Evaluation of Uncertainties in Velocity Probe Calibration Procedures

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NIST Smokestack Emissions Measurement Workshop
June 28, 2017

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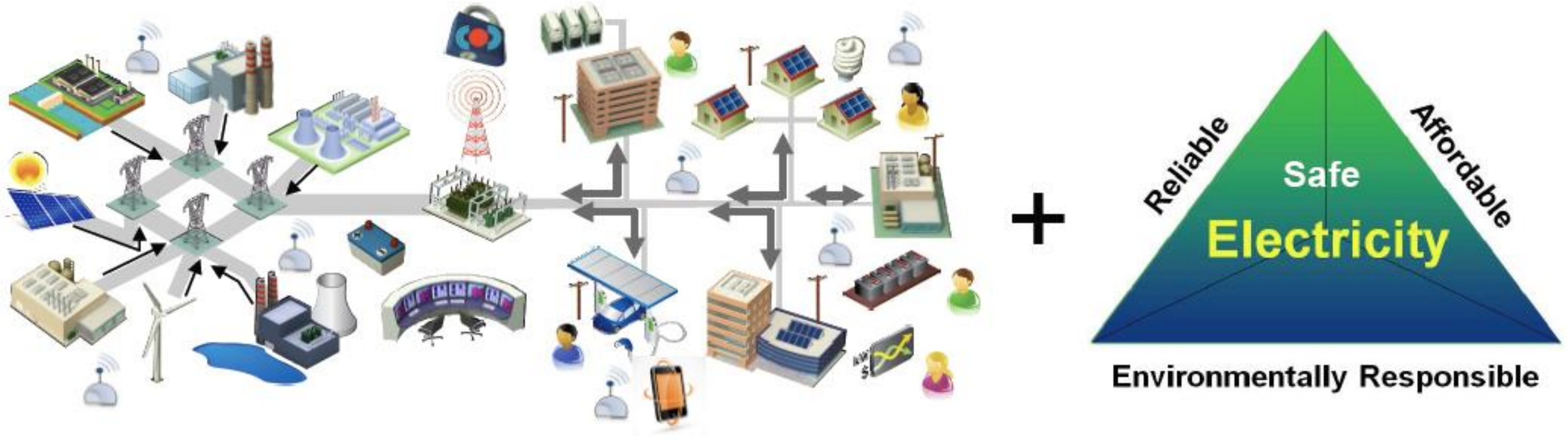
- Focused on electricity generation, delivery, and use in collaboration with the electricity sector, its stakeholders and others



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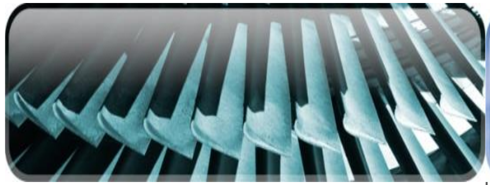
EPRI Sectors



Generation

- Advanced Coal Plants, Carbon Capture and Storage
- Combustion Turbines
- Environmental Controls
- Generation Planning
- Major Component Reliability
- Operations and Maintenance

Nuclear Power

- Material Degradation/Aging
- Fuel Reliability
- High-Level Waste and Spent Fuel Management
- Nondestructive Evaluation and Material Characterization
- Equipment Reliability
- Instrumentation and Control
- Risk and Safety Management
- Advanced Nuclear Technology
- Low-Level Waste and Radiation Management

Power Delivery & Utilization

- Distribution
- Energy Utilization
- Grid Operations and Planning
- Substations and Asset Planning
- Transmission and Increased Power Flow

Environment

- Air Quality
- Global Climate Change
- Land and Groundwater
- Occupational Health and Safety
- T&D Environmental Issues
- Water and Ecosystems
- Renewables

Continuous Emission Monitoring

EPRI Program 77

Importance of Stack Flow Reference Method Accuracy

EPA's Part 75 Continuous Emission Monitoring (CEM) Rule

- Requires mass emission measurement reporting

E = (K) * (C) * (Q) *(H_2O)

Where:

E = SO_2 , NO_x , or CO_2 mass emission rate (lb/hr <u>or</u> tons/hr)

K = Species-specific conversion constant

C = Hourly average SO_2 , NO_x , or CO_2, concentration (ppmv <u>or</u> % CO_2)

Q = Hourly average volumetric flow rate (scfh)

H_2O = Moisture correction term (if SO_2 , NO_x , or CO_2 is measured on a dry basis)

- Requires heat input reporting

HI = (Q) * (1/F) * (1/D)*(H_2O)

Where:

HI = Heat input rate (mmBtu/hr)

Q = Hourly average volumetric flow rate (scfh)

F = Fuel-specific F-factor (dscf/mmBtu or scf CO_2/mmBtu)

D = Diluent gas correction term

H_2O = Moisture correction term (if required)

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Flow measurement uncertainty will directly impact reported mass emission and heat input values

Sources of Uncertainty

Stack flow Reference Method 2F (5-hole pitot probe)

- Velocity probe calibration
- Field instrumentation accuracy
- Stack flow stratification
- Wall effects (Method 2G)
- Manual operator error

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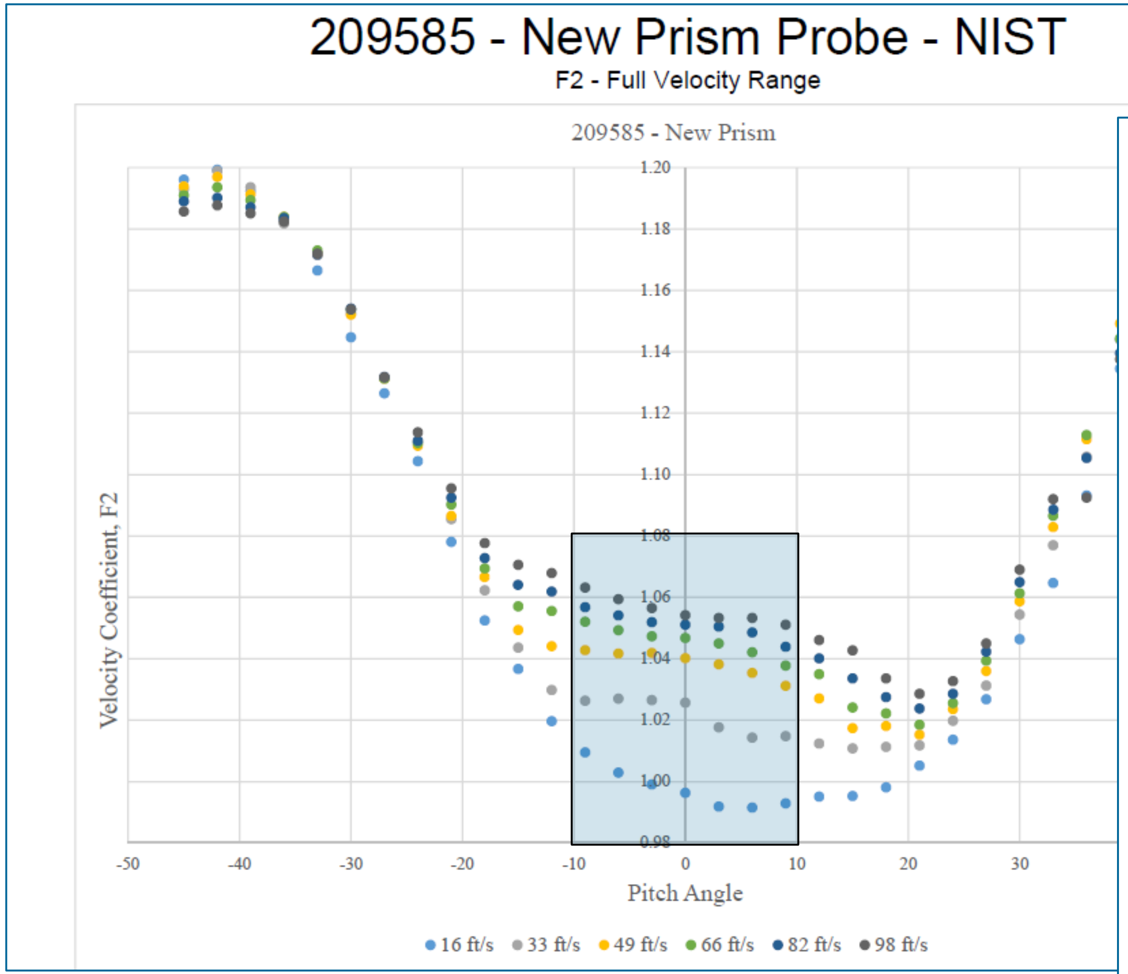
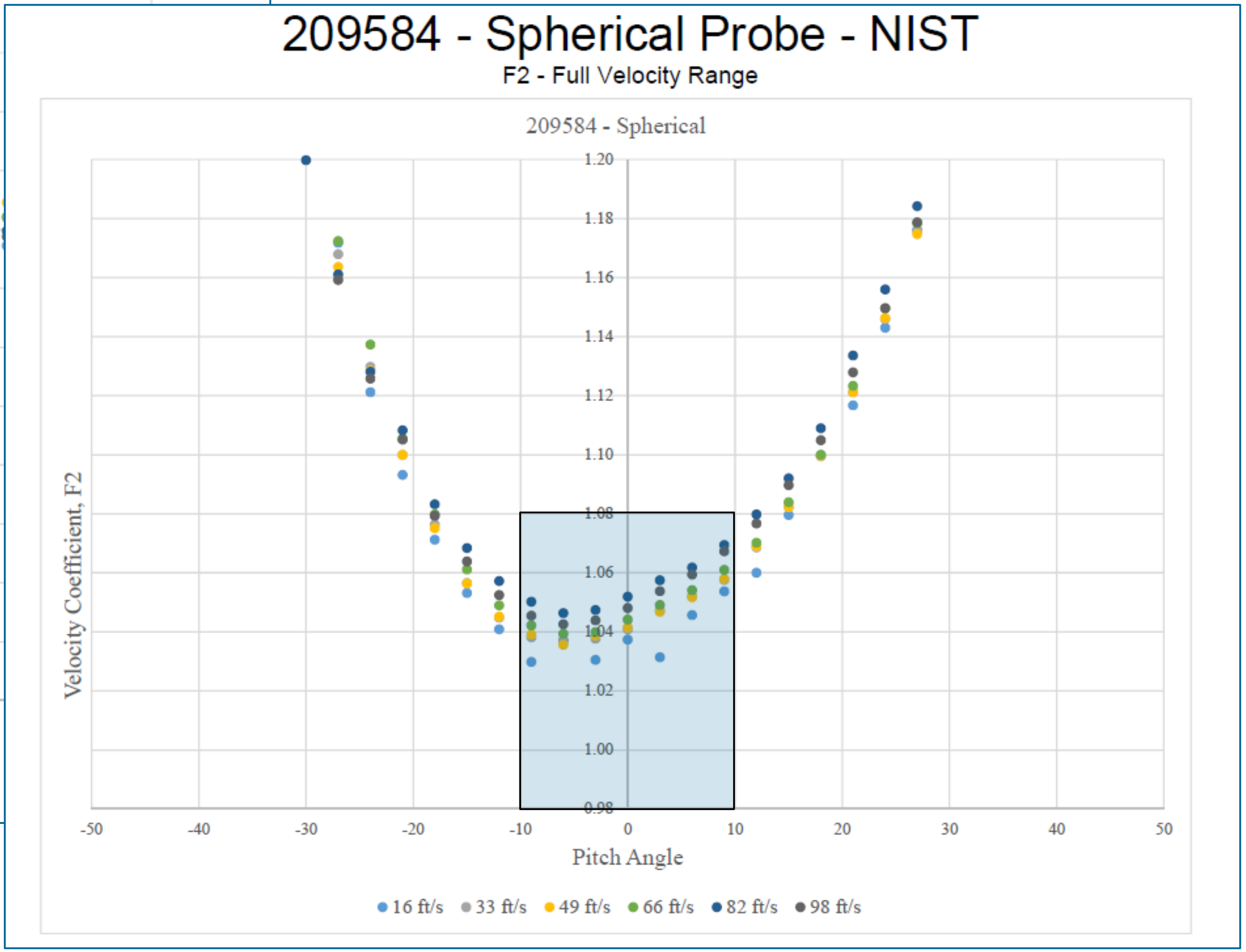
Method 2F Probe Calibration

- Lab instrumentation accuracy
- Calibration apparatus (wind tunnel)
- Velocity sensitivity
- Turbulence sensitivity
- Curve fit
- Manual operator error

Stack Velocity Probe Calibration – Velocity Sensitivity

Method 2F allows using average of 60 and 90 ft/s curves all the way down to 20 ft/s





$$F_2 = C_p \sqrt{\frac{\Delta P_{std}}{(P_1 - P_2)}}$$

$$v_{a(i)} = K_p F_{2(i)} \sqrt{\frac{(P_1 - P_2)_i T_{s(i)}}{P_s M_s}} \left(\cos\theta_{y(i)}\right)\left(\cos\theta_{p(i)}\right)$$

Allowable Uncertainties in Method 2F Cal Procedures

- **Instrumentation choices contribute significantly to calibration uncertainty:**
  - Pressure calibrator accuracy (2F requires at least 0.5%FS)
  - P1-P2 transducer accuracy (2F requires at least 1.0% FS)
  - P1-P2 transducer range (*no requirement in the method*)
  - Transducer calibration agreement (2F requires at least 2%)

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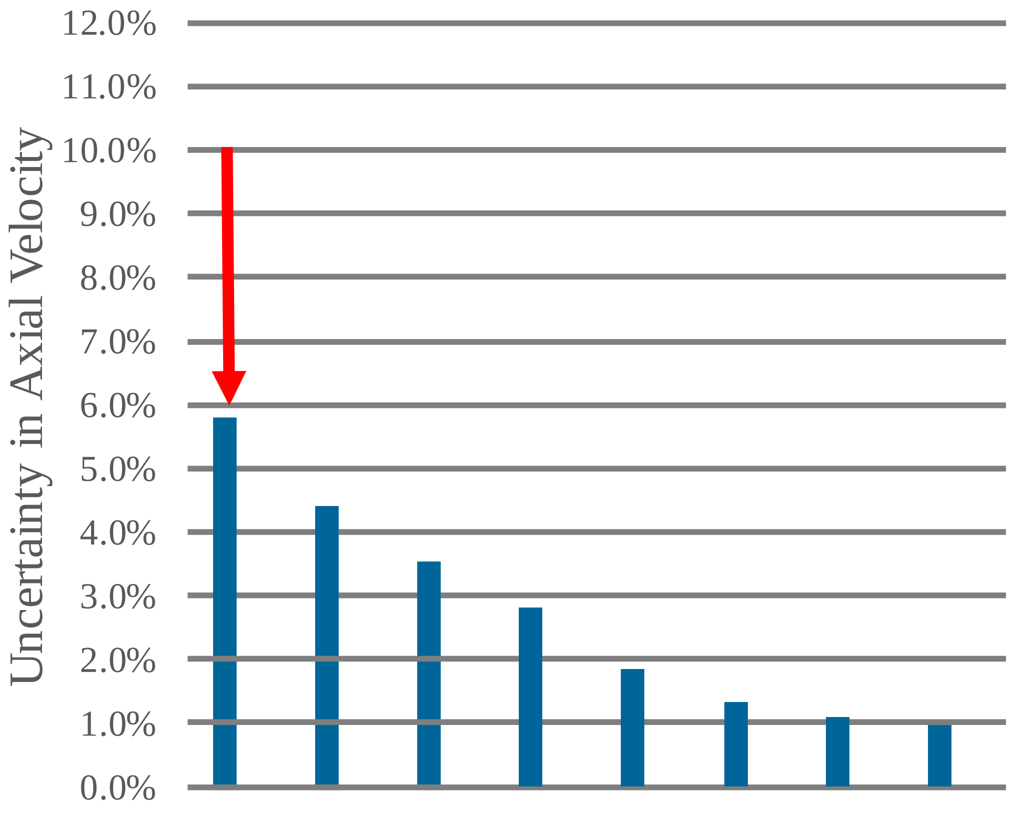
Allowable Uncertainties in Method 2F Cal Procedures

- **90 ft/sec example**

Calibrator Range	5	IWC
Calibrator Accuracy	0.5	%FS
P1-P2 Range	5	IWC
P1-P2 Accuracy	1	%FS
P2-P3 Range	+/- 2.5	IWC
P2-P3 Accuracy	1	%FS
P4-P5 Range	+/- 2.5	IWC
P4-P5 Accuracy	1	%FS
Transducer calibration agreement	2	%FS

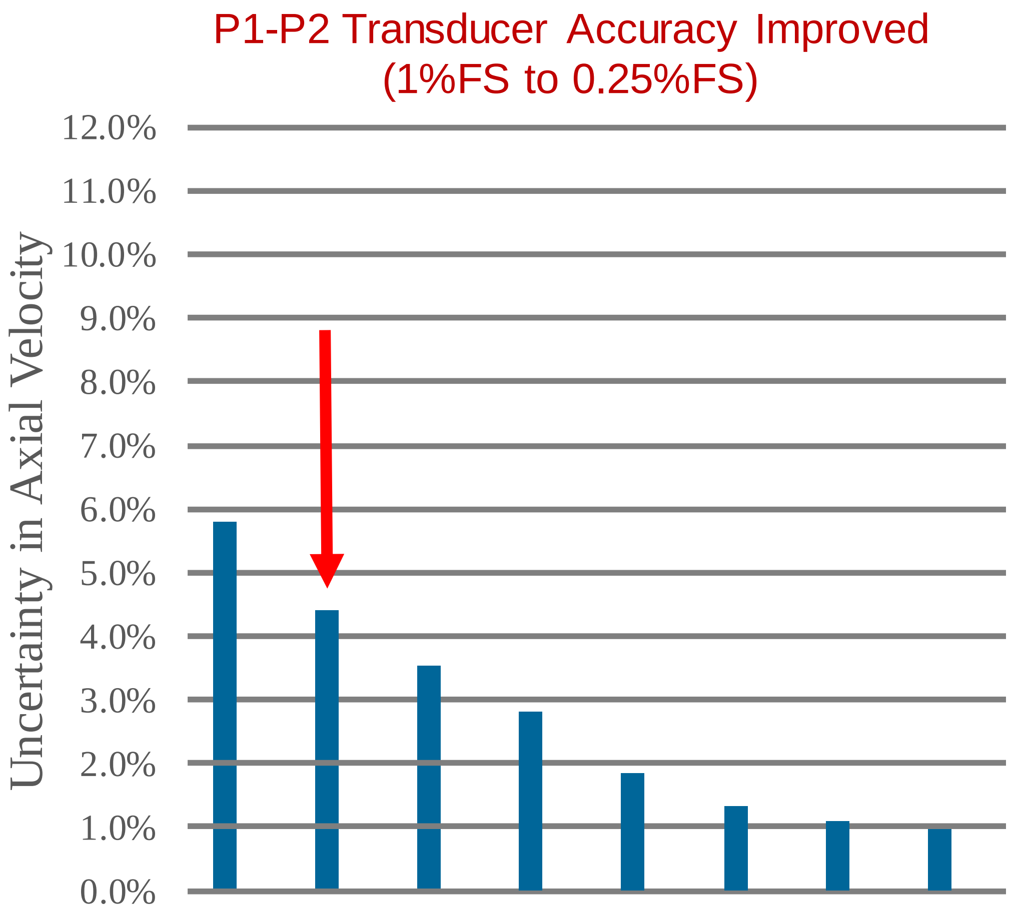
Maximum Allowable Tolerances



Allowable Uncertainties in Method 2F Cal Procedures

- **90 ft/sec example**

Calibrator Range	5	IWC
Calibrator Accuracy	0.5	%FS
P1-P2 Range	5	IWC
P1-P2 Accuracy	0.25	%FS
P2-P3 Range	+/- 2.5	IWC
P2-P3 Accuracy	1	%FS
P4-P5 Range	+/- 2.5	IWC
P4-P5 Accuracy	1	%FS
Transducer calibration agreement	2	%FS



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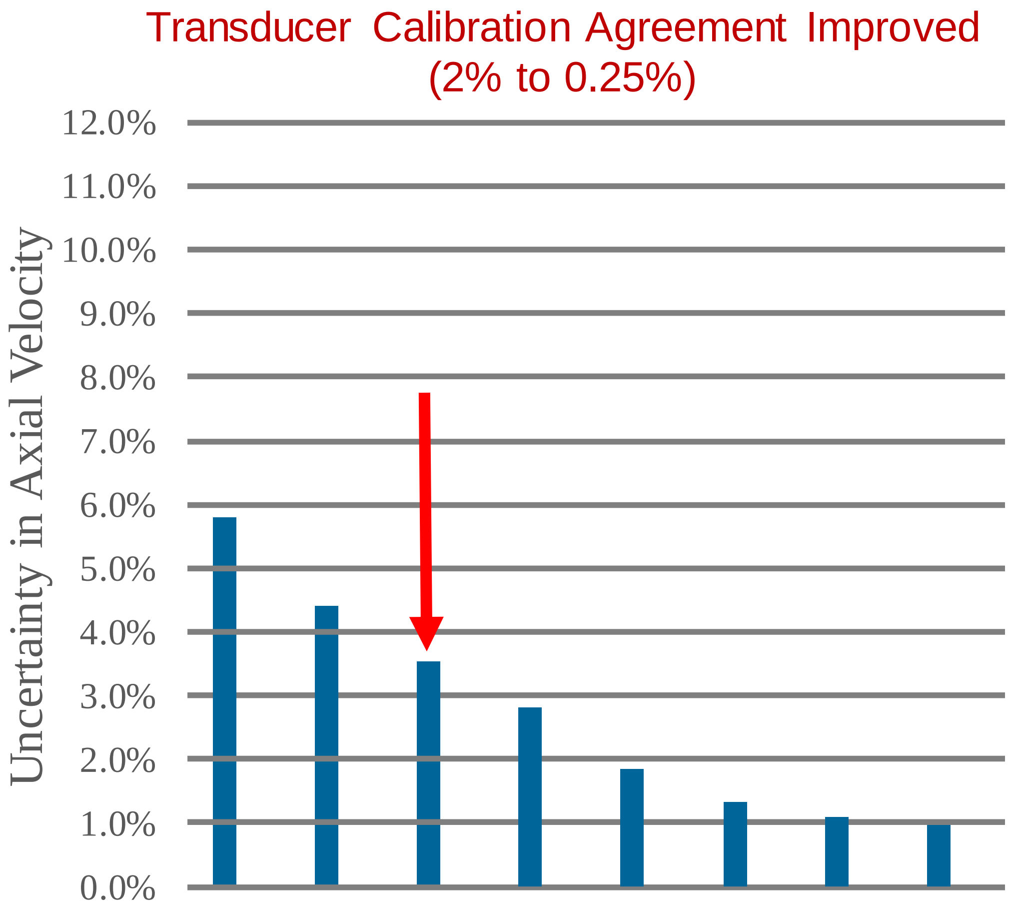

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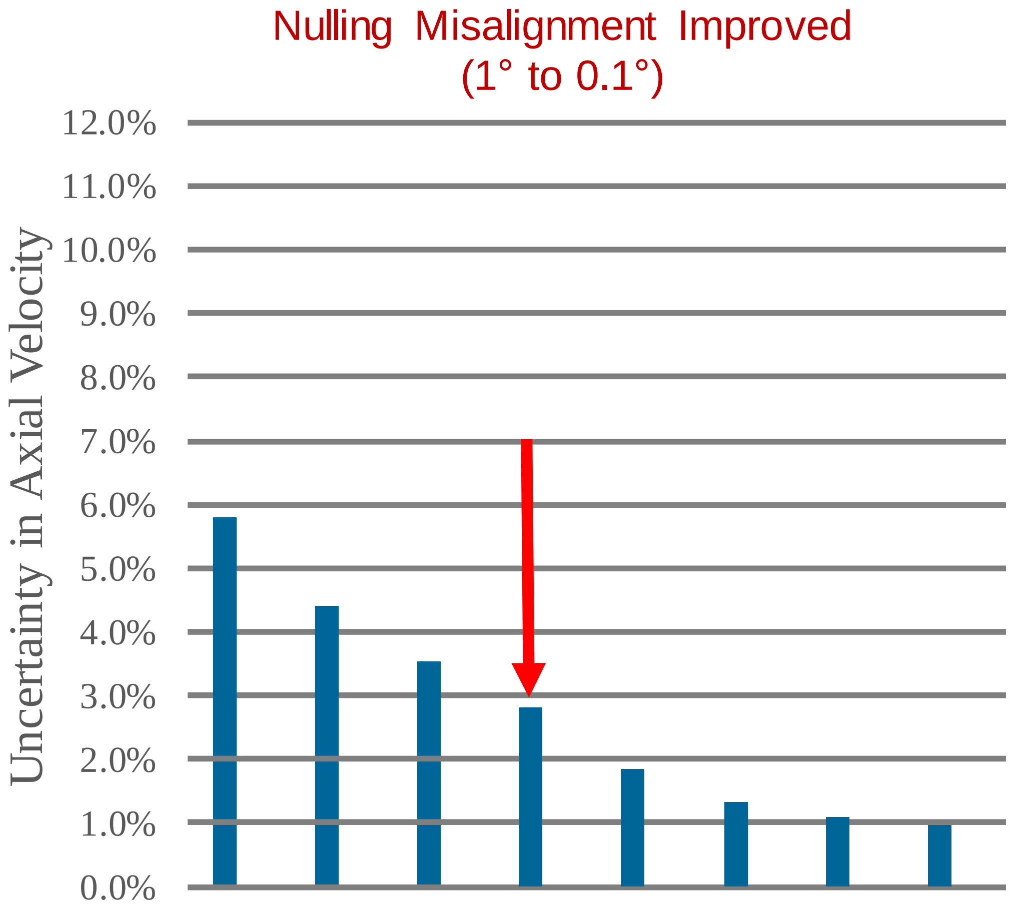

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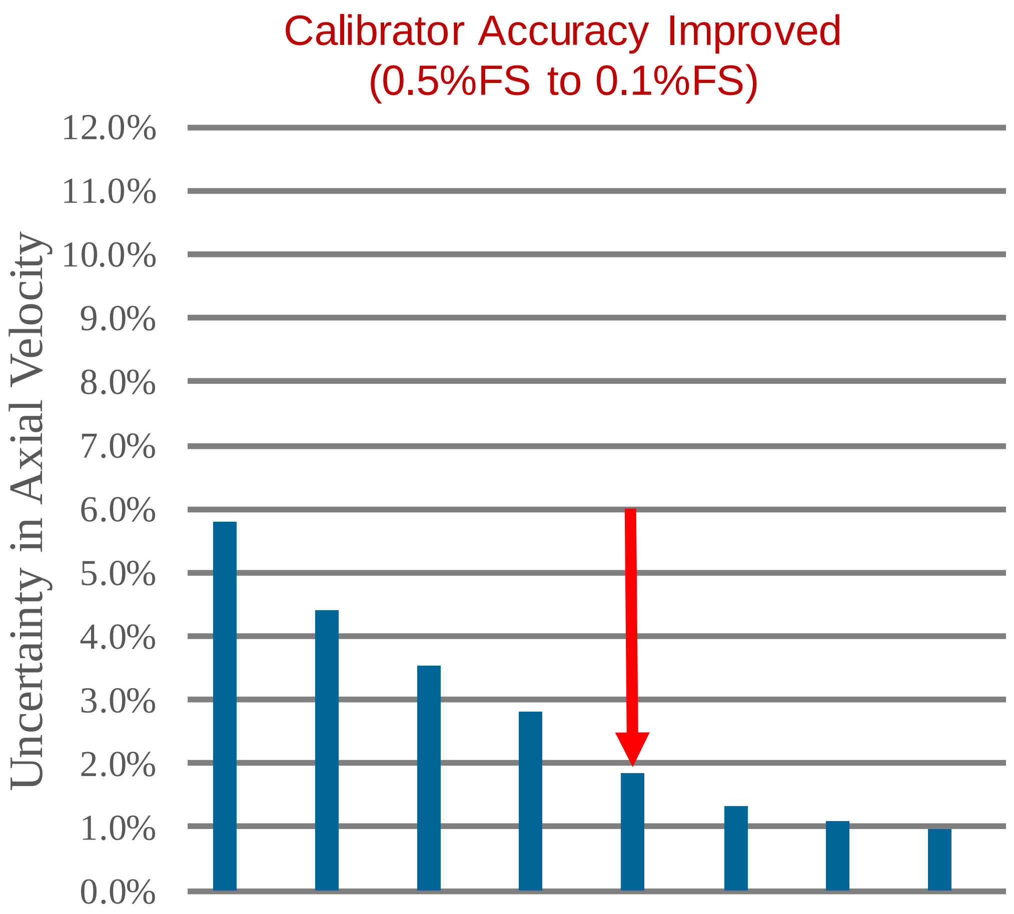
Allowable Uncertainties in Method 2F Cal Procedures

- **90 ft/sec example**

Calibrator Range	5	IWC
Calibrator Accuracy	0.1	%FS
P1-P2 Range	5	IWC
P1-P2 Accuracy	0.25	%FS
P2-P3 Range	+/- 2.5	IWC
P2-P3 Accuracy	1	%FS
P4-P5 Range	+/- 2.5	IWC
P4-P5 Accuracy	1	%FS
Transducer calibration agreement	0.25	%FS



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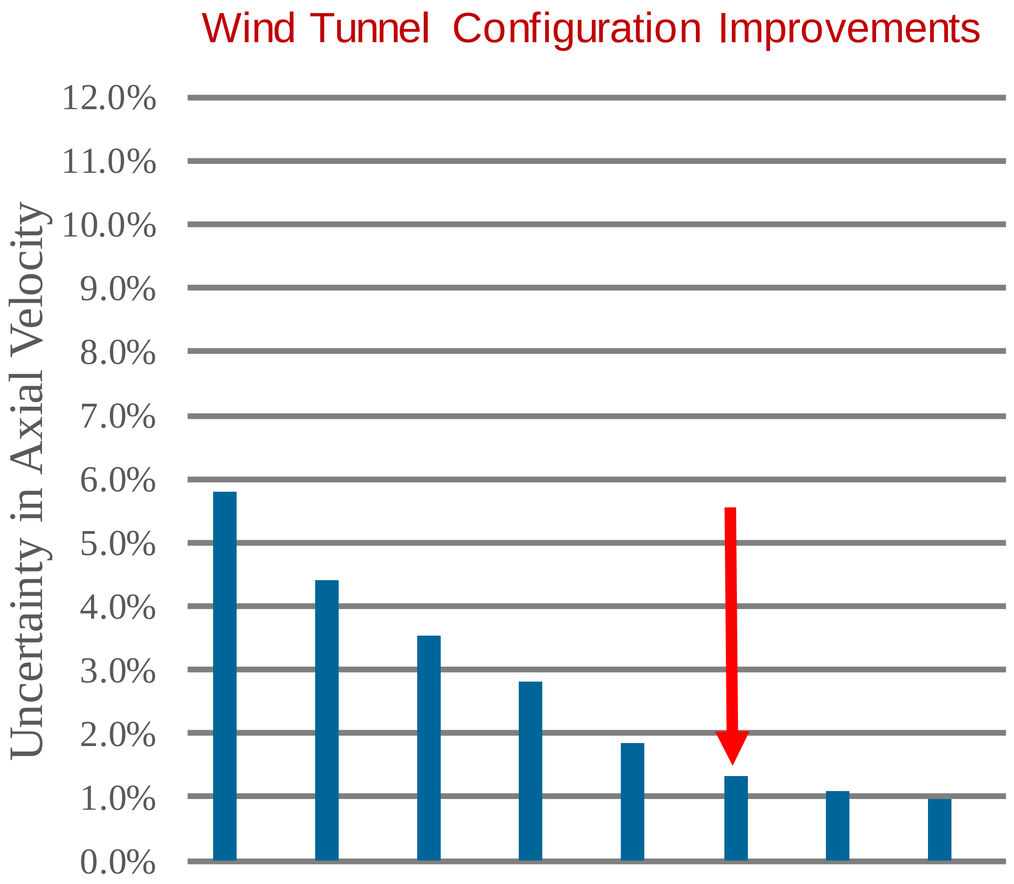

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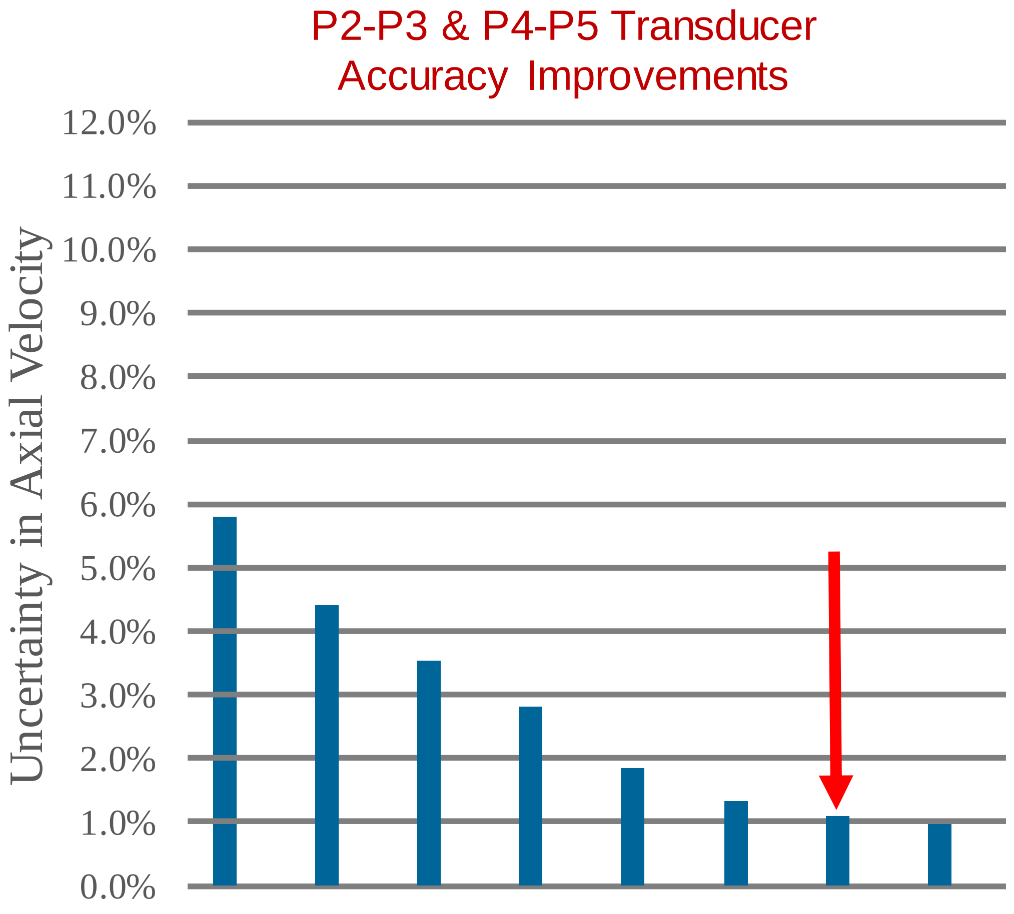

Allowable Uncertainties in Method 2F Cal Procedures

- **90 ft/sec example**

Calibrator Range	5	IWC
Calibrator Accuracy	0.1	%FS
P1-P2 Range	2	IWC
P1-P2 Accuracy	0.25	%FS
P2-P3 Range	+/- 2.5	IWC
P2-P3 Accuracy	0.25	%FS
P4-P5 Range	+/- 2.5	IWC
P4-P5 Accuracy	0.25	%FS
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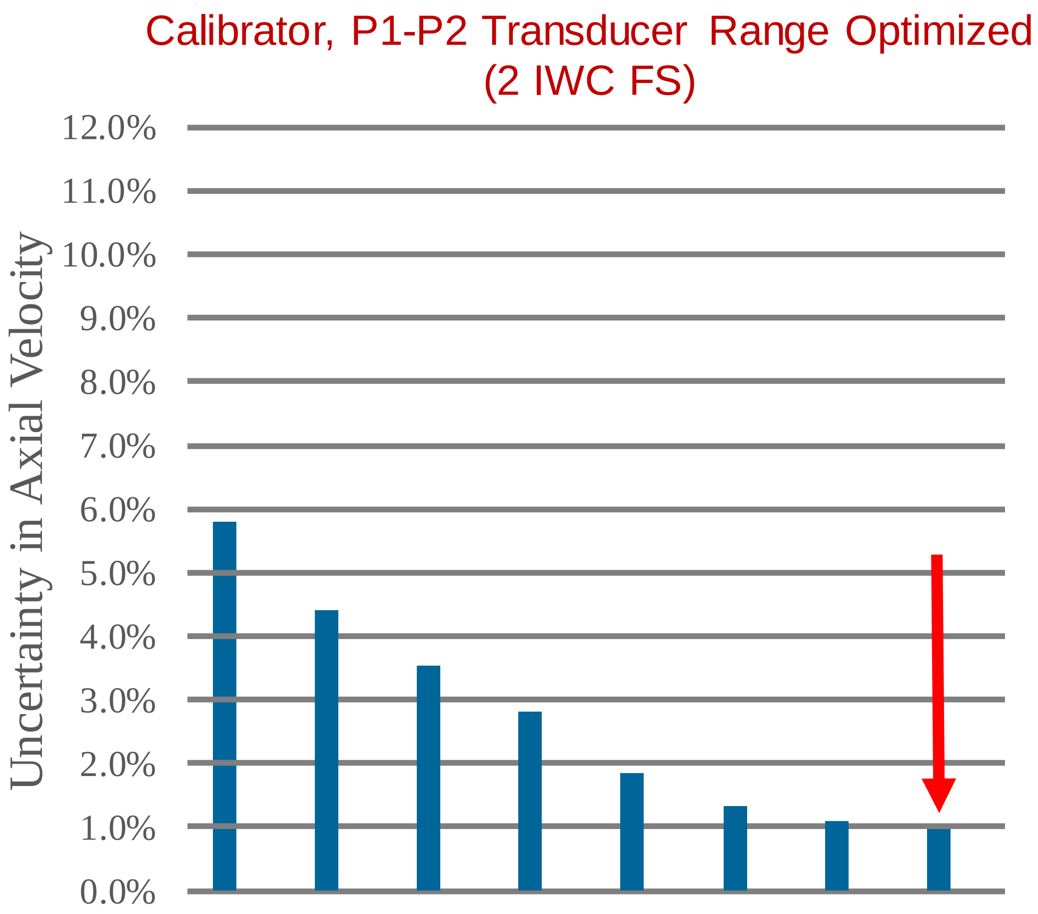
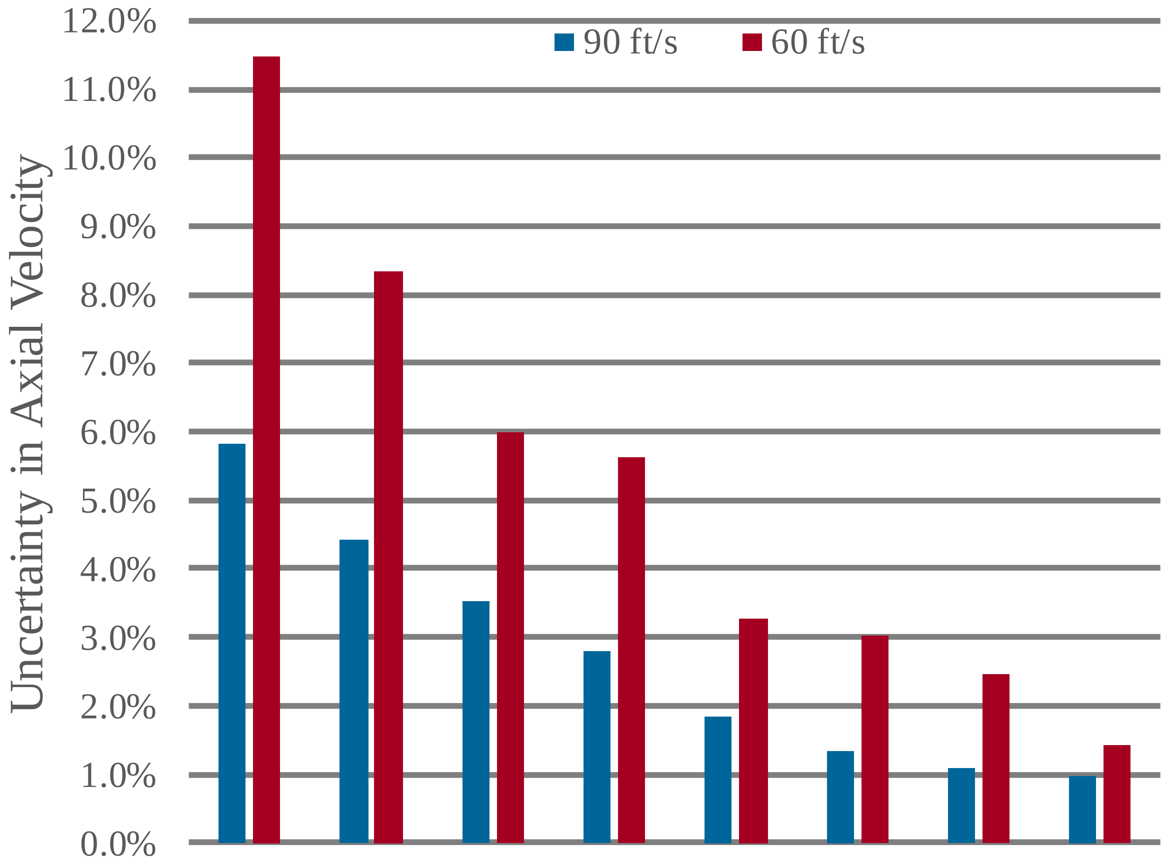


Allowable Uncertainties in Method 2F Cal Procedures

- **90ft/s vs 60ft/sec calibration, using same adjustments**



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Method 2F Wind Tunnel Audits

- 3-5% allowable difference in calibration coefficient, depending on pitch angle
- EPA stopped performing audits in 2009

Excerpt from Method 2F:

10.1.3 Wind tunnel audits.

10.1.3.1 Procedure. Upon the request of the Administrator, the owner or operator of a wind tunnel shall calibrate a 3–D audit probe in accordance with the procedures described in sections 10.3 through 10.6. The calibration shall be performed at two velocities and over a pitch angle range that encompasses the velocities and pitch angles typically used for this method at the facility. The resulting calibration data and curves shall be submitted to the Agency in an audit test report. These results shall be compared by the Agency to reference calibrations of the audit probe at the same velocity and pitch angle settings obtained at two different wind tunnels.

10.1.3.2 Acceptance criteria. The audited tunnel's calibration is acceptable if all of the following conditions are satisfied at each velocity and pitch setting for the reference calibration obtained from at least one of the wind tunnels. For pitch angle settings between −15° and +15°, no velocity calibration coefficient (i.e., F_2) may differ from the corresponding reference value by more than 3 percent. For pitch angle settings outside of this range (i.e., less than −15° and greater than +15°), no velocity calibration coefficient may differ by more than 5 percent from the corresponding reference value. If the acceptance criteria are not met, the audited wind tunnel shall not be used to calibrate probes for use under this method until the problems are resolved and acceptable results are obtained upon completion of a subsequent audit.

Discussion

- There are significant “allowable” calibration uncertainties in EPA’s Method 2F
- How does EPA Method 2F compare to ASME PTC-11? Or other 3D methods?
- What are the actual uncertainties among commercial calibration facilities?
- What is the uncertainty in NIST’s 3D velocity probe calibrations (assumed to be the lowest of all facilities)?
- Given current instrumentation accuracies and costs, what is a reasonable uncertainty to expect from a typical commercial calibration facility?
- **A formal EPRI “round robin” velocity probe calibration study (including NIST) may benefit the industry**
  - **Type S and 3D probes**
  - **Multiple velocity set points**
  - **Include U.S. companies offering commercial calibration services**
  - **Define current range of uncertainties based on calibration facilities, instrumentation and procedures**

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