Next Generation Space Access

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Responsive Space Access Capability Lead & Hypersonics Area Planner

Overview

- **USAF Vision for Assured Space Access**
  - Near Term: Responsive Reusable Booster Stage
  - Far Term: Technology Challenge

AF Responsive Space Access

Expendable Solids & Liquids

Small Launch Vehicle (SLV)

Reusable First Stage

RBS Flagship

Hybrid

Reusable 1st Stage Vertical Takeoff

15K lbs to Low Earth Orbit

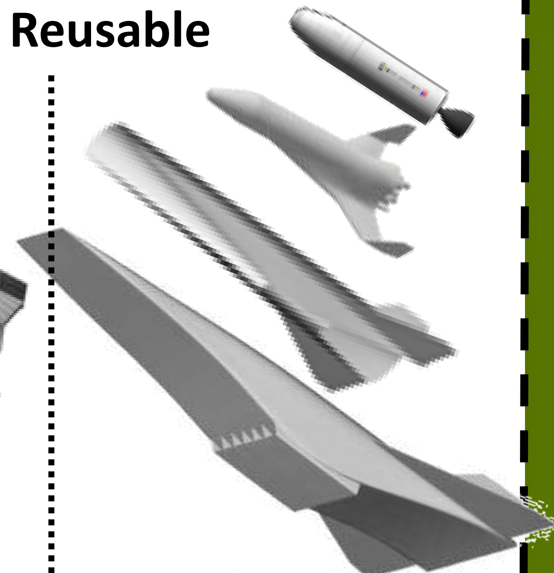
Fully Reusable

Reusable 2nd Stage

Fully Reusable

Payoff – +40% payload incr.

Ex: Reusable Rocket & Rocket-Scramjet Based Combined Cycle

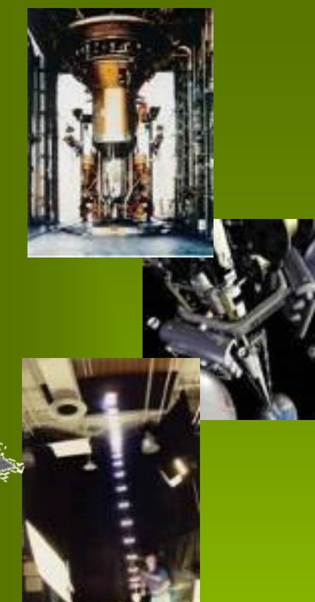


Reusable Horizontal Takeoff 1st Stage

Payoff – Flexible Basing

10K lbs to Low Earth Orbit

Ex: Turbine-Scramjet Based Combined Cycle

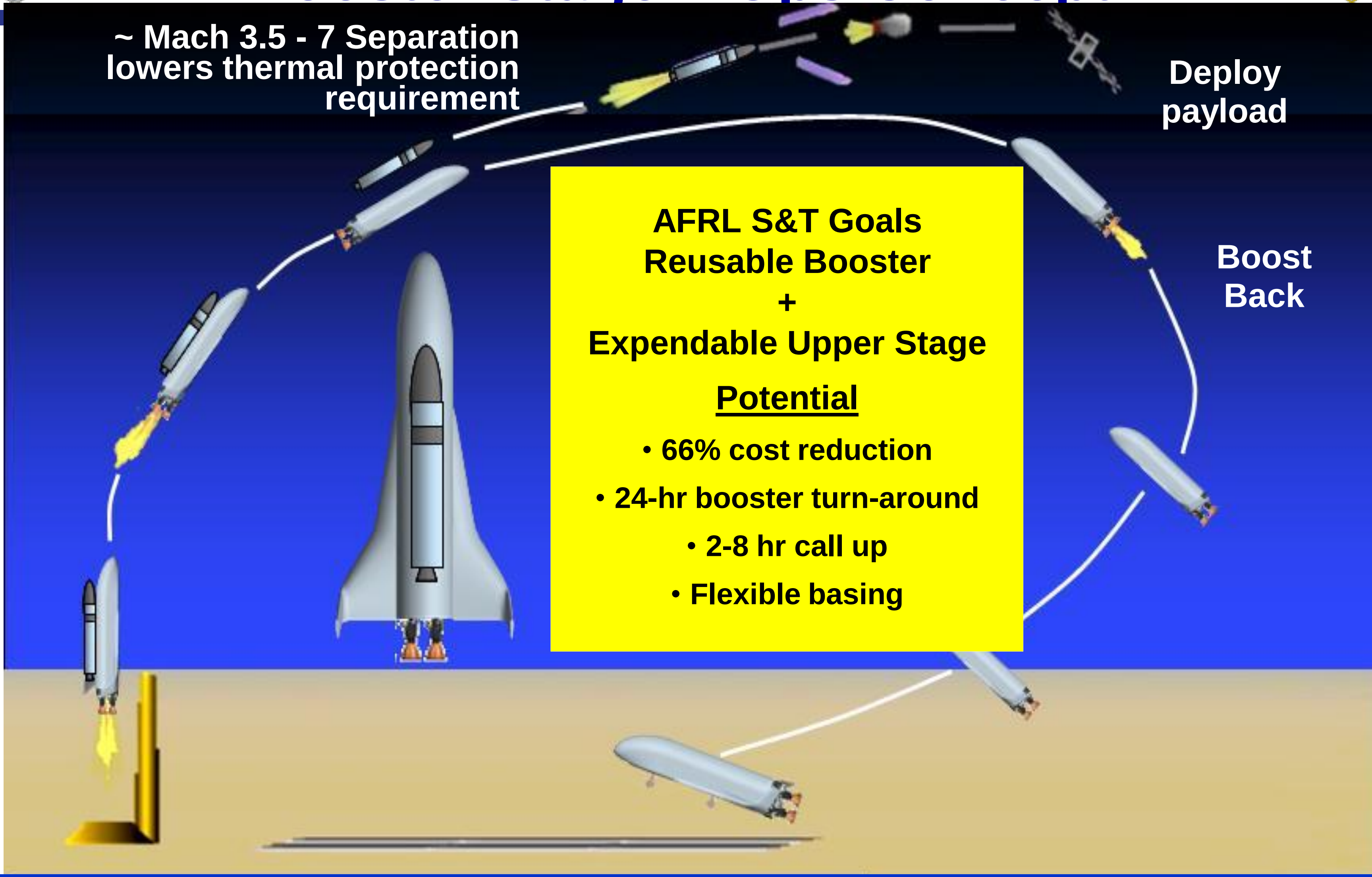


Advanced Concepts

New Paradigms

2010	2017 - 2020	~2025	~2030	2035+

RBS: Responsive, Lower Cost Booster Stage – Ops Concept



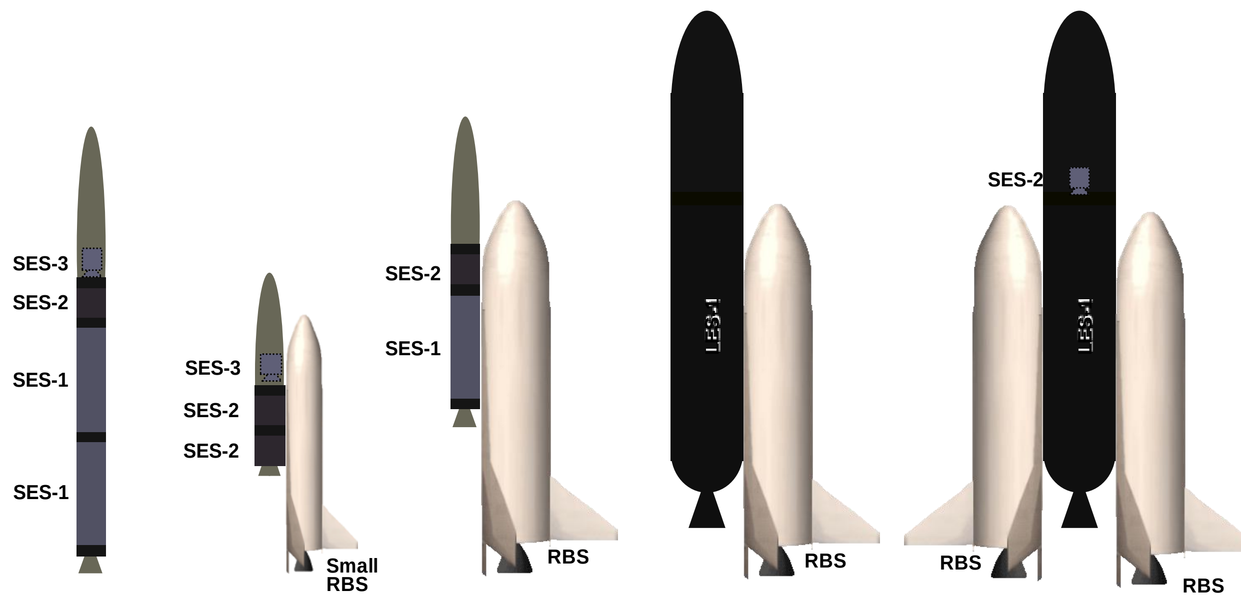
AFRL S&T Goals
Reusable Booster
+
Expendable Upper Stage

Potential

- 66% cost reduction
- 24-hr booster turn-around
- 2-8 hr call up
- Flexible basing

Concept stretches S&T Gamut of Possible Solutions

Next Generation Launch System
Near Term



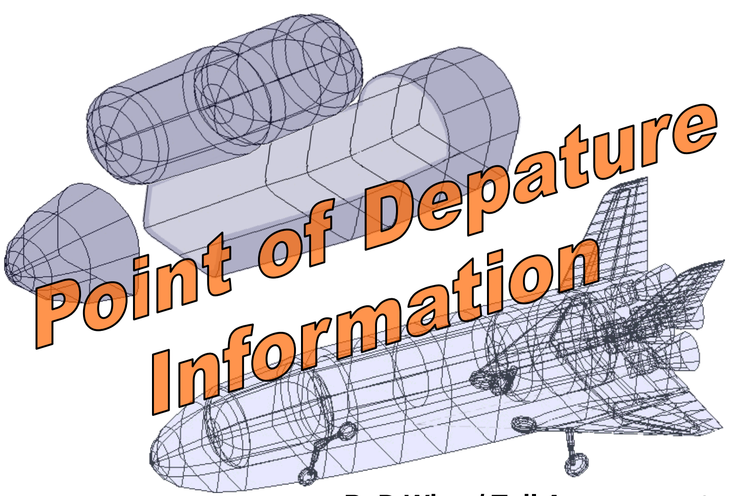
	Small	Small	Med-Lite	Medium	Heavy
Lb to LEO	5,000	5,000	16,500	50,000	64,000
Cost savings	0	~33%	~50%	~50%	~50%
Approx IOC	2015-2020	2019	2025	2025	2030

AEROSPACE

What is RBS Flagship?
- Built Upon Small and Affordable Experiments -

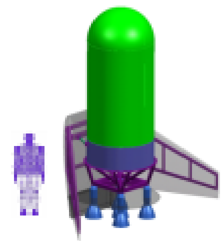
Point of Departure (PoD) Design	
Propulsion	4 Chase-10s
Length	~ 45 ft
GLOW	~ 60K lbm
Dry Weight	~ 16K lbm
Stage PMF Goal	~ 73%

PoD Fuselage Structural Concept



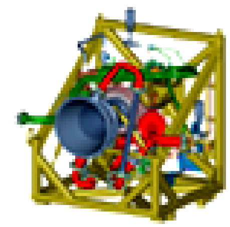
PoD Wing / Tail Arrangement

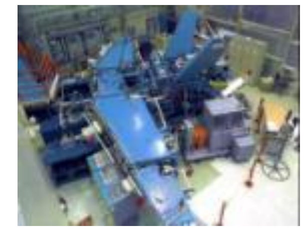
- **Step 1** – Ground experiments



Airframe Experiment

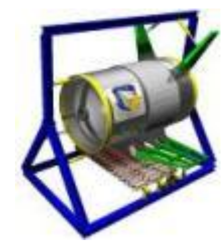
Propulsion Options



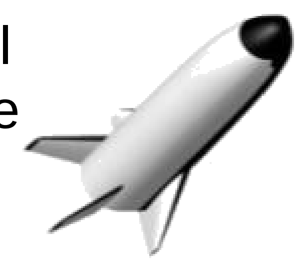


Subsystems Experiment(s)

- **Step 2** – Prove Rocketback

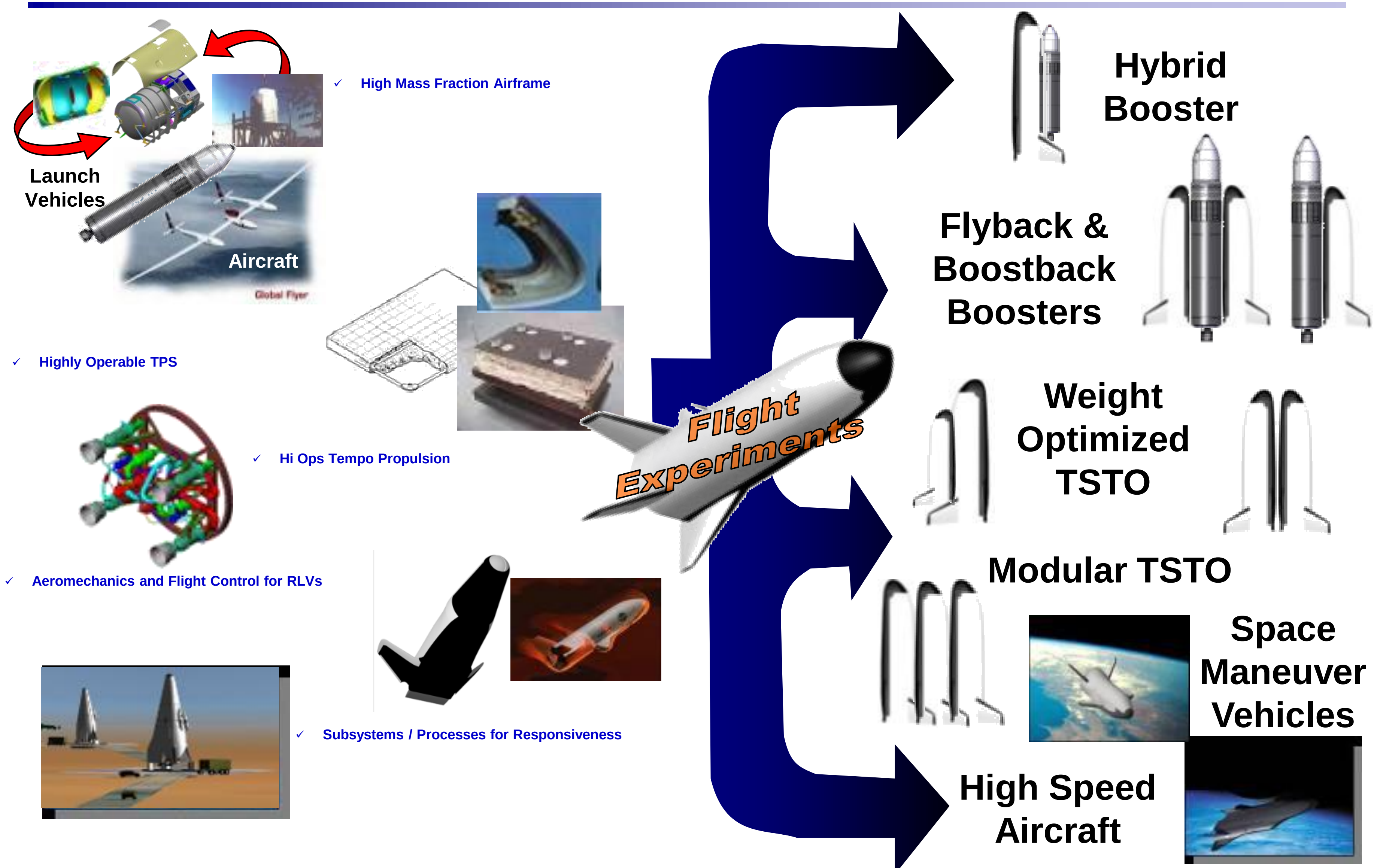


- **Step 3** – Incremental flight test of X-vehicle



RBD Flight Experiment

- Technology for Multiple Future Flight Systems -



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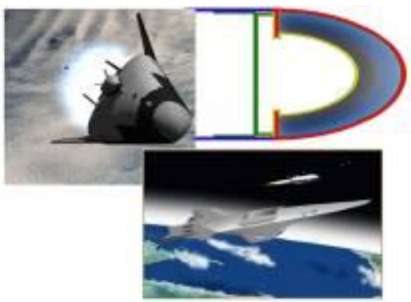
Broad Spectrum of Technologies for Responsive Space Access

Materials

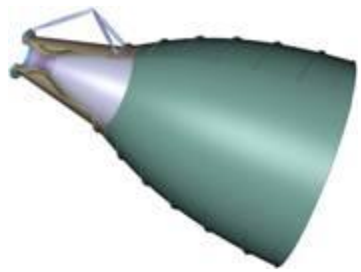
Propellant Tanks



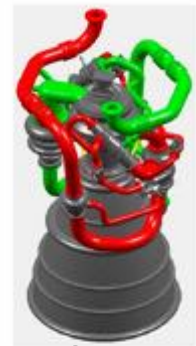
Leading Edges

Thermal Management

Propulsion

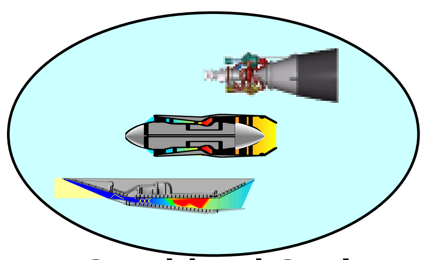


OMS, RCS



HC Boost Engine

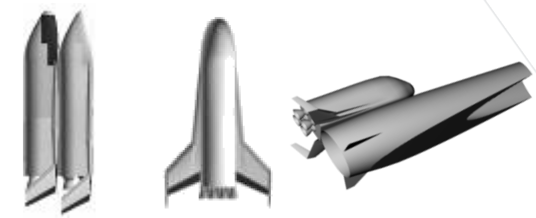
Solids



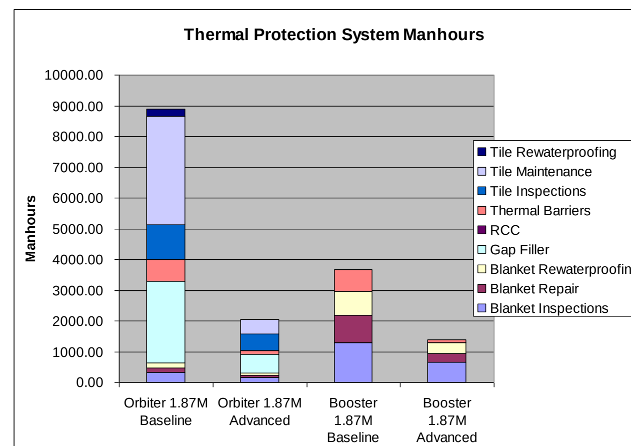
Combined Cycle Engines

Upper Stage Engine

Vehicle Concepts

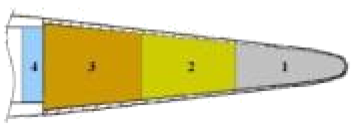


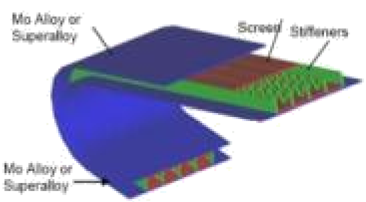
System Trades & Tech Assessment



Broad Spectrum of Technologies for Responsive Space Access

Structures



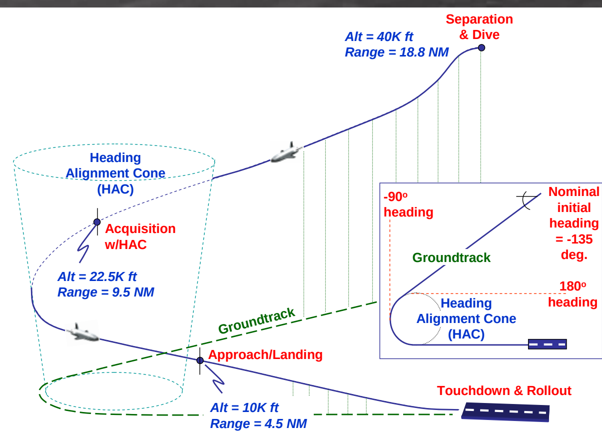


Leading Edges

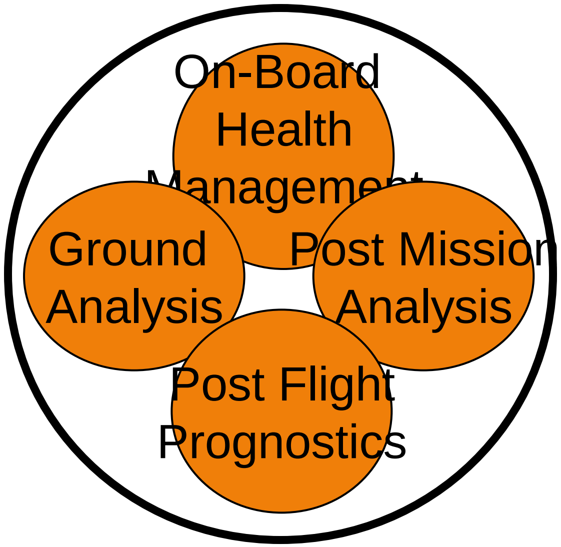
Hot Structures

TPS

Guidance & Control



Vehicle Health Management



Architecture & Hardware

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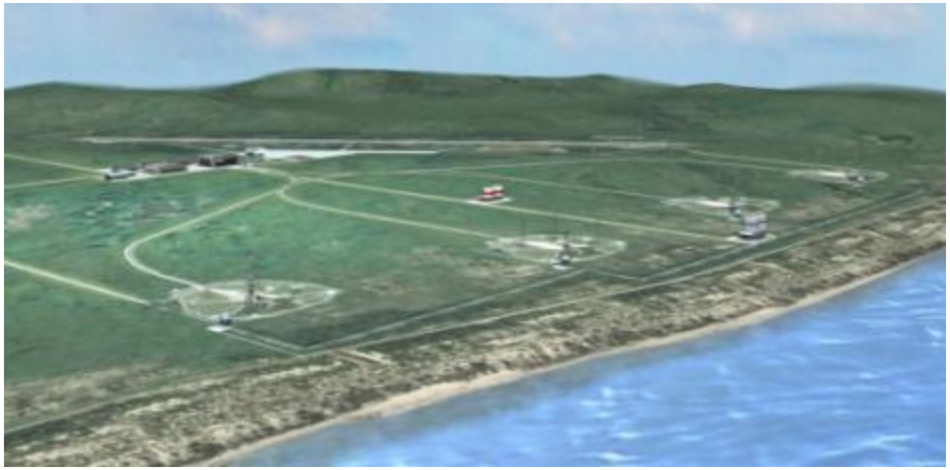
RBS Operations



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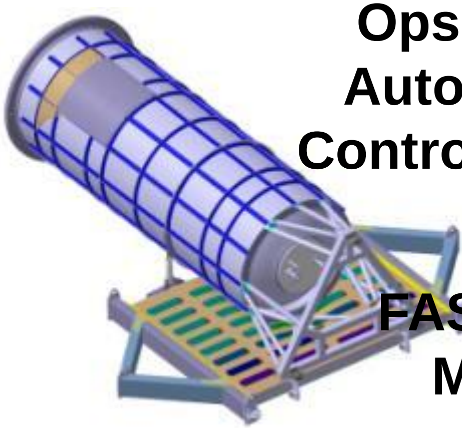
RBS Demos

Pathfinder CONOPS and Rockeback flight demo 2014

Rocket Engine Rapid Remove and Replace 2010 & TPS R&R 2011



Ops Control Center, and Autonomous Guidance & Control Ground Experiments 2011

FAST Airframe and Health Management Ground Experiments 2013

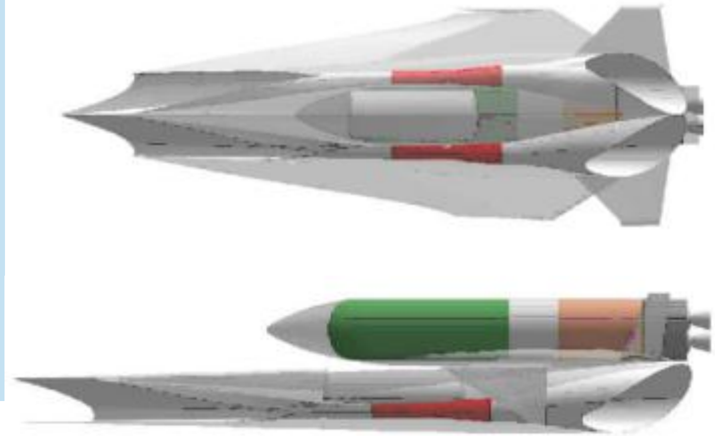
Hydrocarbon Boost 250K lbs thrust Brassboard 2019

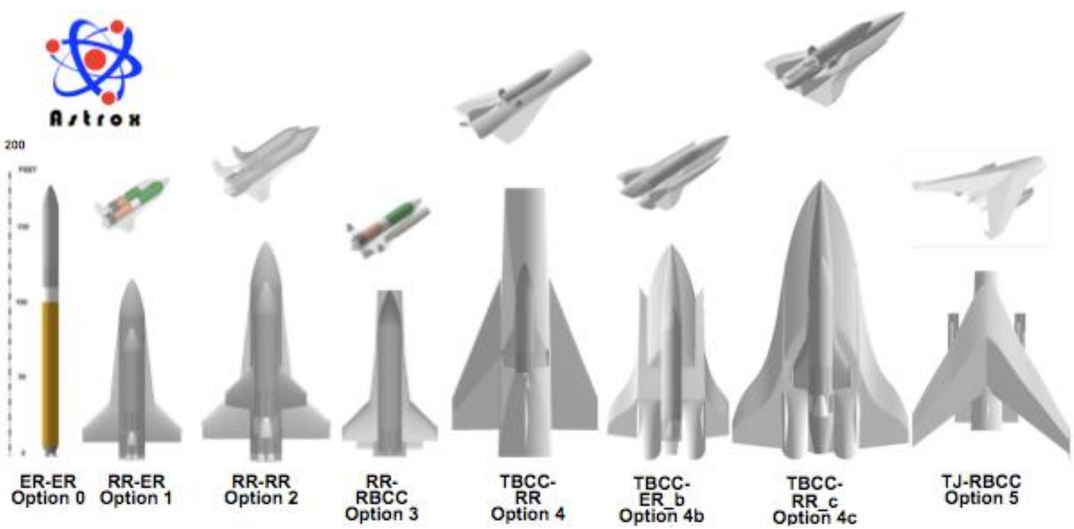
Overview

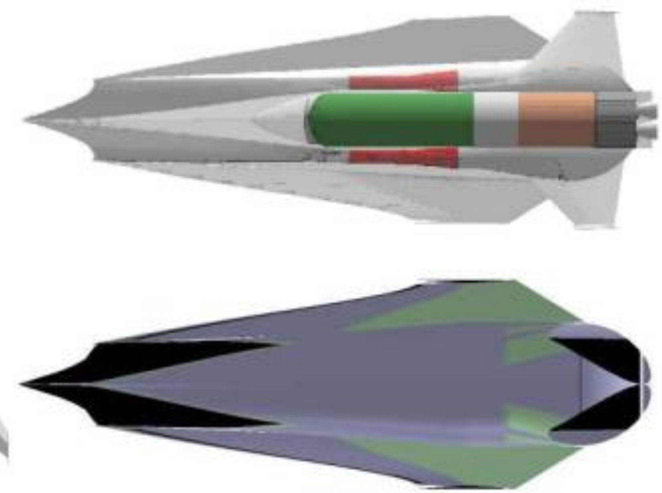
- **USAF Vision for Assured Space Access**
  - Near Term: Responsive Reusable Booster Stage
  - Far Term: Technology Challenge

Airbreathing Two-Stage-to-Orbit (TSTO) Access to Space Vehicles

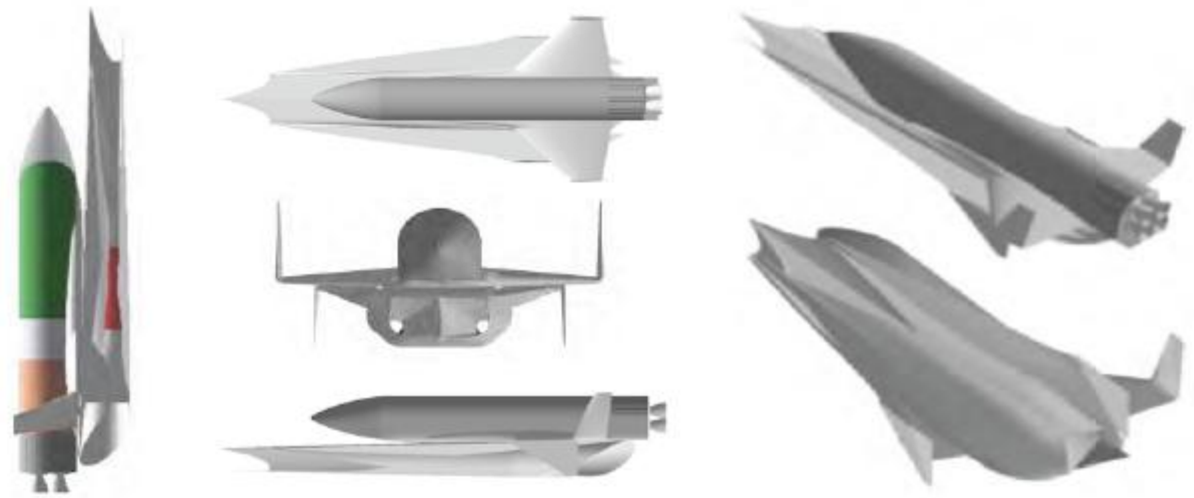
- **Airbreathing systems offer enormous advantages for TSTO access-to-space; reusable space access with aircraft-like operations**
- **Air Force / NASA conducting joint configuration option assessments using Level 1 & 2 analyses**
- **Reusable rockets (RR), turbine-based (TBCC) and rocket-based (RBCC) combined cycles**







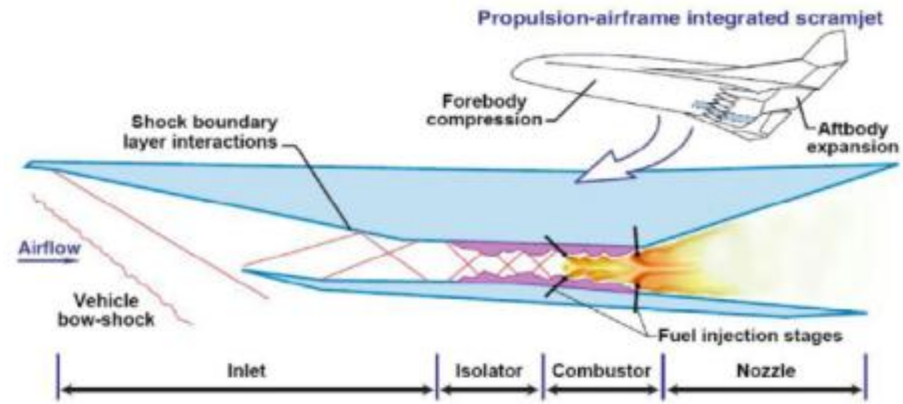
Tech Horizons - 2.26. Reusable Airbreathing Access-to-Space Launch

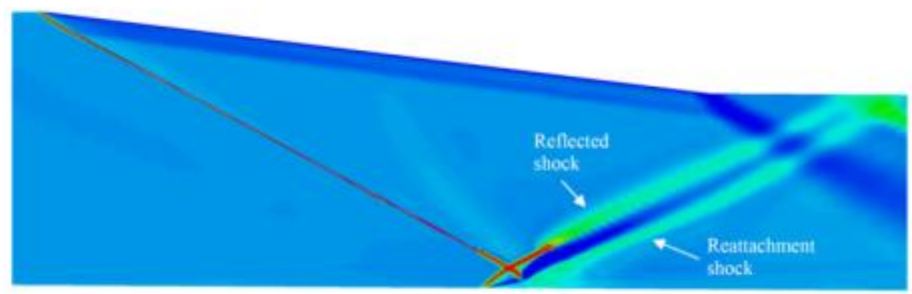


Airbreathing two-stage-to-orbit (TSTO) systems are based on a rocket-based combined-cycle upper stage in which scramjet propulsion eliminates the need to carry a large oxidizer mass, enabling a substantial reduction in the cost per unit mass brought to low Earth orbit.

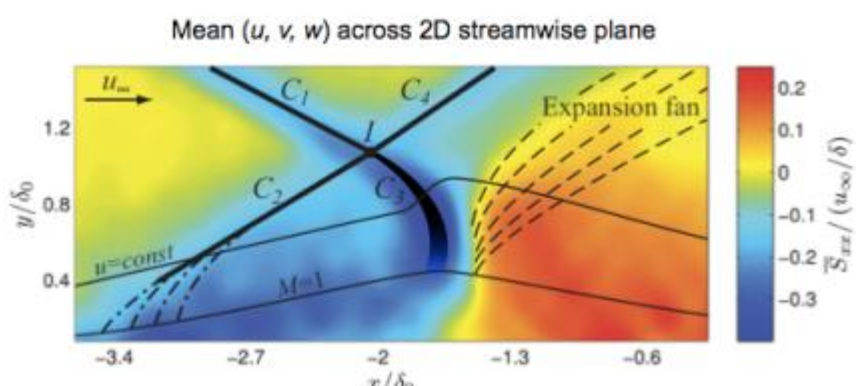
Supersonic Inlets: Shock-Boundary Layer Interaction (SBLI) Control

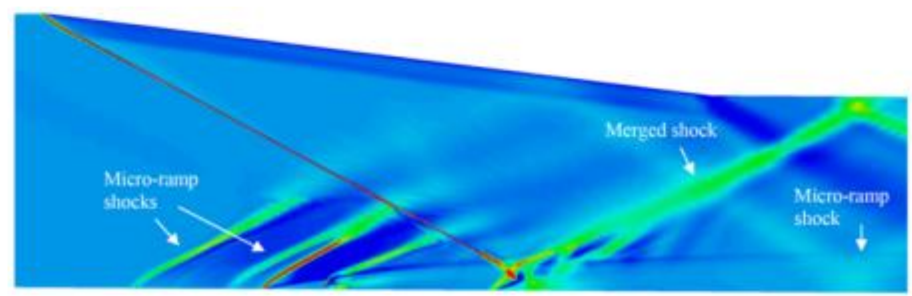
- ❑ Bleedless mixed-compression inlets need methods to avoid BL separation
- ❑ Maximize inlet pressure recovery
- ❑ Shock-boundary layer interaction (SBLI) can trigger separation at or after shocks
- ❑ AFRL using experiments and numerical simulations to develop suitable control
- ❑ Passive sub-boundary layer vortex generator micro-ramps
- ❑ Alternative passive control elements





Simulations of passive control of shock-boundary layer interaction control using micro-ramps (Galbraith et al. 2009)

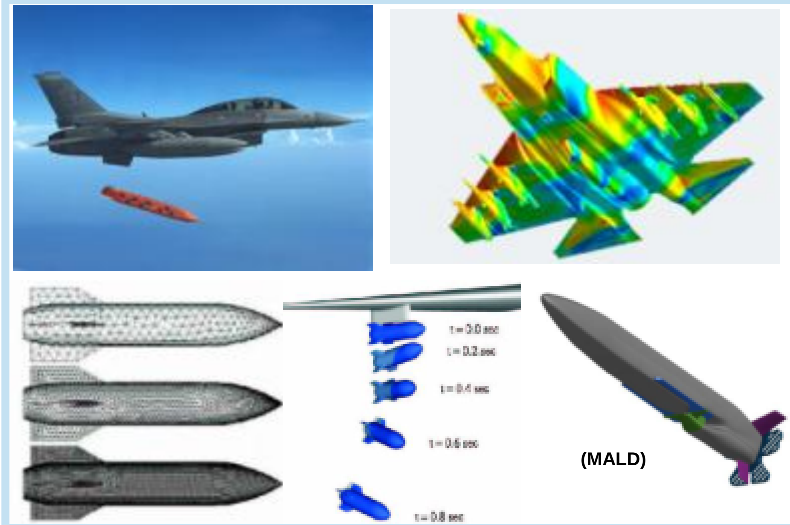


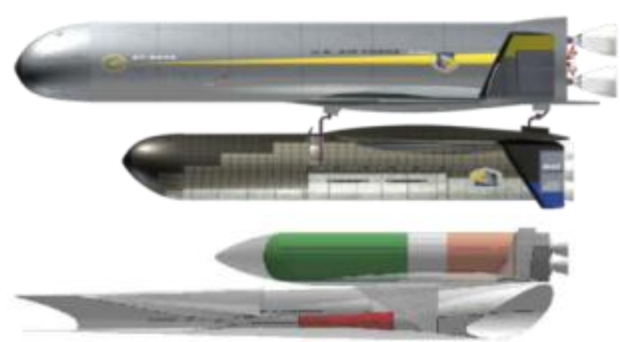


Computational Modeling & Simulation (M&S) to Support Air Force Needs

- Properly integrated M&S can give large reductions in cost of physical testing
- Continued improvements needed in CFD methods (incl. numerics and physics)
- E.g., USAF RBS use of CFD to assess payload separation
- 6-DOF time-accurate trajectory codes using dynamic offset grids
- Platform/staging configurations exceed what can be tested directly

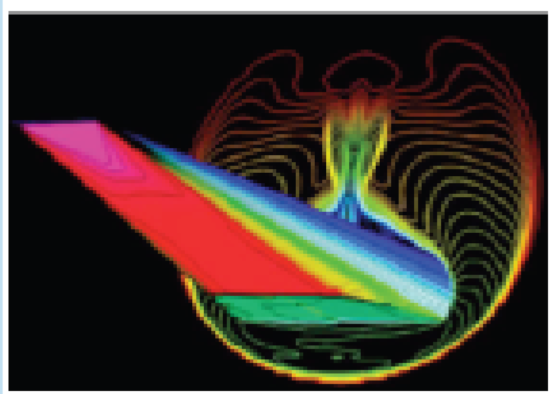
Computational aeromechanics support to Air Force aircraft/stores compatibility and weapons integration





Responsive and Reusable Booster Stage & Two-Stage-to-Orbit Payload Separation

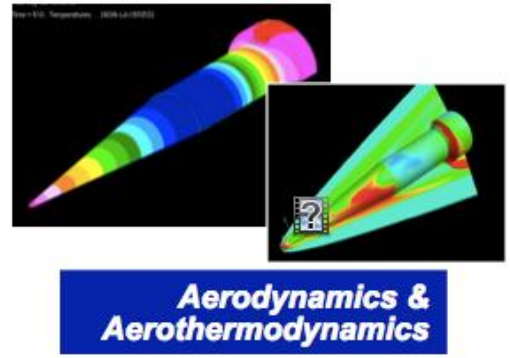
Hypersonic Aerothermal Laminar and Turbulent Flow

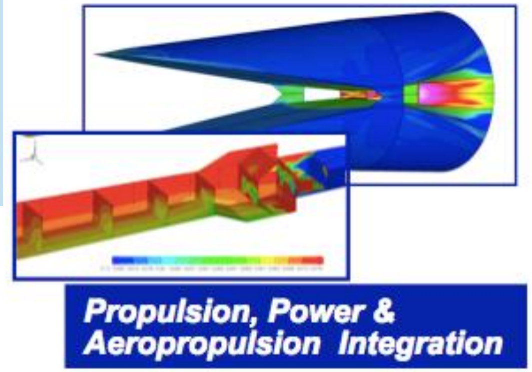


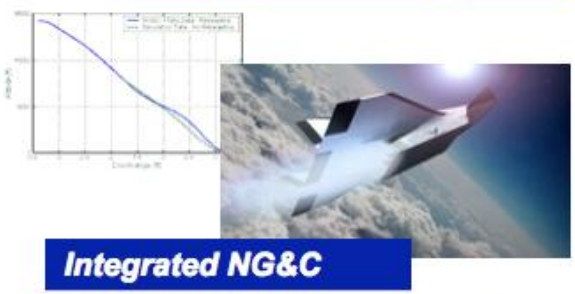
Supersonic & Hypersonic Flowpaths

Hypersonic International Flight Research and Experimentation (HIFiRE) Program

- HIFiRE flights use sounding rocket descent trajectories to explore fundamental hypersonics technologies
- AFRL and Australian DSTO with NASA; rocket flights at Woomera, White Sands, and Pacific Missile Range
- Primary focus on aerosciences and propulsion areas; also stability & control and sensors & instrumentation
- Propulsion experiments on Flights 2 (US), 3 (AUS), and 6-9 (US/AUS)
- Scramjet fueling/combustion, integration, performance

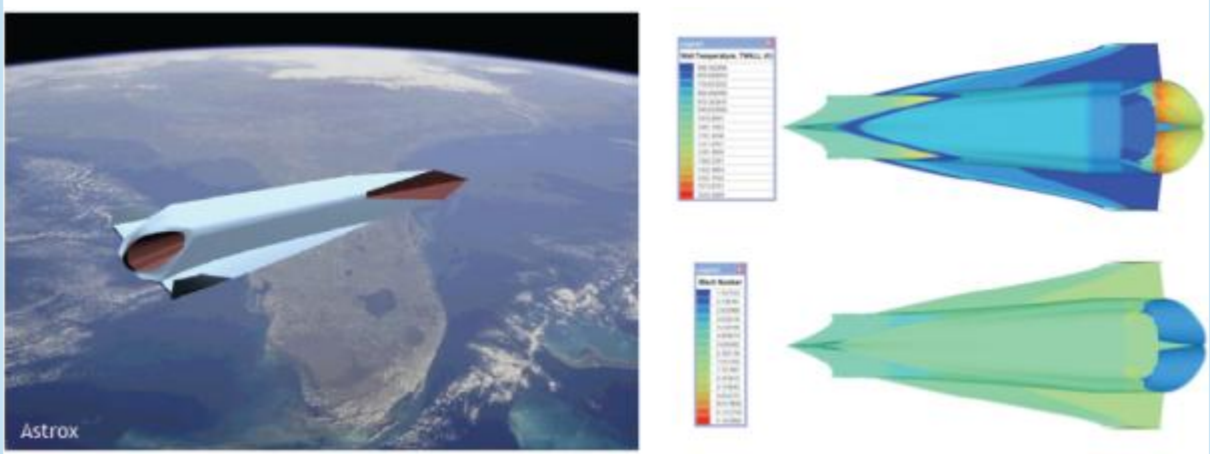






Hypersonic Global ISR Vehicles

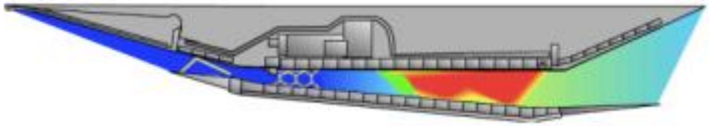
- JP-fueled scramjet propulsion system could potentially enable a medium-size rapid-response ISR vehicle having operationally relevant range capability
- Mach 6 limit avoids complex thermal management penalties at higher Mach
- Vertical takeoff / horizontal landing (VTHL) enables single-stage rocket-based combined-cycle (RBCC) system having 5000 nmi range with 2000 lbs payload
- Integral rocket boost to Mach 3.5 with ram-scram acceleration to Mach 6
- Resulting notional vehicle is 80 ft long with 42,000 lbs empty weight



Notional Mach 6 single-stage reusable VTHL ISR vehicle with 5000 nmi range (Astrox)

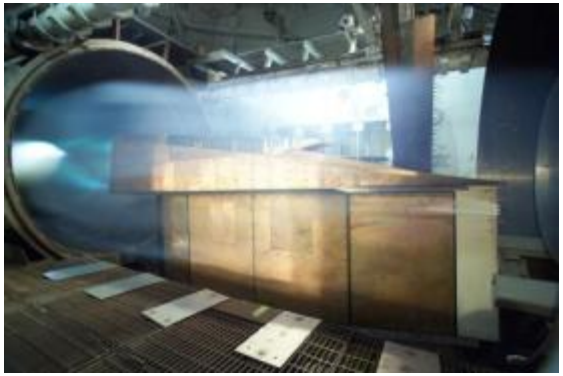
Scramjet Engine Development

- Hydrocarbon-fueled dual-mode ram/scramjet combustor allows operation over Mach range
- Thermal management, ignition, flameholding
- GDE-1 was flight weight hydrocarbon fuelcooled but with open-loop fuel system
- GDE-2 was closed-loop hydrocarbon fuelcooled system intended for NASA X-43C
- SJX61-1,2 were closed-loop HC fuel-cooled development/clearance engines for X-51A

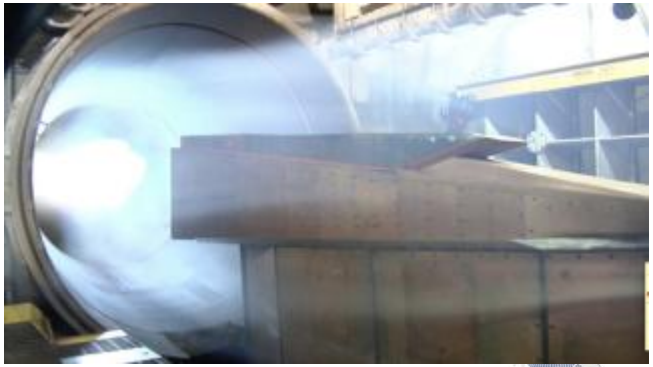


Ground Demo Engine (GDE-2)

SJX61-1 Development Engine



SJX61-2 Flight Clearance Engine

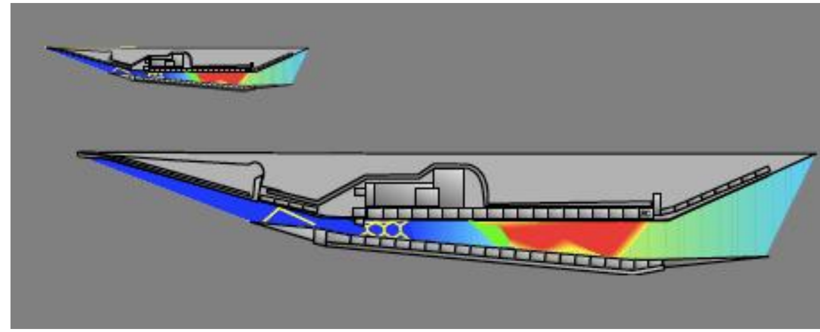


Supersonic Propulsion Integration: Combined-Cycle Scramjet Systems

AEDC APTU tests under FaCET of common turbo-ramjet/scramjet flowpath

Robust Scramjet Scale-Up Program

X-51A uses small-scale combustor

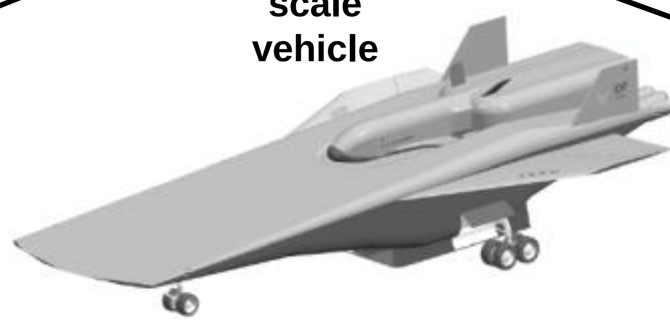


AFRL Robust Scramjet program

Possible follow-on flights to test navigation and inert strike on target

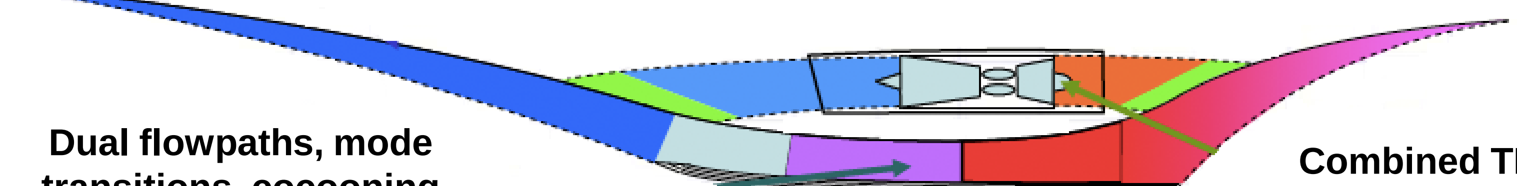
Scale-up and combustor reconfiguration for 3X, 10X, 100X scales?

Large-scale vehicle



Possible ISR or global strike vehicle

Potential step to a future airbreathing TSTO access-to-space system



Dual flowpaths, mode transitions, cocooning

Combined TBCC nozzle

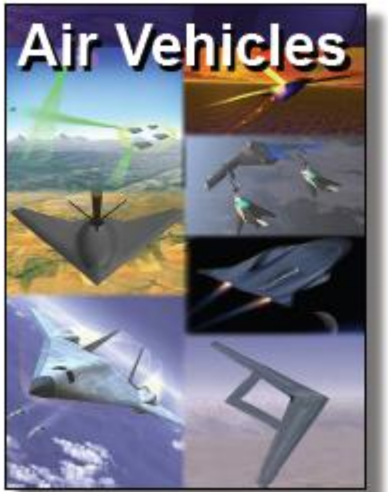
Vision…

A 21st Century of
Diverse, Routine, Reliable & Affordable Space Access!

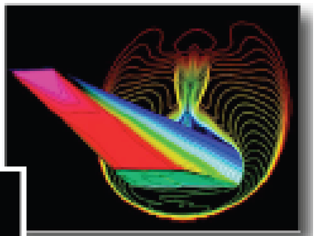
AFRL

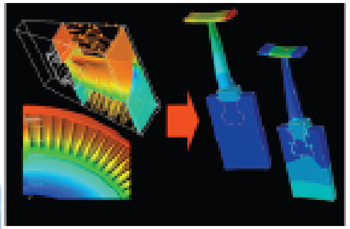
BACKUPS

Supporting Technology Directorates for Responsive Space Access



Aerothermal Dynamics

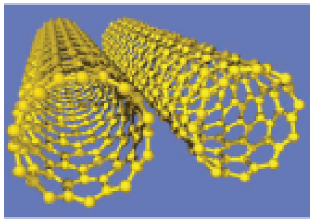




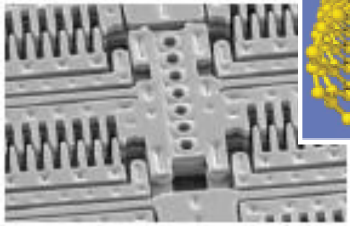
Advanced Hypersonics

Perpetual Simulation

Unmanned Systems



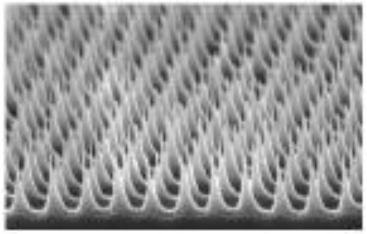
Nano-tailored Materials



Micro-Mechatronics

Computational Simulation

Man-as-machine systems



Nanostructured Surfaces