Advances in PSP Testing in LaRC High Reynolds Number Facilities

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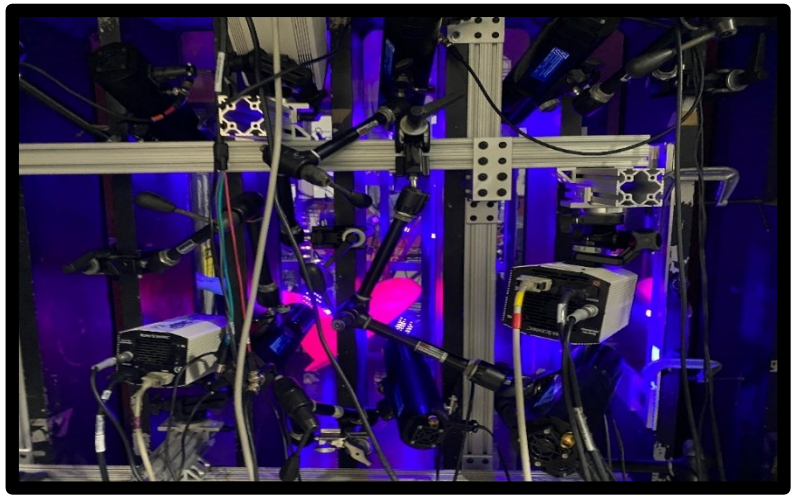
Outline

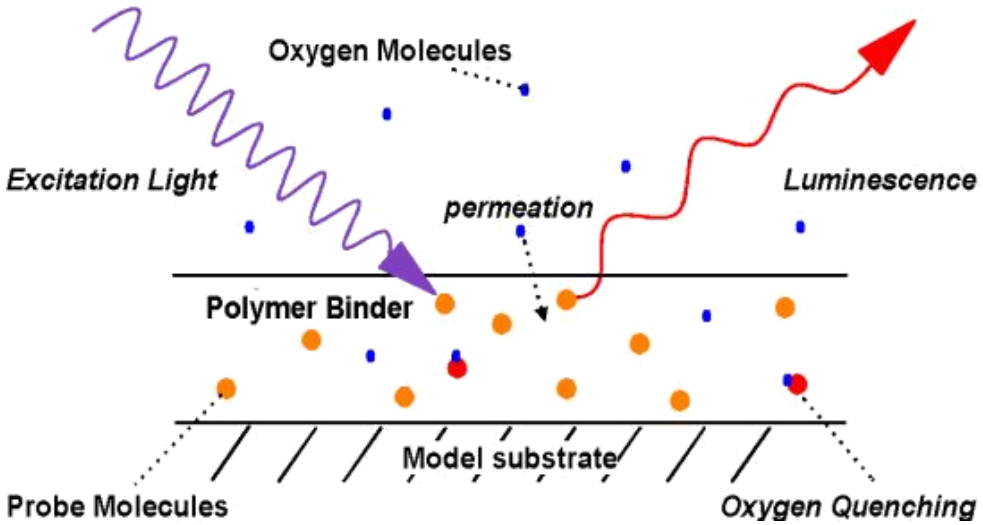
- PSP Background
- High Reynolds Number Facilities at LaRC
  - National Transonic Facility (NTF)
  - Transonic Dynamics Tunnel (TDT)
    - Wind tunnel facility
    - Recent upgrades
    - Preliminary results
- Additional Advancements
- Summary & Conclusions

PSP Background: Technique

Pressure sensitive paint (PSP)

- Powerful optical method providing global measurements of surface pressure.
- Well suited for application in a variety of NASA Langley wind tunnels.
- Can provide time-resolved measurements using a variant of the process known as unsteady PSP (uPSP).



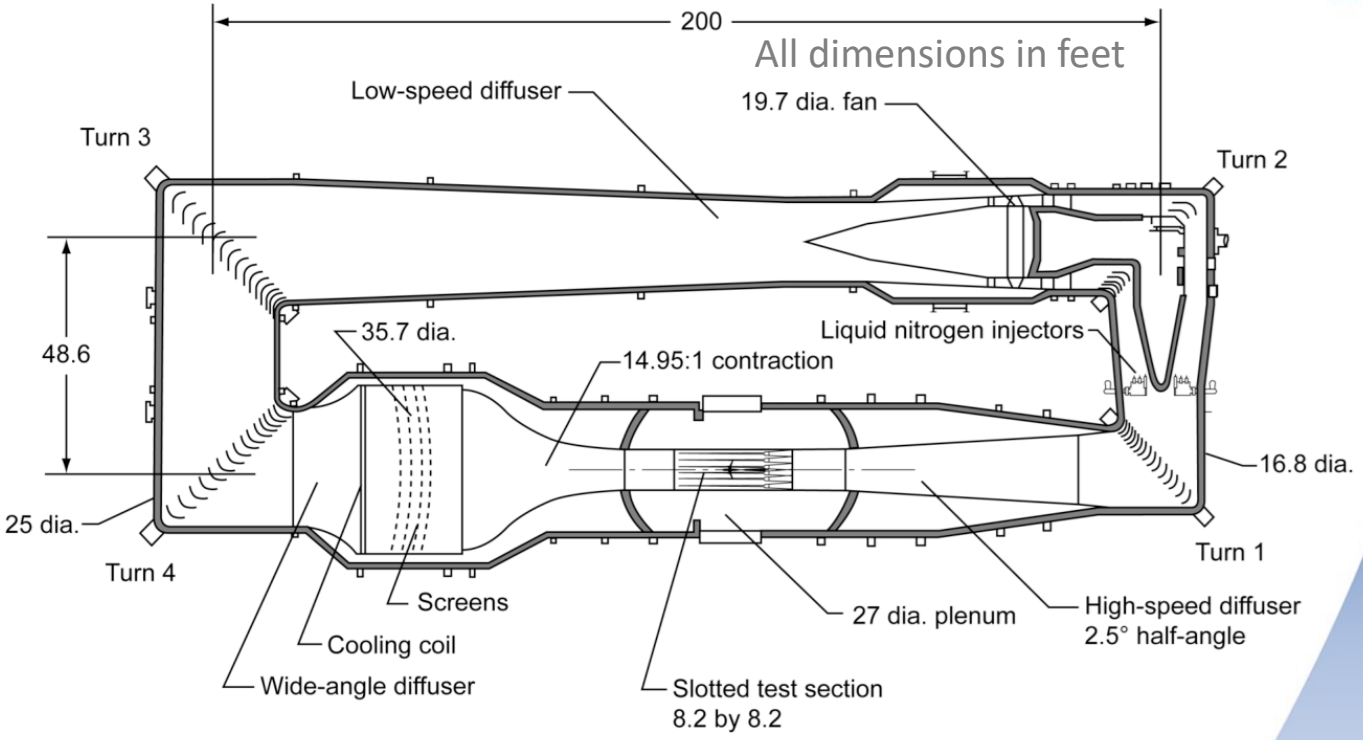


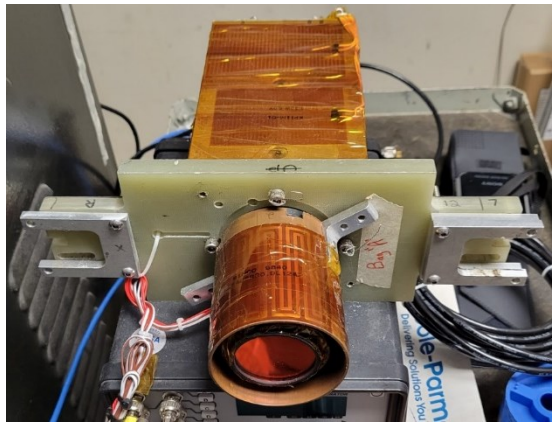
Photophysical Process

1. UV light **excites** luminescent probe molecules suspended in a permeable polymer binder.
2. Excited molecules return to ground state, releasing photons in the process. (i.e. paint **fluoresces**)
3. Emission is **quenched** by oxygen molecules. Higher pressure equates to more O_2, resulting in more quenching.
4. Emission is **captured** by a camera such that darker regions = higher pressure.

NTF: Wind tunnel facility

- National Transonic Facility (NTF)
  - Highest Re_C in the world
    - 146×10^6/ft at Mach 1
  - Isolate Re_C, M, and q effects
  - Mach 0.2 – 1.2
  - Air or nitrogen operation
  - T_t: 116K to 322K (-250 °F to 120 °F)
  - P_t: 100 to 830 kPa (15 to 120 psia)
  - Fan driven/closed circuit
  - 2.5 m x 2.5 m (8.2 ft x 8.2 ft) test section
    - Slotted floor/ceiling
- PSP/TSP testing conducted at NTF since late 1990s





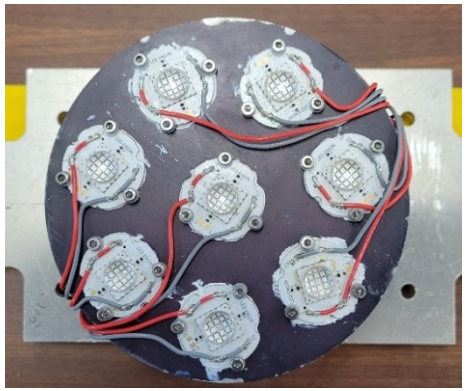
NTF is a high pressure, low temperature environment

All equipment hardened for operation in the plenum (environmental enclosures not practical)

NTF: Recent upgrades — lighting

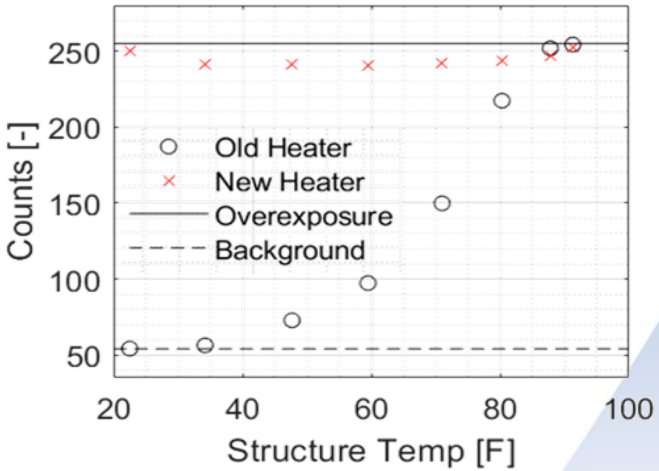
Lighting Improvements

- Over time, existing heating system for LEDs has progressively gotten worse
- Last PSP test showed significant degradation
  - Exposure times increasingly long as tunnel temperature lowered
  - Need for wind-off images showed lighting was extremely unstable
- New heating system devised and implemented for lights
  - Full cryogenic test in 01/2023
  - First used for PSP in 04/2023



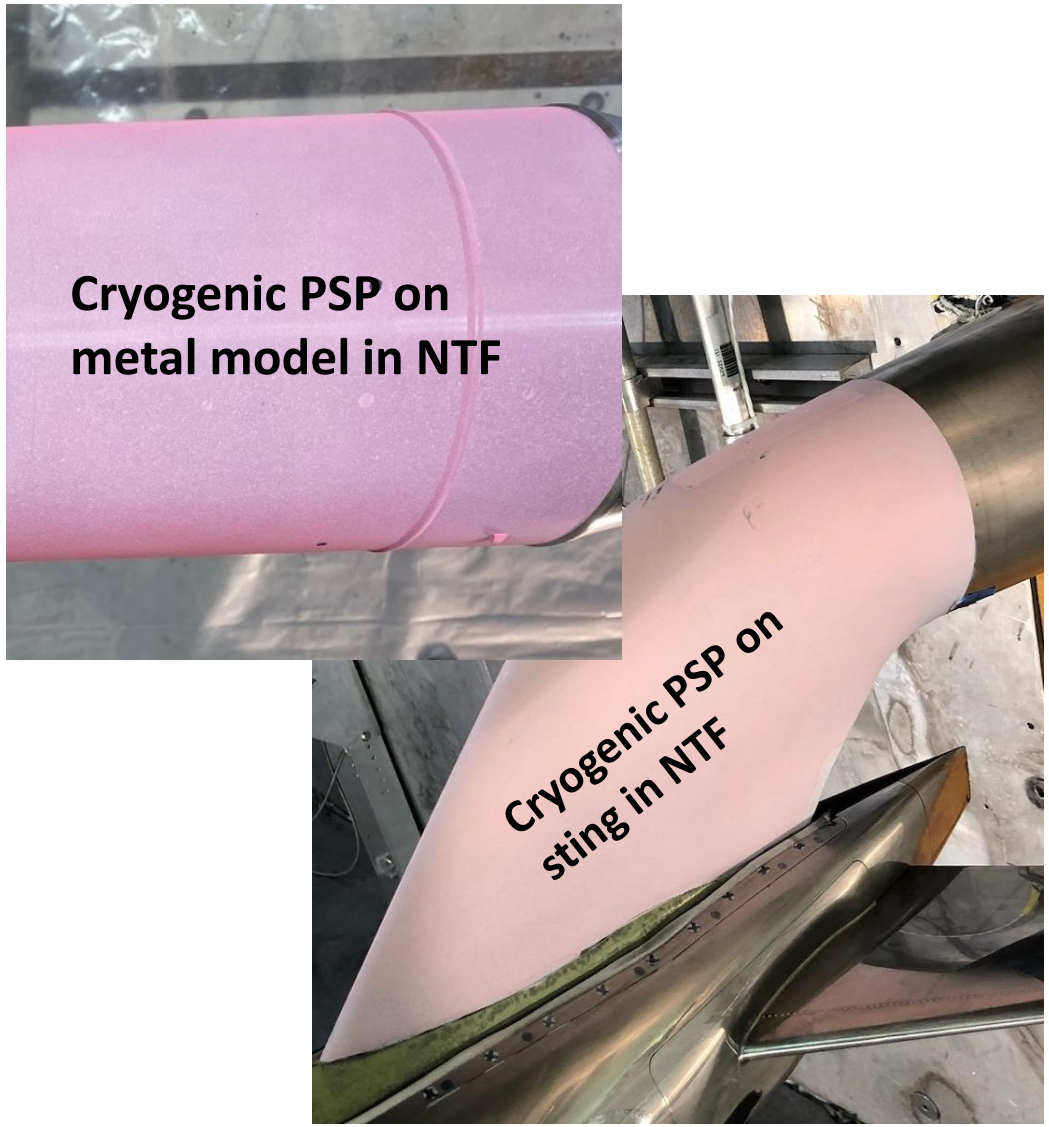
Lighting provided by LED illuminators

- Custom built for NTF optical access
- 400 nm nominal wavelength (~20 nm FWHM)
- Radiant Flux: ~27W (each die)



Preliminary results show new heating method ~5x brighter.

NTF: Recent upgrades — paint application



Paint application improvements

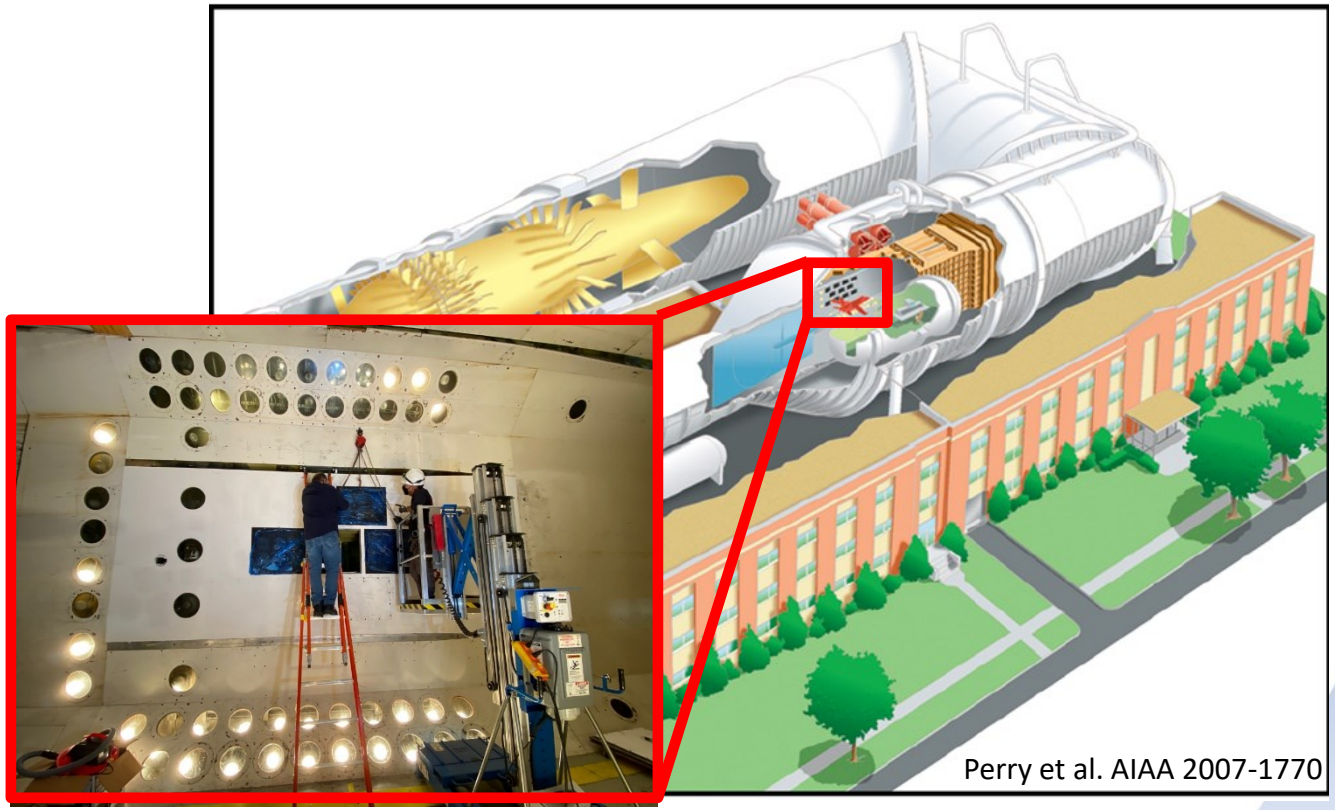
- Traditionally, PSP applied on basecoat
  - Adds significant time, especially when tunnel is at cryogenic conditions
- Now apply cryogenic PSP directly to model surface [Christian Klein, *et al.*, AIAA 2020-0122]
  - Saves significant application time
  - Shows little degradation during tunnel operation (impacts, dust, oil, etc.)
  - Allows for reapplication
    - Wipe off PSP layer and reapply

TDT: Wind tunnel facility

Transonic Dynamics Tunnel (TDT)

- Continuous-flow, closed-circuit
- 16’×16’ slotted test section
- 0.01 atm < P < 1 atm
- 0 < Mach < 1.2
- Max Reynolds number of:
  - 9.6×10^6/ft (in R-143a)
  - 3×10^6/ft (in air)
- Max Q: 26 kPa (550 psf) in R-134a
- Optimized for aeroelastic and dynamic testing

TDT is a low pressure, high temperature environment



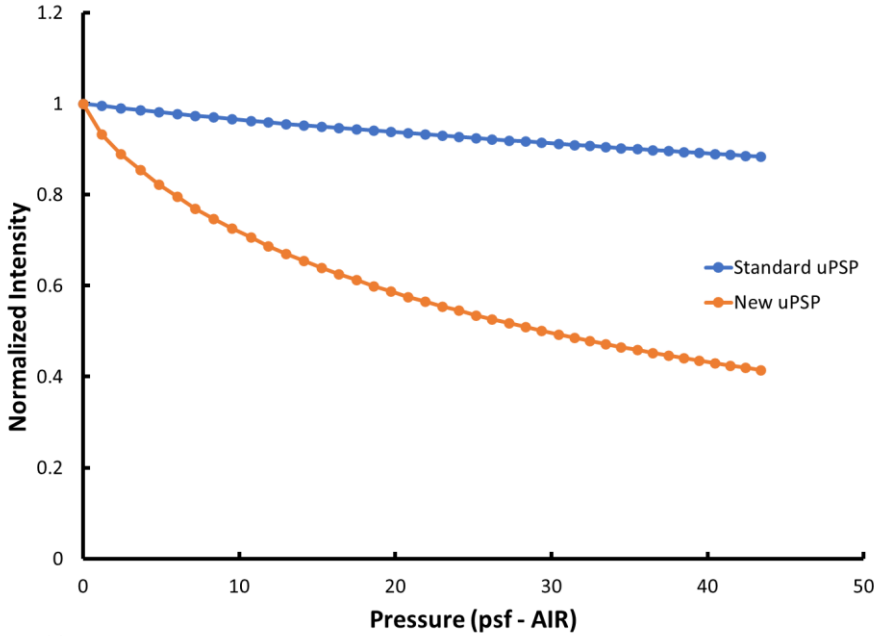
Only facility in the world capable of testing dynamic aeroelastically-scaled models at matched Mach number.

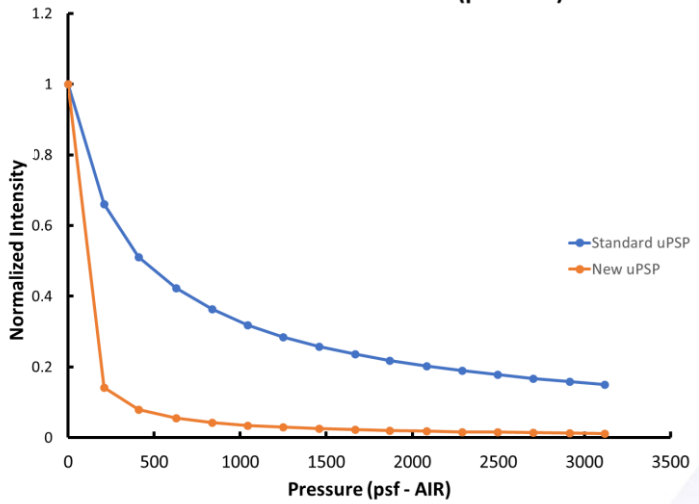
uPSP slated for initial demonstration January 2023

TDT: Recent upgrades — paint formulation

uPSP for rarefied atmospheres:

- uPSP measurements in the TDT need to be able to work in the heavy gas environment (R-134a)
  - Still need oxygen to function
  - Keep “impurity” (air or oxygen) levels as low as possible
  - Need to be able to function in low tunnel pressure environment
- Calibration chamber set up to provide very low concentrations of air
  - Down to ~50 Pa (~ 1 psf)
  - Balance is nitrogen
- Very little sensitivity with standard uPSP
- Designed a newer uPSP formulation for very low oxygen concentrations
- However, this formulation cannot be used in air mode
  - New uPSP formulation rapidly quenches with increasing oxygen concentration
  - Will need the “standard” uPSP formulation for air mode testing
- Will be used in the upcoming test entry

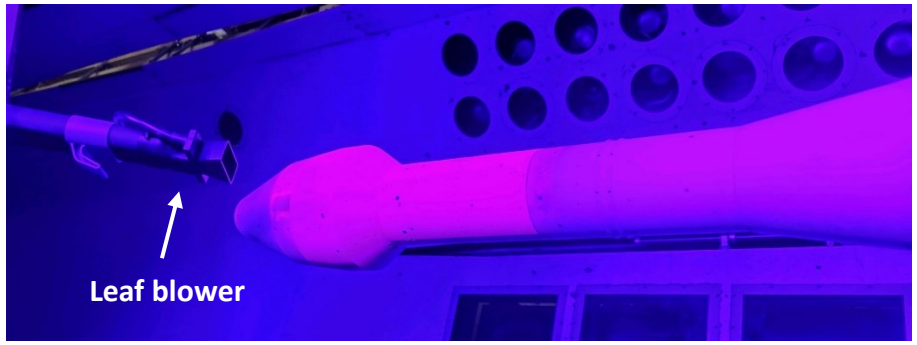


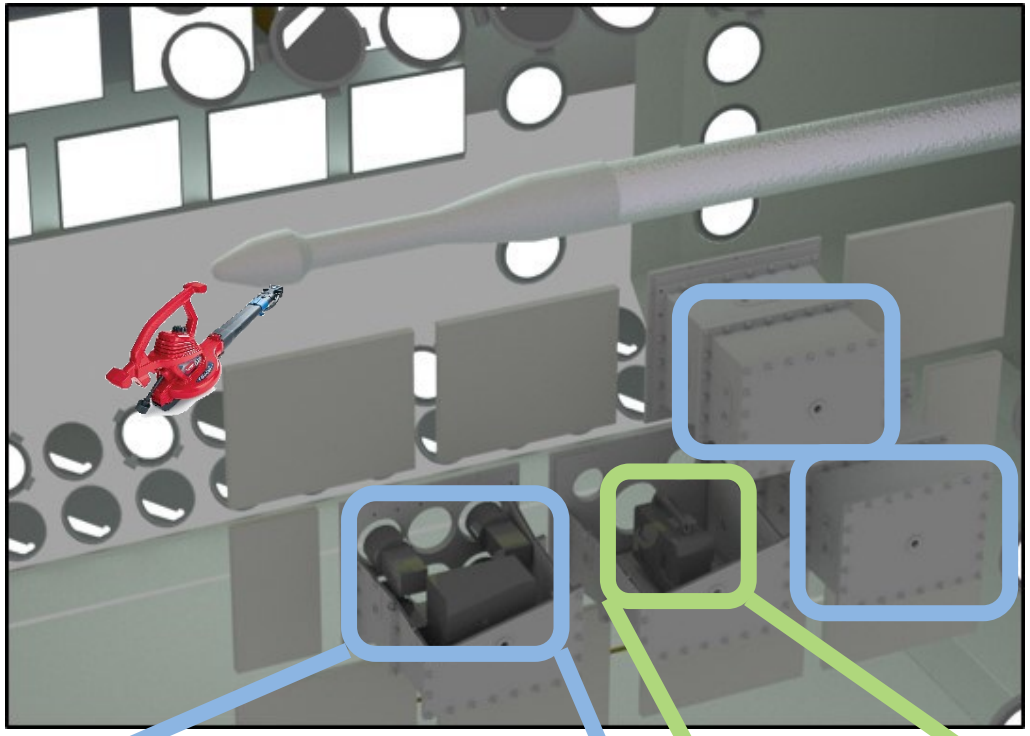


TDT: Recent upgrades — enclosures

“The Enclosures” allow for uPSP in TDT

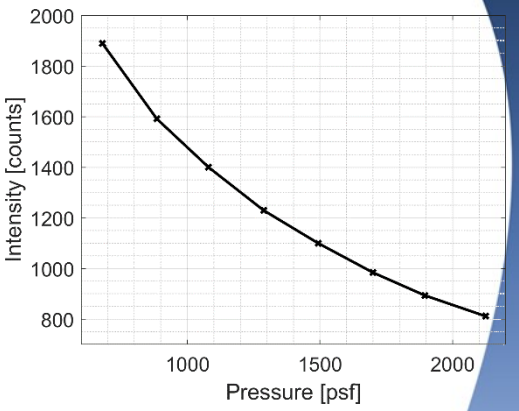
- Modular design to house high-speed camera & high-power UV LED lights.
- Constant supply & venting of cooling air maintains internal room P/T as tunnel P reduced & T increased.
- Remotely monitor interior environment and control all equipment contained within from control room.

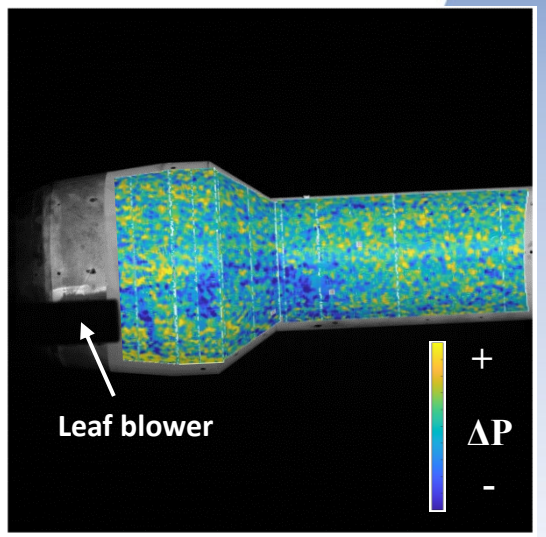




High-Powered UV Lights

High-Speed Camera

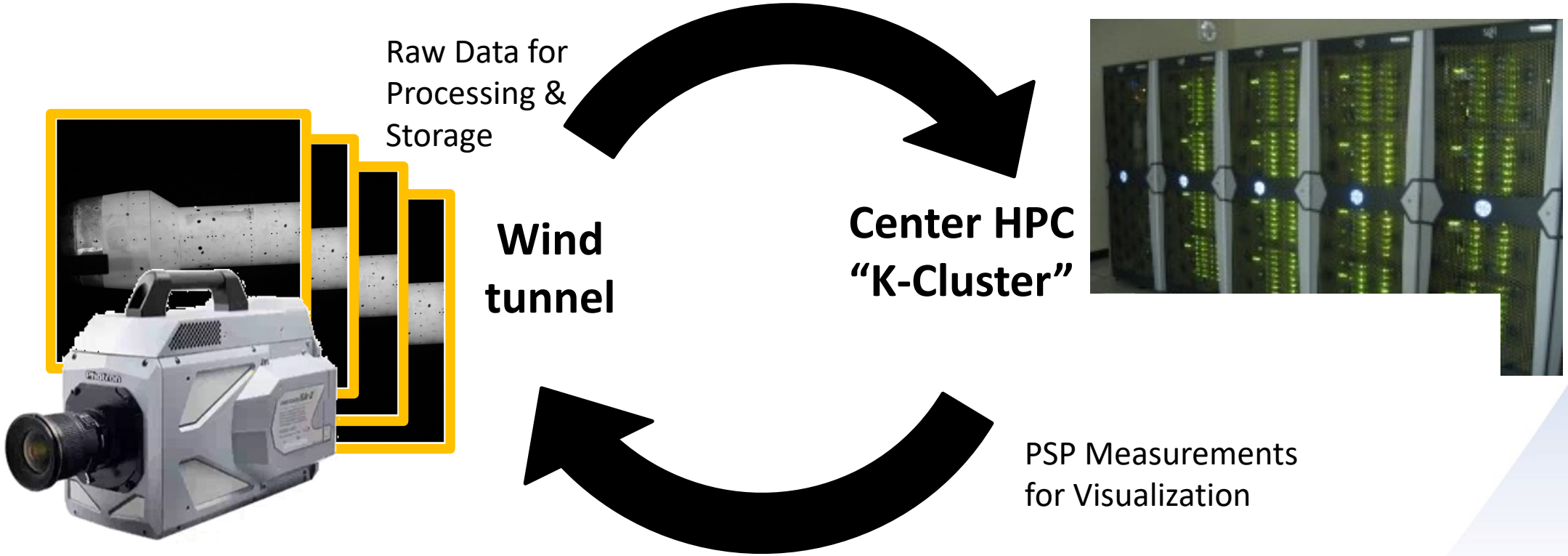




TDT: Recent upgrades — high speed datalink

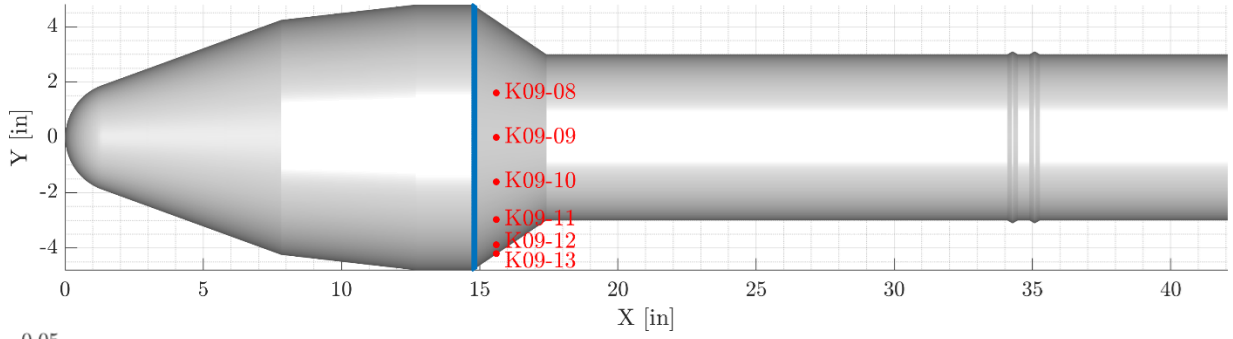
Capturing TB of data per camera each day needing processing and storage

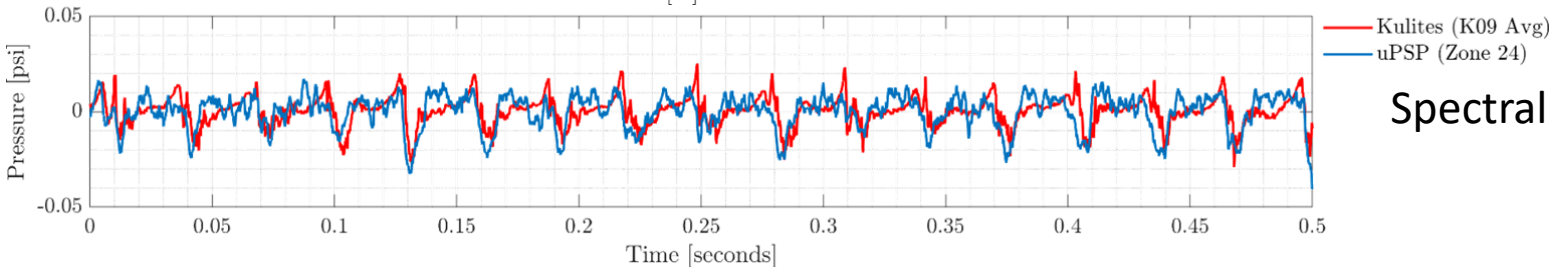
- High speed datalink between wind tunnel and LaRC's high performance compute resource
  - Need way to process/store large datasets quickly → "10 Gbps" line between TDT and K-Cluster
  - Quick turnaround opens the door for "near real time" uPSP results during testing



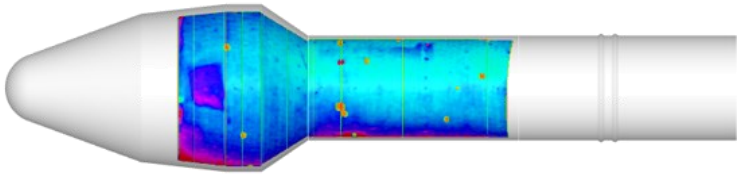
TDT: Preliminary results

Comparison with Kulite sensors

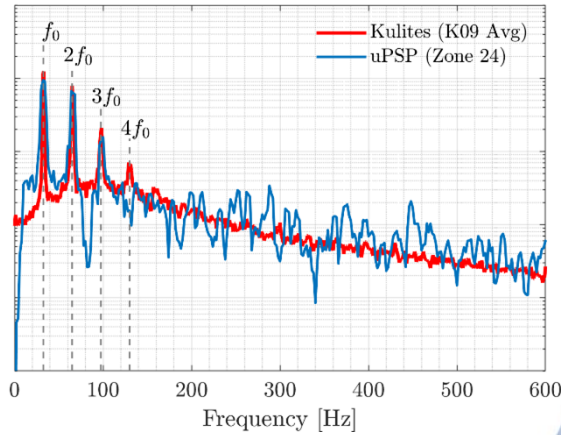




Pressure time history

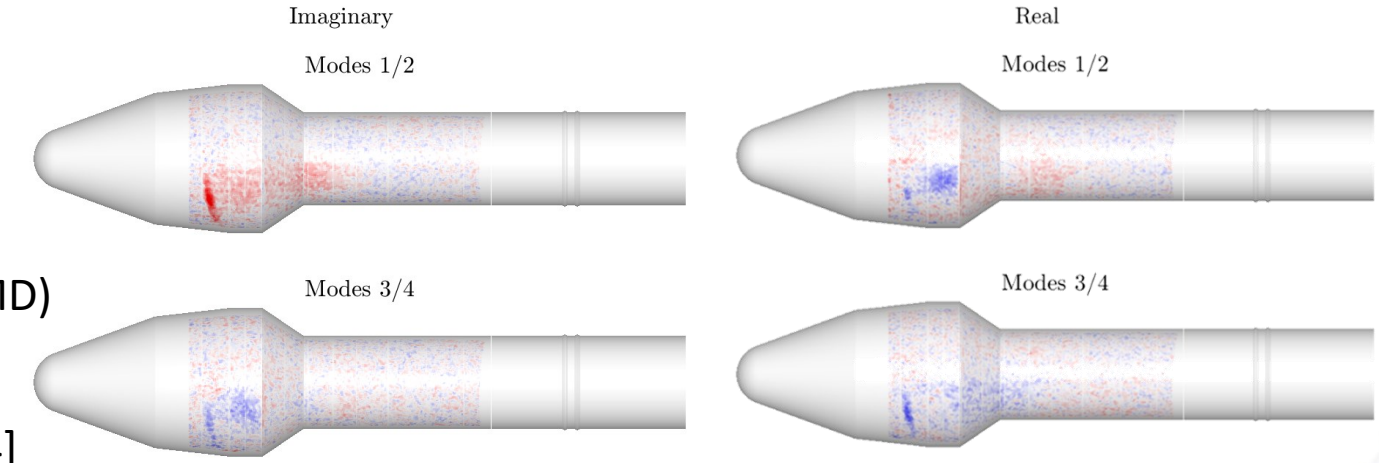


P_{RMS}



Spectral Comparison

Dynamic Mode Decomposition (DMD)



[D. Reese, *et al.*, AIAA-2022-3784]

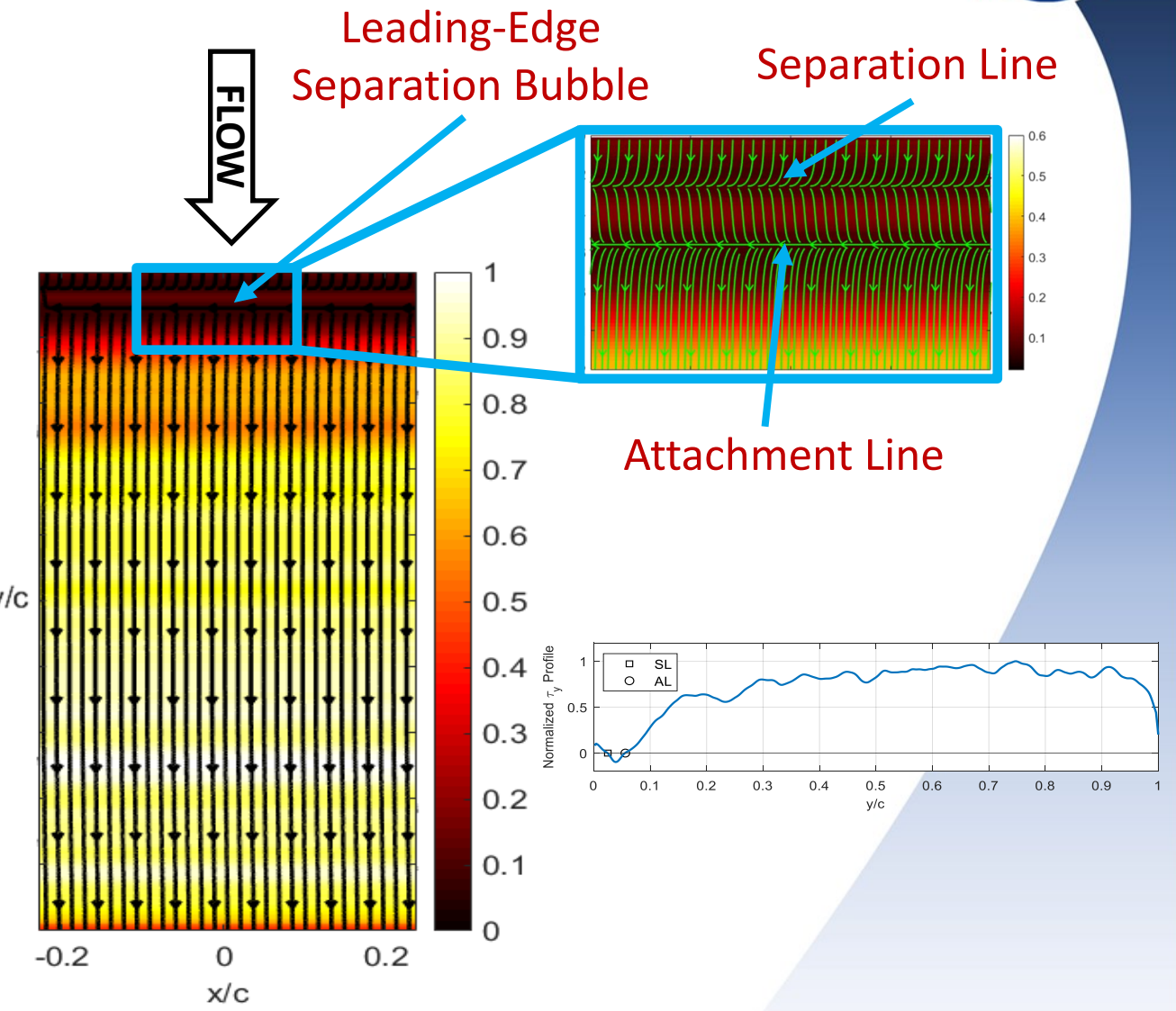
Additional Advancements: Skin friction from PSP

- Qualitative skin friction lines can be calculated from pressure and temperature gradients
- Work currently being done under an SBIR Phase II contract with Innovative Scientific Solutions, Inc. & Western Michigan University
- Requires no additional experimentation
  - If quantified skin friction is required, may need to instrument with a few skin friction sensors
  - Can be used on new or legacy data (in which PSP or TSP information has been acquired)

Skin friction topology extracted from surface pressure data of a supercritical airfoil

Will be implemented in upcoming testing campaigns

[T. Liu, *et al.*, MST 2016]



Extracted Skin Friction Field

Summary & Conclusions

- PSP is a powerful measurement technique well suited for application in a variety of NASA Langley wind tunnels
- uPSP provides time-resolved global surface pressure measurements, a vast improvement over the point measurements returned using traditional dynamic pressure sensors
- Refined UV light heating design shows initial 5x improvement over existing standard
- Improved paint application technique in NTF will yield superior cryogenic PSP measurements
- Enclosures will allow for the first uPSP measurements in the TDT facility, even in heavy gas and reduced pressure
- New paint formulation enables sufficient sensitivity for PSP measurements under rarefied/low O_2 conditions
- Established a high-speed datalink between wind tunnel and center HPC, promoting rapid processing and enabling “near-real-time” pressure measurements
- “Bonus” skin friction measurements can be extracted from PSP and/or TSP data as additional capability to any PSP/TSP data collection

- Funding for this work provided by the following programs in NASA:
  - Transformational Tools and Technologies (TTT) Innovative Measurements (IM) subtask
  - TTT Revolutionary Computational Aerosciences (RCA) subtask
  - Aerosciences Evaluation and Test Capabilities (AETC)