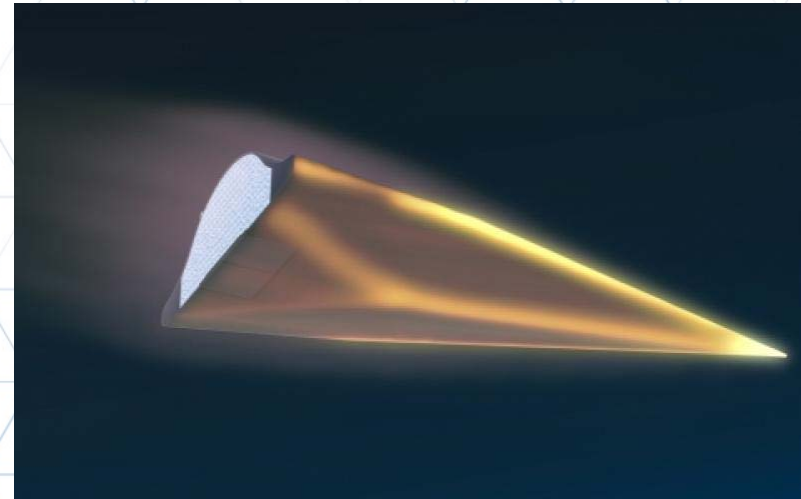


Do Emerging Hypersonic Applications Drive New Test and Telemetry Needs?

Presentation for the 2018 Defense and Aerospace Test and Telemetry Summit

4-7 June 2018

David Van Wie
The Johns Hopkins University
Applied Physics Laboratory
Laurel, Maryland



What is Hypersonics?

Accepted Definition: $Mach\ Number = \frac{Velocity}{Speed\ of\ Sound} > 5$

Supersonics versus Hypersonics

- “Super” and “Hyper” both mean “more than” in Latin and Greek, respectively
- No sharp delineation exists between phenomena occurring at supersonic and hypersonic speeds
- The term “hypersonics” has come to refer to all aspects of vehicles flying at hypersonic speeds

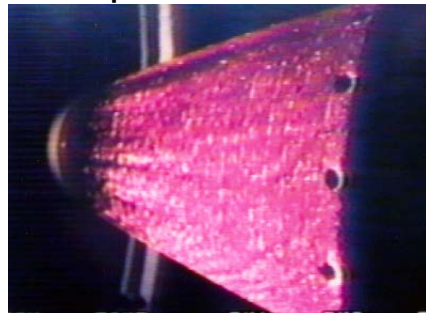
Key Hypersonic Phenomena

Slender vehicles with thin hot shock layers



Waverider test at University of Queensland

High aerothermal loads with high temperature structures



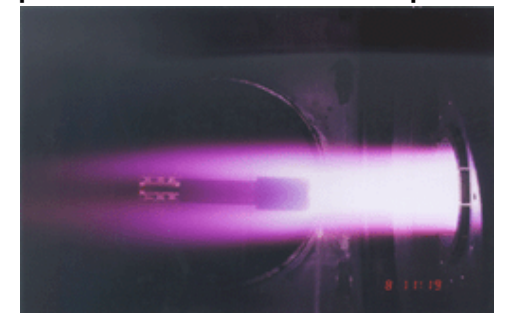
Missile nosecone test Mach 6 conditions

Scramjet engines for sustained powered flight



HyFLY engine test at NASA/LaRC

Unique ground test facilities with imperfect simulation capability



Materials test in VKI Plasmatron facility


Do Emerging Hypersonic Applications Drive New Test and Telemetry Challenges?

- Emerging hypersonic applications
- Sample challenges associated with development of hypersonic systems
- Challenges with flight test instrumentation and telemetry
- Summary and conclusions


Hypersonics: A Wide Diversity of Technologies, Systems and Applications

Demonstrated


Low- β Re-entry Vehicle: Apollo




Space Access






High- β Re-entry Vehicles




Missile Interceptors




Cruise Missiles




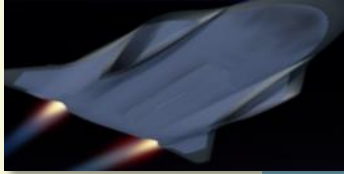
X-15




Boost-Glide Vehicles




Airplanes



Space Access



Hypervelocity Projectiles



Emerging

Hypersonic systems have existed for many years, but new classes of hypersonic systems are emerging

Hypersonics for Space Access

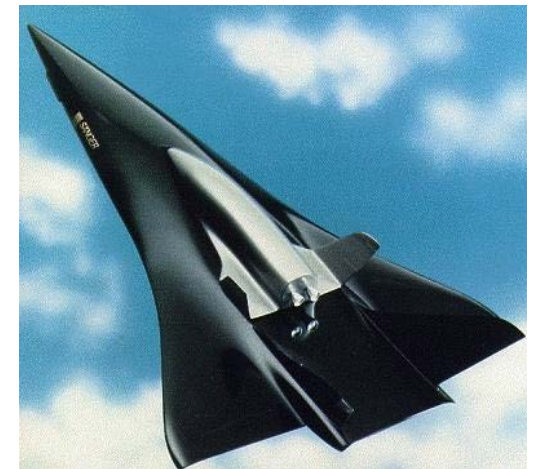
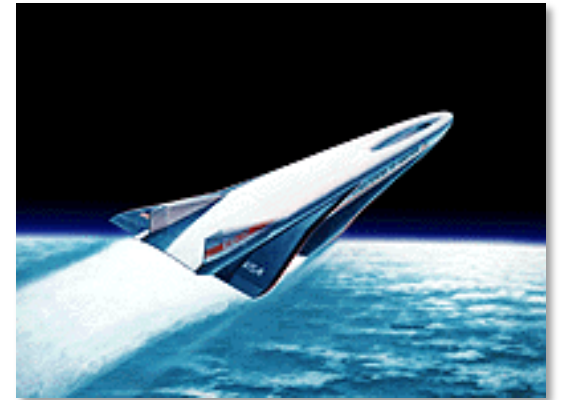
1st Generation Re-Usable Space Launch



Hybrid Space Launch Capability



Fully Re-Usable Space Launch Capability



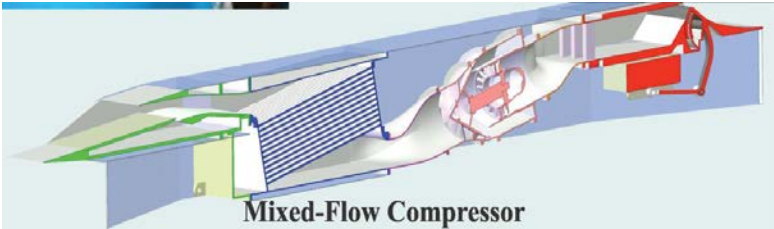
Hypersonic Aircraft



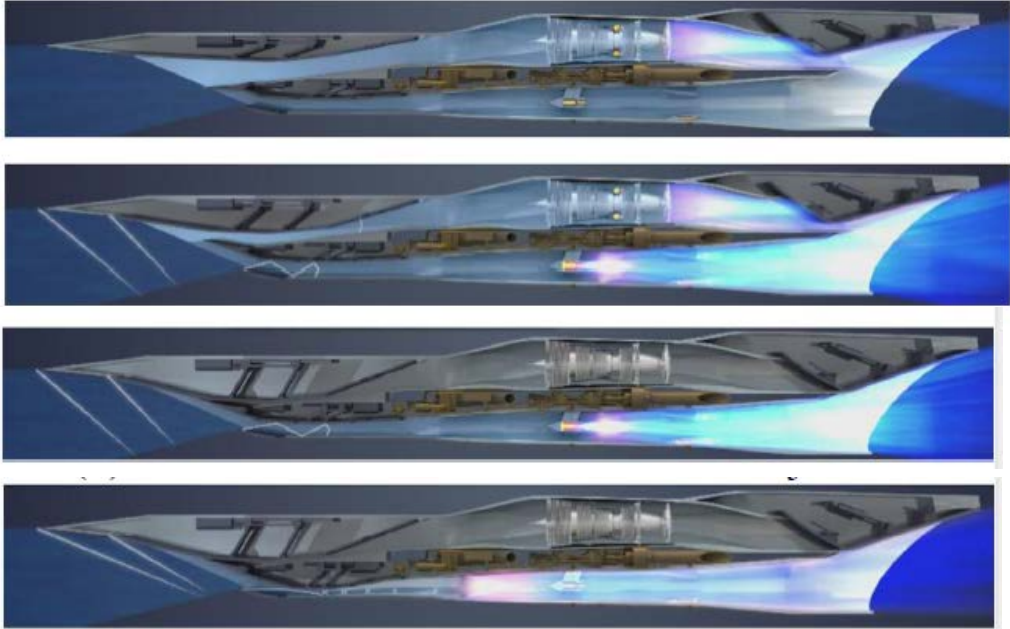
Sabre Engine



JAXA Pre-cooled Turbojet



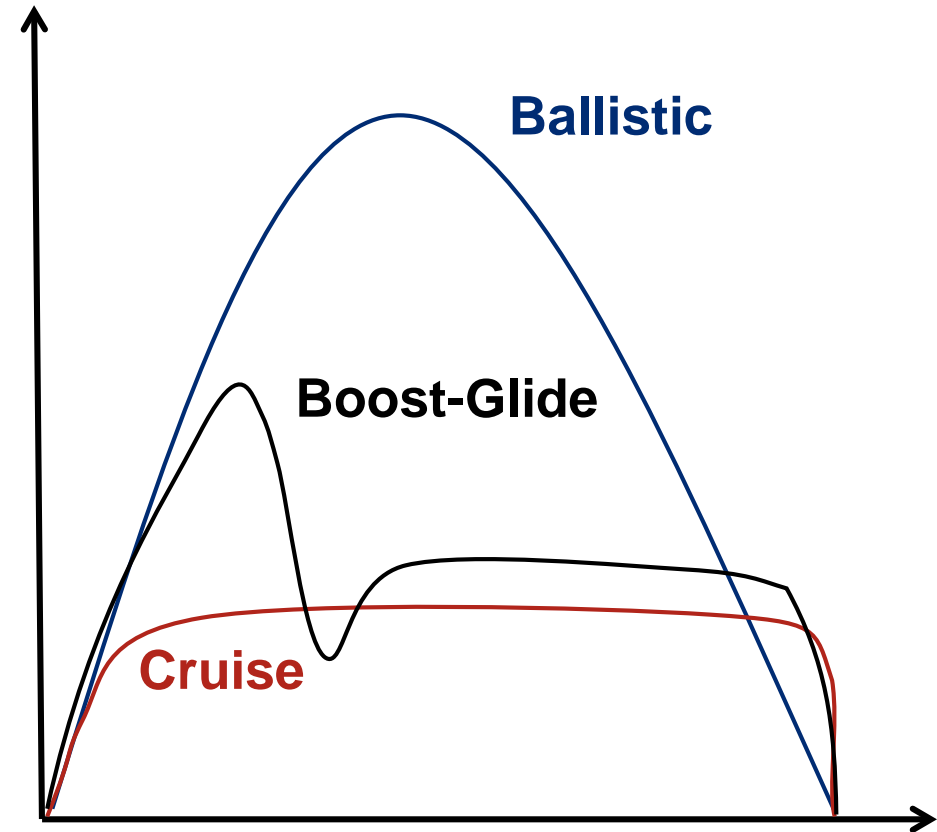
Turbine-Based Combined Cycle Engine



Hypersonic Transatmospheric Weapons

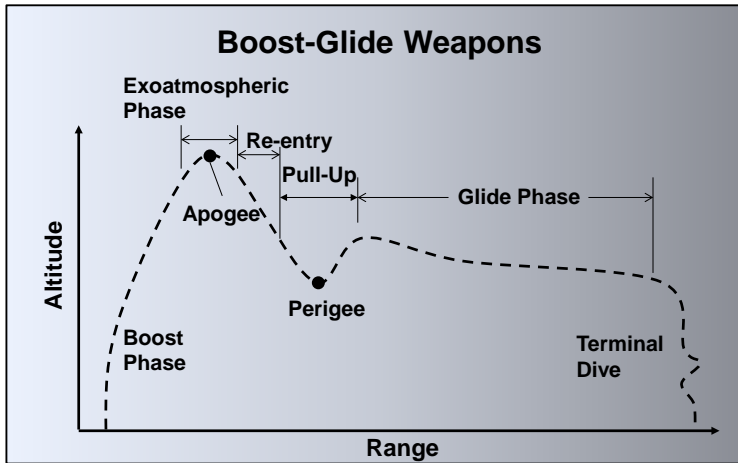
Class	Range (km)
Tactical Ballistic Missile	< 300
Short –Range Ballistic Missile (SRBM)	< 1000
Medium Range Ballistic Missile (MRBM)	1000 - 3000
Intermediate Range Ballistic Missile (IRBM)	3000 - 5500
Intercontinental Ballistic Missile (ICBM)	> 5500
Fractional Orbital Bombardment System (FOBS)*	∞
Theater Ballistic Missile (TBM)	< 3500

Near-Space or Trans-atmospheric Weapons



Hypersonic Weapons

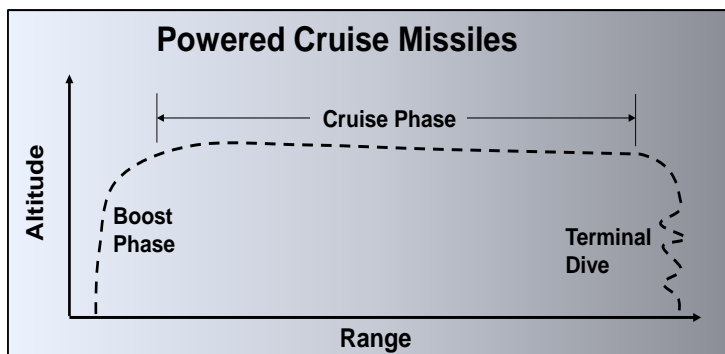
Unpowered Glide Vehicles Boosted to Mach 10+ Conditions



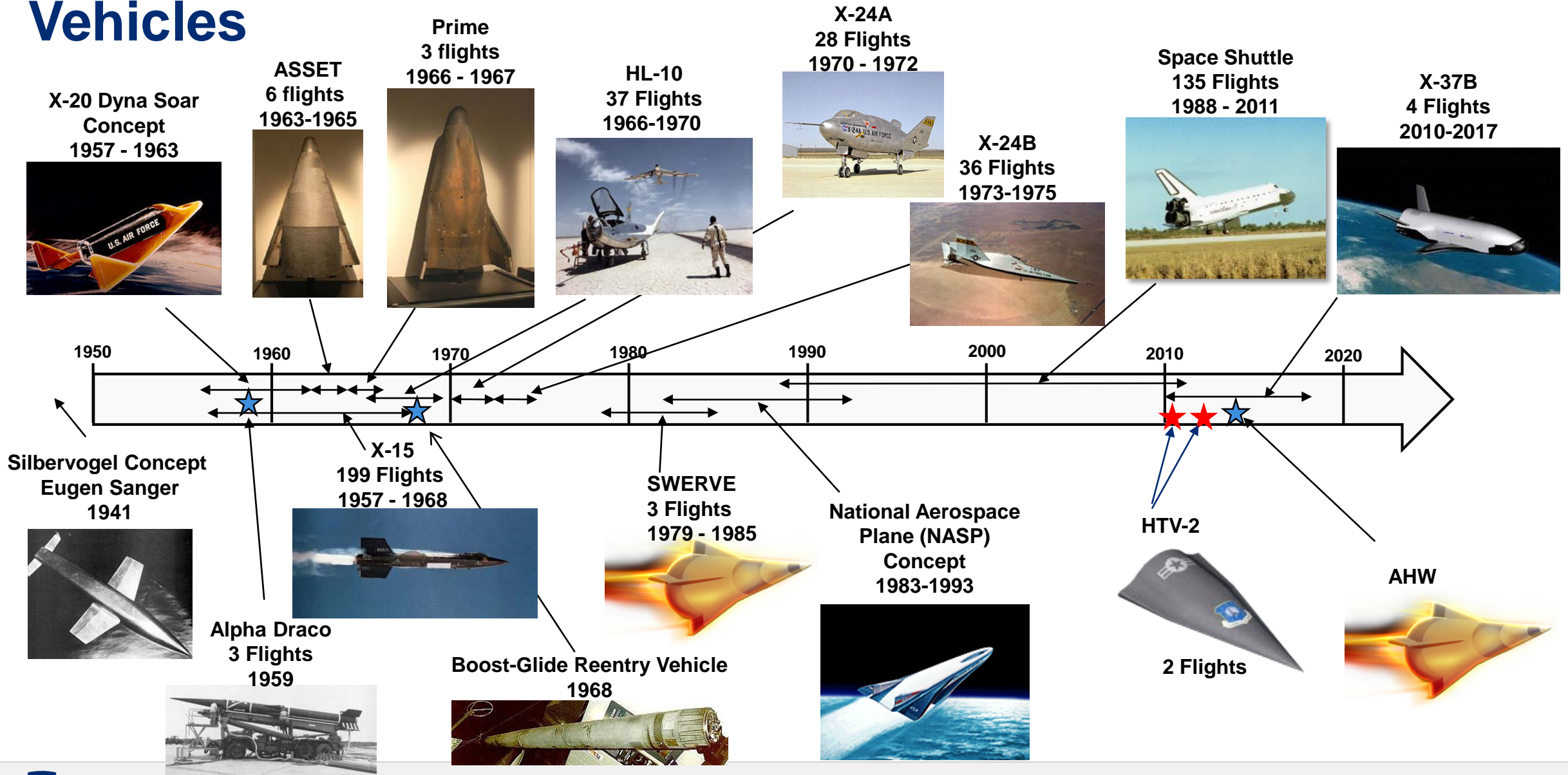
Important Recent U.S. Programs

- HTV-2
- Advanced Hypersonic Weapon (AHW)
- HyFLY
- X-51A

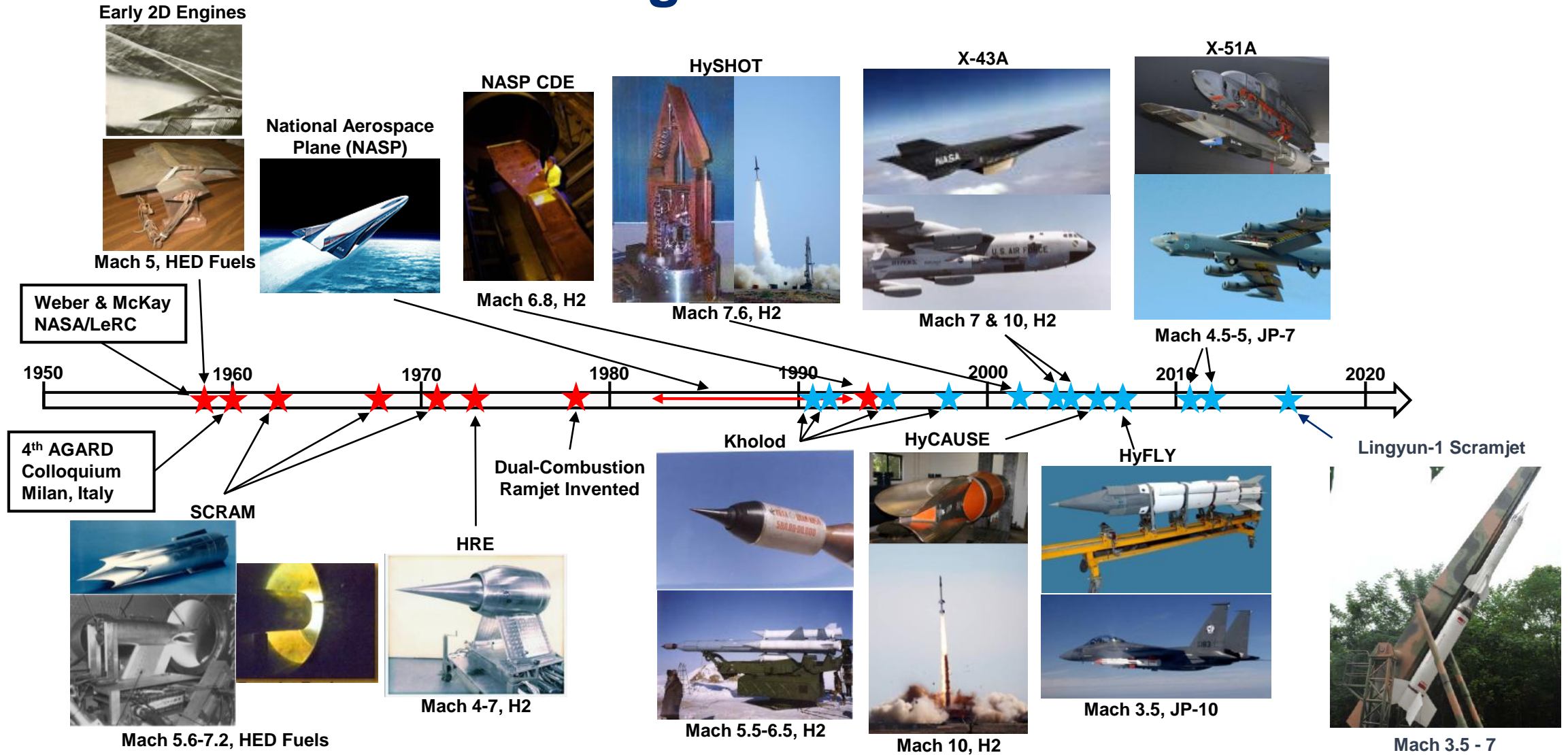
Scramjet-Powered Cruise Missiles Enables Mach 6+ Flight



A Brief History of Hypersonic Lifting and Maneuvering Vehicles



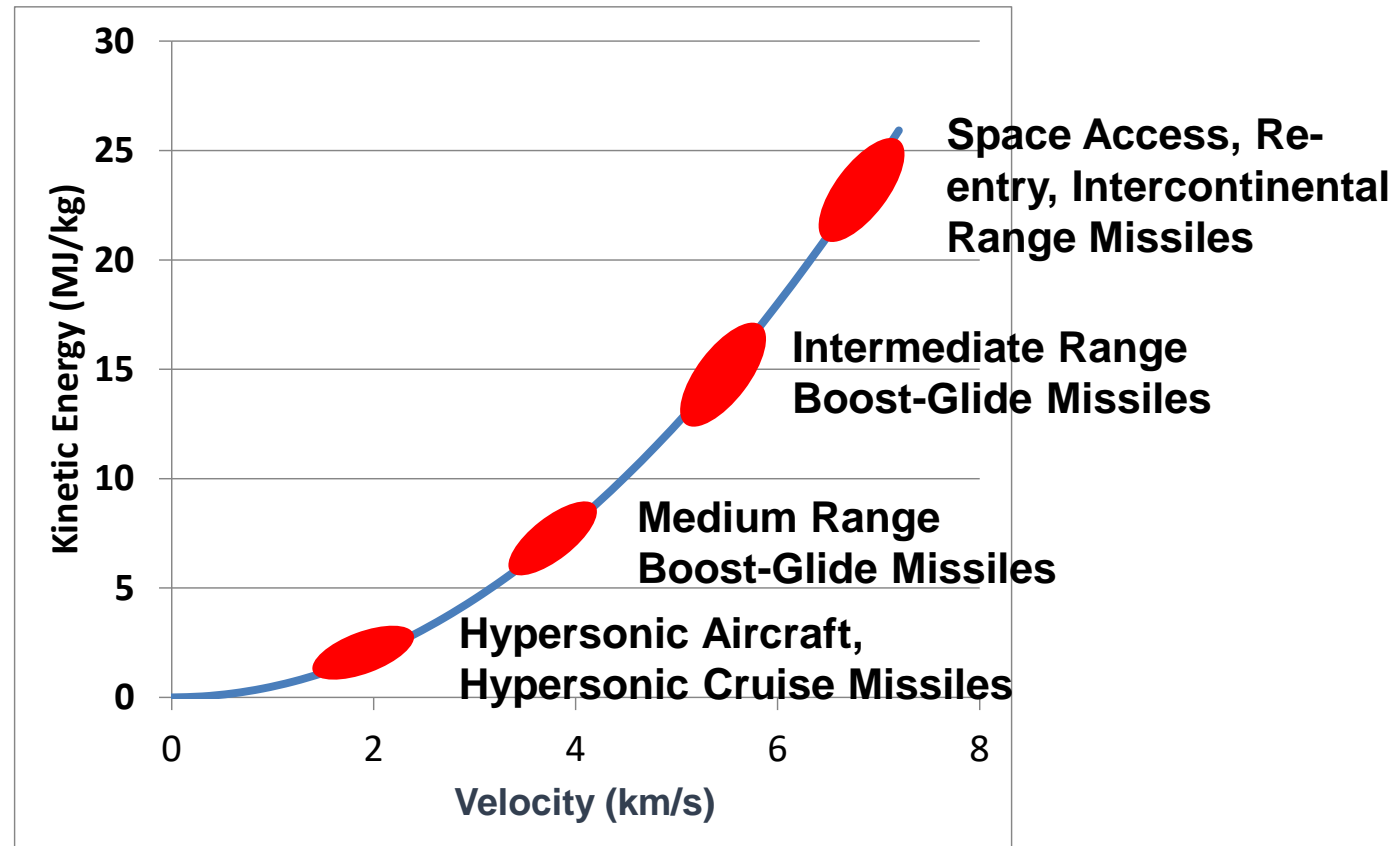
A Brief History of Airbreathing Hypersonics: Transitioning from Ground Tests to Flight



Do Emerging Hypersonic Applications Drive New Test and Telemetry Challenges?

- Emerging hypersonic applications
- **Sample challenges associated with development of hypersonic systems**
- Challenges with flight test instrumentation and telemetry
- Summary and conclusions

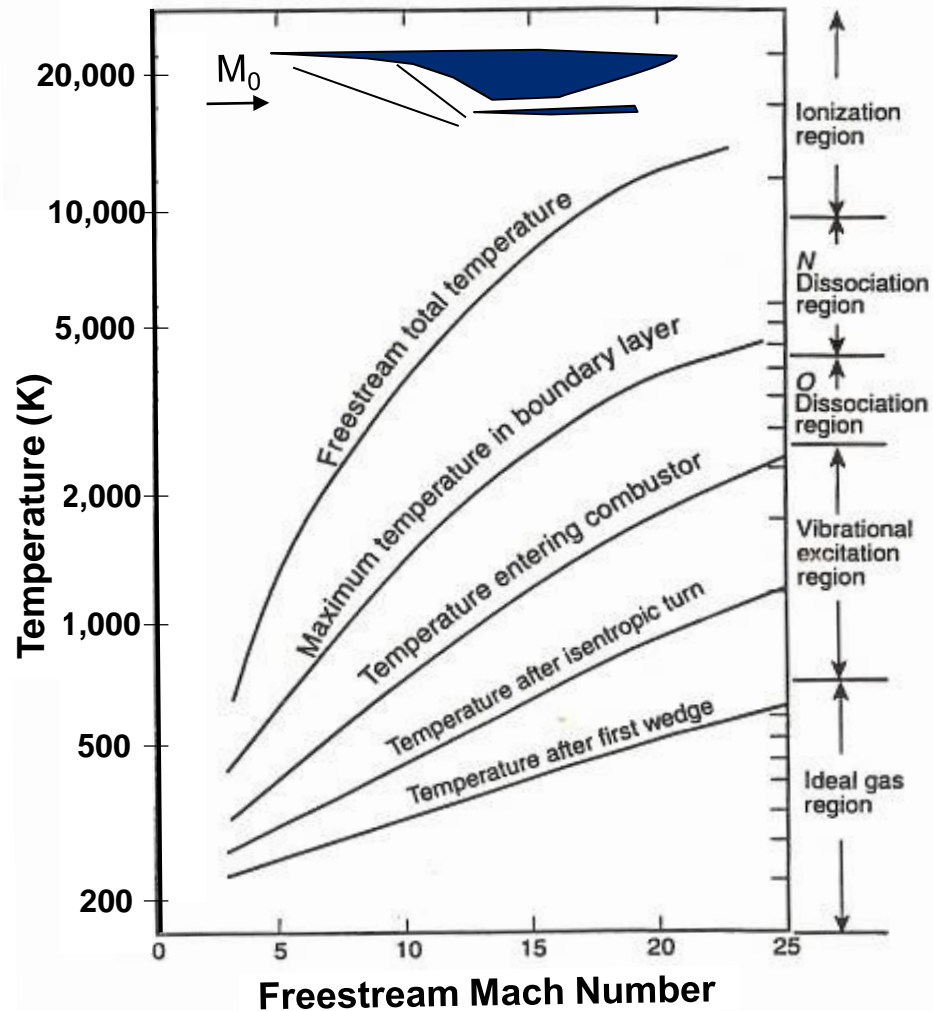
Increasing Energy Content With Increasing Speed



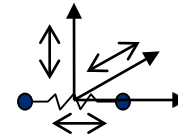
Energy Management Challenges Increase with Square of Velocity

Typical Air Temperatures Encountered Around a Hypersonic Vehicle

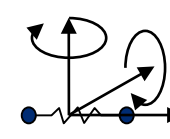
Equilibrium Chemistry – 100 kft



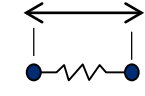
Translational Energy



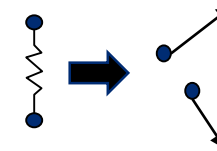
Rotational Energy



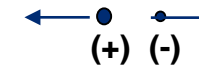
Vibrational Energy



Dissociation



Ionization

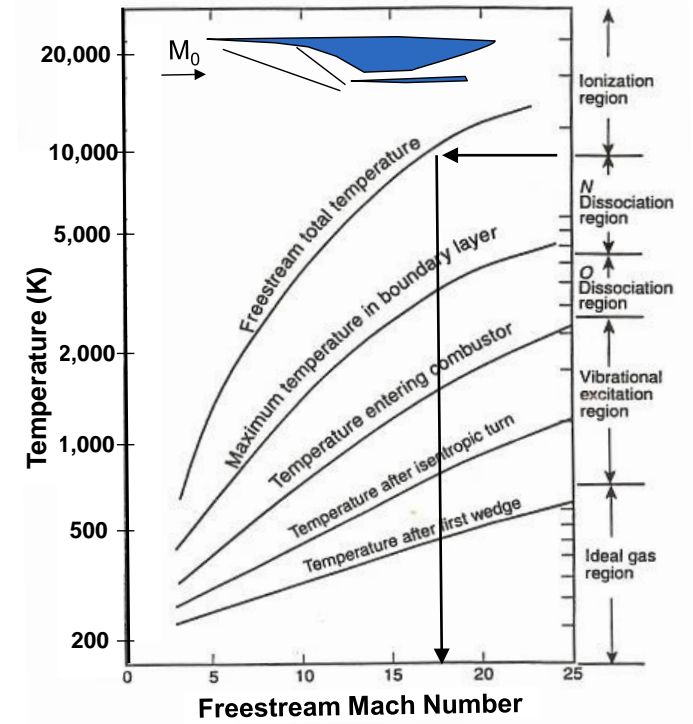
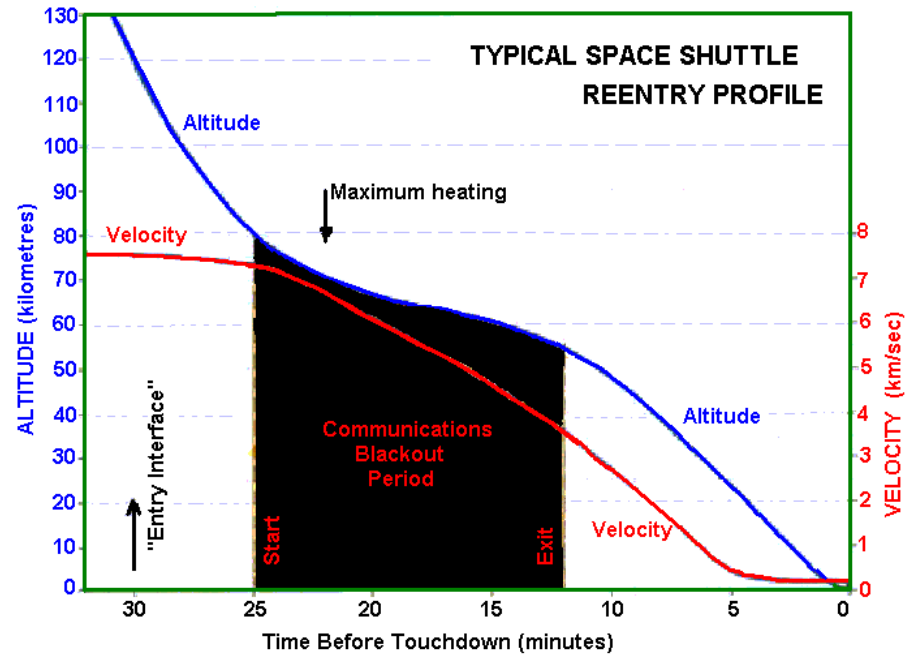
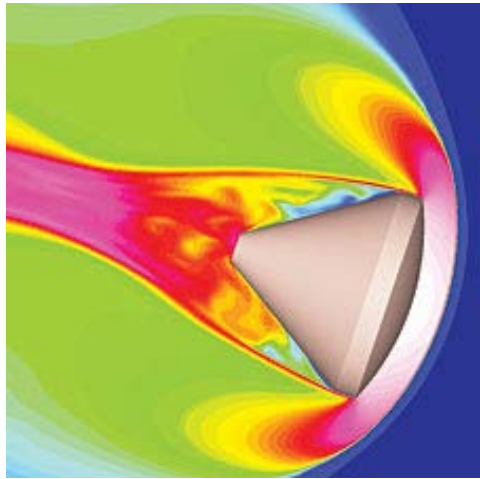


Stagnation Region

- Vibrational energy important at $M > 5$
- Dissociation important at $M > 8$
- Ionization important at $M > 15$

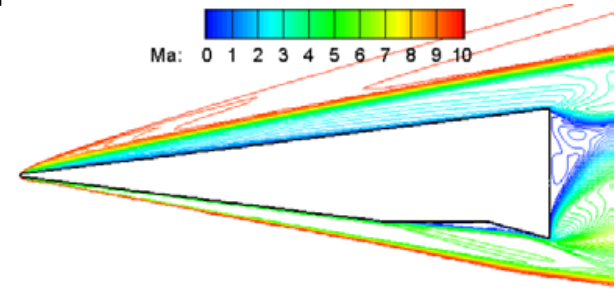
Ionization and Plasma Generation

Blunt Re-entry Capsule



Hypersonic Glide Vehicle

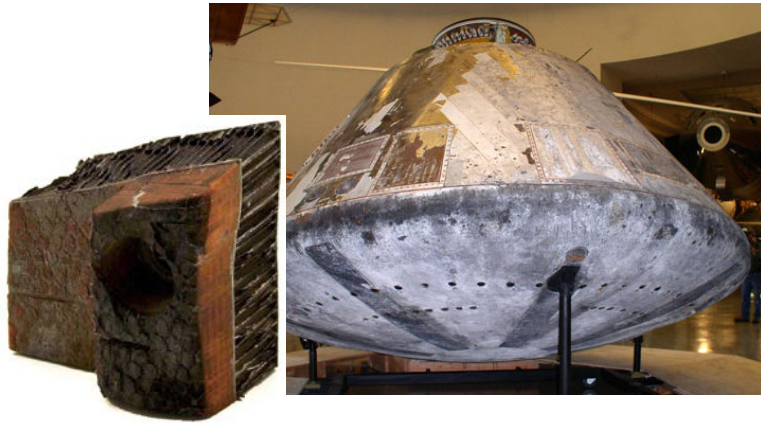
Thin shock layers result in low air ionization levels even at high speeds



Slender hypersonic vehicles will exhibit lower ionization levels compared to blunt bodies

High Temperature Materials and Thermal Management

Apollo 9 Reentry Capsule



Space Shuttle



SR-71



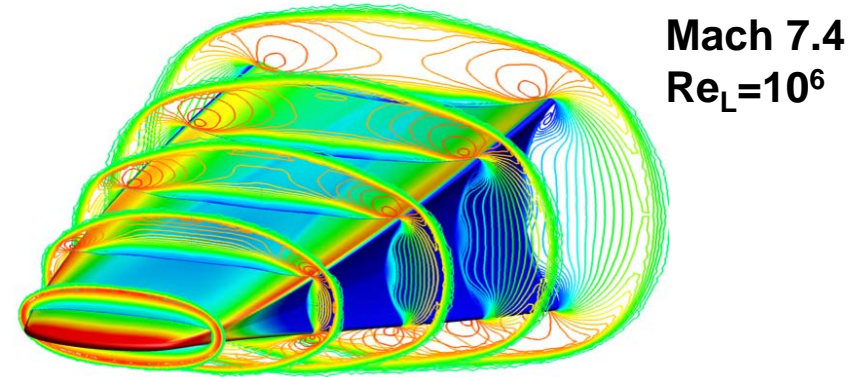
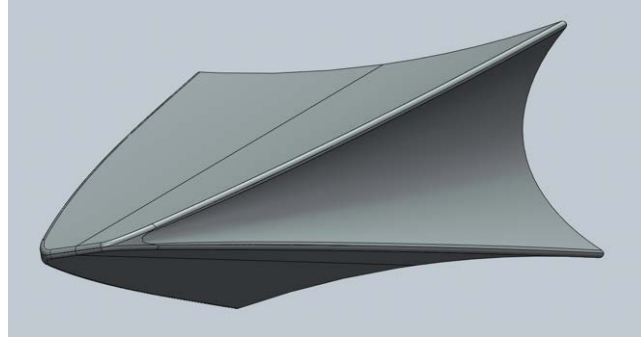
X-15



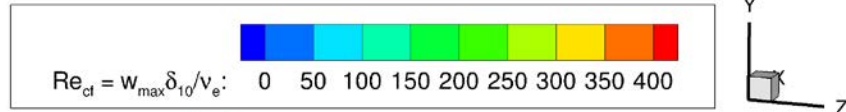
X-15 with MA-25S Ablator



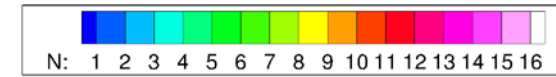
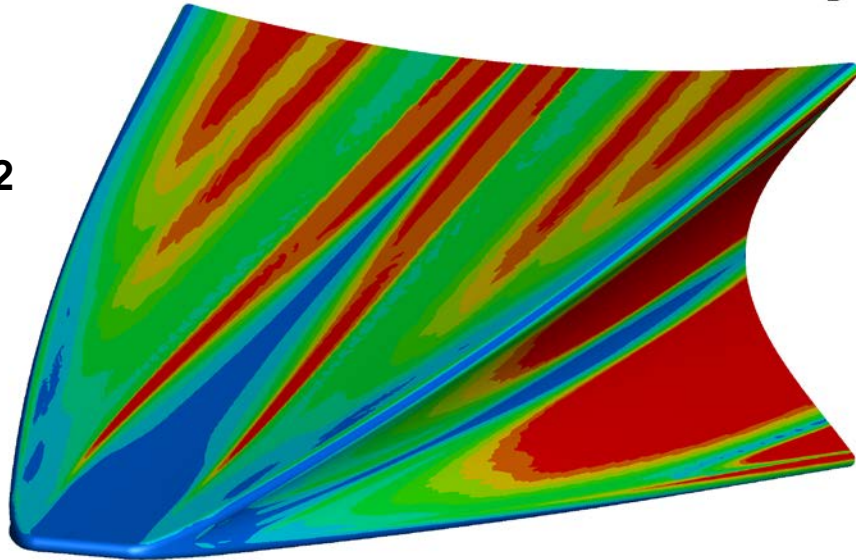
Boundary Layer Transition



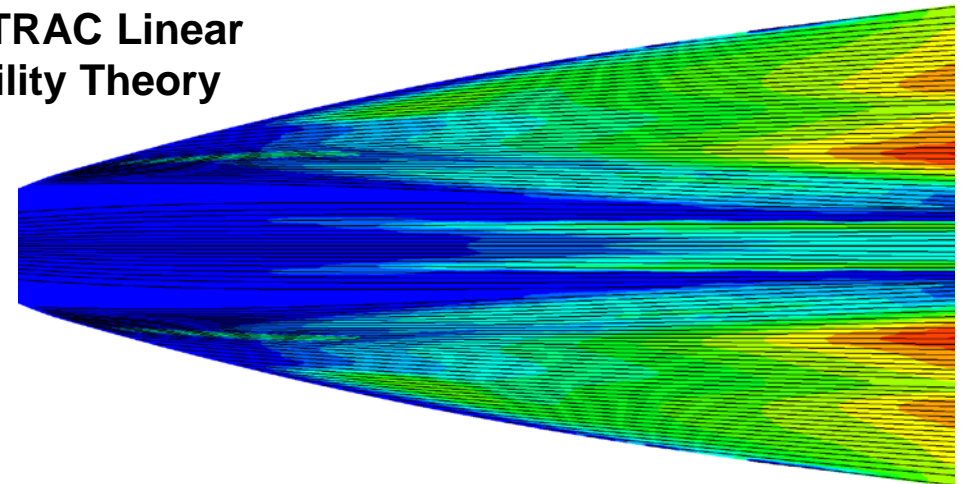
Crossflow Reynolds Number



Mach 5.2
 $Re_L = 10^6$



LASTRAC Linear Stability Theory



Ramjets Versus Scramjet Powered Vehicles

TALOS



Russian GELA
Missile



Yahont



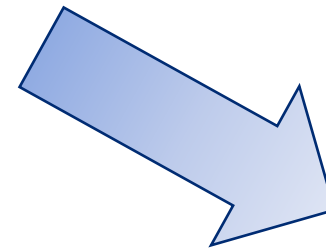
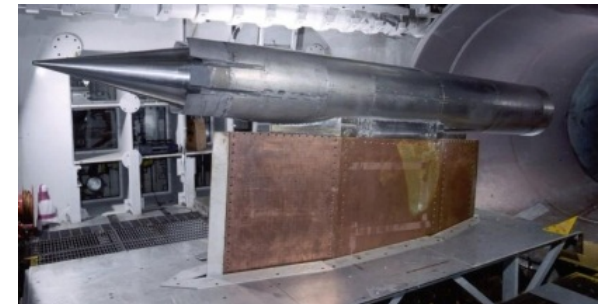
Coyote



Meteor



HyFLY



LEA (France/
Russia)

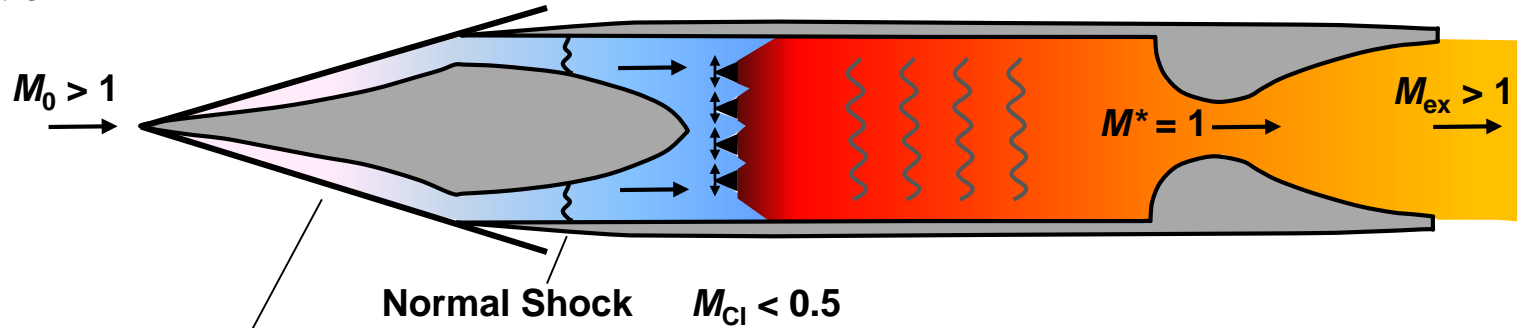


X-51A

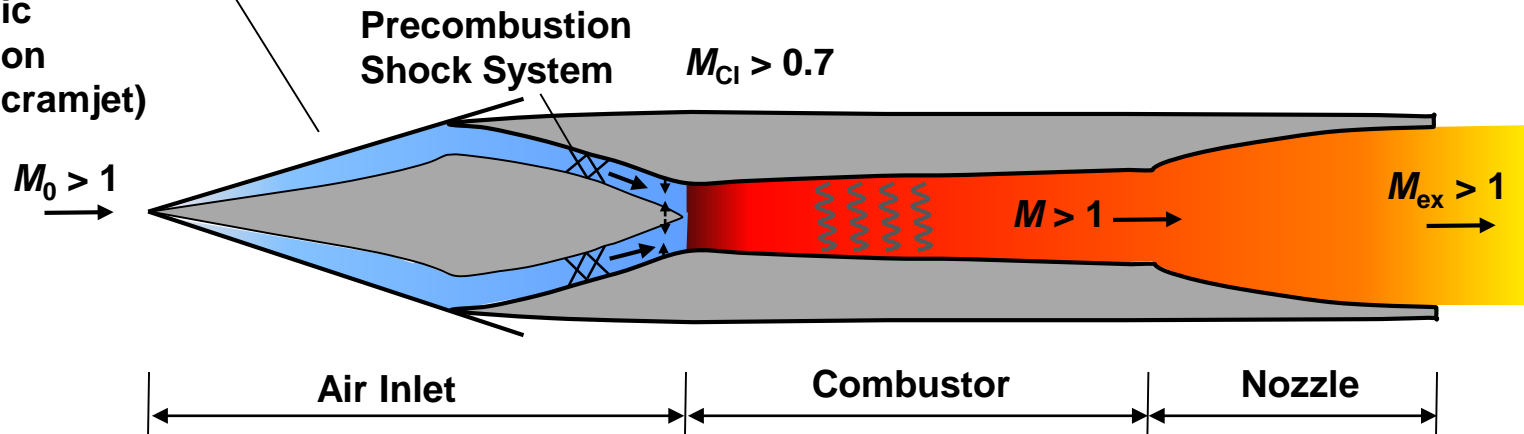


Ramjet Versus Scramjet Engines

Subsonic
Combustion
Ramjet



Supersonic
Combustion
Ramjet (Scramjet)



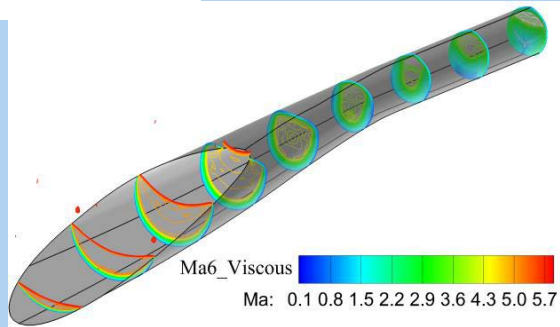
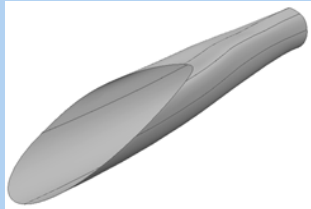
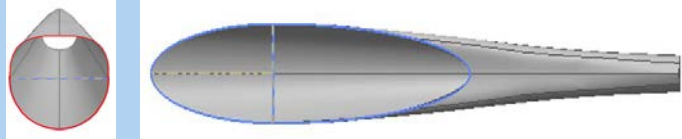
- Inlet diffusion to low subsonic speeds
- Combustion at subsonic speeds
- Converging-diverging nozzle

- Inlet diffusion to transonic or supersonic speeds
- Combustion at transonic or supersonic
- Diverging nozzle

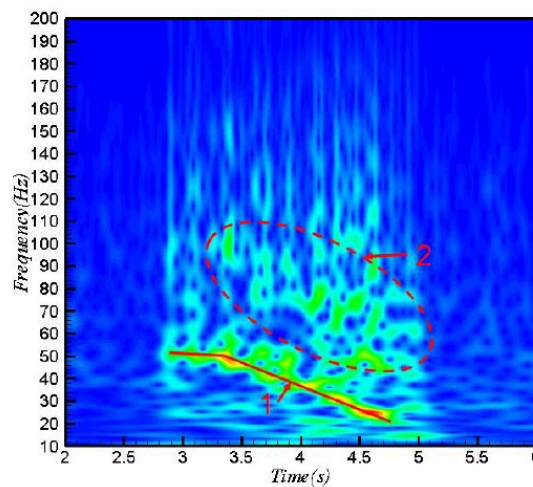
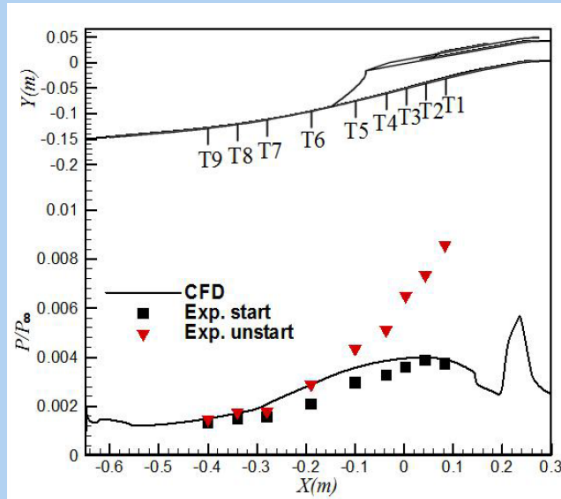
Scramjet Propulsion Challenges

3D Inlet Design for High Performance

Li, et.al, AIAA-2017-2423

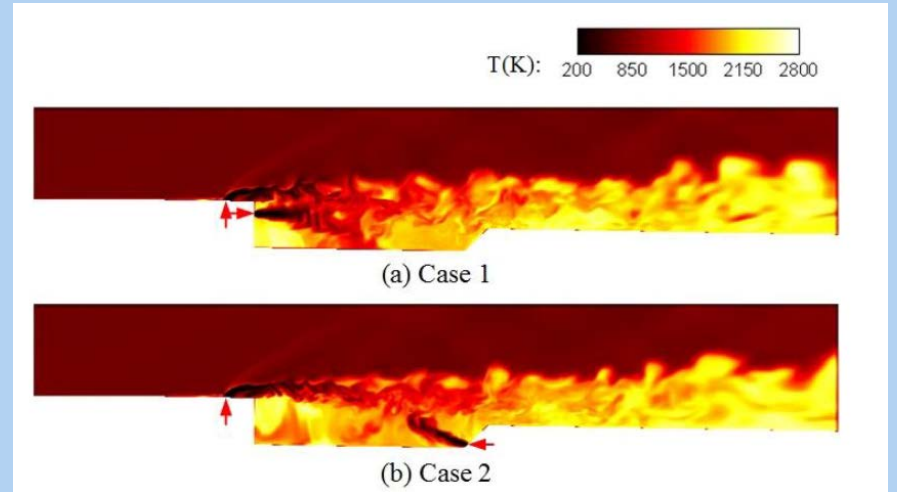
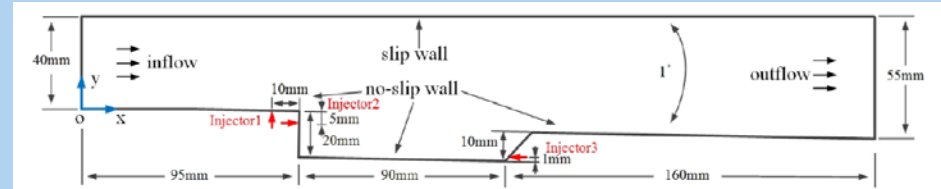


Shock Oscillation and Pressure Fluctuation in Unstarted Inlet, Longsehn et. al., AIAA-2017-2215

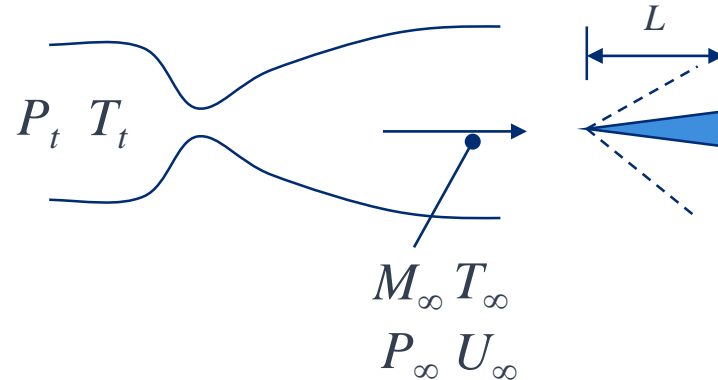


Scramjet Combustor with Rearwall Expansion Cavity

Zun Cai, et. al., AIAA-2017-2148



Hypersonic Simulation Requirements



Mach number and Reynolds number simulation

$$M_\infty = \frac{U_\infty}{a_\infty}, \gamma, \text{Re}_L = \frac{\rho_\infty U_\infty L}{\mu_\infty}, \frac{T_w}{T_\infty}$$

Fully duplicated simulation

$$U_\infty, P_\infty, T_\infty, \rho_\infty, L, \text{gas composition}$$

Advantages

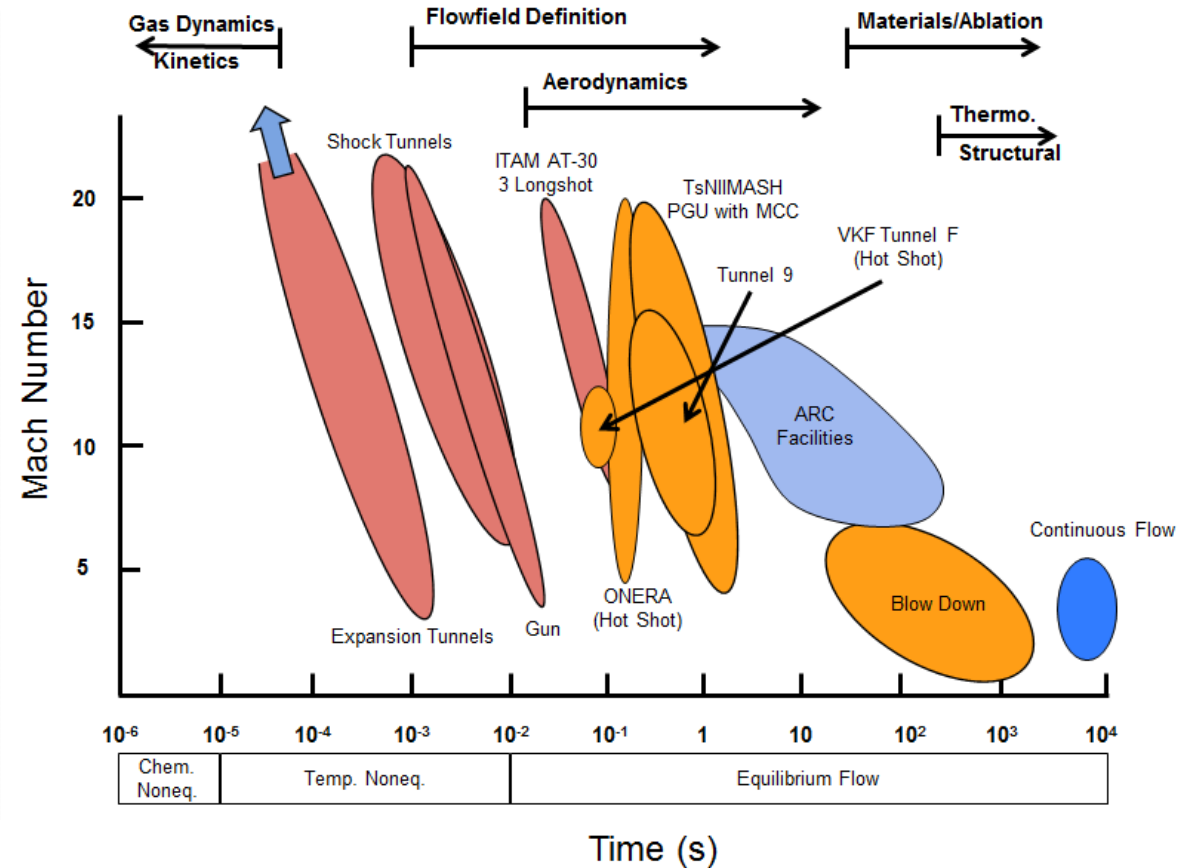
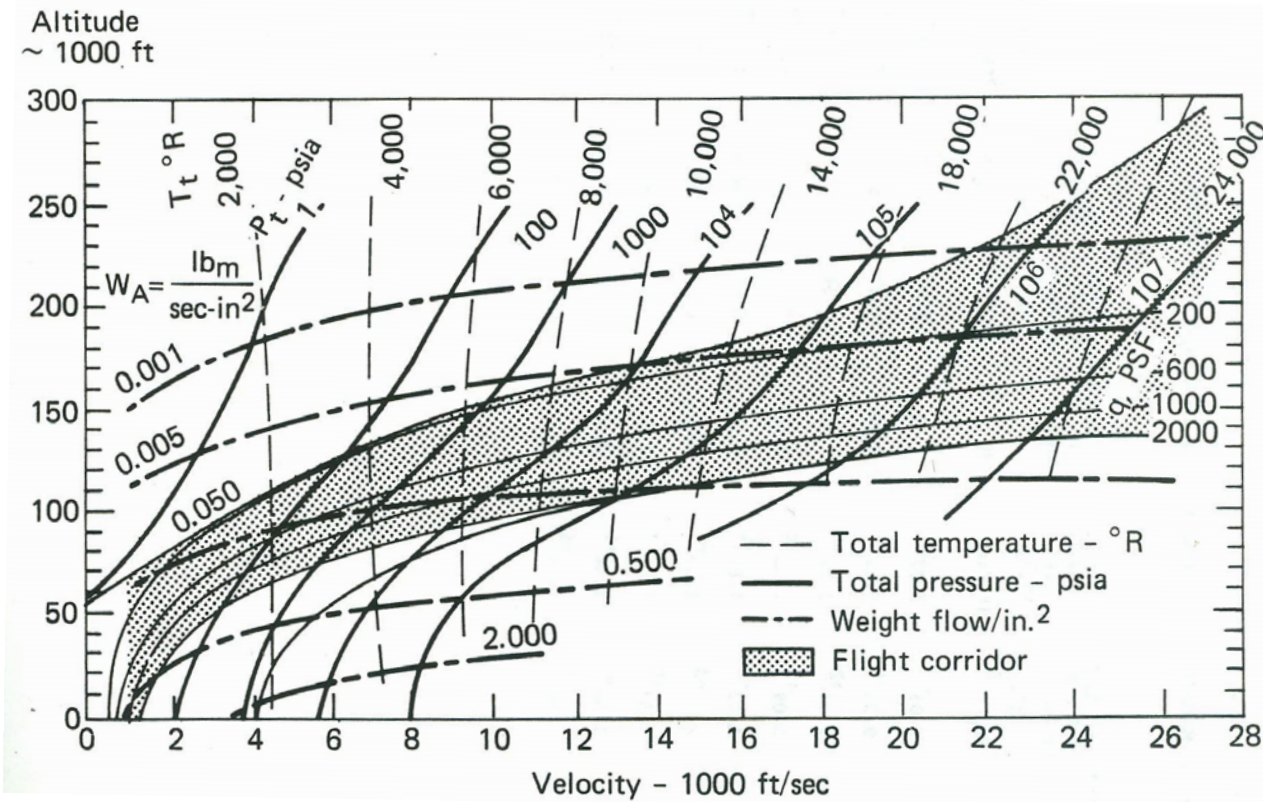
- Captures principal wave structure and viscous effects
- Sub-scale models
- Lower P_t and T_t

- Captures relevant fluid physics

Disadvantages

- Misses high-temperature gas effects
- Cannot be used for material and structural testing
- Significant P_t and T_t requirements
- Full scale models needed

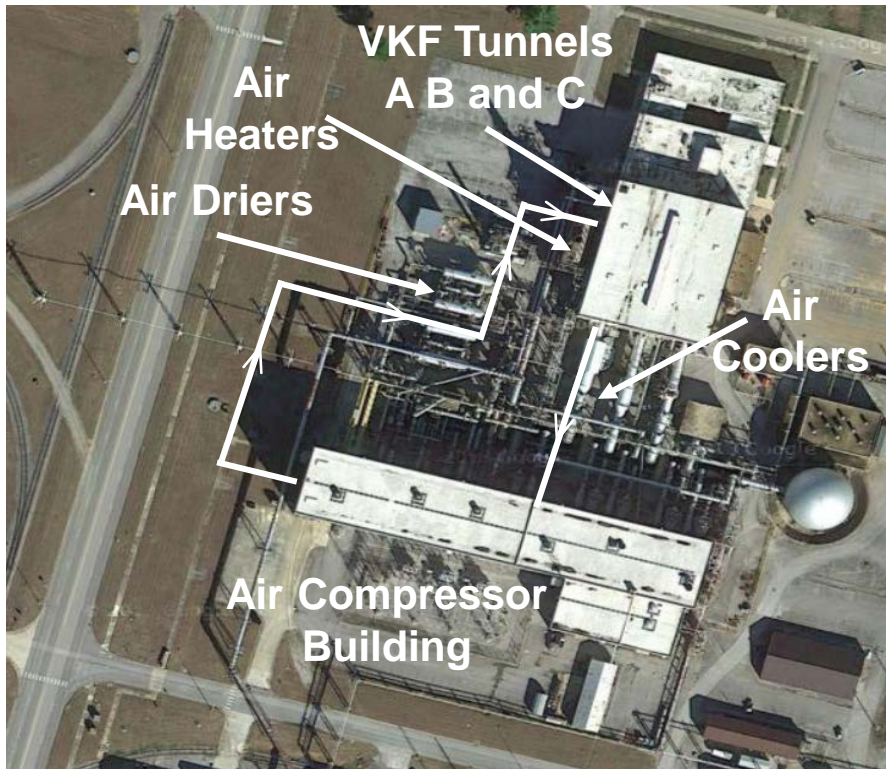
Requirements for Hypersonic Ground Tests



No perfect ground test facility exists for hypersonic system development – Flight testing is required!

Existing Hypersonic Aerodynamic Test Facilities

VKF Facility Air Circuit: Mach 1.5 - 10



Limitations

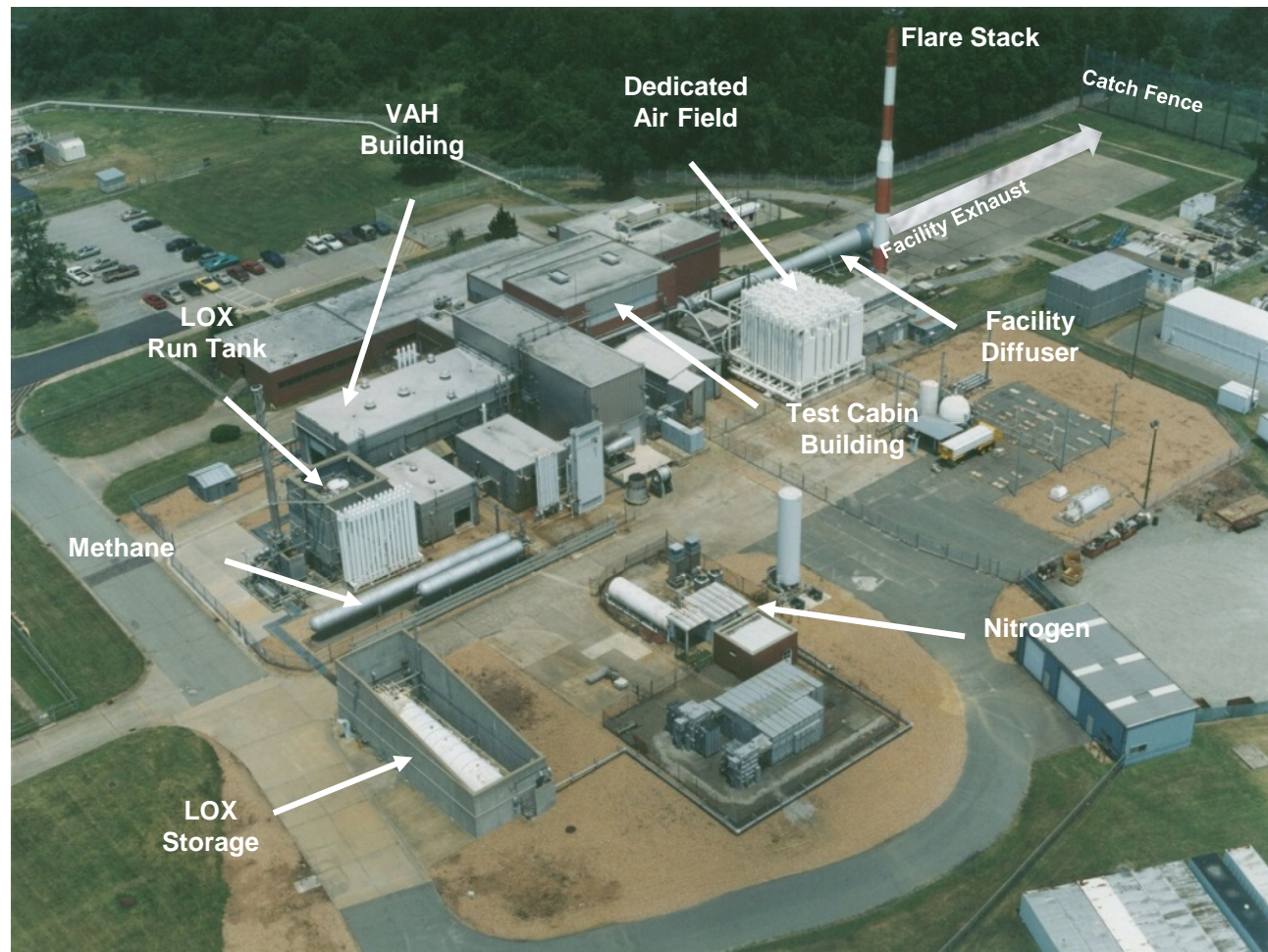
- Ideal gas simulation misses high-temperature gasdynamic effects
- Inability to address aerothermal-material interactions
- “Noisy” conventional tunnels

AEDC Tunnel 9: Mach 7-14



Existing Propulsion Hypersonic Test Facilities

NASA Langley Research Center 8-ft High Temperature Tunnel



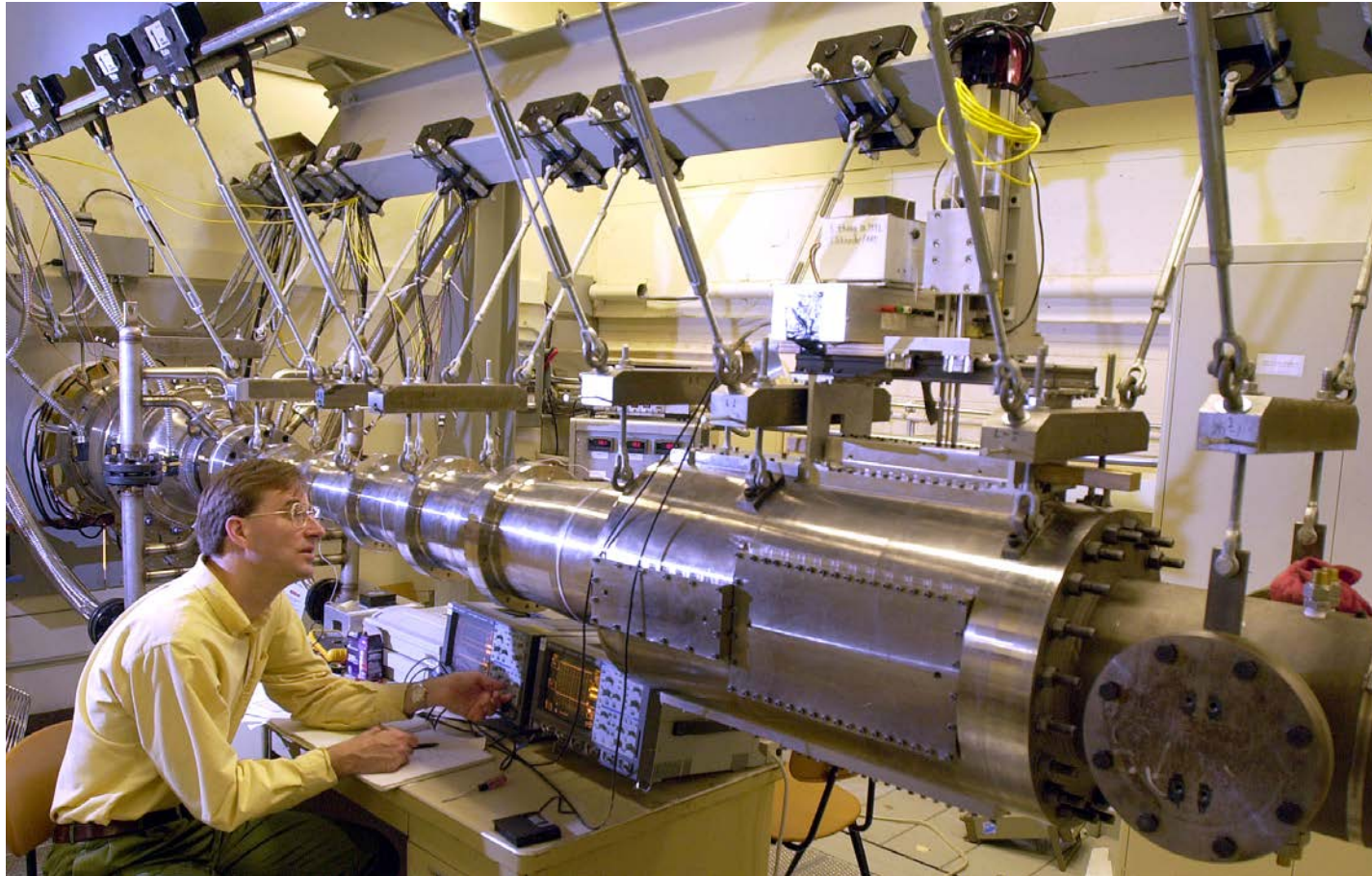
Advantages

- Pressure-enthalpy simulation to Mach 6+ conditions
- Oxygen make-up to simulate atmosphere
- Realistic combustion processes enabled with thermo-structural interactions

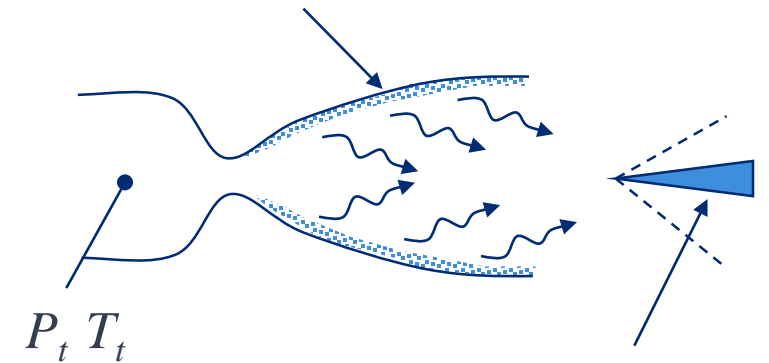
Limitations

- Imperfect air simulation
- Limited run times
- Loads imposed by facility starting and unstaring

Purdue University Mach 6 Quiet Wind Tunnel



Turbulent boundary layers
cause acoustic to radiate
into freestream



Results in early boundary
layer transition on models

Quiet wind tunnel operates with
highly polished nozzle wall to enable
laminar flow on nozzle and “quiet”
tunnel operation

Hypersonic Shock Tunnels

Chinese Institute of Mechanics Long Duration
Hypervelocity Detonation Driven Shock Tunnel

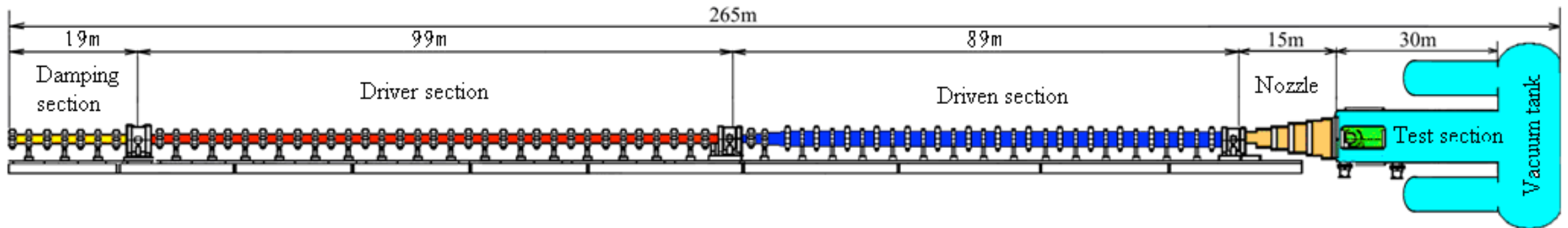


Advantages

- Duplicated freestream conditions
- Enables use of low-cost models

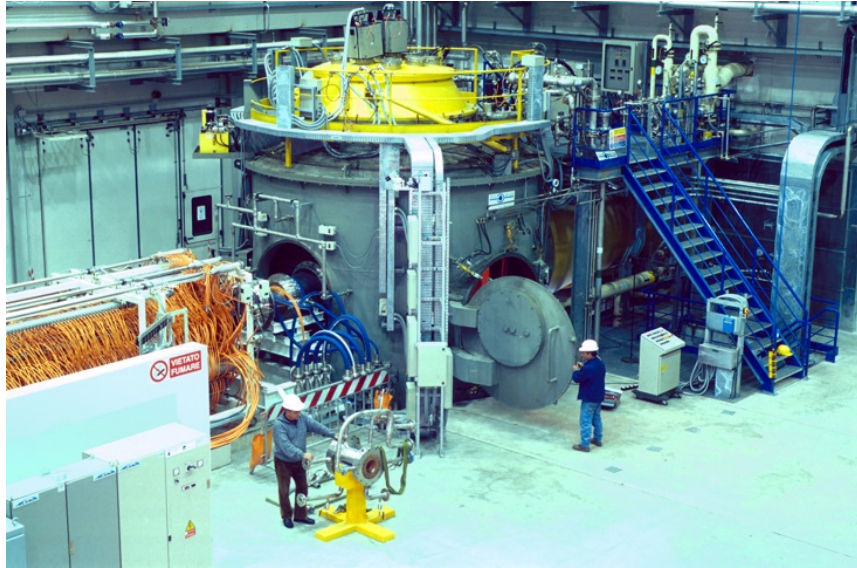
Limitations

- Short run times
- Imperfect freestream conditions at high hypersonic speeds
- Inability to investigate aerothermal/material/structural interactions



Arc-Heated and Plasma Wind Tunnels

CIRA Scirocco Plasma Wind Tunnel

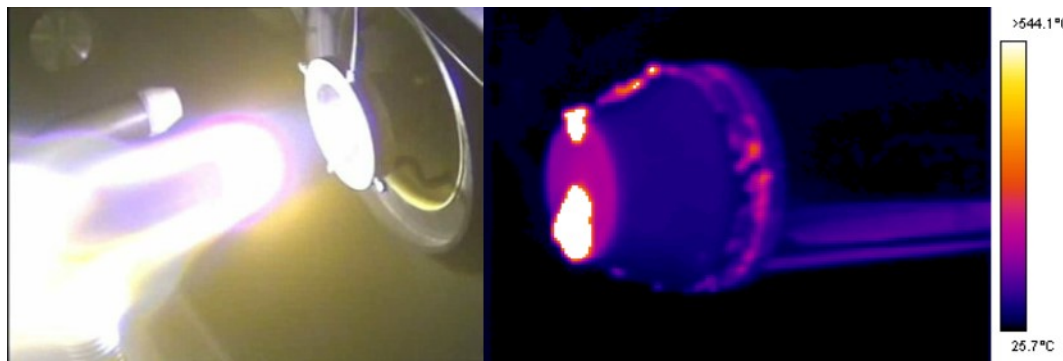


Advantages

- High enthalpy simulation
- Long run times
- Ability to study ablation and surface catalysis

Limitations

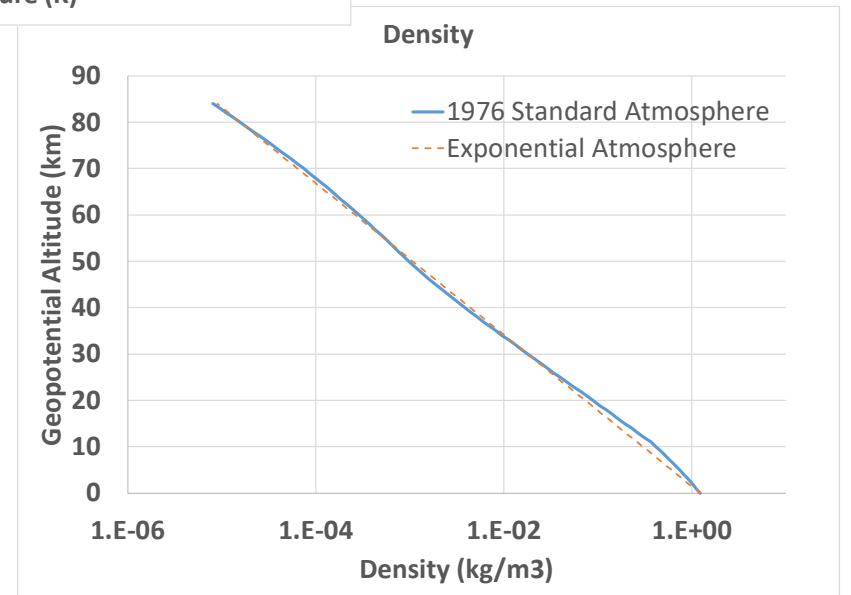
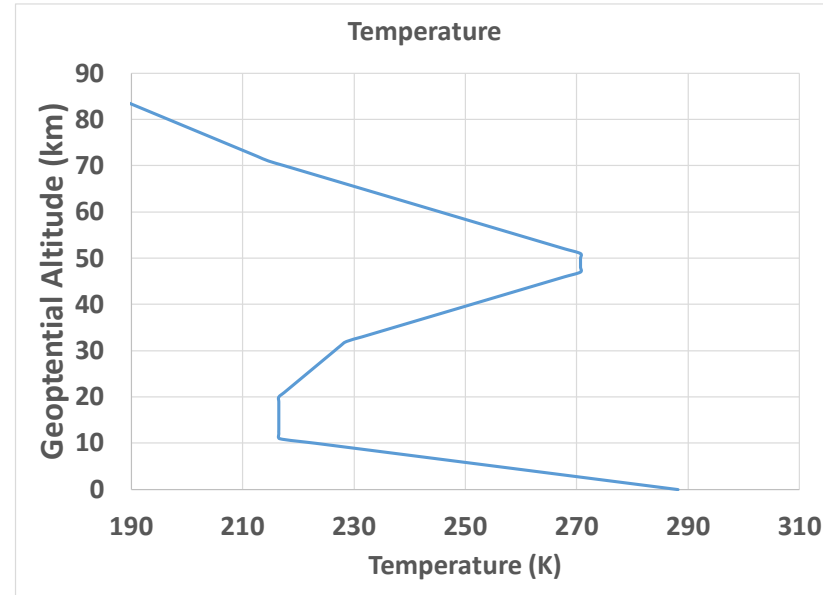
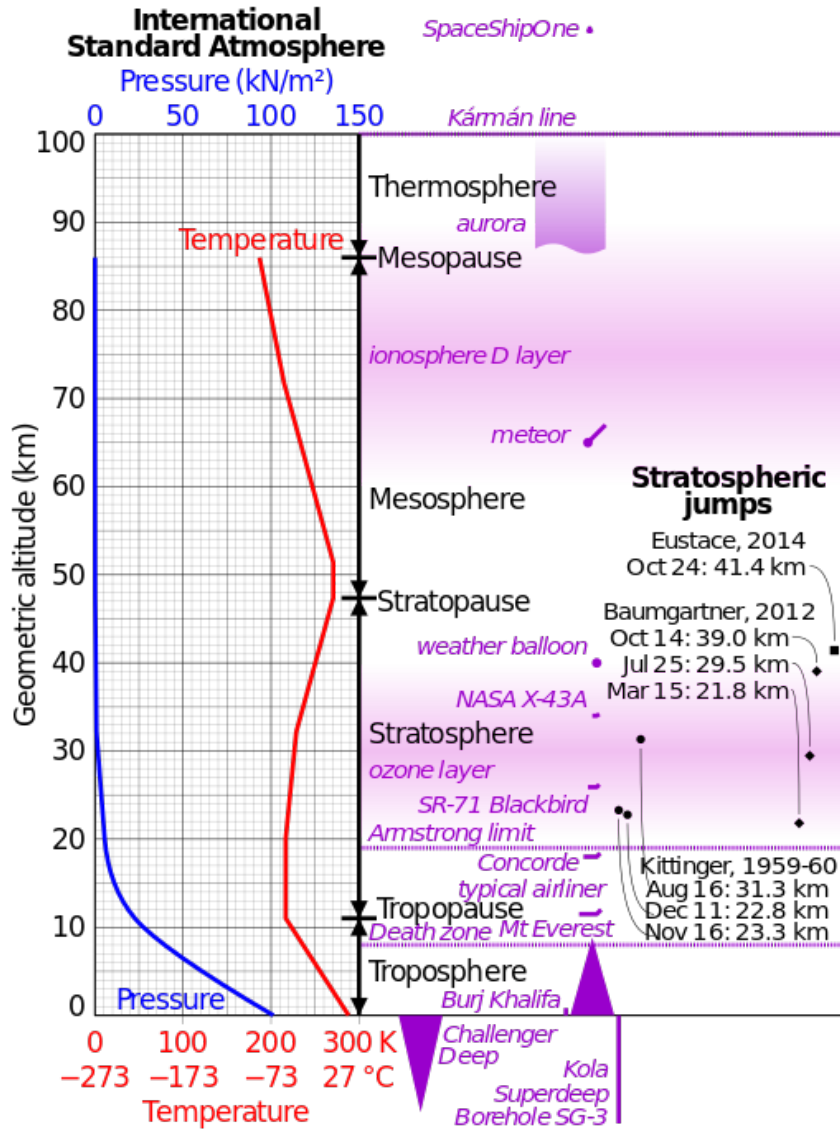
- Imperfect air simulation
- Limited total pressure capability



Do Emerging Hypersonic Applications Drive New Test and Telemetry Challenges?

- Emerging hypersonic applications
- Sample challenges associated with development of hypersonic systems
- **Challenges with flight test instrumentation and telemetry**
- Summary and conclusions

Standard Atmosphere

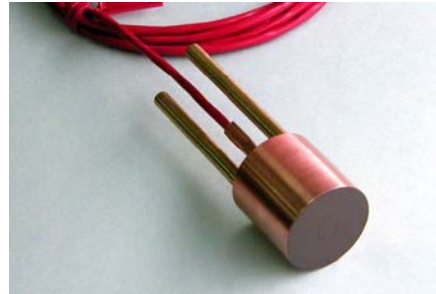


Sample Ground Test Instrumentation

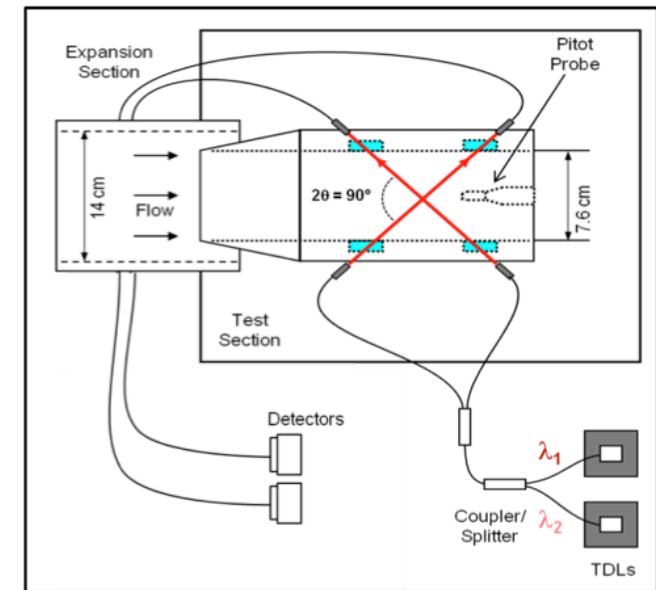
Pressure Transducers



Heat Flux Gauge



Tunable Diode Laser Absorption Spectroscopy (TDLAS)



Thermocouples

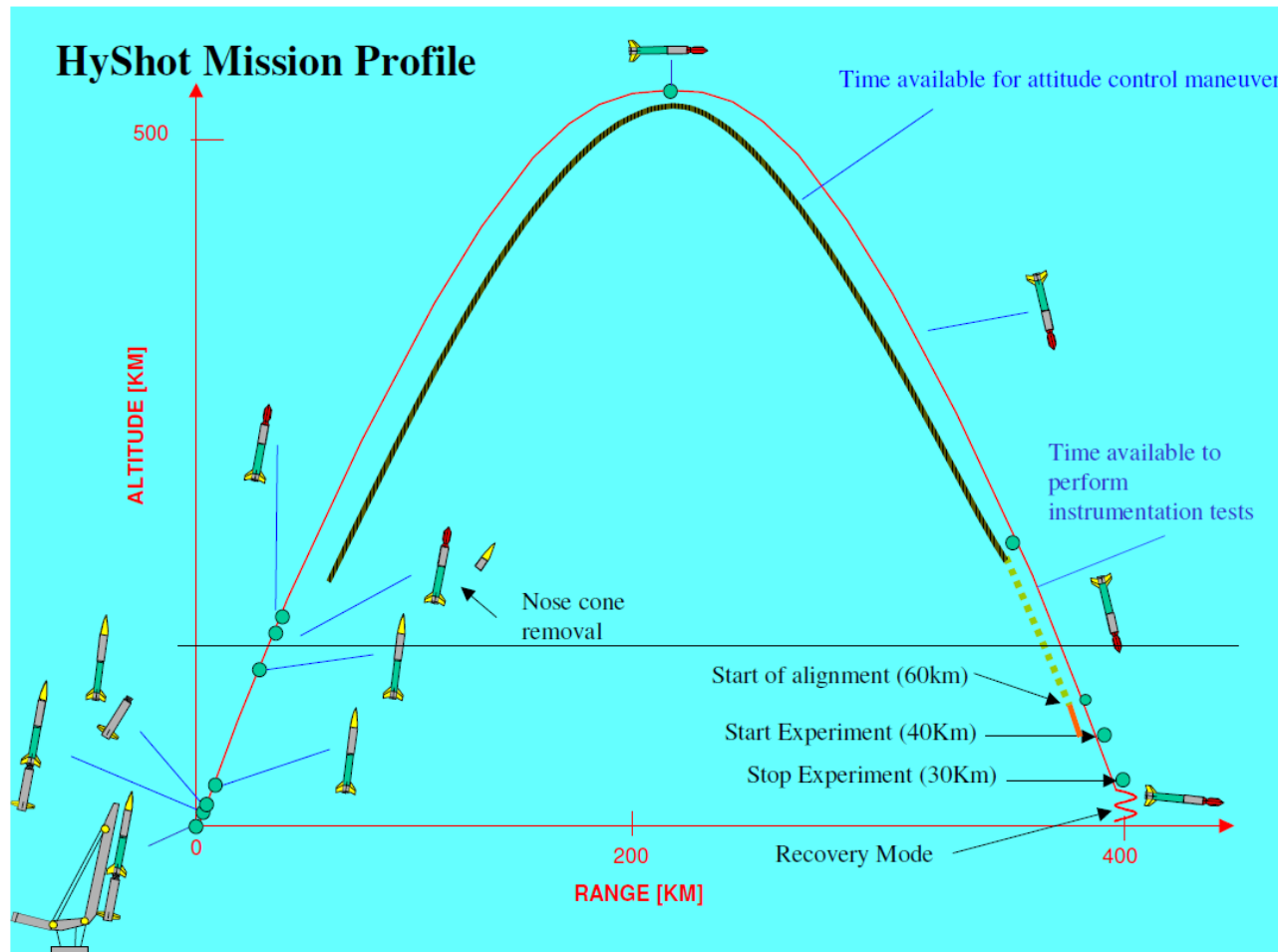


Strain Gauge



Ref: http://psaap.stanford.edu/heat_release_modeling/TDLvelocimetry.html

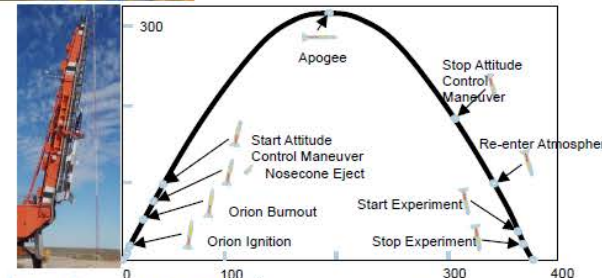
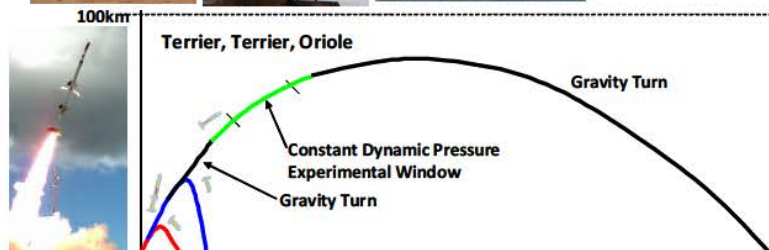
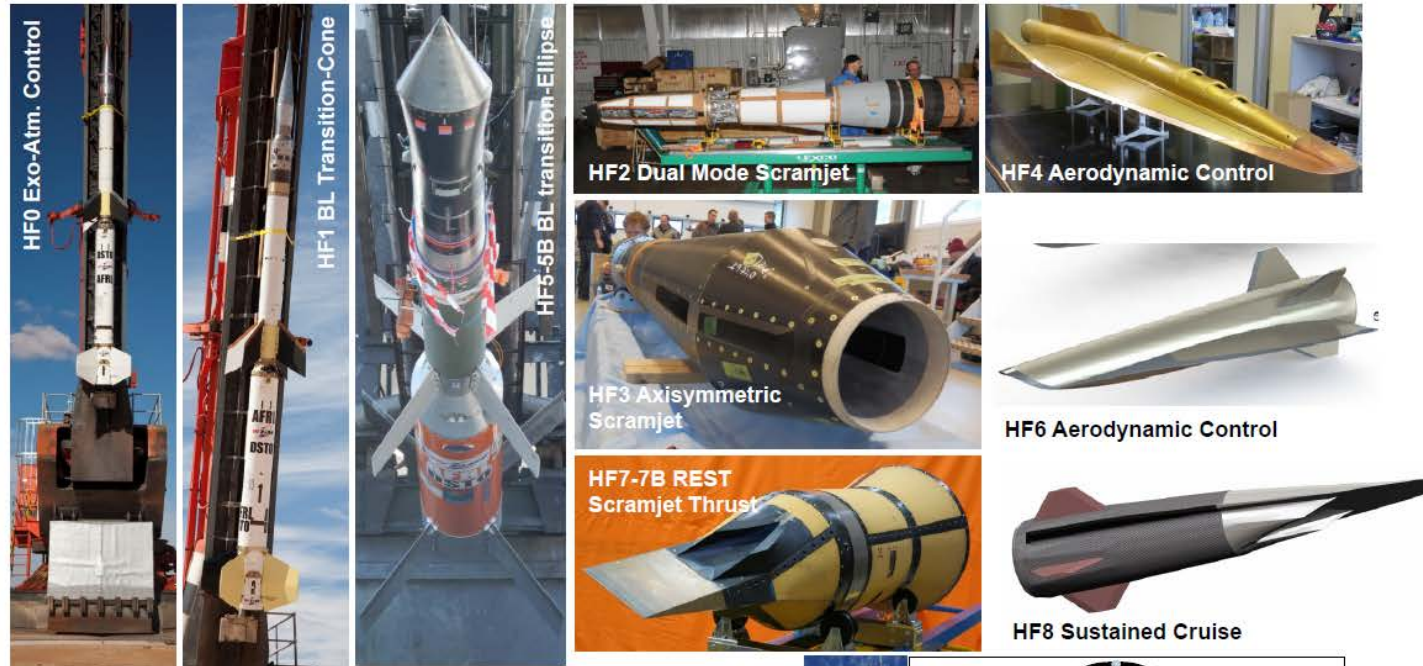
HySHOT II Flight – 30 July 2002



HySHOT flight test series built on a long-term interest in hypersonic technologies and began a focused program on flight testing that continues today

HiFIRE – Hypersonic International Flight Research Experimentation

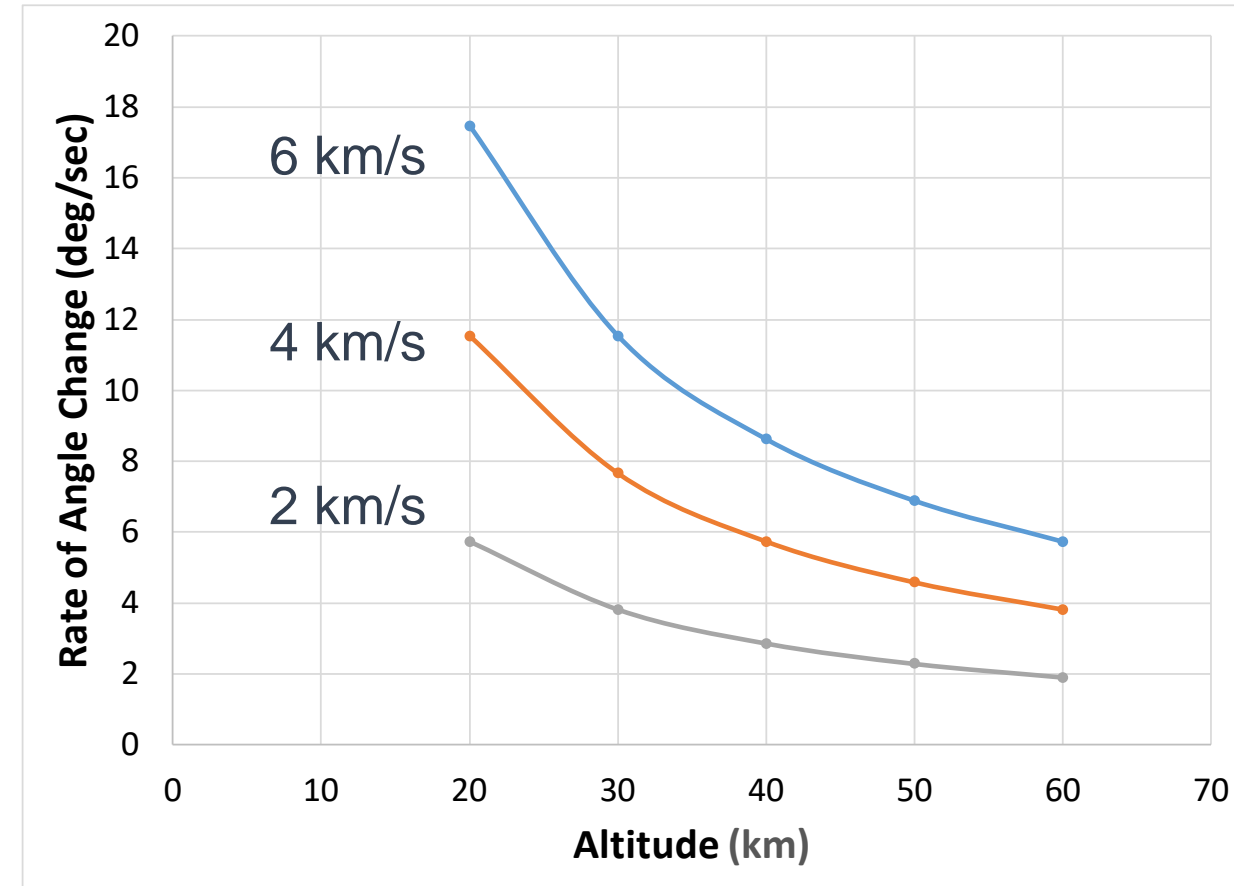
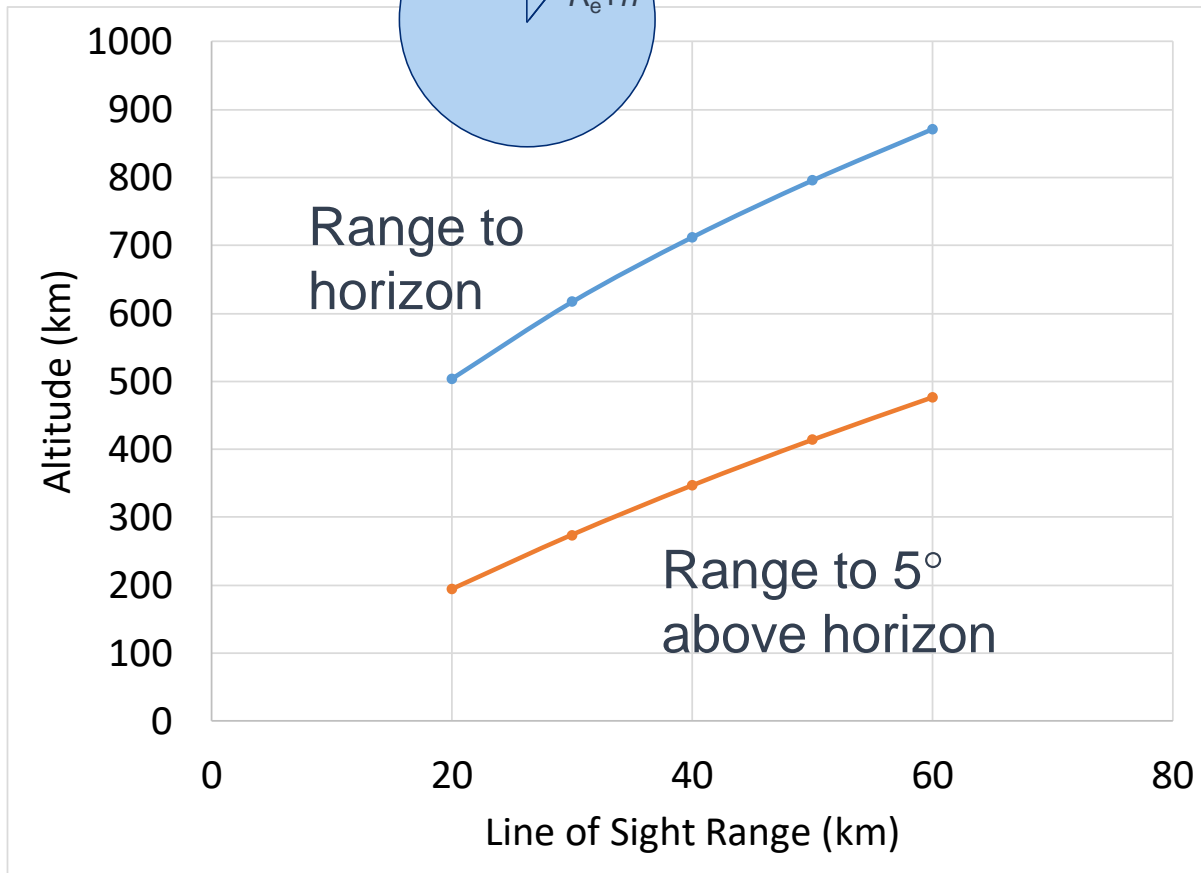
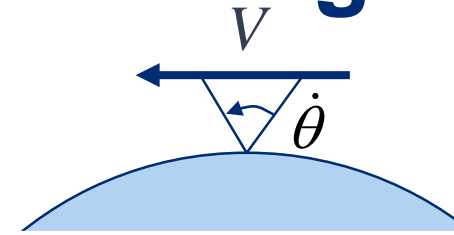
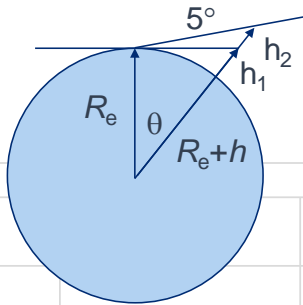
HiFIRE



Flight Test Instrumentation Needs

- Hypersonic air data system
 - Aid in understanding freestream and flight vehicle orientation
- Pressure transducers capable of indicating boundary layer transition
 - Frequency response ~1-2 MHz
- Diagnostic instrumentation to measure ablation and shape change
- Strain gauges for high-temperature structures
- Instream measurements via optical techniques
 - Airflow measurement in scramjet engines
 - Combustion diagnostics

Telemetry Range and Angle Rate Challenges



Additional Test and Telemetry Challenges

- Stressing external surface temperatures
 - Need for high-temperature antennae
- Need for increased power efficiency
 - Challenging on-board thermal environment
- Need for additional transmitted data
 - Increase modulation complexity
 - Increase bandwidth – move to C-band?
- Need for smarter use of available transmission rate
 - Increase on-board processing
 - Adapt transmission needs over flight
- Need for increased flexibility
 - Move towards software-defined telemetry
- Balancing the load between transmit and receive requirements

Do Emerging Hypersonic Applications Drive New Test and Telemetry Challenges?

- Emerging hypersonic applications
- Sample challenges associated with development of hypersonic systems
- Challenges with flight test instrumentation and telemetry
- **Summary and conclusions**

Do Emerging Hypersonic Applications Drive New Test and Telemetry Challenges? – Summary and Conclusions

- A significant history of hypersonic test and telemetry experience exists
 - Space launch, re-entry, experimental aircraft, interceptor missiles, sounding rockets
- New hypersonic systems are emerging
 - Reusable launch vehicles and test capabilities
 - Reusable aircraft
 - Long-range weapons
 - Hypervelocity projectiles
- New applications are driving new needs
 - Challenging new diagnostic information needed
 - Approaches for on-board processing of data
 - Techniques for increasing telemetry capacity
 - Increasing power efficiency
 - Lowering costs



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