Institute for Flow Physics and Control

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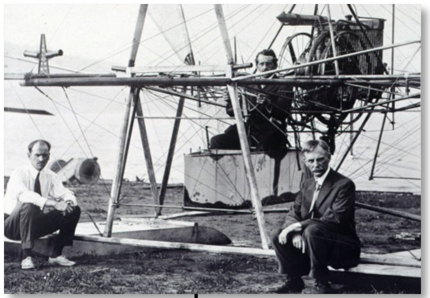
A Tradition of Aeronautic Research



Prof. Zahm & Glenn Curtis

FlowPAC

1888 — 1920 — 1940 — 1992 — 2002 — 2008

Aerospace Building

Hessert Laboratory

White Field Laboratory

72,000 sq-ft of laboratory and office space

Institute for Flow Physics and Control

SIGNATURE RESEARCH AREAS

- Aero-acoustics
- Aero-optics
- Fluid-structure Interactions
- Gas-turbine Propulsion
- Wind Energy
- Multi-phase Flows
- Plasma Dynamics
- Sensors and Flow Control Actuators
- Hypersonic Aerodynamics

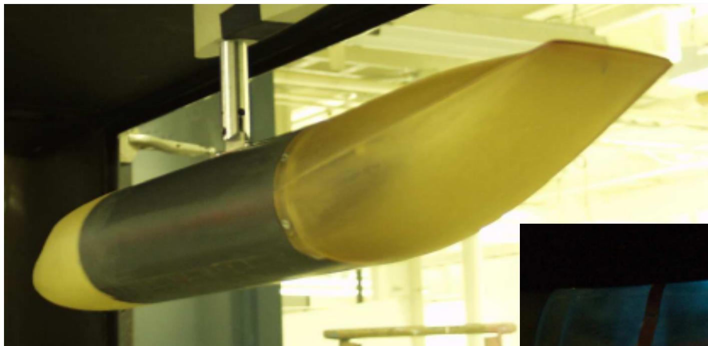
PARTICIPANTS

- 22 T&R Faculty
- 4 R Faculty
- 6 Technical Staff
- 75 Ph.D. Students (85% U.S. citizens)
- 11 U.S. Govt. Agencies
- 25 Companies

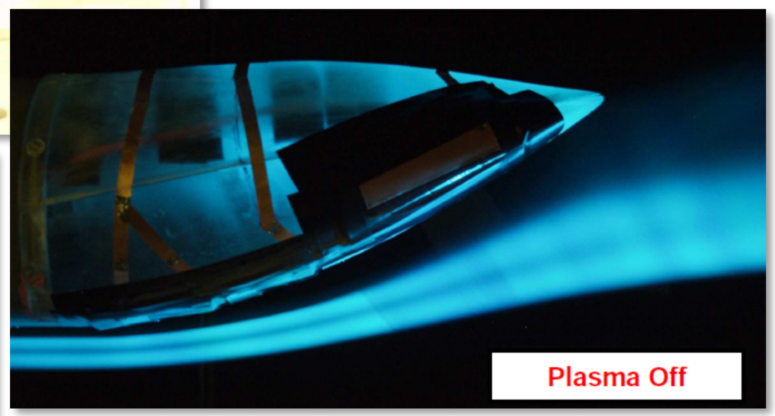
Hessert Laboratory

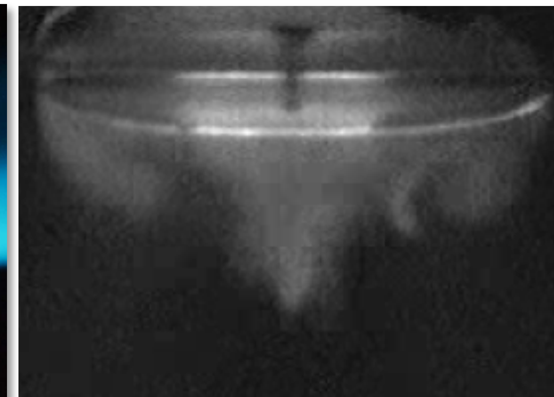
White Field Laboratory

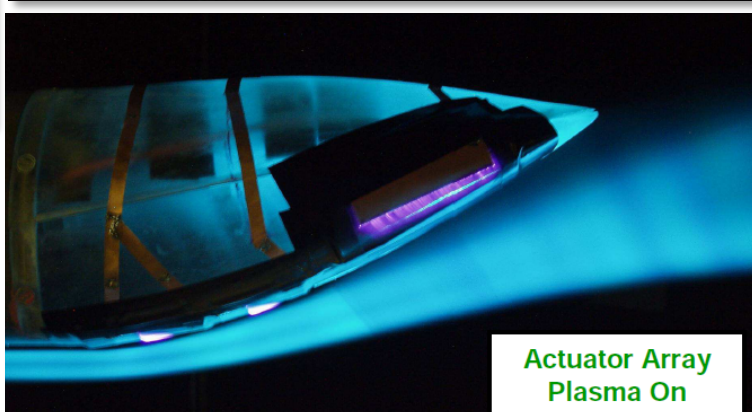
Low-Speed Wind Tunnels

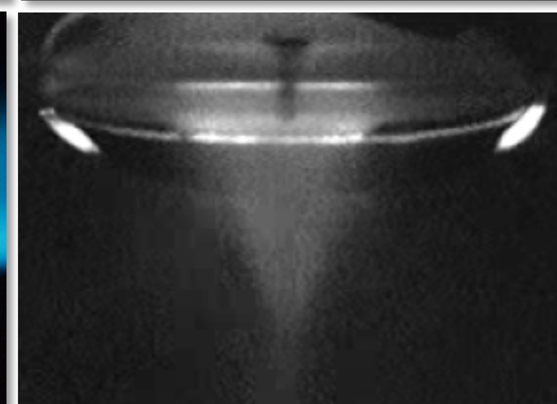


Initial investigations utilizing flow visualization and other flow diagnostic tools (hot-wire, LDV, PIV, etc)



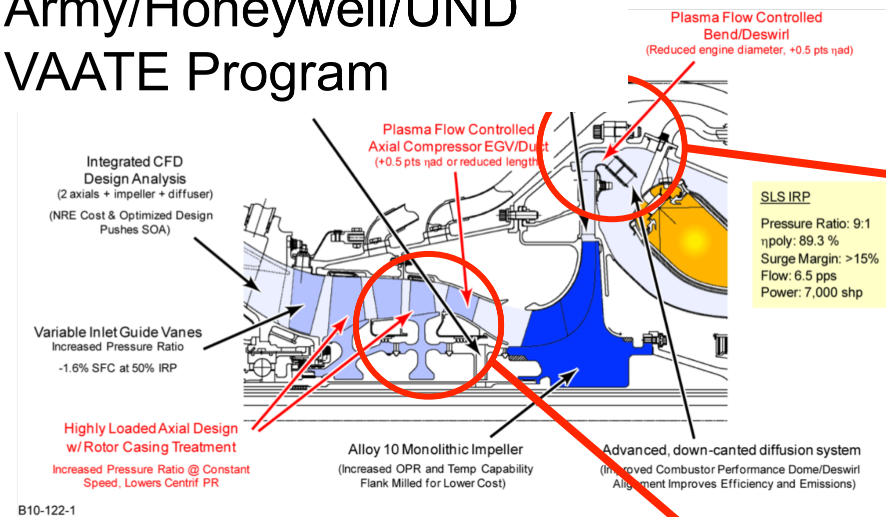


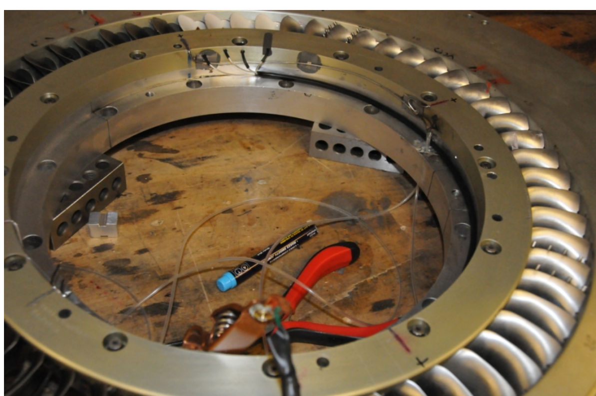




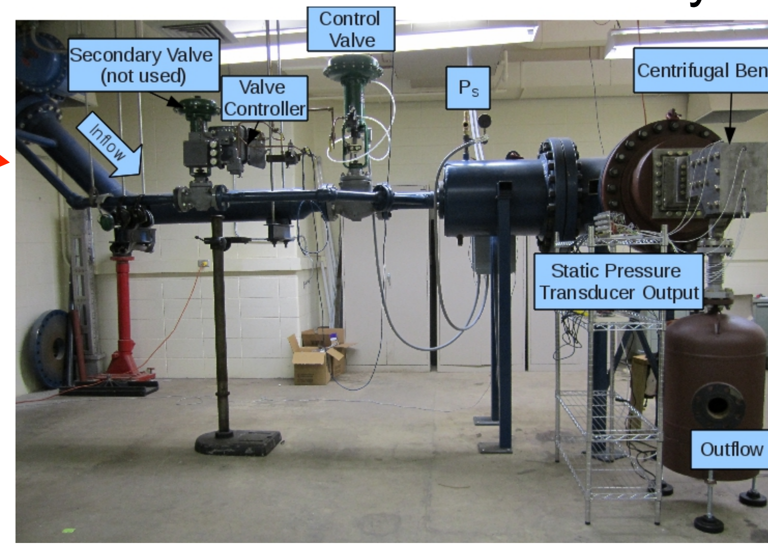
Component Facilities

Army/Honeywell/UND VAATE Program

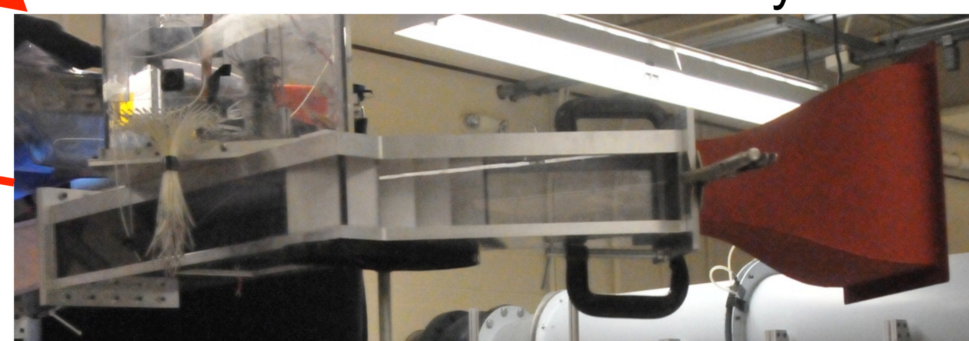




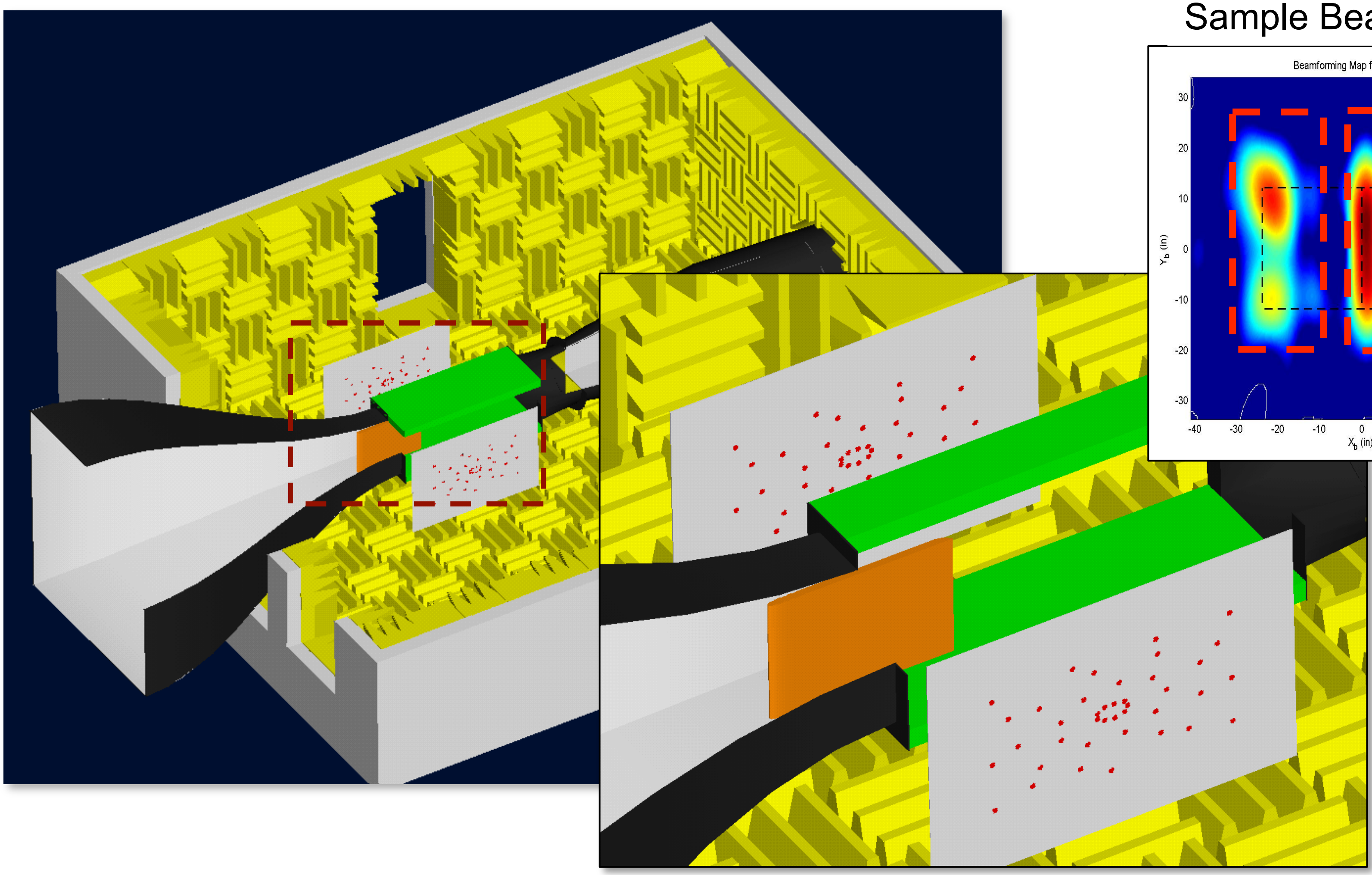
40Bar Blow-down Facility



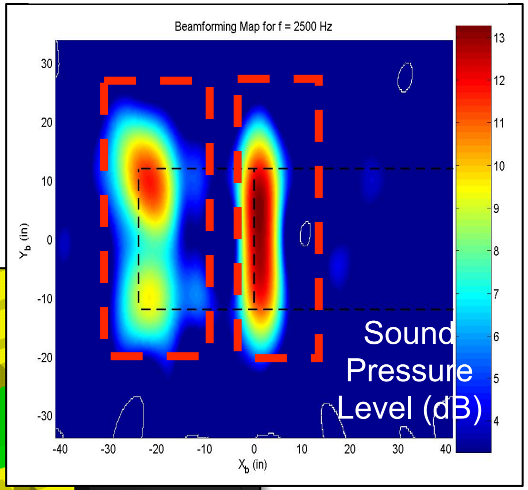
In-draft Tri-Sonic Facility



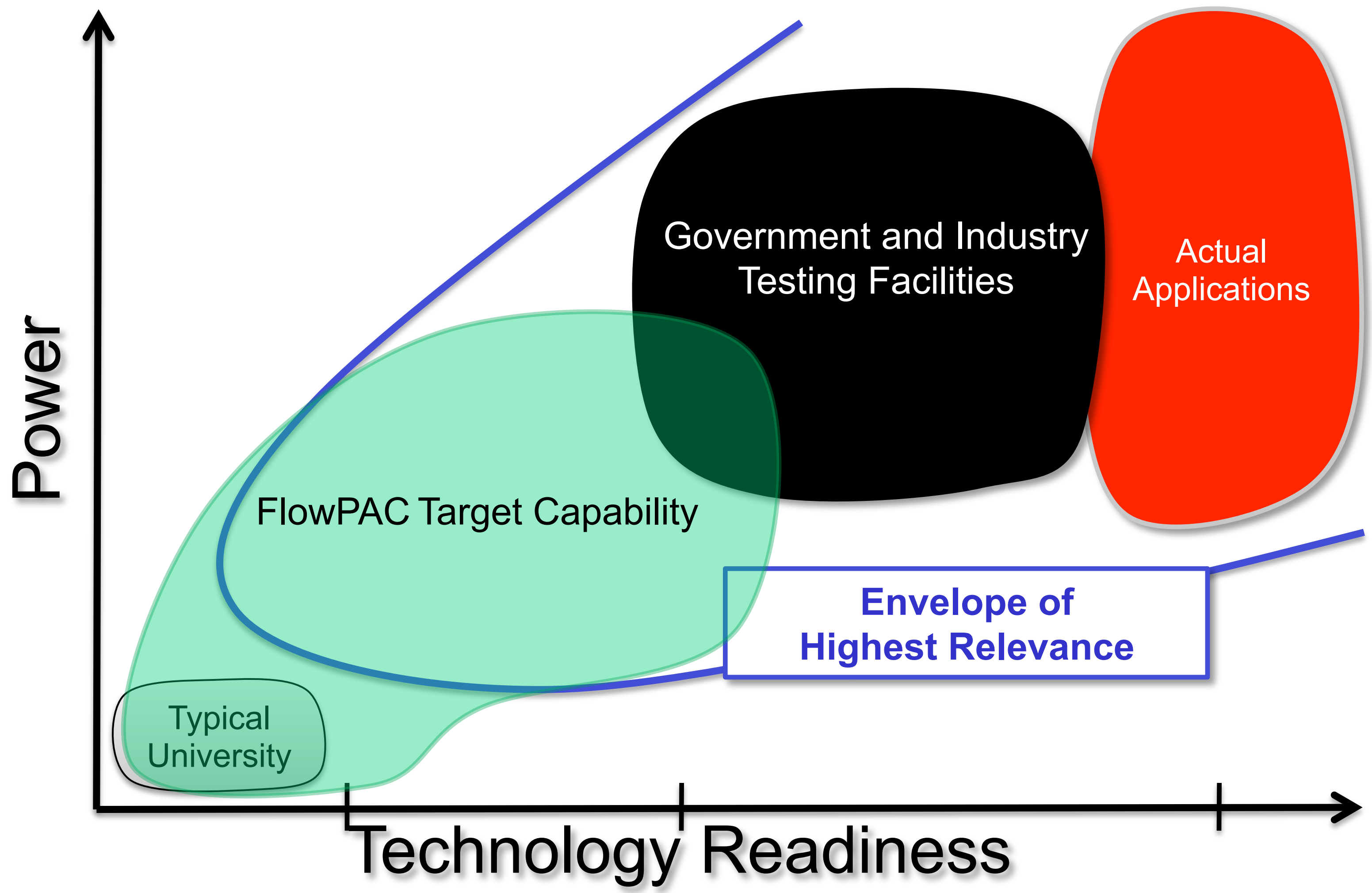
Anechoic Wind Tunnel



Sample Beam Forming



Experimental Facilities Vision

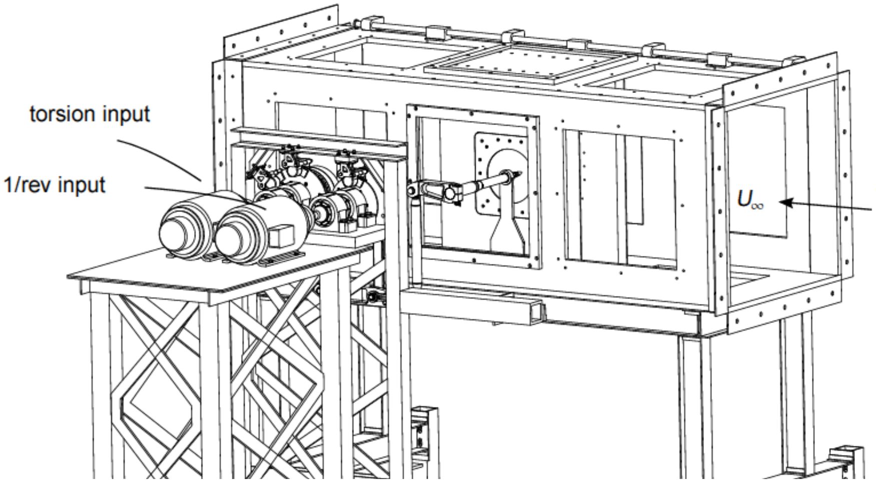


Mach 0.6 Wind Tunnel

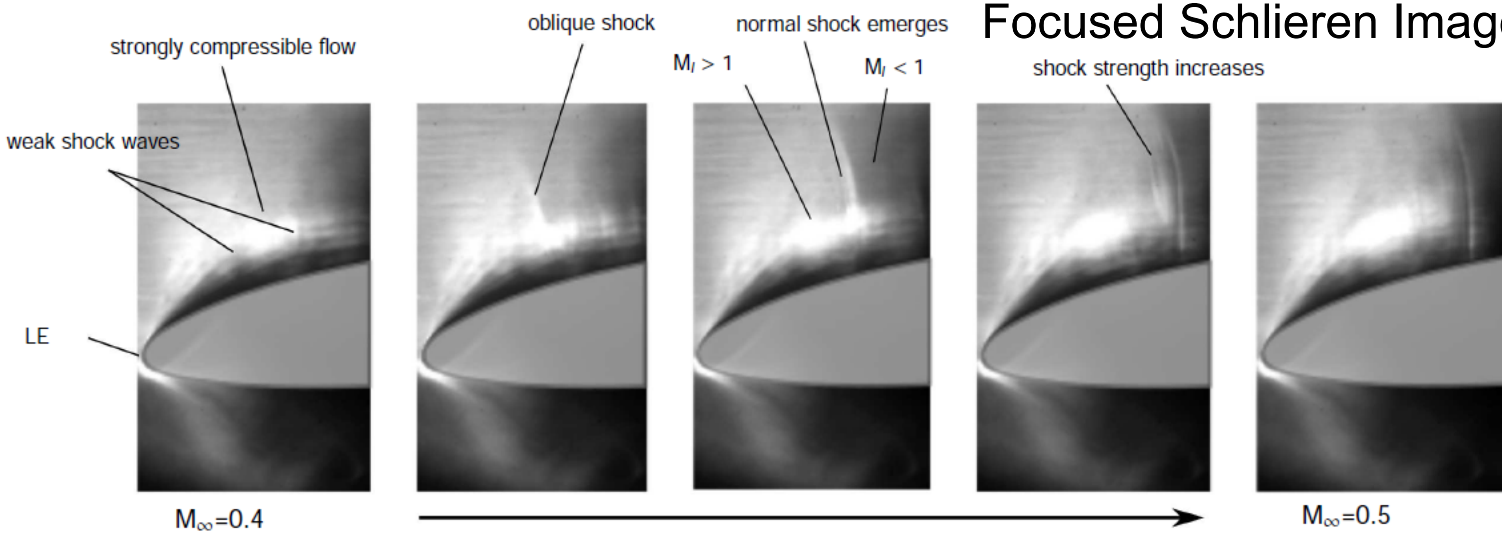
- 3’x3’x9’ test sections
- Large optical access
- Low turbulence
- Temperature controlled

- 1750 H.P. motor
- Variable R.P.M. AC
- 8’ diam., 2-stage fan
- 1000 ton-hr ice-storage chilled water cooling

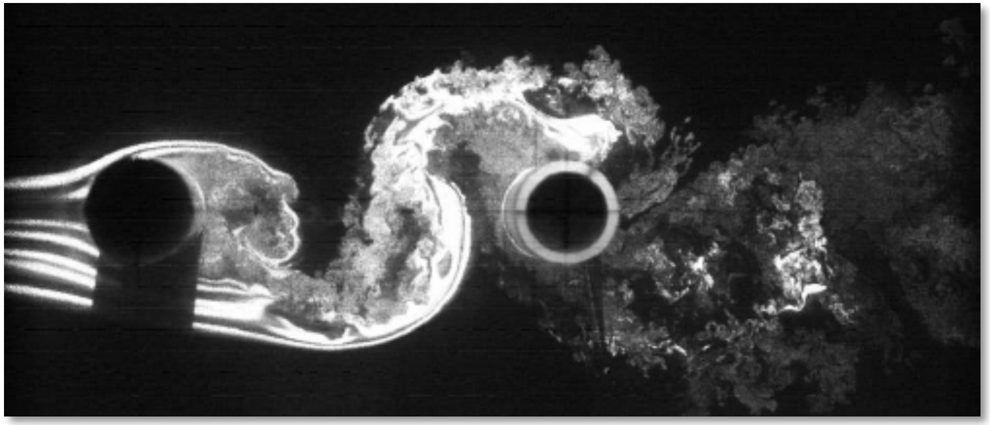
Helicopter Dynamic Stall Facility

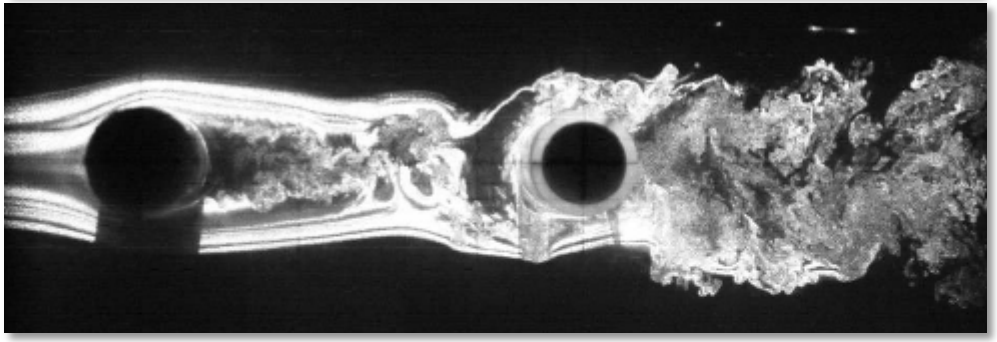


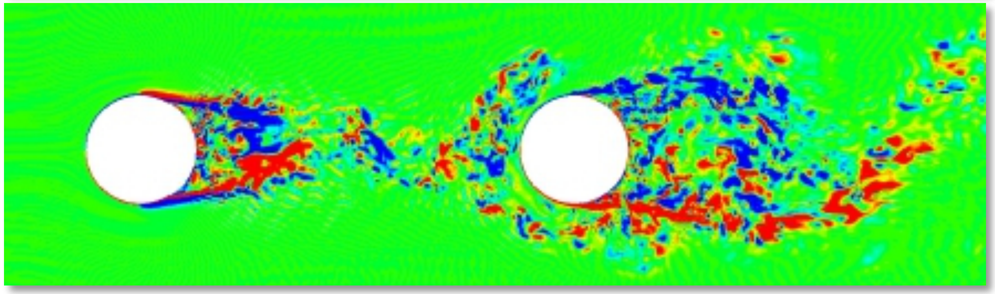
Focused Schlieren Images



Airframe Noise

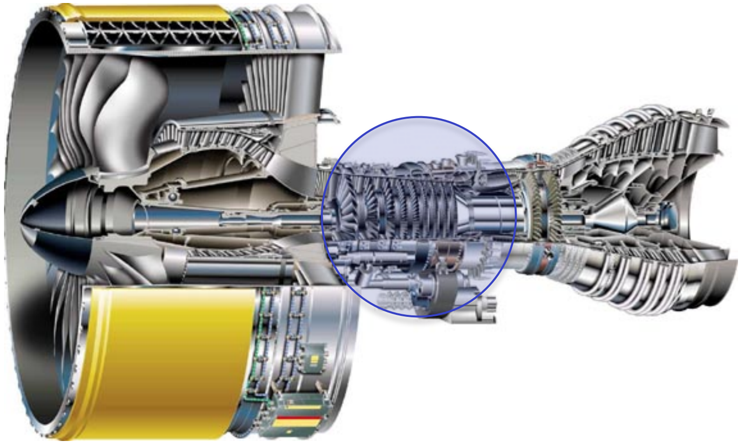




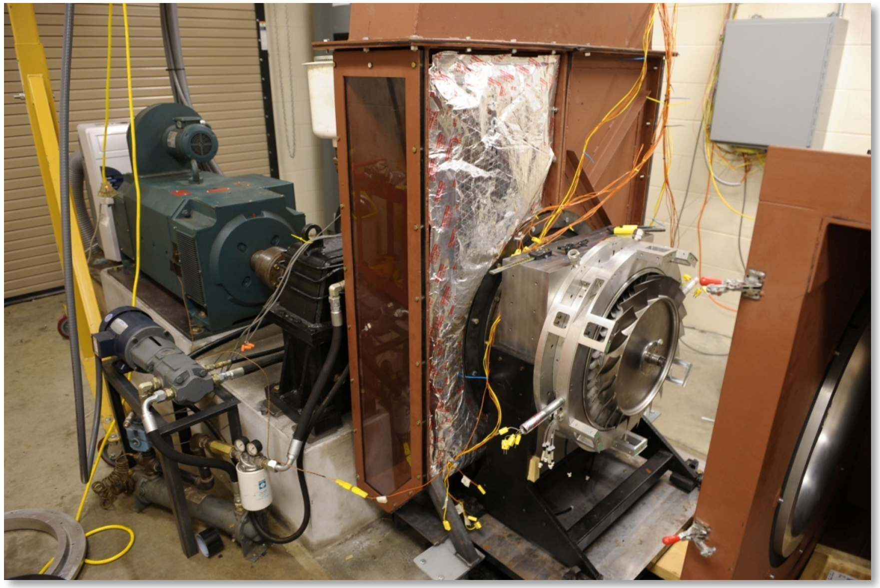


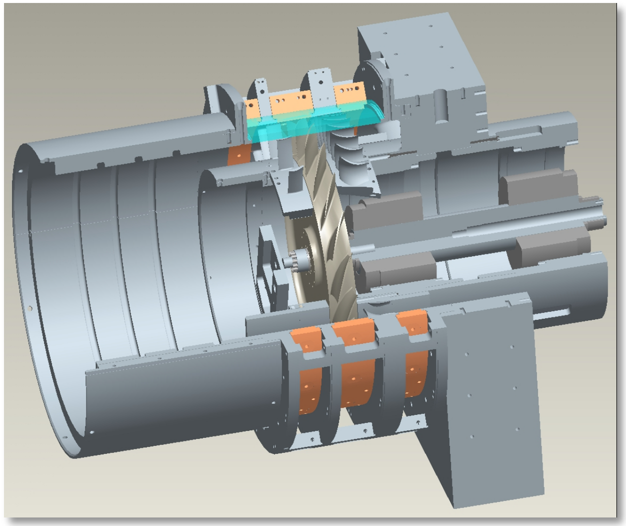
Gulfstream 550 Nose LG

Transonic Compressor Facility

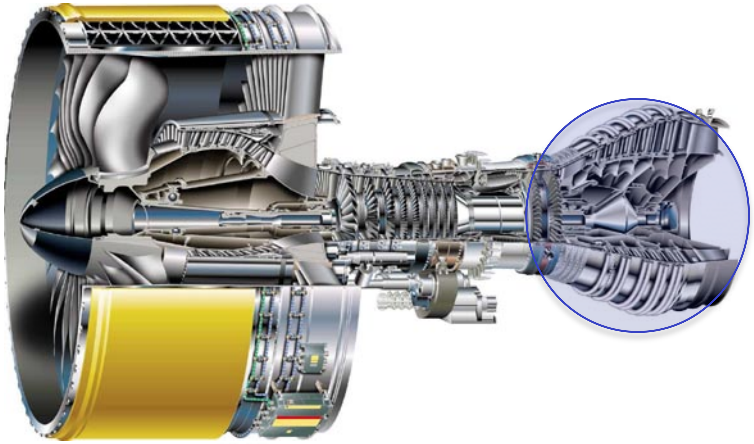


- 400 H.P.
- 15,000 R.P.M.
- Design tip-Mach: 1.2
- Magnetic levitation rotor bearings
- Rotor optical access

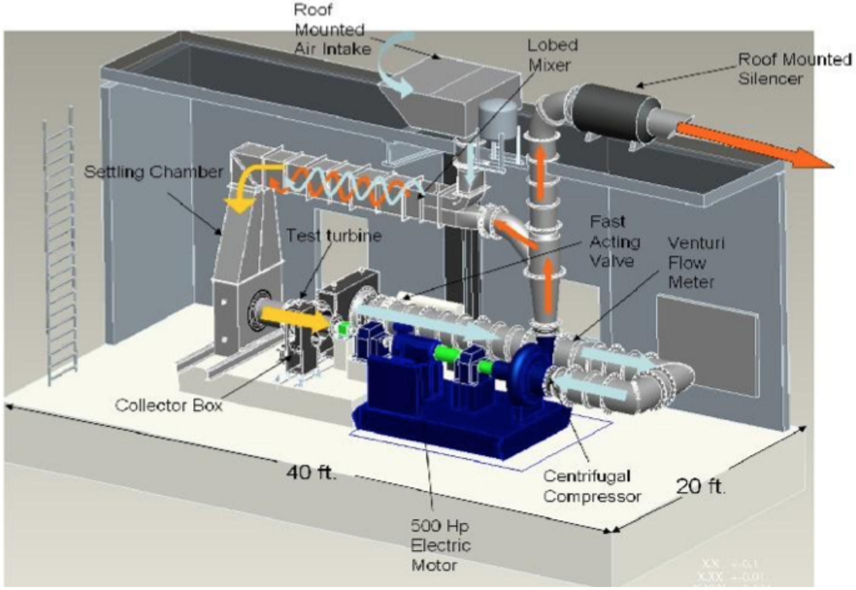


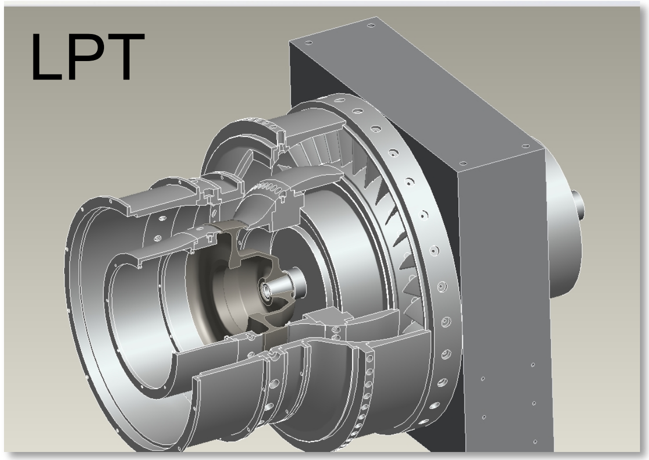


Transonic Turbine Facility



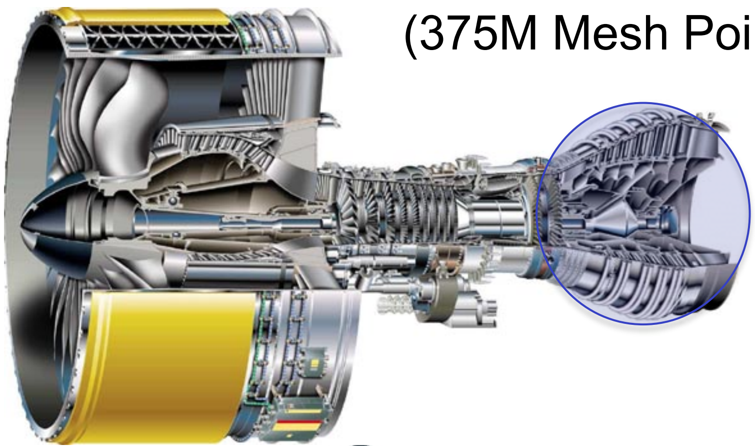
- 800 H.P. compressor
- 500 H.P. motor
- Design 300 H.P. turbine
- Magnetic levitation rotor bearings
- Highly-loading rotor design

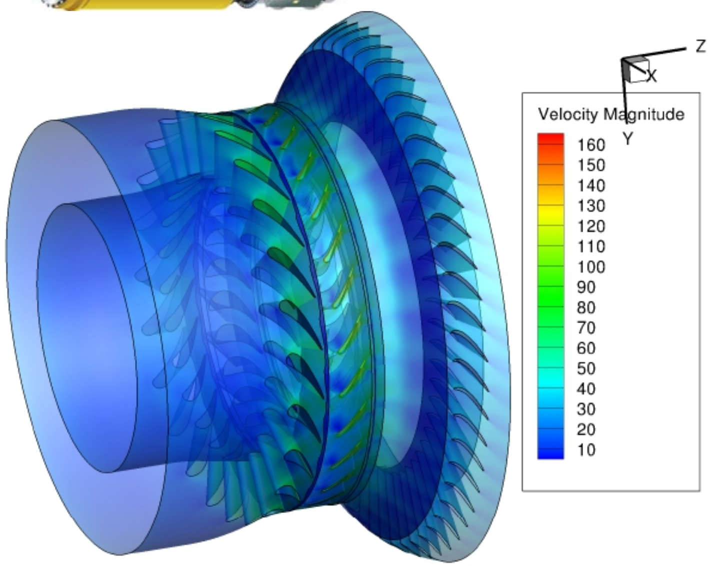


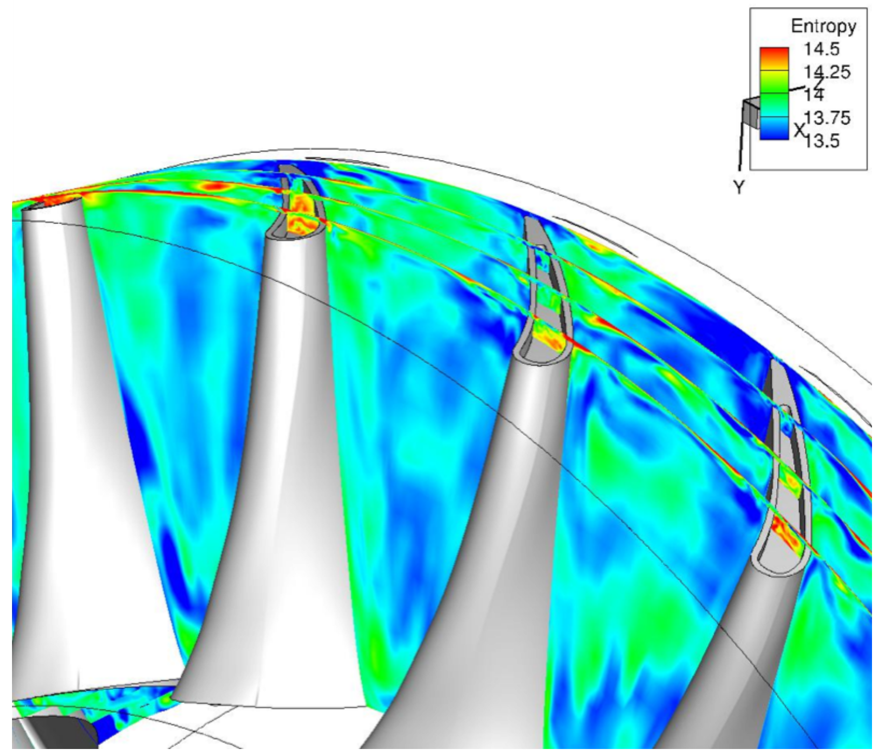


Computational Fluid Dynamics

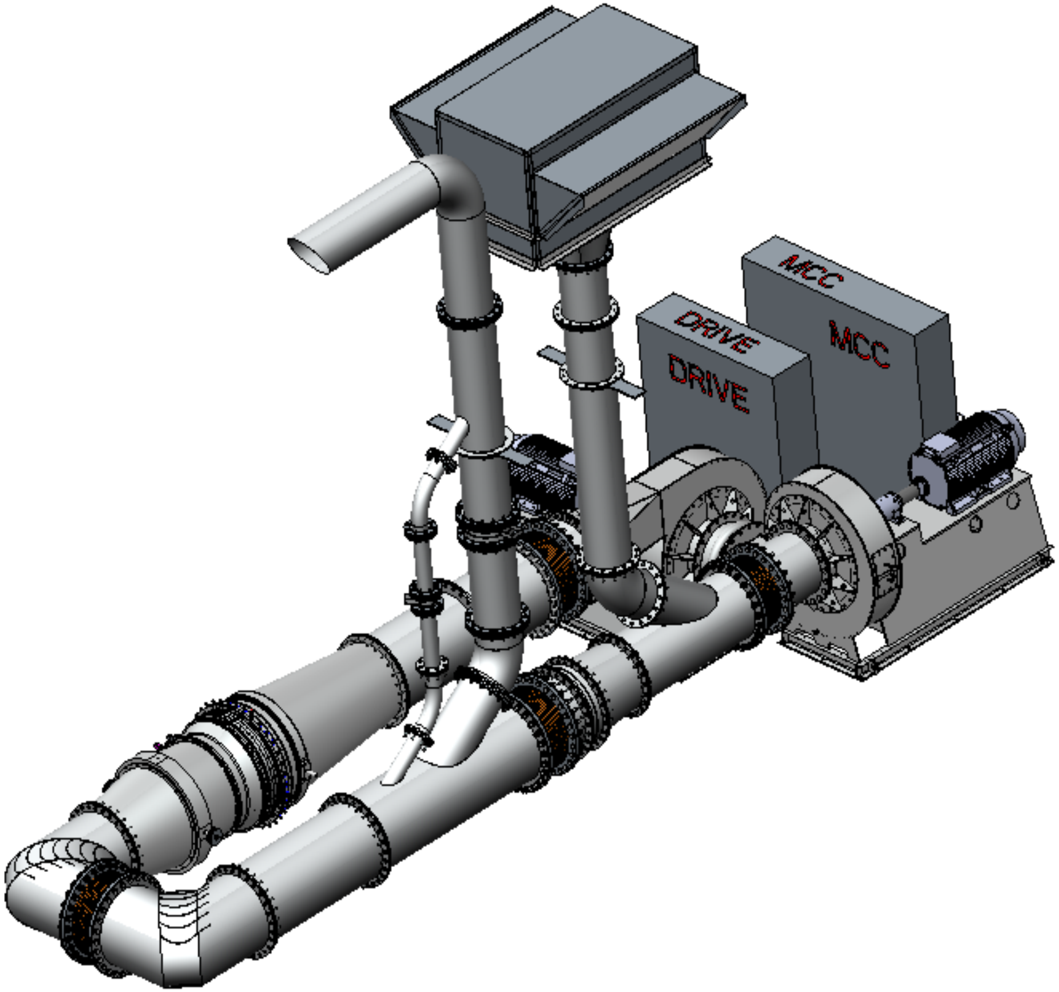
(375M Mesh Points, 512 Processor Cores)





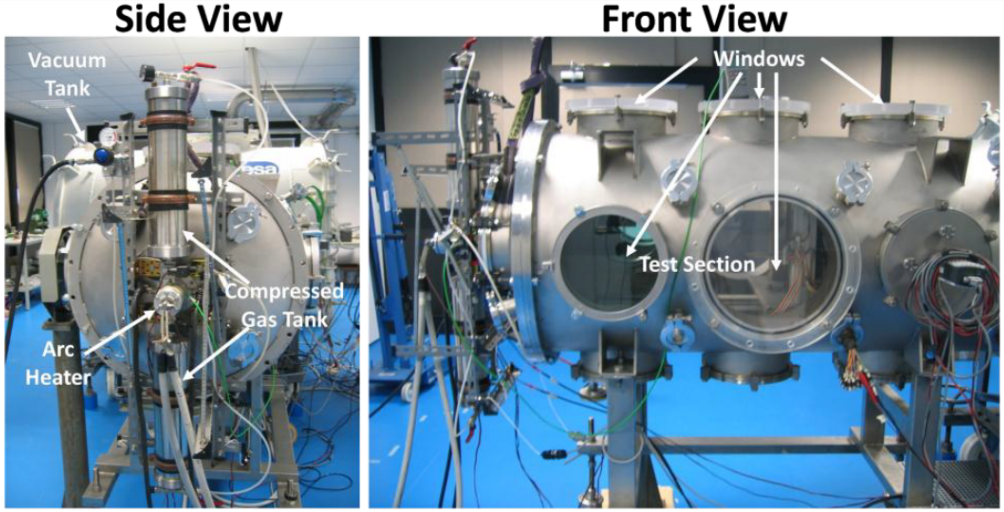


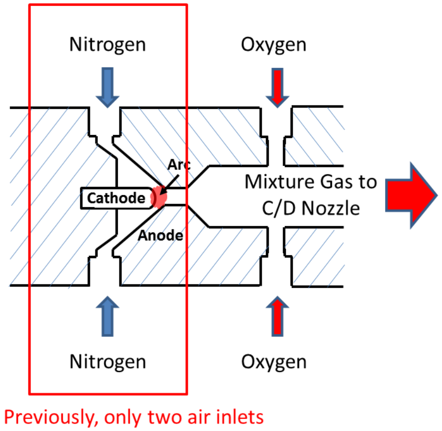
Hot Annular Nozzle Cascade (HANC)

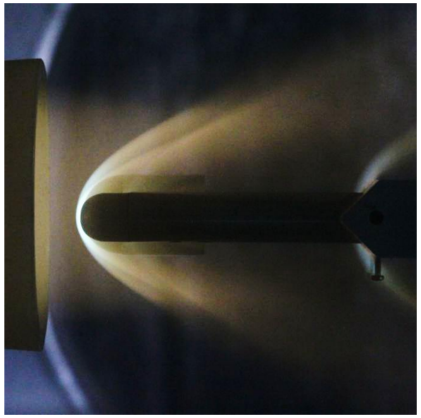


- 700°F primary flow
- Transonic nozzle Mach numbers
- Full secondary cooling systems
- 46 inch diameter
- Controlled inlet turbulence characteristics.
- Highly detailed aero/thermal measurements

Arc Heated Hypersonic Wind Tunnel

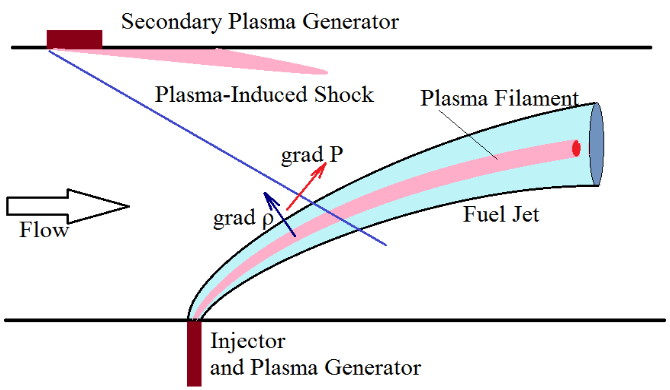


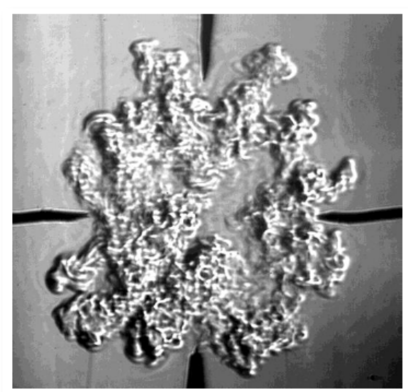


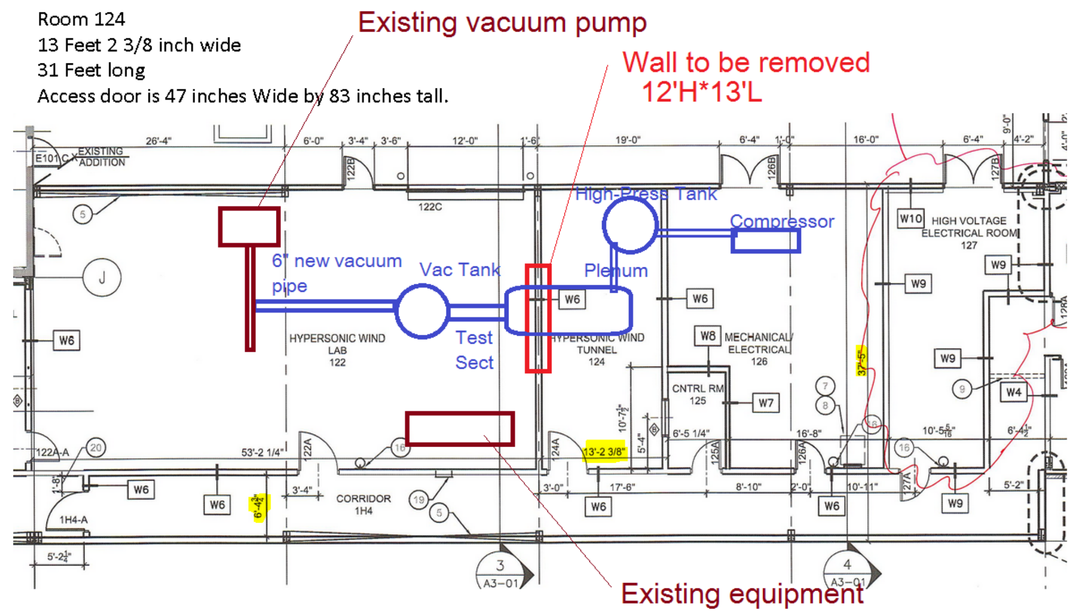


Supersonic Mixing Facility

Mixing Enhancement and Flame Stabilization in High-Speed Combustion Systems by Transient Plasma*

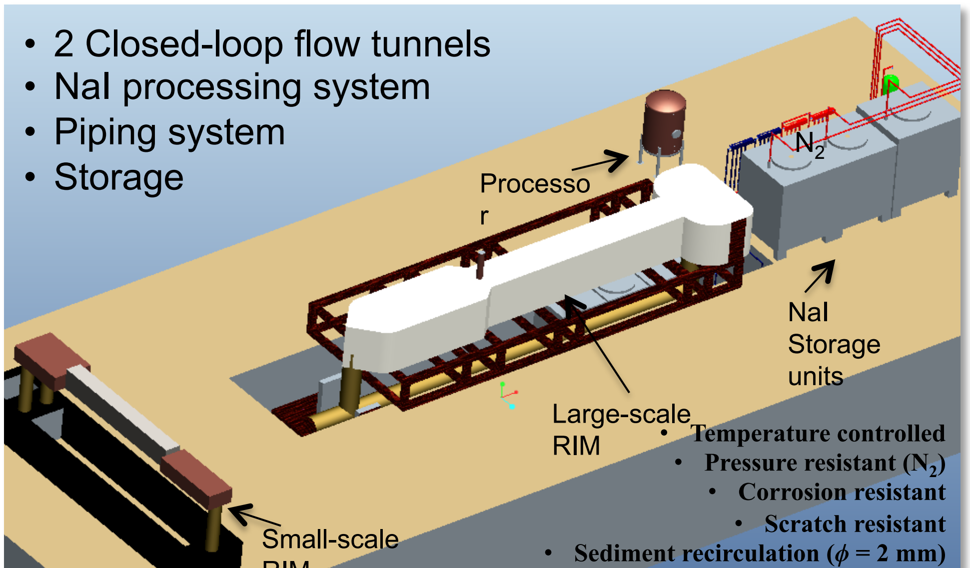




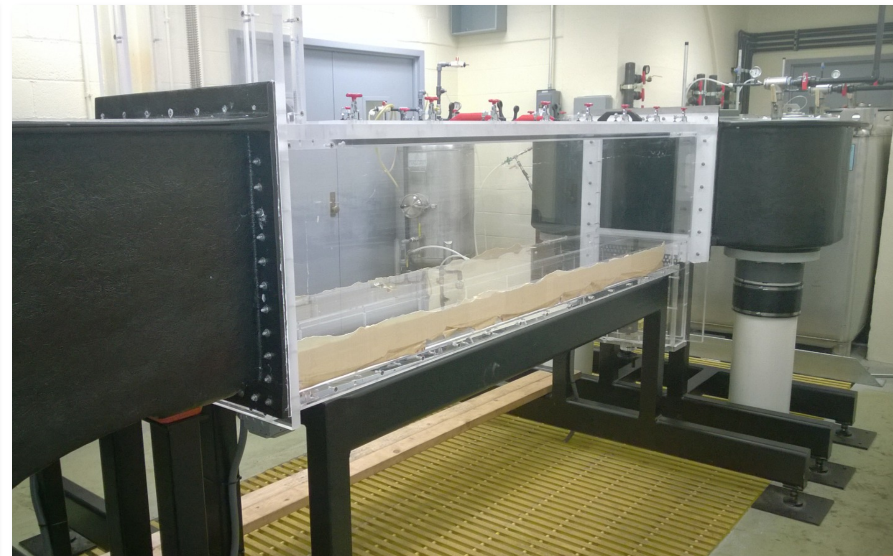


Refractive-Index-Matched (RIM) Flow Facilities*

Laboratory overview

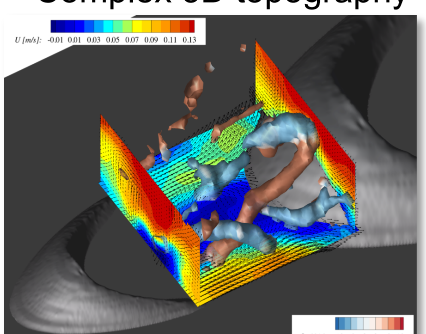


Large-scale RIM

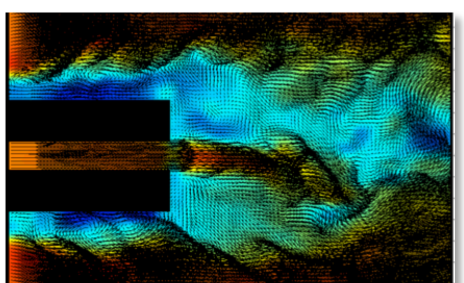


- Total volume: 4200 liters
- Velocity up to ~ 2 ms^{-1}
- Cross section: 0.45 m x 0.45 m
- Length: 2.5 m

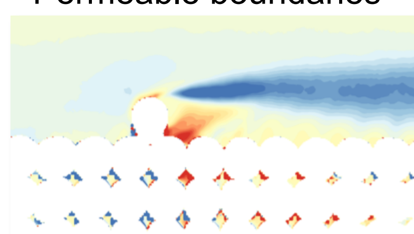
Complex 3D topography



Bluff Bodies



Permeable boundaries



Applications

*AFOSR MURI, Ken Christensen PI

Wind Energy Laboratory (eWiND)

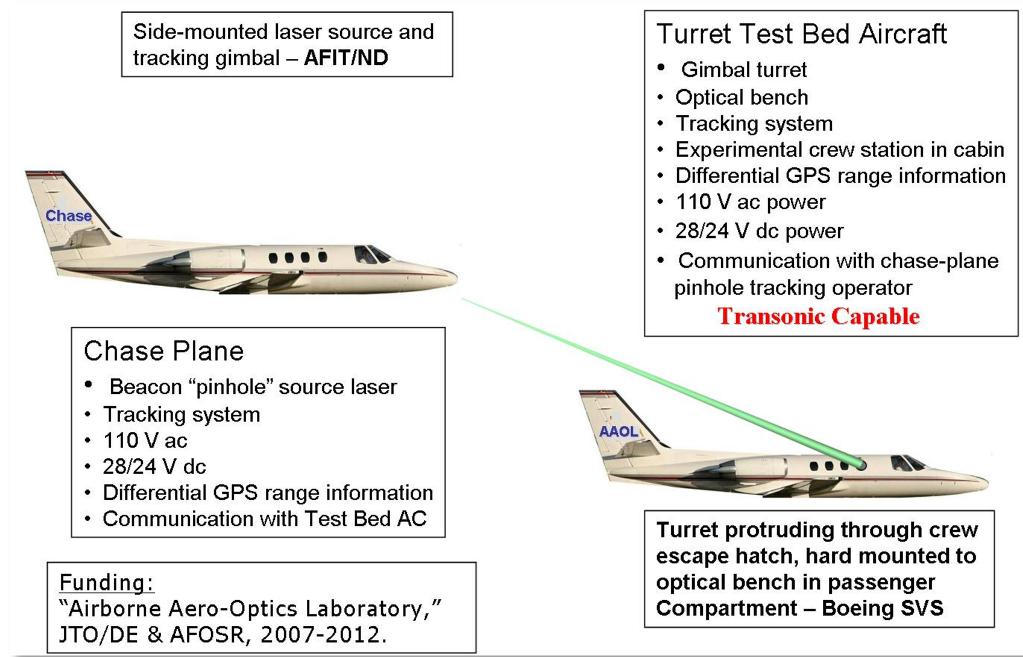
25kW Turbines:

- 30’ Diameter
- 59’ Hub Height
- Pitch Controlled

Meteorological Tower:

- 3-component, fast response ultrasonic anemometers
- Temperature
- Humidity
- Pressure

Airborne Aero-optics Laboratory



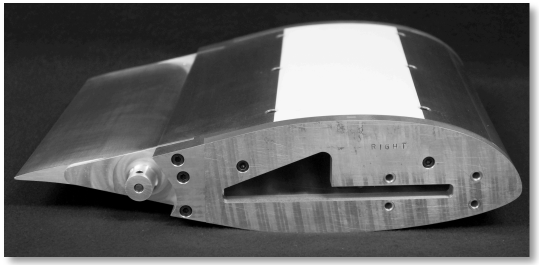
Dynamic correction of optical distortions produced by compressible flow structures

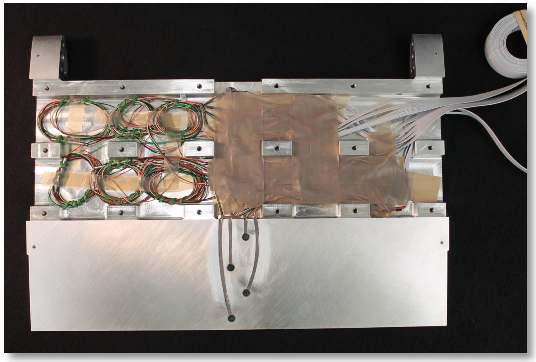
FlowPAC Fabrication Shop

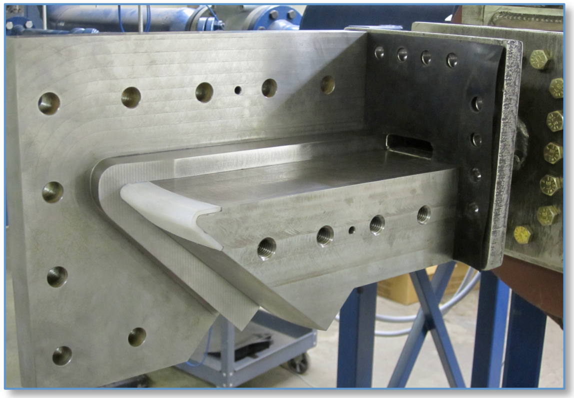
4 Axis Mill

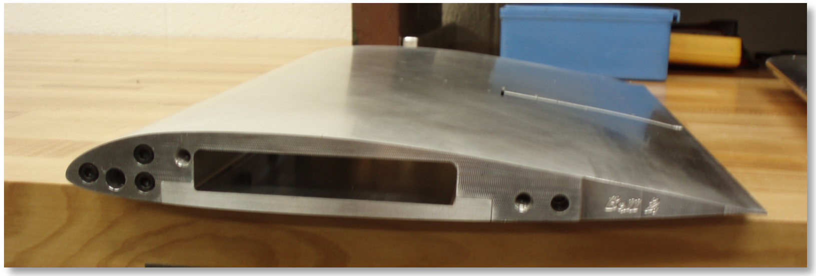
5 Axis Mill

Num. Lathe

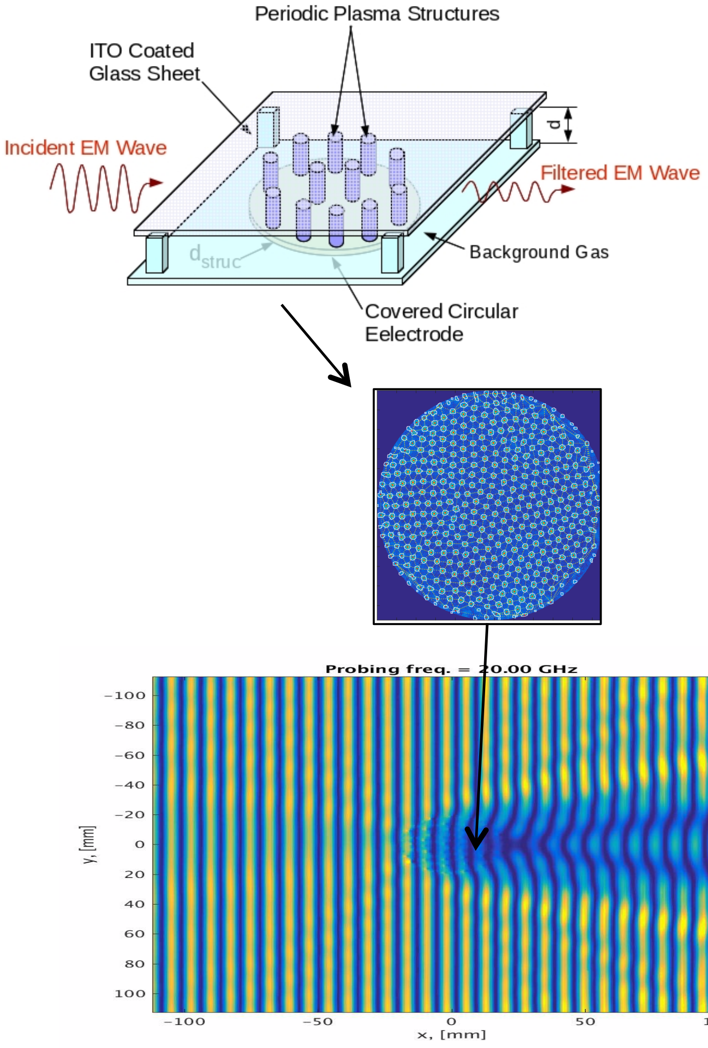




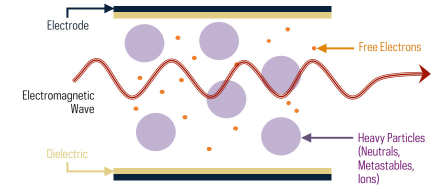




Tunable Plasma Metamaterials

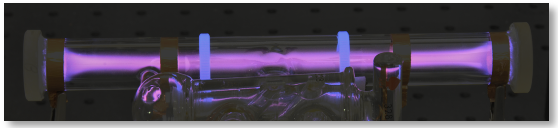


Plasma Adaptive Optics

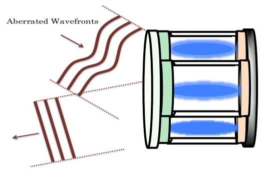


- The free electrons, neutrals, metastables, and ions in an ionized gas can affect the **permittivity to EM waves**.
- Change in the permittivity affects refractive index >>> Plasma Adaptive Optics (PAO). Technology Driver: Bandwidth

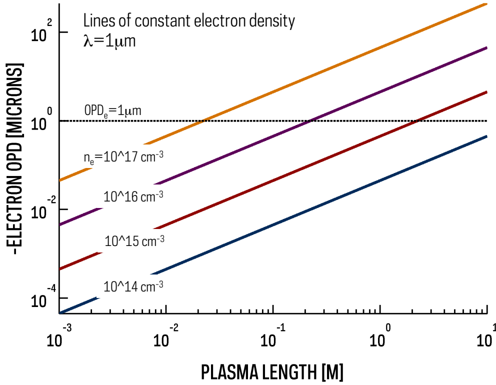
PAO



- Plasma optics OPD depends on the length of the plasma, electron density, EM wavelength, gas composition, and heavy particle density.



PAO Array

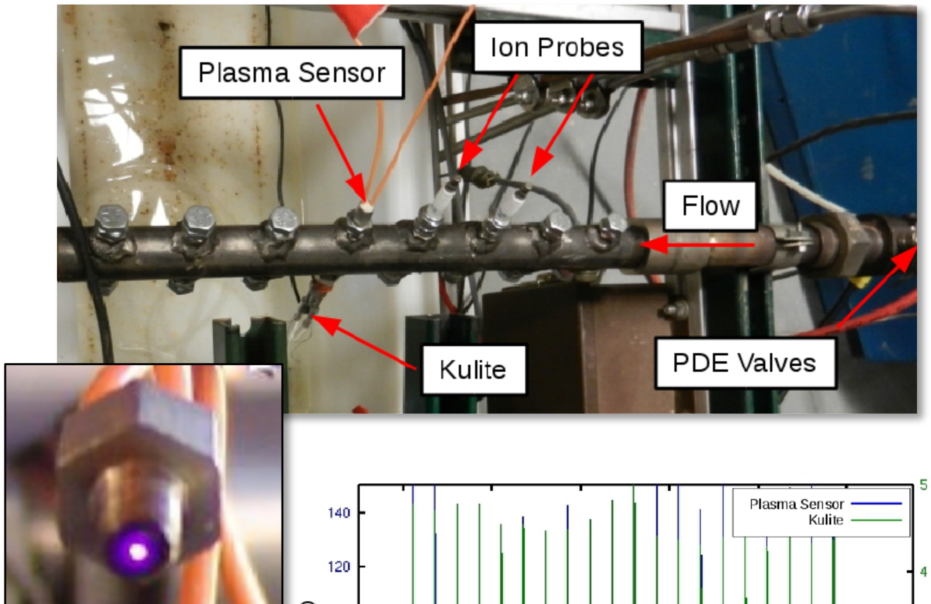


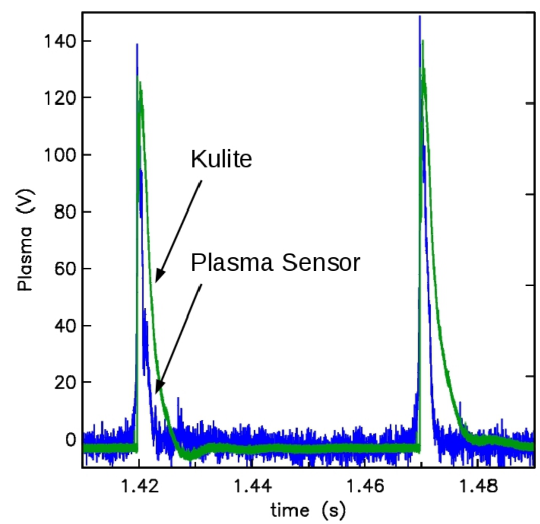
AIAA J., **50**, 1, 123-130 (2012); *AIAA J.*, **51**, 3, 657-664 (2013)

Patent: 8513583

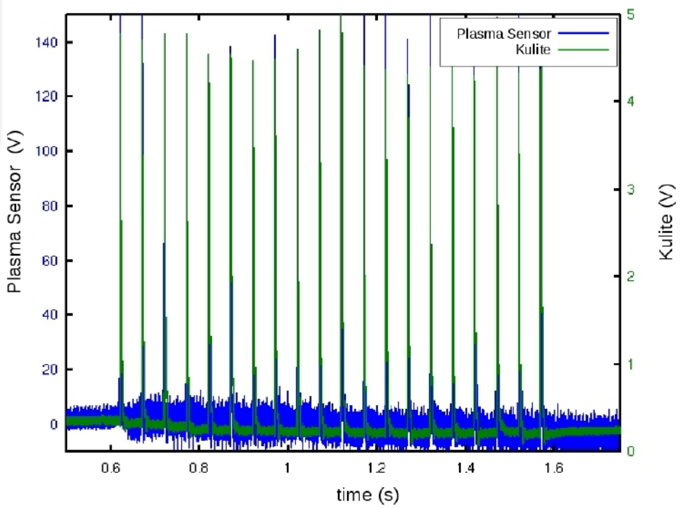
Plasma Temperature/Pressure Sensor

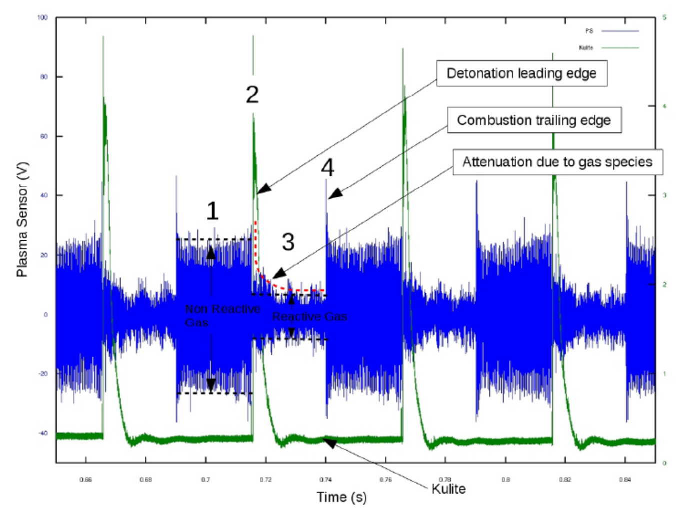
Pulse-detonation Engine





Temperature Mode

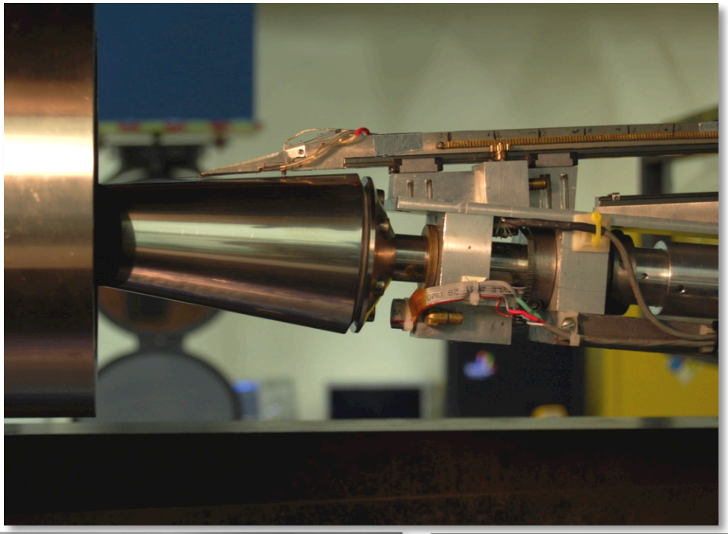


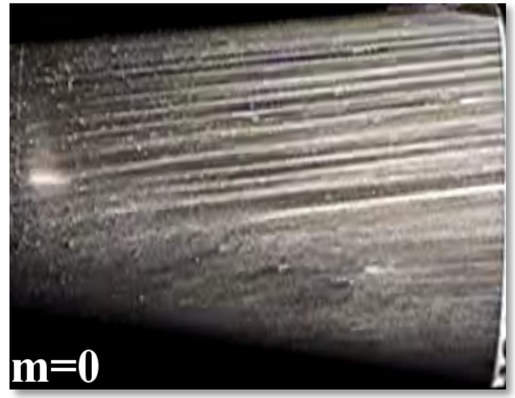


Pressure Mode

Patents: US7275013B1, US7908115

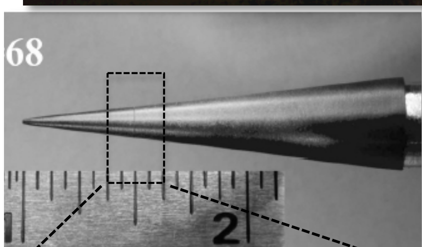
Supersonic Boundary Layer Transition Control

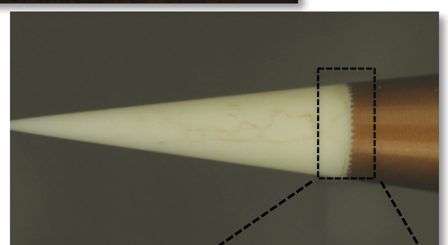


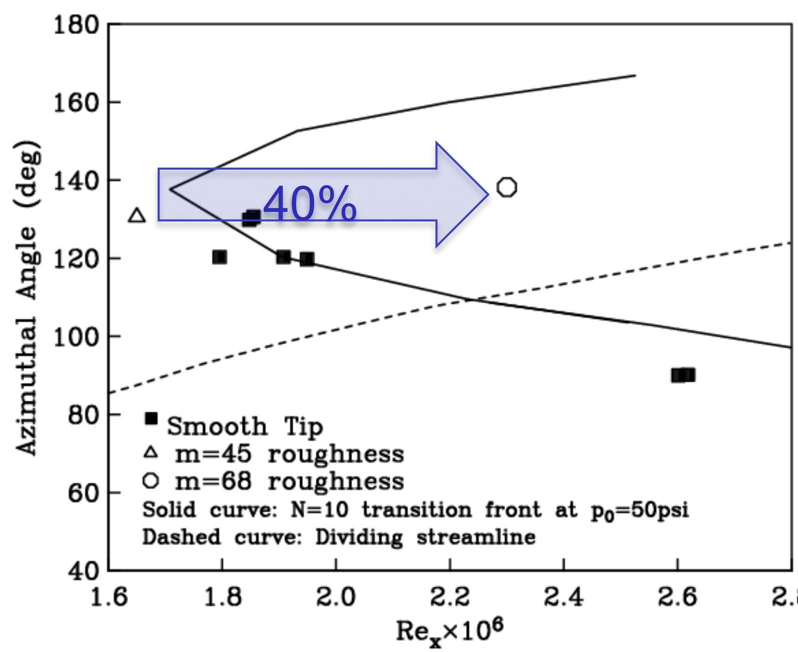


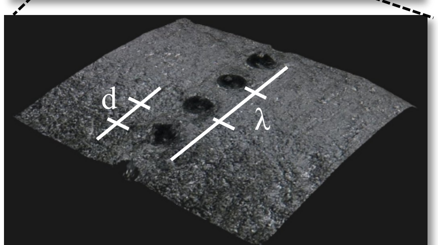
NASA Mach 3.5 0.5m Quiet Nozzle

4° AoA 14° Cone Model



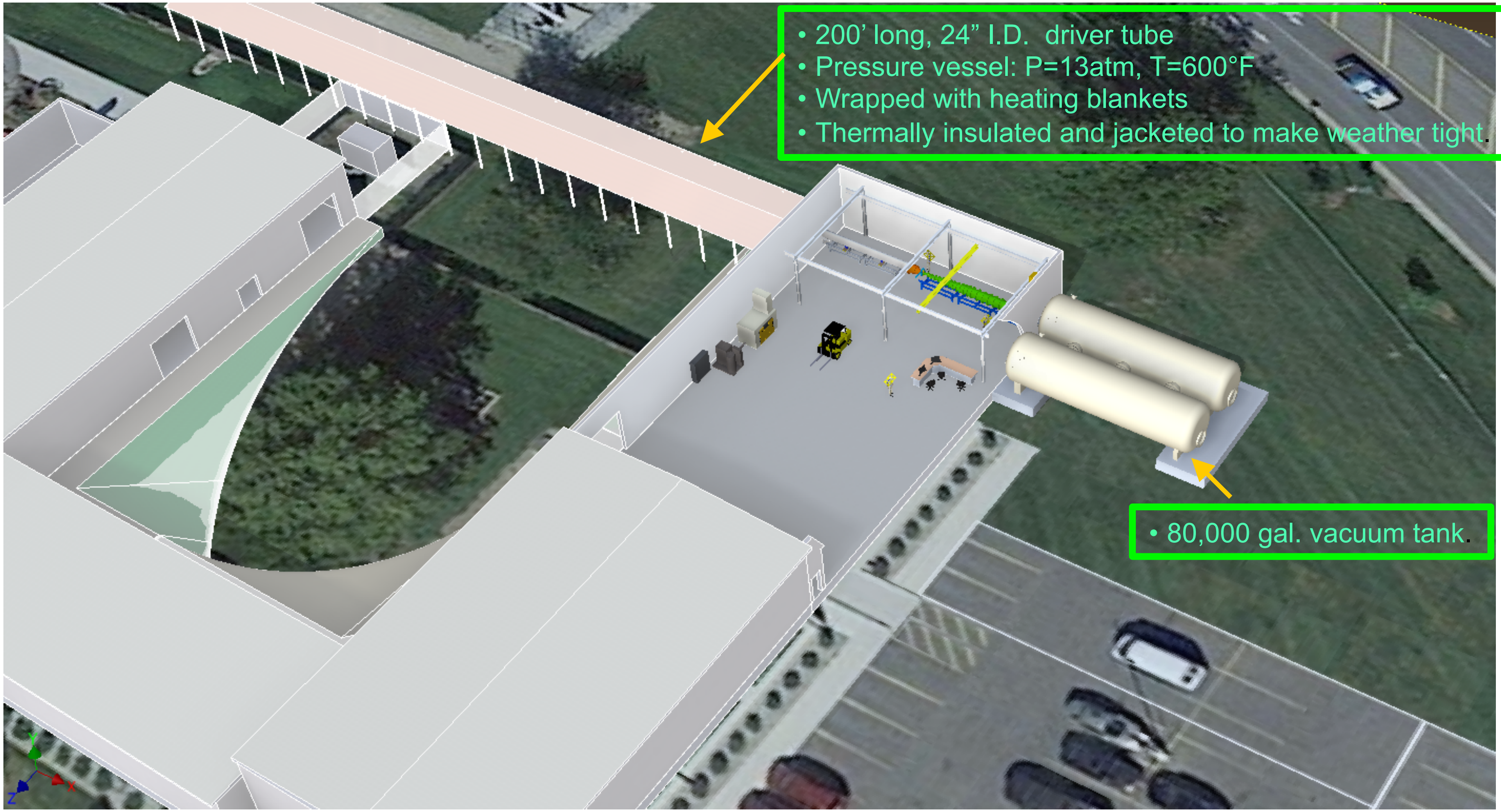






d=76μm
d/λ=0.43

Notre Dame Mach 6 Quiet Wind Tunnel



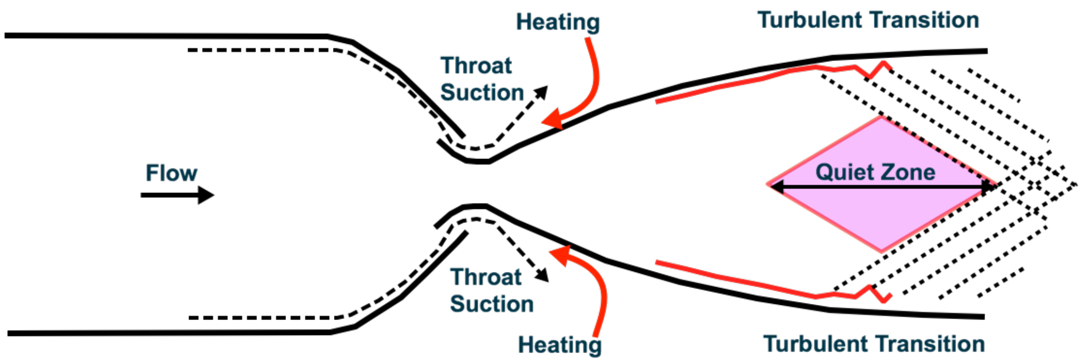
Motivation: Hypersonics for Defense

- Hypersonic flight vehicles are becoming essential to the security of the U.S.
- This is motivated by the need for survivable time-critical strike, as hypersonics is becoming the "new stealth"
- 2017 Senate Armed Services Committee report on the NDAA:
  - "hypersonic technologies are a key component of Third Offset strategies"
  - "concerned that investment has been insufficient to support test infrastructure, advanced testing techniques, and the testing workforce. Without these investments, it is unlikely that hypersonic systems will achieve operational status."

- Hypersonic flight is characterized by extremely high surface heating
- 3x higher surface heating if the boundary layer flow over the vehicle is turbulent
- **Accurate prediction of turbulent transition is essential.**
  - If wrongly predict laminar, vehicle burns up in flight.
  - If wrongly predict turbulent, payload and range are compromised

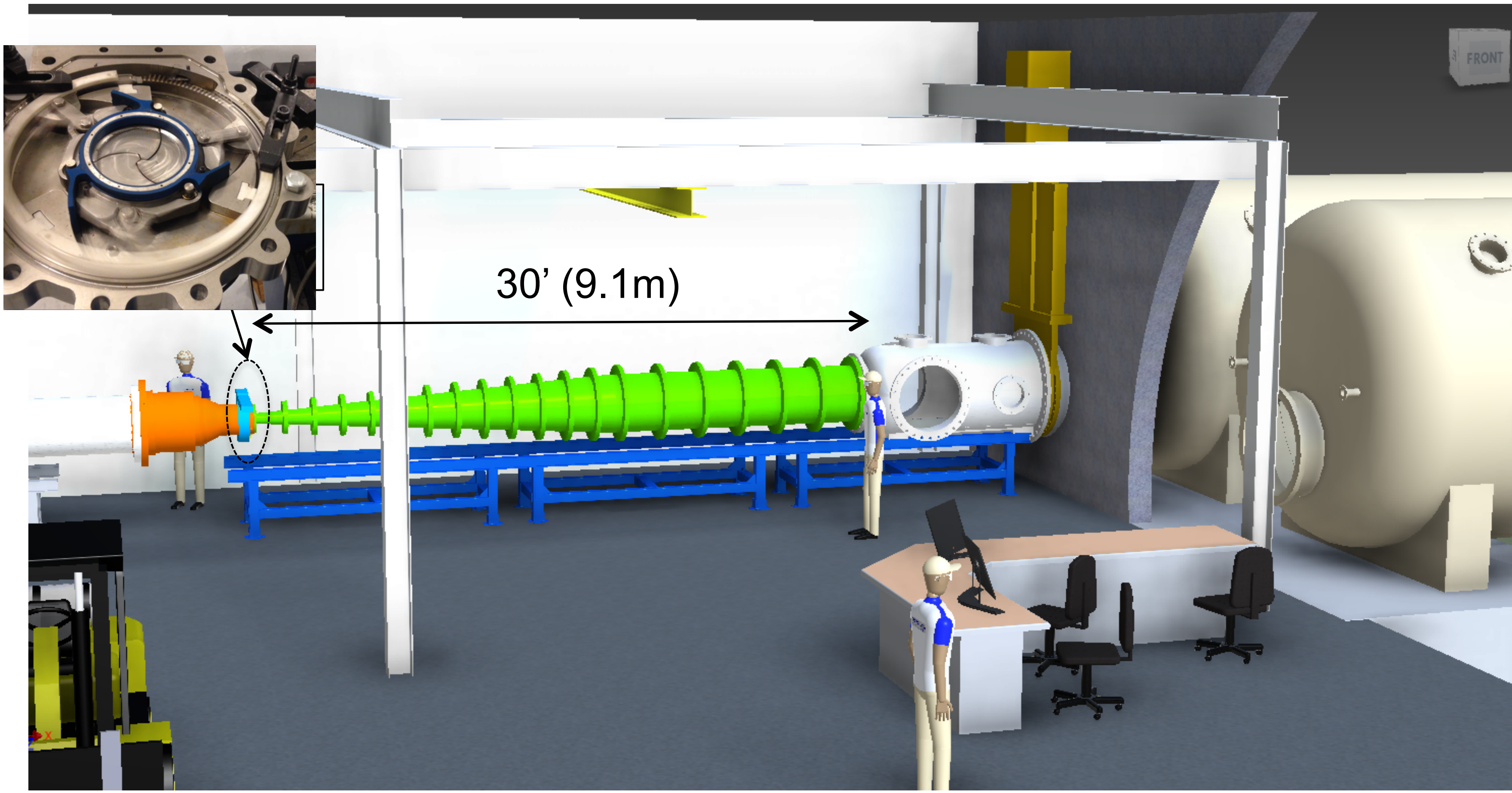
Hypersonic Ground Test Requirements

- Hypersonic ground test facilities need to simulate the flight environment:
- Quiet hypersonic facilities require suppressing turbulent transition on nozzle expansion walls.



- Design involves slow expansion (Görtler instability), throat suction (Mack instability), wall heating (T-S instability) and highly polished surfaces (all of the above).

UND High Re_x Quiet Mach 6 Wind Tunnel



Quiet Design 30' Long Nozzle Expansion

Next Step

Mach number	<5	6.0	8.0	10.0	>10
Minimum stagnation temperature	<330 K (<135 ºF)	430 K (315 ºF)	725 K (850 ºF)	1100 K (1520 ºF)	>1100 K
Stagnation pressure (quiet flow)		1 MPa	3 MPa ?	3 MPa ?	
Freestream unit Re (quiet flow)		11*10^6 /m	7.0*10^6 /m	2.0*10^6 / m	
Is 2nd-mode the primary instability mechanism?	No	Yes	Yes	Yes	Yes
Are real gas effects (dissociation, etc.) important?	No	No	No	Yes	Yes
Has a quiet tunnel worked at this Mach number before?	Yes	Yes (Purdue, TAMU)	Yes, briefly (NASA LaRC)	No	No
Can one be built?	Yes, but why bother?	Yes	Probably	Maybe	Probably not, but no need