Hypersonics

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Who Am I

- Ph.D. Computer Science,
- Ph.D. Nanotechnology
- D.Sc. Cybersecurity
- Four masters (systems engineering, education, applied computer science, strategic and defense studies)
- 45 books
- 27 patents
- Member of the American Physical Society (Physics)
- Senior Member of the IEEE and Senior member of ACM
- Member of American Institute of Aeronautics and Astronautics
- Member of the American Society for Quality (Aviation, Space, and Defense Division)
- INCOSE certified
- **Chuck Easttom, M.Ed., MBA, MSDS, MSSE, Ph.D., D.Sc.**
- **www.ChuckEasttom.com**
- **chuck@chuckeasttom.com**

This Class

- What this class is about?
- How do I teach?
  - Interaction
  - Repetition
    - (Reynolds Number, Ramjet design, Navier-Stokes equations, etc.)
    - Flow calculations (Laminar and Turbulent) as well as boundaries are critical, so we see those several times in this class, not just once.
  - Hands on
- Who are you?
- I need to know about your education/experience (particularly engineering and math)?
- What you want out of this class?

- Logistics

- **https://www.chuckeasttom.com/hypersonics/**

Ideal Background

Math through Partial Differential Equations

Physics through Mechanics

General Chemistry sequence

At least some aerospace engineering

Don’t panic if that is not you!

Reference Materials

- Missile Design and System Engineering (AIAA Education)
- Hypersonic and High-Temperature Gas Dynamics (AIAA Education)
- Standard Handbook for Aerospace Engineers, Second Edition
- Aerospace Engineering Foundations - Hypersonic Aerodynamics and Aerothermodynamics: Master Compressible Flow, Shock Wave Physics, Boundary-Layer ... for Next-Generation Hypersonic Flight
- U.S. Hypersonic Weapons and Alternatives: Printed in Color
- Scramjet Propulsion: A Practical Introduction (Aerospace Series)
- Introduction to Rocket Science and Engineering
- NASA Systems Engineering Handbook:
- Spacecraft Systems Engineering
- Viscous Hypersonic Flow: Theory of Reacting and Hypersonic Boundary Layers (Dover Books on Engineering)

What is hypersonic?

- The term hypersonic originated in 1970s and since then it has been used to refer speed of Mach 5 (5 times the speed of sound i.e. 343 m/s) and above. In the field of aerodynamic the hypersonic speed is one that is highly supersonic. It can alternatively be defined as the speed at which net thrust is not produced by ramjets or any conventional ways but by scramjet .
- **NASA** defines "high" hypersonic speed as the speed which falls in the range of 10 to 25 mach. Mostly spaceplanes operate in this regime during their re-entry in earth's atmosphere.

Hypersonic News

- June 2026: Russia's Oreshnik hypersonic missile reportedly malfunctions and strikes Russian-held territory https://www.the-sun.com/news/16436112/putin-missile-blows-up-russia-troops-war-ukraine0.
- March 27, 2026: China Unveils a Hypersonic Missile That Travels at Mach 31. https://www.middletowncafe.com.au/china-unveils-a-hypersonic-missile-that-travels-at-mach-31-no-defense-system-on-earth-can-stop-it/

- March 24 2026 China is mass-producing hypersonic missiles for $99,000 YKJ-1000 https://kdwalmsley.substack.com/p/on-sale-now-china-is-mass-producing

Hypersonic News

May 21, 2026 GE Aerospace uses generative AI to design hypersonic ramjet engine concepts https://thedefensepost.com/2026/05/21/ge-aerospace-ai-hypersonic-engine

March 18, 2026 Iran deployed Fattah-2 missiles https://www.intellinews.com/iran-debuts-a-new-state-of-the-art-hypersonic-missile-432262/

History of Hypersonics

Today's world of high-speed flight is international, with important contributions having recently been made in Japan, Australia, and Russia as well as in the United States. This was even truer during World War II, when Adolf Hitler sponsored development programs that included early jet fighters and the V-2 missile. America had its own research center at NACA's Langley Memorial Aeronautical Laboratory, but in important respects America was little more than an apt pupil of the wartime Germans. After the Nazis surrendered, the U.S. Army brought Wernher von Braun and his rocket team to this country, and other leading researchers found themselves welcome as well.

Facing the Heat Barrier: A History of Hypersonics
https://www.nasa.gov/wp-content/uploads/2023/04/sp-4232.pdf

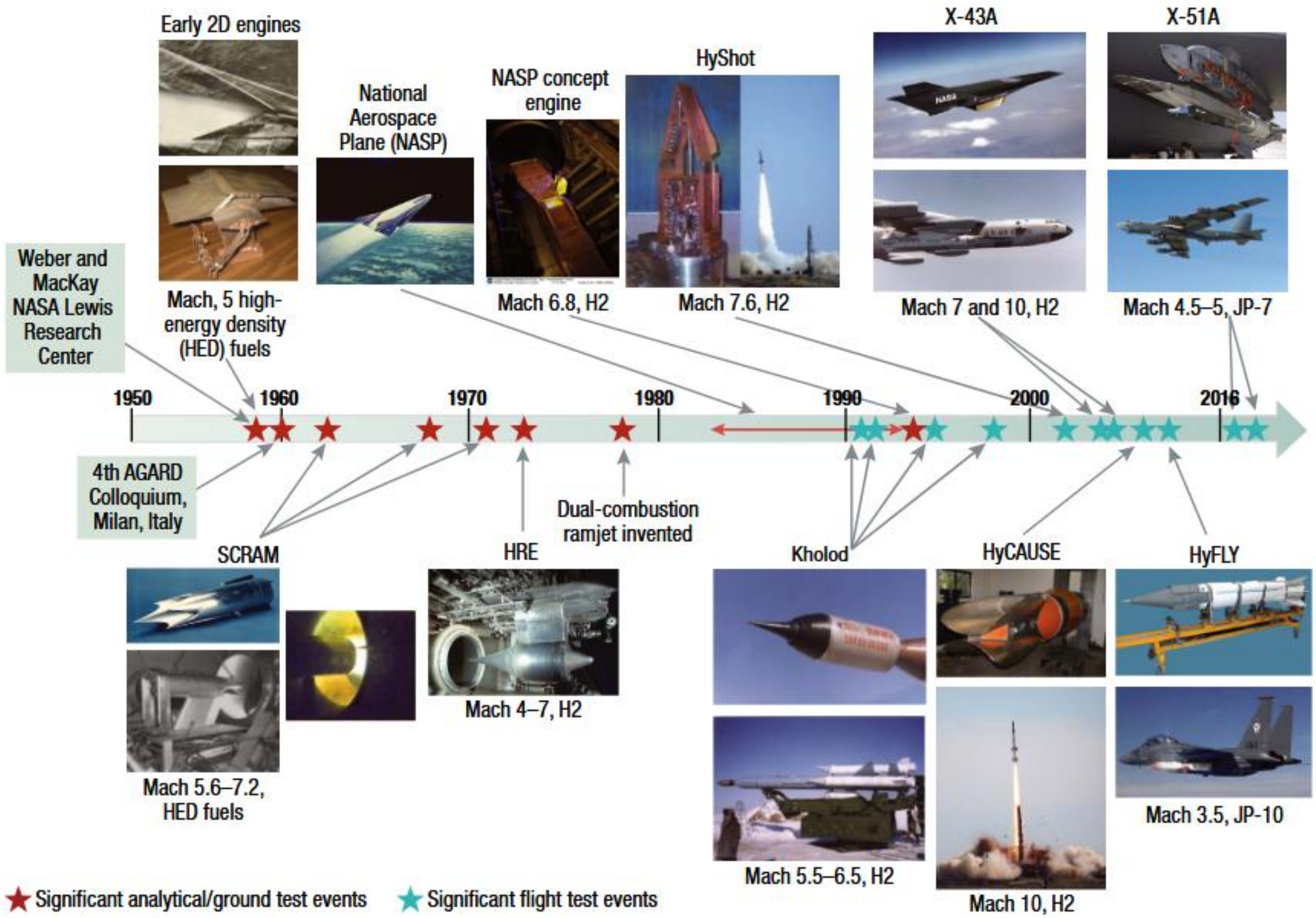
Hypersonics

- Specifically, the hypersonic regime is defined as the realm of speed wherein the physics of flows is dominated by aerodynamic heating. This heating is far more intense than at speeds that are merely supersonic, even though these lesser velocities have defined the performance of the SR-71 and X-7.

- Germany's wartime V-2 rocket flew above Mach 5, but steel proved suitable for its construction and aerodynamic heating played only a limited role in its overall design. The Germans used wind-tunnel tests to ensure that this missile would remain stable in flight, but they did not view its speed regime as meriting a name of its own. Hsue-shen Tsien, an aerodynamicist at the California Institute of Technology, coined the term in 1946. Since then, it has involved three significant areas of application.

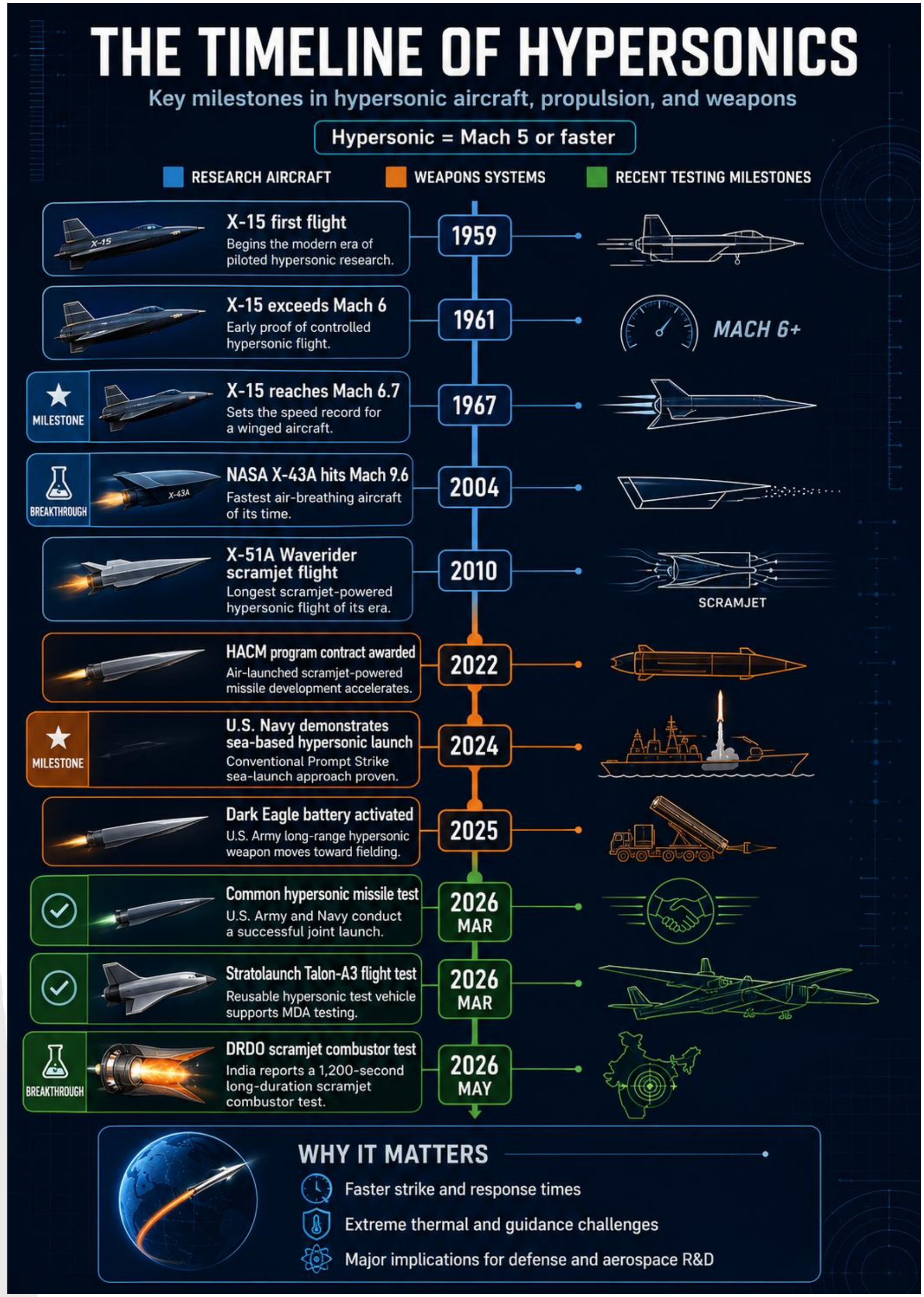
- Heppenheimer, T.A.. Facing the Heat Barrier: A History of Hypersonics . Dover Publications.

History of Hypersonics



Hypersonics: Past, Present, and Potential Future https://secwww.jhuapl.edu/techdigest/Content/techdigest/pdf/V35-N04/35-04-Van%20Wie.pdf

History of Hypersonics



The first hypersonic rocket

The first manufactured body to achieve hypersonic flight was the two-stage Bumper rocket, consisting of a WAC Corporal second stage set on top of a V-2 first stage. In February 1949, at White Sands, the rocket reached a speed of 5,150 miles per hour, or approximately Mach 6.7.The vehicle, however, burned on atmospheric re-entry, and only charred remnants were found. In April 1961, Russian Major Yuri Gagarin became the first human to travel at hypersonic speed, during the world's first piloted orbital flight. Soon after, in May 1961, Alan Shepard became the first American and second person to achieve hypersonic flight when his capsule reentered the atmosphere at a speed above Mach 5 at the end of his suborbital flight over the Atlantic Ocean. In November 1961, Air Force Major Robert White flew the X-15 research airplane at speeds over Mach 6.

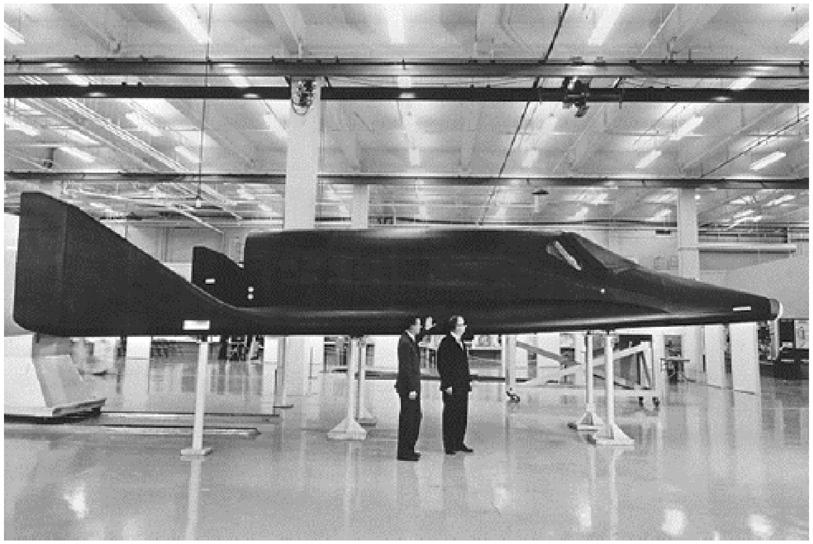
Hypersonic Capabilities

“According to a lot of open-source publications found in the internet and emphasized by Russian President Vladimir Putin on 4 January 2023, hypersonic capabilities are a force to be reckoned with or even a “game changer” when applied to the stability of the overall international security situation.[1] Although hypersonic capabilities are not new, and related technology has been researched since the 1930s, it was almost a century from the first wind tunnel tests of the German “Silbervogel” project to a fielded hypersonic weapon system like Russia’s “Avangard” (claimed operational in December 2019).[2] Within NATO, hypersonic capabilities are considered an emerging and disruptive technology, which emphasizes hypersonic capabilities’ evolving nature. This brought the Joint Air Power Competence Centre (JAPCC), NATO’s first and largest center of excellence, into play since it is the mission of a team of multinational experts to provide key decision-makers with effective solutions to air and space power challenges.[3] JAPCC sees itself as NATO’s catalyst for improving and transforming joint air and space power, delivering practical solutions through independent thought and analysis.”

- - Hypersonic Capabilities: A Journey from Almighty Threat to Intelligible Risk Lt. Col. Andreas Schmidt, German Air Force https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/March-2024/Hypersonic-Capabilities/

Cancellation: X-20 Dyna-Soar

- Re-entry vehicle program from 1957 to 1963
- Designed to increase mission flexibility over capsules that were being used at the time
- Based on the concepts of Sänger in the 1930s



- Several known technical challenges (and other non-technical issues) led to cancellation in 1963
- Great potential was lost, especially for collecting data and increasing knowledge/experience
- One benefit: many of the workers moved to Apollo program after cancellation of X-20

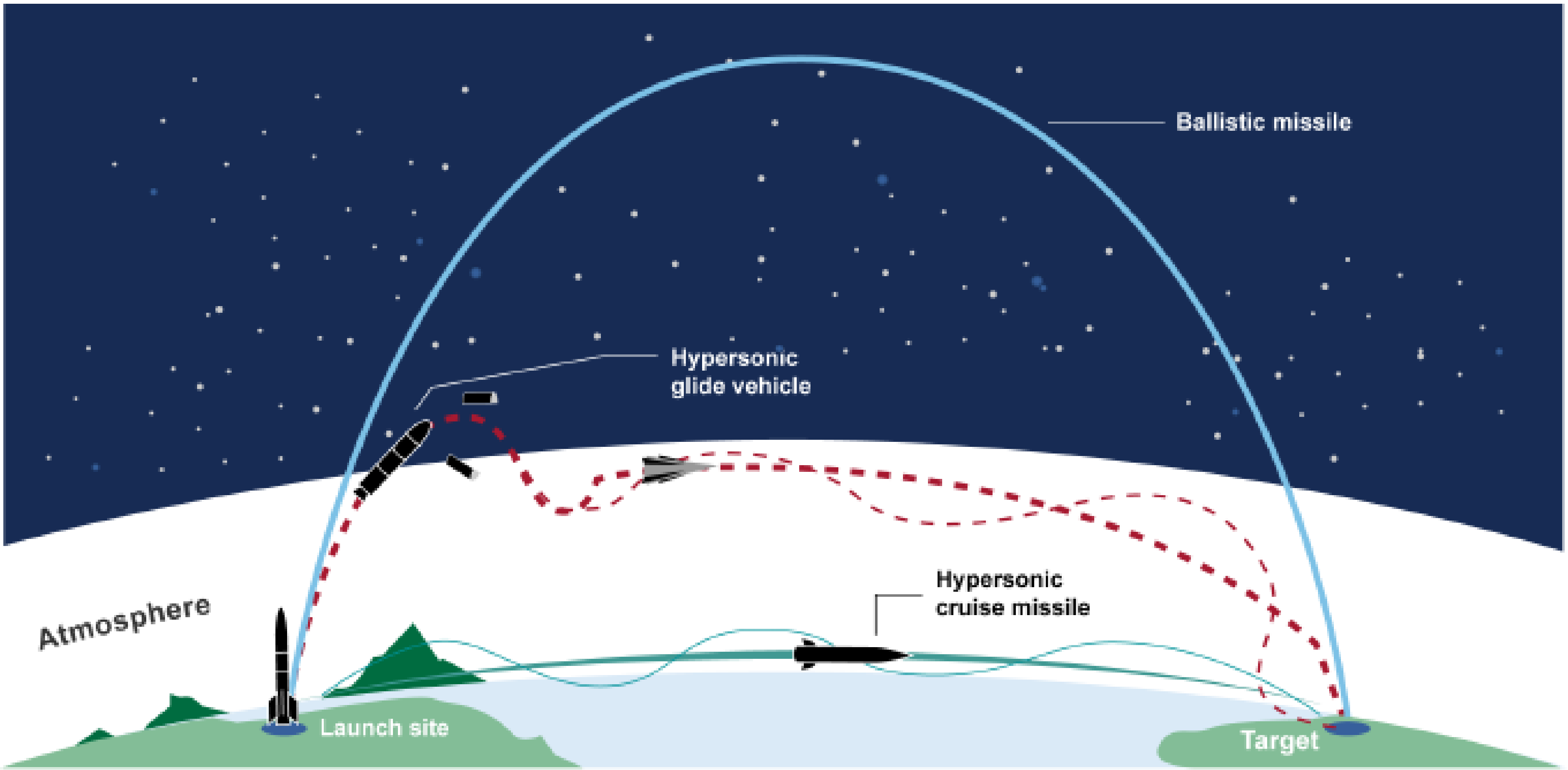
-Hypersonic Weapons Summit 2020

Hypersonic platforms

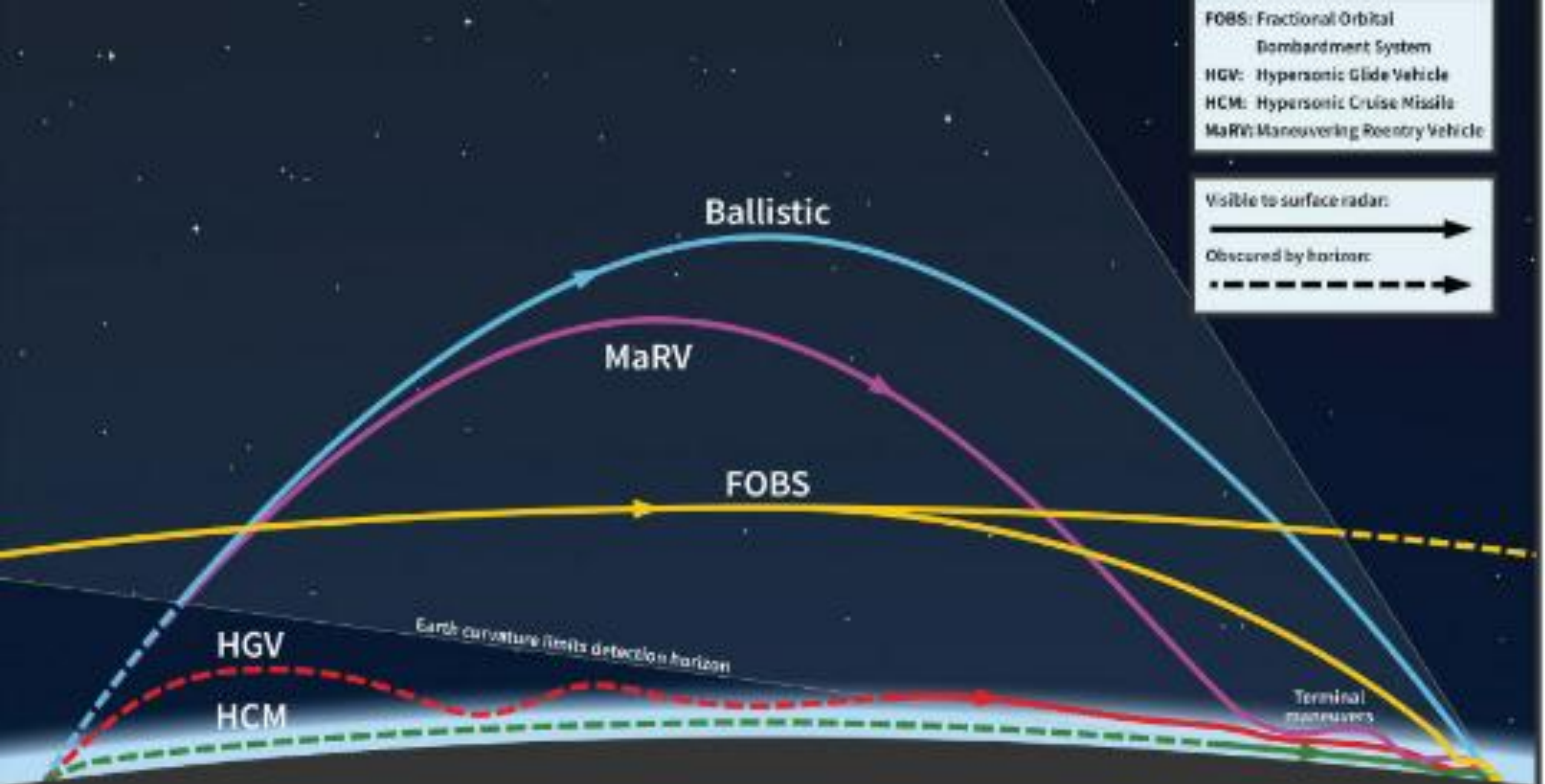
Hypersonic platforms have two main categories depending on the type of engine they use. Hence, both air-breathing and rocket-based systems are categorized as hypersonic systems if they move with a velocity at or above Mach 5. Broadly speaking, vehicles with hypersonic air breathing propulsion systems offer various advantages like rapid response at long range, increased maneuverability, better survivability, and assured access to space.

Historically, rocket boosters have been used to propel hypersonic vehicles for applications such as space launch, long-range ballistic flight, and air defense interceptor missiles. Air breathing propulsion systems are expected to provide a means for sustained and accelerating flight within the atmosphere at hypersonic speeds. Hypersonic propulsion systems can be categorized as liquid- and solid-fueled rockets, turbojets, ramjets, ducted rockets, scramjets, and the dual-combustion ramjets (DCR).

Comparison of Ballistic and Hypersonic Flight Trajectories



-Report to Congressional Addressees HYPERSONIC WEAPONS March 2021.



Comparison of Ballistic and Hypersonic Flight Trajectories

-Karako, Tom; Dahlgren, Masao. Complex Air Defense: Countering the Hypersonic Missile Threat (CSIS Reports) (p. 6). Bloomsbury Publishing. Kindle Edition.

Hypersonic Basics

Beginning around Mach 5, flying objects encounter thermal and aerodynamic phenomena distinct from those encountered in supersonic and exoatmospheric flight. These phenomena define the hypersonic flight regime. The combined characteristics of high speed, lower altitude, and maneuverability make it difficult to predict the trajectories of hypersonic weapons, especially with terrestrial sensors. Although ballistic missiles, cruise missiles, and certain aircraft share some of these characteristics, their combination presents a qualitatively different problem.

- Karako, Tom; Dahlgren, Masao. Complex Air Defense: Countering the Hypersonic Missile Threat (CSIS Reports) (p. 5). Bloomsbury Publishing. Kindle Edition.

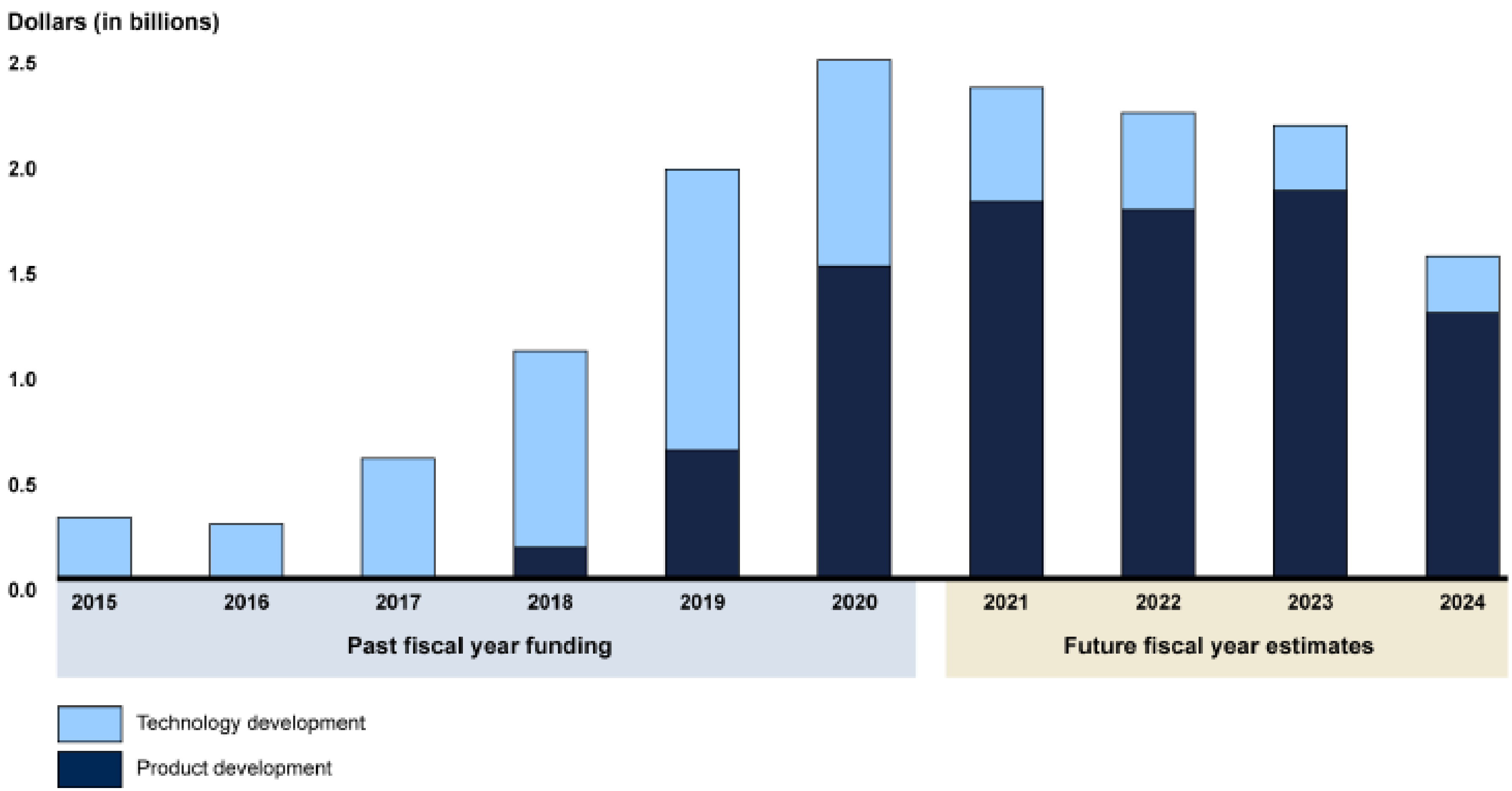
U.S. Hypersonic Efforts

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

- -Report to Congressional Addressees HYPERSONIC WEAPONS March 2021.

U.S. Hypersonic Efforts

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



- -Report to Congressional Addressees HYPERSONIC WEAPONS March 2021

U.S. Hypersonic Efforts

Table 10: Key Selected DOD Hypersonic Development Coordination Mechanisms

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

-Report to Congressional Addressees HYPERSONIC WEAPONS March 2021

The Impact

- Some analysts have asserted that the speed, accuracy, and maneuverability of hypersonic boost-glide weapons will fundamentally change the character of warfare. Former acting Secretary of the Navy Thomas Modly made this case in January 2020 when he noted that these technologies “have already changed the nature of the battlespace” and that they “can destabilize the global security environment and pose an existential threat to our nation.” Others question this assessment. They note that boost-glide systems can reach their targets more quickly than other maneuverable systems, like aircraft and subsonic cruise missiles. But adversaries armed with ballistic missiles have long been able to attack U.S. forces, allies, and territory, even without maneuvering warheads. Consequently, they argue that there is nothing new about the threat from nuclear-armed HGVs, when compared with other nuclear-armed missiles, and nothing existential about a threat from conventionally armed HGVs.

- \- Defense Primer: Hypersonic Boost-Glide Weapons May 5, 2022

The Hypersonic Problem

Situation: High Mach number flight through atmosphere
Distinguishing Features:
Thin Shock Layer → region between shock wave and vehicle surface
Entropy Layer → strong entropy gradients leading to significant vorticity generation and propagation
Viscous Interaction → standard boundary layer transition (BLT) analysis fails
High Temperature Effects → Thermal & chemical non-equilibrium
Possibly Low-Density Flow → Knudsen number

Note: The Knudsen number (Kn) is a dimensionless quantity that characterizes the degree to which a gas behaves as a continuum or as a collection of individual molecules

BLT typically refers to Ballistic Limit Theory analysis, particularly in the context of hypervelocity impact, spacecraft shielding, and aerospace engineering.

Basic Definitions

Hypersonics refers to the study, design, and application of vehicles and technologies that travel at speeds greater than Mach 5 — that is, five times the speed of sound (approximately 3,800 mph or 6,100 km/h at sea level). This field has significant implications for defense, aerospace, and commercial applications.

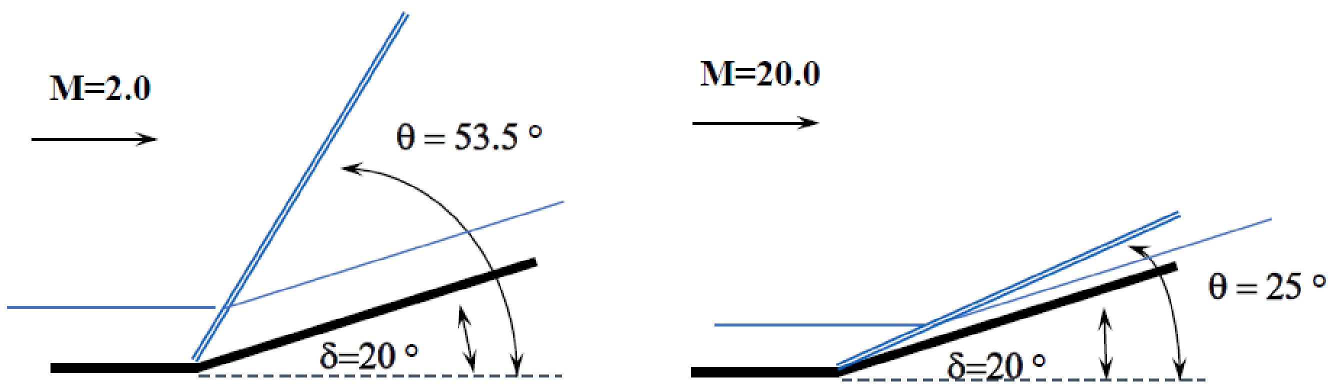
- Subsonic: < Mach 1 (commercial aircraft)
- Supersonic: Mach 1–5 (fighter jets, Concorde)
- Hypersonic: > Mach 5 (e.g., re-entry vehicles, hypersonic missiles)

Characteristics of Hypersonic Flow: Thin Shock Layer

- Shock layer: region between shock and body surface
- Shocks sweep back as Mach increases
- At hypersonic Mach numbers the shocks can be very close to the body

Characteristics of Hypersonic Flow: Thin Shock Layer

Shock layer: flow field region between shock wave and body surface. Compare shock wave on wedge with half-angle of 20° at M = 2.0 with M = 20.0



At low Reynolds number, thick boundary layer can merge with shock wave to form fully viscous shock layer

Note: The Reynolds number (Re) is a dimensionless quantity used in fluid mechanics to predict the flow regime—laminar or turbulent—of a fluid moving past a surface or through a pipe.

Characteristics of Hypersonic Flow: Viscous-Inviscid Interactions

For compressible flow, boundary layer thickness ($\boldsymbol{\delta}$) is proportional to Mach number squared; high altitude flight has low Reynolds number ($\boldsymbol{R}$e)

$$\delta \propto \frac{M_\infty^2}{\sqrt{\mathrm{Re}}}$$

- Boundary layer (BL) can be so thick that flow outside BL greatly affected
- •Viscous-inviscid interaction no longer decoupled
  - •thick BL affects flow outside BL (inviscid region)
  - •changes in flow outside BL affect BL growth

- •Surface pressure and friction increase = increased drag and heating

Types of hypersonics

Hypersonic Glide Vehicles (HGVs):

- Launched via a rocket, then glide through the atmosphere at hypersonic speeds.
- Maneuverable, which makes them harder to intercept (e.g., China's DF-ZF, Russia's Avangard).

Hypersonic Cruise Missiles:

- Powered throughout their flight by scramjets (supersonic combustion ramjets).
- Maintain sustained hypersonic speed within the atmosphere (e.g., U.S. HAWC program).

Spaceplanes / Reentry Vehicles:

- Vehicles that enter from space or orbit and re-enter Earth's atmosphere (e.g., future spaceplane concepts).

Categorizing Hypersonics

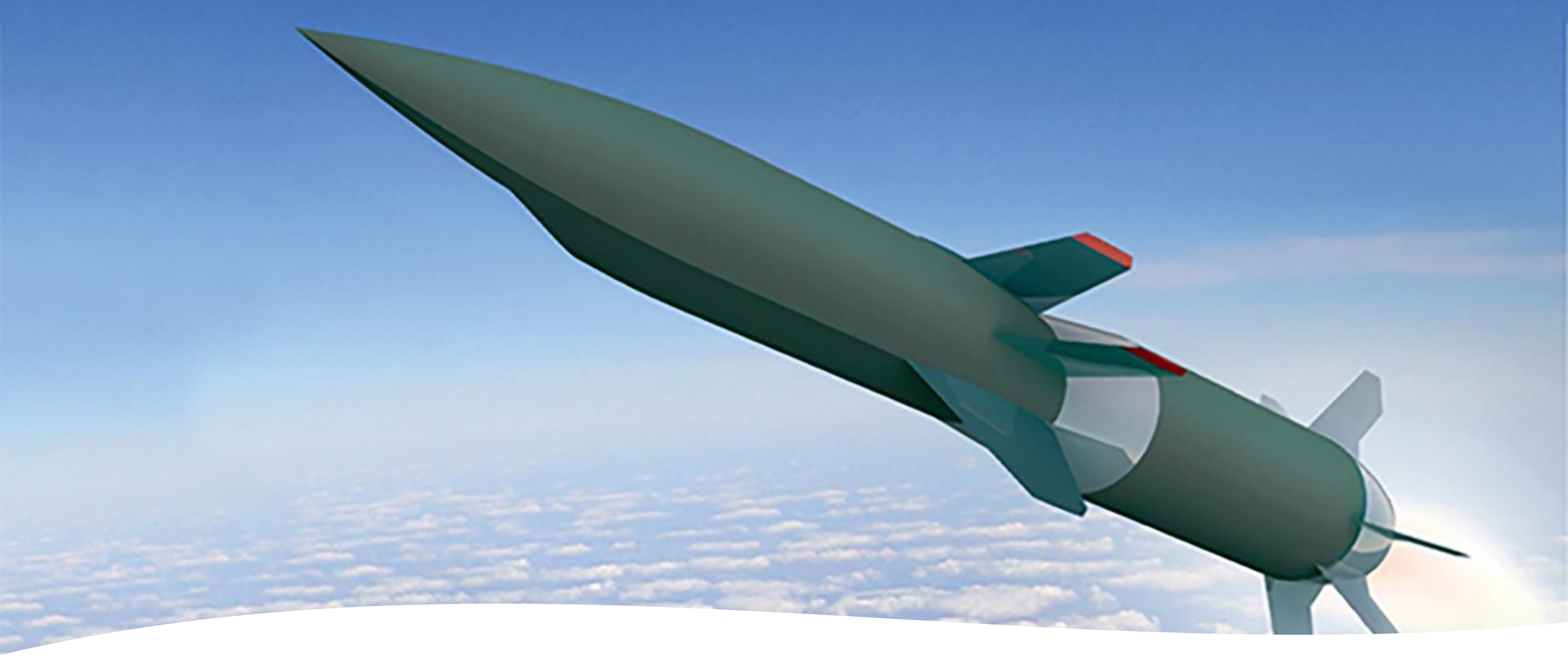
Hypersonic missiles are typically categorized by their source of propulsion: rocket-boosted gliders and air-breathing cruise missiles. While a hypersonic cruise missile (HCM) uses an onboard propulsion system to reach hypersonic speeds, a hypersonic glide vehicle (HGV)—also called a boost-glide vehicle—is unpowered, entering the hypersonic regime after an initial acceleration from a detachable booster. Like a ballistic reentry vehicle, an HGV typically boosts into space or near-space at the beginning of flight using a rocket motor. Instead of continuing along a ballistic trajectory, however, an HGV detaches and reenters the atmosphere at high speeds. With a shape optimized to reduce drag and produce lift, an HGV can then glide through the atmosphere using its inherited momentum.9 Some HGVs use “skip-glide” maneuvers to increase range, skipping like a stone on the density gradient between space and the upper atmosphere. In general, unpowered HGVs gradually lose speed during their glide phase, slowing to lower hypersonic (Mach 5 to 7) or supersonic speeds.

- Karako, Tom; Dahlgren, Masao. Complex Air Defense: Countering the Hypersonic Missile Threat (CSIS Reports) Bloomsbury Publishing. Kindle Edition.

Categorizing Hypersonics

The common HGV/HCM bifurcation oversimplifies the spectrum of hypersonic missile design possibilities. Focusing on these two types alone impedes anticipating future threats. Future hypersonic systems may, for instance, employ a combination of these propulsion methods or another altogether. A scramjet or other device could be integrated into a glider to increase range or maneuverability. Spaceplanes and fractional or multiple orbital bombardment systems further escape the HGV/HCM dichotomy. In July 2021, China reportedly orbited an object that, after circling the earth, deorbited and then executed hypersonic flight maneuvers during atmospheric reentry.

- \- Karako, Tom; Dahlgren, Masao. Complex Air Defense: Countering the Hypersonic Missile Threat (CSIS Reports) Bloomsbury Publishing. Kindle Edition.



Challenges

- Thermal Protection Systems (TPS): Must withstand prolonged, extreme heat.
- Guidance & Control: Navigation at hypersonic speed is difficult due to ionized environments.
- Detection & Defense: Radar and early-warning systems struggle to detect and track maneuverable hypersonic threats.

Challenges

One of the major challenges in hypersonic flight is thermal management. The extreme heat generated by friction can cause serious damage to the aircraft if not managed properly. Engineers design thermal protection systems using materials like ceramics and heat-resistant alloys to withstand the high temperatures. Spacecraft re-entering Earth's atmosphere, such as the Space Shuttle or capsules from crewed missions, encounter hypersonic flow as they slow down from orbital speeds of Mach 25 to subsonic speeds.

In hypersonic flow, the shock waves are much stronger than in supersonic flow, and they create shock layers where the air is significantly compressed and heated. Engineers must design hypersonic vehicles to withstand both the aerodynamic forces and the thermal loads, which often leads to highly specialized shapes, such as blunt bodies that spread the heat over a larger surface area during atmospheric reentry.

-Peterson, Alex. Aerospace Engineering Step by Step: Fundamentals of Aircraft Design, Structures & Systems: From Theory to Practice (Step By Step Subject Guides)

Challenges

At Mach 5+, air compression leads to extremely high temperatures (above 1,000°C). This can cause dissociation of oxygen and nitrogen molecules, plasma formation, and ionization, which complicates both control surfaces and communications (known as "radio blackout").

Strong bow shocks form ahead of the vehicle, altering airflow around it. Unlike in supersonic flight, these shocks interact more intensely with boundary layers, increasing heating and instability.

Speed and Heat

- Mach 5 ~ 3000K
- Mach 9 ~ 4956 K
- Mach 10 ~ 6000 K
- Mach 15 ~ 13000K
- Mach 20 ~ 21,000K
- Mach 25 ~ 36,000K

Note for various reasons data on speeds over Mach 6-8 are somewhat speculative.

Technology Readiness levels

TRL 9
- Actual system “flight proven” through successful mission operations

TRL 8
- Actual system completed and “flight qualified” through test and demonstration (ground or space)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2
- Technology concept and/or application formulated

TRL 1
- Basic principles observed and reported

https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

TRL

As of 2019, according to a U.S. Air Force Scientific Advisory Board report, domestically, the core technologies needed for the development of a tactical range HGV have reached Technology Readiness Level (TRL) 5 out of 9. The board expected the remaining subsystems for such a weapon to reach TRL 6 or higher by 2020. According to GAO best practices, TRL 7 is the level of technology maturity that constitutes a low risk for starting system development. It indicates that a technology has achieved form, fit, and function, and has been demonstrated in an operational environment.

-GAO: Science, Technology Assessment, and Analytics - HYPERSONIC WEAPONS (2019)

Air-breathing Missiles

An air-breathing missile is a type of missile that uses the oxygen from the atmosphere to combust fuel and generate thrust, rather than carrying its own oxidizer like traditional rockets. This propulsion method allows for longer range, reduced weight, and potentially higher sustained speeds—especially at hypersonic levels

Feature	Air-Breathing Missile
Propulsion	Uses ambient air to combust fuel
Oxidizer	Not onboard – taken from atmosphere
Speed Range	From subsonic up to hypersonic (Mach 5–10)
Flight Profile	Low to mid-altitude, level or cruise-based
Launch Method	Typically air-launched or boosted by rocket first
Engine Types	Turbojet, Ramjet, Scramjet

Air-breathing missiles - Examples

Missile System	Propulsion Type	Speed	Notes
AGM-86 ALCM (US)	Turbojet	Subsonic	Long-range strategic cruise missile
BrahMos (India-Russia)	Ramjet	Mach ~3	Supersonic cruise missile
HAWC (US)	Scramjet	Mach 5+	DARPA prototype
SCIFiRE / HACM (US/Australia)	Scramjet	Mach 5–8	Air-launched hypersonic missile in development
3M22 Zircon (Russia)	Scramjet	Mach 8–9	Hypersonic naval missile (claimed)

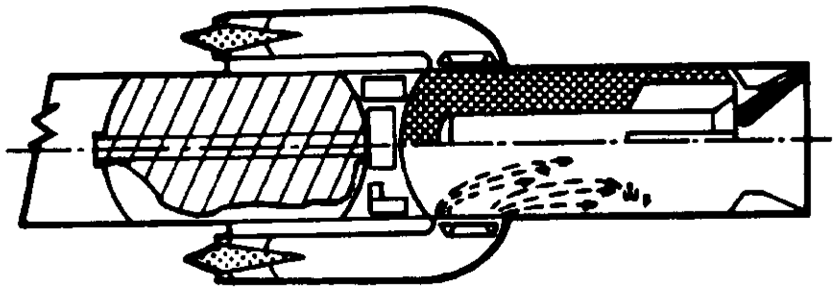
Ramjet

A ramjet is a type of air-breathing jet engine that uses the engine’s forward motion to compress incoming air, without any moving parts like compressors or turbines. It operates efficiently at supersonic speeds (Mach 3–6) and is commonly used in missiles, high-speed aircraft, and experimental propulsion systems.

- A ramjet has three main components:
- Inlet (Diffuser): Air enters at high speed and is compressed due to the vehicle's forward motion. This compression increases air pressure and temperature, slowing it to subsonic speed before combustion.
- Combustion Chamber: Fuel (usually a hydrocarbon like JP-7) is injected and mixed with the compressed air. The mixture is ignited, producing high-temperature, high-pressure gases.
- Nozzle :The hot gases expand through a converging-diverging nozzle, converting thermal energy into thrust. This propels the vehicle forward at very high speed.

Missile Ramjet Propulsion Alternatives

Liquid Fuel Ramjet



Rocket Boost Inboard Profile

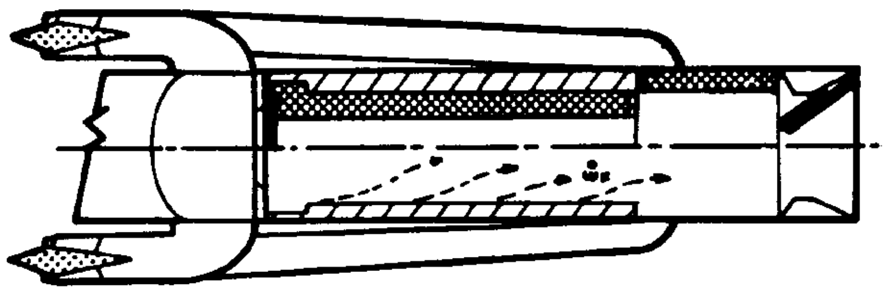
Ramjet Sustain Inboard Profile

Note:

Booster Propellant

Fuel

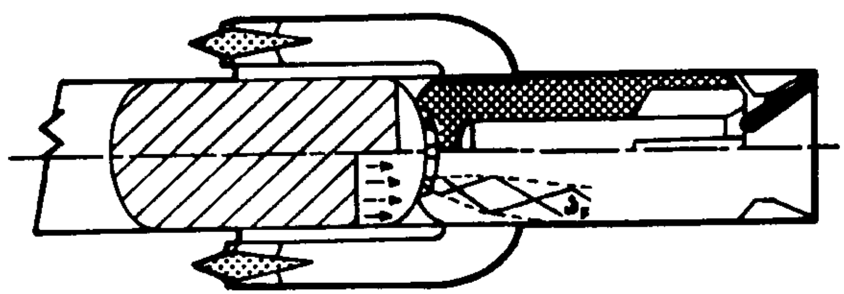
Solid Fuel Ramjet



Boost Inboard Profile

Sustain Inboard Profile

Solid Propellant Ducted Rocket

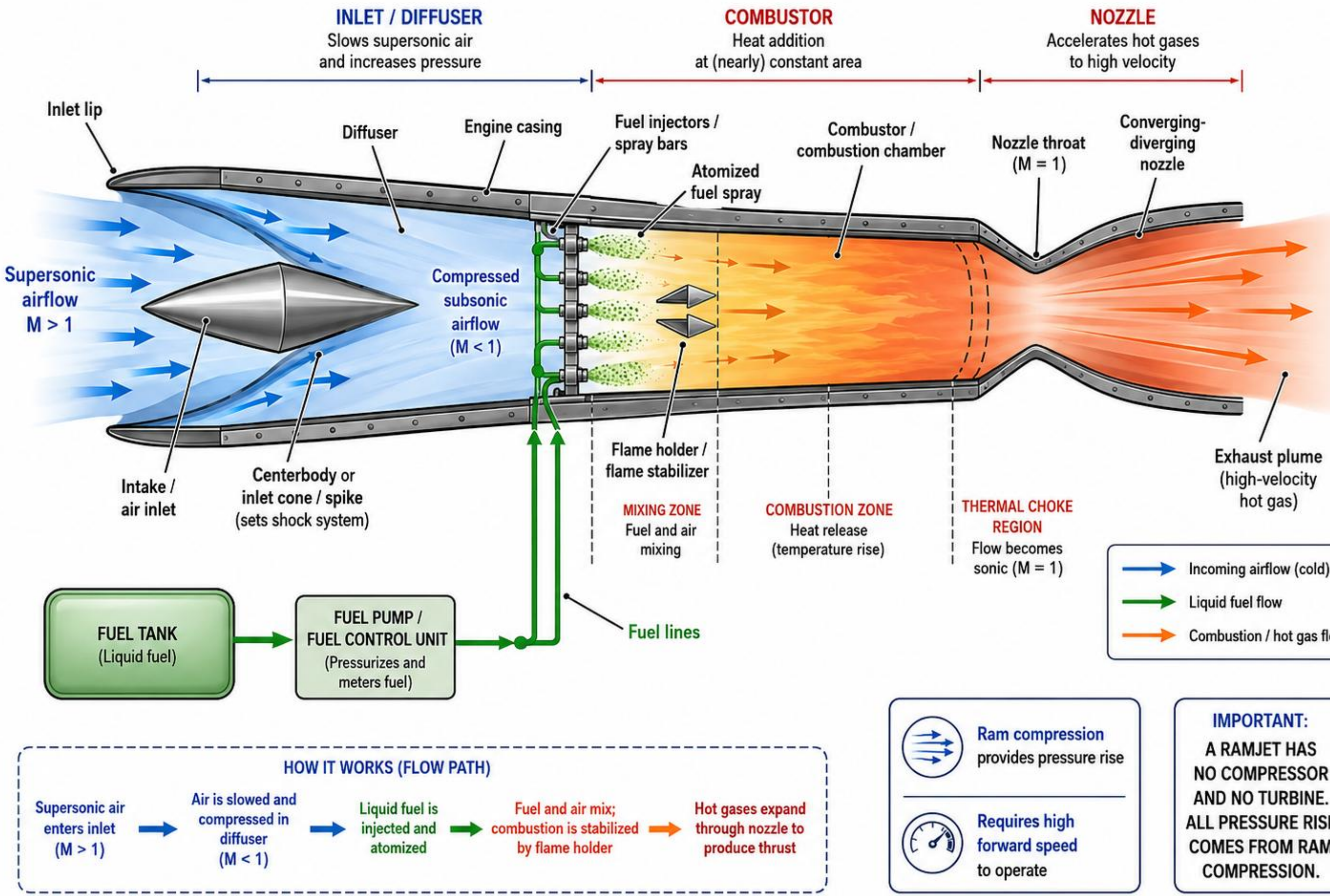


Boost Inboard Profile

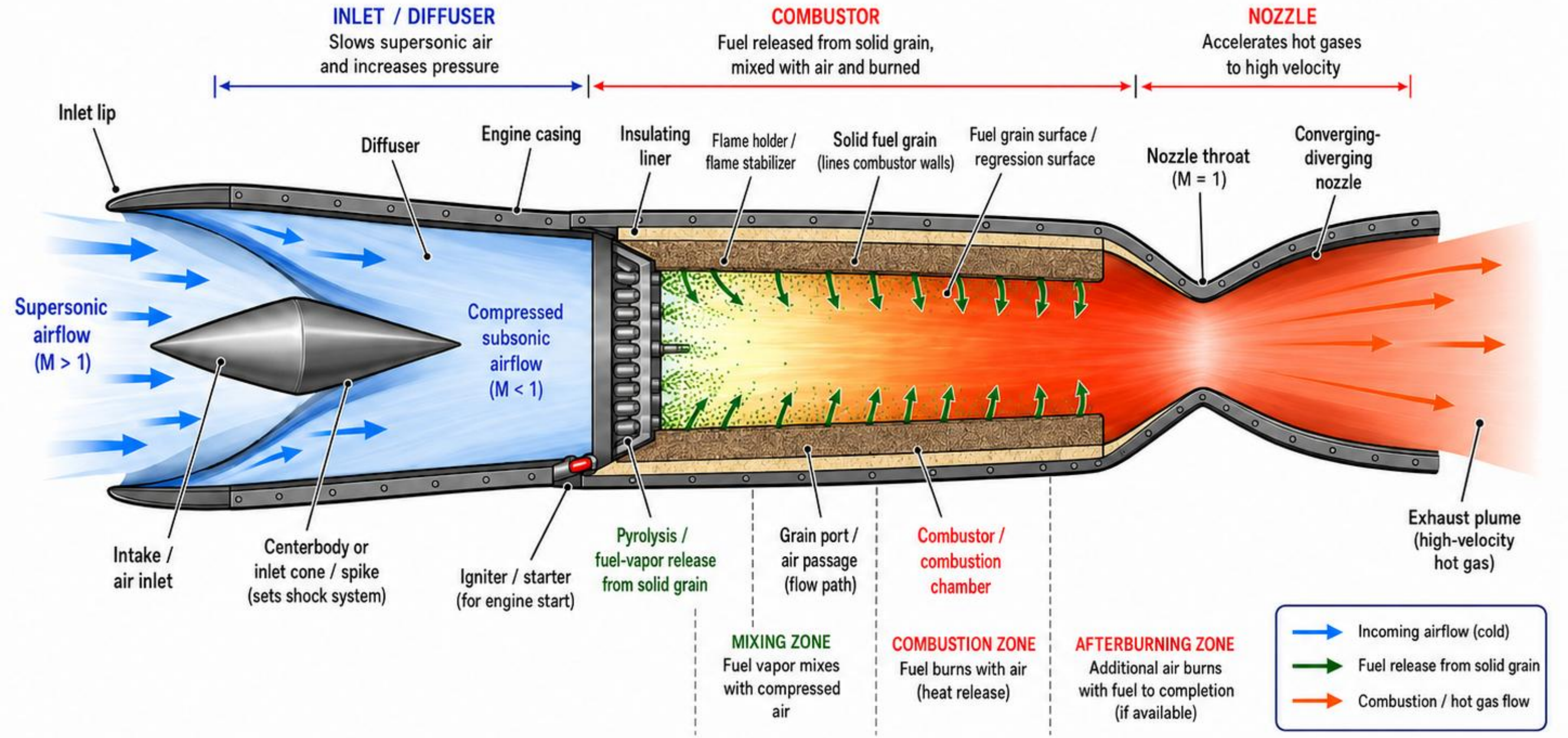
Sustain Inboard Profile

Fleeman, E. (2012). Missile design and system engineering. American Institute of Aeronautics and Astronautics, Inc.

Liquid-Fuel Ramjet



Solid-Fuel Ramjet



HOW IT WORKS (FLOW PATH)

Supersonic air enters inlet (M > 1) → Air is slowed and compressed in diffuser (M < 1) → Heat causes solid fuel grain to pyrolyze and release fuel vapor → Fuel vapor mixes with compressed air behind flame holder → Combustion occurs in combustor (heat release) → Hot gases expand through nozzle to produce thrust

No liquid-fuel system

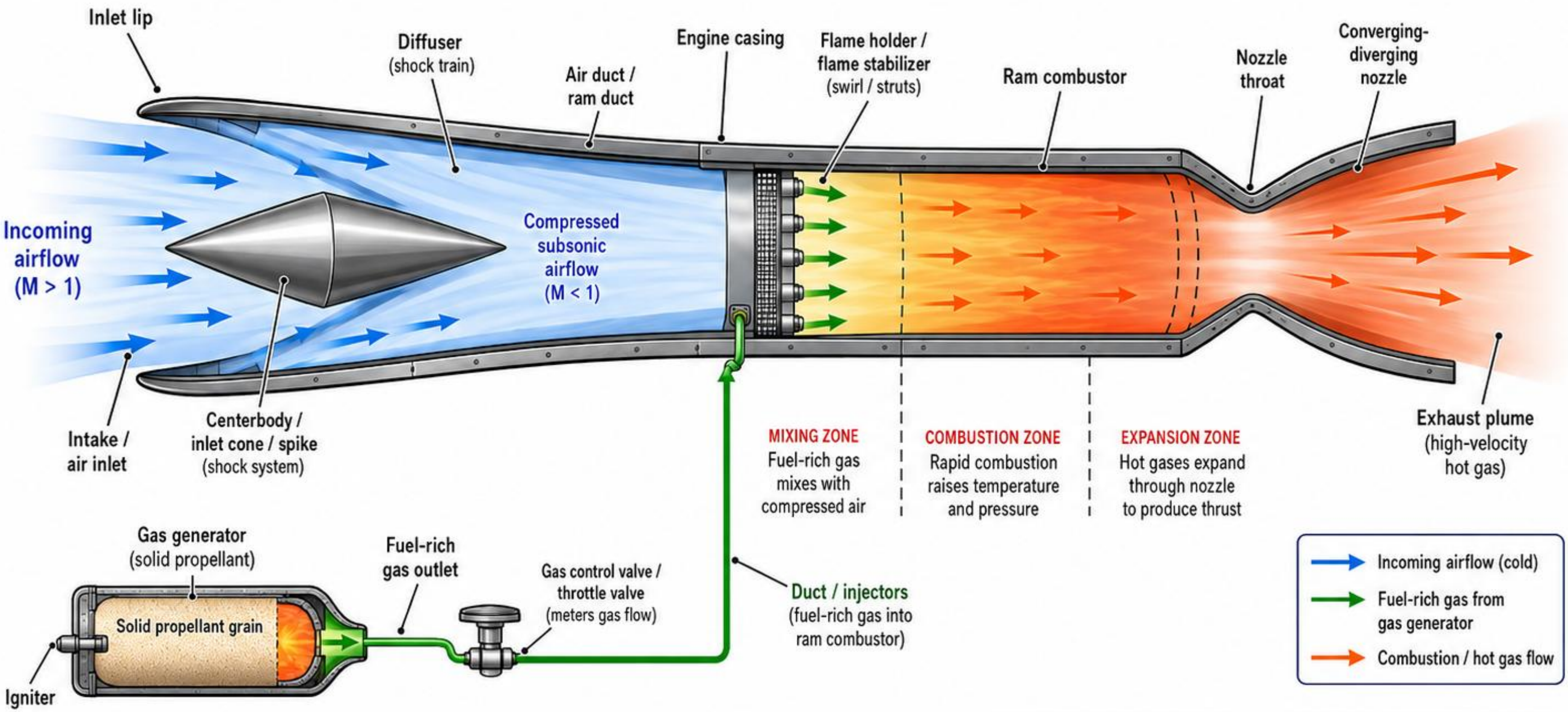
There is no fuel tank or fuel pump.
Fuel is stored in the solid fuel grain that lines the combustor.

Requires initial boost

A booster rocket, turbojet, or other means is typically required to accelerate the vehicle to ramjet operating speed (M ~ 2 to 3+).

NOTE: *Solid-fuel ramjets operate at high speed where the inlet provides compression.*
The solid grain continuously regresses (shrinks) as fuel is consumed.
Grain shape and port design control fuel release rate and performance.

Solid-Propellant Ducted Rocket



HOW IT WORKS (FLOW PATH)

Freestream air enters intake (M > 1) → Air is compressed by ram effect in diffuser / duct (M < 1) → Solid propellant at gas generator produces fuel-rich gas → Gas flow is metered by control valve and injected into duct → Fuel-rich gas mixes with compressed air at flame holder → Combustion raises temperature; hot gases accelerate through nozzle → High-velocity exhaust produces thrust

Gas-generator flow provides throttle-like control of thrust.

Requires initial booster phase to accelerate to ramjet operating conditions.

IMPORTANT DIFFERENCE

This is NOT a solid-fuel ramjet. The solid propellant is in a separate gas generator. Only the fuel-rich gas is injected into the ram combustor; the solid propellant does not line the combustor walls.

Note: System incorporates inlet doors or an inlet start system in practice to manage start/stop and off-design conditions.

Scramjet

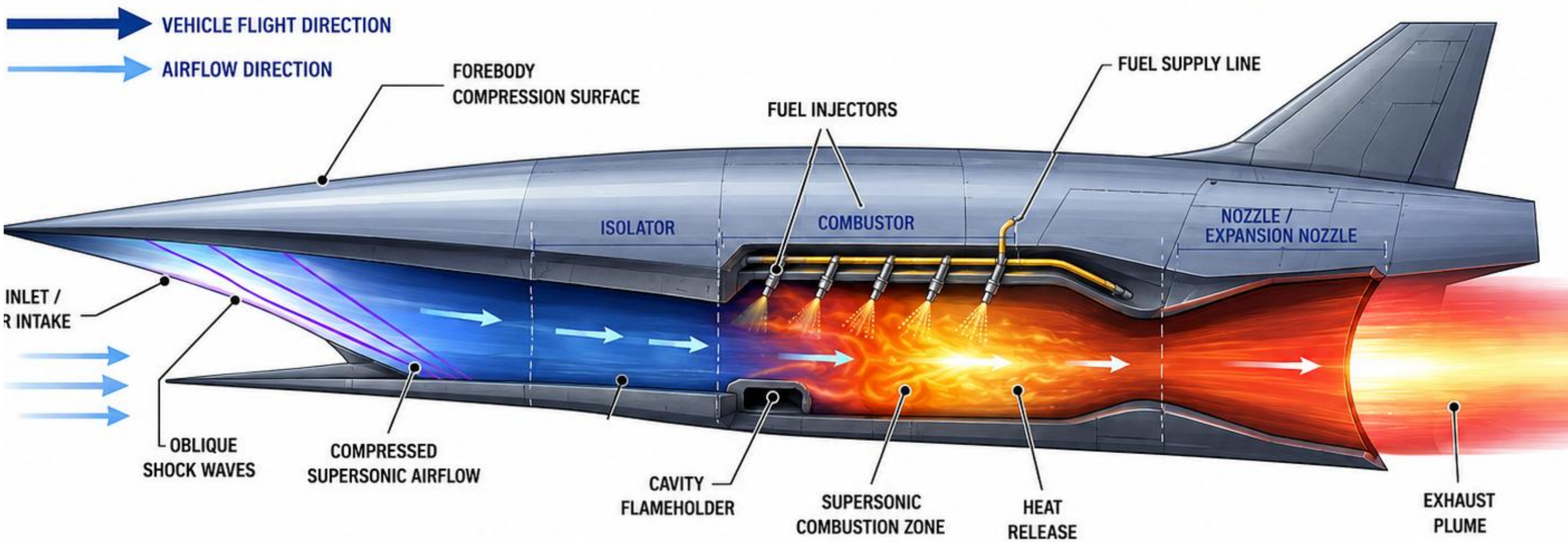
A scramjet, short for supersonic combustion ramjet, is an air-breathing jet engine designed to operate at hypersonic speeds, typically above about Mach 5. Unlike a conventional turbojet or turbofan, a scramjet has no rotating compressor or turbine. It relies on the vehicle's own high-speed motion through the atmosphere to compress incoming air before fuel is injected and burned.

The defining feature of a scramjet is that combustion occurs while the airflow through the engine remains supersonic.

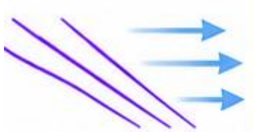
In simplified form, a scramjet does this:

- Capture high-speed air
- Compress it using shock waves
- Inject fuel
- Mix fuel with supersonic air
- Burn the mixture extremely quickly
- Expand the hot exhaust through a nozzle
- Produce thrust

SCRAMJET ENGINE – HYPERSONIC VEHICLE (SIDE CUTAWAY)



) PRESSURE INCREASES IN THE INLET



lique shock waves from the ebody compress the incoming , increasing its pressure d temperature.

2 AIR SLOWS SOMEWHAT BUT REMAINS SUPERSONIC

Through the isolator, the air slows somewhat due to wall friction and heat addition, but remains supersonic.

3 FUEL MIXES RAPIDLY WITH AIR

Fuel is injected and rapidly mixes with the high-speed air in the short combustor.

4 COMBUSTION OCCURS IN SUPERSONIC FLOW

Heat is released as the fuel burns in supersonic flow, rising the temperature and pressure.

5 HOT GASES EXPAND TO PRODUCE THRUST

The hot gases expand through the nozzle, accelerating to very high velocity to produce thrust.

COMBUSTOR DETAIL (INSET)

CAVITY FLAMEHOLDER
Creates a recirculation zone that anchors the flame in supersonic flow.

SUPERSONIC FLAME REGION
Rapid mixing and combustion occur while maintaining supersonic speed.

TYPICAL CHANGES THROUGH THE SCRAMJET ENGINE (EXAMPLE VALUES)

TATION	FREESTREAM (UPSTREAM)	INLET EXIT	ISOLATOR EXIT	COMBUSTOR EXIT	NOZZLE EXIT
ACH NUMBER	6.0	2.5 – 3.0	2.0 – 2.5	2.0 – 2.5	5.0 – 7.0+
TATIC PRESSURE	Low	Higher	Slightly Higher	Higher	Lower
TATIC TEMPERATURE	Low	Higher	Higher	Very High	Slightly Lower

LEGEND

- AIRFLOW (SUPERSONIC)
- SHOCK WAVES
- FUEL SPRAY
- COMBUSTION / HEAT RELEASE
- HOT EXHAUST GAS

Scramjet- How it works

1. Air Intake (Compression)

- High-speed flight compresses incoming air using a converging inlet.
- No mechanical compressor — shockwaves and geometry do the compression.

2. Fuel Injection & Supersonic Combustion

- **Hydrocarbon (like JP-7) or hydrogen fuel** is injected.
- Fuel mixes and burns while air is still supersonic.
- This process is extremely complex due to short residence time (~milliseconds).

3. Exhaust (Expansion and Thrust)

- Combustion increases temperature and pressure.
- Gases expand through a nozzle to produce thrust.

Scramjet Challenges

Challenge	Description
Ignition & Combustion	Fuel must burn in milliseconds under high pressure and speed.
Thermal Management	Intense heat (~2000°C+) can damage engine surfaces.
Materials	Requires exotic heat-resistant alloys or ceramics.
Starting the Engine	Needs to be brought to Mach 4–5 by rocket or ramjet to begin operating.
Controllability	Difficult to manage airflows and flame stability in supersonic regime.

Vehicles using scramjet engines

- NASA X-43A (Hyper-X): Achieved Mach 9.6 using a hydrogen-fueled scramjet in 2004.

- Boeing X-51A Waverider: Reached Mach 5.1 in 2013 using JP-7 hydrocarbon fuel.

- DARPA HAWC & Hypersonic Cruise Missile programs

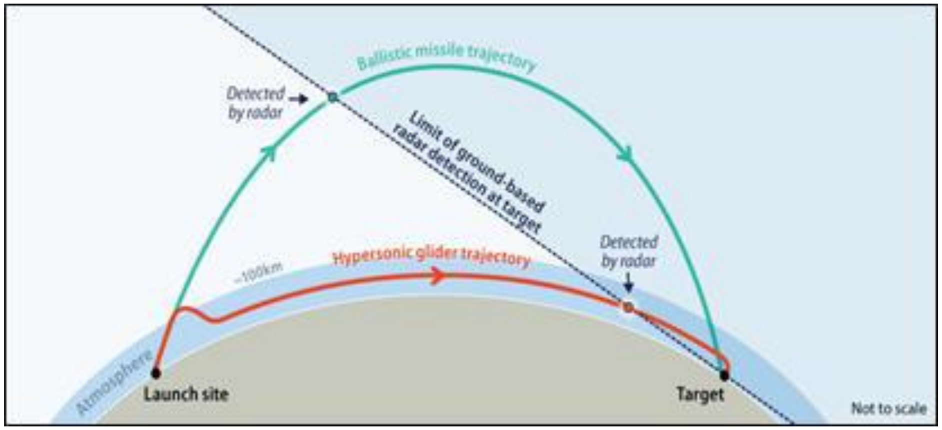
- Russian “Zircon” missile (unconfirmed scramjet)

- India’s Hypersonic Technology Demonstrator Vehicle (HSTDV

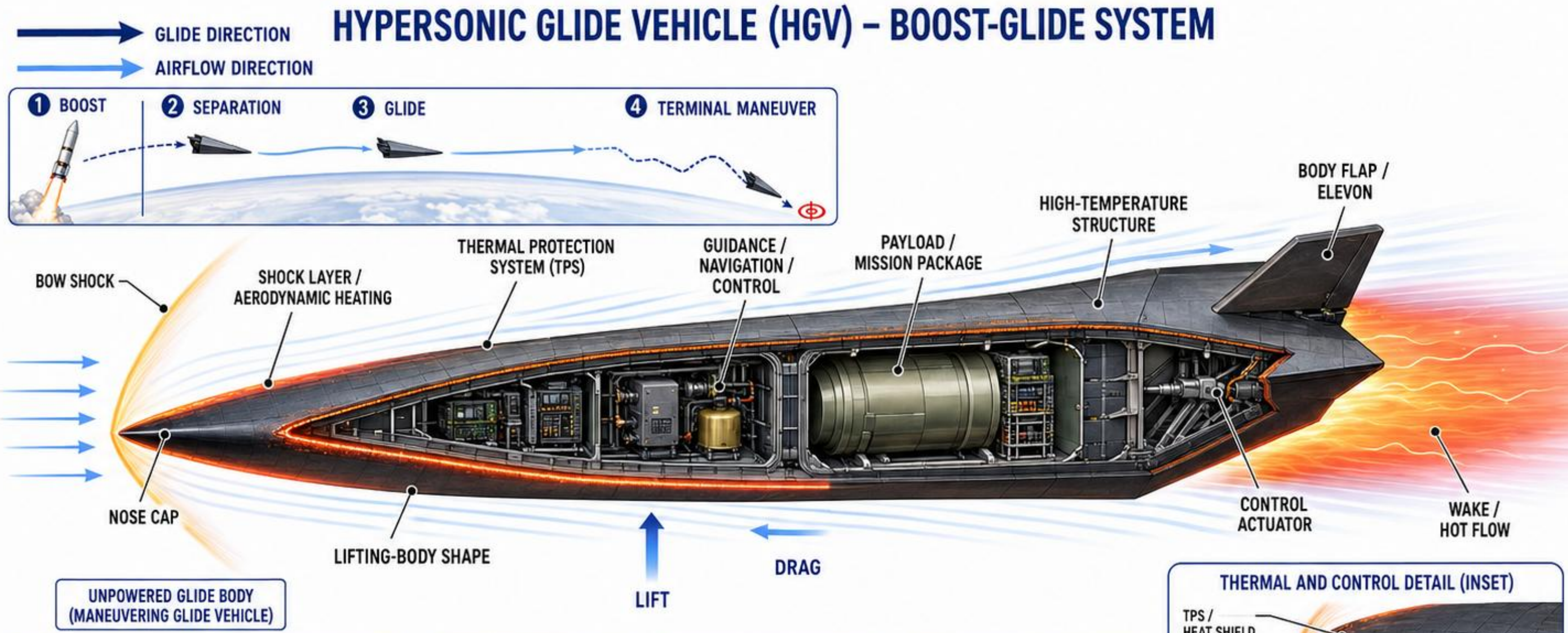
Boost-Glide

Hypersonic glide vehicles (HGVs), like all weapons delivered by medium- and longer-range rocket boosters, can travel at speeds of at least Mach 5, or about 1 mile per second. The key difference between missiles armed with HGVs and missiles armed with ballistic reentry vehicles (i.e., those that travel on a ballistic trajectory throughout their flight) is not their speed, but their ability to maneuver and change course after they are released from their rocket boosters. In addition, although it is not necessary, many concepts for the delivery of HGVs presume that the boosters will launch along a flatter, or depressed, trajectory than standard ballistic missiles, and will release their gliders at a lower altitude of flight.

- - Defense Primer: Hypersonic Boost-Glide Weapons May 5, 2022



HYPERSONIC GLIDE VEHICLE (HGV) – BOOST-GLIDE SYSTEM



1 ROCKET BOOST ACCELERATES THE VEHICLE

A rocket booster lifts the HGV to extremely high speed and altitude, providing the energy needed for long-range glide.

2 GLIDE VEHICLE SEPARATES

The HGV separates from the booster at high altitude and reorients to a stable attitude for atmospheric entry.

3 REENTRY CREATES EXTREME HEATING

Atmospheric reentry generates a bow shock and extreme aerodynamic heating. The thermal protection system (TPS) absorbs the heat and protects the vehicle.

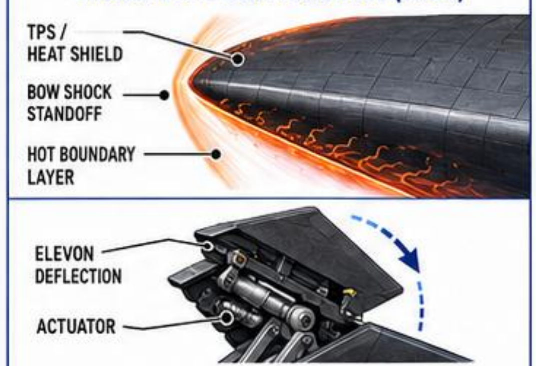
4 LIFT ENABLES LONG-RANGE MANEUVERING GLIDE

The lifting-body shape generates lift, allowing efficient glide and cross-range maneuvering. This creates unpredictable flight paths compared with a purely ballistic reentry vehicle.

5 TERMINAL MANEUVERS COMPLICATE DEFENSE

In the terminal phase, the HGV can maneuver aggressively while remaining at hypersonic speed, making it very difficult to track and intercept.

THERMAL AND CONTROL DETAIL (INSET)



The TPS and hot boundary layer manage extreme heating. Elevon deflection via actuators provides pitch and yaw control for maneuvering in hypersonic glide.

TYPICAL HGV MISSION CHARACTERISTICS (EXAMPLE RANGES)

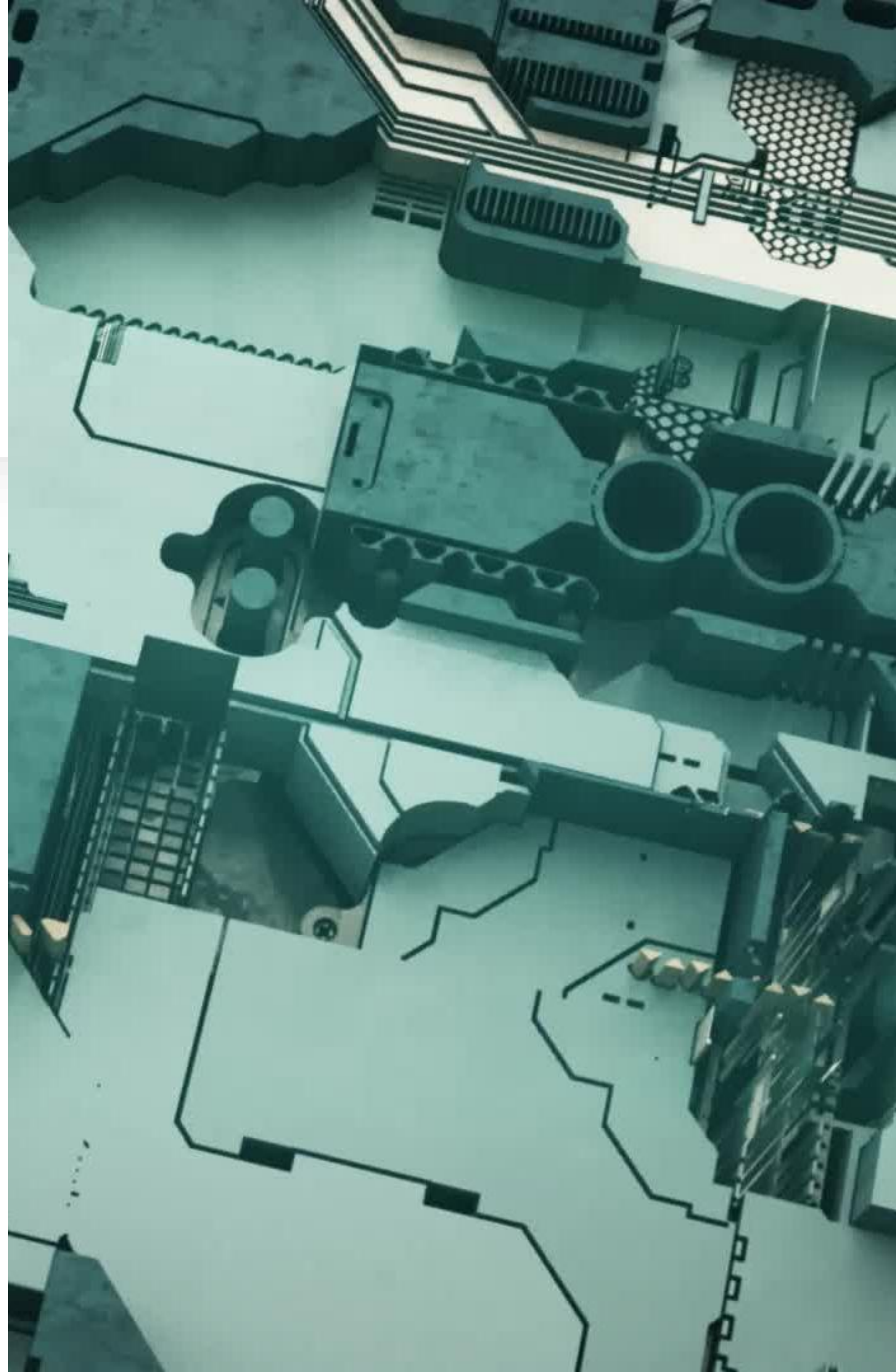
PHASE	BOOST END	SEPARATION	GLIDE PHASE	TERMINAL PHASE
SPEED (MACH)	10 – 20+	10 – 20	5 – 15	5 – 10
ALTITUDE	High exo / upper atmosphere	Upper atmosphere	~30 – 70 km	Descending to lower altitude
PROPULSION	*Rocket booster*	*None*	*Unpowered glide*	*Unpowered glide*
DOMINANT EFFECT	*Acceleration*	*Separation / trim*	*Lift + drag + heating*	*Maneuvering + drag*

LEGEND

Challenges

•**Heat-tolerant materials.** At hypersonic speeds, the exterior temperature of a hypersonic vehicle or weapon can exceed 2,000°F, necessitating advanced materials that will protect interior electronics. Such materials also need to be mechanically strong and efficient.
•**Propulsion technology.** Refinement of engine technology is needed for HCMs. This includes increasing the reliability and efficiency of scramjet engines. New types of engines that allow for propulsion from standstill to hypersonic speeds are also being developed, which would eliminate the need for rockets to provide the initial launch.
•**Weapon tracking.** Defense against a hypersonic weapon would involve tracking and intercepting it, but current radar and satellite systems are inadequate for this task.
•**Limited testing resources.** There are limited places to perform ground tests and flight tests of hypersonic weapons and vehicles in the United States. Currently, there are limited wind tunnel facilities in the country capable of running propulsion tests of hypersonic weapons and vehicles.
•**Safety and control.** Hypersonic velocities require additional improvements of aircraft control and guidance to help ensure the accuracy of hypersonic weapons and to avoid in-flight accidents or loss of control of hypersonic vehicles.

- -GAO: Science, Technology Assessment, and Analytics - HYPERSONIC WEAPONS (2019)



Specific Missiles

The following slides in this lesson describe specific systems from multiple countries. These slides contain only what information is publicly available.

Advanced Strategic Air-Launched Missile

ASALM (Advanced Strategic Air-Launched Missile) was (1970's) a supersonic air vehicle designed to be air-launched from a carrier aircraft. The four aft aerodynamic control vanes are folded to maximize the number of missiles carried on-board. The unfolding (erection) system must be small, energetic, fast, and strong. The materials selected and problems that arose during development of the unfolding system are described. Its speed was reported as Mach 4 to 5.

SABRE

SABRE (Synergistic Air-Breathing Rocket Engine) is an innovative combined-cycle propulsion system under development by Reaction Engines Limited (UK). It is designed to operate efficiently both in air-breathing mode (like a jet engine) and in rocket mode (in vacuum), making it ideal for single-stage-to-orbit (SSTO) vehicles.

- Single-Stage-to-Orbit Vehicle:
- Takes off like an aircraft from a runway.
- Air-breathing ascent up to ~25 km altitude and Mach 5.4.
- Switches to rocket mode for the remainder of ascent to LEO (Low Earth Orbit).
- No staging or boosters — significantly reduces cost and complexity.
- Designed for reusability and fast turnaround.

SABRE

Feature	Description
Dual-mode engine	Functions as both an **air-breathing engine** and a **rocket**
Precooler system	Unique heat exchanger rapidly cools incoming air from ~1000°C to -150°C in <0.01 sec
Hydrogen fuel	Used for combustion and cooling purposes
Operational speed	Mach 0 (takeoff) to **Mach 5.4 in air-breathing mode**, and up to **Mach 25** in rocket mode

SABRE

A. Air-Breathing Mode (Within Atmosphere)

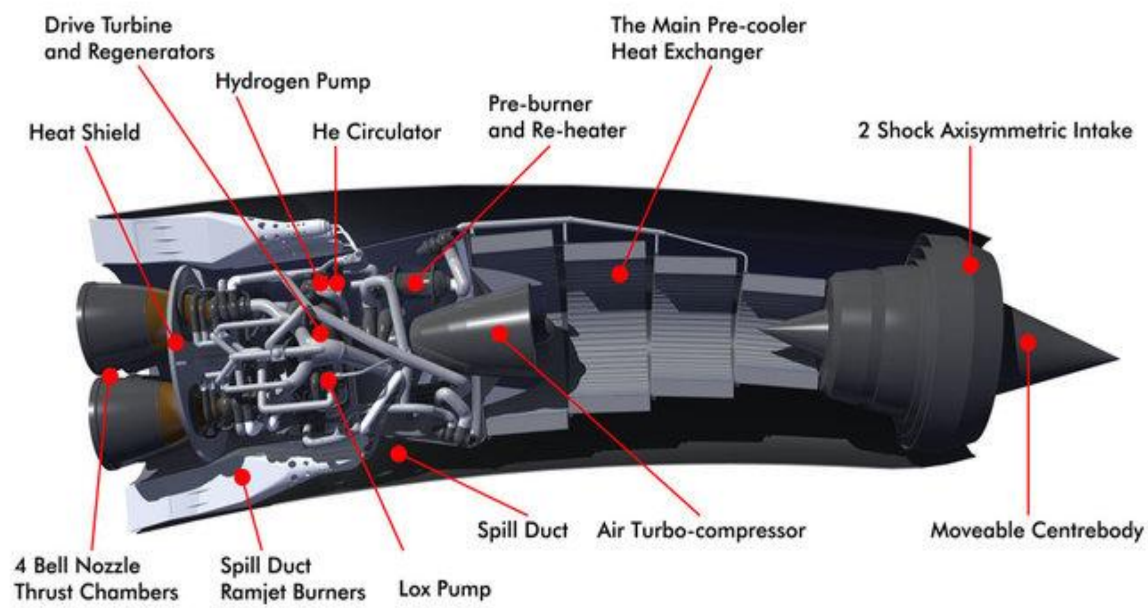
- Operates like a ramjet with a precooler.
- Air is compressed and cooled before entering the combustion chamber.
- Mixed with cryogenic hydrogen fuel, then combusted to produce thrust.
- Operates efficiently up to Mach 5.4 (~6,600 km/h).

B. Rocket Mode (Above Atmosphere)

- Switches to internal oxidizer (liquid oxygen) once air is too thin.
- Operates like a conventional rocket engine.
- Enables orbit insertion without multi-stage rocket systems.

Sabre Engine

The key to the engine is a proprietary heat exchanger capable of taking a core of ram heated inlet air at 1000C (1800F) and cooling it to -150C (-238F) in 1/100th of a second.
Most of the non-core air passes directly through a ring of bypass ramjets.
The cooled core air is fed to four high pressure combined cycle rocket engine combustion chambers.
Thrust (V) = 660,000 lbs Thrust (SL) = 440,000 lbs
Isp (V) = 460 sec (SSME engines) Isp(SL) = 3600 sec (x 7.8!)
Breakthrough was thin wall 3D printed tubes 1/32" ID



Why is the engine curved? The answer is: the air intake on the front of the nacelle needs to point directly into the incoming airflow whereas SKYLON's wings and body need to fly with an angle of incidence to create lift, so the intake points down by 7 degrees to account for this.

Technical history supporting the concept

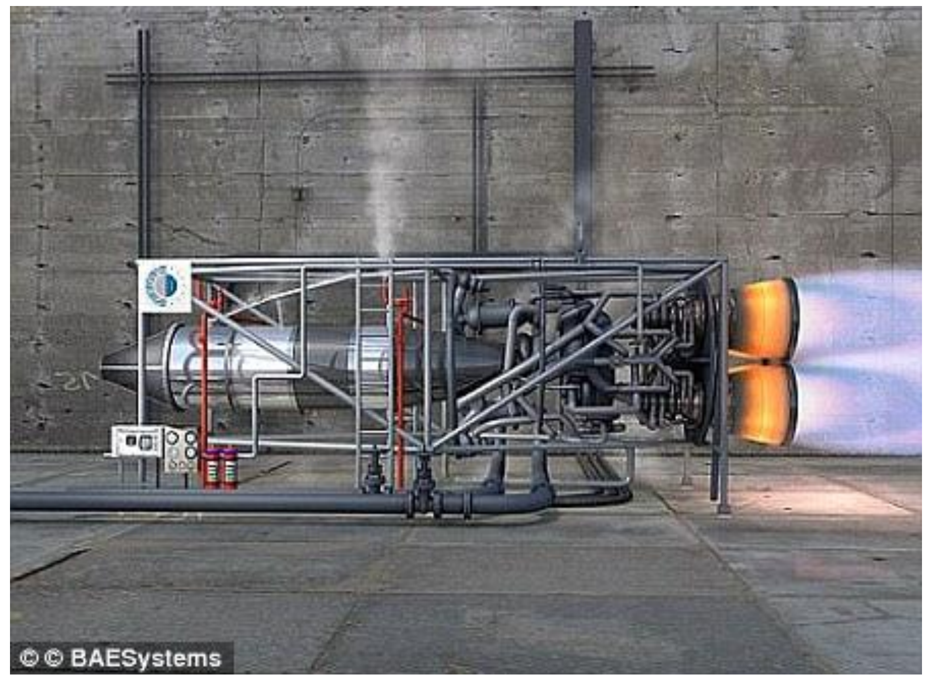
Liquid Air Cycle Engine (LACE) built by General Dynamics in the 1960s as part of USAF aero spaceplane efforts. Limited potential.

Alan Bond at Rolls-Royce invented the "43rd option" in mid 80s called RB545 Swallow, promptly classified by UK gov't as Top Secret. UK funded for 6 years as HOTOL, a Brit Space Shuttle.

UK stopped funding in 1989, Bond et.al. formed Reaction Engines Limited, developed offshoot SABRE to get around Official Secrets Act.

IN 2016, the SABRE project received 60M Lbs Sterling from UK govt and from ESA for a demonstrator engine involving full-cycle.

Real hardware being tested



Sabre Status

Milestone	Status
Precooler demonstrator	Successfully tested at Mach 5 equivalent airflow
Core engine elements tested	Hydrogen cooling, heat exchangers, combustion loop
Partnerships	UK Space Agency, ESA, BAE Systems, Boeing, Rolls-Royce
Flight vehicle (Skylon)	Still under conceptual development and funding review

Reentry-F

The Reentry-F flight test, conducted in 1968, was a pivotal U.S. Air Force experiment aimed at deepening the understanding of hypersonic reentry physics, particularly the transition from laminar to turbulent boundary layers during atmospheric reentry. This research was crucial for enhancing the design and thermal protection of future reentry vehicles.

- Geometry: The test vehicle featured a 5-degree half-angle sharp cone, a shape chosen to simulate the aerodynamic conditions experienced by reentry bodies.
- Length: Approximately 3.66 meters (12 feet).
- Purpose: Designed to collect data on aerothermal heating, boundary layer behavior, and flow field characteristics at hypersonic speeds.

The primary goals of the Reentry-F test included:

- Measuring Heat Flux: Assessing the thermal loads on the vehicle's surface during reentry.
- Boundary Layer Analysis: Studying the transition from laminar to turbulent flow, which significantly affects heat transfer rates.
- Flow field Characterization: Understanding the behavior of the shock layer and wake regions behind the vehicle.

To achieve these objectives, the vehicle was equipped with:

- Thermocouples: For temperature measurements.
- Pressure Sensors: To capture pressure distributions along the surface.
- Flow Visualization Tools: Such as surface oil flow or tufts to observe boundary layer behavior.

Reentry-F

- Shape: Sharp cone with a 5-degree half-angle.
- Length: Approximately 3.66 meters (12 feet).

https://ntrs.nasa.gov/api/citations/19970023404/downloads/19970023404.pdf

X-15

- Hypersonic rocket-powered flight test program from 1955 (project start) through 1968 (final flights)
- X-15 launched from -52 and then used rocket power
- 199 flights broke multiple speed/altitude
- records, including reaching altitude of 108 km and speed of 7,273 km/h
- Pilots included: Neil Armstrong, Scott Crossfield, Bill Dana, Joe Engle, Pete Knight, and Robert White

- -Hypersonic Weapons Summit 2020

X-15

-Hypersonic Weapons Summit 2020

Program	Years	Flights	Failures	2017 $
X-15	1955-1968	199	1	$2.00B
X-20	1957-1963	0	0	$5.30B
X-24A/X-24B	1969-1975	64	0	?
X-30 (NASP)	1986-1993	0	0	$3.24B
X-33	1996-2001	0	0	$1.75B
X-34	1996-2001	0	0	$0.49B
X-37	1999-present	5	0	$0.49B for X-37A
X-38	1995-2002	8 drop tests	0	$0.50B
X-43	2001-2004	3	1	$0.26B
X-51	2005-2013	4	2	$0.34B

X-15A-2

- The X-15A-2 was an advanced variant of the North American X-15, a rocket-powered research aircraft operated jointly by NASA (then NACA), the U.S. Air Force, and the U.S. Navy from the late 1950s to the 1970s. The X-15A-2 was a significantly modified version of the original X-15, specifically Aircraft #2, rebuilt and upgraded after a crash in 1962. The modifications included:
  - Extended fuselage: About 29 inches longer to accommodate more instrumentation and equipment.
  - External fuel tanks: These drop tanks increased fuel capacity, allowing longer engine burns and higher speeds.
  - Ablative coating: To withstand high thermal loads at extreme speeds, the aircraft was covered in a special ablative material (pinkish-white in color) designed to erode and dissipate heat during flight.
- The X-15-A-2 was able to
  - Reach a top speed of Mach 6.7 (approximately 4,520 mph or 7,274 km/h).
  - Fly at altitudes over 102,000 feet (31 km).

- Pilot William J. "Pete" Knight set the speed record on October 3, 1967, reaching Mach 6.7.

Dr. Chuck Easttom, M.Ed, MSDS MBA, MSSE, Ph.D.^{2}, D.Sc.

X-15A-2

Feature	Specification
Crew	1 (pilot)
Length	50 ft 9 in (15.47 m)
Wingspan	22 ft 4 in (6.82 m)
Height	13 ft 6 in (4.12 m)
Wing Area	200 sq ft (18.58 m^2)
Empty Weight	~14,600 lb (6,623 kg)
Gross Weight (with tanks)	~56,000 lb (25,400 kg) (varied by mission)
Powerplant	1 × Reaction Motors XLR99-RM-1 rocket engine

X-15A-2

Feature	Specification
Engine Type	Liquid-fueled rocket engine
Fuel	Anhydrous ammonia (fuel) + liquid oxygen (oxidizer)
Thrust	57,000 lbf (254 kN) at sea level (variable throttle)
Burn Time	~80 to 90 seconds (with external tanks)

X-Plane History

Program	Years	Flights	Failures	2017 $
X-15	1955-1968	199	1	$2.00B
X-20	1957-1963	0	0	$5.30B
X-24A/X-24B	1969-1975	64	0	?
X-30 (NASP)	1986-1993	0	0	$3.24B
X-33	1996-2001	0	0	$1.75B
X-34	1996-2001	0	0	$0.49B
X-37	1999-present	5	0	$0.49B for X-37A
X-38	1995-2002	8 drop tests	0	$0.50B
X-43	2001-2004	3	1	$0.26B
X-51	2005-2013	4	2	$0.34B

X-66

- X-66 being developed by Boeing for NASA due to be ready in 2028. The X-66A is an experimental aircraft developed collaboratively by NASA and Boeing under NASA's Sustainable Flight Demonstrator (SFD) project. It aims to validate innovative technologies that could lead to more sustainable aviation, particularly focusing on reducing fuel consumption and greenhouse gas emissions.

  - Transonic Truss-Braced Wing (TTBW): The X-66A features an ultra-thin, long-span wing supported by diagonal struts (trusses). This design aims to reduce aerodynamic drag and improve fuel efficiency.

  - Advanced Propulsion: Equipped with Pratt & Whitney's Geared Turbofan (GTF) engines, known for their fuel efficiency and lower emissions.

  - Sustainability Goal: Targeting up to a 30% reduction in fuel consumption and emissions compared to current single-aisle aircraft.

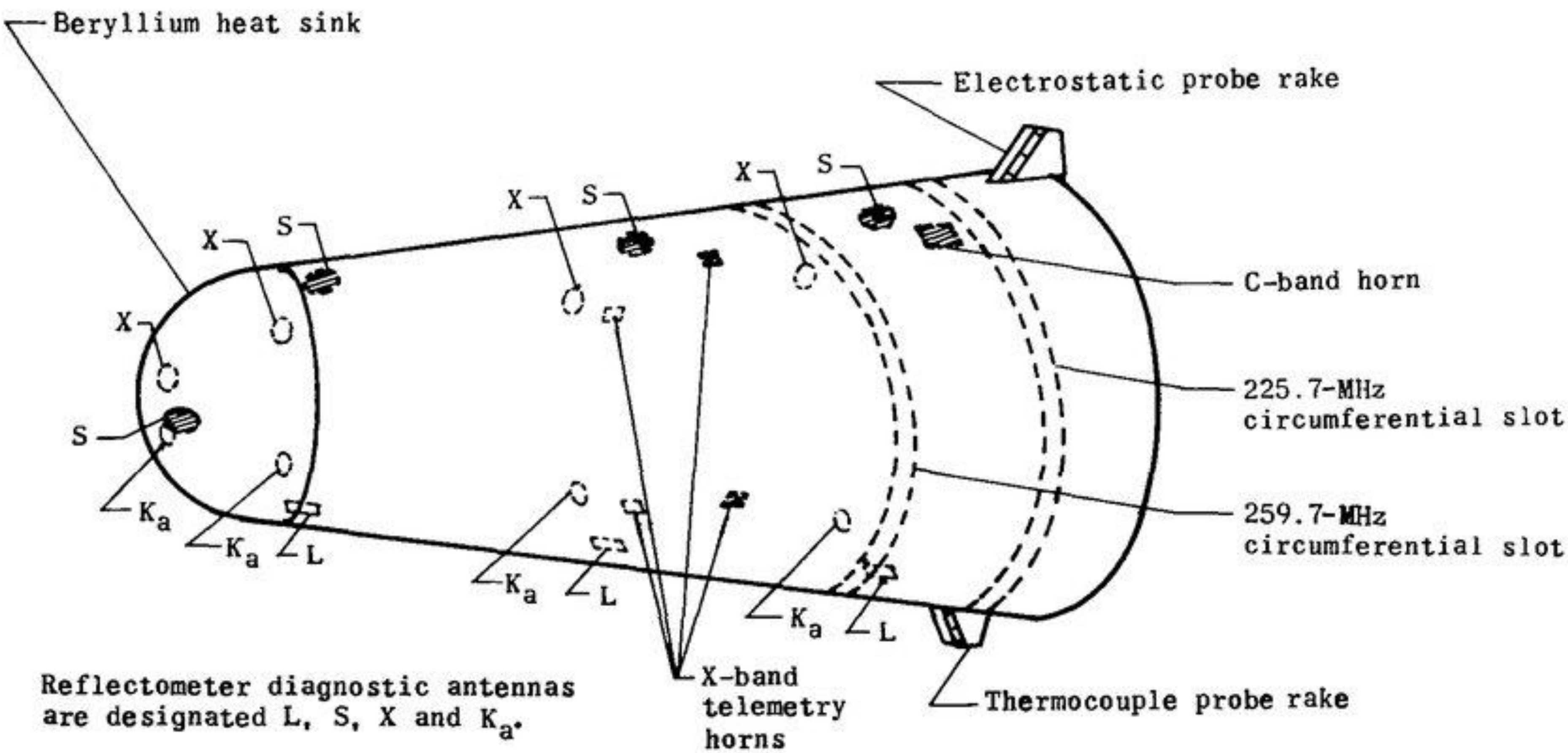
RAM-C

RAM-C was a U.S. hypersonic research project conducted in the late 1960s and early 1970s that focused on the development and flight testing of ramjet propulsion systems. It was one of the most advanced programs of its time aimed at understanding airbreathing hypersonic propulsion, a key enabling technology for future high-speed missiles, reconnaissance vehicles, and spaceplane concepts. RAM-C: Part of the RAM Project Series, where “RAM” stands for Ramjet, with “C” denoting the third iteration or configuration in the series.

- Hydrogen-fueled ramjet/scramjet engine.
- Required to be boosted to hypersonic speeds (~Mach 5–6) before the engine could be tested in real flow conditions.
- RAM-C test vehicles were air-launched from high-altitude balloons or boosted by sounding rockets (such as Nike or Terrier systems).
- Once the test altitude and speed were achieved, the ramjet ignited and operated for short durations (seconds to tens of seconds).
- Speeds: Mach 5 to 6.5
- Altitudes: ~100,000 feet (~30.5 km)
- Approximately 1.3 meters (about 4.3 feet) in length, with a 9-degree cone angle and a nose radius of 0.1524 meters (6 inches)

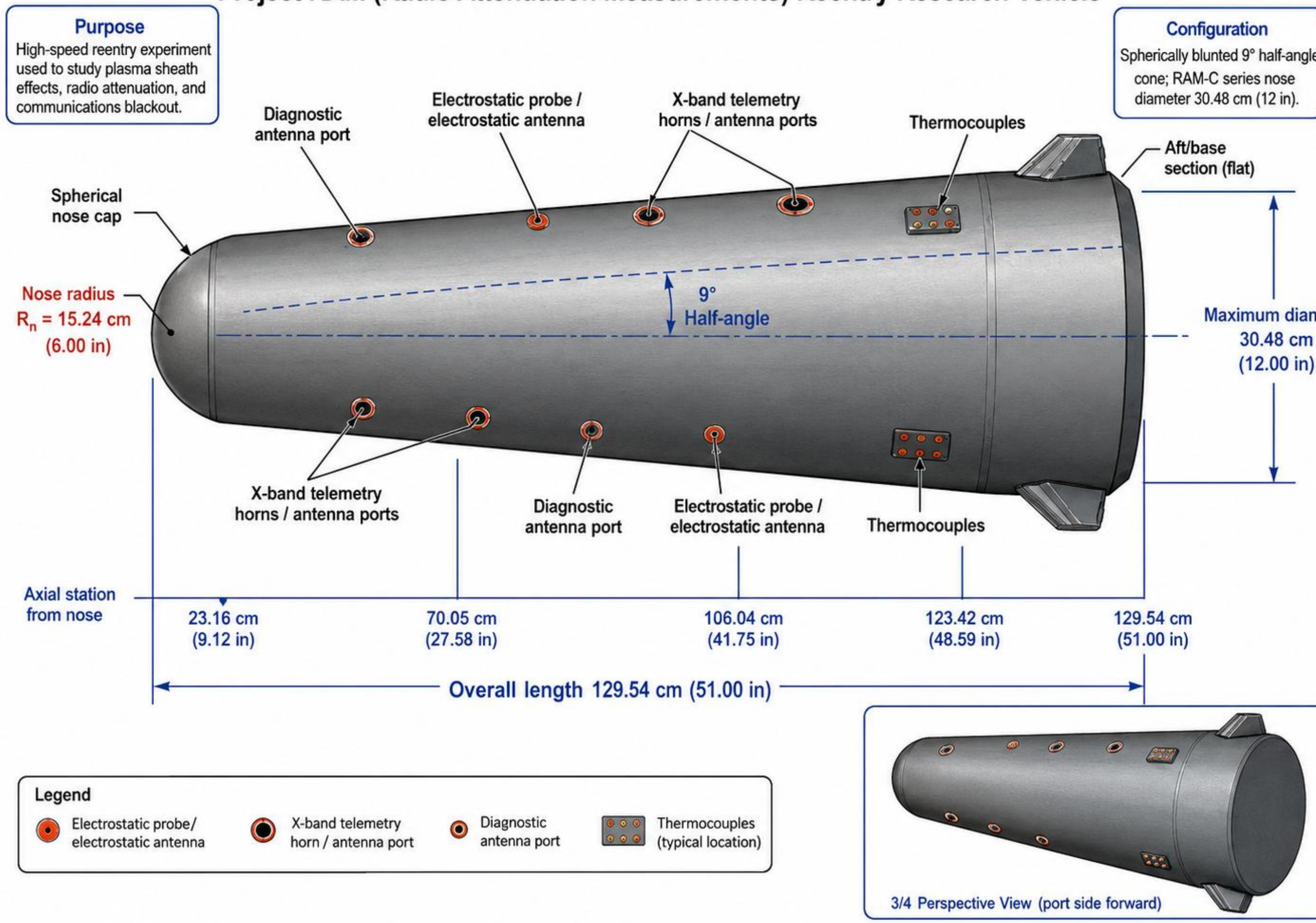
RAM-C

This diagram is of the RAM-C II



RAM-C II

Project RAM (Radio Attenuation Measurements) Reentry Research Vehicle



Project PRIME

Project PRIME (short for Precision Recovery Including Maneuvering Entry) was a U.S. Air Force and NASA joint research initiative conducted during the 1960s. Its primary aim was to test and validate maneuverable reentry technologies—a foundational step toward later spacecraft that could return from space with greater precision and control. Project PRIME was designed to investigate:

- Controlled, aerodynamic reentry into Earth's atmosphere.
- Techniques to improve the accuracy of landing after orbital or suborbital flight.
- The feasibility of lifting body designs as alternatives to traditional ballistic capsules.

Feature	Specification
Type	Subscale lifting body
Structure	Unmanned, heat-shielded reentry testbed
Shape	Flat-bottomed lifting body (SV-5D)
Material	Refractory materials for thermal resistance
Control	Aerodynamic surfaces (elevons, rudder) and internal systems

X-20A

The X-20A Dyna-Soar (short for Dynamic Soaring) was an early U.S. Air Force program in the late 1950s and early 1960s aimed at developing a reusable, manned spaceplane capable of orbital and suborbital missions. Though it never flew, the X-20A was a precursor to later spacecraft like the Space Shuttle and X-37B.

Feature	**Specification**
Length	~35 ft (10.7 m)
Wingspan	~20 ft (6.1 m)
Weight (gross)	~11,000–12,000 lb (4,990–5,450 kg)
Crew	1 (pilot)
Structure	Nickel-alloy and heat-resistant materials
Shape	Delta-wing lifting body
Launch Vehicle	Titan III (planned)

X-43A

The X-43A was a groundbreaking experimental aircraft developed by NASA as part of the Hyper-X program to explore scramjet (supersonic combustion ramjet) propulsion technology. It holds the record as the fastest air-breathing aircraft ever flown and was a major milestone in the pursuit of hypersonic flight. The X-43A's primary goal was to demonstrate that an air-breathing scramjet engine could function at hypersonic speeds, specifically Mach 7 to Mach 10, using hydrogen fuel and atmospheric oxygen (unlike rockets that carry both fuel and oxidizer).

X-43A

Feature	Description
Type	Uncrewed hypersonic research aircraft
Length	~12 ft (3.7 m)
Wingspan	~5 ft (1.5 m)
Weight	~3,000 lb (1,360 kg)
Propulsion	Scramjet engine (hydrogen-fueled)
Top Speed	Mach 9.6 (~7,310 mph / 11,760 km/h)
Altitude	~110,000 ft (~33.5 km)

X-43A

Flight	Date	Speed	Result
1	June 2001	Mach 7	Booster failure (loss)
2	March 27, 2004	Mach 6.83	Success
3	November 16, 2004	Mach 9.68	Success (world record)

ASSET

ASSET stands for Aerothermodynamic/Elastic Structural Systems Environmental Tests. It was a U.S. Air Force and NASA joint experimental program during the early 1960s designed to test and evaluate hypersonic reentry vehicle technology, especially for future spaceplanes like the X-20 Dyna-Soar. ASSET was focused on:

- Studying aerodynamic heating and thermal protection systems (TPS)
- Testing materials and structural behavior under reentry conditions
- Gathering data for the X-20 Dyna-Soar (the Air Force’s planned manned spaceplane)

Rather than building full spacecraft, ASSET used uncrewed subscale reentry vehicles to simulate conditions of high-speed atmospheric reentry.

ASSET

Feature	Details
Shape	Small-scale lifting body/delta-wing shape
Length	~3.2 m (10.5 ft)
Wingspan	~1.5 m (5 ft)
Materials	Refractory metals (e.g., Rene 41), reinforced graphite, and ablative TPS for comparative studies
Launch Mass	~410–520 kg

Dong Feng (DF) 17.20

On 1 October 2019, the 70th anniversary of the establishment of the People's Republic of China, in a parade that reviewed the PLA's troops and weapon systems, the PLA revealed a new hypersonic missile, the Dong Feng (DF) 17.20 An article in the newsfeed for one of China's leading internet agencies, 163.com, described the DF-17 as a "nightmare predator" designed to attack the U.S. aircraft carrier fleet; it said that the defenses against hypersonic missiles were the weakest link in the U.S. defense system. According to the International Institute for Strategic Studies (IISS), the section of a report that discussed regional missiles in the DoD 2019 Missile Defense Review contained only a passing reference to "a previously unpublicized Chinese missile designated 'CSS-X-22.'"

- Hypersonic Weapons Development in China, Russia and the United States: Implications for American Security Policy Wortzel, L. M. (2022). Hypersonic weapons development in China, Russia and the United States. Association of the United States Army, Land Warfare. https://www.ausa.org/sites/default/files/publications/LWP-143-Hypersonic-Weapons-Development-in-China-Russia-and-the-United-States.pdf

SPRINT

The SPRINT missile—short for Sprint Anti-Ballistic Missile—was a high-speed, short-range missile developed by the United States during the Cold War as part of its layered anti-ballistic missile (ABM) defense system. Designed to intercept incoming nuclear warheads in their terminal phase, the SPRINT was one of the fastest accelerating missiles ever built. The SPRINT missile was engineered to:

- Destroy incoming enemy warheads (typically from ICBMs) within seconds of reentry, during their terminal descent phase.
- Protect strategic sites like missile silos or command centers from decapitation strikes.
- Function within the Safeguard ABM system, which included other interceptors like the Spartan missile (longer-range counterpart).

SPRINT

Feature	Specification
Length	~27 feet (8.2 m)
Diameter	~4.5 feet (1.37 m)
Launch Weight	~7,500 pounds (3,400 kg)
Stages	Two (solid propellant)
Top Speed	Mach 10+ (approx. 7,600 mph or 12,250 km/h)
Range	~25 miles (40 km)
Altitude Ceiling	~30 miles (48 km)
Warhead	Low-yield W66 thermonuclear warhead (~1 kt)
Guidance	Ground-command guidance with radar tracking

SPRINT

Deployment: The SPRINT system became operational briefly in 1975 at the Stanley R. Mickelsen Safeguard Complex in North Dakota.
Deactivation: Decommissioned just months after activation due to:

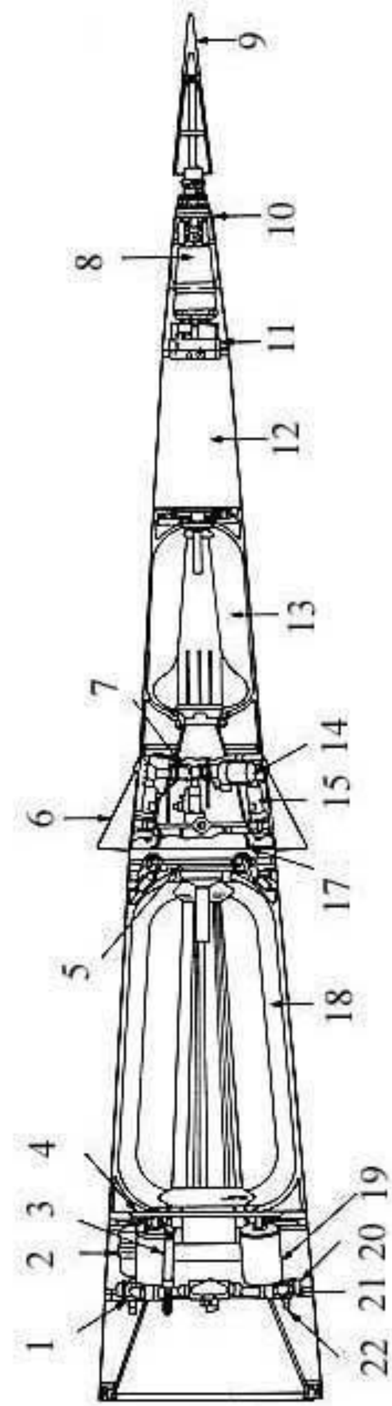
- High cost
- Strategic arms limitation agreements (SALT I)
- Doubts about its effectiveness in a saturation attack scenario
- Risk of nuclear detonation over U.S. territory

SPRINT

- Length: 8.2 meters (27 feet)
- Diameter: 1.35 meters (4.4 feet)
- Launch Weight: Approximately 3,500 kg (7,700 lbs)
- Propulsion:
  - First Stage: Hercules X-265 solid-fuel motor producing 2,900 kN (650,000 lbf) of thrust.
  - Second Stage: Hercules X-271 solid-fuel motor.
- Maximum Speed: Mach 10+ (over 12,000 km/h or 7,500 mph)
- Range: Approximately 40 km (25 miles)
- Ceiling: Up to 30 km (100,000 feet)
- Guidance: Ground-based radio command via phased-array radar systems.
- Warhead: W66 enhanced radiation (neutron) nuclear warhead with a yield of approximately 2 kilotons.
- Operational Highlights
  - Launch Mechanism: The missile was ejected from its underground silo using a gas-powered piston, breaking through a fiberglass cover.
  - Acceleration: Achieved speeds of Mach 10 within 5 seconds, subjecting the missile to extreme aerodynamic heating (up to 6,200°F or 3,400°C).
- Flight Control:
  - First Stage: Utilized fluid-injection thrust vectoring with Freon gas.
  - Second Stage: Employed aerodynamic fins controlled by hydraulic actuators.
  - Guidance Challenges: The high-speed flight created a plasma sheath around the missile, necessitating powerful radio signals from ground-based radars to maintain communication.
- Interception Timeframe: Designed to intercept incoming warheads within 15 seconds of launch, at altitudes between 1.5 km and 30 km.

SPRINT

1.Freon collector;
2.gas generator ;
3.receiver of hydraulic system;
4.collector ;
5.docking station;
6.aerodynamic steering wheels;
7.hydraulic system collector ;
8.control system unit ;
9.head cowl;
10.ring antenna ;
11.autopilot;
12.combat unit;
13.2-stage engine ;
14.hydraulic receiver ;
15.steering machines of steering wheels;
16.steering wheels .
17.heat protection of the step separation system ;
18.1-stage engine;
19.Freon receiver;
20.injection valve;
21.adjusting ring ;
22.reduction valve;



DF-17

The DF-17 medium-range ballistic missile mounted on its road-mobile 10×10 transporter erector launcher (TEL), shown during a 2022 exhibition in Beijing. The Dongfeng-17 (DF-17) is a Chinese solid-fueled medium-range ballistic missile (MRBM) equipped with a hypersonic glide vehicle (HGV) warhead known as the DF-ZF. It is a hypersonic boost-glide missile system, entering People's Liberation Army Rocket Force (PLARF) service in 2019. The DF-17 is road-mobile and designed to carry its HGV payload at hypersonic speeds to regional targets. The DF-17's payload is a single DF-ZF HGV mounted atop the booster. Chinese sources emphasize the DF-17's conventional warhead role, though U.S. intelligence assesses it to be nuclear-capable as well.

The HGV's guidance likely relies on a combination of inertial navigation systems (INS) and satellite positioning (BeiDou) to adjust its glide trajectory. This ensures that even after a long-range ballistic boost and maneuverable glide, the warhead can home in on a fixed target with pinpoint accuracy. If developed into an anti-ship variant (as speculated), the DF-17's guidance might incorporate a terminal seeker (radar or infrared) to hit moving targets like ship.

DF-17

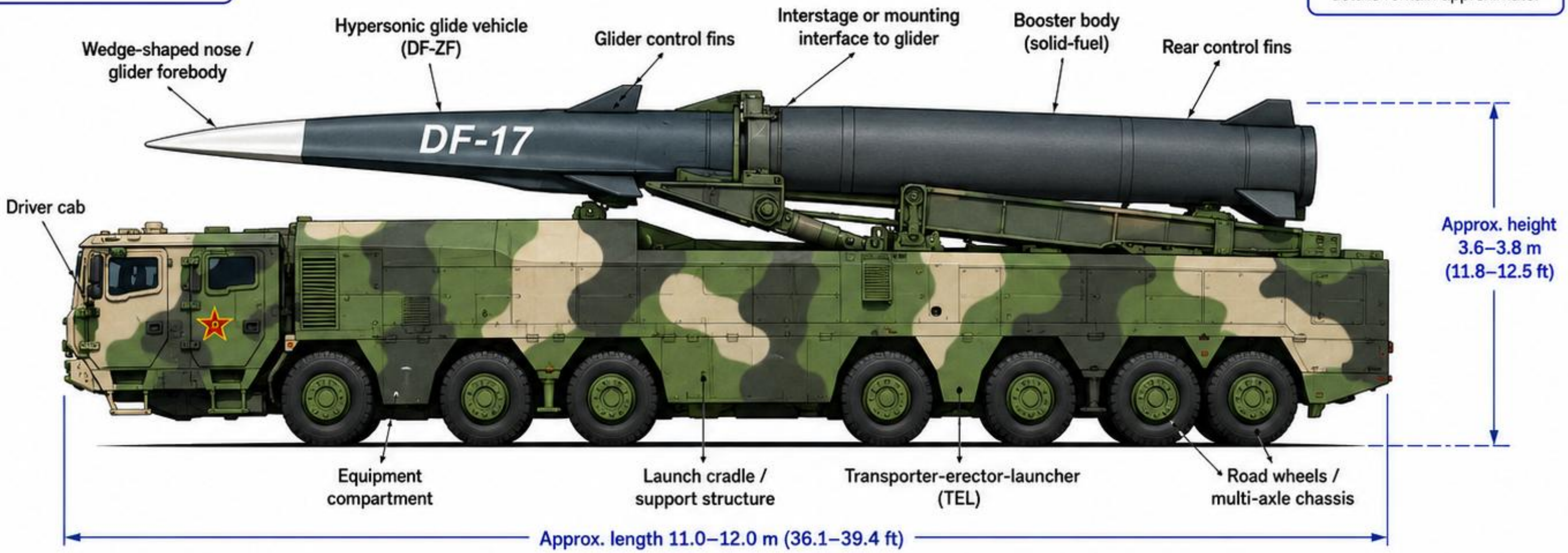
Chinese Road-Mobile Hypersonic Boost-Glide Missile System

Role

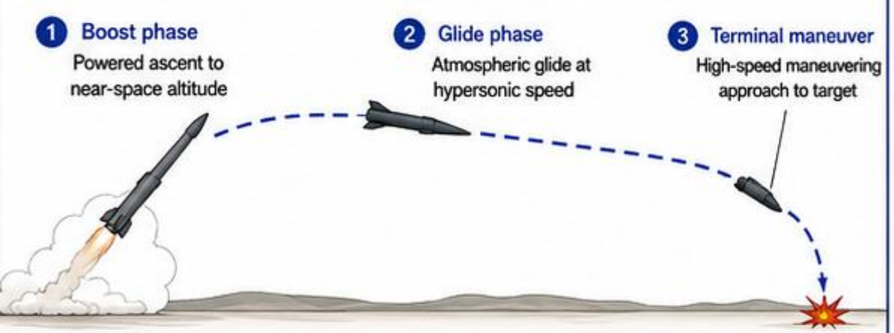
Medium-range boost-glide weapon system designed for prompt regional strike.

Open-source notes

Publicly associated with the DF-ZF hypersonic glide vehicle; exact dimensions and internal details remain approximate.



Flight profile (boost-glide concept)



Open-source key data (approximate)

- **Estimated range:** 1,800–2,500 km
- **Propulsion:** solid-fuel booster
- **Launch platform:** road-mobile TEL
- **Payload type:** hypersonic glide vehicle (DF-ZF)
- **Status:** operational (open-source reporting)

3/4 Perspective View (front left)

Legend

- Glide vehicle (DF-ZF)
- Booster (solid-fuel)
- TEL (road-mobile)
- Flight profile (3-stage concept)

Diagram based on public imagery and open-source reporting; some dimensions and subsystem details are approximate.

All dimensions approximate. Not to scale.

Dong Feng (DF) 17

Chinese/U.S. Designation	DF-17
Role and Mobility	Hypersonic Glide Vehicle-armed Medium-Range Ballistic Missile
Designer/Production	People's Republic of China
Range	1,800 – 2,500 km
Warhead Type and Weight	Conventional, Nuclear, Hypersonic; Unknown
MIRV and Yield	No MIRV Capabilities; Unknown
Guidance System/Accuracy	Unknown; Several Meters
Stages/Propellant	Unknown; Solid
IOC/Retirement	2020; In Service
Status/Number of Units	In Service; Unknown

China’s DF-ZF

The DF-ZF (originally codenamed WU-14 by U.S. intelligence) is a hypersonic glide vehicle (HGV) developed by the People’s Liberation Army Rocket Force (PLARF). It is launched atop a ballistic missile and then glides at hypersonic speeds in the atmosphere toward its target. It is part of China's broader strategy for anti-access/area-denial (A2/AD) and rapid global strike capabilities.

The DF-17 is a solid-fueled, road-mobile medium-range ballistic missile. First publicly revealed during China’s 70th anniversary parade (2019). Designed specifically to carry the DF-ZF HGV, marking China’s first operational hypersonic weapon system.

Feature	Description
Type	Hypersonic Glide Vehicle (HGV)
Launch Platform	Mounted on a medium-range ballistic missile (typically DF-17)
Speed	Mach 5 to Mach 10+ (6,000–12,000+ km/h)
Range	Estimated 1,800–2,500 km (possibly more depending on carrier rocket)
Flight Profile	Boost-glide: Launched on a ballistic trajectory, then detaches and glides
Altitude	Lower than traditional ICBM trajectories (~40–100 km), avoiding radar
Guidance	Likely inertial navigation + terminal guidance (potentially radar or IR)

China’s DF-27

- The DF-27 is still unconfirmed by China and largely known through U.S. and foreign intelligence leaks. Technical details (warhead yield, guidance, MIRV use) remain ambiguous or speculative .

China’s DF-27

- Missile Class: Hypersonic Glide Vehicle (HGV)-armed Intermediate/Intercontinental-Range Ballistic Missile (IRBM/ICBM)
- Origin: First noted in the 2021 U.S. DoD China Military Power Report; PLA documents cite IRBM/ICBM-range (5,000–8,000 km)
- Leaked Test: February 25, 2023 – reportedly flew ~2,100 km in ~12 minutes at hypersonic speeds, deploying an HGV
- Estimated Range: 5,000–8,000 km at full range
- Test Range: ~2,100 km achieved in ~12 minutes — implies avg Mach ~8.6
- Speed: Hypersonic; approximations suggest up to Mach 10+

China’s DF-27

- HGV Warhead: Maneuverable, atmospheric-gliding warhead capable of evading defenses .
- Fuze Options: Likely supports conventional and nuclear warheads. Some reports suggest modular HGV and conventional/nuclear payloads depending on version .
- Anti-Ship Role: Likely includes variants targeting carriers or naval groups.
- Launch Platform: Road-mobile TEL system, akin to DF-26/DF-17 series
- Support Vehicles: Accompanied by command/control and support trucks

North Korea's Hwasong-8

- Type: Boost-glide vehicle (HGV) mounted on a liquid-fueled ballistic missile booster.
- First Test: 29 September 2021
- Subsequent launches followed in January 2022
- Specs: Equipped with arrow-shaped HGV similar to China's DF-17; estimated range 2,000–4,000 km; speed Mach 5+
- Represents DPRK's first public hypersonic demonstration using a MaRV-like warhead

North Korea’s Hwasong-12B

This is unconfirmed. Single-stage, road-mobile, liquid-fueled intermediate-range ballistic missile (IRBM) equipped with a hypersonic glide vehicle (HGV). It derives from the base Hwasong-12 booster but integrates an HGV warhead stage. The booster is a shortened version of the Hwasong-12; mounted on a 6-axle transporter-erector-launcher (TEL)

- Range: Believed to exceed 6,000 km (~3,700 mi), extending it significantly past the ~4,500 km of the original Hwasong-12
- Warhead: Utilizes a hypersonic glide vehicle, capable of maneuvers at hypersonic speeds, making interceptions more challenging than traditional ballistic RVs
- Propulsion: Liquid propellant engine. While exact specs unreported, it's likely based on the “March 18” engine used in both Hwasong-12 and later North Korean ICBMs

Hwasong-12B

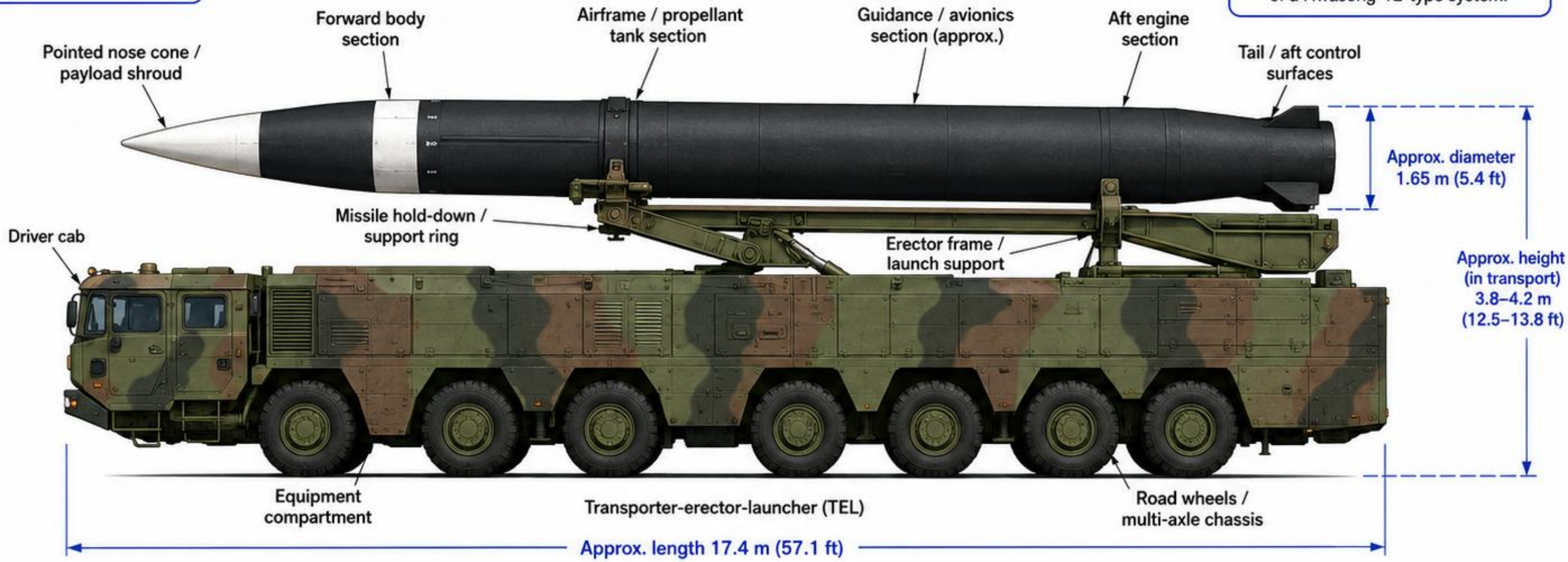
North Korean Road-Mobile Intermediate-Range Ballistic Missile (Open-Source Depiction)

Role

ntermediate-range ballistic
nissile intended to deliver a
conventional warhead for
regional strike missions.

Open-source notes

"Hwasong-12B" details are limited in public sources. Dimensions and subsystem labels are approximate and based on open-source reporting of a Hwasong-12-type system.

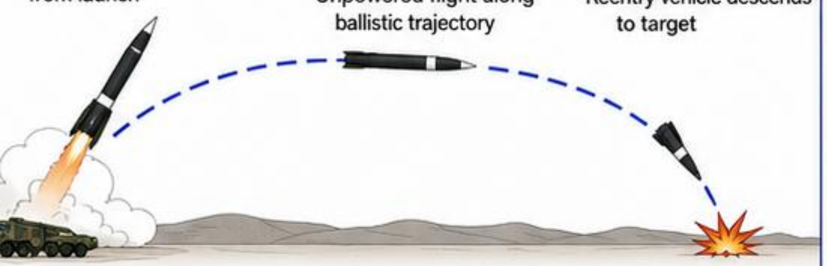


Flight profile (ballistic concept)

1 **Boost phase**
Powered ascent from launch

2 **Midcourse ballistic flight**
Unpowered flight along ballistic trajectory

3 **Reentry / terminal phase**
Reentry vehicle descends to target



Open-source key data (approximate)

- **Estimated range:** up to ~4,500 km
- **Propulsion:** single-stage liquid propellant
- **Payload:** single warhead, ~500 kg
- **Launch platform:** road-mobile TEL
- **Status:** in development / deployed in limited numbers (open-source reporting)

3/4 Perspective View (front left)

Legend

Missile — TEL — Flight profile

Diagram based on public imagery and open-source reporting; some dimensions, terminology, and subsystem details are approximate. Not to scale.

North Korea’s Hwasong Series

Missile	Propulsion	Warhead Type	First Test/Public	Range*	Notes
Hwasong-8	Liquid	Boost-glide HGV	Sep 2021	2,000–4,000 km	Liquid booster, arrow-shaped warhead
Hwasong-12B	Liquid	HGV	Jul 2023	—	Not yet flight-tested
Hwasong-12A	Liquid	MaRV/HGV	Jan 2022	~700 km	“Hypersonic” maneuvering warhead
Hwasong-16A/B	Solid	HGV	Apr 2024 / Jan 2025	~1,000–1,500 km	Solid-fuel, rapid launch, more mobile

Hwasong-17

The Hwasong-17 is a long-range intercontinental ballistic missile (ICBM) developed by North Korea. It is one of the most powerful and advanced missiles in the country's arsenal, representing a significant leap in North Korea's missile development capabilities. The Hwasong-17 is particularly notable for its size, range, and potential to deliver multiple warheads or a large nuclear payload, making it a crucial part of North Korea's nuclear deterrence strategy. It uses a two-stage, liquid-fueled engine

The **Mako Multi-Mission Hypersonic Missile**

Mako is among Lockheed Martin’s first generation of missiles designed entirely in a digital engineering ecosystem. It benefits from model-based systems engineering best practices and an integrated, model-based enterprise supports the life cycle of the weapon. Due to its digital and open architecture design, Mako supports rapid integration of mission-specific elements like warheads and seekers, which empowers users to upgrade Mako with no proprietary entanglements. It enables them to keep pace with evolving threats. Lockheed Martin offered Mako for the U.S. Air Force’s Stand-in Attack Weapon (SiAW) program. While Lockheed Martin chose not to continue into phase 2, Mako benefits from the innovations and maturation efforts invested in it as the Air Force’s first fully digital acquisition missile. It is specifically designed to fit in the internal weapons bay of the F-35A/C and F-22A. It is the first hypersonic weapon compatible with a fifth-generation fighter. The missile was unveiled in April 2024 at the Navy League’s Sea Air Space exposition in Maryland, with Lockheed Martin pitching it to both the U.S. Navy and Air Force.

- https://www.lockheedmartin.com/en-us/capabilities/hypersonics.html?gad_source=1&gad_campaignid=13175313327&gclid=Cj0KCQjwss3DBhC3ARIsALdgYxPUBNOVB54kH9ZEM-xP4AanfwZWlZAX_N-xU-5y3snioIvH7bFaDsQaAtaNEALw_wcB

The **Mako Multi-Mission Hypersonic Missile**

The Mako can be carried (internally) by the U.S. Air Force’s F-35A, the U.S. Navy’s F-35C, as well as fourth generation fighters like the F/A-18 Super Hornet, the F-15, F-16 and even the P-8A Poseidon maritime patrol and reconnaissance aircraft. Lockheed Martin says the weapon has been fit checked on these aircraft to verify they can carry it.

- https://theaviationist.com/2024/08/05/lockheeds-mako-missile/

Russia's Avangard

Avangard is a nuclear-capable hypersonic glide vehicle developed by Russia. It is launched atop an intercontinental ballistic missile (ICBM) and glides toward its target at extremely high speeds within the Earth's atmosphere. It is designed to evade missile defenses, deliver a strategic nuclear payload, and ensure second-strike capability under Russia's deterrence doctrine.

Feature	Description
Type	Hypersonic Glide Vehicle (HGV)
Launch Platform	Primarily UR-100NUTTKh (SS-19 Stiletto) ICBM; future plans for RS-28 Sarmat
Speed	Mach 20–27 (24,000–33,000 km/h; 15,000–20,000 mph)
Range	~10,000+ km (intercontinental)
Payload	Nuclear warhead (~2 megatons reported); conventional use unlikely
Flight Profile	Boost-glide with high atmospheric maneuverability
Operational Status	Declared operational by Russia in 2019
Material TPS	Carbon-carbon composite or ceramic
Nose Radius	~0.5–1.0 m

RS-28 Sarmat

The Sarmat is a Russian three-stage, liquid-fueled missile with a range of 18,000 km and a launch weight of 208.1 metric tons.[7] The missile is 35.3 meters long and 3 meters in diameter.[8] Designated a "heavy" ICBM, the Sarmat can carry a 10 ton payload and can load a wide variety of warhead options.[9] According to Russian media, Sarmat can reportedly load up to 10 large warheads, 16 smaller ones, a combination of warheads and countermeasures, or hypersonic boost-glide vehicles.

-Missile Defense Project, "RS-28 Sarmat," *Missile Threat*, Center for Strategic and International Studies, May 17, 2017, last modified April 23, 2024, https://missilethreat.csis.org/missile/rs-28-sarmat/.

Role

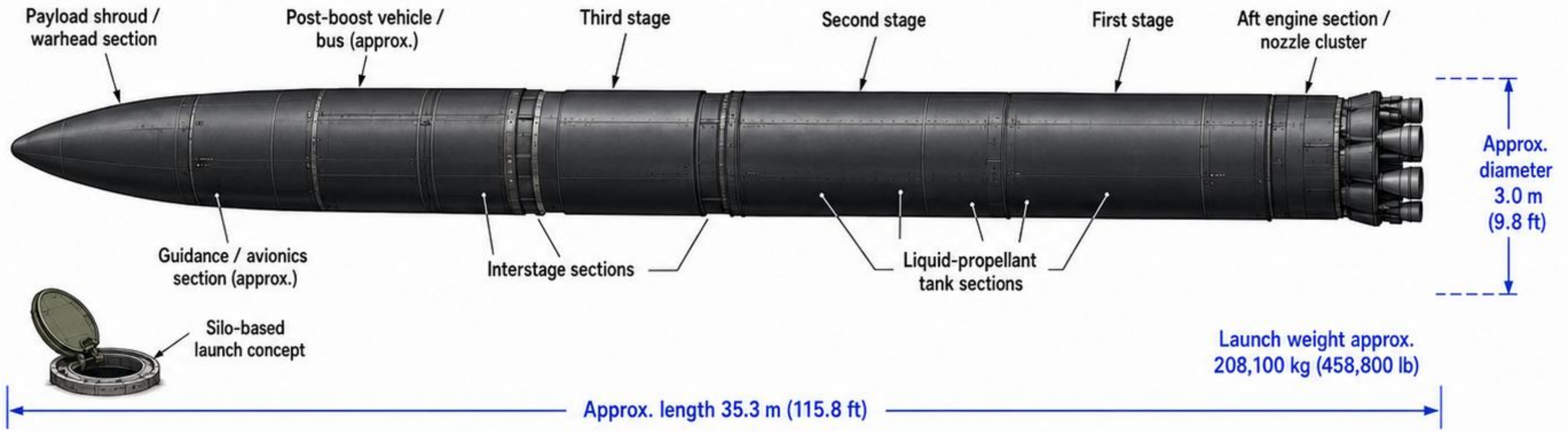
Heavy intercontinental
allistic missile intended for
rategic nuclear deterrence
and long-range strike.

RS-28 Sarmat

Russian Silo-Based Heavy Intercontinental Ballistic Missile (Open-Source Depiction)

Open-source notes

Public reporting on Sarmat varies. Dimensions, payload configuration, and subsystem labels are approximate and based on open-source sources.



Silo-based launch system

Flight profile (ballistic concept)

1 **Boost phase** – Powered ascent from silo launch

2 **Midcourse / bus deployment** – Ballistic flight and payload dispensing

3 **Reentry / terminal phase** – Warheads descend toward targets

Open-source key data (approximate)

- **Estimated range:** 10,000–18,000 km
- **Propulsion:** three-stage liquid-fueled
- **Basing:** silo-based
- **Payload:** up to ~10,000 kg; MIRV or glide payload reporting
- **Launch weight:** ~208,100 kg
- **Status:** testing / deployment claims in open-source reporting

3/4 Perspective View

egend

ⓘ Diagram based on public imagery and open-source reporting; some dimensions, terminology, and subsystem details are approximate. Not to scale.

RS-28 Sarmat

- Length 36 m
- Diameter 3.5 m
- Weight 208 tons
- Speed 25,500 km/h (Mach 20)
- Maximum Warhead Capacity 10,000 k

- There have been major test failures
- https://www.aljazeera.com/news/2024/9/24/russias-new-sarmat-missile-suffered-catastrophic-failure-researchers
- https://www.armscontrol.org/act/2024-11/news/sarmat-failure-casts-doubt-russian-heavy-icbm

RS-28 Sarmat

A Russian RS-28 Sarmat heavy intercontinental ballistic missile (ICBM) exploded in September 2024 at its test launch site, marking another setback for a missile that Russian authorities claim is already on active combat duty. Unlike a previous test failure in February 2023, which was confirmed by U.S. officials, the latest mishap was visible to open-source analysts. Satellite images, taken Sept. 21 by Planet Labs and shared by analysts on social media and later corroborated by images published by Reuters from Maxar Technologies, demonstrated that a Sarmat test silo at the Plesetsk Cosmodrome was destroyed completely either during the missile test or after the test's cancellation.

- https://www.armscontrol.org/act/2024-11/news/sarmat-failure-casts-doubt-russian-heavy-icbm

Hypersonic Air-breathing Weapon Concept (HAWC)

- The Hypersonic Air-breathing Weapon Concept (HAWC) program is a joint DARPA/U.S. Air Force (USAF) effort that seeks to develop and demonstrate critical technologies to enable an effective and affordable air-launched hypersonic cruise missile. The program intends to emphasize efficient, rapid and affordable flight tests to validate key technologies.
- Propulsion: Air-breathing scramjet engine
  - Uses oxygen from the atmosphere, unlike rockets that carry their own oxidizer
- Speed: Greater than Mach 5
- Range: Classified, but expected to be hundreds of miles
- Altitude: High-altitude cruise capability
- Warhead: Capable of carrying conventional (non-nuclear) payloads

Zircon (Tsirkon)

- Developer: NPO Mashinostroyenia (a part of Russia's Tactical Missiles Corporation)
- Operator: Russian Navy (and potentially future deployment by other branches)
- Zircon is designed to engage both sea-based and land-based targets with hypersonic speed and maneuverability, making it extremely difficult to intercept

Feature	Specification
Type	Hypersonic cruise missile
Speed	Up to Mach 8–9 (approx. 9,800–11,000 km/h or 6,100–6,800 mph)
Range	Estimated 400–1,000 km (250–620 miles), with reports of up to 1,500 km (930 miles)
Altitude	High-altitude cruise, terminal dive toward target
Launch Platform	Ships (frigates, corvettes), submarines, and possibly aircraft in the future
Guidance	Inertial navigation system (INS) with terminal guidance (likely radar and/or optical)
Warhead	High-explosive (conventional) or nuclear (reportedly possible)

Zircon (Tsirkon)

- Zircon is part of the arsenal for the modernized Russian naval forces, especially:
- Project 22350 Admiral Gorshkov-class frigates
- Yasen-class nuclear submarines (e.g., Kazan, Severodvinsk)
- Potential integration on Project 885M submarines and future aircraft (hypothetical)

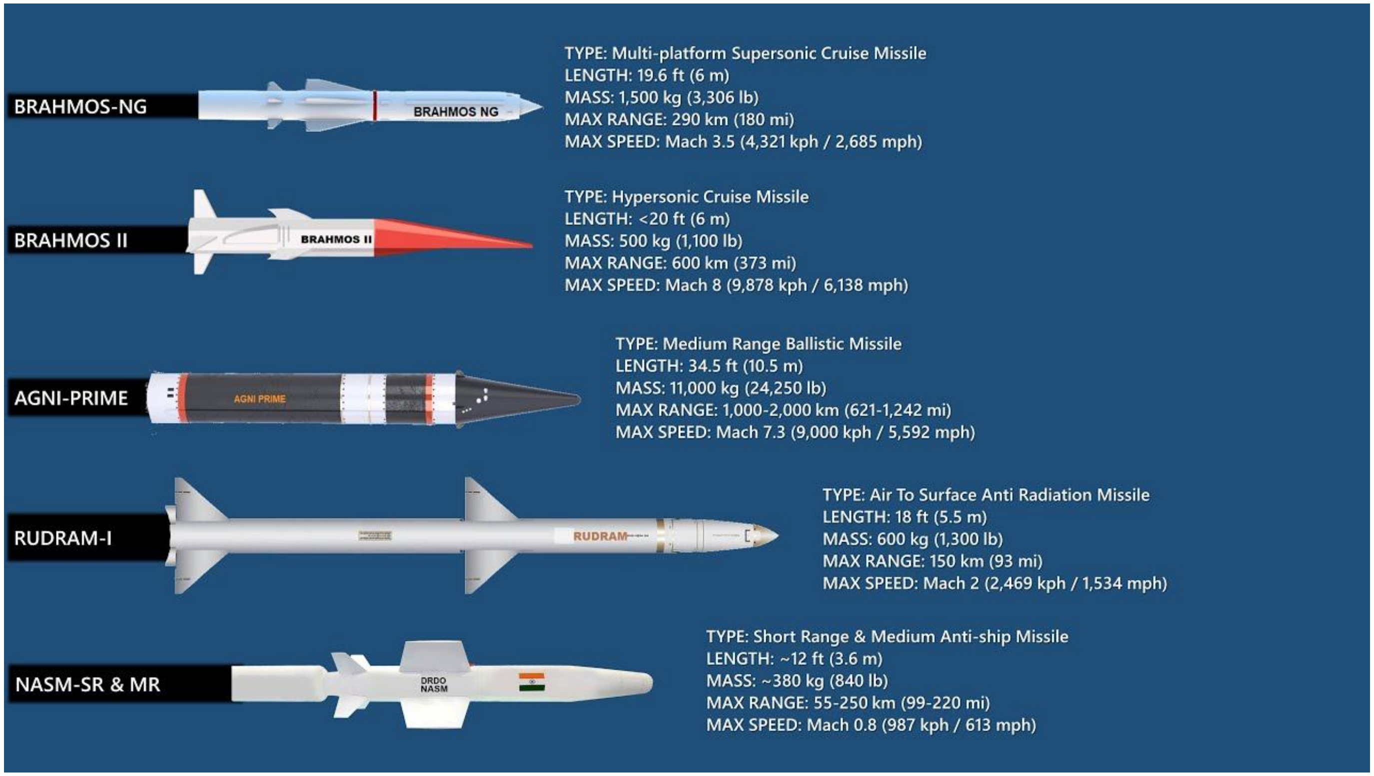
BrahMos-II

Feature	Specification
Speed	Mach 6–7+ (7,400–8,600 km/h or 4,600–5,300 mph)
Range	Estimated 450–600 km (possibly extendable with newer tech)
Payload	Approx. 200–300 kg (high-explosive warhead; possibly nuclear-capable in theory)
Propulsion	Likely scramjet engine, enabling sustained hypersonic speed
Launch Platforms	Ground-based, ship-based, submarine-launched, and possibly aircraft-compatible in the future
Guidance System	Advanced INS + terminal guidance (possibly radar or satellite-aided targeting)

- The BrahMos-II is a next-generation hypersonic cruise missile under joint development by India and Russia, building on the success of the subsonic BrahMos missile. It represents a significant technological leap in speed and strike capabilities and is intended to be one of the fastest cruise missiles in the world.
- Name: BrahMos-II (also referred to as BrahMos Mark II or BrahMos 2K)
- Developers: India: Defence Research and Development Organization (DRDO)
- Russia: NPO Mashinostroyenia
- Joint Venture: BrahMos Aerospace (formed in 1998 for the original BrahMos program)
- Missile Type: Hypersonic cruise missile

BrahMos-II

- Derived from Russia's Zircon technology and adapted for Indian operational needs
- Designed to penetrate advanced air defense systems by virtue of its extreme speed and maneuverability
- Capable of engaging both land-based and naval targets
- The missile's speed drastically reduces reaction time and increases survivability against interception



France’s V-MAX

Name: V-MAX (Véhicule Manoeuvrant Expérimental)
Type: Hypersonic Glide Vehicle (HGV)
Developer: ArianeGroup (under DGA supervision)
Speed: Hypersonic (target: Mach 5+)
Purpose: Defense technology demonstrator and research platform
Launch Platform: Ballistic missile launcher (testbed)

First Test Flight

- Date: June 26, 2023
- Location: Biscarrosse missile test range (southwest France)
- Launch System: Medium-range ballistic missile as booster
- Outcome: Described as a success by DGA, marking France's entry into active hypersonic test regimes

D.Sc.

France’s V-MAX

Feature	Details
Speed	Mach 5+ (classified exact speed)
Flight Profile	Ballistic launch → atmospheric glide phase
Maneuverability	Designed to perform evasive maneuvers mid-flight
Thermal Shielding	Advanced heat-resistant materials tested
Payload	Non-nuclear (for testing); operational intent unclear

X-51A waverider

- After the successful flight demonstrations of the NASA X-43A scramjet vehicle, the most significant activity in the United States was the Air Force SED-WR Program. The joint Air Force Research Laboratory (AFRL)/Defense Advanced Research Projects Agency (DARPA) X-51A Scramjet Engine Demonstrator-WaveRider (SED) vehicle was the flight demonstration of AFRL's Hypersonic Technology (HyTech) program. The HyTech program had several successful engine ground tests, but true scramjet viability was demonstrated with the X-51A SED in a series of 4 flight tests that began in 2010. With the X-51A waverider, the program demonstrated a practical scramjet engine burning JP-7 jet fuel at flight speeds between Mach 6.0 and 7.0+. At the same time, it aimed to extend the scramjet burn time to 300 seconds or more – a full 5 minutes of hypersonic flight.

- Musielak, Dora. Scramjet Propulsion: A Practical Introduction (Aerospace Series) . Wiley. Kindle Edition.

X-51A waverider

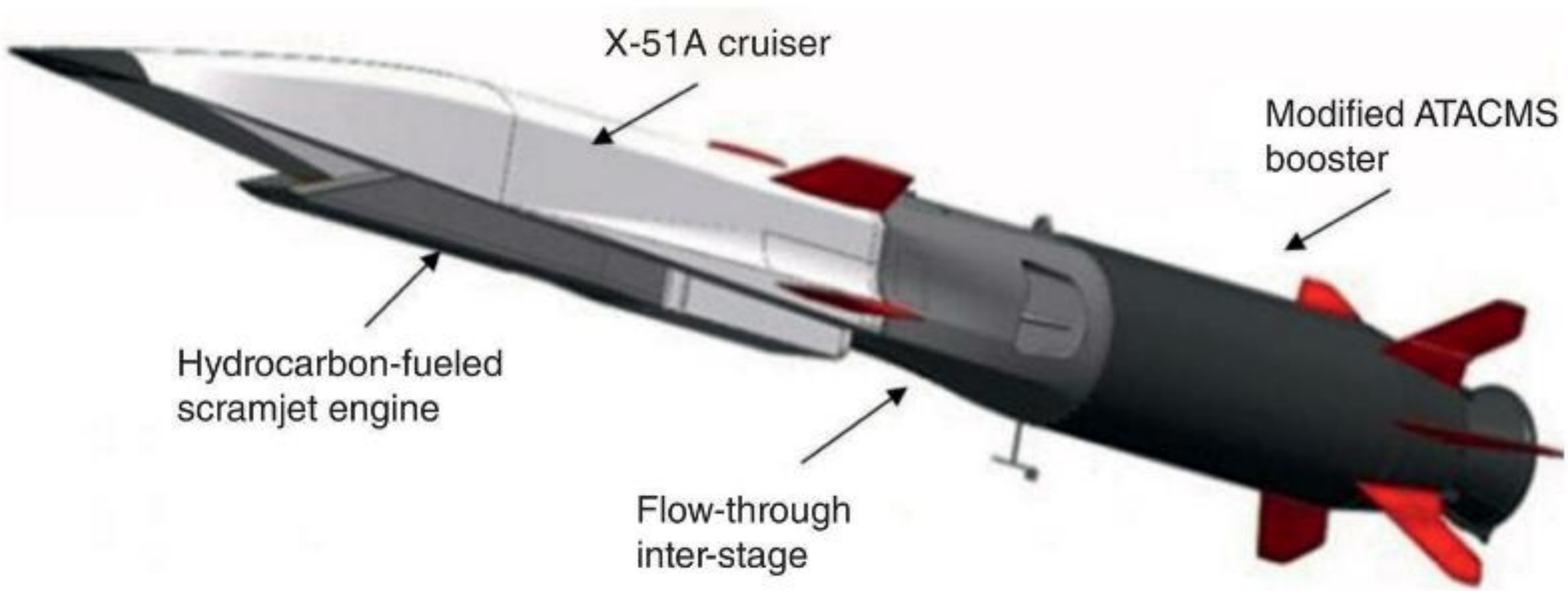
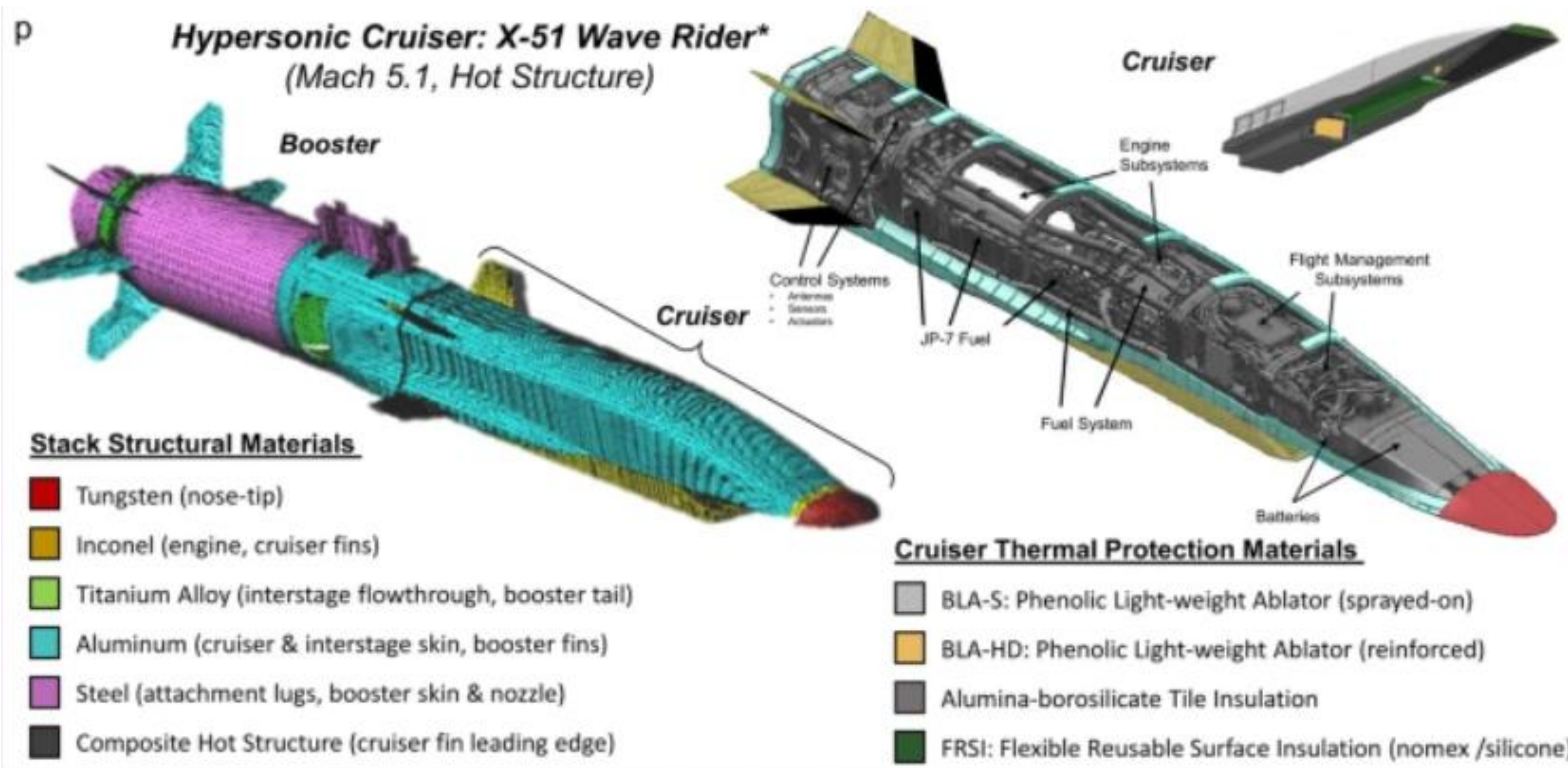


Figure 1.13 USAF X-51A Stack.

X-51A waverider



Long Range Hypersonic Weapon (LRHW) – Dark Eagle

In August 2023, the Army transitioned to Middle Tier of Acquisition (MTA) rapid fielding authorities to deliver a ground-launched Long Range Hypersonic Weapon (LRHW) (Dark Eagle). The Army program consists of the LRHW transporter-erector-launcher (TEL) and battery operations center (BOC). The Navy is developing the prototype All-Up Round (AUR) under the Conventional Prompt Strike (CPS) program, which is being reported on in a separate article, and supplying them to the Army

Long Range Hypersonic Weapon (LRHW) – Dark Eagle

Design & Components

1. Booster:

- Two-stage solid-fuel rocket (34.5″ diameter), built by Lockheed Martin (with Northrop Grumman and Dynetics support) .

2. Common Hypersonic Glide Body (C-HGB):

- Unpowered glider developed by Dynetics (Leidos subsidiary), based on the Alternate Re-Entry System, designed for high-speed, maneuverable glide flight

3. All-Up-Round (AUR):

- The complete missile-stack (booster + C-HGB + canister), ready for launch.

Performance Specs

- Range: ~1,725 miles (~2,775 km)
- Speed: ≥ Mach 5 (reports up to Mach 17 during glide phase)
- Altitude: Climbs into upper atmosphere before gliding
- Unit Cost: ~US $41 million per round

Kinzhal

The Kh-47M2 Kinzhal (NATO: AS-24 Killjoy) is Russia's air-launched hypersonic ballistic missile, a key strategic asset in its arsenal.

•Type: Hypersonic, air-launched ballistic missile
•Based on: Modified Iskander-M SRBM airframe with added rocket motor
•First public launch: March 2018 from a MiG-31K interceptor.
•Length: ≈ 7.2 m, diameter: ≈ 1.2 m
•launch weight: ~4,300 kg

•Warhead: Conventional or nuclear (5–50 kt yield)

•Range:

- From MiG-31K: ~1,500–2,000 km

•Speed: Up to Mach 10–12 (~3,400 m/s)

Kinzhal

- Entered operational service in December 2017–2018
- First combat use reported in Ukraine conflict (2022)
- Designed to penetrate advanced air defenses, striking high-value targets, including ships and ground infrastructure
- Recent reports suggest Ukrainian Patriot systems have successfully intercepted multiple Kinzhal missiles

Feature	Kh-47M2 Kinzhal
Launch	MiG-31K, Tu-22M3
Weight	~4,300 kg
Range	1,500–3,000 km
Speed	Mach 10–12
Warhead load	Conventional or nuclear
Guidance	INS + mid-course, terminal maneuvering
Operational since	2017–18
Combat use	Ukraine (2022)
Intercept reports	Patriot systems have reportedly succeeded

Iran’s Fattah-1

Iran’s Fattah-1 (also spelled Fateh) is Iran’s first claimed hypersonic ballistic missile, developed by the IRGC Aerospace Force and unveiled in 2023.

Feature	Reported Specs
Type	Solid-fueled, road-mobile MRBM with HGV/MaRV
Length	~12 – 15.3 m
Diameter	~0.8 – 1 m
Launch Weight	~12,000 kg
Range	~1,400 km (some mention 1,500–2,000 km) (missiledefenseadvocacy.org, defsecme.com)
Speed	Mach 13–15 (~15,000–18,500 km/h)
Warhead/Payload	350–450 kg fragmentation or conventional high-explosive
Guidance	Inertial + GNSS (INS/BeiDou/GPS) with claimed CEP of 10–25 m
Trajectory	Maneuverable reentry (MaRV) or HGV, claimed maneuverability to evade interceptors
Launch Platform	Road-mobile TEL on 10×10 truck chassis

Iran’s Fattah-1

Possible strengths:

- Hypersonic Speed & Maneuverability: Claimed to evade defenses like Iron Dome and Patriot due to high speed (Mach 13–15) and in-flight course changes
- Tactical Precision: GNSS/INS guidance purportedly achieves ~10–25 m CEP, making it accurate against critical targets .
- Mobile Launch Capability: Road mobility enables launch from various locations, complicating detection and pre-emption
- Potential Naval Variant: Plans reported to deploy Fattah on naval platforms like Moudge-class destroyers, widening its utility

Note: Some analysts question the “hypersonic” classification, suggesting it might be a MaRV-equipped ballistic missile rather than a true HG

IRAN'S FATTAH-1 HYPERSONIC MISSILE

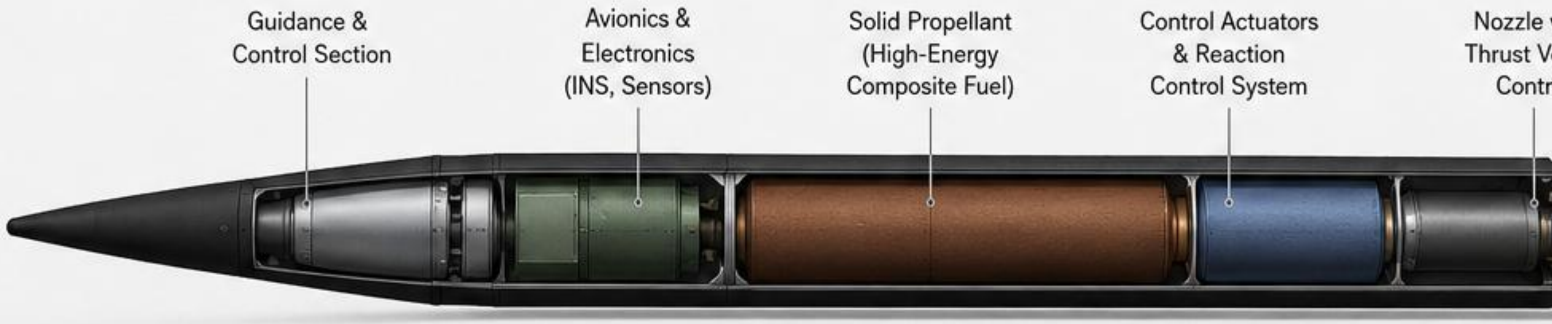
Iran's first operational hypersonic missile unveiled in June 2023

The Fattah-1 is a solid-fuel, maneuverable hypersonic missile designed to penetrate advanced air defenses with speed, agility and precision.

SPECIFICATIONS

Type: Hypersonic Ballistic Missile
Propulsion: Solid Fuel
Length: ~12 m (39 ft)
Diameter: ~0.80 m (31.5 in)
Weight: ~3,500 – 4,000 kg
Warhead: ~450 – 650 kg (conventional)
Range: ~1,400 km (750 – 900 miles)
Speed: Mach 13 – Mach 15+
Guidance: Inertial Navigation System with terminal maneuvering
Launch Platform: Mobile TEL (Transporter Erector Launcher)

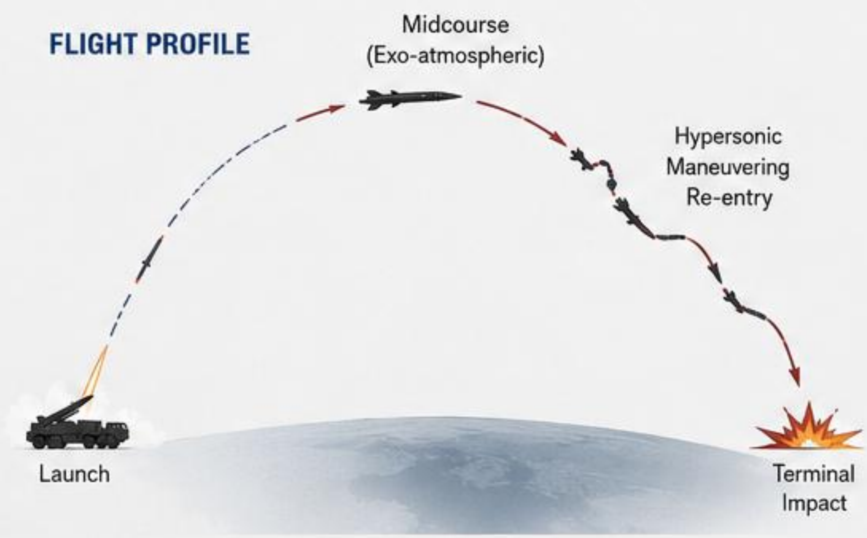
COMPONENTS (CUTAWAY VIEW)



LAUNCH PLATFORM

Mobile TEL (Transporter Erector Launcher)

FLIGHT PROFILE



KEY FEATURES

- Hypersonic speed (Mach 13-15+
- Highly maneuverable in terminal
- Solid fuel for quick launch readi
- Designed to evade advanced m defense systems
- Capable of precision strikes on c targets

COMPARISON (SELECT HYPERSONI

Missile	Speed	
Fattah-1 (Iran)	Mach 13-15+	~
DF-17 (China)	Mach 5-10	~2
Avangard (Russia)	Mach 20+	~6
RS-28 Sarmat (Russia)	Mach 20+	~1

Note: Specifications are based on open-source assessments and may not reflect exact values.

Sources: Open-source intelligence (OSIN

Hypersonic Missile Comparison

Parameter	Dark Eagle	Avangard	Zircon	Kinzhal	DF-17
Speed	Mach 5–17	Mach 27–30	Mach 8–9	Mach 10	Mach 5–10
Range	~2,775 km	ICBM/global	~400–1,000 km	~500 km	1,800–2,500 km
Platform	Tel-mobile, sea, sub	ICBM	Ships/subs	Air-launched	Road-mobile
Role/Payload	Conventional prompts	Nuclear strategic	Anti-ship, conventional	Tactical conventional	Conventional tactical

Today's New Problem- "The Proto-zone"

The area above commercial airspace, i.e. 21 Km and below the area that can allow satellites to stay in orbit above Earth, i.e. 160 Km is finding more and more applications and this region needs to be considered formally by space legal experts.

Uses of this region include stable high altitude and stratospheric craft such as aerostats, Unmanned Aerial Systems (UAS), High Altitude Platform Systems (HAPS), and so-called "dark sky" research and relay stations.

These stable "non velocity" systems are in contrast to systems travelling at altitude, i.e. robotic stratospheric freighters, space planes, hyper sonic or super sonic aircraft, or military craft.

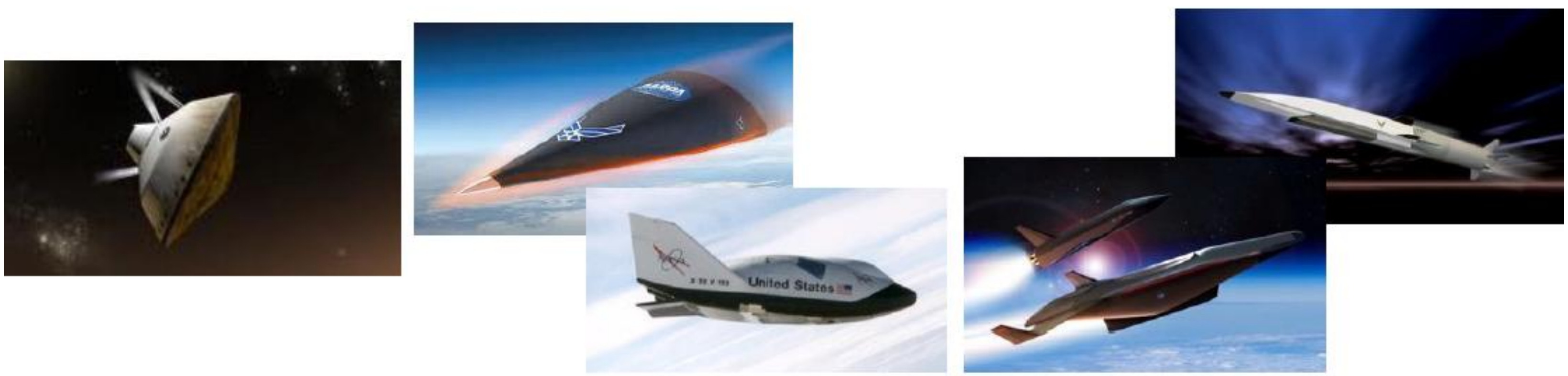
There is much discussion about the need for space traffic management and control, but there is an equal need to establish Protospace traffic management and control and coordinated use of this region that has increasing levels of use.

There is the additional element of concern for pollution to the stratosphere, especially with space planes with solid fuels.

NASA Hypersonics

HYPERSONICS

- Blunt Body Re-entry
- Unpowered Atmospheric Flight
- Powered / Sustained Atmospheric Flight



-NASA Hypersonics Overview November 2017

Dr. Chuck Easttom, M.Ed, MSDS, MBA, MSSE, Ph.D.[2], D.Sc.

NASA Hypersonics

Hypersonic air-breathing technologies enable horizontal flight and aircraft-like operations

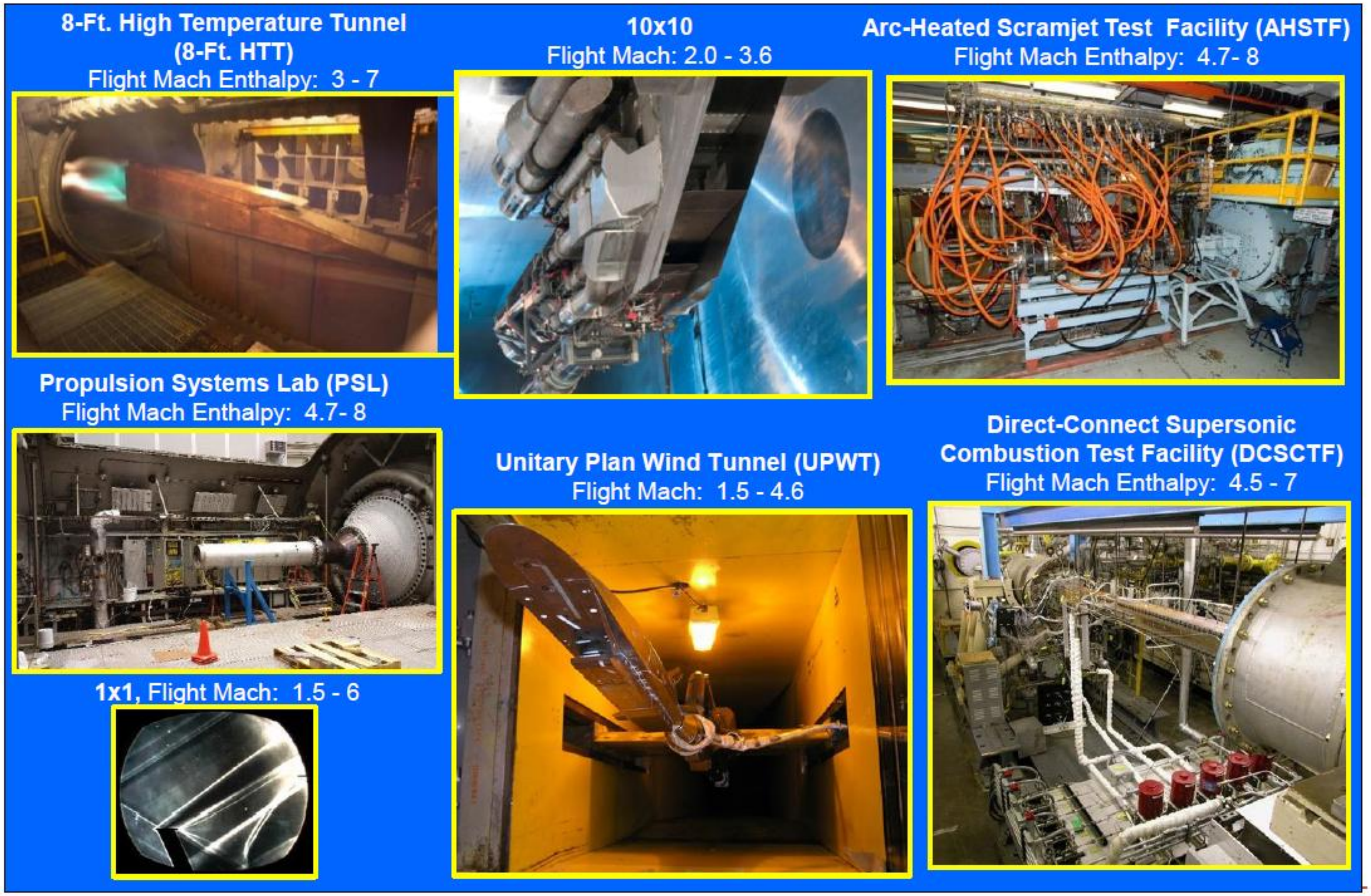
- Potential to seamlessly blend into national airspace
- Aerodynamic flight enables abort modes across the flight profile
- Conventional runway basing offers potential for more flexibility in operations including increased options for launch windows and increased orbit change / offset capability

Potential Applications

- Payload delivery, crew delivery, in-space servicing

-NASA Hypersonics Overview November 2017

NASA Hypersonics



-NASA Hypersonics Overview November 2017

MARV

A MaRV is a warhead or reentry vehicle mounted on a ballistic missile that can change trajectory after reentering Earth’s atmosphere. It uses aerodynamic control surfaces, thrusters, or reaction control systems to perform maneuvers.

- Boost Phase: Launched by a missile (e.g., MRBM or ICBM).
- Midcourse: Coasts through space like a standard ballistic trajectory.
- Reentry: As it descends into the atmosphere, aerodynamic controls activate.
- Maneuvering: It changes direction laterally or vertically to:
    - Evade interceptors
    - Correct trajectory for precision
    - Hit moving or hardened targets

MARV Examples

Missile System	Country	Notes
DF-21D	China	Anti-ship MaRV for carrier targeting
Agni-P	India	Features MaRV with terminal guidance
Pershing II	USA (retired)	Cold War-era nuclear MaRV with radar terminal guidance
Shaheen-III MaRV	Pakistan	Claimed to include MaRV-type terminal maneuverability
Iskander-M	Russia	Dual-capable SRBM with MaRV-like quasi-ballistic profile

FOBS

Feature	Description
Full Name	Fractional Orbital Bombardment System
Function	Places warhead into *partial* Earth orbit, then de-orbits to strike
Trajectory	Orbital or near-orbital (not a full revolution)
Launch Profile	Low Earth Orbit (LEO) arc with global reach capability
Reentry Profile	De-orbits at a chosen point to impact target area
Origin	USSR (1960s); concept revived in 2020s by China and possibly North Korea

FOBS stands for Fractional Orbital Bombardment System, a Cold War-era and now re-emerging concept involving orbital delivery of nuclear or conventional warheads. Unlike traditional intercontinental ballistic missiles (ICBMs), which follow a predictable high-arc ballistic trajectory, a FOBS weapon places its warhead into low Earth orbit and then de-orbits to strike a target from any direction—especially from angles not covered by early-warning systems.

FOBS

In August 2021, China tested what the U.S. Defense Department assessed as a hypersonic glide vehicle launched via FOBS, completing a fractional orbit before striking a ground target

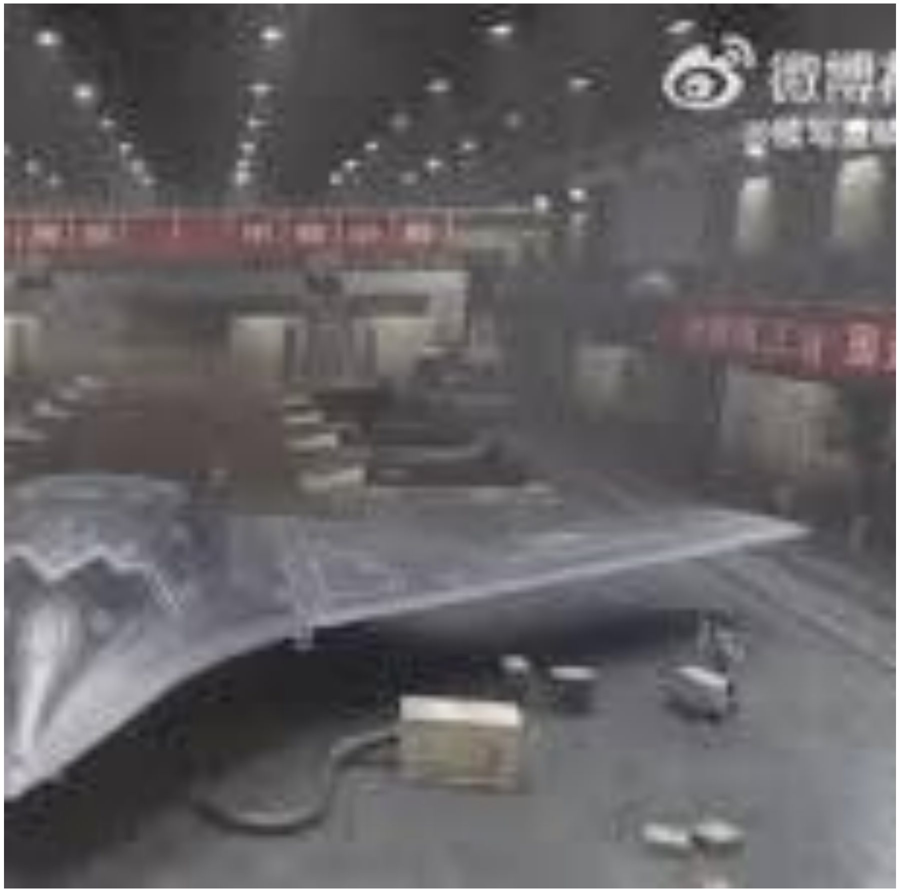
North Korea claimed in 2023 it tested a "hypersonic missile" using a FOBS-like trajectory, potentially to defeat U.S. and South Korean missile defenses

Feature	**FOBS**	**ICBM**	**HGV-based Missile**
Flight Profile	Partial orbit, deorbit strike	Suborbital ballistic arc	Boost-glide through upper atmosphere
Direction	Any (can approach from south)	Polar trajectories (northward)	Directional but maneuverable
Detectability	Difficult for legacy systems	Easily detected post-boost	Hard to track after boost
Precision	Low to moderate	Moderate	High (with terminal guidance)
Payload Types	Nuclear, conventional	Nuclear, conventional	Conventional, potentially nuclear

China's H-20 Stealth Bomber

Analysts estimate its operational range at 8,500 km (5,300 miles) or more, enabling it to strike targets across the Second Island Chain, including Guam, Hawaii, and potentially parts of the continental U.S.

.Payload capacity is believed to be at least 10 tons, with some estimates suggesting up to 45 tons of conventional or nuclear weapons including hypersonic weapons.



H-20

Chinese Stealth Strategic Bomber (Open-Source Depiction)

All dimensions, configuration, and subsystem labels are approximate and based on open-source analysis and concept imagery.

ROLE

A long-range stealth bomber designed to conduct strategic conventional and possible nuclear strike missions against high-value, time-sensitive targets.

OPEN-SOURCE NOTES

The H-20 has not been publicly unveiled. Details are based on limited imagery, official statements, and open-source reporting. Dimensions, configuration, and subsystem locations remain unconfirmed and approximate.

APPROXIMATE DIMENSIONS (ESTIMATED)

Estimated Wingspan: ~45–52 m | Estimated Length: ~20–25 m | Estimated Height: ~4–5 m

MISSION PROFILE (CONCEPTUAL)

1 Long-Range Ingress

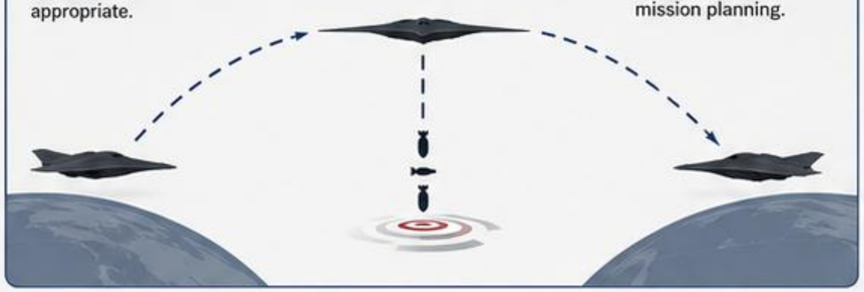
Stealthy penetration using low-observable design and terrain/EMCON where appropriate.

2 Weapons Release / Strike

Internal payload release against high-value targets.

3 Egress

Exit threat area using stealth, speed, and mission planning.



OPEN-SOURCE KEY DATA (APPROXIMATE)

Role:	Stealth Strategic Bomber
Configuration:	Subsonic Flying Wing
Estimated Range:	At least 8,500 km
Estimated Payload:	At least 10 metric tons
Crew:	Likely 2
Status:	In Development / Not Publicly Unveiled

3/4 PERSPECTIVE VIEW (CONCEPT)

LEGEND: Aircraft (Conceptual) | Mission Path (Conceptual) | Internal Weapons Bay (Approx. Location) | Engine Inlet (Approx. Location) | Exhaust (Shielded / Low Observable)

Diagram based on open-source reporting and concept imagery; not to scale.