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SPACE TRANSPORTATION TECHNOLOGY WORKSHOP
MARSHALL SPACE FLIGHT CENTER
OCTOBER 11-12, 2000

Airframe/TPS

AIRFRAME DESIGN AND INTEGRATION

- **Integrated Design Tools and Methods**
- **Integrated Airframe Trade Studies**
  NRA 8-21 Overview
- **Risk and Reliability Assessment**

LaRC Points of Contact:

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Airframe/TPS

AIRFRAME DESIGN AND INTEGRATION: Major Areas

- Decompose operational, safety, and cost requirements into a comprehensive and consistent set of design criteria for different structural and material concepts for Reusable Launch Vehicles (RLVs)

- Develop compliance methods to ensure that different structural and material concepts are assessed at a consistent and adequate level of fidelity and safety

- Develop and assess weight reduction potential of integrated airframe concepts for RLVs, e.g. Thermal Protection System (TPS)/ TPS Support (TPSS)/ Cryogenic Tank (CT) System

- Compare performance and weight of various airframe structural and material concepts and structural arrangements and identify technology development needs

- Develop high fidelity parametric models that include airframe structural interactions and major design drivers

AIRFRAME INTEGRATION TRADE STUDIES
GENERAL OBJECTIVES

- Define vehicle requirements, definition, packaging
- Define airframe structural design requirements and develop compliance methods
- Define load conditions, loads, factors of safety, and materials
- Define integrated concepts
- Develop methods, perform analysis, and sizing
- Calculate system weights
- Assess concepts

Airframe/TPS

TRADE STUDIES: GENERAL APPROACH

RLV Requirements

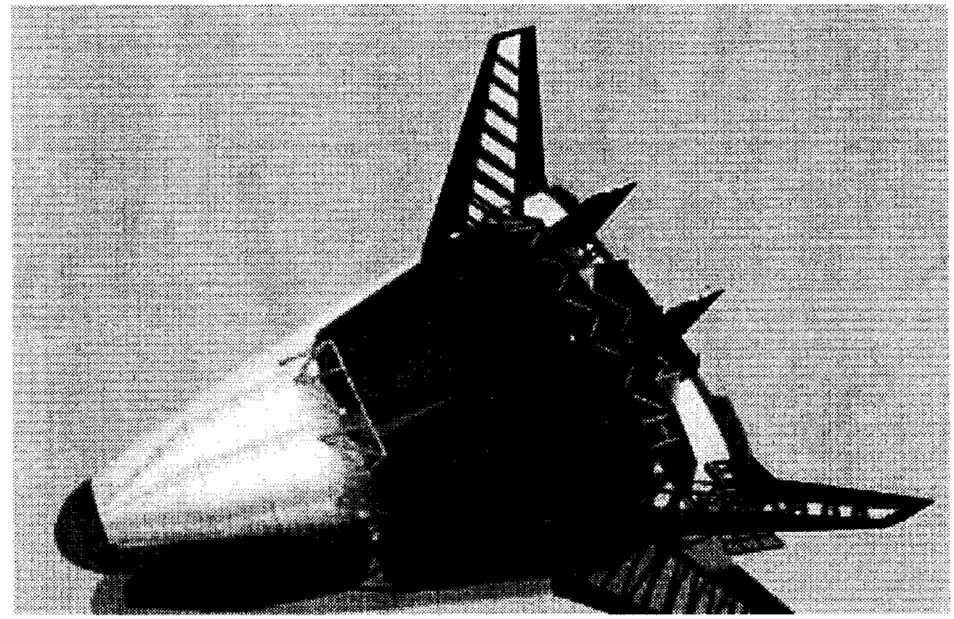
- Lightweight
- Fully reusable
- Easily maintained

Vehicle Definition

- Single Stage to Orbit (SSTO)
- Lifting body

Major Components

- Aerospike engines
- Engine Thrust Structure
  (integrates engines, fins, tanks, and main landing gear)



- Liquid Oxygen (LOX) Tank
- Liquid Hydrogen (LH2) Tanks
- Intertank
- Metallic Thermal Protection System and support structure

Airframe/TPS

SYSTEM DEFINITION

- **John T. Dorsey** — Airframe Integration & Concepts, Vehicle Loads, Weights (Study Lead, NRA 8-21)
- **Max Blosser** — TPS Concepts (TPS Team Lead)
- **Carl Poteet** — TPS Thermal Analysis and Sizing, TPS Concepts
- **Roger Chen** — TPS Panel Acoustic, Fatigue, Creep Analysis & Sizing
- **Irv Schmidt** — TPS Panel and Tank Stiffening Design
- **John Wang** — Semi-Conformal & Lobed Tank Analysis and Sizing
- **Su-Yuen Hsu** — TPS Panel Structural Analysis and Sizing
- **Lynn Bowman** — Non-Optimum and Vehicle Weights
- Jeff Cerro — Material Properties, Vehicle Loads
- Nani Balakrishnan — TPS Panel Structural Analysis and Sizing
- David Myers — Packaging, Weights, & TPS

- **Kevin Rivers** — 2nd Gen RLV Airframe Integration and Trades Lead
- **Kim Bey** — Aerothermal Loads, Thermal Analysis, TPS Sizing

Airframe/TPS

TRADE STUDY TEAM

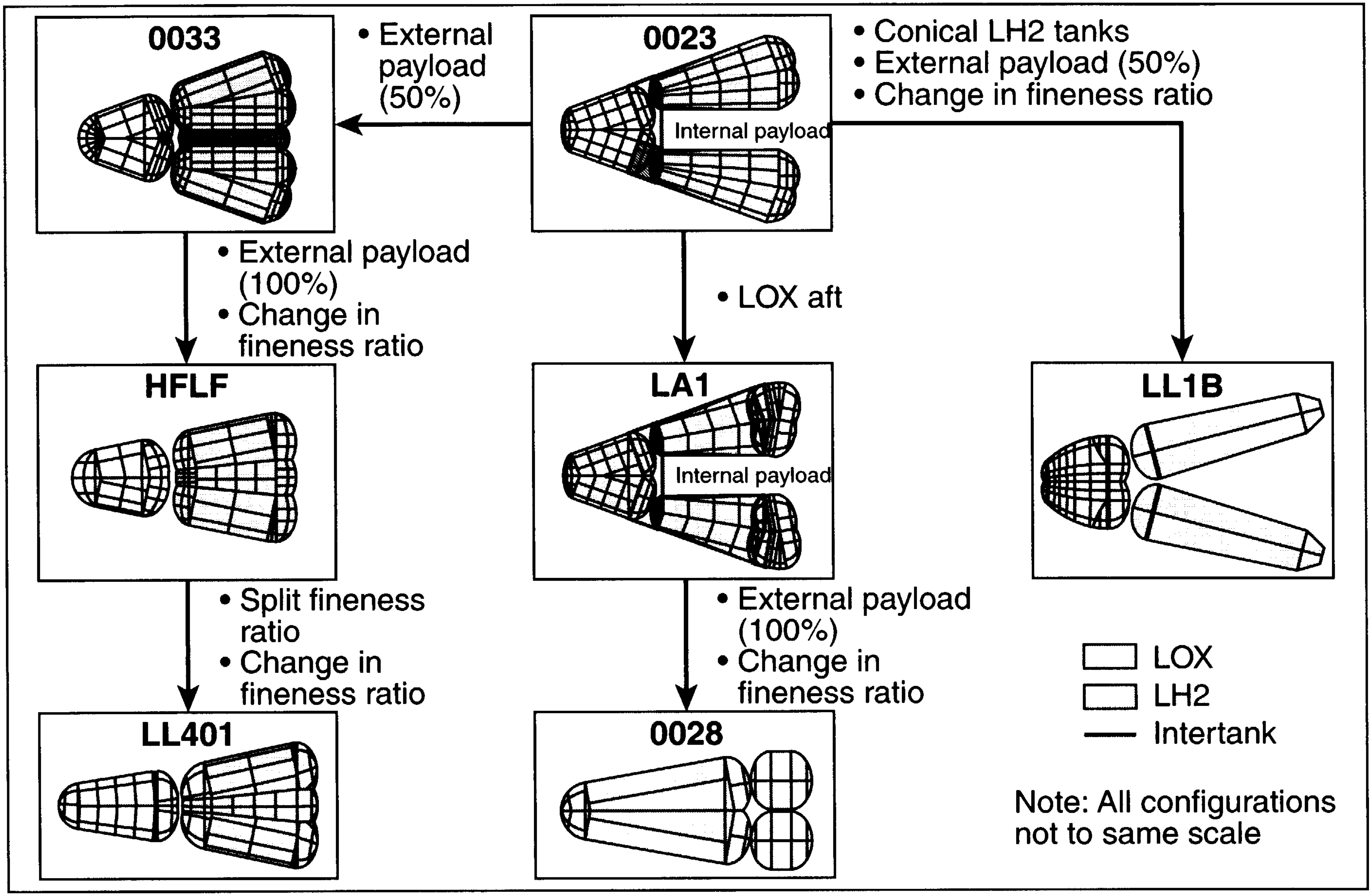
- Tank Packaging and Geometry
  - Packaging configurations
  - Lobed versus conformal tanks
  - Minimize Distance between Outer Mold Line (OML) and Tank

- Component Trade Studies
  - Tanks
  - TPS and support structure

- Integrated TPS, TPS support, and tanks
  - Applicable to several architectures
  - In progress

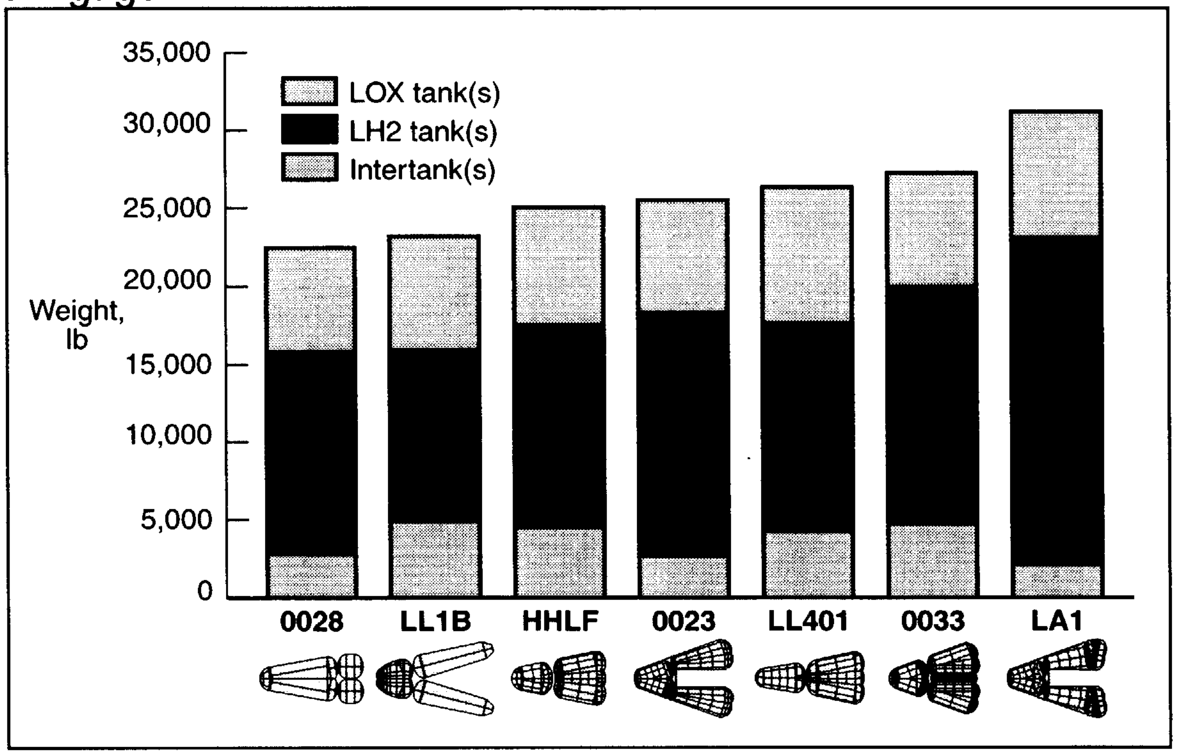
Airframe/TPS

TRADE STUDIES FOR NRA 8-21: MAJOR CATEGORIES



PACKAGING CONFIGURATIONS

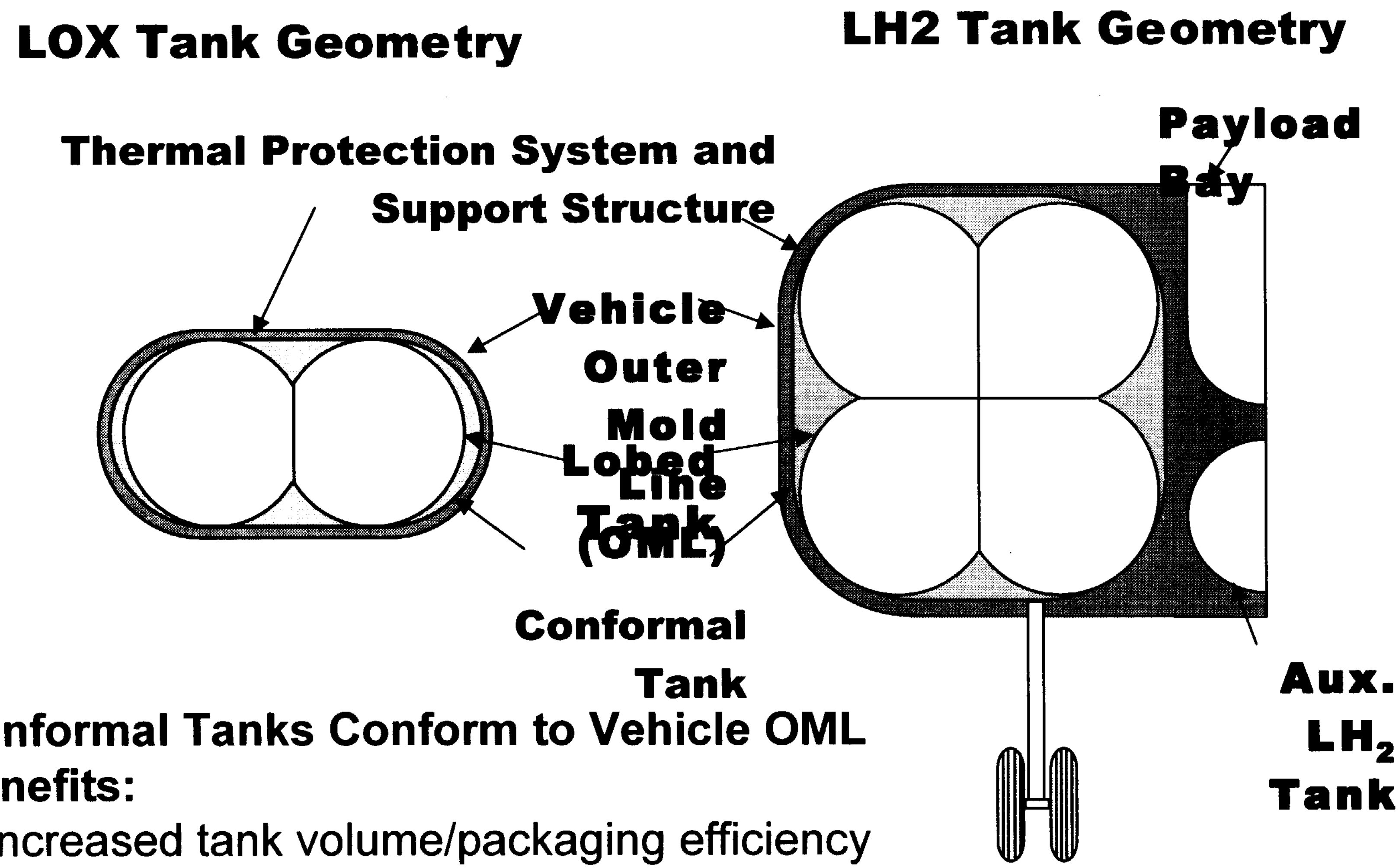
- **Material Specifications**
  - Quasi-isotropic PMC laminates
  - Limit strain 6000 μin./in.
  - Minimum gage
- **Load Cases**
  - Launch (1.355 g's)
  - Max acceleration (3 g's)



- **Interactions:**
  - LOX-aft: reduced LH2 ullage pressure for tank stabilization changes engine operating requirements
  - External payload and aerodynamics

Airframe/TPS

CONFIGURATION SIZING



Conformal Tanks Conform to Vehicle OML

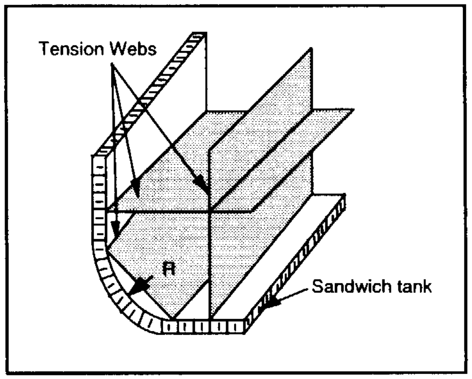
Benefits:

- Increased tank volume/packaging efficiency
- Reduced TPS support structure
- Improved thrust load paths

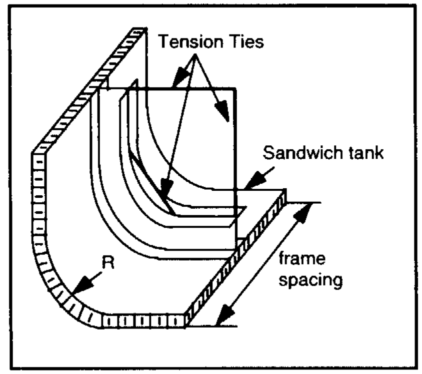
Airframe/TPS

TANK GEOMETRY TRADE STUDIES

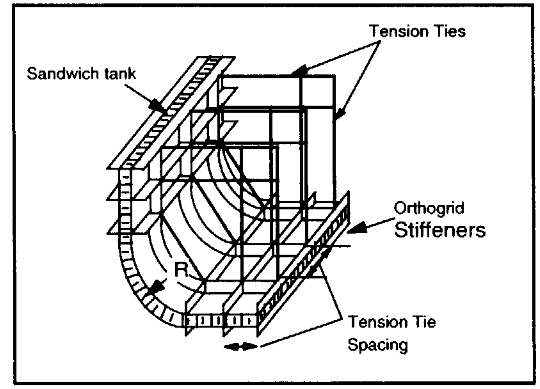
Axial Tension Webs



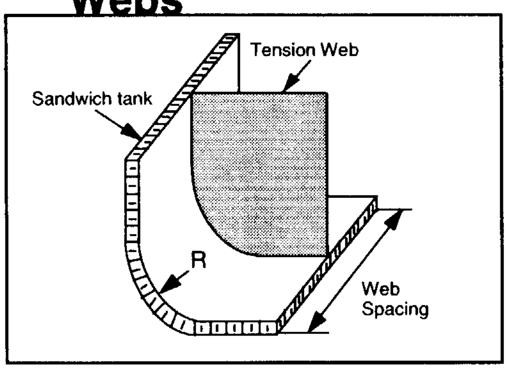
Frames & Ties



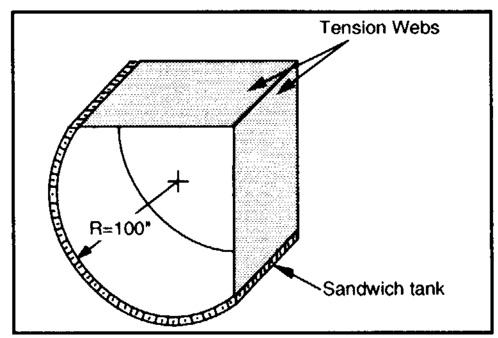
Orthogrid & Ties



Transverse Webs

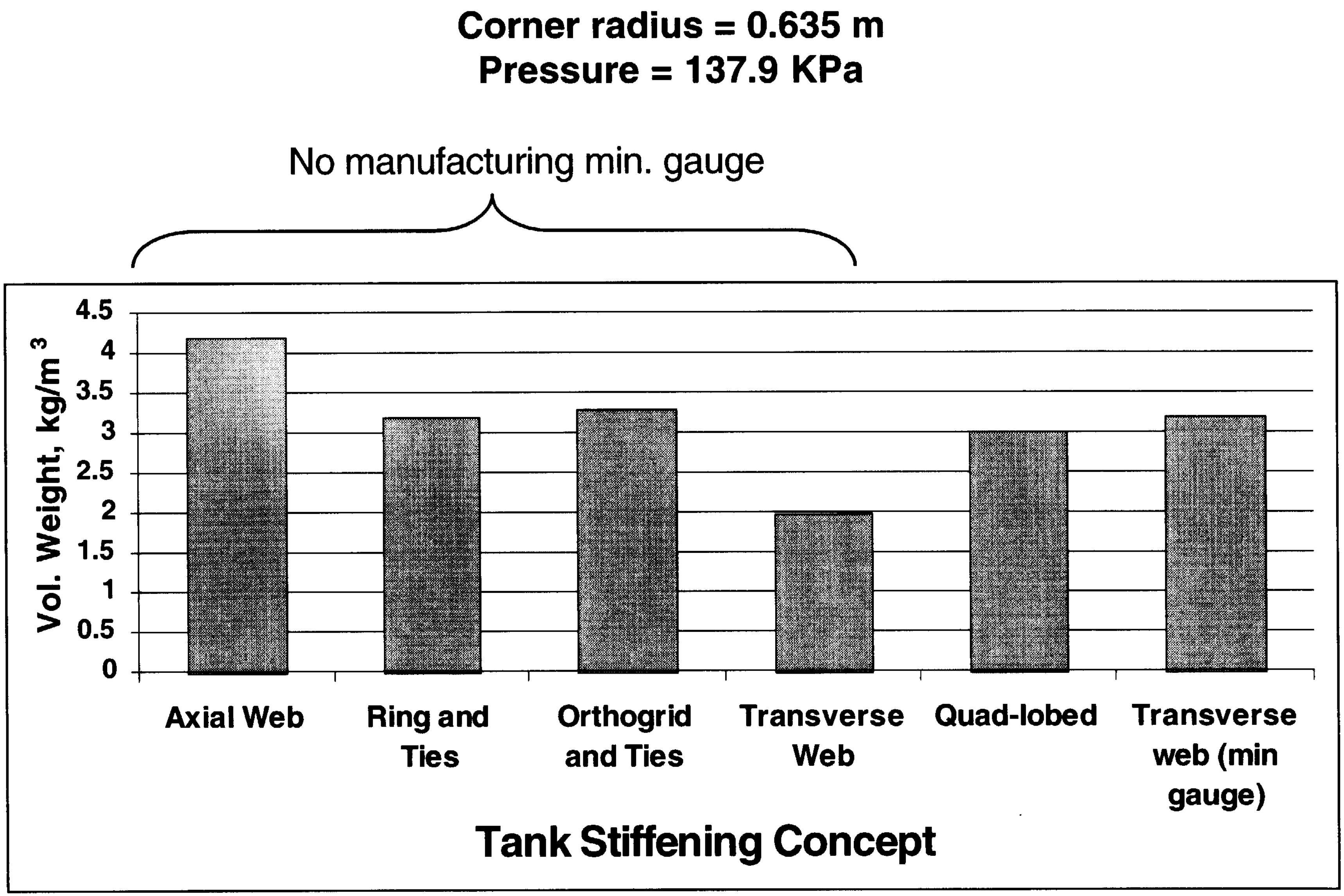


Quad-lobe & Webs



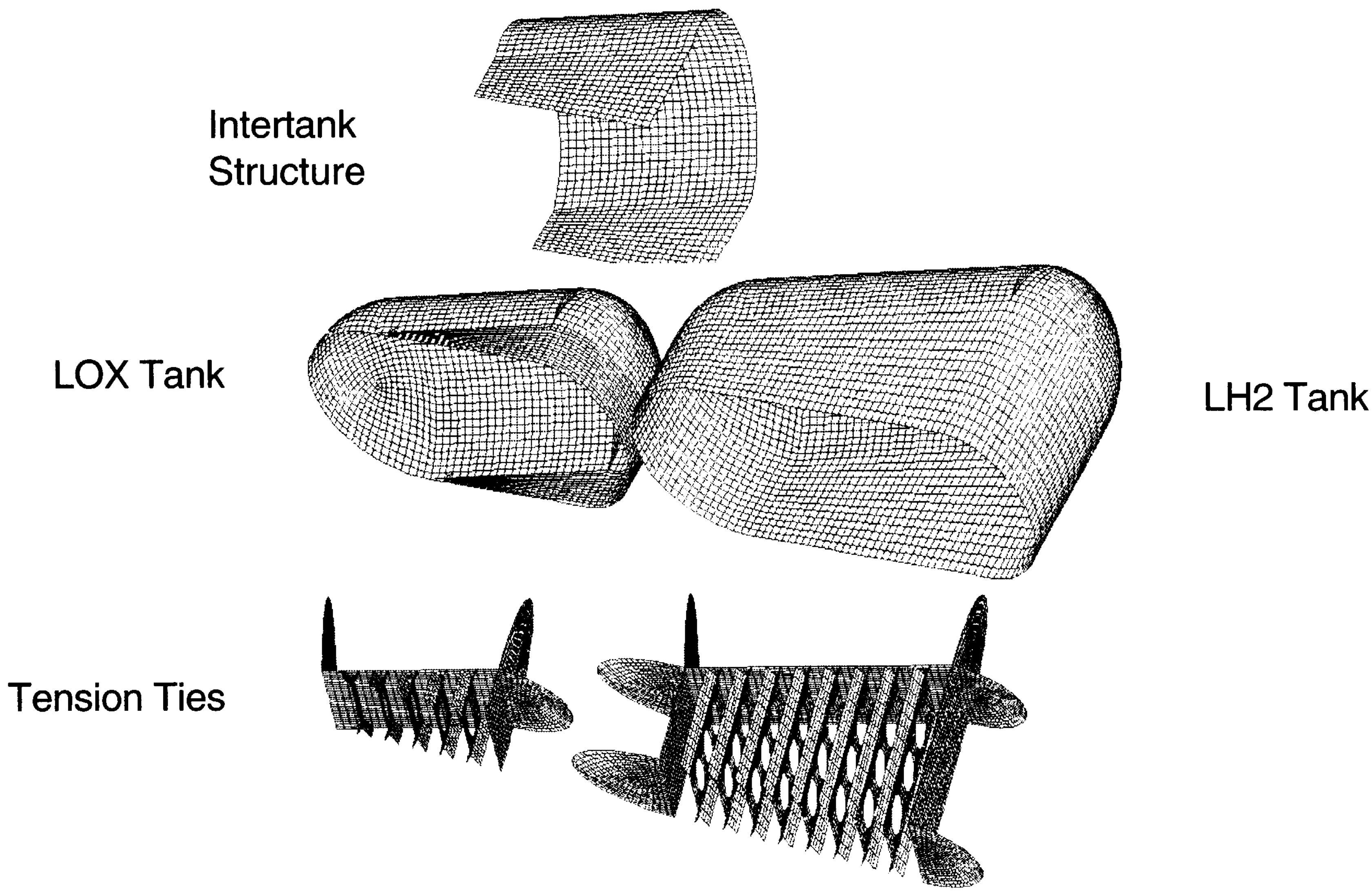
Airframe/TPS

TANK STIFFENING CONCEPTS CONSIDERED



Airframe/TPS

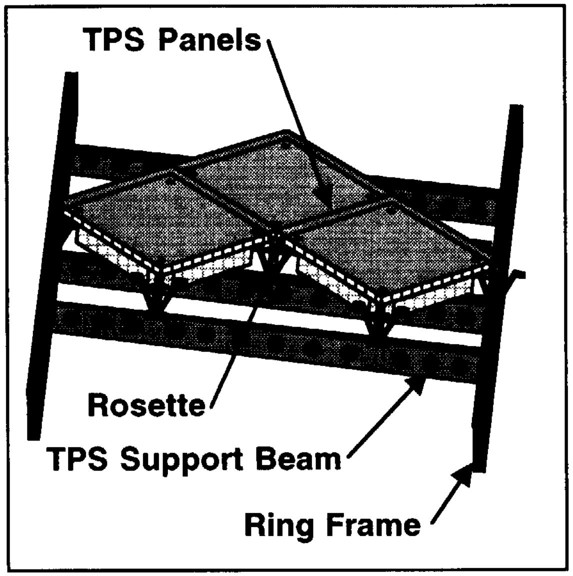
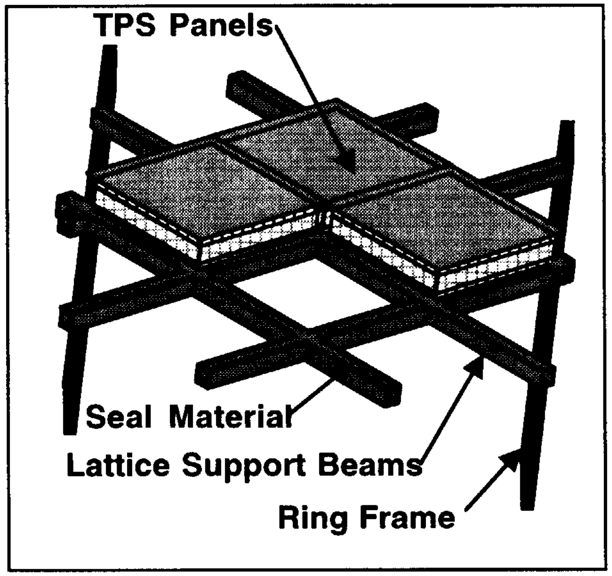
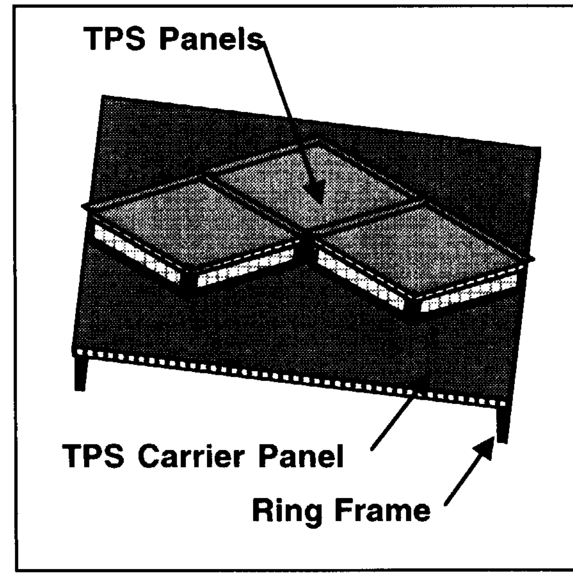
TANK STIFFENING WEIGHTS COMPARISON



Airframe/TPS

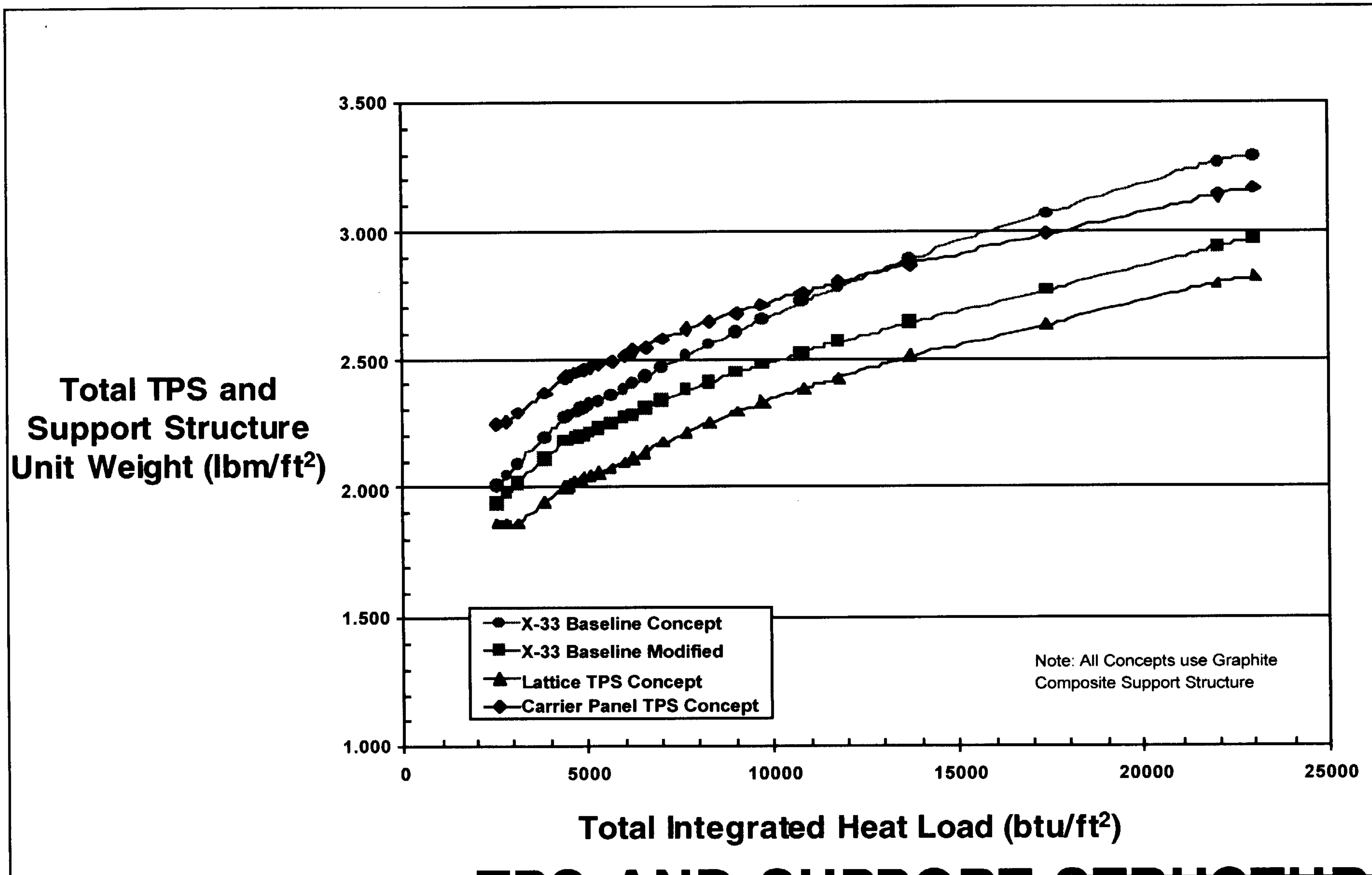
SEMI-CONFORMAL SANDWICH TANK SYSTEM: FEM FOR SIZING (In Progress)

Metallic TPS Concepts for Windward Aeroshell Surfaces

Rohr X-33 Concept (baseline)	LaRC-Type TPS Panels with Lattice Seal & Support Frames	LaRC-Type TPS Panels Mounted to Carrier Plates
		
•Thermal stresses minimized •Light weight system •Simplified manufacturing •Seals on hot surface •Hot surfaces carry aero pressures •Panel damage/loss potentially catastrophic	•Seals and pressure bearing surface moved to cooler region •Tolerant to outer surface damage •More complex support structure •More costly TPS panel •Panel loss potentially catastrophic	•Carrier panel increases TPS options •Improved damage tolerance •Reduces number of seals •Pressure carried on large, cool panel •Heavier than other concepts •Complicates removal for inspection •Potential thermal stress issues

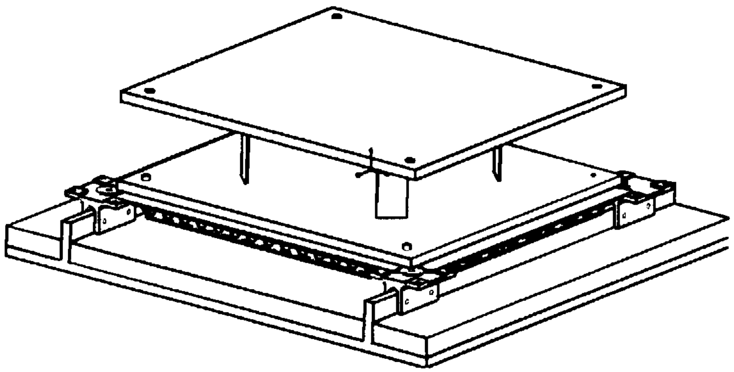
Airframe/TPS

TPS TRADE STUDY CONCEPTS

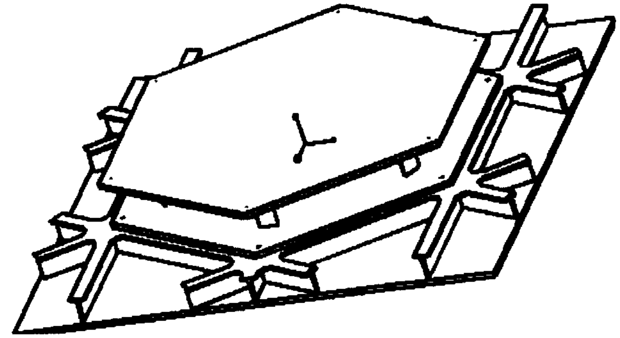


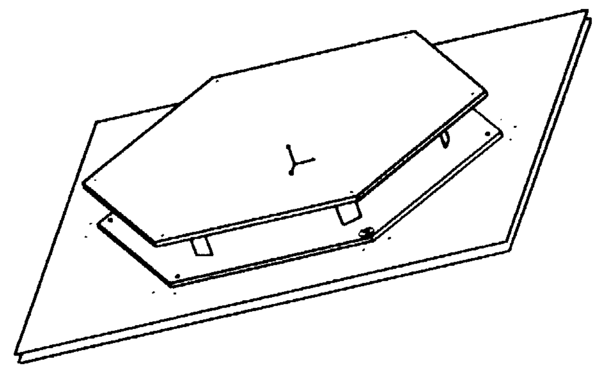
TPS AND SUPPORT STRUCTURE WEIGHTS

REPRESENTATIVE STRUCTURAL CONCEPTS



FEATURES
- Metallic TPS
- TPS Support Structure
- Purge Gap
- Cryogenic Foam
- Sandwich or Stiffened Skin Tank Wall





FEATURES
- Metallic TPS
- Direct Attach TPS
- Cryogenic Foam
- Sandwich, Stiffened Skin, or Integrally-Stiffened Tank Wall

Airframe/TPS

INTEGRATED TPS/TPSS/TANK SYSTEM DEFINITION

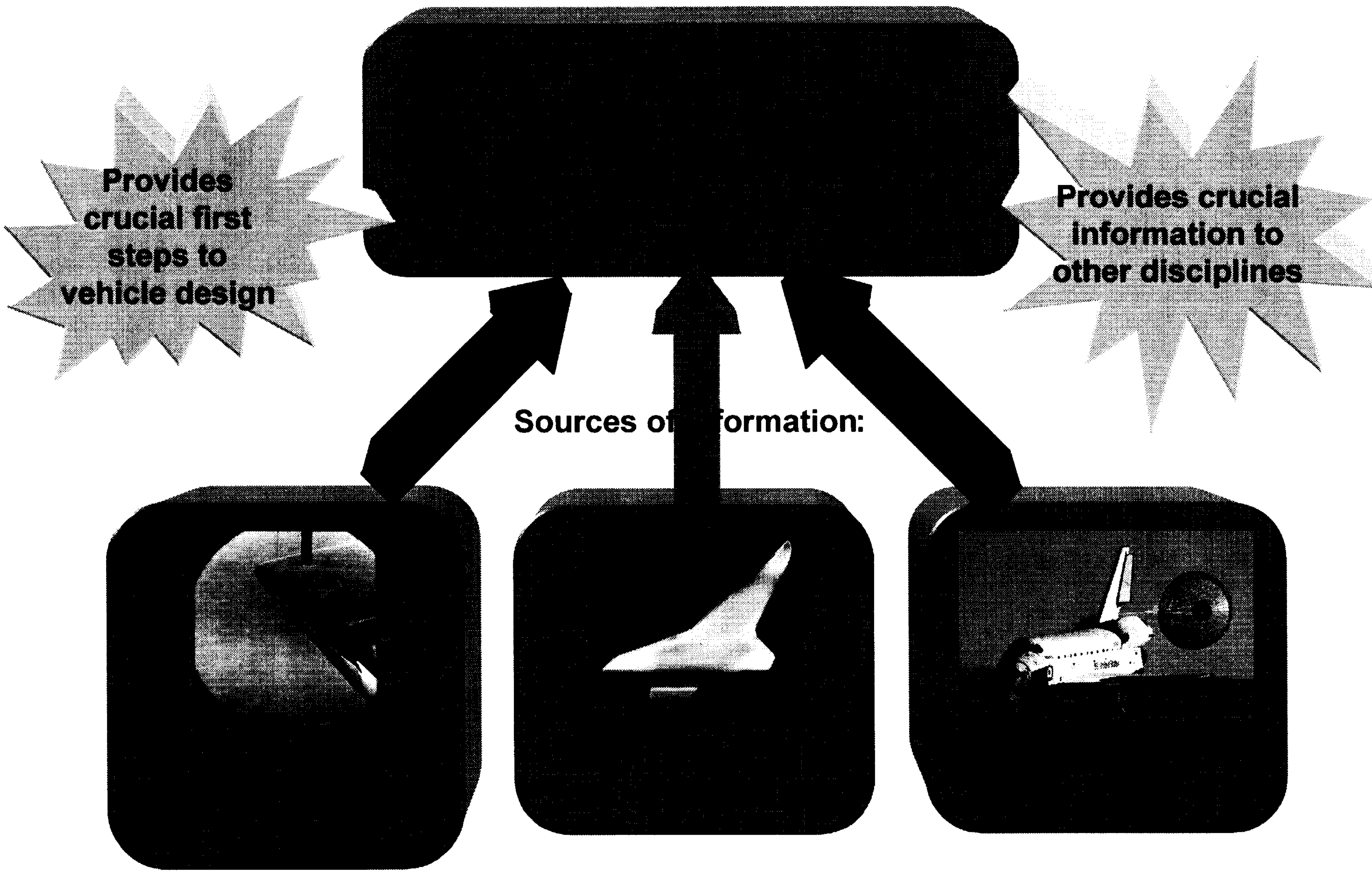
- Hierarchy of sizing methods are needed to support trade studies and concept assessment. Even low fidelity sizing must capture effect of major design drivers (e.g. geometry, size, load, ...)

- Major deficiencies exist in the types of material data needed to optimize integrated airframe (TPS/TPS Support/Tank systems) for both metallic and polymeric composite systems

- Critical interactions exist within airframe systems, and between airframe and vehicle systems. New analytical formulations and/or tools are needed to take advantage of those interactions which significantly improve or enable vehicle/system viability.

Airframe/TPS

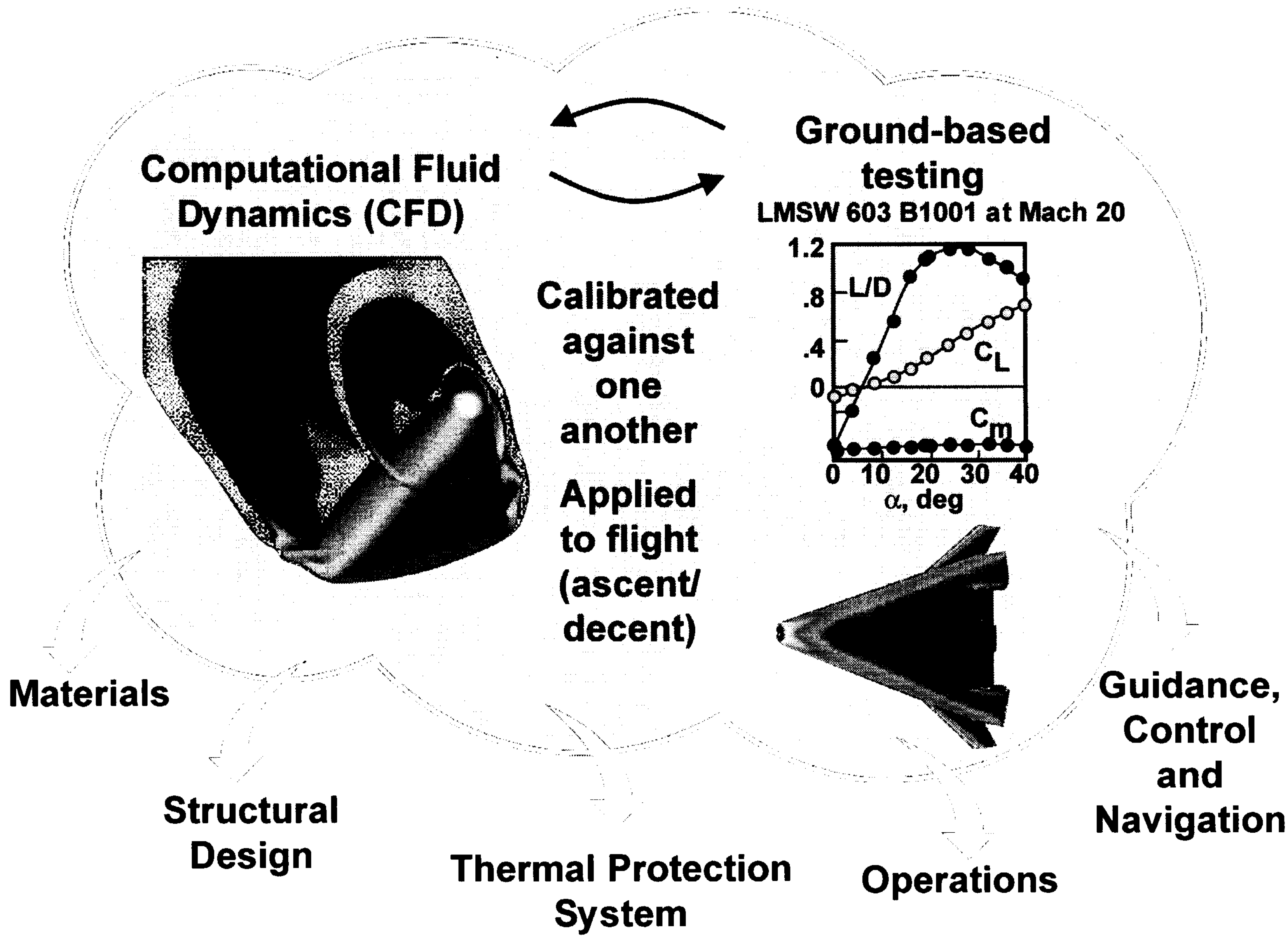
CONCLUDING REMARKS

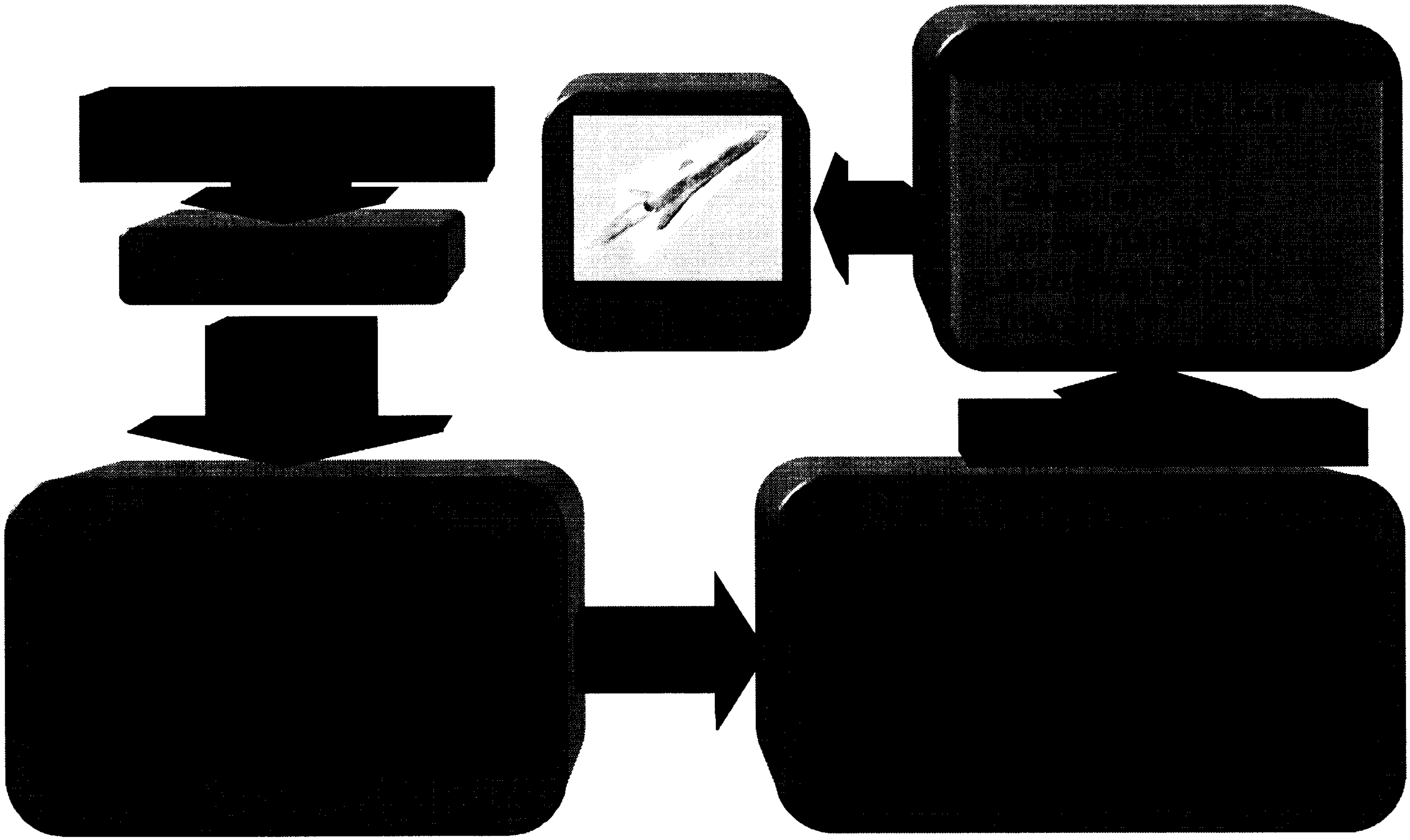


Airframe/TPS - Aerothermodynamics

Aerothermodynamics

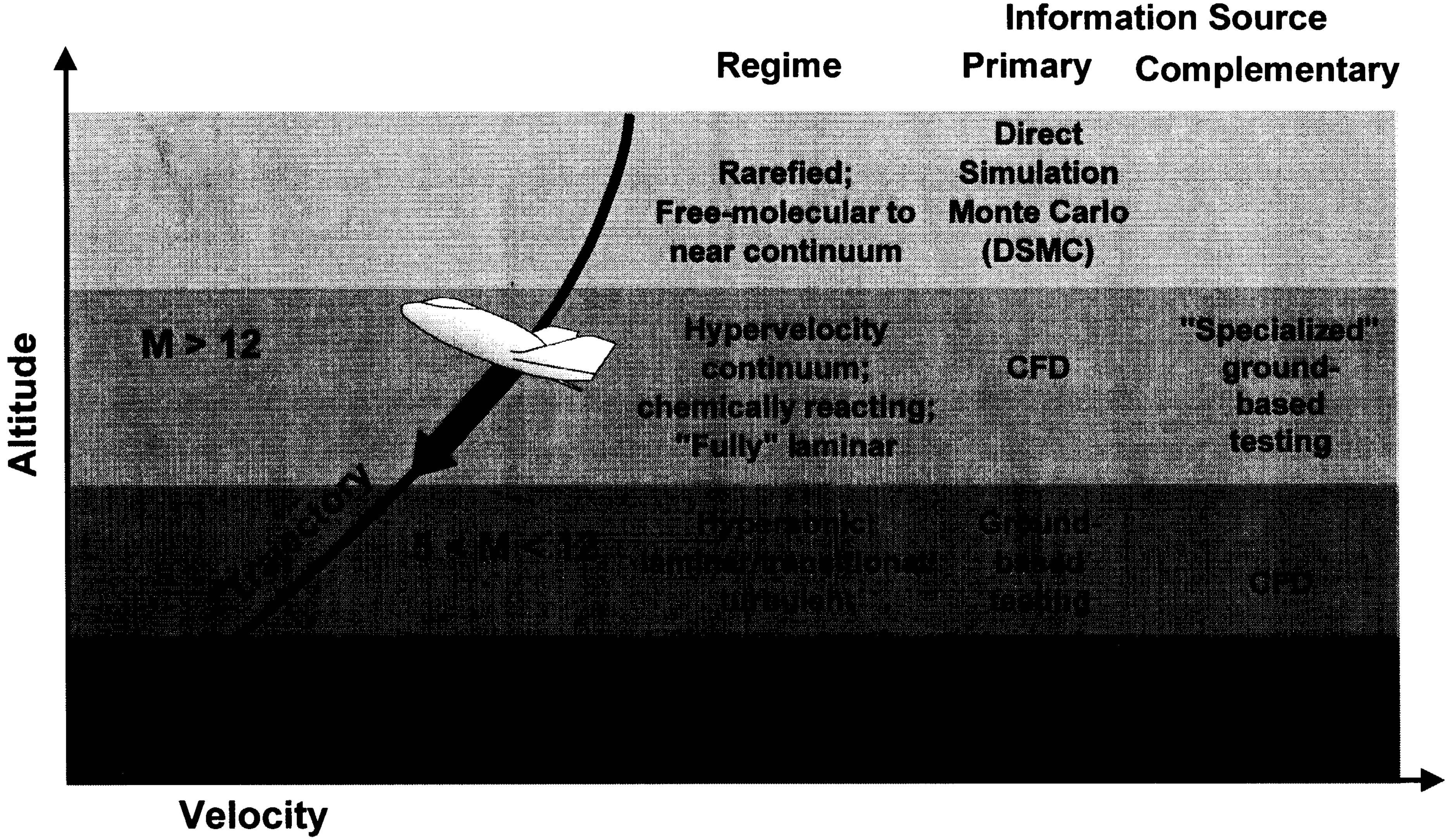
Aerothermodynamics Provides Critical - Path Information





Airframe/TPS - Aerothermodynamics

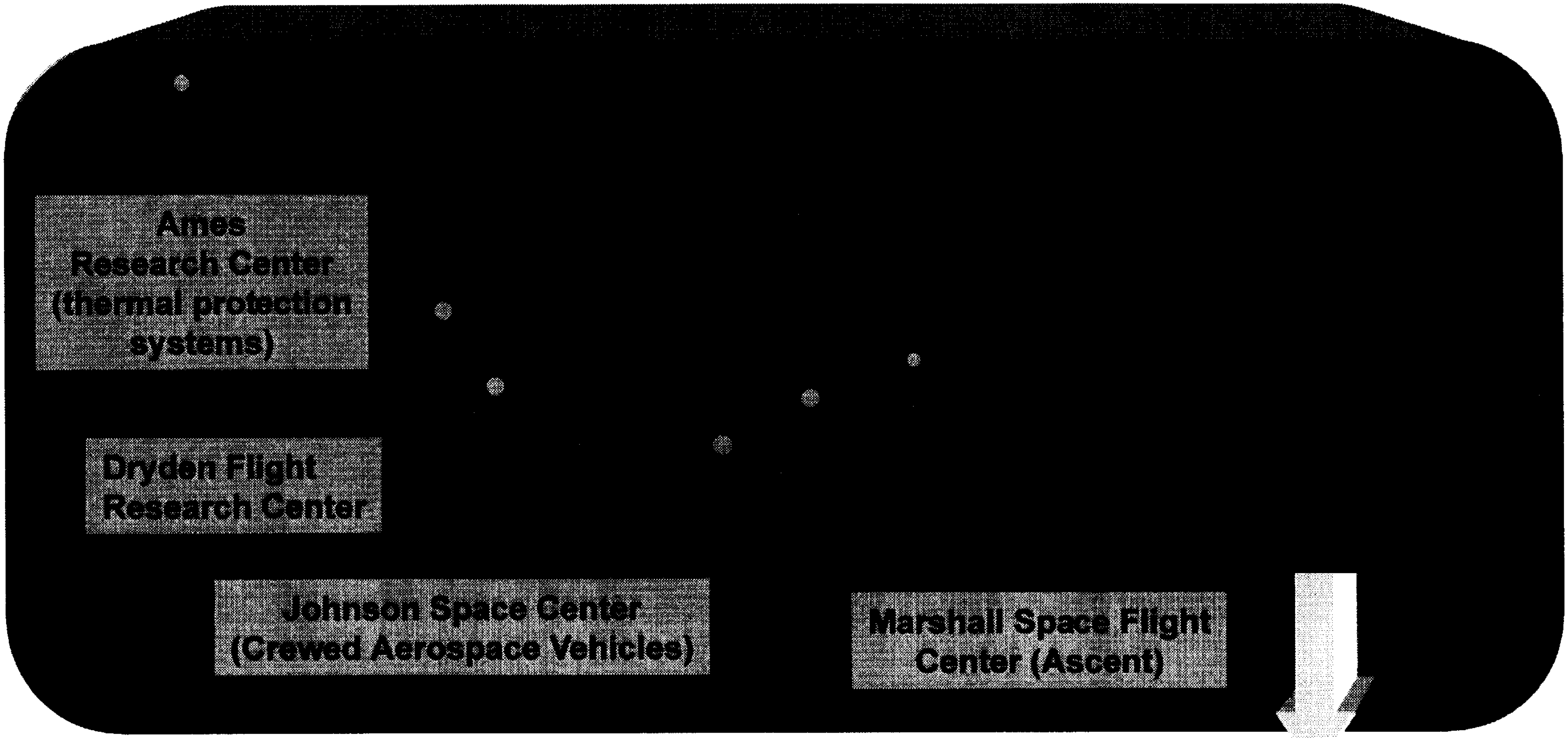
Aerothermodynamic Process



Airframe/TPS - Aerothermodynamics

Aerothermodynamic Methodology

LaRC is NASA Lead For Aerothermodynamics

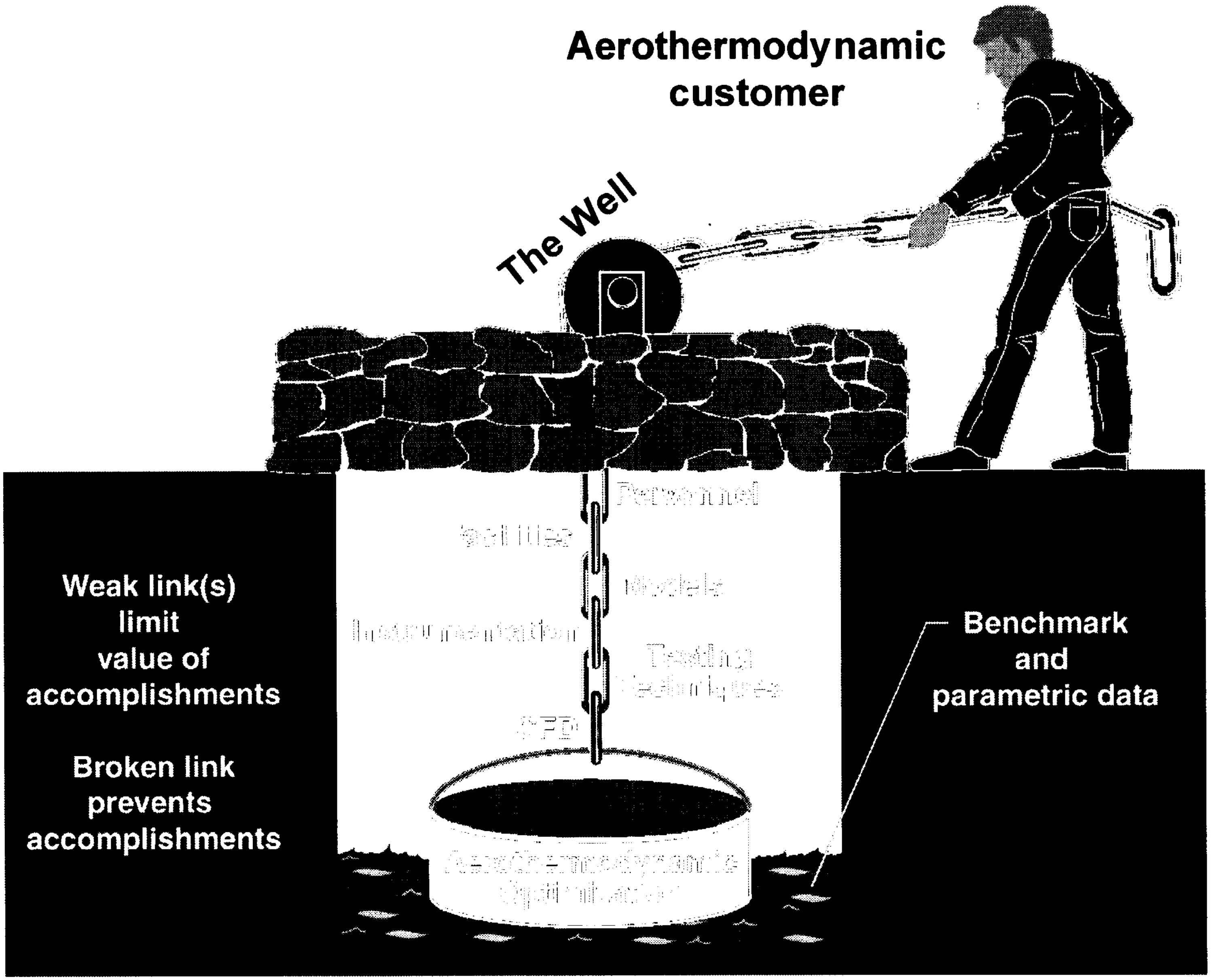


Langley Aerothermodynamic Facilities Complex (AFC)

20-Inch
Mach 6
Air

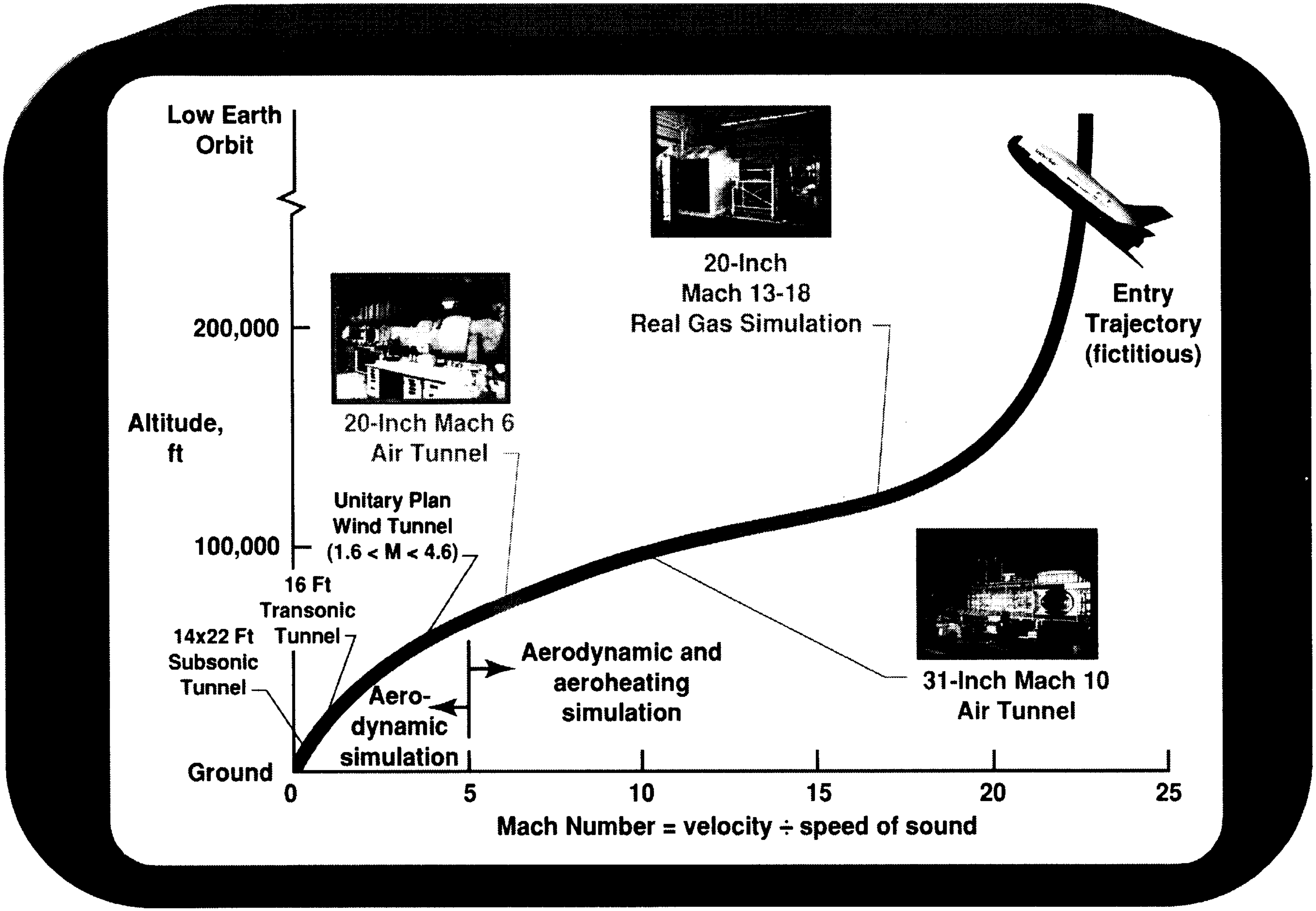
31-Inch
Mach 10
Air

20-Inch
Mach 13-18
Real Gas
Simulation



Airframe/TPS - Aerothermodynamics

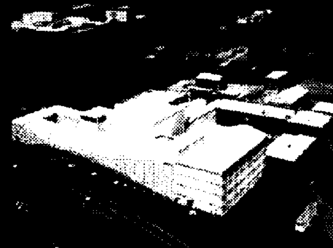
Aerothermodynamic "Chain"



Airframe/TPS - Aerothermodynamics

Aerothermodynamic Flight Simulation Capability

Low Turbulence Pressure Tunnel

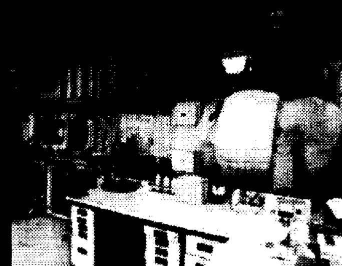


14-by 22-Foot Subsonic Tunnel

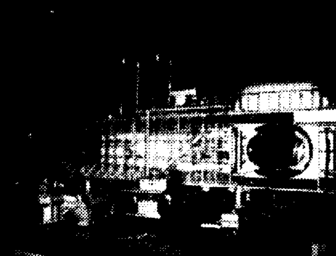
16-Foot Transonic Tunnel

National Transonic Facility

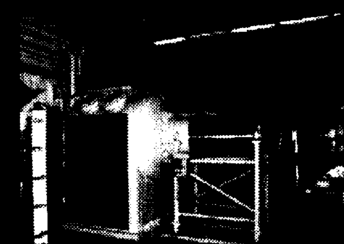
Unitary Plan Wind Tunnel



20-Inch Mach 6 Air Tunnel



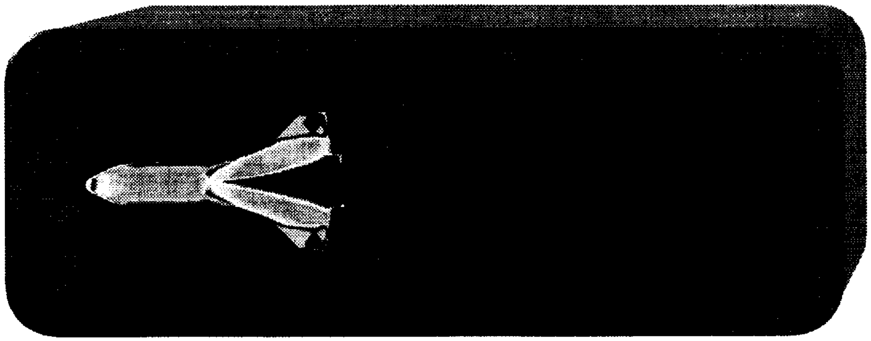
31-Inch Mach 10 Air Tunnel

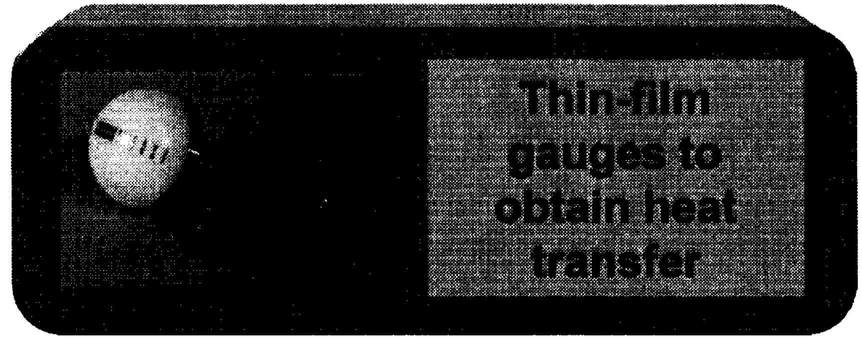


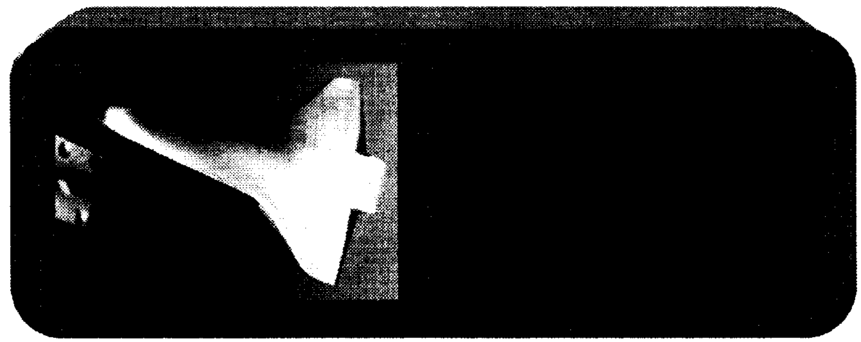
20-Inch Mach 6 CF_4 Tunnel (Mach 13-18 Real Gas Simulation)

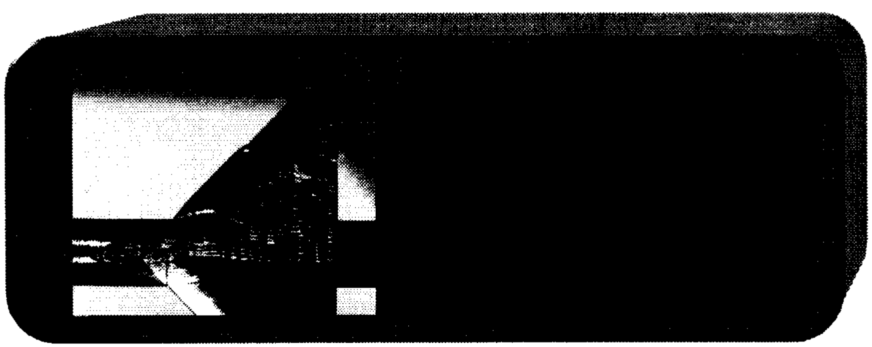
Airframe/TPS - Aerothermodynamics

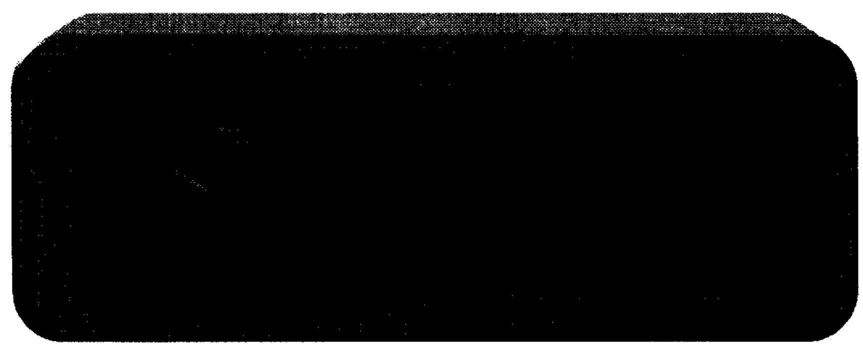
LaRC Subsonic-to-Hypersonic Wind Tunnels











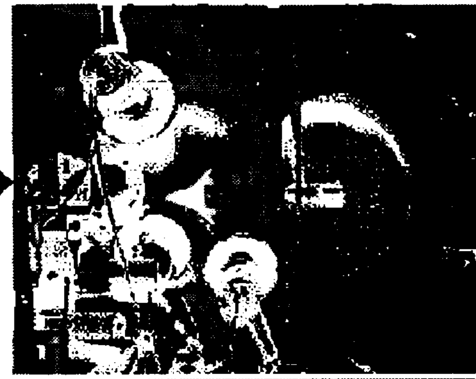
Airframe/TPS - Aerothermodynamics

Testing Techniques

Vehicle Concept

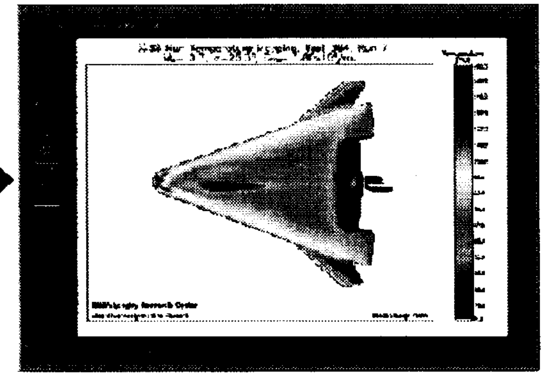
Model Fabrication

- Casting of ceramic models
- Rapid turnaround
- Complex shapes



Wind Tunnel Testing

- Two-color fluorescence
- State-of-art computerized acquisition system



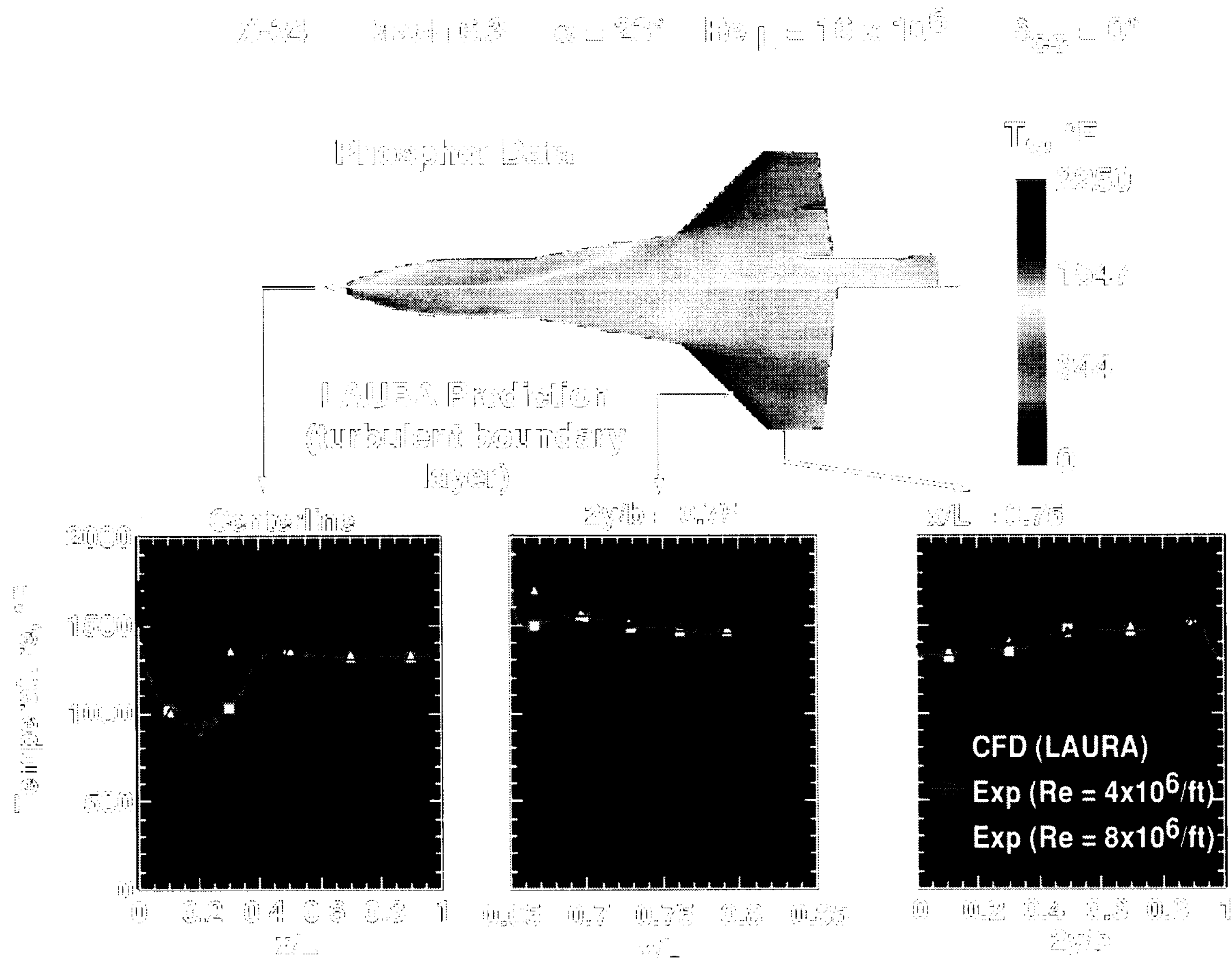
Analysis of Measurements

- Nonlinear theory to infer accurate temperatures
- User-friendly computer program (IHEAT)

Aeroheating data to customers

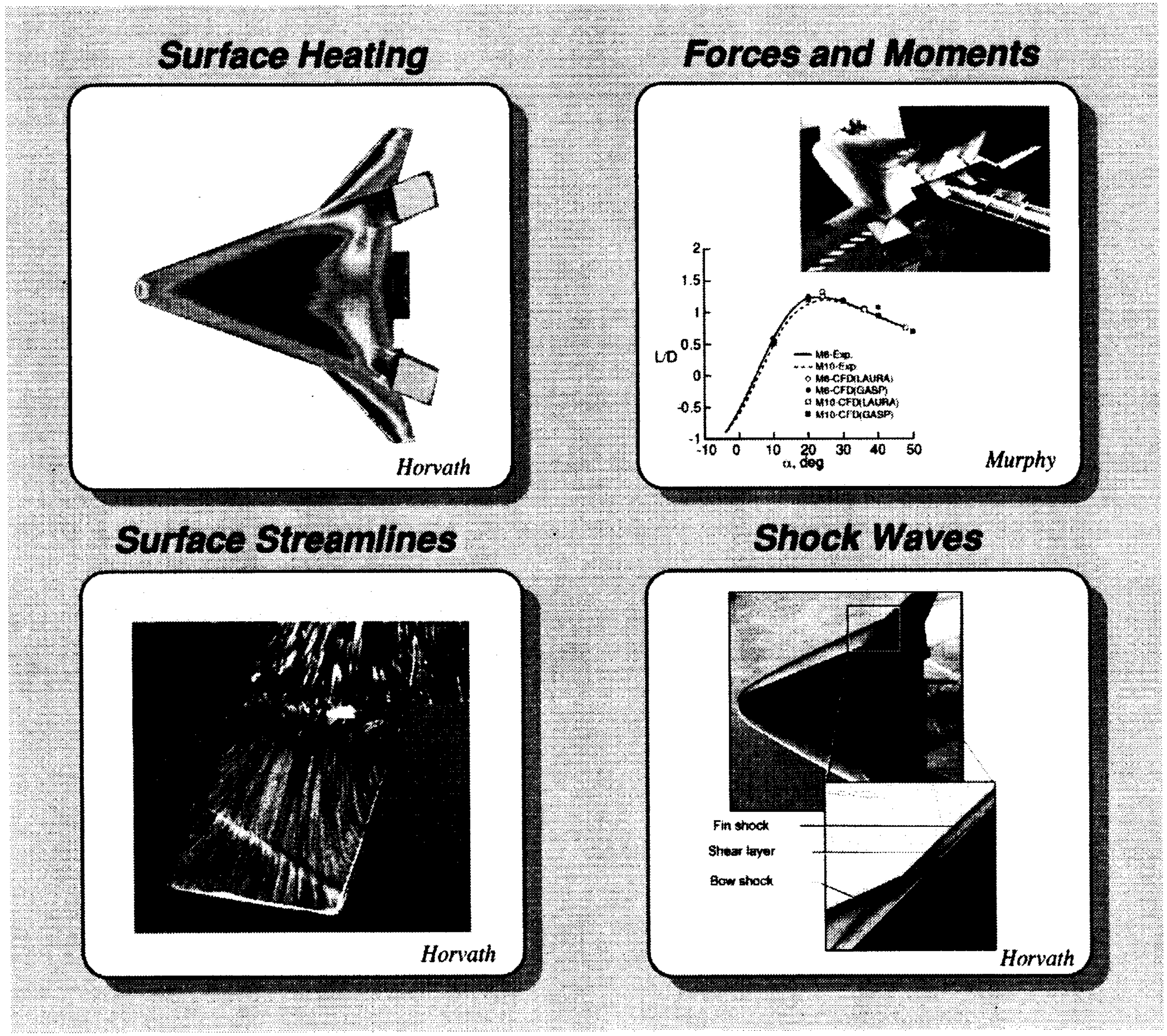
Airframe/TPS - Aerothermodynamics

Phosphor Thermography Process



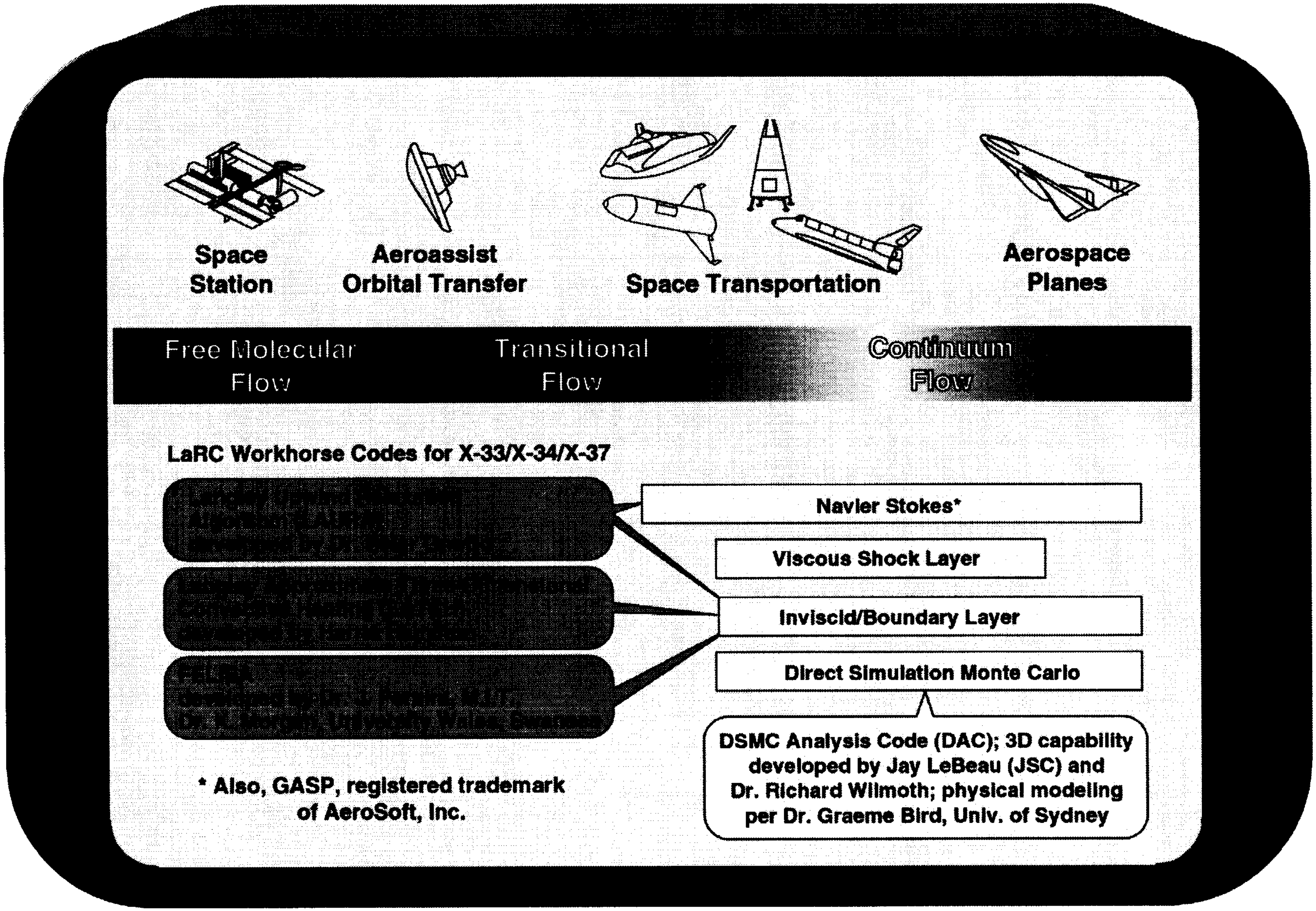
Airframe/TPS - Aerothermodynamics

Extrapolation of Measurements to Flight



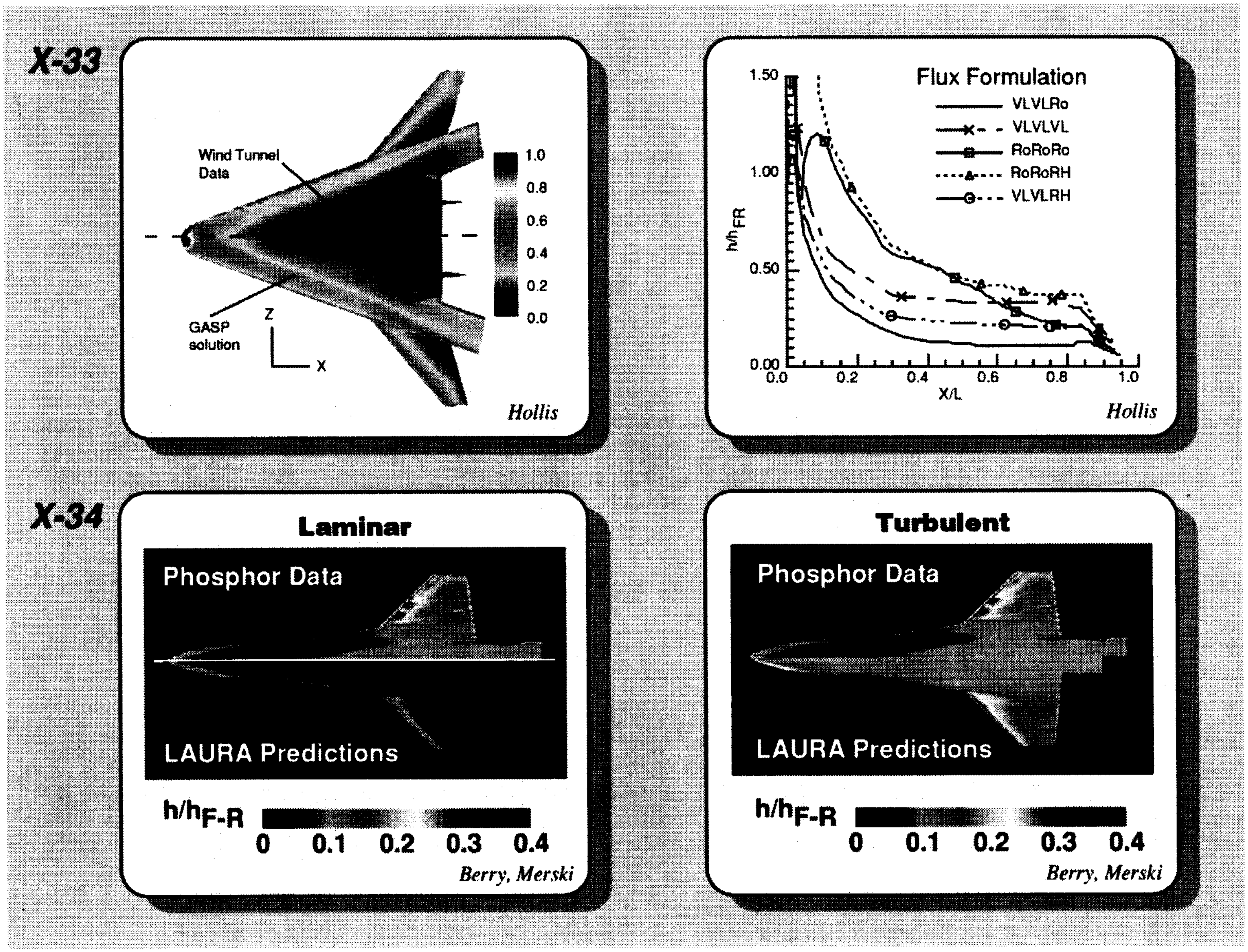
Airframe/TPS - Aerothermodynamics

Complementary Measurements: X-33



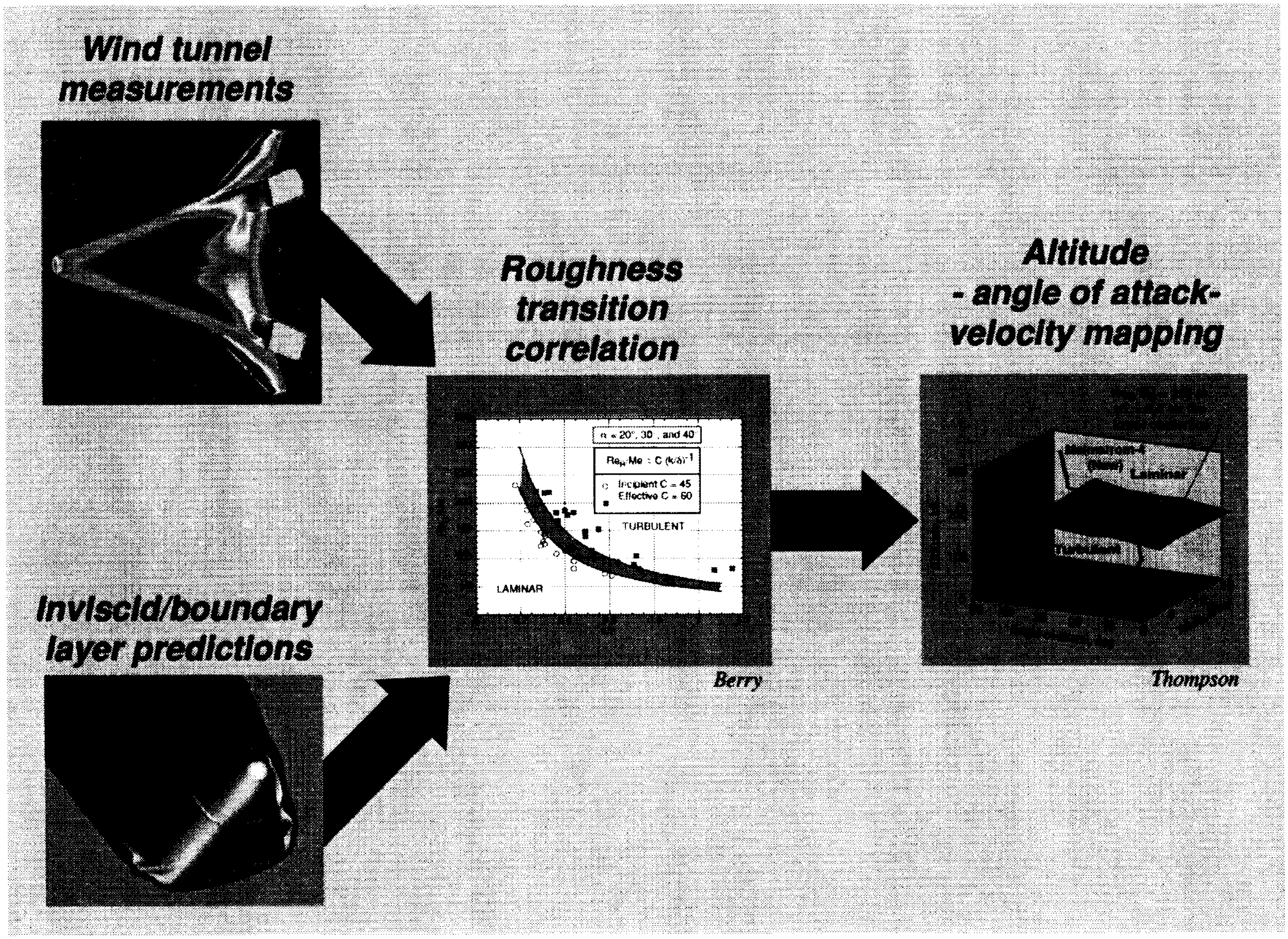
Airframe/TPS - Aerothermodynamics

Computational Fluid Dynamics (CFD)



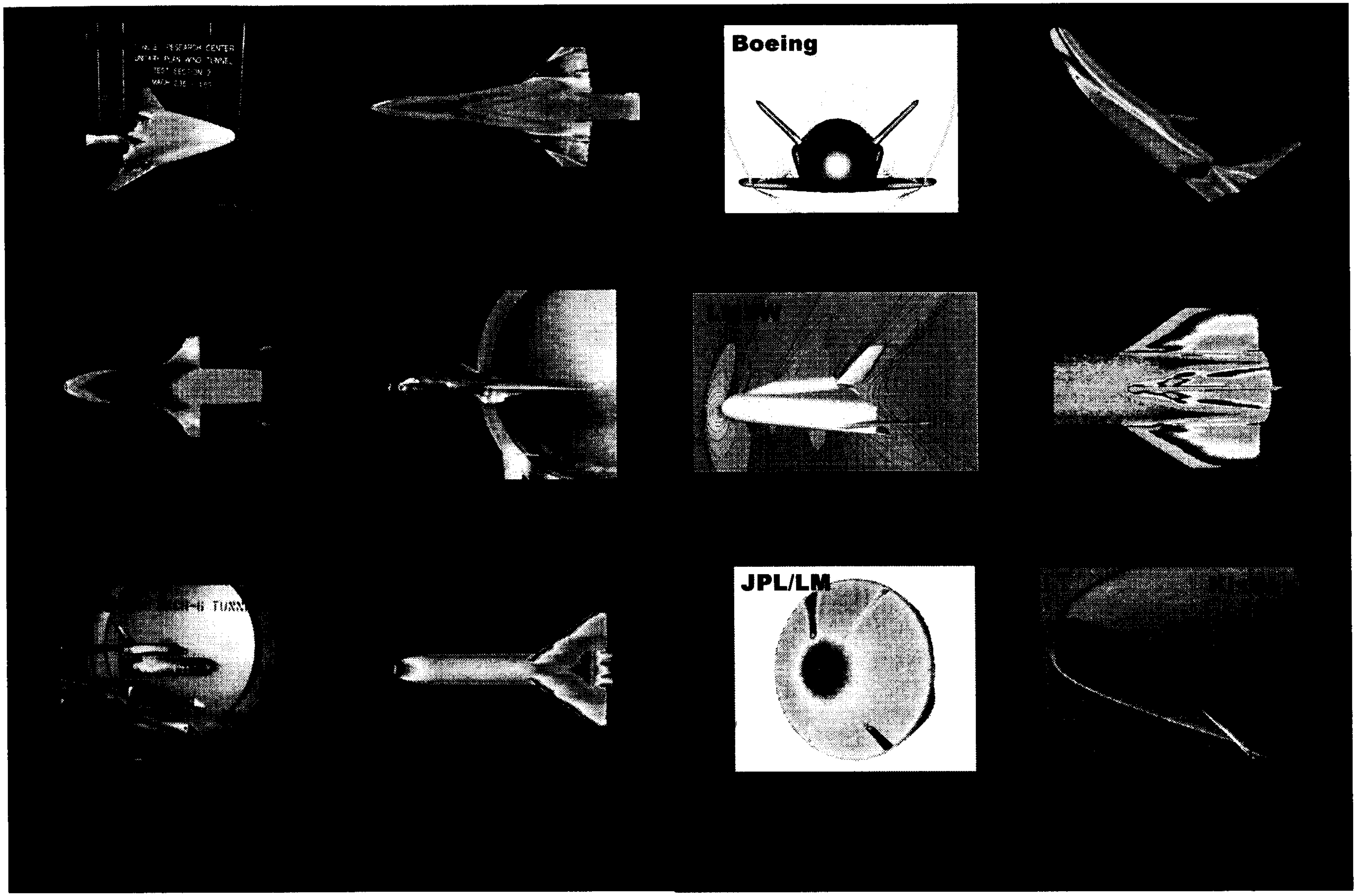
Airframe/TPS - Aerothermodynamics

Computational - Experimental Synergism



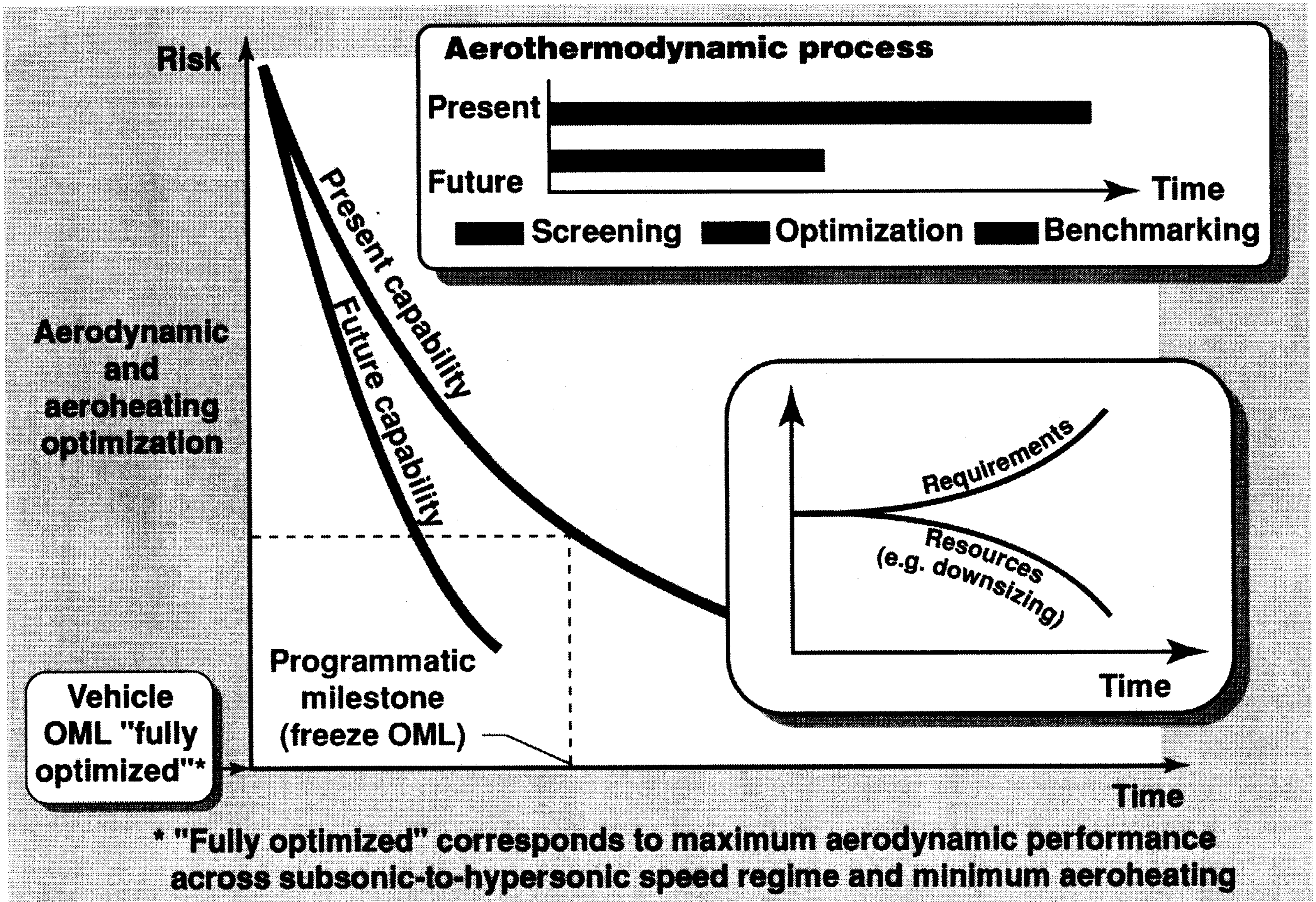
Airframe/TPS - Aerothermodynamics

X-33 Boundary Layer Transition Methodology



Airframe/TPS - Aerothermodynamics

Recent LaRC Aerothermodynamic Contributions

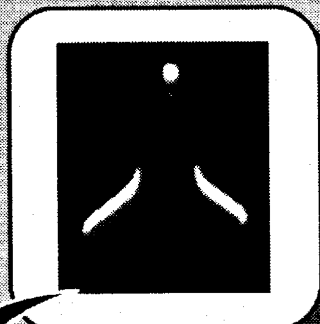


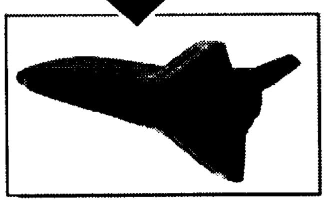
Aerospace Vehicle Design: Risk vs. Time

Calibration/validation of experimental and computational tools via comparisons to flight data

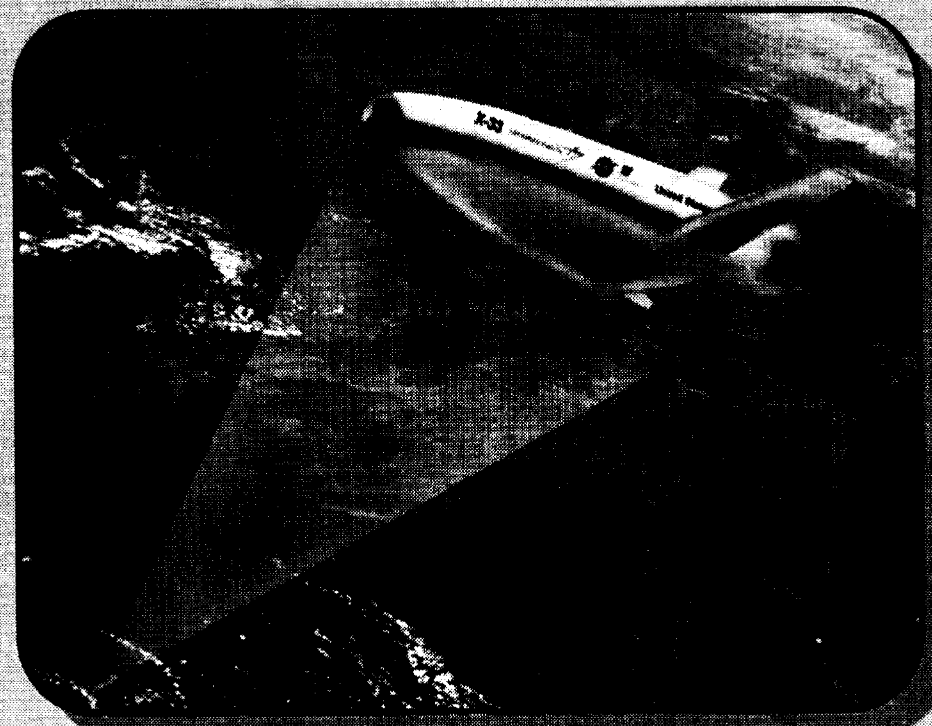
- **Aerodynamic performance/aeroheating characteristics extracted from flights**

BMDO/ISTEF
IR Image of
STS-96





LaRC Mapping
Code



Demonstrate on Orbiter
prior to X-33 application

On-board and off-board aeroheating measurements

Airframe/TPS - Aerothermodynamics

Future Plans

- "Review of X-33 Hypersonic Aerodynamic and Aerothermodynamic Development"; ICA-0323

  Richard A. Thompson, NASA Langley Research Center

  Presented at 22nd International Congress of Aeronautical Sciences, August 27 - Sept 1, 2000, Harrogate, United Kingdom

  Paper available:

  http://techreports.larc.nasa.gov/ltrs/PDF/2000/mtg/NASA-2000-22cicas-rat.pdf

  Extensive list of references

- Journal of Spacecraft and Rockets; Vol. 36, No. 2, Mar-Apr 1999
  Special Section: X-34; pages 153-239
  (collection of nine papers)

Reference Sources for Recent RLV Studies

- 12:45 - 1:00 Introduction 2nd Gen RLV Airframe — S. Welch
- 1:00 - 1:20 Airframe Design and Integration — S. Scotti
- 1:20 - 1:40 Aerothermodynamics — C. Miller
- 1:40 - 2:00 Structures and Materials — T. Johnson
- 2:00 - 2:20 Tanks — D. Smith
- 2:20 - 2:40 Thermal Protection Systems — M. Rezin
- 2:40 - 3:00 Integrated Airframe Demonstrations — D. Glass

- 3:00 - 3:05 BREAK

- 3:05 - 3:30 Introduction 3rd Gen RLV Airframe — D. Bowles
- 3:30 - 3:55 Integrated Design and Analysis — T. Gates
- 3:55 - 4:20 Integrated Thermal Str. & Materials — B. Jensen
- 4:20 - 4:45 Thermal Protection Systems — S. Johnson

2nd Gen Airframe/TPS - Structures and Materials:

Agenda