PHYSICAL PHENOMENA ASSOCIATED WITH HYPERSONIC WEAPON VEHICLES

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OVERVIEW

For the development of "game-changing technology", with a goal of "industrializing" hypersonic missile production, Michael D. Griffin, DoD Under Secretary for Research and Engineering, indicates:

- **Hypersonic weapons have the unprecedented ability to maneuver and then to *strike almost any target in the world within a matter of minutes*.**
- **Capability of traveling at more than *15 times the speed of sound*.**
- **Arriving at their targets in a blinding, destructive flash, *before any sonic booms or other meaningful warning*.**
- **Kinetic energy at the time of impact makes them powerful enough to penetrate any building material or armored plating with the force of three to four tons of TNT.**

A National Academies of Sciences, Engineering and Medicine report from 2016 indicates that hypersonics aren't *"simply evolutionary threats"* to the United States, but could in the hands of enemies *"challenge this nation's tenets of global vigilance, reach and power."*

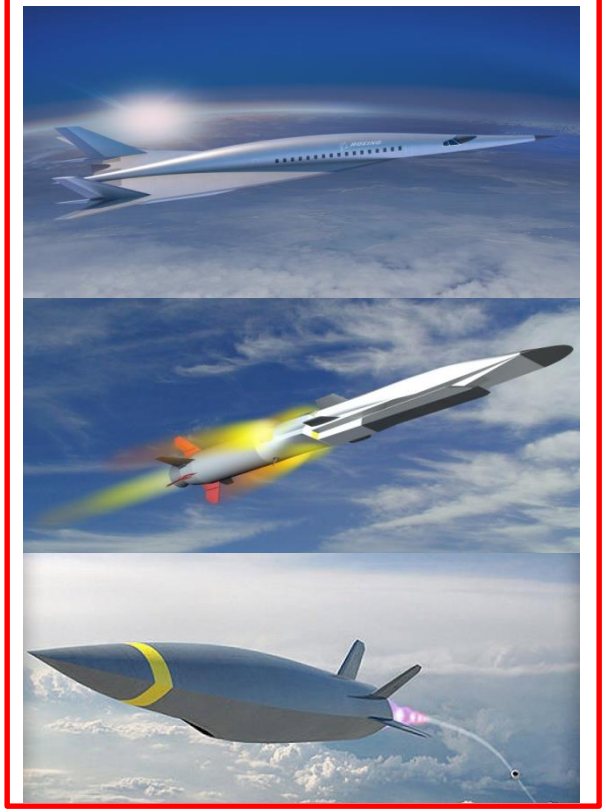
Hypersonic Flight Vehicles

Orbiter: All rocket
Booster: TBCC

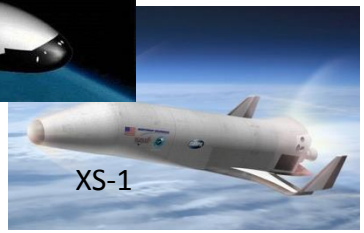
Spaceplane: Air-breathing rocket

Hypersonic Airbreathing Propulsion (HAP) Cruise Vehicles

$5 < M_0 < 12$



Winged Re-Entry Vehicles



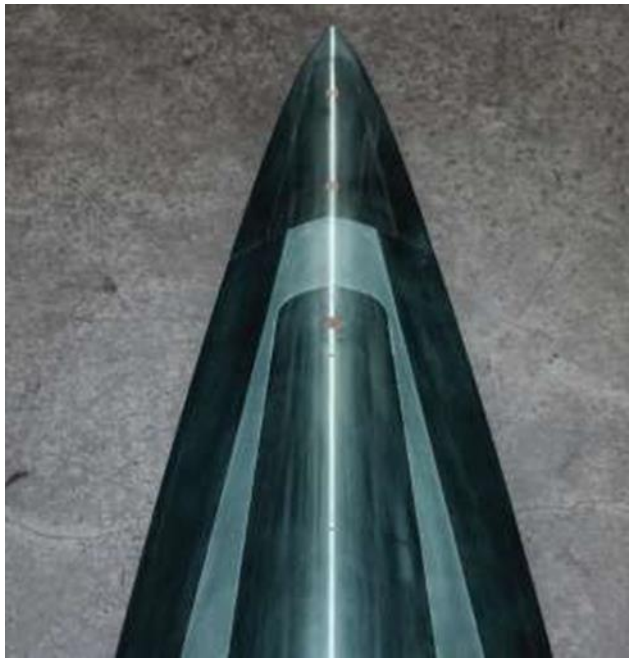
Non-Winged Re-Entry Vehicles

Flow past HAP vehicle is true hypersonic flow

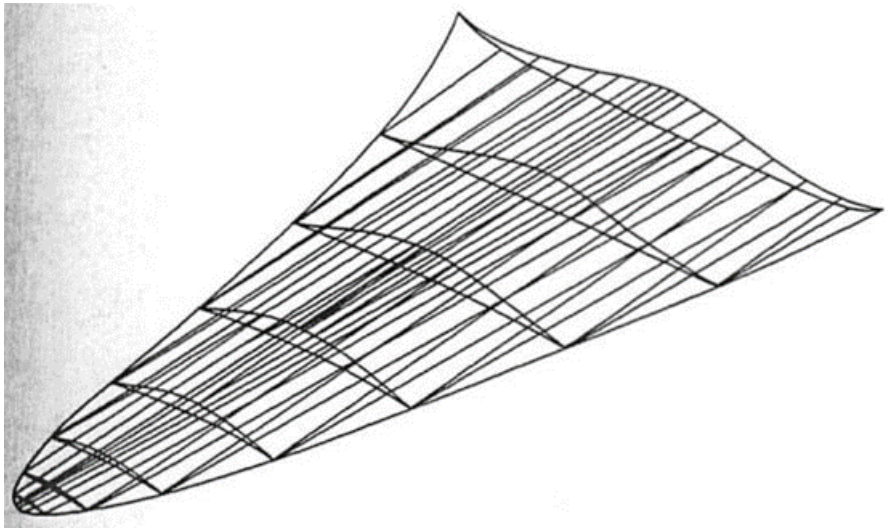
X-51A Wave Rider.

(1) B-52 Bomber. (2) Minotaur solid rocket booster. (3) Wave Rider with scramjet power.

Compression lift produced by own shock waves.



Viscous-optimized hypersonic Wave Rider.



A Mach 14 Wave Rider Glide Vehicle, with ability to generate high lift and ride on its own shock waves.

"Boost glide" vehicles **achieve speed and range by "skipping off the upper atmosphere" and then ricocheting downward through different atmospheric layers.**

Propelled by a conventional missile and then acting as a hypersonic glider, with wings or with a variation of a canonical shape:
● maneuverable ● high-speed ● high "lift over drag ratio."

THERMAL / FLUID SCIENCES TECHNICAL ISSUES

- shock wave structure
  - shock wave unsteadiness
    - laminar-turbulent transition
      - viscous and dissipative kinetic heating
        - heat transfer and thermal transport
          - thermal acoustic heat transfer
            - wave induced heat flux
              - wave drag
                - rarefaction effects and slip phenomena
                  - gas dissociation and plasma effects

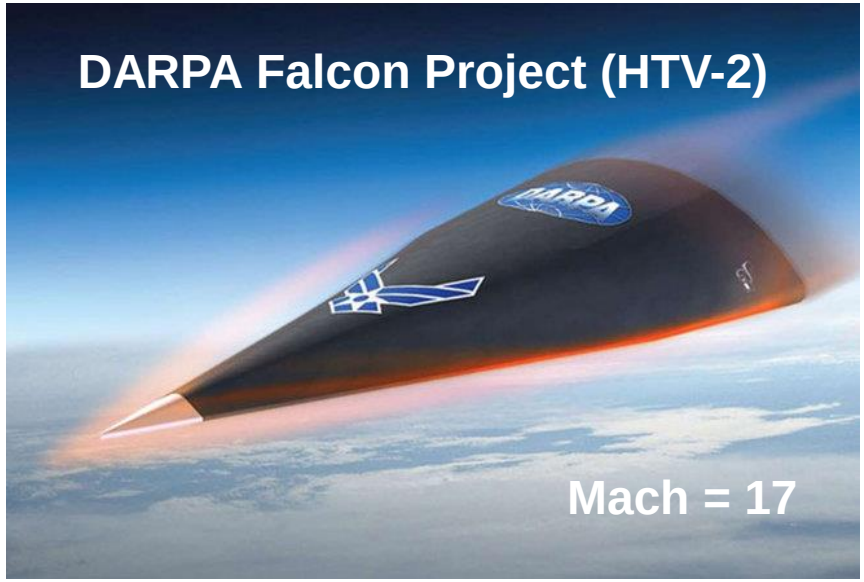
THERMAL / FLUID SCIENCES TECHNICAL ISSUES

Hypersonic Experimental and Flight Tests

Supersonic (2 < M < 5) and especially Hypersonic (M >5) flight entails:

1. *intense aerodynamic heating and drag*
2. *propulsion system complexity: supersonic combustion, high thrust > wave drag*
3. *sophisticated thermal protection systems (TPS):*
   - *resisting oxidizing air and high temperatures >2000 C*
   - *high thermal inertia but low density*

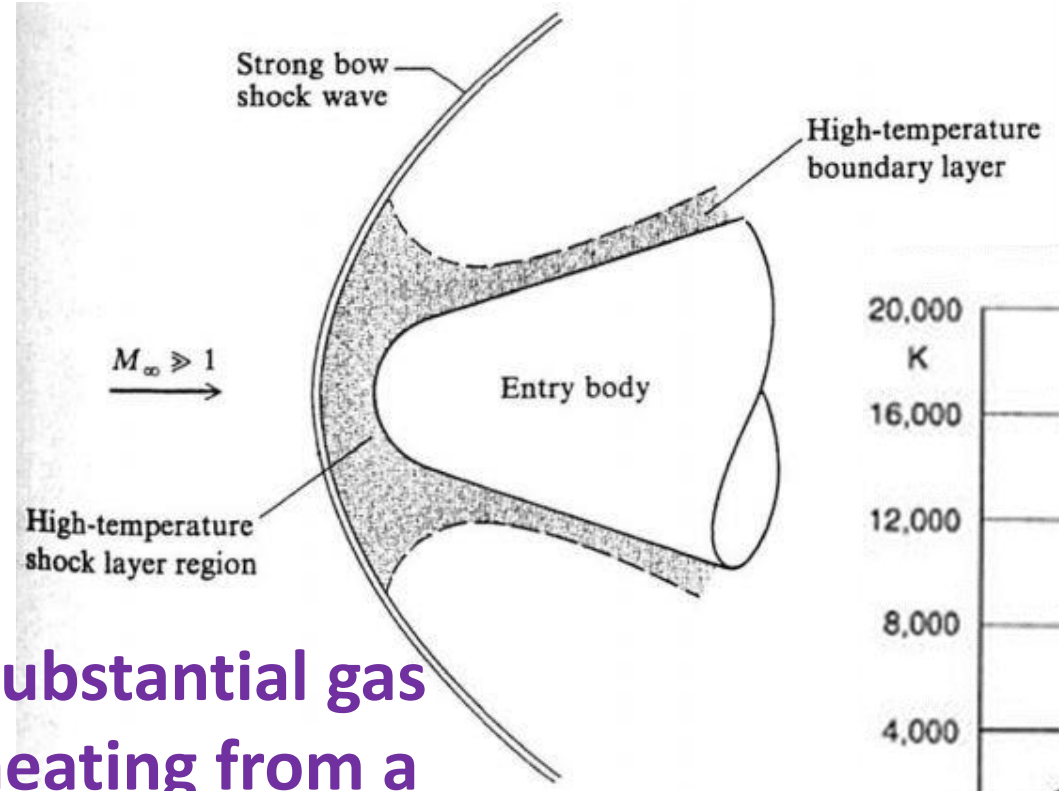
VARIATION OF 2000 m/s in velocity over a distance of 2 mm boundary layer thickness!



oxidizing atmosphere, intense heating

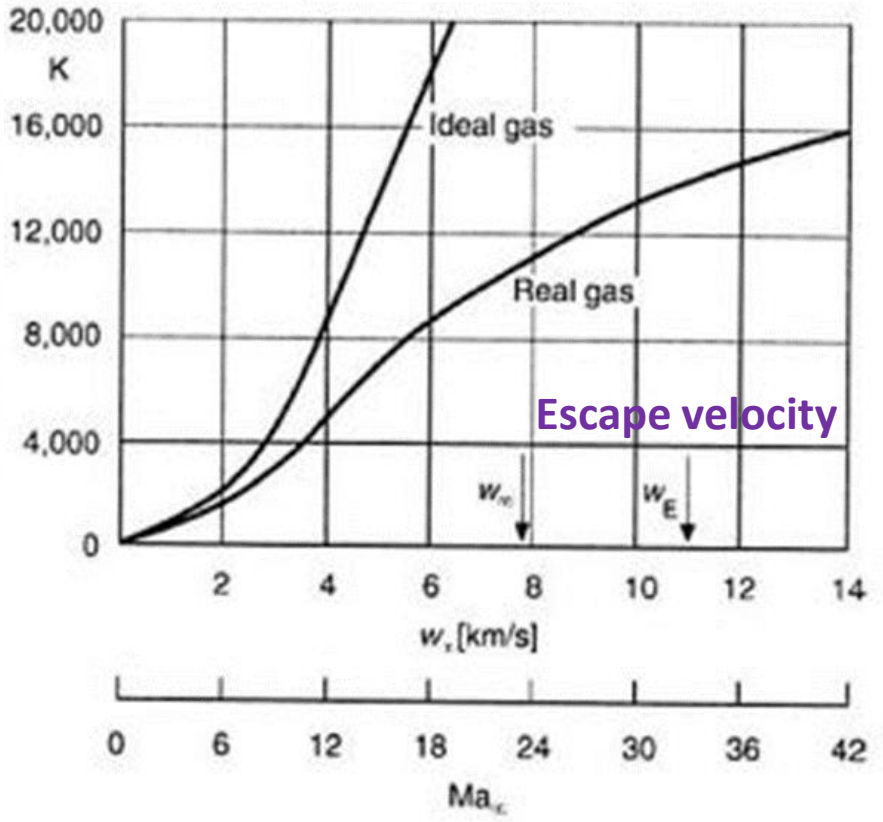
Transition and turbulence production in hypersonic boundary layers important because of relevance to hypersonic vehicle flight.

THERMAL / FLUID SCIENCES TECHNICAL ISSUES



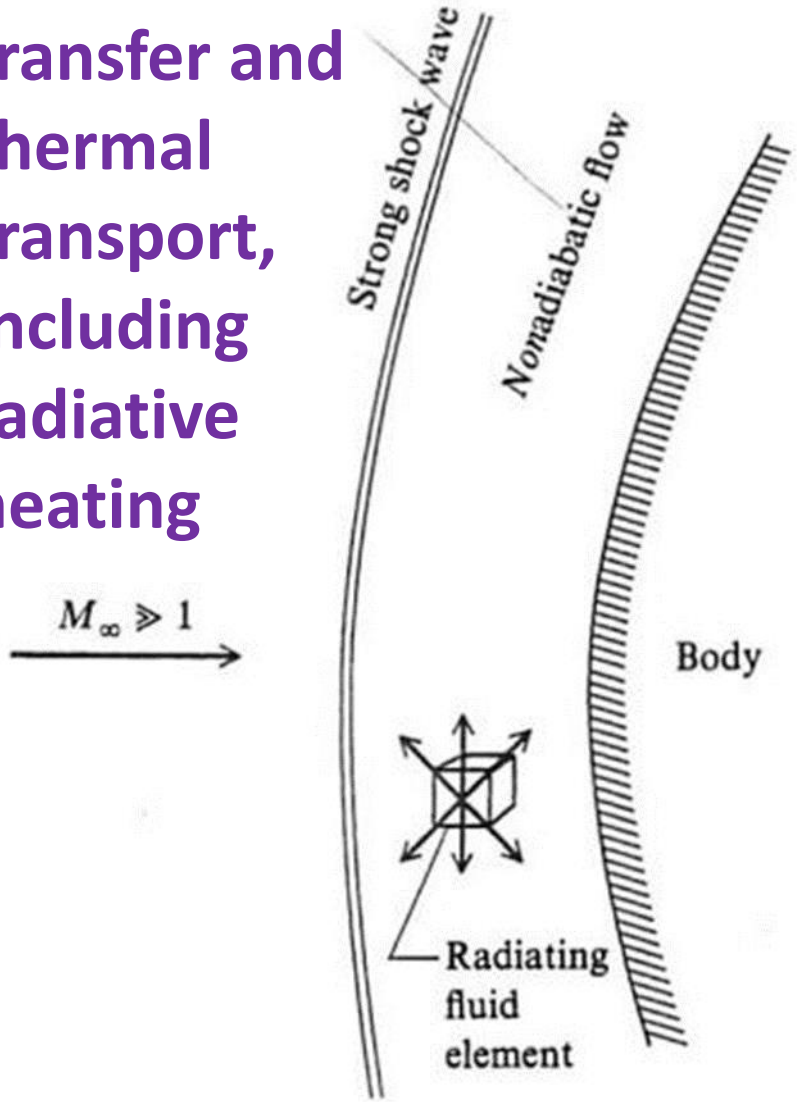
Substantial gas heating from a shock wave - compresses and heats the gas

Temperature increase as dependent upon flight speed

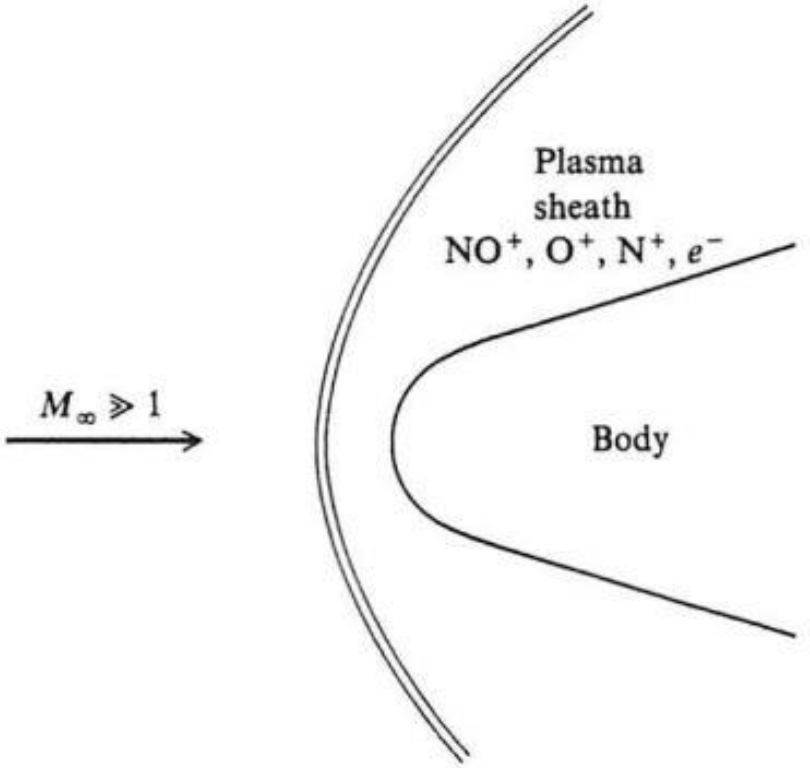


THERMAL / FLUID SCIENCES TECHNICAL ISSUES

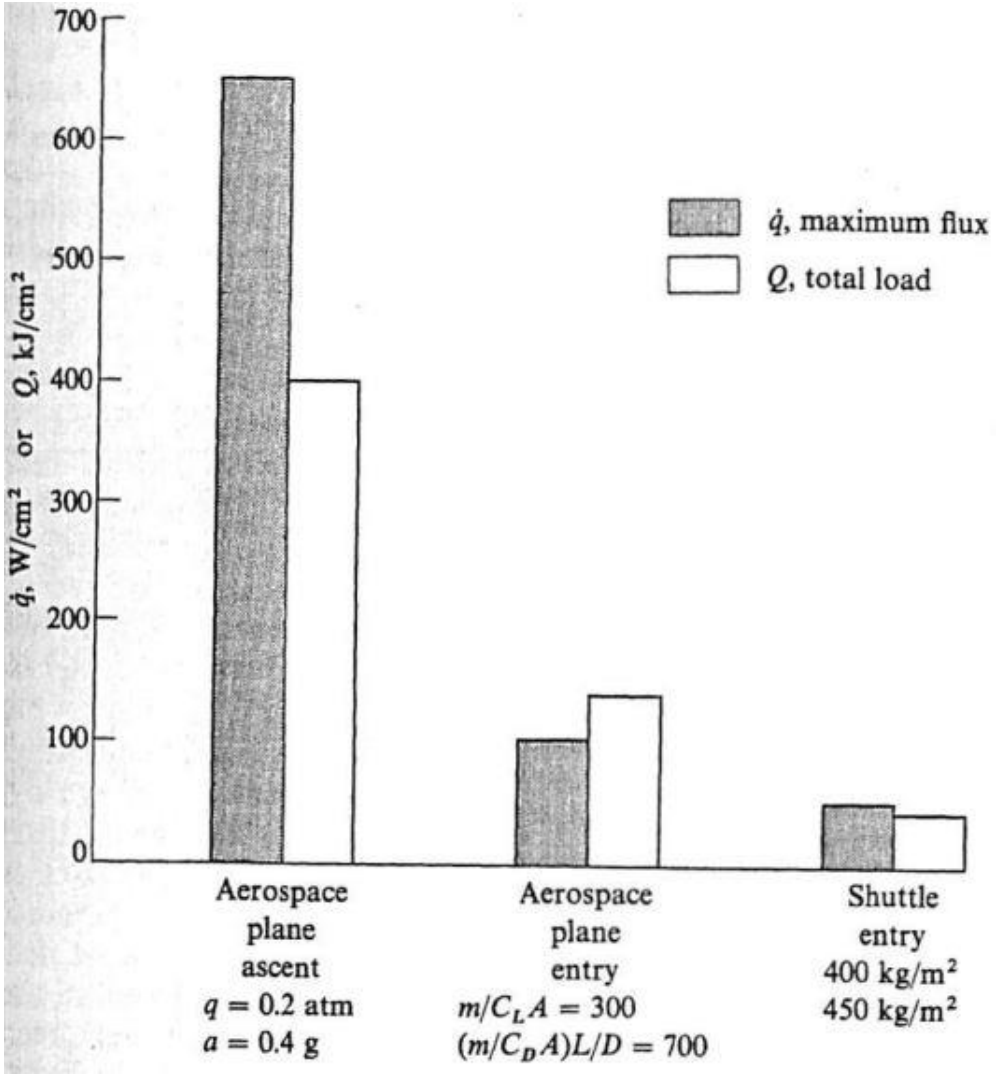
Heat transfer and thermal transport, including radiative heating



Gas dissociation within plasma sheath – if sufficient temperature, dissociation of air into different species



THERMAL / FLUID SCIENCES TECHNICAL ISSUES



Comparison between ascent and reentry stagnation-point aerodynamic heating for an aerospace plane and the reentry stagnation-point heating of the space shuttle.

THERMAL / FLUID SCIENCES TECHNICAL ISSUES

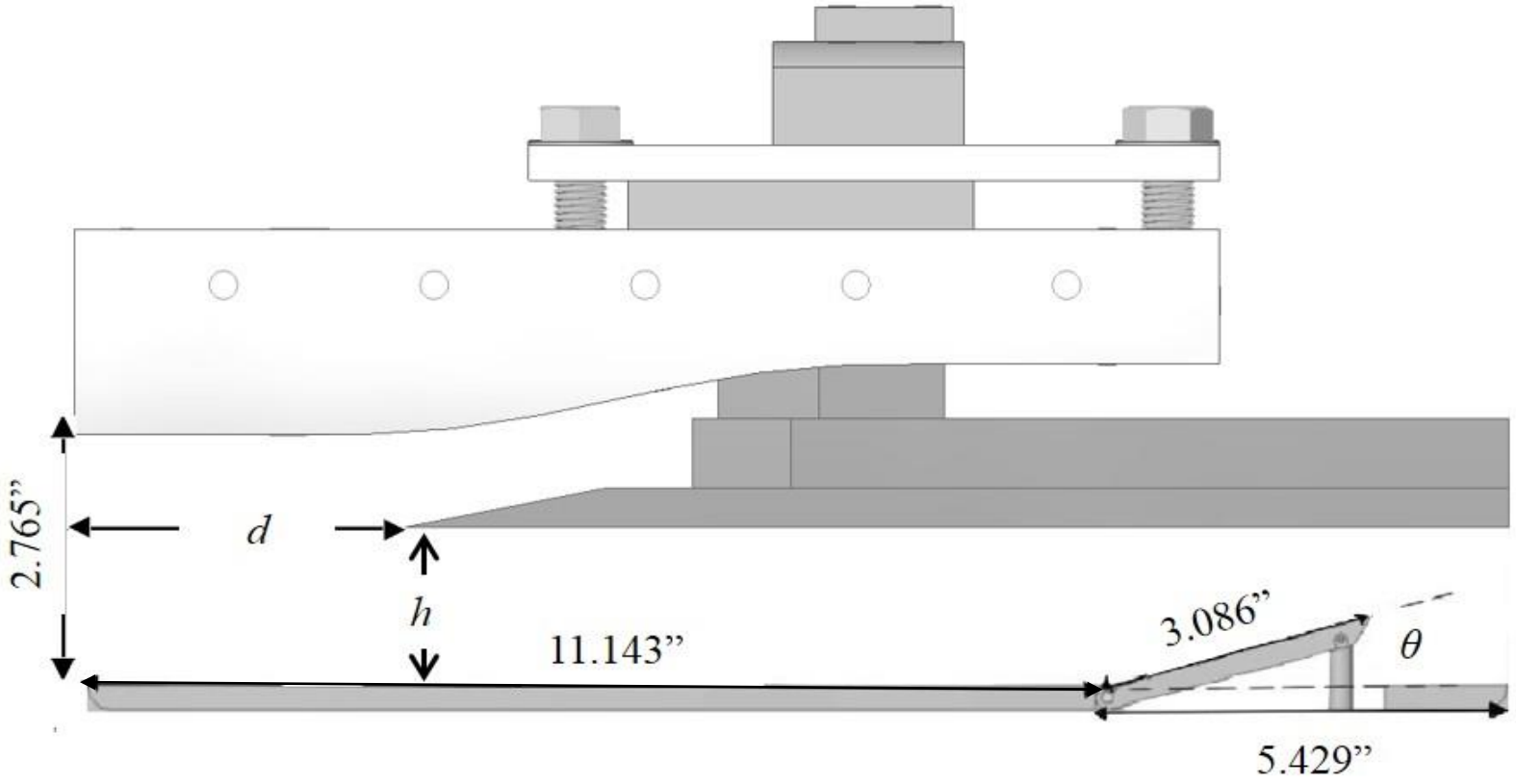
SuperSonic/TransSonic/WindTunnel

Increased capabilities relative to many other facilities.

- Inlet supply and exit exhaust plenums minimize propagation of unsteady flow disturbances
- Extensive testing times….
- Test section inlet Mach numbers (current) up to 3.0.
- Test section inlet Mach numbers (future) of 3.0 to 6.0.
- Capabilities to include *combustion* and *heat transfer*, with *time- and spatially-resolved surface heat transfer measurements*.

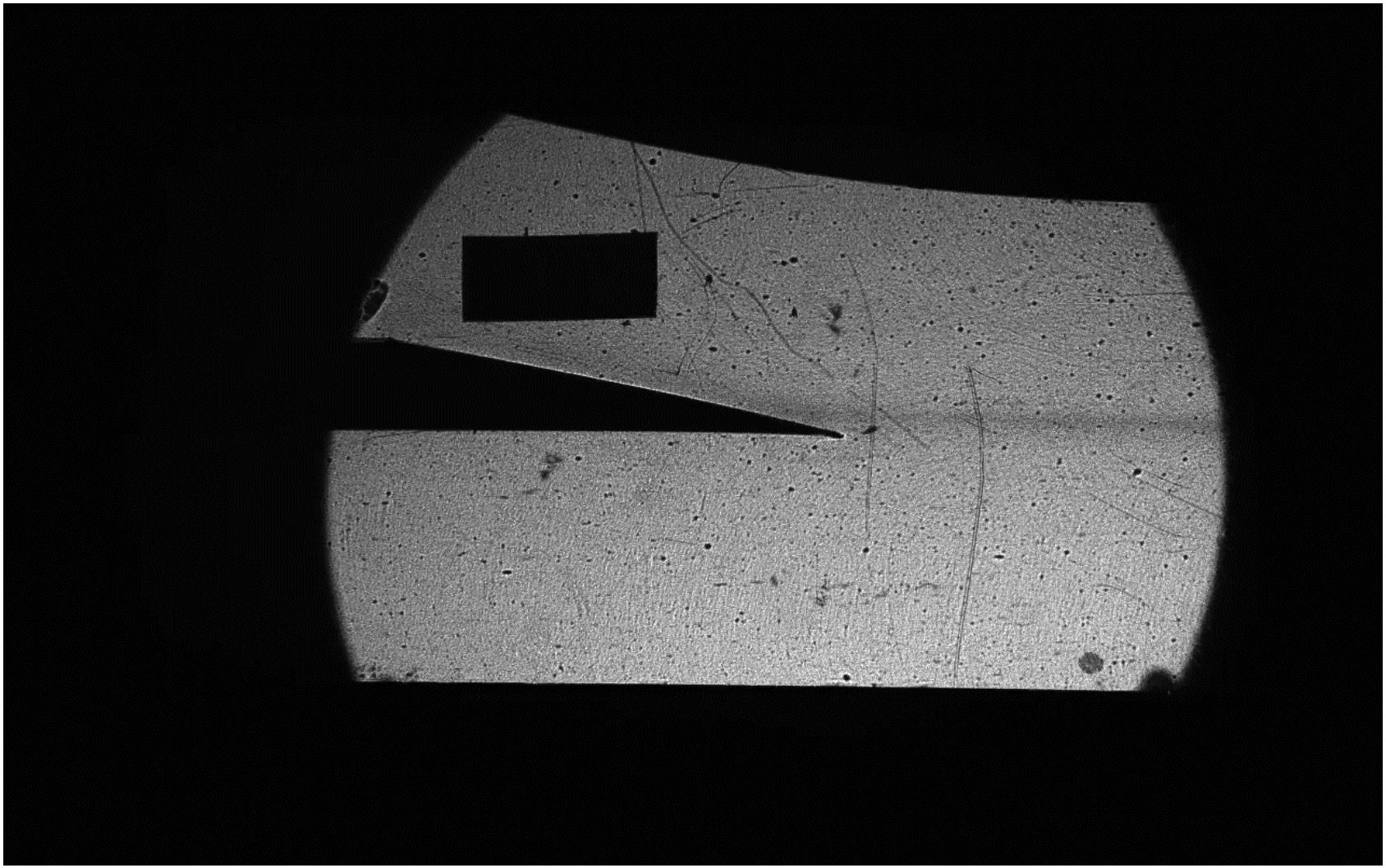
Wind Tunnel Test Section

Modifications for SHOCK WAVE CONTROL



THERMAL / FLUID SCIENCES TECHNICAL ISSUES

Shock wave structure and unsteadiness



SUMMARY

For the development of "game-changing technology", with a goal of "industrializing" hypersonic missile production, understanding of fundamental phenomena, and controlling associated physical effects are required.

Addressing such basic, fundamental science and engineering areas is *ideally suited to university research*.

Tim Sakulich, Executive Lead for Implementing the Air Force S&T Strategy, Air Force Research Laboratory.

"We are interested boundary layer phenomenology to better understand and examine heat flux on hypersonic weapons that allows us to do optimization of the thermal management to provide that lethality and reach we are looking for……"