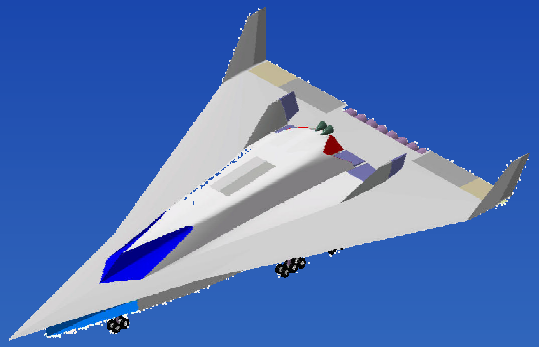
Engineering, Operations & Technology
Boeing Research & Technology

Routine & Affordable Access to Space

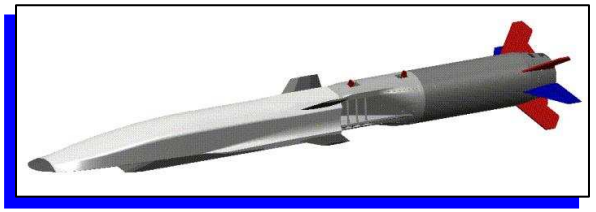


Hypersonics Industry Team Exhibition – Hypersonics Panel
Rosslyn, VA
24 May, 2011

Dr. Kevin G. Bowcutt
Senior Technical Fellow
Chief Scientist of Hypersonics
The Boeing Company

Possible Applications of Hypersonic Vehicles

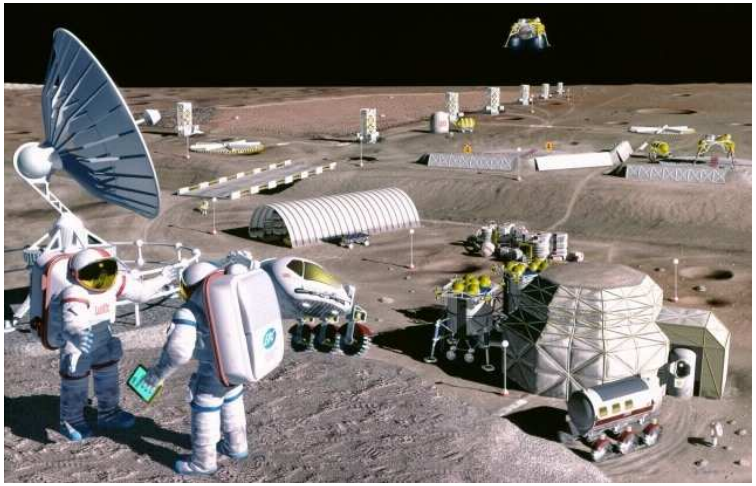
- High speed cruise missiles (Mach 6-8)
  - Hundreds of miles in minutes
  - High kinetic energy: lethality and penetration of hard / buried targets
  - High survivability (as stealth benefits wane)
  - Operational flexibility of air-breathing engines
- Rapid global transportation
  - Anywhere in the world in a few hours
  - Global strike and reconnaissance
  - Commercial passenger and/or cargo transport
- Routine, affordable, safe access to space
  - Smaller gross weight allows horizontal takeoff
  - Aircraft-like operations and maintenance
  - Operational flexibility and safety



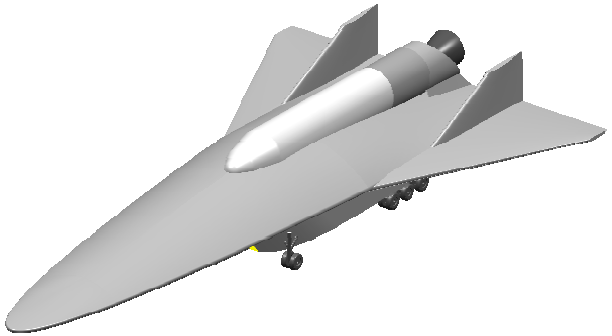
Looking Forward To Operational Hypersonic Systems … We Need A Less Expensive Way to Get to Earth Orbit!

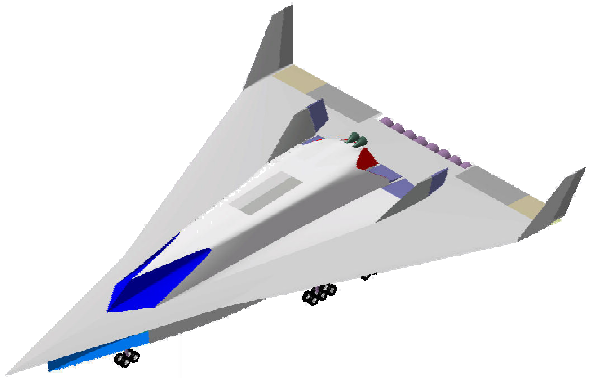
Current launch costs of $5,000 to $10,000 per lb would require tens of $B just to put manned space exploration payloads in low earth orbit

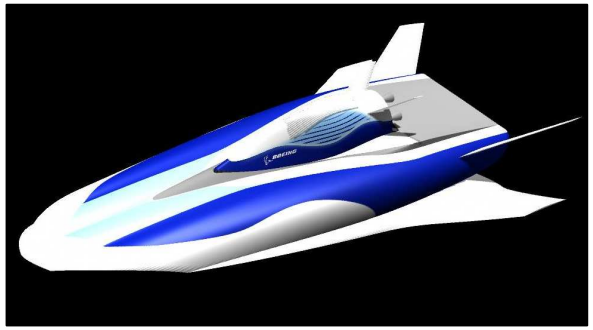
- **Reductions limited with expendable systems**

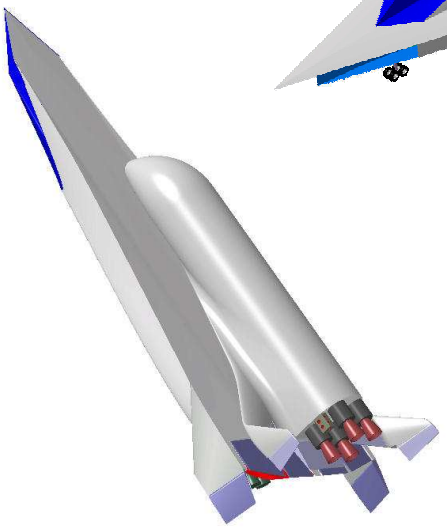


Reusability and Utilization Rate Are Primary Drivers of Launch Affordability









Launch costs as low as $200 to $500 per lb possible with a fully reusable system, high system utility, and sufficient markets

- **Hypersonic technology and horizontal launch beneficial to goal**

Possible Advantages of Airbreathing Launch Vehicles

- **Less propellant required**
  - **Permits increased dry weight to enhance system robustness/safety/reliability**
- **Less sensitive to dry weight growth**
- **Reduced gross weight**
  - **Airbreathing second stage reduces stage weight – results in smaller first-stage or larger orbital payload**
  - **Makes horizontal takeoff practical, increasing basing flexibility and reducing base vulnerability to attack**
- **Horizontal takeoff increases launch window, flight trajectory, and orbit flexibility**
- **Same technology required for hypersonic ISR aircraft and hypersonic missiles**
- **Viable growth path for ultimate single-stage-to-orbit**

Many Existing and Emerging Markets Can Be Addressed by an Affordable Launch System

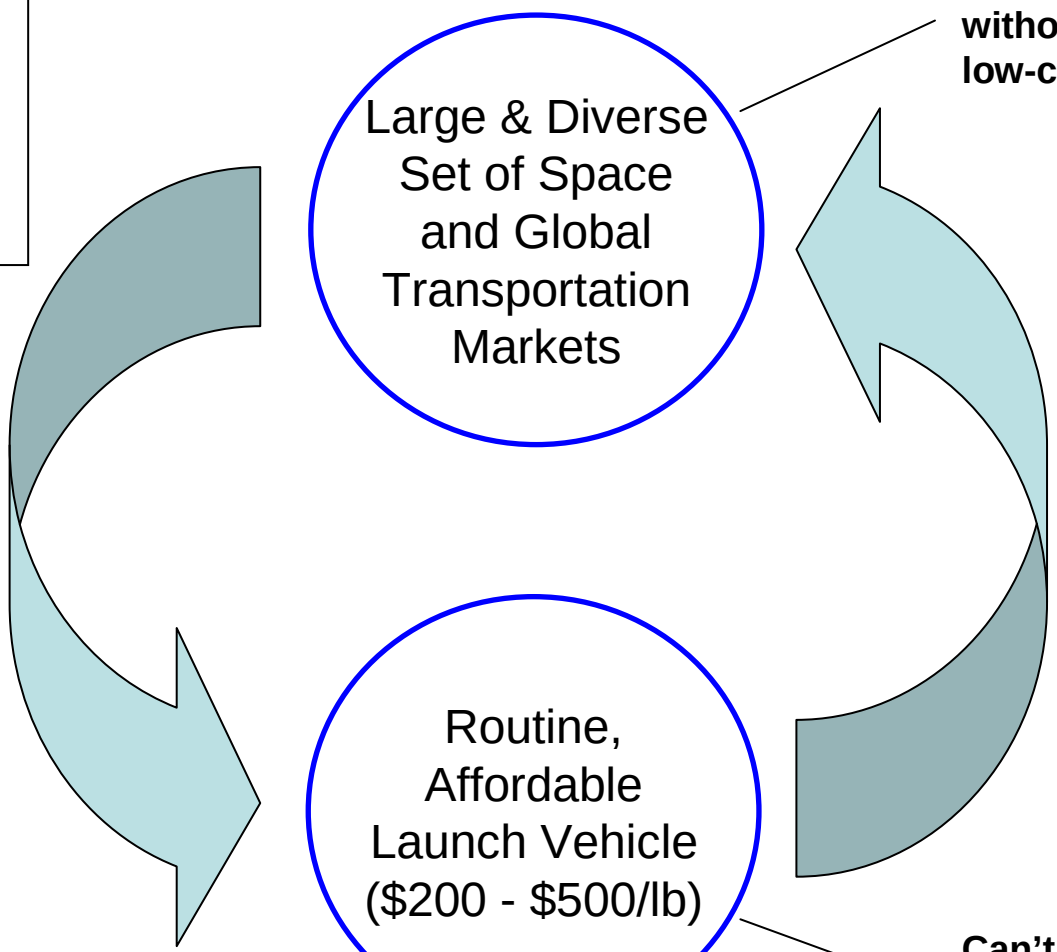
- **More responsive and lower cost satellite launch**
- **Affordable launch of space-based solar power hardware, space science and manufacturing payloads, ISS re-supply, modular space exploration hardware, satellite maintenance and repair, etc.**
- **Orbital and suborbital space tourism**

Same Technology Enables Hypersonic Aircraft

- **Responsive ISR to enhance or substitute for lost satellite capability**
- **Time-critical transport of personnel and cargo**
- **Business/first-class high-speed travel**

Space Transportation “Chicken or Egg” Dilemma

Q: How do we jump-start the low-cost launch / expanded space market cycle?



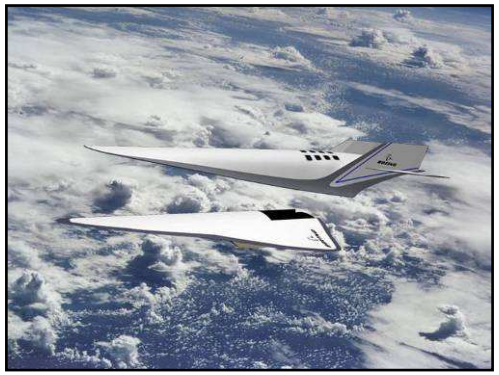
Can’t validate markets without first having a low-cost launch system

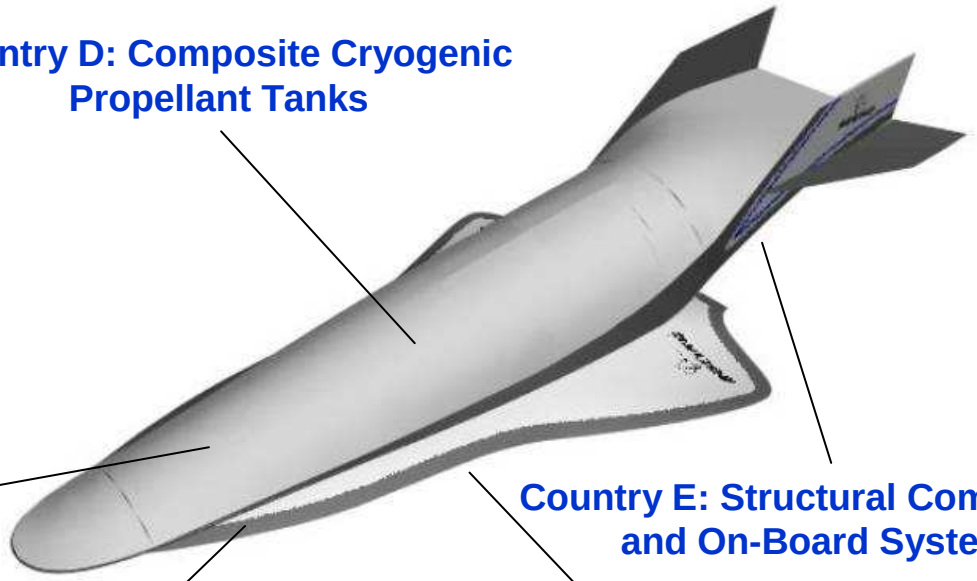
Can’t justify business risk without having validated markets

A Different Approach To “Closing The Business Case”

- **Joint commercial and governmental international venture**
  - **Access large pool of financial resources and global markets**
  - **Leverage knowledge, experience, financial and human resources of corporations, governments, and entrepreneurs**
- **Leverage existing space access and high-speed global travel ambitions and latent markets of several countries**
  - **United States, Europe, Japan, Australia, India, …**
- **Focused international research effort**
  - **Advance technical knowledge, technology maturation, system design, and operational approaches**
  - **Integrate analysis, simulation, ground test, flight experiments, and spiral flight demonstration (increasing scope and physical scale)**

International Approach to Hypersonic Transportation System Development May Be Required For Economic Feasibility





Country D: Composite Cryogenic Propellant Tanks

Country C: Primary Structure and IVHM

Country E: Structural Components and On-Board Systems

Country B: Thermal Protection Systems and On-Board Systems

Country A: Engines, Flight Controls, and System Integration

A Plausible Roadmap to Operational Hypersonic Systems

Engineering, Operations & Technology | **Boeing Research & Technology** **Platform Performance Technology**

2000 2005 2010 2015 2020 2025 2030 2035

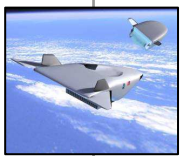
Enabled Capabilities

Regional Strike | Prompt Global Strike | Regional ISR | Routine & Affordable Space Access

Operational System Off-Ramps

Cruise and Boost-Glide Missiles

Theater Cruise Aircraft



TSTO Reusable Launch Vehicle

Flight Experiments and Demos

- **X-43A** - Heat-Sink H2 scramjet
- **X-51A** - Fuel-Cooled Hydrocarbon Scramjet
- **HIFiRE** - Multiple Experimental Payloads
- **Mid-Scale HXV** - Mid-Scale - Hydrocarbon Scramjet - TBCC
- **Large-Scale HXV** - Integrated RLV Prototype

System Design
CONOPS / NCO
Integration Studies

- **Missiles (Small / Large, Mid-Range / Long-Range)**
- **Regional ISR UAV**
- **TSTO RLV & High-Speed Pt-to-Pt Global Transport**

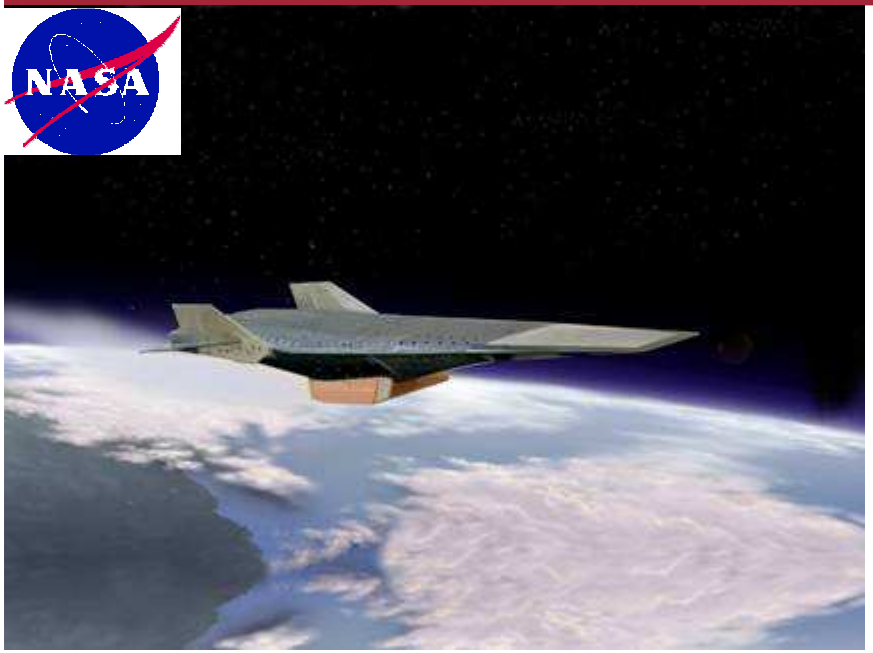
Enabling Technology Maturation

- **AFRL, NASA, DARPA, ONR, Industry**
- **HIFiRE**

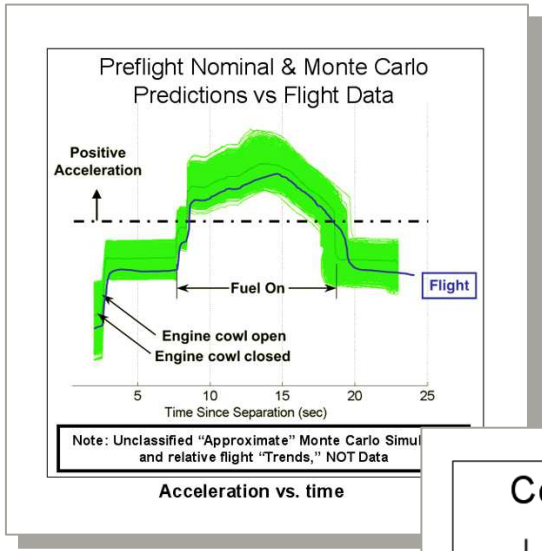
Fundamental Research

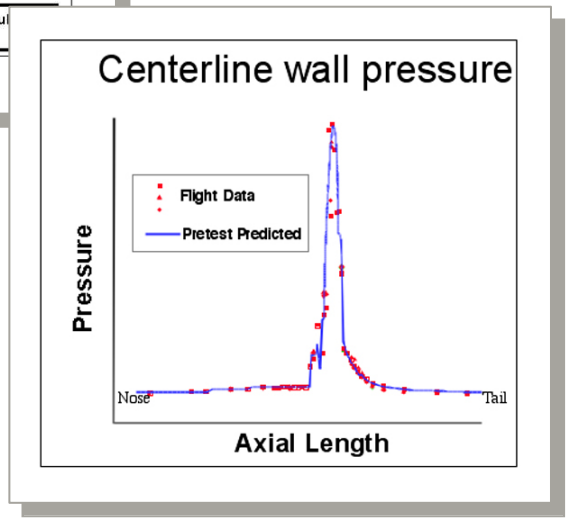
- **NASA NRAs**
- **AFOSR grants**
- **AFSOR-NASA National Hypersonic Science Centers**

X-43A: Scramjet Operation and Performance Proven in Flight



Two flights at Mach numbers of 6.83 and 9.68 achieved in 2004





Technical Objectives:

- **Hypersonic vehicle design risk reduction**
- **Flight validation of design methods**
- **Design method enhancement**

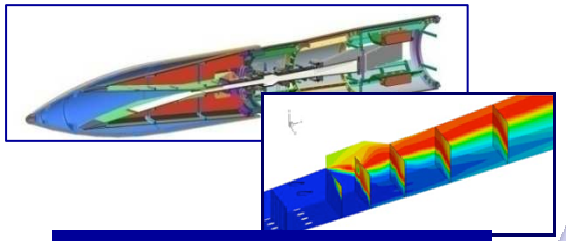
X-51A 1st Flight Accomplishments

- On its first flight in May 2010, an ATACMS booster accelerated X-51A WaveRider to ~ Mach 4.7, then a JP-7 scramjet engine accelerated vehicle to ~ Mach 5
- Reached an altitude of ~ 70,000 ft
- Experienced the longest scramjet burn time in history at ~ 140 sec
- Accomplished most test objectives
- Thrust, drag, trim, stability, and acceleration very close to predictions
- First operation of a practical, flight-weight hydrocarbon-fueled scramjet

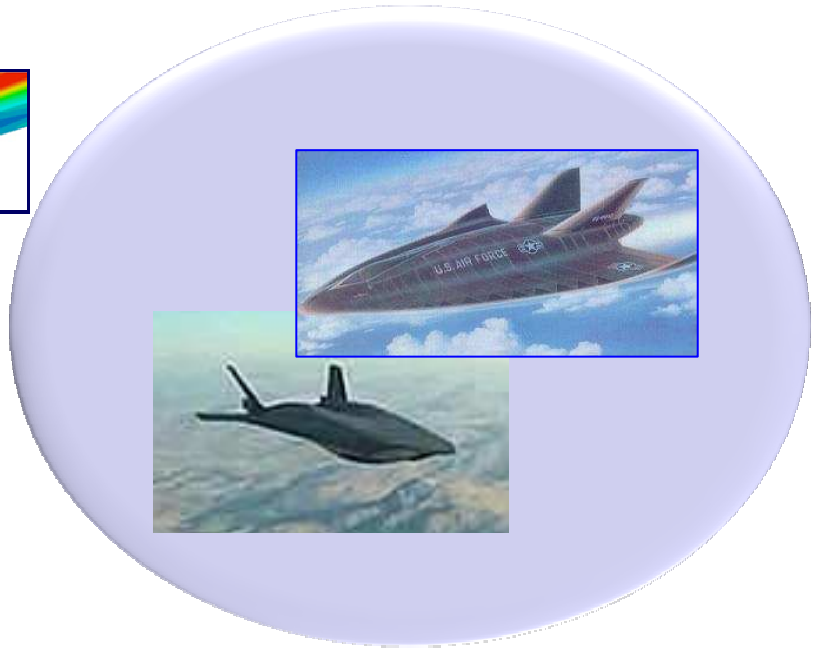
2nd flight scheduled for June 2011

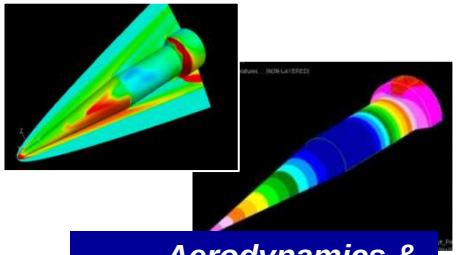
HIFiRE: Hypersonic International Flight Research & Experimentation

Joint US-Australian Flight Experiments Aimed at Fundamental Science Investigations and Enabling Technology Development for Hypersonics



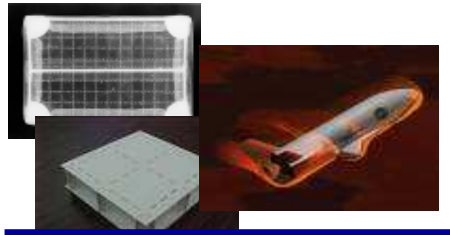
Propulsion and Aero-Propulsion Integration



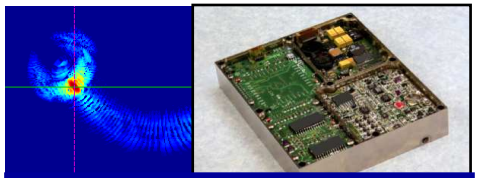


Aerodynamics & Aerothermodynamics

Leading Edges & Hot Structures



Thermal Protection Systems & Engine Structures



Seekers, Sensors and GPS

Integrated GNC

Summary

- **Enabling technologies for hypersonic vehicles are maturing rapidly via ground and flight test**
- **Hypersonic vehicles can provide valuable new capabilities for defense, space access, and global transportation**