or, potentially, underground facilities.[8]

Hypersonic weapons could challenge detection and defense due to their speed, maneuverability, and low altitude of flight.[9] For example, terrestrial-based radar cannot detect hypersonic weapons until late in the weapon's flight.[10] **Figure 1** depicts the differences in terrestrial-based radar detection timelines for ballistic missiles versus hypersonic glide vehicles.

5 The United States, Russia, China, Australia, India, France, and Germany are developing hypersonic weapons technology. See Richard H. Speier et al., *Hypersonic Missile Proliferation: Hindering the Spread of a New Class of Weapons*, RAND Corporation, 2017, https://www.rand.org/pubs/research_reports/RR2137.html.

6 When HGVs are mated with their rocket booster, the resulting weapon system is often referred to as a hypersonic boost-glide weapon.

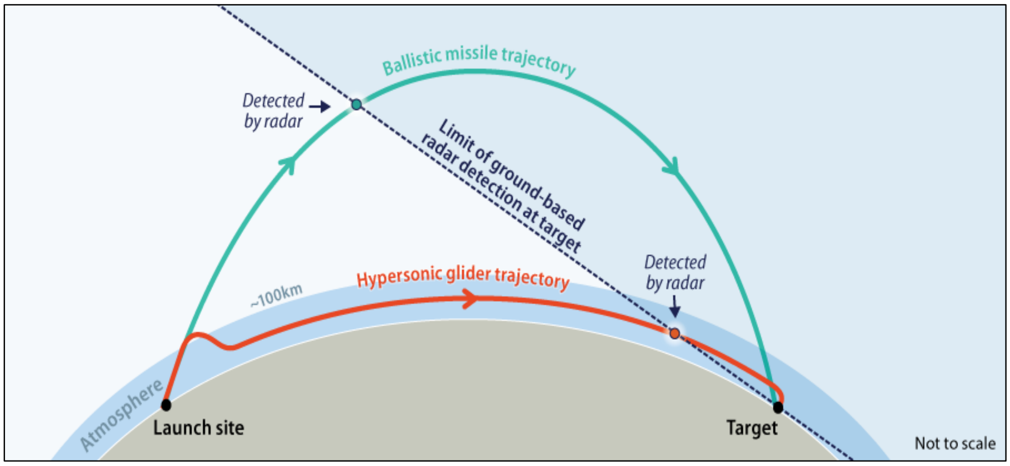
7 U.S. Congress, Senate Committee on Armed Services, "Testimony of John E. Hyten," Hearing on United States Strategic Command and United States Northern Command, February 26, 2019, https://www.armed-services.senate.gov/imo/media/doc/Hyten_02-26-19.pdf.

8 Richard H. Speier et al., *Hypersonic Missile Proliferation: Hindering the Spread of a New Class of Weapons*, p. 13.

9 See Department of Defense, *2019 Missile Defense Review*, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.PDF.

10 Richard H. Speier et al., *Hypersonic Missile Proliferation: Hindering the Spread of a New Class of Weapons*.

Figure 1. Terrestrial-Based Detection of Ballistic Missiles vs. Hypersonic Glide Vehicles



Source: CRS image based on an image in "Gliding missiles that fly faster than Mach 5 are coming," *The Economist*, April 6, 2019, https://www.economist.com/science-and-technology/2019/04/06/gliding-missiles-that-fly-faster-than-mach-5-are-coming.

This delayed detection compresses the timeline for decision-makers assessing their response options and for a defensive system to intercept the attacking weapon—potentially permitting only a single intercept attempt.[11]

Furthermore, U.S. defense officials have stated that both terrestrial- and current space-based sensor architectures are insufficient to detect and track hypersonic weapons, with USD R&E Griffin noting that "hypersonic targets are 10 to 20 times dimmer than what the U.S. normally tracks by satellites in geostationary orbit."[12] Some analysts have suggested that space-based sensor layers—integrated with tracking and fire-control systems to direct high-performance interceptors or directed energy weapons—could theoretically present viable options for defending against hypersonic weapons in the future.[13] Indeed, the *2019 Missile Defense Review* notes that "such sensors take advantage of the large area viewable from space for improved tracking and potentially targeting of advanced threats, including HGVs and hypersonic cruise missiles."[14]

Other analysts have questioned the affordability, technological feasibility, and/or utility of wide-area hypersonic weapons defense.[15] As physicist and nuclear expert James Acton explains, "point-defense systems, and particularly [Terminal High-Altitude Area Defense (THAAD)], could very plausibly be adapted to deal with hypersonic missiles. The disadvantage of those systems is that they can only defend small areas. To defend the whole of the continental United States, you

[11] Bradley Perrett et al., "U.S. Navy sees Chinese HGV as part of Wider Threat," *Aviation Week*, January 27, 2014.

[12] David Vergun, "DOD Scaling Up Effort to Develop Hypersonics," *DoD News*, December 13, 2018, https://dod.defense.gov/News/Article/Article/1712954/dod-scaling-up-effort-to-develop-hypersonics/; see also "Testimony of Michael Griffin"; and "Testimony of John E. Hyten."

[13] "Testimony of Michael Griffin"; and "Testimony of John E. Hyten."

[14] Department of Defense, *2019 Missile Defense Review*, p. XVI, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.PDF.

[15] See James M. Acton, "Hypersonic Weapons Explainer," Carnegie Endowment for International Peace, April 2, 2018, https://carnegieendowment.org/2018/04/02/hypersonic-weapons-explainer-pub-75957; and Margot van Loon, "Hypersonic Weapons: A Primer."

would need an unaffordable number of THAAD batteries."[16] In addition, some analysts have argued that the United States' current command and control architecture would be incapable of "processing data quickly enough to respond to and neutralize an incoming hypersonic threat."[17] (A broader discussion of hypersonic weapons defense is outside the scope of this report.)

United States

The Department of Defense (DOD) is currently developing hypersonic weapons under the Navy's Conventional Prompt Strike program, which is intended to provide the U.S. military with the ability to strike hardened or time-sensitive targets with conventional warheads, as well as through several Air Force, Army, and DARPA programs.[18] Those who support these development efforts argue that hypersonic weapons could enhance deterrence, as well as provide the U.S. military with an ability to defeat capabilities such as advanced air and missile defense systems that form the foundation of U.S. competitors' anti-access/area denial strategies.[19] In recognition of this, the *2018 National Defense Strategy* identifies hypersonic weapons as one of the key technologies "[ensuring the United States] will be able to fight and win the wars of the future."[20]

Programs

Unlike China and Russia, the United States is not currently developing hypersonic weapons for use with a nuclear warhead. As a result, U.S. hypersonic weapons will likely require greater accuracy and will be more technically challenging to develop than nuclear-armed Chinese and Russian systems. Indeed, according to one expert, "a nuclear-armed glider would be effective if it were 10 or even 100 times less accurate [than a conventionally-armed glider]" due to nuclear blast effects.[21]

According to open-source reporting, the United States has a number of major offensive hypersonic weapons and hypersonic technology programs in development, including the following (see **Table 1**):

- U.S. Navy—Conventional Prompt Strike (CPS);
- U.S. Army—Long-Range Hypersonic Weapon (LRHW);
- U.S. Air Force—AGM-183 Air-Launched Rapid Response Weapon (ARRW, pronounced "arrow");

[16] Acton, "Hypersonic Weapons Explainer."

[17] Margot van Loon, "Hypersonic Weapons: A Primer" in *Defense Technology Program Brief: Hypersonic Weapons*, American Foreign Policy Council, May 17, 2019. Some analysts have suggested that future command and control systems may require autonomous functionality to manage the speed and unpredictability of hypersonic weapons. See John L. Dolan, Richard K. Gallagher, and David L. Mann, "Hypersonic Weapons Are Literally Unstoppable (As in America Can't Stop Them)," *Real Clear Defense,* April 23, 2019, https://www.realcleardefense.com/articles/2019/04/23/hypersonic_weapons__a_threat_to_national_security_114358.html.

[18] For a full history of U.S. hypersonic weapons programs, see CRS Report R41464, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, by Amy F. Woolf.

[19] Roger Zakheim and Tom Karako, "China's Hypersonic Missile Advances and U.S. Defense Responses," Remarks at the Hudson Institute, March 19, 2019. See also Department of Defense Fiscal Year (FY) 2020 Budget Estimates, Army Justification Book of Research, Development, Test and Evaluation, Volume II, Budget Activity 4, p. 580.

[20] Department of Defense, "Summary of the 2018 National Defense Strategy of The United States of America," p. 3, https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

[21] James M. Acton, "China's Advanced Weapons," Testimony to the U.S. China Economic and Security Review Commission, February 23, 2017, https://carnegieendowment.org/2017/02/23/china-s-advanced-weapons-pub-68095.

- DARPA—Tactical Boost Glide (TBG);
- DARPA—Advanced Full-Range Engine (AFRE);
- DARPA—Operational Fires (OpFires); and
- DARPA—Hypersonic Air-breathing Weapon Concept (HAWC, pronounced "hawk").

These programs are intended to produce operational prototypes, as there are currently no programs of record for hypersonic weapons.[22] Accordingly, funding for U.S. hypersonic weapons programs is found in the Research, Development, Test, and Evaluation accounts, rather than in Procurement.

U.S. Navy

In a June 2018 memorandum, DOD announced that the Navy would lead the development of a common glide vehicle for use across the services.[23] The common glide vehicle is being adapted from a Mach 6 Army prototype warhead, the Alternate Re-Entry System, which was successfully tested in 2011 and 2017.[24] Once development is complete, "Sandia National Laboratories, the designer of the original concept, then will build the common glide vehicles…. Booster systems are being developed separately."[25]

The Navy's Conventional Prompt Strike (CPS) is expected to pair the common glide vehicle with a submarine-launched booster system, achieving initial operational capability (IOC) on a Virginia-class submarine with Virginia Payload Module in FY2028.[26] The Navy is requesting $1 billion for CPS in FY2021—an increase of $415 million over the FY2020 request and $496 million over the FY2020 appropriation—and $5.3 billion across the five-year Future Years Defense Program (FYDP).[27]

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[22] Steve Trimble, "New Long-Term Pentagon Plan Boosts Hypersonics, But Only Prototypes," *Aviation Week*, March 15, 2019, https://aviationweek.com/defense/new-long-term-pentagon-plan-boosts-hypersonics-only-prototypes.

[23] The services coordinate efforts on a Common Hypersonic Glide Body Board of Directors with rotating chairmanship. Sydney J. Freedberg, Jr., "Army Ramps Up Funding For Laser Shield, Hypersonic Sword," *Breaking Defense*, February 28, 2020, https://breakingdefense.com/2020/02/army-ramps-up-funding-for-laser-shield-hypersonic-sword/.

[24] Steve Trimble and Guy Norris, "Sandia's Swerve Could Lead to First-gen Hypersonic Production Line," *Aviation Week*, October 11, 2018, http://aviationweek.com/air-dominance/sandia-s-swerve-could-lead-first-gen-hypersonic-production-line; and Sydney J. Freedberg Jr., "Army Warhead Is Key To Joint Hypersonics," *Breaking Defense*, August 22, 2018, https://breakingdefense.com/2018/08/army-warhead-is-key-to-joint-hypersonics/.

[25] Trimble and Norris, "Sandia's Swerve."

[26] Department of the Navy, "Highlights of the Department of the Navy FY 2021 Budget," February 10, 2020, https://www.secnav.navy.mil/fmc/fmb/Documents/21pres/Highlights_book.pdf. Vice Admiral Terry Benedict, former director of the Navy Strategic Systems Program, has stated that CPS will eventually be deployed on both Ohio- and Virginia-class submarines. Navy leadership has also discussed the possibility of deploying CPS on Arleigh Burke- and Zumwalt-class destroyers. See Jason Sherman and Lee Hudson, "Navy reveals plans to put hypersonic strike weapons on submarines," *Inside Defense*, November 8, 2017, https://insidedefense.com/inside-missile-defense/navy-reveals-plans-put-hypersonic-strike-weapons-submarines; and Paul McLeary, "SecNav Tells Fleet Hypersonic Competition Demands 'Sputnik Moment;' Glide Body Test Set," *Breaking Defense*, January 31, 2020, https://breakingdefense.com/2020/01/secnav-tells-fleet-hypersonic-competition-demands-sputnik-moment-glide-body-test-set/.

[27] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Navy Justification Book of Research, Development, Test and Evaluation, Volume II, Budget Activity 4, p. 1419, https://www.secnav.navy.mil/fmc/fmb/Documents/21pres/RDTEN_BA4_Book.pdf; see also CRS In Focus IF10831, *Defense Primer: Future Years Defense Program (FYDP)*, by Brendan W. McGarry and Heidi M. Peters.

U.S. Army

The Army's Long-Range Hypersonic Weapon program is expected to pair the common glide vehicle with the Navy's booster system. The system is intended to have a range of 1,400 miles and "provide the Army with a prototype strategic attack weapon system to defeat A2/AD capabilities, suppress adversary Long Range Fires, and engage other high payoff/time sensitive targets."[28] The Army is requesting $801 million for the program in FY2021—$573 million over the FY2020 request and $397 million over the FY2020 appropriation—and $3.3 billion across the FYDP.[29] It plans to conduct flight tests for LRHW from FY2021 to FY2023, field combat rounds in FY2023, and transition to a program of record in the fourth quarter of FY2024.[30]

U.S. Air Force

The AGM-183 Air-Launched Rapid Response Weapon is expected to leverage DARPA technology to develop an air-launched hypersonic glide vehicle prototype capable of travelling at speeds up to Mach 20 at a range of approximately 575 miles.[31] Despite testing delays due to technical challenges, ARRW completed a successful flight test in June 2019 and is expected to complete flight tests in FY2022.[32] The Air Force has requested $382 million for ARRW in FY2021—up from $286 million in the FY2020 request and appropriation—and $581 million across the FYDP, with no funds requested beyond FY2022.[33] ARRW is a project under the Air Force's Hypersonics Prototyping Program Element, which is intended to demonstrate concepts "to [enable] leadership to make informed strategy and resource decisions … for future programs."[34]

In February 2020, the Air Force announced that it had cancelled its second hypersonic weapon program, the Hypersonic Conventional Strike Weapon (HCSW), which had been expected to use the common glide vehicle, due to budget pressures that forced it to choose between ARRW and

[28] Department of Defense Fiscal Year (FY) 2020 Budget Estimates, Army Justification Book of Research, Development, Test and Evaluation, Volume II, Budget Activity 4, pp. 579-584, https://www.asafm.army.mil/documents/BudgetMaterial/fy2020/rdte_ba4.pdf; and Sydney J. Freedberg Jr., "Army Sets 2023 Hypersonic Flight Test; Strategic Cannon Advances," *Breaking Defense*, March 19, 2019, https://breakingdefense.com/2019/03/army-sets-2023-hypersonic-flight-test-strategic-cannon-advances/.

[29] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Army Justification Book of Research, Development, Test and Evaluation, Volume II, Budget Activity 4, p. 613, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2021/Base%20Budget/rdte/RDTE_BA_4_FY_2021_PB_RDTE_Vol%202_Budget_Activity_4.pdf.

[30] Department of the Army, "FY 2021: President's Budget Highlights," February 2020, p. 18, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2021/pbr/Overview%20and%20Highlights/Army_FY_2021_Budget_Highlights.pdf.

[31] Stephen Trimble, "Lockheed Martin claims both USAF hypersonic programmes," *Flight Global*, August 7, 2018, https://www.flightglobal.com/news/articles/lockheed-martin-claims-both-usaf-hypersonic-programm-450968/.

[32] The Air Force's budget request notes that "further schedule details can be provided in the appropriate forum." Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Air Force Justification Book of Research, Development, Test and Evaluation, Volume II, p. 128. See also Lee Hudson and Steve Trimble, "Top U.S. Hypersonic Weapon Program Facing New Schedule Pressure," *Aviation Week*, January 11, 2019, http://aviationweek.com/defense/top-us-hypersonic-weapon-program-facing-new-schedule-pressure.

[33] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Air Force Justification Book of Research, Development, Test and Evaluation, Volume II, p. 121, https://www.saffm.hq.af.mil/Portals/84/documents/FY21/RDTE_/FY21%20Air%20Force%20Research%20Development%20Test%20and%20Evaluation%20Vol%20II.pdf?ver=2020-02-12-145218-377.

[34] Ibid., p. 121.

HCSW.[35] Air Force acquisition chief Will Roper explained that ARRW was selected because it was more advanced and gave the Air Force additional options. "[ARRW] is smaller; we can carry twice as many on the B-52, and it's possible it could be on the F-15," he explained.[36] The Air Force will continue its technical review of HCSW through March 2020.[37]

DARPA

DARPA, in partnership with the Air Force, continues to test Tactical Boost Glide, a wedge-shaped hypersonic glide vehicle capable of Mach 7+ flight that "aims to develop and demonstrate technologies to enable future air-launched, tactical-range hypersonic boost glide systems."[38] TBG will "also consider traceability, compatibility, and integration with the Navy Vertical Launch System" and is planned to transition to both the Air Force and the Navy. DARPA has requested $117 million—down from the $162 million FY2020 request and the $152 million FY2020 appropriation—for TBG in FY2021.[39]

DARPA's Operational Fires reportedly seeks to leverage TBG technologies to develop a ground-launched system that will enable "advanced tactical weapons to penetrate modern enemy air defenses and rapidly and precisely engage critical time sensitive targets." DARPA has requested $40 million for OpFires in FY2021—down from the $50 million FY2020 request and appropriation—and intends to transition the program to the Army.[40]

In the longer term, DARPA, with Air Force support, is continuing work on the Hypersonic Air-breathing Weapon Concept, which "seeks to develop and demonstrate critical technologies to enable an effective and affordable air-launched hypersonic cruise missile."[41] DARPA has requested $7 million to develop HAWC in FY2021—down from the $10 million FY2020 request and $20 million FY2020 appropriation.[42]

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[35] Valerie Insinna, "US Air Force kills one of its hypersonic weapons programs," *Defense News*, February 10, 2020, https://www.defensenews.com/smr/federal-budget/2020/02/10/the-air-force-just-canceled-one-of-its-hypersonic-weapons-programs/.

[36] John A. Tirpak, "Roper: The ARRW Hypersonic Missile Better Option for USAF," March 2, 2020, https://www.airforcemag.com/arrw-beat-hcsw-because-its-smaller-better-for-usaf/. Tirpak additionally notes that "the F-15 could accelerate the ARRW to Mach 3 before launch, potentially reducing the size of the booster needed to get the weapon to hypersonic speed."

[37] Ibid.

[38] "Tactical Boost Glide (TBG) Program Information," DARPA, https://www.darpa.mil/program/tactical-boost-glide; and Guy Norris, "U.S. Air Force Plans Road Map to Operational Hypersonics," *Aviation Week*, July 27, 2017, https://aviationweek.com/defense/us-air-force-plans-road-map-operational-hypersonics.

[39] DARPA states that the decline in the budget request "reflects completion of full-scale testing and final program reporting." Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Defense Advanced Research Projects Agency, Defense-Wide Justification Book 1 of 5, pp. 162-164, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol1_DARPA_MasterJustificationBook_PB_2021.pdf.

[40] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Defense Advanced Research Projects Agency, Defense-Wide Justification Book 1 of 5, p. 165, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol1_DARPA_MasterJustificationBook_PB_2021.pdf.

[41] "Hypersonic Air-breathing Weapon Concept (HAWC) Program Information," DARPA, https://www.darpa.mil/program/hypersonic-air-breathing-weapon-concept.

[42] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Defense Advanced Research Projects Agency, Defense-Wide Justification Book 1 of 5, p. 165, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol1_DARPA_MasterJustificationBook_PB_2021.pdf.

Table 1. Summary of U.S. Hypersonic Weapons Programs

Title	FY2020 ($ in millions)	PB2021 ($ in millions)	Schedule
Conventional Prompt Strike (CPS)	512	1,008	IOC in FY2028
Long-Range Hypersonic Weapon (LRHW)	404	801	Flight tests through 2023
AGM-183 Air-Launched Rapid Response Weapon (ARRW)	286	382	Flight tests through 2022
Hypersonic Conventional Strike Weapon (HCSW)	290	0	Cancelled in 2020
Tactical Boost Glide (TBG)	152	117	Testing through at least 2021
Operational Fires (OpFires)	50	40	Testing through at least 2021; transitions to weapon system integration planning and design in 2021
Hypersonic Air-breathing Weapon Concept (HAWC)	20	7	Complete flight tests in 2020; final program reviews in 2021

Source: Program information taken from U.S. Navy, Army, Air Force, and DARPA FY2021 Justification Books, available at https://comptroller.defense.gov/Budget-Materials/.

Hypersonic Missile Defenses

DOD is also investing in counter-hypersonic weapons capabilities, although USD R&E Michael Griffin has stated that the United States will not have a defensive capability against hypersonic weapons until the mid-2020s, at the earliest.[43] In September 2018, the Missile Defense Agency (MDA)—which in 2017 established a Hypersonic Defense Program pursuant to Section 1687 of the FY2017 NDAA (P.L. 114-840)—commissioned 21 white papers to explore hypersonic missile defense options, including interceptor missiles, hypervelocity projectiles, laser guns, and electronic attack systems.[44] In January 2020, MDA issued a draft request for prototype proposals for a Hypersonic Defense Regional Glide Phase Weapons System interceptor. This effort is intended to "reduce interceptor key technology and integration risks, anchor modeling and simulation in areas of large uncertainty, and to increase the interceptor technology readiness levels (TRL) to level 5."[45] MDA has also awarded four companies—Northrop Grumman, Raytheon, Leidos, and L3Harris—with $20 million contracts to design prototype space-based

[43] "Media Availability With Deputy Secretary Shanahan and Under Secretary of Defense Griffin at NDIA Hypersonics Senior Executive Series," U.S. Department of Defense, December 13, 2018, https://dod.defense.gov/News/Transcripts/Transcript-View/Article/1713396/media-availability-with-deputy-secretary-shanahan-and-under-secretary-of-defens/.

[44] P.L. 114-840, Section 2, Division A, Title XVI, §1687; and Hudson and Trimble, "Top U.S. Hypersonic Weapon Program"; Steve Trimble, "A Hypersonic Sputnik?," p. 21.

[45] Missile Defense Agency, "Draft Request for Prototype Proposal: Hypersonic Defense Regional Glide Phase Weapon System," January 30, 2020, p. 8. TRL measures a technology's level of maturity; TRL 5 requires validation in a relevant environment. For information about specific TRLs, see Troy Carter, "The 9 Technology Readiness Levels of the DOD," TechLink, https://techlinkcenter.org/technology-readiness-level-dod/.

(low-Earth orbit) sensors by October 31, 2020.[46] Such sensors could theoretically extend the range at which incoming missiles could be detected and tracked—a critical requirement for hypersonic missile defense, according to USD Griffin.[47] MDA requested $206.8 million for hypersonic defense in FY2021—up from its $157.4 million FY2020 request—and $659 million across the FYDP.[48] In addition, DARPA is working on a program called Glide Breaker, which "will develop critical component technology to support a lightweight vehicle designed for precise engagement of hypersonic threats at very long range."[49] DARPA requested $3 million for Glide Breaker in FY2021—down from $10 million in FY2020.[50]

Infrastructure

According to a study mandated by the FY2013 National Defense Authorization Act (P.L. 112-239) and conducted by the Institute for Defense Analyses (IDA),[51] the United States had 48 critical hypersonic test facilities and mobile assets in 2014 needed for the maturation of hypersonic technologies for defense systems development through 2030. These specialized facilities, which simulate the unique conditions experienced in hypersonic flight (e.g., speed, pressure, heating),[52] included 10 DOD hypersonic ground test facilities, 11 DOD open-air ranges, 11 DOD mobile assets, 9 NASA facilities, 2 Department of Energy facilities, and 5 industry or academic facilities.[53] In its 2014 evaluation of U.S. hypersonic test and evaluation infrastructure, IDA noted that "no current U.S. facility can provide full-scale, time-dependent, coupled aerodynamic and thermal-loading environments for flight durations necessary to evaluate these characteristics above Mach 8." Since the 2014 study report was published, the University of Notre Dame has opened a Mach 6 hypersonic wind tunnel and at least one hypersonic testing facility has been inactivated. Development of Mach 8 and Mach 10 wind tunnels at Purdue University and the University of Notre Dame, respectively, is ongoing.[54] In addition, the University of Arizona plans to modify one of its wind tunnels to enable Mach 5 testing by early 2021, while Texas A&M University—in partnership with Army Futures Command—plans to complete construction of a kilometer-long Mach 10 wind tunnel by 2021.[55] (For a list of U.S. hypersonic test assets and their capabilities, see the **Appendix**.)

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[46] Sandra Erwin, "Missile Defense Agency selects four companies to develop space sensors," *Space News*, October 30, 2019, https://spacenews.com/missile-defense-agency-selects-four-companies-to-develop-space-sensors/. Experts disagree on the cost and technological feasibility of space-based missile defense.

[47] Media Availability With Deputy Secretary Shanahan and Under Secretary of Defense Griffin."

[48] Missile Defense Agency, Budget Estimates Overview: Fiscal Year 2021, p. 12, https://www.mda.mil/global/documents/pdf/budgetfy21.pdf.

[49] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Defense Advanced Research Projects Agency, Defense-Wide Justification Book 1 of 5, p. 164.

[50] Ibid.

[51] P.L. 112-239, Section 2, Division A, Title X, §1071.

[52] These conditions additionally require the development of specialized materials such as metals and ceramics.

[53] This list is taken directly from a 2014 Institute for Defense Analysis report and, therefore, may not be current. See (U//FOUO) Paul F. Piscopo et al., *(U) Study on the Ability of the U.S. Test and Evaluation Infrastructure to Effectively and Efficiently Mature Hypersonic Technologies for Defense Systems Development: Summary Analysis and Assessment*, Institute for Defense Analyses, September 2014. Permission to use this material has been granted by the Office of Science and Technology Policy.

[54] Oriana Pawlyk, "Air Force Expanding Hypersonic Technology Testing at Two Indiana Universities," Military.com, April 23, 2019, https://www.military.com/daily-news/2019/04/23/air-force-expanding-hypersonic-technology-testing-two-indiana-universities.html.

[55] University of Arizona, "Mach 5 Quiet Ludwieg Tube,"

The United States also uses the Royal Australian Air Force Woomera Test Range in Australia and the Andøya Rocket Range in Norway for flight testing.[56] In January 2019, the Navy announced plans to reactivate its Launch Test Complex at China Lake, CA, to improve air launch and underwater testing capabilities for the conventional prompt strike program.[57]

In addition, in March 2020, DOD announced that it had established a "hypersonic war room" to assess the U.S. industrial base for hypersonic weapons and identify "critical nodes" in the supply chain.[58] Initial findings are to be released in mid-2020.[59]

Russia

Although Russia has conducted research on hypersonic weapons technology since the 1980s, it accelerated its efforts in response to U.S. missile defense deployments in both the United States and Europe, and in response to the U.S. withdrawal from the Anti-Ballistic Missile Treaty in 2001.[60] Detailing Russia's concerns, President Putin stated that "the US is permitting constant, uncontrolled growth of the number of anti-ballistic missiles, improving their quality, and creating new missile launching areas. If we do not do something, eventually this will result in the complete devaluation of Russia's nuclear potential. Meaning that all of our missiles could simply be intercepted."[61] Russia thus seeks hypersonic weapons, which can maneuver as they approach their targets, as an assured means of penetrating U.S. missile defenses and restoring its sense of strategic stability.[62]

Programs

Russia is pursuing two hypersonic weapons programs—the Avangard and the 3M22 Tsirkon (or Zircon)—and has reportedly fielded the Kh-47M2 Kinzhal ("Dagger"), a maneuvering air-launched ballistic missile.[63]

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https://transition.arizona.edu/facilities/qlt5?_ga=2.62515882.768526379.1582843192-983632914.1582843192; and Ashley Tressel, "Army to open hypersonic testing facility at Texas A&M," Inside Defense, October 13, 2019, https://insidedefense.com/daily-news/army-open-hypersonic-testing-facility-texas-am. Additional universities such as the University of Maryland, the California Institute of Technology, the Georgia Institute of Technology, the Air Force Academy, the University of Tennessee, and Virginia Polytechnic Institute and State University also maintain experimental hypersonic facilities or conduct hypersonic research.

[56] (U//FOUO) Paul F. Piscopo et al., *(U) Study on the Ability of the U.S. Test and Evaluation Infrastructure*.

[57] "Update: US Navy to develop China Lake to support CPS weapon testing," *Jane's*, February 12, 2019, https://janes.ihs.com/Janes/Display/FG_1644858-JMR.

[58] Aaron Mehta, "Pentagon launches hypersonic industrial base study," *Defense News,* March 3, 2020, https://www.defensenews.com/pentagon/2020/03/02/pentagon-launches-hypersonic-industrial-base-study/.

[59] Ibid.

[60] United Nations Office of Disarmament Affairs, *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control,* February 2019, https://www.un.org/disarmament/publications/more/hypersonic-weapons-a-challenge-and-opportunity-for-strategic-arms-control/.

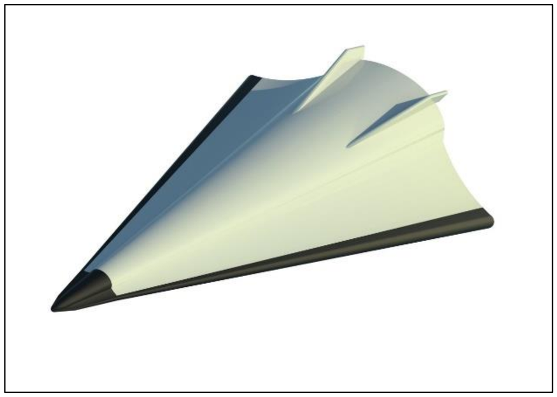
[61] Vladimir Putin, "Presidential Address to the Federal Assembly," March 1, 2018, http://en.kremlin.ru/events/president/news/56957.

[62] In this instance, "strategic stability" refers to a "bilateral nuclear relationship of mutual vulnerability." See Tong Zhao, "Conventional Challenges to Strategic Stability: Chinese Perceptions of Hypersonic Technology and the Security Dilemma," Carnegie-Tsinghua Center for Global Policy, July 23, 2018, https://carnegietsinghua.org/2018/07/23/conventional-challenges-to-strategic-stability-chinese-perceptions-of-hypersonic-technology-and-security-dilemma-pub-76894.

[63] Although the Kinzhal is a maneuvering air-launched ballistic missile rather than a hypersonic glide vehicle or hypersonic cruise missile, it is often included in reporting of Russia's hypersonic weapons program. For this reason—

Avangard (**Figure 2**) is a hypersonic glide vehicle launched from an intercontinental ballistic missile (ICBM), giving it "effectively 'unlimited' range."[64] Reports indicate that Avangard is currently deployed on the SS-19 Stiletto ICBM, though Russia plans to eventually launch the vehicle from the Sarmat ICBM. Sarmat is still in development, although it may be deployed by 2021.[65] Avangard features onboard countermeasures and will reportedly carry a nuclear warhead. It was successfully tested twice in 2016 and once in December 2018, reportedly reaching speeds of Mach 20; however, an October 2017 test resulted in failure. Russian news sources claim that Avangard entered into combat duty in December 2019.[66]

Figure 2. Artist Rendering of Avangard



Source: https://janes.ihs.com/Janes/Display/FG_899127-JIR.

In addition to Avangard, Russia is developing Tsirkon, a ship-launched hypersonic cruise missile capable of traveling at speeds of between Mach 6 and Mach 8. Tsirkon is reportedly capable of striking both ground and naval targets. According to Russian news sources, Tsirkon has a range of between approximately 250 and 600 miles and can be fired from the vertical launch systems mounted on cruisers *Admiral Nakhimov* and *Pyotr Veliky*, Project 20380 corvettes, Project 22350 frigates, and Project 885 Yasen-class submarines, among other platforms.[67] These sources assert that Tsirkon was successfully launched from a Project 22350 frigate in January 2020.[68] U.S. intelligence reports indicate that the missile will become operational in 2023.[69]

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and because it poses defensive challenges that are similar to other hypersonic weapons—it is included here for reference.

[64] Steve Trimble, "A Hypersonic Sputnik?," *Aviation Week*, January 14-27, 2019, p. 20.

[65] Ibid. Sarmat could reportedly accommodate at least three Avangard vehicles. See Malcolm Claus, "Russia unveils new strategic delivery systems," *Jane's*, https://janes.ihs.com/Janes/Display/FG_899127-JIR

[66] "First regiment of Avangard hypersonic missile systems goes on combat duty in Russia," *TASS*, December 27, 2019, https://tass.com/defense/1104297.

[67] "Russia makes over 10 test launches of Tsirkon seaborne hypersonic missile," *TASS*, December 21, 2018, http://tass.com/defense/1037426. See also *Russia Military Power: Building a Military to Support Great Power Aspirations*, Defense Intelligence Agency, 2017, p. 79, https://www.dia.mil/portals/27/documents/news/military%20power%20publications/russia%20military%20power%20report%202017.pdf.

[68] "TASS: Russia Conducts First Ship-Based Hypersonic Missile Test," *Reuters*, February 27, 2020, https://www.voanews.com/europe/tass-russia-conducts-first-ship-based-hypersonic-missile-test.

[69] Amanda Macias, "Russia again successfully tests ship-based hypersonic missile—which will likely be ready for combat by 2022," *CNBC*, December 20, 2018, https://www.cnbc.com/2018/12/20/russia-tests-hypersonic-missile-that-could-be-ready-for-war-by-2022.html; and "Russian Navy to accept latest Tsirkon hypersonic missile for service in 2023—source," *TASS*, March 20, 2019, http://tass.com/defense/1049572.

In addition, Russia has reportedly fielded Kinzhal, a maneuvering air-launched ballistic missile modified from the Iskander missile. According to U.S. intelligence reports, Kinzhal was successfully test fired from a modified MiG-31 fighter (NATO code name: Foxhound) as recently as July 2018—striking a target at a distance of approximately 500 miles—and is expected by U.S. intelligence sources to become ready for combat by 2020.[70] Russia plans to deploy the missile on both the MiG-31 and the Su-34 long-range strike fighter.[71] Russia is working to mount the missile on the Tu-22M3 strategic bomber (NATO code name: Backfire), although the slower-moving bomber may face challenges in "accelerating the weapon into the correct launch parameters."[72]

Russian media has reported Kinzhal's top speed as Mach 10, with a range of up to 1,200 miles when launched from the MiG-31. The Kinzhal is reportedly capable of maneuverable flight, as well as of striking both ground and naval targets, and could eventually be fitted with a nuclear warhead. However, such claims regarding Kinzhal's performance characteristics have not been publicly verified by U.S. intelligence agencies, and have been met with skepticism by a number of analysts.[73]

Infrastructure

Russia reportedly conducts hypersonic wind tunnel testing at the Central Aero-Hydrodynamic Institute in Zhukovsky and the Khristianovich Institute of Theoretical and Applied Mechanics in Novosibirsk, and has tested hypersonic weapons at Dombarovskiy Air Base, the Baykonur Cosmodrome, and the Kura Range.[74]

China

According to Tong Zhao, a fellow at the Carnegie-Tsinghua Center for Global Policy, "most experts argue that the most important reason to prioritize hypersonic technology development [in China] is the necessity to counter specific security threats from increasingly sophisticated U.S. military technology, including [hypersonic weapons]."[75] In particular, China's pursuit of hypersonic weapons, like Russia's, reflects a concern that U.S. hypersonic weapons could enable the United States to conduct a preemptive, decapitating strike on China's nuclear arsenal and supporting infrastructure. U.S. missile defense deployments could then limit China's ability to conduct a retaliatory strike against the United States.[76]

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[70] Amanda Macias, "Russia's new hypersonic missile, which can be launched from warplanes, will likely be ready for combat by 2020," *CNBC*, July 13, 2018, https://www.cnbc.com/2018/07/13/russia-new-hypersonic-missile-likely-ready-for-war-by-2020.html.

[71] Mark B. Schneider, "Moscow's Development of Hypersonic Missiles … and What It Means" in *Defense Technology Program Brief: Hypersonic Weapons*, American Foreign Policy Council, May 17, 2019.

[72] Dave Majumdar, "Russia: New Kinzhal Aero-Ballistic Missile Has 3,000 km Range if Fired from Supersonic Bomber," *The National Interest*, July 18, 2018, https://nationalinterest.org/blog/buzz/russia-new-kinzhal-aero-ballistic-missile-has-3000-km-range-if-fired-supersonic-bomber.

[73] David Axe, "Is Kinzhal, Russia's New Hypersonic Missile, a Game Changer?," *The Daily Beast*, March 15, 2018, https://www.thedailybeast.com/is-kinzhal-russias-new-hypersonic-missile-a-game-changer.

[74] "Aerodynamics," Central Aerohydrodynamic Institute, http://tsagi.com/research/aerodynamics/; "Russia announces successful flight test of Avangard hypersonic glide vehicle," *Jane's*, January 3, 2019, https://janes.ihs.com/Janes/Display/FG_1451630-JMR; and "Avangard system is tested, said to be fully ready for deployment," Russian Strategic Nuclear Forces, December 26, 2018, http://russianforces.org/blog/2018/12/avangard_system_is_tested_said.shtml.

[75] Tong Zhao, "Conventional Challenges to Strategic Stability: Chinese Perceptions of Hypersonic Technology and the Security Dilemma."

[76] Tong Zhao, "Conventional Challenges to Strategic Stability"; and Lora Saalman, "China's Calculus on Hypersonic

China has demonstrated a growing interest in Russian advances in hypersonic weapons technology, conducting flight tests of a hypersonic-glide vehicle (HGV) only days after Russia tested its own system.[77] Furthermore, a January 2017 report found that over half of open-source Chinese papers on hypersonic weapons include references to Russian weapons programs.[78] This could indicate that China is increasingly considering hypersonic weapons within a regional context. Indeed, some analysts believe that China may be planning to mate conventionally armed HGVs with the DF-21 and DF-26 ballistic missiles in support of an anti-access/area denial strategy.[79] China has reportedly not made a final determination as to whether its hypersonic weapons will be nuclear- or conventionally-armed—or dual-capable.

Programs

China has conducted a number of successful tests of the DF-17, a medium-range ballistic missile specifically designed to launch HGVs. U.S. intelligence analysts assess that the missile has a range of approximately 1,000 to 1,500 miles and could be deployed in 2020.[80] China has also tested the DF-41 intercontinental ballistic missile, which could be modified to carry a conventional or nuclear HGV, according to a report by a U.S. Congressional commission. The development of the DF-41 thus "significantly increases the [Chinese] rocket force's nuclear threat to the U.S. mainland," the report states.[81]

China has tested the DF-ZF HGV (previously referred to as the WU-14) at least nine times since 2014. U.S. defense officials have reportedly identified the range of the DF-ZF as approximately 1,200 miles and have stated that the missile may be capable of performing "extreme maneuvers" during flight.[82] Although unconfirmed by intelligence agencies, some analysts believe the DF-ZF will be operational as early as 2020.[83]

According to U.S. defense officials, China also successfully tested Starry Sky-2 (or Xing Kong-2), a nuclear-capable hypersonic vehicle prototype, in August 2018.[84] China claims the vehicle

Glide," August 15, 2017, Stockholm International Peace Research Institute, https://www.sipri.org/commentary/topical-backgrounder/2017/chinas-calculus-hypersonic-glide.

[77] Lora Saalman, "China's Calculus on Hypersonic Glide."

[78] Lora Saalman, "Factoring Russia into the US-China Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, https://www.sipri.org/sites/default/files/Factoring-Russia-into-US-Chinese-equation-hypersonic-glide-vehicles.pdf.

[79] Lora Saalman, "China's Calculus on Hypersonic Glide"; and Malcolm Claus and Andrew Tate, "Chinese hypersonic programme reflects regional priorities," Jane's Defence Weekly, March 12, 2019, https://janes.ihs.com/Janes/Display/FG_1731069-JIR.

[80] Ankit Panda, "Introducing the DF-17: China's Newly Tested Ballistic Missile Armed with a Hypersonic Glide Vehicle," *The National Interest*, December 28, 2017, https://thediplomat.com/2017/12/introducing-the-df-17-chinas-newly-tested-ballistic-missile-armed-with-a-hypersonic-glide-vehicle/; and Bill Gertz, "China's new hypersonic missile," *Washington Times*, October 2, 2019, https://www.washingtontimes.com/news/2019/oct/2/china-shows-df-17-hypersonic-missile/.

[81] *U.S.-China Economic and Security Review Commission 2018 Annual Report*, p. 235, https://www.uscc.gov/sites/default/files/annual_reports/2018%20Annual%20Report%20to%20Congress.pdf.

[82] "Gliding missiles that fly faster than Mach 5 are coming," *The Economist*, April 6, 2019, https://www.economist.com/science-and-technology/2019/04/06/gliding-missiles-that-fly-faster-than-mach-5-are-coming; and Franz-Stefan Gady, "China Tests New Weapon Capable of Breaching US Missile Defense Systems," *The Diplomat*, April 28, 2016, https://thediplomat.com/2016/04/china-tests-new-weapon-capable-of-breaching-u-s-missile-defense-systems/.

[83] *U.S.-China Economic and Security Review Commission 2015 Annual Report*, p. 20, https://www.uscc.gov/sites/default/files/annual_reports/2015%20Annual%20Report%20to%20Congress.PDF.

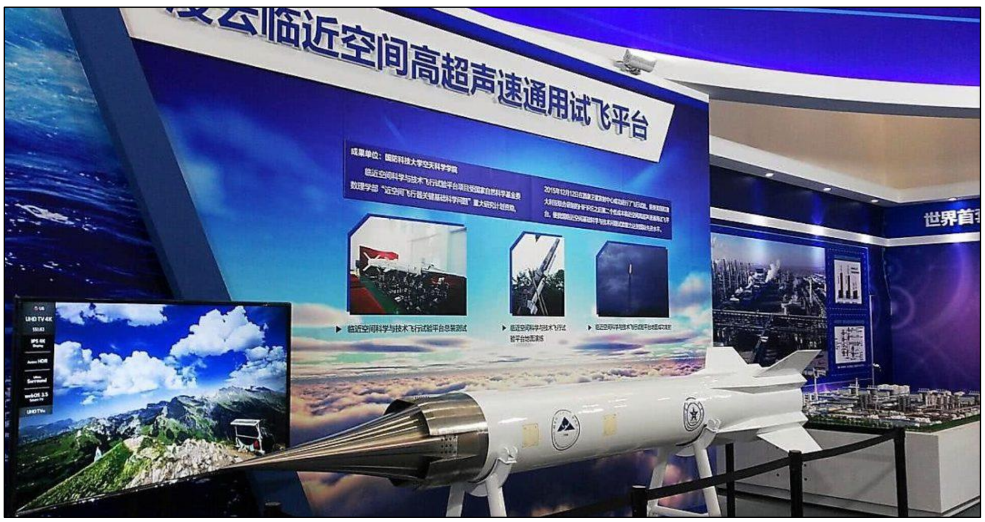
[84] Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2019,* May 2, 2019, p. 44, https://media.defense.gov/2019/May/02/2002127082/-1/-

reached top speeds of Mach 6 and executed a series of in-flight maneuvers before landing.[85] Unlike the DF-ZF, Starry Sky-2 is a "waverider" that uses powered flight after launch and derives lift from its own shockwaves. Some reports indicate that the Starry Sky-2 could be operational by 2025.[86] U.S. officials have declined to comment on the program.[87]

Infrastructure

China has a robust research and development infrastructure devoted to hypersonic weapons. USD (R&E) Michael Griffin stated in March 2018 that China has conducted 20 times as many hypersonic tests as the United States.[88] China tested three hypersonic vehicle models (D18-1S, D18-2S, and D18-3S)—each with different aerodynamic properties—in September 2018.[89] Analysts believe that these tests could be designed to help China develop weapons that fly at variable speeds, including hypersonic speeds. Similarly, China has used the Lingyun Mach 6+ high-speed engine, or "scramjet," test bed (**Figure 3**) to research thermal resistant components and hypersonic cruise missile technologies.[90]

Figure 3. Lingyun-1 Hypersonic Cruise Missile Prototype



Source: Photo accompanying Drake Long, "China reveals Lingyun-1 hypersonic missile at National Science and Technology expo," *The Defense Post*, May 21, 2018.

1/1/2019_CHINA_MILITARY_POWER_REPORT.pdf.

[85] Jessie Yeung, "China claims to have successfully tested its first hypersonic aircraft. *CNN*, August 7, 2018, https://www.cnn.com/2018/08/07/china/china-hypersonic-aircraft-intl/index.html.

[86] *U.S.-China Economic and Security Review Commission Report 2015*, p. 20.

[87] Bill Gertz, "China Reveals Test of New Hypersonic Missile," *The Washington Free Beacon*, August 10, 2018, https://freebeacon.com/national-security/chinas-reveals-test-new-hypersonic-missile/.

[88] *U.S.-China Economic and Security Review Commission Report 2015*, p. 20.

[89] Malcolm Claus and Andrew Tate, "Chinese hypersonic programme reflects regional priorities," *Jane's Defence Weekly*, March 12, 2019, https://janes.ihs.com/Janes/Display/FG_1731069-JIR.

[90] Jeffrey Lin and P.W. Singer, "China's hypersonic military projects include spaceplanes and rail guns," *Popular Mechanics*, June 26, 2018, https://www.popsci.com/chinas-hypersonic-work-speeds-up.

According to *Jane's Defence Weekly*, "China is also investing heavily in hypersonic ground testing facilities."[91] CAAA operates the FD-02, FD-03, and FD-07 hypersonic wind tunnels, which are capable of reaching speeds of Mach 8, Mach 10, and Mach 12, respectively.[92] China also operates the JF-12 hypersonic wind tunnel, which reaches speeds of between Mach 5 and Mach 9, and the FD-21 hypersonic wind tunnel, which reaches speeds of between Mach 10 and Mach 15.[93] China is expected to have an operational wind tunnel capable of reaching speeds of Mach 25 by 2020.[94] China is known to have tested hypersonic weapons at the Jiuquan Satellite Launch Center and the Taiyuan Satellite Launch Center.

[91] Tate, "China conducts further tests."

[92] Kelvin Wong, "China claims successful test of hypersonic waverider," *Jane's Defence Weekly*, August 10, 2018, https://janes.ihs.com/Janes/Display/FG_1002295-JDW.

[93] Jeffrey Lin and P.W. Singer, "A look at China's most exciting hypersonic aerospace programs," Popular Science, April 18, 2017, https://www.popsci.com/chinas-hypersonic-technology.

[94] Tate, "China conducts further tests."

Global Hypersonic Weapons Programs

Although the United States, Russia, and China possess the most advanced hypersonic weapons programs, a number of other countries—including Australia, India, France, and Germany—are also developing hypersonic weapons technology. Since 2007, the United States has collaborated with Australia on the Hypersonic International Flight Research Experimentation (HIFiRE) program to develop hypersonic technologies. The most recent HIFiRE test, successfully conducted in July 2017, explored the flight dynamics of a Mach 8 hypersonic glide vehicle, while previous tests explored scramjet engine technologies. In addition to the Woomera Test Range facilities—one of the largest weapons test facilities in the world—Australia operates seven hypersonic wind tunnels and is capable of testing speeds of up to Mach 30.

India has similarly collaborated with Russia on the development of BrahMos II, a Mach 7 hypersonic cruise missile. Although BrahMos II was initially intended to be fielded in 2017, news reports indicate that the program faces significant delays and is now scheduled to achieve initial operational capability between 2025 and 2028. Reportedly, India is also developing an indigenous hypersonic cruise missile as part of its Hypersonic Technology Demonstrator Vehicle program and successfully tested a Mach 6 scramjet in June 2019. India operates approximately 12 hypersonic wind tunnels and is capable of testing speeds of up to Mach 13.

France also has collaborated and contracted with Russia on the development of hypersonic technology. Although France has been investing in hypersonic technology research since the 1990s, it has only recently announced its intent to weaponize the technology. Under the V-max (Experimental Maneuvering Vehicle) program, France plans to modify its air-to-surface ASN4G supersonic missile for hypersonic flight by 2022. Some analysts believe that the V-max program is intended to provide France with a strategic nuclear weapon. France operates five hypersonic wind tunnels and is capable of testing speeds of up to Mach 21.

Germany successfully tested an experimental hypersonic glide vehicle (SHEFEX II) in 2012; however, reports indicate that Germany may have pulled funding for the program. German defense contractor DLR continues to research and test hypersonic vehicles as part of the European Union's ATLAS II project, which seeks to design a Mach 5-6 vehicle. Germany operates three hypersonic wind tunnels and is capable of testing speeds of up to Mach 11.

Finally, Japan is developing the Hyper Velocity Gliding Projectile (HVGP) to improve the country's defense of the Ryukyu Islands. According to *Jane's*, Japan invested $122 million in the program in FY2019. It plans to deploy Block I of the HVGP in FY2026 and Block II in FY2033. The Japan Aerospace Exploration Agency operates three hypersonic wind tunnels, with two additional facilities at Mitsubishi Heavy Industries and the University of Tokyo.

Other countries—including Iran, Israel, and South Korea—have conducted foundational research on hypersonic airflows and propulsion systems, but may not be pursuing a hypersonic weapons capability at this time.

Note: For additional information about global hypersonic weapons programs, see Richard H. Speier et al., Hypersonic Missile Proliferation.

Issues for Congress

As Congress reviews the Pentagon's plans for U.S. hypersonic weapons programs during the annual authorization and appropriations process, it might consider a number of questions about the rationale for hypersonic weapons, their expected costs, and their implications for strategic stability and arms control. This section provides an overview of some of these questions.

Mission Requirements

Although the Department of Defense is funding a number of hypersonic weapons programs, it has not established any programs of record, suggesting that it may not have approved requirements for hypersonic weapons or long-term funding plans.[95] Indeed, as Assistant Director for Hypersonics (USD R&E) Mike White has stated, DOD has not yet made a decision to acquire hypersonic weapons and is instead developing prototypes to "[identify] the most viable

[95] Steve Trimble, "New Long-Term Pentagon Plan Boosts Hypersonics."

overarching weapon system concepts to choose from and then make a decision based on success and challenges."[96] As Congress conducts oversight of U.S. hypersonic weapons programs, it may seek to obtain information about DOD's evaluation of potential mission sets for hypersonic weapons, a cost analysis of alternative means of executing these mission sets, and an assessment of the enabling technologies—such as space-based sensors or autonomous command and control systems—that may be required to employ or defend against hypersonic weapons.

Funding Considerations

Assistant Director for Hypersonics (USD R&E) Mike White has noted that DOD is prioritizing offensive programs while it determines "the path forward to get a robust defensive strategy."[97] This approach is reflected in DOD's FY2021 request, which allocates $206.8 million for hypersonic defense programs—of a total $3.2 billion request for all hypersonic-related research.[98] Similarly, in FY2020, DOD requested $157.4 million for hypersonic defense programs—of a total $2.6 billion for all hypersonic-related research.

Although the Defense Subcommittees of the Appropriations Committees increased FY2020 appropriations for both hypersonic offense and defense above the FY2020 request, they expressed concerns, noting in their joint explanatory statement of H.R. 1158 "that the rapid growth in hypersonic research has the potential to result in stove-piped, proprietary systems that duplicate capabilities and increase costs."[99] To mitigate this concern, they appropriated $100 million for DOD to establish a Joint Hypersonic Transition Office to "develop and implement an integrated science and technology roadmap for hypersonics" and "establish a university consortium for hypersonic research and workforce development" in support of DOD efforts.[100] Given the lack of defined mission requirements for hypersonic weapons, it may be challenging for Congress to evaluate the balance of funding for hypersonic weapons programs, enabling technologies, supporting test infrastructure, and hypersonic missile defense.

Strategic Stability

Analysts disagree about the strategic implications of hypersonic weapons. Some have identified two factors that could hold significant implications for strategic stability: the weapon's short time-of-flight—which, in turn, compresses the timeline for response—and its unpredictable flight path—which could generate uncertainty about the weapon's intended target and therefore heighten the risk of miscalculation or unintended escalation in the event of a conflict. This risk could be further compounded in countries that co-locate nuclear and conventional capabilities or facilities.

[96] Ibid.

[97] Aaron Mehta, "Is the Pentagon Moving Quickly Enough on Hypersonic Defense?" *Defense News*, March 21, 2019, https://www.defensenews.com/pentagon/2019/03/21/is-the-pentagon-moving-quickly-enough-on-hypersonic-defense/.

[98] Department of Defense Fiscal Year (FY) 2021 Budget Estimates, Missile Defense Agency Defense-Wide Justification Book Volume 2a of 5, p. 10, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB21_Justification_Book.pdf.

[99] "Department of Defense Appropriations Act, 2020: Joint Explanatory Statement," Defense Subcommittees of the Appropriations Committees, December 16, 2019, https://appropriations.house.gov/sites/democrats.appropriations.house.gov/files/HR%201158%20-%20Division%20A%20-%20Defense%20SOM%20FY20.pdf.

[100] Ibid.

Some analysts argue that unintended escalation could occur as a result of warhead ambiguity, or from the inability to distinguish between a conventionally armed hypersonic weapon and a nuclear-armed one. However, as a United Nations report notes, "even if a State did know that an HGV launched toward it was conventionally armed, it may still view such a weapon as strategic in nature, regardless of how it was perceived by the State firing the weapon, and decide that a strategic response was warranted."[101] Differences in threat perception and escalation ladders could thus result in unintended escalation. Such concerns have previously led Congress to restrict funding for conventional prompt strike programs.[102]

Other analysts have argued that the strategic implications of hypersonic weapons are minimal. Pavel Podvig, a senior research fellow at the United Nations Institute for Disarmament Research, has noted that the weapons "don't … change much in terms of strategic balance and military capability."[103] This, some analysts argue, is because U.S. competitors such as China and Russia already possess the ability to strike the United States with intercontinental ballistic missiles, which, when launched in salvos, could overwhelm U.S. missile defenses.[104] Furthermore, these analysts note that in the case of hypersonic weapons, traditional principles of deterrence hold: "it is really a stretch to try to imagine any regime in the world that would be so suicidal that it would even think threating to use—not to mention to actually use—hypersonic weapons against the United States ... would end well."[105]

Arms Control

Some analysts who believe that hypersonic weapons could present a threat to strategic stability or inspire an arms race have argued that the United States should take measures to mitigate risks or limit the weapons' proliferation. Proposed measures include expanding New START, negotiating new multilateral arms control agreements, and undertaking transparency and confidence-building measures.[106]

The New START Treaty, a strategic offensive arms treaty between the United States and Russia, does not currently cover weapons that fly on a ballistic trajectory for less than 50% of their flight, as do hypersonic glide vehicles and hypersonic cruise missiles.[107] However, Article V of the treaty states that "when a Party believes that a new kind of strategic offensive arm is emerging, that Party shall have the right to raise the question of such a strategic offensive arm for consideration in the Bilateral Consultative Commission (BCC)." Accordingly, some legal experts hold that the

[101] United Nations Office of Disarmament Affairs, *Hypersonic Weapons.*

[102] For a history of legislative activity on conventional prompt global strike, see CRS Report R41464, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, by Amy F. Woolf.

[103] Amy Mackinnon, "Russia's New Missiles Are Aimed at the U.S.," *Foreign Policy*, March 5, 2019, https://foreignpolicy.com/2019/03/05/russias-new-missiles-are-aimed-at-you-weapons-hypersonic-putin-united-states-inf/.

[104] David Axe, "How the U.S. Is Quietly Winning the Hypersonic Arms Race," *The Daily Beast*, January 16, 2019, https://www.thedailybeast.com/how-the-us-is-quietly-winning-the-hypersonic-arms-race. See also Mark B. Schneider, "Moscow's Development of Hypersonic Missiles," p. 14.

[105] Jyri Raitasalo, "Hypersonic Weapons are No Game-Changer," *The National Interest*, January 5, 2019, https://nationalinterest.org/blog/buzz/hypersonic-weapons-are-no-game-changer-40632.

[106] See United Nations Office of Disarmament Affairs, *Hypersonic Weapon*; and Richard H. Speier et al., *Hypersonic Missile Proliferation.*

[107] In some cases, hypersonic glide vehicles may be launched from intercontinental ballistic missiles that are already covered by New START, as is reported to be the case with Russia's Avangard HGV. See Rachel S. Cohen, "Hypersonic Weapons: Strategic Asset or Tactical Tool?"

United States could raise the issue in the BCC of negotiating to include hypersonic weapons in the New START limits.[108] However, because New START is due to expire in 2021, unless extended through 2026, this solution is likely to be temporary.[109]

As an alternative, some analysts have proposed negotiating a new international arms control agreement that would institute a moratorium or ban on hypersonic weapon testing. These analysts argue that a test ban would be a "highly verifiable" and "highly effective" means of preventing a potential arms race and preserving strategic stability.[110] Other analysts have countered that a test ban would be infeasible, as "no clear technical distinction can be made between hypersonic missiles and other conventional capabilities that are less prompt, have shorter ranges, and also have the potential to undermine nuclear deterrence."[111] These analysts have instead proposed international transparency and confidence-building measures, such as exchanging weapons data; conducting joint technical studies; "providing advance notices of tests; choosing separate, distinctive launch locations for tests of hypersonic missiles; and placing restraints on sea-based tests."[112]

[108] James Acton notes: "during [New START] negotiations, Russia argued that boost-glide weapons might constitute 'a new kind of strategic offensive arm,' in which case they would trigger bilateral discussions about whether and how they would be regulated by the treaty—a position [then] rejected by the United States." James M. Acton, *Silver Bullet?: Asking the Right Questions about Conventional Prompt Global Strike*, Carnegie Endowment for International Peace, 2013, p. 139, https://carnegieendowment.org/files/cpgs.pdf.

[109] CRS Report R41219, *The New START Treaty: Central Limits and Key Provisions*, by Amy F. Woolf.

[110] Mark Gubrud, "Test Ban for Hypersonic Missiles?" Bulletin of the Atomic Scientists, August 6, 2015, https://thebulletin.org/roundtable/test-ban-for-hypersonic-missiles/.

[111] Tong Zhao, "Test Ban for Hypersonic Missiles?"

[112] Rajaram Nagappa, "Test Ban for Hypersonic Missiles?"; see also James M. Acton, *Silver Bullet?*, pp. 134-138.

Appendix. U.S. Hypersonic Testing Infrastructure[113]

Table A-1. DOD Hypersonic Ground Test Facilities

Facility	Capability	Location
Air Force Arnold Engineering and Development Complex (AEDC) von Karman Gas Dynamics Facility Tunnels A/B/C	Tunnel A: 40-inch Mach 1.5-5.5; up to 290 °F Tunnel B: 50-inch Mach 6 and 8; up to 900 °F Tunnel C: 50-inch Mach 10; up to 1700 °F	Arnold AFB, TN
Air Force AEDC High-Enthalpy Aerothermal Test Arc-Heated Facilities H1, H2, H3	Simulate thermal and pressure environments at speeds of up to Mach 8	Arnold AFB, TN
Air Force AEDC Tunnel 9	59-inch Mach 7, 8, 10, and 14; up to 2900 °F	White Oak, MD
Air Force AEDC Aerodynamic and Propulsion Test Unit	Mach 3.1-7.2; up to 1300 °F	Arnold AFB, TN
Air Force AEDC Aeroballistic Range G	Launches projectiles of up to 8 inches in diameter at speeds of up to Mach 20	Arnold AFB, TN
Holloman High Speed Test Track	59,971 ft. track; launches projectiles at speeds of up to Mach 8	Holloman AFB, NM
Air Force Research Laboratory (AFRL) Cells 18, 22	Mach 3-7	Wright-Patterson AFB, OH
AFRL Laser Hardened Materials Evaluation Laboratory (LHMEL)	High-temperature materials testing	Wright-Patterson AFB, OH
AFRL Mach 6 High Reynolds Number (Re) Facility	10-inch Mach 6	Wright-Patterson AFB, OH
Test Resource Management Center Hypersonic Aeropropulsion Clean Air Test-bed Facility	Up to Mach 8; up to 4040 °F	Arnold AFB, TN

Source: (U//FOUO) Paul F. Piscopo et al.

113 The following information is derived from the 2014 report (U//FOUO) Paul F. Piscopo et al., *(U) Study on the Ability of the U.S. Test and Evaluation Infrastructure*, and therefore, may not be current. Permission to use this material has been granted by the Office of Science and Technology Policy.

Table A-2. DOD Open-Air Ranges

Range	Location
Ronald Reagan Ballistic Missile Defense Test Site	Kwajalein Atoll, Republic of the Marshall Islands
Pacific Missile Range Facility (PMRF)	Kauai, HI
Western Range, 30th Space Wing	Vandenberg AFB, CA
Naval Air Warfare Center Weapons (NAWC) Division	Point Mugu and China Lake, CA
White Sands Missile Range (WSMR)	New Mexico
Eastern Range, 45th Space Wing	Cape Canaveral Air Force Station/Patrick AFB/Kennedy Space Center, FL
NASA Wallops Flight Facility	Wallops Island, VA
Pacific Spaceport Complex (formerly Kodiak Launch Complex)	Kodiak Island, AK
NAWC Weapons Division R-2508 Complex	Edwards AFB, CA
Utah Test and Training Range	Utah
Nevada Test and Training Range	Nevada

Source: (U//FOUO) Paul F. Piscopo et al.

Table A-3. DOD Mobile Assets

Asset
Navy Mobile Instrumentation System
PMRF Mobile At-sea Sensor System
MDA Mobile Instrumentation System *Pacific Collector*
MDA Mobile Instrumentation System *Pacific Tracker*
Kwajalein Mobile Range Safety System 2
United States Navy Ship *Lorenzen* missile range instrumentation ship
Sea-based X-band Radar
Aircraft Mobile Instrumentation Systems
Transportable Range Augmentation and Control System
Re-locatable MPS-36 Radar
Transportable Telemetry System

Source: (U//FOUO) Paul F. Piscopo et al.

Table A-4. NASA Research-Related Facilities

Facility	Capability	Location
Ames Research Center (ARC) Arc Jet Complex	High-temperature materials testing	Mountain View, CA
ARC Hypervelocity Free Flight Facilities	Launches projectiles at speeds of up to Mach 23	Mountain View, CA
Langley Research Center (LaRC) Aerothermodynamics Laboratory	31-inch Mach 10, 20-inch Mach 6, and 15-inch Mach 6	Hampton, VA
LaRC 8-foot High Temperature Tunnel	96-inch Mach 5 and Mach 6.5	Hampton, VA
LaRC Scramjet Test Complex	Up to Mach 8 and up to 4740 °F	Hampton, VA
LaRC HyPulse Facility	Currently inactive	Long Island, NY
Glenn Research Center (GRC) Plumbrook Hypersonic Tunnel Facility Arc Jet Facility	Mach 5, 6, and 7 and up to 3830 °F	Sandusky, OH
GRC Propulsion Systems Laboratory 4	Mach 6	Cleveland, OH
GRC 1' x 1' Supersonic Wind Tunnel	12-inch Mach 1.3-6 (10 discrete airspeeds) and up to 640 °F	Cleveland, OH

Source: (U//FOUO) Paul F. Piscopo et al.

Table A-5. Department of Energy Research-Related Facilities

Facility	Capability	Location
Sandia National Laboratories Solar Thermal Test Facility	High-temperature materials testing and aerodynamic heating simulation	Albuquerque, NM
Sandia National Laboratories Hypersonic Wind Tunnel	18-inch Mach 5, 8, and 14	Albuquerque, NM

Source: (U//FOUO) Paul F. Piscopo et al.

Table A-6. Industry/Academic Research-Related Facilities

Facility	Capability	Location
CUBRC Large Energy National Shock (LENS)-I/-II/-XX Tunnels	LENS I: Mach 6-22 LENS II: Mach 2-12 LENS XX: Atmospheric re-entry simulation	Buffalo, NY
ATK-GASL Test Bay 4		
Boeing Polysonic Wind Tunnel	48-inch up to Mach 5	St. Louis, MO
Lockheed Martin High Speed Wind Tunnel	48-inch Mach .3-5	Dallas, TX

Boeing/Air Force Office of Scientific Research (AFOSR) Quiet Tunnel at Purdue University	9.5-inch Mach 6	West Lafayette, IN
AFOSR-University of Notre Dame Quiet Tunnel	24-inch Mach 6	Notre Dame, IN

Note: Hypersonic wind tunnels are under construction at the following universities: Texas A&M University (Mach 10 quiet tunnel expected to be complete in 2021), the University of Arizona (Mach 5 quiet tunnel expected to be complete in 2021), Purdue University (Mach 8 quiet tunnel expected to be complete in 2022), and the University of Notre Dame (Mach 10 quiet tunnel expected to be complete in 2023). Additional universities, such as the University of Maryland, the California Institute of Technology, the Georgia Institute of Technology, the Air Force Academy, the University of Tennessee Space Institute, and Virginia Polytechnic Institute and State University, also maintain experimental hypersonic facilities or conduct hypersonic research.

Source: (U//FOUO) Paul F. Piscopo et al.; Oriana Pawlyk, "Air Force Expanding Hypersonic Technology Testing"; University of Arizona, "Mach 5 Quiet Ludwieg Tube"; and Ashley Tressel, "Army to open hypersonic testing facility."

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