Laser Velocimetry Measurement Uncertainty Reduction

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Reduced Uncertainties at Low Velocities is Gaining Importance

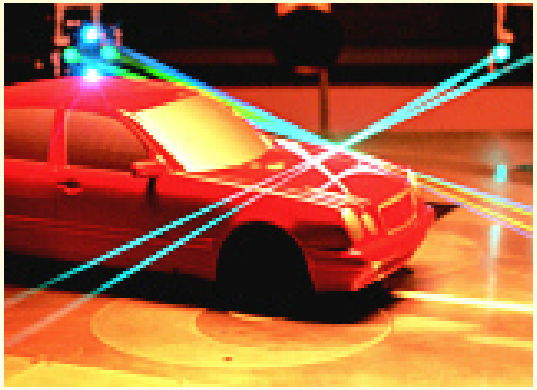
- Precise air velocity measurements are required in industry and government operations
  - Pharmaceuticals, environmental, and maintenance applications
- Air velocity measurement systems are becoming more accurate
- Calibration techniques and systems must reduce their uncertainty (Test Uncertainty Ratio) to appropriate levels
  - Bench Top Wind Tunnel is often used as standard
  - DOD does over 1000 calibrations of anemometers/year

Conventional Bench-Top Wind Tunnel (WT) Operates in Manual Mode

- Venturi with a 10cm x 10cm throat area
- Honeycomb flow straighteners
- Laminar flow (<1% turbulent intensity)
- Flow proportional to square root of DP
- Two nozzle plates used to achieve low flows
- Velocity set manually with blower control knob

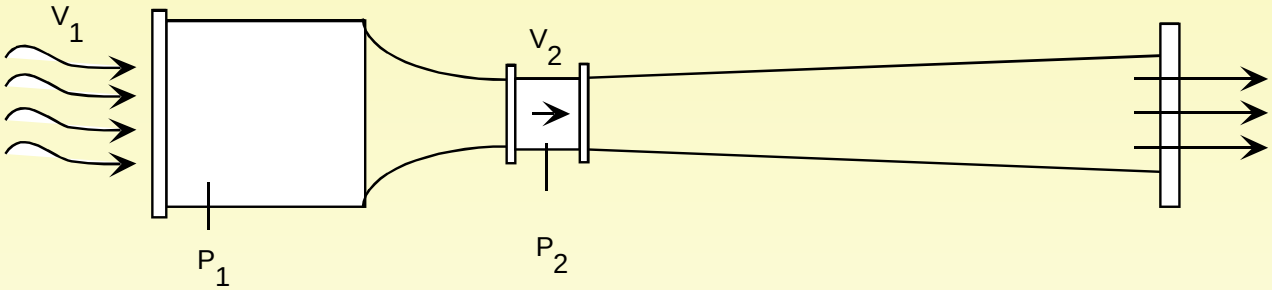
ORNL's Improvement Approach Included Uncertainty Analysis, Laser Doppler Velocimetry (LDV), and System Automation

- Uncertainty analysis led to improving process measurements, especially the differential pressure and absolute pressure instrumentation
- LDV is now used by NIST as their low speed standard
  - Range: 0.2 - 8.0 m/s
    Uncertainty: ± 0.006 m/s
    Confidence Level: 95%



- Automation
  - Data collection automated
  - Velocity actively controlled via feedback

Standard Expression for Measurement Uncertainty to Produce Sensitivity Coefficients



$$V_2 = \frac{\sqrt{2}}{\sqrt{1-\beta^4}} \frac{1}{\sqrt{\rho}} \sqrt{\Delta P} \quad ; \qquad \rho = F(P,\ T,\ RH)$$

$$u_c^2(v) = \left[\frac{\partial V}{\partial P}\right]^2 u_P^2 + \left[\frac{\partial V}{\partial \Delta P}\right]^2 u_{\Delta P}^2 + \left[\frac{\partial V}{\partial T}\right]^2 u_T^2 + \left[\frac{\partial V}{\partial RH}\right]^2 u_{RH}^2$$

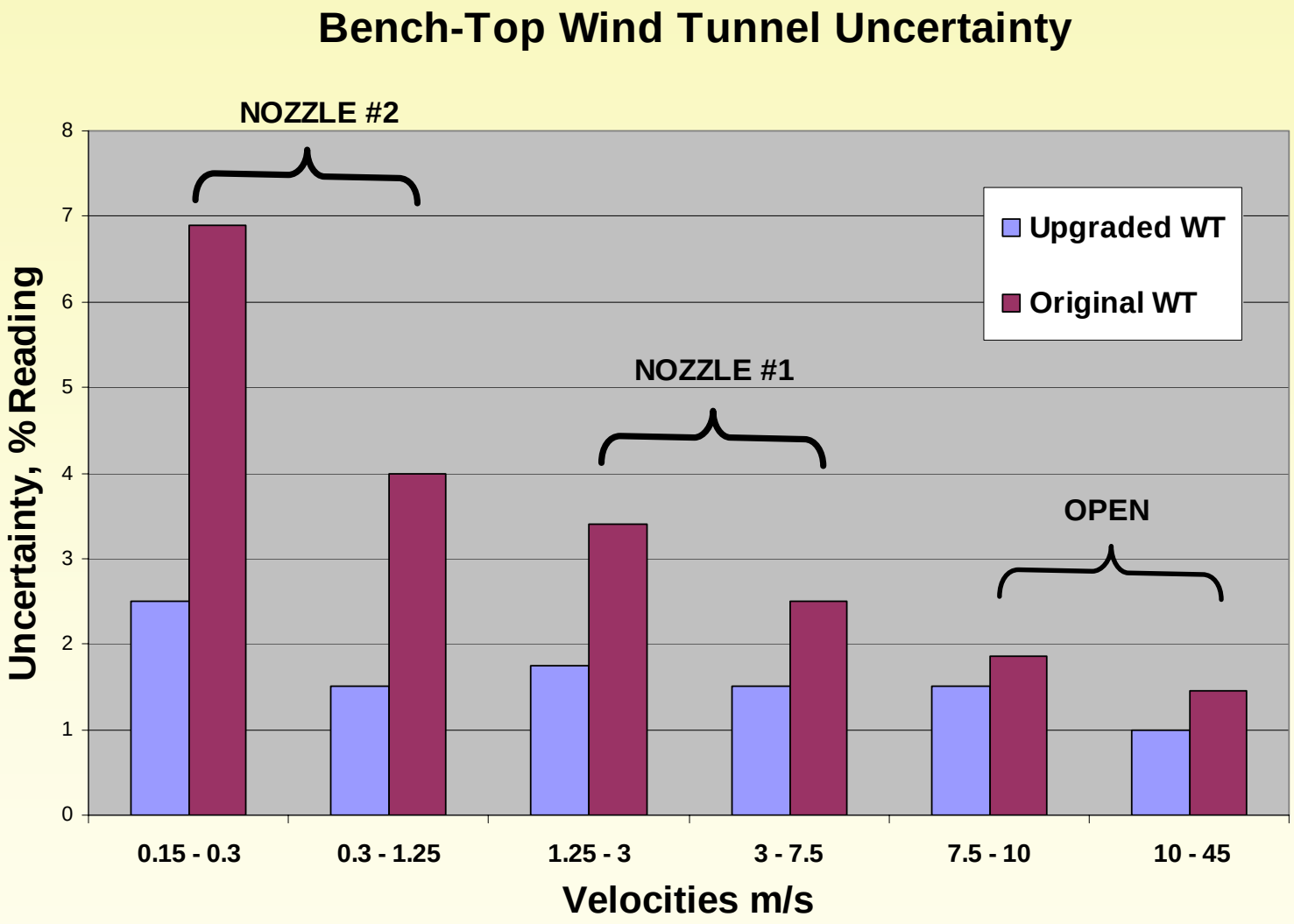
Uncertainty Analysis Led to Sensitivity Values and Improved Accuracy

- Differential pressure measurement is the largest contributor to the uncertainty – followed by the absolute pressure
- Humidity is the least important contributor
- Overall uncertainty is the combined values from the static uncertainties of the process instrumentation, turbulence in the wind tunnel, standard velocity uncertainties, and curve-fit bias errors (fitting data to the standard)

Improved Process Instrumentation Reduced Uncertainties Significantly

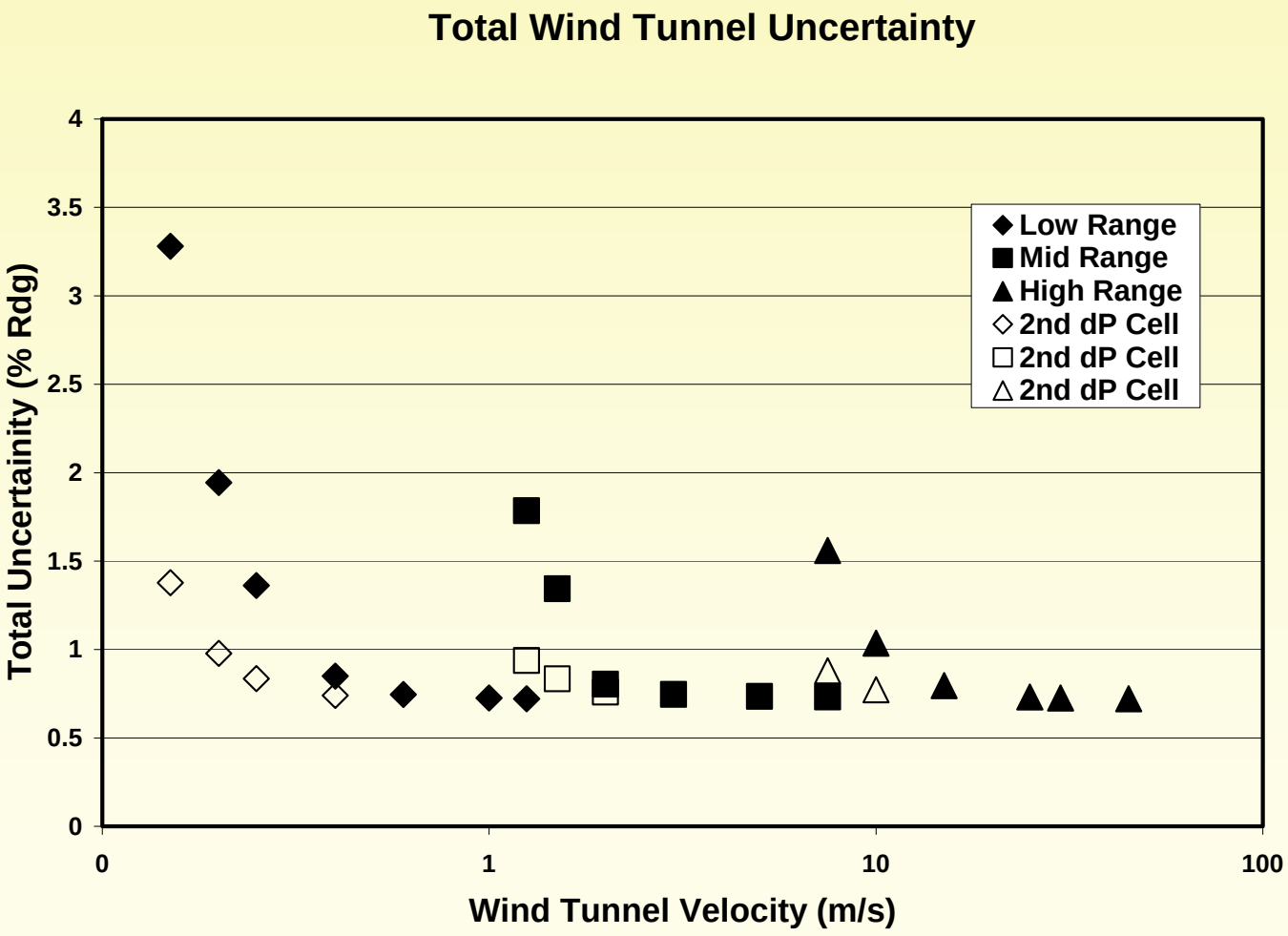
	UNCERTAINTY	
PARAMETER	ORIGINAL	UPGRADED
Absolute Pressure	±0.04 FS	± 0.15% Rdg
Differential Pressure	±0.5% FS	± 0.04% Rdg
Temperature	± 0.2K	± 0.1K
Humidity	Not specified	± 2.0% RH
Analog Signal	±0.25% Rdg	± 0.01% Rdg

Uncertainty Reductions (Coverage Factor of 2) Were 2-3 At Low Velocities (<3 m/s)

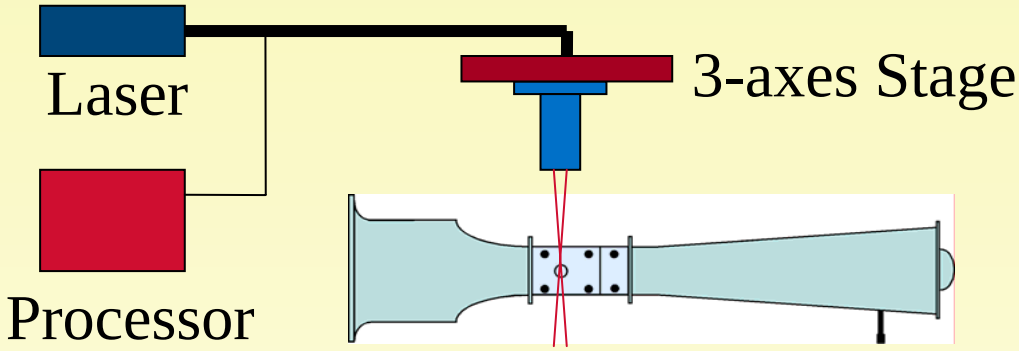


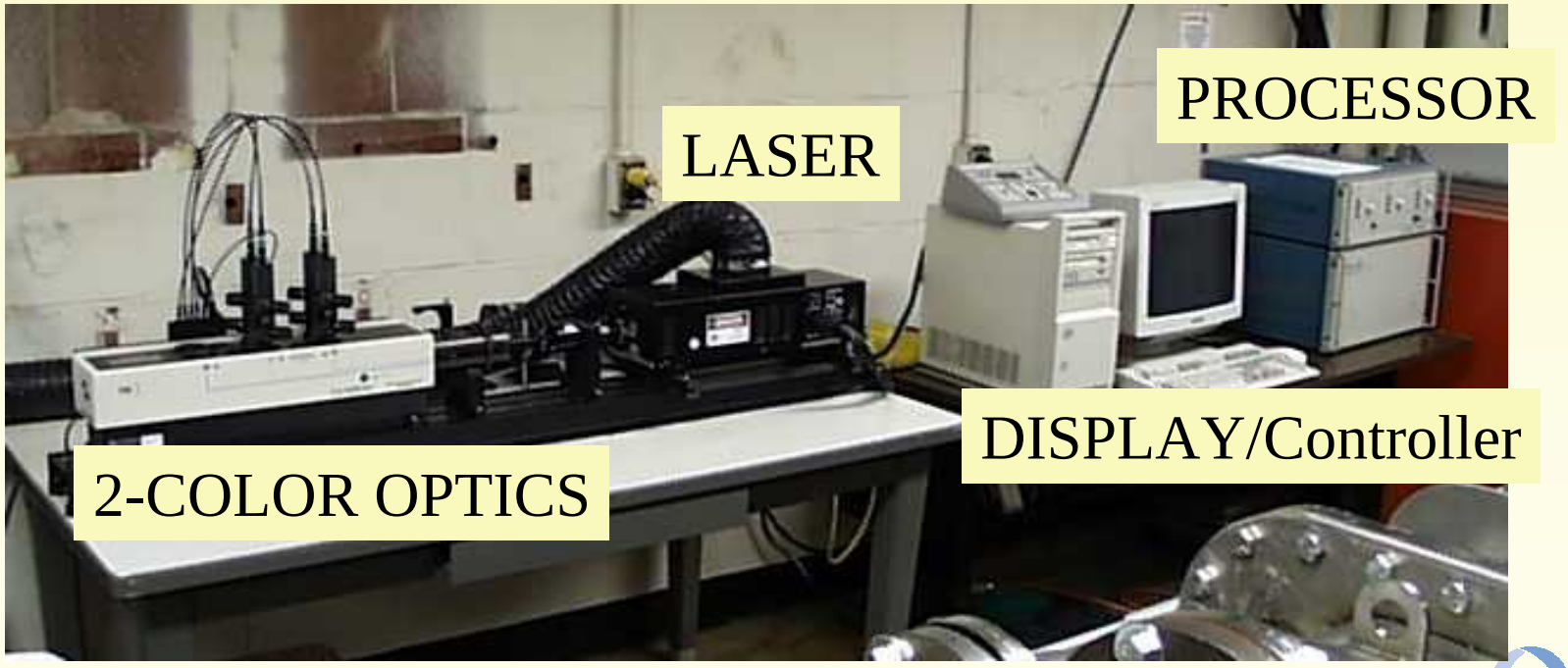
A Second, Lower-Range dP Transducer Was Added To Further Reduce Uncertainty

(In Parallel with the original dP cell)



Second Phase of Reduction Was to Compare Improved Wind Tunnel to a LDV

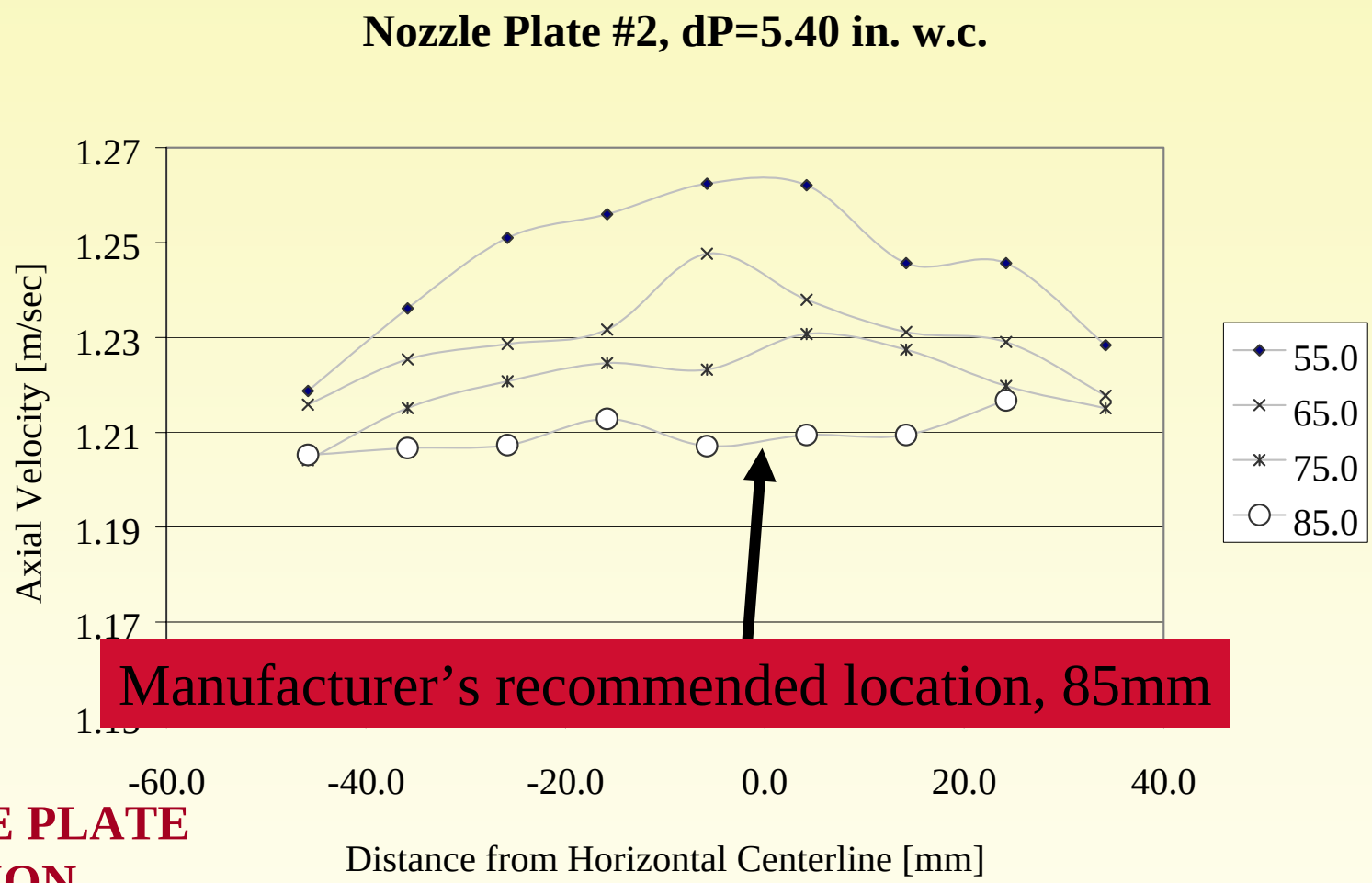




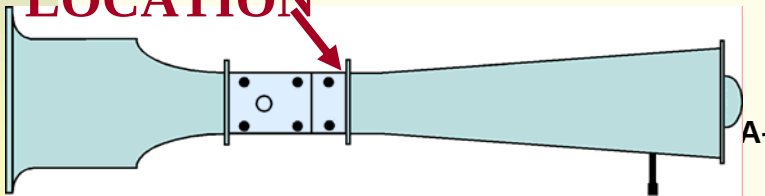
LDV Calibrated Using NIST Methodology

- LDV velocity measurement dependent on wavelength of laser light, intersection angle of two beams, and frequency burst by particles traversing the beam intersection
- Wavelength and intersection angle were verified as well as frequency measurement
- LDV geometric uncertainty is ±0.2% Rdg. and compared well with NIST-calibrated pitot tube for velocities > 8 m/sec
- 3-axes stage calibrated and LDV aligned with WT test section prior to testing

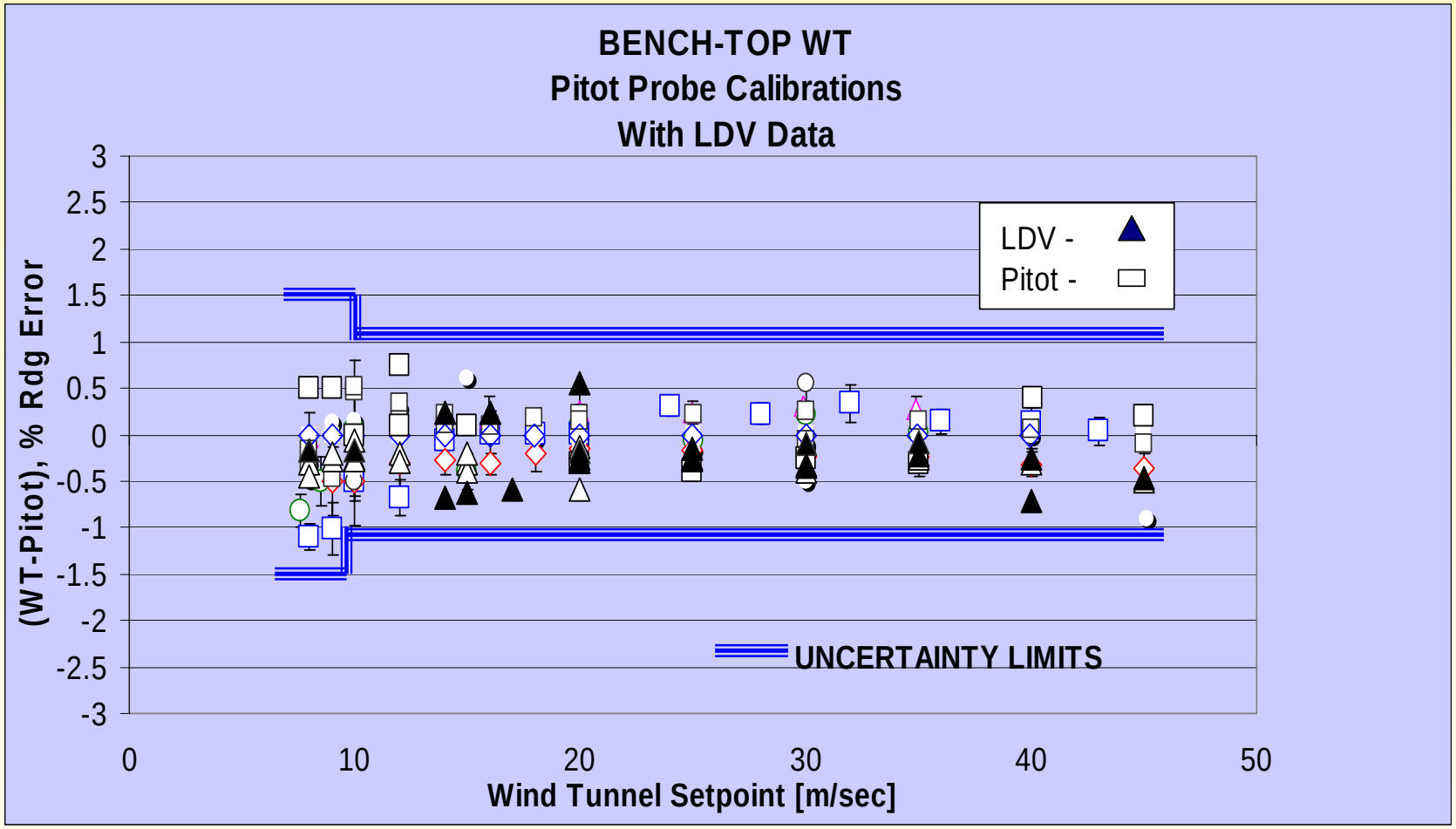
Velocity Profile Flat at Recommended Measurement Location



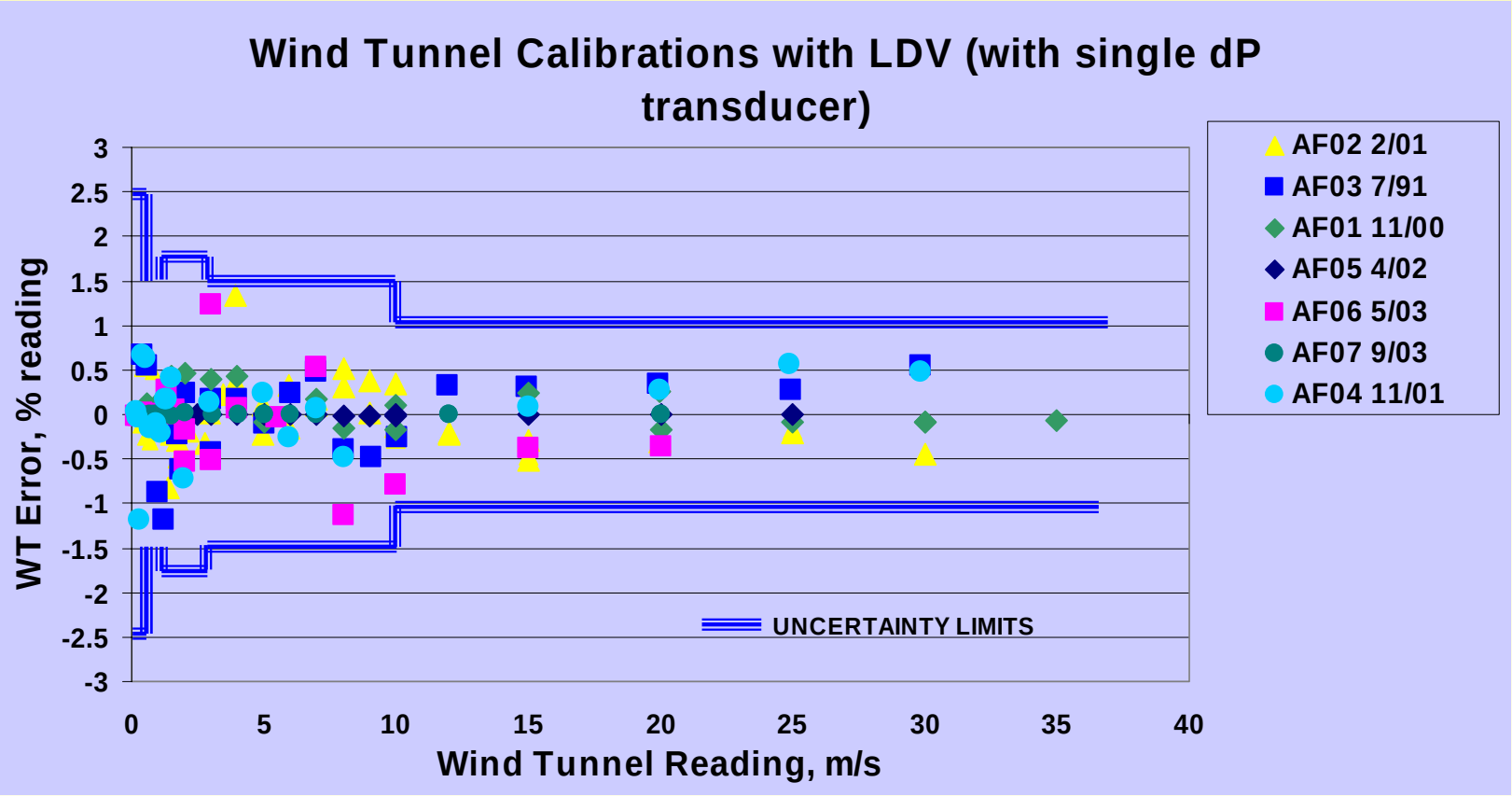
NOZZLE PLATE LOCATION



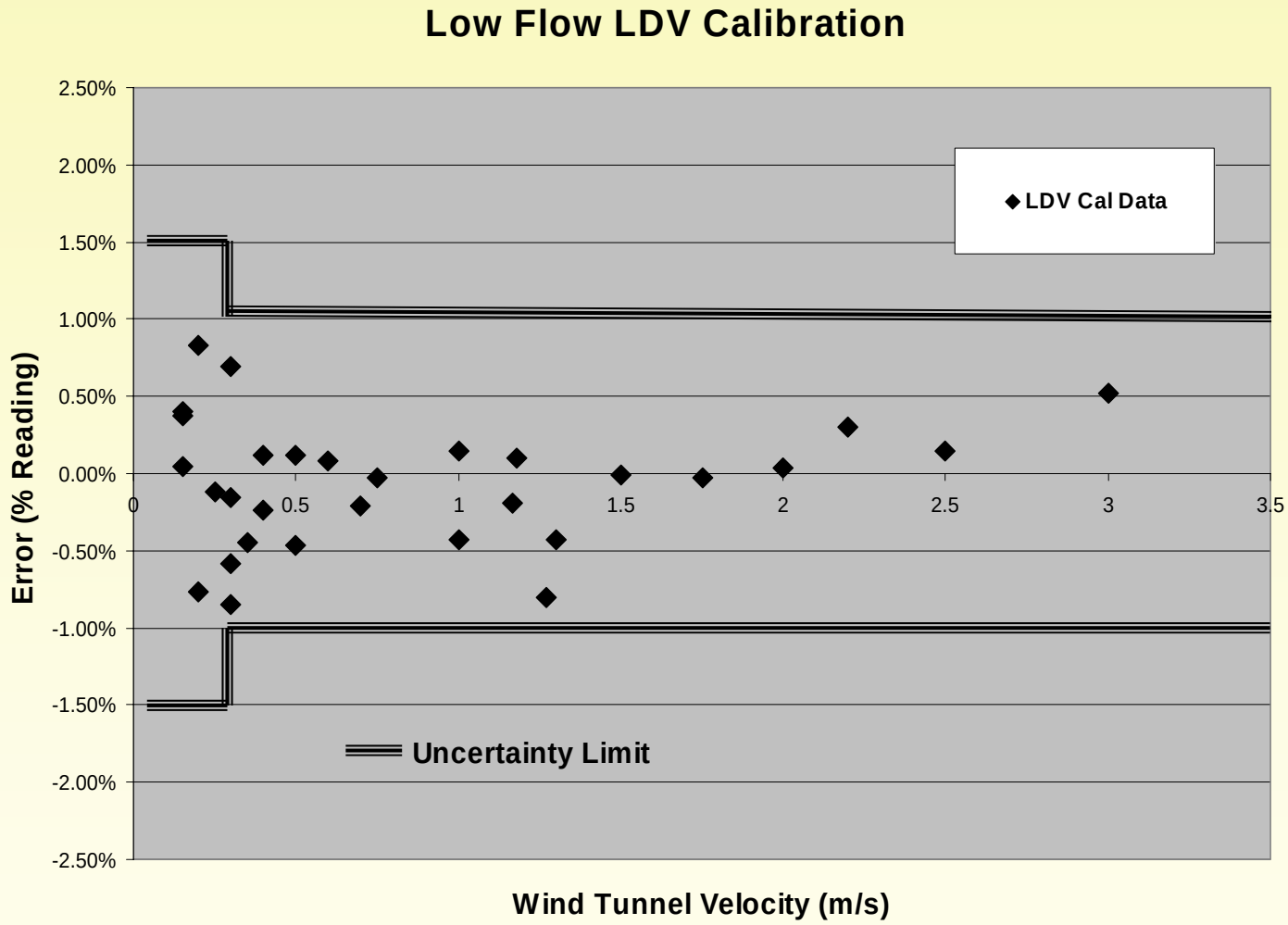
Compared LDV to NIST Calibrated-Pitot Tube – Excellent Agreement



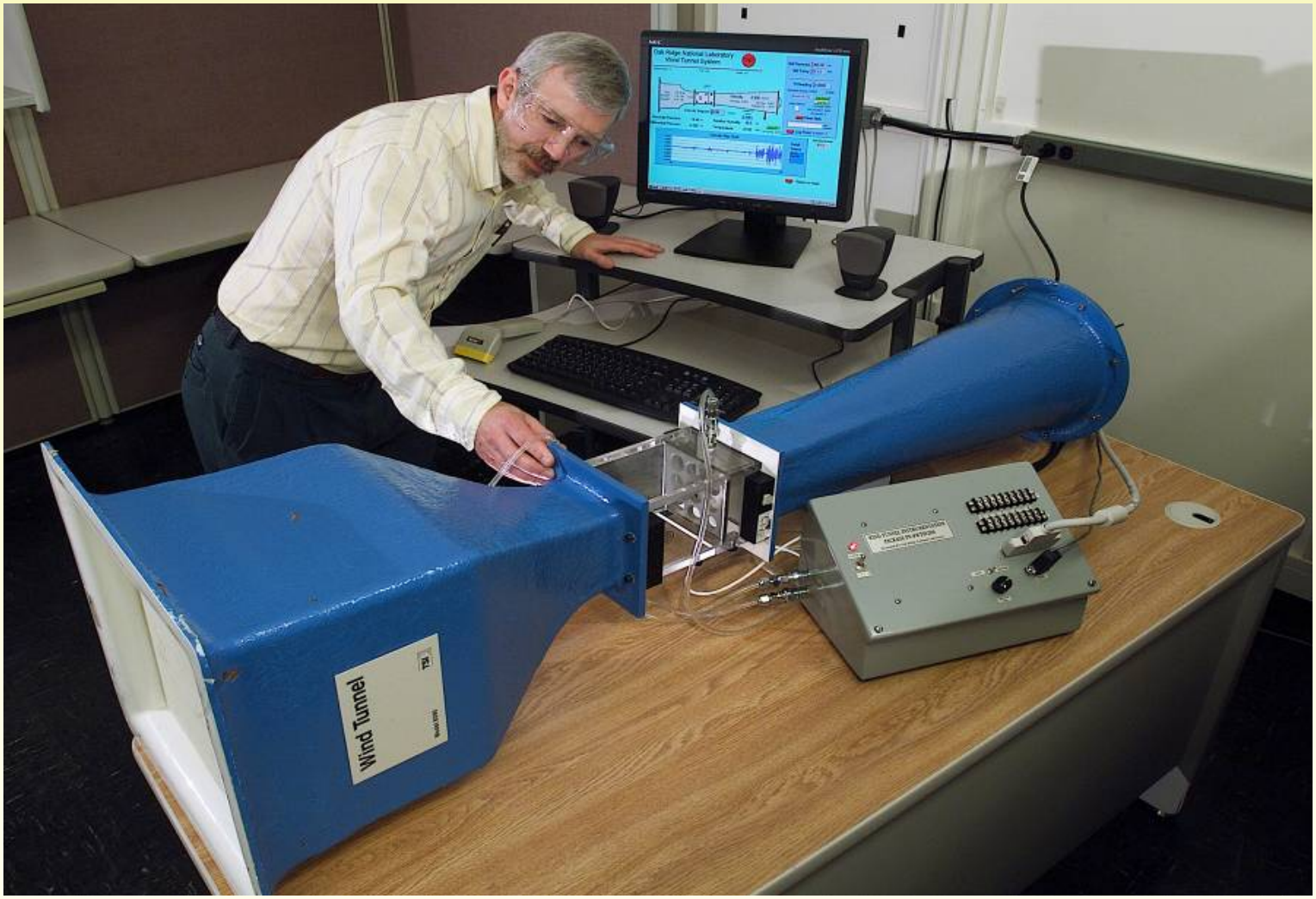
LDV Calibration of Several Wind Tunnels (with Single dP Transducer)



Low Flow Calibration <±1% Uncertainty, 0.15 to 3 m/s (Dual dP cell Arrangement)



Automated Wind Tunnel System



In Summary, LDV/Uncertainty Analysis Reduces WT Uncertainty Significantly

- Lowest velocity range uncertainty reduced by factor of ~5
- LDV excellent standard for low flow velocities
- Dual dP transducer arrangement lowered uncertainty by a factor of about 2
- Automated system reduced calibration time and increased system accuracy

Acknowledgements

- David Madden and Jim Baird of the Air Force Metrology and Calibration Laboratory
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