Hypersonics R&D: Status in the U.S. and Other Nations

Mark J. Lewis
IDA Science & Technology Policy Institute

Presented to ASEB
National Research Council
10 October 2013

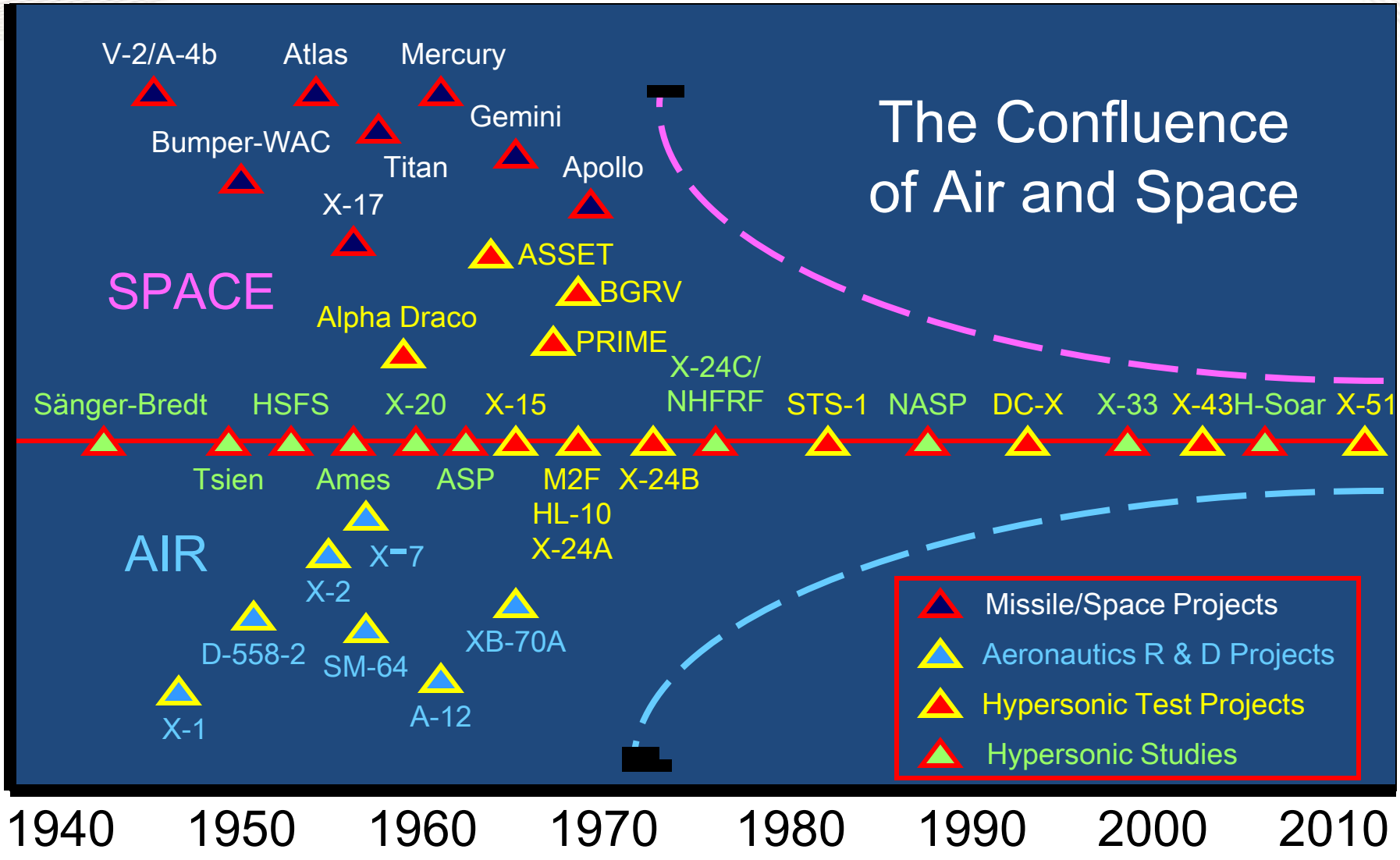
Key U.S. Program Status

- X-51A Waverider
  - Flight 4 success
  - Next steps?
- Prompt Global Strike
  - Advanced Hypersonic Weapon (AHW)
  - Hypersonic Test Vehicle (HTV-2)
- HIFire
- Fundamental Program (AFOSR)
- High Speed Strike Weapon (HSSW)

Current Studies

- STPI/OSTP Hypersonics Red vs. Blue Report
- Congressionally mandated hypersonic facilities review (OSTP, DoD, STPI)
- NRC Air Force Studies Board “Defense Against Hypersonic Systems” (Cappuccio, Lewis)
- USAF SAB

75 Years of Effort…



"Hypersonics is the Future…And It Always Will Be…"

G. Muellner

…70 Years' Consistent Endorsement…

- "Speed is imperative for effective action [and] safety against enemy counter-measures." T. von Kármán, *Science: Key to Air Supremacy*, (1946).

- "If the Air Force is to execute faster than an enemy in the 21st century, then… the only alternative is to go faster." *SAB, New World Vistas,* (1995).

- "Hypersonic air-breathing missiles allow large standoff ranges against fleeting targets....The Airborne Hypersonic Missile would open a new regime in the battlespace (range, speed, etc.) that provides the commander increased options." SAB, *Why and Whither Hypersonics Research* (2000).

- "A long range, survivable, cruise missile is needed in the near and mid-term to enhance survivability and to extend the reach of the current bomber fleet." SAB, *Long-Range Strike in Joint Force Missions* (2003).

- "Hypersonic missiles …could increase target timeliness and flexibility and thus increase operational utility in the 2018 time period." NRC, *Future AF Needs for Survivability* (2007).

From Gen Mark Welsh (AF/CC):

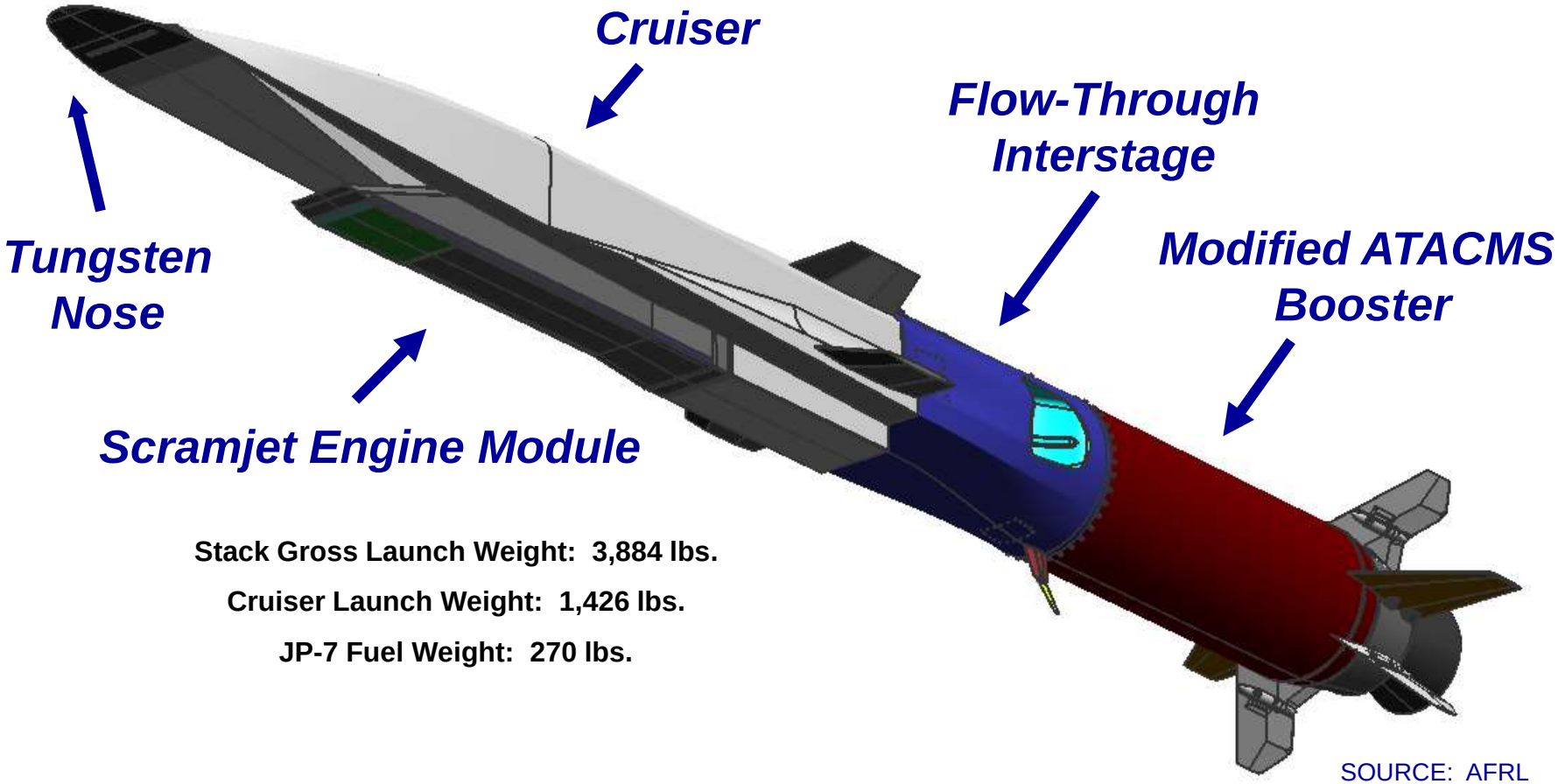
- “Speed really compresses kill chains, and real speed REALLY compresses kill chains.”
- “[Hypersonics will] make decision cycles tougher for the enemy.”
- “Hypersonics can rejuvenate the combat capability of our aging legacy aircraft force.”

What's New in the U.S.?

- X-51A fully successful, has taken the doubt out of scramjet propulsion!
- AHW fully successful, building on boost-glide expertise
- HTV-2 flights reminded us of continuing unknowns, importance of test and facilities
- General focus on weapon systems, finally learning lessons of the past
- USAF/DoD leadership acknowledging future role
- Engagement of Intel Community
- Asia-Pacific "pivot"
- NASA disengagement

For the World, X-51 is the Baseline

Cruiser length:		**168 inches**	**$240 million**
Overall Stack length:	**301 inches**		**5 minute flights**
Cruiser max width:	**23 inches**		**Flew 2012-2013**



Stack Gross Launch Weight: 3,884 lbs.

Cruiser Launch Weight: 1,426 lbs.

JP-7 Fuel Weight: 270 lbs.

SOURCE: AFRL

Developed & Flown <10 Years

PROPULSION

Subscale Performance Test

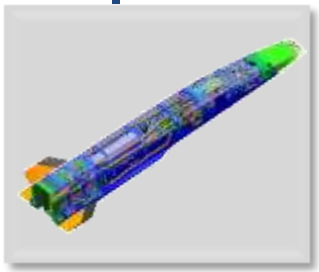
Full Scale Performance

X-51A Flight Clearance Test

FLIGHT TEST

2000 — 2005 — 2010

X-51A Wind Tunnel & CFD Complete



X-51A CAD Complete

X-51A Assembly Complete

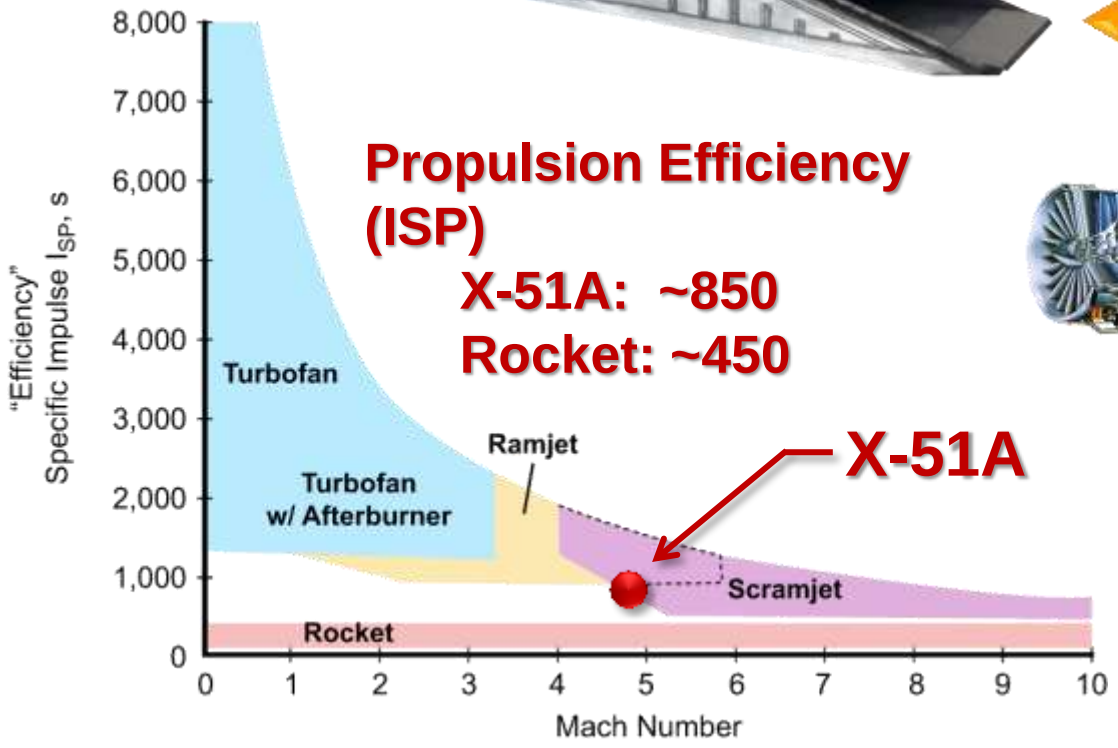
AIR VEHICLE

Advantages of Scramjets

(Efficiency)

- Greater efficiency

- Less Parts
- Less Weight



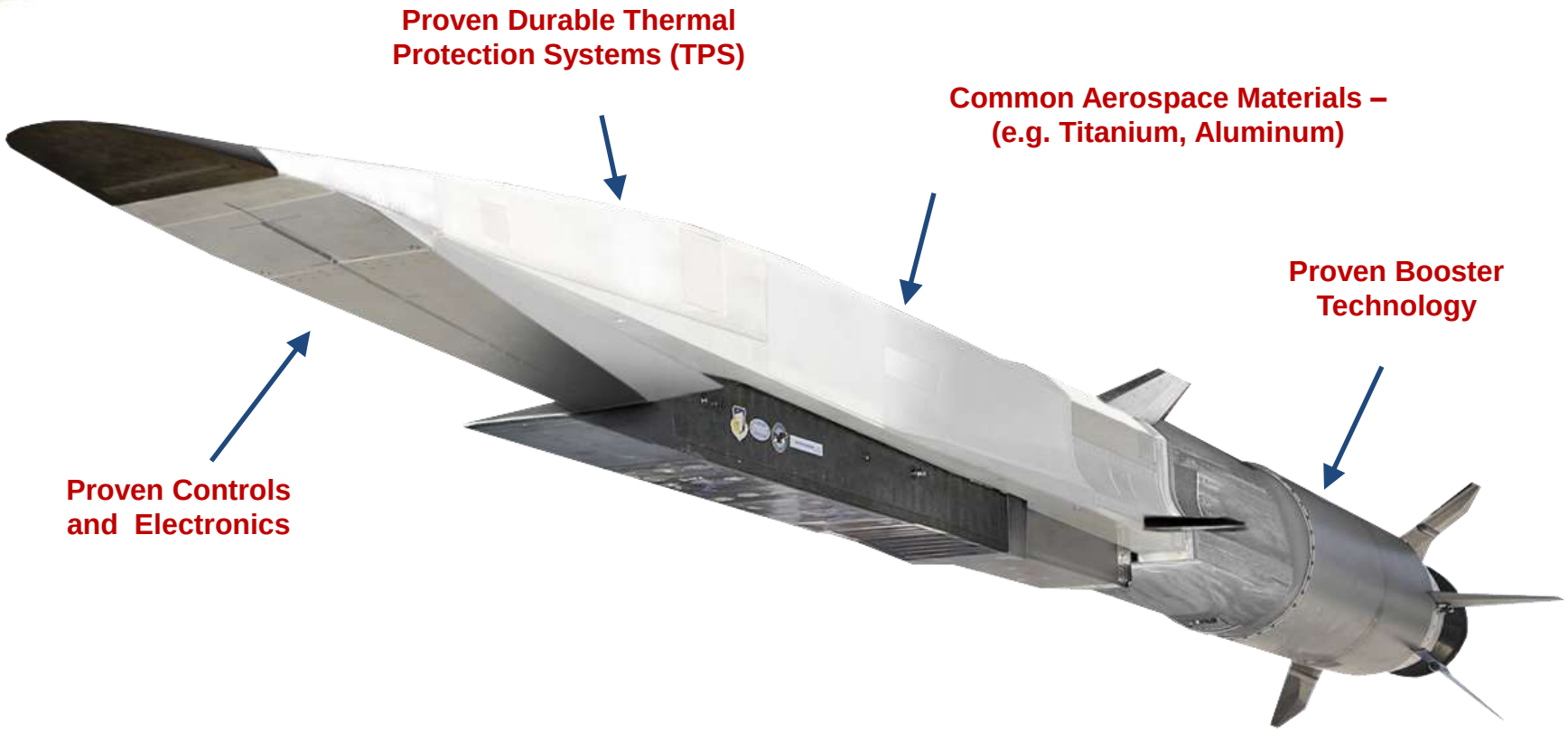
Propulsion Efficiency (ISP)

X-51A: ~850

Rocket: ~450

Air-breathing propulsion system with rocket like speeds that approaches efficiency of more complex high Mach turbofans

Optimized Air Vehicle Design



Optimally integrated airframe, engine and booster with thermal protection and flight control & guidance to overcome the demanding environment of hypersonic flight

X-51 Flight Test

Four X-51 Flight Tests

- Flight 1: 5/26/10: M = 4.87
  - 143 seconds powered: The “Kitty Hawk Moment”
- Flight 2: 6/13/11: Unstart at ignition
  - Resulted in refined fuel injection system
- Flight 3: 8/14/12: Fin failure at boost
  - Unrelated to hypersonic technology
- Flight 4: 5/1/13: M = 5.10
  - 240 seconds powered: The “Lindbergh Moment”

X-51 Team Receiving AFA John R. Alison Award

Right: Lt. Gen (ret.) George Muelner, AFA
Maj. Gen Tom Masiello, AFRL/CC
and Darryl Davis, Boeing Phantom Works

Below: X-51 government/industry team leads

In recognition of "the most outstanding contribution by industrial leadership to national defense."

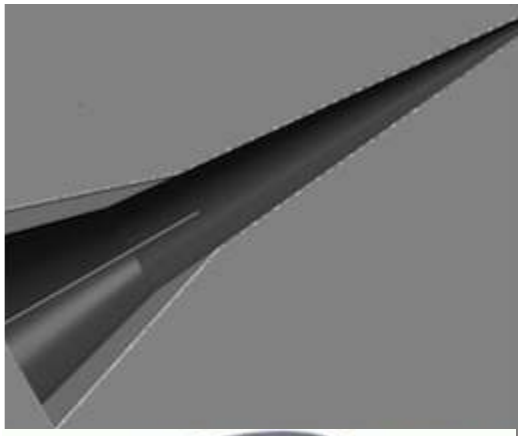
9 Sept. 2013

The Next Steps…

- *Move from TRL 4 to TRL 6-7*
  - *Sensors*
  - *Payloads*
  - *Configuration Options and Modularities*
  - *Platform Integration*
  - *CONOPS / Scenario "Test Againsts"*

Prompt Global Strike

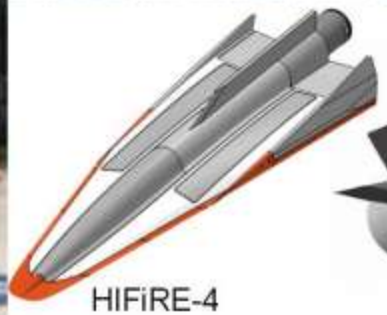
- Army/Sandia Advanced Hypersonic Weapon
  - Boost-glide, launched on a
  - Builds on Sandia's SWERVE legacy
  - Successful flight 17 Nov. 2011 at Reagan TS
- DARPA HTV-2
  - Lifting body
  - Vehicles flown, lost in 2010, 2012
  - Materials response, boundary layer transition behavior unexpected
  - New instrumentaiton techniques, exquisite flight-ground-CFD data comparisons
  - Decades-old assumptions proven wrong

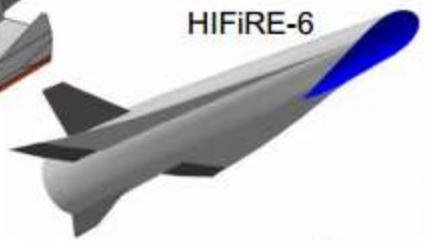


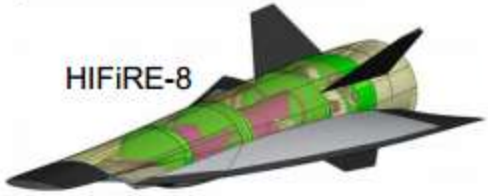
Hypersonic International Flight Research Experimentation Program

- Developed from AFOSR basic research program (Schmisseur, Dolvin)
- Goal is multiple low-cost flights, built around fundamental science
- Leveraging Woomera facility, University of Queensland HyShot experience
- AFRL, DSTO leads; NASA, Boeing
- Flights thus far:
  - May 7, 2009 – System shakedown
  - March 22, 2010 – Boundary layer transition
  - May 10, 2012 – hydrocarbon scramjet to Mach 8, 12 sec
  - Sept 13, 2012 - axi-symmetric hydrogen-fueled scramjet

HiFIRE Flight Tests







Foundational Hypersonic S&T

Past

First hypersonic flight data to capture shock interaction unsteadiness

Ongoing

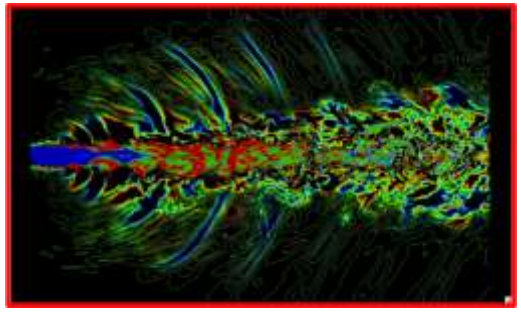
National Hypersonic Foundational Research Plan

Joint Technology Office – Hypersonics Basic Science Roadmap

Jointly-Sponsored National Hypersonic Science Centers

Office of Naval Research

Assessment of SOA and Future Research Directions



Basic Research for Understanding and Controlling Noise from High-Speed Jets

Driving a new scientific paradigm for high-speed flows

Future

AFOSR Strategic Vision

Innovation from other disciplines

Goal: Understand, Predict & Exploit Energy Dynamics

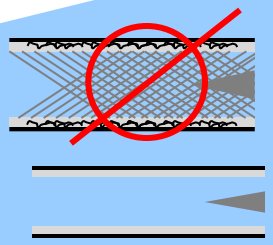
Sustainable Infrastructure for High Mach Science

New Insight Into Critical Fine-Scale Phenomena

Towards Model-Free Simulations

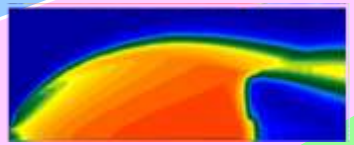
Facilities

Expansion Tubes – Study Noneq. Flows

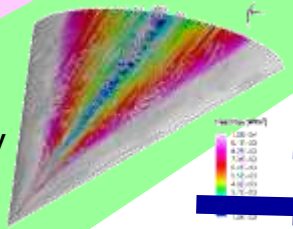


Quiet Tunnels

Ludwieg Tubes: Mach 6 at low cost



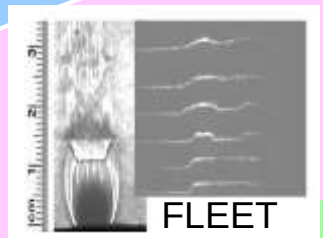
VENOM



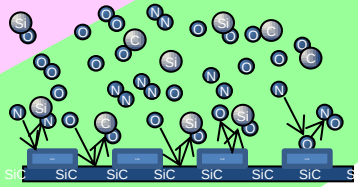
High-Fidelity CFD

Tech Transition

Diagnostics



FLEET



GSI

Unprecedented Insight into Critical Molecular- and Micro-Scale Phenomena

Simulations

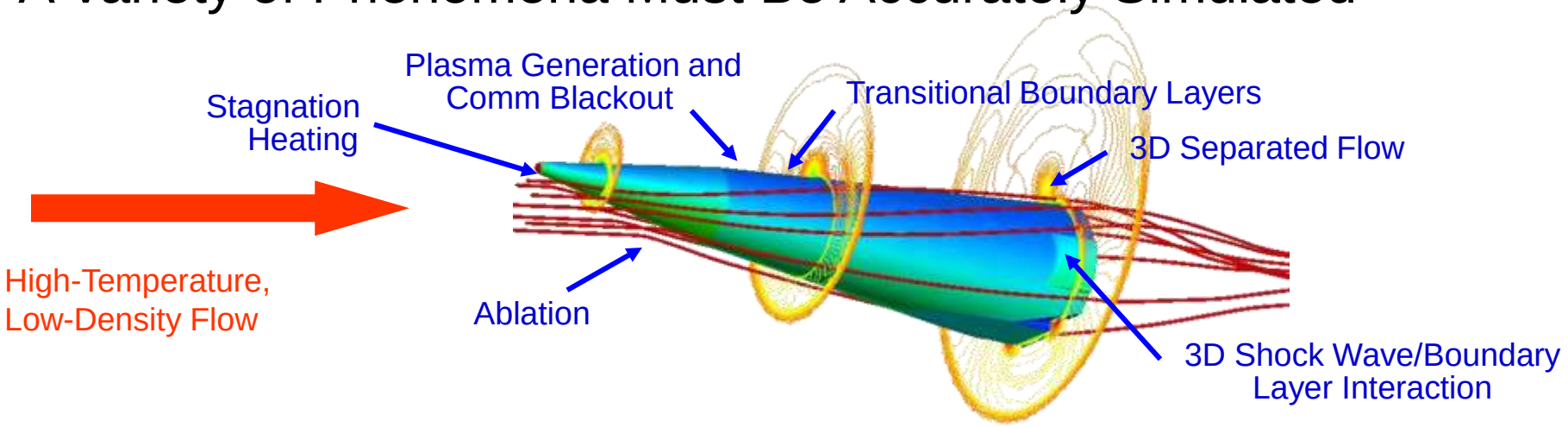
Accel. MD

Hypersonics is More Than Aero…But that's Where it Starts

Aerothermodynamic Base State

- **Aero Performance**
  - Range
  - Agility
- **GN&C**
  - Control Effectiveness
- **Com and Signature**
  - Plasma Generation
- **Thermal Protection**
  - Surface Heating
- **Surface Response**
  - Change in Aero,TPS requirements
- **Engine Inflow Condition**

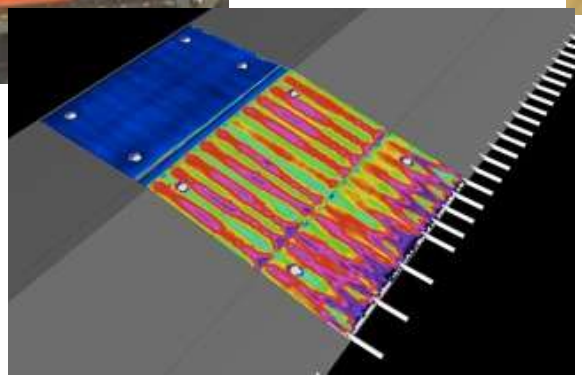
A Variety of Phenomena Must Be Accurately Simulated



USAF/TRMC Hypersonic T&E Workforce

Pilot program funded by AFOSR, TRMC, AEDC in conjunction with Univ. of MD placing U.S. students and faculty at one of the nation's premiere hypersonic tunnels

Funding in place for dedicated experiments, Instrumentation development, CFD



AEDC Hypervelocity Tunnel 9

Mach 7-14, High Re Blowdown design
5 ft test section, 1900 atm,
15 second run time, dynamic sweep

Congressionally-Directed Hypersonics Study and Report

*2013 NDAA Study Requirement **

Section 1071: STUDY ON ABILITY OF NATIONAL AIR AND GROUND TEST AND EVALUATION INFRASTRUCTURE FACILITIES TO SUPPORT DEFENSE HYPERSONIC TEST AND EVALUATION ACTIVITIES.

*The **Director of the Office of Science and Technology Policy**, working with the Secretary of Defense and the Administrator of the National Aeronautics and Space Administration (NASA), **shall conduct a study on the ability of the national test and evaluation infrastructure**, including ground test facilities and open air ranges of the Department of Defense, and leveraging NASA and private facilities, when appropriate, **to effectively and efficiently mature hypersonic technologies for defense systems development in the short and long term**.*

* Section 1071 requirements supersede the hypersonic T&E infrastructure study directed in the Senate Report 112-173

Congressionally-Directed Hypersonics Study and Report

2013 NDAA Reporting Requirements

- **REPORT AND PLAN:**

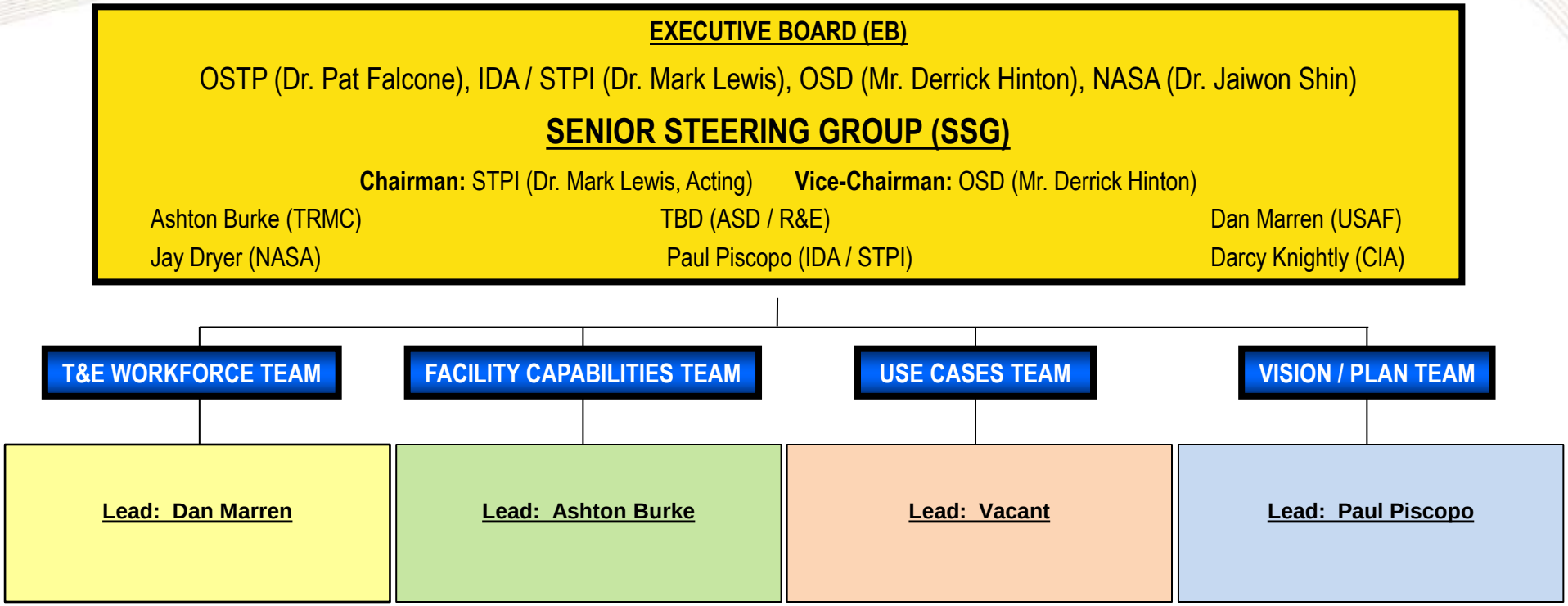
*Not later than **one year** after the date of the enactment of this Act, **the Secretary of Defense shall submit** to the appropriate congressional committees **a report…together with a plan** for requirements and proposed investments **to meet DoD needs through 2030**.*

- **Planned Content:**

1. *An **assessment of the current condition and adequacy** of the hypersonics test and evaluation infrastructure within the Department of Defense, NASA, and the private sector to support hypersonic research and development within the Department of Defense*
2. *An **identification of test and evaluation infrastructure outside the Department of Defense that could be used** to support Department of Defense hypersonic research and development and assess means to ensure the availability of such capabilities to the Department in the present and future*
3. *A **time-phased plan to acquire required** hypersonics research, development, test and evaluation **capabilities**, including identification of the resources necessary to acquire any needed capabilities that are currently not available*
4. *Other matters the Secretary determines are appropriate*

Congressionally-Directed Hypersonics Study and Report

Overall Integrated Study / Report Team Organizational Structure



Hypersonic Ground Test Centers and Facilities

AEDC Tunnel 9

AEDC VKF Tunnel B

AEDC H2 Arc Jet Heater

AEDC

NASA Langley

AFRL

NASA Ames

AEDC APTU

LaRC 8' HTT

ATK-GASL Test Bay 4

Holloman HSTT

Sandia HWT

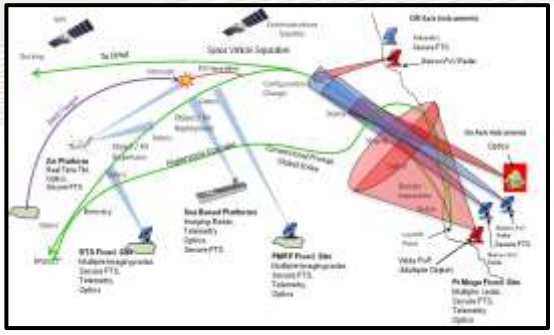
CUBRC LENS

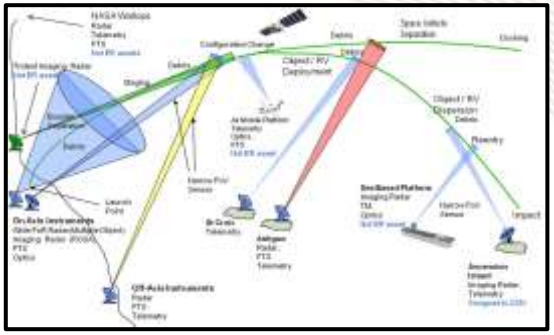
Boeing PWST

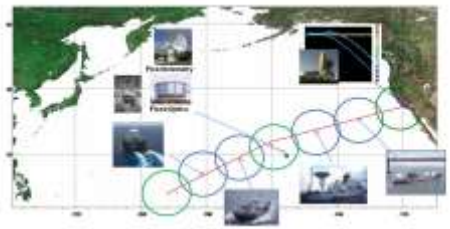
L-M HSWT

Purdue Quiet Tunnel

Hypersonic Open-Air Ranges







International Efforts

- China
- Russia
- India
- France
- Germany
- Australia
- Japan

China (cont.)

- China Ministry of Science and Technology has listed hypersonics as one of 16 national "megaprojects."
  - Indication of significant state prioritization
  - One of the three that are defense-related
- Building wind tunnels, including world's largest shock tunnel
  - Scramjet tests at Mach 5 to 9
  - 260m length, 3.5 m test cell, 100 msec test time

Chinese Academy of Sciences 260m Shock Tube

China (cont.)

- Flight Tests: Shenlong Space Operations Vehicle
  - Photos on internet 2007
  - Looks much like X-34
  - Developed by Chengdu Aircraft Industries (also building J-20 fighter)

- Actively publishing and presenting
  - Approx. 1/3 of papers at AIAA Hypersonics Meeting
  - Research heavily focused on Mach 6-7 cruise missiles
  - Many universities involved, with well-focused research groups

Russia

Russia

- Significant support from Deputy Prime Minister Rogozin
  - "…should be raised to highest state level"
  - "breakthrough comparable to nuclear weapons"
- Already developing weapons:
  - Naval cruise missile Tsirkon
  - Hypersonic Glide Vehicle
  - Hypersonic BrahMos with India
  - Hypersonic cruise missile for nextgen bomber

India

- Enthusiastic about hypersonics but limited apparent indigenous capability
- Building a Mach 5-12 freejet facility to test scramjets
- Believed to be pursuing hypersonic cruise missiles, space access
  - Reusable launch vehicle technology demonstrator
  - Hypersonic technology demonstrator vehicle , Intended to pave the way for a Mach 6.5, 1,500 kg cruise missile
  - Hypersonic BrahMos with Russia

France

- Lyotnii Experimentalnii Apparat (LEA)
  - French vehicle design
  - Russian testing
  - Mach 4, 6, 8
  - Flights in 2014-15
  - Delayed 1 year

- Wind tunnels
- MBDA focused on ramjet-powered missiles

Path Forward

- Establish a requirement for a high-speed weapon system (fish or cut bait)
- Congressionally-mandated report will include recommendations on a robust, sustainable, and integrated national T&E capability (including workforce)
- NASA future is uncertain, leadership support exists, but applications tied to DoD mission