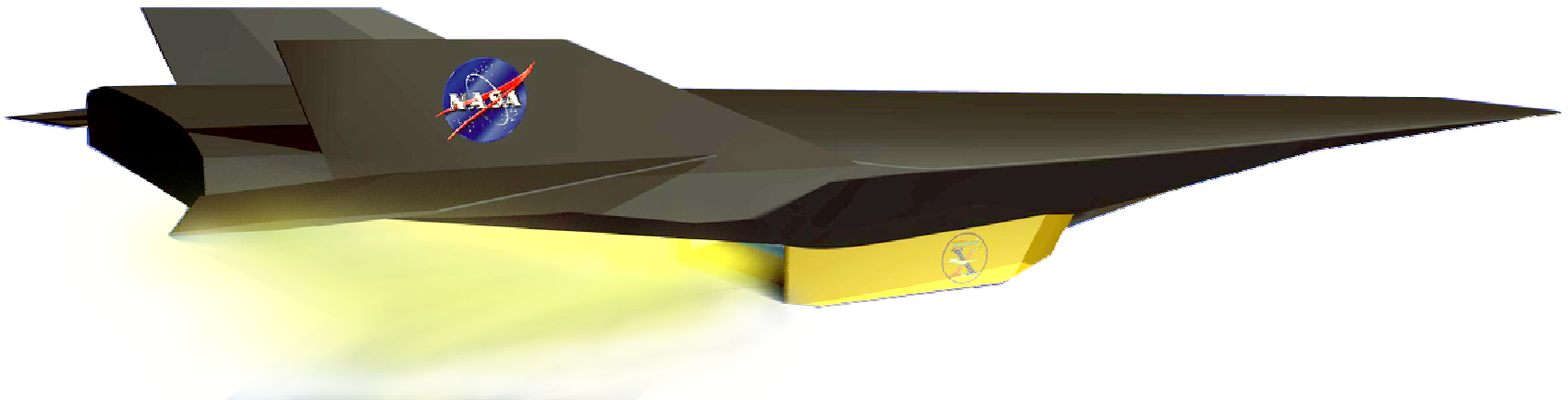




Hyper-X Program Overview

Walt Engelund

NASA Langley Research Center, Hampton, VA



Virginia Tech

Aerospace and Ocean Engineering Dept. Seminar

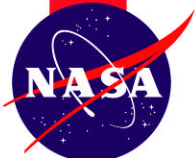
May 2, 2001





Outline

- Abbreviated history of hypersonic scramjet research
- NASA's Hyper-X Program
- Hyper-X / X-43A Vehicle Descriptions and Mission Flight Profile
- X-43A Vehicle Design and Analysis
- First Flight test status
- Summary





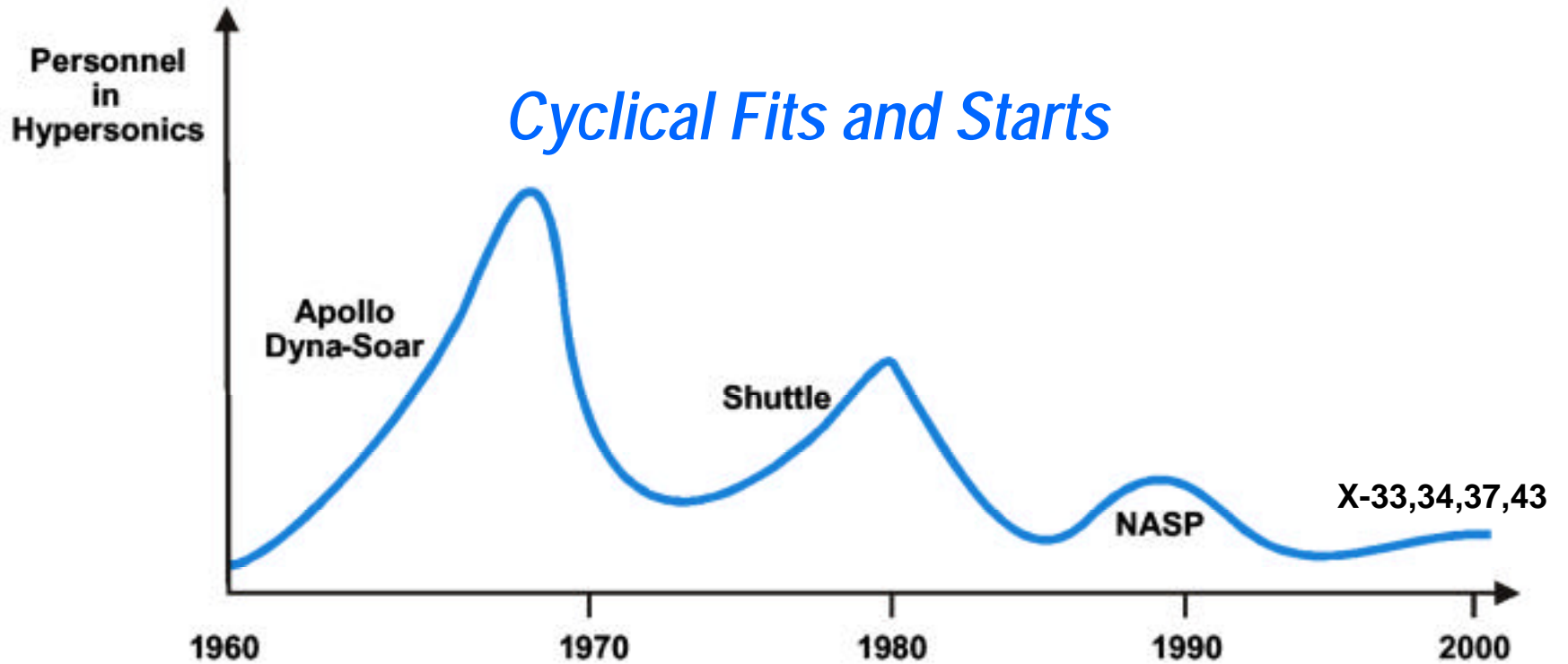
History of NASA's Focused Scramjet Research (Supersonic Combustion Ramjet)

- Laboratory environment for over 40 years ...
- Hypersonic Research Engine (HRE)
- National AeroSpace Plane (NASP)
- Russian CIAM experiments
- Hyper-X Program
- Hyper-X / X-43A will be the **world's first airframe integrated scramjet flight test vehicle**





History of Hypersonics



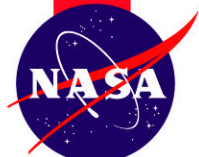


History of Hypersonics

*HYPERSONICS IS AT THE SAME CROSSROADS
SUPERSONICS WAS FIFTY YEARS AGO*

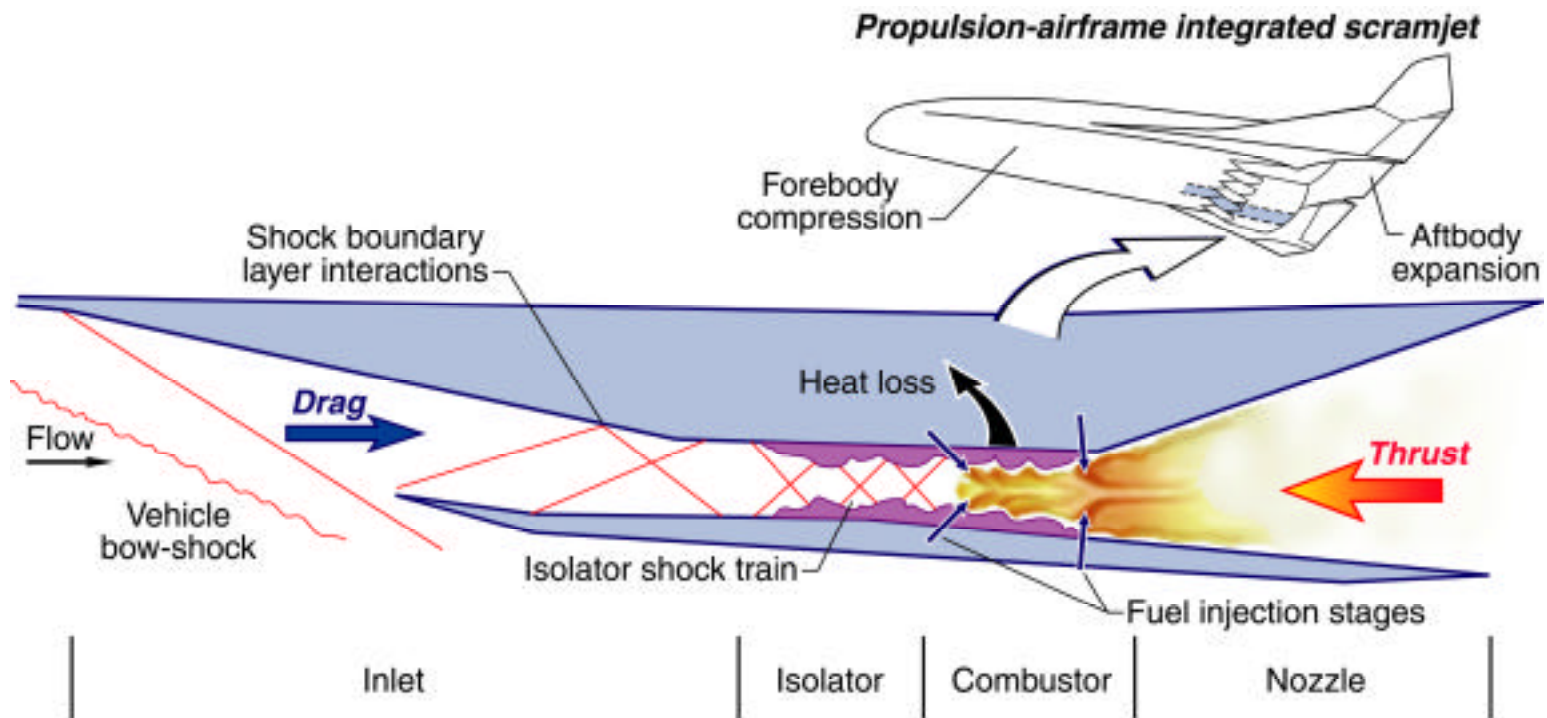
- Inadequate Federal organizational structure
- Serious ground test facility shortfalls
- Inherent risk and design uncertainties
- Subscale substitutes: weighted bodies then, AARMD now
- Controversial Tech Demonstrators: X-1 then, Hyper-X now
- Disadvantageous economic (Defense spending) conditions
- *NO OBVIOUS OPERATIONAL REQUIREMENT*

But would a reasonable person today say we made a mistake supporting supersonic research and development???





Scramjet Features



Important Terms/Concepts for the X-43 Experiment

Inlet starting

Ignition/Flameout/Flameholding

Combustor/isolator interaction

Fuel equivalence ratio/

KPRL402072001





Potential Air Breathing Hypersonic Applications

Weapons (missiles)

- Time Critical Mobile targets
- Hard and Deeply Buried Targets
- Reactive Lethal SEAD
- Counter Air
- BMD/TBMD



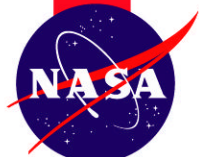
Aircraft

- Global Strike/Recce
- Survivable DEW/ABL Platform
- Rapid resupply



Space Operations

- Routine launch
- Replace & maintain key satellites
- Protect US/Coalition satellites
 - Anti-ASAT
- Deny hostile/non-combatants use of space
 - ASAT
 - Satellite capture/disable





HYPER-X PROGRAM GOALS & OBJECTIVES

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

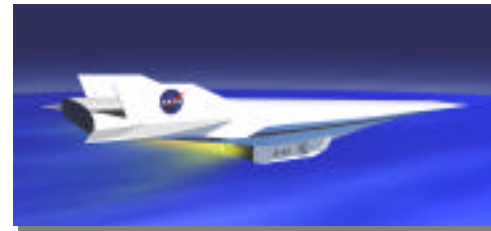
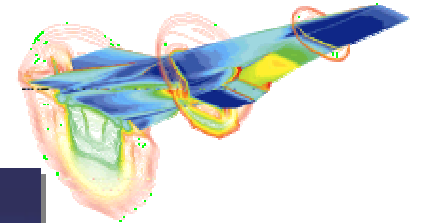
FLIGHT OBJECTIVES:

- Free-flight demonstrations (Two @ Mach 7, one @ Mach 10)
- Methods verification
- Scaling confirmation

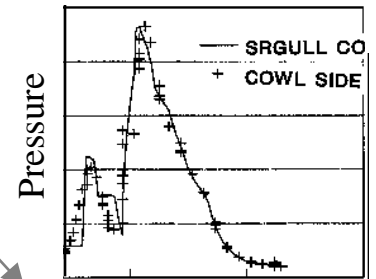
Primary Metric: Accelerate

TECHNOLOGY OBJECTIVES:

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



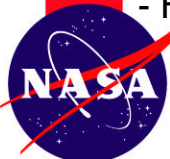
SRGULL Data



Comparison of Ground & Flight Data



Wind Tunnel-to-Wind Tunnel Comparison





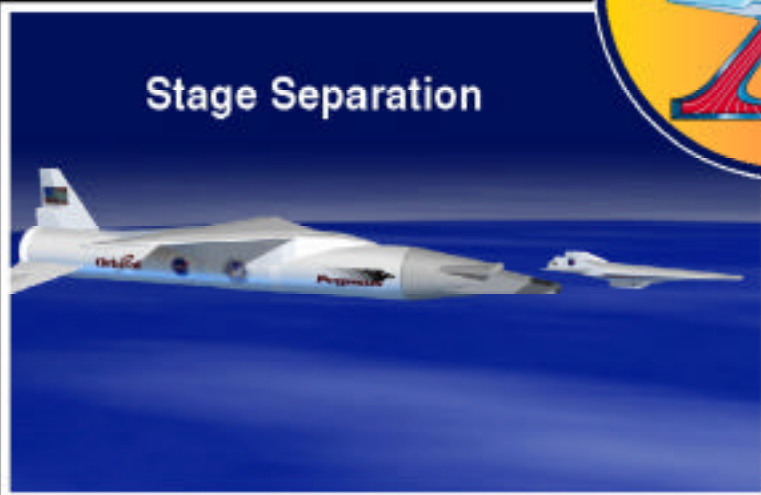
HYPER-X RESEARCH VEHICLE KEY MISSION EVENTS



B-52 Captive Carry



Pegasus Boost



Stage Separation

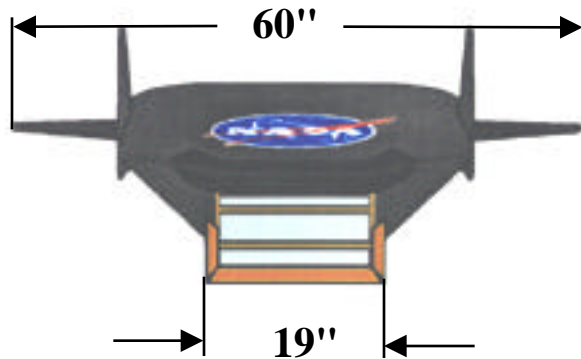
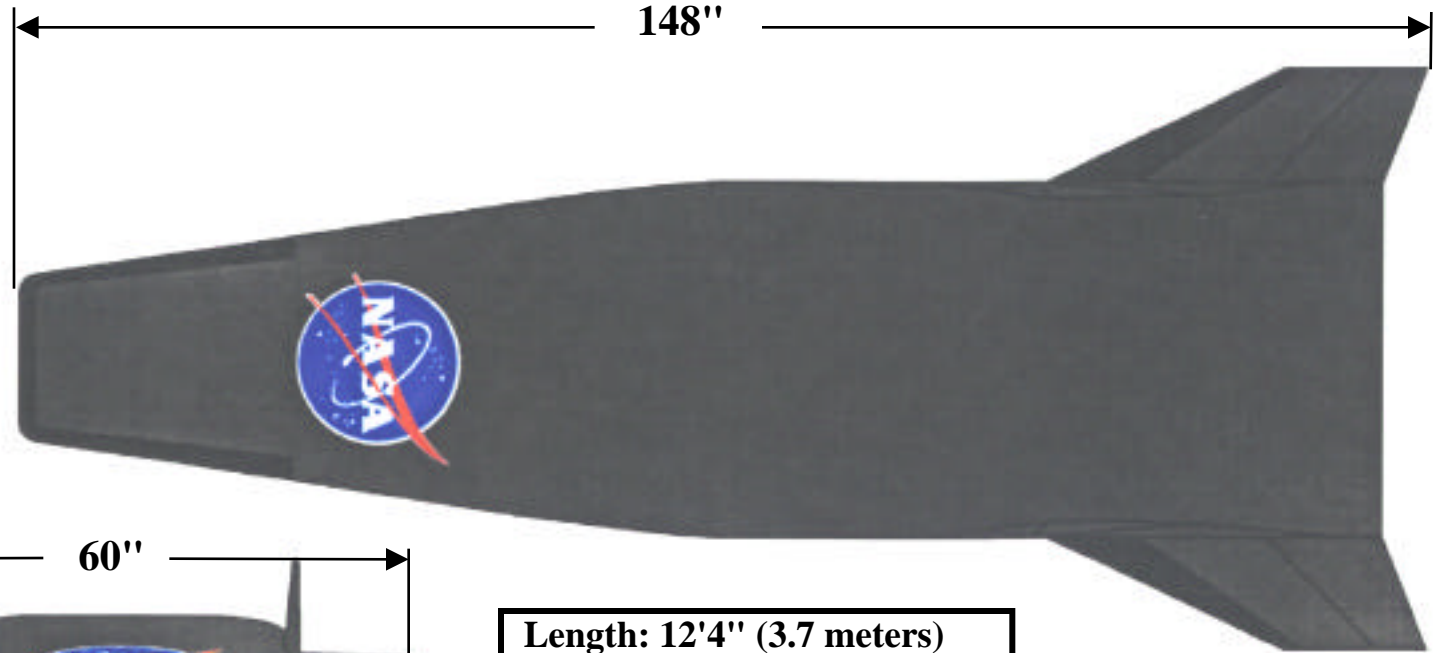


Scramjet Engine Operation

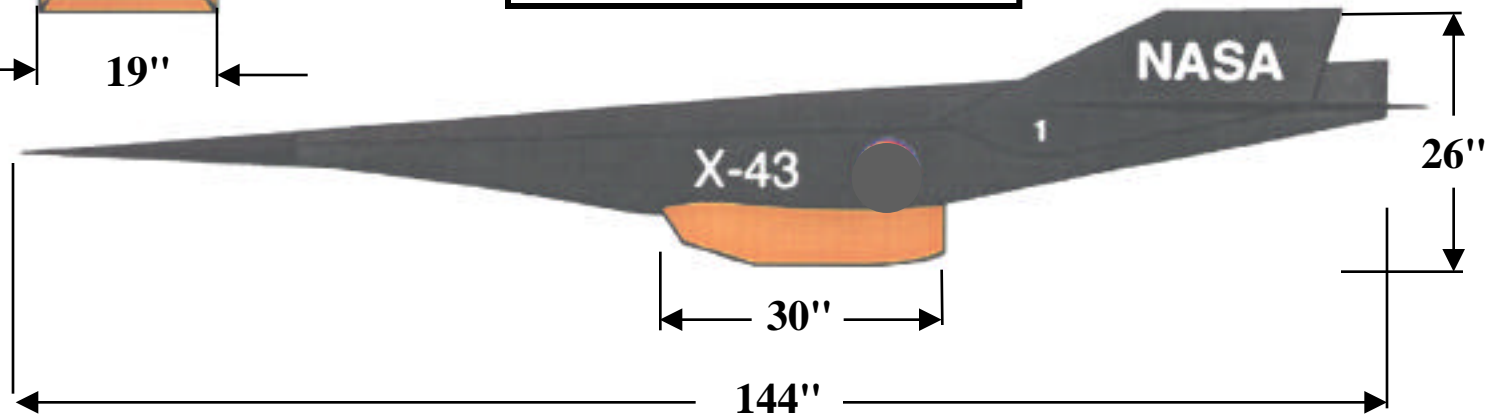




HYPER-X / X-43A RESEARCH VEHICLE GEOMETRY



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





HYPER-X LAUNCH CONFIGURATION

Pistons will Push
X-43 Away

Adapter

X-43A
Airframe (Top)

Built By
Micro Craft

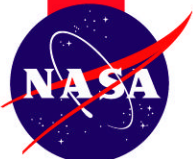


Vehicle Constructed
By Micro Craft

Booster Built by
Orbital Sciences

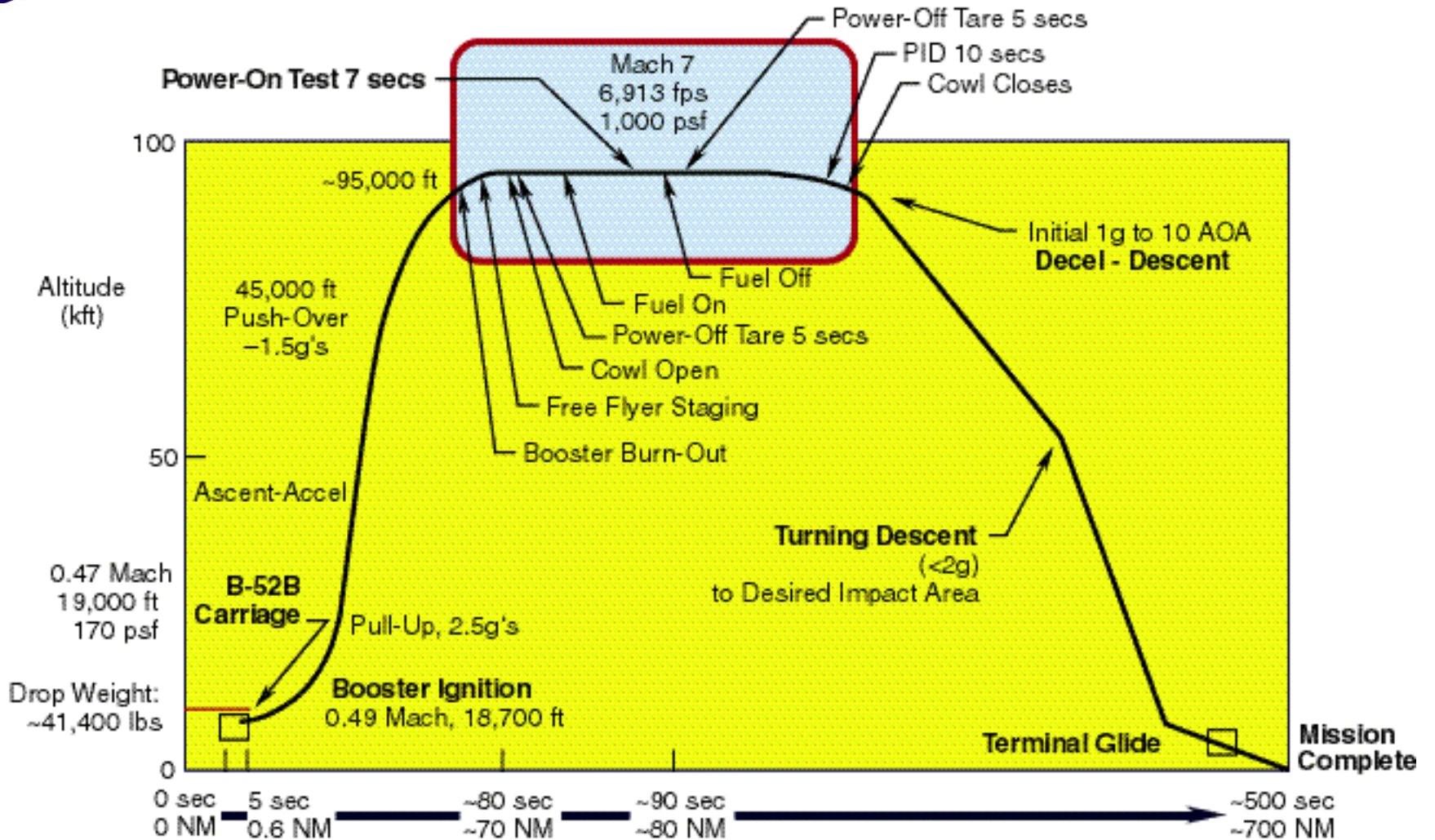


Rocket Motor
Thrust ~
100,000 lbs



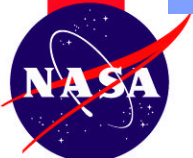


Nominal Mach 7 Hyper-X Flight Trajectory Profile





HYPER-X / X-43A RANGE TRACK





FLIGHT VEHICLE STATUS

Mach 7, Veh. No. 1

Design, fabrication, verification completed

Risk reduction technology completed

Validation testing ~ 99.9% complete

First flight: May '01

Mach 7, Veh. No. 2

Vehicle delivery mid-Nov. '00

Validation testing ~ 25% complete

Mach 10, Veh. No. 3

Vehicle fabrication 75% complete

Risk reduction technology continuing





BOOSTER AND WING PYLON



Rocket Motor

- Orian 50S motor assembly received from Alliant Technologies
- Wings, tails and fairings built by Scaled Composites
- Booster assembly and guidance system by Orbital Sciences Corporation
- B-52 wing pylon from X-15 program



Booster

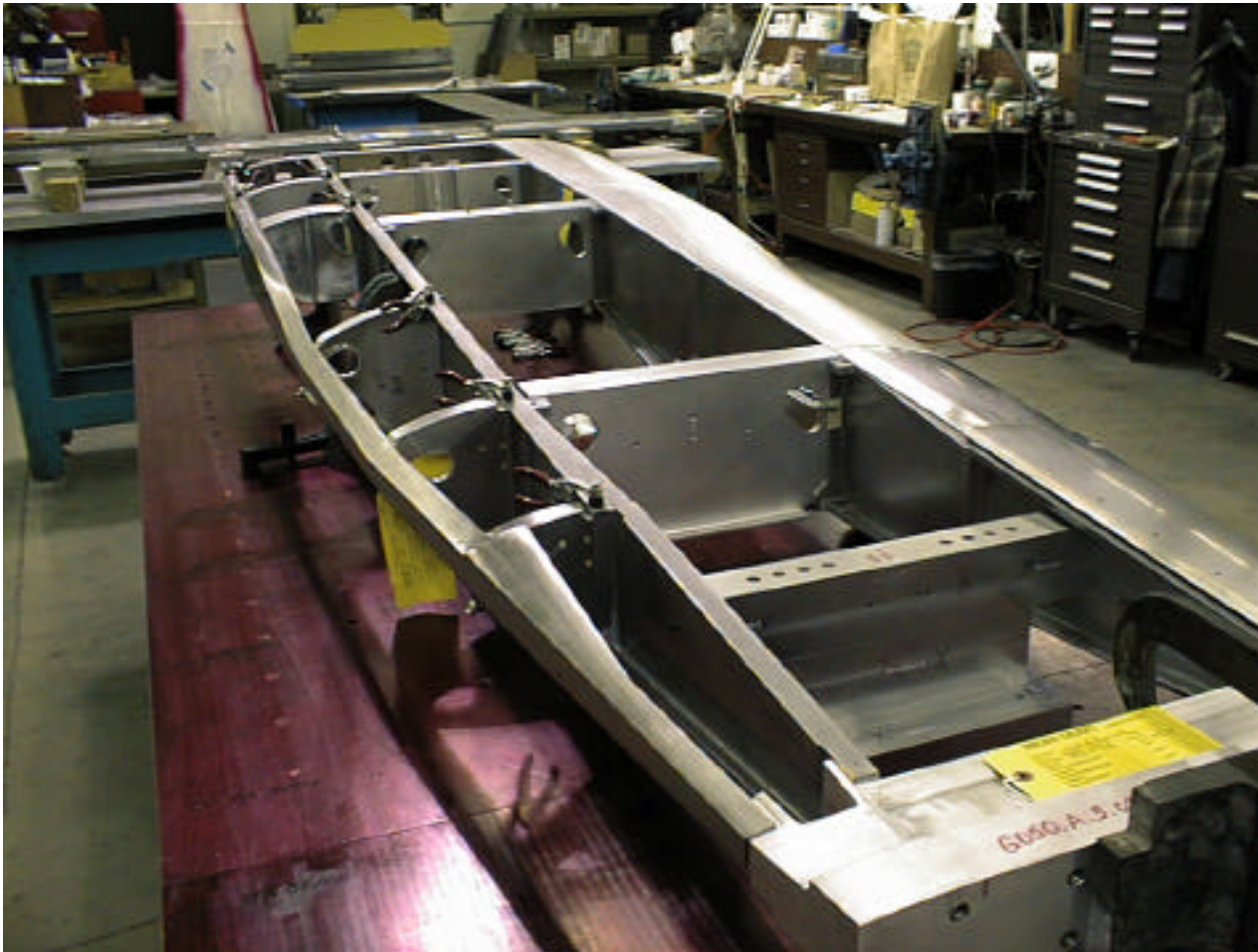


Wing Pylon





X-43A AIRFRAME STRUCTURE

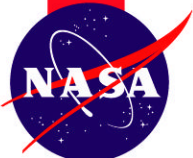
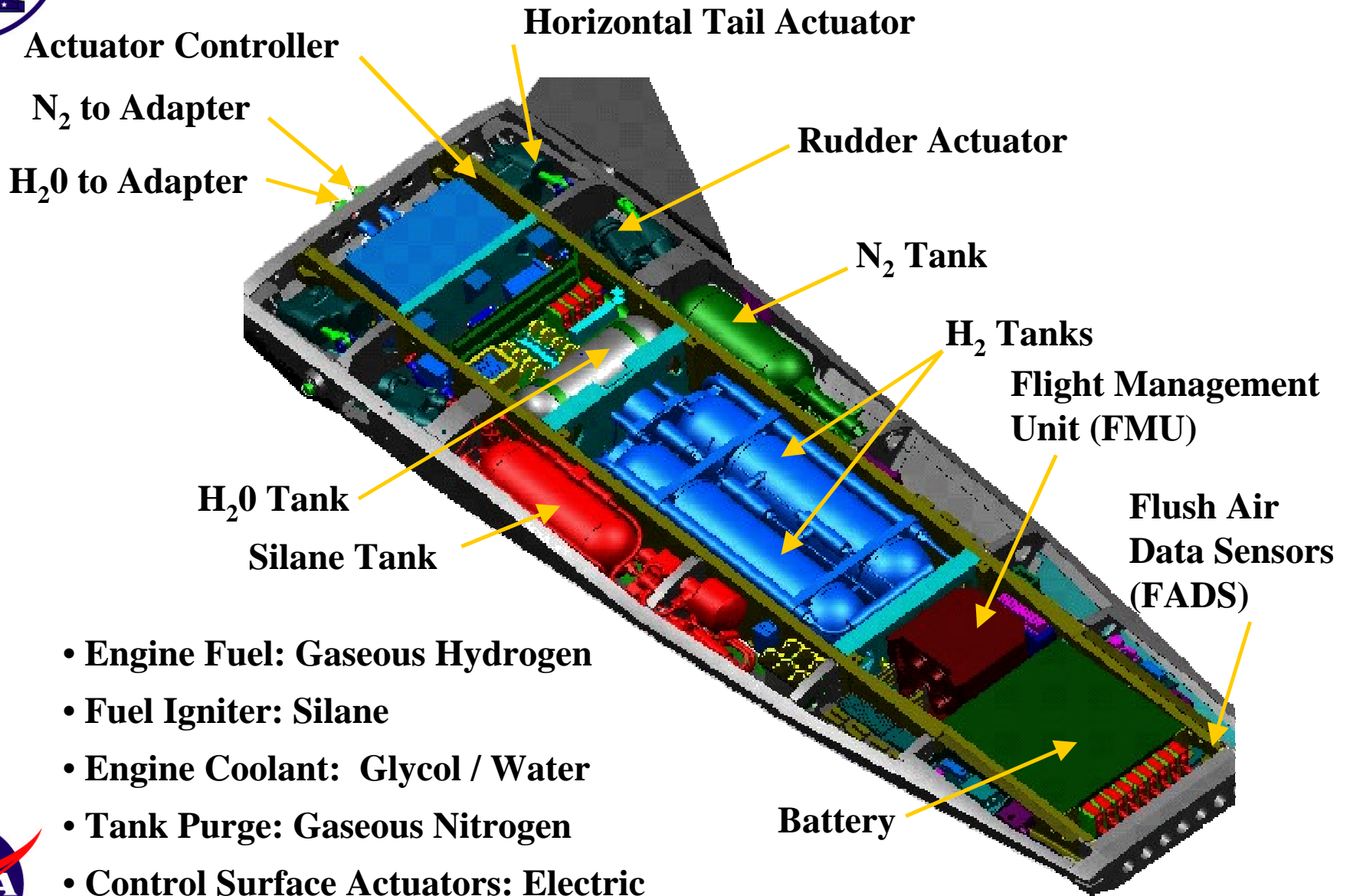


- **Cool Structure**
- **Steel Keel Beams**
- **Aluminum and Titanium Bulkheads**
- **Aluminum and Steel Skins**





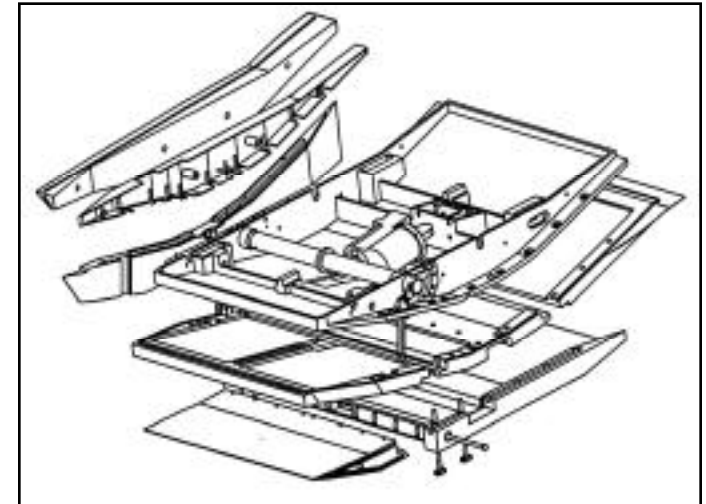
X-43A INTERNAL LAYOUT



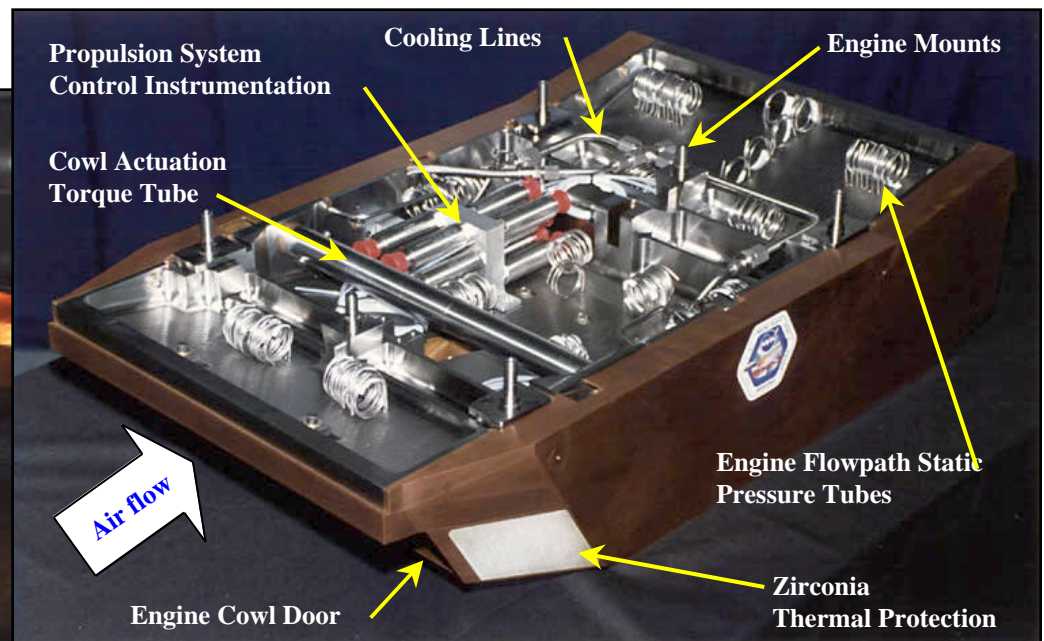


SCRAMJET ENGINE

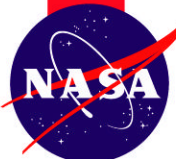
- Engine built by GASL
- Airframe-integrated, Scramjet flowpath
- Gaseous hydrogen fuel; silane ignitor
- Heat-sink copper alloy material (Glidcop)
- Stainless steel strong-back
- Actuated inlet cowl door
- Water-cooled leading edges



Engine in Langley 8-ft HTT







Engine Module

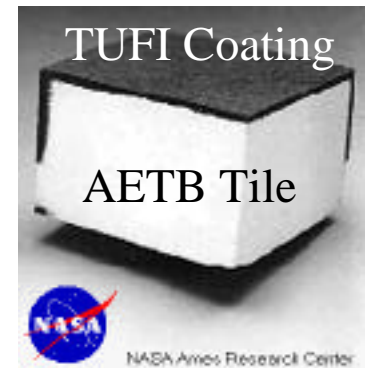
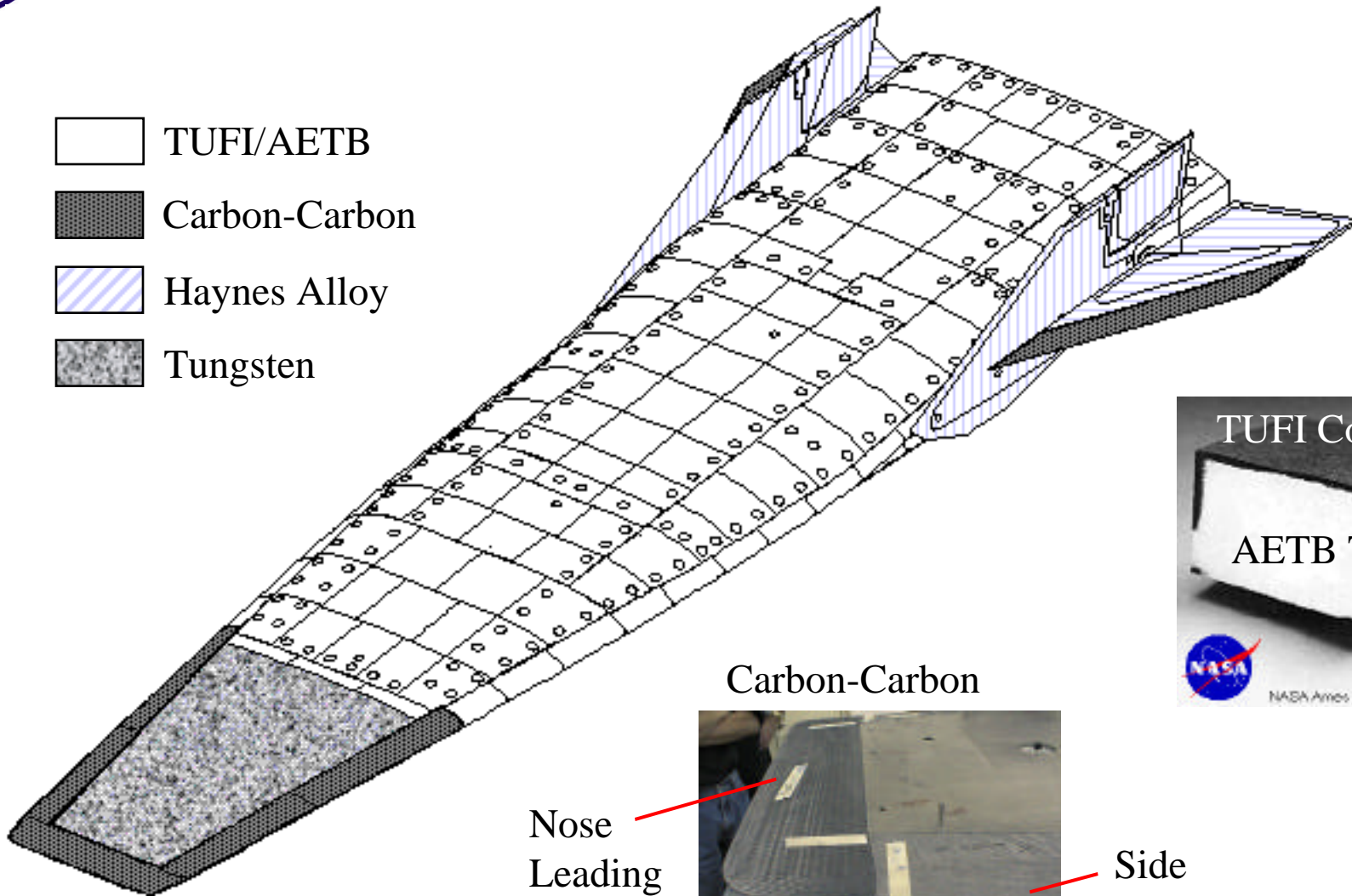




X-43A THERMAL PROTECTION

Mach 7 Vehicles

-  TUF1/AETB
-  Carbon-Carbon
-  Haynes Alloy
-  Tungsten



Carbon-Carbon



Nose
Leading
Edge

Side
Chine



TUF1 = Toughened Uni-piece Fibrous Insulation
AETB = Alumina Enhanced Thermal Barrier



Hyper-X / X-43A (Ship 1) Mated to the HXLV (Feb. '01)



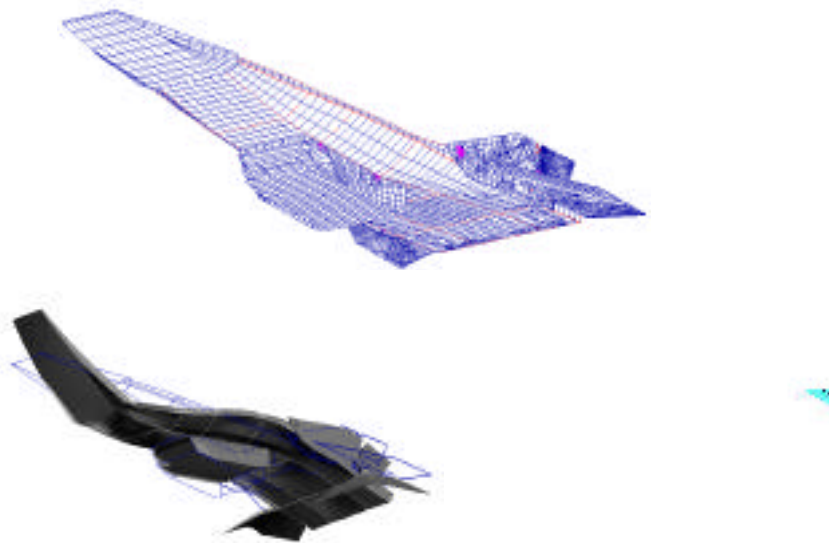


STRUCTURES TESTS & ANALYSES

- Thermal / stress analyses
- Structural dynamic analyses
- Aeroelastic analyses
- Mass & inertia measurements
- Ground vibration tests



Roll Inertia Measurement



Structural Dynamics

Thermal Analyses



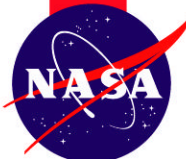
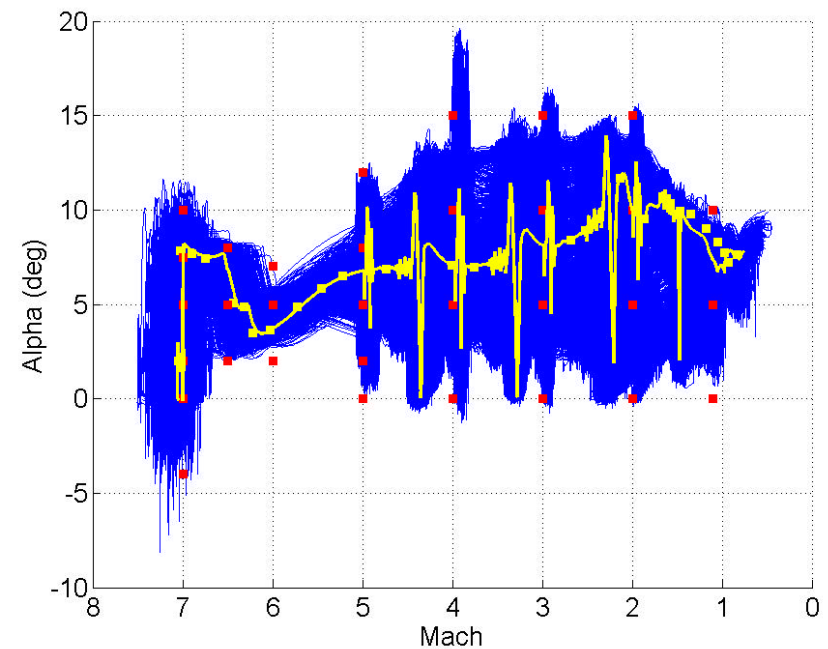
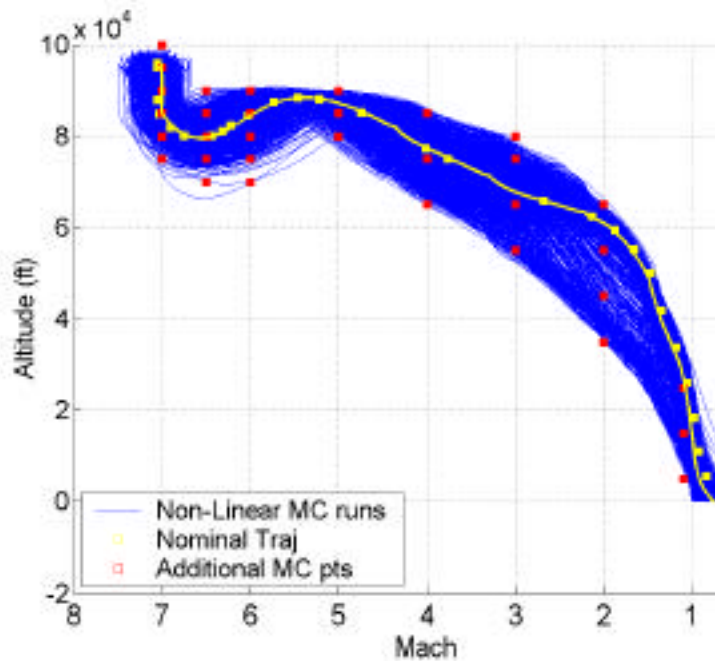
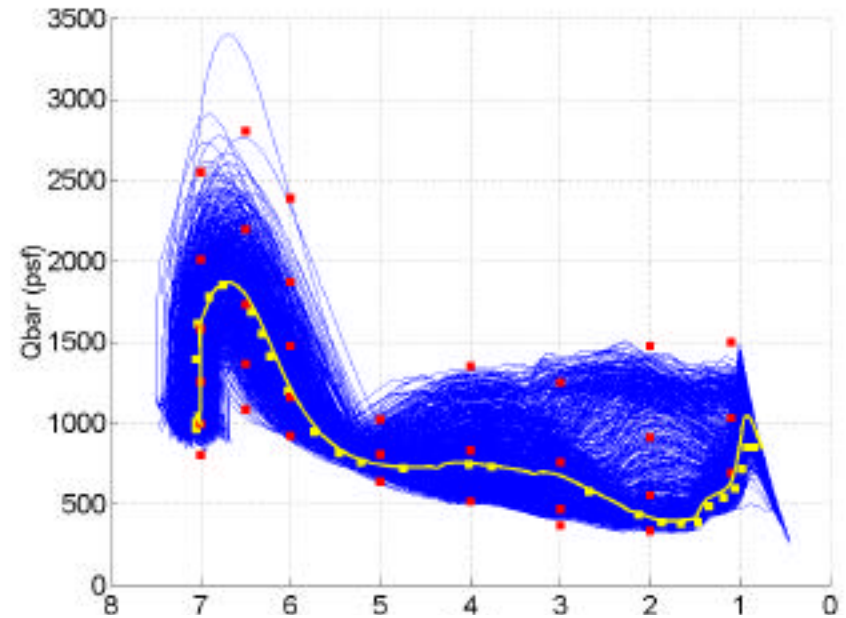
Ground Vibration Test





Flight Controls: Monte-Carlo Analysis Assessments

- Linear Stability Monte-Carlo Analysis
 - Examine changes in stability margins and damping in the presence of model and measurement uncertainties
 - Examine along a nominal trajectory and across nonlinear Monte Carlo dispersions
 - 3dB, 20°

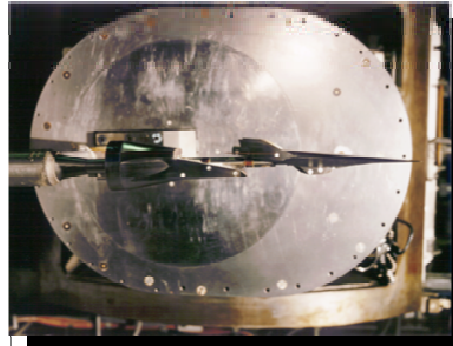
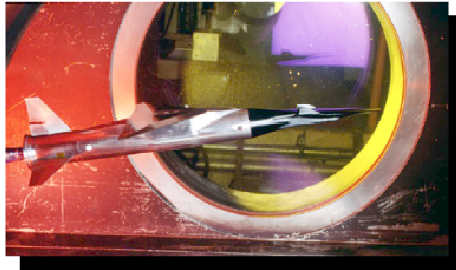




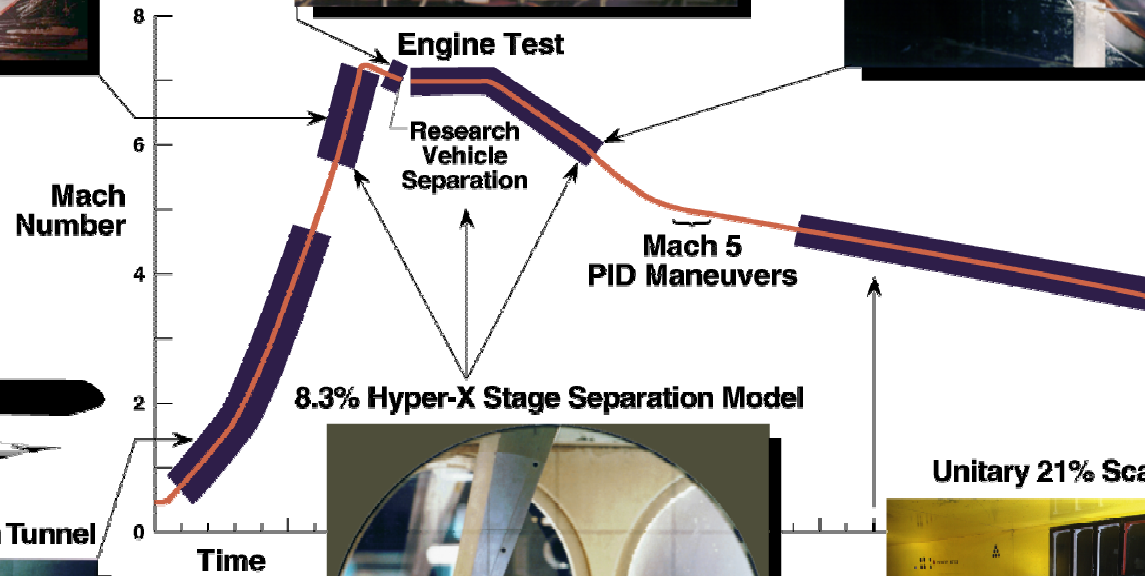
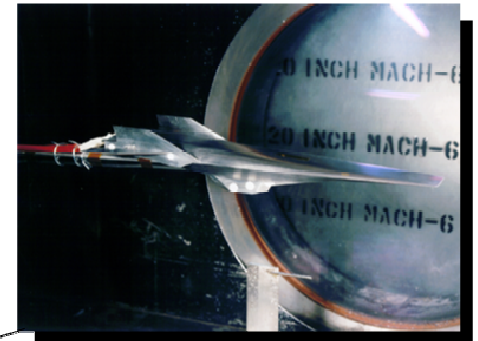
HYPER-X AERODYNAMIC WIND TUNNEL TESTING

8.33% HXRV Stage Separation Model

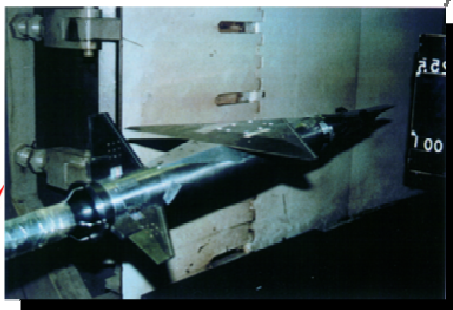
3% HXLV in 20-Inch Mach 6 Tunnel



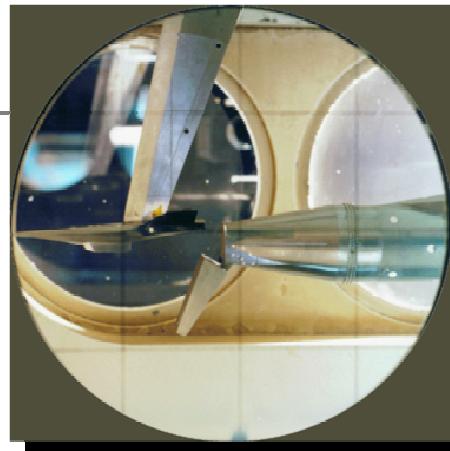
8.33% HXRV, Cowl Closed



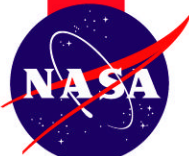
6% HXLV in Lockheed Martin Tunnel



8.3% Hyper-X Stage Separation Model



Unitary 21% Scale Model





Hyper-X Research Vehicle Aerodynamics and Propulsion Design Tools

AIRFRAME AERODYNAMICS

APAS/SHABP - Preliminary aerodynamic design and sizing tools

GASP,
OVERFLOW,
USM3D

- Euler/thin layer
Navier-Stokes CFD:
External airframe, inlet,
nozzle afterbody analyses

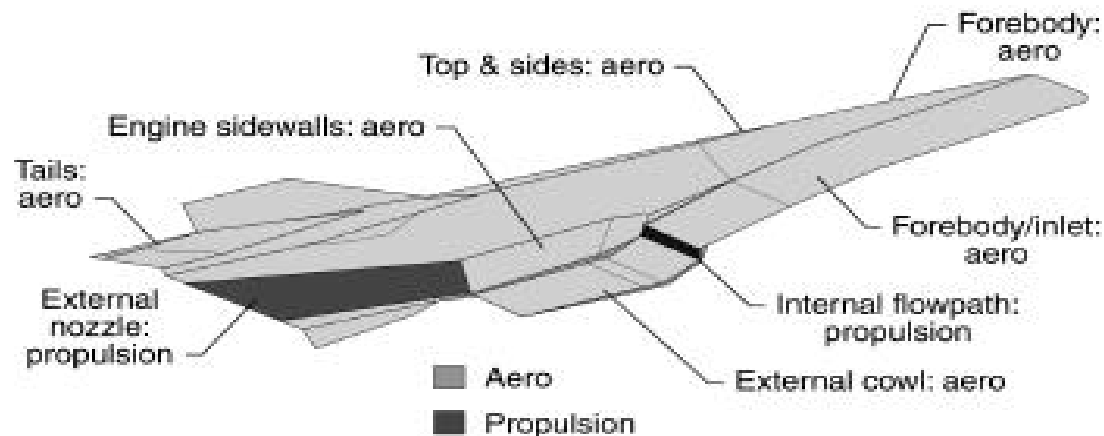
PROPULSION FLOWPATH

SRGULL - 1D/2D flowpath cycle analysis

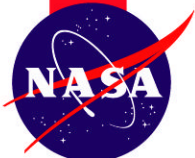
SHIP - 2D/3D H₂/air mixing/combustion

SCRAM3L - Chemical kinetics

GASP - 2D/3D Forebody/Inlet/Nozzle

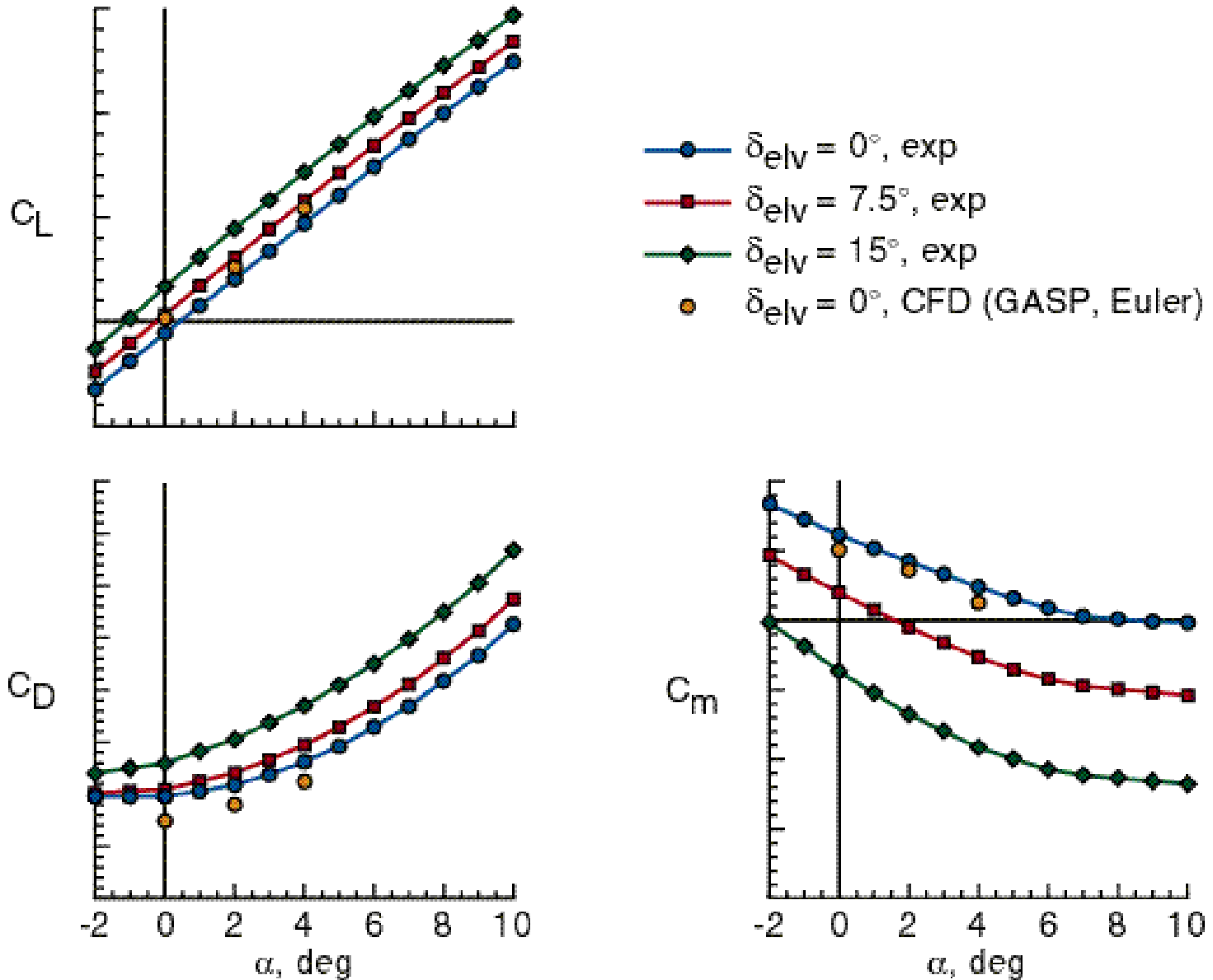


- Supplemented with and validated by extensive aerodynamic wind tunnel and propulsion facility experimental data
- Well defined airframe/propulsion flowpath lines for force accounting



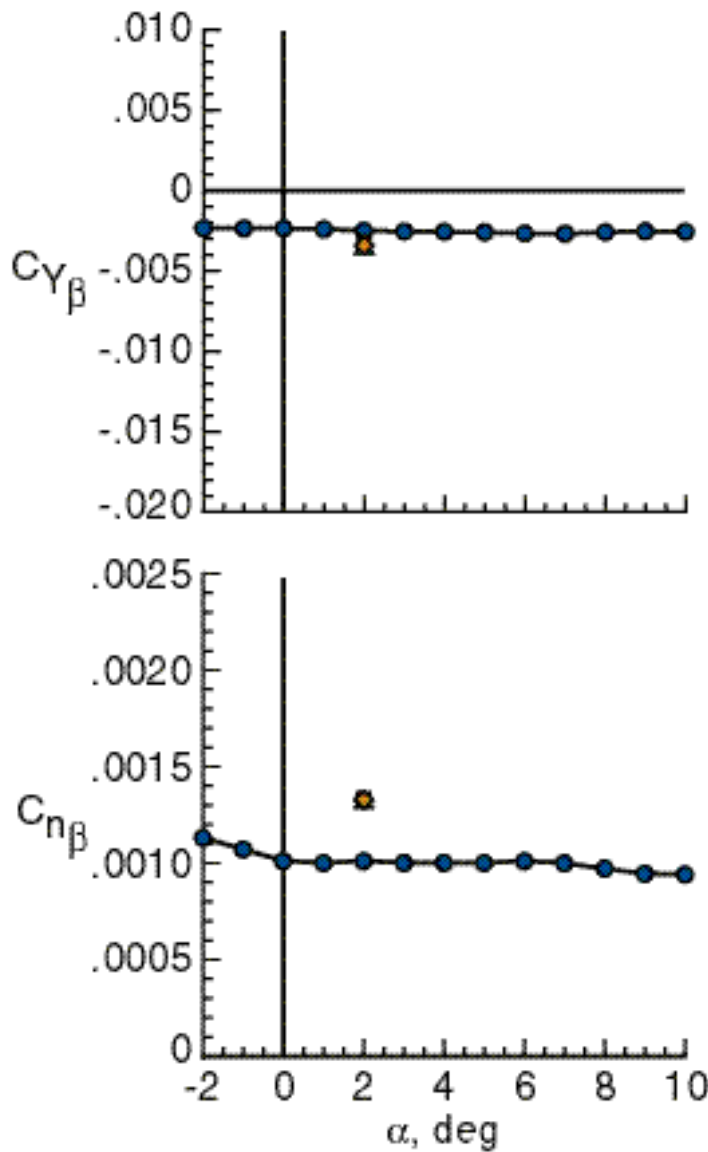


HXRV Mach 6 Basic Longitudinal Aerodynamic Characteristics (Wind Tunnel and CFD Results)

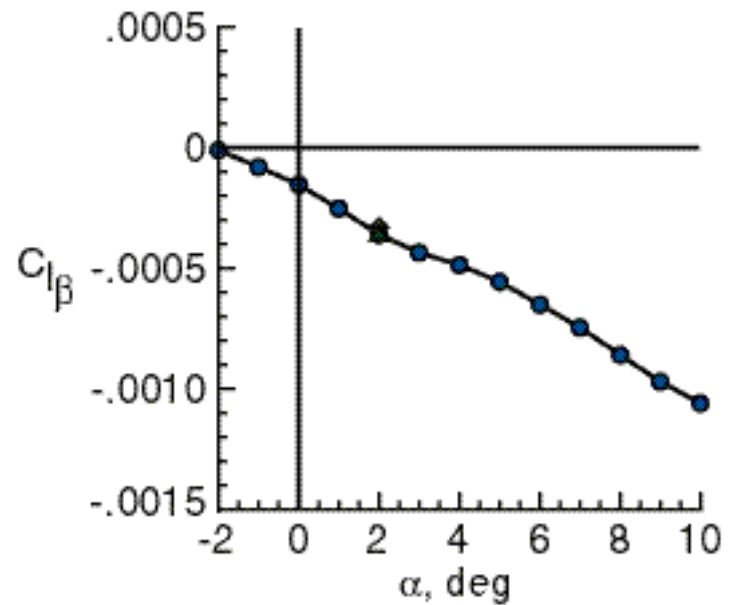




Comparison of the HXR/V Inlet Closed and Inlet Open, Unpowered and Powered Basic Lateral-Directional Characteristics (Wind Tunnel and CFD)



- Inlet closed, exp.
- Inlet closed, CFD (GASP, Euler)
- ▲ Inlet open, power off, CFD (GASP, Euler)
- ◆ Inlet open, power on, CFD (GASP, Euler)



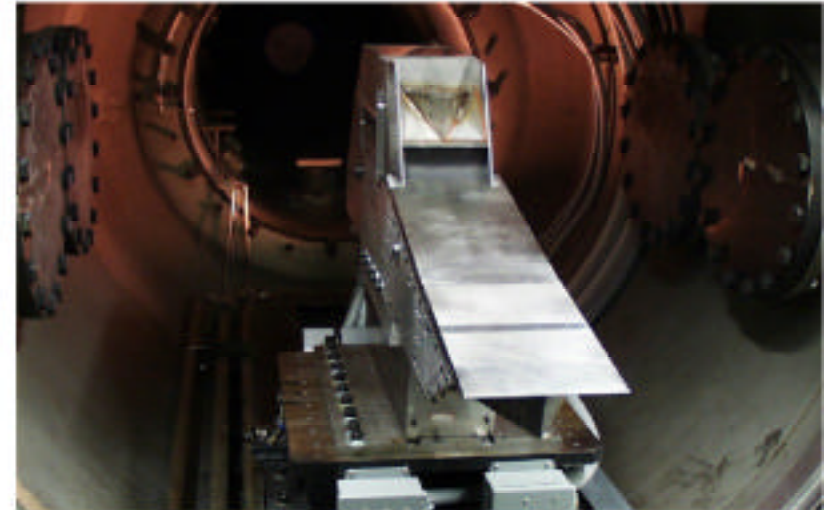


Hyper-X Propulsion Testing and Analysis

AHSTF



HYPULSE



8'HTT

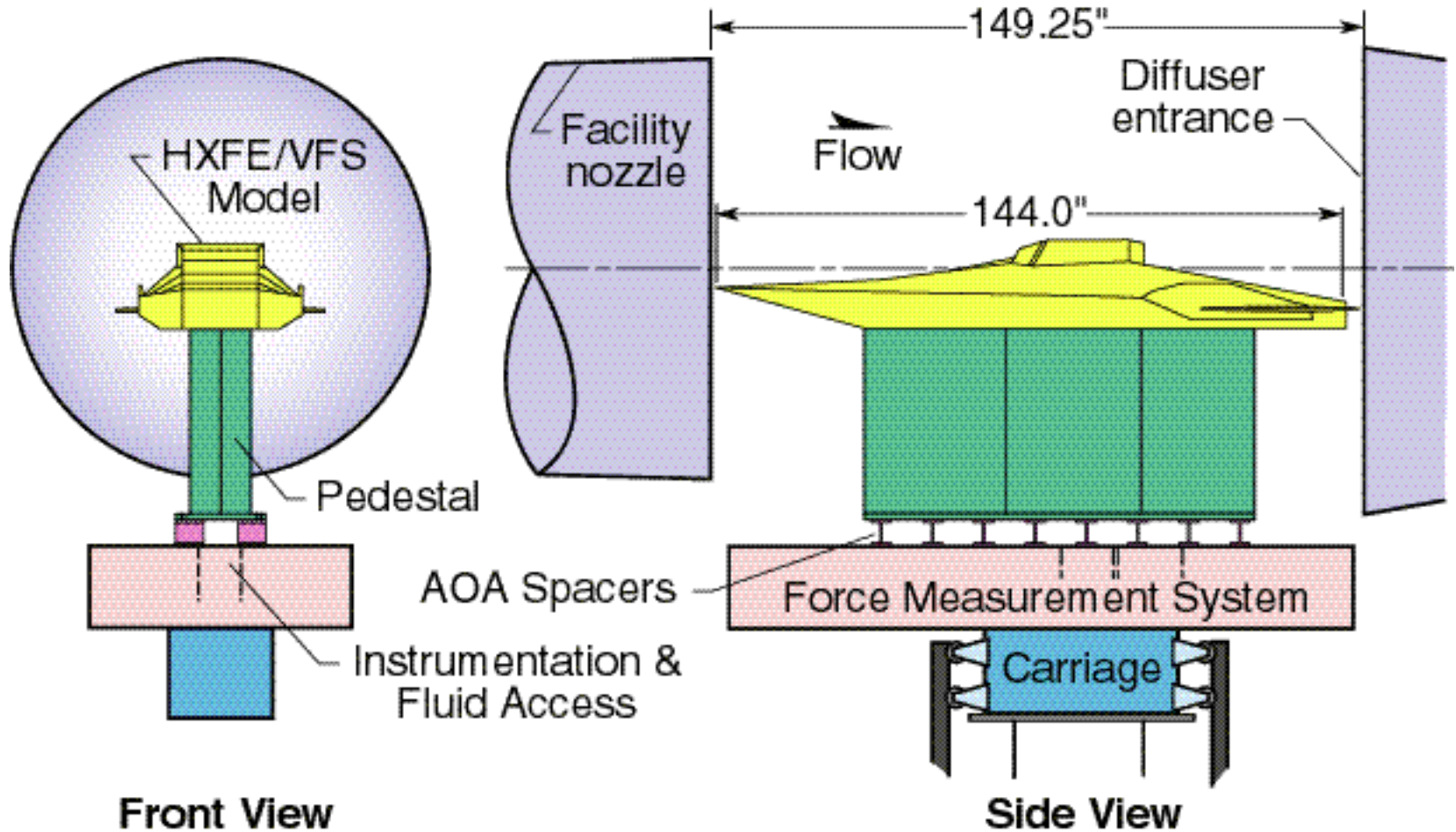


- **Verify engine performance**
- **Determine engine operability**
- **Verify design methods**
- **Provide database for flight comparison**
- **Verify facility contamination effects (same lines all facilities)**
 - **Facility vs. facility**
 - **Facility vs. design methods**
 - **Facility vs. flight**
- **Develop validate pulse tunnel testing**



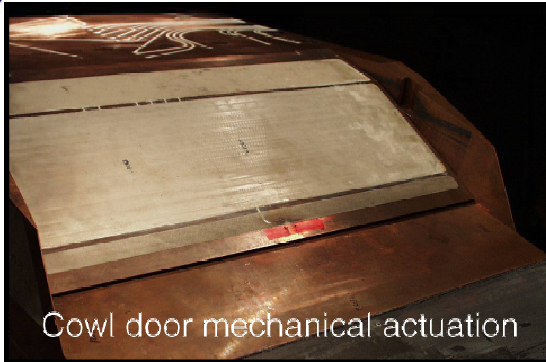


Hyper-X Flight Engine/Vehicle Flowpath Simulator Installed in the LaRC 8-ft HTT





HYPER-X / X-43 PROPULSION VALIDATION TESTS IN THE NASA LANGLEY 8ft HTT

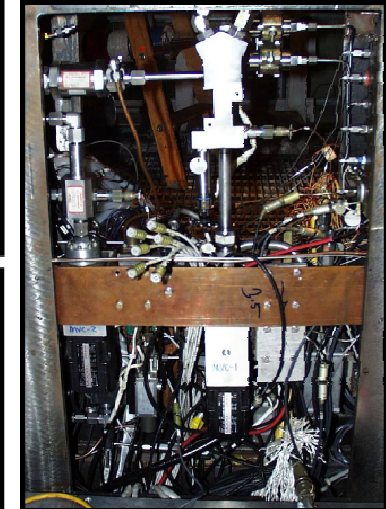


Cowl door mechanical actuation

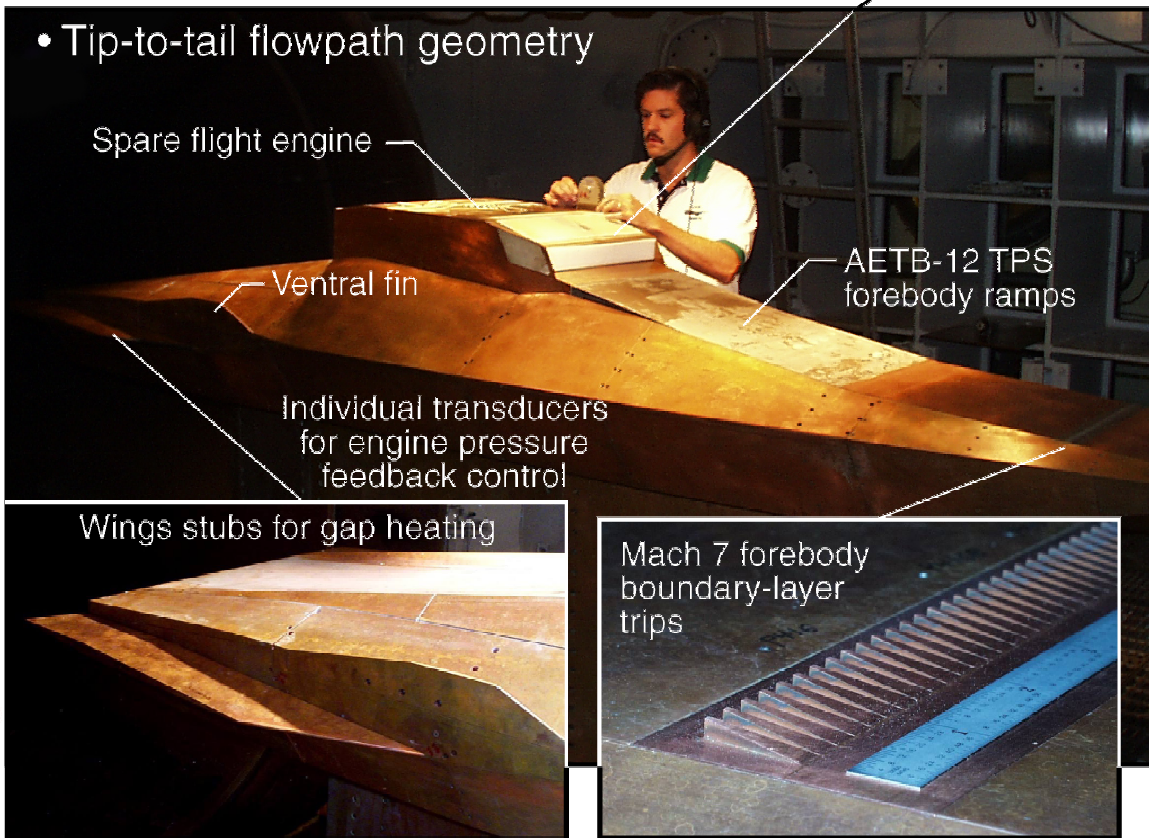


Cowl/sidewall leading-edge
water cooling

Ignitor/fuel motorized control
valves, venturi flow meters,
and mixing manifold



Propulsion subsystem control
computer and customized software

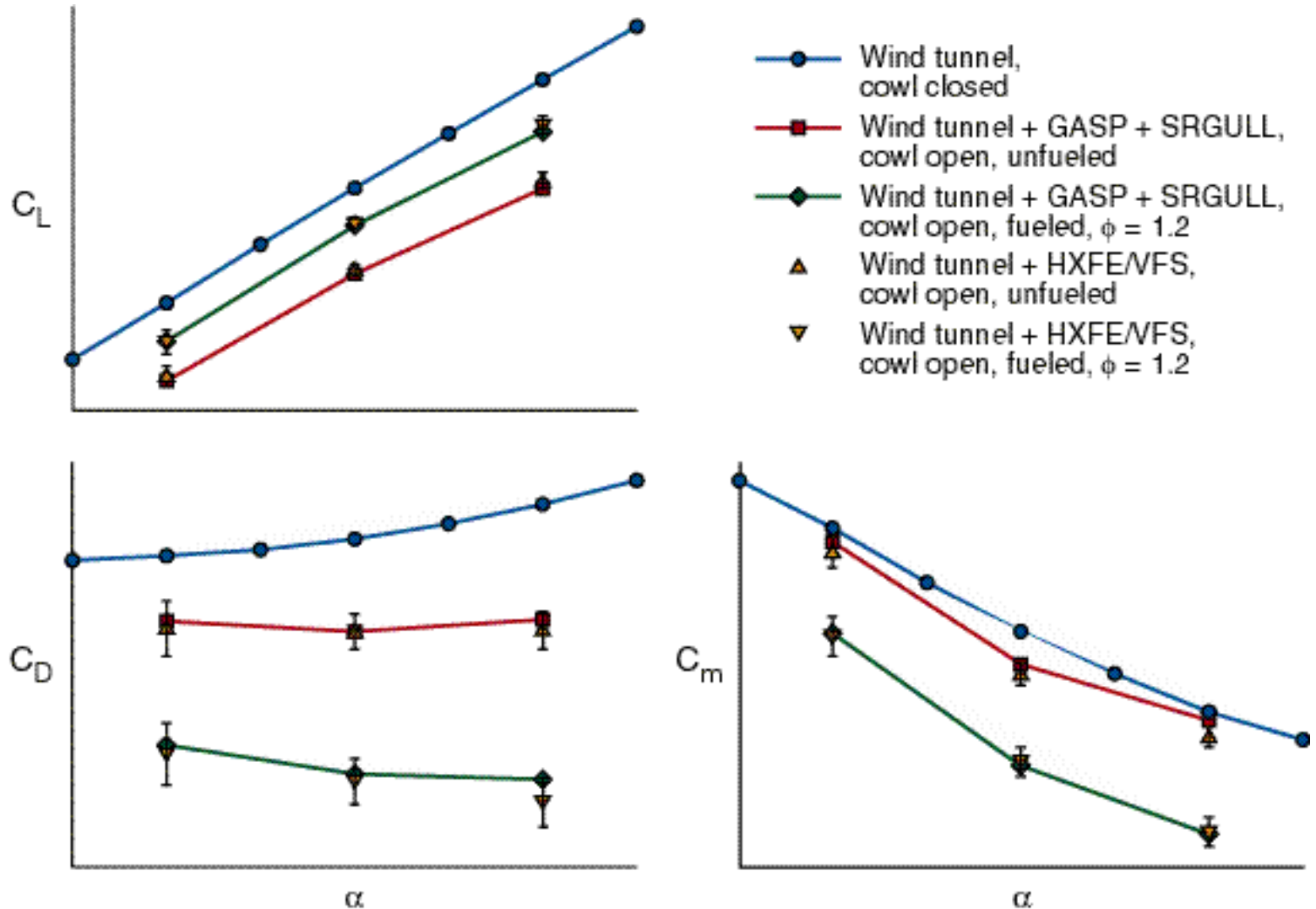


I/X-43 FLGHT SYSTMSIMcClinton





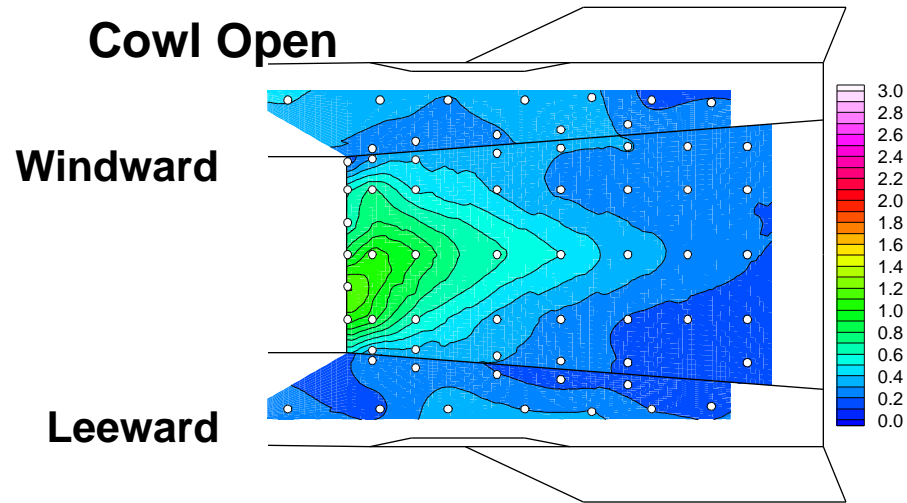
X-43A Longitudinal Forces and Moments: Inlet Open Unpowered and Powered Modes (Including Validation Results From the 8-FT HTT Tests)





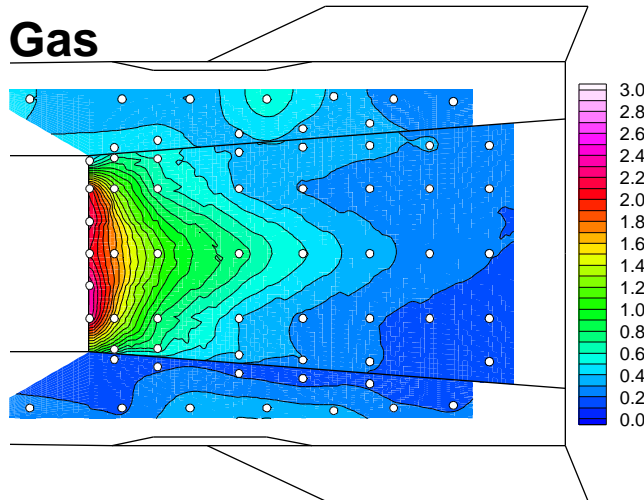
Aftbody Pressure Contours (psia)

$M_\infty = 6.92$, $q_\infty = 1000$ psf, $\alpha = 2^\circ$, $\beta = -3^\circ$



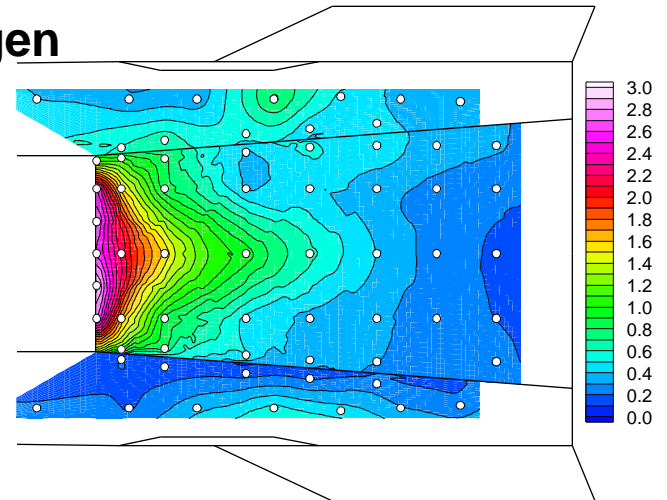
Ignitor Gas

$\phi = 0.25$



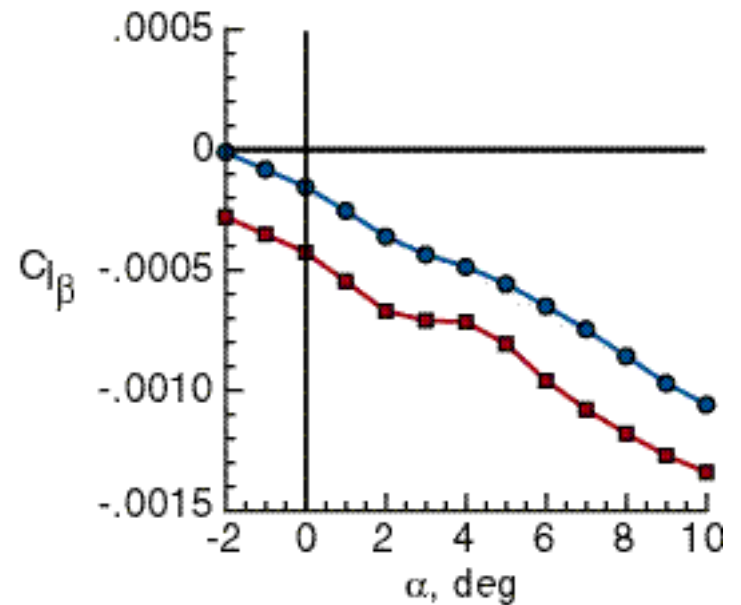
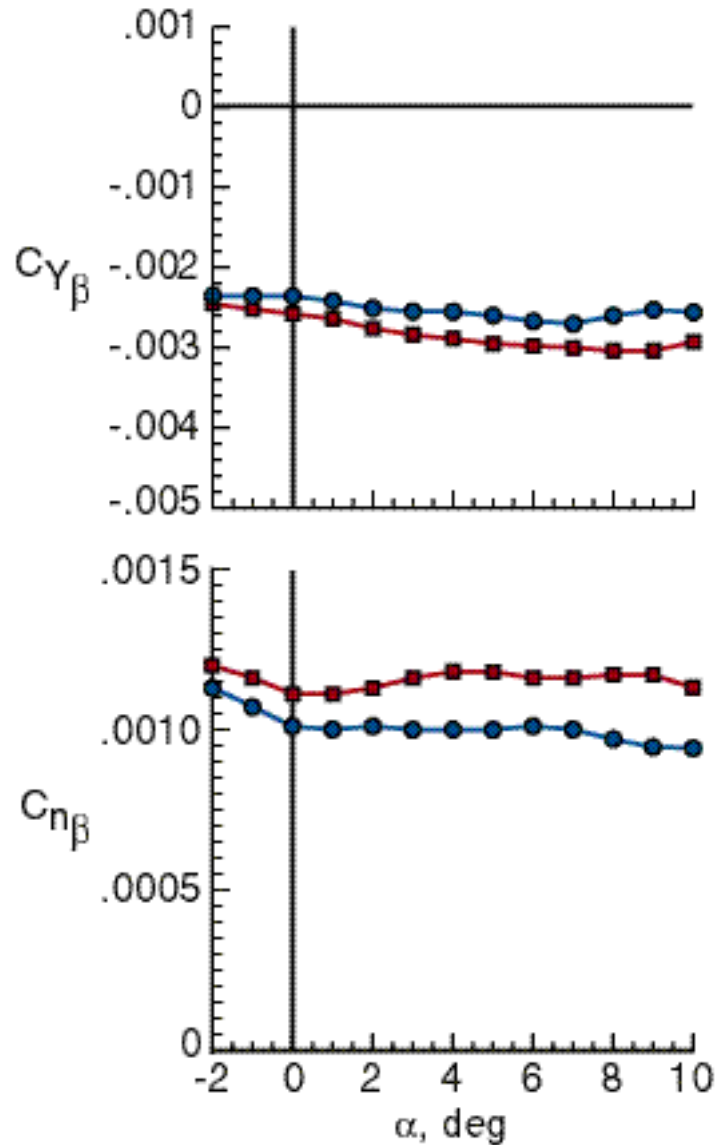
Hydrogen

$\phi = 1.20$





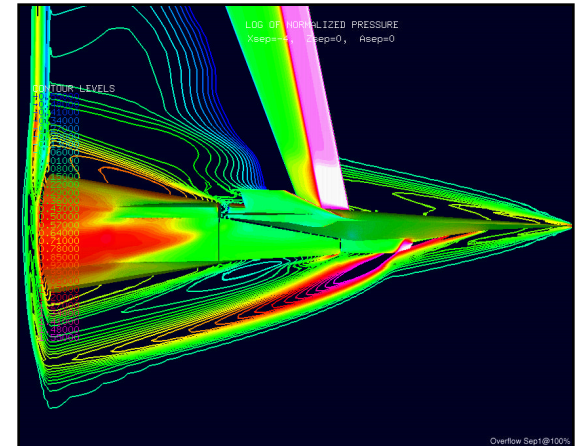
Effects of Elevator Position on the HXR/V Basic Lateral-Directional Characteristics





STAGE SEPARATION

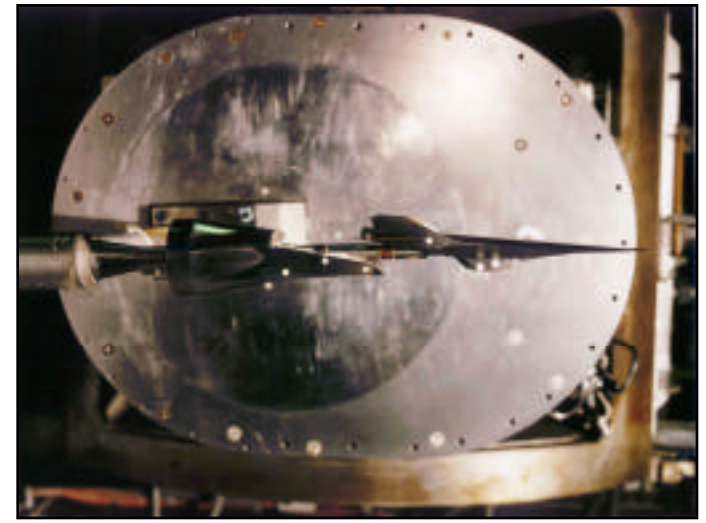
- Greatest challenge, highest risk event
- Wind-tunnel tests and CFD analyses
- 14 degree-of-freedom simulation, animation and Monte Carlo analyses [O(10^5 MC runs)]
- Full-scale hardware tests



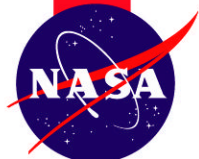
Pressure contours using OVERFLOW



Full-scale separation hardware test



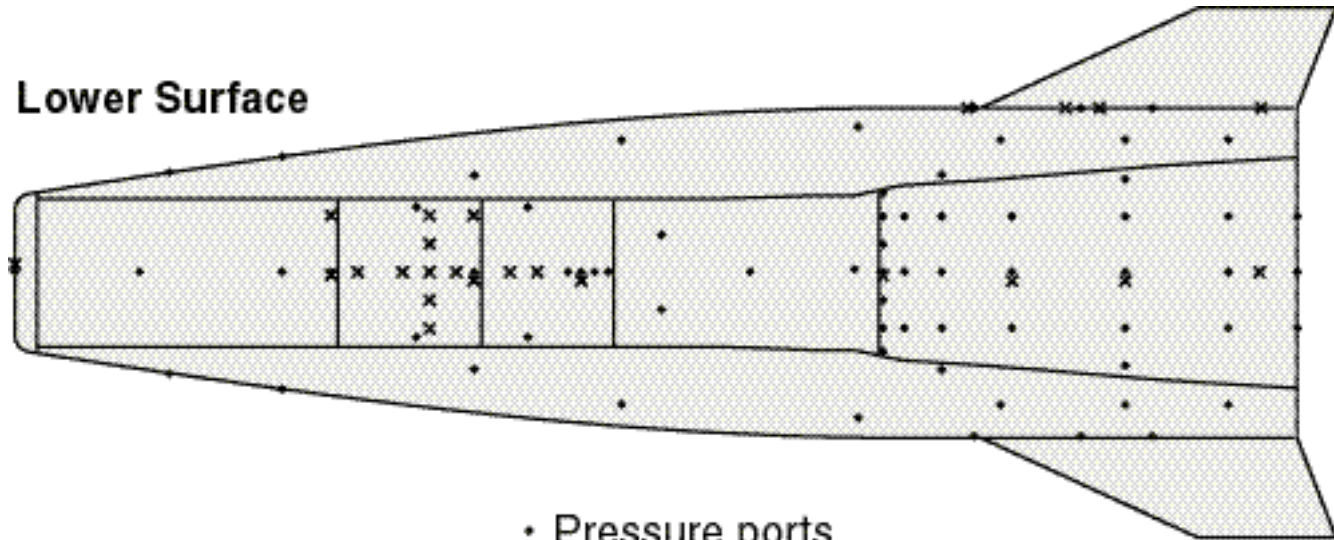
Langley aerodynamic tests at Mach 6
& 10





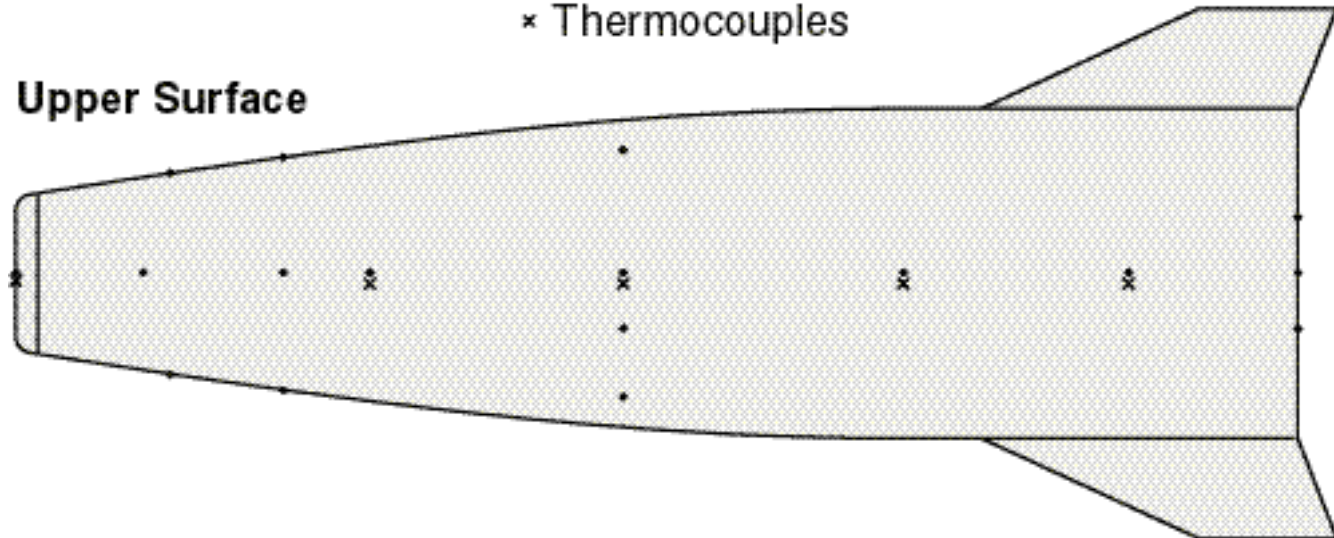
PRESSURE TRANSDUCER AND THERMOCOUPLE LAYOUT ON THE X-43A AIRFRAME NO. 1

Lower Surface



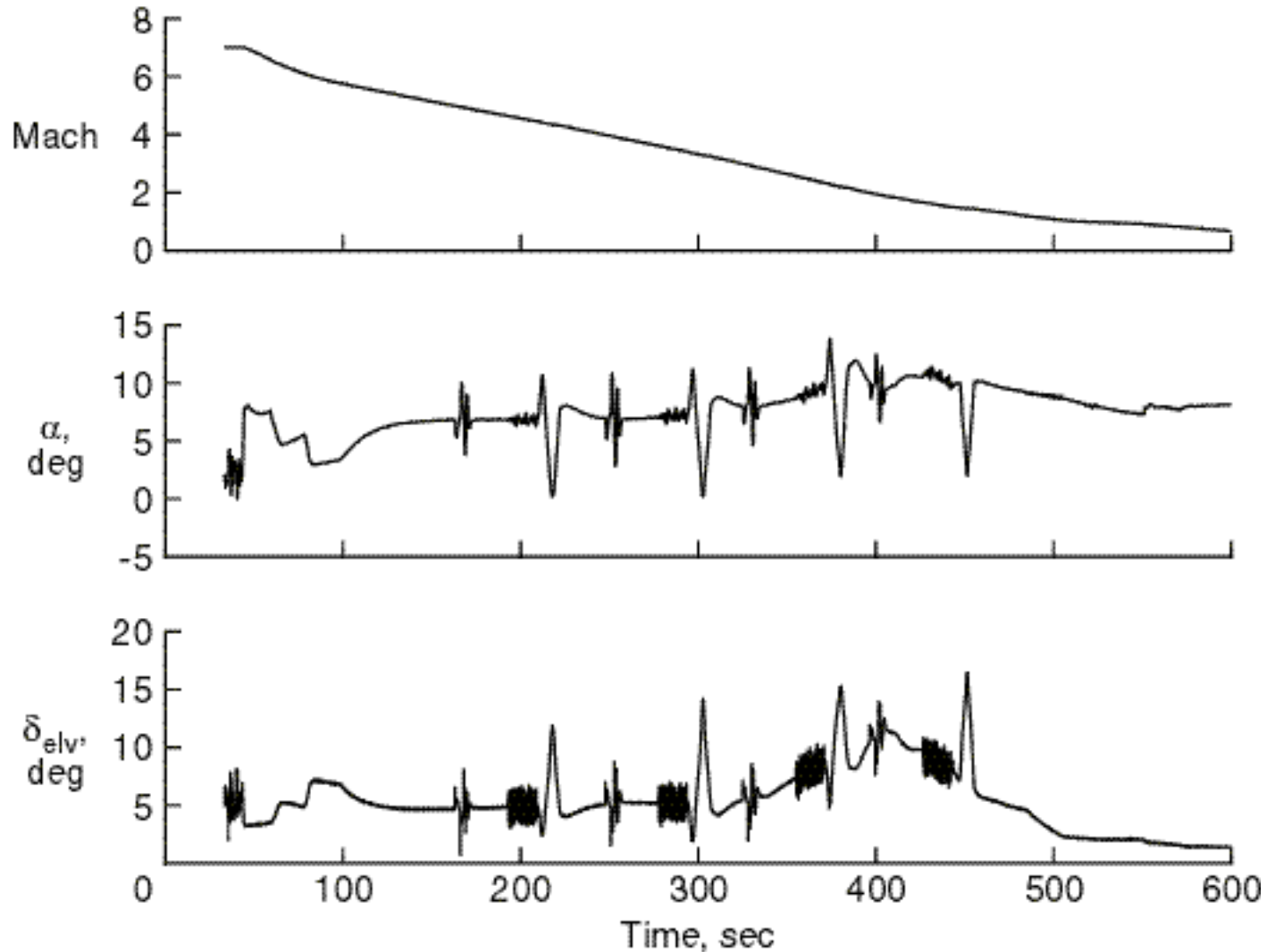
- Pressure ports
- × Thermocouples

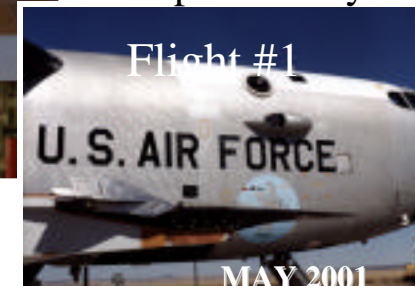
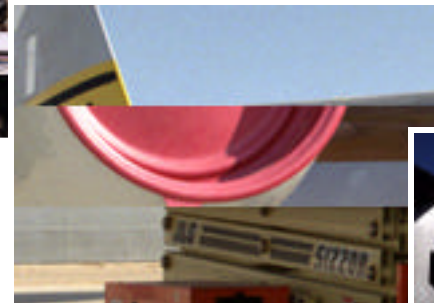
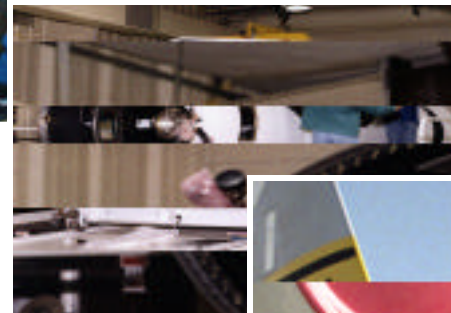
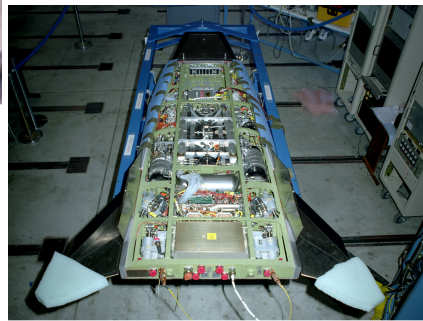
Upper Surface





Post Test Descent Trajectory: Angle-of-Attack and Control Surface Deflection Profiles w/ PID and PO-PU Maneuvers





- ✓ Ground Vibration, Mode Interaction, Initial Mass Properties Testing
- ✓ Final Weight/Balance and Mass Properties Test
 - ✓ VMS Hardware-In-Loop and Aircraft-In-Loop Tests
 - ✓ RF Systems Tests
 - ✓ Fuel Systems — High Pressure Bench Test
 - ✓ Environmental Systems Test
 - ✓ Installed Leak and Functional Test
 - ✓ Full Mission Simulation With Inert
 - ✓ Full Mission Simulation With Real Gas Test

- ✓ HXRV/Adapter Systems Validation
- ✓ HXRV/Adapter Integration Tests

- ✓ Standalone HXLV Tests
- ✓ HXLV/HXRV Integration

- ✓ Stack Hook Release
- ✓ B-52 Systems Test
- ✓ B-52/Stack Integration
- ✓ Combined System Test
- ➔ Captive Carry

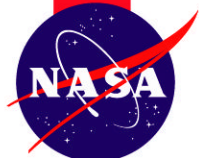
**TEST, TEST,
TEST
...Preparing
for Flight at
DFRC**





CAPTIVE CARRY TEST

Completed at DFRC April 28, 2001

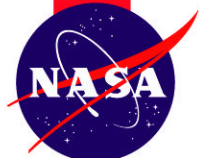


NEXT STEP ---> FLIGHT TEST (~3 weeks)!



Summary

- **Renewed resurgence in hypersonics and scramjet propulsion**
- **Hyper-X Program has made significant strides in the advancement of the state-of-the-art in hypersonic airbreathing propulsion and associated technologies**
- **Tremendous knowledge base developed through ground test and CFD analysis on scramjet engine/airframe interaction and the resulting aerodynamic characteristics**
- **X-43A flight test will provide the first opportunity to flight test an airframe integrated scramjet propulsion system**
- **Enthusiastic, NASA and industry team making final preparations for X-43A first flight (STAY TUNED!!!)**





Hypersonic Propulsion Approach (National Hypersonics Plan - NASA, USAF, Navy DARPA)

- Complete demonstration of scramjet technology for operation over the Mach 3-7 (hydrocarbon) by 2010 and and 3-15 (hydrogen) speed range by 2015
 - Technologies also supportive of USAF, Navy and USA Weapons Systems Needs



- Leverage investment in IHPTET/VAATE, UEET, IHPRPT, and other base technology to integrate turbine and rocket engines with scramjet engines and air vehicles



- Enable efficient hypersonic systems operating over the full Mach number range for both SSTO and TSTO space access and for aircraft systems

