Hyper-X/ X-43A: Dryden's Role

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X-43A Flight 3 Chief Engineer
NASA Dryden Flight Research Center

Lockheed Martin Interchange
August 14, 2012

X-43A (Hyper-X) Project Overview

Project Start	Flt 1	Flt 2	Flt 3	Proj. End
1995	6/2001	3/2004	11/2004	12/2004

- First ever flight demonstration of an airframe-integrated scramjet powered hypersonic vehicle
- Primary objective was to validate the tools, test and analysis techniques, & design methods of scramjet powered, hypersonic vehicles
- Three flight project
  - Two flights at Mach 7
  - One flight at Mach 10

Hyper-X Research Vehicle (HXRV)

Research Vehicle Adapter

Hyper-X Launch Vehicle (HXLV)

Hyper-X Research Vehicle (HXRV): ATK-GASL
- Hydrogen fueled scramjet engine
- Scaled version of a Mach 10 "cruise" configuration

Hyper-X Launch Vehicle (HXLV) - OSC
- Air launched from NASA's B-52
- Boosts HXRV to test condition
- Modified 1st Stage Pegasus booster

Hyper-X Program Model

LaRC

Program Management

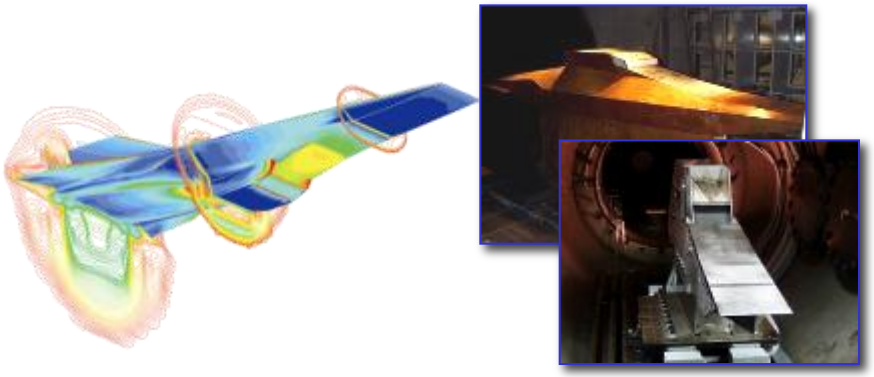
Shared Mission Success

LaRC

Technology Development and Validation

DFRC

Flight Research and Test



- **Research and Technology Objectives**
- **Analytical and experimental performance verification (CFD, Wind Tunnel)**
- **Flight Validation of Design Predictions**
- **Improve Scramjet Design Tools**

- **Flight Research and Operations**
- **Vehicle Build, Integration and Validation**
- **Ground, Flight and Range Safety**
- **Flight Performance Assessment**
- **Responsiveness to Technology Objectives**

The Hyper-X Partnership

Drawing on Expertise from Coast-to-Coast

NASA Dryden Flight Research Center
Edwards, CA

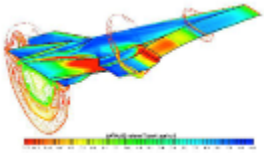
Research/Flight Operations
Airworthiness, Flight Safety, Range Safety

ATK - GASL
Ronkonkoma, NY

Engine & Fuel Systems

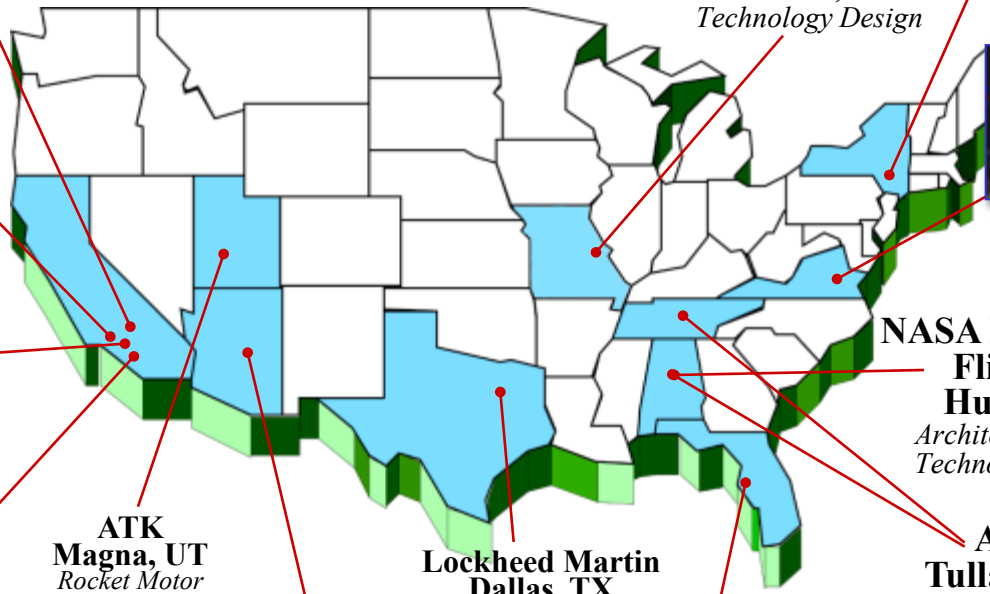
Boeing
St Louis, MO
Technology Design

NASA Langley Research Center
Hampton, VA



Technology Design and Experimental Test

Air Force Flight Test Center, Vandenberg AFB
Naval Air Warfare Center, Pt. Mugu
Pacific Sea Range



MicroCraft
Ontario, CA

Airframe Assembly

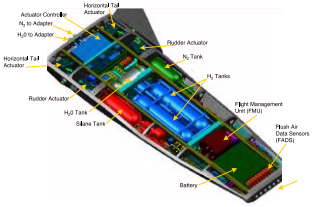
NASA Marshall Space Flight Center
Huntsville, AL
Architecture Studies and Technology Assessments

ATK
Magna, UT
Rocket Motor

Lockheed Martin
Dallas, TX
Wind Tunnel Testing

ATK - GASL
Tullahoma, TN and Huntsville, AL

Boeing
Long Beach, CA



Systems/Software Design and Integration

Orbital Sciences Corp.
Chandler, AZ

Launch Vehicle Development

Honeywell
Clearwater, FL
Research Vehicle Flight Computer

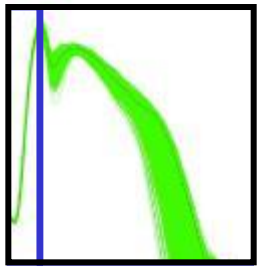
Systems Installation

Research and Launch Vehicle Interface Stage Separation Testing

Highly Integrated Effort Required

Propulsion

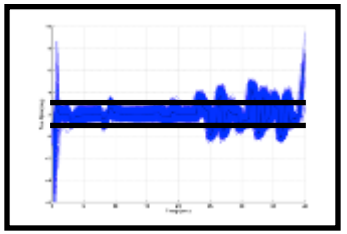
Simulation



Stage Separation

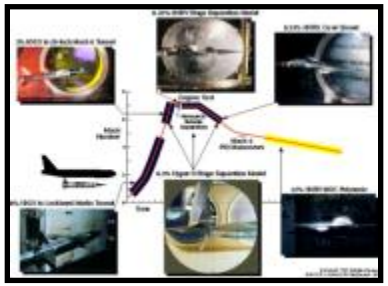
Systems

GNC



Structures

Aerodynamics



Flight Operations

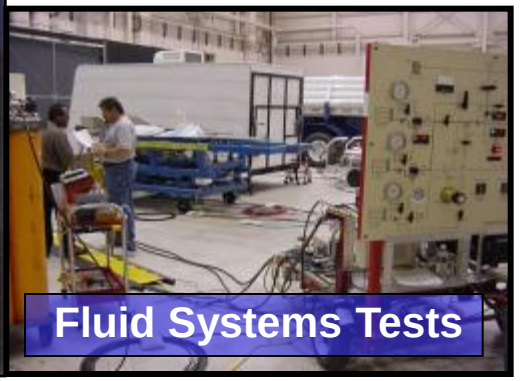
Launch Vehicle

Propulsion

DFRC Role | Partner Role

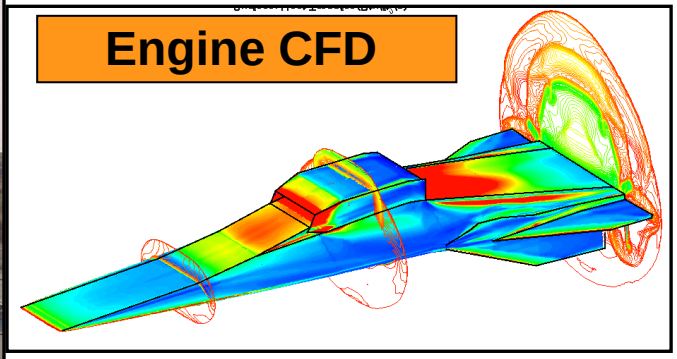
Propulsion Wind Tunnel Tests

Engine Design

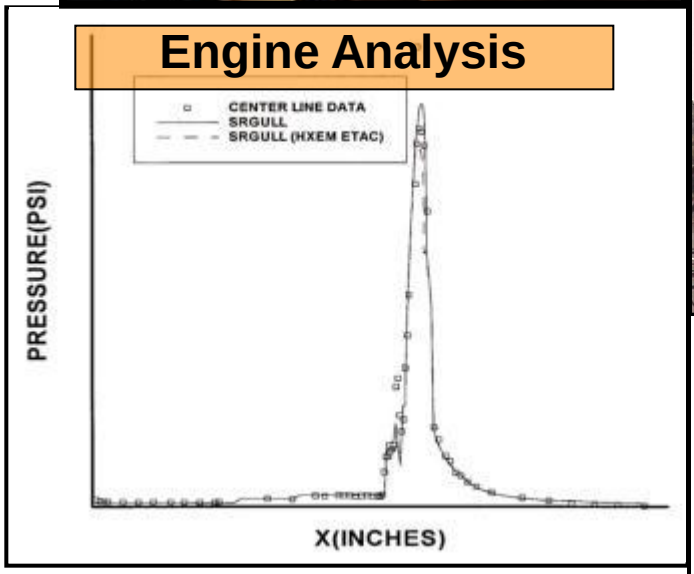


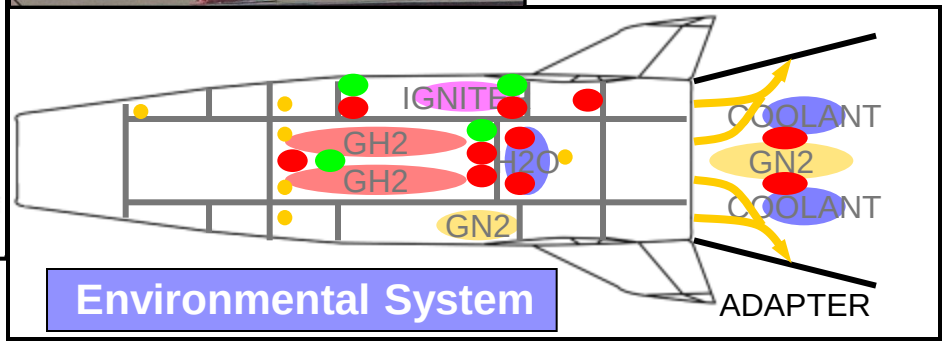
Hazardous Fueling

Engine CFD



Engine Analysis

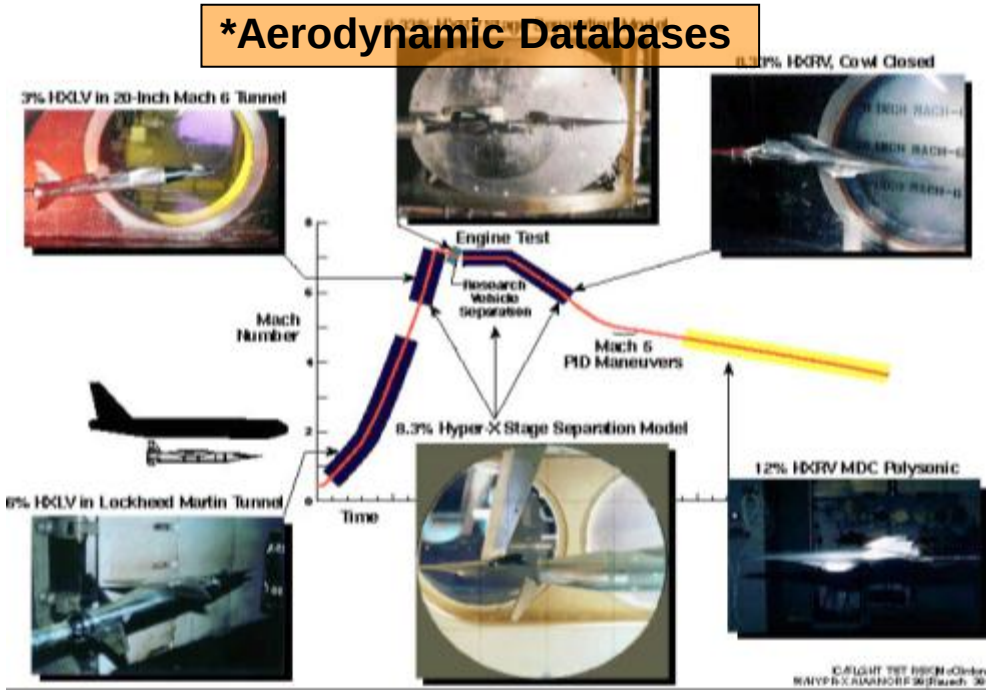


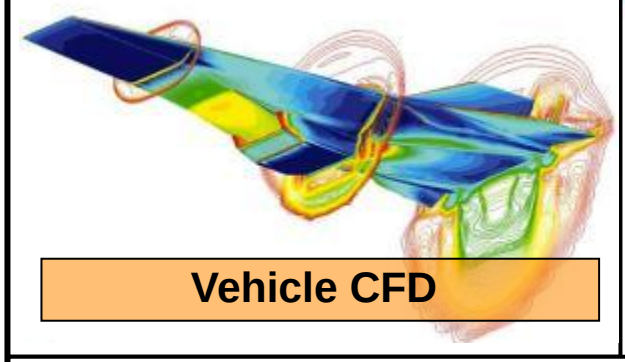


Aerodynamics

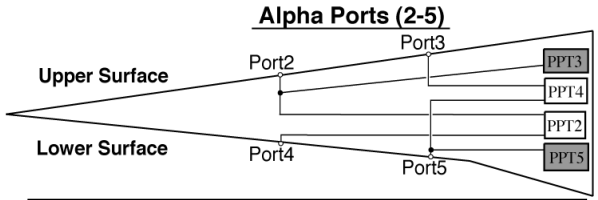
DFRC Role | Partner Role

*Aerodynamic Databases





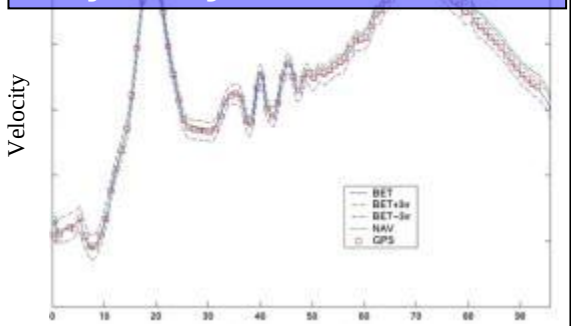
Vehicle CFD



FADS

*Parameter Identification

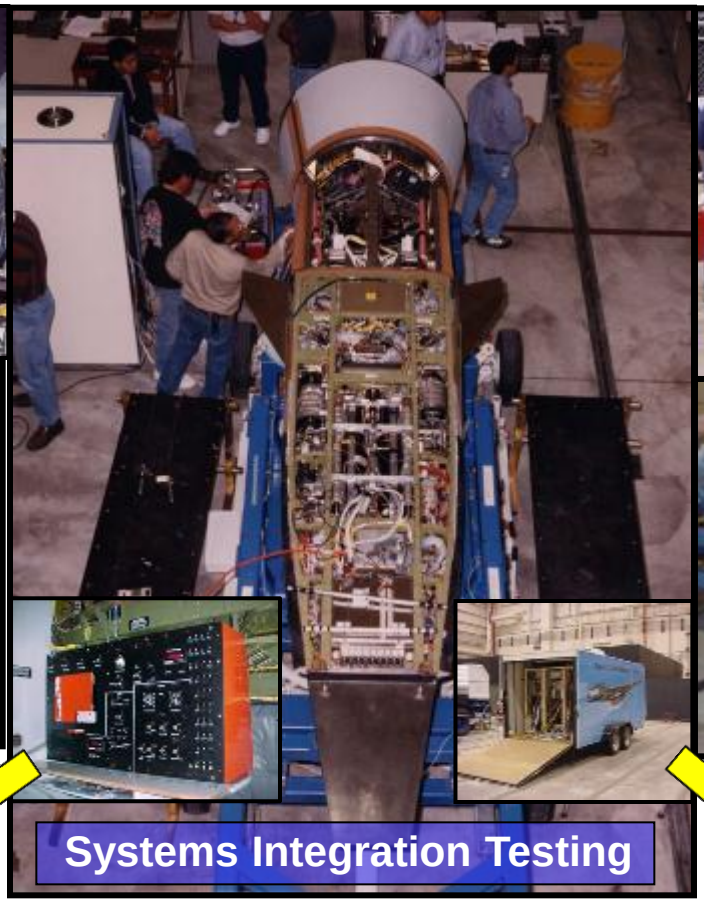
Atmospheric Definition & Trajectory Reconstruction



* DFRC Role:
X-43A Descent

Systems

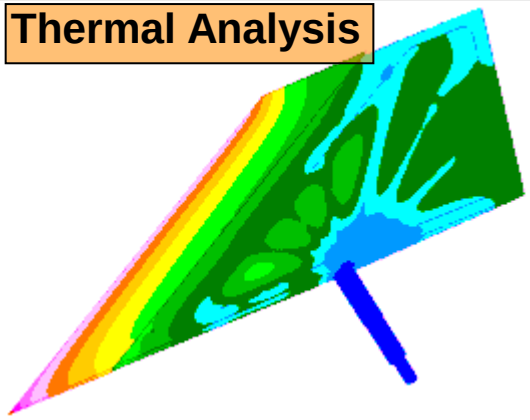
DFRC Role | Partner Role

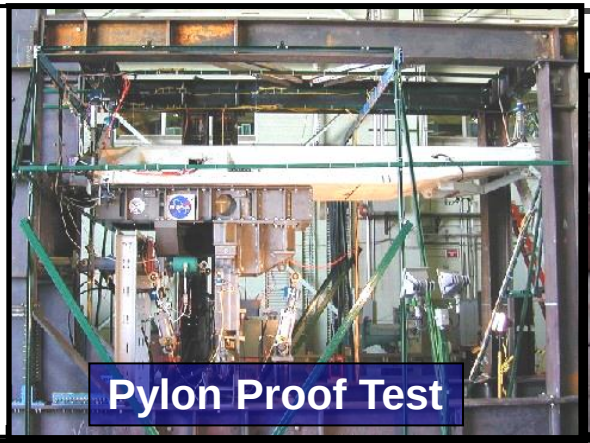


Structures

DFRC Role | Partner Role

Thermal Analysis





Pylon Proof Test

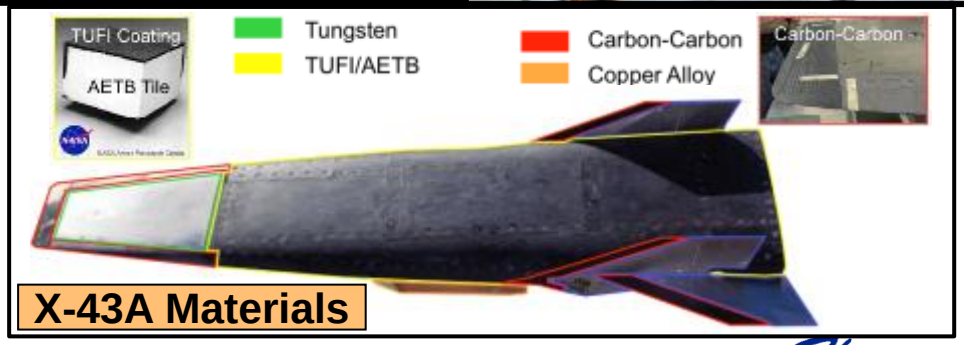
X-43A Mass Properties

Instrumentation Install

Ground Vibration Test

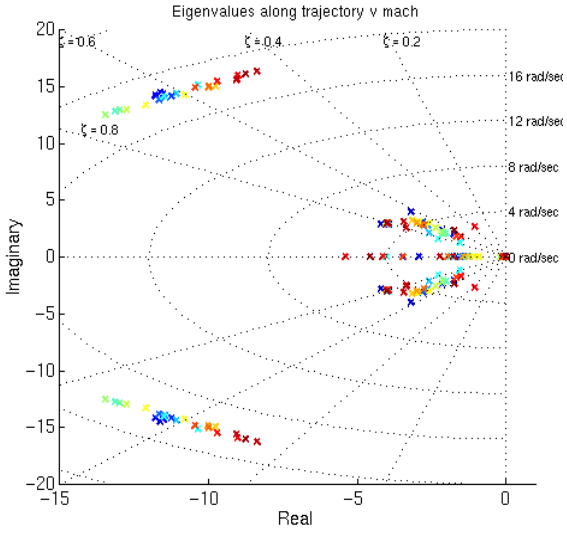
X-43A Inertias

Loaded Actuator Test

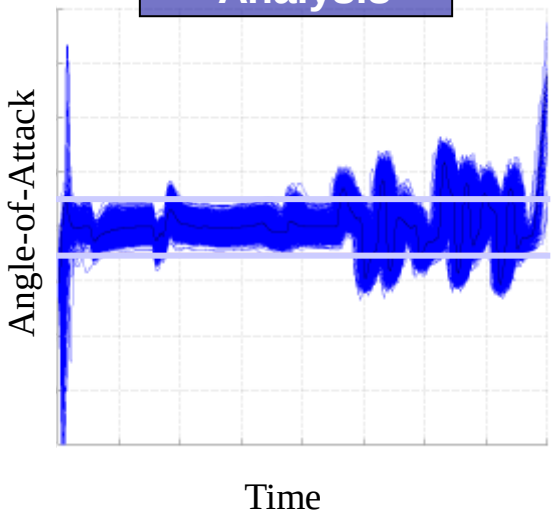


X-43A Materials

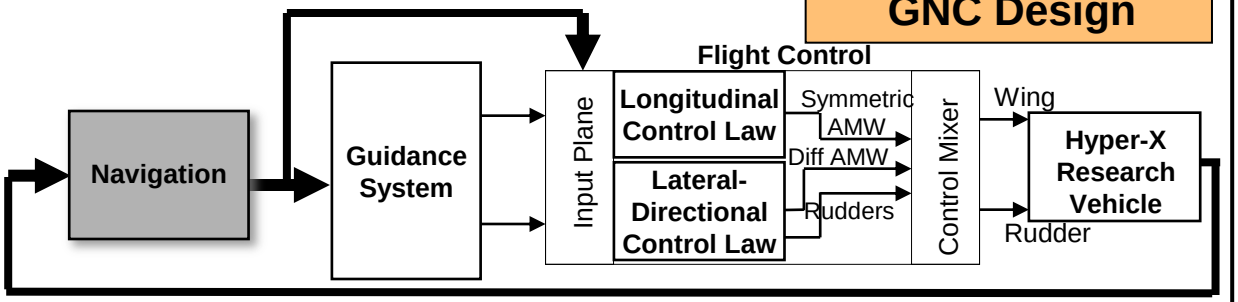
Guidance, Nav, & Flight Controls

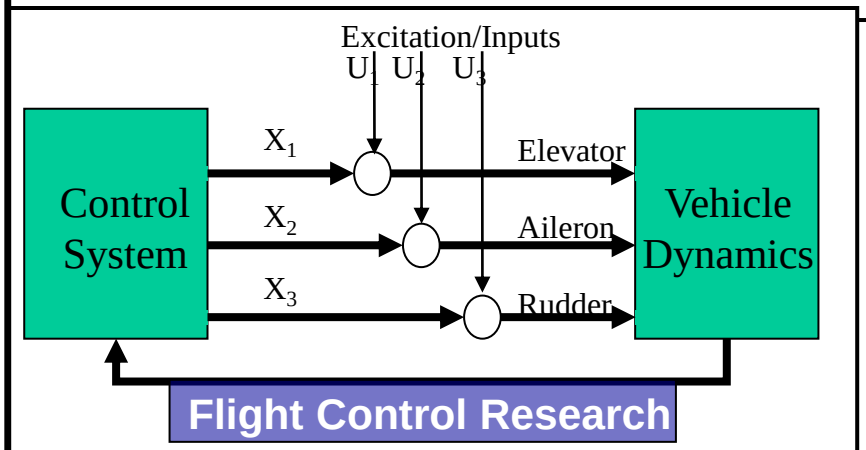


Analysis



GNC Design

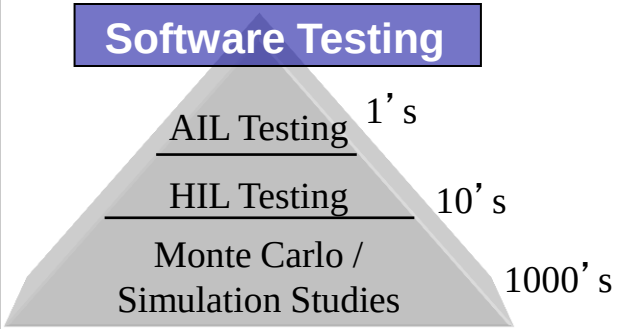




DFRC Role

Partner Role

Software Testing

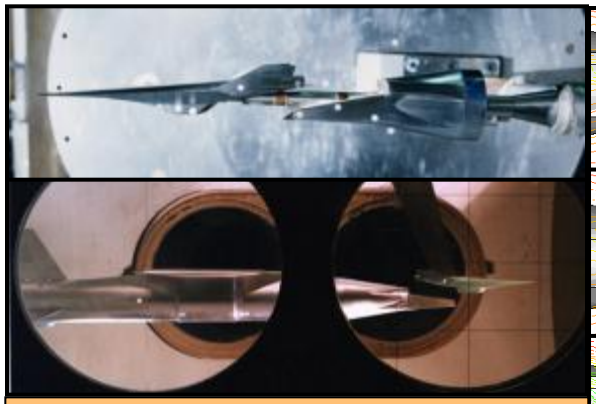


Additional Activities

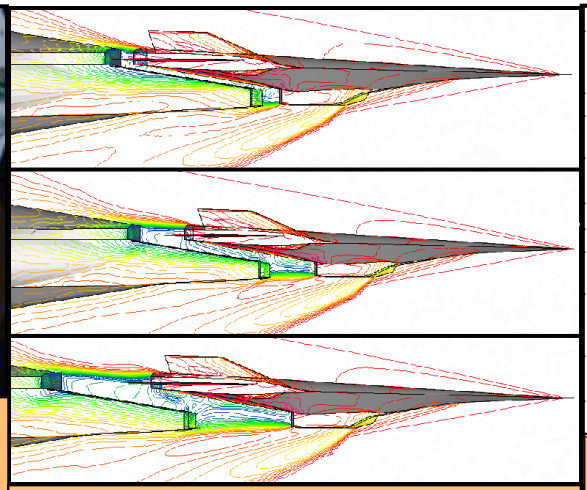
- F2 & F3 SW Updates
- F3 Controller Design
- Performance & Stability Analysis

Stage Separation

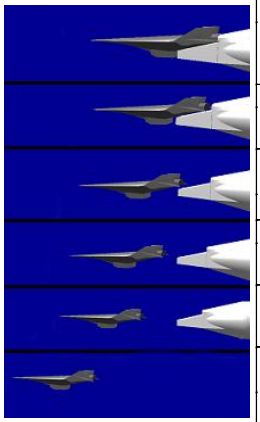
DFRC Role | Partner Role



Separation Aerodynamic Database Development

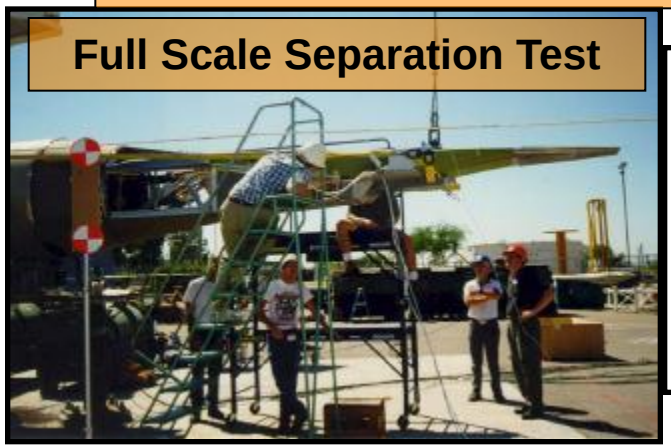


CFD Separation Analyses

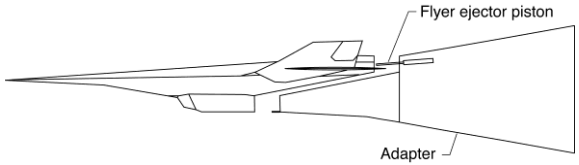


0 msec	Start of Separation Mach = 7 q_{bar}= 1066psf
100 msec	End of Piston push 9 in. extension
250 msec	Beginning Transition to free aero x_{sep} = -44 in.
350 msec	Free aerodynamics x_{sep} = -69 in.
500 msec	All feedback control loops closed
2.5 sec	End of separation / Start of test a = 2.5°, b = 0°

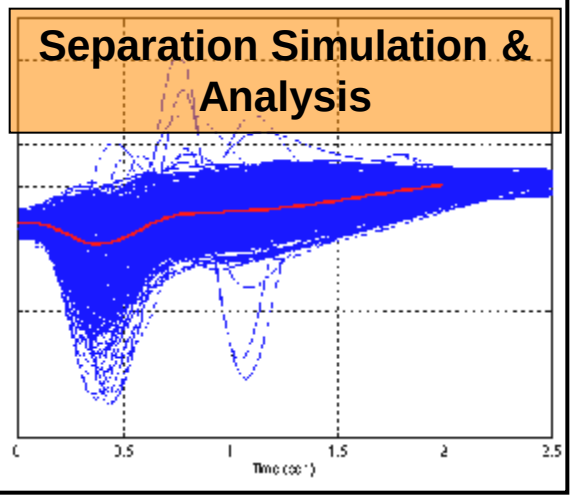
Separation Control Logic



Full Scale Separation Test



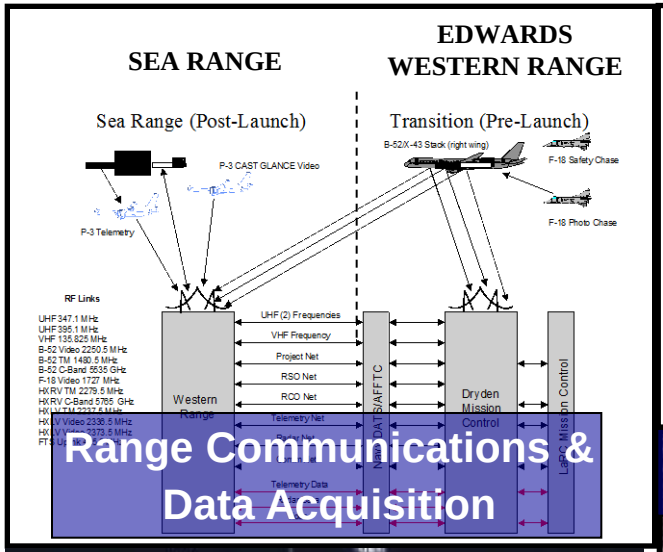
Separation System



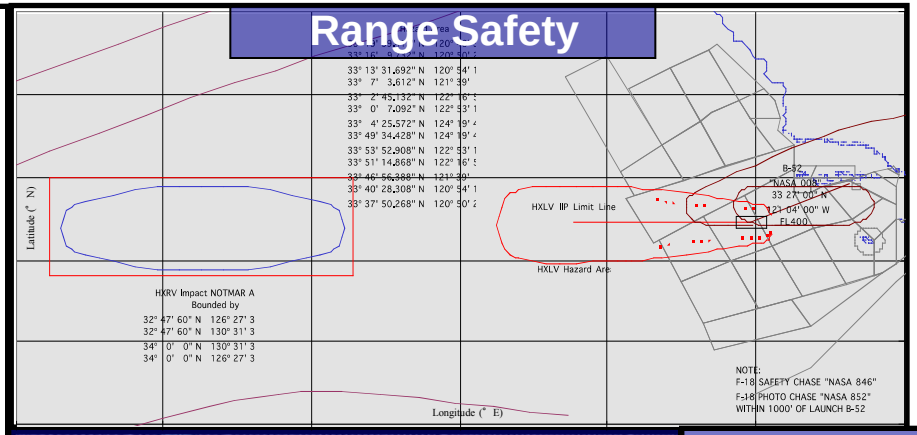
Instrumentation & Range

DFRC Role

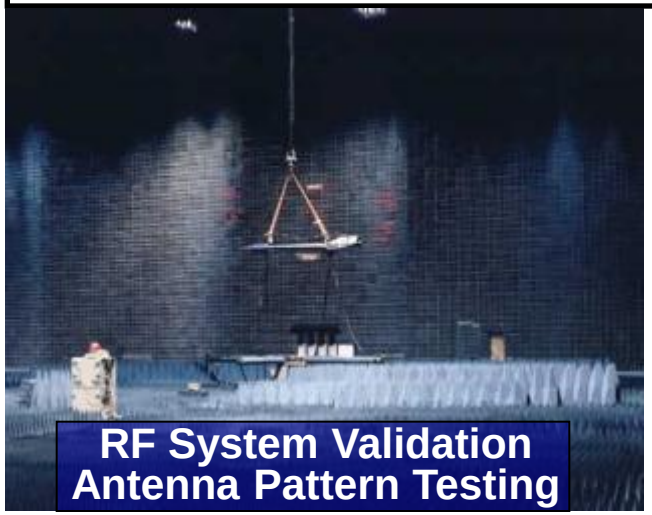
Partner Role



Range Communications & Data Acquisition



Range Safety



RF System Validation Antenna Pattern Testing

Instrumentation Systems Tests

RV Instrumentation System

Pressures	175
Temperatures	113
Strain Gages	14
Misc Analog	9
1553 Bus	792
TOTAL	1103

X-43A Simulation

DFRC Role | Partner Role

Hyper-X Sim Laboratory

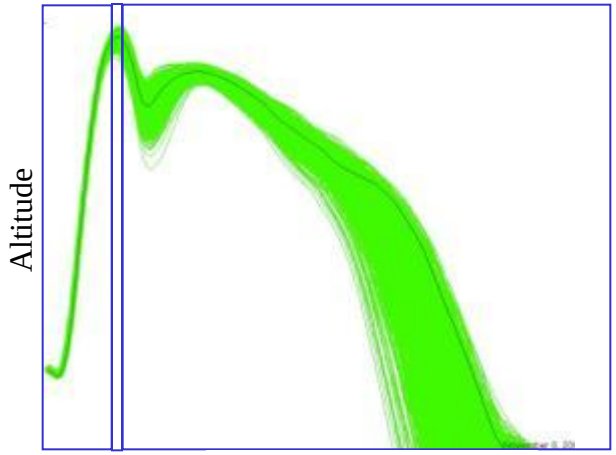
Hardware-in-Loop Tests

Aircraft-in-Loop Testing

Additional Sim Activities

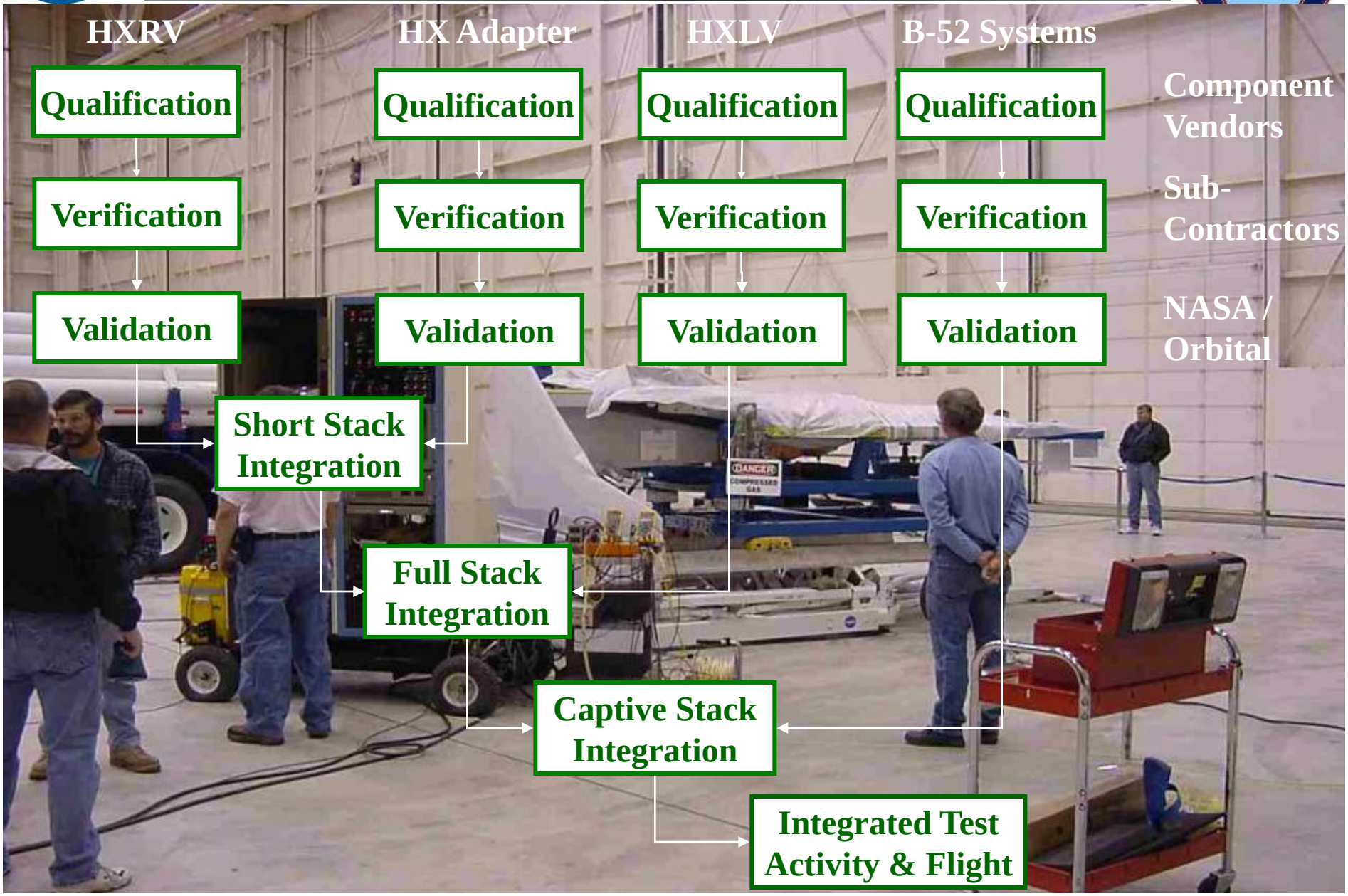
- Analytical End-to-End Mission Simulation
  - LVsim ⇨ SepSim ⇨ RVsim

Vehicle Analysis



Control Room Training

Test and Integration Activities



Flight Operations

DFRC Role | Partner Role

Vehicle Rollout

Pre-Flight Servicing

Control Room & Flight Ops

Pre-flight Tests

Emergency Training

Vehicle Testing

Vehicle Integration

Short Stack Mate

B-52 Operations

X-43A Mission Details

Flight 2
Flight 3

MACH 9.6

Power-Off Tare (5 sec) (3-7 sec)

PID (10 sec) NONE

Power-On Test

Mach 7
6,913 fps
1,000 psf

Cowl Closes

100

~95,000 ft

110,000 ft

Push-Over
-0.3 g's

-0.5g's

Accel - Ascent

Altitude
(kft)

Fuel Off

Fuel On

Power-Off Tare (5 sec)

Cowl Open

(3 sec)

Stage Separation

Booster Burn-Out

Pull-Up
1.7 g's

2.5g's

50

B-52B
Carriage

Mach 0.80
40,000 ft
q=189 psf

Drop Weight:
~37,500 lbs

Decel - Descent
Initial 1g to 10° AOA

6° AOA

Parameter ID Maneuvers
to Desired Impact Area

Terminal Glide

Mission
Complete

0

0 sec 5 sec ~95 sec ~105 sec ~115 sec ~700 sec

~400 nm 850 nm

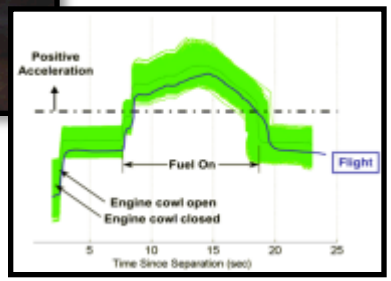
Hyper-X

Flight 2 – March 27, 2004

Flight 3 – November 16, 2004

Concluding Remarks

- Why were we successful?
  - Rigorous processes for design, development, testing, and validation
  - Strong technical expertise and team work between NASA, ATK GASL, Boeing & Orbital Sciences
  - A dedicated project team that worked for eight years to make these revolutionary flights a reality




Questions ???

Backup Charts

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.

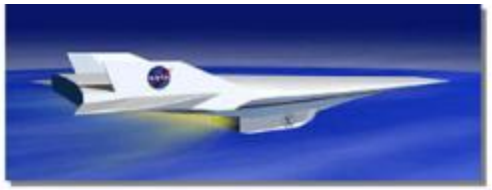
FLIGHT OBJECTIVES:

- Three flights: **two @ Mach 7 and one Mach 10**
- Methods verification
- Scaling confirmation

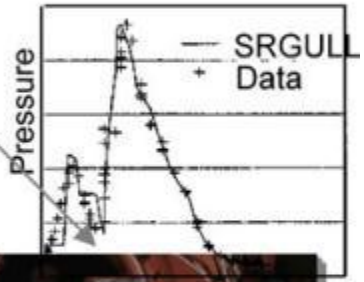
Primary Metric: Accelerate

TECHNOLOGY OBJECTIVES:

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

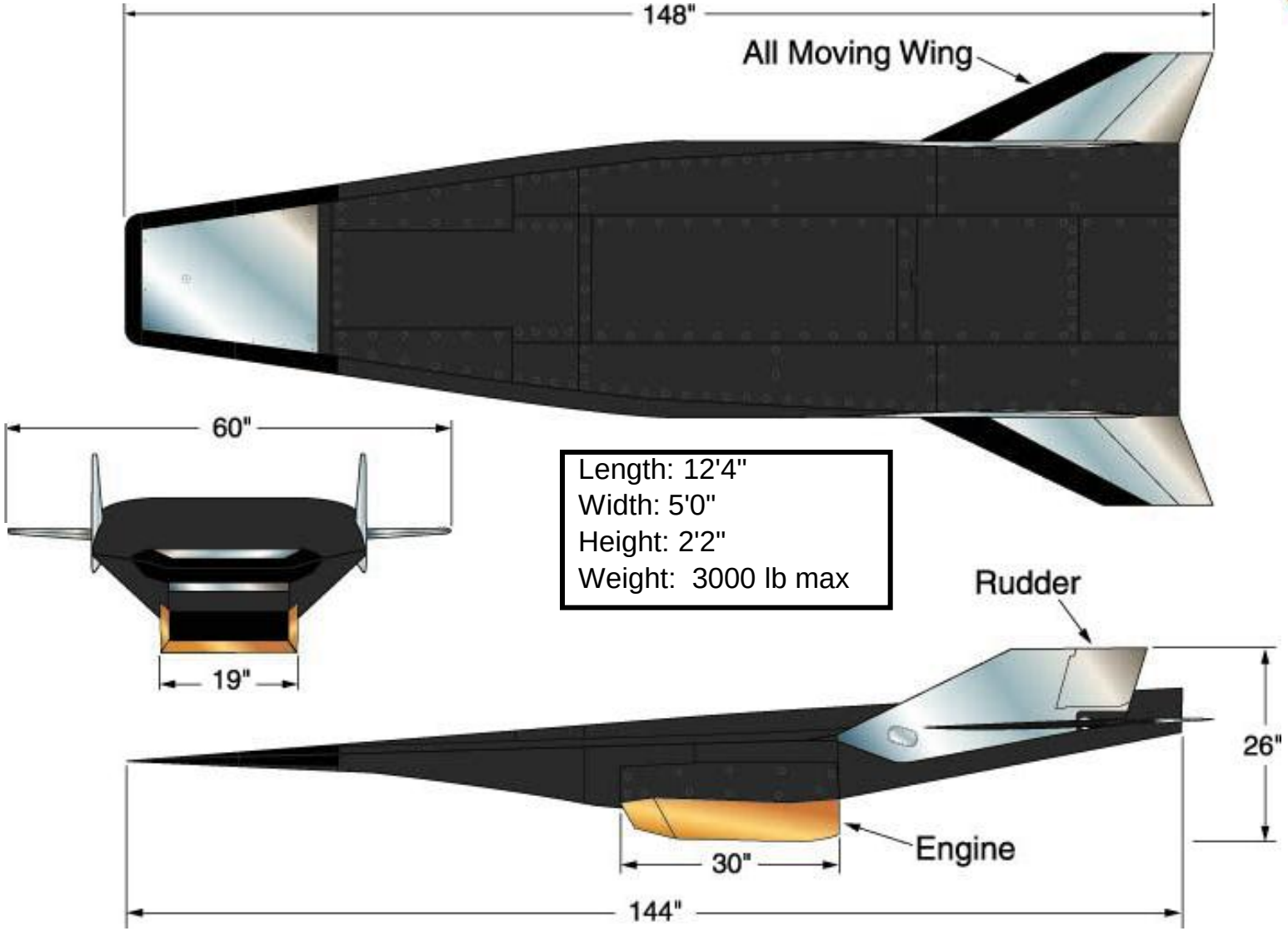


Comparison of Ground & Flight Data

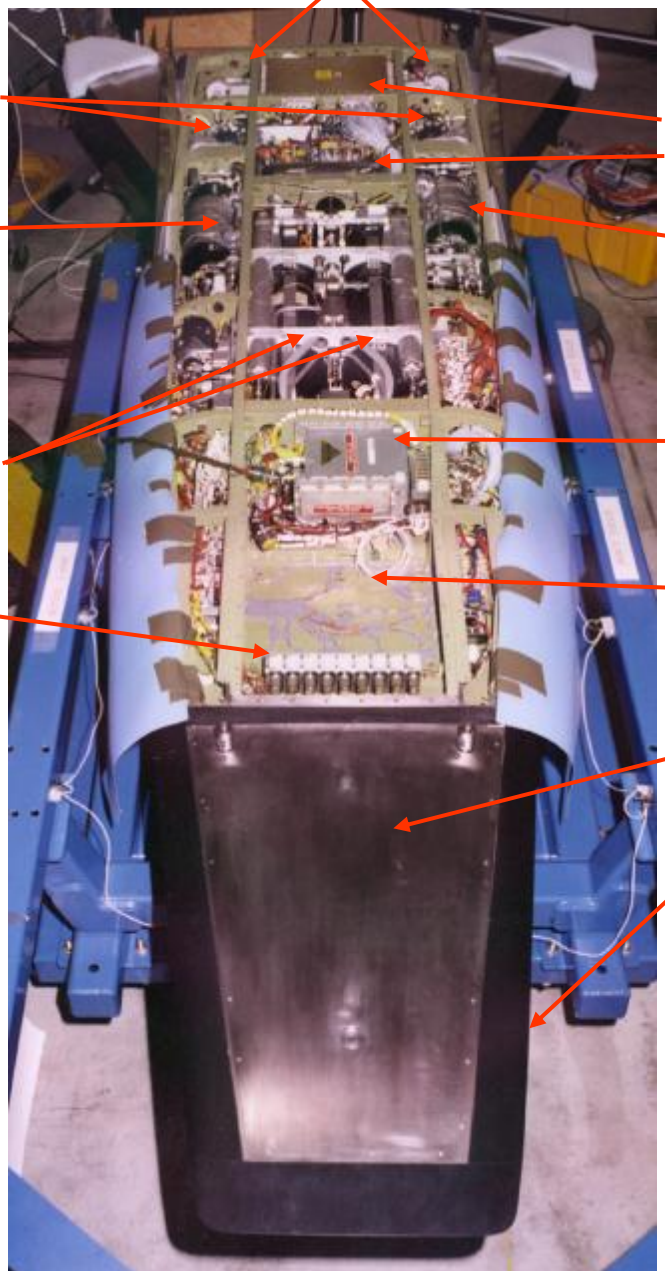


Wind Tunnel-to-Wind Tunnel Comparison

X-43A External Configuration



X-43A Internal Layout



Fuel: Hydrogen
Igniter: Silane
Thermal Barrier: Shuttle Tiles
Engine Coolant: Water
Nitrogen Purge
Electric Actuators

Length: 12 ft
Width: 5 ft
Height:: 2 ft
Weight: 3000 lb

- ✓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 Gas Test
- ✓Full Mission Simulation With Real Gas Test

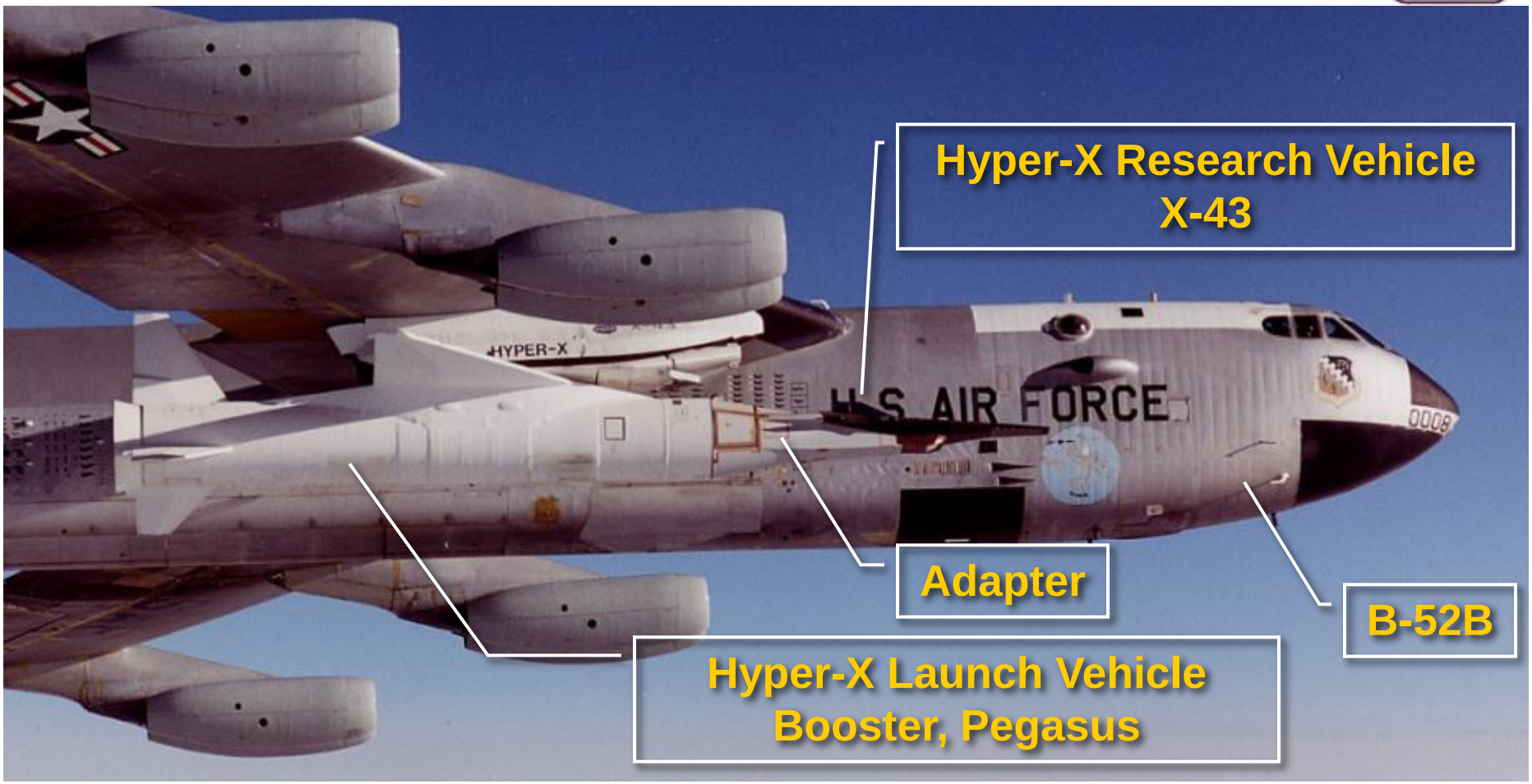
- ✓HXRV-Adapter Systems Validation
- ✓HXRV/Adapter Integration Tests

- ✓Standalone HXLV Tests
- ✓HXLV/HXRV Integration

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

Hardware and Software Testing …Preparing for Flight at DFRC

Hyper-X Components



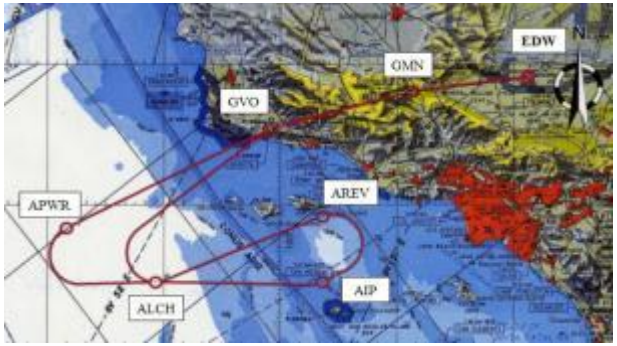
Launch Stack = HXLV + Adapter + HXRV

Hyper-X is a complex system with multiple interfaces.

Operations on Day of Flight

Day of Flight Ground Operations

- Control Room Staffing
- System power up and checkout
- B-52 engine start / power transfer
- Final X-43A closeout



B-52 Take-off

Flight Operations

- In flight systems / range checks
  - HXRV Built In Tests
  - FTS auto gain control
  - HXLV Fin Actuation System
- Launch and Free Flight

Flight 3 Right Adapter Camera Image

- Time between images is 33.3 milliseconds - 1/30th of real-time.
- Right Adapter Camera Position