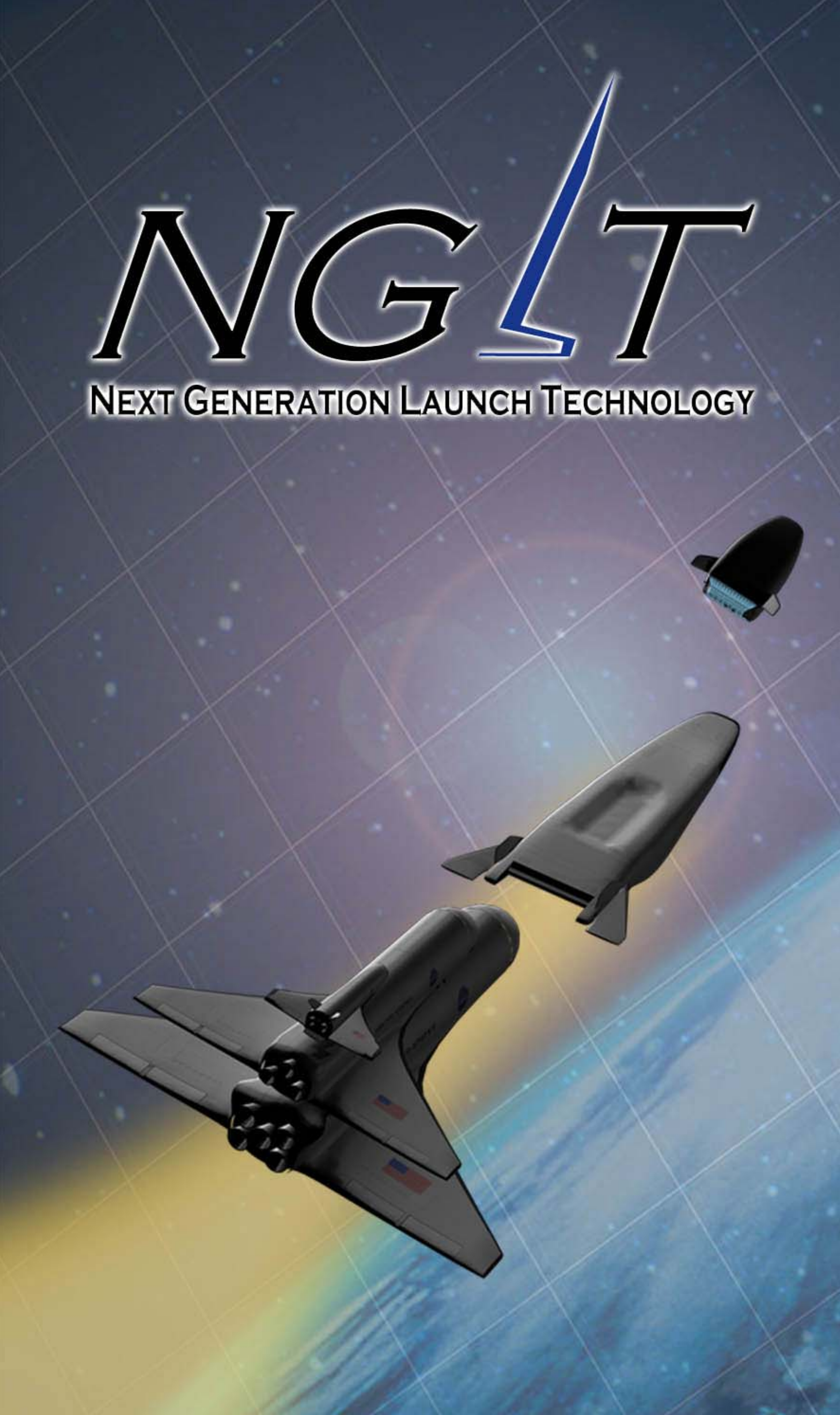


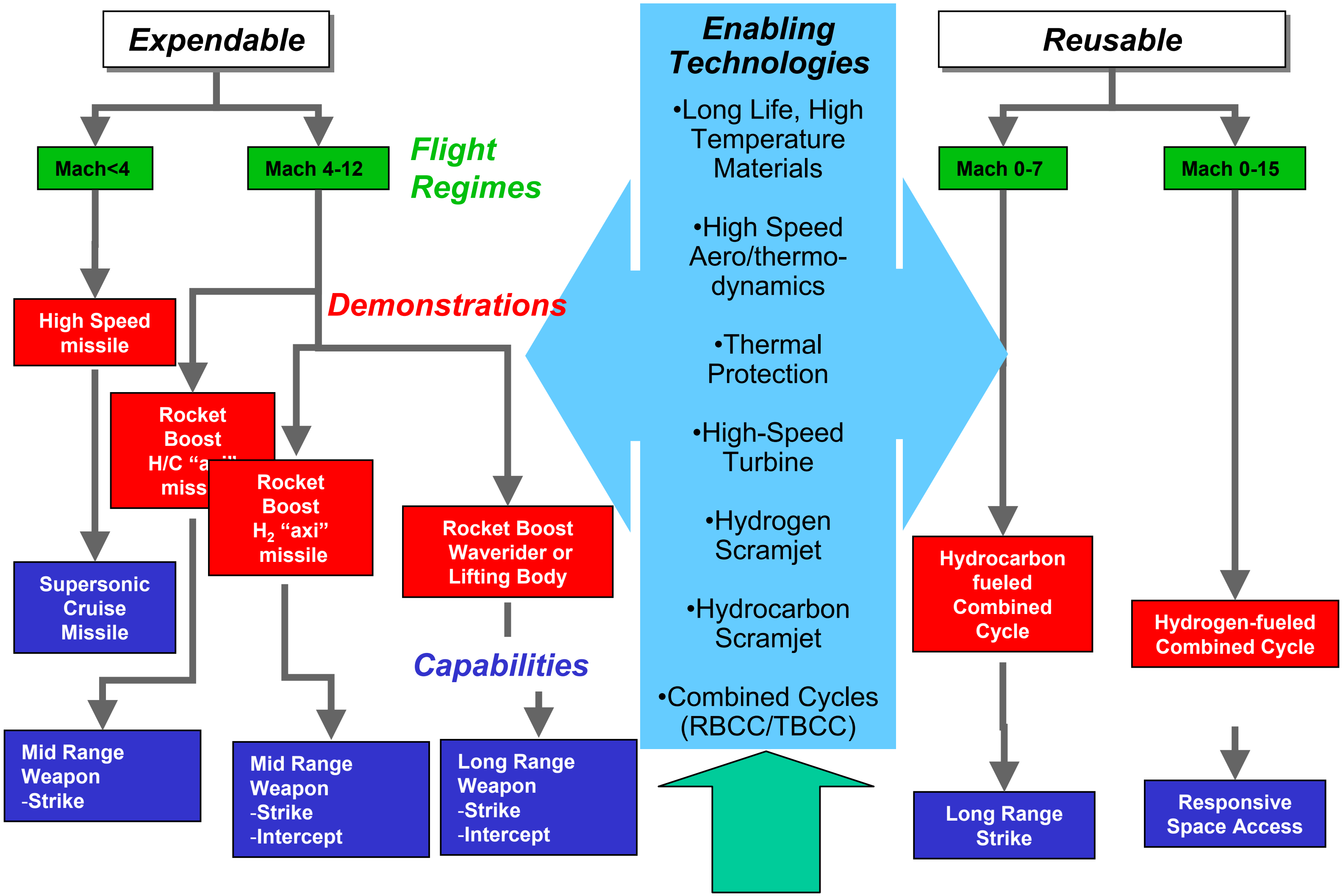
The Hyper-X Program

14th ANNUAL THERMAL & FLUIDS ANALYSIS WORKSHOP

August 21, 2003

Vince Rausch
757-864-3736

Enabling Technologies for Hypersonic Systems



THERMAL & FLUIDS ANALYSIS REQUIRED FOR ALL!

X-43A

Goals/Objectives of Hyper-X 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.

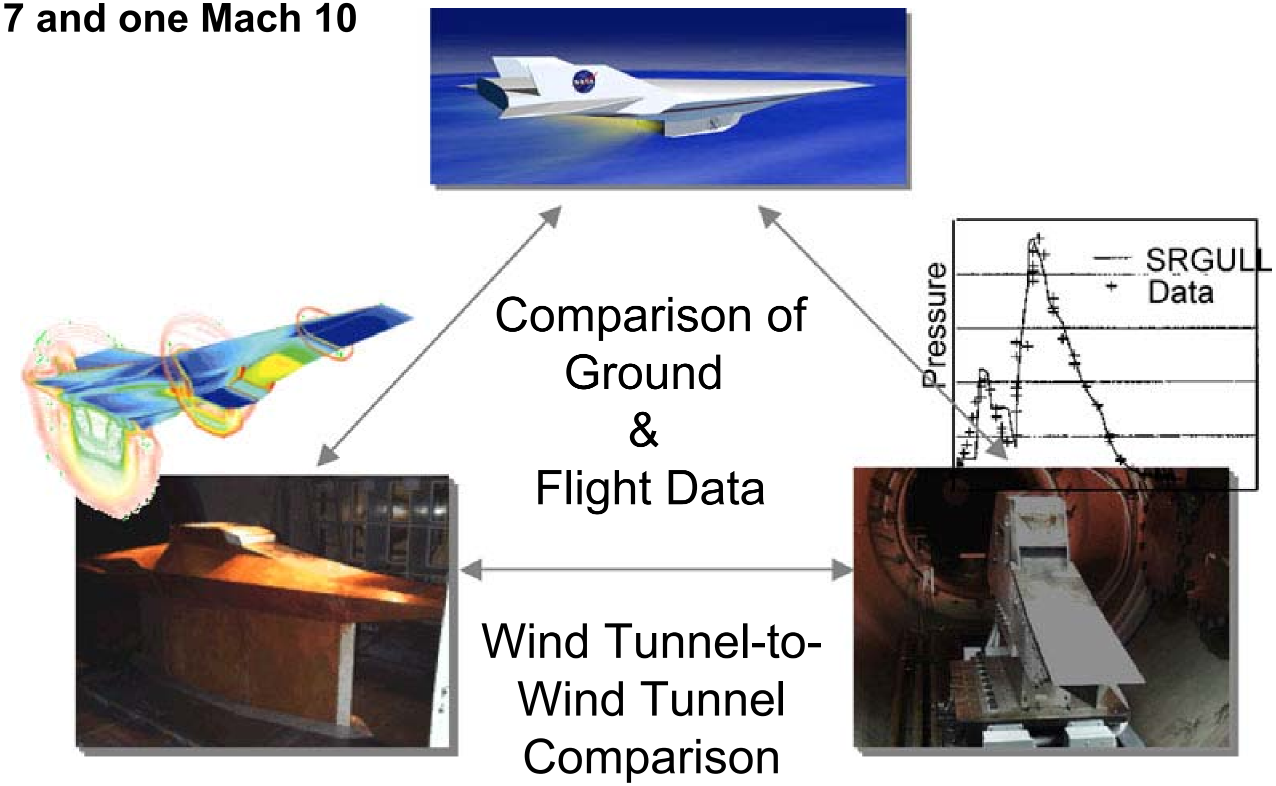
FLIGHT OBJECTIVES:

- Three flights: **two @ Mach 7 and 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



Technical Challenges for X-43

Forebody and Lee Side

Boundary layer transition
Boundary layer trips
Sharp LE structure
Flush Air Data System

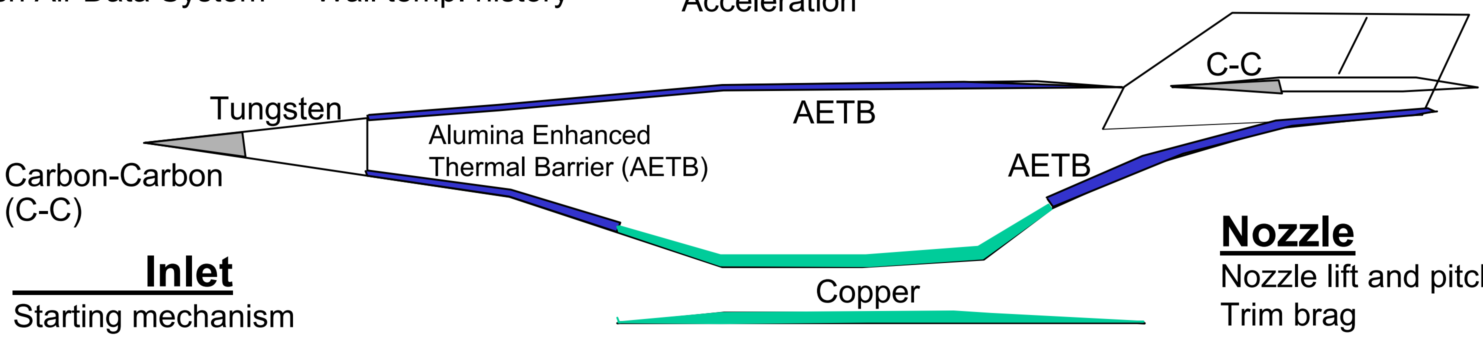
Thermal load
Flight scaling
Shear drag
Wall temp. history

Systems/Packaging

Scale!
Antenna interference
Captive carry man-rated
Stiffness
Weight vs. scale vs. acceleration
Acceleration

Wings and Tails

Sizing
Scale effects on trim
Thermal stresses/growth
Gap and corner flows
Shock impingement



Inlet

Starting mechanism
Starting pitch moment
Cowl closed heating
- Trips - gap leakage
- Seals - Corner flows

Performance
- drag - mass capture
- on - off design

Sidewall length
3-D spillage
Cowl leading edge heating

Isolator

Facility effect
Aspect ratio

Combustor

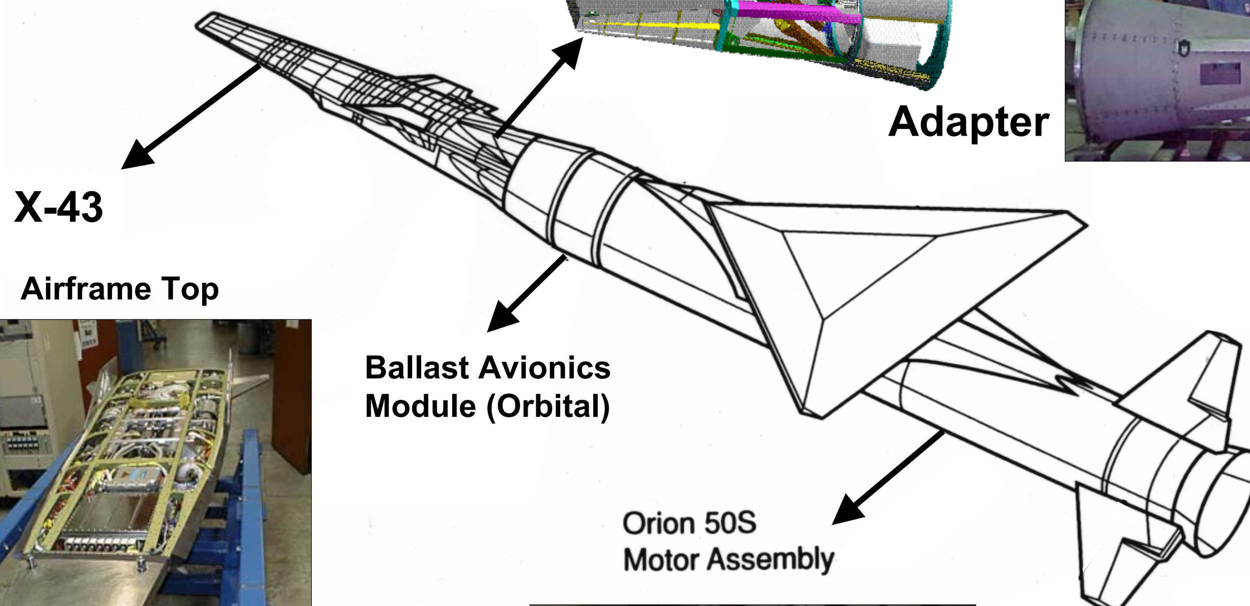
Small fuel injector survival
Combustor reaction rates
thermal loads
Test condition uncertainty
- AOA and Yaw effects
- dynamic press. and Mach

Fuel control laws
Facility effects on ignition, flameholding and comb. pressure

Nozzle

Nozzle lift and pitch moment
Trim brag
Boundary layer relaminarization
Propulsion-airframe interaction

Hyper-X Baseline Configuration



Adapter built by Allied Aerospace, Tullahoma, TN

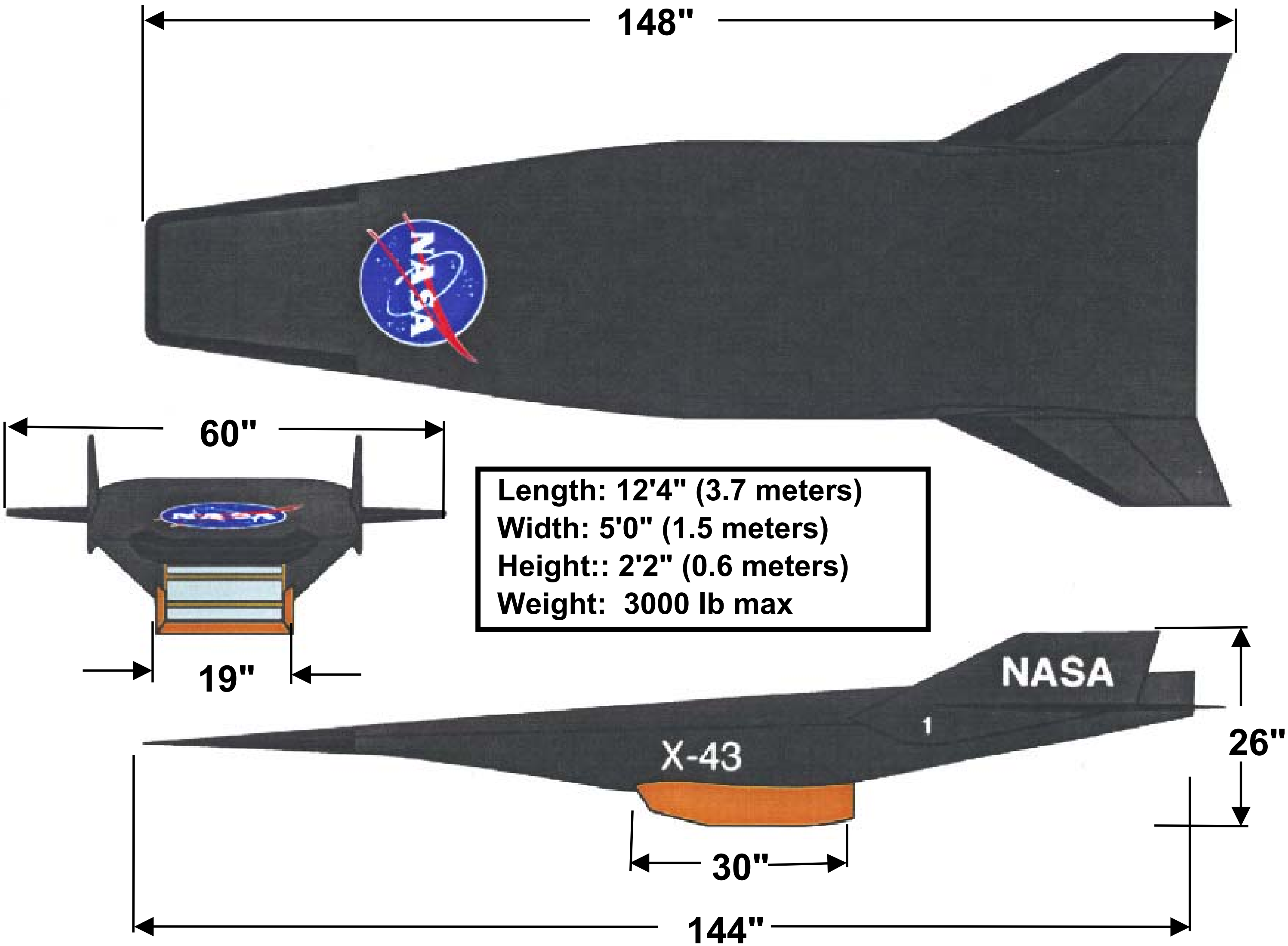
Airframe Top

Vehicle Under Construction by Allied Aerospace at Ontario, CA and Tullahoma, TN and Boeing, Long Beach, CA

Booster built by Orbital Sciences Corp., Chandler, AZ

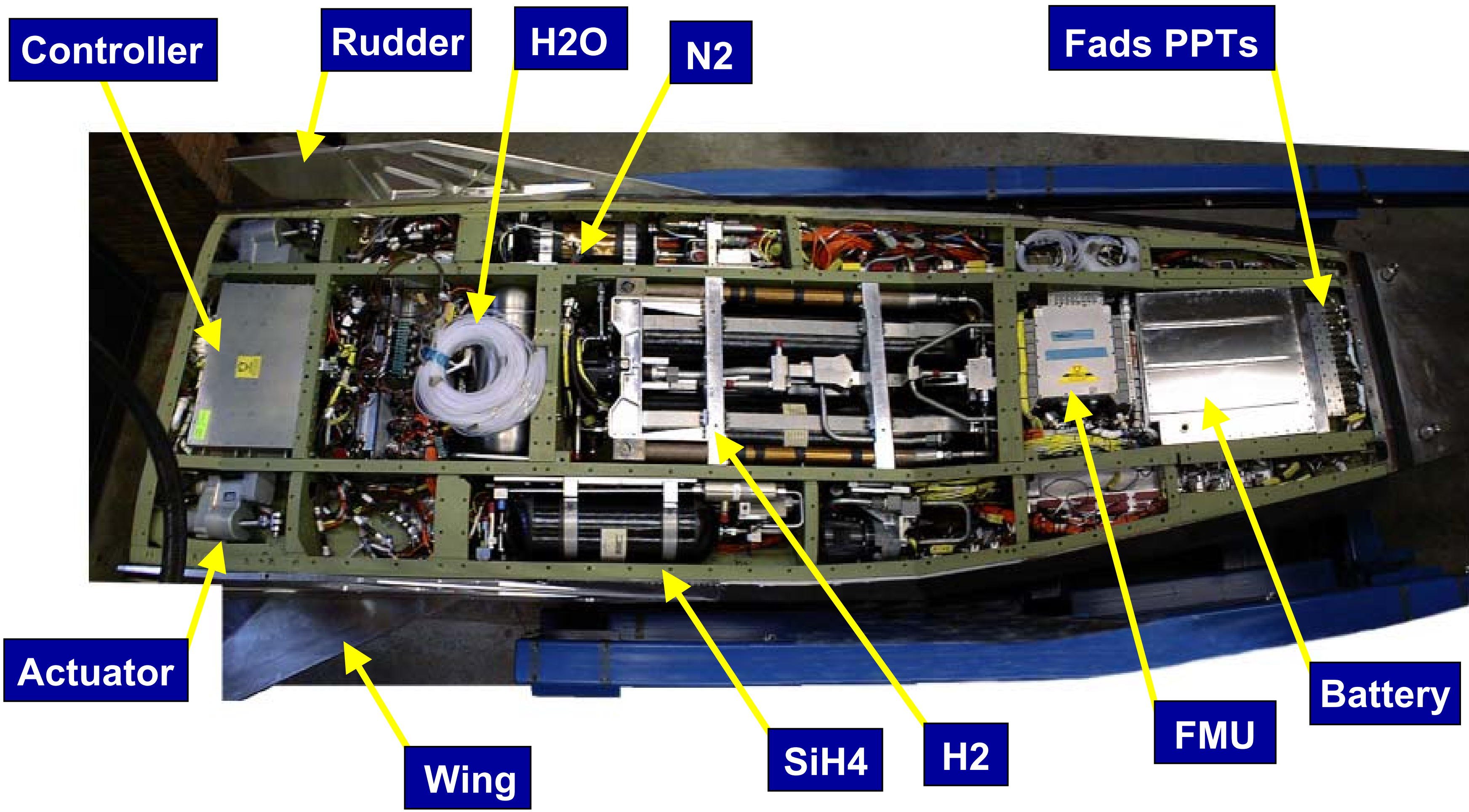
Rocket Motor (~100,000 lbs Thrust)

X-43 Vehicle Geometry

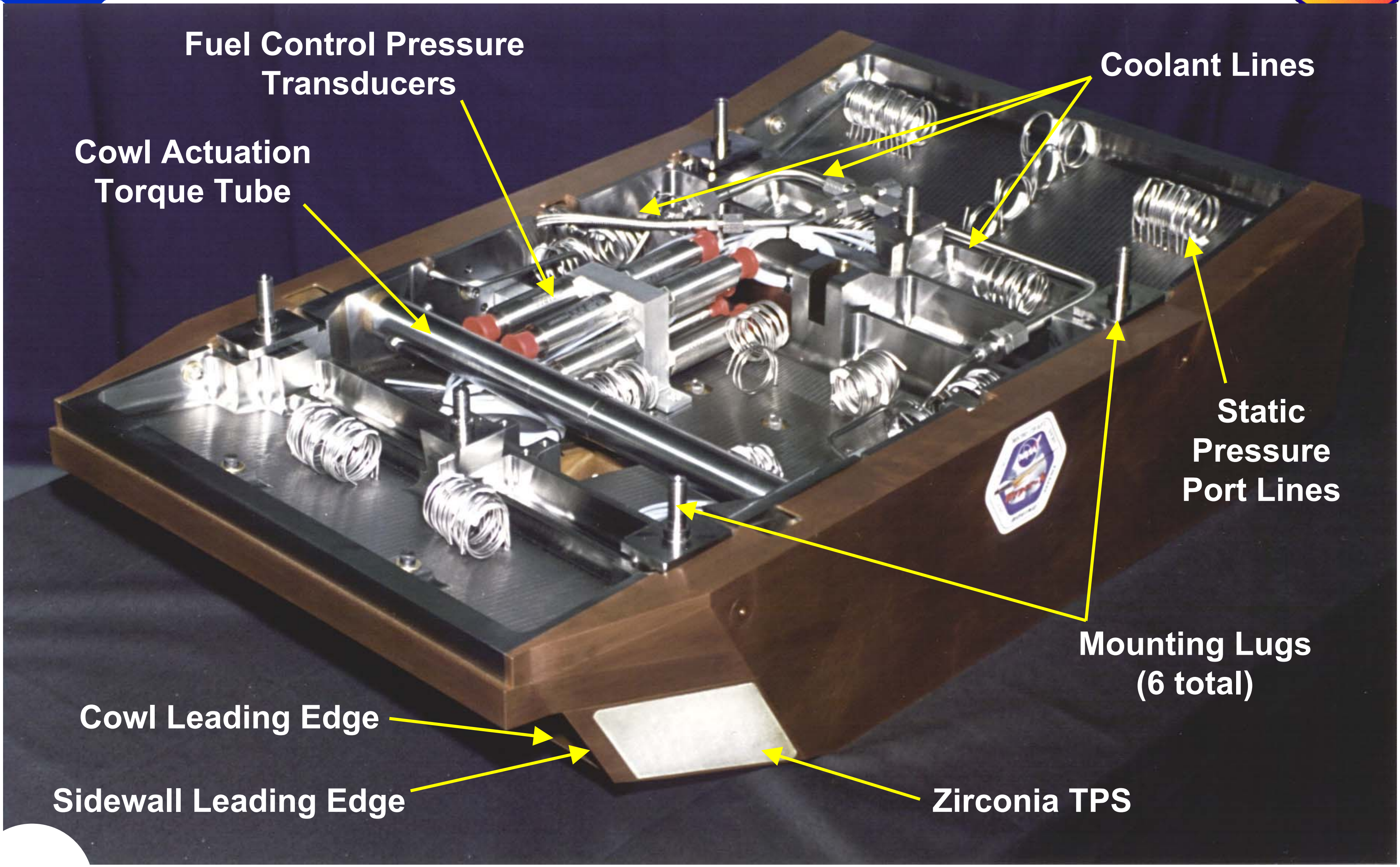


Length: 12'4" (3.7 meters)
Width: 5'0" (1.5 meters)
Height:: 2'2" (0.6 meters)
Weight: 3000 lb max

X-43 Vehicle Layout



HYPER-X MACH 7 ENGINE



HYPER-X INSTRUMENTATION

Launch Vehicle

Vibration	6
Pressure	2
Strain	31
Temperature	66
FTS	24
Power Distribution	30
Ordnance/ADAM	36
Ordnance	56
Status	77
Adapter Inst.	32
Masc./Sync/Spare	34
Subtotal	**384 (400 Max)**
GN/GPS words	400
Grand Total	**784**

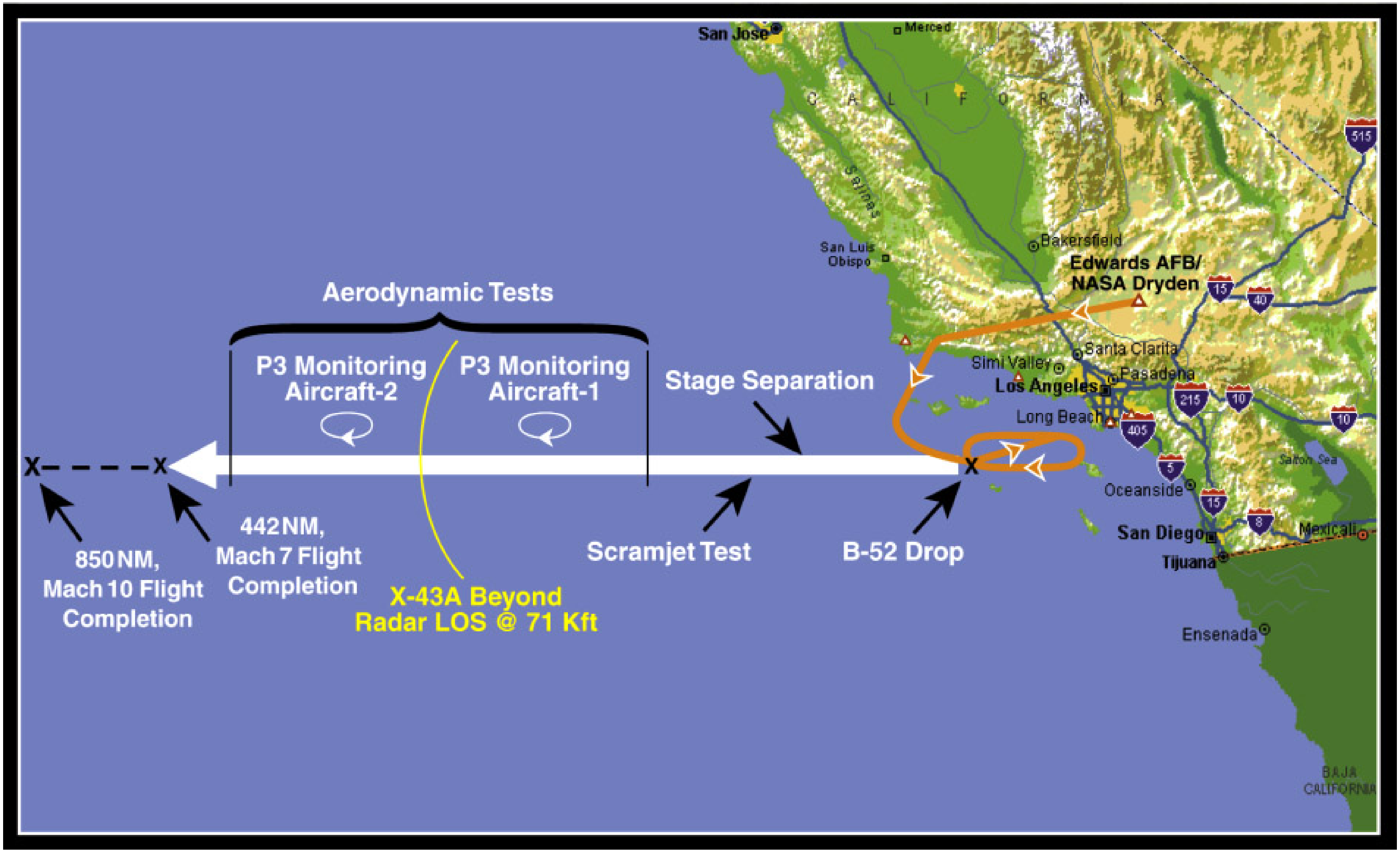
X-43 Research Vehicle

System Breakdown		
Instrumentation Sub-System		291
Vehicle Management System		212
Total		**503**
Criticality Breakdown		
Flight Safety		54
Mission Critical		196
Research		253
Total		**503**
General Breakdown		
Instrumentation/Measurement		359
Pressure	194	
Temperature	107	
Other	45	
Strain Gauge	13	
Parameters (words)		120
Rebroadcast Parameters		24
Total		**503**

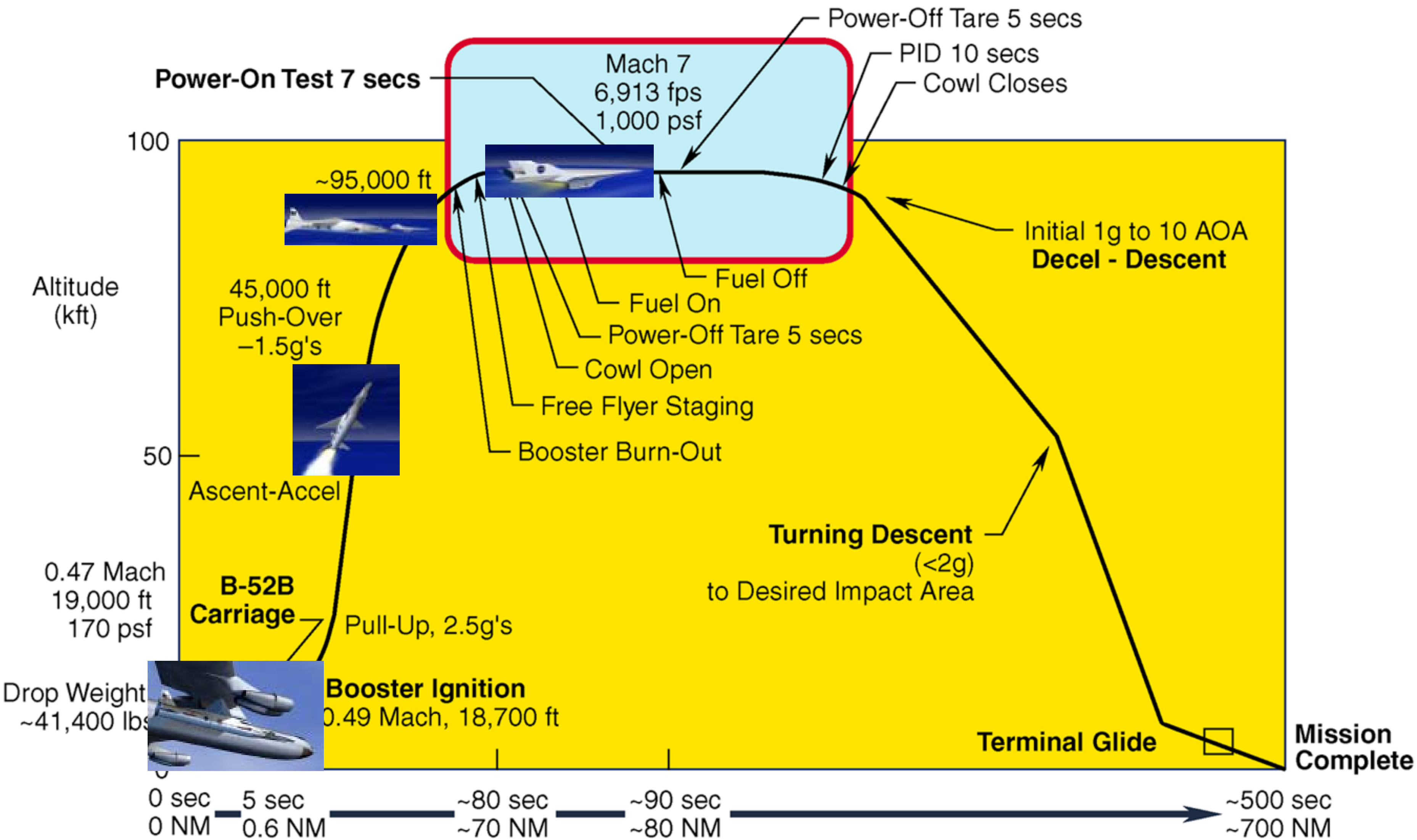
X-43A Return to Flight Status

Key Mission Events

B-52 and X-43 Ground Track



X-43 Mach 7 Flight Trajectory
(Pre Flight 1)



First Flight Mishap
June 2, 2001

- Nominal flight to launch point
- Drop of booster stack and ignition at 5 seconds after drop nominal
- At ~13 seconds after drop booster departed controlled flight -- right fin broke off, followed, within one second, by left fin and rudder
- Wing broke off at 15 seconds
- Booster data stream lost at 21 seconds
- At 48.5 seconds, FTS initiated by Navy Range Safety Officer while booster was within cleared corridor – no hazard to civilians on ground or air crews
- X-43 data stream lost at 77.5 seconds

Mishap Description

X-43A Return to Flight

- X-43A Mishap Investigation Board (MIB) was convened on June 5, 2001 and submitted its draft report March 8, 2002
- Report released July 23, 2003
- Return to Flight (RTF) commenced in March 2002 with development of:
  - Corrective Action Plan in response to the MIB findings/recommendations
  - Overall approach/roadmap for Return to Flight

X-43A RTF Risk Reduction Major Actions

Launch Vehicle

- Higher fidelity models
  - Aerodynamics
  - Actuators
  - Structures
  - Autopilot
- Actuator upgrade for greater torque capability
- Lower loads trajectory: booster propellant off-load
- Autopilot trades/optimization
- Independent simulation

Stage Separation

- Higher fidelity models
- Additional separation mechanism testing
- Control law refinements for robustness
- Independent simulation

Research Vehicle

- Higher fidelity models
- Increased AOA for flameout robustness and greater thrust
- Upgraded engine control logic for unstart robustness
- Adapter fluid systems improvements
- Redesign of wing control horns
- Aircraft-in-the-loop timing tests
- Independent simulation

Synergism of Hypersonic Scramjet Flowpath Development

Flight Test

Quantification of facility/model effects

Design database and trade studies
Test interpretation and analysis of off-trajectory points

Design database and parametric testing
Viable scramjet operation that meets objectives

Simulation

Verification of flight scaling
Data for analytical model development

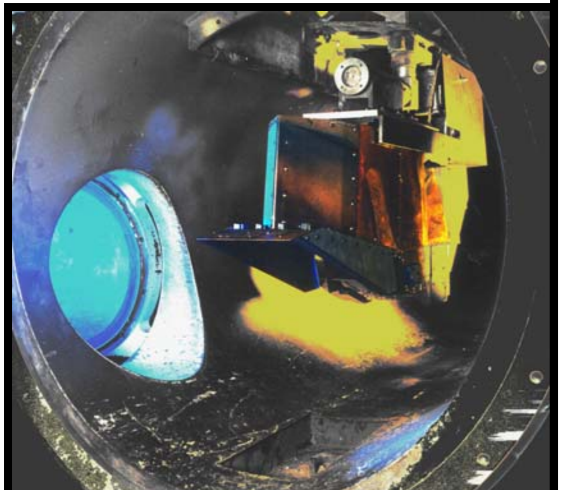
Verification of computational methodology
Data for analytical model development

Facility/model configuration assessment & gauge placement
Data consistency & test interpretation

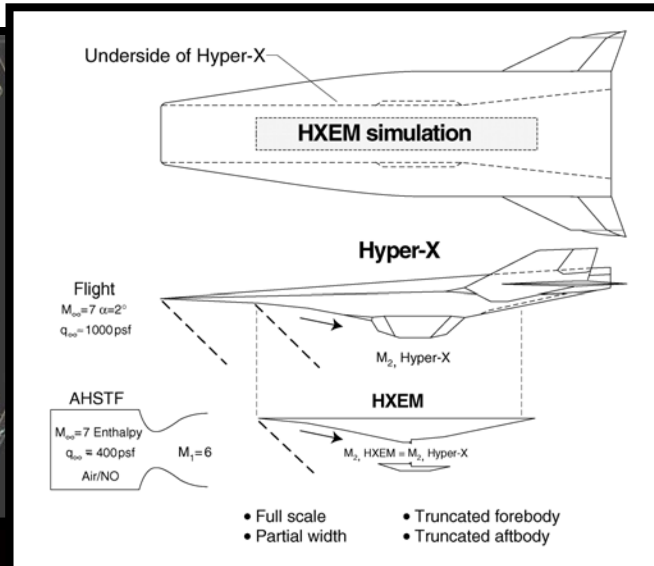
Ground Test

HYPER-X MACH 4.5 TO 15 SCRAMJET TESTS

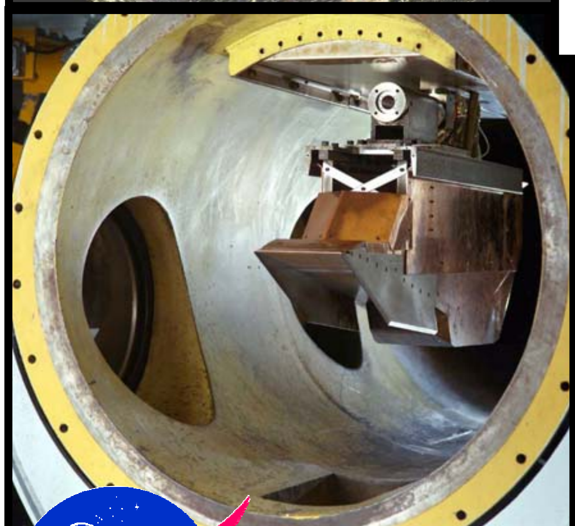
DFX in the AHSTF; Mach 7



HXEM Simulation

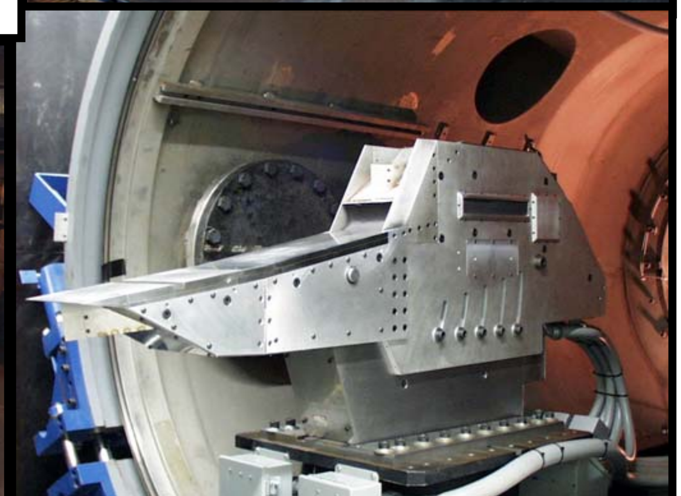


HXEM/FFS in LaRC 8' HTT; Mach 7



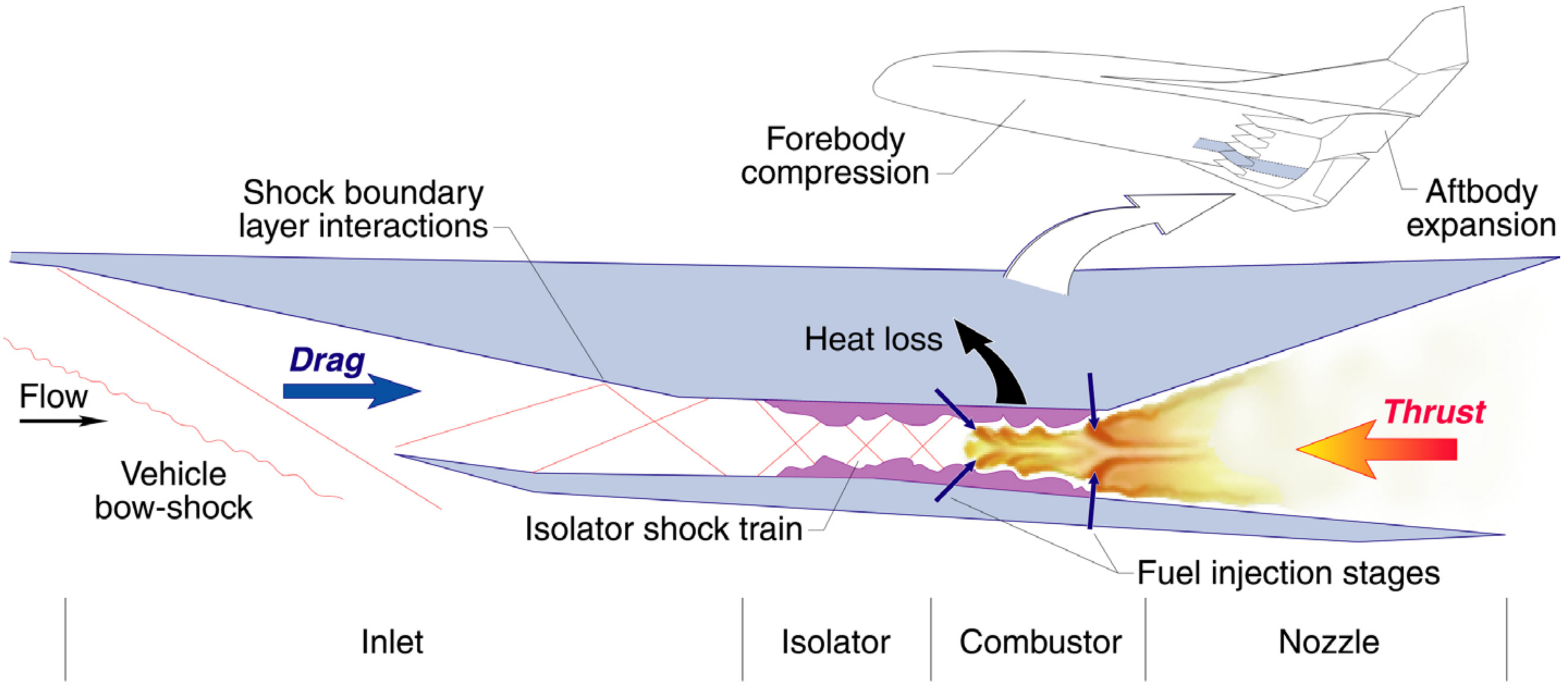
HXEM in LaRC AHSTF; Mach 7 (also Mach 4.5-6 In CHSTF)

HXFE/VFS in LaRC 8' HTT; Mach 7



HSM in HYPULSE at GASL Mach 7, 10 and 15

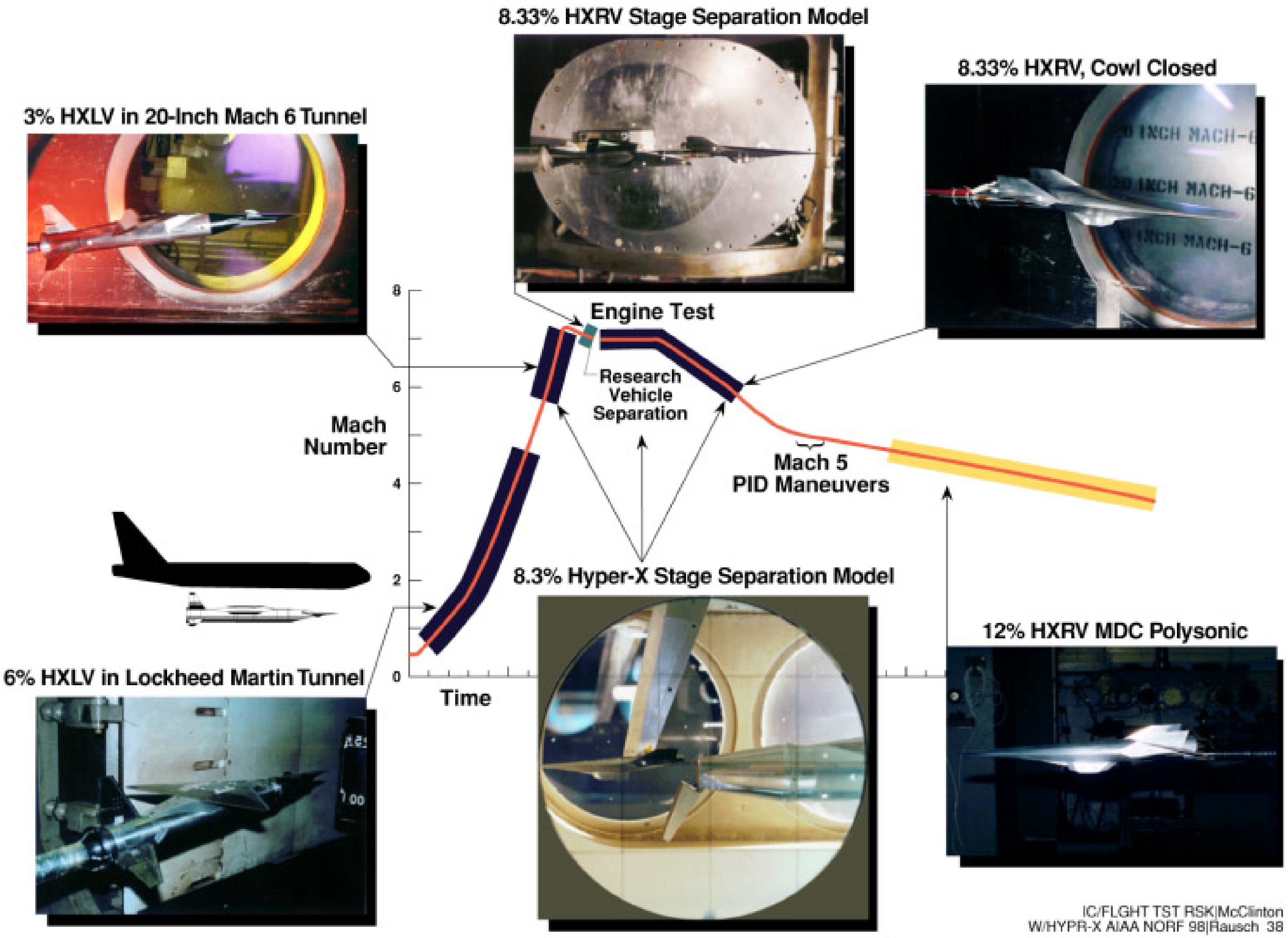
Scramjet Unstart Prevention: Durascram



- Unstart occurs when pressure from combustion causes isolator shock train to propagate forward into the inlet causing massive flow spillage
- Actively controlling fuel flow via isolator pressure feedback (Durascram) to enhance unstart robustness

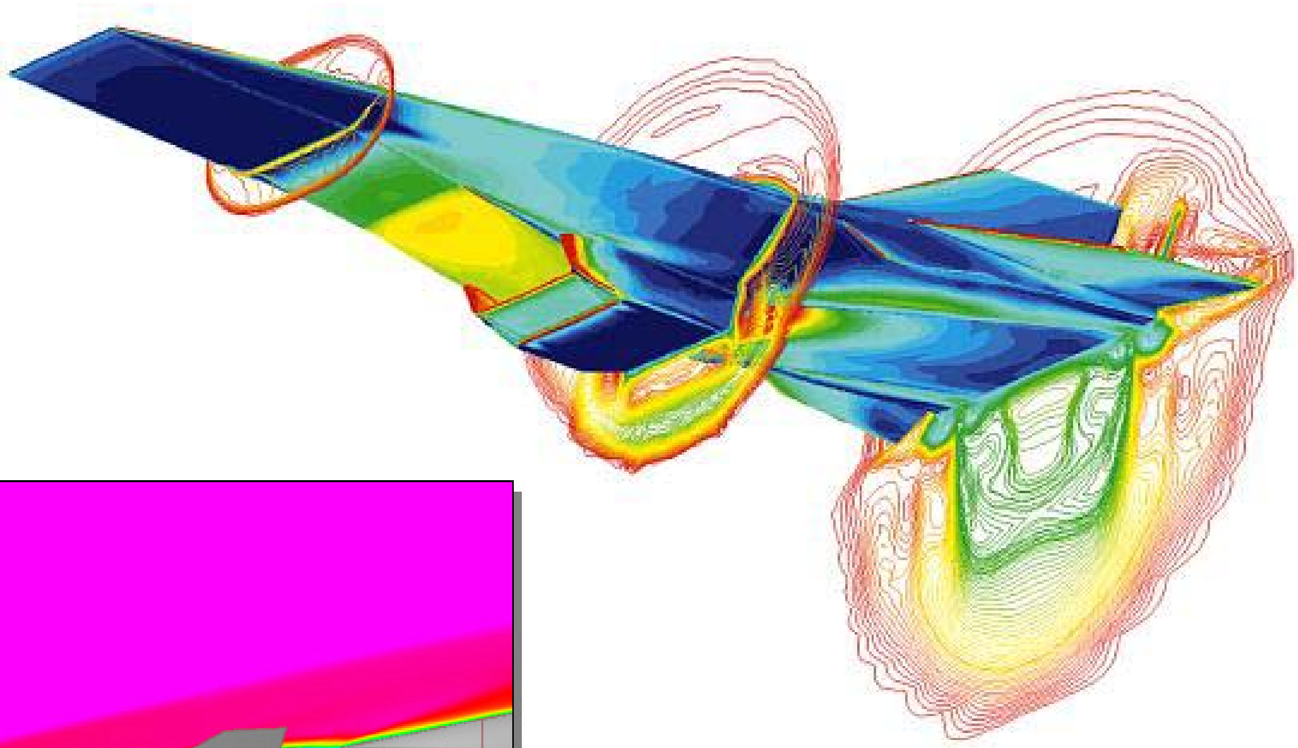
Hyper-X Experimental Research

Flight Test Risk Reduction: Aerodynamic Database Development



IC/FLGHT TST RSK|McClinton
W/HYPR-X AIAA NORF 98|Rausch 38

CFD Vehicle Performance/Stability Analysis



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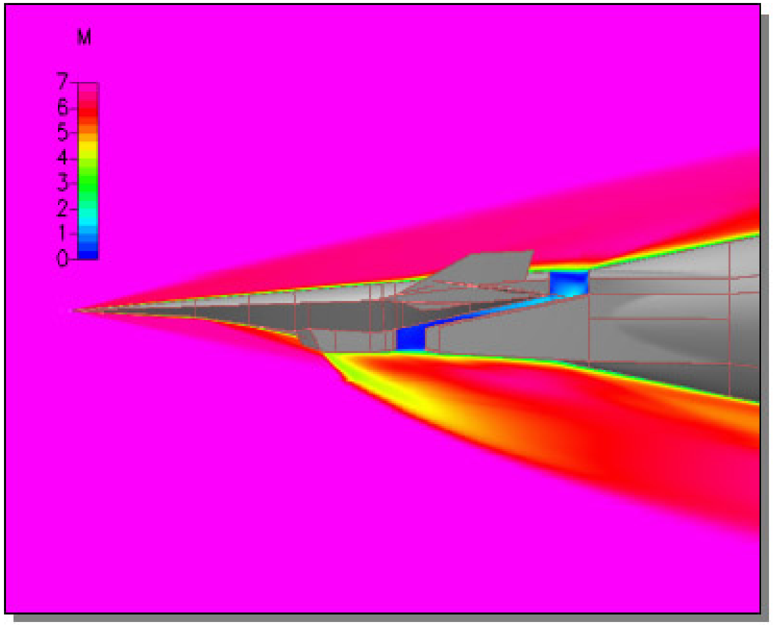
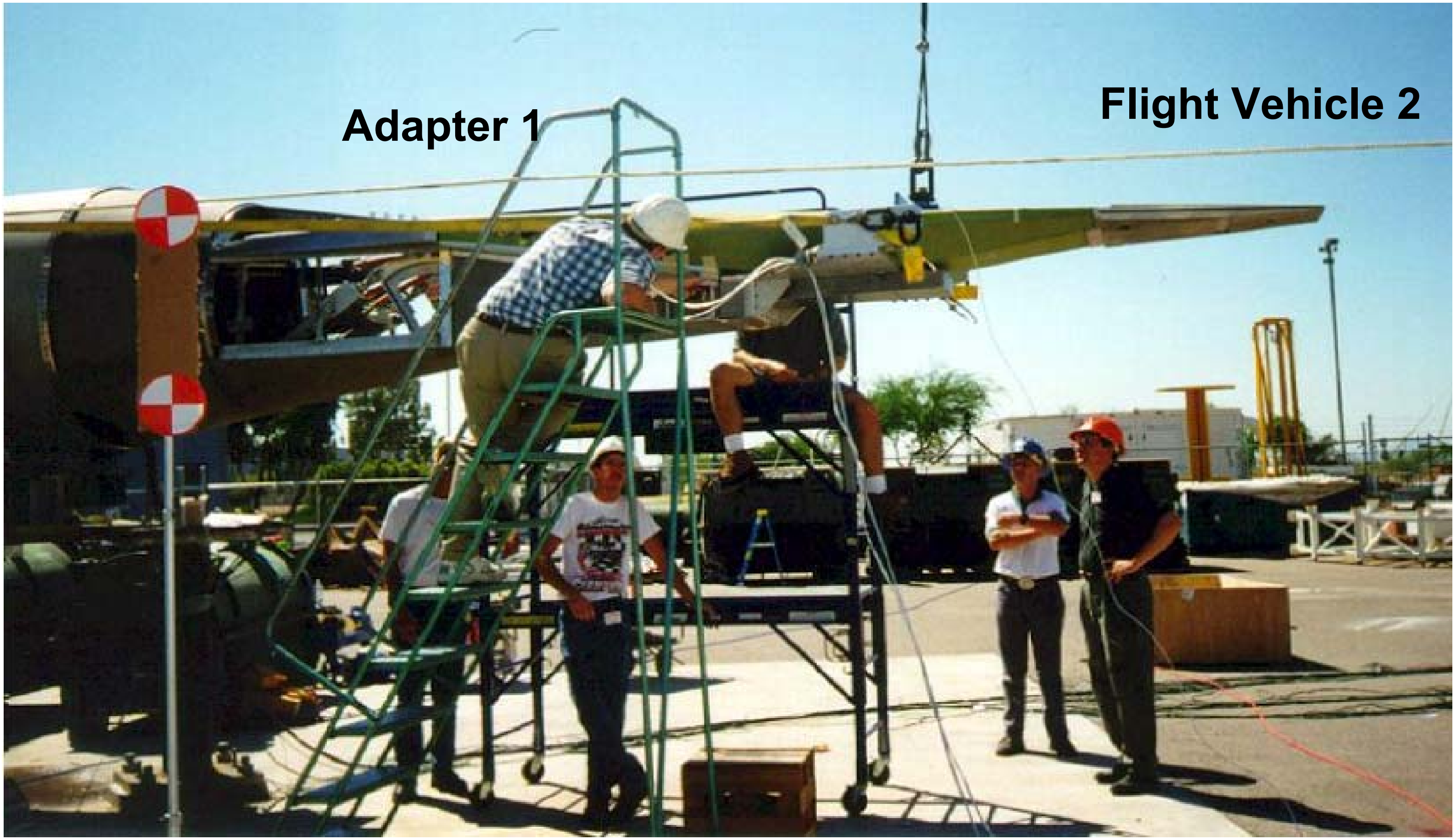
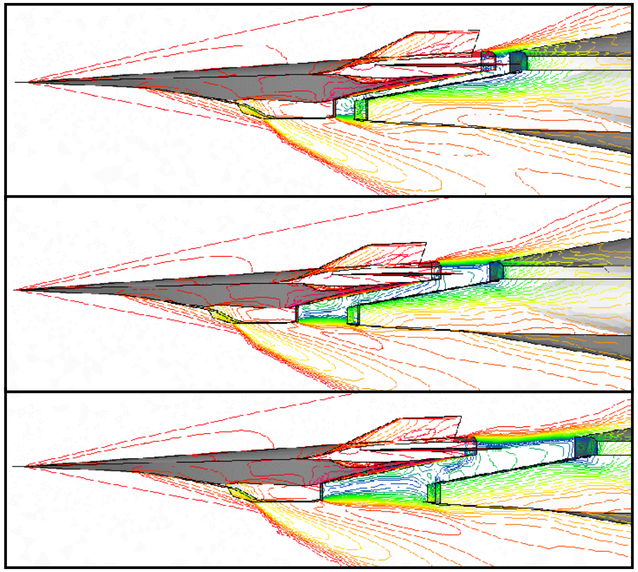


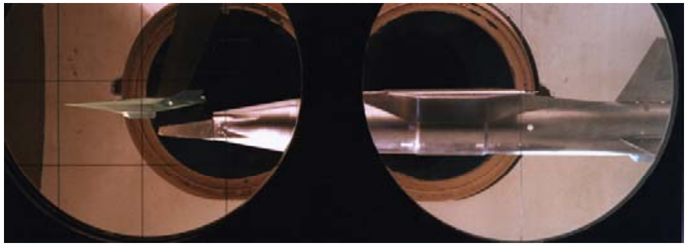
"Full-Scale" Stage Separation Test



Hyper-X Stage Separation Aerodynamics



Stage separation at the extreme environmental conditions associated with flights at Mach 7 and 10 and dynamic pressures in excess of 1000 psf is a high risk element of the X-43A program



AEDC SEPARATION WIND TUNNEL TEST

- Multi-body dynamic simulation (14 DOF) stage separation simulation model utilized by Govt. team for risk reduction:

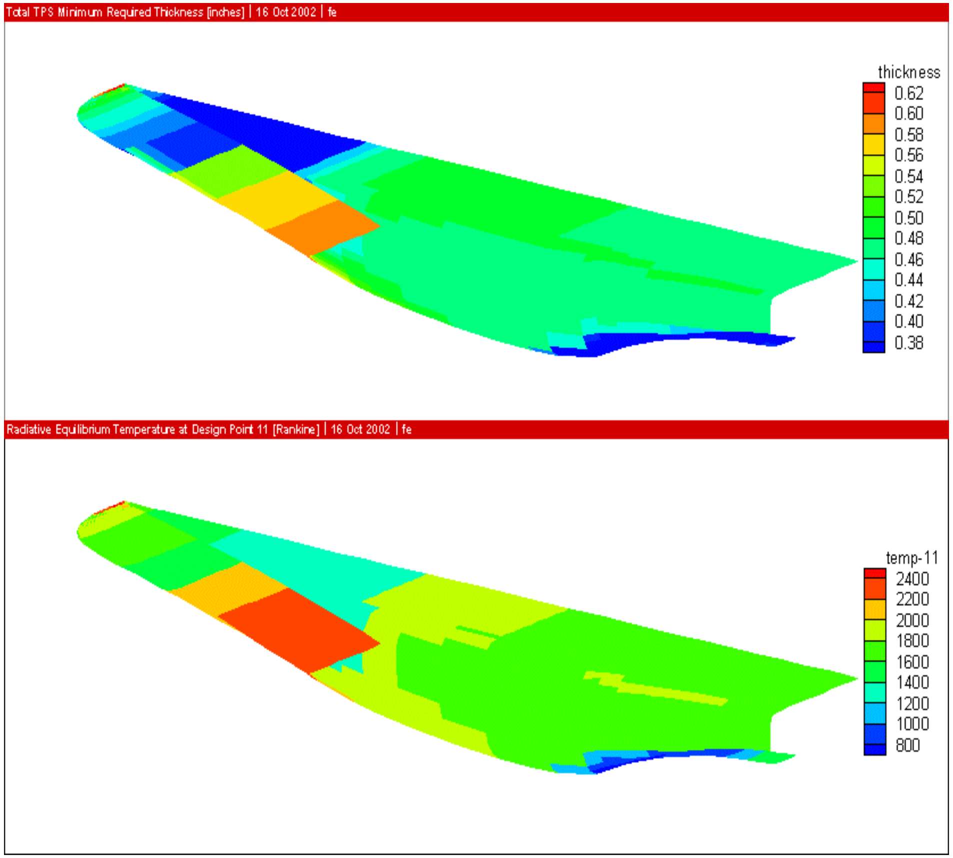
  6 DOF HXRV + 6DOF HXLV + 2 DOF ejection pistons

- Aerodynamics input to the simulation is based on extensive database developed from AEDC/LaRC tests, supplemented w/ CFD analyses.

- Accomplished additional independent reviews of multibody stage separation aero modeling, uncertainties development, and simulation implementation.

Aerothermodynamics

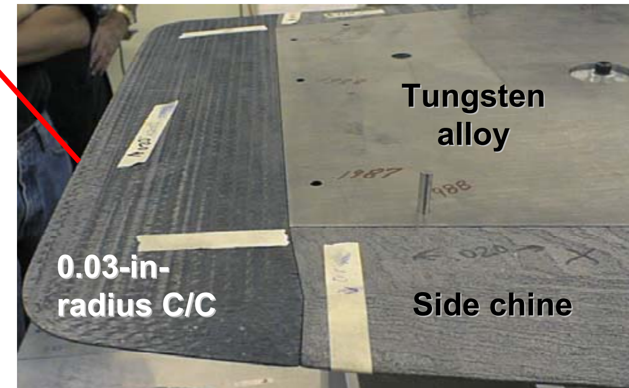
- Thermal loads development
  - –Leading edge heating
  - –Acreage radiative equilibrium heating
  - –Trajectory and computational methods uncertainty factors
  - –Shock-shock interaction amplification
- Engineering code development
  - –Vehicle TPS design and weight estimation
  - –Hypersonic leading edge heating
- Transient aeroheating analysis of active and passive TPS designs for hypersonic vehicle demonstrators
  - –Vehicle airframe acreage
  - –Critical engine components



Hyper-X Experimental Research

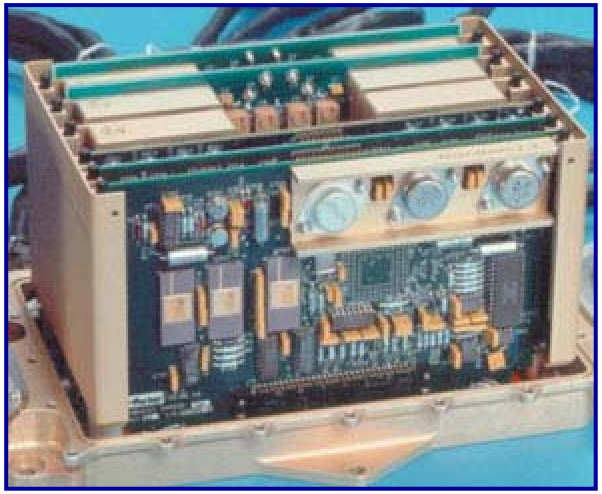
Mach 10 C/C Nose Leading-Edge Coating Evaluation

- **Mach 10 vehicle C/C nose leading edge predicted to reach ~ 4000°F**
- **Exceeds single use temperature (3250°F) of Mach 7 vehicle SiC coating**
- **Objective**
  - Validate an ultra high temperature, passive[1] leading edge for use on the Mach 10 vehic
- **Approach**
  - Evaluate multiple material systems (coating and substrates) and fabrication process at simulated flight conditions in AEDC arc-je facility
- **Status**
  - Five of six leading-edge test articles survived the first test with negligible recession



[1] Validated cooled Mach 10 leading edge design in a separate test program

Booster Fin Actuation System Upgrade



Electronic Control Unit (ECU)

Actuator

- **Objective: To increase the FAS hinge torque capability from 1850 ft-lbs to 3000+ ft-lbs**
- **Modifications:**
  - **Add second motor in torque summing arrangement**
  - **Fabricate new gears to handle higher loads**
  - **Change housing material from aluminum to stainless steel**
  - **Add two additional batteries**
  - **Redesign the power and pre-driver boards in the ECU**
- **New FAS units have been built and tested**

Propellant Off-Load

- **Approximately 3,350 lbs of propellant removed**

Halfway through Machining

Machining Completed

Flight Simulations

Boost	Separation	Research Flight

Primary

NRTSim (Orbital)
- Full Stack sim up to separation
- Pegasus heritage
- LV analysis, autopilot design, trajectory analysis

SepSim (Langley)
- 6+6 DOF sim of LV & RV during separation
- Built on MSC/ADAMS code
- Sep analysis, sensitivity studies, collision detection

RVSim (Dryden)
- RV flight from post separation to splash
- Dryden sim environment
- RV analysis, autopilot design, sensitivity studies

Drop-to-Splash (Dryden)
- Full mission simulation
- NRTSim + StepSim + RVSim
- Manual linking of sims
- Validation of individual sim phases/integrated flight

Back-Up

LVSim-D (Dryden)
- Independent LV sim
- Dryden sim environment
- Independent LV analysis

Post 2 Sep (Langley)
- 6+6 DOF sep simulation
- Built on POST2 code
- Independent Sep analysis

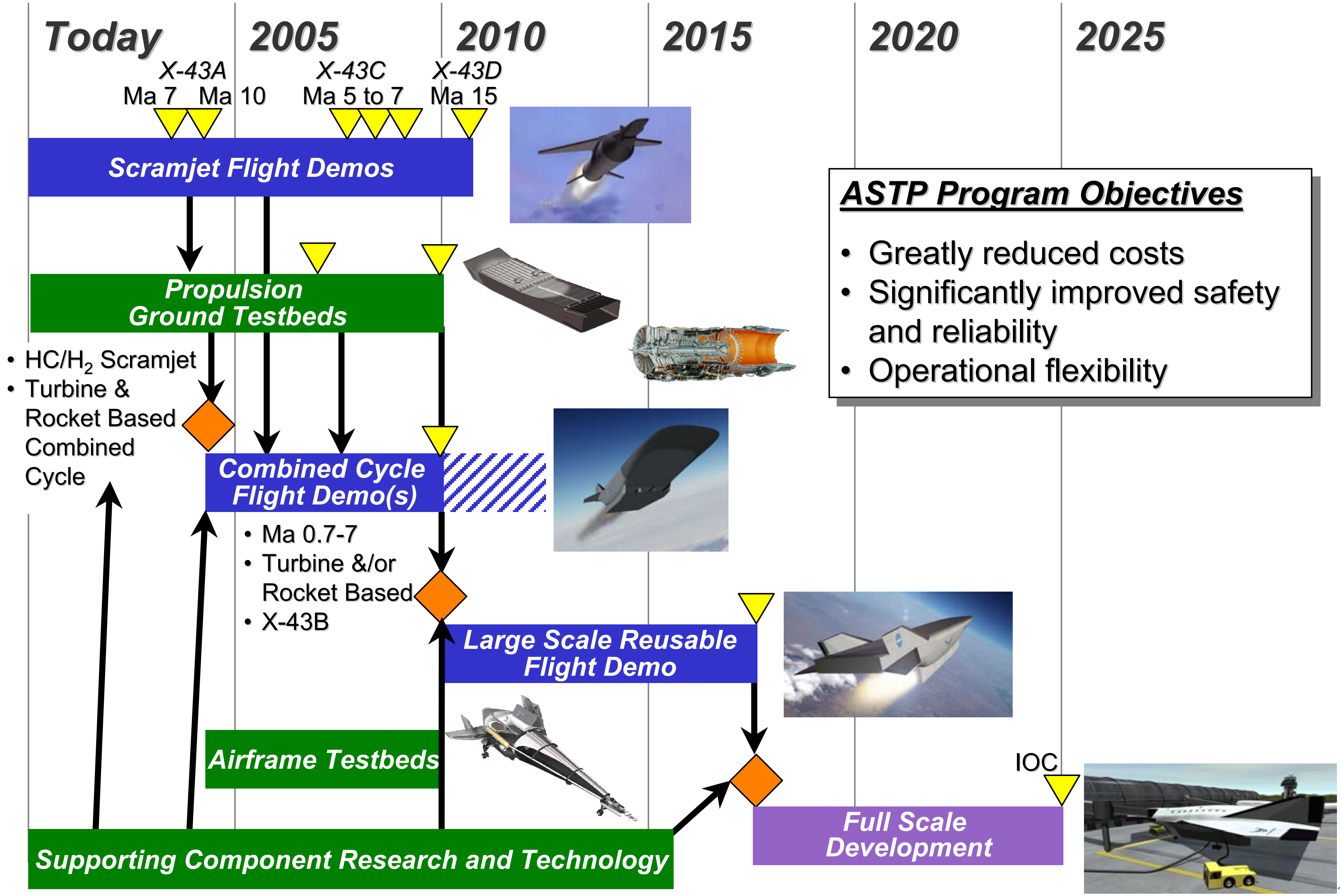
End-to-End Sim (Langley)
- Full mission simulation
- NRTSim + SepSim + RVSim
- Single user interface, automated linking/integration
- Validation of Drop-to-Splash & individual sims

End-to-End Visualization: Nominal Trajectory

Hyper-X X-43A Flight #2 Success Criteria

- Minimum Success Criteria:
  - Safely conduct ground operations, captive carry and research flight
  - Successfully launch booster stack and boost to stage separation point
  - Successfully perform stage separation resulting in controlled flight of the X-43A at the scramjet test point
  - Conduct the scramjet propulsion experiment and obtain data
- Additional Research Objectives:
  - Vehicle acceleration during the scramjet propulsion experiment
  - Obtain data from all flight phases
    - Captive carry (Launch Vehicle (LV) and Research Vehicle (RV))
    - Boost (LV and RV)
    - Stage separation (LV and RV)
    - Stage separation video (LV)
    - Free flight (RV)
  - Obtain RV aero, structural, GNC, and other data to splash
  - Validate RV Flush Air Data System operation

Hypersonic Access to Space Roadmap



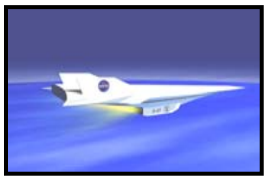
ASTP Program Objectives

- Greatly reduced costs
- Significantly improved safety and reliability
- Operational flexibility

Hypersonic Flight Demonstration Projects

NGLT Hypersonic Flight Demonstrators

X-43A

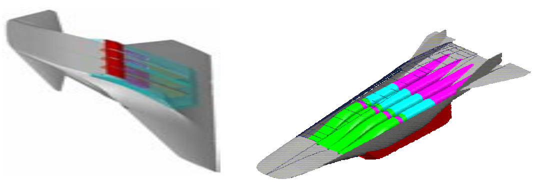


Uncooled DMSJ
Expendable
GH_2 fuel
10 sec. powered
M=7, 10
First flight failure 6/01

X-43C

NASA – Air Force
Cooled Flt. Wt. DMSJ
(HyTech Based)
Expendable
HC fuel
5 min. powered
M 5 to 7

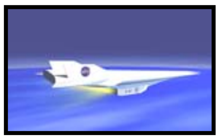
X-43B



NASA – Air Force

Cooled RBCC	Cooled TBCC
ISTAR RBCC	RTA Turbojet
Reusable	Reusable
HC fuel	HC fuel
10+ min. powered	10+ min. powered
M 0.7 to 7	M 0.7 to 7

X-43D



Cooled DMSJ
Expendable
LH_2 fuel
1+ min. powered
M 10 - 15

Large-scale Demonstrator

FUNDED

STUDY

Incremental development leading to 2025 IOC

Summary

X-43A is on track to return to flight by mid-Nov.