Parallax
ADVANCED RESEARCH

Ohio Federal Research Network
Driving Innovation Through Strategic Partnerships

WELCOME!

Agenda

- **9:00 - 9:15 am – OFRN/OnRamp Hub: Ohio: Overview** *by Mark Bartman, Maj Gen (Ret.), VP for Advanced Development, Parallax Advanced Research*

- **9:15 - 9:45 am – An Overview of AFRL and AFIT Research Opportunities in Hypersonic Systems Analysis & Design** *by Dr. José Camberos, P.E., Director, Applied Research Center for Hypersonics, AFIT/ENY – Dept. of Aeronautics & Astronautics, Associate Professor of Aerospace Engineering*

- **9:45 - 10:15 am – The NASA Hypersonic Technology Project** *by Lois J. Weir, Senior Technologist for Hypersonic Propulsion, NASA Glenn Research Center*

- **10:15 - 10:25 am - Opportunity Review** *by Morgan Buck, Parallax Advanced Research*

- **10:25 - 10:30 am** - Wrap-up

Introductions & Thank you

Parallax Team & Event Volunteers

- **Emcee:** Mark Bartman, Maj Gen (Ret.), VP for Advanced Development, Parallax Advanced Research

- **Parallax Team:**
  - Becky Mescher
  - Lauren Jones
  - Jess Pacheco
  - John Jackson

- **Event Speakers:**
  - Dr. José Camberos, *P.E., Director, Applied Research Center for Hypersonics, AFIT/ENY – Dept. of Aeronautics & Astronautics, Associate Professor of Aerospace Engineering*
  - Lois J. Weir, *Senior Technologist for Hypersonic Propulsion, NASA Glenn Research Center*

- **Opportunity Review:**
  - Morgan Buck, OFRN Intern, Parallax Advanced Research

- **Government partners:** AFRL, NAMRU-D, NASA-GRC, NASIC, Ohio National Guard

OFRN Construct

Ohio Federal Research Network
Driving Innovation Through Strategic Partnerships

NASA Glenn Research Ctr (GRC) Priorities

Air Force Research Lab (AFRL) Priorities

National Air & Space Intelligence Ctr (NASIC) Priorities

State of Ohio

Industry Needs

PARALLAX & The Ohio State University

Naval Medical Research Unit (NAMRU) Priorities

Ohio National Guard Priorities

Executive Review Board

Technical Review Council

OFRN Program Impact – to date

23
Universities & colleges engaged

4+1
Government Partners

106
Business partners engaged

1,100+
Indirect jobs created

374
Direct jobs created

13
Spin out companies created

$61.8M
State of Ohio Investment - ODHE

$374+M
Follow-on Funding Awarded

$39.8M
Cost Share

Defense Innovation Unit (DIU) OnRamp Hub: Ohio

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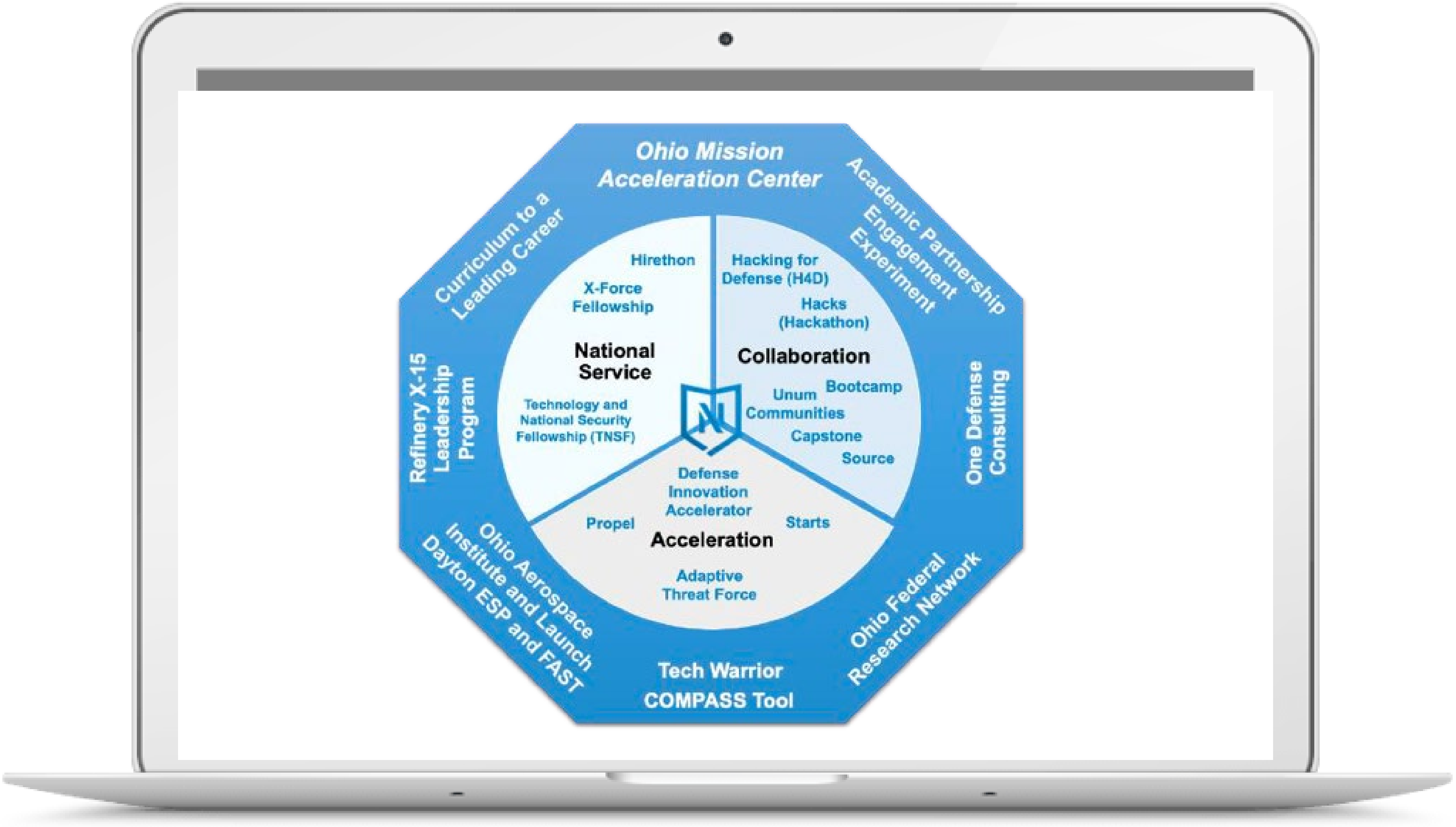
DEPARTMENT OF DEFENSE · DEFENSE INNOVATION · UNITED STATES OF AMERICA

ddc dayton development coalition

OneDefense

JobsOhio

What the OnRamp Hub: Ohio will do:



- ✓ **Front Door** to defense innovation for DoD to Ohio Businesses, academia, state organizations, and non-traditional innovators
- ✓ Parallax Research will coordinate DIU & NSIN programs across the State of Ohio to ensure success
- ✓ Locations across Ohio will provide physical and digital space for entrepreneurs to meet, collaborate and innovate
- ✓ OnRamp Hub will solve DoD problems and transition technologies
- ✓ Provide classified workspace as needed

The OnRamp Hub National Network

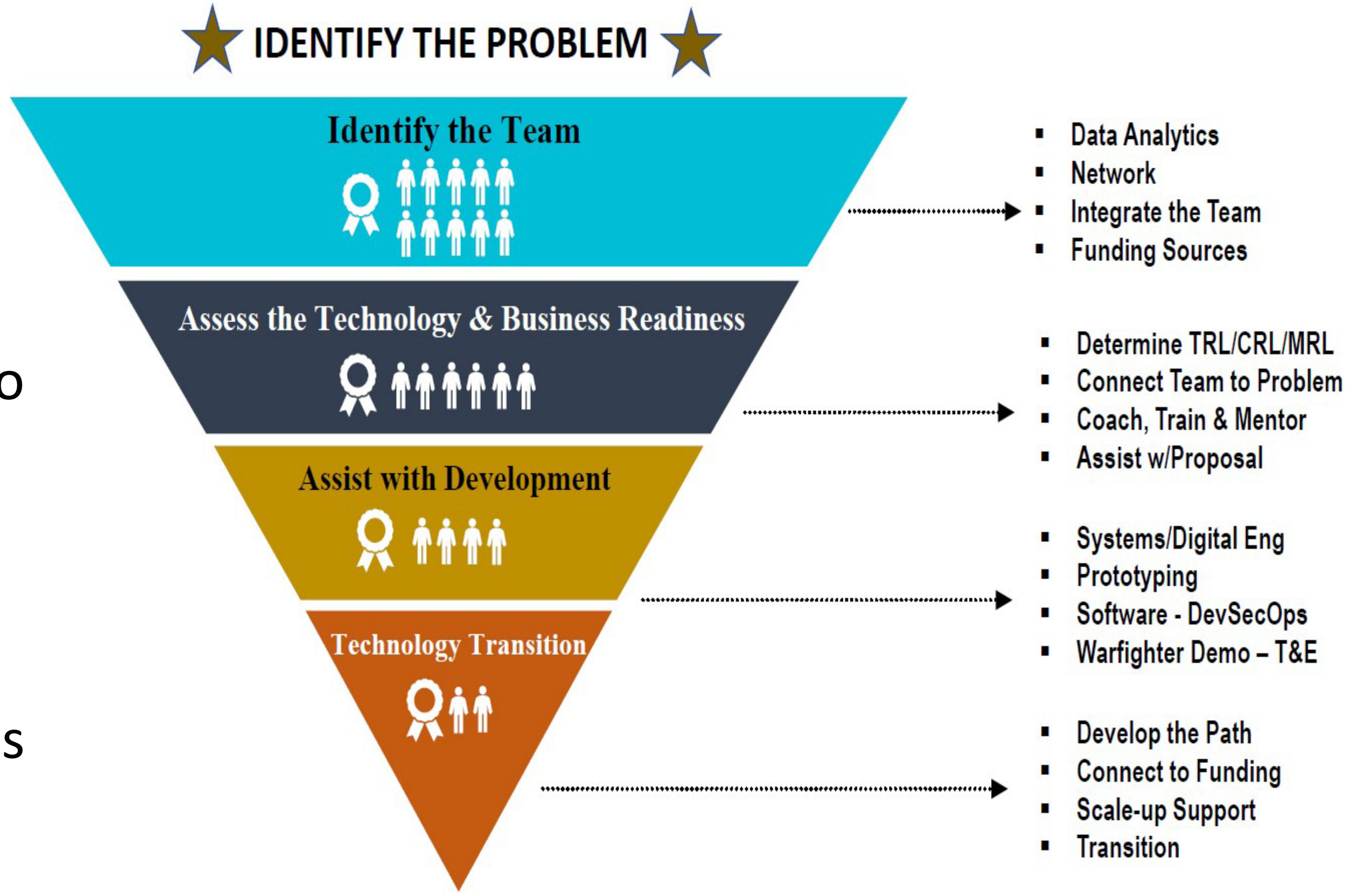
Parallax ADVANCED RESEARCH

What Makes Us Unique

- ✓ **Established existing ecosystems for entrepreneurs and small businesses that have experience working with federal agencies'**
  - **Arizona, Hawaii, Kansas, Ohio & Washington**
- ✓ **Robust networks of angel investors and venture capital**
- ✓ **Extensive State funding to help with startups (ESP, TVSF)**
- ✓ **Follows a systems engineering approach to reduce risk and speed transition**
  - **Ecosystems for prototyping and manufacturing (WBI, CDME, MEPs etc.)**
  - **Test locations – AAM range in Springfield, National Guard locations, Tech Warrior experience**
  - **Airworthiness support from AFLCMC**
  - **Software Factory – Hanger 18 – DevSecOps, Cloud, AoA**

Positioning the Right Solution

The DIU OnRamp Hub: Ohio leverages technology scouting to find the most advanced and promising technologies to meet the DOD's operational demands



Academic Partnership Engagement Experiment

Mission: To connect universities, businesses, and the government together; build collaborations between these sectors; identify their transformational operational defense solutions and capabilities; and advance defense technology transition/transfer and reduce risk for the Department of the Air Force.

Core Competencies:

IDENTIFY collaborators, innovators and technology opportunities using robust data analytics and active connection programs

BUILD & CONNECT a nationwide network of innovators and technologists from universities, small businesses and government

DEVELOP & DEPLOY & DRIVE INNOVATION through targeted education programs providing hands on training to university and small business innovators on how to effectively interface with the DoD

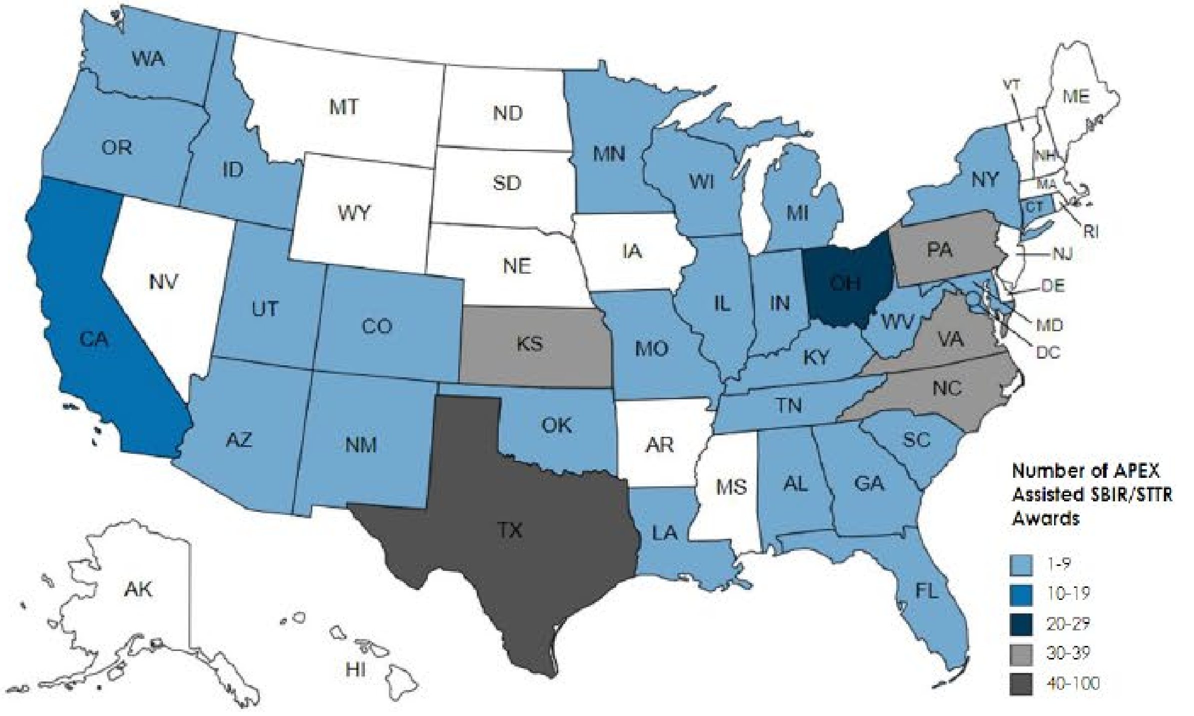
ACCELERATE & DIVERSIFY the transition pipeline via challenge problems, novel and targeted small business and technology transition opportunities with the DoD and its suppliers

APEX

Parallax
ADVANCED RESEARCH

Nationwide Impact:

APEX has assisted over 300 small businesses throughout 33 states and over 130 research institutions throughout 26 states with receiving R/R&D funding to bring innovation to the warfighter.



Parallax ADVANCED RESEARCH

APEX ACADEMIC PARTNERSHIP ENGAGEMENT EXPERIMENT

Gov't Return on Investment

To date, the PIA has expended $32.2M of our obligated funds since the inception of the program in 2019.

In this time, the team has achieved some major milestones with benefits to the DAF, academia and industry focused on technology transfer and transition.

$45.5M Obligated

APEX ACADEMIC PARTNERSHIP ENGAGEMENT EXPERIMENT

$32.2M Expended

>$213M

$98.5M Assisted STRATFI/TACFI Awards

$115M Assisted SBIR/STTR Awards

11 SBIR/STTR TECH TRANSITIONS

>$1.5M Additional Sales

>$425,000 Additional Investments

>$11.8M non-DAF Gov't Contracts

833 Facilitated Introductions Via Matchmaking

>130 RIs awarded

>300 SBCs awarded

APEX has expanded the DoD supply chain ecosystem & enhanced economic development in underserved regions with identification of technology for the DAF that would not otherwise be found; increasing innovation and tech transition.

Thank you

Mark Bartman, Maj Gen (Ret.), USAF
VP for Advanced Development
Mark.bartman@parallaxresearch.org

John Owen, Program Manager
OnRamp Hub: Ohio
John.owen@parallaxresearch.org

Also contact us at
OnRampHubOH@parallaxresearch.org

Dr. Jose Camberós

Air Force Institute of Technology

Hypersonic Systems Analysis & Design

jose.camberos@us.af.mil

Ohio Federal Research Network

12 September 2024

ARCH Mission & Vision

AIR FORCE INSTITUTE OF TECHNOLOGY

MISSION

Deliver outstanding interdisciplinary expert solutions to *defense-focused* challenges in hypersonics through applied research, workforce development, and education

VISION

Recognized as the preeminent source for *defense-focused* expertise, research, and education in the field of hypersonics

Education & Workforce Development → ***Basic & Applied Research*** → ***Subject Matter Expertise***


7

PV2 AL



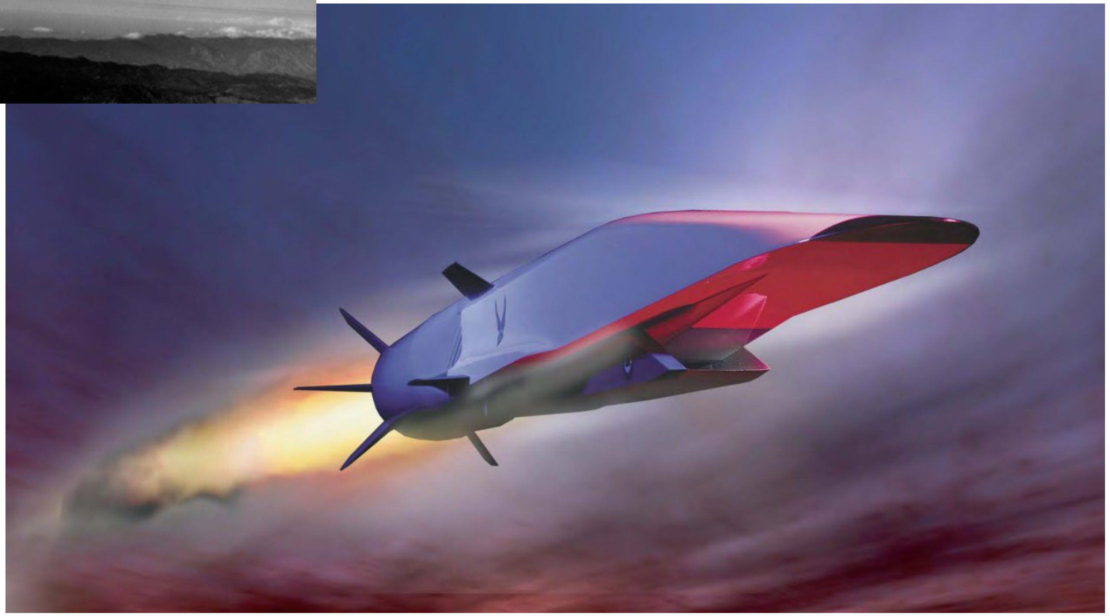
300
CVW-1


SA
344


206


NASA
X-43A


NASA
U.S. AIR FORCE
USAF



Mission

AFRL

Leading the discovery, development and integration of affordable warfighting technologies for our air, space and cyberspace forces

WHO WE ARE

We are experts in a wide range of technical fields.

LEAD

We lead the Air Force in science and technology.

WHAT WE DO

We explore, research and push the boundaries of technology.

DISCOVER

We are at the forefront of innovation.

WHY OUR WORK MATTERS

We provide the Air Force with the technology it needs to defend America.

DEVELOP

We bridge the gap between research and application.

WHEN WE DELIVER

We identify future needs and advance technologies to support these capabilities.

DELIVER

We provide superior technology to warfighters in a continuous manner.

USSF

Vision

We defend America by unleashing the power of innovative air and space technology.

AIR FORCE RESEARCH LABORATORY

Core Technical Competencies (CTC)

AFRL

USSF

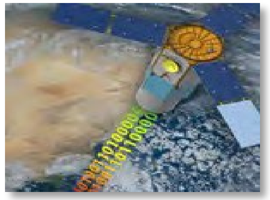
MATERIALS & MANUFACTURING

Structural Materials, Functional Materials, Manufacturing Technology, Support of Operations

HUMAN PERFORMANCE

Training, Adaptive Warfighter Interfaces, Bioeffects, Aerospace & Operational Medicine, and Bioengineering; Aerospace & Operational Medicine education, training, and consultation; Human Systems Integration analysis and implementation

SPACE VEHICLES



Space Environment, Advanced Space Resilience Technologies, Space Communication & Navigation Technologies, Space Awareness and Command & Control

INFORMATION

Processing & Exploitation, Connectivity & Dissemination Autonomy, Command & Control and Decision Support, Cyber Science and Technology

BASIC RESEARCH

Engineering & Information Sciences, Physical & Biological Sciences

SENSORS

Radio Frequency (RF) Sensing, Electro Optical (EO) Sensing Spectrum Warfare, Trusted & Resilient Mission Systems, Multi-domain Sensing Autonomy, Enabling Sensor Devices & Components

AEROSPACE SYSTEMS

Aerospace Vehicles, Control, Power & Thermal Management, High Speed Systems, Rocket Propulsion, Turbine Engines

DIRECTED ENERGY

Laser Systems, Weapons Modeling, Simulation & Analysis, High Power Electromagnetics (HPEM), Directed Energy and Electro Optics for Space Superiority

MUNITIONS

Munitions Airframe, Guidance, Navigation & Control, Terminal Seeker Sciences, Modeling & Simulation Evaluation Sciences Ordnance Sciences

EXPERIMENTATION

Capability & Technology Prototyping

Investment Categories

AFRL

USSF

6.1

Basic Research

Science Knowledge

Greater knowledge or understanding fundamental aspects

Observable facts

Without specific applications toward processes or products

New Science

$319 M

6.2

Applied Research

Technologies

Applying knowledge or understanding to determine the means by which a recognized and specific need may be met

Science to Application

$1,411 M

6.3

Advanced Technology Development

Capability Concepts

The development and integration of hardware for field experiments and tests

From Application to Capability

$862 M

Non S&T

Other AF Funds Executed

Operational Development / Experimentation

- **Research, Development, Test and Evaluation**
- **Strategic Development Planning Experimentation**
- **Small Business Innovation Research Program**
- **Air Force Surgeon General**

Experimentation

$1,377 M

FY18 data S&T (6.1 - 6.3)

Non S&T (6.4 – 6.7, DHP, OM)

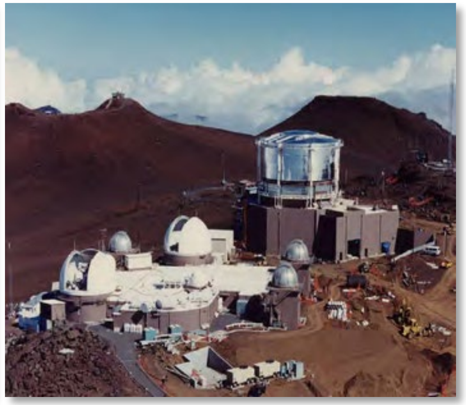
Locations by State

AFRL

AFRL

World-class Facilities and State-of-the-art Capabilities

Rocket Propulsion Test Facilities



AF Maui Optical & Supercomputing Site (AMOS)

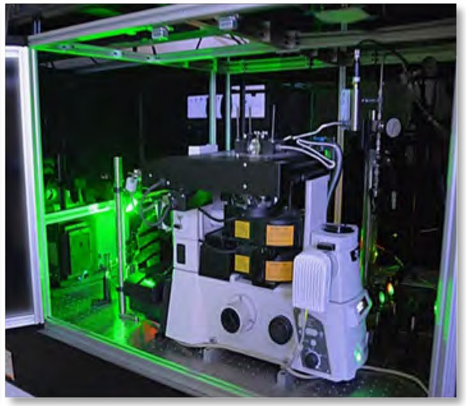
Hypersonic Wind Tunnel

Radar Towers – Sensors Complex

Outdoor Antenna Test Ranges

Starfire Optical Range

Human-rated Centrifuge, USAF School of Aerospace Medicine



Autonomous Research Systems Robotic Testing

DoD Supercomputing Resource Centers (DSRC)

High Explosives R&D HERD Facility

Future Technologies - Big Bets

AFRL

USSF

QUANTUM INFORMATION SCIENCE

Harnesses certain laws of particle physics to dramatically improve the acquisition, transmission and processing of information.

Applications include computing, communication and sensing. Quantum can be used to teleport information, create secure communication networks, gather location data in GPS-denied environments and enhance supercomputing capabilities.

ARTIFICIAL INTELLIGENCE / AUTONOMY

Facilitates the use of machine generated information by creating knowledge from observations gathered.

AI can provide expertly-planned courses of action, streamline business processes, enhance situational awareness and increase mission effectiveness. It could save time, money, manpower and lives.

DIRECTED ENERGY WEAPONS

Strike critical targets at the speed of light and defeat attacks in an effective, affordable and expedient manner.

DEWs precisely engage targets with little to no collateral impacts or detectable disturbance. They can be integrated with aircraft, munitions or used on the ground.

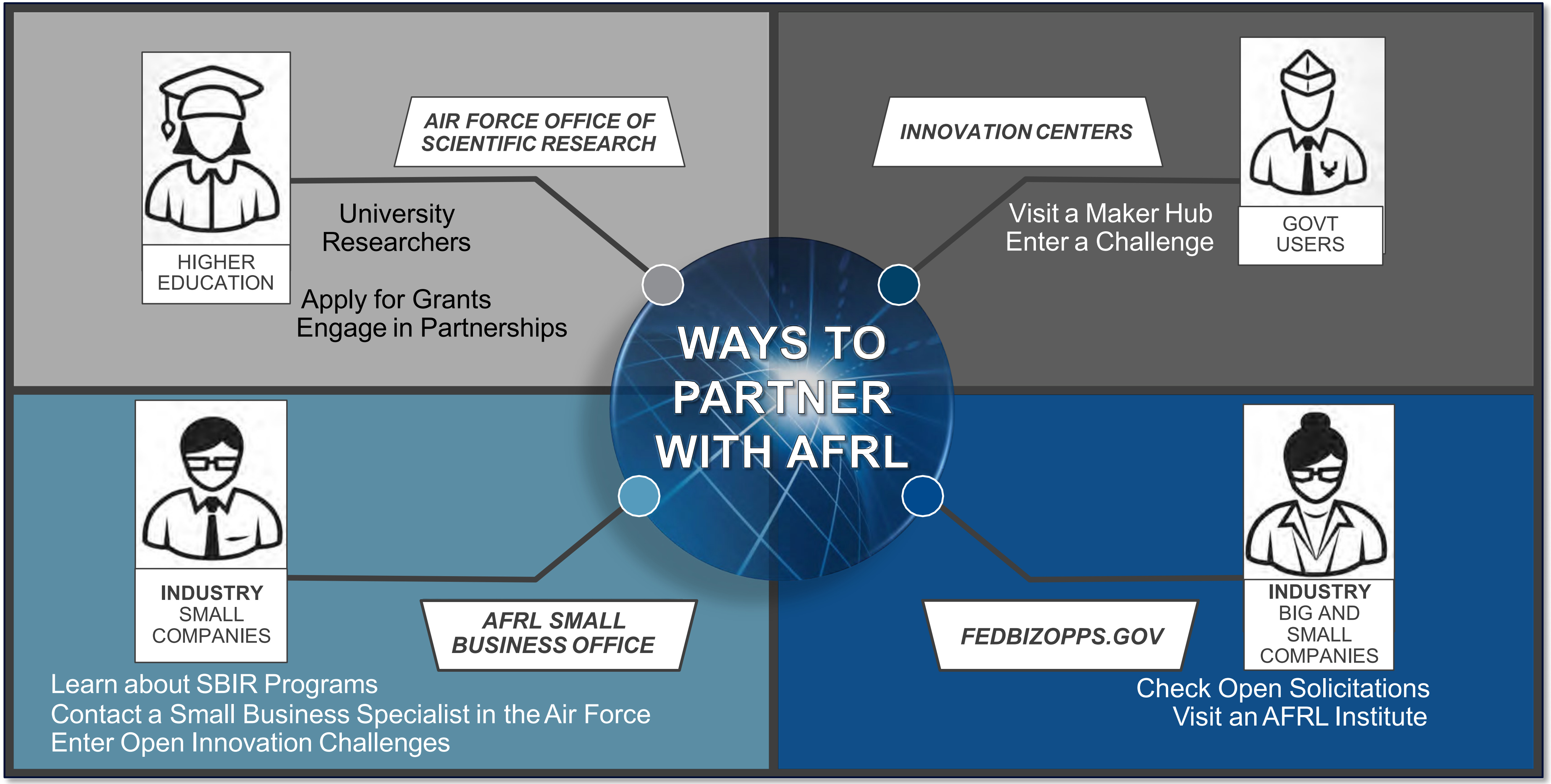
HYPERSONICS

Flying at five times the speed of sound, also known as Mach 5 or higher.

Hypersonic flight could enable the U.S. to conduct longer range military operations with shorter response times and enhanced effectiveness.

Partnering with AFRL

For more information, visit
AFRESEARCHLAB.COM



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Hypersonic vehicle technology

Major Developments

For this Seminar…

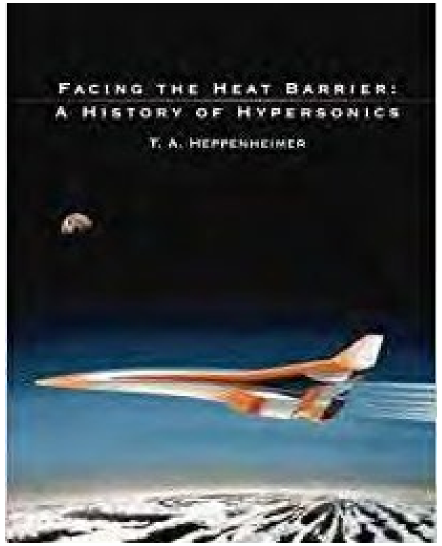
- To motivate the understanding of the *fundamental aspects* of "hypersonic flow," especially *relevant physical phenomena*
- To facilitate a *basic understanding of hypersonic vehicle analysis and design*
- Basic Flow Physics Include:
  - Compressible Flow
  - Aerodynamic Forces in Hypersonic Flow
  - Aerodynamic Heating in Hypersonic Flow

On Hypersonics

- Critical Flow Phenomena
  - Shock-shock and shock-boundary layer interactions
  - Non-equilibrium effects
  - Flow-structure interactions
  - Ablation
  - Flight controls
  - Atmospheric Noise
- Thermal Management, external and internal
- Multidisciplinary due to fully-coupled physics
- Coupling effects can be beneficial or adverse
- Systems Level Analysis and Design Optimization

AFRL Initiative "*Game Changer*"

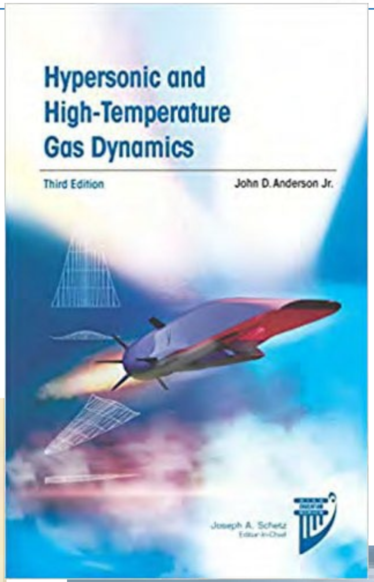
IT'S ALL ABOUT THE HEAT!!!

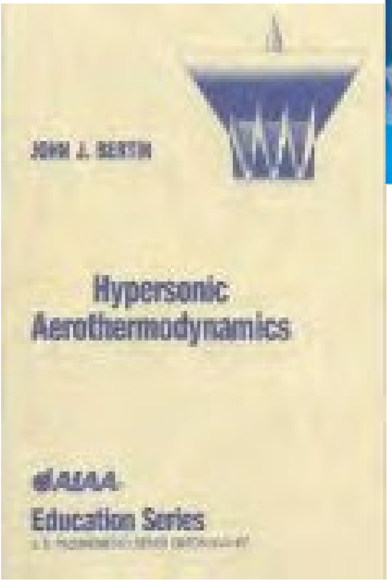


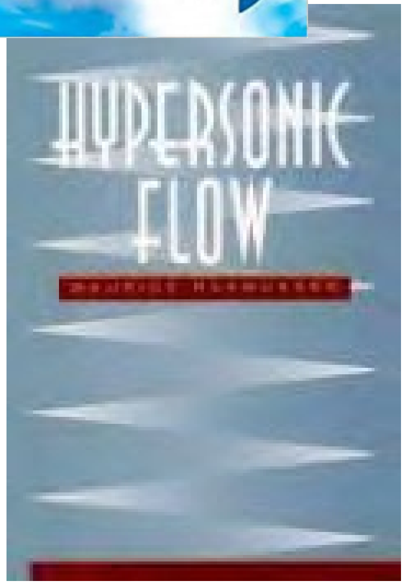
Facing the Heat Barrer: A History of Hypersonics by T. A. Heppenheimer

My Favorite Books on Hypersonics

- *Hypersonic and High Temperature Gas Dynamics*
  - John D. Anderson, (AIAA 2006, 2001; McGraw-Hill, 1989)
- *Hypersonic Aerothermodynamics*
  - John J. Bertin, (AIAA, 1994)
- *Hypersonic Flow*
  - Maurice Rasmussen, (Wiley & Sons Inc., 1994)







Other Useful/Interesting References

Basics of Aerothermodynamics

E. H. Hirschel, Springer-Verlag, jointly with AIAA, 2005

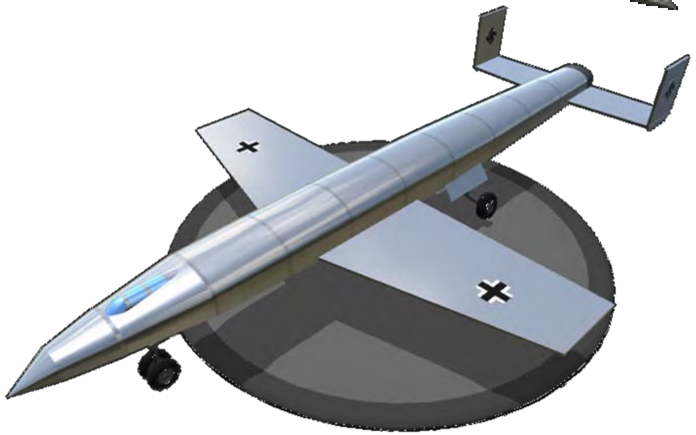
Selected Aerothermodynamic Design Problems of Hypersonic Flight Vehicles

E. H. Hirschel & C. Weiland, Springer-Verlag, jointly with AIAA, 2009

Historical, Misc. Other

- Heppenheimer, T.A. *Facing the Heat Barrier*: *A History of Hypersonics*. NASA SP-2007-4232 https://history.nasa.gov/sp4232.pdf
- Magazine articles, Technical papers, Technology & Design Studies, Popular literature, historical, etc.

Sanger Silbervogel ~ 1934



Specs ca 1934

Mass: 133,773 kg

Payload: 5,000 kg

L/D: 5.1

Mach at burn-out: 13

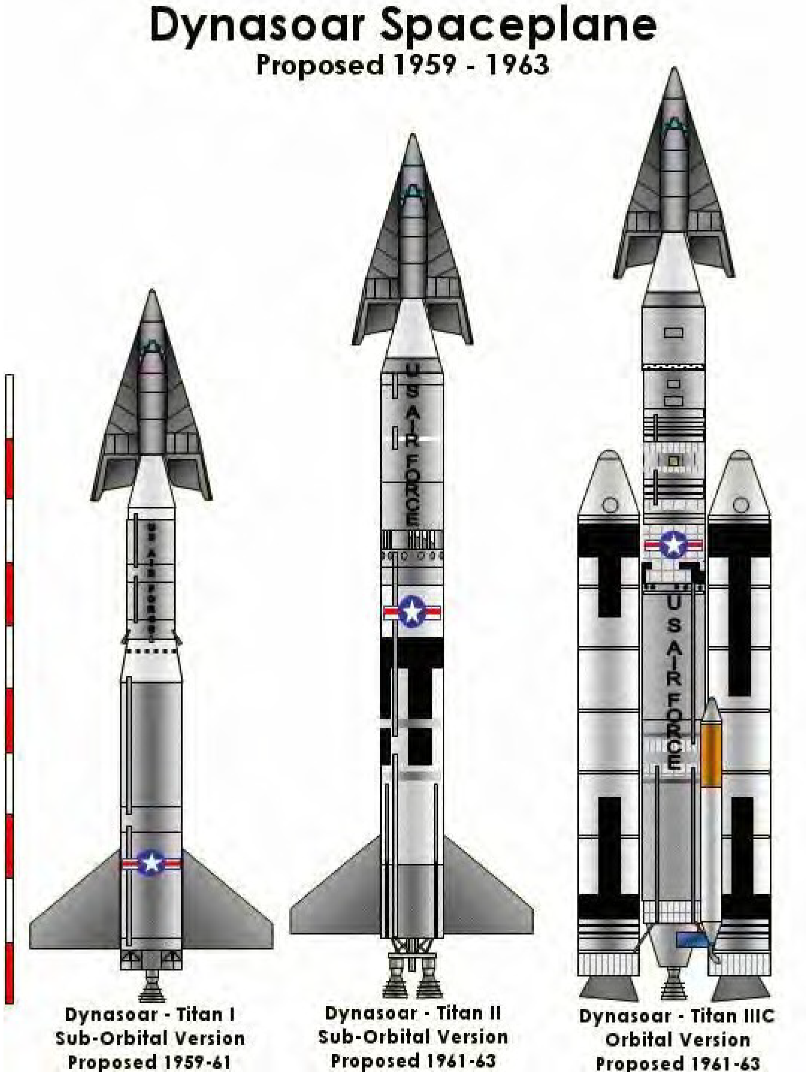
Cruise Mach: 3.3

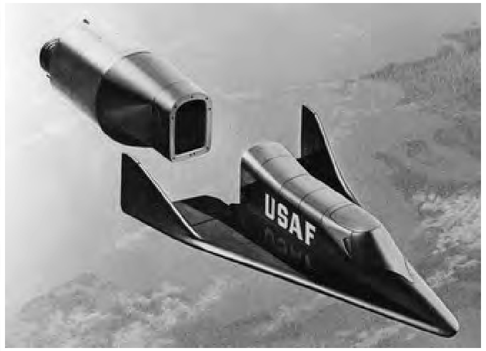
Cruise altitude: 50 km

- ***Silbervogel*, German for Silver Bird, by Eugen Sänger & Irene Bredt ~ late 1930s**
- **Liquid-propellant rocket-powered sub-orbital bomber**
- **Sled launch, sub-orbital, atmospheric skip to extend range**

X-20 DynaSoar

- Piloted reusable space vehicle, 35.5 ft long & 20.4 ft wingspan
- 11 manned flights planned from Cape Canaveral starting Nov 1964 & 1st orbital flight ~ 1965
- Program canceled Dec 1963:
  - X-20 had no viable military mission
  - Too expensive for a research vehicle
  - X-20 funding moved to the Manned Orbiting Laboratory which used Gemini capsules



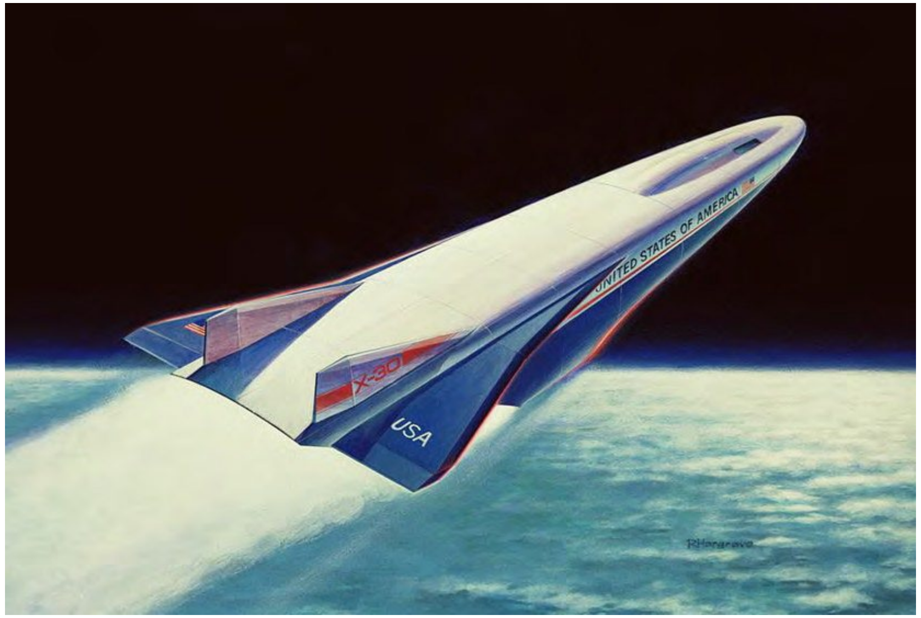


X-15

- Joint NACA, USAF, Navy program; North American Aviation selected Sep 55
- 3 flight vehicles produced; 199 flights; 1 fatality
- Conventional aero controls plus reaction control system
- Heat sink structure w/ Inconel X skin; ablative with sealant for high Mach
- Initially 2 XLR-11 engines (16 Klb thrust); later XLR-99 engine (67 Klb thrust)
- First application of hypersonic theory & wind tunnel work to actual flight
- Max altitude: 354,200 feet on 22 Aug 1963
- Max Mach: 6.72 on 3 Oct 1967
- Type 4 SBLI w HRE

National Aero Space Plane (NASP)

- Overly ambitious program for HTHL single stage to orbit, 1986 - 1995
- Highly integrated air breathing propulsion system from SLS to Mach 25
- High reliance on CFD; eliminate wind tunnel testing
- No intermediate demonstrations for key components/subsystems



X-43 Hyper-X

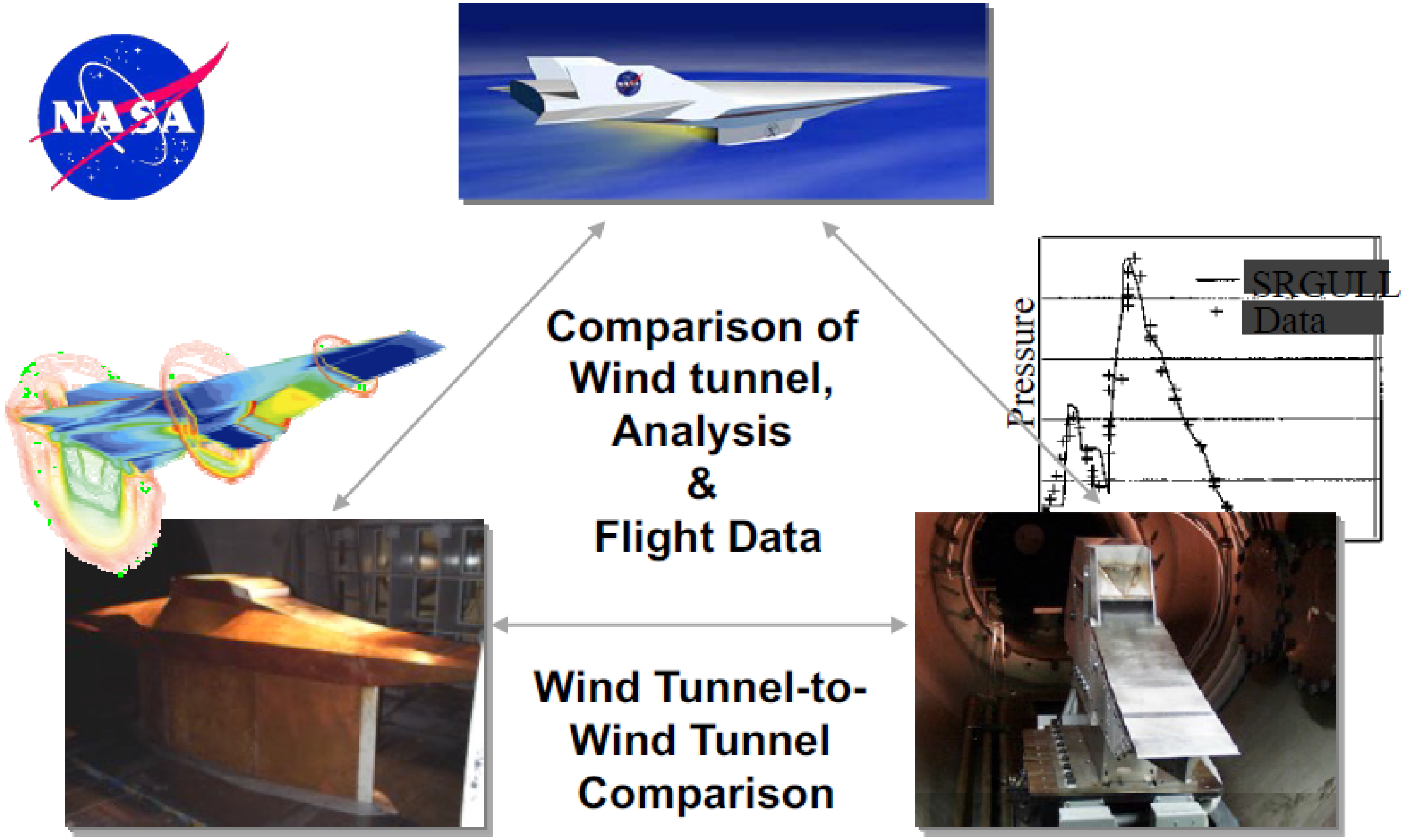
X-43 Demonstrator Program

- GOALS: Demonstrate, validate and advance the technology, experimental techniques, and computational methods and tools for design and performance predictions of a hypersonic aircraft powered with an airframe-integrated, scramjet engine

FLIGHT OBJECTIVES:
- Free-flight demonstrations (Two @ Mach 7, one @ Mach 10)
- Methods verification
- Scaling confirmation
  Primary Metric: Accelerate

TECHNOLOGY OBJECTIVES:
- Vehicle design & risk reduction
- Flight validation of design methods
- Design method enhancement
- Hyper-X Phase 2 and beyond

RESULTS:
- 1st flight ended during boost, 2001
- 2nd flight successful Mach 7, 2004
- 3rd flight successful Mach 10, 2004



X-51 Flight Test Summary

Four Powered Flights over Three Years (May '10 – May '13)

First Flight: May 26th, 2010

- 143 seconds of scramjet operation
- Peak Mach of 4.87; 150 nm travelled
- Seal / nozzle breach ended flight early

Second Flight: June 13th, 2011

- Engine "unstarted" nine seconds after scramjet ignition
- Post-flight investigation and ground testing yielded several scramjet operability lessons learned

Third Flight: August 14th, 2012

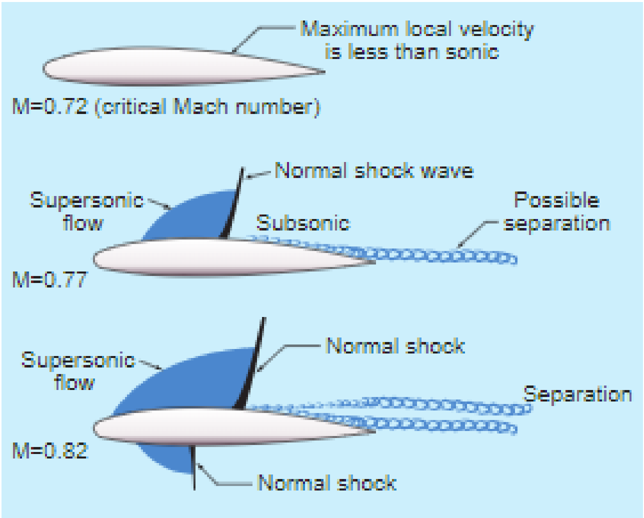
- Run-away control fin actuator and loss of control prior to engine light

Fourth Flight: May 1st, 2013

- Full duration flight: ~209 seconds of scramjet operation and 377 seconds of controlled flight
- Peak Mach of 5.1; ~240 nm travelled in six minutes

Hypersonic Flow

- What is it?
  - Subsonic Flow: $M_\infty < 1$
    - Incompressible $M_\infty \leq 0.3$
    - Compressible $0.3 \leq M_\infty \leq 0.7$
  - Transonic: $0.7 \leq M_\infty \leq 1.3$
  - Supersonic Flow: $M_\infty > 1$
  - Hypersonic Flow: $M_\infty \gtrsim 5$

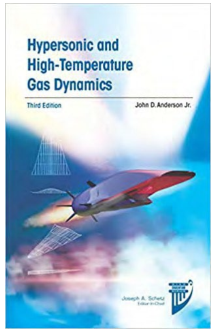


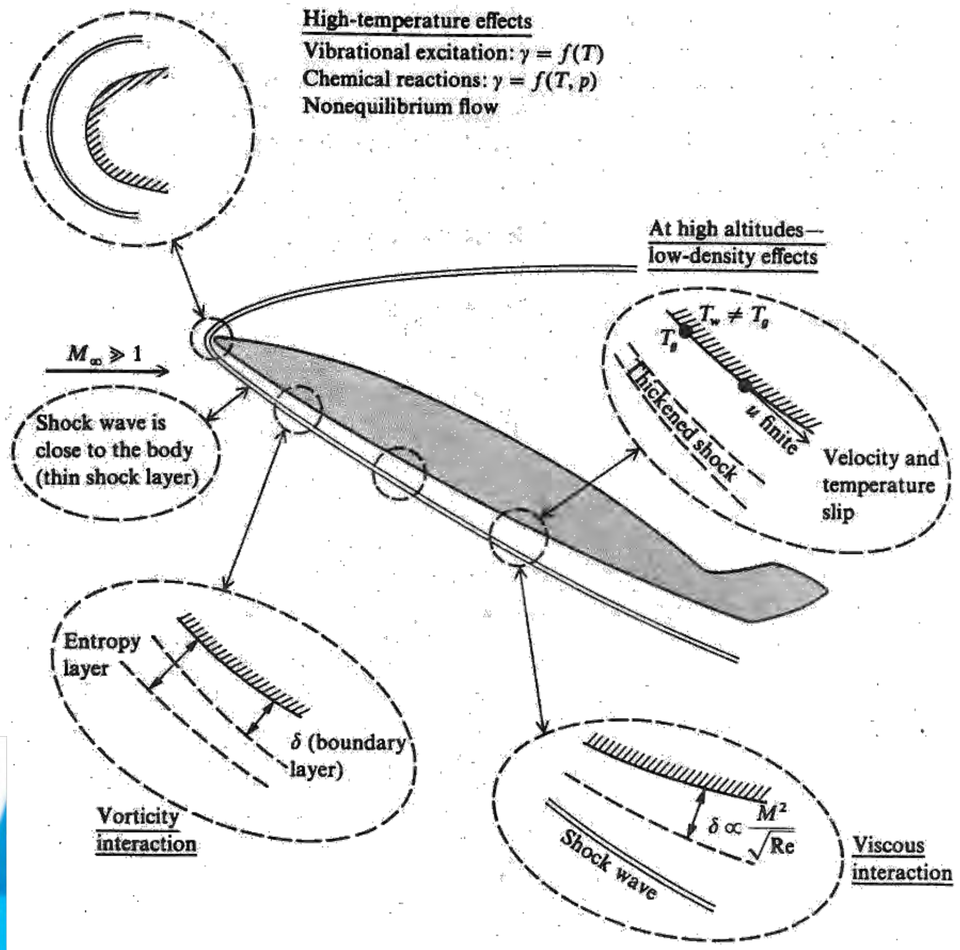
https://en.wikipedia.org/wiki/Shock_wave

- Most experts agree: Hypersonic flow @ M ~ 4-6

Hypersonics – Basic Features

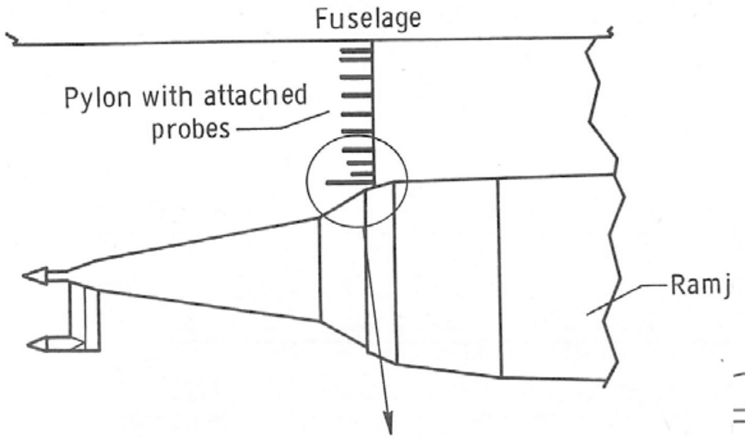
- Basic:
  - High Mach number flight through atmospheric medium
- Distinguishing Features:
  - Thin Shock Layer → region between shock wave and vehicle surface
  - Entropy Layer → strong entropy gradients leading to significant vorticity generation and propagation
  - Viscous Interaction → standard BLT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



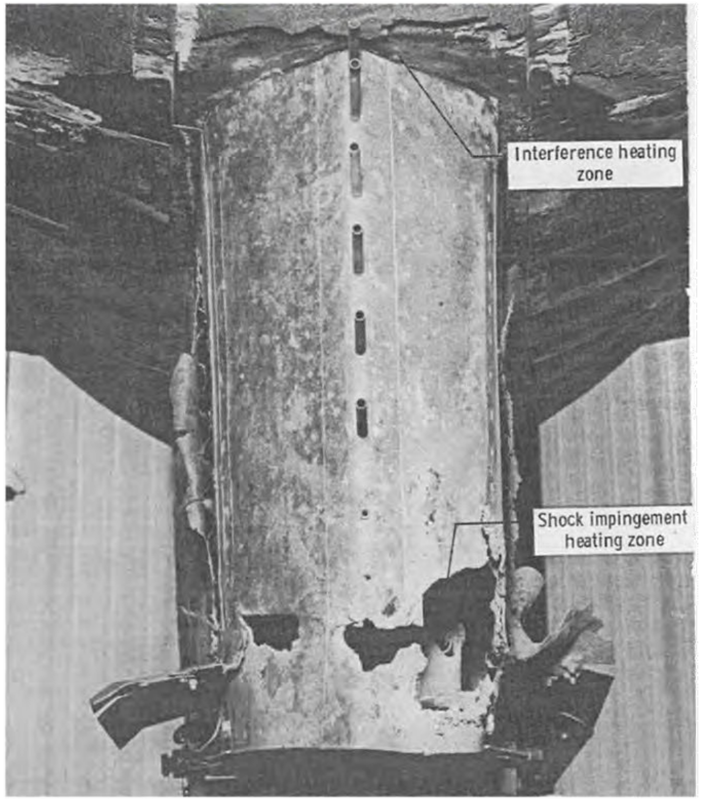


Surprise!

Dummy ramjet installed



The result melted the metal with temps > 2795° F, 10/3/67



Structure: Inconel X (a nickel-chromium alloy) plus an ablative cover

From Iliff and Shafer, AIAA Paper 93-0311and NASA TM X-1669

1950's Hypersonics Challenge

Ballistic Missile Atmospheric Entry

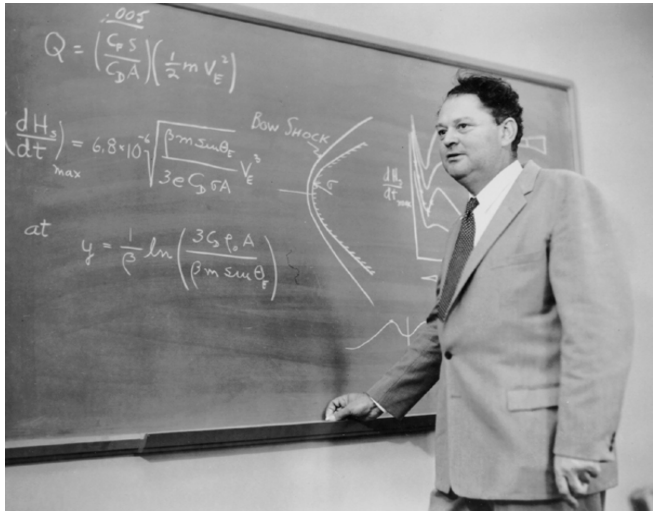
1st thought: a slender shape with pointed nose would be best

But! H. Julian Allen and A.J. Eggers, Jr.:

A blunt nose forces a detached shock and most of the heat goes off the surface and into the flowfield, not the vehicle, and enables practical re-entry "vehicles"

This was the major theoretical advance in the 1950s

-NACA R 1381, H. Julian Allen and A.J. Eggers, Jr., "A Study of the Motion and Aerodynamic Heating of Ballistic Missiles Entering the Earth's Atmosphere at High Supersonic Speeds," 1953



Allen showed:

$$\dot{q}_{\substack{\text{max}\\ \text{laminar}}} \sim \frac{1}{\sqrt{R_{LE}}}$$

Surface Pressure

Local slope rules differ in supersonic and hypersonic flows

<u>Linearized supersonic flow</u>

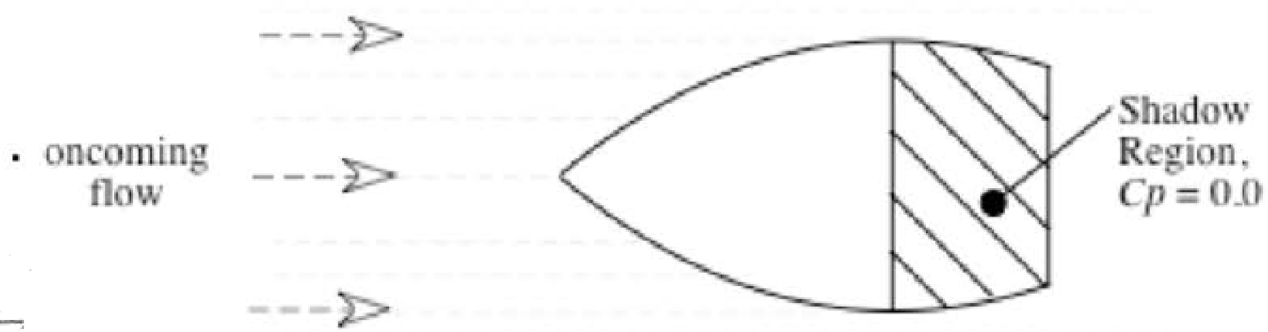
$$C_p = \frac{2\theta}{\sqrt{M_\infty^2 - 1}}$$

<u>Hypersonics: Newtonian flow rule</u>

$$C_p = 2\sin^2\theta$$

No Mach number!
Nonlinear! ($M = \infty$, $\gamma = 1$)

Many other hypersonic "rules" available



$$C_p = C_{p_{\max}} \sin^2\theta$$

Cp_{max} is Cp behind a normal shock
- For $\gamma = 1.4$, Cp_{max} at $M = \infty$ is 1.84, at $M = 4$, $Cp_{max} = 1.79$

Newtonian/Modified Newtonian is typically good for blunt bodies with large inclination angles

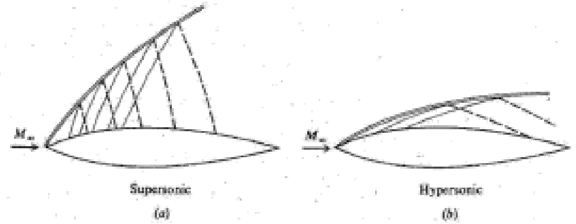
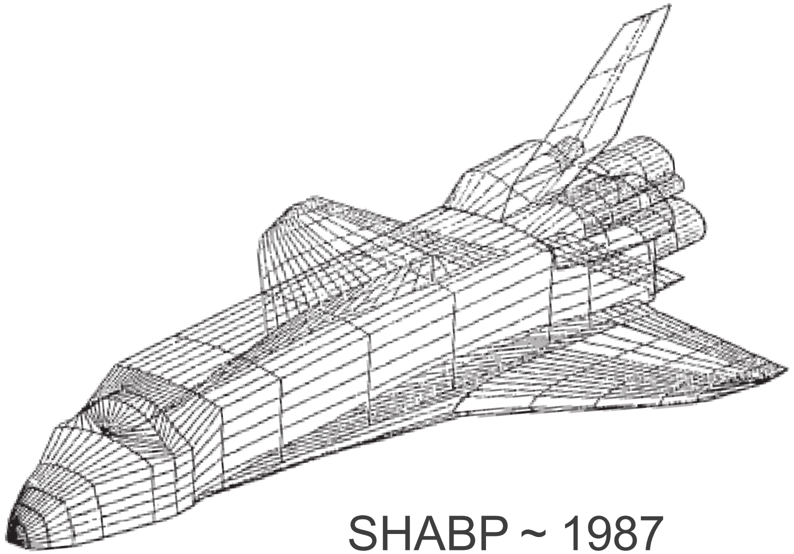


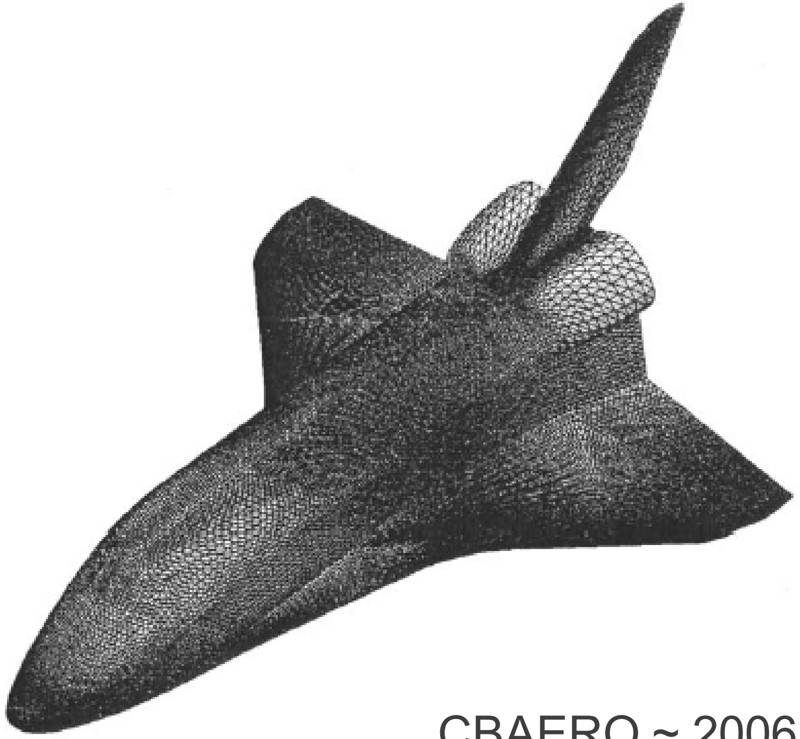
FIGURE 3.22
Schematic of shock wave and Mach wave patterns: (a) Supersonic; (b) hypersonic.

Computational Models



SHABP ~ 1987

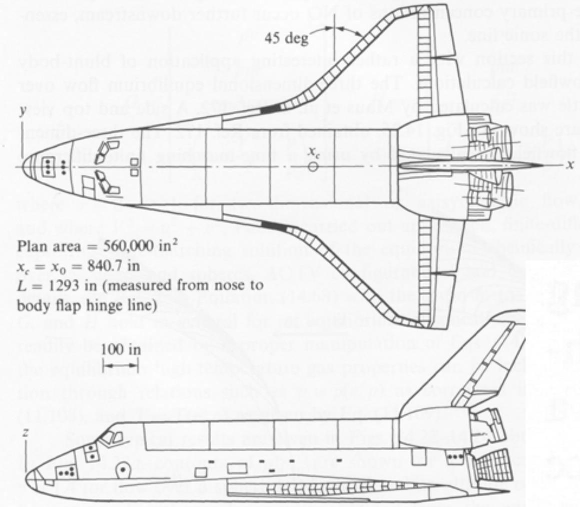
Fisher, Carren, M. E., "Experiences Using the Mark IV Supersonic Hypersonic Arbitrary Body Program," *Aerodynamics of Hypersonic Lifting Vehicles*, AGARD Conference Proceedings 428, 1987, pp. 31-1–31-18.



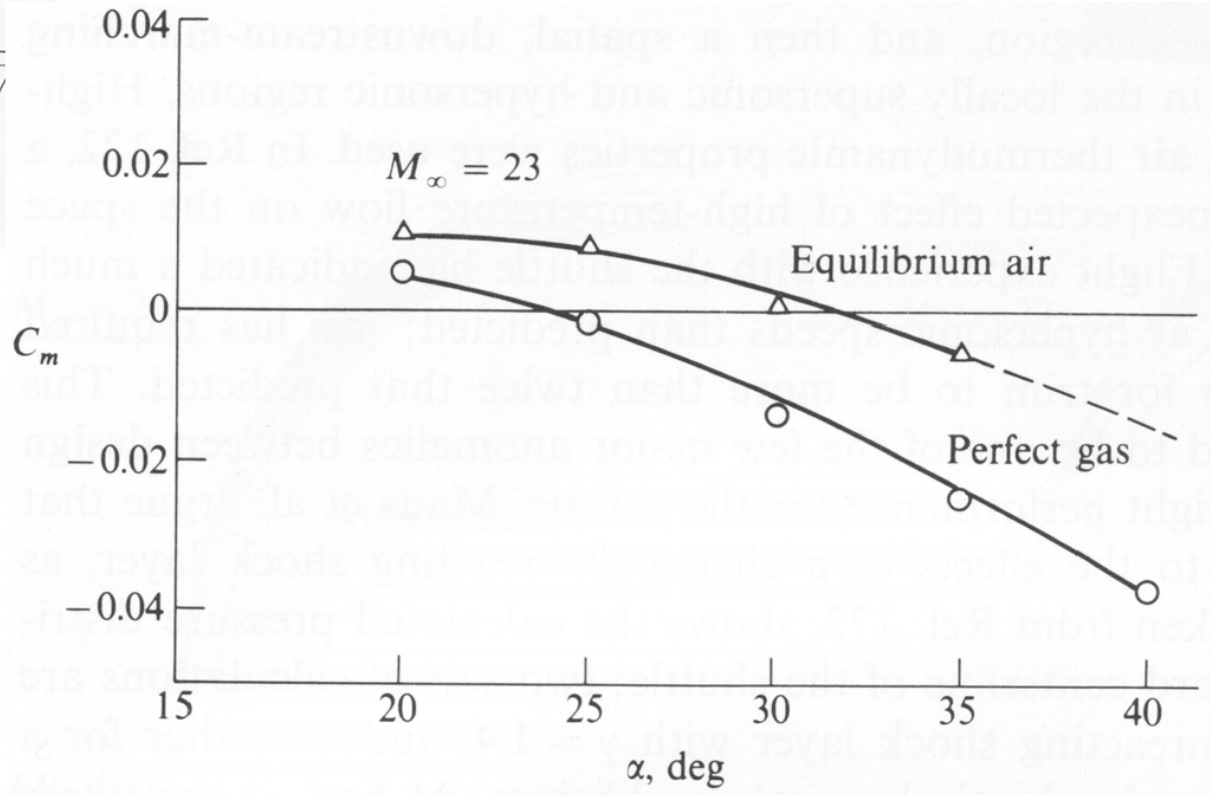
CBAERO ~ 2006

Kinney, David J., and Garcia, Joseph A., "Predicted Convective and Radiative Aerothermodynamic Environments for Various Reentry Vehicles Using CBAERO," AIAA Paper 2006-659, Jan. 2006.

High Temperature Gas Effects



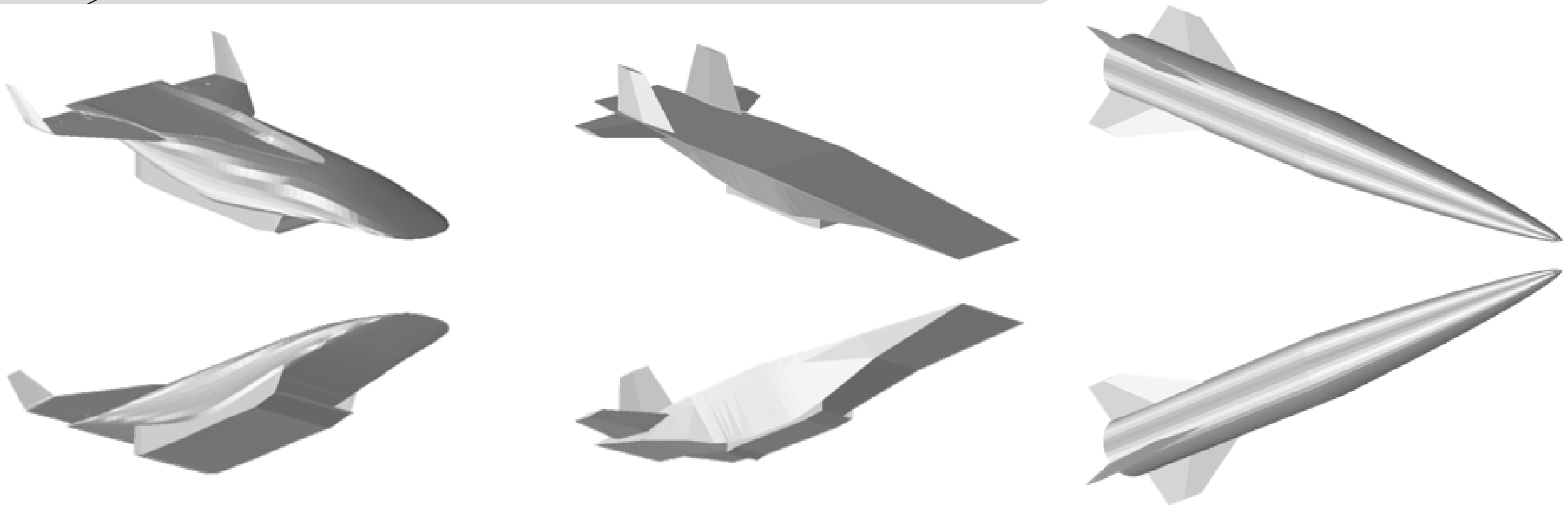
They almost ran out of deflection to trim - could have been a disaster!



From Anderson, *Hypersonic and High Temperature Gas Dynamics*, but originally from Maus, et al, *JSR* Mar-Apr 1984, pp 136-141

Things to Note

- *Understanding the physics of hypersonics is key* to technology development
- Accurate modeling of relevant physics prevents disasters
- Application/mission of a hypersonic system determines relevant physics
- *Relevant physics in hypersonics strongly influence system design and performance* (not to mention cost, operability, …)



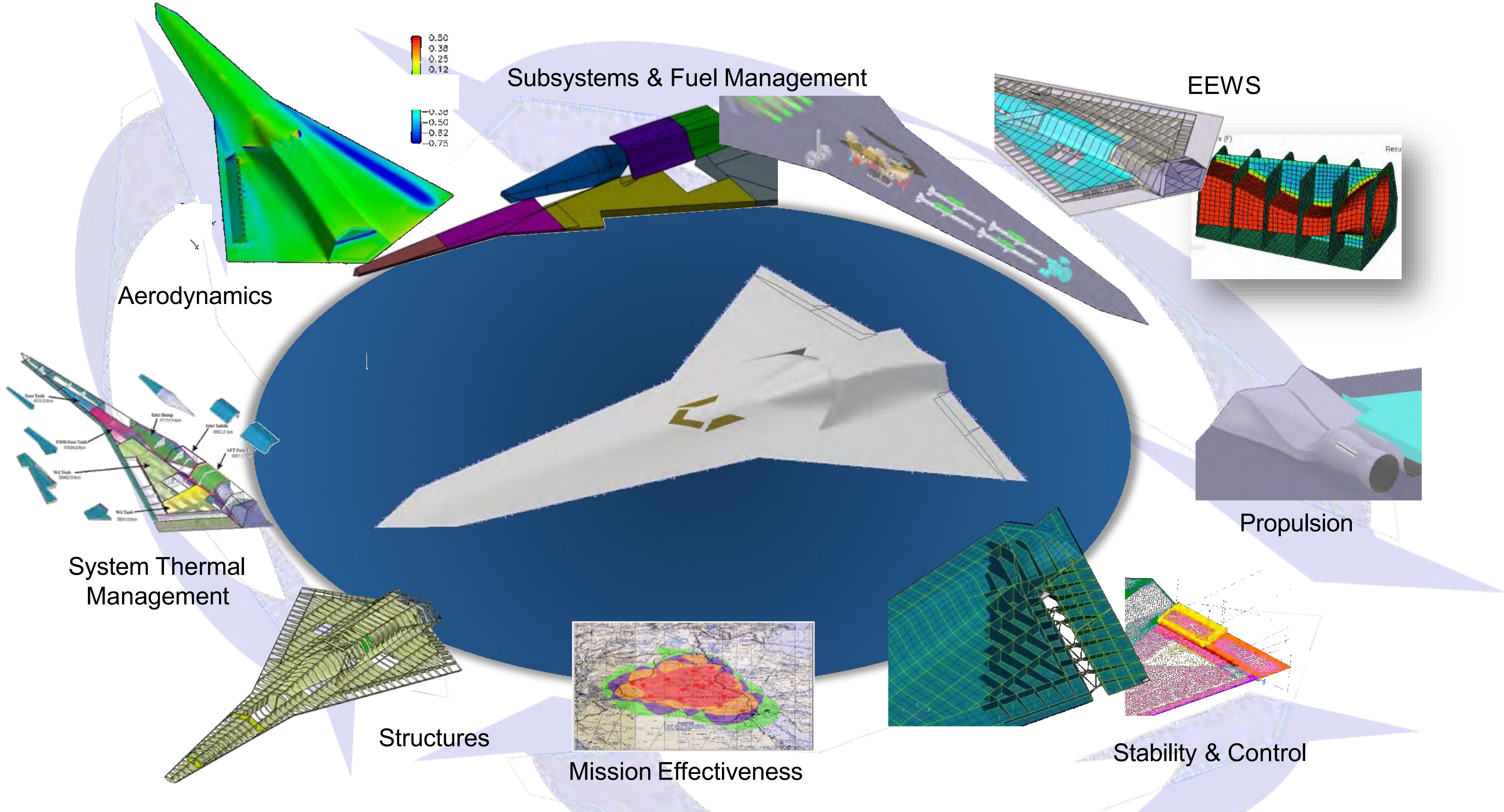
NASA Vision Vehicle | AFRL ISR Hypersonic Cruiser | AFRL IC3X High Speed Vehicle

https://a2srl.engin.umich.edu/research/maccs/hyper_flexible-2/

Hypersonic Vehicle Design

Systems Integration, Analysis, Design, and Optimization

Integrated Design Process - Systems Engineering



Add All Disciplines, Couplings, & Fidelity - Early

Conceptual Design

Abstract Creation *Theoretical Drawing*

"**Conceptual modelling** is the **abstraction of a simulation model** from the part of the real world it is representing ('the real system'). The real system may, or may not, currently exist. Abstraction implies the need for simplification of the real system and for assumptions about what is not known about the real system. In other words, all simulation models are simplifications of the real world. The *secret to good conceptual modelling is to get the level of simplification correct*, that is, *to abstract at the right level*."

– Robinson, "Conceptual Modeling for Simulation," *Proc. of the 2013 Winter Simulation Conference*

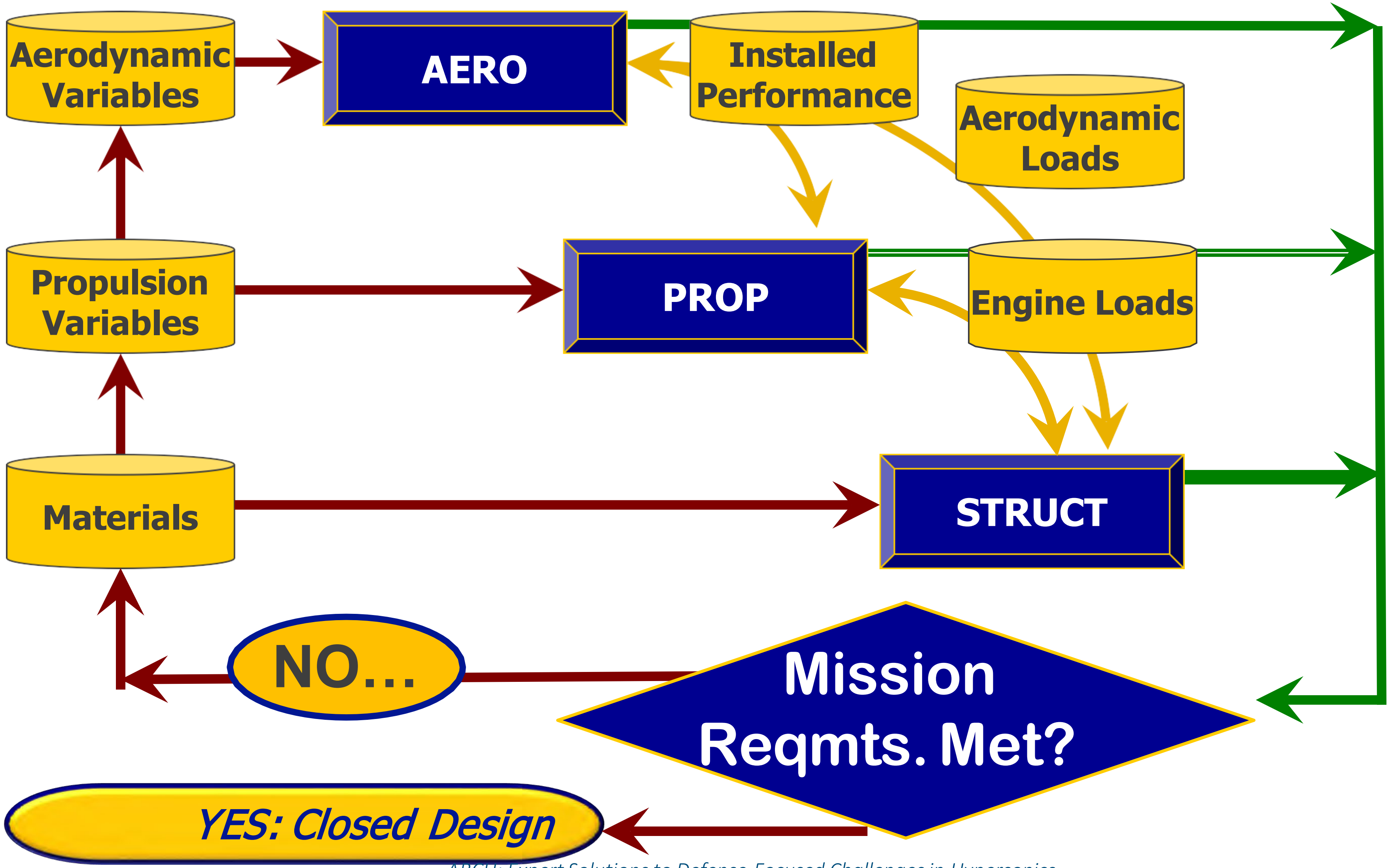
- Conceptual Design differs from one organization to another; depends on objectives
- Generally conceptual design intended for *design space exploration*, the testing out multiple options before down-selecting the *system concept*.

Conceptual Design

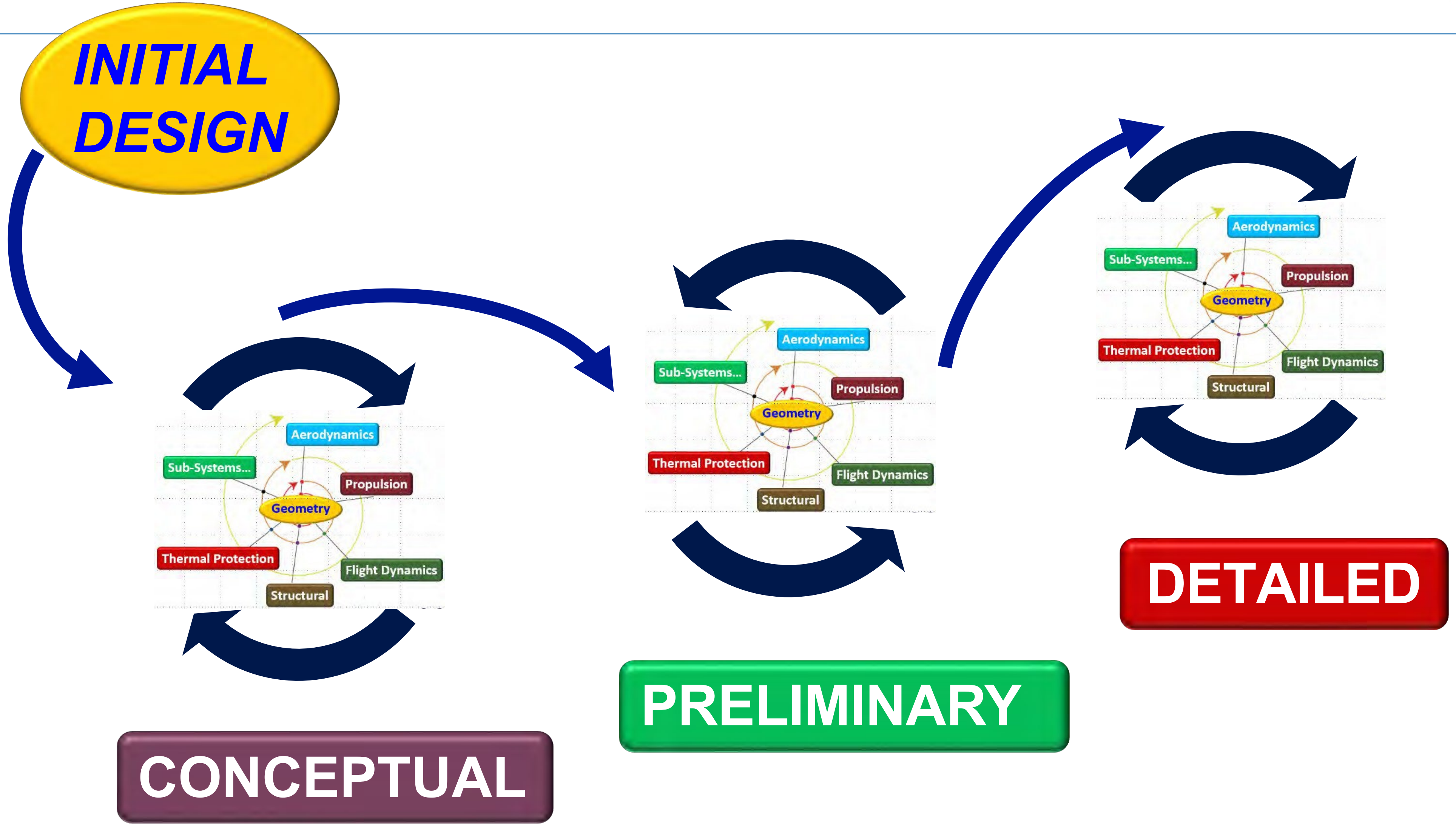
Fidelity Level	System Level	Review	Description	Timeframe
0	System	Initiation	rapid assessment of system architectures (generally no geometry).	Weeks (1-4)
1	Subsystem	Pre-Conceptual	initial assessment of as-drawn system design	Months (2-6)
2	Component	Conceptual (CoDR)	refined assessment of as-drawn system & subsystem design	Months (6-18)
3	Part	Preliminary (PDR)	preliminary assessment of as-drawn system, subsystem & component design	Years (1-5)
4	Part	Detailed (CDR)	detailed assessment of as-drawn system, subsystem, component & part design	Years (3-7)

"Conceptual Design"

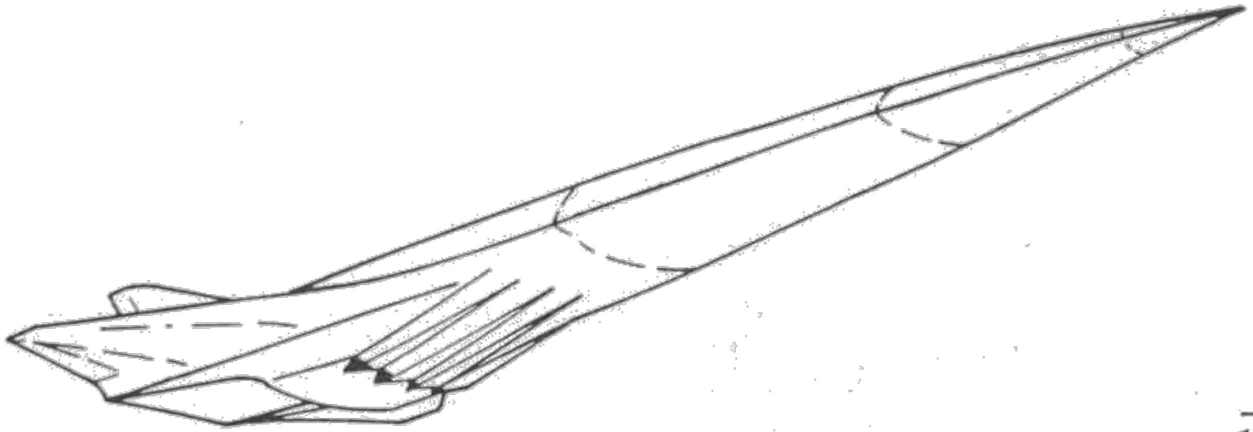
System Synthesis



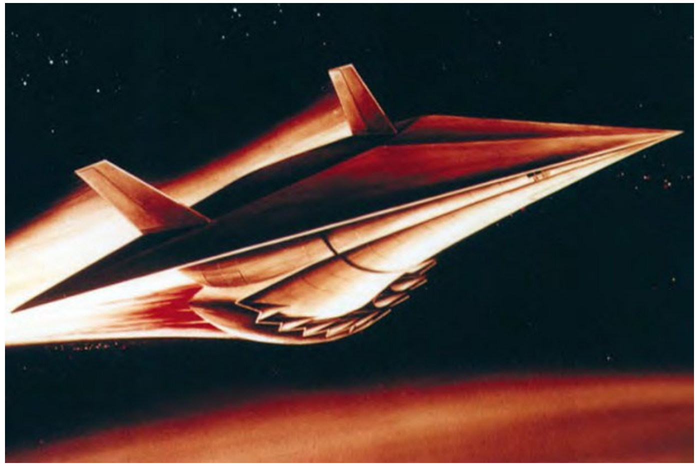
Design Spiral

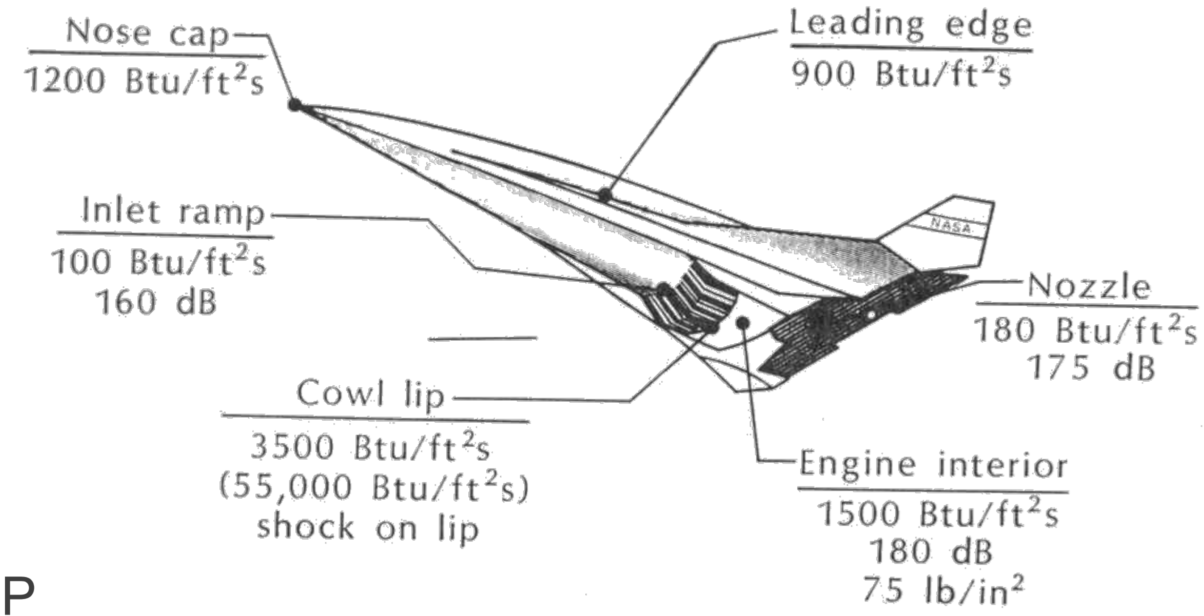


Hypersonic Air-Breathing Concepts



Hypersonic Vehicle Concept
ca.1970's





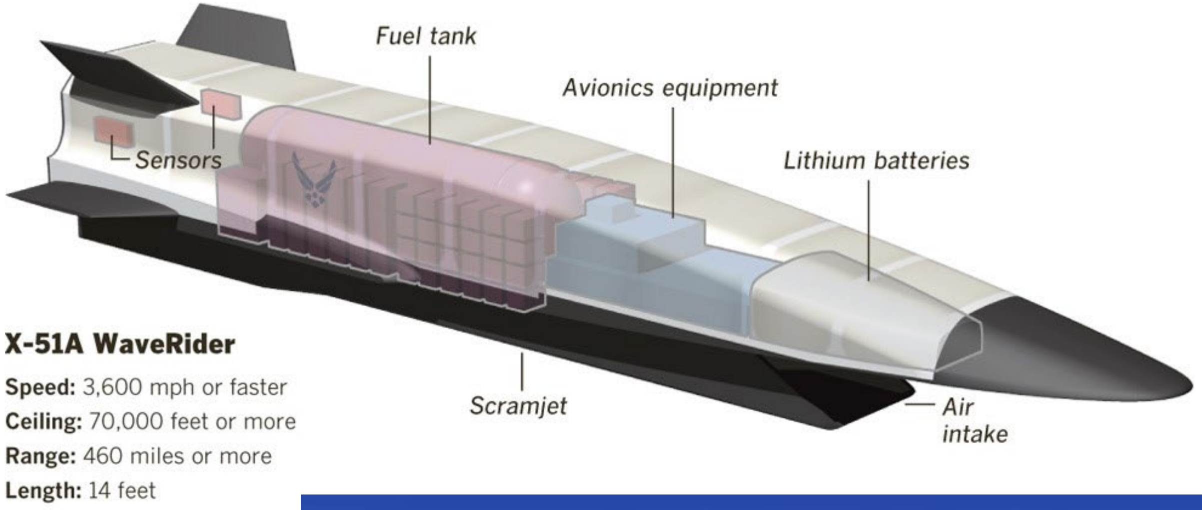
Typical aerothermo-dynamic constraints on NASP during ascent.

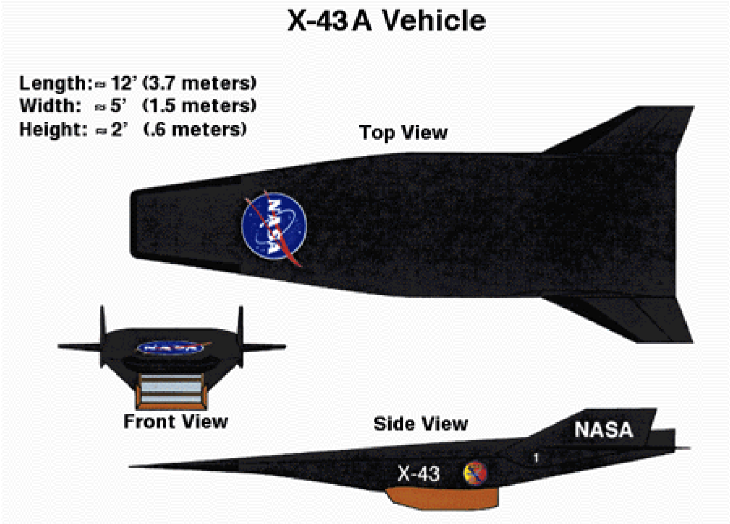
Design Tools & Process

- Theoretical Analyses.
- Computational Fluid Physics.
- Ground-Based Testing & Experimentation.
- Flight Tests (scale models, full-scale).
- Ultimately, only flight of full-scale vehicle at actual conditions provides true representation (expensive, time consuming, and high risk).
- Optimum configuration will require fully integrated multi-disciplinary approach.

Recognize the strengths and weaknesses of each tool and range of applicability!

Recent Success





Lois J. Weir
NASA GRC

National Aeronautics and Space Administration

The NASA Hypersonic Technology Project

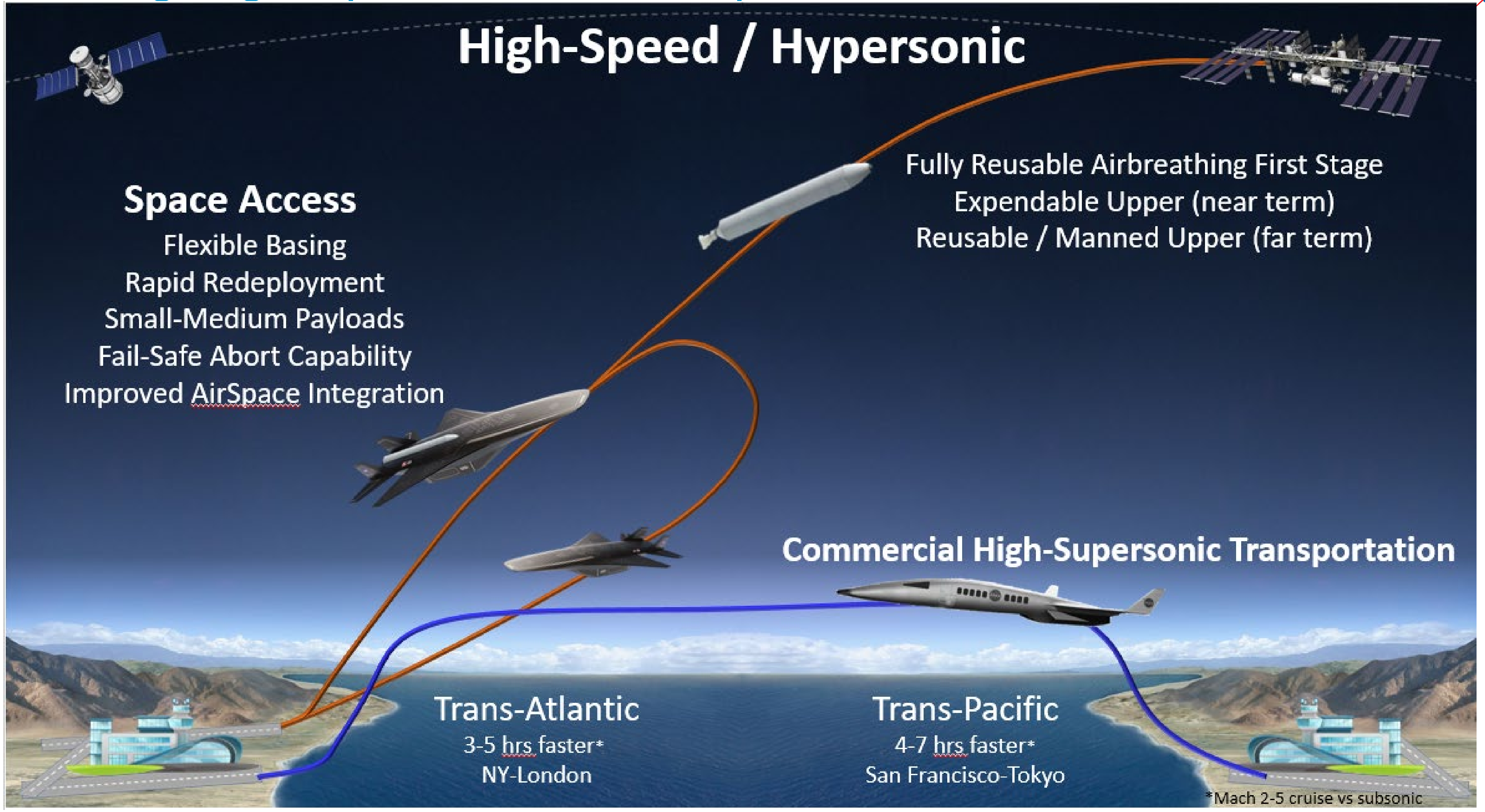
September 12, 2024

Lois Weir, Senior Technologist for Hypersonic Propulsion
Francisco Sola-Lopez, Associate Project Manager
NASA Glenn Research Center

Outline

- High Speed Civilian Airspace
- Hypersonic Technology Project
  - Organizational Structure
  - Vision, Mission, Approach
  - Investment Areas
    - RT-1: System-Level Design, Analysis, and Validation
    - RT-2: Propulsion Technologies
    - RT-3: Vehicle Technologies
    - RT-4: High Temperature, Durable Materials
- Summary

Envisioning High-Speed Civilian Airspace of Tomorrow



Project Org Chart: Detailed View

HYPERSONIC EXECUTIVE TEAM

Project Manager:	Mary Jo Long-Davis (GRC)
Deputy Project Manager:	Andrea Storch (LaRC)
Associate Project Manager:	Shelly Ferlemann (LaRC)
Associate Project Manager:	Francisco Sola (GRC)
Associate Project Manager:	Craig Stephens (AFRC)
APM for Partnerships:	Andrew Brune (LaRC)
Senior Technical Advisor:	Jeff Robinson (LaRC)

PROJECT SUPPORT TEAM

Project Analysts:	Shatonda Douglas (LaRC/Lead) Tyler Schlenbaker (GRC)
Scheduler:	Jennifer Tomak (GRC)
Risk Manager:	Eric Overton (GRC)
Security Specialists:	Steve Sanders (LaRC/Lead) Alex Oppenheim (detail) (GRC)
Project Coordinator:	Nikki Newcomb (LaRC)

ACADEMIC OUTREACH

Coordinators:	Aaron Auslender (LaRC/Lead) Manan Vyas (GRC)

NASA DIRECTED RESEARCH (Technical Challenges and Research Topics)

* **HTP-TC-2: TBCC Mode Transition**	Lancert Foster (GRC)
* **HTP-TC-3: DMRJ Scaling Laws**	Andrew Norris (LaRC) Mike Bynum (LaRC)
* **RT-1: System Level Design, Analysis, Validation**	Tom West (LaRC)
* **RT-2: Propulsion Technologies**	Lancert Foster (GRC) Tom Drozda (LaRC)
RT-3: Vehicle Technologies	Ian Neel (LaRC)
* **RT-4: High-Temperature, Durable Materials**	Chris Kostyk (AFRC)

DoD COLLABORATIONS

• TBCC: turbine based combined cycle • DMRJ: dual-mode ramjet/scramjet * GRC-involvement

Hypersonic Technology Project Vision, Strategy & Goals

VISION

Enable routine, reusable, airbreathing hypersonic flight

MISSION

Advance core capabilities and critical technologies underpinning the mastery of hypersonic flight to support U.S. enterprise in hypersonics

APPROACH

Conduct fundamental and applied research to enable a broad spectrum of hypersonic systems and missions

OVERARCHING STRATEGY

Develop technologies applicable to reusable vehicle requirements and leverage partnerships to demonstrate technologies to TRL 6

KEY PARTNERS / STAKEHOLDERS/ CUSTOMERS

NASA / OGA / INDUSTRY / UNIVERSITIES

LONG-TERM GOALS

By 2035: Develop capabilities and enabling technologies up to TRL 6 for Reusable Airbreathing Hypersonic Vehicles With Speeds up to Mach 8

By 2040+: Develop capabilities and enabling technologies up to TRL 6 for Sustainably-Fueled Reusable Airbreathing Hypersonic Vehicles With Speeds up to Mach 12

ENDURING PROJECT PRIORITIES

#1 - Support NASA/DOD partnerships and deliver on external commitments

#2 - Execute Technical Challenges to deliver critical enabling technologies

#3 - Continue NASA-directed research; sustain/grow core competencies and capabilities

#4 - Develop the next generation of U.S. hypersonic experts

HTP Investment Areas: Challenges to Reusable Hypersonic Flight

* RT-1: System-Level Design, Analysis, and Validation

- Methods development / validation
- System-level uncertainty quantification
- Vehicle conceptual design studies

RT-2 / TC-2 / TC-3: Propulsion Technologies *

❖ Combined cycle mode transition
❖ Scaling laws for dual mode ramjets
- Propulsion control methods
- Dual mode ramjets and scramjets
- Advanced sensors technologies
- Innovative, high-speed inlets and nozzles
- Application of alternative fuels (SAF, H2,…)

RT-3: Vehicle Technologies

- Vehicle flow physics (boundary layer transition)
- Aero-heating effects
- Non-intrusive (e.g., optics-based) instrumentation

❖ =Technical Challenge (TC)

RT-4 High Temperature, Durable Materials *

- CMC heat exchanger
- Static and dynamic high-temperature seals
- Advanced metallic materials and manufacturing
- Advanced CMC hot structures
- Advanced structural instrumentation

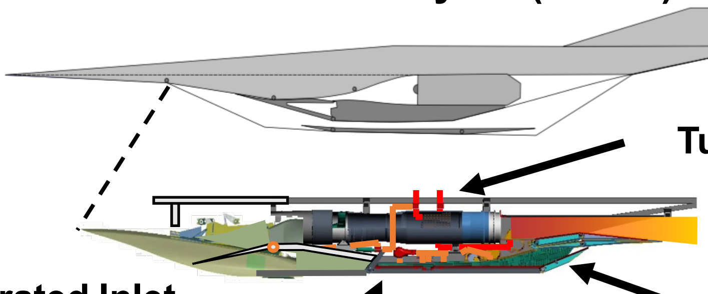
* GRC-involvement

TC-2: TBCC Propulsion Mode Transition *

Demonstrate automated control and establish performance / operability assessment methodologies through mode transition for TBCC powered hypersonic vehicles

Technical Lead: Lancert Foster (GRC)

Turbine-Based Combined Cycle (TBCC) Concept

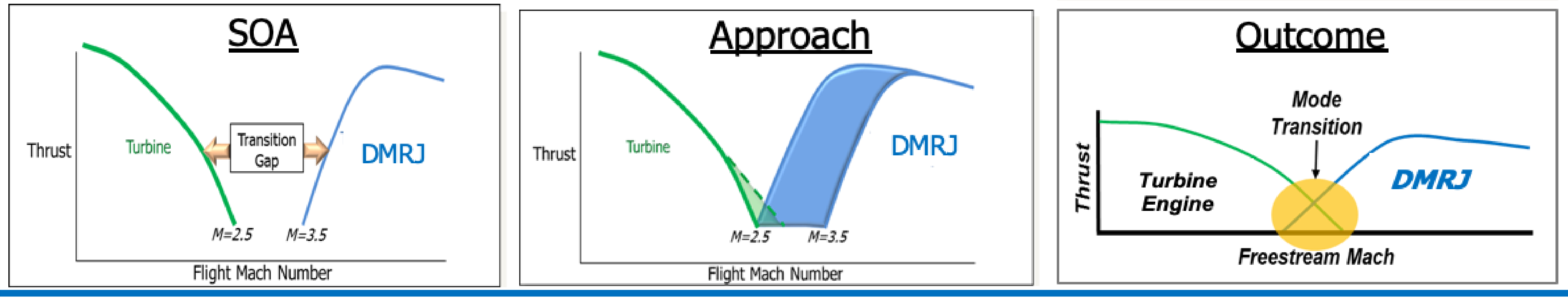


Expanded Mach Operation
- Increase operational Mach number of low-speed turbine engine system
- Decrease operating Mach number of high speed DMRJ system

Control Algorithm Development and Automated Control Demonstration
- Develop control algorithms for CC inlet, turbine engine, and DMRJ
- Demonstrate automated controls for CC inlet, simulated turbine and DMRJ, and live turbine and simulated DMRJ

Performance / Operability Assessment Methodology and Database Development
- Define assessment methodology for CC inlet, turbine, and DMRJ
- Generate CC inlet, turbine, and DMRJ databases

Provides data on mode transition technologies, identifies unknown-unknowns, & delivers the methodology and control theory for automated propulsion mode transition

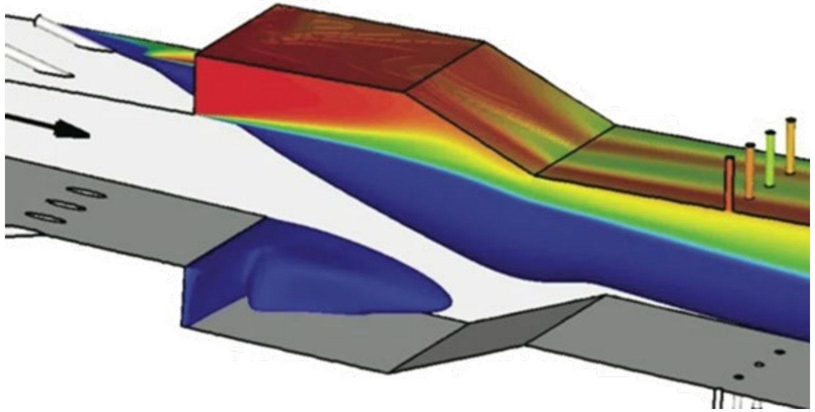


* GRC-involvement

TC-3: Development of Improved Combustor Scaling Laws for Dual-Mode Ramjets

Deliver mathematical models, and associated validation test data with quantified uncertainty, to enable design of large-scale high-speed combustors inclusive of green fuels

Co-PIs: Andrew Norris (LaRC) and Michael Bynum (LaRC)



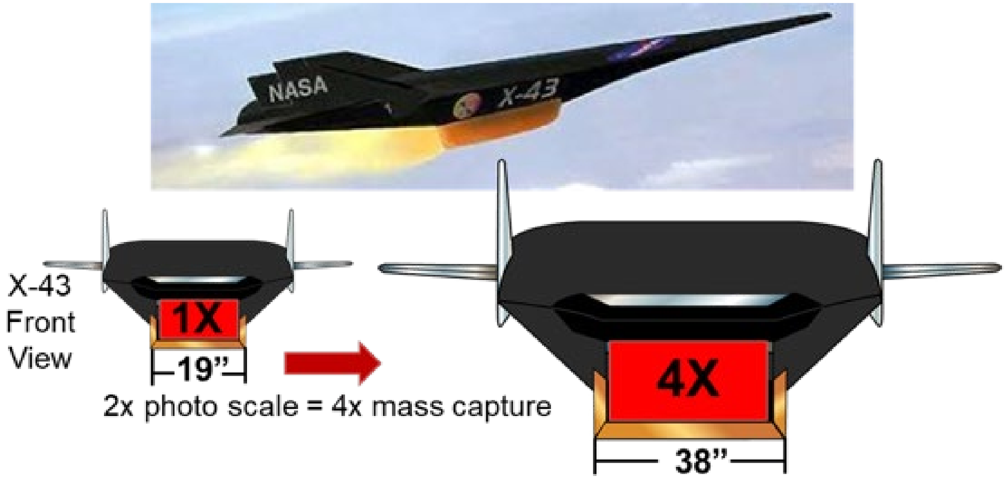
Provides an understanding and a process to enable the optimization of flameholding cavities in high-speed engines, enabling fully reusable hypersonic vehicles.

Computational Analysis *

- Evaluate, simulate, and optimize legacy AFRL cavity combustor test rig geometry
- Determine planar cavity performance and cavity and core performance plus optimization
- Apply models to HIFiRE Direct Connect Rig (HDCR) and develop cavity relationships, cavity and core models

Ground Testing

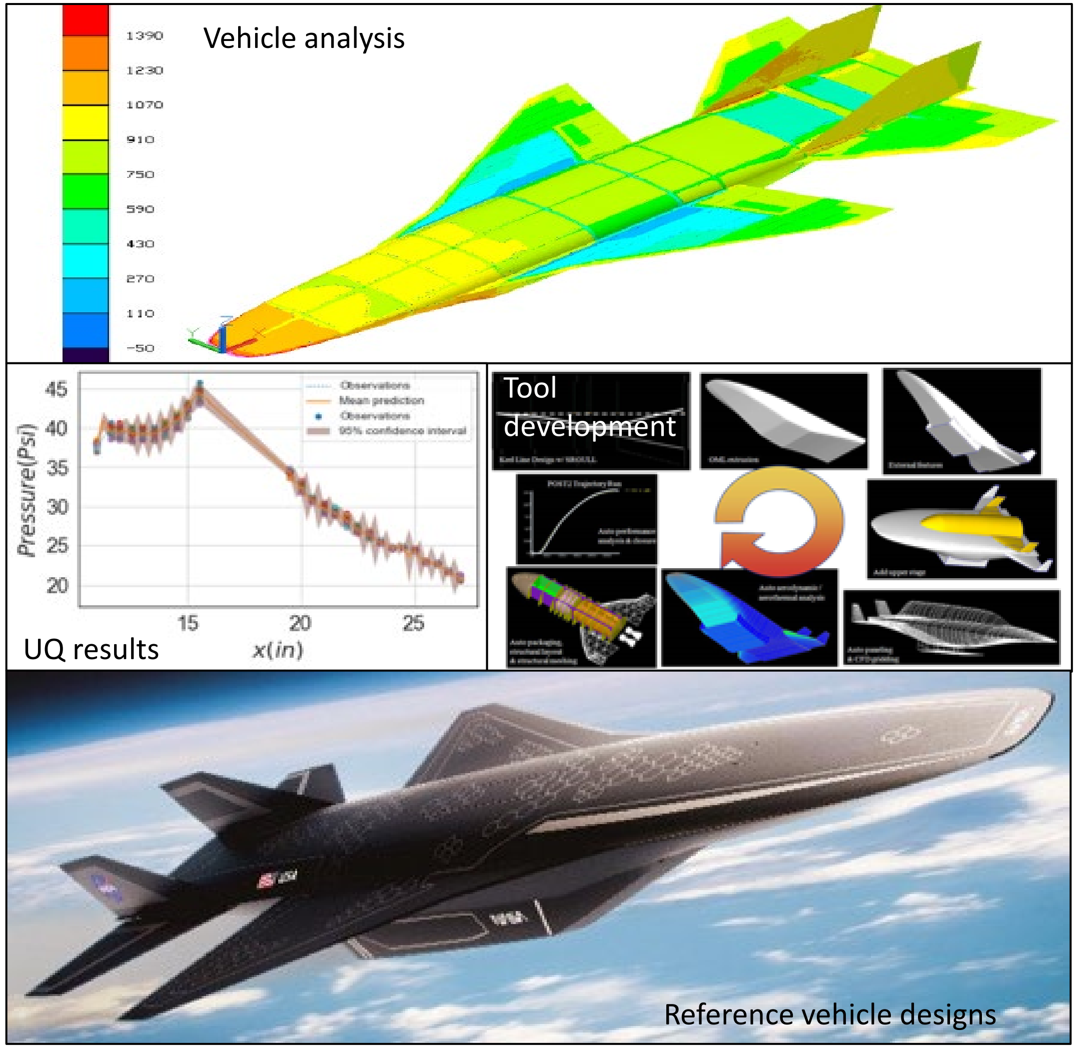
- Design ground test rig with variable cavity sizes and upstream injector blocks and facility nozzles
- Perform tests of core flow ignition article
- Compare ground test results with CFD predictions
- Develop and deliver relationships for cavity sizing and axisymmetric vs. planar cavity design



* GRC-involvement

RT-1: System Level Design, Analysis, & Validation

Lead: Tom West (LaRC)



RT-1.1: *
Multidisciplinary Design/Optimization and Uncertainty Quantification (MDAO & UQ)

RT-1.2:
Fluid-Thermal-Structural Interaction (FTSI)

RT-1.3: *
Power and Thermal Management Systems (PTMS)

RT-1.4: *
Vehicle Design

RT-1.5:
Aerosciences Capability Development

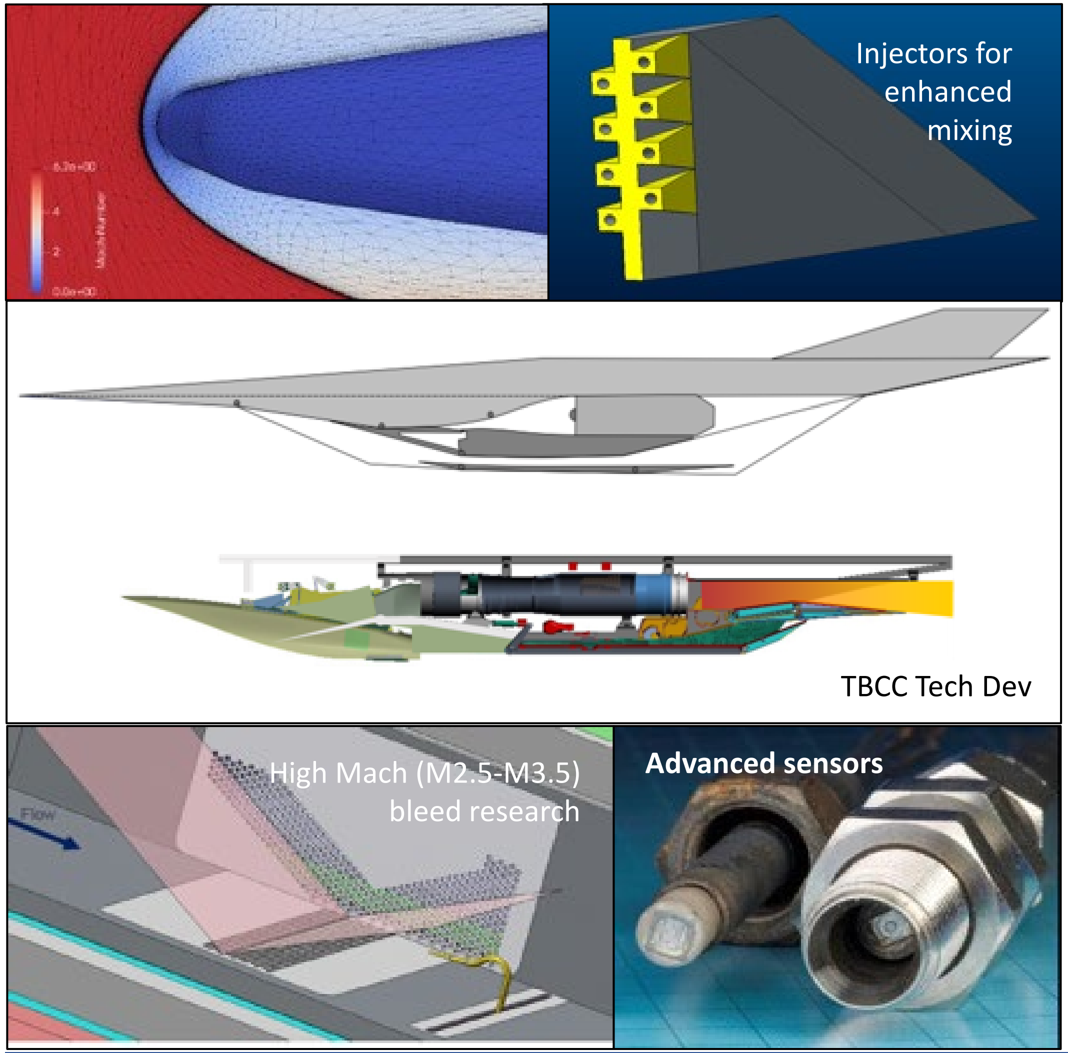
RT-1.6:
Design Fidelity Enhancement

Design and analyze civil-relevant reference vehicles and inform programmatic decision-making

* GRC-involvement

RT-2: Propulsion Technologies

Co-Leads: Tom Drozda (LaRC) and Lance Foster (GRC)



RT-2.1: Enhanced Injection and Mixing

RT-2.2: VULCAN-CFD Development

RT-2.4: * Advanced Pressure Sensors for Adaptive Controls and Health Monitoring

RT-2.6: Isolator Dynamics Research Lab (IDRL)

RT-2.8: * High Mach Turbine Engine Technology Development

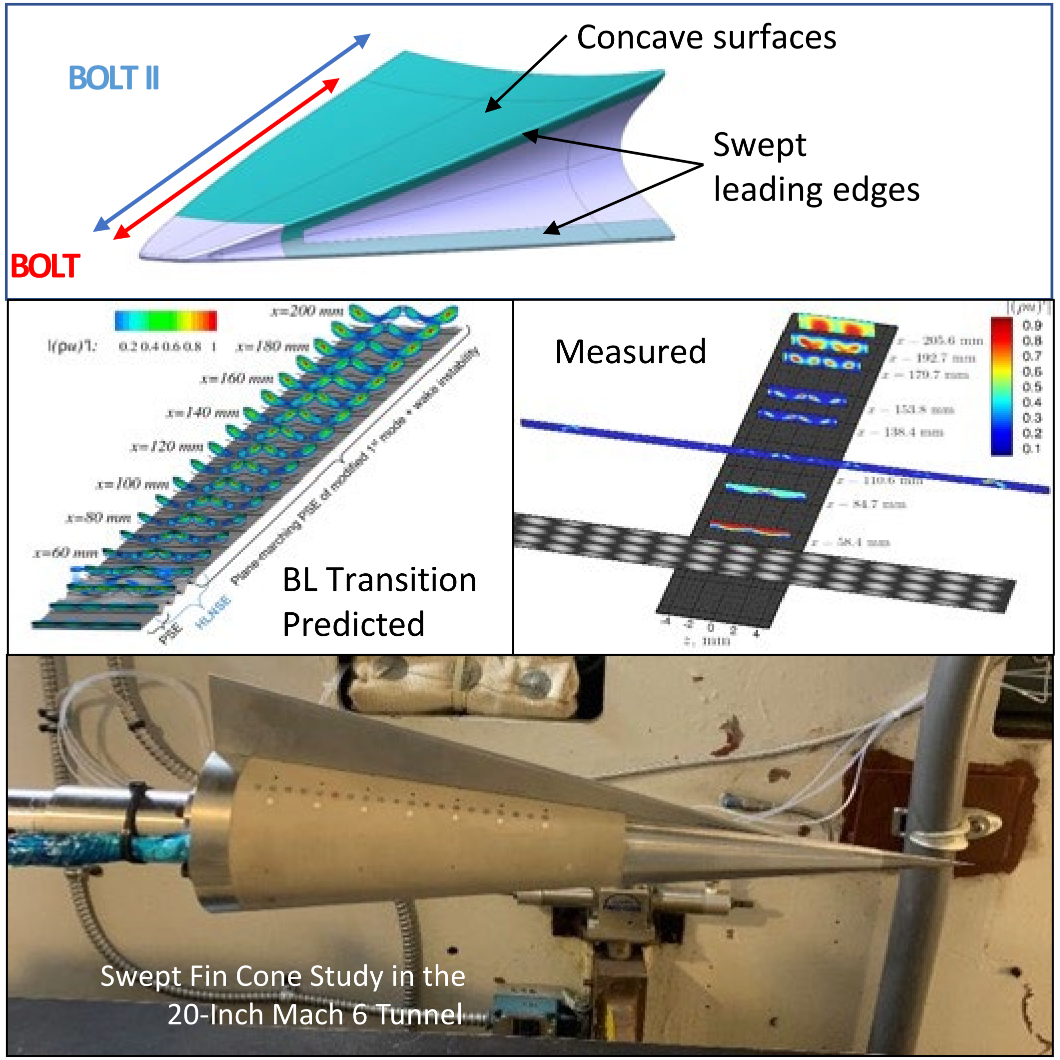
RT-2.9: * Aether Subscale Ground Test Propulsion Database Development

Maturing airbreathing propulsion technologies necessary for hypersonic TBCC vehicles

* GRC-involvement

RT-3: Vehicle Technologies

Lead: Amanda Chou (LaRC)



RT-3.1:
Flight Testing / Program Support

RT-3.2:
Boundary Layer Transition Validation and Computational Tools

RT-3.3:
Fluid-Structure Interaction

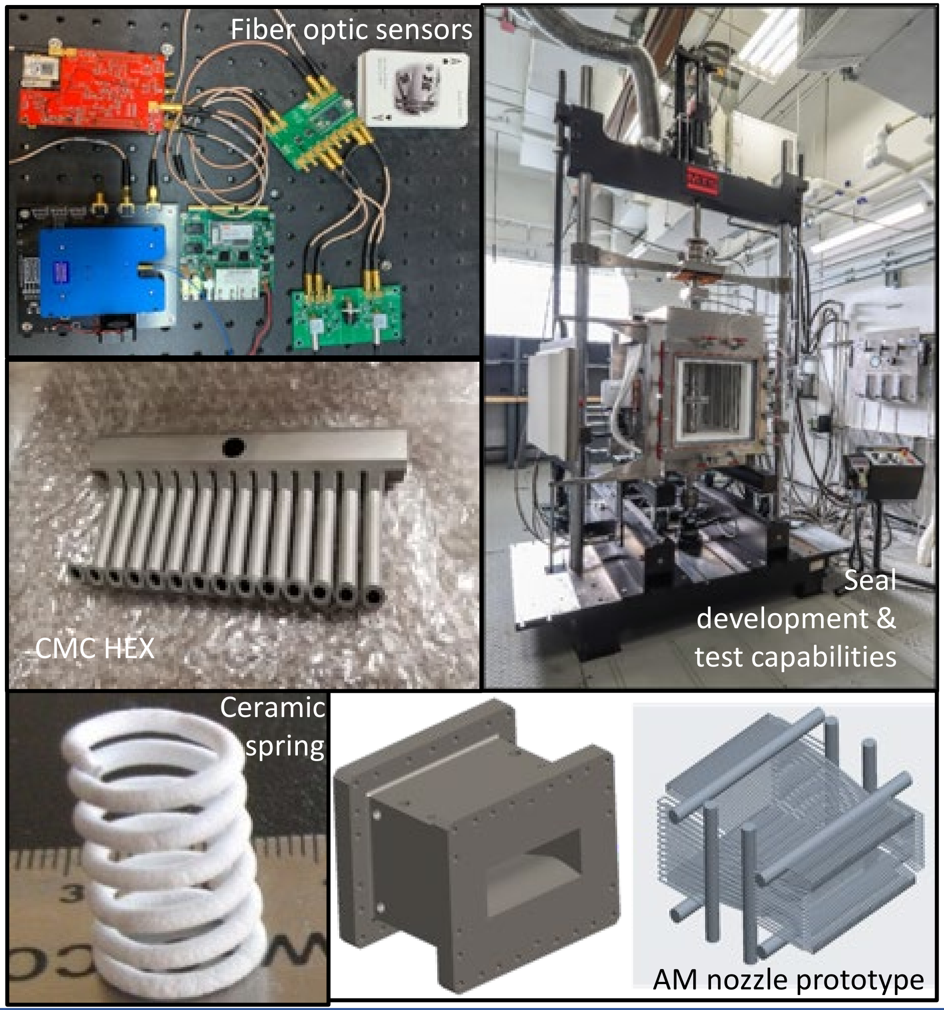
RT-3.4:
Shock-Shock/Shock-Boundary Layer Interactions

RT-3.5:
Flow Control Applications

Foster development of tools and technologies from fundamental to applied hypersonic vehicles

RT-4: High Temperature, Durable Materials

Lead: Chris Kostyk (AFRC)



RT-4.1: *
Ceramic Matrix Composite (CMC) Heat Exchanger (HEX)

RT-4.2: *
High Temperature Seals

RT-4.5:
High-Temperature Fiber Optic Sensors

RT-4.6:
Materials and Structures for Hypersonic Airframe Components

RT-4.7: *
Materials and Structures for Hypersonic Propulsion Components

RT-4.8:
Ground Test Techniques

Provide demonstrated high temperature material and component solutions/ data/ lessons learned to enable reusable hypersonic vehicles

* GRC-involvement

Summary

- The NASA Hypersonic Technology Project is working to enable routine, reusable, airbreathing hypersonic flight through:
  - System-Level Design, Analysis, and Validation
  - Propulsion Technologies
  - Vehicle Technologies
  - High Temperature, Durable Materials
- HTP has existing collaborations with Other Government Agencies

Questions?

Opportunity Review

FY24 NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION OFFICE-WIDE BROAD AGENCY ANNOUNCEMENT (BAA)

Solicitation #N00421-24-S-0001

- **Who**
  - The Naval Air Warfare Center Aircraft Division (NAWCAD)
  - *Eligibility*: ALL
- **What**
  - The type of solicitation: Grant, BAA
- **When**
  - Released: June 21, 2024
  - Due: 20 June, 2025
- **Where**
  - Webpage: https://grants.gov/search-results-detail/355077
  - Contact information:
  - NAWCAD BAA Academia Coordinator: NAWCAD-Academia-BAA@us.navy.mil
  - NAWCAD BAA Industry Coordinator: NAWCAD-Industry-BAA@us.navy.mil
- **Why**
  - *Funding*
    - Approx. $160,000.00 - $200,000.00 per award
    - Multiple awards
  - *Technical*
    - The Naval Air Warfare Center Aircraft Division is interested in receiving white papers for R&D projects that strengthen NAWCAD operations with priority given to Hypersonic system research.
    - Areas of research include but are not limited to, high-speed aerodynamic, multi-physic modeling, hypersonic systems, high temperature and specific strength materials, structures and coatings, guidance, navigation and control, and advanced air-breathing propulsion

Long Range Broad Agency Announcement (BAA) for NSWC Crane

Solicitation # N0016424SNB35

- **Who**
  - Gov't: DoD -Naval Sea Systems Command
  - *Eligibility*: Unrestricted
- **What**
  - The type of solicitation: BAA
- **When**
  - Released: 1 February 2024.
  - Due: 7 February 2025
- **Where**
  - Webpage: https://grants.gov/search-results-detail/352238
  - Contact information
  - Technical Point of Contact: Patrick Shaffer
  - Patrick.j.shaffer.civ@us.navy.mil
- **Why**
- *Funding*
  - *Varies depending on technology area and technical approach*
- *Technical*
  - R&D of technologies that support the development, integration, testing, and evaluation of HWS to include;
    - aerodynamics
    - aerothermal prediction and analysis
    - navigation and control
    - high-temperature materials
    - thermal management, sensors, and supporting algorithms.

Research Interests of the United States Air Force Academy (formerly USAFA-BAA-202) (HVSI)

FA7000-21-S-0001

- **Who**
  - Air Force Academy
  - *Eligibility*: ALL

- **What**
  - The type of solicitation: BAA

- **When**
  - Released: 02 DEC 2020
  - Due: Applications are accepted on a rolling basis

- **Where**
  - Webpage:
  - https://sam.gov/opp/dfe0bf3dadef4a039cfbd10cbc10bf21/view
  - Contact information: Russell M. Cummings, Ph.D.
  - (719) 333-9223
  - russ.cummings@afacademy.af.edu

- **Why**
  - *Funding*
    - *Award information –*
    - Up to $99,000,000
    - *Technical*

•The Hypersonic Vehicle Simulation Institute (HVSI) funds and performs a range of hypersonic research tasks in support of the DoD High Performance Computing Modernization Program (HPCMP).

•Specific science and technology areas include turbulence, boundary layer transition, fluid-structure-thermal interactions, non-equilibrium chemistry, ablation, and combustion

USASMDC TC BAA For Science, Technology, and Test and Evaluation Research

W9113M-24-R-BAA1

- **Who**
  - DoD- U.S. Army Space and Missile Defense Command (USASMDC)
  - *Eligibility*: ALL
- **What**
  - The type of solicitation: BAA
- **When**
  - Released: 28 AUG 2024
  - Due: 26 AUG 2029
- **Where**
  - Webpage: https://www.smdc.army.mil/ORGANIZATION/TC/
  - https://sam.gov/opp/9ec1895f936843368d8f1edc32e4912f/view
  - *A change to SMDTC's published BAA topics is not an amendment to this BAA and will not be posted on https://www.grants.gov/ and https://www.SAM.gov/. A change to this document (i.e., the BAA itself) will be considered an amendment and will be posted on https://www.grants.gov/ and https://www.SAM.gov/*
  - Contact information: Kayla James
  - kayla.m.james15.civ@army.mil
- **Why**
  - *Funding*
    - *Award information –*
      - Multiple awards given
    - *Technical*
      - areas of interest: tactical responsive space and high-altitude technologies, test and evaluation, strategic weapon technologies, and hypersonic defeat

Broad Agency Announcement for Air Delivered Effects (BAA)

Solicitation # FA8651-22-S-0001

- **Who**
  - *Gov't*: Air Force Defense Research Sciences Program
  - *Eligibility*: Nonprofits, other than institutions of higher education
  - Public and state controlled as well as private institutions of higher education
  - Small businesses

- **What**
  - The type of solicitation: Contract, BAA

- **When**
  - Released: 22 March 2022
  - Update: 18 July 2024
  - Due: 21 March 2027

- **Where**
  - Webpage: https://grants.gov/search-results-detail/338821
  - Contact information:
  - RWK BAA Monitors:
  - Amy Fortenberry: amy.fortenberry.1@us.af.mil
  - Shaun Williams: shaun.williams.8@us.af.mil

- **Why**
  - *Funding*
    - Up to $750,000,000
  - *Technical*

The goal:

- to perform R&D of agile weapon airframes deployed/dispensed from unmanned/manned platforms which can deliver precision-controlled effects against fixed and mobile ground and air targets in contested engagement scenarios
- Areas of interest:
  - agile weapon airframes for high-speed flight
  - high-agility airframes capable of aggressive flight maneuvers
  - networked collaboration
  - compressed carriage munitions and release mechanisms for small weapons
  - small weapon design, carriage, and dispensing technology.

University Consortium for Applied Hypersonics
TEES/JHTO-RPP-2024-001 Request for Proposal

Project Call Announcement #: TEES/JHTO-RPP-2024-001

- **Who**
  - *University consortium for Applied Hypersonics powered by the Texas A&M Engineering Experiment Station and The Texas A&M University System*
  - *Joint Hypersonics Transition Office (JHTO)*
  - *Eligibility*: Candidate must be a University Consortium Member prior to submitting a Notice of Intent (NOI)
- **What**
  - The type of solicitation: Contract
- **When**
  - Released: 23 July 2024
  - Notice of Intent Deadline: 11 October 2024
  - Prototype Proposal Submission Deadline: 15 November 2024
- **Where**
  - Webpage: https://hypersonics.tamu.edu/request-for-prototype-proposals-questions-tees-jhto-rpp-2024-001/https://hypersonics.tamu.edu/request-for-prototype-proposals-questions-tees-jhto-rpp-2024-001/
  - Contact information:
  - UCAH@tamu.edu
- **Why**
  - *Funding*
    - Up to $9,000,000 (dependent upon topic)
  - *Technology Areas of interest:*
    1. Rotating Detonation Engine Advancement
    2. Durable seals for extreme environments
    3. Seeing through high-speed turbulence for EO seekers
    4. Directed Energy – Non-kinetic methods for integrated air and missile defense (IAMD)
    5. UCAH 2024 Grand Challenge – Jet Interaction in Hypersonic Flight

The AFRL Materials and Manufacturing Directorate (RX) Multiple-Authority Announcement (MAA) Photonic, Electronic & Soft Materials Division (RXE)

- A Multiple Authority Announcement (MAA) is a unique solicitation method in which various solicitation authorities are consolidated under a single announcement.
- Includes the authorities covering Broad Agency Announcements (BAA), Commercial Solution Openings (CSO), Funding Opportunity Announcement (FOA), and 10 U.S.C. 4021, 4022, 4023

Photonic, Electronic & Soft Materials Division (RXE)

- Leads research and development activities of materials for advanced battlespace awareness and sensing; materials for enhanced electromagnetic spectral dominance; and advanced materials and processes to support contested logistic

Manufacturing and Industrial Technologies Division (RMX)

- to identify, prioritize, and integrate DAF industrial base requirements to provide the manufacturing processes, techniques, systems, energy, and equipment needed for acquisition, production, operation, and repair of DAF systems.

For more information visit: https://www.afrl.af.mil/RX/Opportunities/
https://sam.gov/opp/b95ddb585e624e549952112dd61408dd/view

FY 2025 DoD SBIR/STTR BAA Release Schedule

- In October, the BAA release schedule will change
- 12 releases
- New BAA topics will open on the first Wednesday of every month
- Some dates have changed from previous notifications
- For more information visit https://www.defensesbirsttr.mil/SBIR-STTR/Opportunities/

FY 2025 DoD SBIR/STTR BAA Release Schedule			
Solicitation Cycle	**Pre-Release**	**Open**	**Close**
25.4/D Release 1	Oct 2, 2024	Oct 23, 2024	Nov 20, 2024
25.4/D Release 2	Nov 6, 2024	Dec 4, 2024	Jan 8, 2025
25.4/D Rel. 3 **Joint 25.1/A**	Dec 04, 2024	Jan 08, 2025	Feb 05, 2025
25.4/D Release 4	Jan 08, 2025	Jan 29, 2025	Feb 26, 2025
25.4/D Release 5	Feb 05, 2025	Feb 26, 2025	Mar 26, 2025
25.4/D Release 6	Mar 05, 2025	Mar 26, 2025	Apr 23, 2025
25.4/D Rel. 7 **Joint 25.2/B**	Apr 02, 2025	Apr 23, 2025	May 21, 2025
25.4/D Release 8	May 07, 2025	May 28, 2025	Jun 25, 2025
25.4/D Release 9	Jun 04, 2025	Jun 25, 2025	Jul 23, 2025
25.4/D Release 10	Jul 02, 2025	Jul 23, 2025	Aug 20, 2025
25.4/D Rel. 11 **Joint 25.3/C**	Aug 06, 2025	Aug 27, 2025	Sep 24, 2025
25.4/D Release 12	Sep 03, 2025	Sep 24, 2025	Oct 22, 2025

Helpful Links

1. SAM.gov – Contract opportunities
2. GRANTS.gov – Federal funding opportunities
3. SBIR.gov – SBIR/STTR information and solicitations
4. defensesbirsttr.mil – DoD-specific solicitation information
5. dodsbirsttr.mil – DoD-specific solicitations
6. sbir.nasa.gov – NASA-specific solicitations
7. ohiofrn.org – Help with identifying opportunities, matchmaking, and proposal development
8. apex-innovates.org – Help with SBIR/STTR process navigation and matchmaking

Upcoming Events

- **AFA National Convention** – in-person @ National Harbor, MD, September 14-15
- **AFA Air, Space & Cyber Conference** – in-person @ National Harbor, MD, September 16-18
- **Export Compliance Roadshow with Dept. Of Commerce** – in-person @ OAI, Cleveland, OH, September 17-18
- **Hypersonic Weapons Summit –** in-person @ Bethesda, MD, September 17-18
- **DDC AAM Forum** – in-person @ Dayton OH, September 19
- **Hypersonic Technology & Systems Conference** - in-person @ North Logan, UT September 23-26
- **Ohio Tech Day** – in-person @OAI, Cleveland, OH, September 27
- **Digital Avionics Systems Conference –** in-person @ San Diego, CA, September 29-October 3
- **DDC Ohio Defense and Aerospace Forum** – in-person @ Dayton, OH, October 8
- **2nd Annual Innovation Day** – in-person @ Youngstown State University, October 8
- **AI Horizons Summit** – in-person @ Pittsburgh, October 14
- **AUSA** – in-person @ Washington DC, October 14-16
- **Global Aerospace Update and Outlook** – in-person @ OAI, Cleveland OH, October 17
- **Keystone Space Annual Conference** – in-person @ Pittsburgh, October 29
- **NASA Evening with the Stars** – in-person @ Cleveland OH, November 20

Thank you

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