

Turbine Based Combined Cycle BASIC Research Challenges

(New Scientific Questions For Basic Research in Hypersonics Workshop)



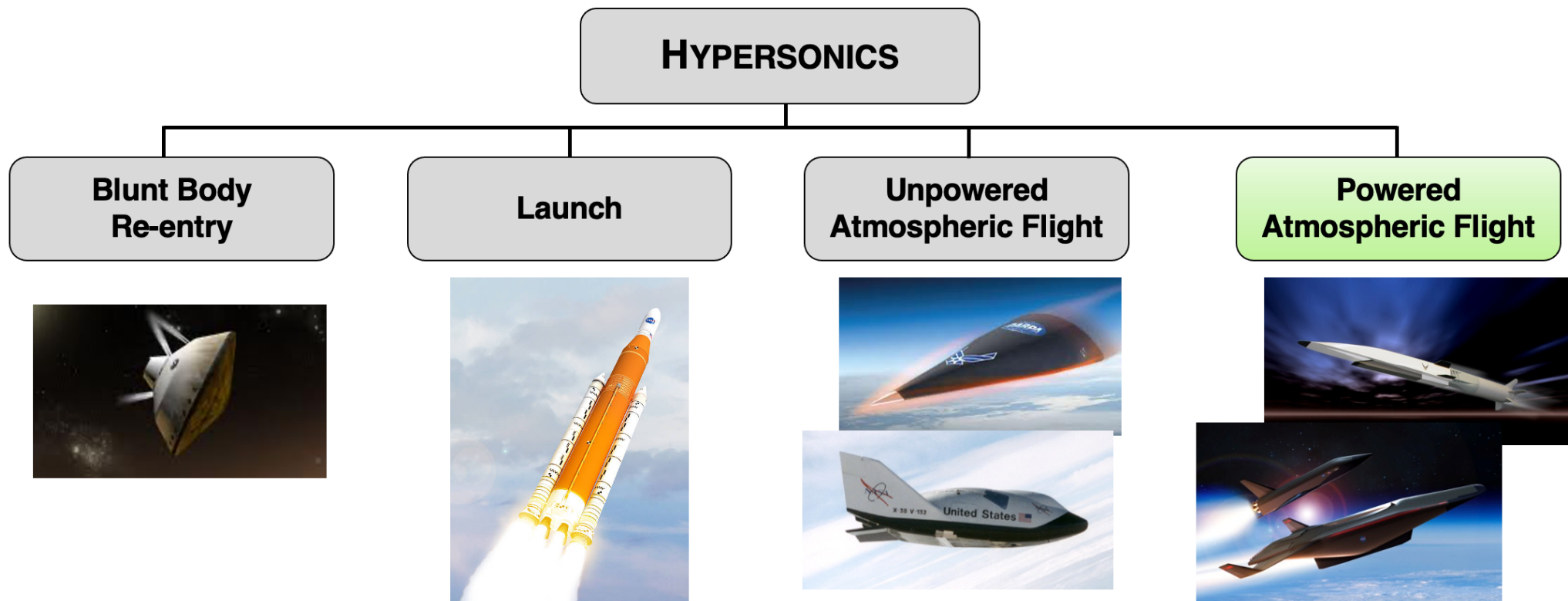
China tests hypersonic TBCC engine ...
thaimilitaryandasianregion.blogspot.com



NASA X-43 - Wikiwand
wikiwand.com

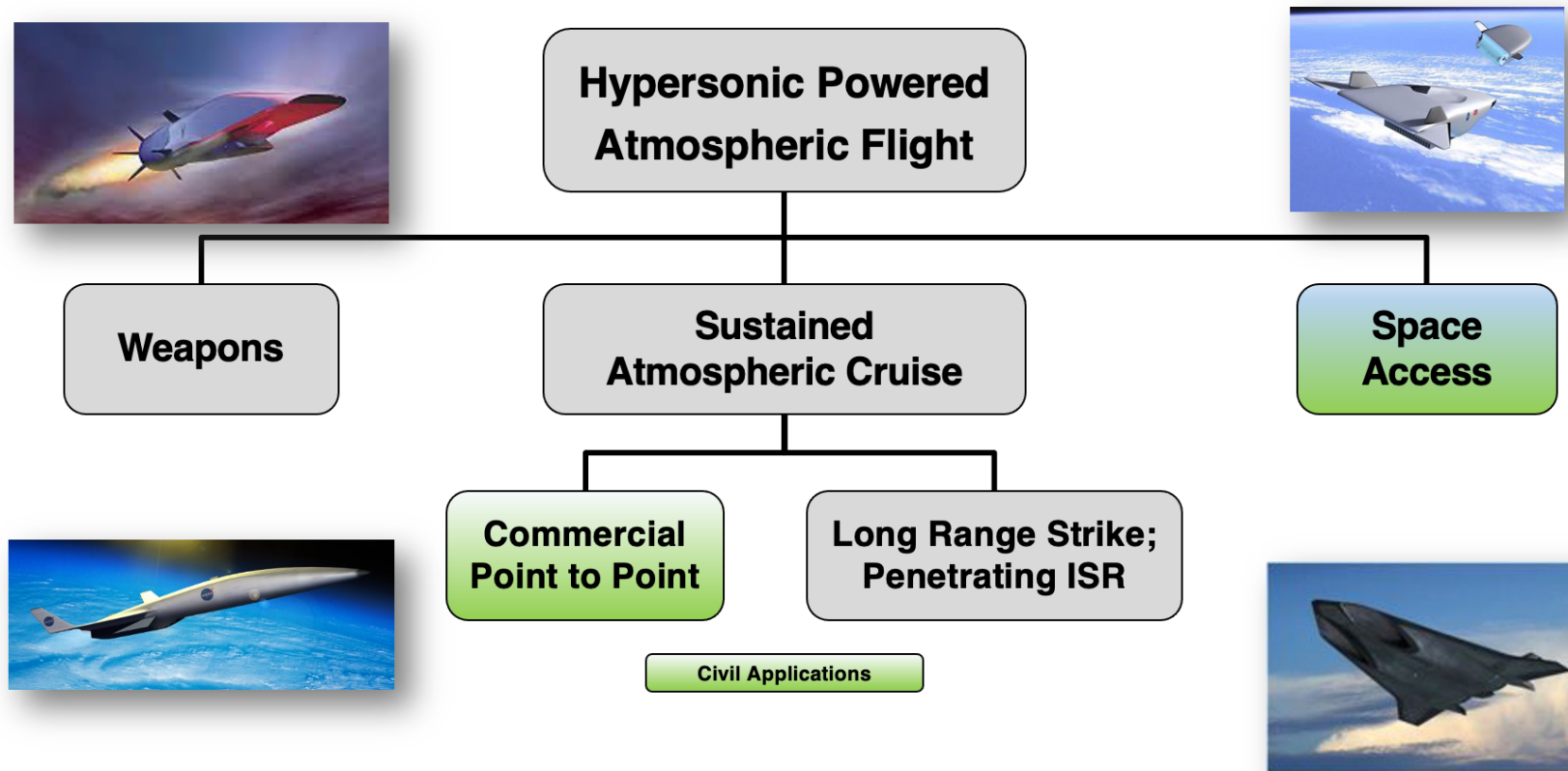
Dr. Aaron Auslender
NASA Langley Research Center
Hampton, VA.

NASA Hypersonic Applications



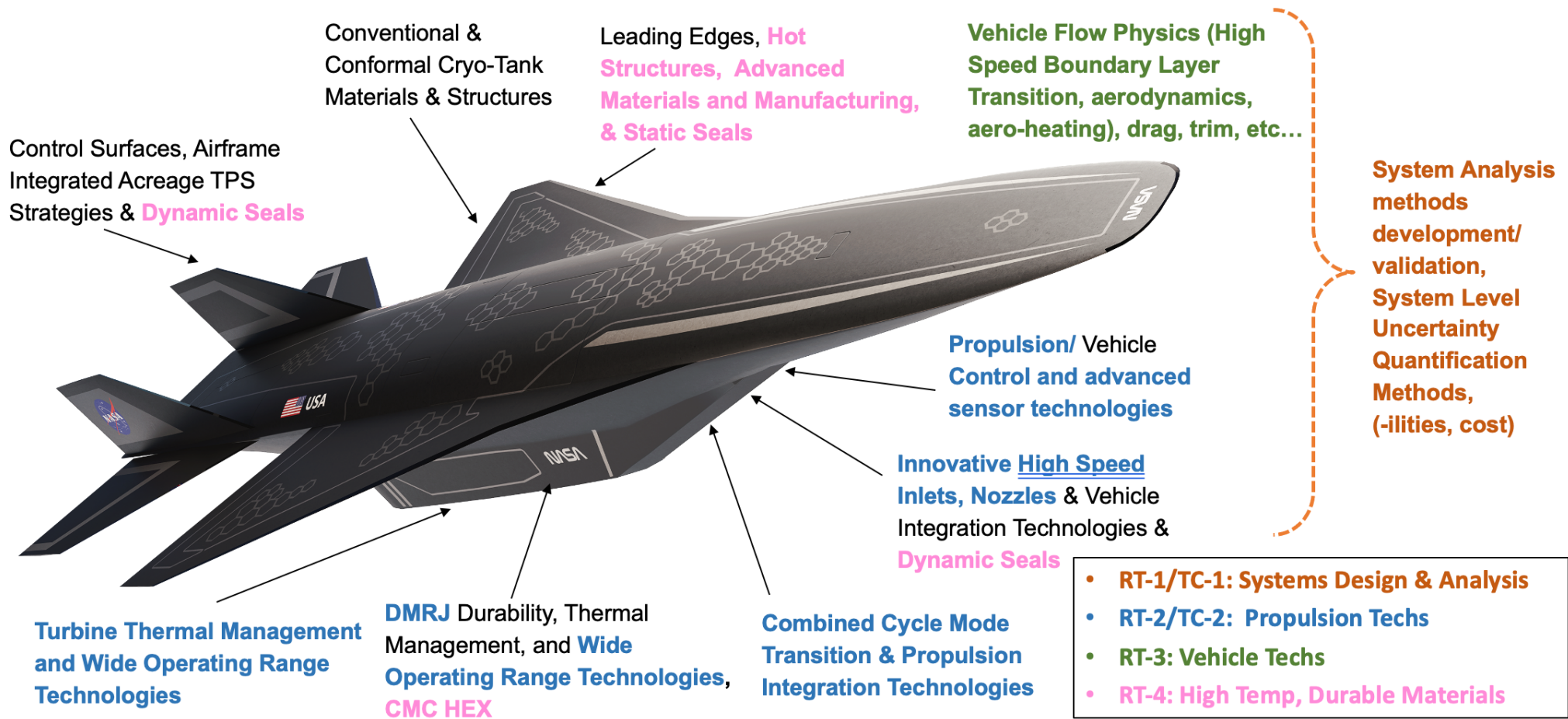
Multiple NASA applications require mastery of hypersonic flight

Synergic BASIC Research Needs

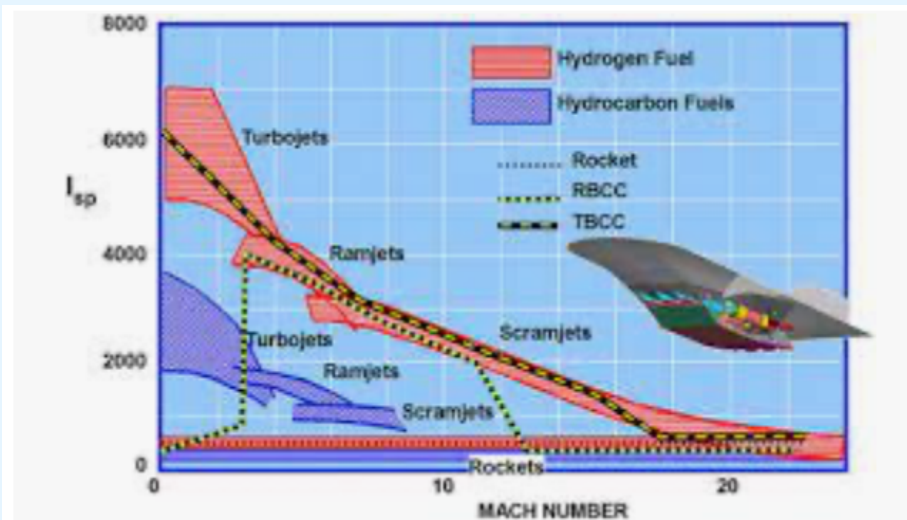


Partnership between NASA and DoD is critical to progress in hypersonic flight

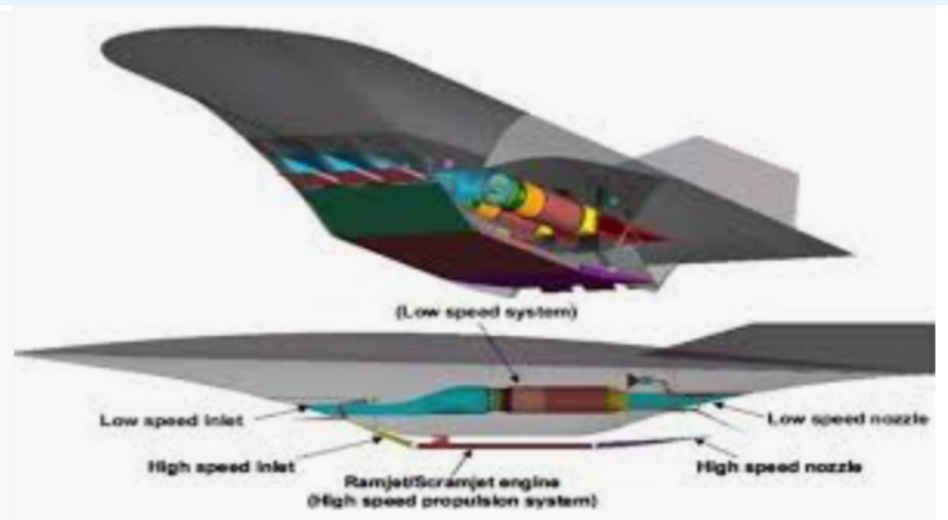
NASA Investment Areas in the Barriers to Reusable Hypersonic Flight



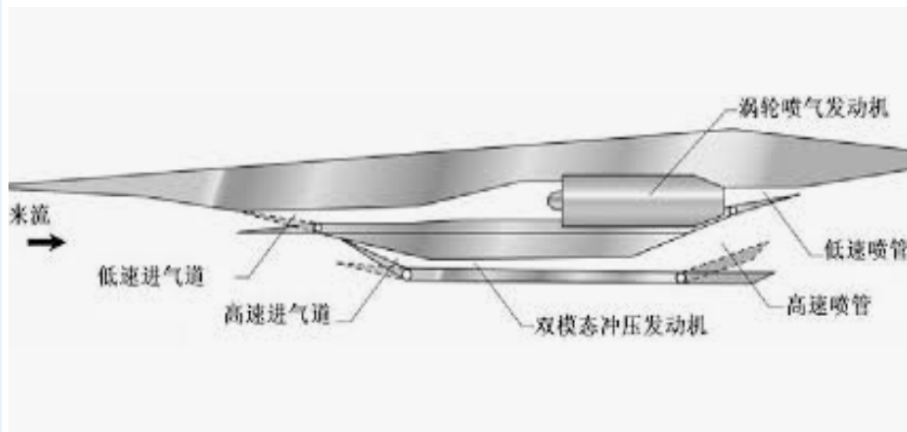
TBCC Technology Research Motivation(s)



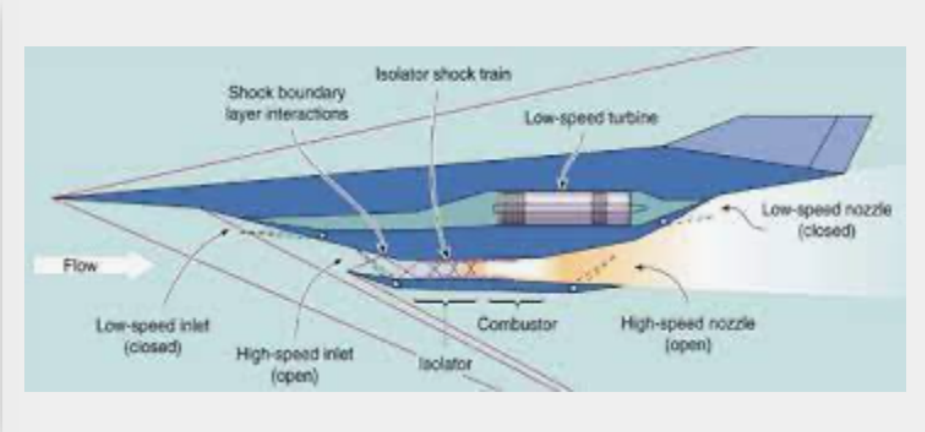
Combined-Cycle Engine - an overview ...
[sciencedirect.com](https://www.sciencedirect.com)



Turbine-Based Combined Cycle (TBCC ...
threadreaderapp.com



Combined Cycle Engine ...
forum.nasaspaceflight.com



Combined-Cycle Engine - an overview ...
[sciencedirect.com](https://www.sciencedirect.com)

TBCC = Dual-Mode Flowpath + Turbine + Vehicle

- Central Institute of Aviation Motors (CIAM) and NASA jointly flight tested a CIAM-designed dual-mode scramjet, which acquired 77 seconds of regenerative-cooled, hydrogen-fueled engine data at Mach numbers from 3.6 to 6.5 (1998)

NASA/TP-1998-206548



EC98 44463-05

Figure 8. The SA-5 booster and HFL launch configuration.

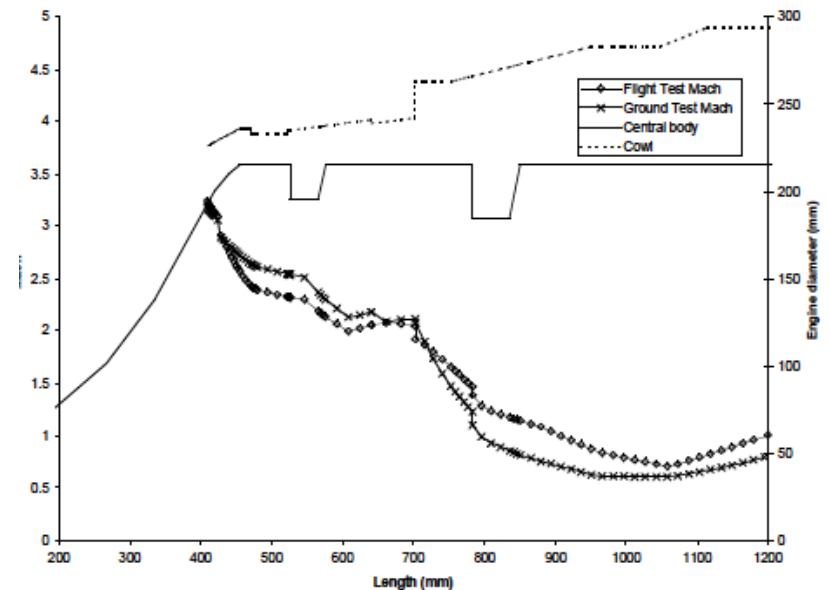
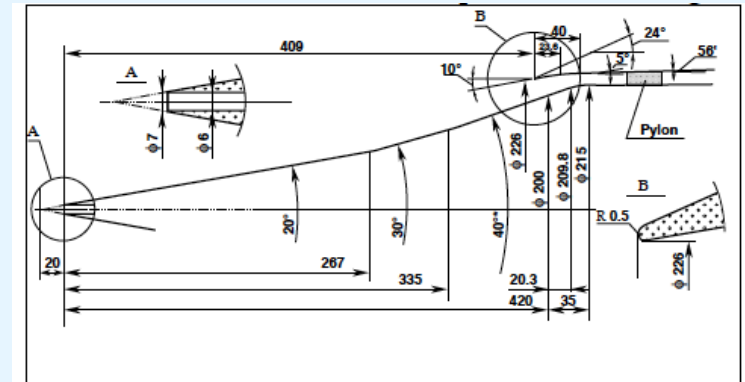
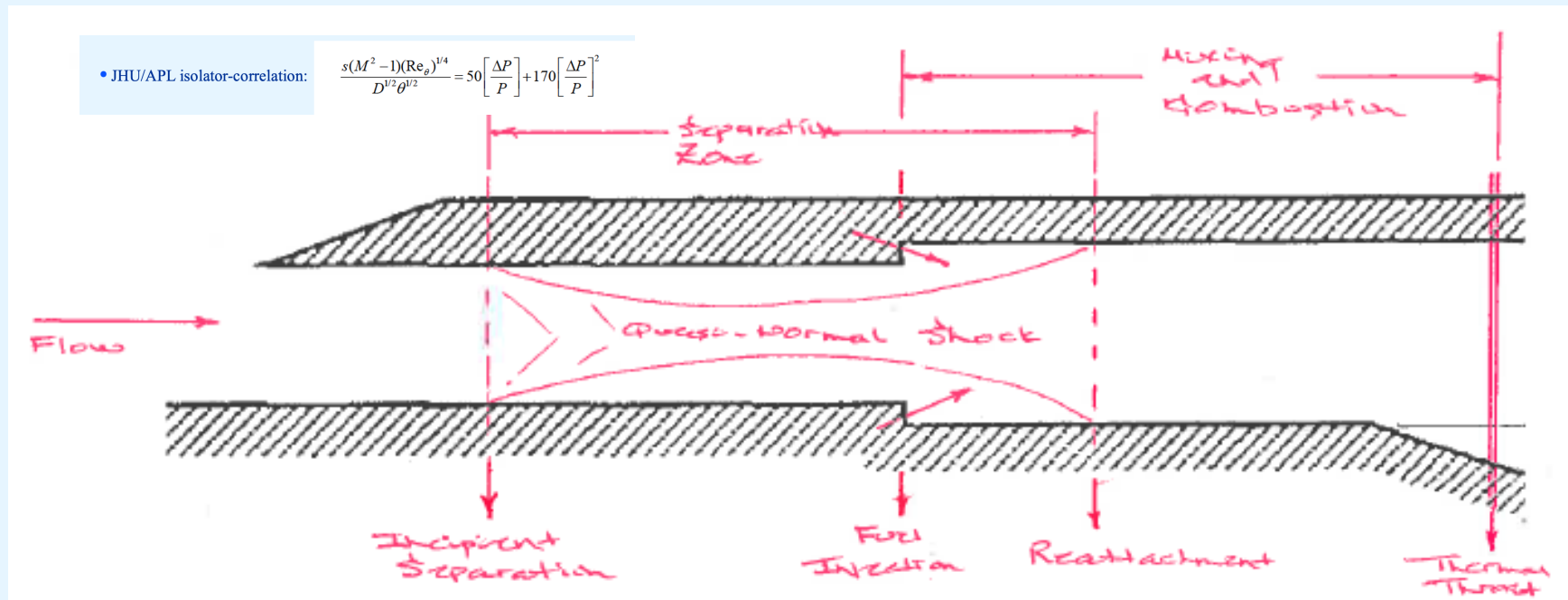


Figure 13. Mach number vs distance.

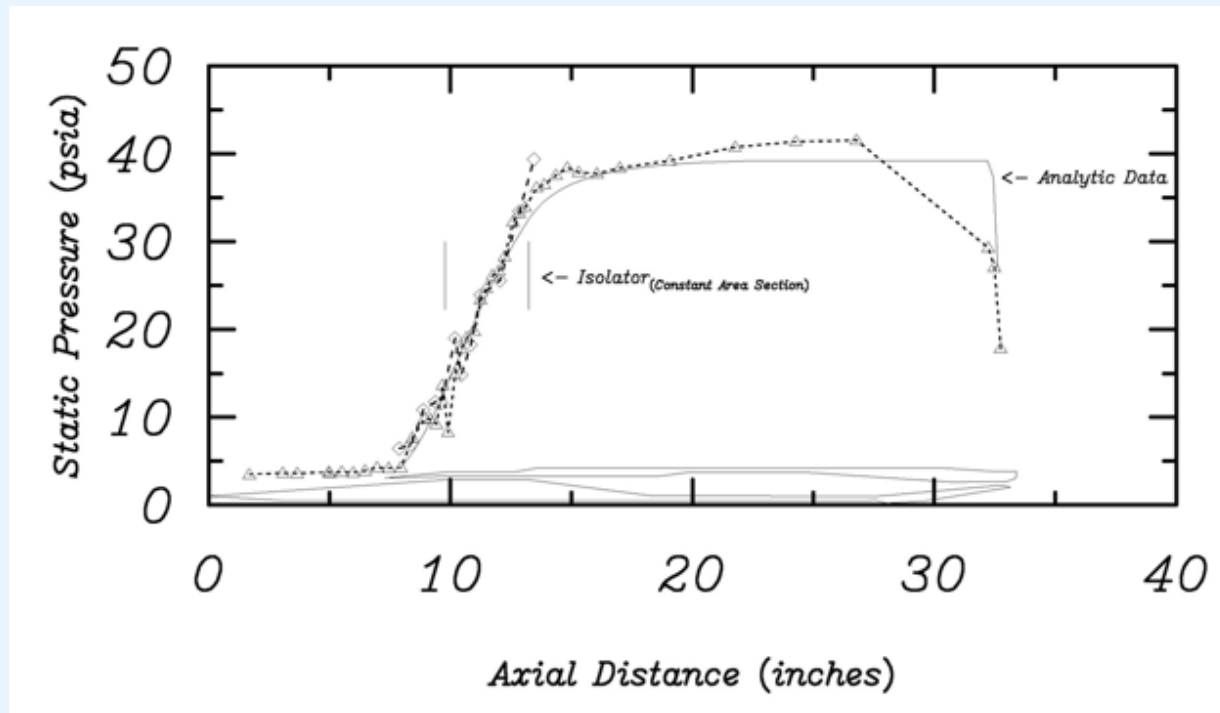
Dual-Mode: BASIC Research Questions (How does one)

- Minimize variable-geometry requirements to enable a robust operational envelope ?
- Simultaneous establishment of the **incipient-separation**, **re-attachment** and associated **thermal-throat** locations across a wide operational envelope ?
- Obtaining near-optimal performance, while maintaining sufficient unstart margins ?



Dual-Mode: BASIC Research Questions (How does one)

- Valid analytic models for multi-scales (shocks + combustion) [CFD/LES ...] ?
- Chemical Kinetics and endothermic fuel [catalytic reactions, coking, ROM(s) ...] ?
- Valid turbulent-combustion analysis [pdf(s), combustion physics ...] ?
- Robust sensors and active-control algorithms [Sparse sensing ...] ?



Note : (Normal - Shock - Value = $9.577 * 4.29 = 41.09$)

TBCC(s) Place in the Hierarchy



Scramjet Technology Development Approach



**Stair-step
approach builds
upon prior
successes**

1980 ~ 2010 2015 2020 2030



Hypersonic Missiles
(Time-Critical Targets)



Hypersonic Missiles/
Small Launch Systems



Large Hypersonic Missiles
Small Launch Systems

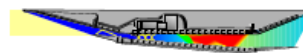


Operationally Responsive Spacelift
(Robust, Responsive)

**Small
Scramjets**



**Medium
Scramjets**



**Large
Scramjets
and CCEs**



Ramjets



☒ TRL=6 1980

☐ TRL=6 2010

X-51 Program

Cleared for Public Release Case Number: 88ABW-2011-0846

“Rubric” : (2-D, 2-Shock-Cancellation)

- Throat conditions (inviscid-2D-system with complete shock cancellation) at $M=5$:

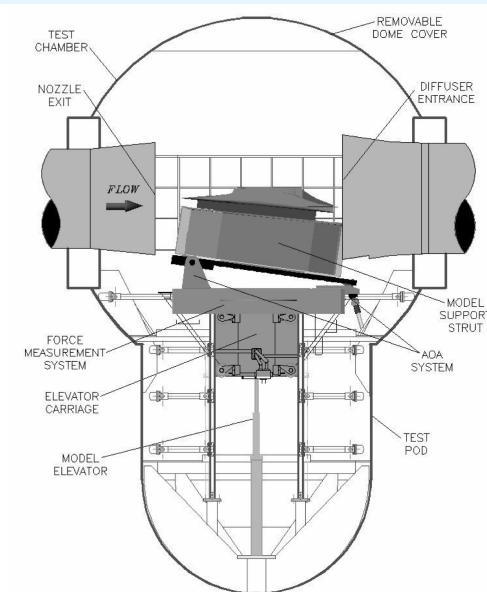
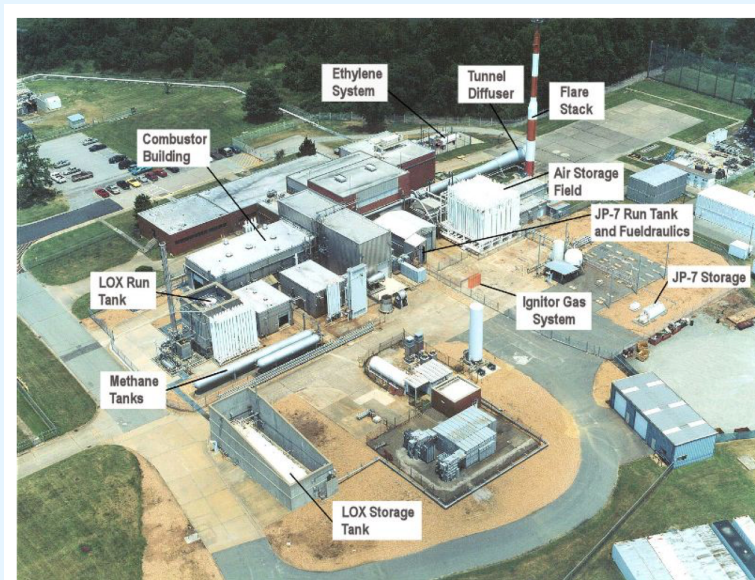
Mach Number [-]	Dynamic Pressure [lbf]	Velocity [ft/sec]	Mass-Flow-Rate/Area [lbm/sec/(ft*ft)]	Pressure [psia]	Temperature [Rankine]
2.64	8494	4039	26.53	12.23	981

- Inlet Drag = 439 lbf per one ft^2 of projected capture-area @ $CR= 5.1$ and a Static-Pressure Ratio = 15.4
- Power Consumption is ~ 2.9 MW: (similar to a heavy-diesel-electric locomotive which generates about 3-5 MW at peak power operation)



Test Paradigm Shift(s): BASIC Research Questions (How does one ...)

- “Tyrrany of scale” ground-test problem [Size, Cost, Power ...] ?
- Simulate complete duty-cycle(s) for fluid/structural/thermal ?
- True Total-Enthalpy ground facilities (+ modulating conditions) ?
- Diagnostics and sensors (test article + facility +flight) ?
- Robust data acquisition of off-body information ?
- Robust electronics (test article + ground + flight capable) ?
- Data acquisition (test article + flight-down loading) ?



Vehicle and Subsystems: BASIC Research Questions

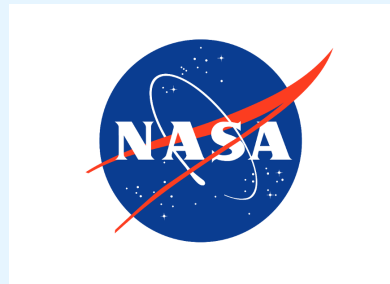
(How does one ...)

- Vehicle state morphing characterization (spatial and temporal) ?
- Robust off-body data acquisition (complete environment) ?
- Robust electronics (flight capable: vibration, thermal, g-loads) ?
- Data acquisition and processing (collection and down-loading) ?
- Design for uncertainty (free-stream, transition, forced transition) ?
- Address manufacturing specifications (Additive Manufacturing) ?
- Aero-optical interactions and signatures ?
- GNC (control for highly maneuverable system) ?

Vehicle and Subsystems: BASIC Research Questions

(How does one ...)

- Dynamic/static seals (vehicle and engine concern) ?
- Valid “material-life/fatigue” algorithm(s) (reusable + single-use) ?
- Health monitoring (IVHM: vehicle and engine concern) ?
- On-board power generation (volumetrically efficient sources) ?
- Thermal management (vehicle and engine concern) ?
- Design for reuse and minimal ground-ops between flights ?
- Digital “twins” for quantifying risk(s) ?
- Pollution/Noise and Environmental impact quantification(s) ?



Questions and Comments