Natural Gas Flow Meters - Why Calibrate? (...and how to)

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(In operation since 1991)

Why flow calibrate your meter?

- You sus
- Your ur mete
- The eter requ
- Your pute.
- You for gas meter.
- You ssible.
- It's c ce.

What can bias errors in an ultrasonic flow meter cost?

- AGA Report No. 9 maximum error = ±0.7% (for dia. ≥ 12”)
- Assume transmission grade gas at 850 psi flows through an ultrasonic meter at 50 ft/sec.
- Value of a 0.25% bias error corrected via flow calibration (for $4/mscf gas):

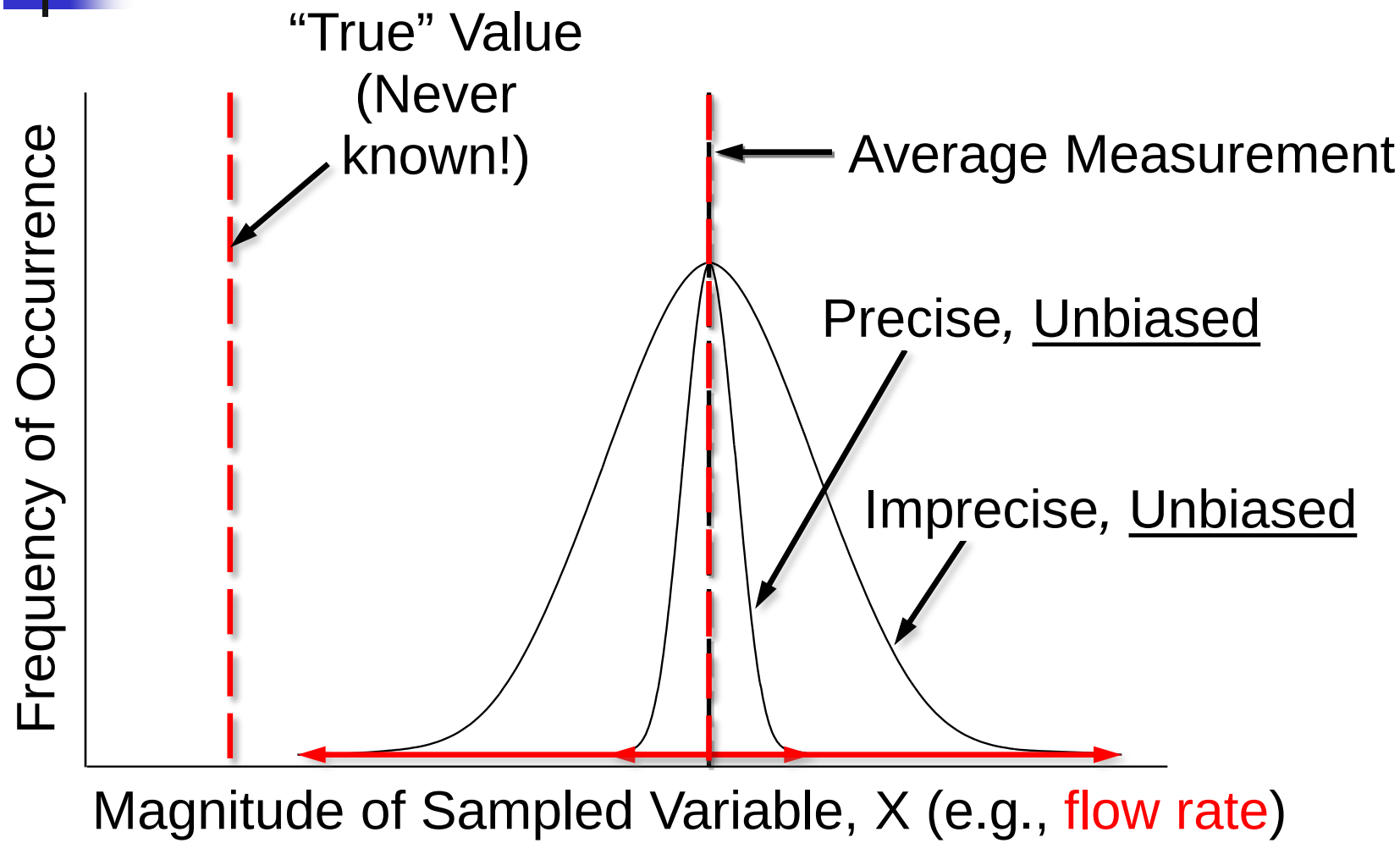
Diameter (inches)	Annual Value
8	$ 320,000
12	$ 716,000
16	$ 1,273,000
20	$ 1,989,000
24	$ 2,864,000

Calibration cost for a 12-inch meter recouped in less than a week’s time!

Let's begin with some terminology…

- Accuracy (a.k.a., error) - A qualitative concept of the closeness in agreement of a measured value and an accepted "reference" or "true" value.
- Repeatability (a.k.a., precision) - The variation in measurements taken by a single person or instrument on the same item (e.g., flow meter) and under the same conditions over a short period of time.
- Reproducibility - The variation in measurements that occurs when any of the repeatability conditions have changed (e.g., person, instrument, time, etc.).

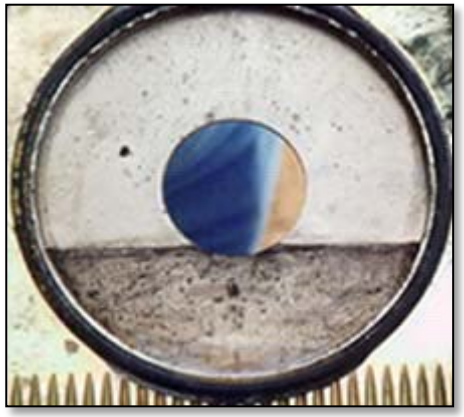
Measurement Uncertainty
(a.k.a., the upper limit of the measurement error)



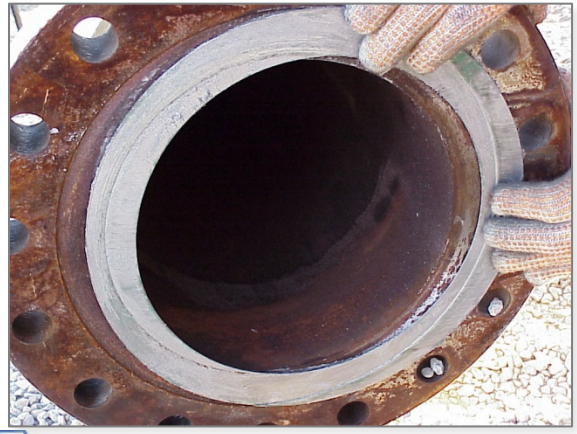
("Normal" or "Gaussian" Distribution)

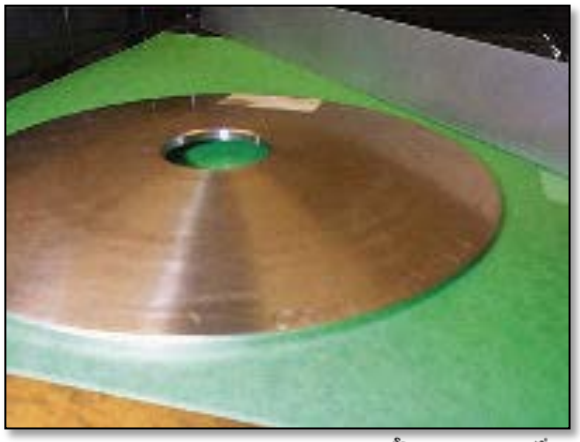
What can cause metering errors?

Adverse Operational Effects

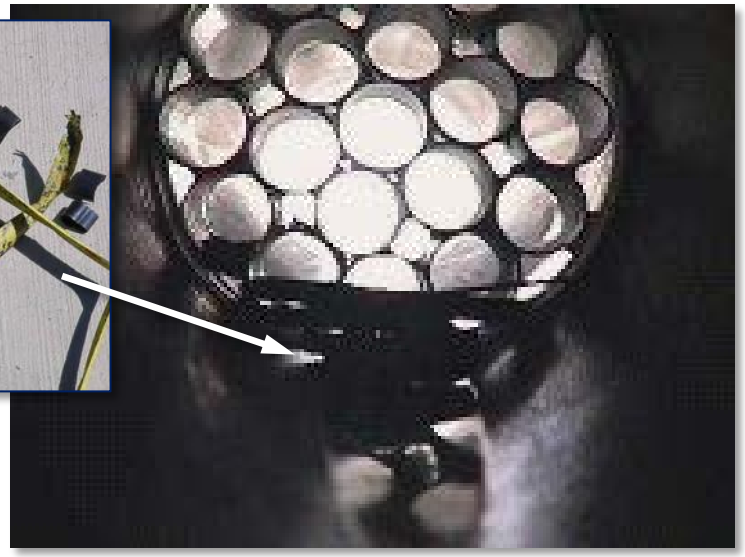








More Operational Effects...



Reported Orifice Meter Measurement Error Sources

Operational Characteristic	Approximate Flow Rate Error (% of reading)
Orifice plate surface roughness	Up to -0.7%
Notches/grooves on orifice edge	-0.6% to +1.0%
Plate thickness and bevel angle	-3.7% to +0.4%
Plate installed backwards	Up to -20%
Liquid film on plate	Up to ±1.5%
Liquid film on meter tube	Up to +1%
Grease on surface of plate	Up to -13%
Bent/warped plate	Over-measurement <+0.5%, if deflection angle < 1° Under-measurement beyond -1.5% for larger deflection
Orifice eccentricity	Within ±0.1%, if maintained at allowable limits
Swirl effects	Up to +5.2%, depending on swirl type
Location of downstream thermowells	< ±0.28% for TWs as close as 1.63 pipe diameters
High differential pressures (ΔP > 100 in. H_20)	< ±0.1%, if allowable limits are followed
Low differential pressures (ΔP < 10 in. H_20)	Can exceed ±4%, if ΔP <20" H_2O column
Pulsation effects (SRE always over-registers)	Can exceed ±0.5%, if $\Delta P_{r\ avg}$ > 0.25 psi
Acoustic noise	Can exceed ±0.23%, if pulsations >155 dBA

Over-registration | Under-registration | Over- or Under-registration

The upstream piping geometry can "distort" the flow in the pipe...

- Changes in direction or pipe bends
  - Elbows
  - Ys, tees, headers, etc.
- Blockages/obstructions
  - Valves
  - Pressure regulators
  - Filters/separators
  - Orifice plates
  - Flow conditioners

Meter Sensitivity to Flow Field Distortion

- Flow meters sensitive to flow field distortions...
  - Orifice
  - Ultrasonic
  - Straight tube (radial mode) Coriolis
  - Pitot-probe type
  - Turbine (sometimes)
- Flow meters <u>not</u> sensitive to flow field distortions...
  - Positive displacement (e.g., rotary & diaphragm)
  - Bent tube Coriolis
  - Turbine (sometimes)

Flow Meter Calibration Options

- Field (in-situ) proving
  - American Gas Association Report No. 6 "Field Proving of Gas Meters Using Transfer Methods," March 2013
    - Proving meters using critical flow devices
    - Proving field meters with "master" meters
- Flow lab calibration
  - "Open" system, i.e., side branch on a pipeline
  - Closed-loop (recirculating) system

Field Meter Proving…

In-situ Sonic Nozzle Meter Proving Field Test

(Example data provided by Dr. Frank Ting - Chevron)

- O
- O
- Fl
- P
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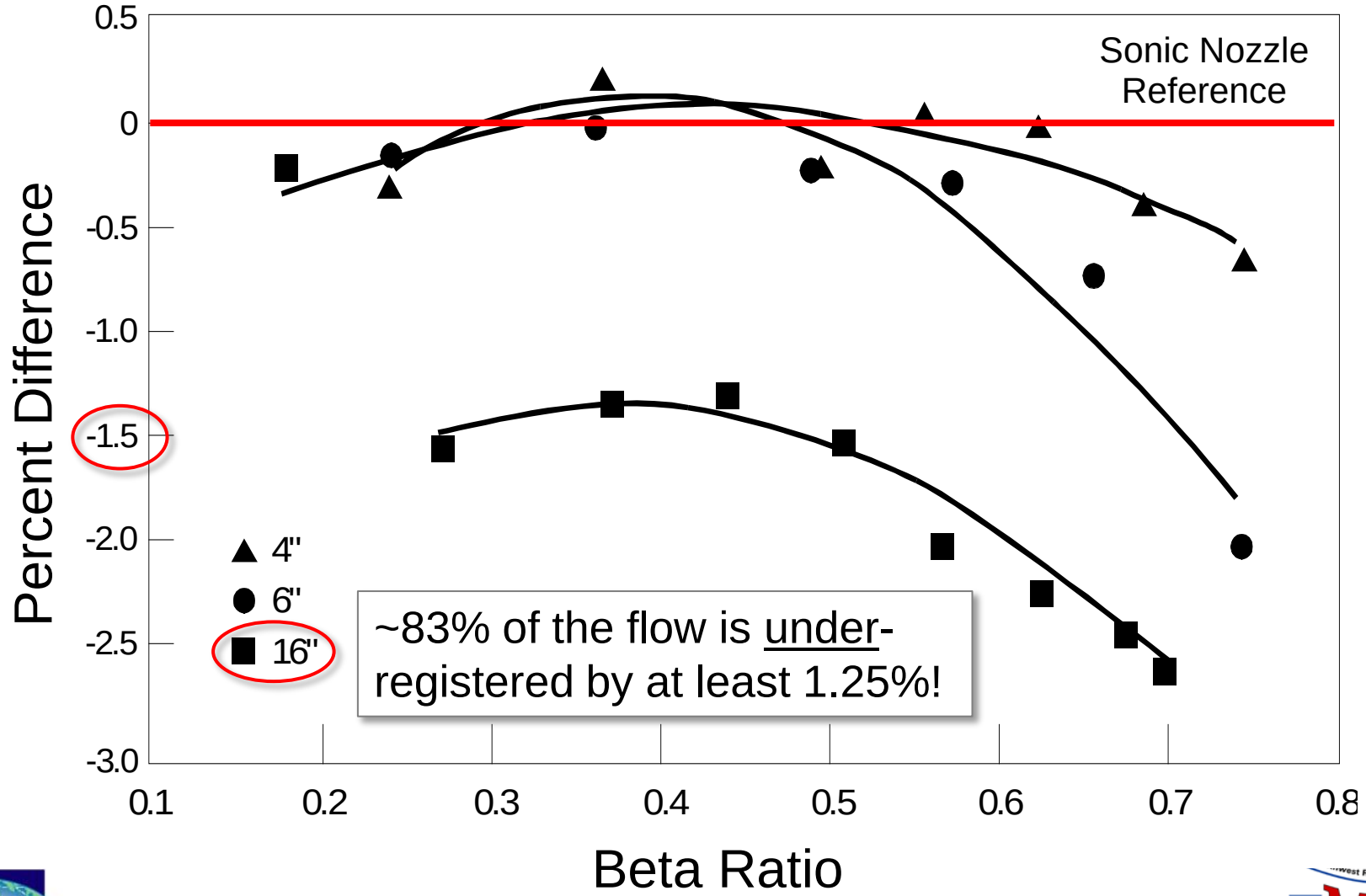
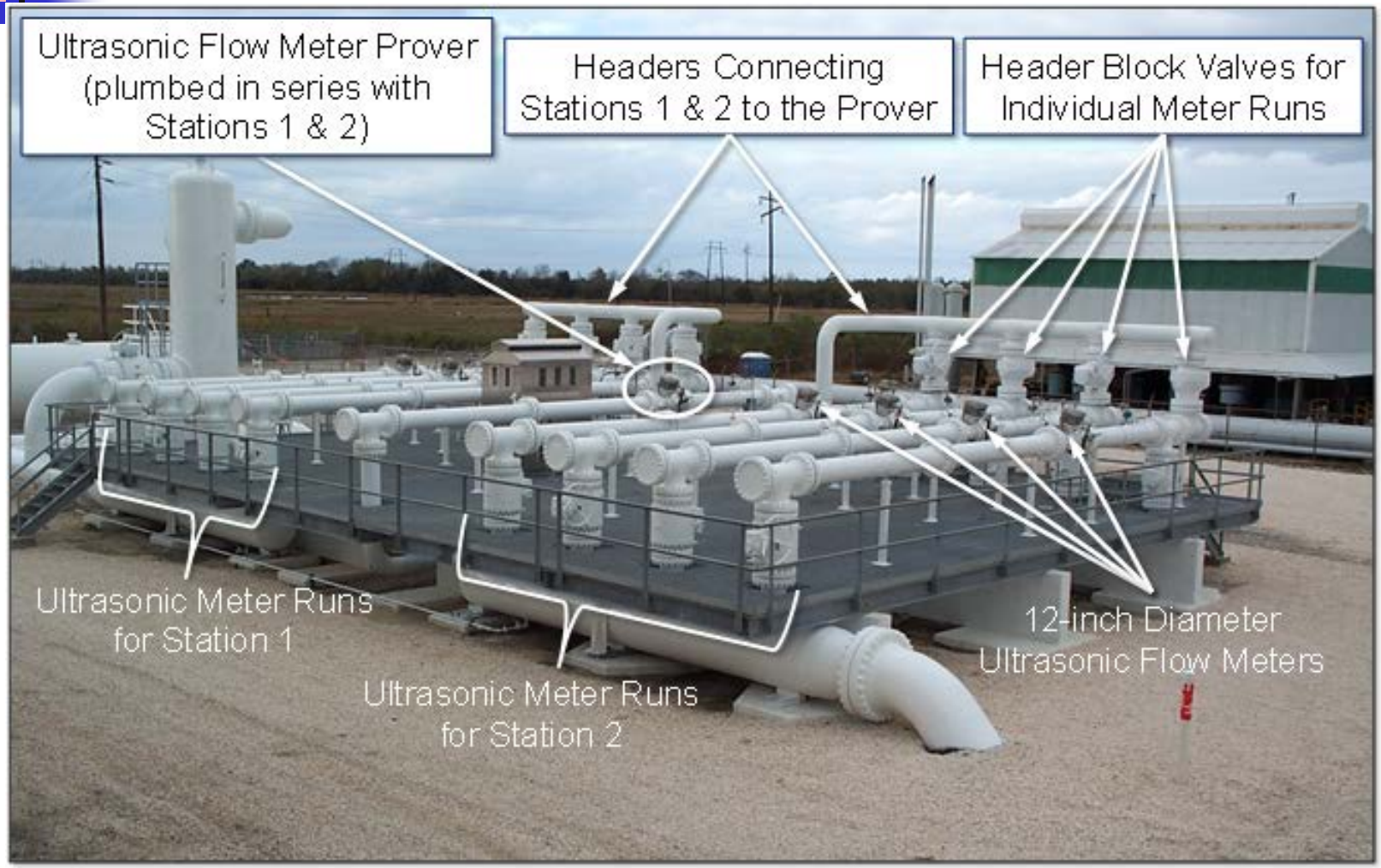
In-situ Sonic Nozzle Proving - Example Flow Performance



Field Meter Station with an Ultrasonic Flow Meter Plumbed in Series for Performing In-situ Meter Calibration Checks

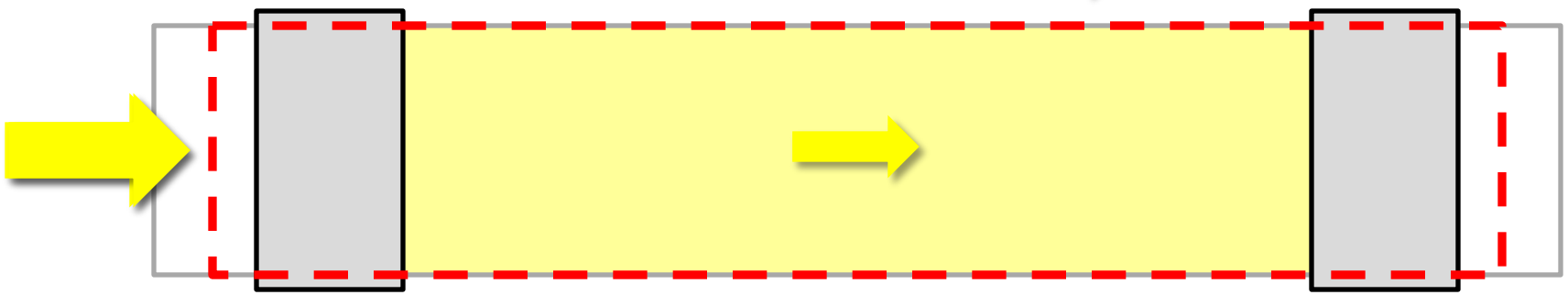


The Basis of All Flow Meter Calibrations

Conservation of **MASS** (simplified)

$$Q_m = (\rho A V)_1 = (\rho A V)_2$$

Flow Direction



Meter No. 1
(Field meter being checked @ P_1, T_1, ρ_1, A_1, & V_1)

Control Boundary

Steady Flow
(The desired test condition!)

Meter No. 2
(Prover @ P_2, T_2, ρ_2, A_2, & V_2)

Flow Meter Calibration Facilities

- Two basic types of calibration facilities...
  - Open design – uses existing pipeline flow (side branch).
  - Closed-loop – purpose-built flow meter calibration facility.
- Secondary measurement (lab “working” standard):
  - Turbine meter(s)
  - Sonic nozzle(s) (a.k.a., critical flow Venturi)
  - Rotary meter(s)
- Primary measurement
  - Sliding piston/swept volume
  - Pressure, (fixed) volume, temperature, time (PVTt) system
  - Weigh tank
- Inter-lab comparison testing provides information on equivalence of different lab facilities.

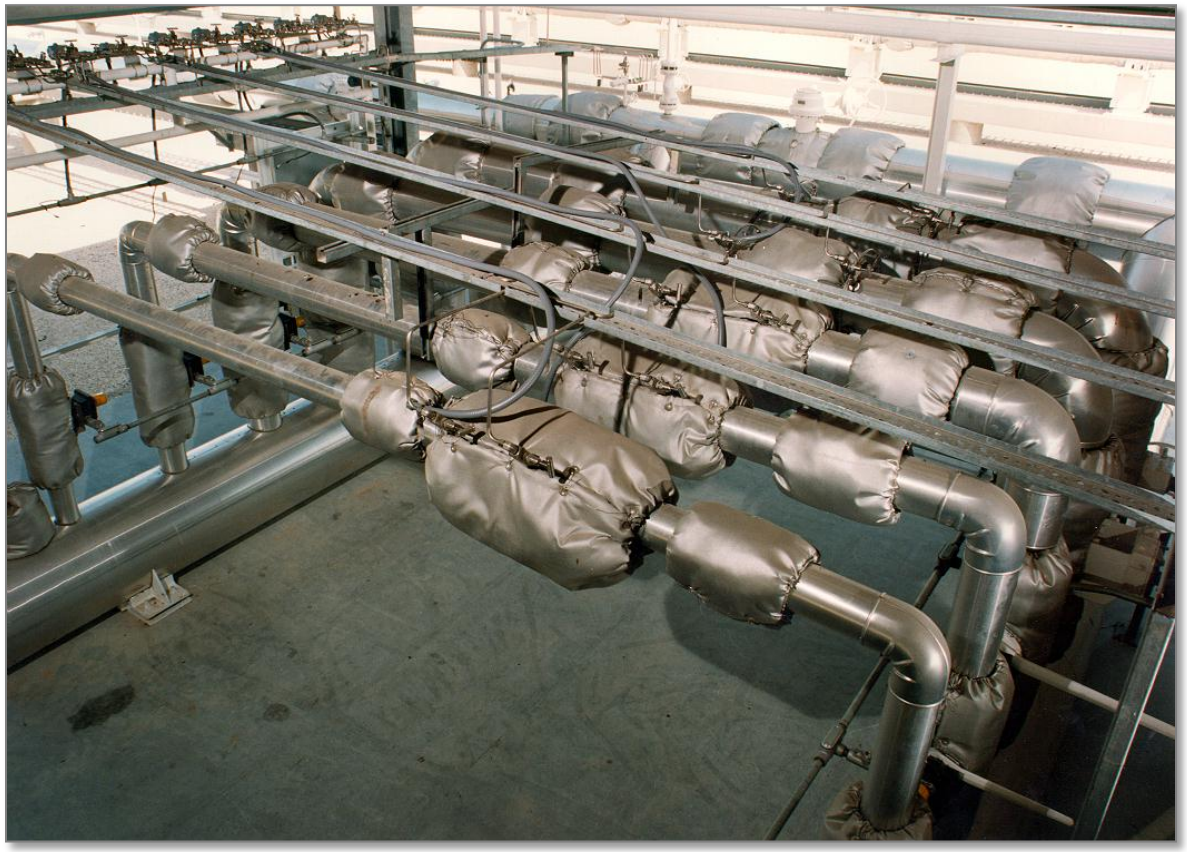
Primary Gas Calibration System Total Measurement Uncertainty

- Primary systems are those that determine flow rate from fundamental measurements of mass, length, & time.
- Lowest measurement uncertainty - typically in the range of ±0.02 to ±0.05% of reading.

MRF Weigh Tank

Secondary ("Working") Gas Calibration System Total Measurement Uncertainty

- Secondary systems are those calibrated using a primary system.
- Typically include empirical calibration coefficients.
- Measurement uncertainty is typically in the range of ±0.05 to ±0.15% of reading.



MRF Critical Flow Venturis
(i.e., sonic nozzles)

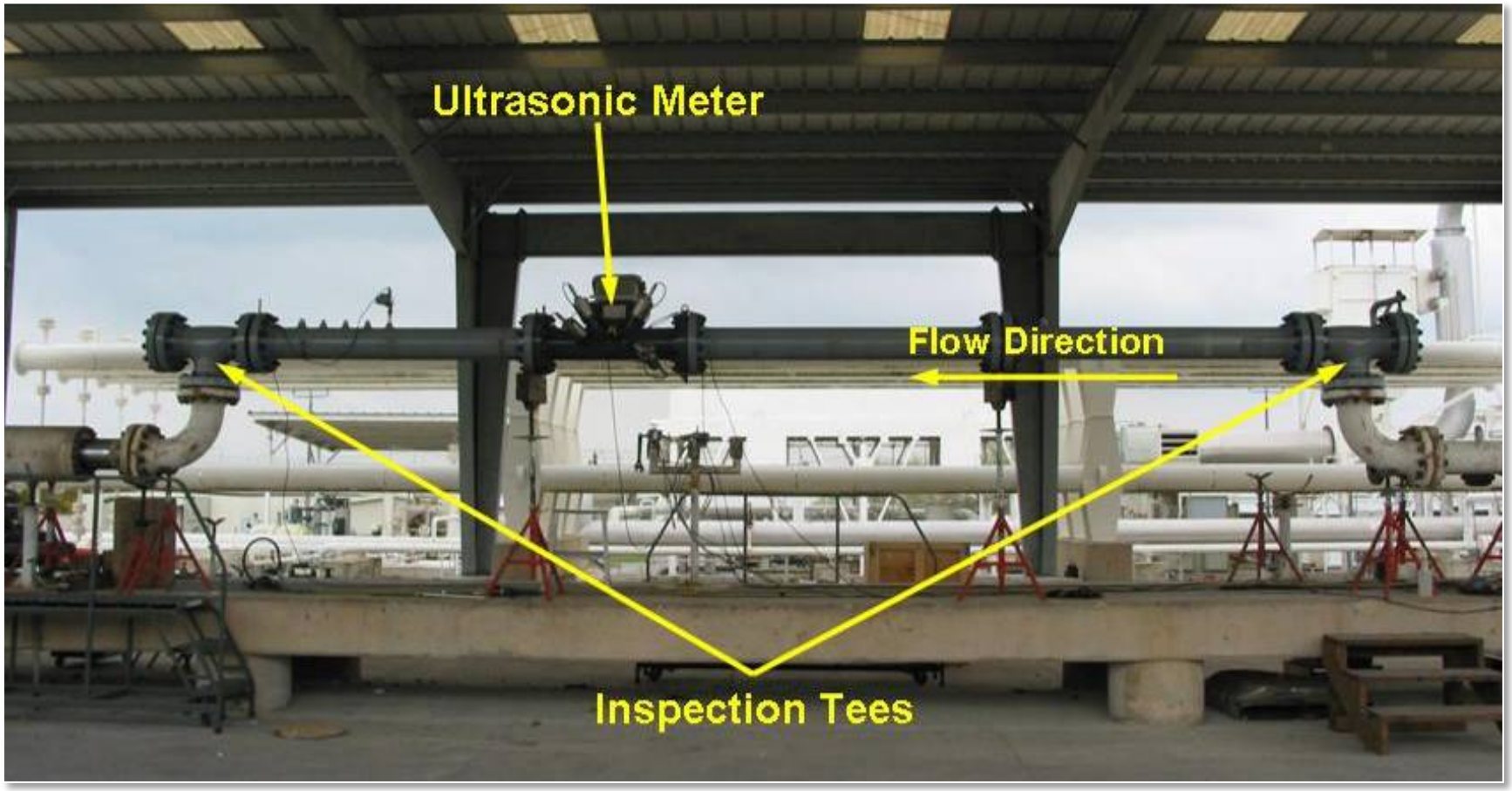
Meter Calibration Considerations

- Meter only vs. meter with upstream/downstream piping included.
- Digital vs. analog flow meter/lab interface.
- “As-found” testing allows assessment of potential measurement biases from meter/adjacent piping/flow conditioner fouling for meters removed from service.
- Scheduling: Lab backlog times vary (1-3 months is typical), so plan ahead as much as possible.
- Flow meter owner/operator/manufacturer test witnessing varies.

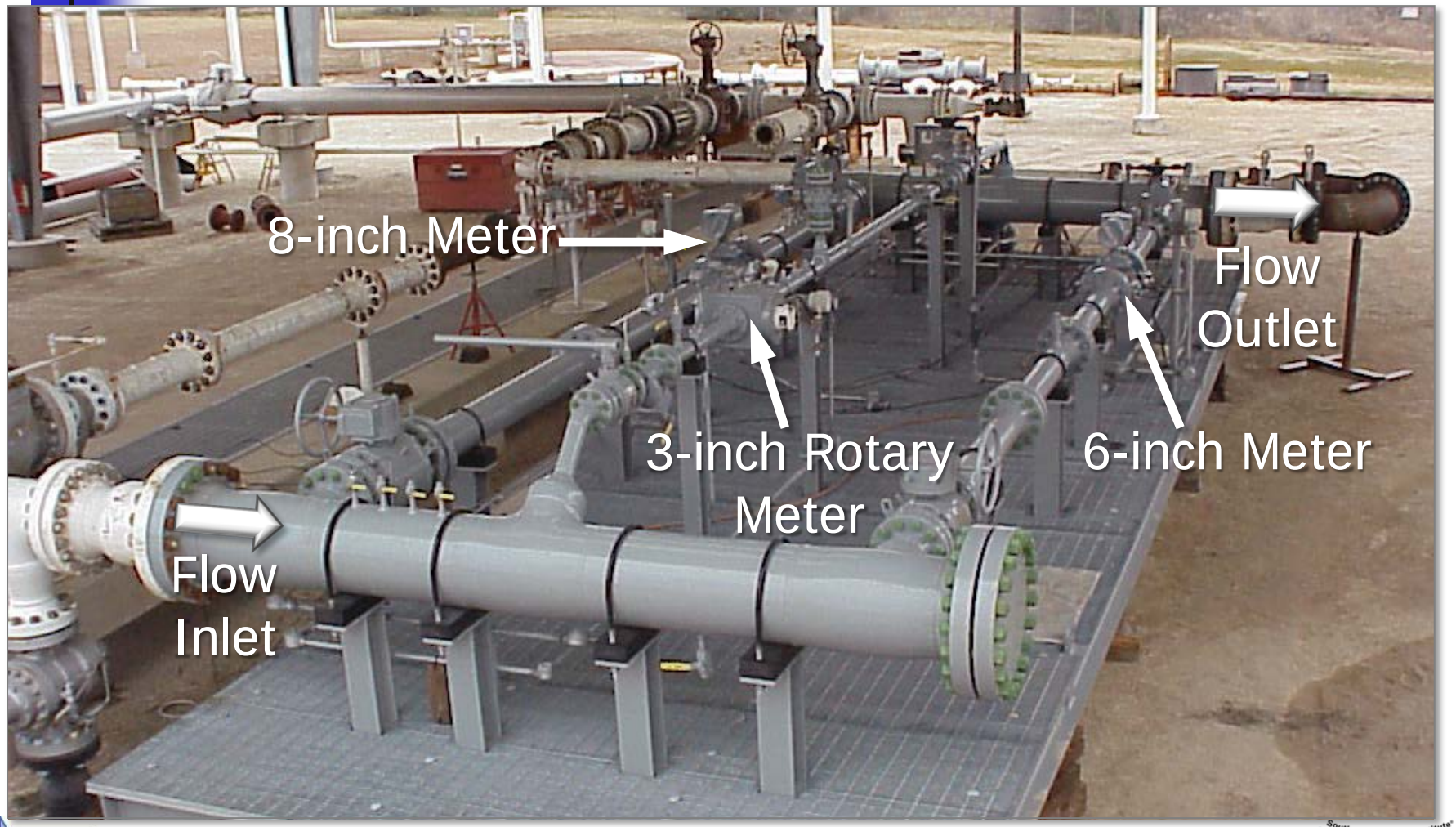
Flow Meter Installation

- Flow meter is shipped pre-assembled or is assembled at the flow calibration facility.
  - On-site assembly of piping components typically proceeds from upstream to downstream to allow internal inspection of flange alignment.
- Meter power, data communication, and secondary instrumentation installation.
  - Lab instrumentation is typically used for pressure and temperature measurements.
  - Initial meter checkout typically is done prior to the flow calibration.
- Example piping configurations follow.

Example Single Flow Meter Installation



Ultrasonic Meters Flow Calibrated in a Skid



Meter Calibration Details
(Example: Ultrasonic flow meter)

- Establish stable flow/pressure and ensure thermal stability.
- Test over a range of flow rates: For ultrasonic flow meters, AGA-9 recommends 100, 75, 50, 25, 10, 5, 2.5% of full scale, but other points can be used, depending on the application.
- At the MRF, we acquire multiple samples at each flow rate (3 to 6 measurement points, each of 90 to 300 seconds in duration).
- Record path-by-path and other diagnostic information and examine for consistency (run log files).
- Compare speed of sound measurement to those values produced using AGA-10.

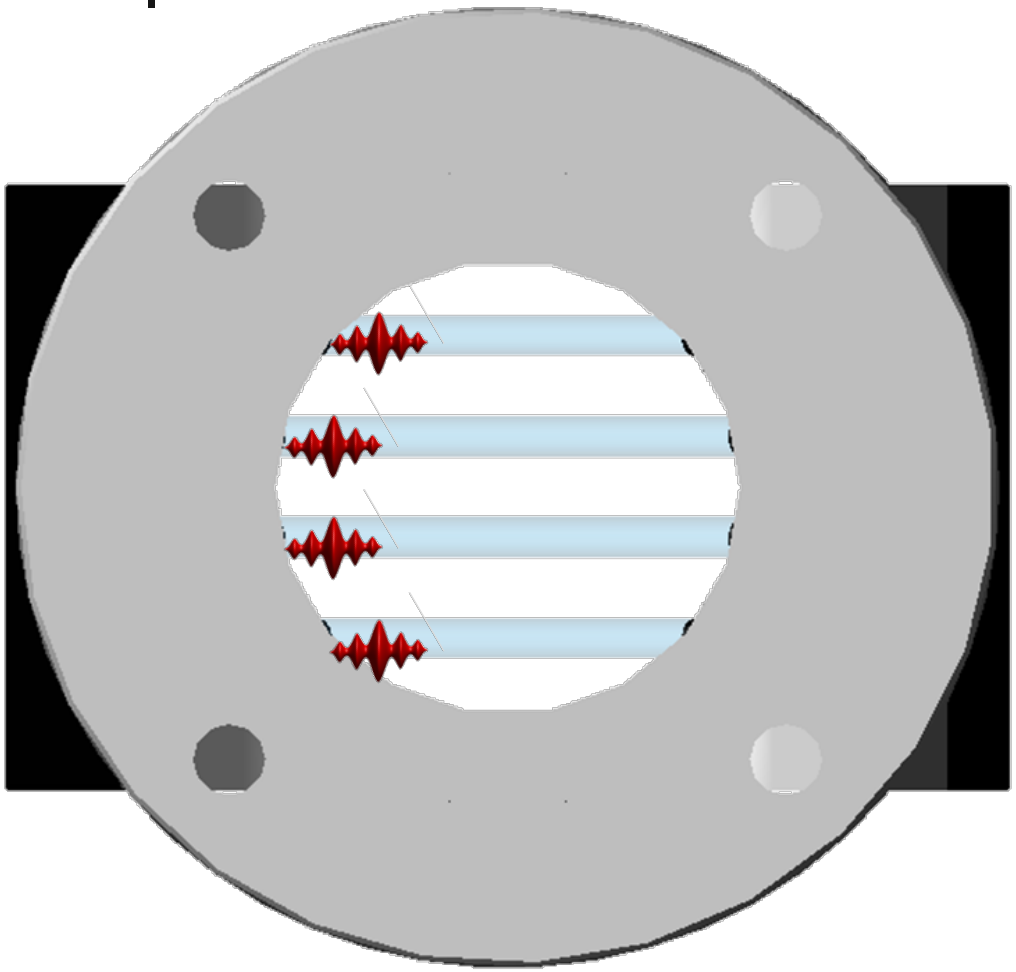
Meter Calibration Documentation

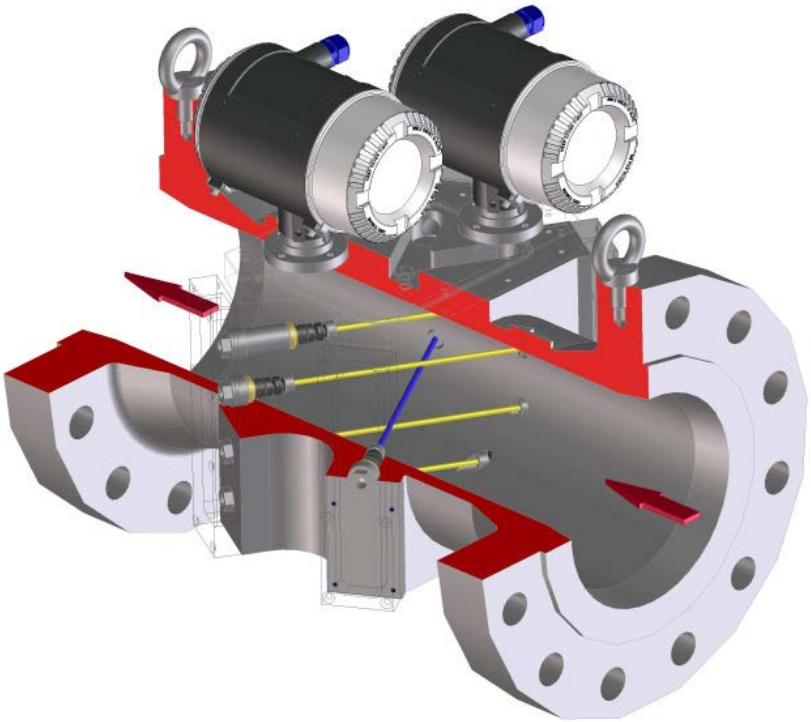
- AGA-9 recommends 15 items that should be included in the meter calibration report. Examples include:
  - Flow lab calibration procedure
  - Meter manufacturer, model, & serial number
  - Description of mechanical installation
  - Raw data, adjustment factor(s), and test method used (should include measurement uncertainty estimate)
  - Final meter configuration, including firmware revision number

Some things to consider, depending on your type of flow meter…

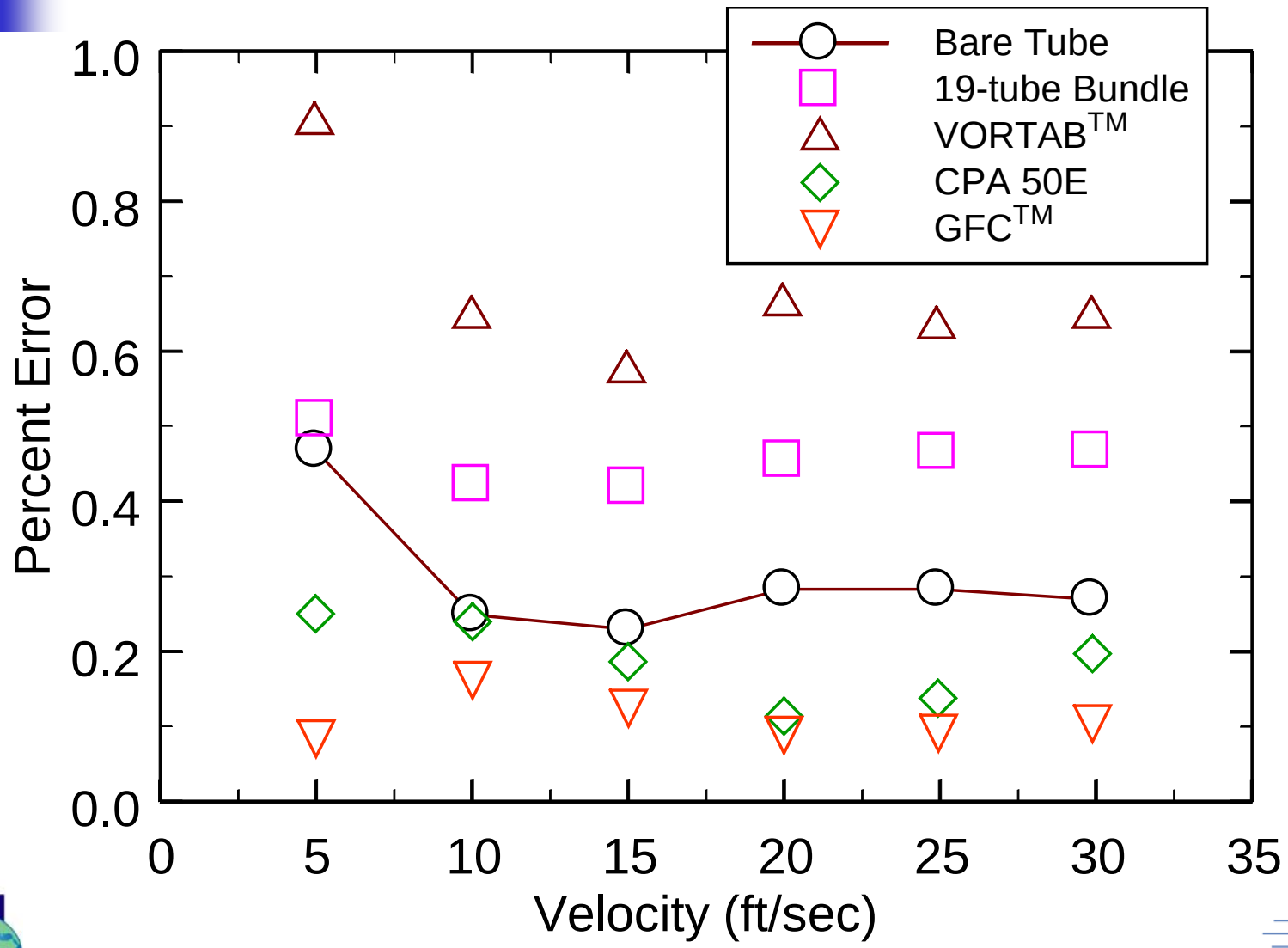
Ultrasonic Flow Meters

(Image courtesy of Sick, Inc.)





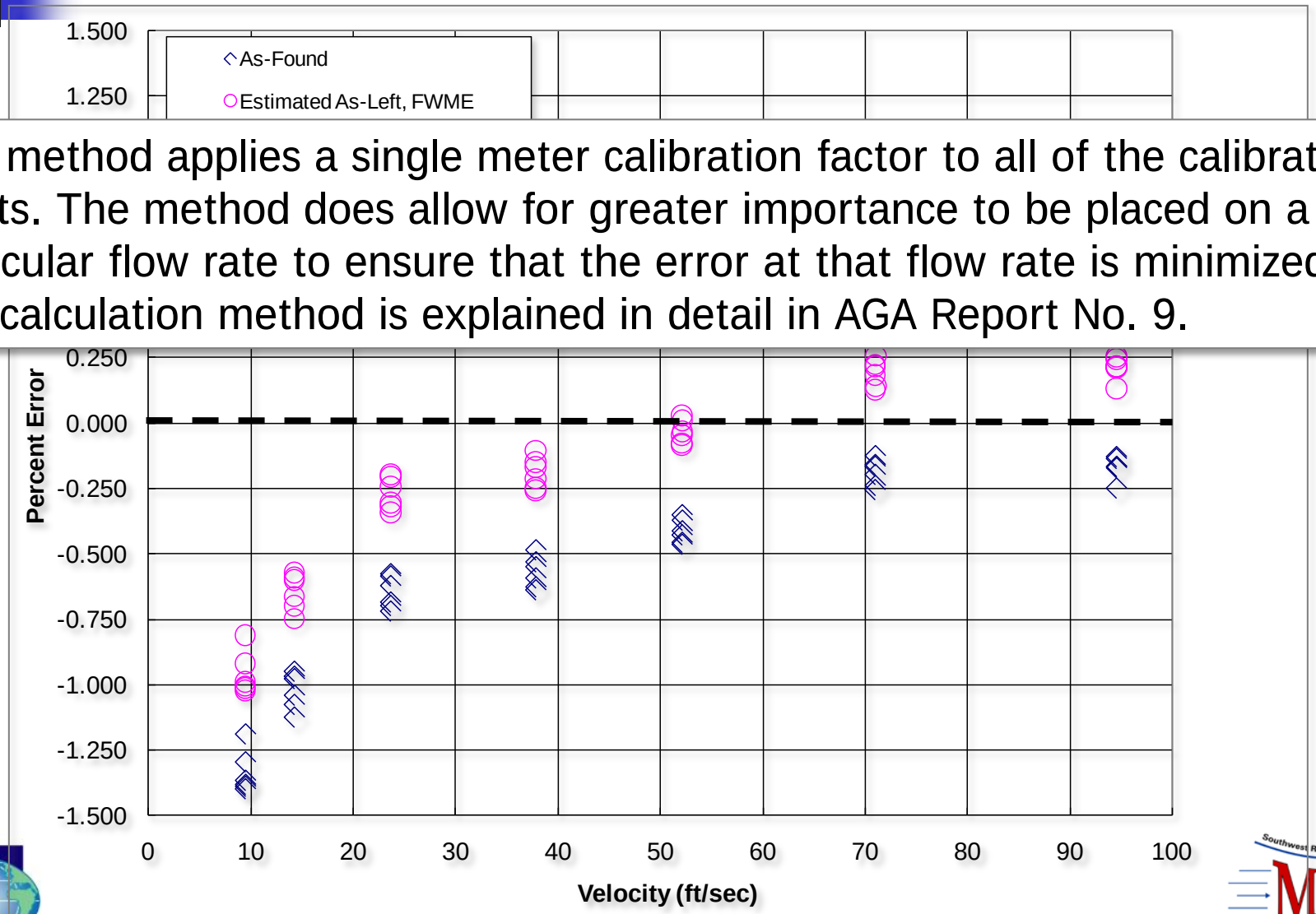
Ultrasonic Meter 'A' with Flow Conditioning
(97 diameters of straight pipe upstream)



Ultrasonic Meter Adjustments

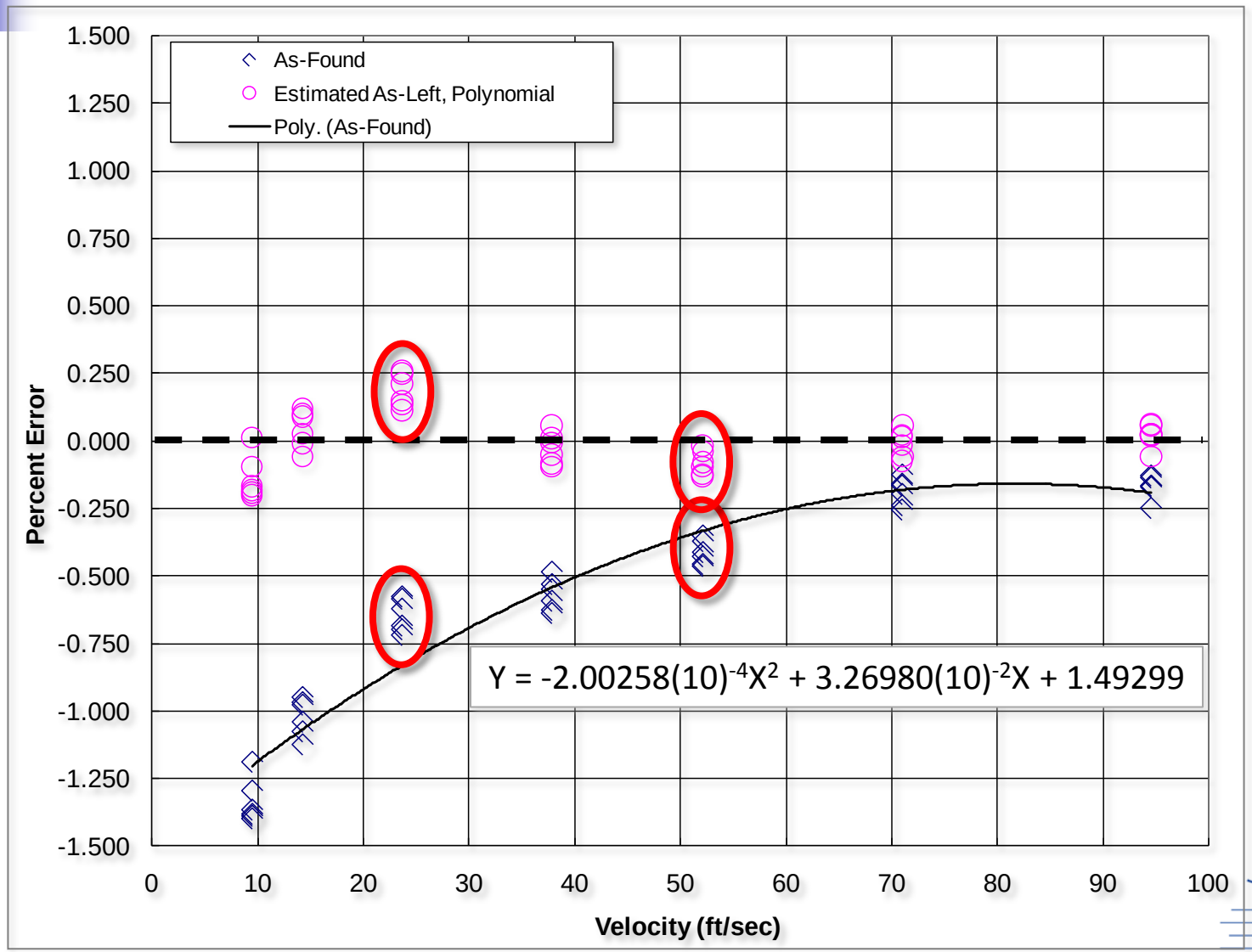
- AGA-9 references three common methods of correcting the meter output:
  - Flow Weighted Mean Error (FWME) correction
  - Polynomial error correction
  - Multi-point (point-by-point) linearization
- Depending on the characteristics of the meter error curve, one of the above methods may be preferred over the others.

FWME Correction

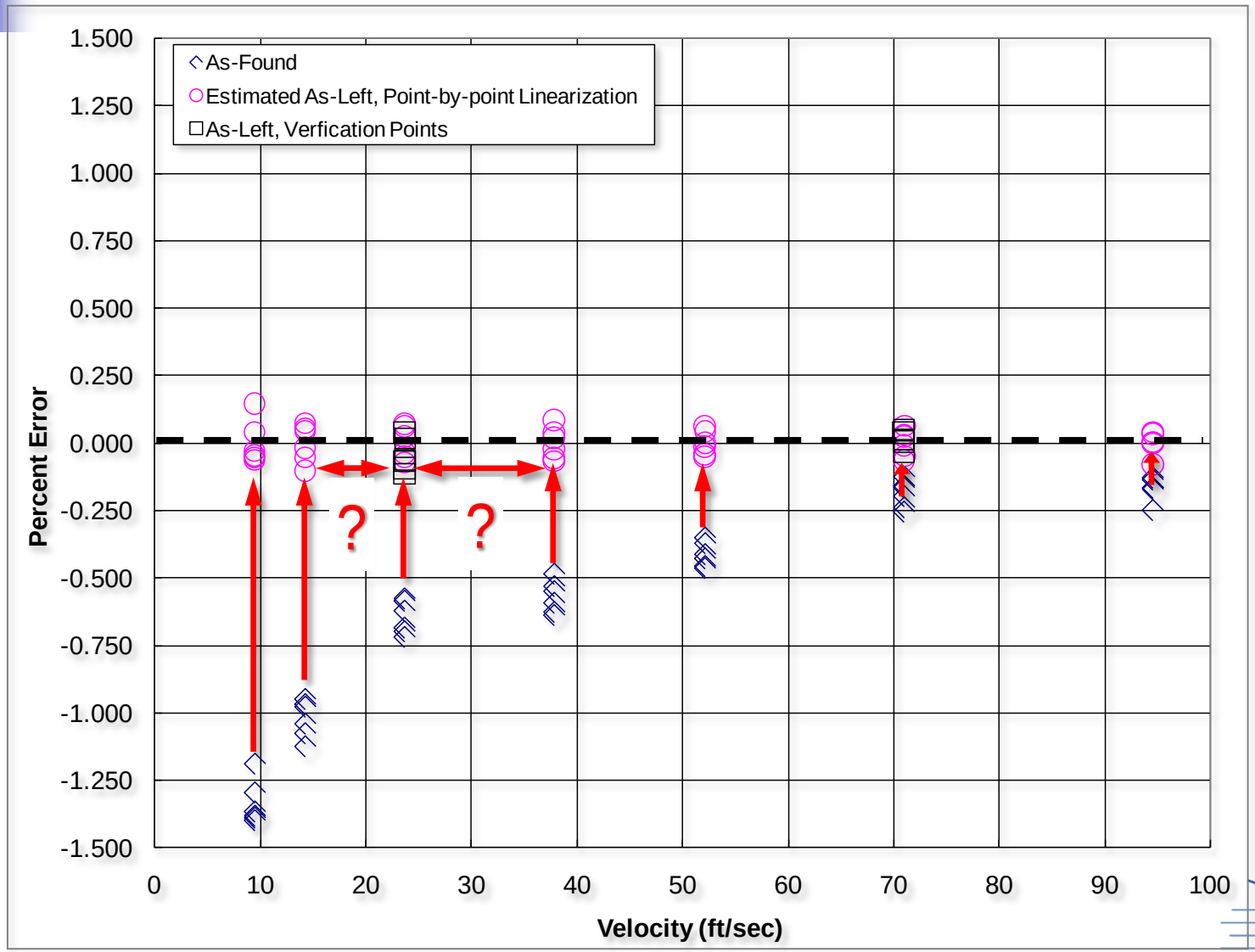


This method applies a single meter calibration factor to all of the calibration points. The method does allow for greater importance to be placed on a particular flow rate to ensure that the error at that flow rate is minimized. The calculation method is explained in detail in AGA Report No. 9.

Polynomial Correction

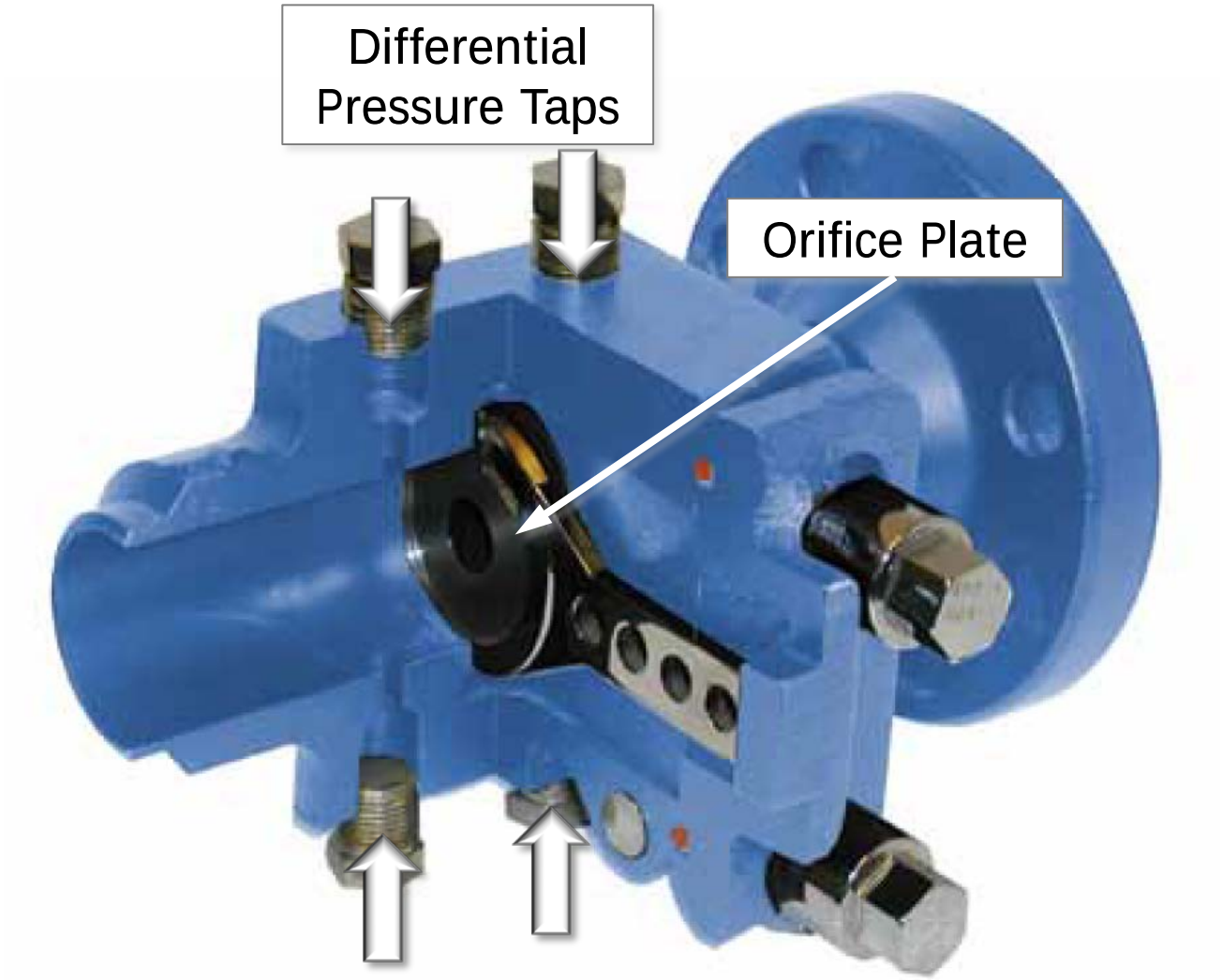


Point-by-Point Linearization

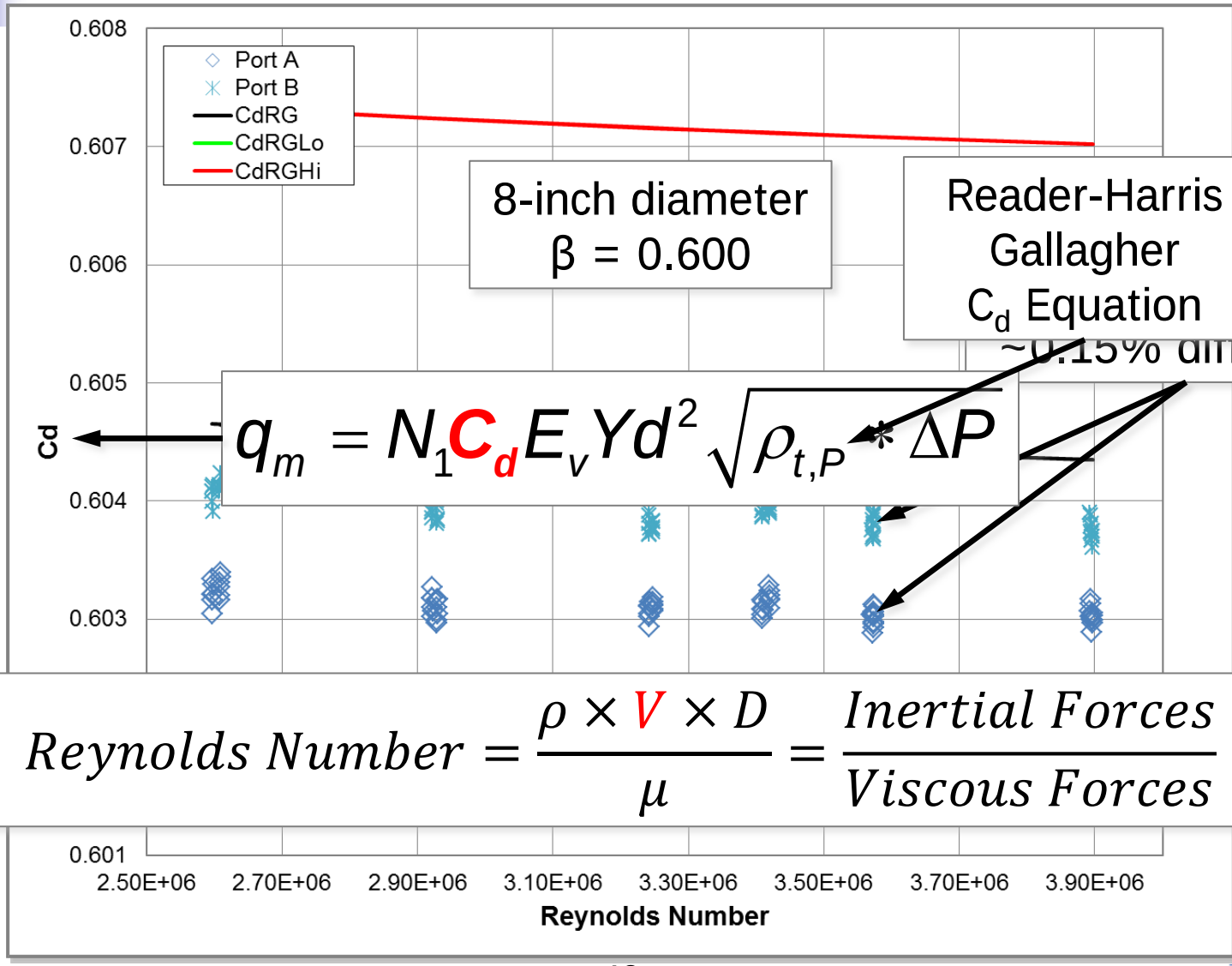


Orifice Flow Meters

(Built to specifications of American Gas Association Report No. 3)



Orifice Flow Meter Calibration



8-inch diameter
β = 0.600

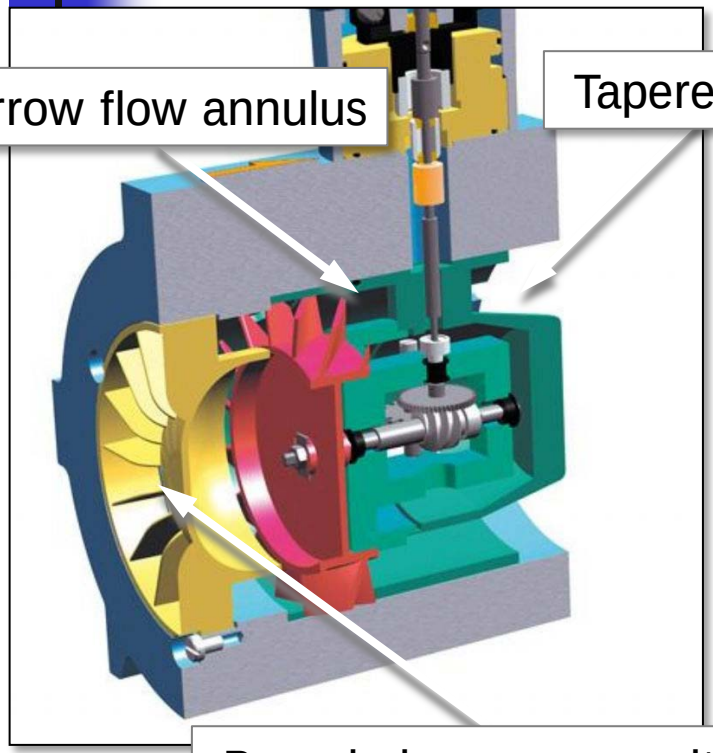
Reader-Harris
Gallagher
C_d Equation

ap
n"
~0.15% difference

$$q_m = N_1 C_d E_v Y d^2 \sqrt{\rho_{t,P} * \Delta P}$$

$$Reynolds\ Number = \frac{\rho \times V \times D}{\mu} = \frac{Inertial\ Forces}{Viscous\ Forces}$$

Turbine Flow Meters



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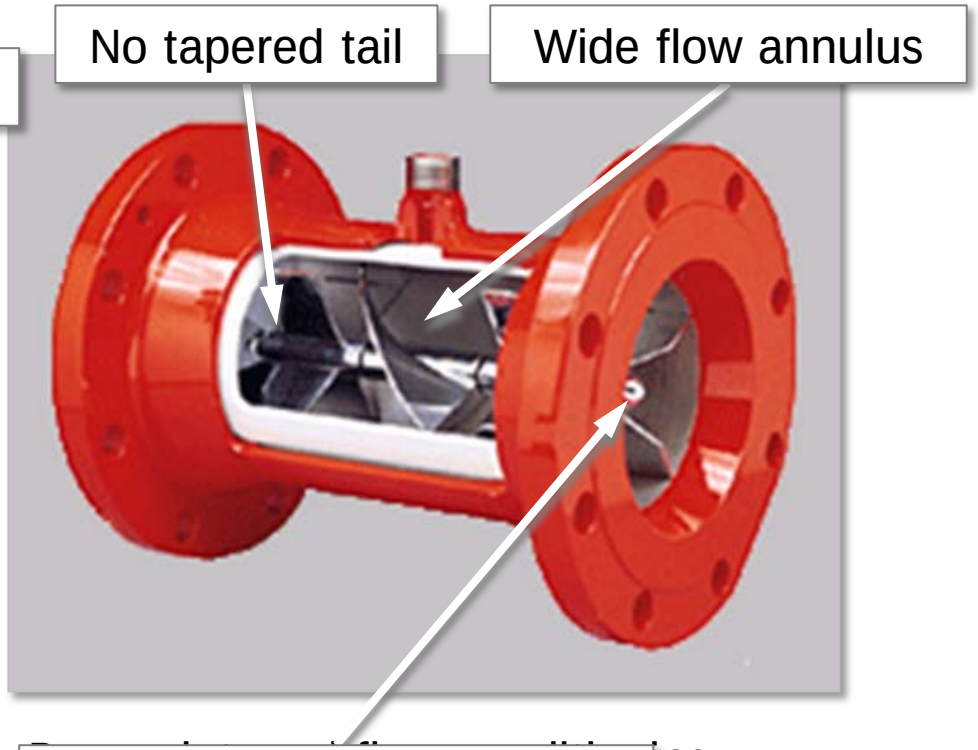
vanes, contracting inlet cross section, and tapered exit).



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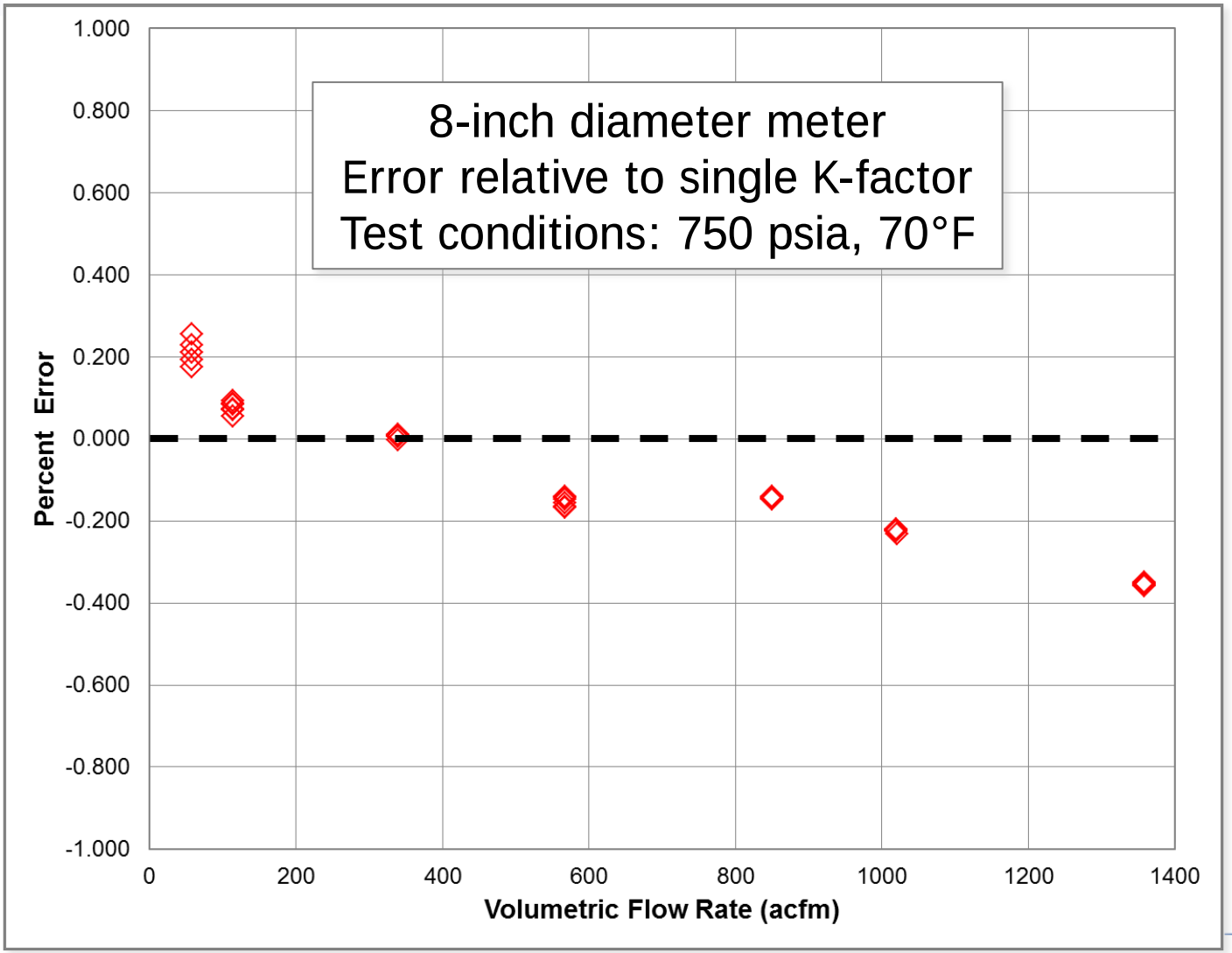
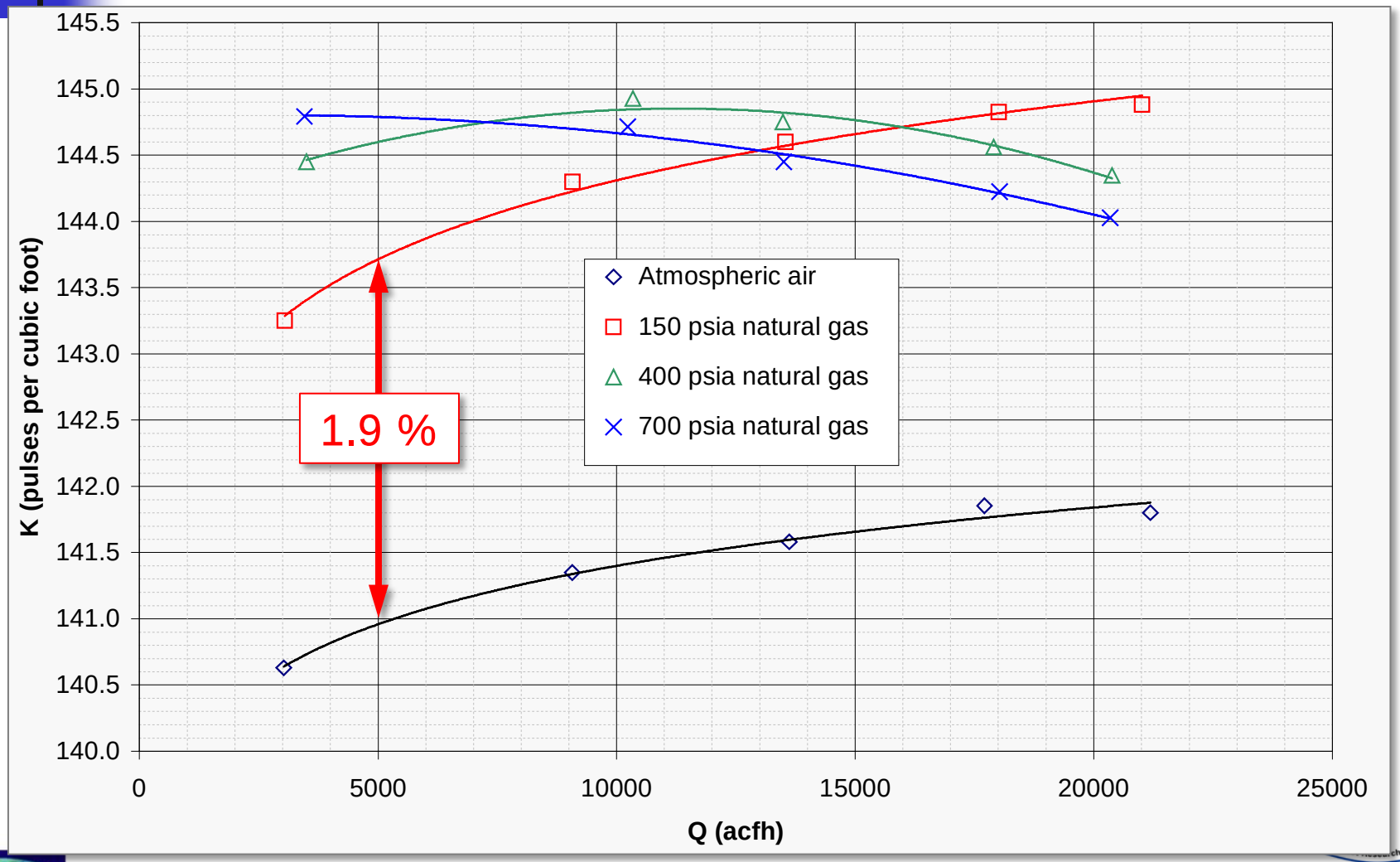
more
open cross section).

Turbine Flow Meter Calibration



Example Calibration Factor vs. Flow Rate
(4-inch diameter meter)

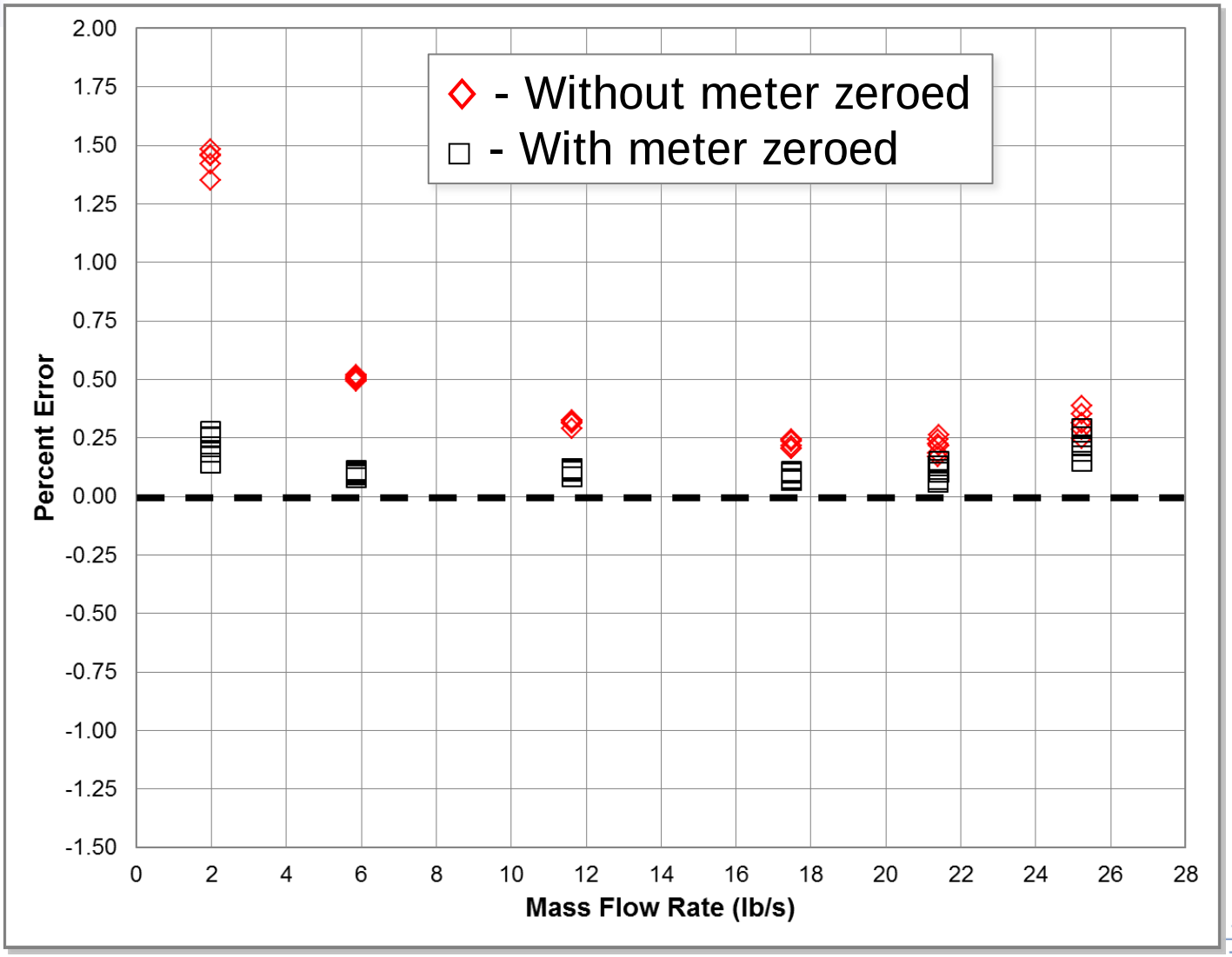


Turbine Meter Calibration Notes

- Turbine meters should be characterized as a function of Reynolds number (per AGA-7).
- Calibration at operating pressure can further reduce the measurement uncertainty.
- Characterizing a turbine meter by a single K-factor can lead to error.
- Multi-point linearization can be built into the flow computer to minimize the error.

Coriolis Flow Meters
(Bent tube and straight tube designs)

Coriolis Flow Meter Calibration



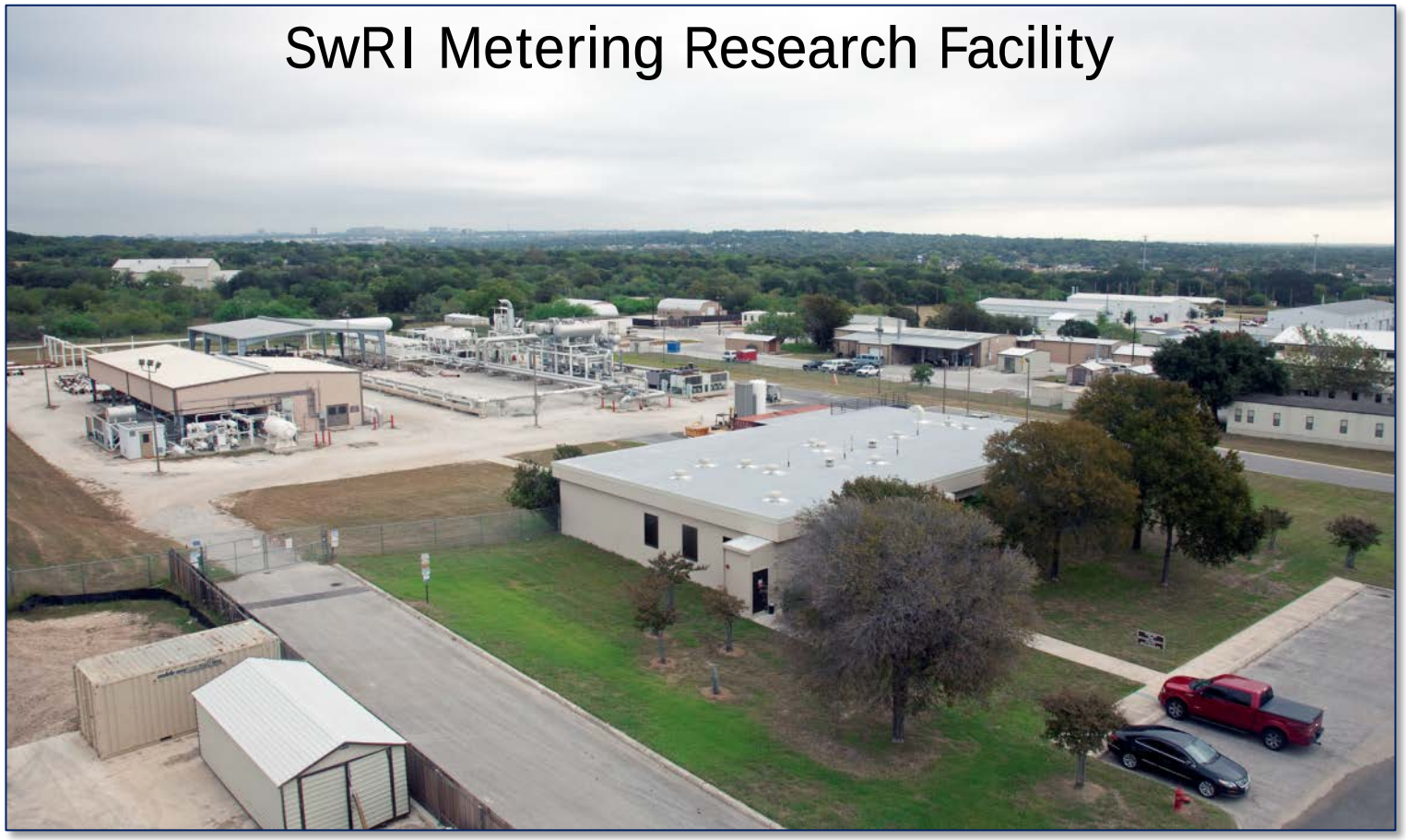
Coriolis Meter Calibration Notes

- Zeroing the meter provides the reference condition upon which Coriolis meters are highly dependent.
- Gas calibrations at elevated pressure should consider the pressure sensitivity of the meter.

Conclusions

- Informed users can make good choices for calibration requirements. For instance, decide how accurate your meter needs to be!
- Calibration facilities can offer advice to help with your decisions and planning.
- Properly calibrated flow meters provide an accurate means of measurement that will reduce system measurement biases - and associated operating costs.
- An initial meter calibration prior to field installation provides both verification of meter performance and removal of any measurement bias error - and provides baseline (reference) diagnostic information for monitoring of meter health in the future.

Thank you. Any questions?



Southwest Research Institute Website: www.mrf.swri.org

tgrimley@swri.org

Example FWME Calculation & Correction

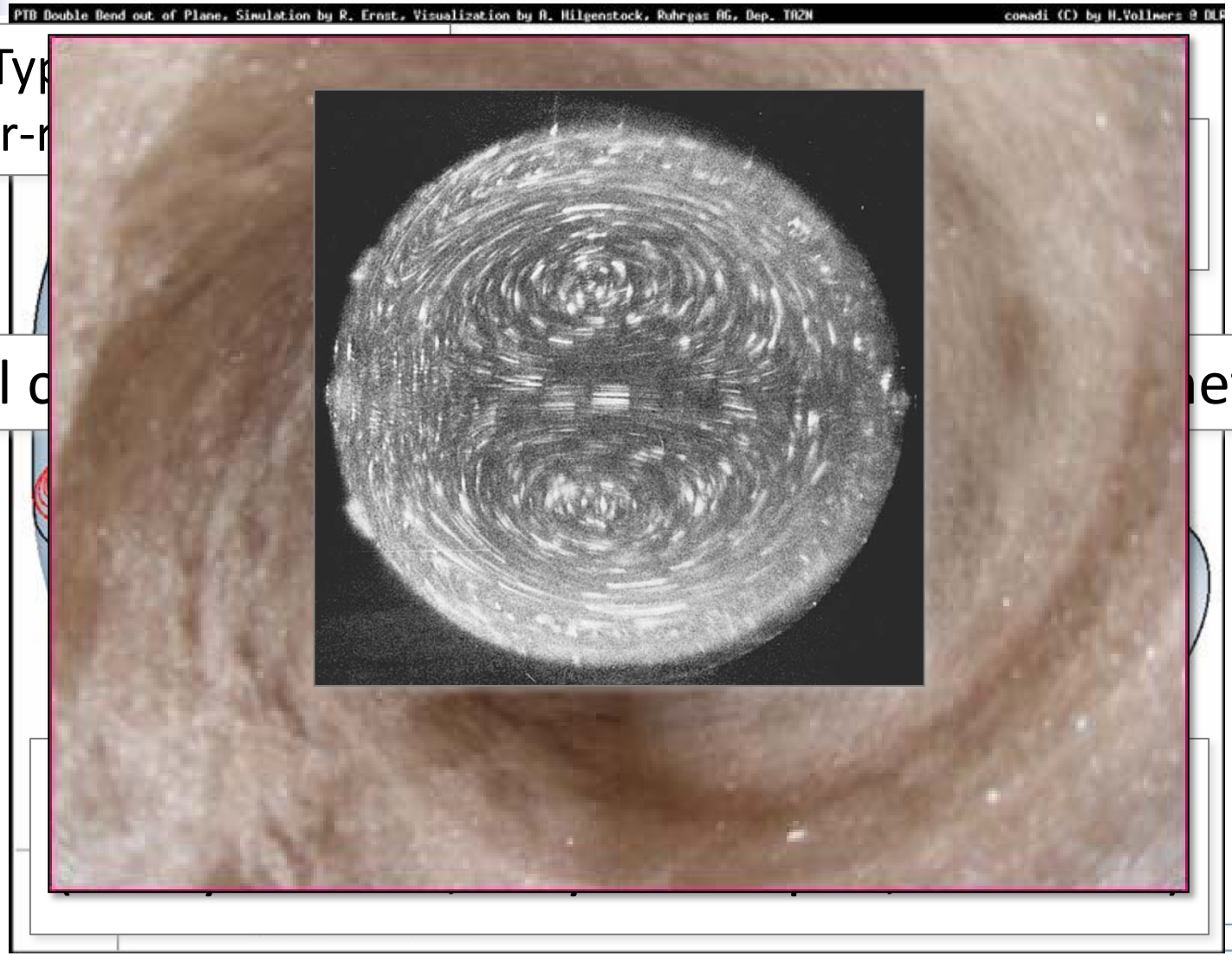
$$FWE = \frac{Flow\ Rate}{100\ ft/s} \cdot Error$$

Point	Velocity (ft/s)	Error (%)	Full Scale Fraction	Flow Weighted Error	FWME Corrected Error (%)
1	94.558	-0.169	0.946	-0.160	0.212
2	70.983	-0.190	0.710	-0.135	0.191
3	52.117	-0.414	0.521	-0.216	-0.034
4	37.820	-0.570	0.378	-0.216	-0.191
5	23.628	-0.648	0.236	-0.153	-0.269
6	14.217	-1.023	0.142	-0.145	-0.646
7	9.443	-1.338	0.094	-0.126	-0.961
		Sum =	3.028	-1.151	

$$FWME = \frac{\sum FWE}{\sum \frac{Flow\ Rate}{Full\ Scale\ Flow\ Rate}} = \frac{-1.151}{3.028} = -0.380\%$$

$$Corrected\ Error = \left(\frac{1}{FWME + 100}\right) \times (Error + 100) - 1$$

Example Flow Distortion (Swirl) Caused by Two 90° Elbows, 90° Out of Plane



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Swirl c

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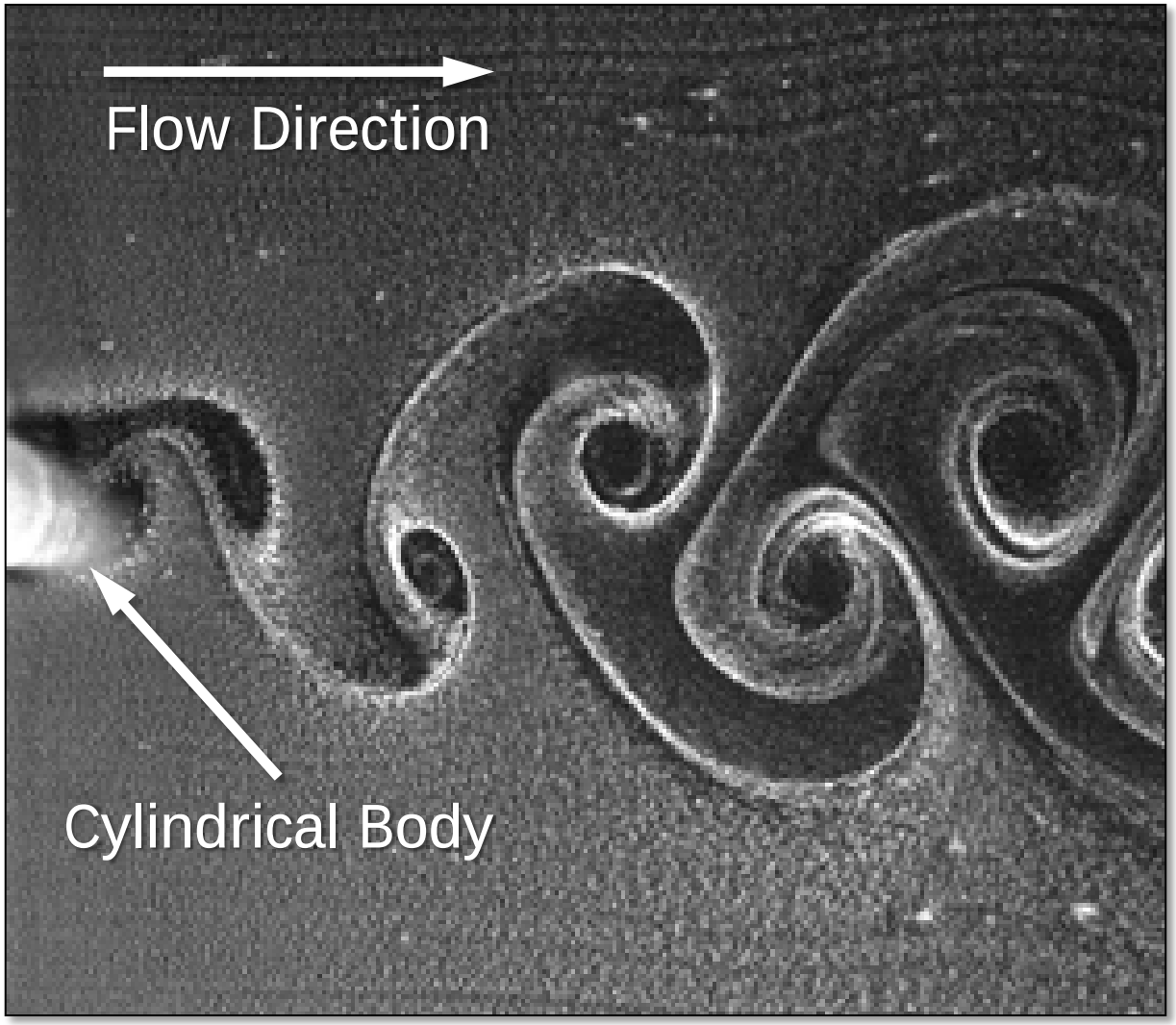
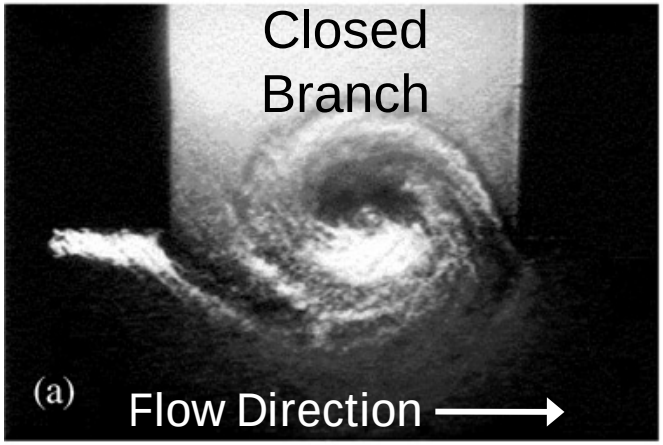
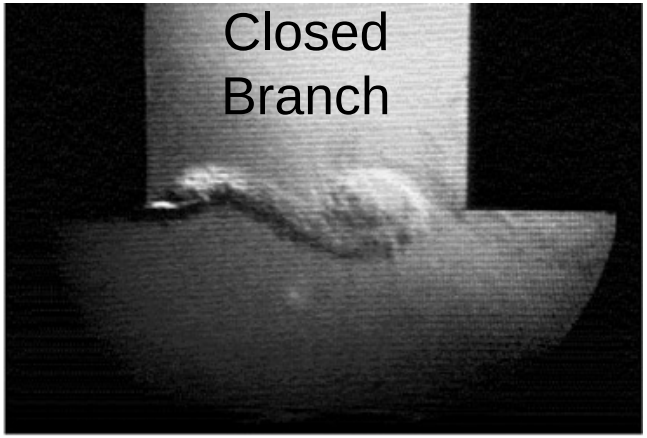
Wake Downstream of a Cylindrical Body
(e.g., thermowell or gas sample probe)

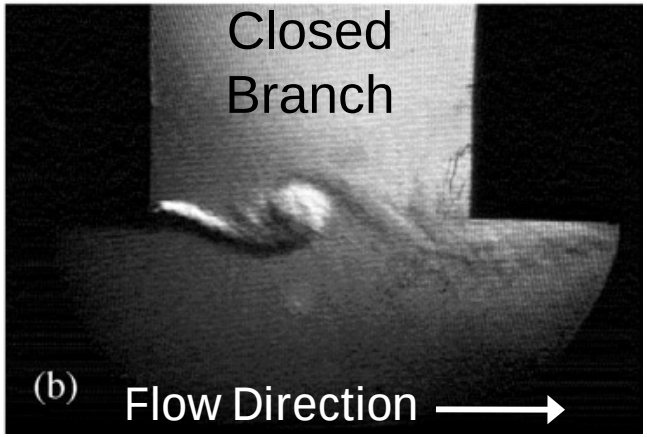


Side Branches or Splits in the Flow Stream



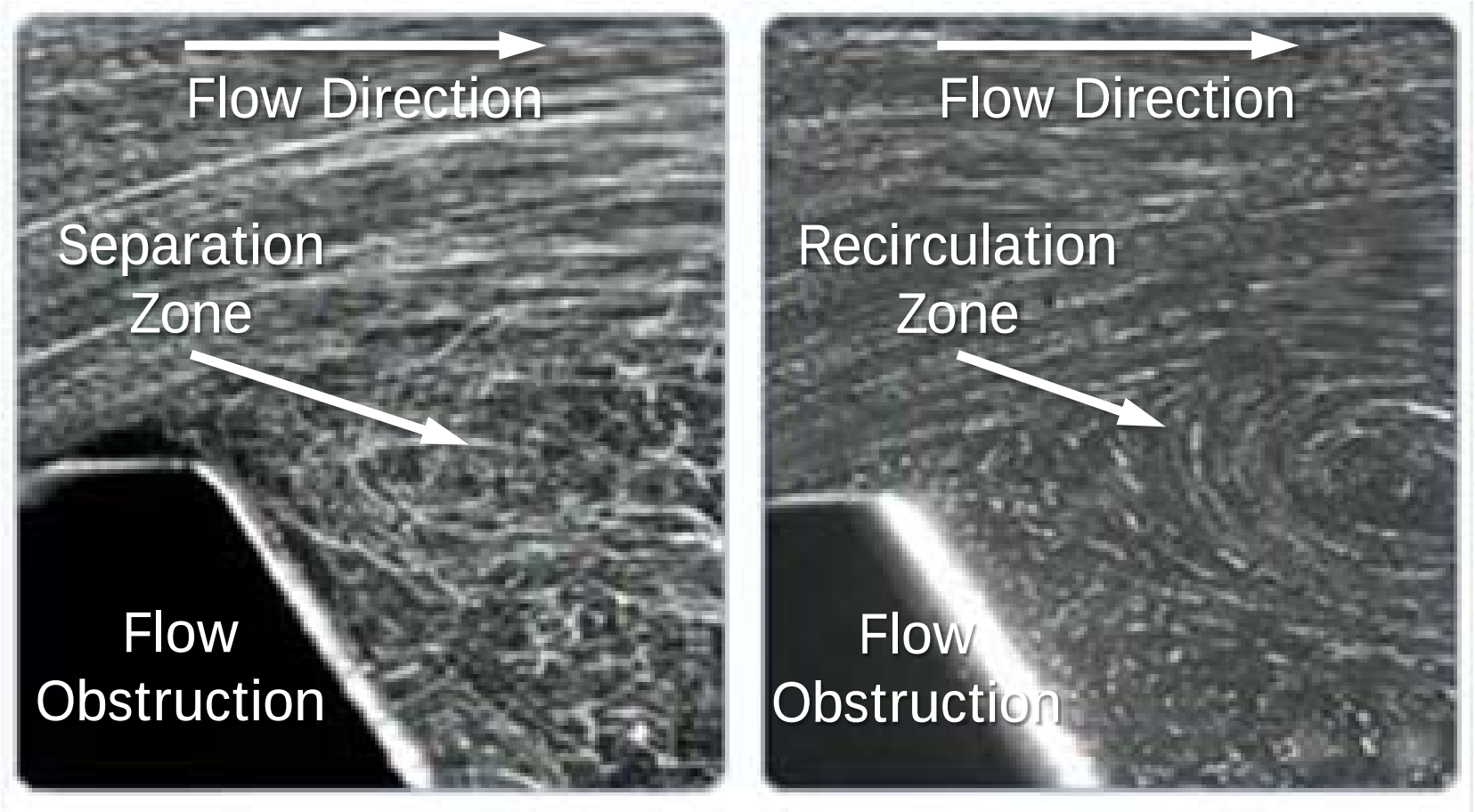
First-order or
Fundamental Mode



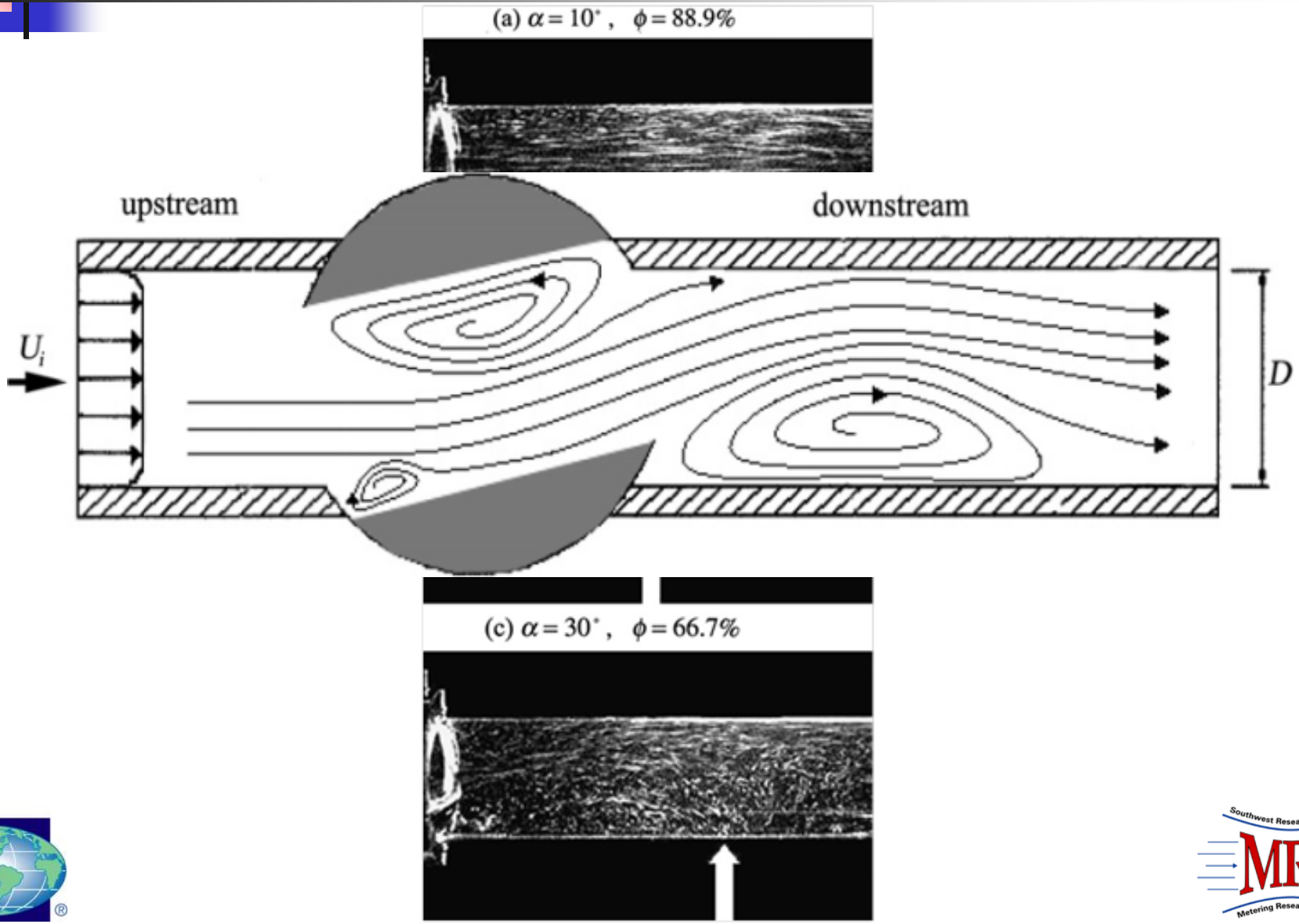


Second-order Mode

Flow Separation Downstream of an Obstruction
(e.g., partially closed valve, protruding gasket, orifice...)

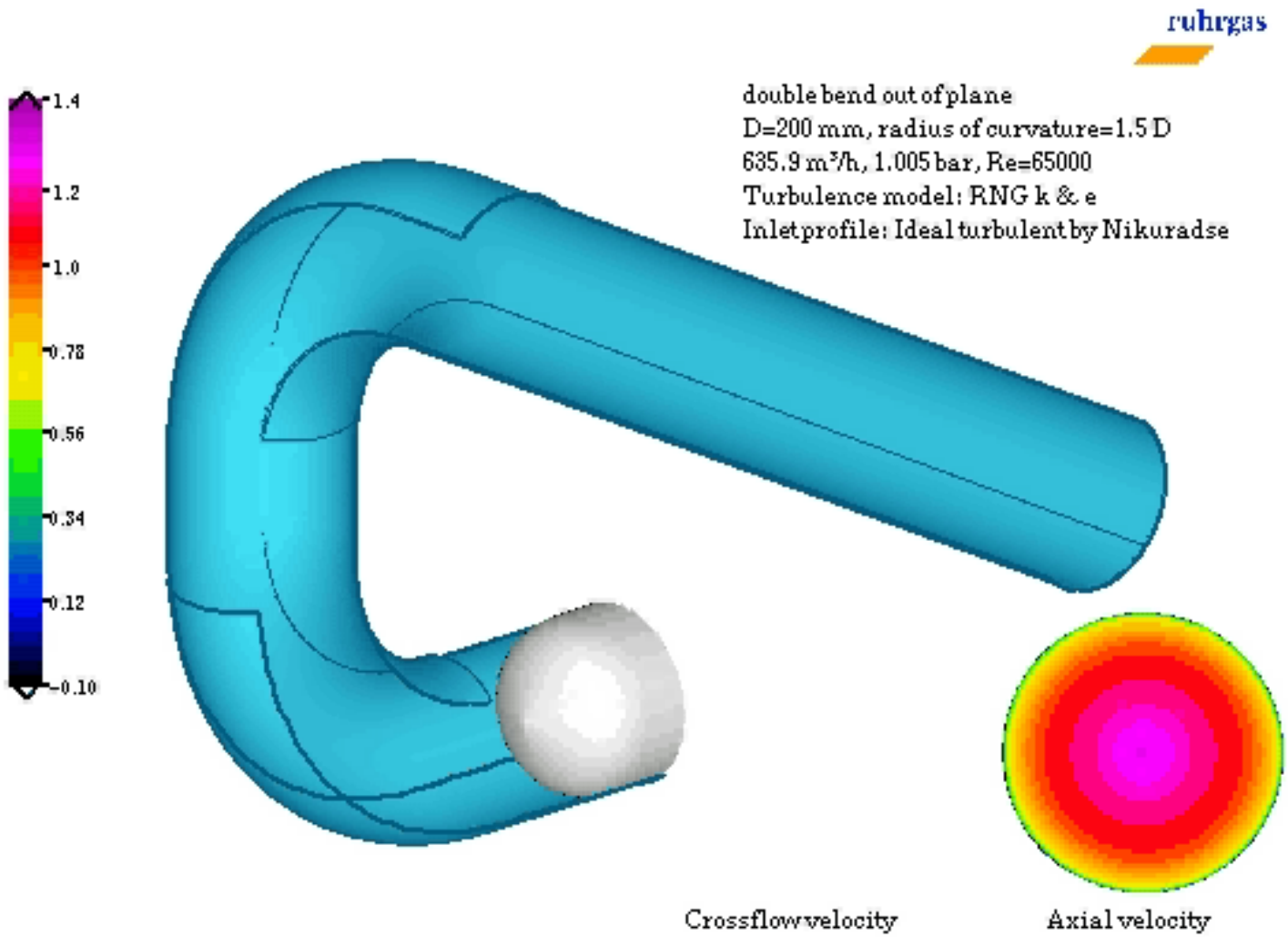


Partially Closed Valves
(Ball valve example)

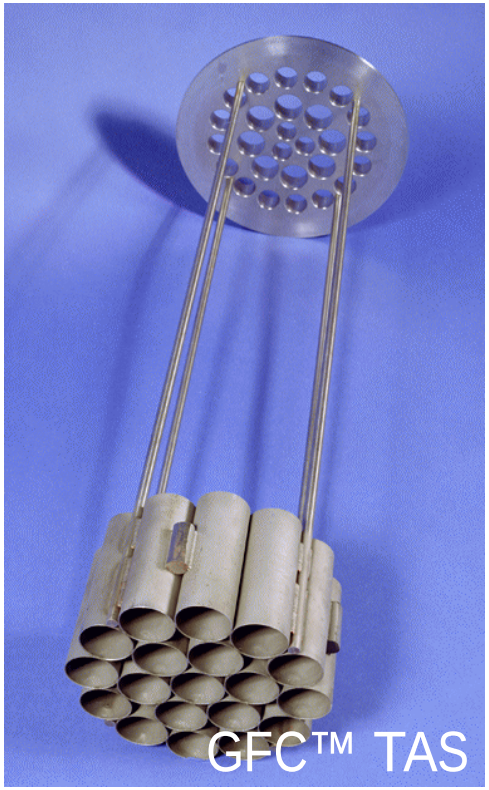


Example Flow Distortion (Swirl) Caused by Two 90° Elbows, 90° Out of Plane

(Numerical simulation courtesy of E-on Ruhrgas)



Is a flow "conditioner" necessary?



Example Flow Conditioners
(They do not all perform the same!)

Flow “conditioners” also disturb the flow!

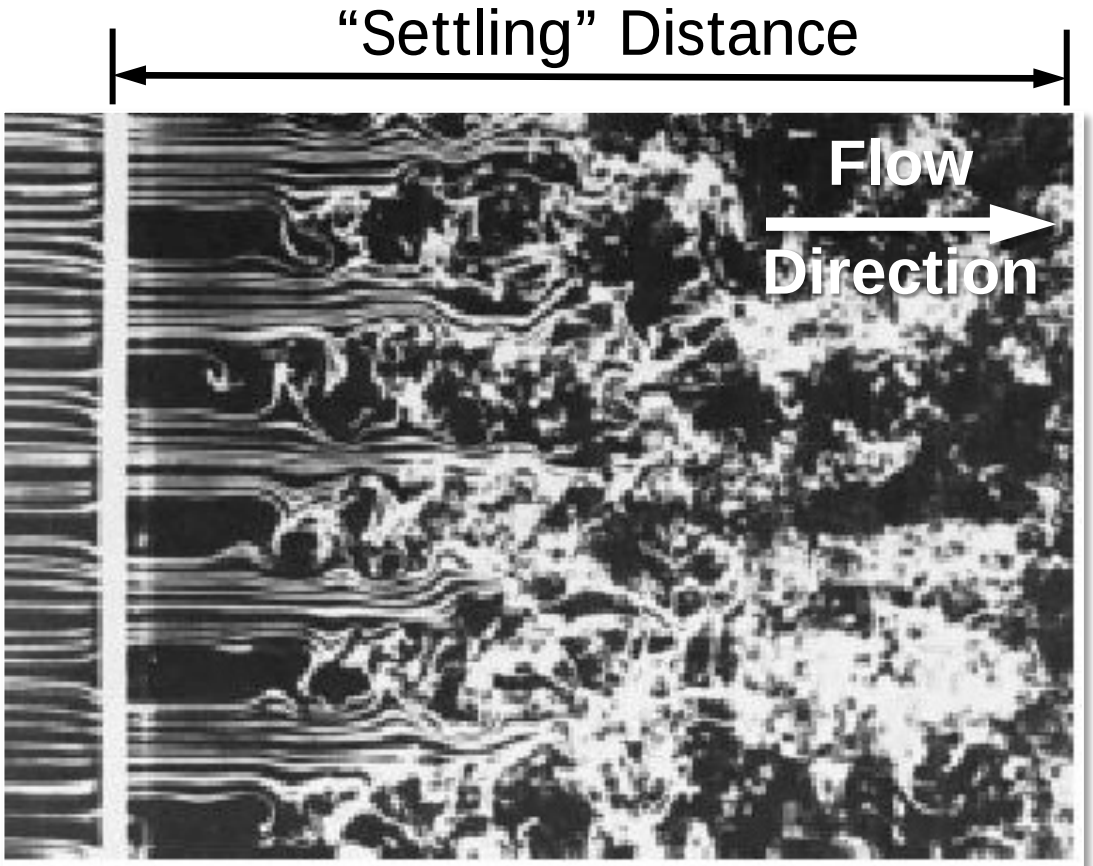
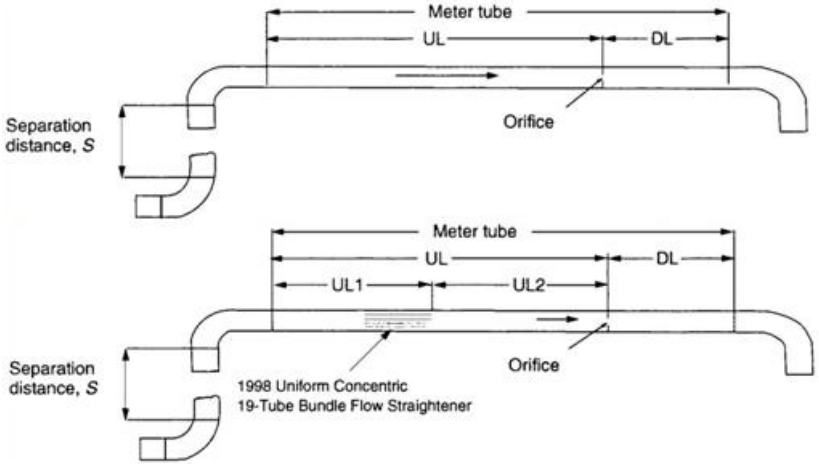
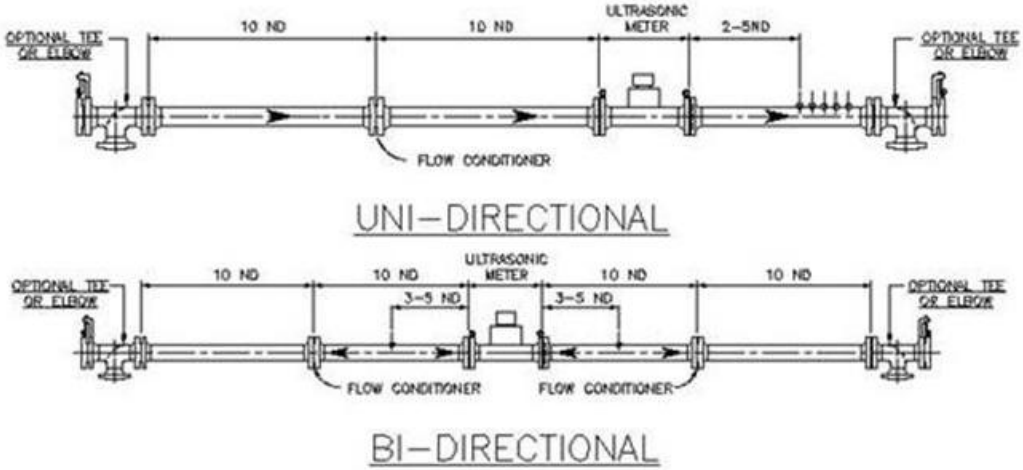


Figure 1: Smoke visualization of uniform laminar stream owing through a perforated plate, showing laminar, transitional, and turbulent flow, photograph by Thomas Corke and Hassan Nagib.

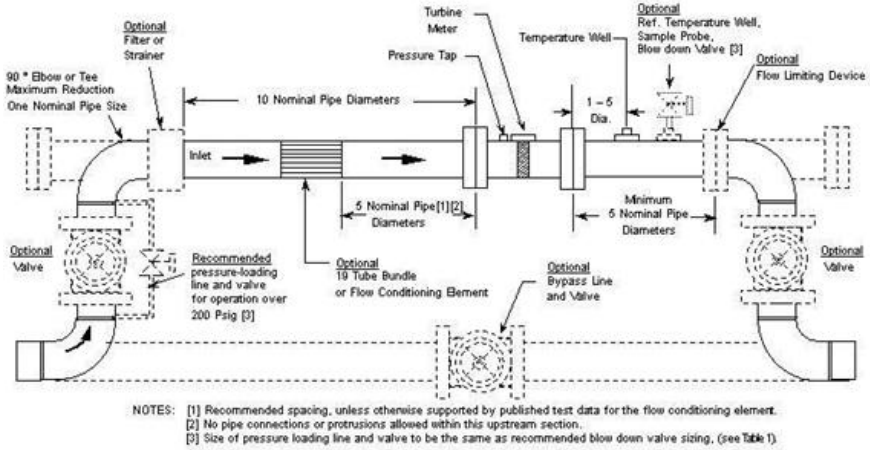
Installation Guidelines Are Included in the Applicable Standards



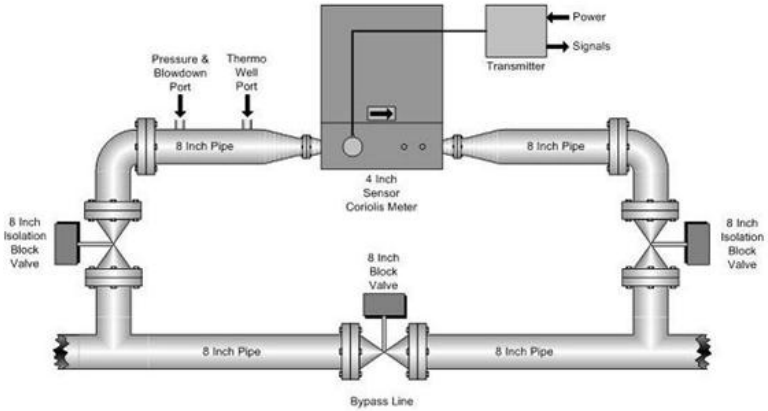
Orifice Meters



Ultrasonic Meters

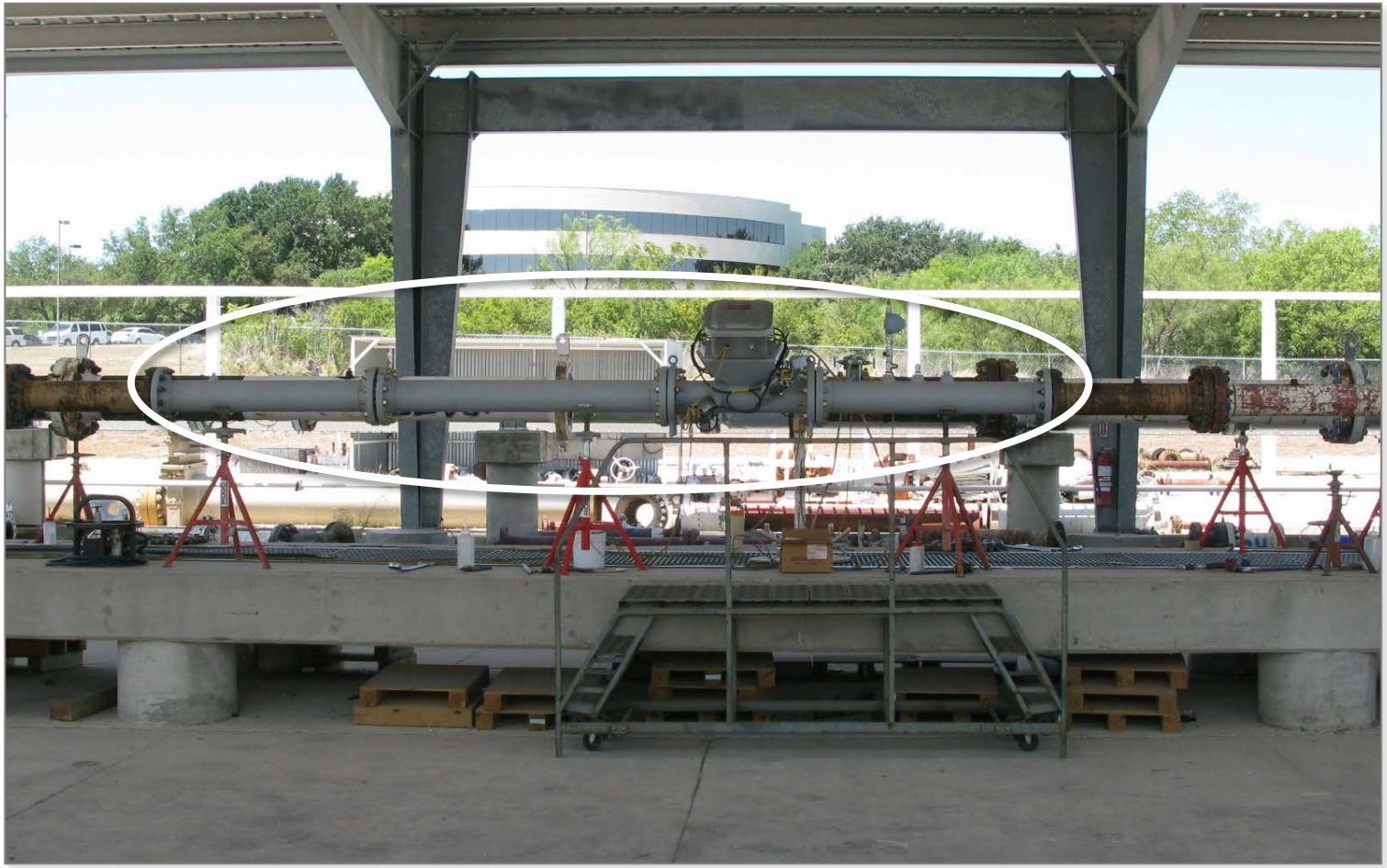


Turbine Meters

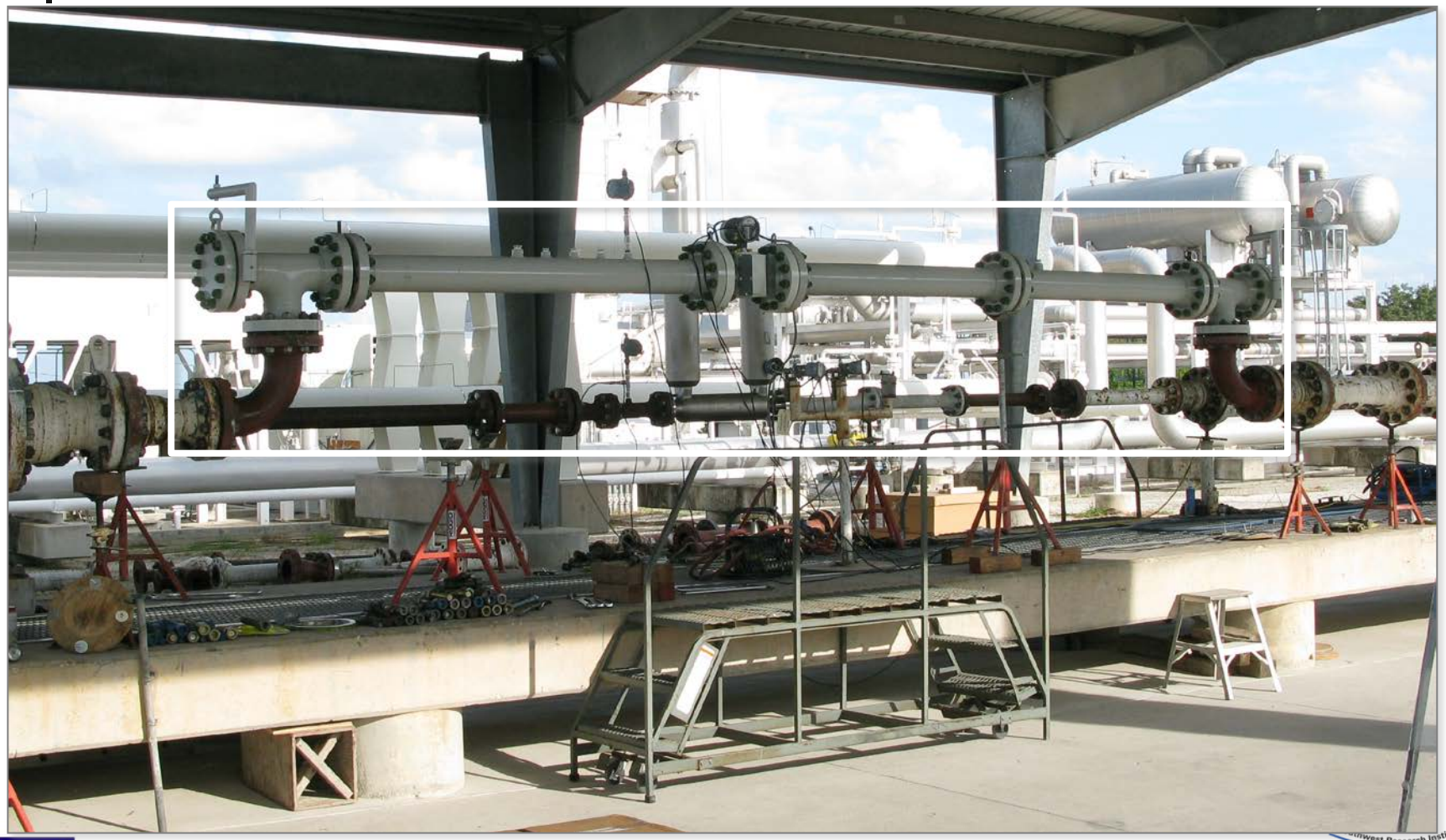


Coriolis Meters

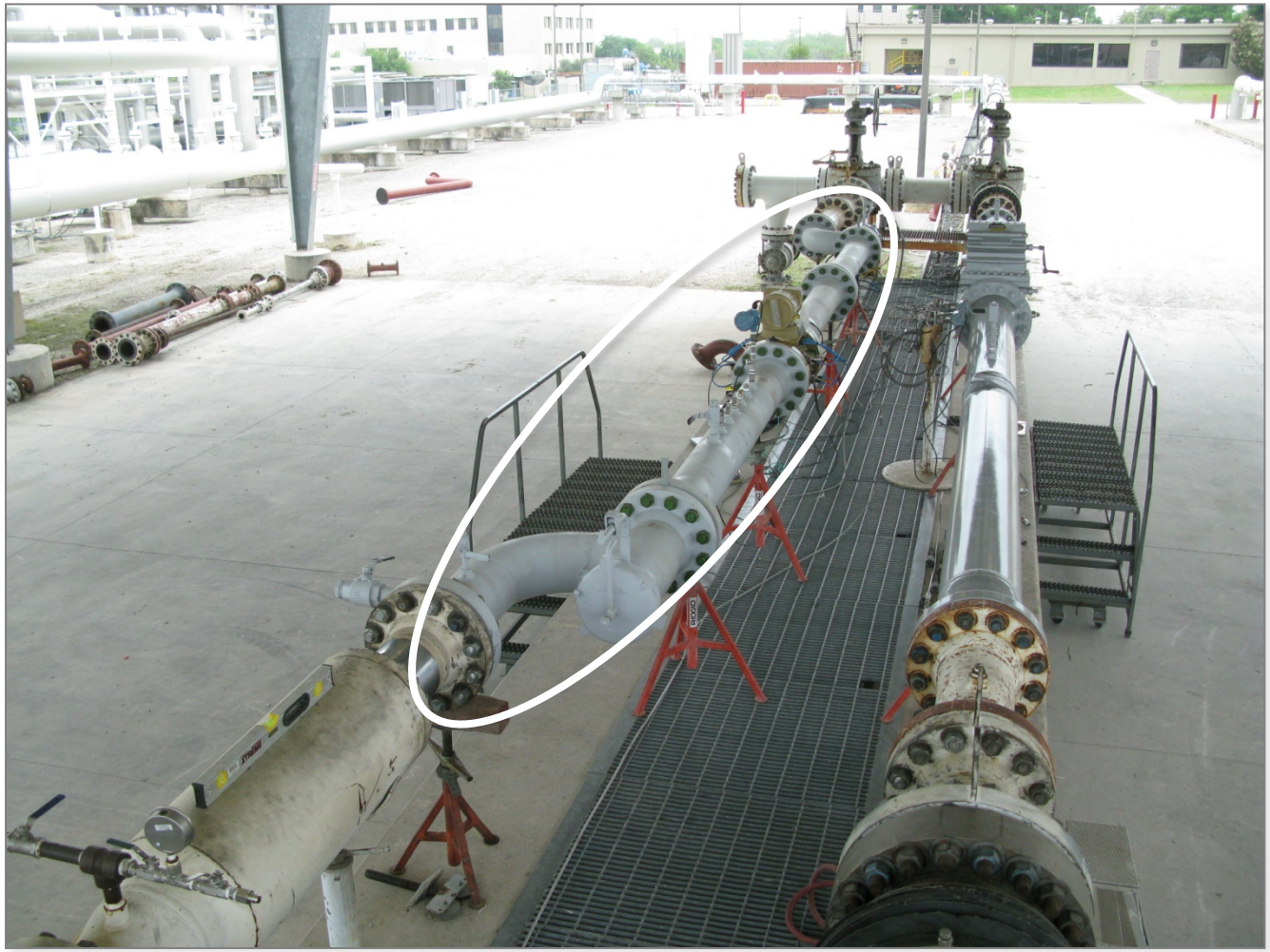
Straight Pipe Installation



Installation with Inlet Elbows and Cleanout Tees



Integral Elbow-Tee-Cleanout Combination



Z-pattern - Two Meters in Series in a Header