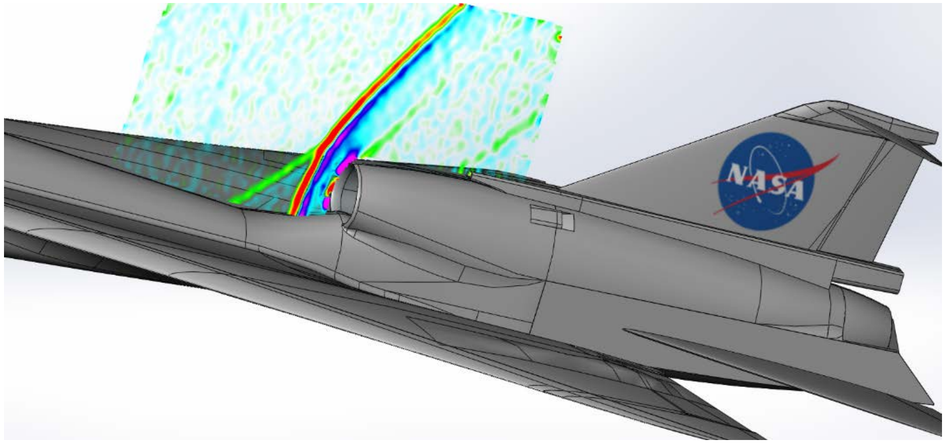
Advanced Optical Instrumentation for the NASA Glenn Research Center's Aeronautical Test Facilities

NASA Technical Interchange Meeting on Active Optical Systems for Supporting Science, Exploration, and Aeronautics Measurements Needs

Columbia, MD
July 31 – Aug 3, 2018



Mark R. Woike/LCP
Grigory Adamovsky/LCS
NASA Glenn Research Center

NASA Glenn Research Center

National Aeronautics and Space Administration

- 1 of 10 NASA field centers located across the US.

NASA Glenn Campuses

Lewis Field (Cleveland)

- 350 acres
- ~1561 civil servants and ~1476 contractors

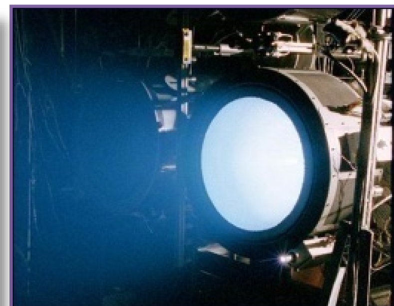
Plum Brook Station (Sandusky)

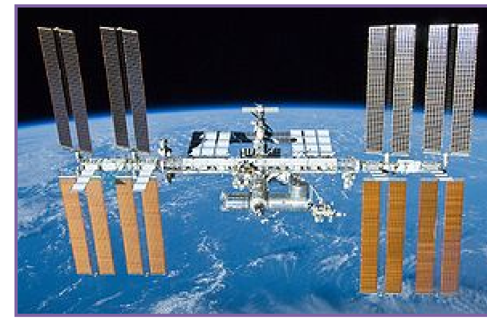
- 6500 acres
- ~18 civil servants and ~89 contractors

NASA Glenn Missions

Glenn's Mission:

We drive research, technology, and systems to advance aviation, enable exploration of the universe, and improve life on Earth.





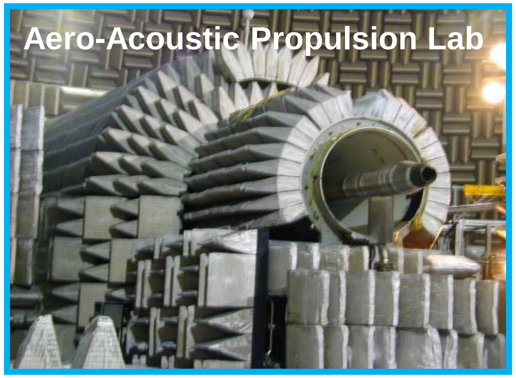
Glenn's Core Competencies:

1. Air-Breathing Propulsion
2. In-Space Propulsion and Cryogenic Fluids Management
3. Physical Sciences and Biomedical Technologies in Space
4. Communication Technology and Development
5. Power, Energy Storage and Conversion
6. Material and Structures for Extreme Environments

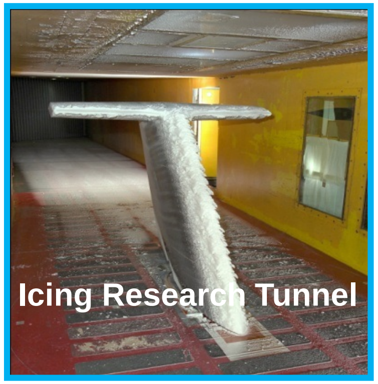
NASA Glenn Unique Aeronautics Test Facilities

Subsonic Propulsion Wind Tunnel
- Noise suppression
- Inlet/Airframe integration
- STOVL hot gas ingestion

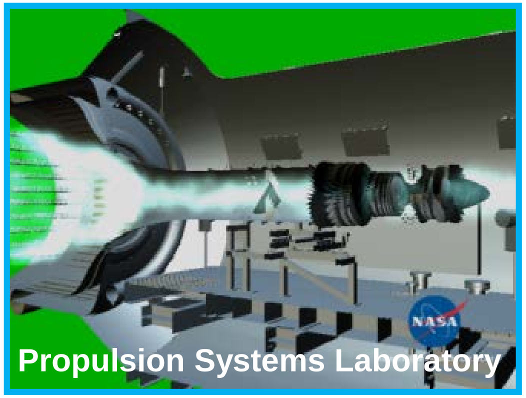
Transonic and Supersonic Propulsion Wind Tunnels
- Advanced propulsion concepts
- Inlet/Airframe Integration
- Internal/external aerodynamics



Engine Acoustic Research Facility
- Fan/nozzle acoustics research
- Simulate hot engine nozzles in flight
- Aerodynamic and Aeroacoustic measurements capabilities



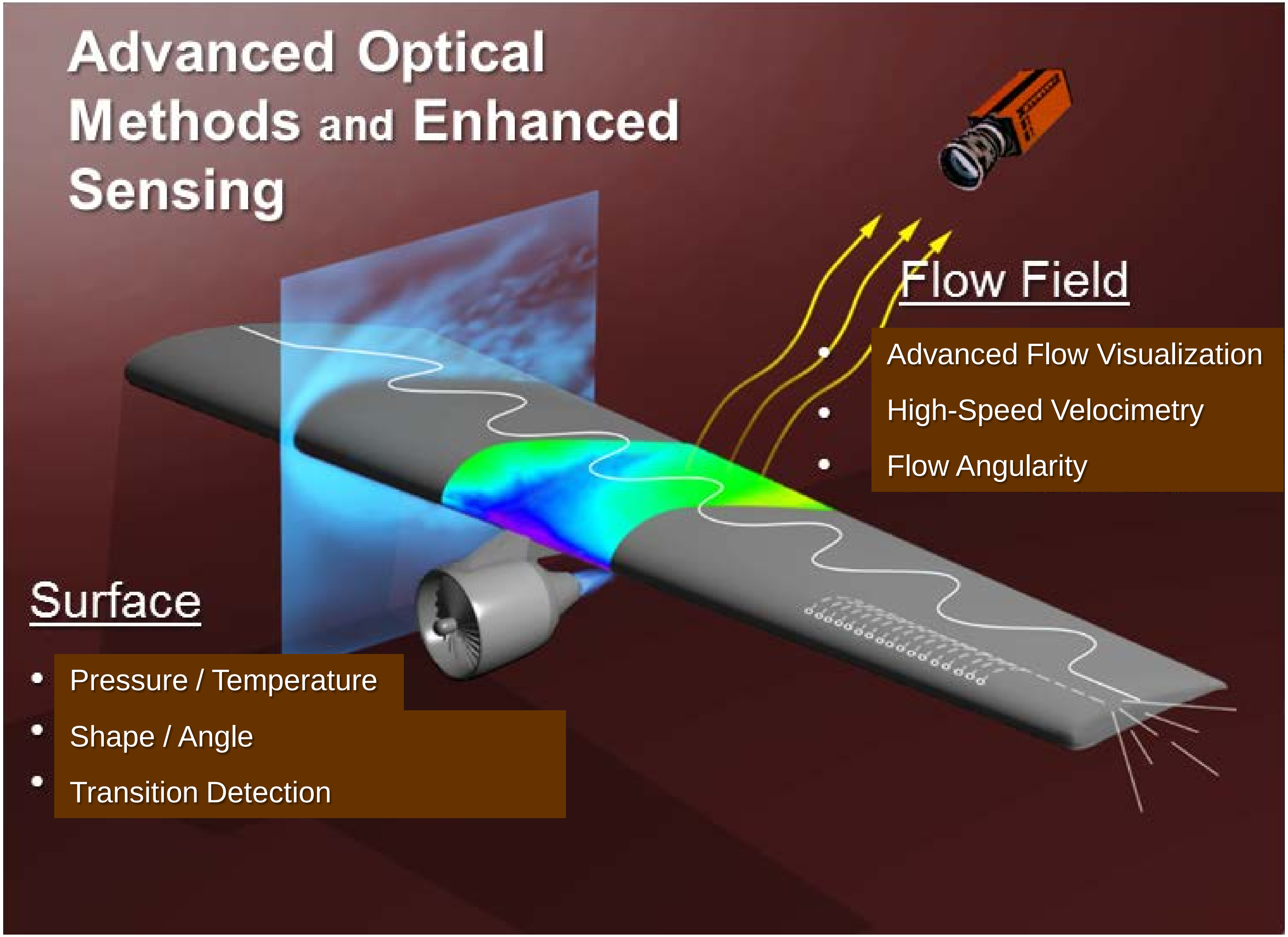
Largest Icing Tunnel in US
- Aircraft icing certification
- Ice protection systems development
- Icing prediction/code validation



NASA's only altitude full-scale engine facility
- Jet Engine Icing Research
- Engine operability/performance
- Nozzle-engine integration

Over 50 Versatile Engine Component Facilities
- Combustor and Heat Transfer
- Compressor and Turbine
- Inlets and Nozzles

Optical Instrumentation for Flow Field & Surface Measurements



ARMD Projects for Instrumentation Development

- **The Transformational Tools and Technologies (T3) Project , Innovative Measurements (IM) Discipline**

  emerging Technical Challenge (eTC)

  – "Develop new and improved non-intrusive measurement technologies to support and validate flow field and structural measurements of velocity, temperature, density, pressure, and deflection. Demonstrate new or fivefold improvement in existing techniques in terms of accuracy, precision, efficiency, bandwidth, spatial resolution, or temporal resolution over the current state-of-the-art** supporting planned ARMD unsteady flow field validation experiments."

- **The Aerosciences Evaluation and Test Capability (AETC) Portfolio, Test Technology (TT) Subproject**

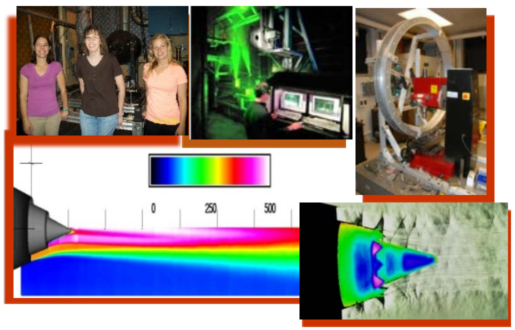
  Capability Challenge CC-TT-01 - Optical Instrumentation

  – "Provide initial deployment of advanced optical instrumentation in AETC facilities to support CFD validation, wind tunnel characterization, flow diagnostics, and assessment of wind tunnel model performance. Enable acquisition of next generation aerodynamic test data required by researchers and modelers to further develop CFD tools. Improve measurement capabilities (pressure, force, flow, and temperature), test techniques and processes, and develop technologies critical to meeting NASA research needs and applicable to a multitude of facilities."

Optics and Photonics Branch (LCP)

http://www.grc.nasa.gov/WWW/Optinstr/

Optical Instrumentation



- Our data and instrumentation help designers understand the fundamental physics of new systems, validate aeronautics computational and life models, and improve space optical communications for human and robotic explorations.
- Our data leads to improved designs, validation and verification of systems' performances, increased communications, safety and security and reduced design cycle times for many of the core technologies developed at Glenn and across NASA.

Photonics and Health Monitoring

Flow/Noise/Combustion Diagnostics
- Particle imaging Velocimetry (PIV)
- Background Oriented Schlieren
- Rayleigh Scattering
- PIV Tomography
- Raman Diagnostics (Species, T)
- Plasma generation

Surface Diagnostics
- Temperature Sensitive Paint
- Pressure Sensitive Paint
- Stress Sensitive Film

Engine Icing
- Light Extinction Tomography
- Light Extinction Probes
- Raman Spectroscopy
- Impedance Sensor

Optical Communications

Free Space Optical Communications
- Optical Teletennas
- Beaconless Pointing Systems
- High Data Rate for Deep Space & Near Earth

Secure Quantum Optical Communications
- Quantum Entanglement
- Pulsed photon Pairs
- Quantum Illumination
- Quantum Key Distributions

Mobile and Remote Sensing
- On-Orbit Solar Cell Characterization MISSE 5-8; TACSAT- 4;
- Hyperspectral Imaging
- Mobile Sensing Platforms

Communications
- Communications over power lines
- Communications Interface Boards
- High Data Rate

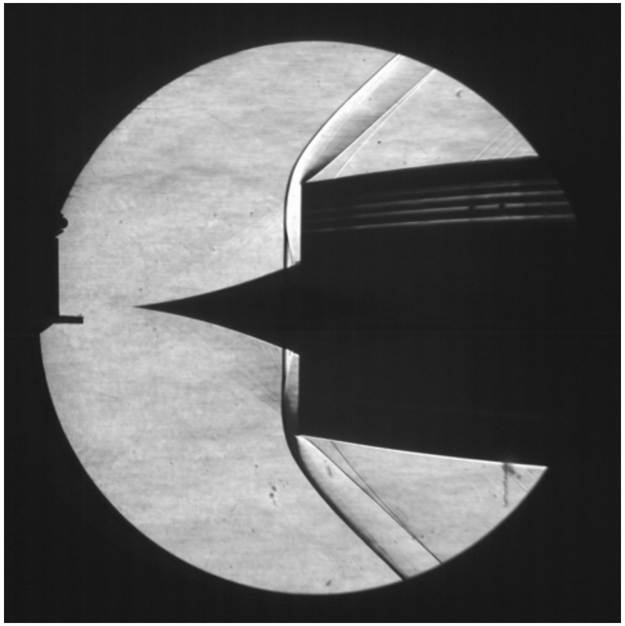
Propulsion Health Monitoring
- Advanced Blade Tip Clearance
- Self diagnostic Accelerometer
- Fiber optics sensors
- Morphology dependent resonance
- Phosphor Thermography
- Wireless and wired techniques
- Light driven actuators

Flow Field Diagnostics

Schlieren Flow Visualization Technology

- "Conventional" Schlieren
  - Upgrade technique to utilize new LED lighting and high speed camera technologies.

- New Advanced Techniques in development (more robust, more portable, greater viewing capability)
  - Background Oriented Schlieren (BOS)
  - Focusing Schlieren



Large Scale Low Boom Inlet Test - 8x6 SWT

Jet Surface Interaction Tests – Engine Research Bldg

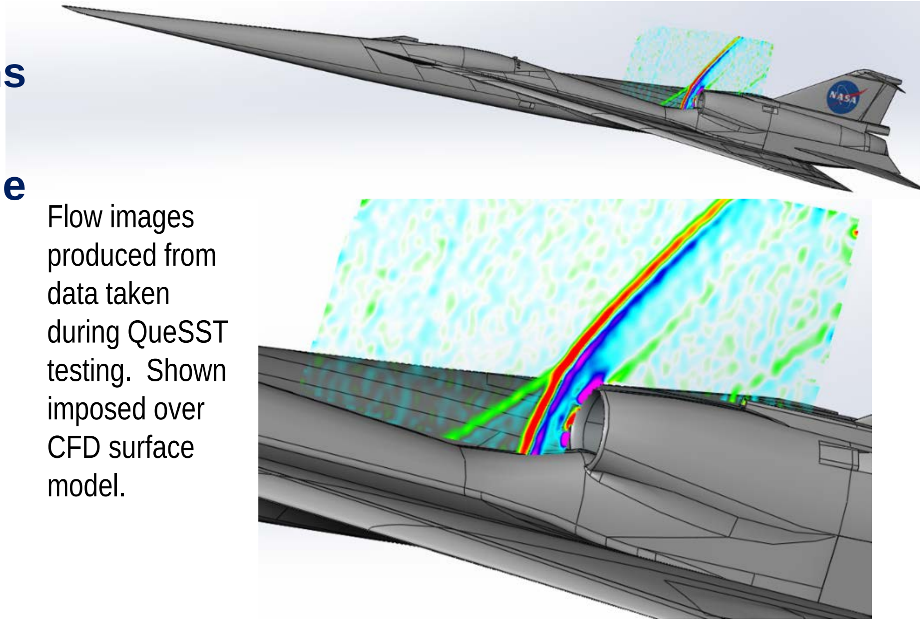
- Overall Goal
  - Transition schlieren from a flow visualization to a quantitative flow measurement tool
  - Allow better simulation, measurement and validation of conditions that a "vehicle" is experiencing in our test facilities

POC: Mark Woike (GRC)

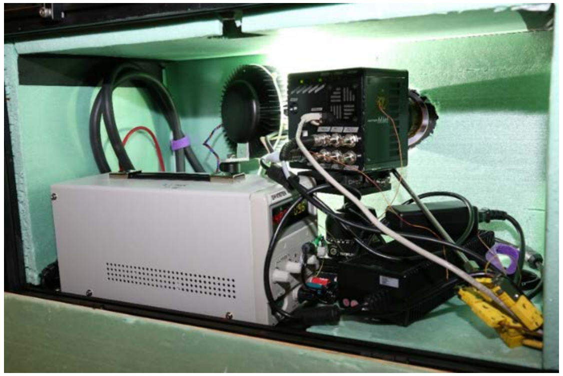
Background Oriented Schlieren (BOS)

- BOS is a more recent development of the schlieren and shadowgraph techniques.
- Based on an apparent movement of the background when imaged through a density field onto a detector plane.
- BOS captures the density field but only requires a CCD camera, light source, and a high-contrast “speckled” background
- **More portable than traditional systems**
- **Can use it to view a wider range of locations on a test article**
- **Can be used to calculate the density of the flow field**

BOS installed in 8x6 SWT for QueSST



Flow images produced from data taken during QueSST testing. Shown imposed over CFD surface model.



Camera and light box setup for QueSST

POC: Jonathon Ponder (GRC)

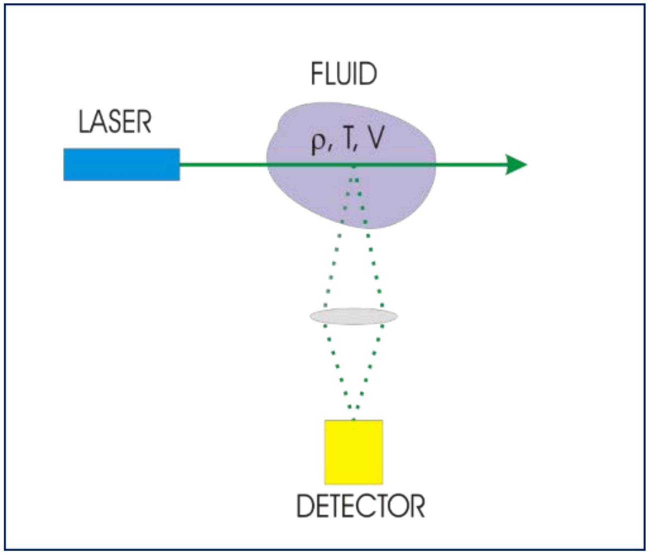
Rayleigh Scattering

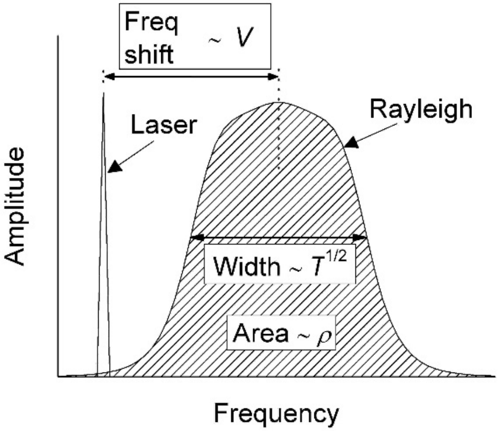
<u>Rayleigh scattering as a flow diagnostic</u>:

- Uses spectral characteristics of laser light elastically scattered from gas molecules to extract velocity, temperature, and density information.

<u>Methodology</u>:

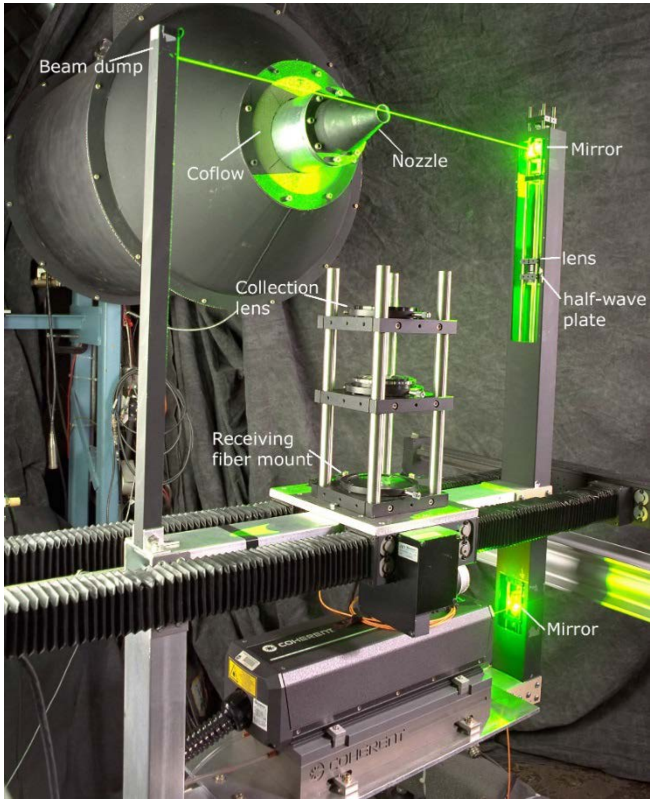
- Total signal strength is proportional to number density directly ($I \propto \rho$)
- Scattered signal is not species specific, therefore cannot be used to determine individual species concentrations
- Frequency shift between laser and Rayleigh spectral peaks yields one component of gas velocity ($\Delta f \propto V$)
- Thermal motion of the molecules causes spectral line broadening that is proportional to the speed of sound in the gas, and hence a measure of temperature (linewidth $\propto \sqrt{T}$)

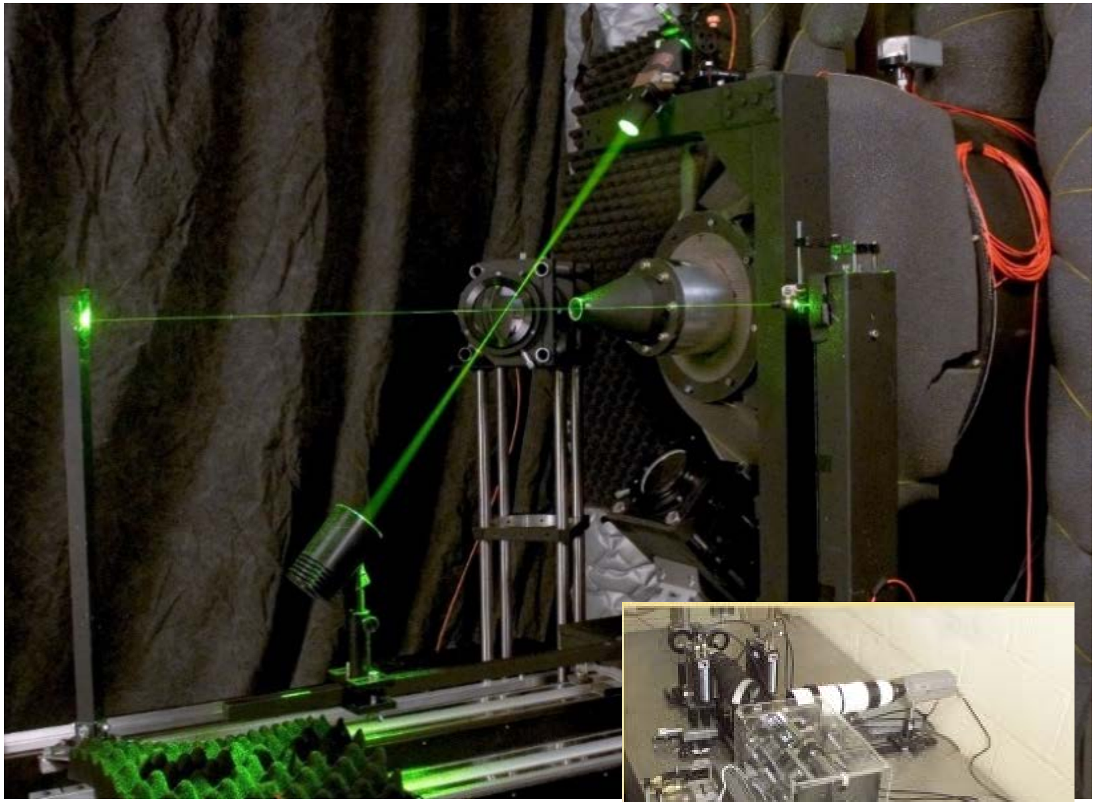




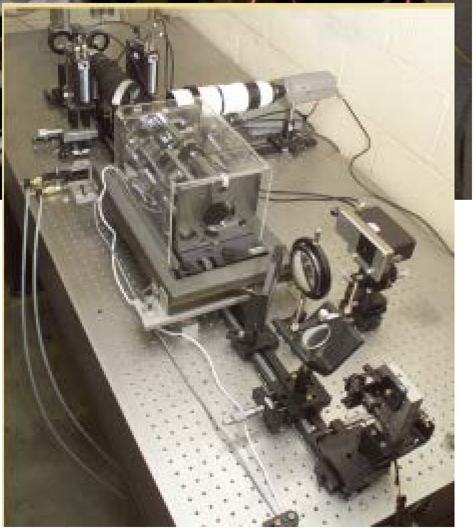
POC: Amy Fagan (GRC)

Rayleigh Scattering





Rayleigh Scattering in Free Jets (CW-17)



Typical Setup for Analysis and Detection of Rayleigh Signals

POC: Amy Fagan (GRC)

TomoPIV

PROBLEM
Classic Stereo particle imaging velocimetry (PIV) measurements are limited to 3-component velocity measurements across a single plane. Development of a Tomographic PIV technique which can provide high spatial resolution, 3-component velocity measurements across a volume is needed.

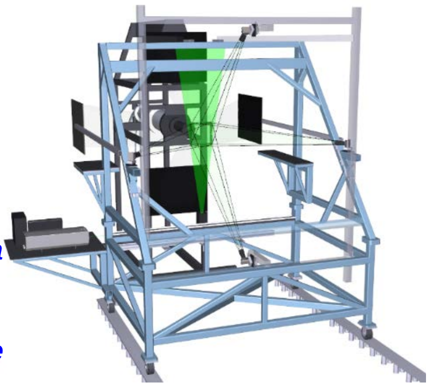
ACCOMPLISHMENT
This is the first application of tomoPIV in supersonic jet flows, and represents one of the highest resolution tomoPIV reconstructions ever performed.

The data were compared against 2-component PIV and Stereo PIV measurements in the same facility. tomoPIV data were concentrated around a shock cell in the underexpanded flow enabling full 3-component, 3D reconstruction of the Mach disk in the flow.

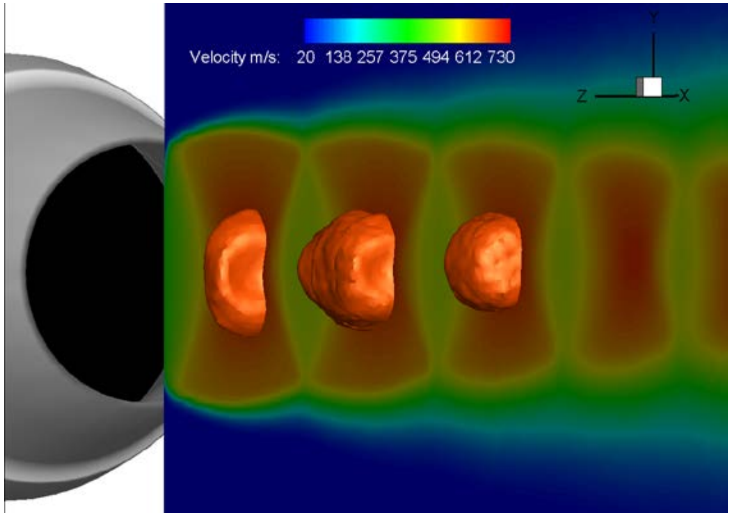
SIGNIFICANCE
Tomographic PIV can provide velocity measurements across a volume – yielding previously unavailable flow properties such as all three components of shear stress and vorticity.

MILESTONES
Successful TomoPIV demonstration in Large Scale Facility CST Level II Milestone:
Completed

4-camera TomoPIV installation in the acoustic dome



TomoPIV data from a Mach 1.4 supersonic jet, showing the 3D reconstruction of the Mach disk.

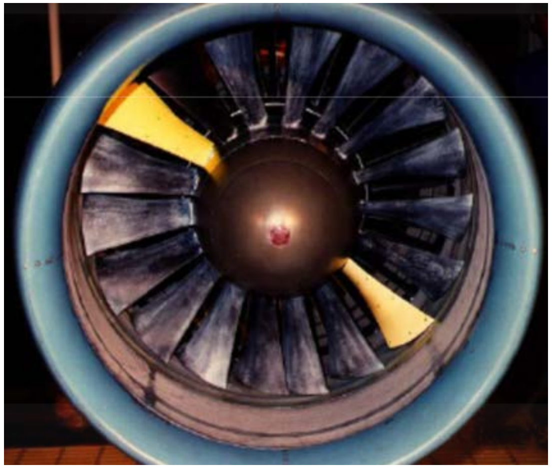


POC: Mark Wernet (GRC)

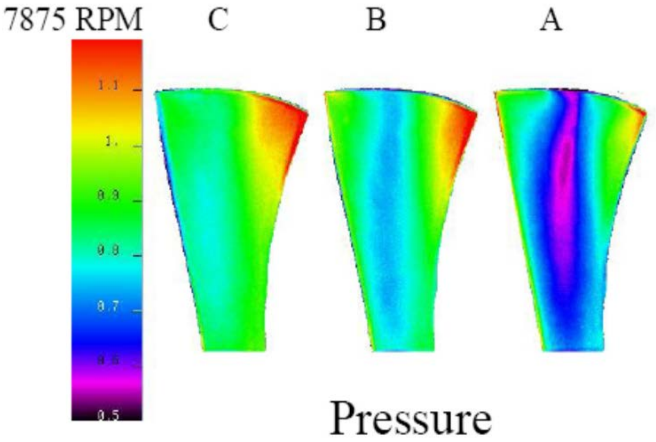
Surface Diagnostics

Pressure Sensitive Paint (PSP) Measurement Technique

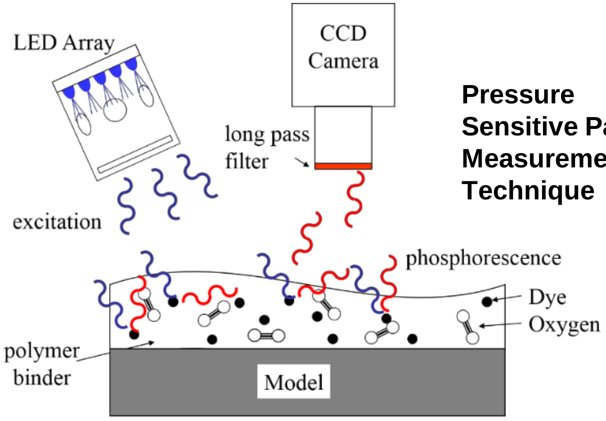
- Motivation: To achieve non-intrusive global pressure measurements on an aerodynamic surface
  - Image based technique
  - O2 sensitive fluorescent dye in a O2 permeable (polymer) binder
    - When a dye molecule is excited, it recovers to a ground state by emitting a photon of longer wavelength
    - In some materials, O2 interacts with molecule causing a non-radiative transition (O2 quenching).
    - Higher pressure = Higher O2 = Higher quenching = Lower intensity of returned light
- Acquisition is accomplished by coating surface, illuminating it with the proper excitation light, and imaging it with a filter to separate the luminescent signal from the excitation light



Painted Blades for pressure measurements



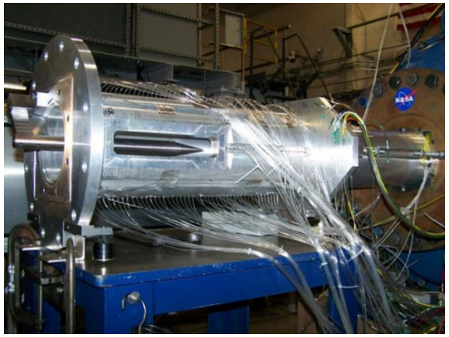
Blade pressure profiles for 3 different test conditions



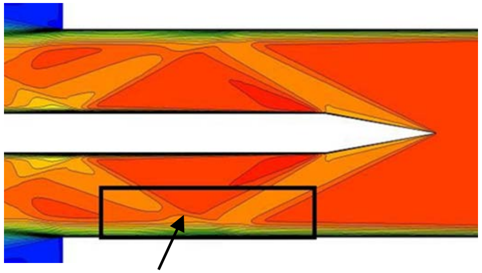
Pressure Sensitive Paint Measurement Technique

Pressure Sensitive Paint (PSP) - Examples

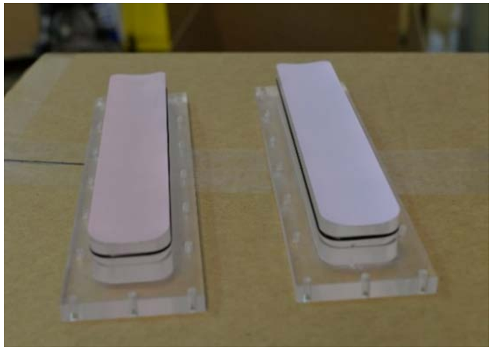
Shockwave Boundary Layer Interaction Experiment



Axisymmetric test section with shock generator installed

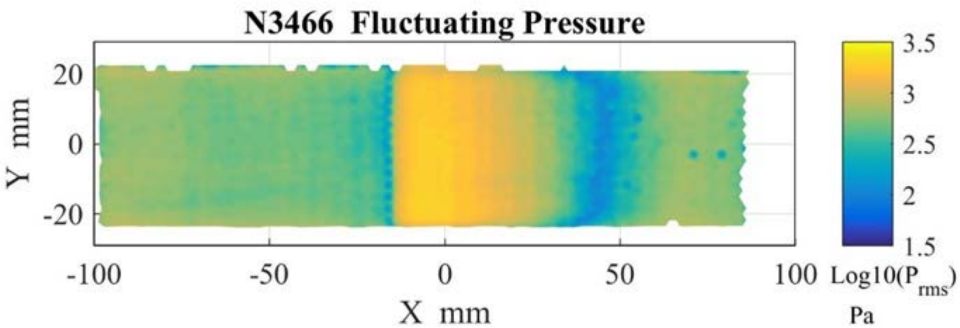


Shock wave boundary layer interaction area of interest



Fast PSP Windows

- The goal of this validation experiment was to better characterize the shock wave boundary layer interaction region with more refined and detailed measurements for CFD validation
- PSP was applied to the inner flow surface side of specially made windows and imaged from the backside looking through the window to make unsteady pressure measurements (intensity based technique)



Mach 2.5 with 13.5 deg. shock generator at Reynolds numbers of 5E6:

POC: Mark Woike / Jonathon Ponder (GRC)

Luminescence-Based TBC Diagnostics

PROBLEM
Thermal barrier coatings (TBCs) lack robust non-intrusive diagnostics for coating performance and temperature monitoring below TBC is nonexistent.

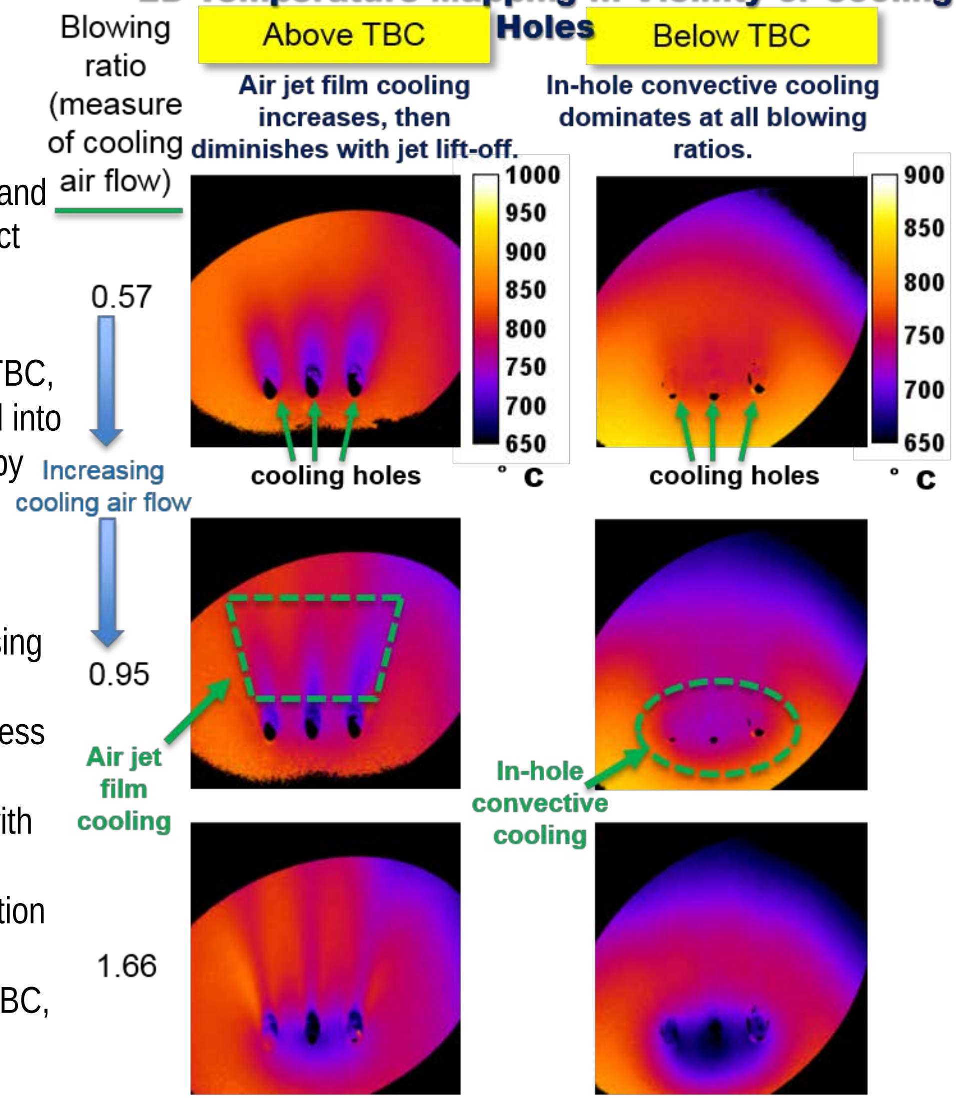
OBJECTIVE
Develop luminescence-based mapping of temperature both above and below thermal environmental barrier coatings (TBCs) used to protect turbine engine components.

APPROACH
Develop 2D full-field temperature mapping both above and below TBC, using luminescence lifetime imaging from sensing layers integrated into TBC. Demonstrate ability to map temperature gradients produced by air film cooling in combustion environments.

Progress
- Developed custom thermographic phosphors for nonintrusive integration of sensing layers into TBCs for temperature mapping using luminescence lifetime imaging.
- Successfully demonstrated 2D temperature and cooling effectiveness mapping above and below TBC with high temperature and spatial resolution in presence of strong background radiation associated with combustor burner flame.
- First ever temperature mapping below TBC, where thermal protection needs to be monitored.
- Data revealed that air film cooling was severely degraded below TBC, while in-hole convective cooling was significantly enhanced.
- Important implications for cooling hole design for TBC-coated components.

POC: Jeff Eldridge (GRC)

2D Temperature Mapping in Vicinity of Cooling Holes



2D temperature maps show TBC degrades air jet film cooling but enhances in-hole convective cooling.

Icing Diagnostics

Light Extinction Tomography

- New measurement technique developed to measure the uniformity and density of the Icing Clouds used in the GRC Icing Test Facilities
  - Propulsion Systems Laboratory (PSL) – Icing effects on engines
  - Icing Research Tunnel (IRT) – Icing effects on wings, tails, aero surfaces, etc.

Ice Accretion Testing – Icing Research Tunnel

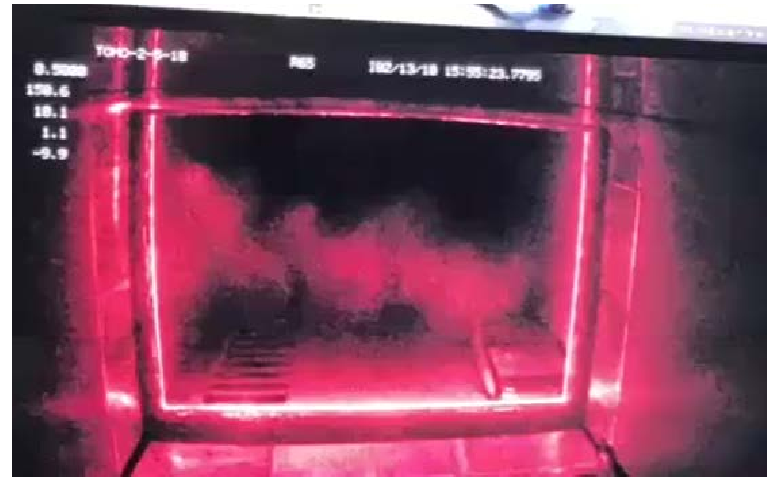
Engine Icing - Propulsion Systems Laboratory

POC: Mark Woike / Jonathon Ponder / Tim Bencic (GRC)

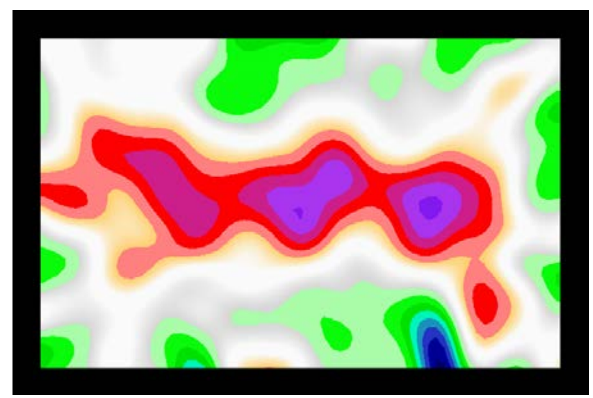
IRT Icing Tomography System

- IRT Prototype Tomography System
  - 6’ x 9’ Square geometry
  - 60 light sources and 120 detectors

- Light extinction tomography
  - One light source fires, many detectors measure light extinction due to cloud/particles in the optical path from the lasers to the detectors
  - Sequential firing of light sources located around the periphery yields a 2D reconstruction of the cloud
  - Utilizes tomographic reconstruction techniques



Video of a typical icing cloud spray



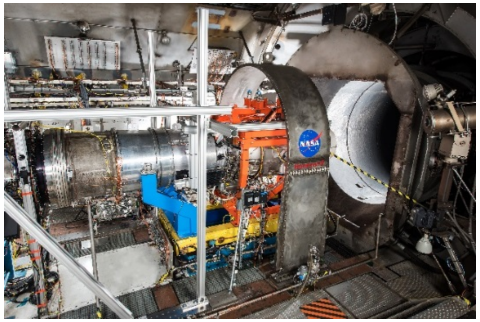
2D tomographic reconstruction of icing cloud spray

From development in the lab to implementation in the test facility

POC: Mark Woike / Jonathon Ponder / Tim Bencic (GRC)

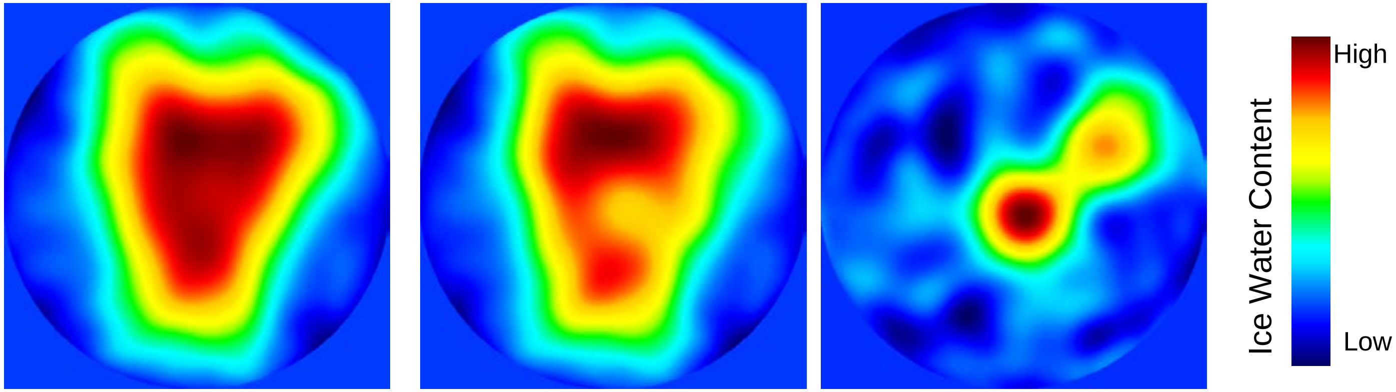
PSL Light Extinction Tomography Results

PSL Icing Tomography System



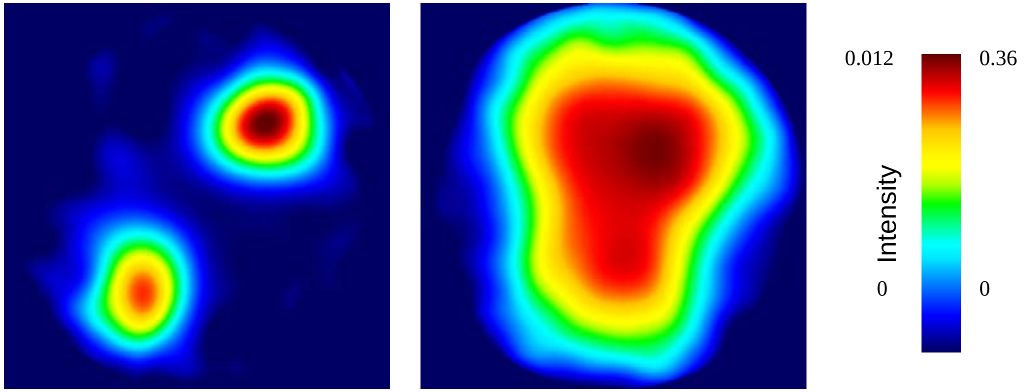
PSL Icing Tomography System

Icing spray nozzle diagnostic monitoring capability



30 Nozzles | 28 Nozzles | Difference

Extremes of spray system water flow



0.08 GPM | 8.2 GPM

POC: Tim Bencic (GRC)

Other Areas of Instrumentation Development for the Test Facilities

- High Temperature Sensors
- Model Attitude Sensors
- Force Measurement Technology
- Wind Tunnel Characterization Instrumentation

- Questions?

Thank you!