NIST Experiences with Multipath Ultrasonic Flow Meters for Stack Applications

NIST Workshop

Improving Measurement for Smokestack Emissions

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Gaithersburg, MD

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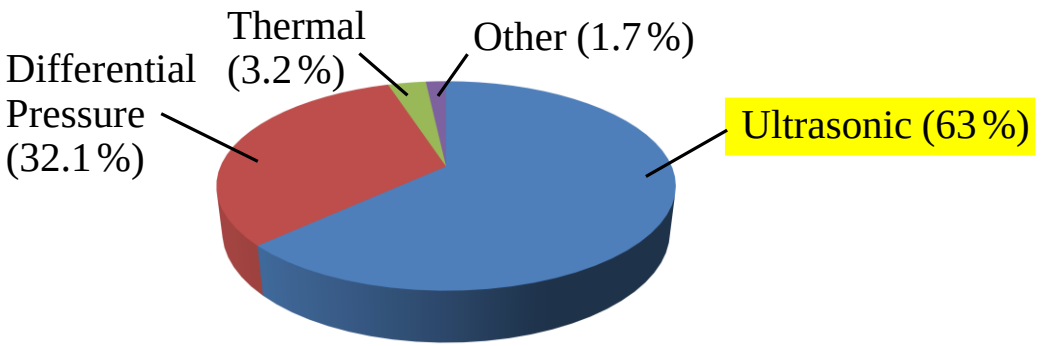
How accurate can CEMS ultrasonic flow measurements be made?

- Single path?
- X-pattern?
- Other Multipath Configurations?
  - 2 path X-pattern Mid Radius

Application:

Power Plant Smokestack Flow Measurements



$$\dot{m}_{GHG} = \int y_{GHG}\, \rho u\, dA$$

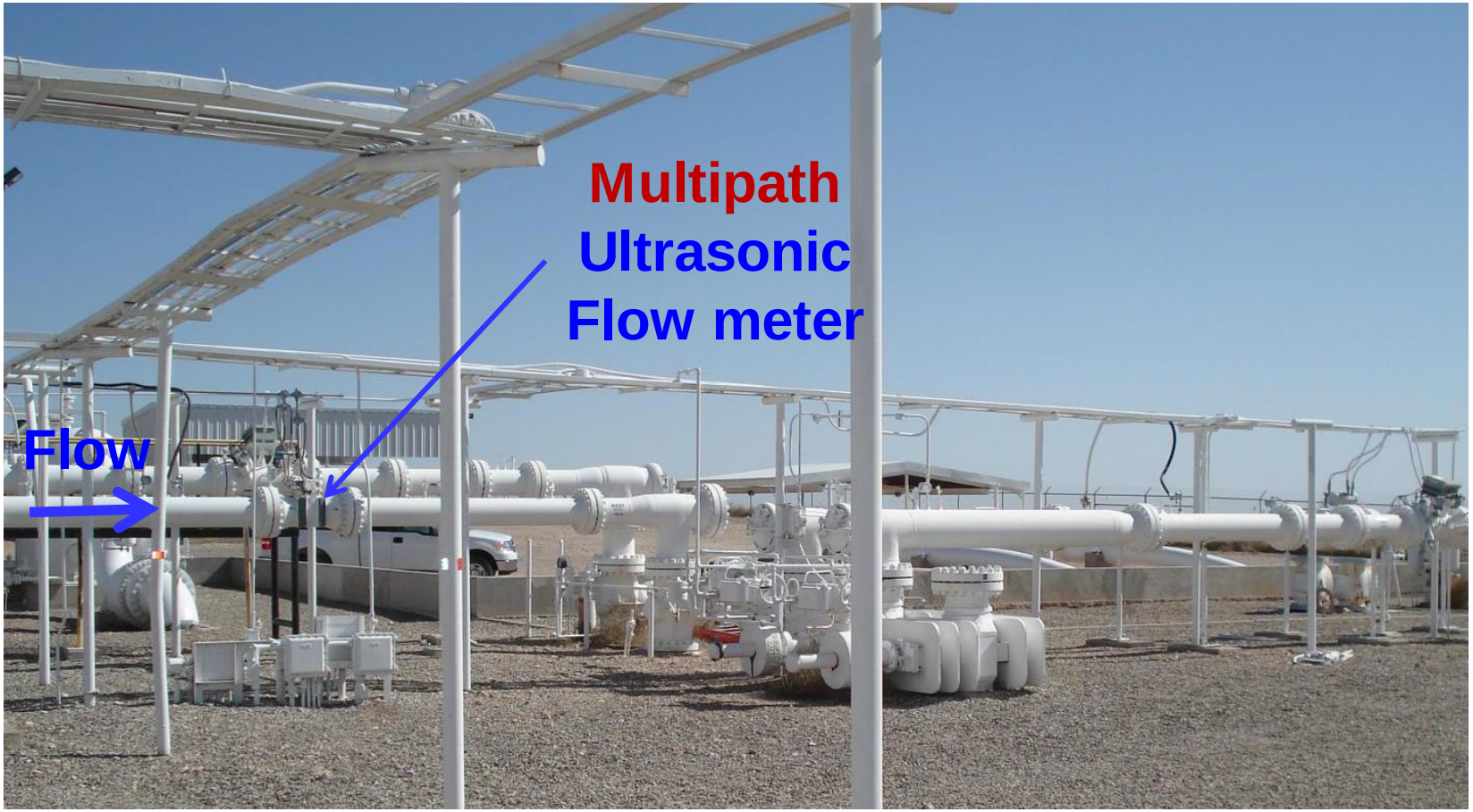
USM Velocity

Usually measured by a single, diametric path

Application:

Custody Transfer of Pipeline Scale Natural Gas

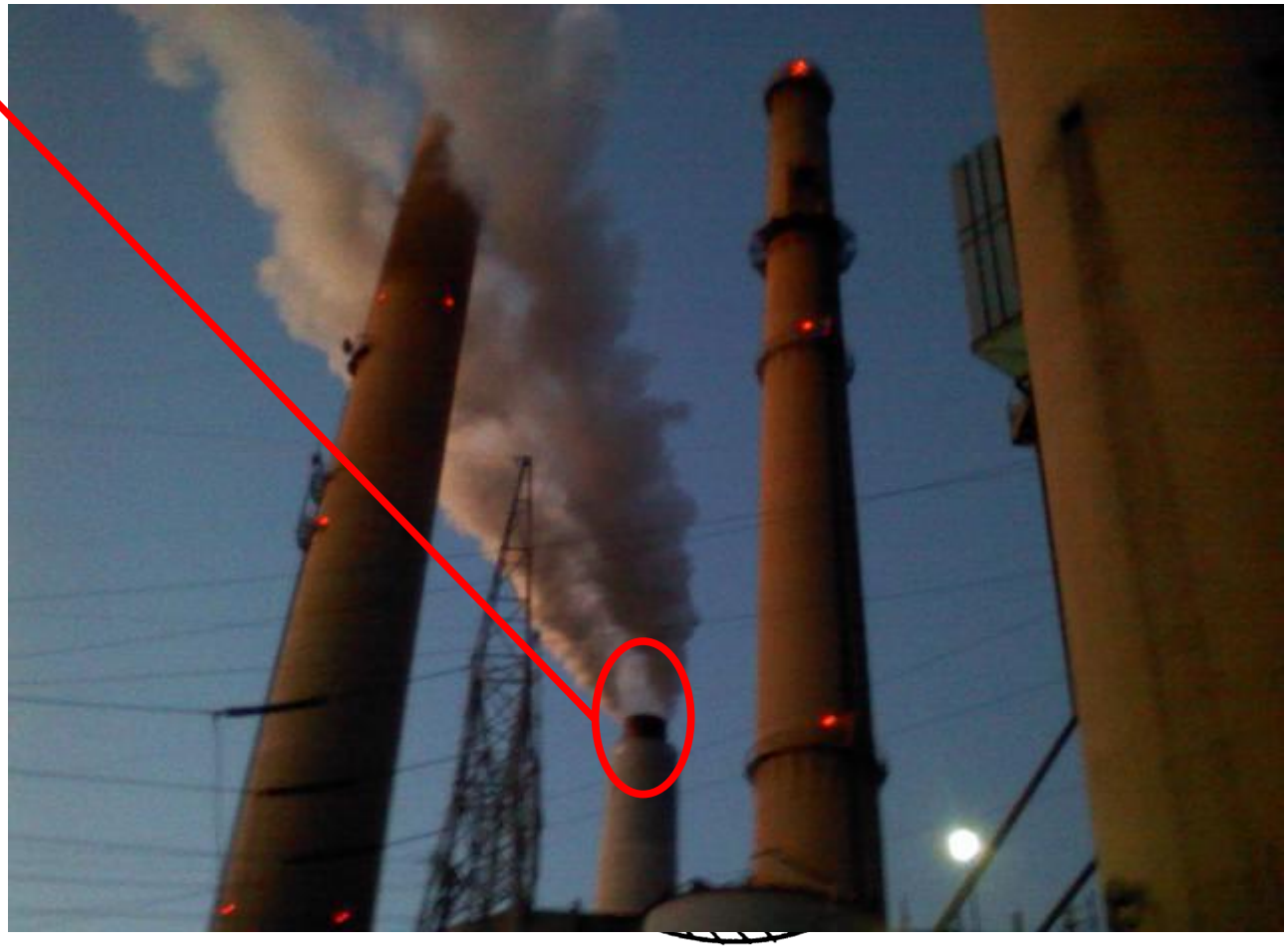
Natural Gas Meter Station in Roswell New Mexico



Measurement Performance Typically < 0.3 %

Flow is Complicated

Real stacks have swirl and turbulence



NIST's Scale-Model Smokestack Simulator (SMSS)

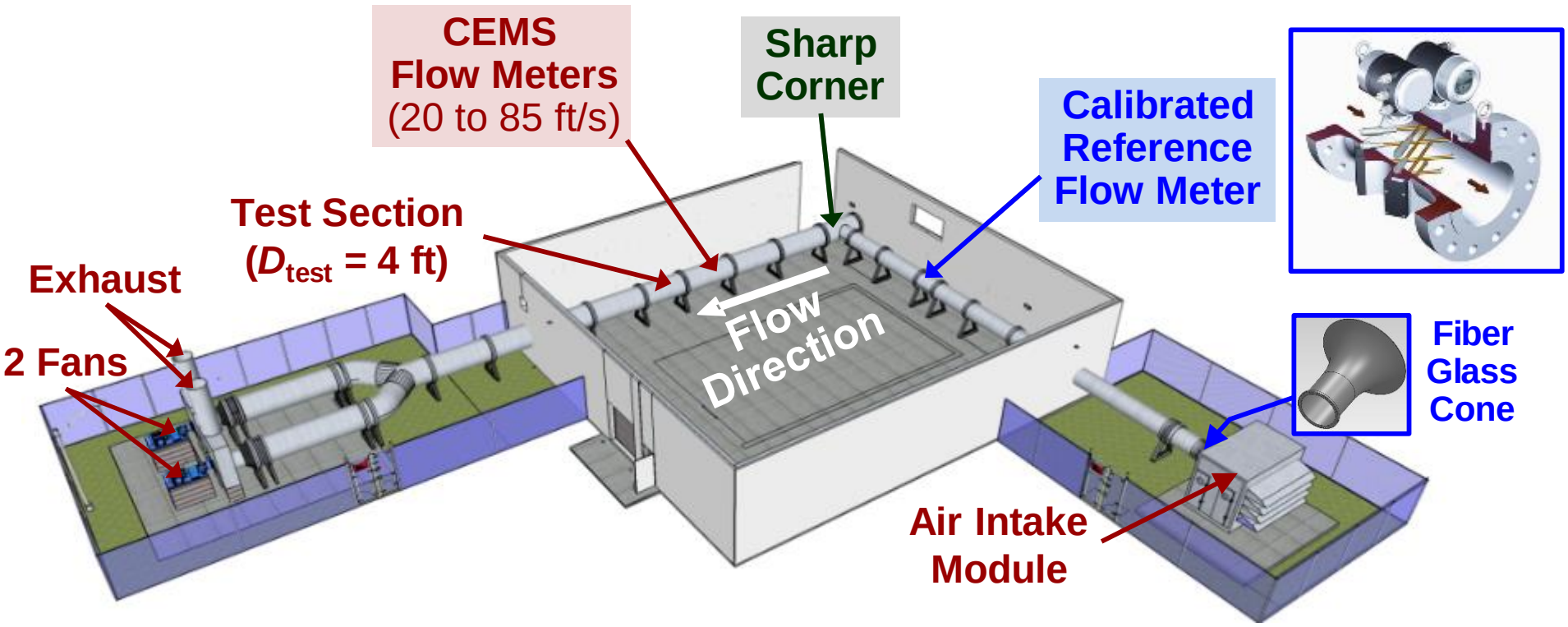
Unique Capabilities

1) Generates complex smokestack-like flows in a 4 ft test section.

2) Measures the bulk flow to better than 0.7% uncertainty using NIST traceable flow standard

Test Bed to Assess the Performance of CEMS Multipath Ultrasonic Flow Meters

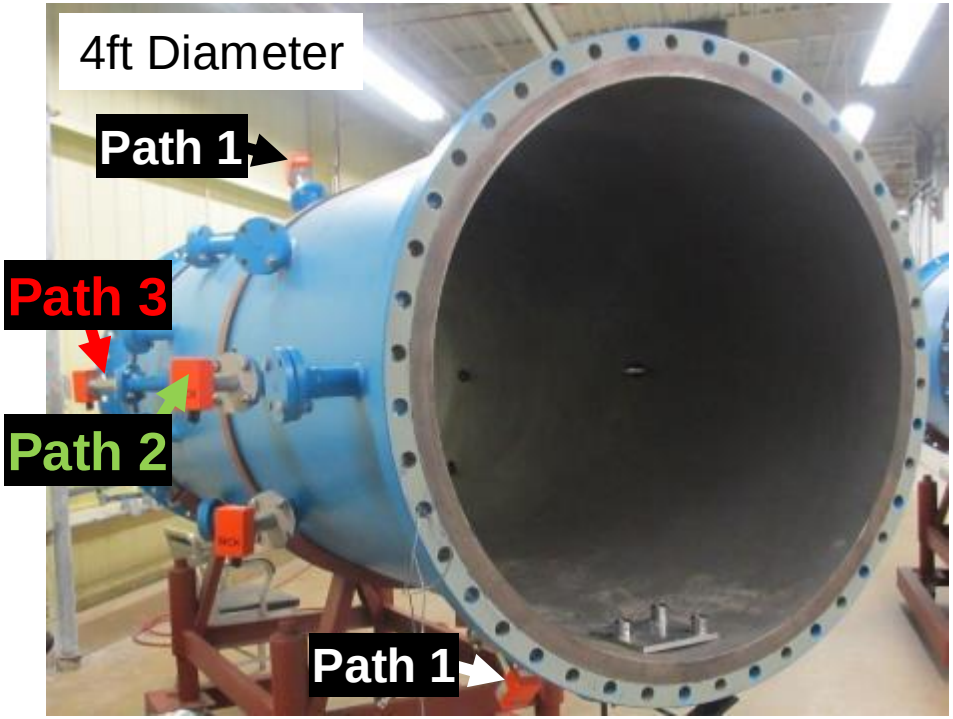
Scale-Model Smokestack Simulator (SMSS)

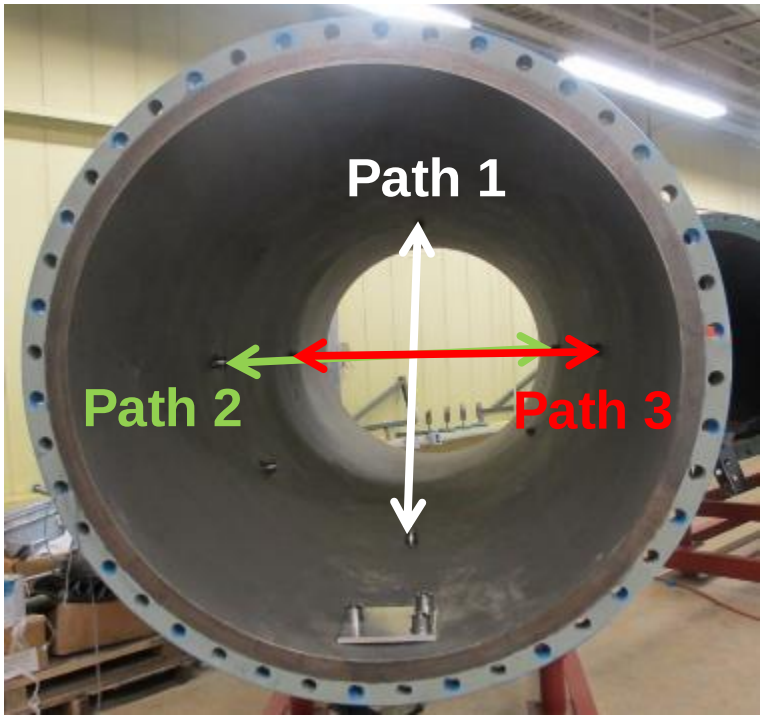


1) 8 path ultrasonic flow meter measures flow to better than 0.5 %
2) Stack flow conditions (high swirl and skewed velocity profile) realized by sharp corner section
3) CEMS Flow Monitor installed in SMSS Test Section
   - ❑ Single path ultrasonic flow monitors
   - ❑ X-pattern ultrasonic flow monitor

CEMS USM Installed in 4ft Test Section of SMSS

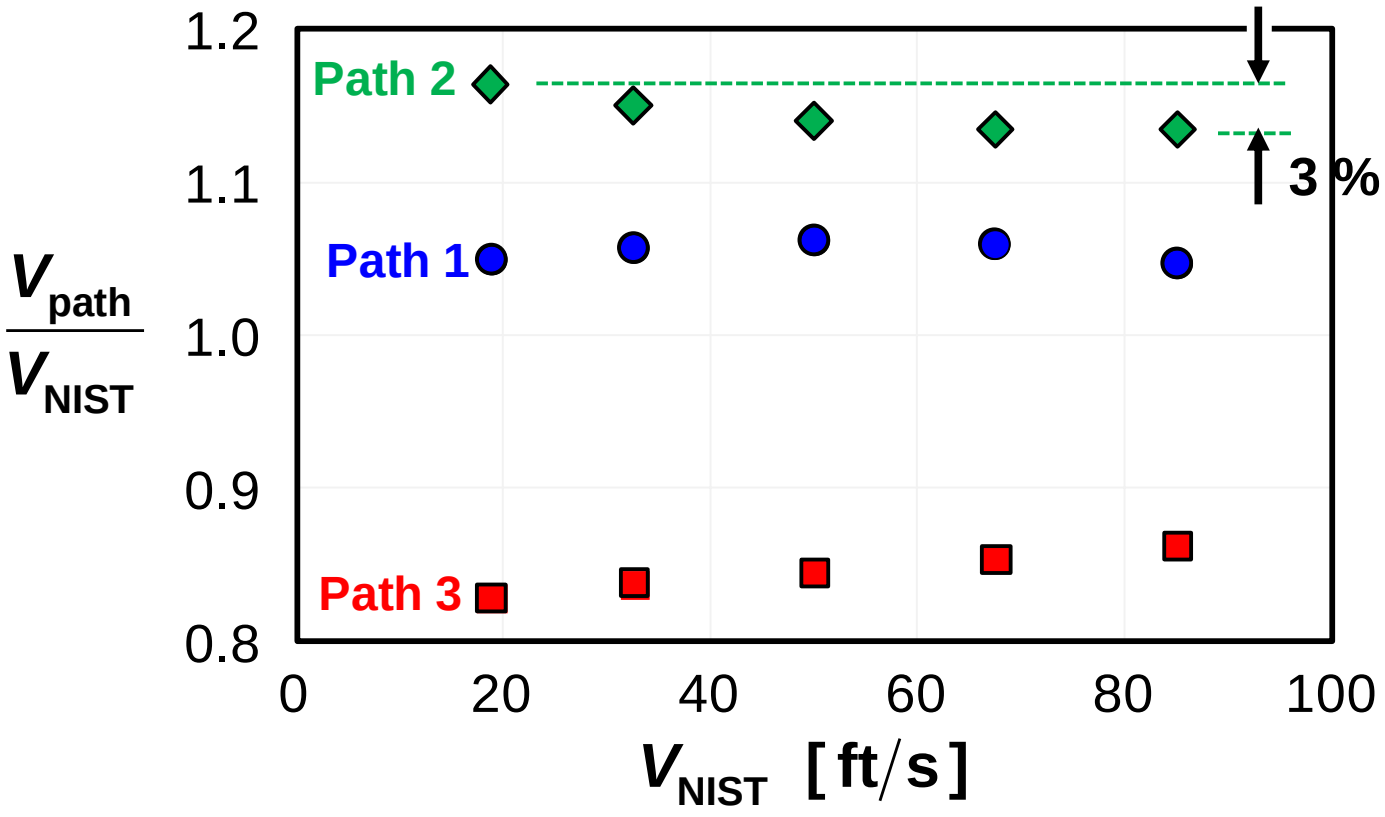
(Ultrasonic Flow Meter Path Layout)





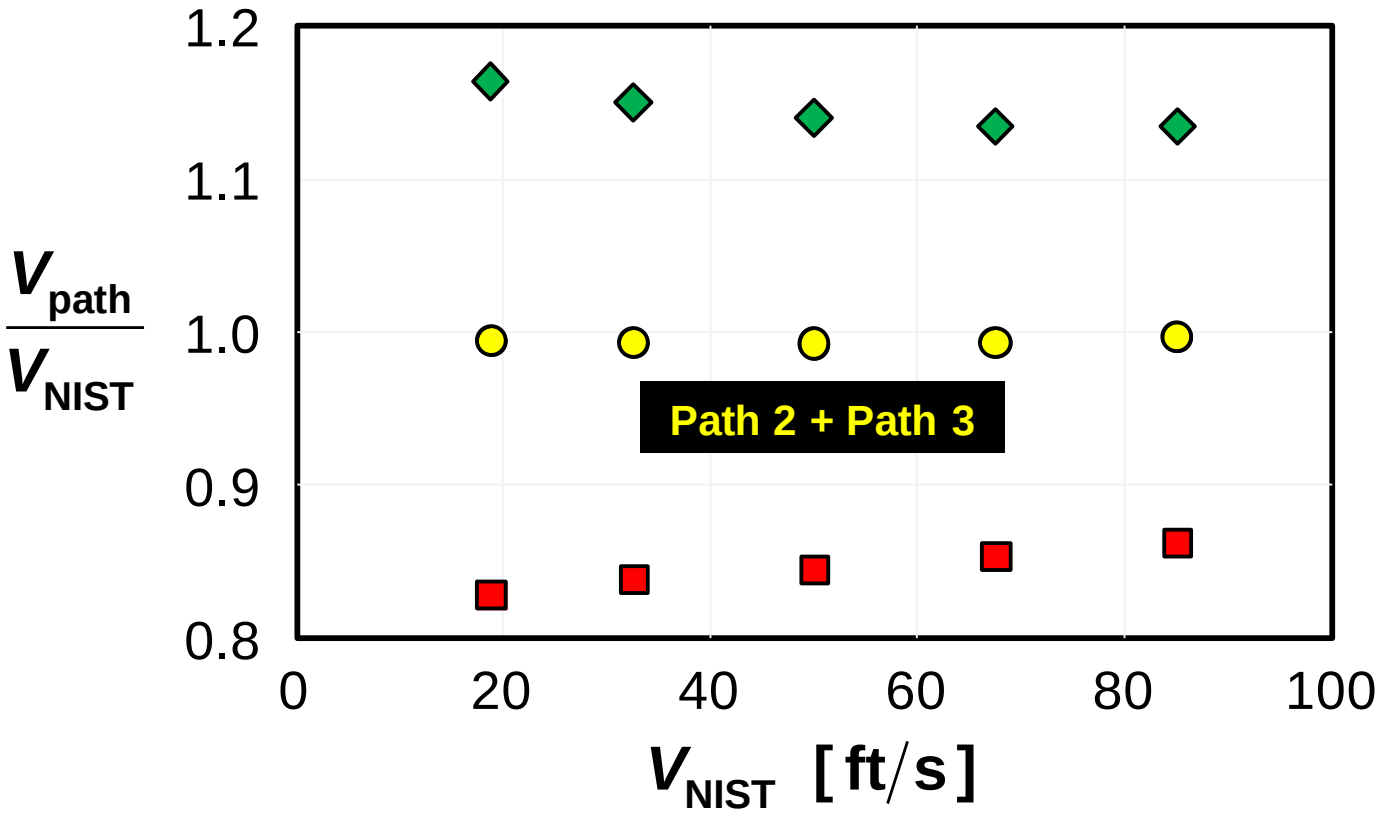
- USM pipe spool incorporates both single path and X-pattern designs
- Path 1 is vertically oriented at a 45° path angle with respect to pipe axis
- Paths 2 and 3 form a *X-pattern configuration* (*i.e.*, crossing paths) and are oriented horizontally at a 45° angle with respect to pipe axis

Single Path Orientations



- Path orientation significantly affects measurement performance (absolute errors range from 5 % to 17 %)

The Advantage of X-pattern



- X-pattern ultrasonic flow meter compensated for swirl and had **errors of only 0.5 %** over entire flow range
- More immune to changes in flow pattern

Complex Flow Caused by Sharp Corner

CEMS Flow Meters (20 to 85 ft/s)

1 **Sharp Corner**

Test Section (D_{test} = 4 ft)

Flow Direction

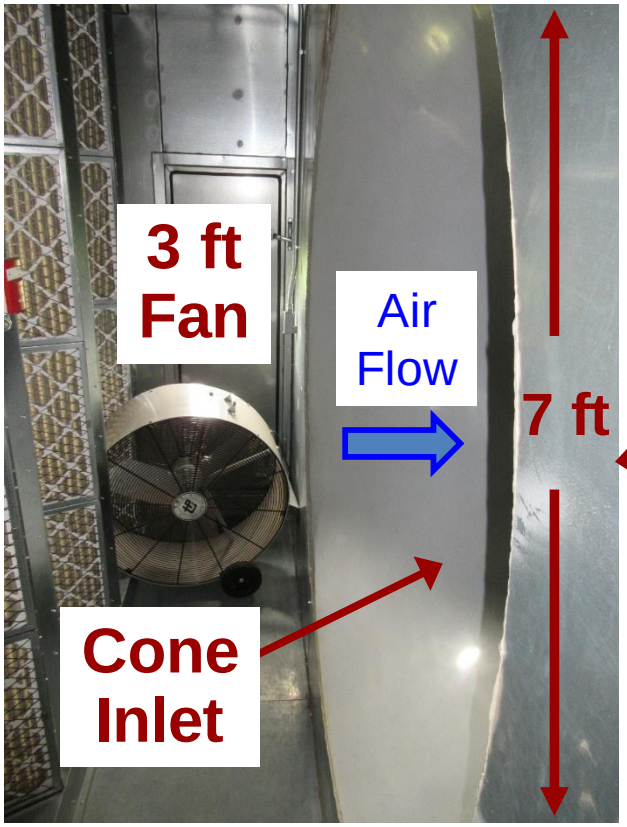
2 **Introduced Cross Flow at Inlet**

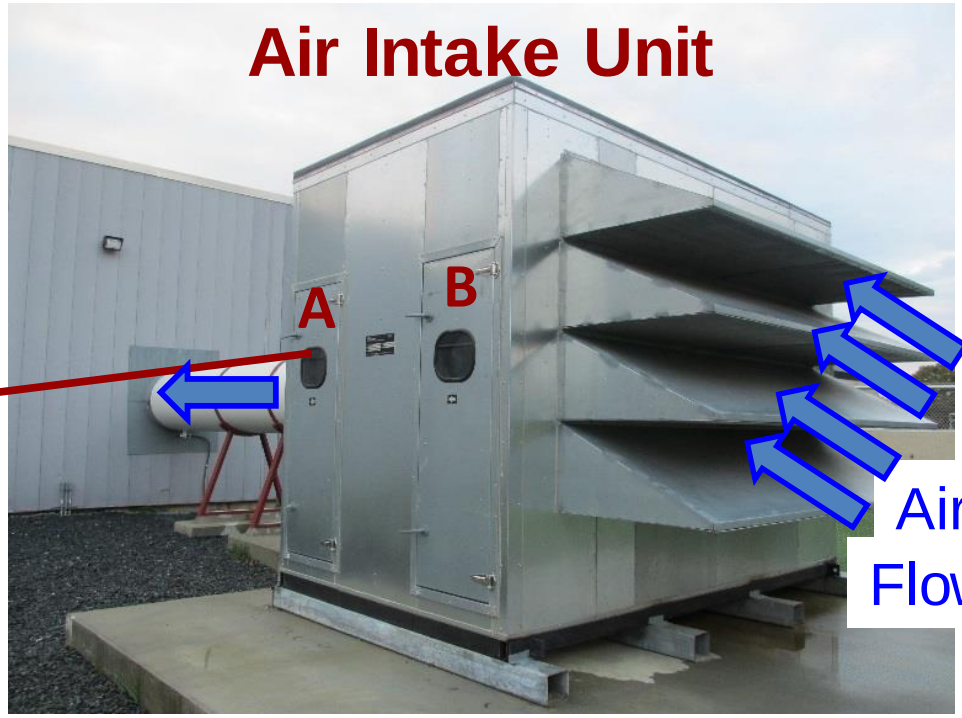
1) **Flow complexity caused by the sharp corner** upstream of test section (*i.e.*, complexity due to flow installation effect)

2) **Flow complexities** due to installation effects **vary from stack to stack**

3) Do the results hold up for different flow complexities?

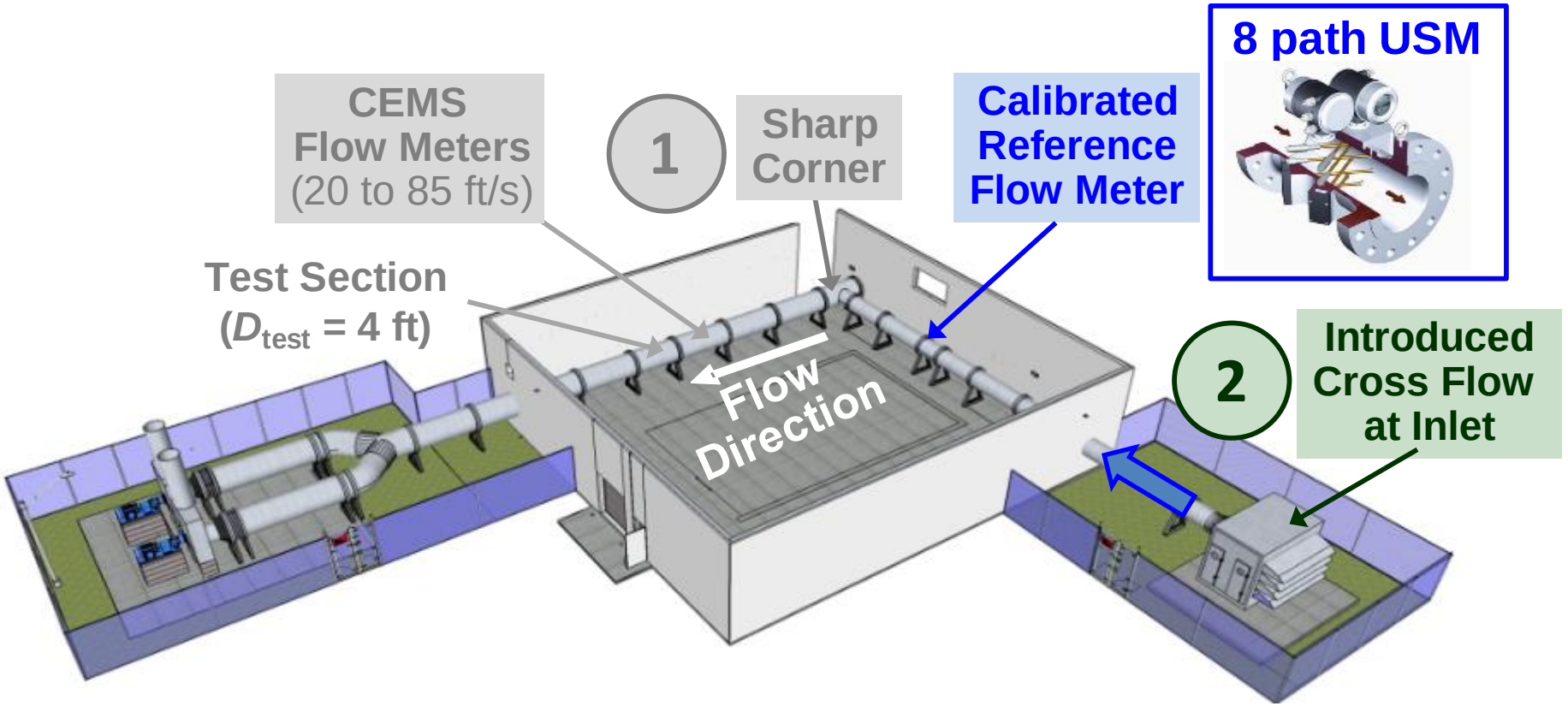
Cross Flow Introduced at Inlet





- 3ft diameter fan installed in air intake unit
- Air inlet velocity into cone without 3ft fan is approximately 3 m/s
- Cross flow velocity attributed to 3 ft fan is 5.5 m/s

Complex Flow Caused by Sharp Corner



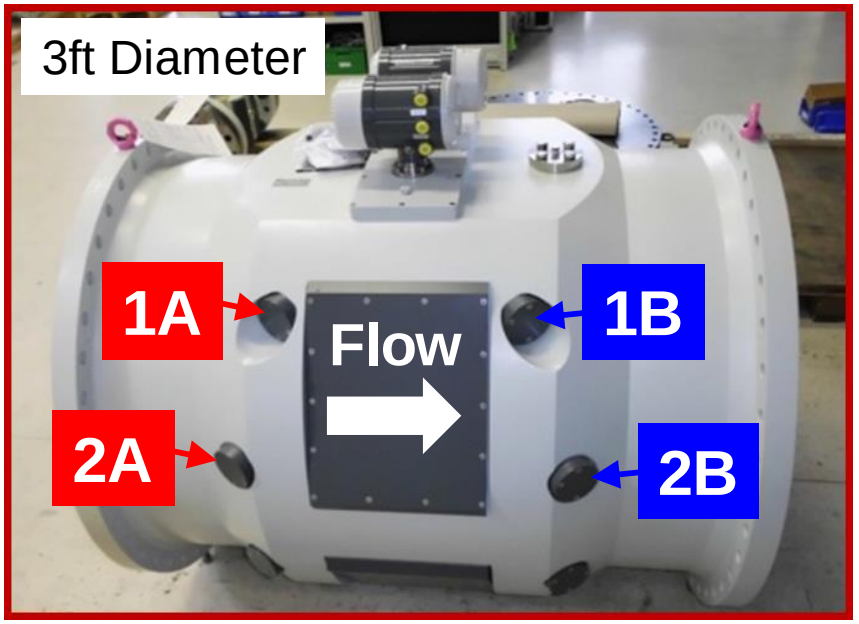
1) CEMS flow meter and ***Calibrated Reference Flow Meter*** (i.e., an 8 path USM) are subjected to the cross flow

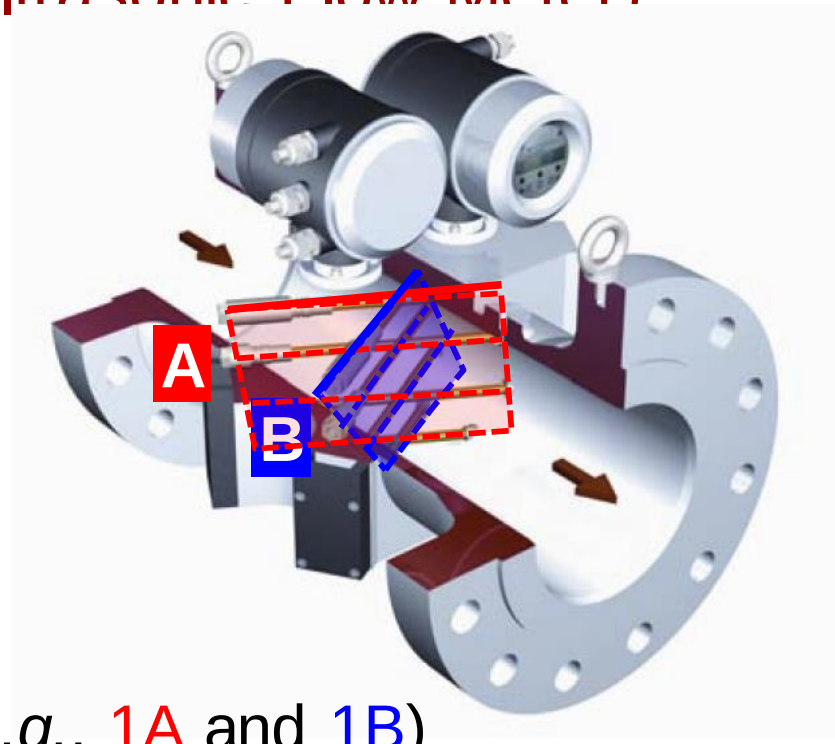
2) The 8 path ultrasonic flow meter (USM) by virtue of its design is largely immune to installation effects

3) Must verify the accuracy of 8 path before assessing CEMS

8 Path REF USM

(8 Path Reference Section Ultrasonic Flow Meter)

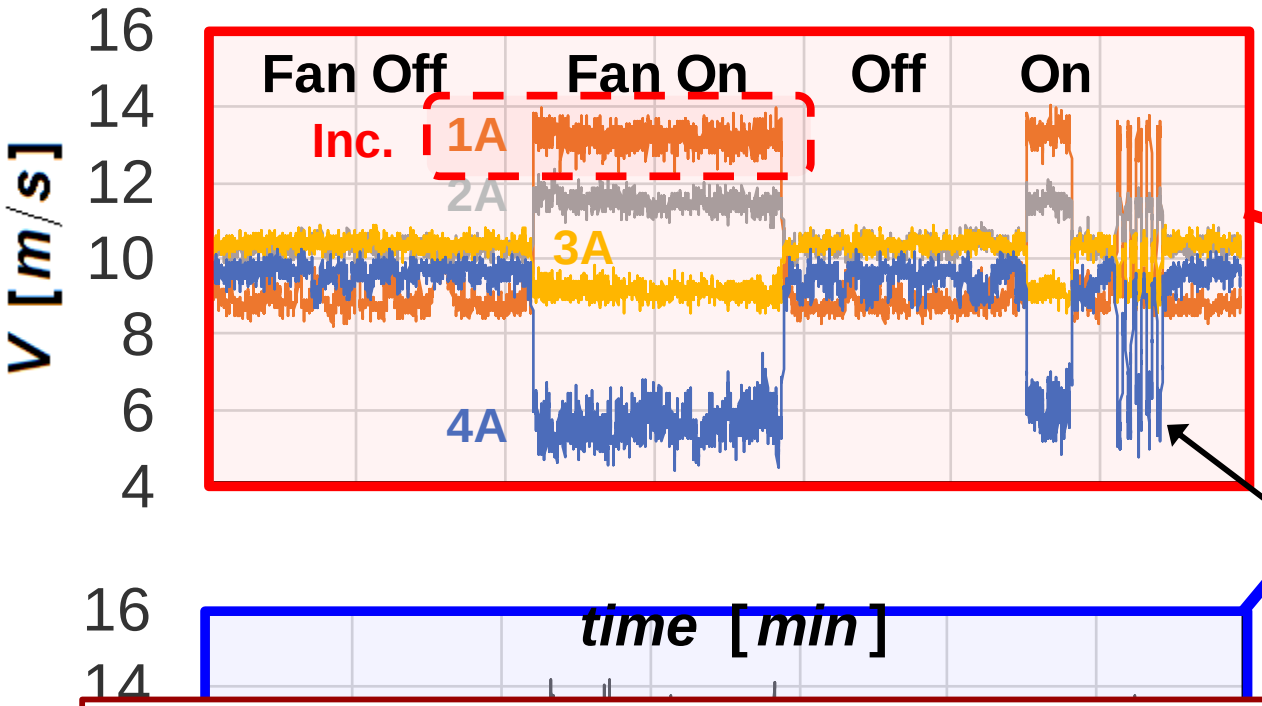


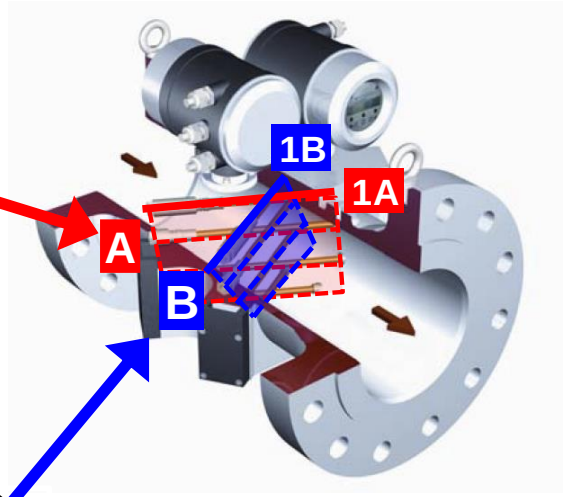


- Cross paths compensate for swirl (*e.g.*, 1A and 1B)
- Paths in same plane compensate for velocity profile effects (*e.g.*, 1A, 2A, 3A, 4A)
- Diagnostics of Multipath USM
  - Speed of sound
  - Average temperature
  - Estimate of turbulence intensity

8 Path Reference Section USM

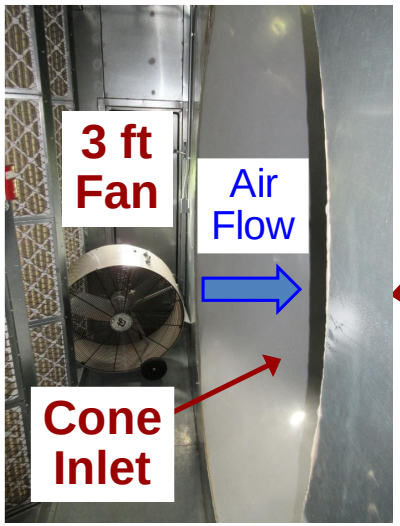
(Sensitivity to Cross Flow)

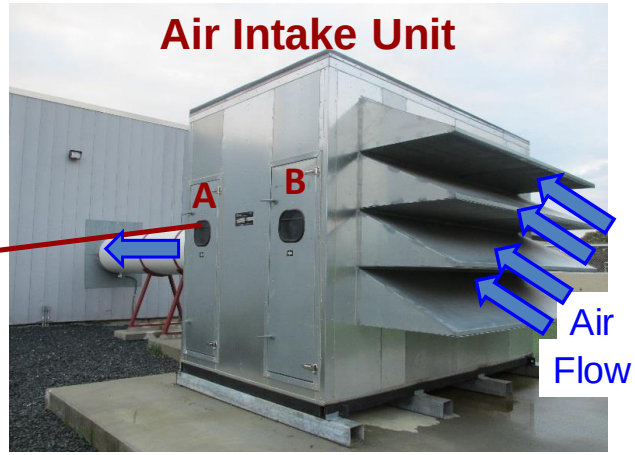




Cycled fan on/off at 20 sec intervals

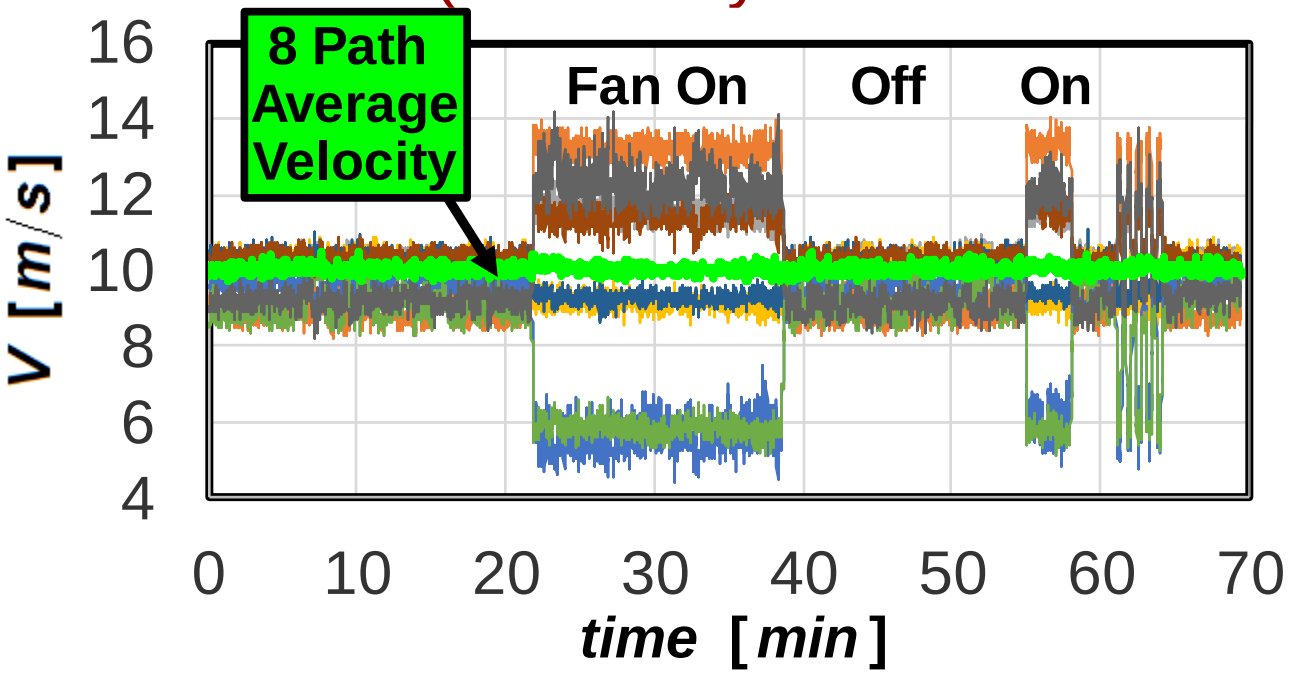
Cross flow Introduced by Fan at Inlet

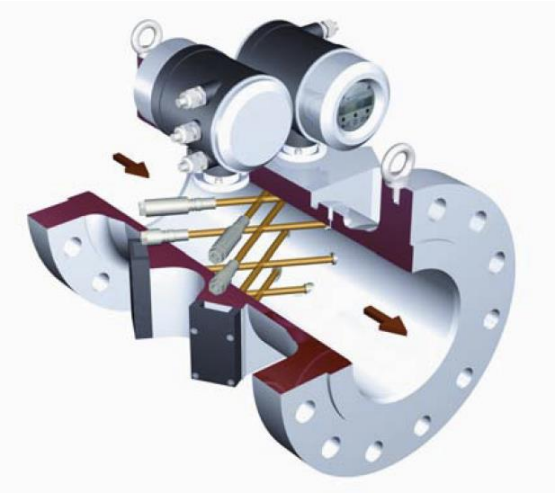




8 Path Reference Section USM

(Sensitivity to Distorted Velocity)





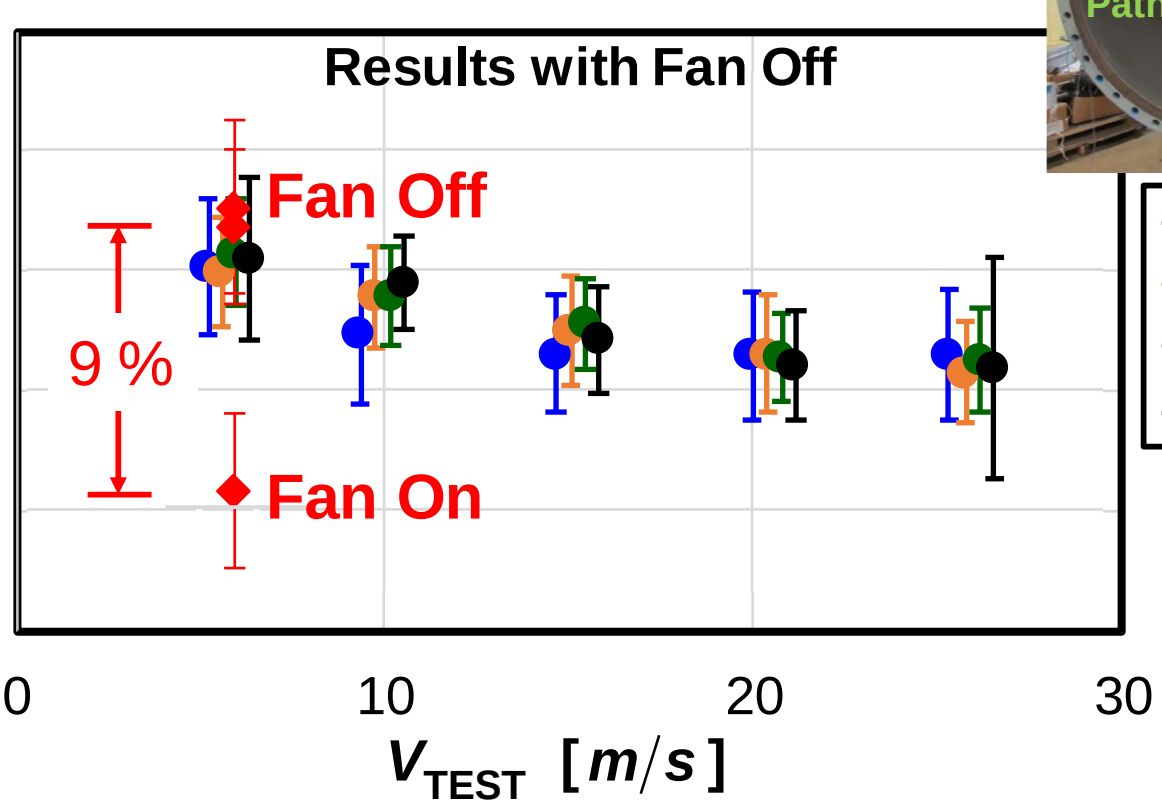
- **Average flow velocity of 8 path USM remains constant** to within 1 % flow stability of the SMSS facility
- Demonstrates the 8 Path compensates for cross flow (i.e., swirl) and profile effects

What is the effect of cross flow on the CEMS USM installed in the test section? Single path? Cross Path (or X-pattern)?

Test Section

(CEMS USM Path 2 Calibration Factor)

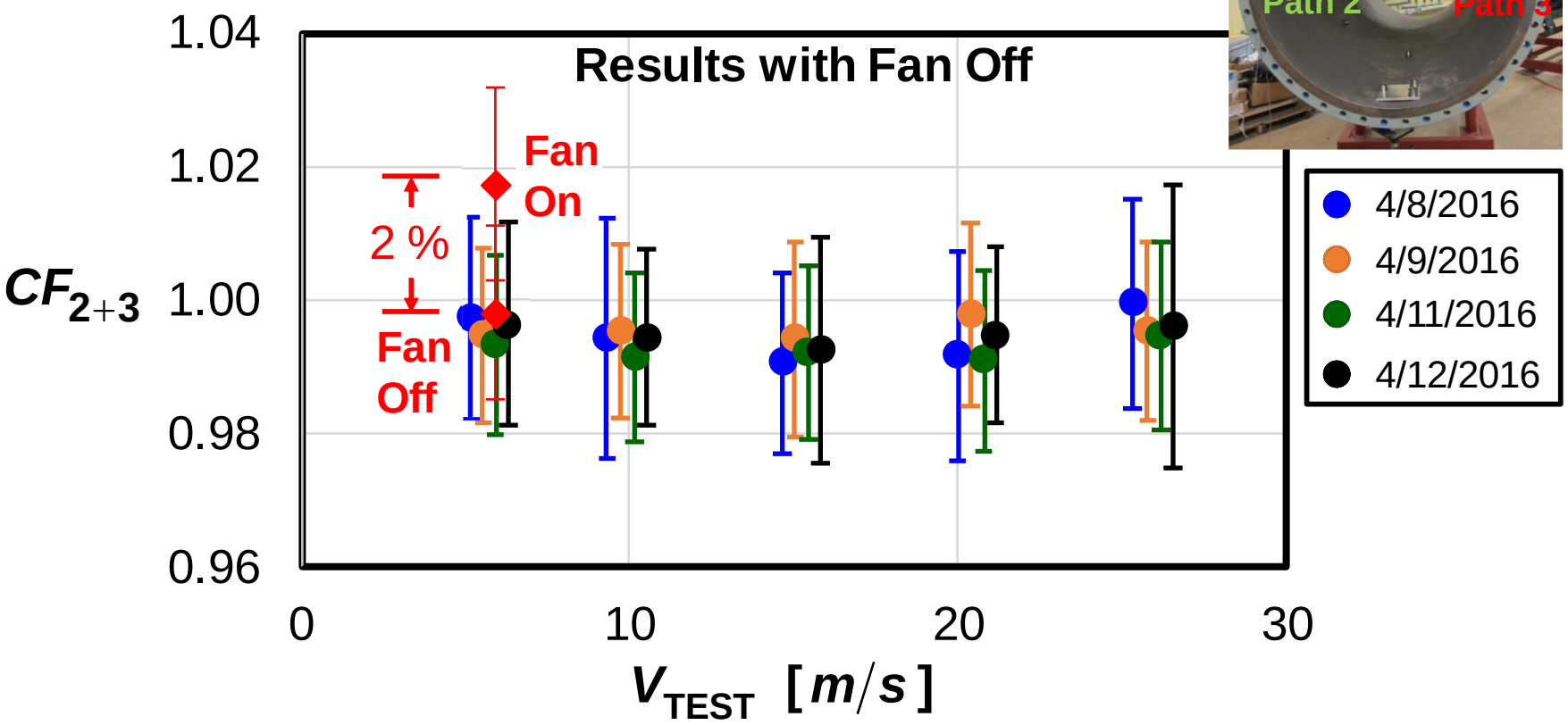
$$CF_2 = \frac{V_{path2}}{V_{TEST}}$$



9 percent shift in calibration factor attributed to fan generated cross in air intake unit

Test Section

(CEMS USM Paths 2 & 3 Calibration Factor)



Crossing paths reduce shift attributed to fan generated cross in air intake unit **from 9 % to 2 %**

Summary of Ultrasonic CEMS Flow Monitor

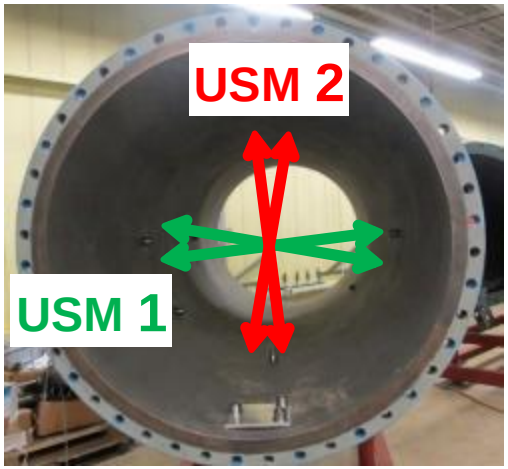
- **Single path CEMS**
  - ❖ Absolute errors ranged from 5 % to 17 %
  - ❖ Single path performance depends on installation angle
  - ❖ Subject to load dependent calibration factor (3 %)
  - ❖ Not immune to changes in upstream flow field (changed by 9 % due to fan cross flow)

- **X-Pattern CEMS**
  - ❖ accuracy of 0.5 % in SMSS facility
  - ❖ Calibration factor independent of load
  - ❖ immune to changes in upstream flow field relative to single path (changed by 2 % due to fan cross flow)

Desired RATA Field Test
(NIST wish List)

- **Assess NIST calibrated 3D probe in Real Stack**
  - Compare Method 2F vs. NIST non-nulling Method
  - Repeat traverse with same probe to determine typical reproducibility errors at constant load
  - Repeat traverse with different 3D probe to assess probe specific uncertainties
  - Measure Stack Turbulence Level

- **Ideally, testing would be done at the same time with 2 X-pattern ultrasonic flow meters 90° apart**



- **Field test would occur at a power plant with natural gas fuel**

Questions?