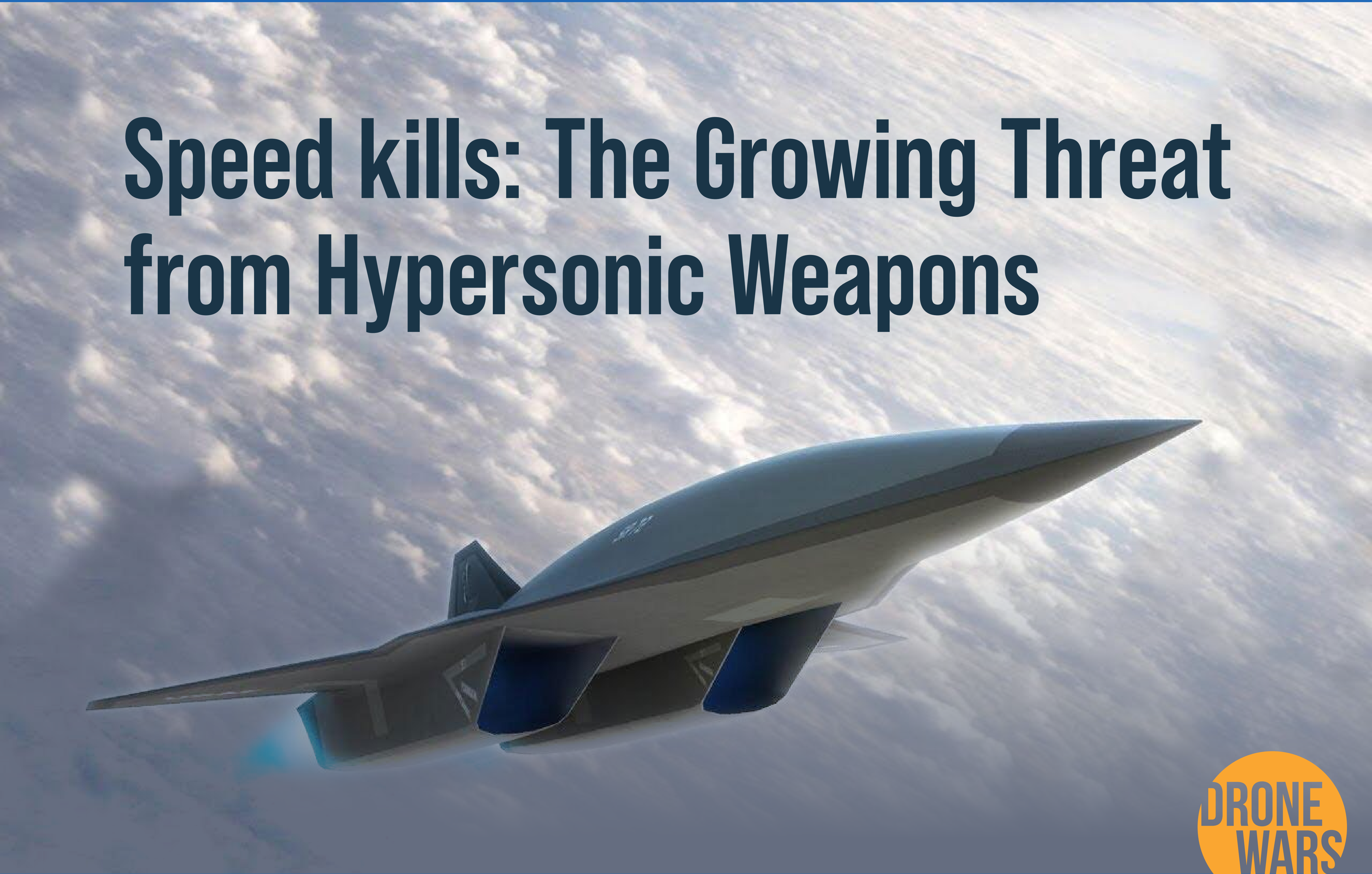
Speed kills: The Growing Threat from Hypersonic Weapons



DRONE WARS

Introduction

Behind the scenes, arms companies and military powers are quietly developing a new class of weapon system that uses speed to project deadly force. Through travelling at extreme speed, hypersonic weapons can strike targets anywhere in the world in a very short period of time.

While these weapons are mostly at the development stage, once deployed they could introduce great instability and threaten global peace and security, particularly at times of crisis. A nation under attack would be unable to tell where a hypersonic missile is going, or whether it carries a nuclear warhead, creating a significant risk of misunderstanding and escalation. The speed of hypersonic weapons would dangerously narrow the time available for working out the nature of an attack and making a reasoned decision on how to respond, and would create 'use it or lose it' pressure on nations to strike first.

This briefing, the first in a series published by Drone Wars UK as part of our 'Future Wars' project, examines the development of hypersonic weapons, the UK's involvement, and the risks they pose to peace and security.

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Cover: An artist's impression of the Lockheed Martin SR-72 hypersonic drone. Lockheed Martin hope to fly a test version of the aircraft in 2023. **Credit:** Lockheed Martin.

What are hypersonic weapons and how do they work?

Hypersonic systems are missiles and aircraft which are able to fly at more than five times the speed of sound.

Although the propulsion system is at the heart of hypersonic technology, an understanding of high-speed aerodynamics, thermodynamics and rapidly responding control systems is also important in enabling flight at hypersonic speeds.

Travel at very high speeds poses a number of challenges. The first of these is developing an engine with the thrust necessary to generate the acceleration to bring an aircraft to hypersonic speeds. Hypersonic engines are usually based around the ramjet concept. Ramjets are a form of air-breathing jet engine that use the engine's rapid forward motion to compress incoming air without requiring any means of mechanical compression. Ramjets cannot operate when the vehicle is not moving or is moving at a low speed, so they require an assisted take off, for example with a booster rocket, to accelerate them to a speed at which they are able to develop thrust. Ramjets operate at speeds of around Mach 2 to Mach 5.

To achieve higher speeds, a modification of the ramjet known as a scramjet (supersonic combustion ramjet) is used.

Diagram of ramjet: Intake air is compressed using nozzles created in the compression areas, and the flow speed is reduced to subsonic speeds to improve combustion. A flame holder ignites the fuel-air mixture to produce a high pressure high velocity gas stream that exits the engine at supersonic speeds.

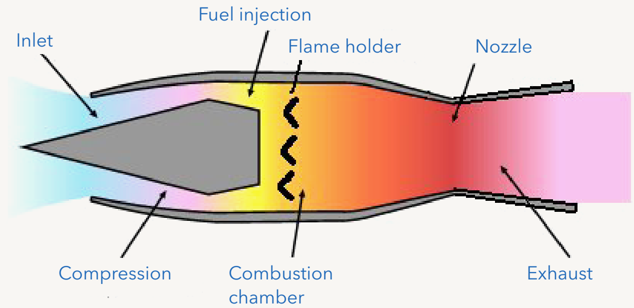
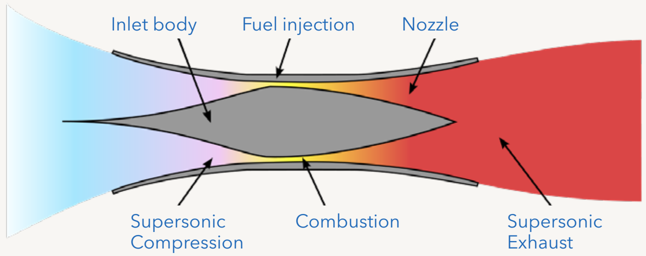


Diagram of scramjet: Scramjets have a different arrangement of compression, combustion, and expansion regions to ramjets, allowing air to move at supersonic speeds throughout the whole engine.



Credit: Wikimedia

1 'Hypersonic Weapon Basics'. Missile Defense Advocacy Alliance. missiledefenseadvocacy.org/missile-threat-and-proliferation/missile-basics/hypersonic-missiles/

The high vehicle speed compresses incoming air but whereas the air in a ramjet decelerates to subsonic velocities before combustion, in a scramjet it moves at supersonic speeds through the whole engine, allowing scramjet engines to generate extremely high speeds of above Mach 4.5. Scramjet engines have powered test vehicles of speeds of Mach 9.6 and are theoretically capable of travelling at speeds of over Mach 20.[1]

A second difficulty is managing the aerodynamics of flight at hypersonic speeds and controlling the travel of the missile. At such high speeds even tiny imbalances can cause aerodynamic instability and result in destruction of the vehicle. Flaps or tabs used to control conventional aircraft will have gaps that could disrupt the airflow, while jet or rocket thrusters used in missiles could also interact with flow in unexpected ways. Precise modelling over a range of high Mach numbers is needed to predict the behaviour of the vehicle in flight, requiring access to specialised high speed wind tunnels. Flight must be controlled by sophisticated avionics controlled by advanced computer systems in order to react with the necessary speed and sensitivity, and the electronic systems must also be protected from the intense heat generated during flight.

Controlling the vehicle remotely is also a problem. At high hypersonic speeds, molecules in the air surrounding the vehicle break apart, creating an electrically charged plasma around the vehicle.

The 'plasma shield' surrounding the vehicle creates a barrier to radio transmissions, making it difficult to send control signals to the vehicle.

During hypersonic flight the high kinetic energy is in part dissipated as heat, and temperatures of up to 1,000°C can be generated at Mach 5 and above. Developing and manufacturing materials and components able to resist these extreme temperatures, and in designing and building an airframe so as to manage thermal stress, is extremely problematic. Special composite materials such as high-performance carbon, ceramic, and metal mixes are necessary for the fabrication of critical components. Similar materials are used in intercontinental ballistic missiles and spacecraft.

The costs of developing and testing a hypersonic vehicle raise further issues. Although much of the early development work can be done through simulation and computer modelling work, flight tests will eventually be necessary. These require purpose-built test ranges equipped with the necessary instrumentation and telemetry to track flight through a very large area of airspace, which for safety reasons must be unoccupied.

Two types of hypersonic weapons are currently under development. Hypersonic glide vehicles are launched using ballistic missiles and are then released at high altitudes before gliding at hypersonic speeds towards the target, manoeuvring to avoid air defence systems. Hypersonic cruise missiles are launched conventionally from air, land, or sea-based platforms and use scramjet technology to fly at relatively low altitudes to the target.[2] The kinetic energy of either type of weapon would be so high that it could be able to destroy certain types of target without the need for an explosive payload.

2 'Hypersonic Weapon Basics'. Missile Defense Advocacy Alliance, op cit.

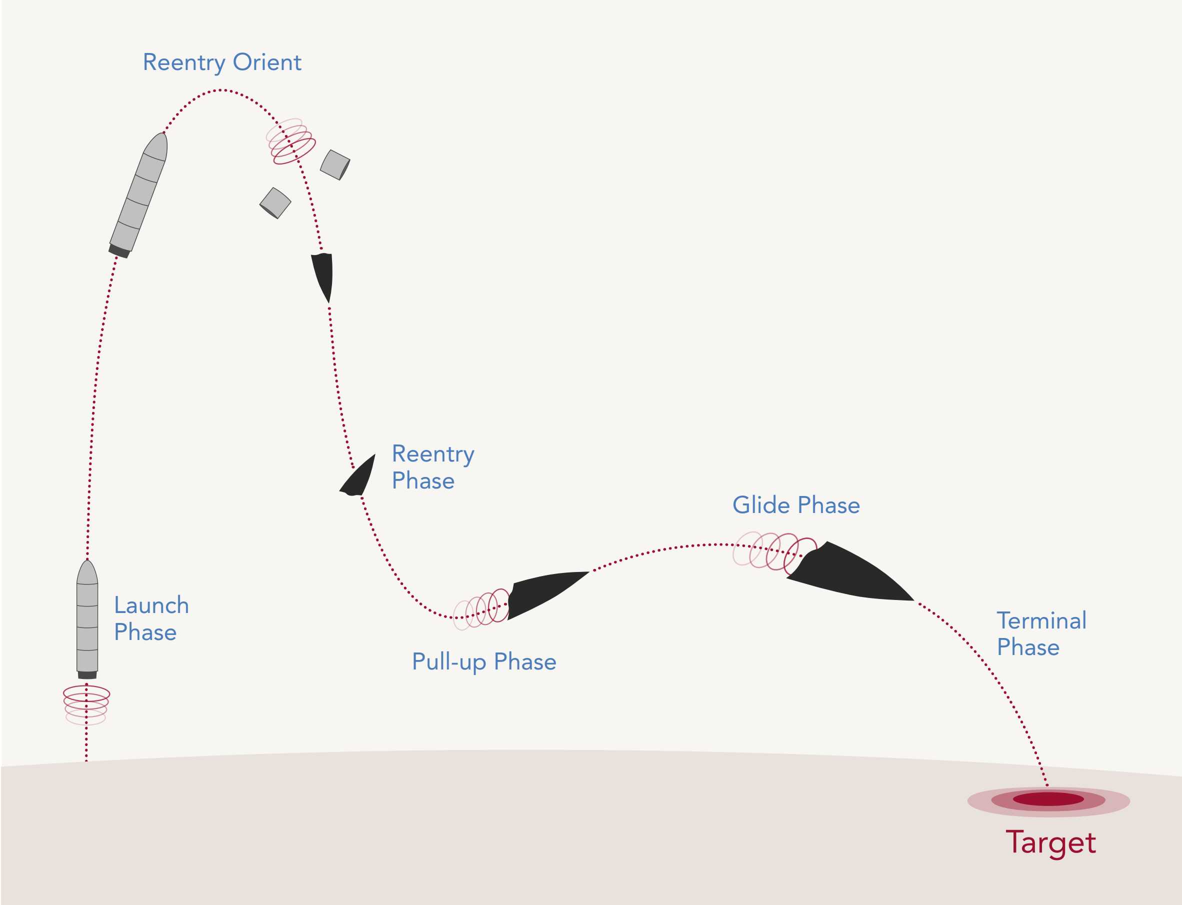
Hypersonic weapons: Current Developments

Hypersonic flight dramatically reduces the time it takes to travel from one place to another, potentially putting any place on Earth within a 90-minute flight time. They are therefore attractive to military planners for conducting rapid attacks, even on mobile targets, over a wide area of the globe, while allowing the enemy the minimum of time to respond. The US military sees such weapons as contributing to a 'Prompt Global Strike' capability.[3] Hypersonic missiles also combine speed with unpredictability. Unlike ballistic missiles, they can be manoeuvred enroute to their destination, making it difficult for the enemy to predict the target and intercept the missile, which means they can threaten large areas of territory.

Hypersonic glide vehicles are also difficult to track using conventional systems, as over-the-horizon early warning radars are currently optimised to detect ballistic missiles at higher altitudes. Infra-red missile warning satellites in orbit detect the heat plume of missile launches during the boost phase of the launch and it is harder for them to track a glide vehicle in the glide phase where it is flying

3 Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues. Report R41464, Congressional Research Service. 14 Feb 2020. fas.org/sgp/crs/nuke/R41464.pdf

Hypersonic missile flight overview



closer to sea level. Hypersonic weapons can therefore overfly existing air defence systems and under-fly missile defence systems.[4]

Russia and China, driven by a desire to counter developing US ballistic missile defence capabilities, both claim to have deployed hypersonic strike missiles. Russia has stated that its Avangard hypersonic glide vehicle, said to be nuclear capable and with a range of 6,000 km, has now entered into service alongside the air-launched Kinzhal ballistic missile. Russia is also believed to be developing the Zircon hypersonic cruise missile, GZUR guided missile, and an air-launched weapon for the Sukhoi Su-57 aircraft. China displayed its DF-17 hypersonic glide vehicle during a military parade in 2019, but it is unclear whether the missile is a prototype or in service yet. The US claims that China is also testing a hypersonic glide vehicle with an intercontinental range, and has developed a ballistic missile that could be armed with a hypersonic weapon.[5]

The US is currently testing the AGM-183A Air-launched Rapid Response Weapon (ARRW), manufactured by Lockheed Martin, which it hopes will enter service in 2022, and is investing in a number of other hypersonic research programmes.[6] France, India, and Japan may also be seeking to develop a hypersonic strike capability.

The US Army is reportedly developing a loitering munition, known as 'Vintage Racer', able to travel to its designated target area at hypersonic speeds. The system was flight tested in 2019 and, with a required capability to loiter on station for 60-90 minutes, would have many of the characteristics of a drone. The weapon is also likely to display autonomous features: the launching unit would not necessarily need to know the exact location of the target before firing the weapon, which would then use its own target recognition system to locate and destroy a target. Vintage Racer is intended to be a low cost multi-role hypersonic vehicle, with a modular payload allowing it to undertake a range of missions.[7]

In another development, Lockheed Martin is said to be working on the SR-72, a hypersonic drone intended to replace the US Air Force's retired SR-71 Blackbird spy plane. Although the aircraft has been described as a platform for intelligence, surveillance, and reconnaissance activities it will also be capable of firing hypersonic missiles. Lockheed Martin has stated that a prototype of the SR-72 is scheduled to fly in 2025, but to date the US Air Force has given no public indication as to whether it is interested in operating the aircraft.[8]

While China and Russia appear to see hypersonic weapons as strategic weapons, able to strike strategic targets from great distances with either conventional or nuclear warheads, the US may be looking more towards tactical uses for such weapons. This could include not only air-to-ground missiles able to destroy enemy air defences from a stand-off range, but also hypersonic air-to-air missiles able to destroy enemy aircraft at great distances before they can pose a threat, or hypersonic reconnaissance aircraft.[9]

4 Mark Thompson: 'Putting the Hype in Hypersonic Weapons'. Project on Government Oversight, 7 Feb 2019. pogo.org/analysis/2019/02/putting-the-hype-in-hypersonic-weapons/

5 James Bosbotinis: 'International Hypersonic Strike Weapons Projects Accelerate'. Aviation Week, June 15, 2020. aviationweek.com/defense-space/missile-defense-weapons/international-hypersonic-strike-weapons-projects-accelerate

6 Joseph Trevithick: 'Air Force Is Buying Eight Of These Missiles That Are Set To Become Its First Hypersonic Weapons'. The War Zone, 3 June 2020. thedrive.com/the-war-zone/33841/the-air-force-is-buying-eight-of-these-missiles-set-to-become-its-first-hypersonic-weapons

7 Joseph Trevithick: 'Pentagon Has Tested A Suicide Drone That Gets To Its Target Area At Hypersonic Speed'. The War Zone, 8 June 2020. thedrive.com/the-war-zone/33934/pentagon-has-tested-a-suicide-drone-that-gets-to-its-target-area-at-hypersonic-speed

8 Artie Villasanta: 'U.S. Pushes Hard To Build SR-72 Hypersonic Fighter'. Business Times, 23 Nov 2018. btimesonline.com/articles/105181/20181123/u-s-pushes-hard-build-sr-72-hypersonic-fighter.htm

9 John A. Tirpak: 'The Great Hypersonic Race'. Air Force Magazine, 27 June 2018. airforcemag.com/article/The-Great-Hypersonic-Race/

The UK and Hypersonic Weapons

Although the UK has expertise in the hypersonic field dating back for several decades, much of this is dispersed and disconnected, and the UK does not at the present time have a consistent and clearly defined programme for developing hypersonic weapons. However, it maintains an active research interest in the field and faces opportunities for collaborating with allies to develop such weapons.

The United Kingdom's interest in hypersonic flight dates back to the 1950s, when experiments with hypersonic aerodynamics took place at the Weapons Research Establishment at Woomera, Australia.

A hypersonic research vehicle named Jabiru, intended to fly at nine times the speed of sound at an altitude of 20-30 kilometres with a British-designed solid fuel rocket motor, was developed jointly by aerodynamics teams at the Royal Aircraft Establishment (RAE) and the Weapons Research Establishment. Test flights took place at Woomera from 1959 until November 1974 to investigate flight aerodynamics at hypersonic speeds, heating of the airframe by friction, and different wing and nosecone geometries.[10] Work on the Chevaline nuclear weapons programme in the 1970s added considerably to the UK's expertise in the field of high speed thermodynamics.[11]

The UK gained experience in developing ramjet engine technology in the 1960s and 1970s for anti-aircraft missiles such as Bloodhound and Sea Dart, though these themselves were not capable of travelling at hypersonic speeds. More recently the European missile manufacturer MBDA - which has in part evolved from the missile division of BAE Systems and its predecessors - has developed products that can fly at near-hypersonic speeds, such as the Meteor air-to-air missile which arms RAF Typhoon aircraft. The missile is powered by a solid-fuelled ducted ramjet motor which allows the missile to travel at a speed of over Mach 4.

The Meteor programme brought the UK, France, Germany, Italy, Spain and Sweden together to develop the missile, and through it MBDA has gained a body of knowledge on high-speed flight, thermodynamics and control. Much of this expertise resides within the company's French and German divisions, however, rather than its UK element. MBDA's next generation air defence missile system, Twister, is intended to provide defence against future air threats such as ballistic missiles and hypersonic glide vehicles, and provides an opportunity for the UK to take part in further international collaboration on hypersonic systems.[12]

As well as the MBDA's work on ramjets, the UK has also undertaken some experiments with scramjet engines. In the early 2000s QinetiQ undertook trials of a scramjet engine called Hyshot 3, developed jointly with Australian researchers and allegedly able to achieve speeds of up to 9000 kph.[13] The UK has also investigated a different type of hypersonic engine technology as part of the HOTOL (Horizontal Take-Off and Landing) programme for

10 Peter Morton: 'Fire Across The Desert. Woomera and the Anglo-Australian Joint Project 1946-1980. Department of Defence (Australia), 1989. Pp 405-6. dst.defence.gov.au/sites/default/files/publications/documents/Fire%20Across%20the%20Desert.pdf

11 Kerrie Dougherty and Jean-Jacques Serra: 'Hypersonic Research at Woomera: Falstaff - the Unclassified Story'. Paper presented at the 55th International Astronautical Congress 2004, Vancouver, Canada. arc.aiaa.org/doi/abs/10.2514/6.IAC-04-IAA.6.15.3.07

12 Tim Robinson: 'The UK's need for speed'. Royal Aeronautical Society, 3 March 2020. aerosociety.com/news/the-uk-s-need-for-speed/

13 'Hyshot III - QinetiQ Returns to Woomera for Scramjet Flight Test'. Defence Aerospace, 26 March 2006. defense-aerospace.com/articles-view/release/3/67612/scramjet-tested-in-australia-(mar-27).html

German air force personnel prepare to load an MBDA Meteor ramjet missile onto a Eurofighter Typhoon. **Credit:** MBDA.

developing an orbital space launch vehicle able to take off and land like a conventional aircraft. HOTOL was itself an extension of concept plans developed in the 1960s by the British Aircraft Corporation for a space shuttle capable of hypersonic flight known as 'Mustard'.

While the overall HOTOL programme was cancelled in 1989, the central feature of the HOTOL vehicle was a hybrid propulsion system, developed by Rolls-Royce as the RB545 engine, capable of accelerating HOTOL to hypersonic speeds of up to Mach 5.

Research on the engine technology was continued by Reaction Engines Ltd, who have taken the concept further as the SABRE (Synergetic Air Breathing Rocket Engine) engine. The engine uses air to oxidise hydrogen fuel while operating within the atmosphere and uses liquid oxygen as an oxidant when in space. Air enters the engine via a pre-cooler, cooling the air to allow it to operate at high speeds, and inside the engine core a turbine compresses and feeds the cooled air into a rocket engine where it is burnt, with a ramjet system using surplus air to generate extra thrust.[14] According to the manufacturers, the SABRE engine is capable of generating a speed of Mach 25 for space access. Unlike conventional hypersonic engines, the engine is able to throttle back and accelerate to allow ground take-off and landing[15].

Work on the SABRE engine remains at the developmental stage, and a test facility for the engine is under construction at the former site of the Rocket Propulsion Establishment at Westcott, Buckinghamshire. In October 2015 BAE Systems bought a 20% stake in Reaction Engines Ltd to help develop the SABRE engine further, and Boeing and Rolls-Royce have also invested in the company.[16]

14 Jonathan Amos: 'UK's Sabre space plane engine tech in new milestone'. BBC News, 8 April 2019. bbc.co.uk/news/science-environment-47832920

15 Note that the speed of sound changes with altitude because of changes in air density. The Mach number therefore also varies with altitude and the Mach number of an object travelling at sea level is not the same as the Mach number of an object travelling at the same speed at high altitude.

16 'A 30 year history of engineering innovation'. Reaction Engines Ltd. reactionengines.co.uk/about/story-so-far

The US Defence Advanced Projects Research Agency (DARPA) has likewise supported development work on the engine through its hypersonic programme, and in 2019 the pre-cooler heat exchanger element of the engine was successfully tested at the Colorado Air and Space Port at Denver.[17] Since 2015 the UK Space Agency has provided £50 million in funding for Reaction Engines, most recently with a £3.9 million grant to support further development of the SABRE Engine.[18]

Although the UK has gained considerable expertise in various elements of hypersonic engineering, its knowledge base in the field currently appears to be fragmented and so far has not been used to develop an integrated hypersonic weapon. The UK also lacks the industrial capability to manufacture large solid rocket motors and does not have certain critical research facilities such as high speed wind tunnels. At present collaboration with international partners appears to be the most realistic and affordable outcome for the UK in the hypersonic sector.[19]

To this end, work is underway on a joint UK – France project which commenced in 2017 with the aim of replacing existing missiles such as the air-ground Storm Shadow missile and the maritime Exocet and Harpoon anti-ship missiles with a new hypersonic strike capability. The study is currently at the early concept stage and the new missile is not expected to be available until 2030 at the earliest.

A joint feasibility study, the 'Thresher' project, is also under way between the Defence Science and Technology Laboratory and the US Air Force Research Laboratory to explore a development concept for a hypersonic missile, focusing on the aerodynamics, warhead, and propulsion for the system. The study, investigating the prospects for developing an air launched hypersonic glide vehicle with a range of 2500 – 3000 km and a mass of 900 kg capable of delivering a warhead of 350 kg, is intended to be completed by 2023. A memorandum of understanding signed between the US Missile Defence Agency and the Ministry of Defence in 2003 may allow further scope for joint research with the US to develop hypersonic missile defence systems - which may be the most realistic goal for UK aspirations to develop hypersonic technology.[20]

According to air technology analysts, the UK will be required to make key decisions over the next two to three years if it wishes to have an international presence in hypersonic engineering. Further development of UK hypersonic engine technology will require considerable investment, and it is not clear whether this will be forthcoming, particularly in the post-Covid economic climate.

17 Andrew Chuter: 'British-made hypersonic engine passes key milestone at Colorado test site'. Defense News, October 22, 2019. defensenews.com/global/europe/2019/10/22/british-made-hypersonic-engine-passes-key-milestone-at-colorado-test-site/

18 'Reaction Engines secures new UK Government funding for Space Access Programme'. Press release, UK Space Agency, Department for Transport, and Department for Business, Energy & Industrial Strategy. 8 July 2021. gov.uk/government/news/reaction-engines-secures-new-uk-government-funding-for-space-access-programme

19 Tim Robinson: 'The UK's need for speed', op cit.

20 Steve Trimble, Guy Norris, and Tony Osborne: 'Hypersonic Threshold'. Aviation Week & Space Technology, 6-19 April 2020. Pp 14-17. aviationweek.com/sites/default/files/2020-04/AWST_200406S.pdf

Hypersonic Weapons: The Threat to Human Security

Firstly, it important to understand that like most new weapons systems, the capabilities of hypersonic weapons are overstated by their proponents. Claims, for example, that hypersonic missiles could evade current missile defence systems must be judged against the fact that the US's ballistic missile defence capabilities are still rudimentary and would be unable to defend itself against anything more than the most modest ballistic missile attack. While it is technically feasible to manoeuvre a hypersonic missile to its target, the high speed of flight makes it extremely difficult to do so, while other difficulties are caused by the heat generated during hypersonic flight, which makes it difficult to equip hypersonic missiles with reliable navigation sensors and also gives an incoming missile a high infra-red radiation signature.[21] A study based on computer modelling of the characteristics of the US's Hypersonic Technology Vehicle 2 concluded that hypersonic weapons travel intercontinental distances more slowly than ballistic missiles, remain visible to existing space-based sensors for the majority of their flight, and that a poor lift-to-drag ratio imposed fundamental physical limitations on performance.[22]

Separate from questions of how well such systems would actually work in practise, the development of hypersonic weapons pose a number of threats to peace and global security.[23]

Hypersonic weapon programmes appear to be driven, at least in part, by general advances in technology rather than a desire to achieve a specific military objectives. Decisions to develop and buy new military systems based on emerging technologies can be disproportionately influenced by arms companies, usually in their own interests and at the cost of significant financial and human resources. Such spending not only diverts resources away from meeting real human security and development needs; it also creates an arms race dynamic in which research and development in one country creates an incentive for others to follow suit.

The development of hypersonic weapon programmes also contributes to an arms race dynamic by driving research and development of technologies to defend against them, including missile defence programmes and systems which may have potential uses as offensive weapons. Some nuclear-armed states appear to be concerned that the development of hypersonic strike capabilities might pose a threat to their nuclear retaliatory capabilities. Attempts to develop effective defence systems against hypersonic weapons could also increase the militarization of space.

21 Mark Gubrud: 'Hypersonic missiles: Junk nobody needs'. Bulletin of the Atomic Scientists. 24 July 2015. thebulletin.org/roundtable_entry/hypersonic-missiles-junk-nobody-needs/
Ivan Oelrish: 'Hypersonic missiles: Three questions every reader should ask'. Bulletin of the Atomic Scientists, 17 Dec 2019. thebulletin.org/2019/12/hypersonic-missiles-three-questions-every-reader-should-ask/

22 Cameron L. Tracy and David Wright: 'Modelling the Performance of Hypersonic Boost-Glide Missiles.' Science & Global Security, 2020. Vol. 28, No. 3. P135-170 scienceandglobalsecurity.org/archive/2020/12/modelling_the_performance.html

23 'Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control'. United Nations Office for Disarmament Affairs and United Nations Institute for Disarmament Research, op cit. 'Hypersonic Weapons'. Article 36. Feb 2019. article36.org/wp-content/uploads/2019/06/hypersonic-weapons.pdf

However, perhaps the real concern is that due to the uncertainty and ambiguity they introduce into military calculations, hypersonic weapons could pose considerable risks for stability at times of crisis. A nation under attack would be unable to tell where a hypersonic missile is going or whether it carries a conventional or nuclear warhead, creating a significant risk of misunderstanding and escalation during a crisis. The rapid speeds of hypersonic weapons would dangerously narrow the time available for working out the nature of an attack and making a reasoned decision on how to respond, and would create 'use it or lose it' pressure on nations to strike first during a crisis. This is likely to increase the risk of the use of nuclear weapons in a crisis. The United Nations Office for Disarmament Affairs has warned that "some States could amend doctrines to expand the conditions necessary for the use of nuclear weapons in response the deployment of hypersonic weapons," and that "postures might also be adapted, including by placing nuclear forces on higher alert levels".[24]

Overall, the development of hypersonic weapons reflects and contributes to broad military security dynamics, especially in relation to the development of missile defence capabilities and related space-based infrastructure. Hypersonic weapons increase instability and the risk of rapid conflict escalation, and run exactly opposite to much needed confidence building and de-alerting initiatives, as well as undermining arms control and disarmament efforts.

> **"Hypersonic weapons increase instability and the risk of rapid conflict escalation, and run exactly opposite to much needed confidence building and de-alerting initiatives, as well as undermining arms control and disarmament efforts"**

24 'Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control'. United Nations Office for Disarmament Affairs and United Nations Institute for Disarmament Research, 2019. https://www.unidir.org/files/publications/pdfs/hypersonic-weapons-a-challenge-and-opportunity-for-strategic-arms-control-en-744.pdf

Shining a spotlight
on military drones

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