Hypersonics & Defense: Accelerated Product, Process and Materials Development

CCAM Research Days

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UNIVERSITY of VIRGINIA

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- Director, Aerospace Research Laboratory
- University Consortium for Applied Hypersonics
  - Workforce Development Group
  - Research Engagement Committee
- AIAA Hypersonic Technologies and Aerospace Planes Technical Committee
- Aerospace Advisory Council for the Governor of Virginia
- Chair, Virginia Space Grant Consortium (VSGC) Advisory Council
- Trained at University of Queensland, Australia
- 20+ years research experience in field of hypersonics
- Learn more about hypersonics research at UVA:

  https://engineering.virginia.edu/research/engineering-technologies-sustainable-and-connected-world/hypersonic-research

  or Google: "UVA Hypersonics"

Background

- The United States is in a race with global competitors to develop and deploy hypersonic weapons and aircraft
- Hypersonic vehicles are very difficult to defend against due to their speed and maneuverability
- They present the risk of destabilizing many regions around the world if the U.S. and its allies are not appropriately equipped
- The U.S. is “five years behind in terms of where the Chinese are,” Sen. Angus King, I-Maine, Chair of the Senate Armed Services Subcommittee on Strategic Forces

POLITICO

DEFENSE

U.S. ‘not as advanced’ as China and Russia on hypersonic tech, Space Force general warns

While the Pentagon has pushed the development of new hypersonic missiles, the Army isn’t slated to field its first missile until 2024.

In this photo taken from a video distributed by Russian Defense Ministry Press Service on Oct. 7, 2020, Russian Zircon hypersonic cruise missile is launched. Washington, D.C.’s two primary competitors, China and Russia, are racing ahead in this technology. | Russian Defense Ministry Press Service via AP

By PAUL MCLEARY and ALEXANDER WARD
11/20/2021 04:30 PM EST

The Washington Post
Democracy Dies in Darkness

U.S. touts progress in hypersonic arms race with China, Russia

The Pentagon says it completed a successful hypersonic missile test this week and secured a $1.3 billion deal to help defend against such threats

By Karoun Demirjian
July 19, 2022 at 2:25 p.m. EDT

FOX NEWS .com

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Can the US catch China’s hypersonic missiles?

By Jennifer Griffin, Liz Friden

Published July 15, 2022

Fox News

It's been almost one year since China surprised the Pentagon and the world by carrying out a hypersonic glide vehicle test that traveled around the world and landed just two dozen miles from its target.

"The significance was it scared the hell out of everybody," Sen. Angus King told Fox News. "If the thing is dwelling over Kansas City, you're talking you're reducing 15 to 20 minutes to two to three minutes. That's a qualitative change."

Some officials in the Pentagon described it as a "Sputnik" moment because the Chinese leapfrogged the U.S. with a technology that could evade billions of dollars of missile defense, setting off an arms race.

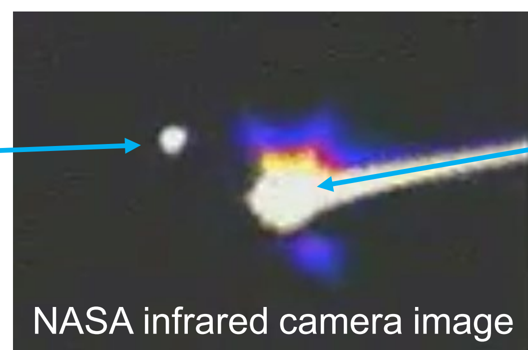
Hypersonic weapons fly at speeds of at least Mach 5, are highly maneuverable, are able to change course during flight and can fly 100 feet above the ocean undetected.

What is "Hypersonic"?

- Flight in excess of five times the speed of sound (> 1,800 mph)
- Speed of aircraft changes chemistry of the air (dissociation and ionization)
- High temperature flows (> 2,000 F)
- Heat transfer is high
- High skin friction on surfaces
- Pressure loads are high
- A spacecraft in orbit is hypersonic (Mach 25)

High Speed ISR/Strike Aircraft concept, Mach 6 TBCC. Source: Lockheed Martin

NASA X-43 hypersonic research vehicle in free flight at Mach 6.8



Solid rocket booster

Hypersonic air-breathing propulsion

Scramjets

- Air-breathing engine
- Supersonic combustion
- Mach 4 - 15
- Dual-mode scramjet: Mach 4 - 6

High speed strike

High speed aircraft
Source: USAF

Access to space

Source: NASA

Ramjet and scramjet compared to gas turbine

$$M = \frac{\text{velocity}}{\text{speed of sound}}$$

Gas turbine

$0 \leq M_0 \leq 3$

Subsonic combustion
$M_3 = 0.2 - 0.3$

Ramjet

$3 \leq M_0 \leq 5$

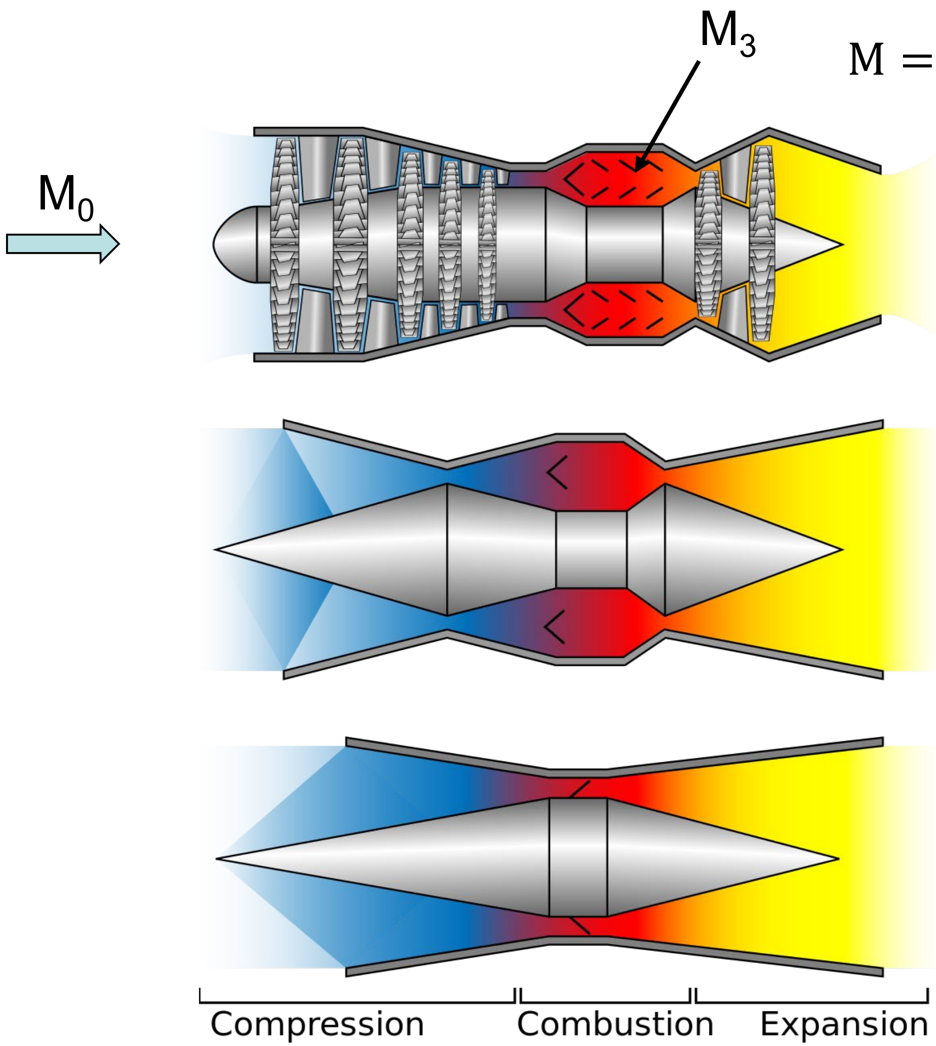
Subsonic combustion
$M_3 = 0.2 - 0.3$

Scramjet

$4 \leq M_0 \leq 15$ (?)

Supersonic combustion
$M_3 = 2 - 4$

(need Mach 25 to get to orbit)

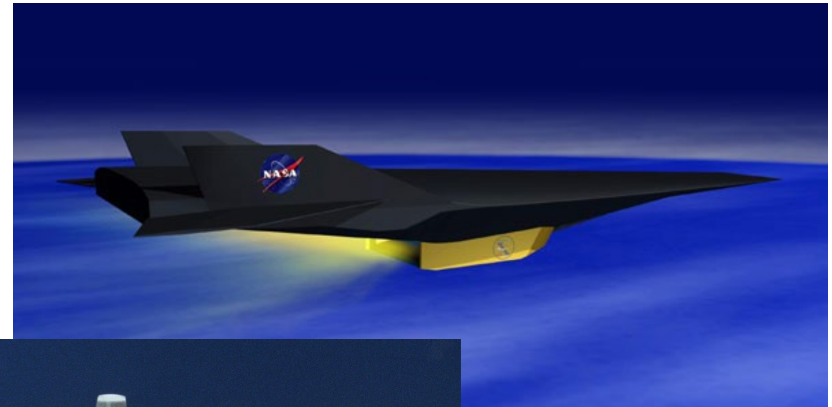


Source: Wikipedia, Grey Trafalgar (2014)

Scramjet flight firsts

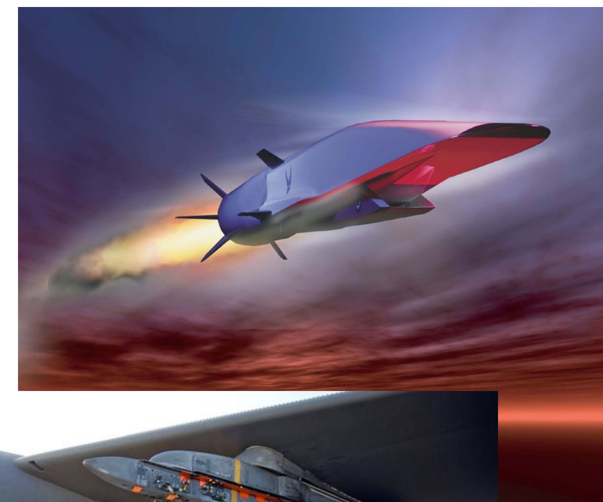
First supersonic combustion, Mach 7.6, 2002, HyShot, University of Queensland

Source: UQ



Source: NASA

Fastest air-breathing aircraft, Mach 9.6, 2004, Hyper-X, NASA



Greatest endurance, 4-6 min @ Mach 5, 2013, X-51, USAF

Source: USAF

University of Virginia

Airframe integrated concept

Source: Business Traveler

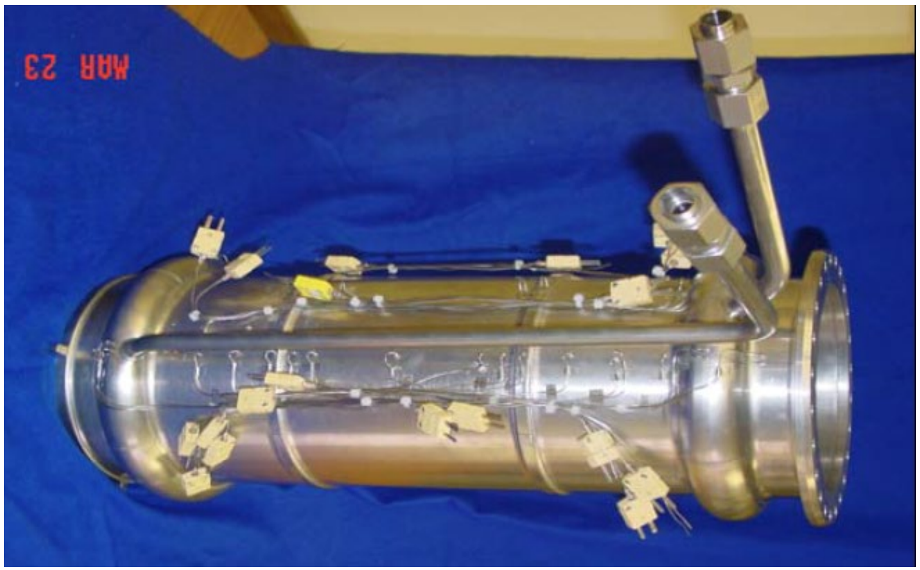
- Typical commercial aircraft (Boeing 747-400)
- Mach 0.85
- “Tube-and-Wing" concept
- Engine in “pods” on pylons

Source: Lockheed Martin

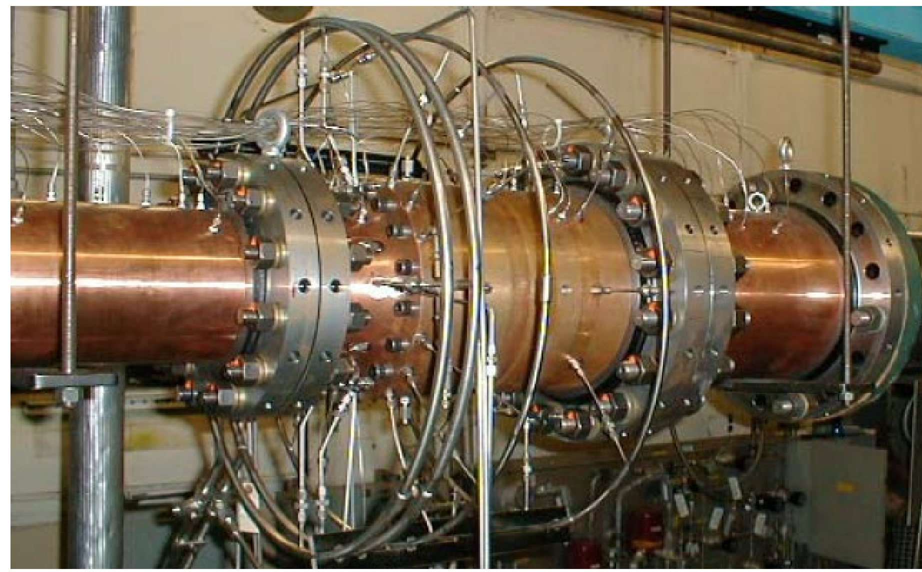
- High Speed Strike Weapon, Mach 6 hypersonic missile concept
- Airframe integrated concept
- Engine is part of the vehicle
- Vehicle is part of the engine
- Multidisciplinary design challenges

Need for AM in Scramjet Production

- Complex changes in flow-path shape are required
- Modern scramjets are three-dimensional
- Scramjet parts typically need internal cooling passages



Fuel-cooled, flight-weight, circular scramjet combustor by Northrop Grumman (ATK GASL), Bakos (2008)

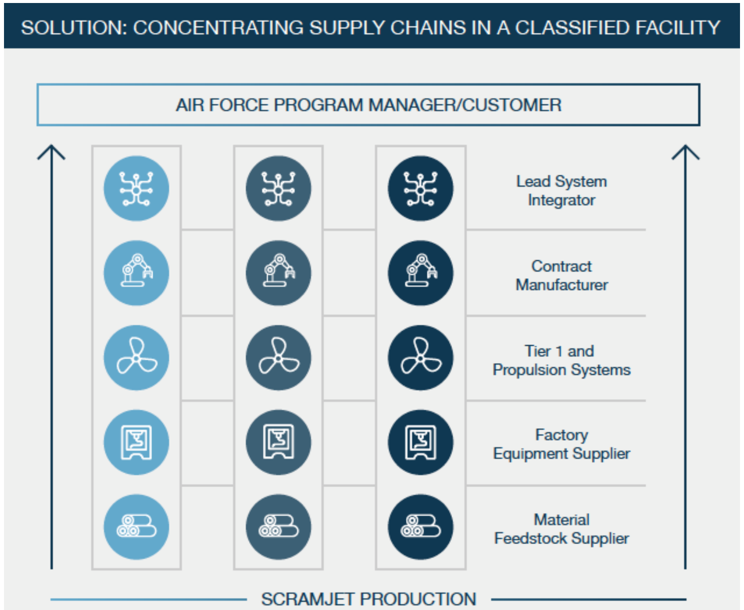


Scramjet installed in NASA Langley wind tunnel, Bakos (2008)

- But it can take 10-15 years to certify new materials, designs and manufacturing processes

Need for new approach

- DARPA sponsored a study to examine ways to speed up research, development and manufacturing of hypersonic technology
- This study was led by ASTRO America
- ASTRO engaged with UVA, Virginia Tech and others to provide subject matter expertise on hypersonic technology and advanced manufacturing
- Following extensive engagement with stakeholders and the hosting of a major industry workshop, the DARPA study led to the recommendation of the establishment of the Hypersonic Production Accelerator Facility (HPAF)



Source: ASTRO America

HPAF Goals

1. Accelerate the adoption of new materials and processes
2. Reduce the typical time of design-build-test cycles, and
3. Employ novel designs enabled by these rapid cycles

- One of the key attributes of HPAF is acceleration though the co-location of all levels of the supply chain
  - This includes government and OEM representatives
  - Design engineers, feed stock suppliers, additive machine suppliers and operators, qualification staff, integration/assembly specialists, and test and evaluation staff

UVA/CCAM Seed Program

- CCAM Innovation Fund
  - Catalyze new exploratory efforts between UVA and CCAM
- Objectives
  1. To execute preliminary work to enhance grant proposal development for external funding
  2. To create or demonstrate basic capabilities at CCAM
  3. To support activities related to the work of graduate students at CCAM
- 1:1 state matching, primarily for use at CCAM
- 12-month effort
- Collaboration between UVA faculty/students and CCAM staff

HPAF Digital Enterprise

- The DARPA study concluded with a recommendation that HPAF be established
- Plans were developed for the physical layout of the facility, the specifications for additive and subtractive manufacturing processes, and labor needs determined
- However, the **digital enterprise** of HPAF was not fully developed
- Siemens says a digital enterprise "*fully incorporates digital tools and technologies across all aspects of the operations, from ideation thru realization to utilization.*" This includes product design, production, testing and commissioning.
- We are using the CCAM Innovation Fund to help develop a state-of-the-art digital backbone for HPAF

Approach

- Our plan is to fully specify the digital enterprise of HPAF in order to assist the federal government in the development of the facility
- We are bringing together the expertise of UVA in hypersonic technologies (PI **Goyne**) and advanced manufacturing (co-PI **Fitz-Gerald**), with the expertise of CCAM in digital systems, digital thread technologies and manufacturing automation (**Haas**, **Vaughan**, **Holterman, Austin** and **Stremler**)
- In order to develop requirements that will suit the needs of customers and OEM user:
  - **ASTRO America** is providing input that results from significant previous stakeholder engagement for HPAF
  - **Calspan** is bringing industrial experience in hypersonic technology design, fabrication and testing

Conclusion

- Hypersonic technology is a key priority for the Department of Defense
- Hypersonic technology will create new capabilities for the US, including high speed missiles and aircraft, and access to space
- Hypersonic air breathing propulsion is well suited to additive manufacturing
- Additive manufacturing is expected to be a cornerstone of facilities such as the Hypersonic Production Accelerator Facility (HPAF)
- CCAM expertise in digital systems, digital thread technologies and manufacturing automation will be very beneficial for the development of facilities such as HPAF

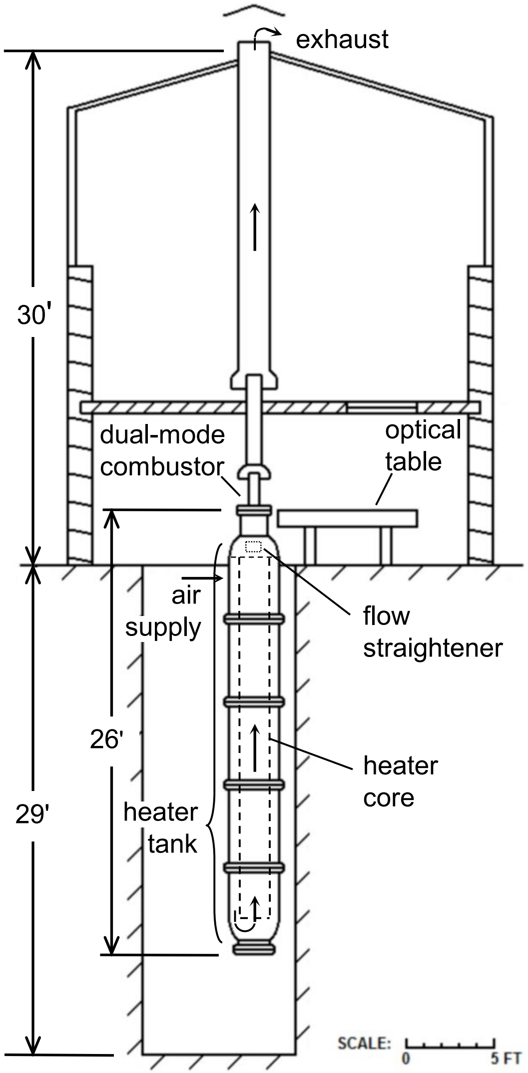
Questions?

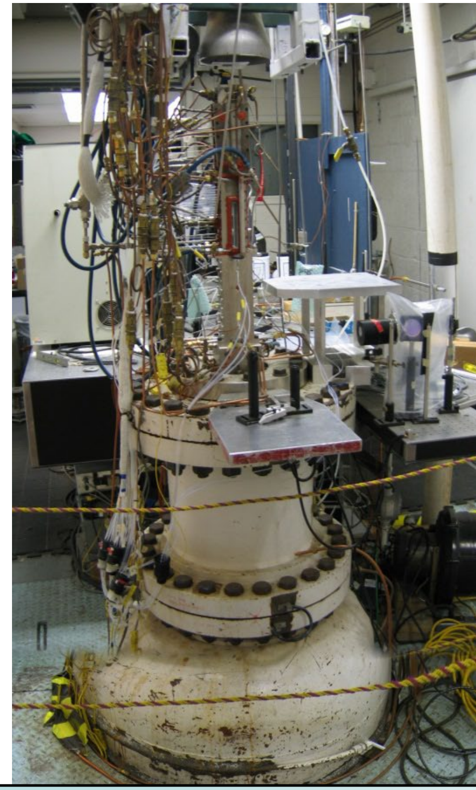
High Speed Strike Weapon concept, Mach 6 missile demonstrator. Source: Lockheed Martin

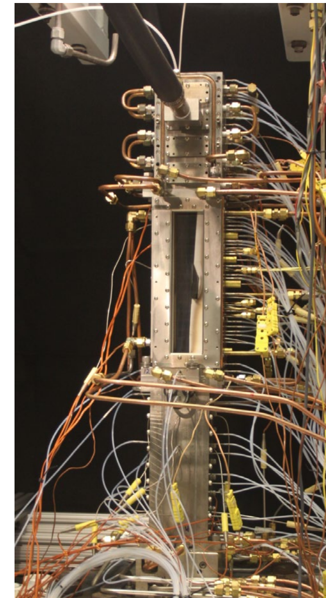
High Speed ISR/Strike Aircraft concept, Mach 6 TBCC. Source: Lockheed Martin

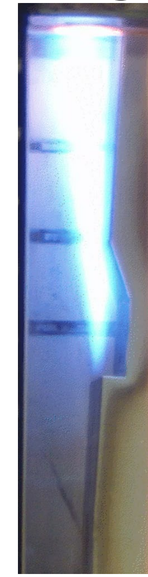
Backup slides

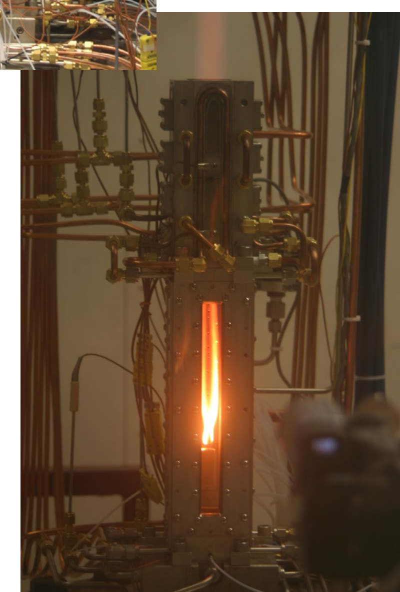
UVA Supersonic Combustion Facility









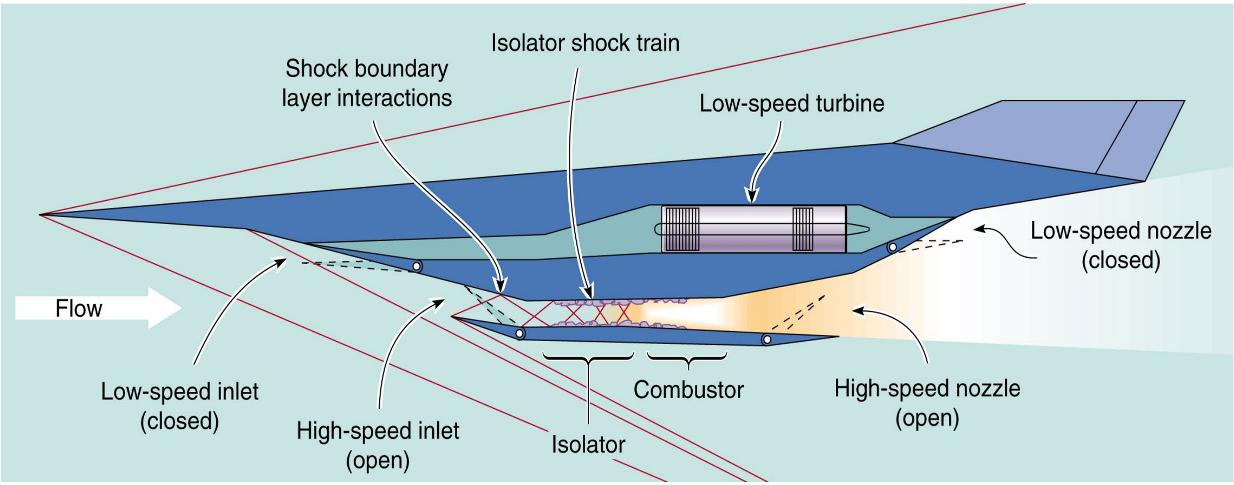


Capabilities:

- Electrically heated
- Continuous testing for several hours
- Direct-connect
- T_o = 1200 K (M5 enthalpy)
- M2 and M3 nozzles

Combined Cycle: TBCC concept

Turbine Based Combined Cycle



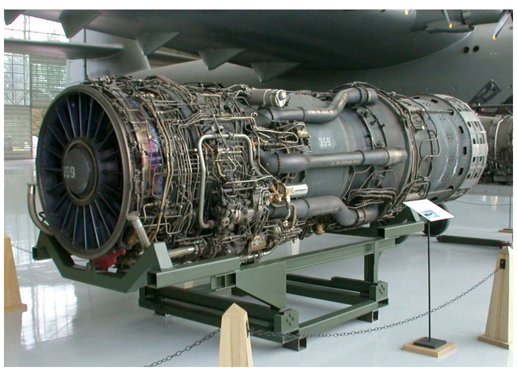
Source: University of Virginia

- "Over-under" configuration
- Gas turbine provides thrust at take-off and low speed
- Take advantage of efficiencies of two air-breathing cycles
- Challenges:
  - Mode-transitions: turbojet-ram ~ M3, ram-scram ~ M5
  - "Cocooning" gas turbine

TBCC Examples: Turbo-ramjets

SR-71

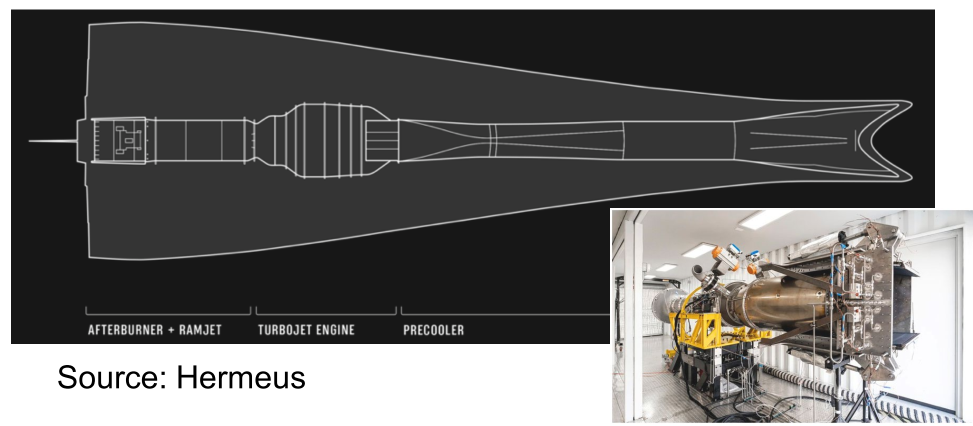
Source: NASA



Source: Greg Goebel
https://www.flickr.com/photos/37467370@N08/7461871088

- Fastest piloted air-breathing aircraft, Mach 3.3 in 1976
- 2 x P&W J58 turbojet with afterburner

Hermeus Quarterhorse



Source: Hermeus

- Chimera: Pre-cooler, GE J85 turbojet and M 2.75+ ramjet
- Goal is Mach 5 in 2023