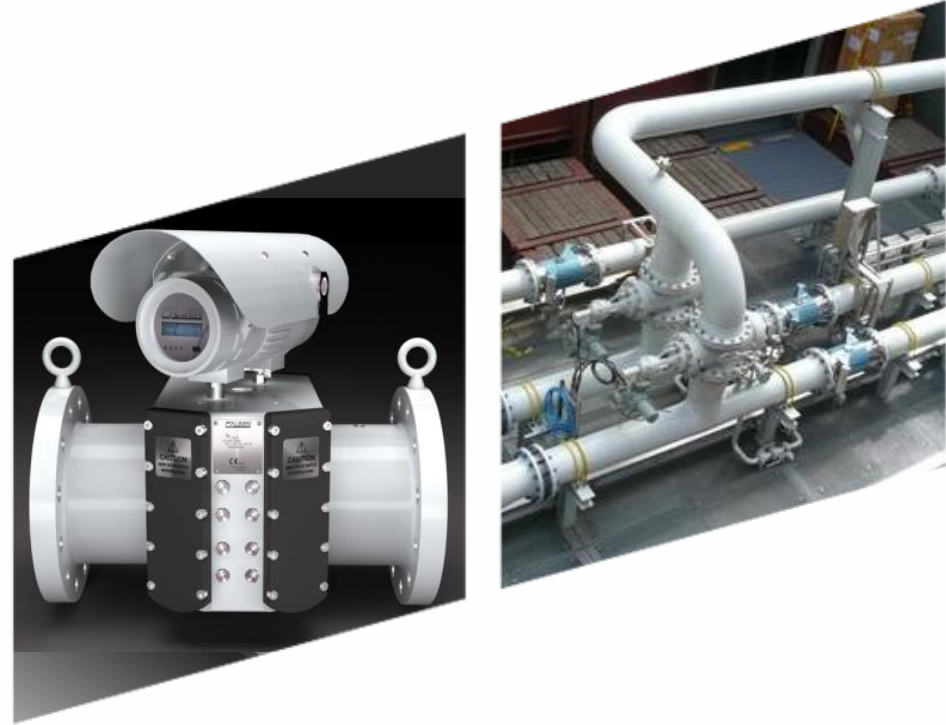
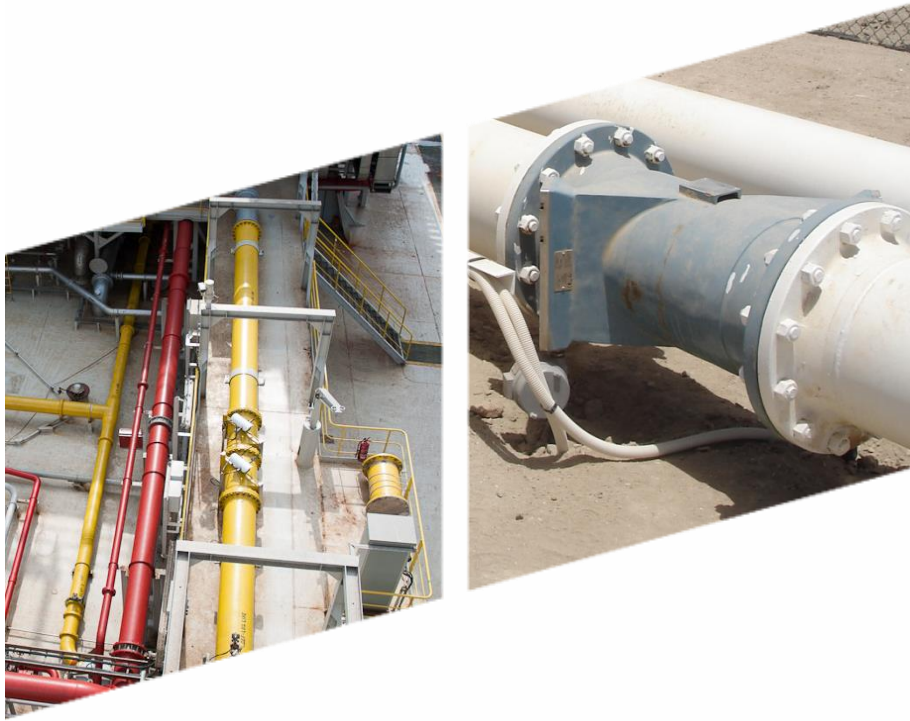


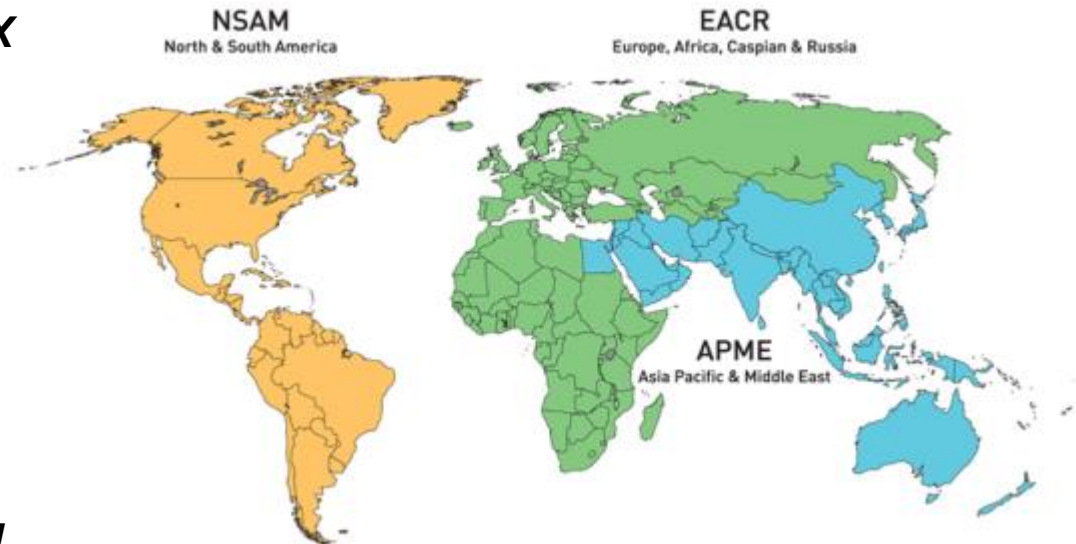
# Caldon LEFM Ultrasonics - Leading Edge Flow Meters for Custody Transfer



**Dr Gregor Brown  
Caldon Ultrasonics  
Cameron**

## **Cameron is a leading provider of flow equipment products, systems and services to the oil, gas and process industries**

- *Products used to control, direct, adjust, process, measure and compress flows*
- *Headquartered in Houston, TX*
- *\$ 6+ billion in annual orders*
- *2/3 of business non-USA*
- *20,000 + employees*
- *300 + locations worldwide*
- *60 + strong product brands*
- *10 operating divisions holding leading positions in global oil & gas and process markets*





# Agenda

- Caldon LEFM product history
- Product line overview
- Why 4 and 8 paths?
- Issues with conventional flow conditioners
- The Caldon Gas Meter and Reducing Nozzle liquid ultrasonic flowmeter
- Calibration and traceability
- Application experiences

# LEFM History

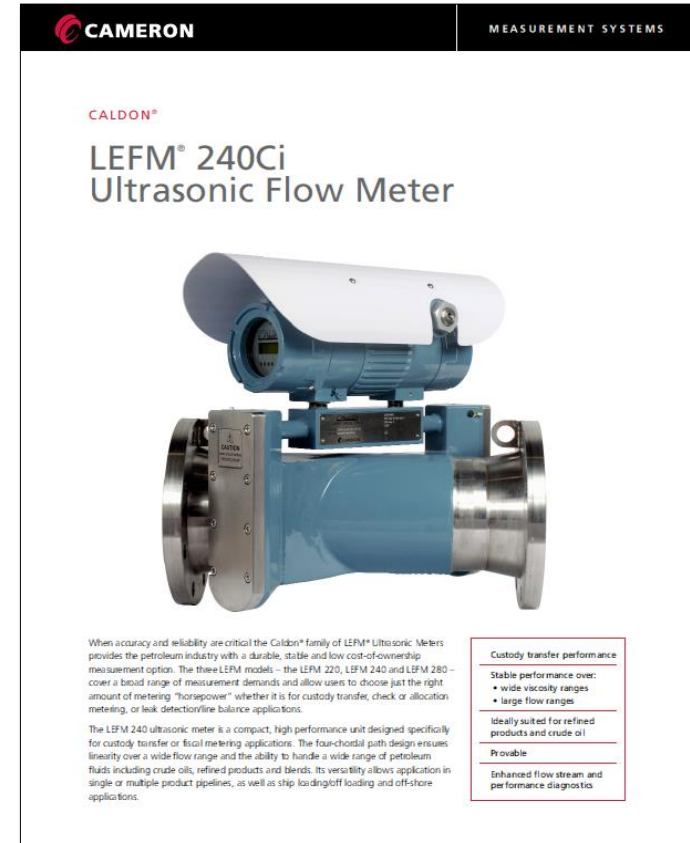
# History of Caldon meters

- **1965** - LEFM (Leading Edge Flow Meter) ultrasonic technology is developed by Westinghouse Electric Corporation
- **1968/1971** - Patent applied for and granted to Westinghouse for the first chordal multipath meter design using Gaussian integration
- **1975** – Nuclear Industry (Prairie Island primary reactor coolant loop, 4-path, 31-inch diameter meter)
- **1976** – TransAlaska pipeline, Petroleum (23 x 48-inch 4-path meters)
- **1989** - LEFM technology acquired by Caldon Inc. 
- **2000** - Caldon 8-path meter introduced for liquid applications
- **2006** - Caldon Inc. acquired by Cameron 
- **2012** - Caldon 380Ci 8-path meter introduced for gas applications

# The Leading Edge Flow Meter (LEFM) Product Range

## Caldon LEFM 240Ci

- 4 Paths (Gaussian Arrangement)
- Linearity
  - +/- 0.15 % multi-product
- Turndown
  - 10:1 (below 10")
  - 15:1 (10" and above)
- Flow conditioning
  - Recommended
  - Tube bundle
- Reynolds no. for best accuracy
  - Greater than 10,000



## Caldon LEFM 280Ci

- 8 Paths (Gaussian Arrangement)
- Linearity
  - +/- 0.1 % multi-product
- Turndown
  - 10:1 (4, 6 and 8")
  - 15:1 (10" and above)
- Flow conditioning
  - Not Required
- Reynolds no. for best accuracy
  - Greater than 10,000


MEASUREMENT SYSTEMS

**CALDON®**

**LEFM® 280Ci**  
Ultrasonic Flow Meter



When accuracy and reliability are critical the Caldon® family of LEFM® Ultrasonic Meters provides the petroleum industry with a durable, stable and low cost-of-ownership measurement option. The three LEFM models – the LEFM 220, LEFM 240, and LEFM 280 – cover a broad range of measurement demands and allow users to choose just the right amount of metering “horsepower” whether it is for custody transfer, check or allocation metering, or leak detection/line balance applications.

The LEFM 280Ci ultrasonic meter offers the highest level of performance of any ultrasonic flow meter on the market today. Its design makes it immune to swirl and less sensitive to other installation effects. This fact makes the LEFM 280Ci the ideal meter for the transfer of laboratory calibration to the field. It can be used with confidence in remote applications, where provers are not practical, or where space and weight allowances are limited.

**Master meter performance**

Compact measurement solution

Immune to swirl errors

Ideally suited for:

- LNG, refined products, and crude oils
- check and master metering
- complete condition monitoring

Provable

Superior flow stream and performance diagnostics



## Caldon LEFM 280CiRN

- 8 Paths (Gaussian Arrangement)
- Linearity
  - +/- 0.1 % multi-product
- Turndown
  - 10:1 (6 and 8")
  - 15:1 (10" and above)
- Flow conditioning
  - Not Required
- Reynolds no. for best accuracy
  - NO LIMITATIONS
- Best repeatability/provability of the range


MEASUREMENT SYSTEMS

**CALDON®**

**LEFM® 280CiRN**  
Ultrasonic Flow Meters



Measuring oils having high viscosity and/or low flow conditions may involve operating at Reynolds numbers below 8,000. Ultrasonic flow meter performance has traditionally been degraded for Reynolds numbers below 8,000 because the liquid velocity profile erratically switches between laminar and turbulent characteristics.

Cameron has developed a new ultrasonic flow meter design with a reduced bore, modeled after flow nozzle technology, in which the liquid velocity profile is stabilized by forces much larger than the forces imposed by fluid viscosity. The meter design stabilizes the flow profile while preventing boundary layer separation under all operating conditions, greatly improving performance.

The 280CiRN provides the highest possible performance and has an excellent success rate of achieving a data spread of 0.05% in 5 prover runs.

custody transfer performance down to Reynolds Numbers of 1000 and lower

ideally suited for higher viscosity oils and/or low flow rates

High success rate for provability to 0.05% in 5 runs with standard size prover

Minimal requirements for upstream/downstream piping

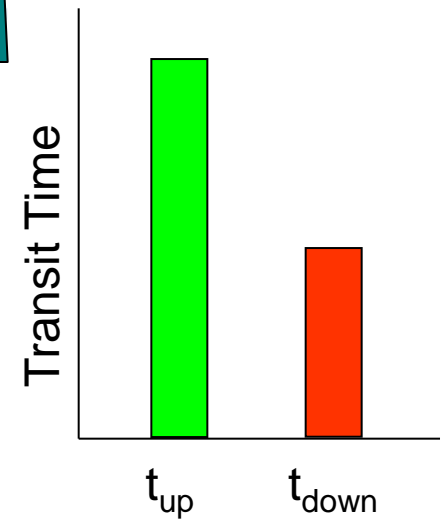
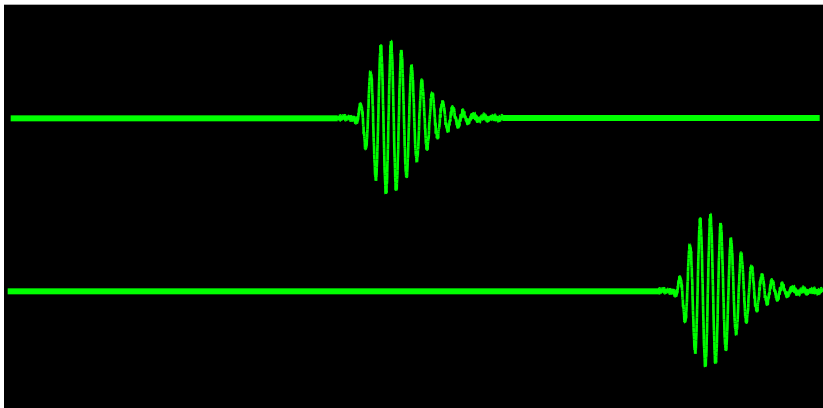
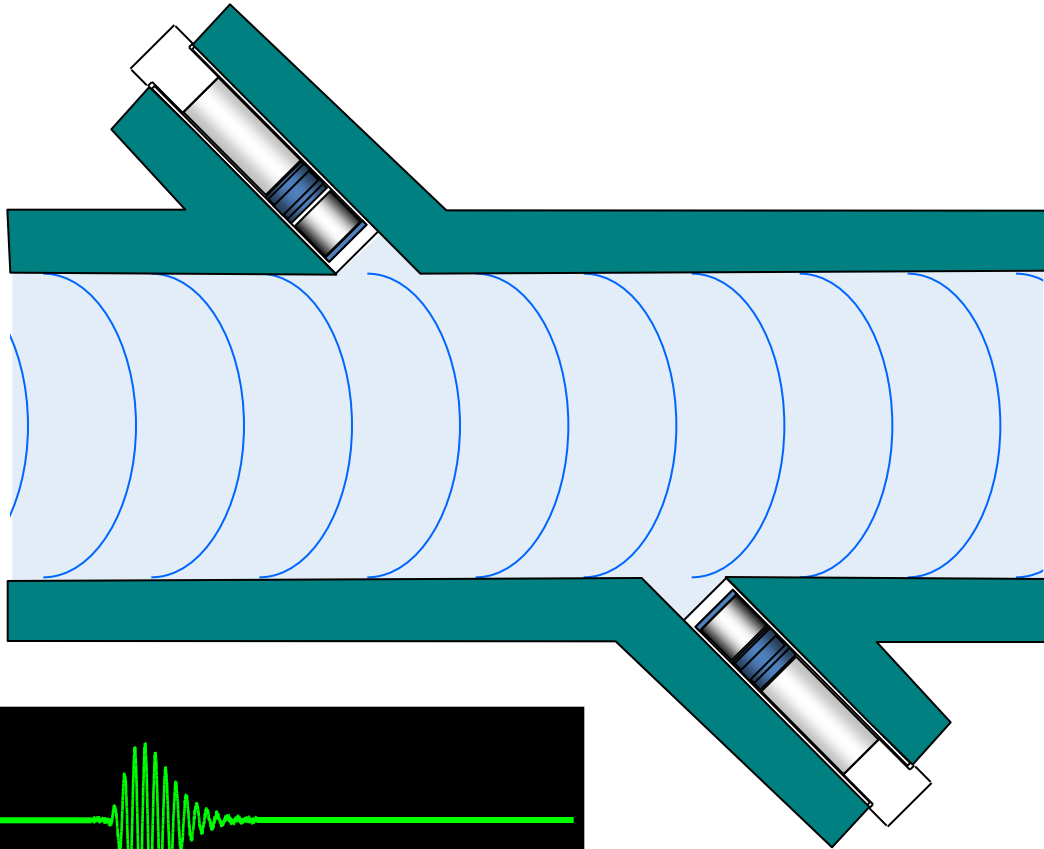
# Caldon LEFM 380Ci

- 8-path (Gaussian) design, swirl immunity without the need for flow conditioning
- 5D minimum upstream installation length
- Transducers isolated in pressure retaining housings and removable under full line pressure without the need for special tools
- Coated meter body to maintain integrity of the meter's calibration



# Why 4 and 8 paths?

# Transit time difference principle

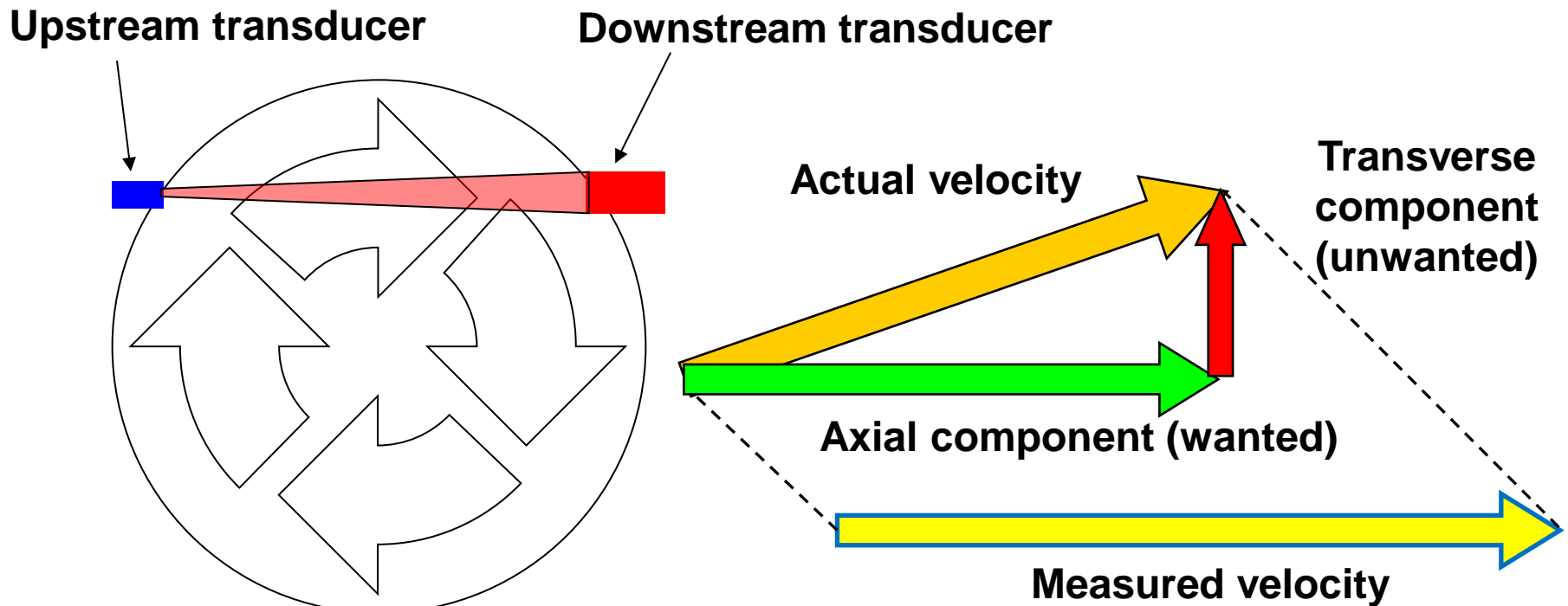


## Contributors to installed uncertainty

- Traceability of the calibration standard
- Calibration residual errors (linearisation)
- Consistent geometry
- Transit time measurement accuracy in application conditions
- **INSTALLATION EFFECTS**
  - VELOCITY PROFILE
  - **SWIRL**

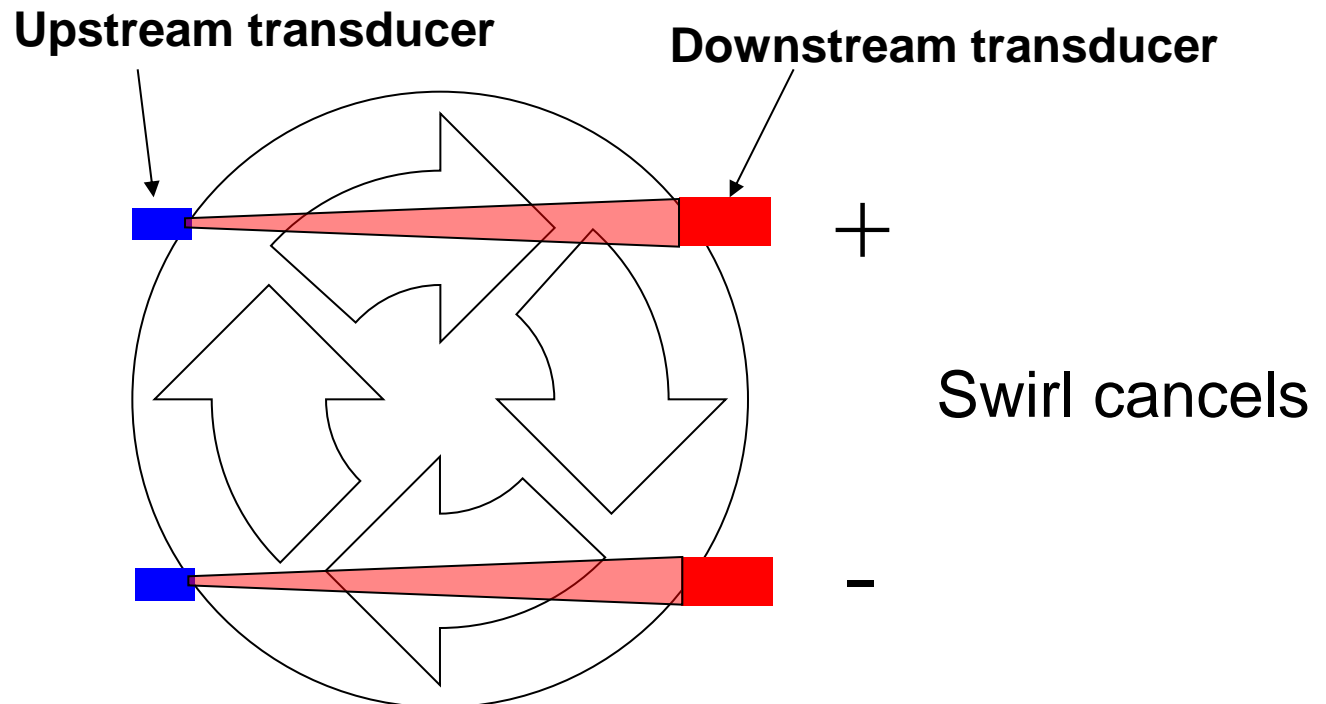
# The effects of swirl

- Non-axial flow components (swirl) result in systematic errors in individual path velocities



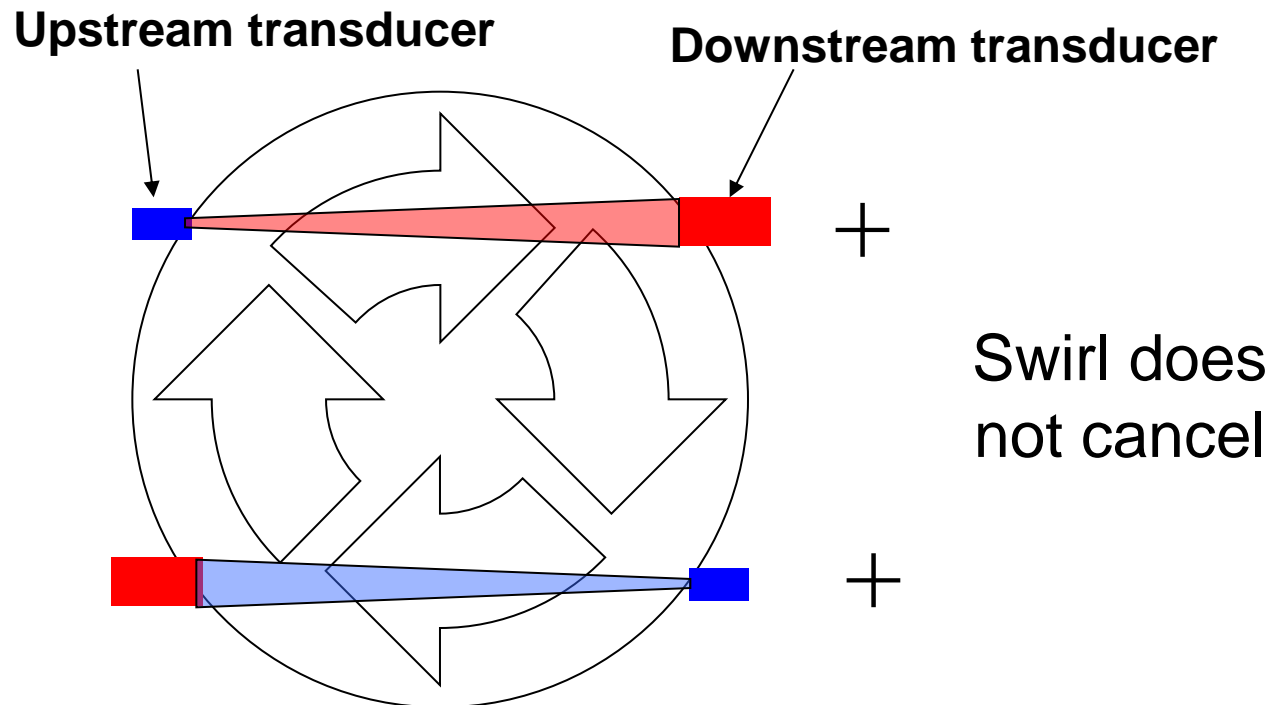
# Swirl

- When dealing with non-axial flow we also have to consider the path orientation



# Swirl

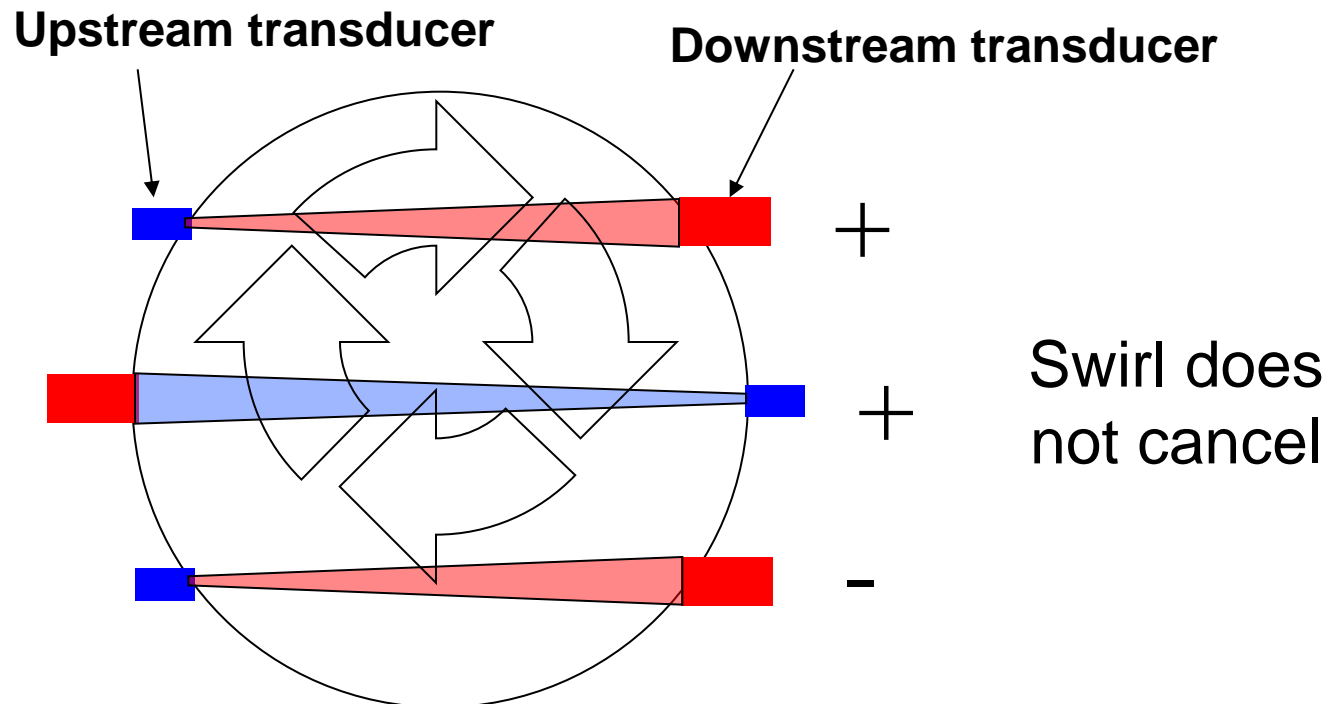
- Crisscrossed paths behave differently to parallel paths





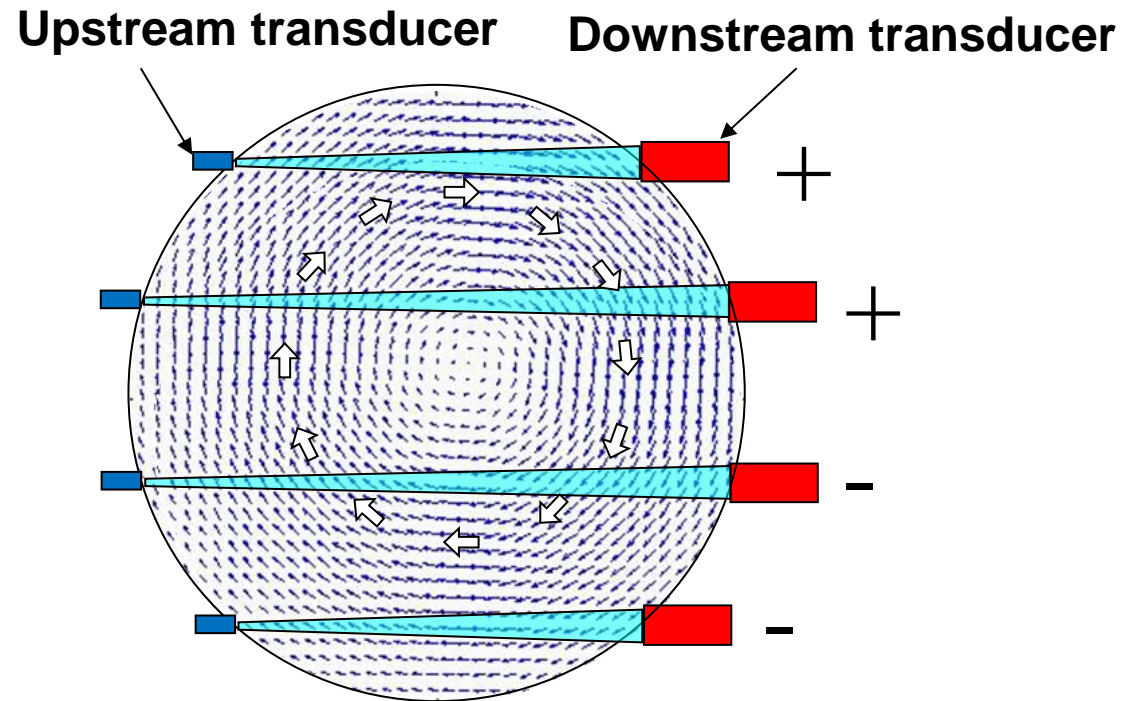
# Swirl

- With single plane or criss-crossing arrangements, swirl only cancels when perfectly centred

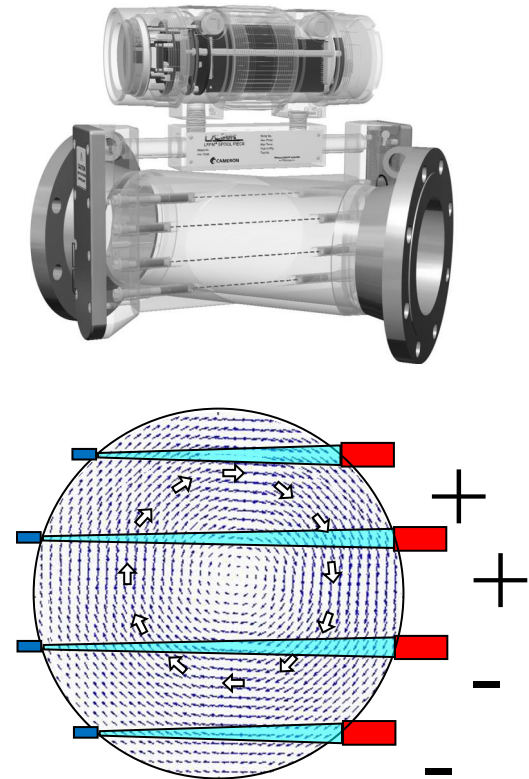
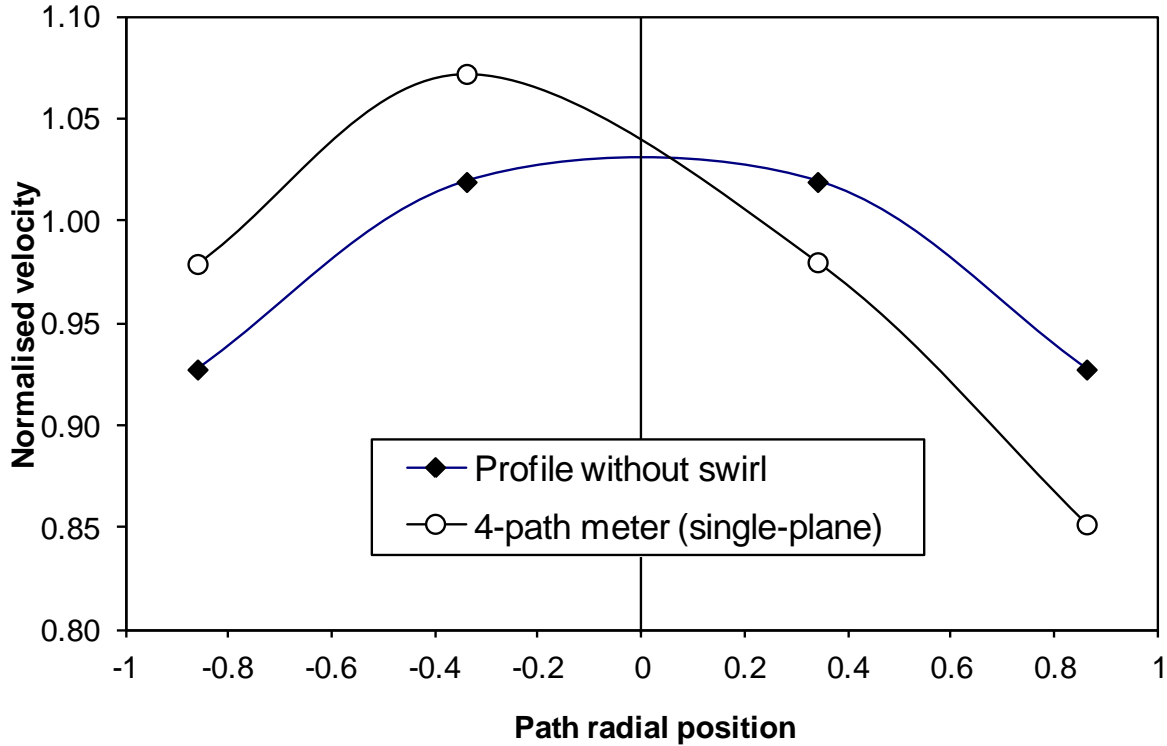


# 4-path, planar configuration

- With a planar arrangement, swirl only cancels when perfectly centred

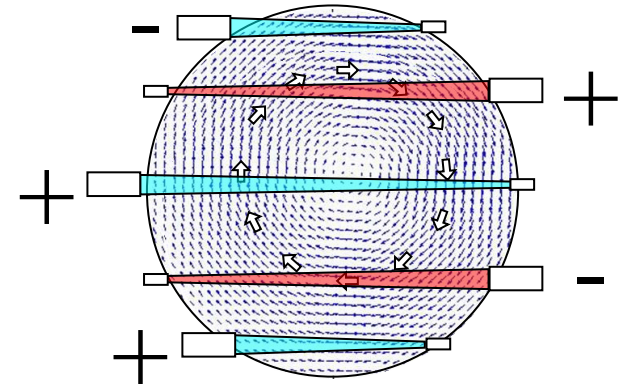
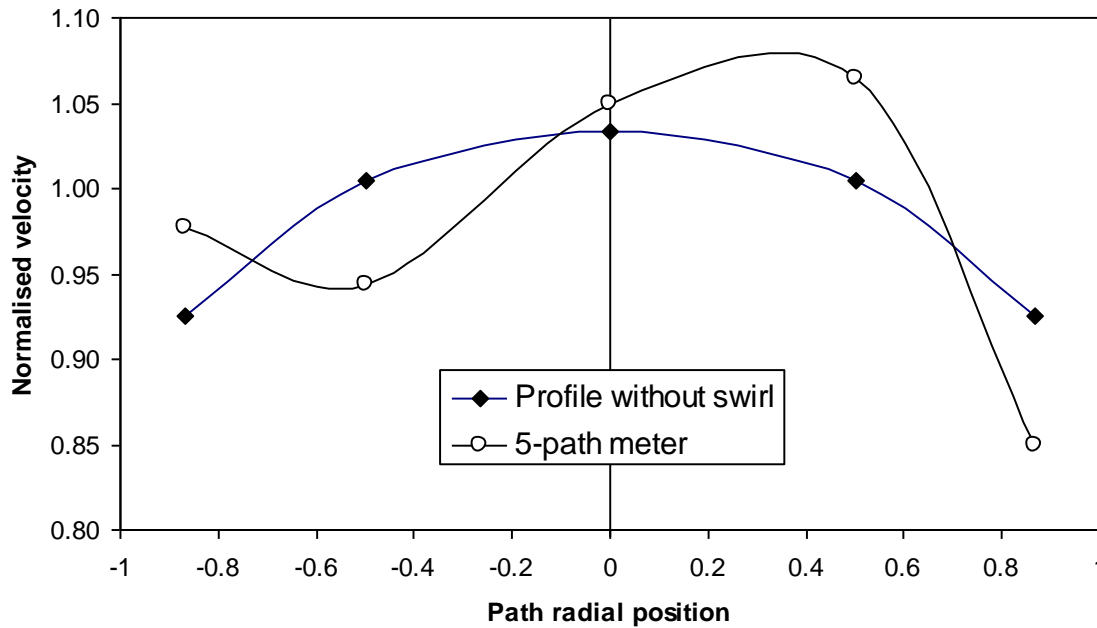


# 4-path, planar configuration



- Swirl error = 0.26 %

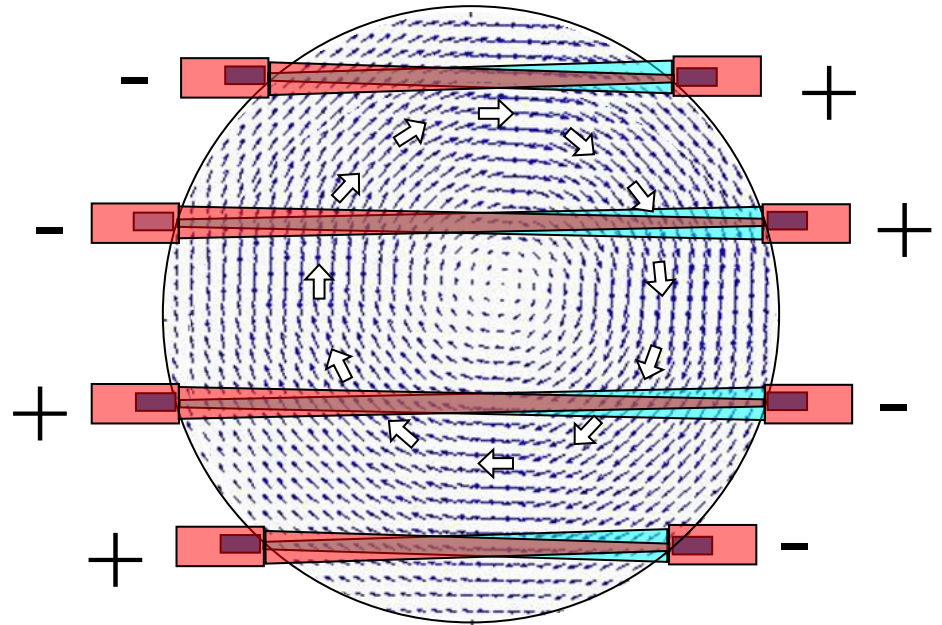
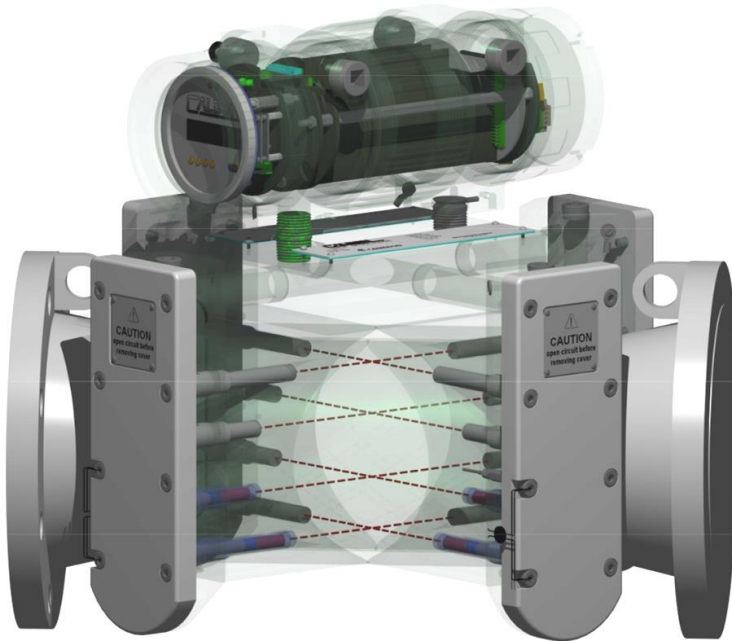
# 5-path, non-planar configuration



- Swirl error = 0.33 %

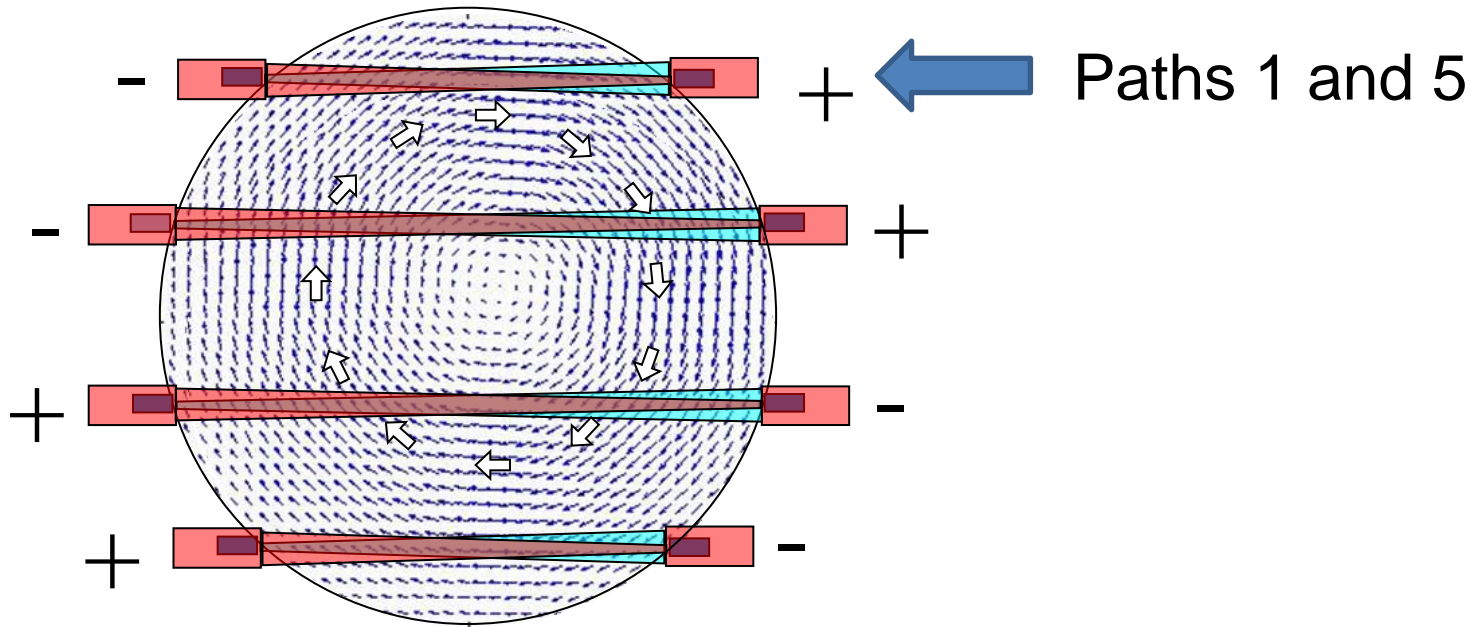
## Eight-path Caldon 280Ci/380Ci

- Designed for swirl immunity
- Flow conditioning not required

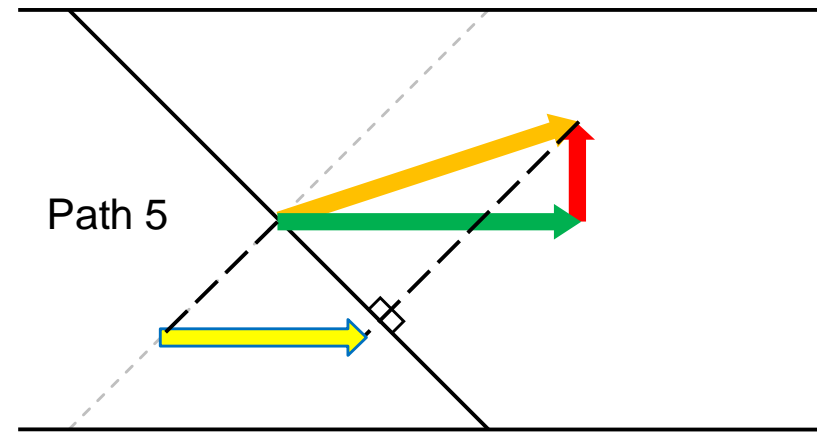
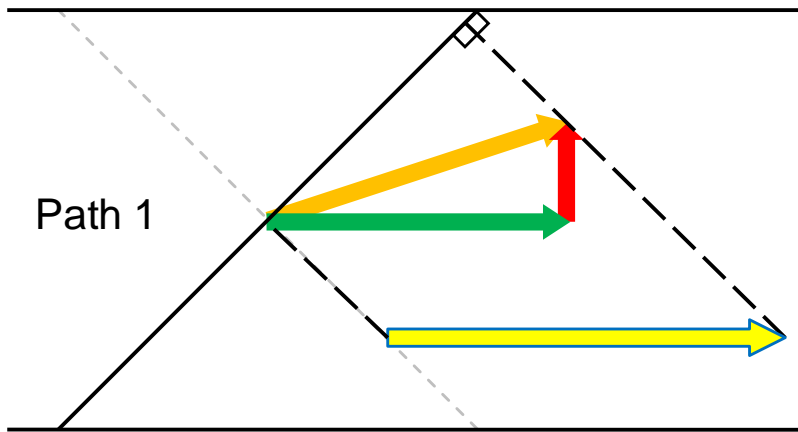


# How the crossed paths work

- Two crossing paths are placed precisely in each chordal plane

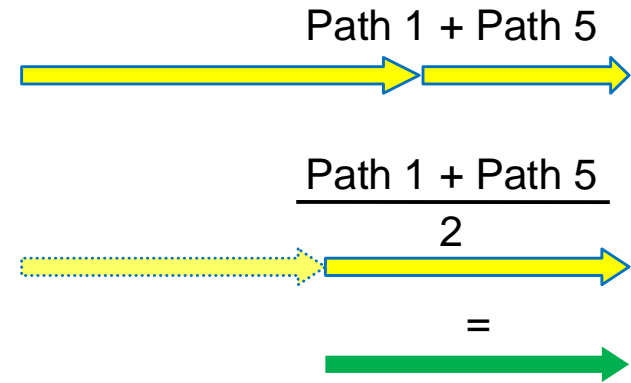


# How the crossed paths work

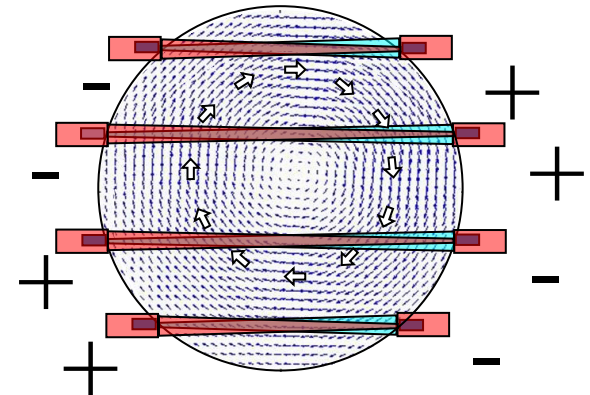
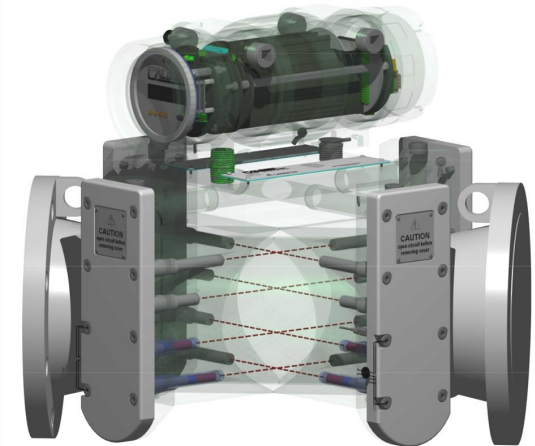
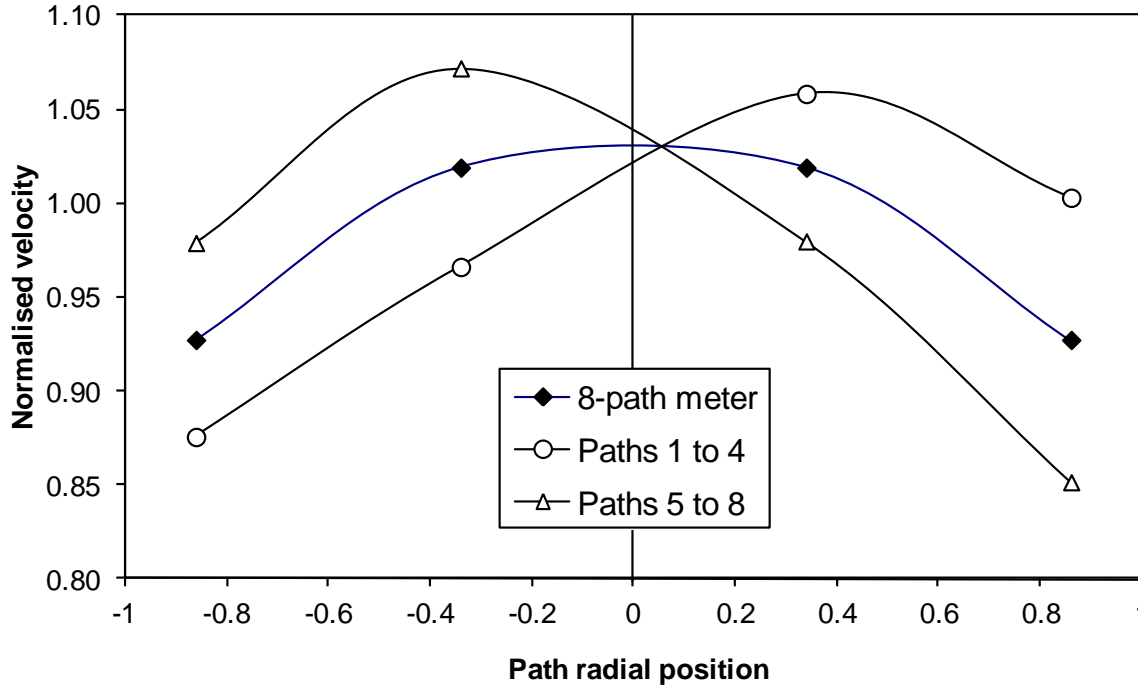


Key:

- Actual velocity
- Axial component (wanted)
- Transverse component (unwanted)
- Measured velocity



# Eight-path crossed plane design

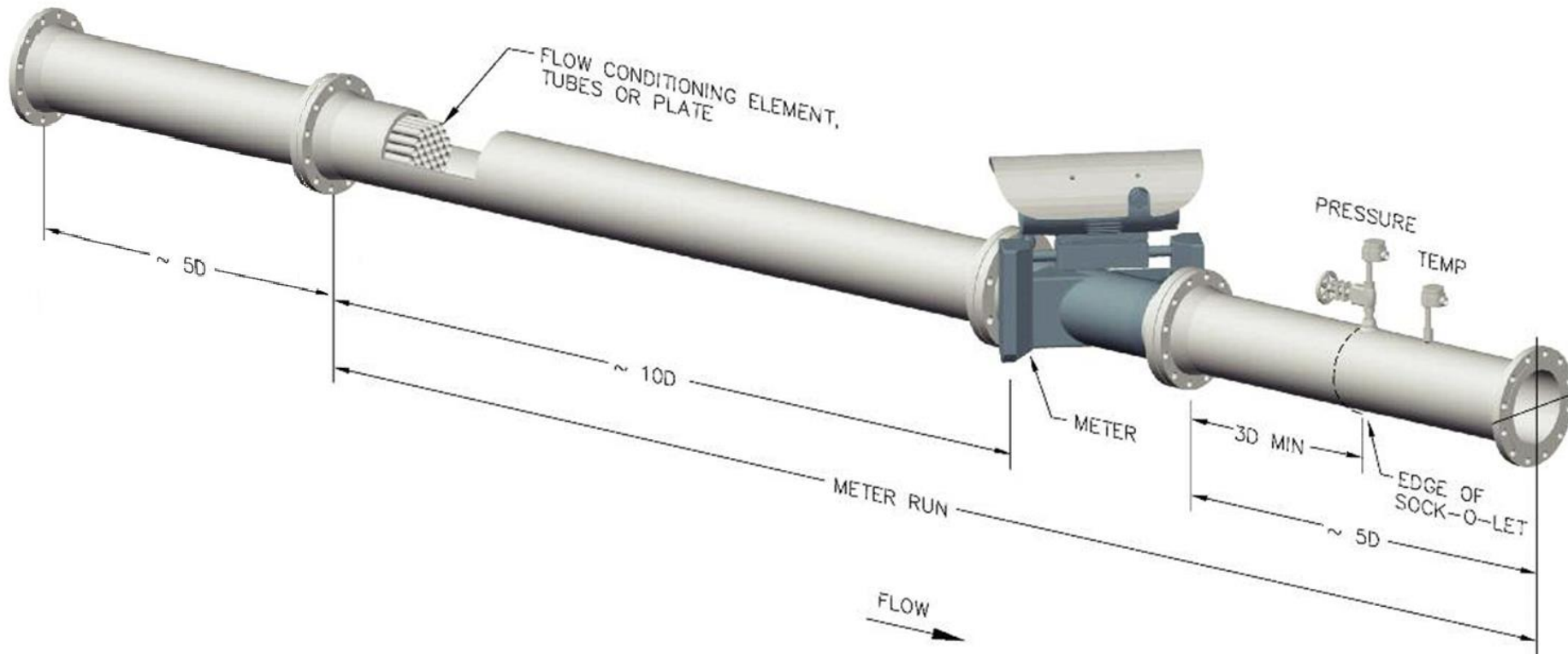


- Swirl error = 0 %



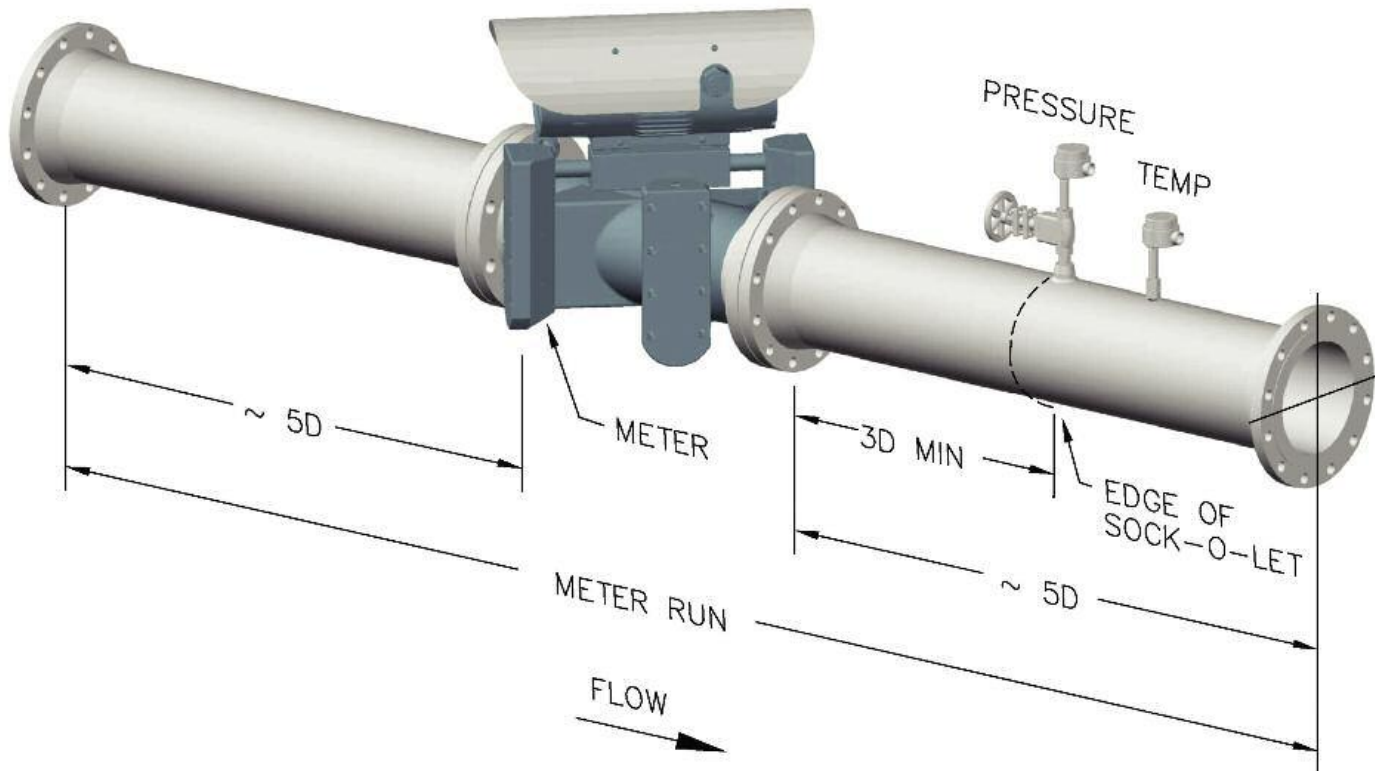
# 240Ci 4-path meter installation

- Upstream 10 diameters inclusive of a flow conditioner and a further 5D, typically 23D in total



# 280Ci/280CiRN 8-path meter installation

- Upstream 5 diameters, no flow conditioner, typically 13D in total



# Issues with Flow Conditioners

## Flow Conditioners

- These can be used to eliminate swirl, however...



**Tube Bundle**

**Vortab**

**Zanker**

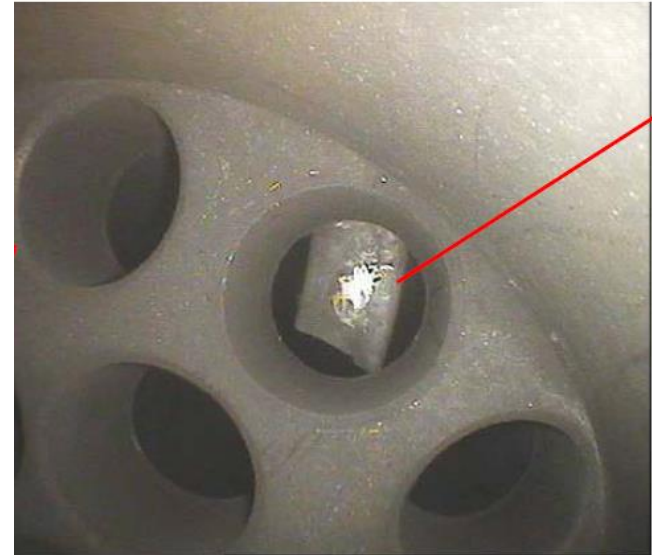
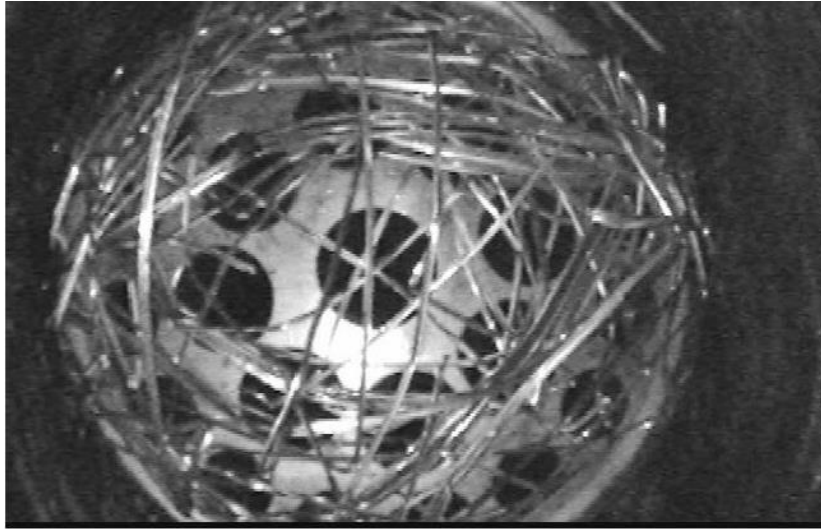
**Mitsubishi**

**CPA**

## Flow conditioners

- They create pressure loss
  - For the Keystone pipeline the estimated value of the pressure losses over the operation of the life of the pipeline was estimated to exceed 20 million US dollars
- They have to be applied properly
- They have to be maintained

# Flow conditioner maintenance



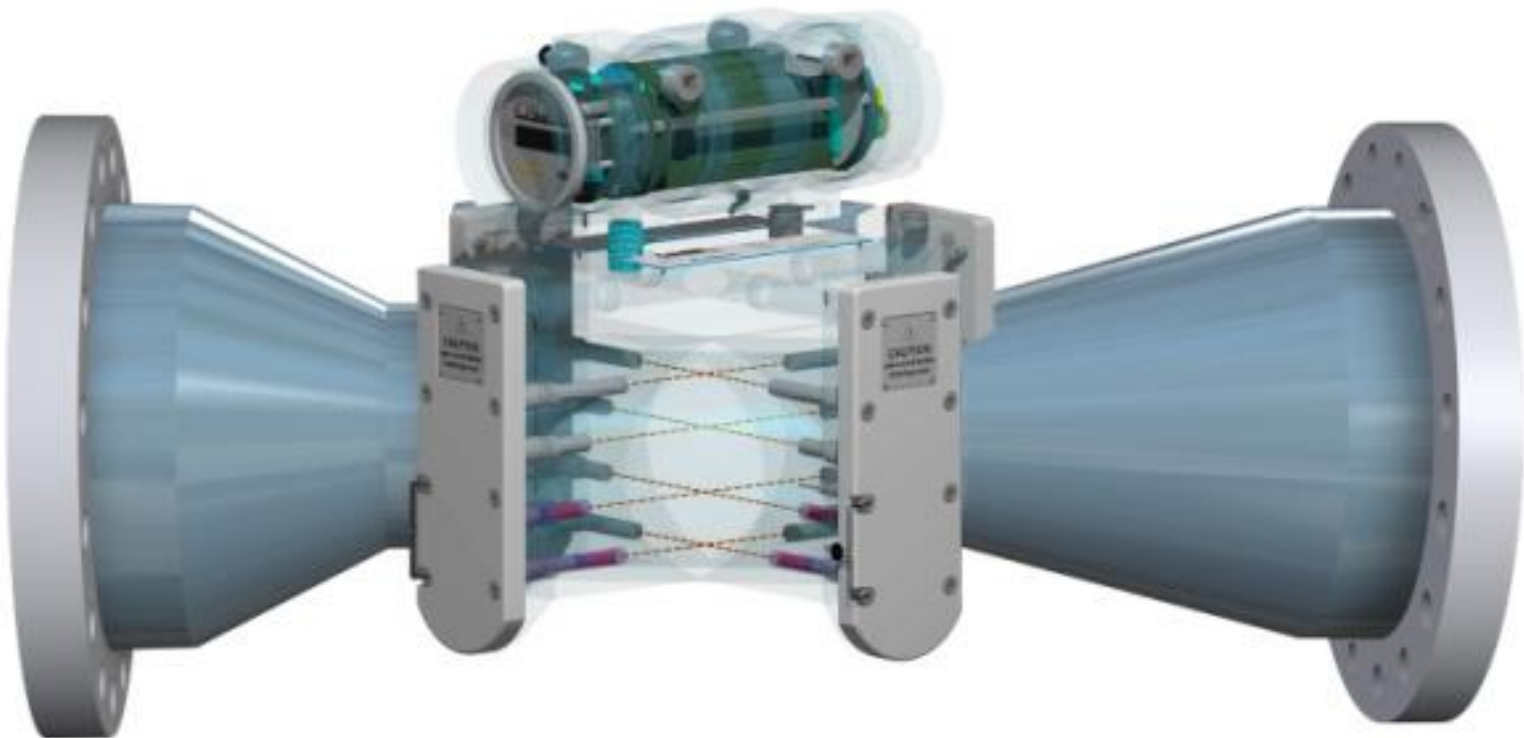
Blockage



**Caldon LEFM 280CiRN  
for  
High Viscosity Liquids  
and In-Situ Proving**

# Caldon meter with reducing nozzle

- LEFM 280CiRN
- 8-path, 4-chord measurement section in throat



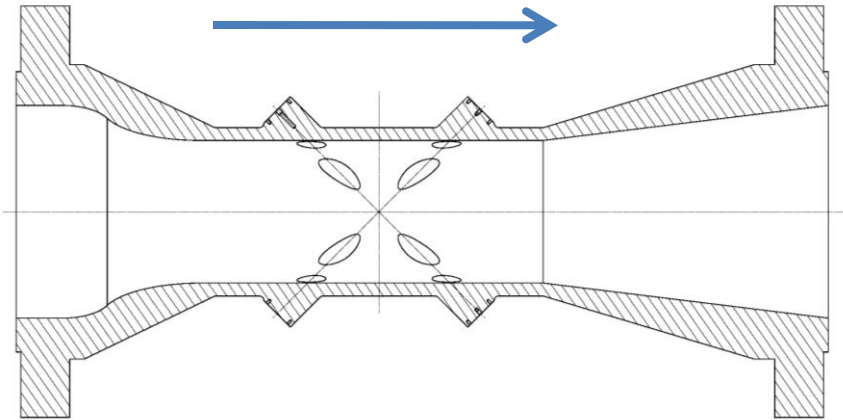


## **Caldon meter with reducing nozzle**

- Developed to tackle heavy crudes and compete with PD meter performance even through the laminar/turbulent transition region where ultrasonic meters and turbine meters perform poorly

# Caldon meter with reducing nozzle

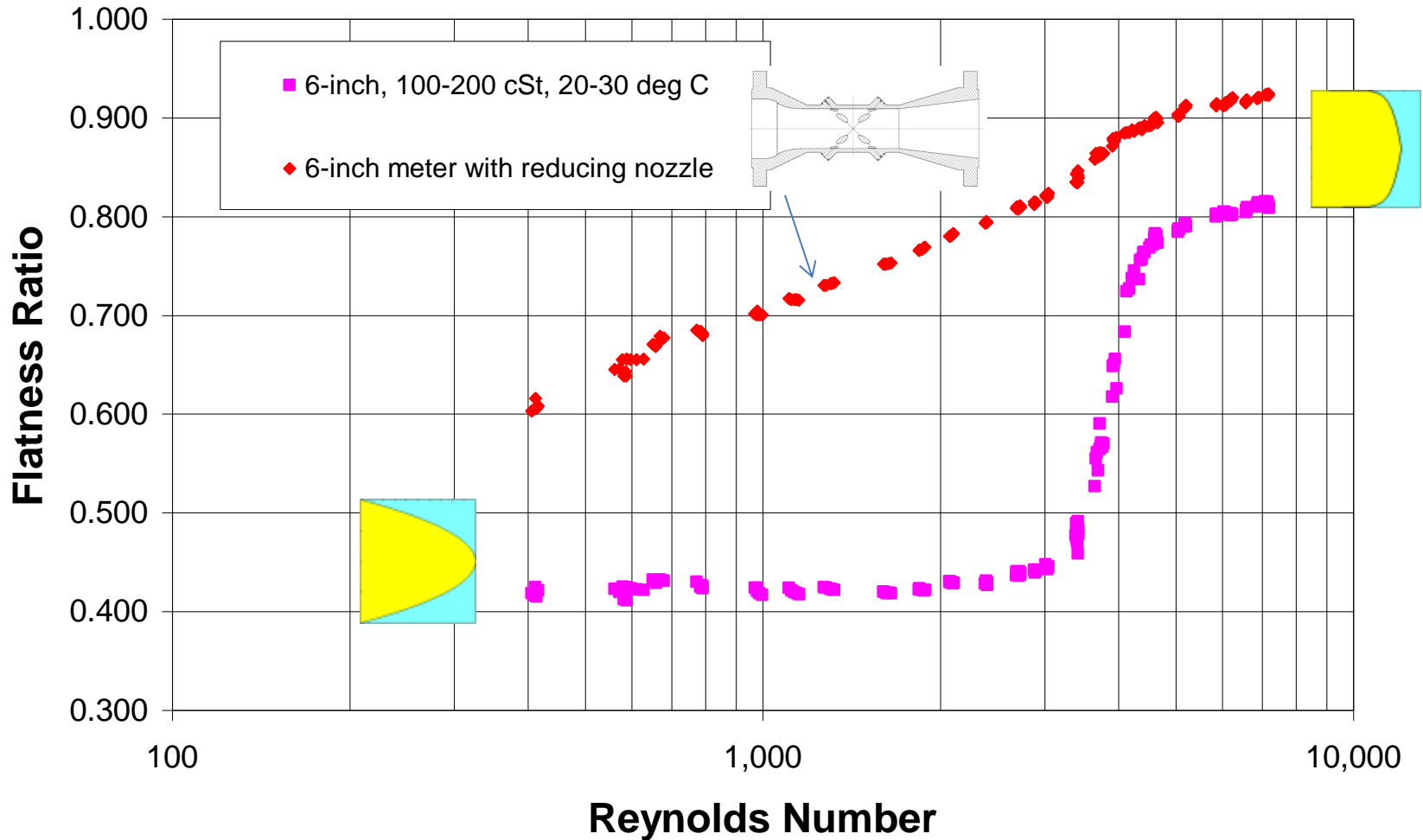
- Reducing **elliptical nozzle shaped inlet**
- **Substantial diameter/area reduction**
- **Beta < 0.64, area ratio < 0.41**
- Downstream pressure recovery cone



## What does it do?

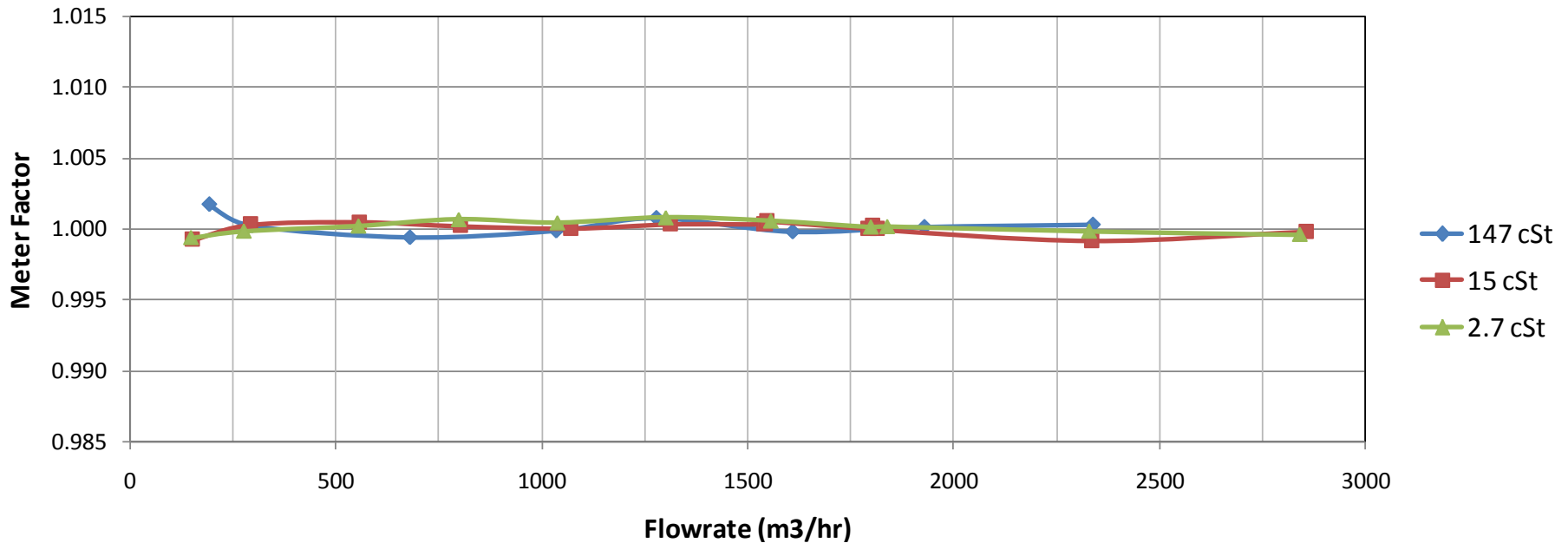
- The reducing nozzle works by:
  - Increasing the Reynolds number in the throat
  - **Flattening the velocity profile and smoothing out the transition between laminar and turbulent flows**
  - Reducing the relative magnitude of the non-axial velocities

# Modified velocity profile behaviour



# Caldon meter with reducing nozzle

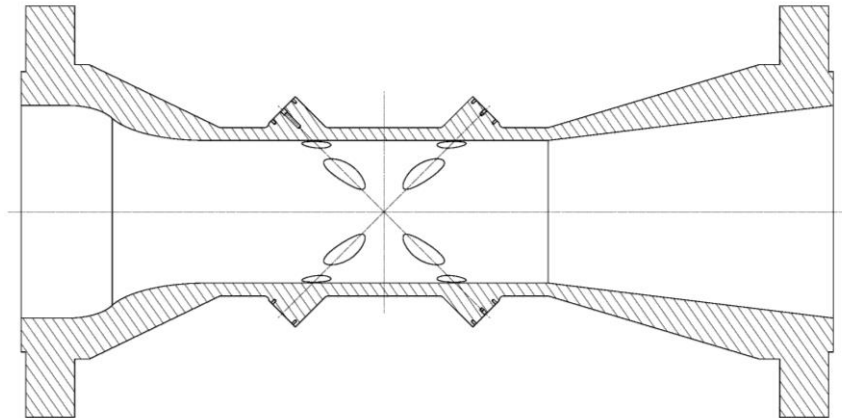
- Equals PD meter performance even through the laminar/turbulent transition region
- OIML certified with no Reynolds no. limitation



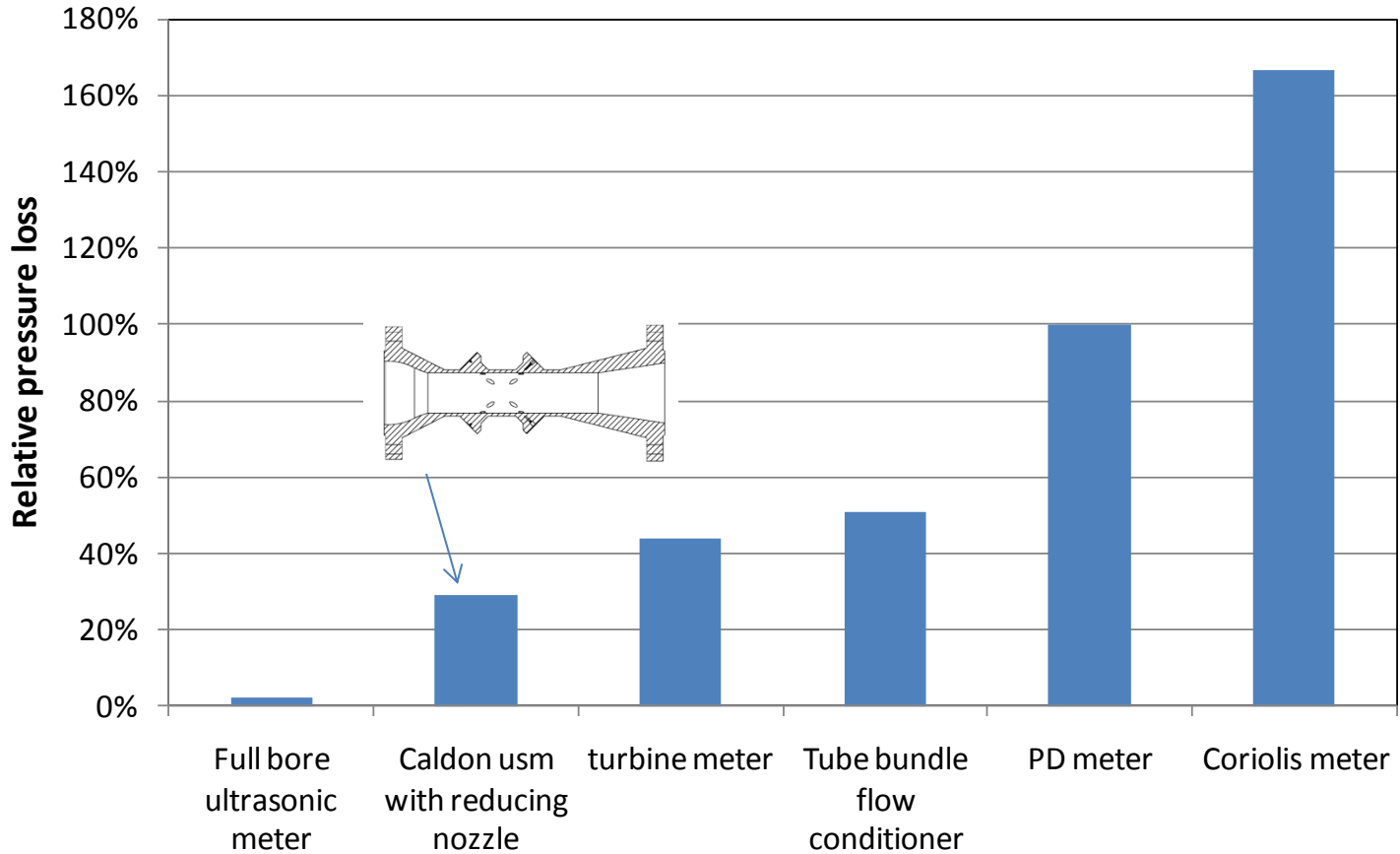
# Pressure loss

- Pressure loss

- Losses are minimised by using a conical expansion downstream of the throat

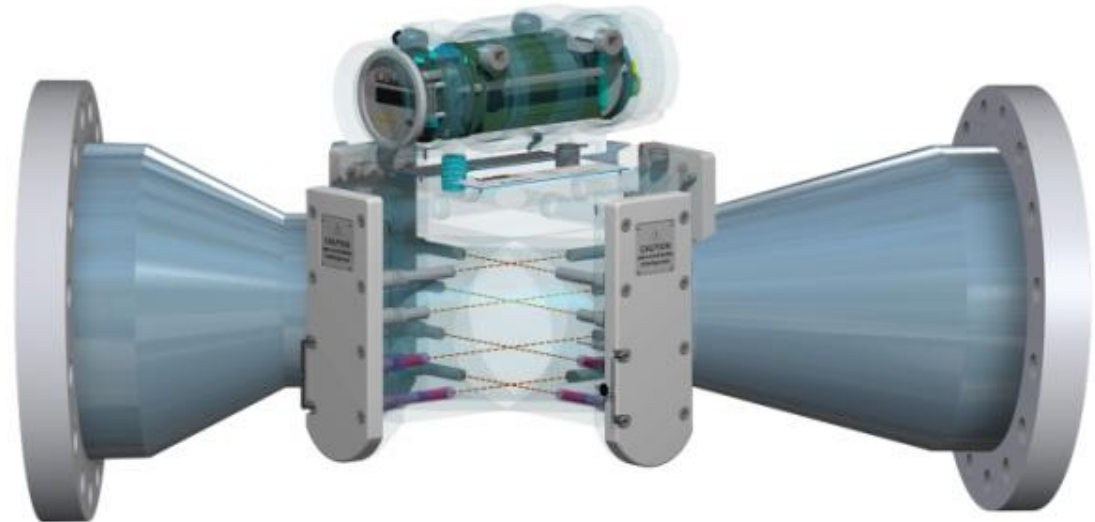


# Relative pressure loss



## Caldon 280CiRN meter with reducing nozzle

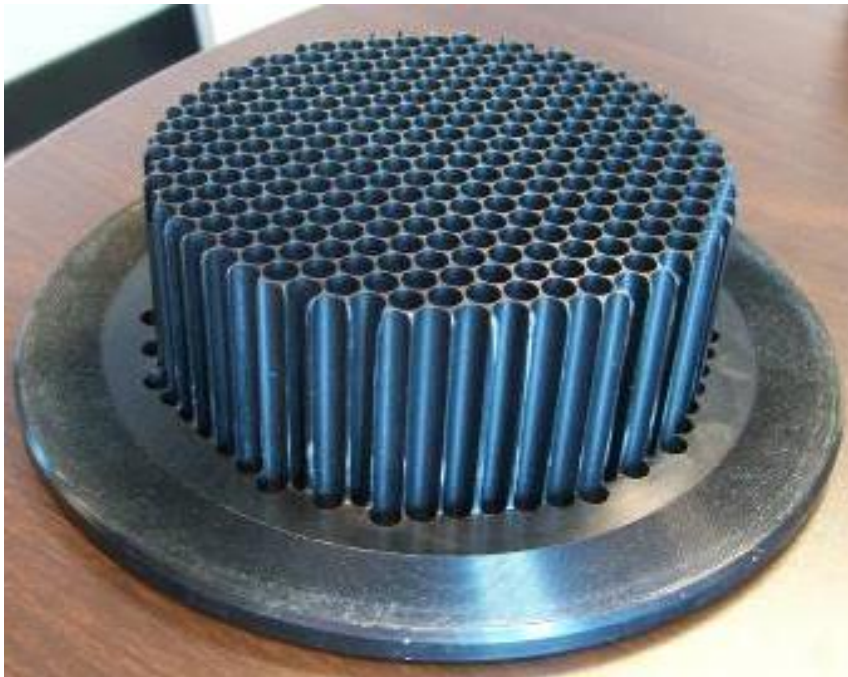
- Rapid acceleration of the flow via the smooth contour of the nozzle increases the axial velocity at the measurement section and reduces the relative magnitude of the turbulent features in the flow
- This results in a significant improvement in repeatability



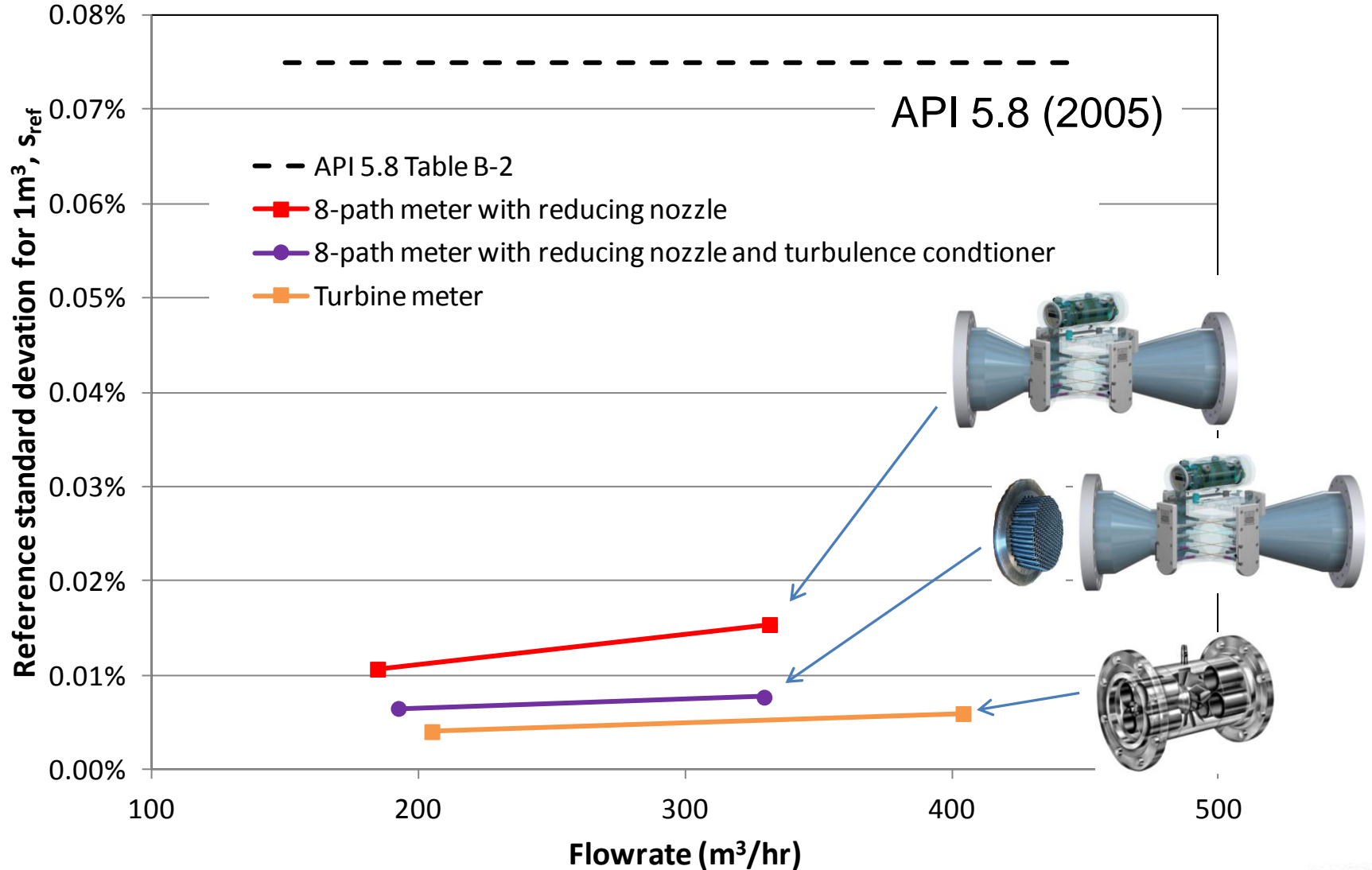


## Turbulence conditioner

- Restricts the size of turbulent eddies resulting in higher frequency turbulence and better averaging

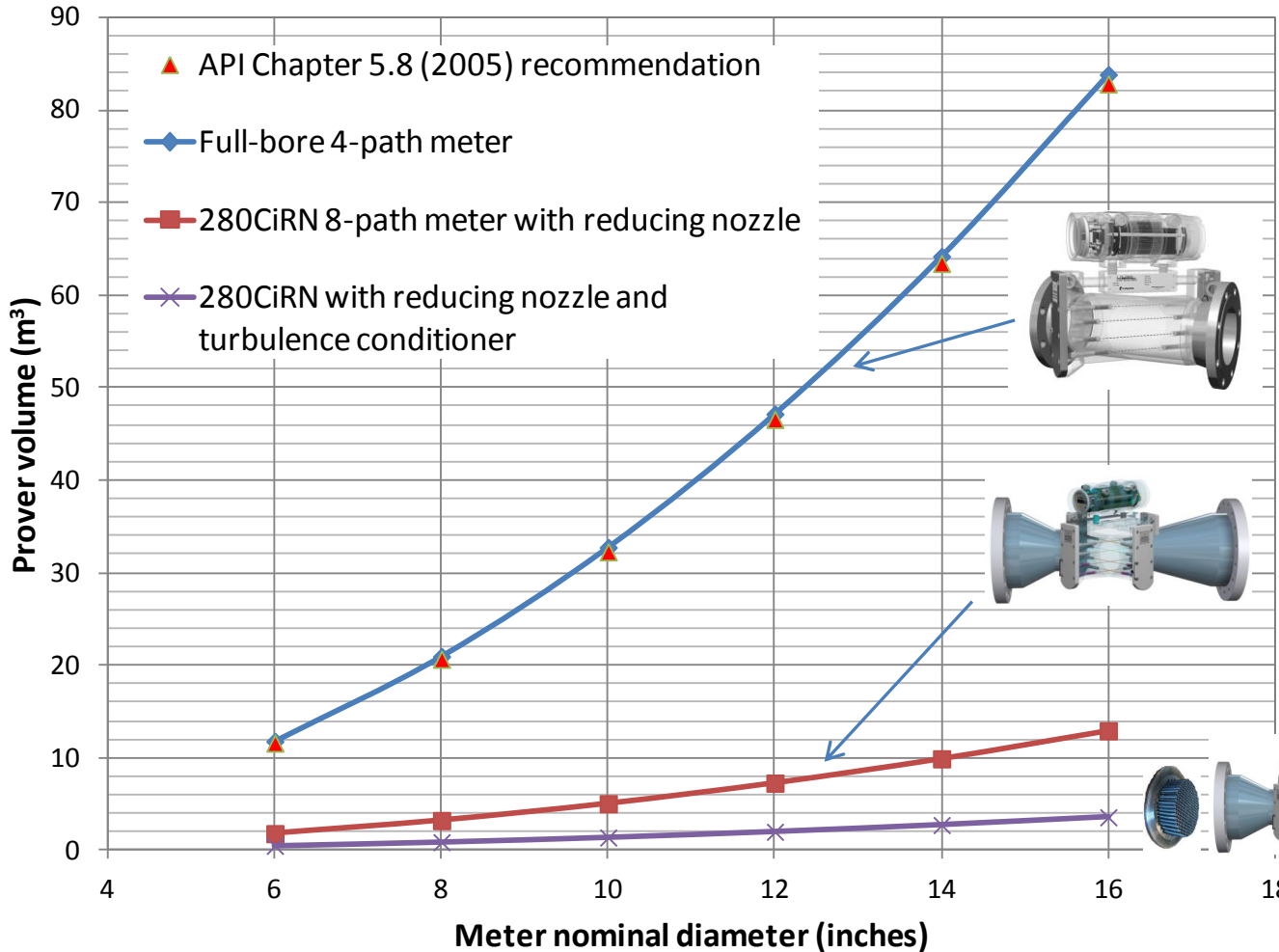


# Reducing nozzle & turbulence conditioner



# Impact on proving volumes required

- Comparison at 60% success rate



Field Calibration

Prover and master meter combination




Ball prover, direct calibration

SVP, direct calibration

# **Custody transfer certification and traceable calibration for liquid measurement**

## Custody transfer certification

- Certification of full product range by NMI, the leading European metrology certification body
- MID – Measurement Instruments Directive
- OIML R117 – Dynamic measuring systems for liquids other than water

		<b>Evaluation Certificate</b>
		Number TC7381 revision 5 Project number 10200358 Page 1 of 1
Issued by	NMI Certin B.V.	
In accordance with	– WELMEC guide 8.8 "General and Administrative Aspects of the Voluntary System of Modular Evaluation of Measuring Instruments under the MID." – OIML R117-1 Edition 2007 (E) "Dynamic measuring systems for liquids other than water".	
Manufacturer	Cameron Measurement Systems 1000 McClaren Woods Drive Coraopolis, PA15108, United States of America	
Measuring instrument	A <b>Measurement sensor</b> (ultrasonic sensor and belonging electronics), intended to be used as a part of a measuring instrument. Type : LEFM 220CI; LEFM 220CAI; LEFM 240CI; LEFM 280CI; LEFM 240CIRN; LEFM 280CIRN. Destined for the measurement of : liquid petroleum and related products, liquid food and chemical products in liquid state, with viscosities 0,1 mPa·s to 3000 mPa·s. $Q_{min} - Q_{max}$ : see paragraph 1.2 of Description Minimum measured quantity : see paragraph 1.2 of Description Accuracy class : 0,3 (LEFM 220CAI; LEFM 240CI; LEFM 240CIRN; LEFM 280CI & LEFM 280CIRN) Environment classes : M2 / E2 Temperature range liquid : -40°C / +70°C (LEFMxxCI and LEFMxxCIRN) : -50°C / +110°C (LEFMxxCI-R and LEFMxxCIRN-R) : -200°C / +110°C (LEFMxxCI LT-R and LEFMxxCIRN LT-R) Temperature range ambient : -40°C / +55°C	
Remarks	Further properties are described in the annexes: – Description TC7381 revision 5 – Documentation folder TC7381-3 An overview of performed tests is given in Appendix TC7381 revision 5. This revision 5 replaces revision 4 except for its documentation folder.	
Issuing Authority	NMI Certin B.V. 2 August 2010  C. Oosterman Head Certification Board	
NMI Certin B.V. Hugo de Grootplein 1 3314 EG Dordrecht The Netherlands T +31 78 6322332 certin@nmi.nl www.nmi.nl		This document is issued under the provision that no liability is accepted and that the applicant shall indemnify third-party liability. The designation of NMI Certin B.V. as Notified Body can be verified at <a href="http://ec.europa.eu/enterprise/newapproach/naibo">http://ec.europa.eu/enterprise/newapproach/naibo</a> Parties concerned can lodge objection against this decision, within six weeks after the date of submission, to the general manager of NMI (see <a href="http://www.nmi.nl">www.nmi.nl</a> ). Reproduction of the complete document only is permitted.
		

## Custody transfer certification

- Broadest range of certification in the market
- Highest available accuracy class (0.2 % MPE)
- Covers 4 and 8 path meters, full bore and reducing nozzle variants
- Meter diameters from 4 to 24 inch
- Viscosity range 0.1 to 3000 cP
- Temperature from -200 °C to +110 °C
- Turndown of 50:1 possible

## Caldon meter calibration

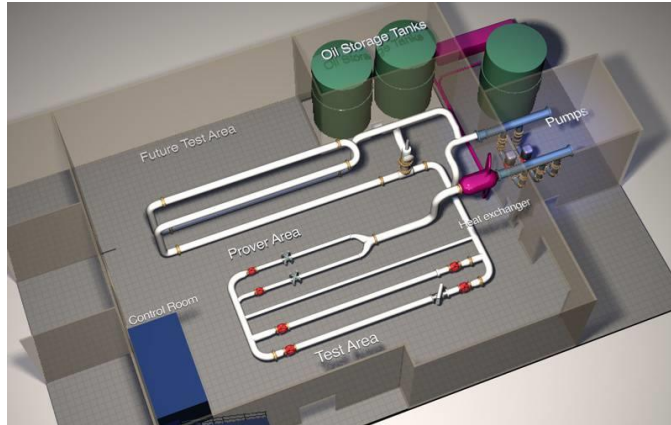
- Every Caldon meter is given a fully traceable flow calibration using liquid hydrocarbons . . . even if it is going to be proven in-situ
- This ensures the highest possible performance (lowest uncertainty) in the final application

CALDON ULTRASONICS  
TECHNOLOGY CENTRE  
CALIBRATION LABORATORY





## Main laboratory area



- Prover
- Master meters
- Heat exchanger
- Test meter lines
- 7.5 ton bridge crane
- Main control room

The floor is recessed (7 inches) to provide containment in case of a possible spill

## Calibration fluids

- Refined hydrocarbon oils
- Oils chosen to give a good range of viscosity for Reynolds number overlap
  - EXXSOL D80, kerosene substitute, approx. 3 cSt
  - DRAKEOL 5, approx. 15 cSt
  - DRAKEOL 32, approx. 150 cSt



# Unidirectional ball prover

- 20-inch diameter, 10 cubic meter calibrated volume ball prover, flow range of 40 to 2200 m<sup>3</sup>/hr



## Chosen route for certification/accreditation

- NEL, Trapil and SPSE are all accredited to ISO17025 by the recognised authority in their respective countries (UKAS, COFRAC)
- Equivalence required that the Caldon laboratory should also have ISO17025 accreditation
- Various providers in the USA
- Caldon chose to use the National Voluntary Laboratory Accreditation Program (NVLAP) operated by the National Institute of Standards and Technology (NIST)


## Mutual recognition arrangements

- NVLAP is a signatory to the following MRA's:
  - ILAC - International Laboratory Accreditation Cooperation
  - APLAC - Asia Pacific Laboratory Accreditation Cooperation
  - IAAC - Inter American Accreditation Cooperation




## NVLAP Certified Uncertainties

- 10 to 750 m<sup>3</sup>/hr
  - Small volume prover 0.03%
  - Turbine master meter 0.04%
- 150 to 2200 m<sup>3</sup>/hr
  - Ball prover 10 m<sup>3</sup> 0.04%
  - Ball prover 3.3 m<sup>3</sup> 0.07%
  - One master meter 0.09%
- 600 to 3900 m<sup>3</sup>/hr
  - Two master meters 0.08%



**National Voluntary  
Laboratory Accreditation Program**



DEPARTMENT OF COMMERCE  
UNITED STATES OF AMERICA

**SCOPE OF ACCREDITATION TO ISO/IEC 17025:2005**

Cameron Measurement Systems  
Caldon Ultrasonics Technology Center  
1000 McClaren Woods Drive  
Coraopolis, PA 15108-7766  
Mr. Bobbie Griffith  
Phone: 724-273-9134 Fax: 724-273-9301  
E-mail: bobbie.griffith@c-a-m.com

CALIBRATION LABORATORIES

NVLAP LAB CODE 200813-0  
Scope Revised: 2011-08-19

**MECHANICAL**

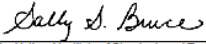
NVLAP Code: 20/M05  
Flow Rate (Hydrocarbon Fluids Only)<sup>Notes 1,2</sup>

Range in m <sup>3</sup> /h	Best Uncertainty (±) in % <sup>note 1</sup>	Remarks
10 to 750	0.03	Brooks Small Volume Prover
10 to 750	0.04	One Master Meter
150 to 2200	0.04	10 Cubic Meter Prover Volume
50 to 200	0.07	3.3 Cubic Meter Prover Volume
300 to 2000	0.09	One Master Meter
600 to 3900	0.08	Two Master Meters

<sup>1</sup> Represents an expanded uncertainty using a coverage factor, *k* = 2, at an approximate level of confidence of 95 %.  
<sup>2</sup> The laboratory performs calibrations of pulse generating flow meters.  
<sup>3</sup> The laboratory performs volumetric flow calibrations only (not mass flow).

2011-07-01 through 2012-06-30

Effective dates



For the National Institute of Standards and Technology

Page 1 of 1
NVLAP-219 (REV. 2004-10-31)

## Calibration Process

- For Coriolis meters the calibration process typically involves tests on multiple fluid viscosities and entry of the resulting data in a look up table in the meter's electronics
- This creates a meter that is insensitive to changes in viscosity/Reynolds number over the range covered by the test fluids

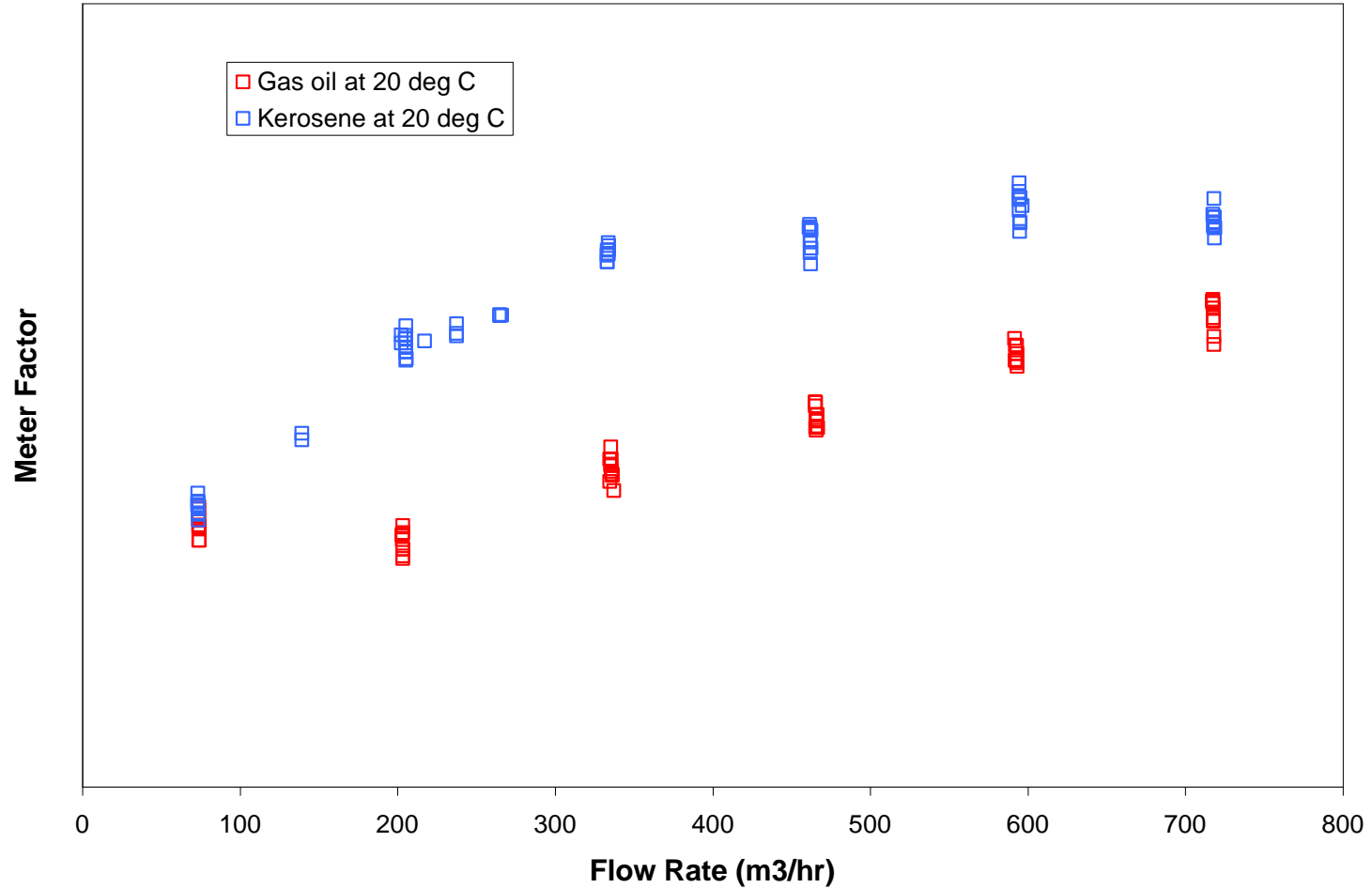
## Reynolds number

- Reynolds number describes the flow conditions in terms of velocity, pipe diameter and viscosity, and essentially defines the flow velocity profile characteristics of importance to ultrasonic meters

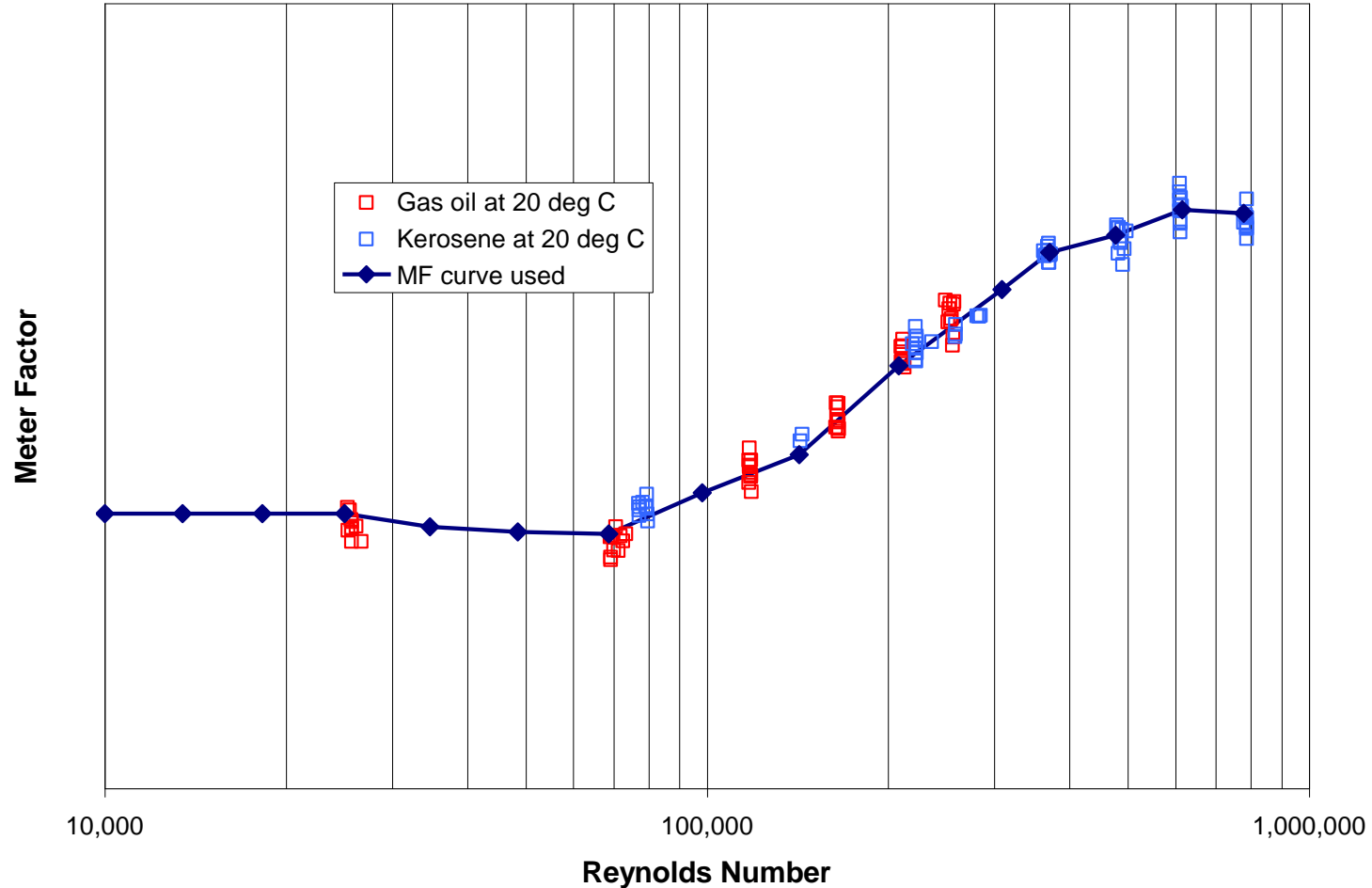
$$\textit{Reynolds number} = \frac{\textit{Velocity} \times \textit{Diameter}}{\textit{Kinematic viscosity}}$$



# Raw Calibration vs Flow Rate



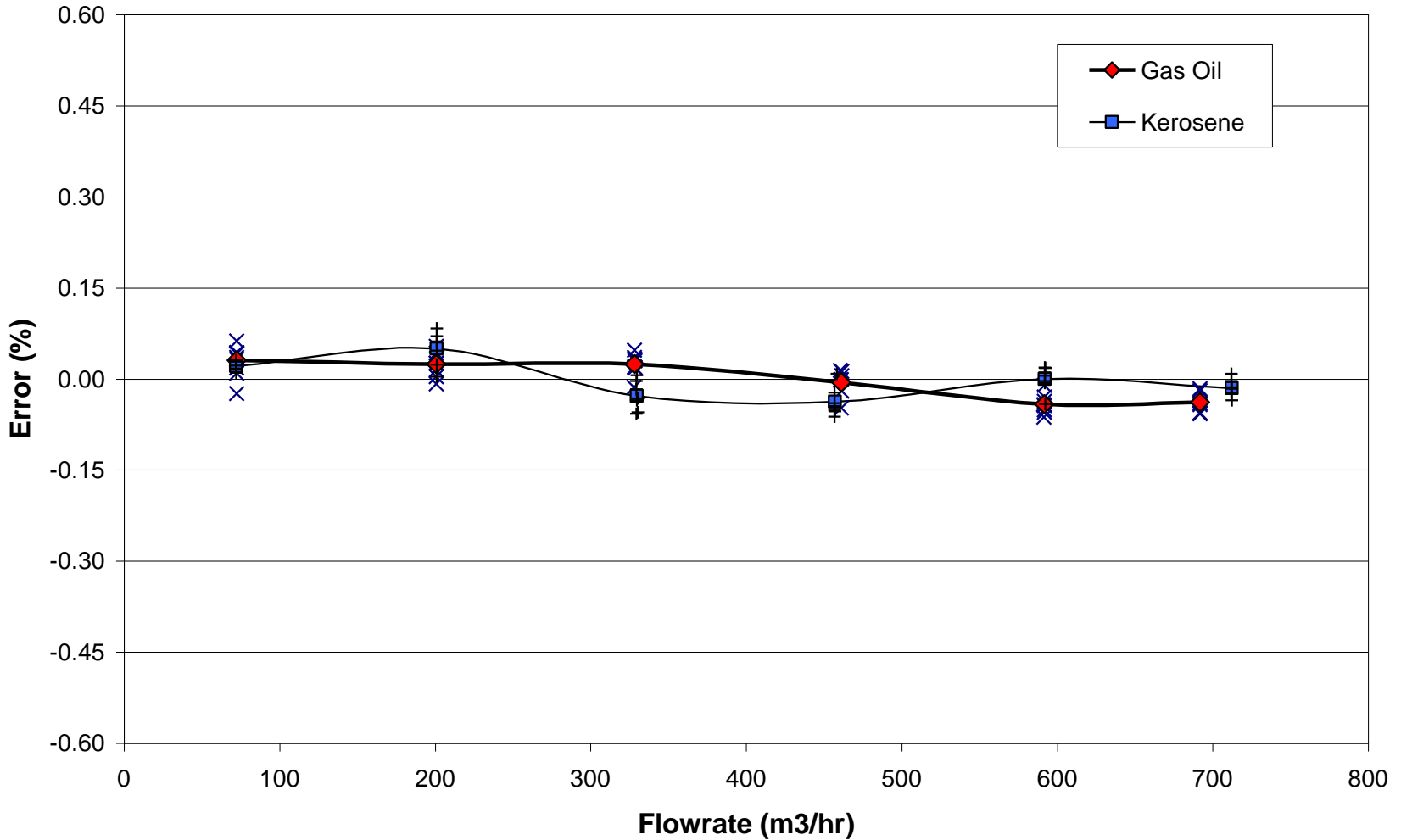
# Raw Calibration vs Reynolds Number



## Calibration




- The data is arranged in the form of a curve of meter factor versus Reynolds number and measured velocity profile shape
- This curve is then entered into the flow meter electronics, where the Reynolds number and velocity profile shape are calculated without the need of user inputs
- The result is a meter that is linear even when the fluid viscosity changes over a wide range

# Final Calibration



## Method acknowledged in NMI certification

- “If a measurement sensor is intended to be used with single or multiple liquids without adjustments, then the sensor has to be calibrated over the applicable range of Reynolds number, using one or more fluids, while the accuracy conditions are met for each fluid.”

		<b>Evaluation Certificate</b>
		Number TC7381 revision 5 Project number 10200358 Page 1 of 1
Issued by	NMI Certin B.V.	
In accordance with	– WELMEC guide 8.8 “General and Administrative Aspects of the Voluntary System of Modular Evaluation of Measuring Instruments under the MID.” – OIML R117-1 Edition 2007 (E) “Dynamic measuring systems for liquids other than water”.	
Manufacturer	Cameron Measurement Systems 1000 McClaren Woods Drive Coraopolis, PA15108, United States of America	
Measuring instrument	<b>A Measurement sensor</b> (ultrasonic sensor and belonging electronics), intended to be used as a part of a measuring instrument. Type : LEFM 220CI; LEFM 220CAI; LEFM 240CI; LEFM 240CAI; LEFM 280CI; LEFM 280CAI; LEFM 280CIRN; LEFM 280CIRN.	
Destined for the measurement of	liquid petroleum and related products, liquid food and chemical products in liquid state, with viscosities 0,1 mPa·s to 3000 mPa·s.	
Q <sub>min</sub> – Q <sub>max</sub>	: see paragraph 1.2 of Description	
Minimum measured quantity	: see paragraph 1.2 of Description	
Accuracy class	: 0,3 (LEFM 220CAI; LEFM 240CI; LEFM 240CIRN; LEFM 280CI & LEFM 280CIRN) 0,5 (LEFM 220CI)	
Environment classes	: M2 / E2	
Temperature range liquid	: -40°C / +70°C (LEFMxxCI and LEFMxxCIRN) : -50°C / +110°C (LEFMxxCI-R and LEFMxxCIRN-R) : -200°C / +110°C (LEFMxxCI LT-R and LEFMxxCIRN LT-R)	
Temperature range ambient	: -40°C / +55°C	
Further properties are described in the annexes:	– Description TC7381 revision 5 – Documentation folder TC7381-3	
Remarks	An overview of performed tests is given in Appendix TC7381 revision 5. This revision 5 replaces revision 4 except for its documentation folder.	
Issuing Authority	<b>NMI Certin B.V.</b> 2 August 2010  C. Oosterman Head Certification Board	
<b>NMI Certin B.V.</b> Hugo de Grootplein 1 3314 EG Dordrecht The Netherlands T +31 78 6323232 certin@nmi.nl www.nmi.nl		This document is issued under the provision that no liability is accepted and that the applicant shall indemnify third-party liability.  The designation of NMI Certin B.V. as Notified Body can be verified at <a href="http://ec.europa.eu/enterprise/newapproach/naibo">http://ec.europa.eu/enterprise/newapproach/naibo</a>
		Parties concerned can lodge objection against this decision, within six weeks after the date of submission, to the general manager of NMI (see <a href="http://www.nmi.nl">www.nmi.nl</a> ).  Reproduction of the complete document only is permitted.
		

## Summary

- Every Caldon meter goes through a calibration process that ensures it meets custody transfer performance requirements over the full range of the customers operating conditions
- Each meter is provided with a calibration certificate according to Cameron's NVLAP and VSL certification, meaning that the meter has sufficient traceability to ensure custody transfer accuracy in the field

## Summary

- For meters that will be proven in situ, each meter goes through this process once before shipping but thereafter there is no requirement to return the meter to return to the lab for recalibration
- In the case of in-situ proving, the calibration therefore allows for optimisation of meter linearity and also serves as a final quality assurance check on the whole meter against a flow standard of low uncertainty

# APPLICATION EXAMPLES

## Custody Transfer Metering



# **Conventional systems with permanently installed provers**

# PEMEX – Bi-directional direct proving

- Gulf of Mexico
- Yuum Kak Naab FPSO
- Five 12-inch Caldon 240Ci USMs
- Large 30-inch bi-directional ball prover

Yuum K'ak'Naab FPSO

Contract duration: 2007 – 2022 (2025)

Oil handling capacity 600,000 bbl/d

Oil processing capacity 200,000 bbl/d

Gas compression capacity 120 mmscfd

Storage capacity 2,200,000 bbl

Mooring: Turret

Location/field: Mexico/KMZ

Client: Pemex



# PEXEX – Yuum Kak Naab FPSO





# Proving with portable provers

# Sunoco Toledo refinery, 8-path meter





0-16-3

15" 3000 PSI

JTG

91  
DN

SUNOCO PIPELINE  
TOLEDO RETRIEVAL

213  
426  
710  
710

BOOMER  
BOOMER  
BOOMER



## Toledo refinery proving reports

Flowrate	3203.8
Totalizer	0
Throughput	0
API @ 60 F	64.0
R.D. @ 60 F	0.72380
Viscosity	0
Avg Prvr Temp	63.4
Avg Prvr Press	172.0
Repeatability	0.038%
MF	1.0012
MF Variation	0.0080

Flowrate	3044.2
Totalizer	0
Throughput	0
API @ 60 F	42.5
R.D. @ 60 F	0.81320
Viscosity	0
Avg Prvr Temp	66.0
Avg Prvr Press	168.0
Repeatability	0.043%
MF	1.0011
MF Variation	1.0011

Flowrate	2138.4
Totalizer	0
Throughput	0
API @ 60 F	35.5
R.D. @ 60 F	0.84730
Viscosity	0
Avg Prvr Temp	75.3
Avg Prvr Press	247.0
Repeatability	0.022%
MF	1.0010
MF Variation	1.0010

### Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure	0	psig
Eq. Vapor Pressure	0	psig
CPL	1.00000	

### Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure	0	psig
Eq. Vapor Pressure	0	psig
CPL	1.00000	

### Liquid Properties at Metering Conditions for CMF

Normal Op. Pressure	0	psig
Eq. Vapor Pressure	0	psig
CPL	1.00000	

#### RUN Accepted?

#### IMF

14	1	Yes	1.00114
16	2	Yes	1.00125
11	3	Yes	1.00146
17	4	Yes	1.00110
19	5	Yes	1.00112
<b>5074</b>			<b>1.00121</b>

#### RUN Accepted?

#### IMF

2	1	Yes	1.00114
2	2	Yes	1.00096
6	3	Yes	1.00139
11	4	Yes	1.00104
5	5	Yes	1.00098
<b>0512</b>			<b>1.00110</b>

#### RUN Accepted?

#### IMF

607	1	Yes	1.00096
940	2	Yes	1.00107
028	3	Yes	1.00085
817	4	Yes	1.00105
867	5	Yes	1.00098
<b>9.4120</b>			<b>1.00098</b>



## 6-inch 280CiRN – SVP, DIRECT proving



### Meter Proving Report

Location : [REDACTED]

Date & Time : 12/12/2011 14:28

Report Number : 28,955

Product : RAW

Meter S.G. : 0.4535

Current Gross Accumulator: 3,422

Prover Data				Meter Data			
Prover Name: WestTexas				Measurement Type: Volume			
Dnstream Prover Base Vol (BPV): 0.9518370 Bbls				Meter ID: INOLE_ACK			
Upstream Prover Base Vol (BPV): 0.9518370 Bbls				Meter Size: 6.00 inches			
Inside Diameter (ID): 20.50 inches				Meter K Factor (NKF): 2,000.00 ppb			
Wall Thickness (WT): 3.51 inches				Meter to Prover Position: UpStream			
Elasticity (E): 28,000,000 per psi							
External Shaft (GI): 0.0000096 per deg F							
Cubic Expansion (GC): 0.0000000 per deg F							
Area Thermal Coeff (GA): 0.0000192 per deg F							
Type: SmallVolume				Gravity Basis: Live Analysis			
Internal Detectors: Y				Reporting Method: Avg Data Method			
Serial Number: ST-0502267				Minimum # of Runs Criteria: 5 Runs			
Manufacturer: Calibron				Passes Per Run: 4			
Waterdraw Date: 10/05/2011				Repeatability Criteria Limit: 0.00050			
				Calculated Repeatability (R): 0.00047			
				Repeatability Met?: Yes			

Run	Temperature (F)			Pressure (psig)		Pulses	Flow Rate	SG60	Run (IMF)
	Tp	Ts	Tm	Pp	Pm	Ni	Gross Bbls		
3	78.8	63.5	79.2	467.5	473.5	1,897.060	2,006.57	0.4535	NA
4	78.8	63.4	79.2	471.0	476.5	1,896.870	1,987.95	0.4535	NA
5	78.9	63.2	79.2	474.6	480.3	1,897.630	1,975.63	0.4535	NA
6	78.8	62.9	79.2	474.0	479.1	1,896.850	1,969.05	0.4535	NA
7	78.8	62.7	79.2	472.9	479.0	1,896.330	2,024.40	0.4535	NA
Average:	78.8	63.1	79.2	472.0	478.0	1,896.868	1,993.52	0.4535	NA

(1) Determination of GSVp  
 BPV      CTSp      CPSp      CTLp      CPLp      =      GSVp  
 0.951837   x   1.00039   =   1.00010   x   0.95580   x   1.01335   =   0.92236

(2) Determination of ISVm  
 Avg Pulses      Pulses / BBL      =      Gross Mtr Vol      x      CTLm      x      CPLm      =      ISVm  
 1,896,970      /      2,000      =      0.948440      x      0.95480      x      1.01372      =      0.91799

Determined K Factor (NKF / MF) : 1,990  
 Meter Factor For Proof (GSVp / ISVm) : 1.0048

Six Previous Meter Factors based on      Product : RAW      Flowmeter : SEMINOLE\_ACK  
 DATE/TIME      Meter Factor      BPH      Avg Press      Avg Temp      SG60      ProvingResultsID

Reporting Method: Avg Data Method  
 Minimum # of Runs Criteria: 5 Runs  
 Passes Per Run: 4  
 Repeatability Criteria Limit: 0.00050  
 Calculated Repeatability (R): 0.00047  
 Repeatability Met?: Yes

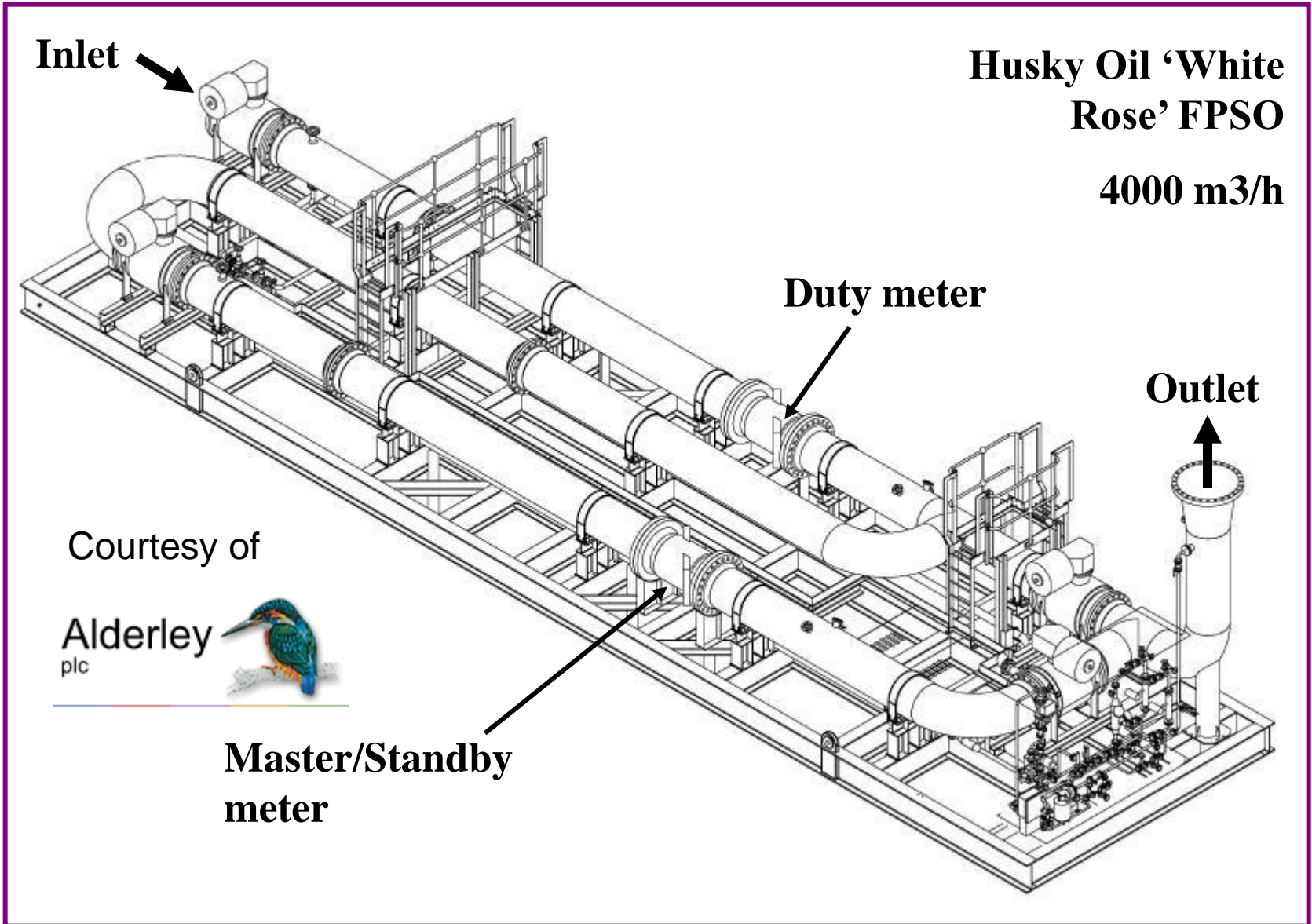
Comments:

Signature [REDACTED] Date 12/12/2011 Company Represented [REDACTED]  
 Signature [REDACTED] Date 12/12/2011 Company Represented [REDACTED]

# Master/Duty or Pay/Check installations

# Tullow Oil, 4-path pay and check









## FPSO Aoka Mizu, Nexen/Bluewater, UK North Sea



- Design Capacity 6500 m<sup>3</sup>/h
- Configuration: 2+Master Meter
- 14" LEFM 240C
- Master Meter Proving



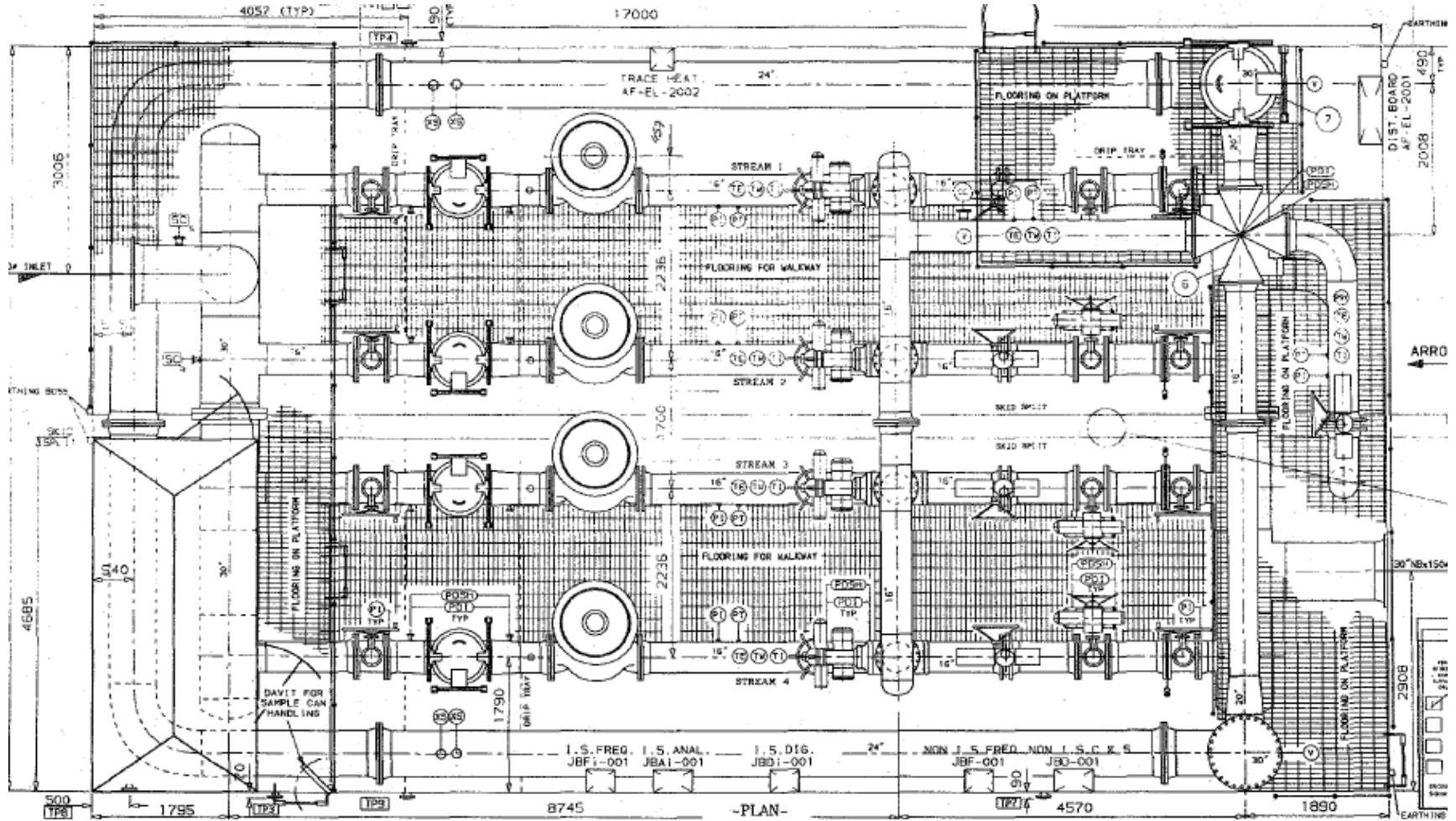
# **Retrofit/replacement of traditional mechanical meters**

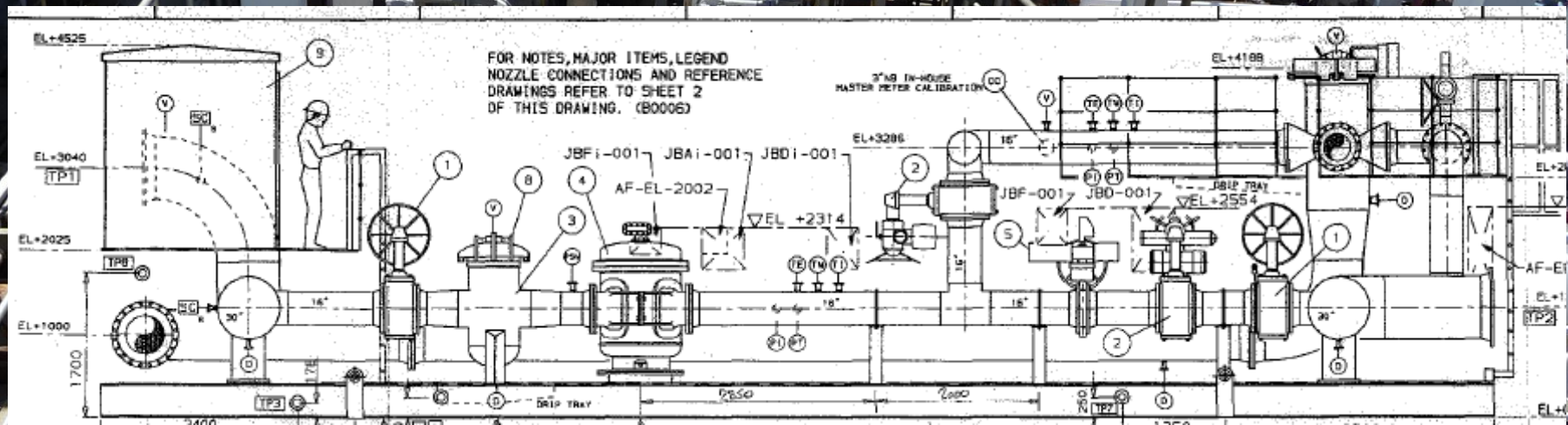


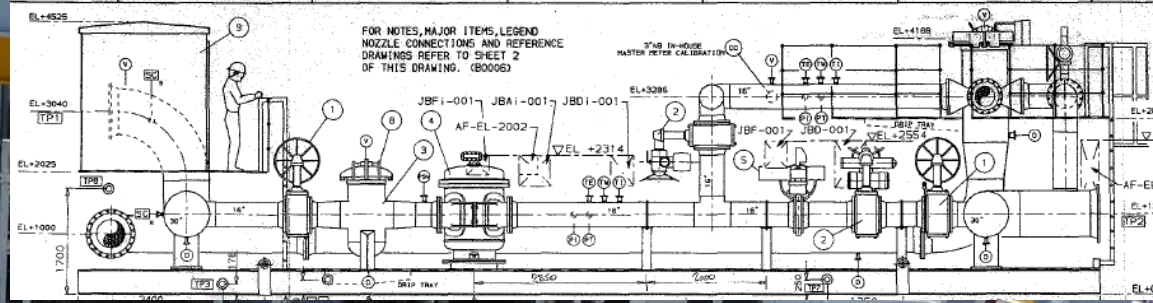
## Replacement of PD meters

- Replacement of failed system based on positive displacement (PD) meters
- Limited installation space as PD meters are not sensitive to installation effects
- 16-inch Caldon 8-path 280Ci flowmeters installed
- 5 diameters of upstream pipe, 3 diameters of downstream pipe
- Approved by the UK regulator (DECC)

# Original PD meters and bi-direction prover







# Pipeline Leak Detection

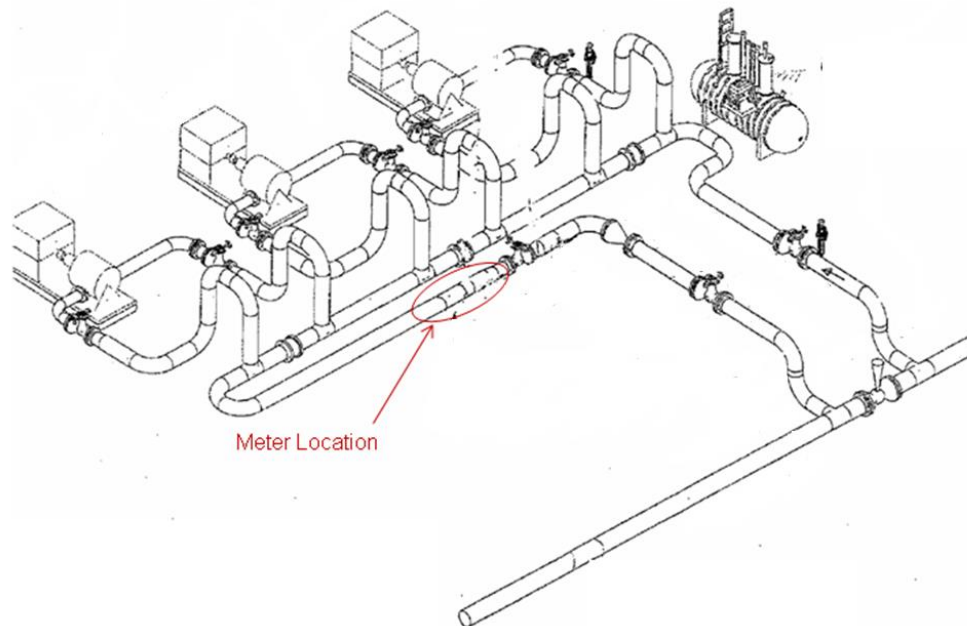
# Leak Detection - Keystone Pipeline

- TransCanada and ConocoPhillips joint venture
- 2,148 mile crude oil pipeline from Alberta to US markets
- **39 pumping stations along the line**
- **One meter per station**



# Pumping station layout

- Meters to be installed in 20-inch section downstream of out-of-plane bends
- Location requires flow conditioning or an 8-path meter to achieve the required accuracy



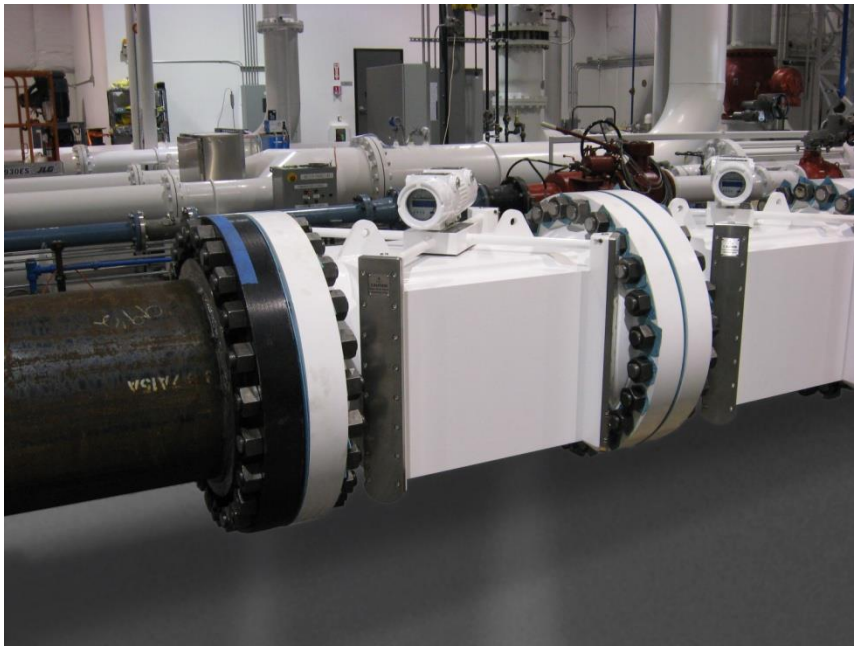
## Pumping Cost

- Use of flow conditioners at each station would generate significant pressure loss
- The present value of the pressure losses over the operation of the life of the pipeline was estimated to exceed 20 million US dollars
- Therefore the Caldon 8-path meter was selected as it does not require flow conditioning



## Keystone meter calibration

- Each meter was flow calibrated in the Cameron facility with three oils to cover the multi-product application conditions

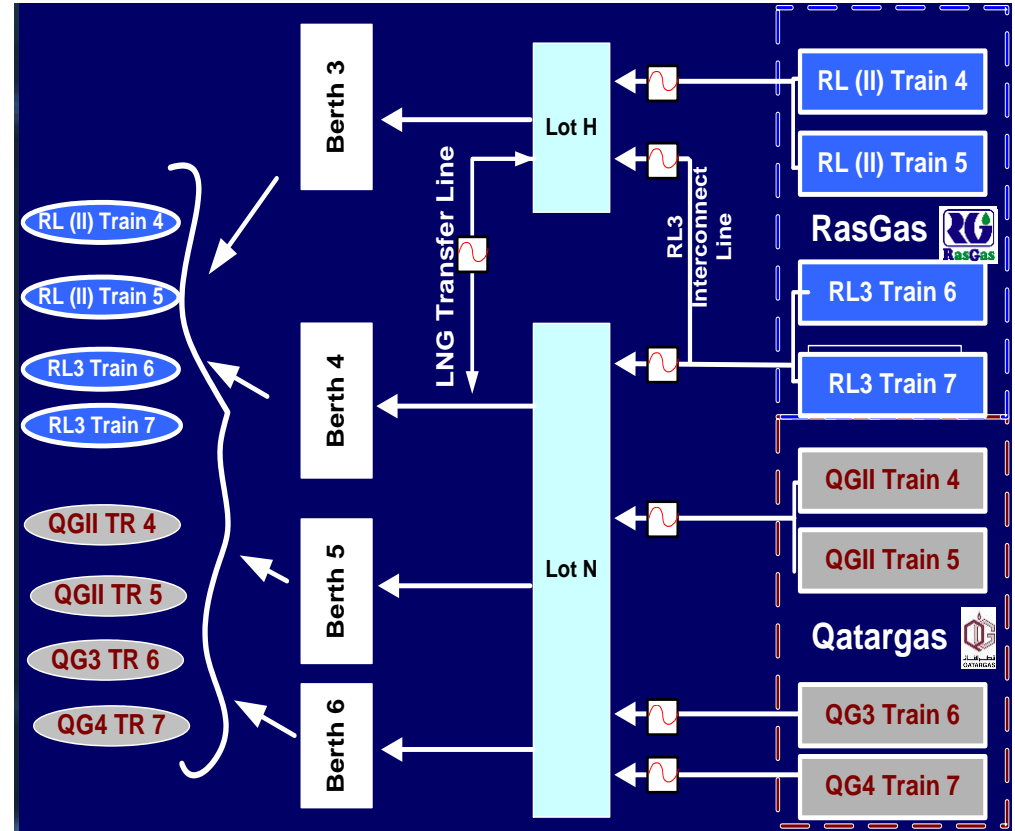




# LNG Allocation and Custody Transfer

## Qatar Common LNG Facilities

- Common storage and shared offloading for multiple production joint ventures
- Massive cost savings (estimated 1 billion \$ us)
- Allocation metering is a key enabling technology

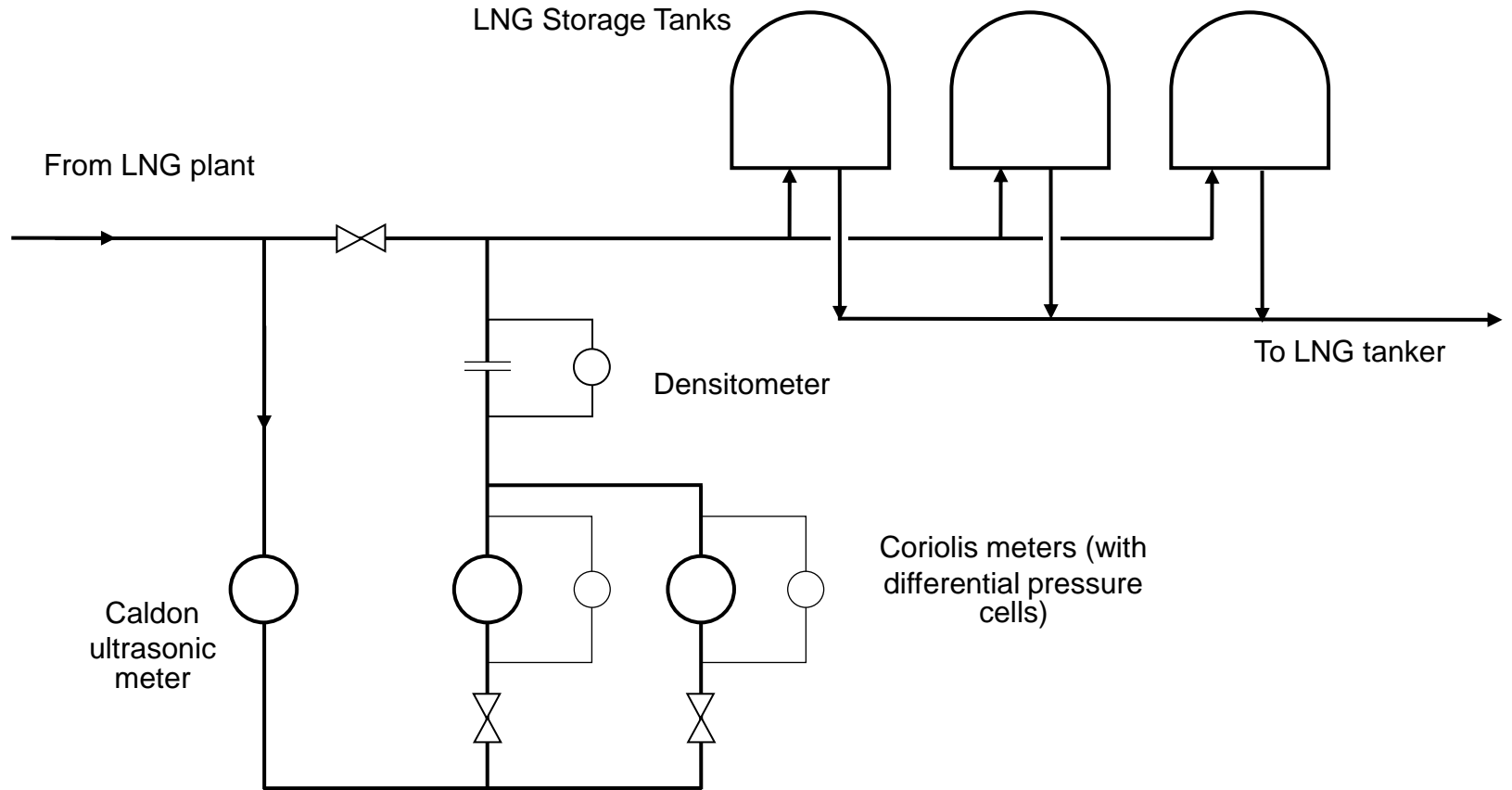


## Field tests

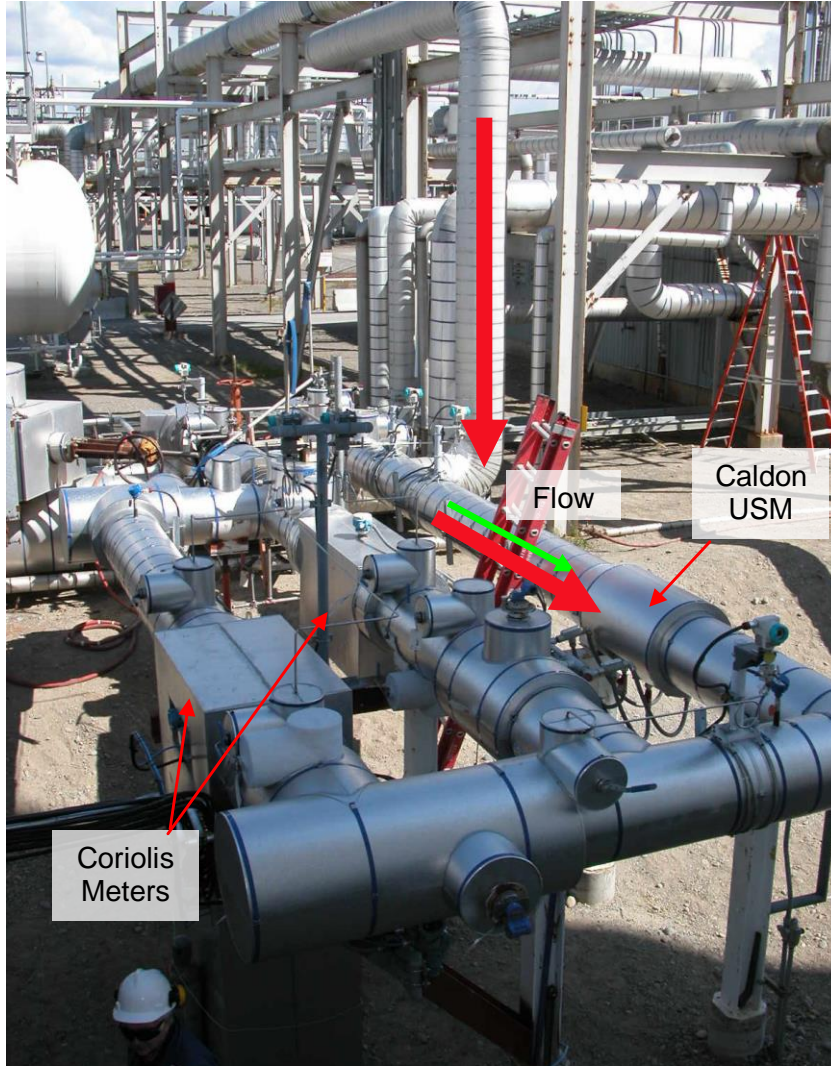
- A six-inch 8-Path Caldon 280C was selected for the tests, along with Coriolis meters from two different manufacturers
- Tests were carried out at the ConocoPhillips LNG plant in Kenai, Alaska



# Test site



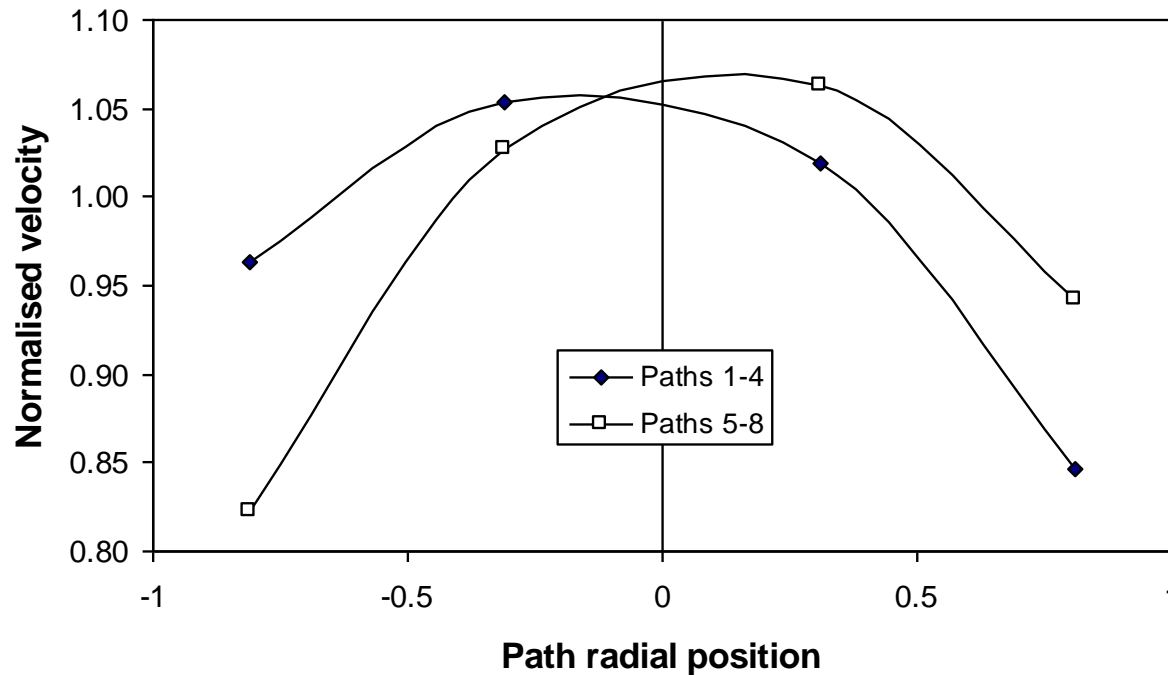
# Out-of-Plane Bends



37 diameters of straight pipe  
upstream



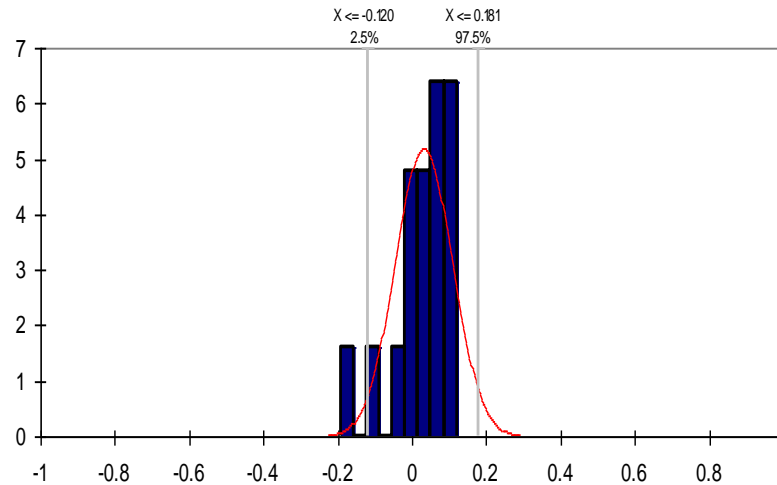
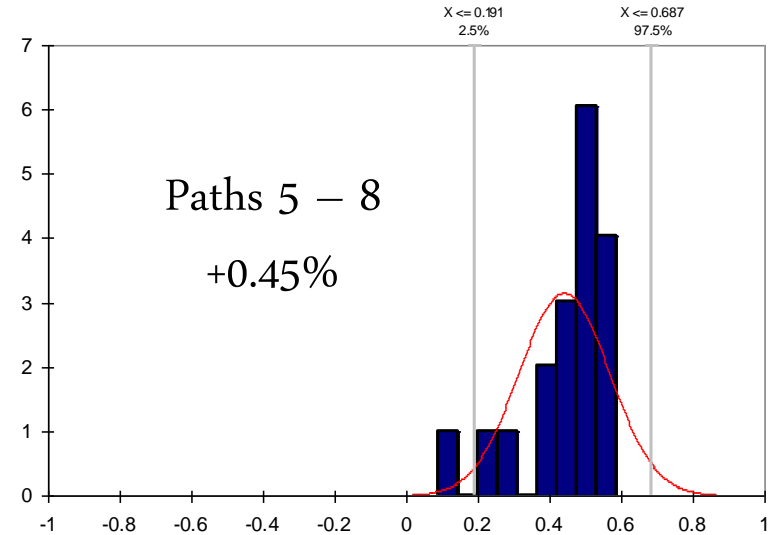
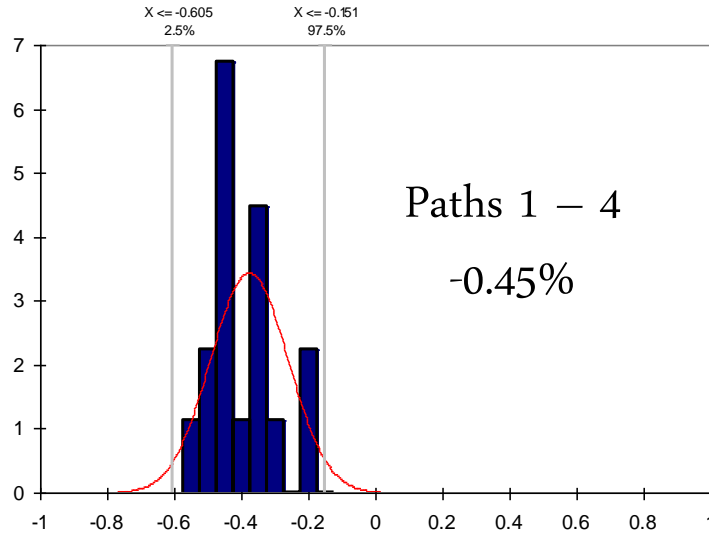
# Path Velocities Confirm Swirl



- Max swirl angle of approx 5 degrees (or one full rotation every 48 pipe diameters)



## A and B Outputs



8-Path result  
<0.1%

## Test Outcomes

- 22 Caldon LEFM 280C-LT flow meters employed for allocation metering at Ras Laffan
- Same technology selected for custody transfer of LNG at the Dajeh receiving facilities in India



# Dahej Re-Gasification Plant, India



## Dahej Re-Gasification Plant, India

- Expansion project includes new storage facility and new jetty
- New Jetty will be able to dock Q-Flex and Q-Max tankers
- Contract with Qatar to receive 7.5 MTPA LNG
- Dynamic measurement of LNG to Gas using LEFM 280C meters

# Dahej Re-Gasification Plant, India

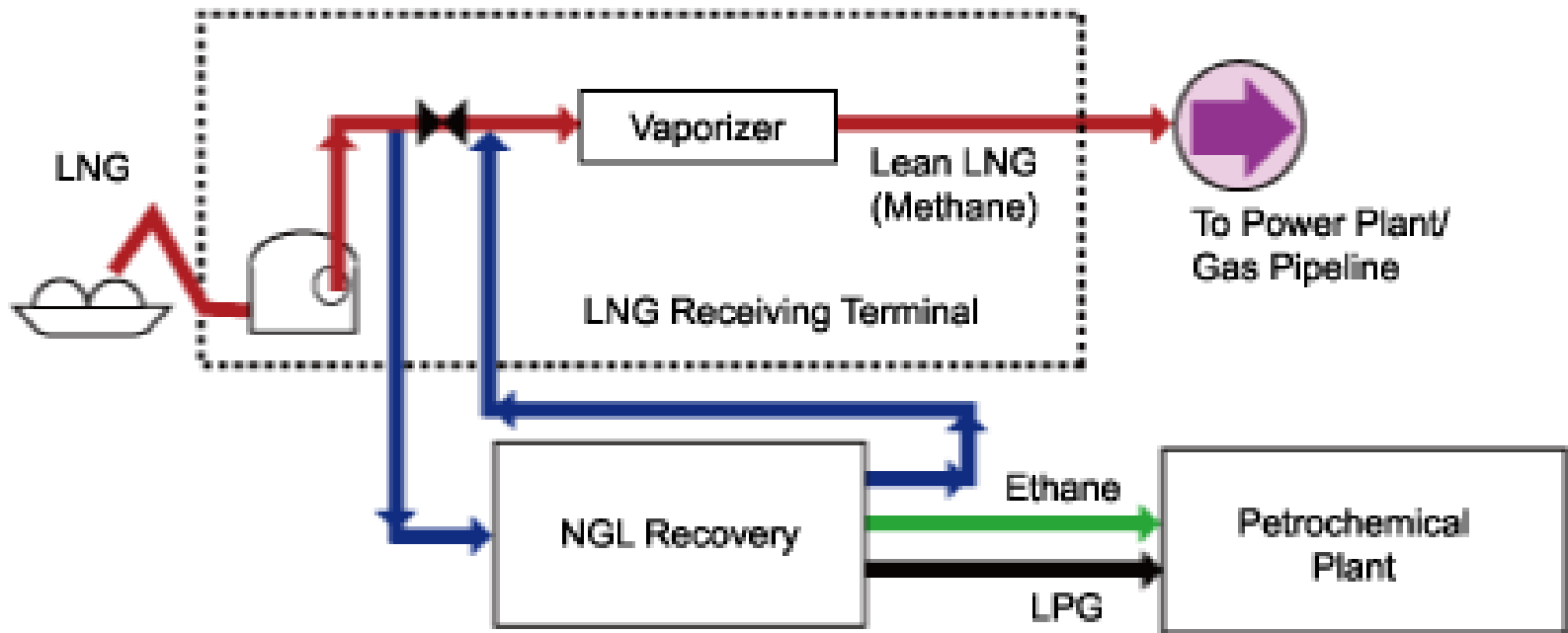


New Jetty

Metering  
skid

# LNG Custody Transfer

- ONGC India & partners
- Dahej receiving terminal
- NGL recovery and gas transmission by ONGC and Gail



# Dahej Re-Gasification Plant, India



Constructed  
by Toyo Eng  
for Petronet

Two 8 path  
meters in series  
for redundancy

## SUMMARY

- Caldon products have been engineered to provide high accuracy in a diverse range of applications
- The 8-path configuration enables elimination of flow conditioning and reduction of the installation footprint for the metering system
- The Reducing Nozzle variant of the meter enables measurement of high viscosity oils and improved repeatability
- The products are supplied with traceable calibration, enabling low uncertainty field use with or without in-situ proving