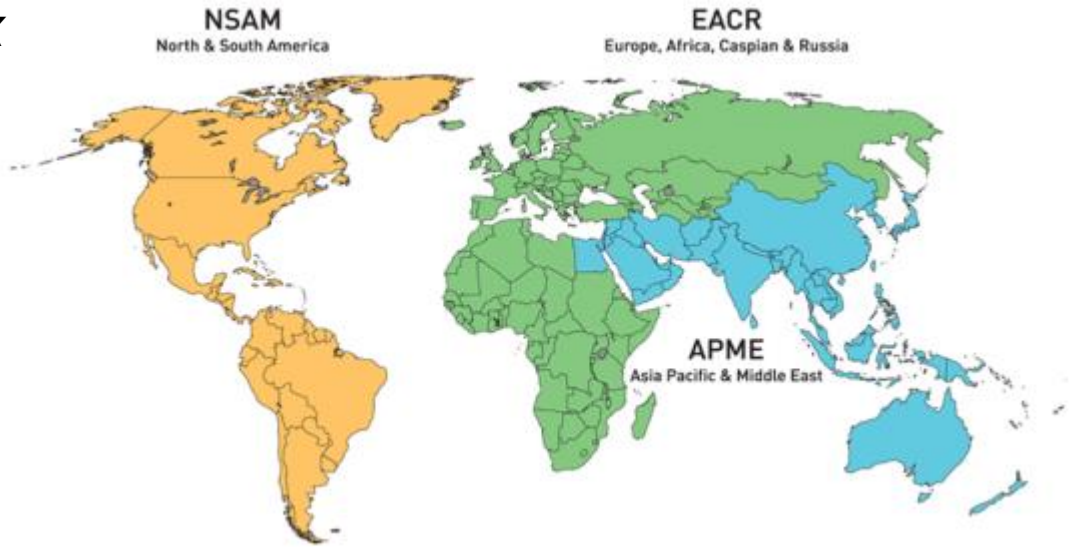
Caldon LEFM Ultrasonics - Leading Edge Flow Meters for Custody Transfer




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


CAMERON MEASUREMENT SYSTEMS

CALDON®

LEFM® 240Ci
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 240 ultrasonic meter is a compact, high performance unit designed specifically for custody transfer or fiscal metering applications. The four-chordal path design ensures linearity over a wide flow range and the ability to handle a wide range of petroleum fluids including crude oils, refined products and blends. Its versatility allows application in single or multiple product pipelines, as well as ship loading/off loading and off-shore applications.

Custody transfer performance

Stable performance over:
- wide viscosity ranges
- large flow ranges

Ideally suited for refined products and crude oil

Provable

Enhanced flow stream and performance diagnostics

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


CAMERON 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

CAMERON | 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 a excellent success rate of achieving a data spread of 0.05% in 5 prover runs.

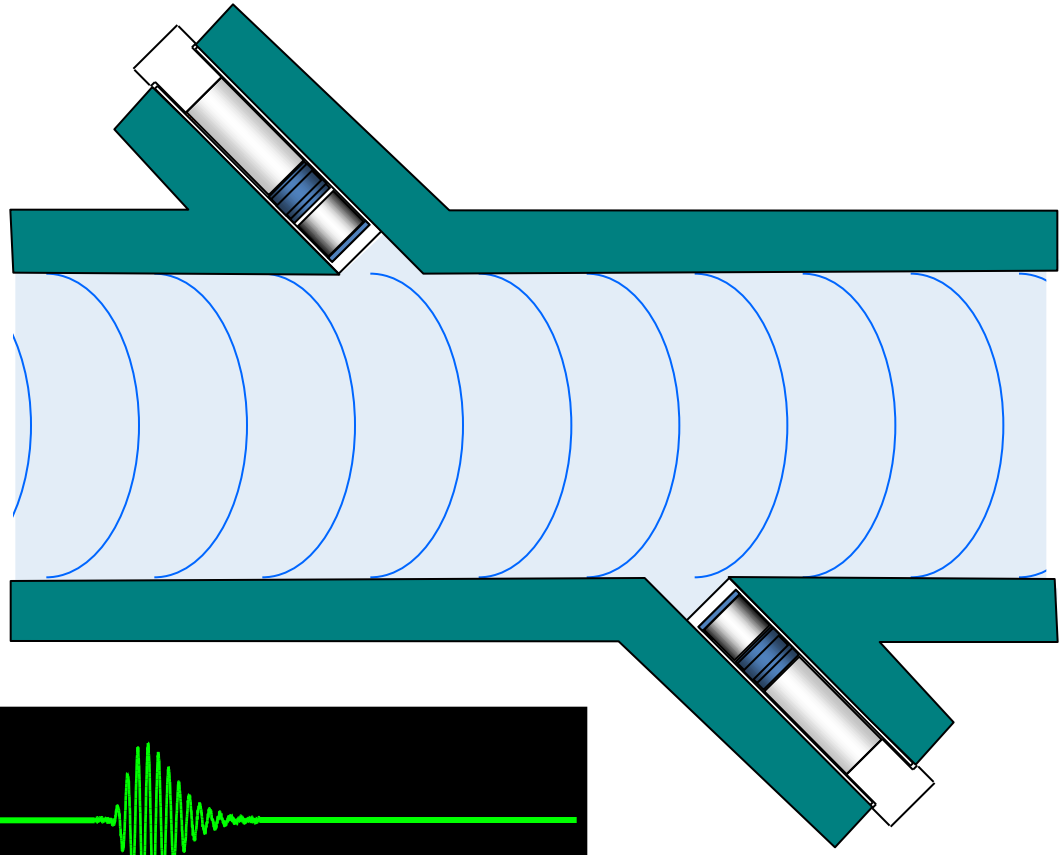
- Custody transfer performance down to Reynolds Numbers of 1000 and lower
- Ideally suited for higher viscosity oils and/or low flow rates
- High success rate for provability to 0.05% in 5 runs with standard size prover
- Minimal requirements for upstream/downstream piping

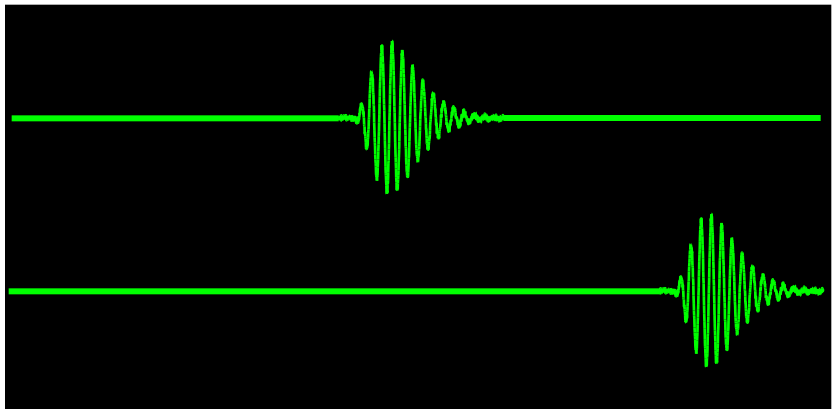
Caldon LEFM 380Ci

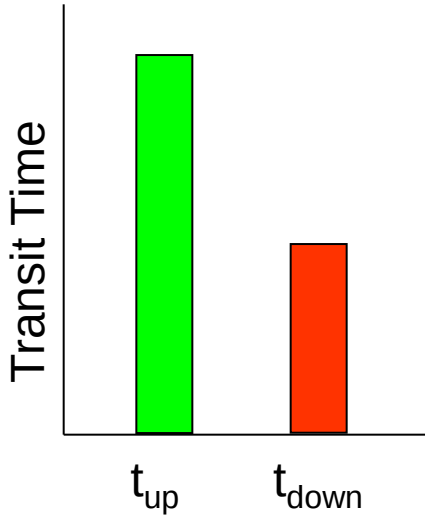
- 8-path (Gaussian) design, swirl immunity without the need for flow conditioning
- 5D minimum upstream installation length
- Transducers isolated in pressure retaining housings and removable under full line pressure without the need for special tools
- Coated meter body to maintain integrity of the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

Why 4 and 8 paths?

Transit time difference principle





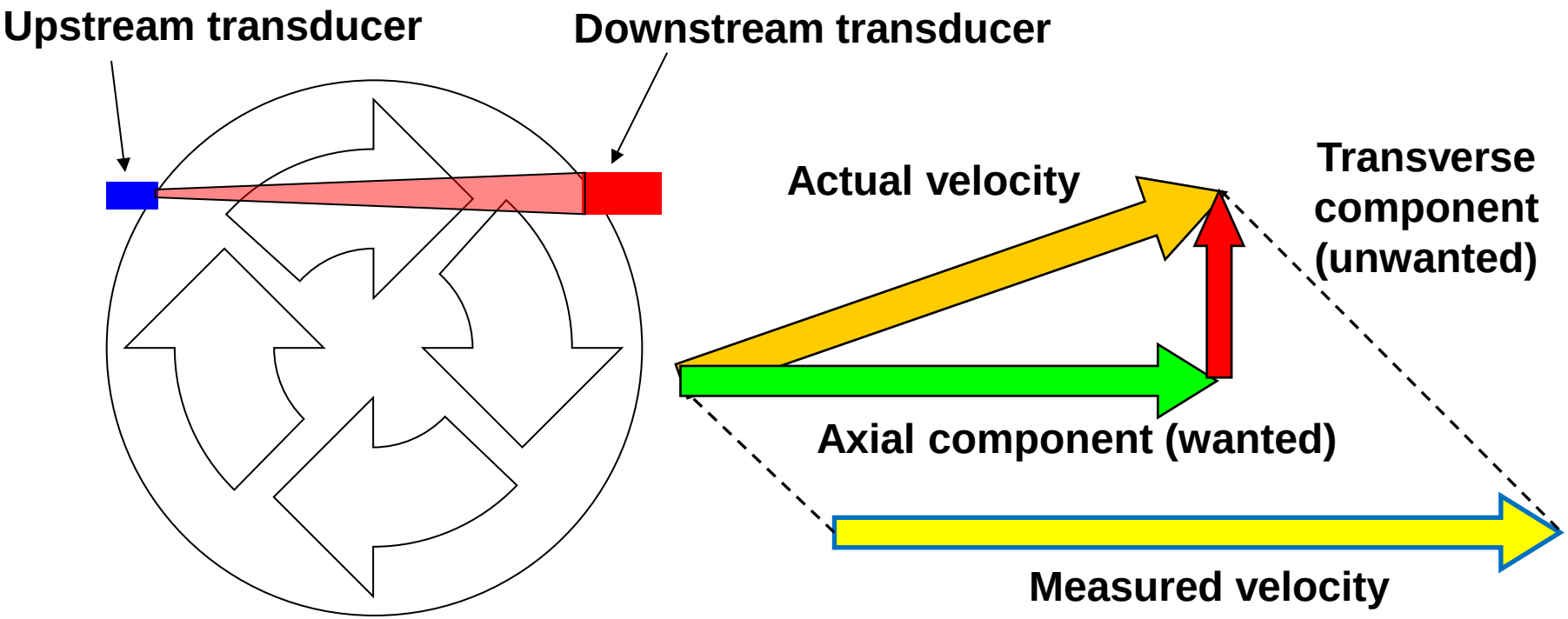


Contributors to installed uncertainty

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

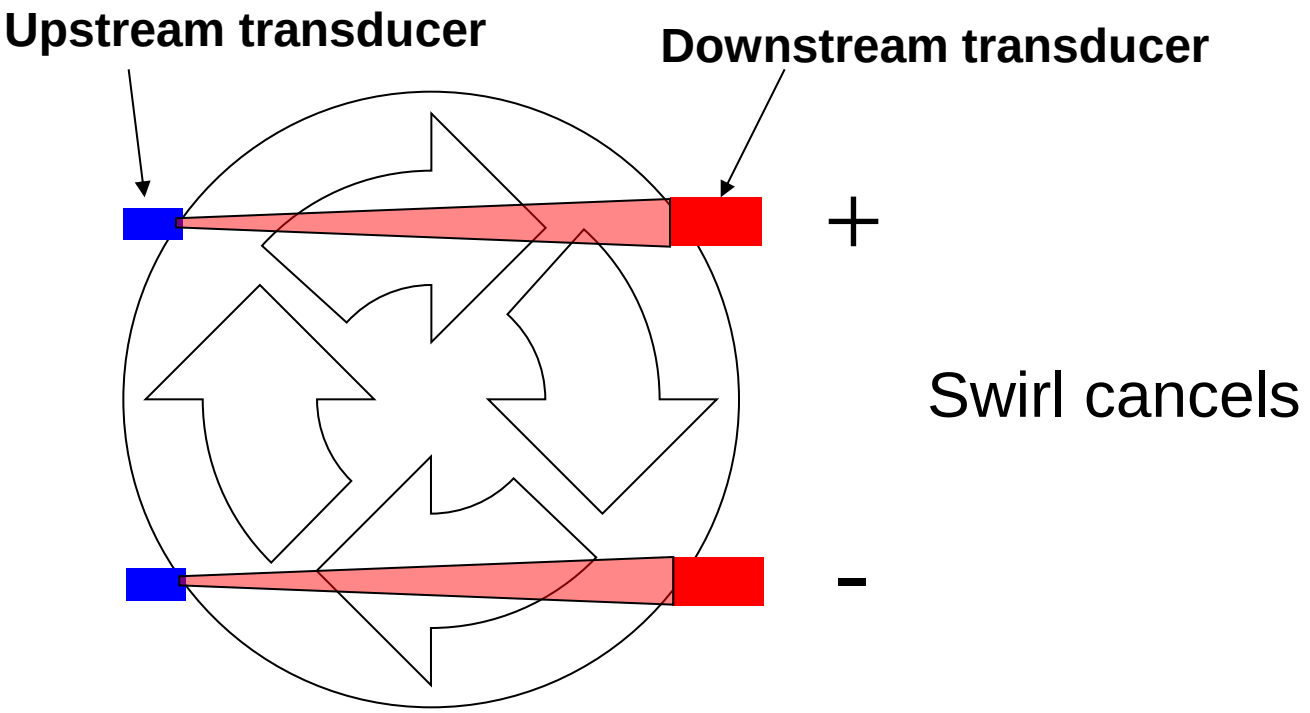
The effects of swirl

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



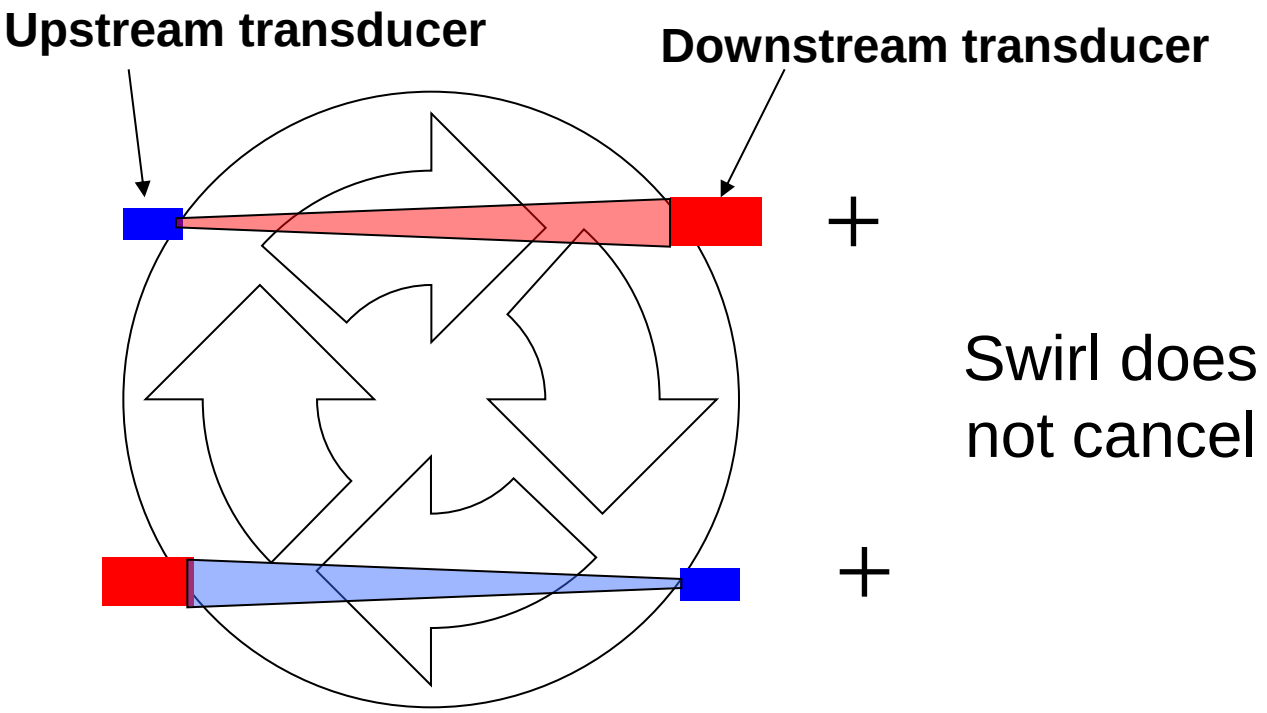
Swirl

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



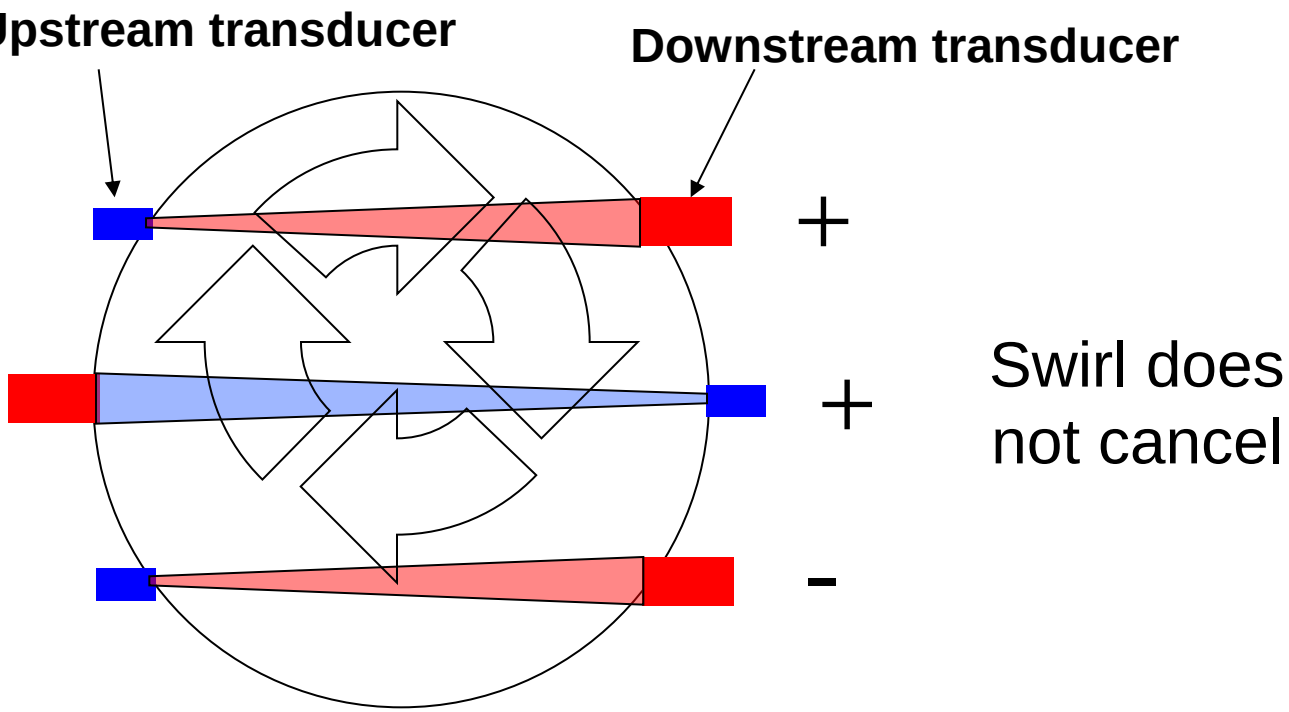
Swirl

- Crisscrossed paths behave differently to parallel paths



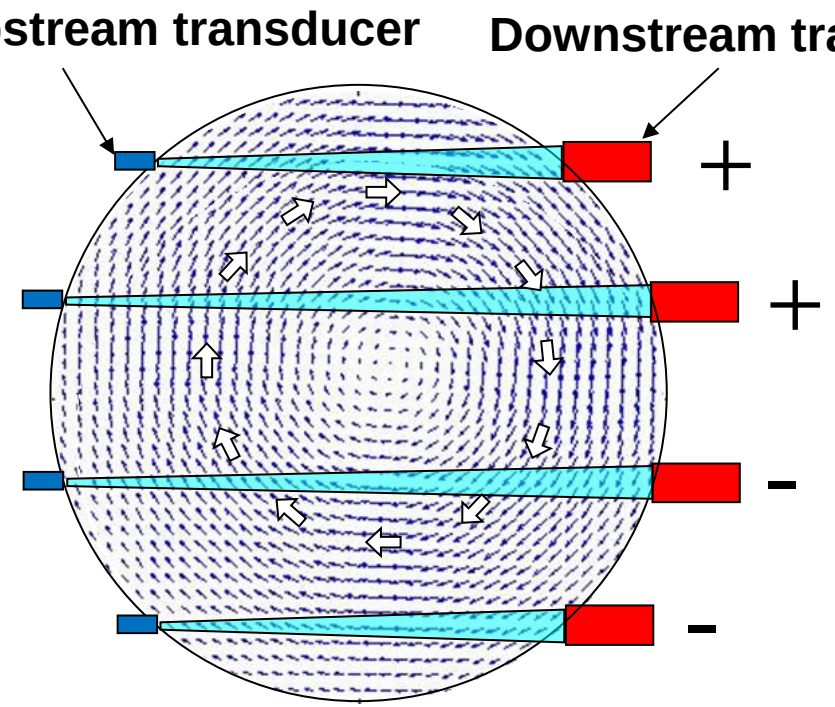
Swirl

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

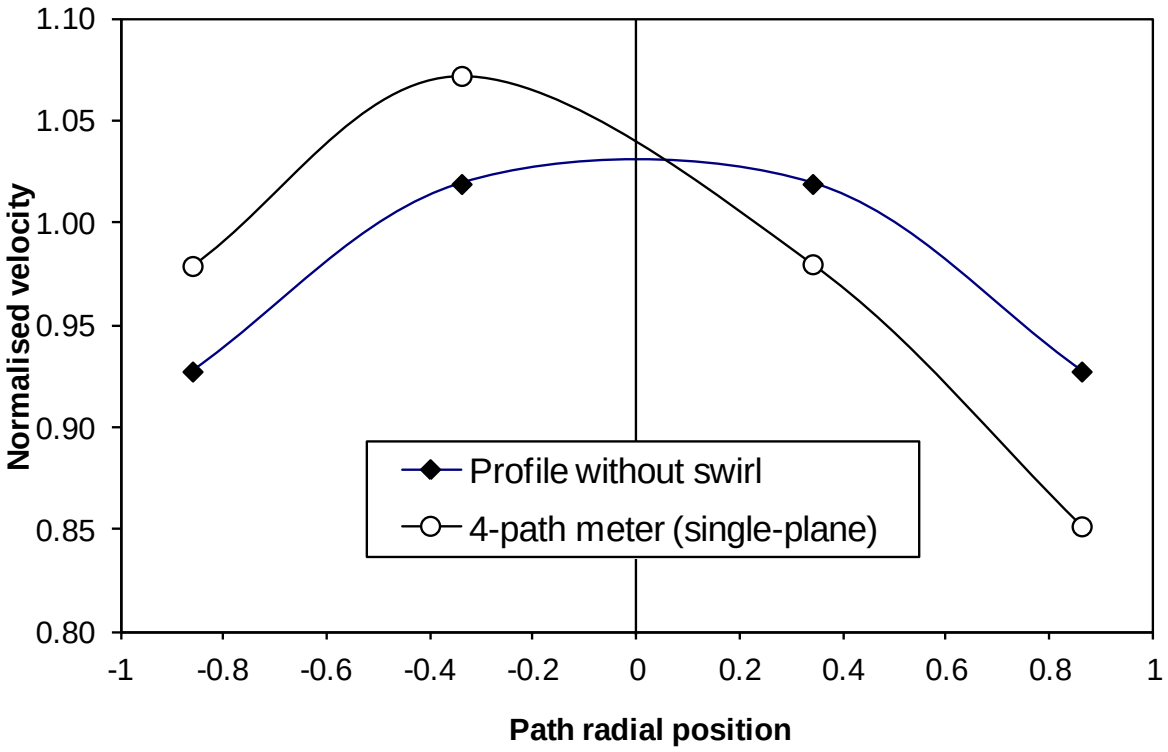


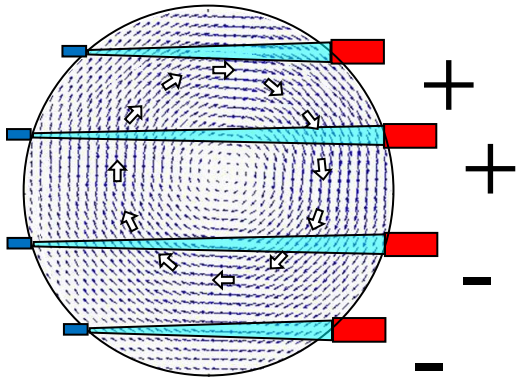
4-path, planar configuration

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



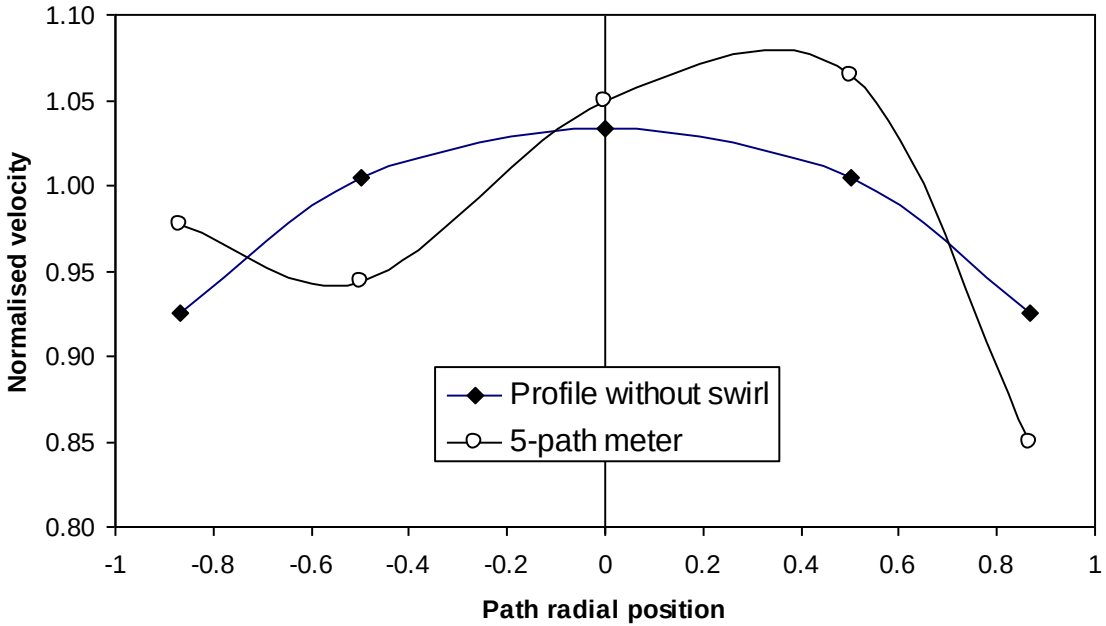
4-path, planar configuration

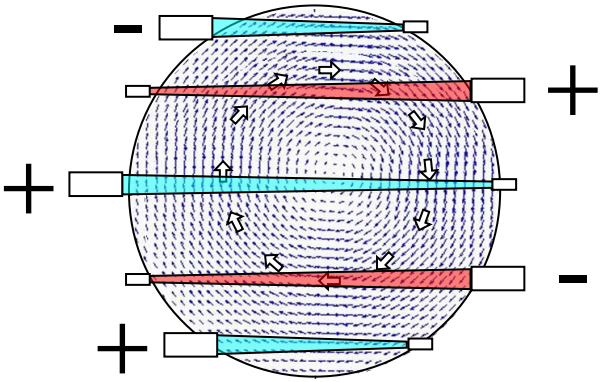




- Swirl error = 0.26 %

5-path, non-planar configuration

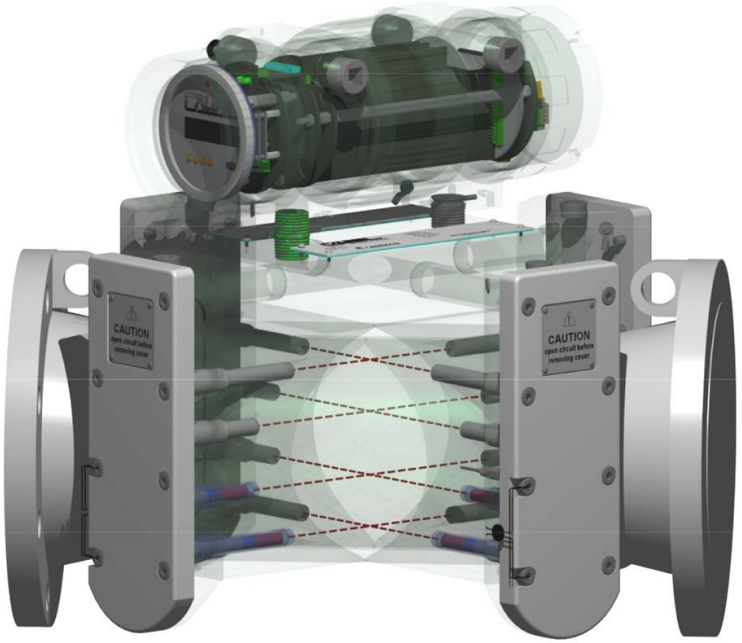


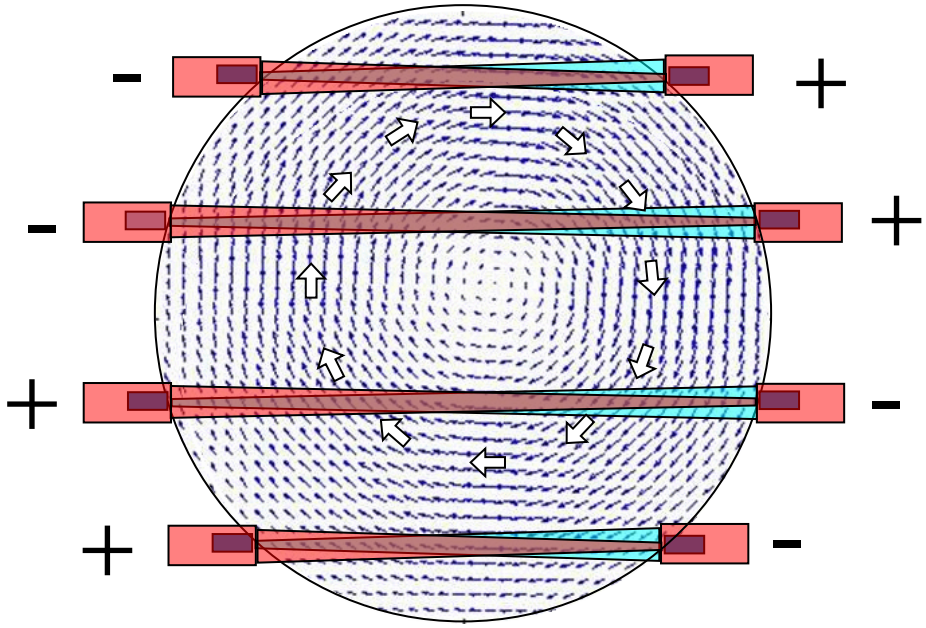


- Swirl error = 0.33 %

Eight-path Caldon 280Ci/380Ci

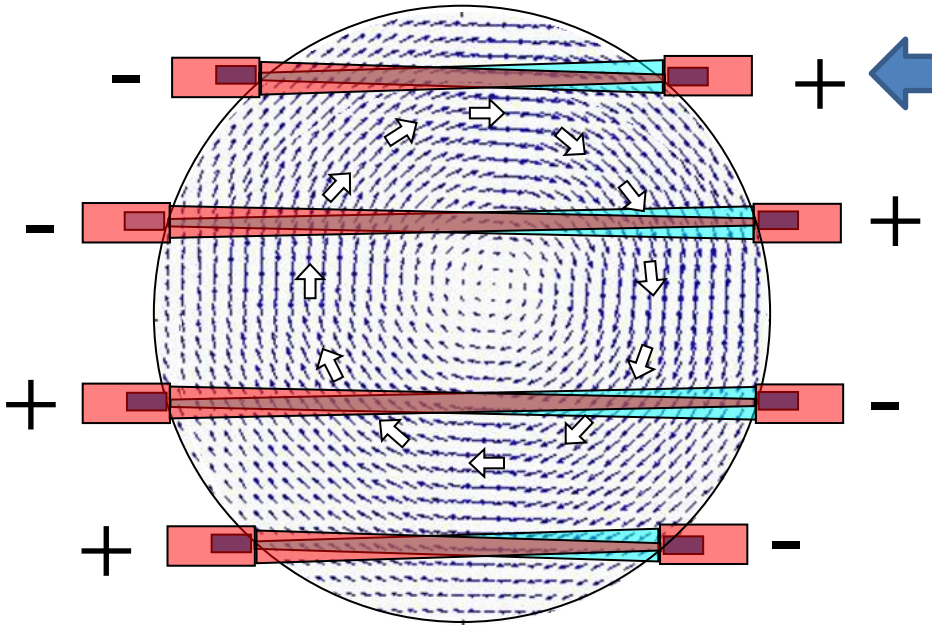
- Designed for swirl immunity
- Flow conditioning not required





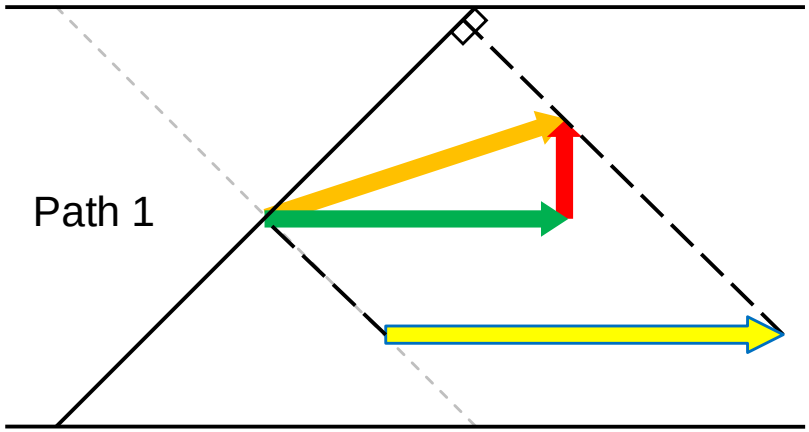
How the crossed paths work

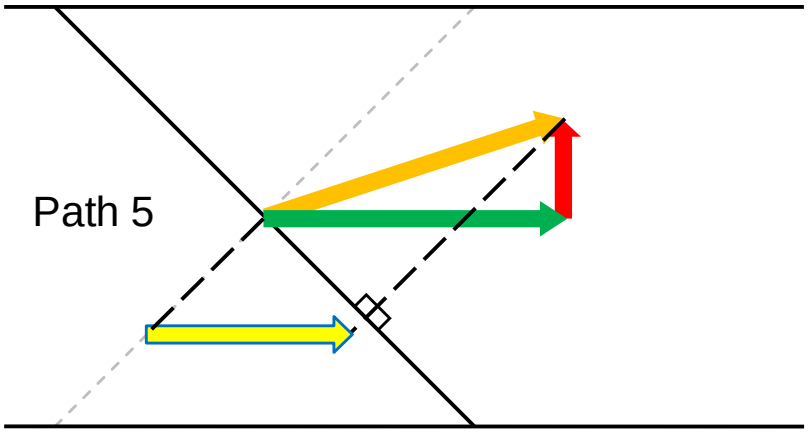
- Two crossing paths are placed precisely in each chordal plane



Paths 1 and 5

How the crossed paths work





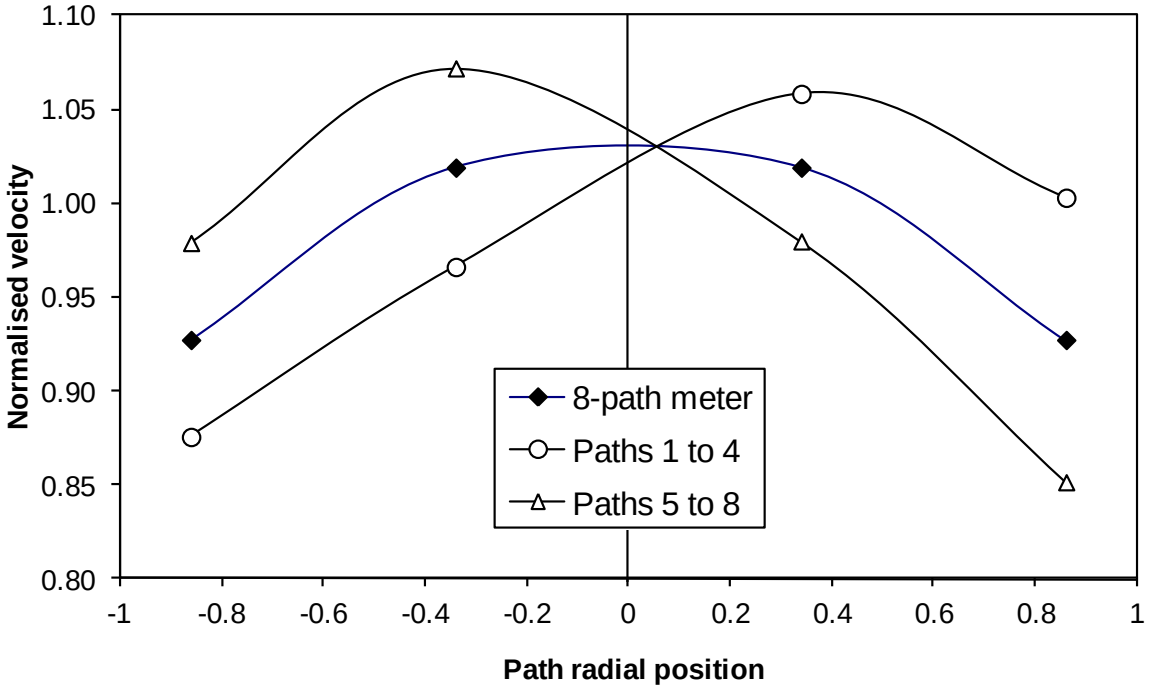
Key:

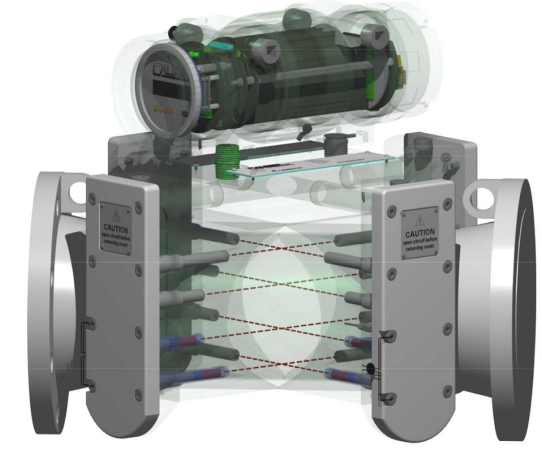
- Actual velocity
- Axial component (wanted)
- Transverse component (unwanted)
- Measured velocity

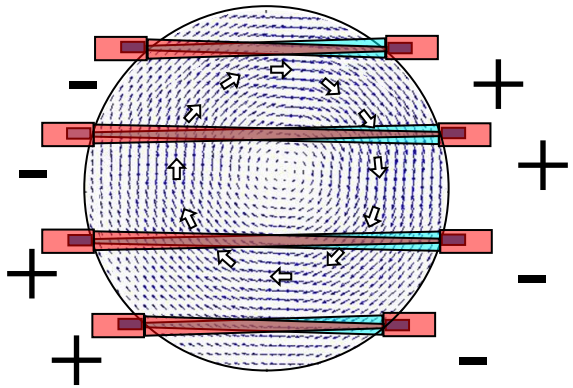
Path 1 + Path 5

$$\frac{\text{Path 1 + Path 5}}{2} = \text{Path 1 + Path 5}$$

Eight-path crossed plane design



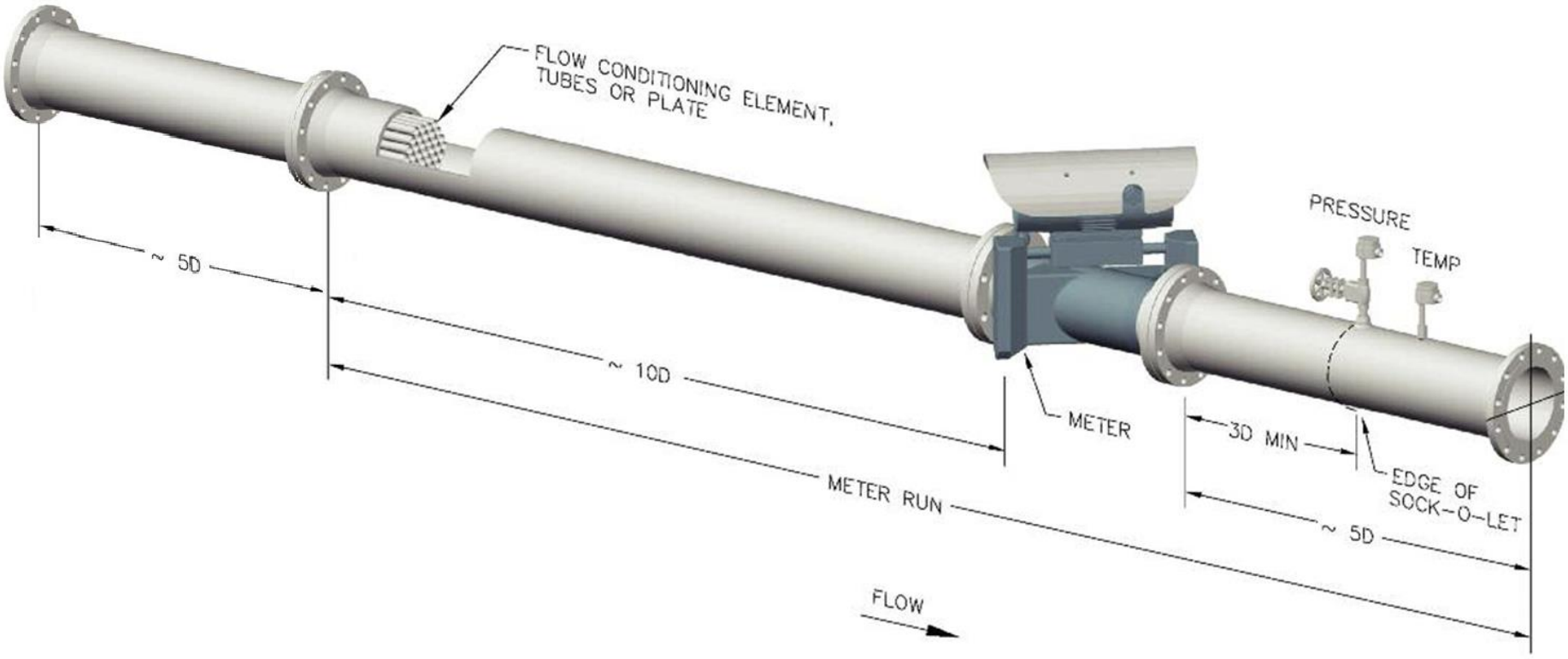




- Swirl error = 0 %

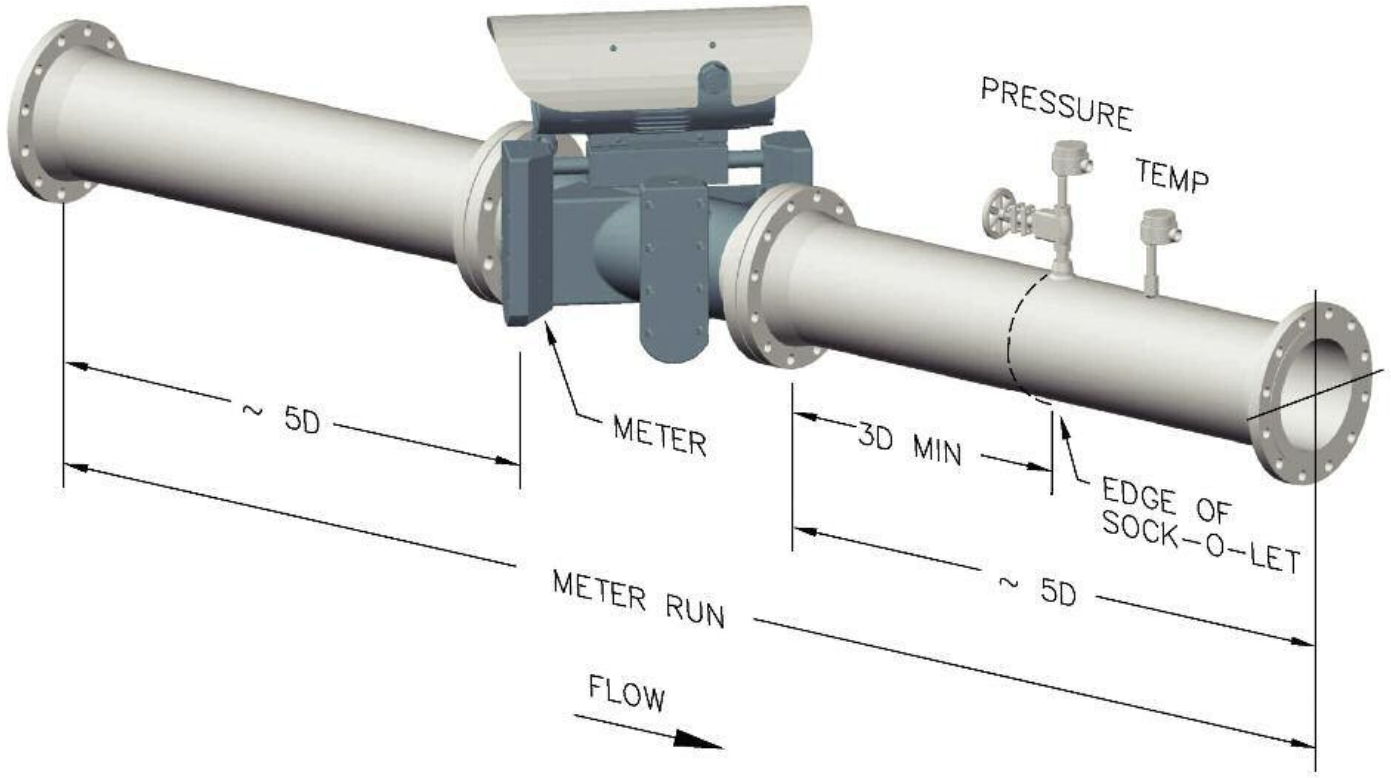
240Ci 4-path meter installation

- 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

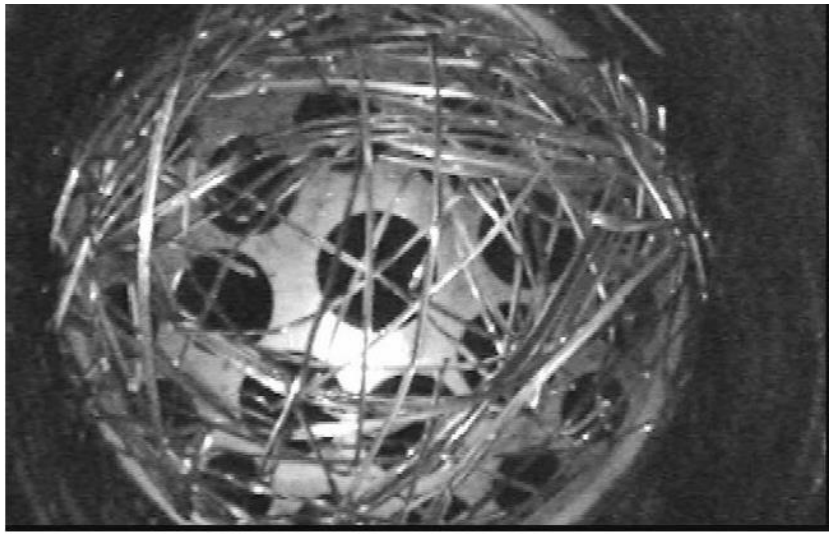
- These can be used to eliminate swirl, however...

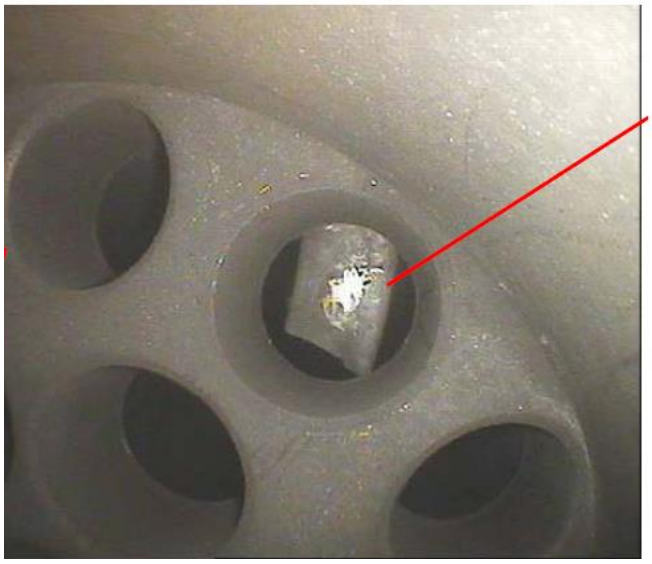
Tube Bundle Vortab Zanker Mitsubishi CPA

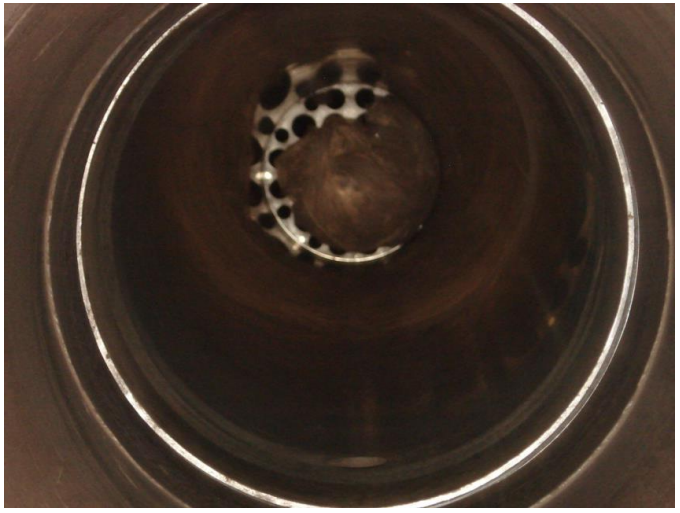
Flow conditioners

- 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



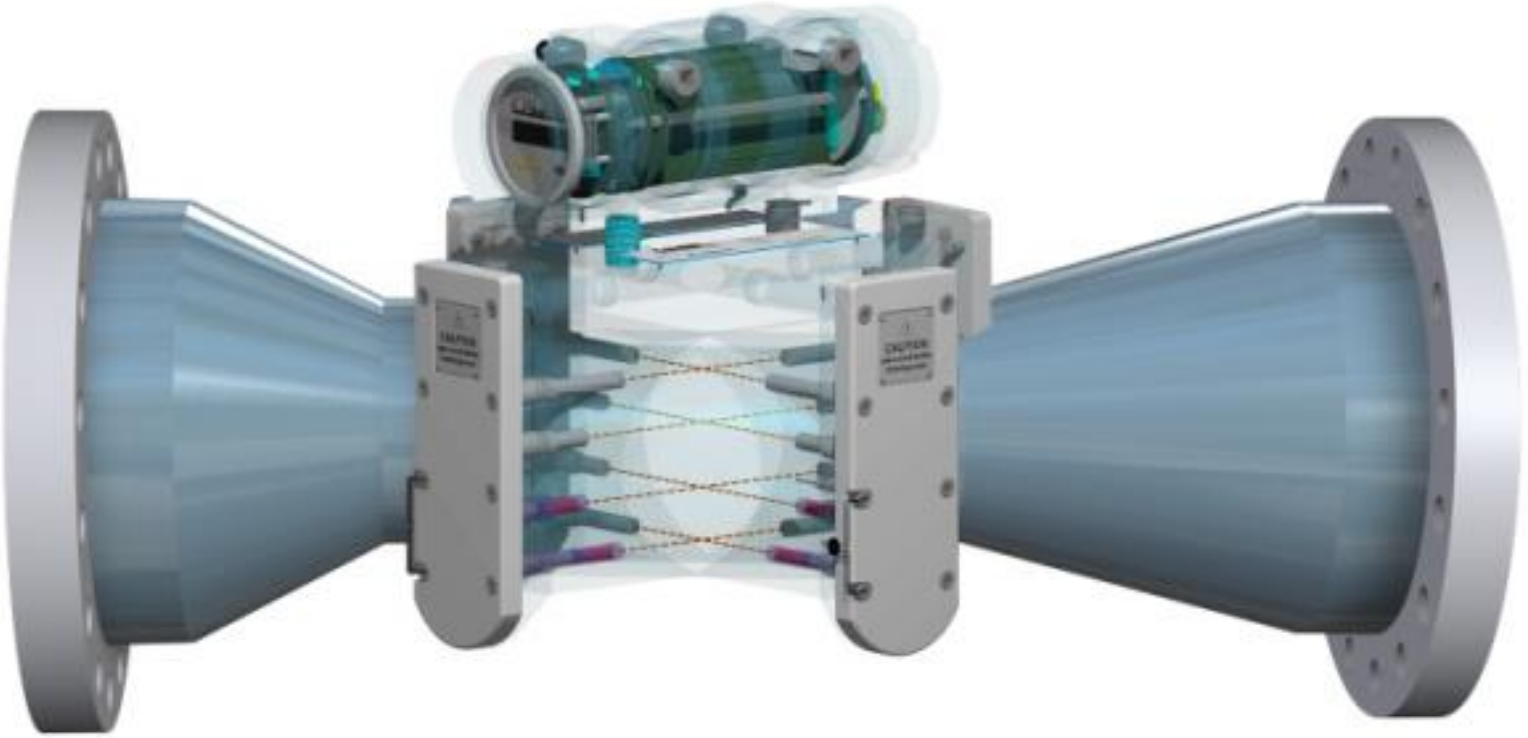




Caldon LEFM 280CiRN
for
High Viscosity Liquids
and In-Situ Proving

Caldon meter with reducing nozzle

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

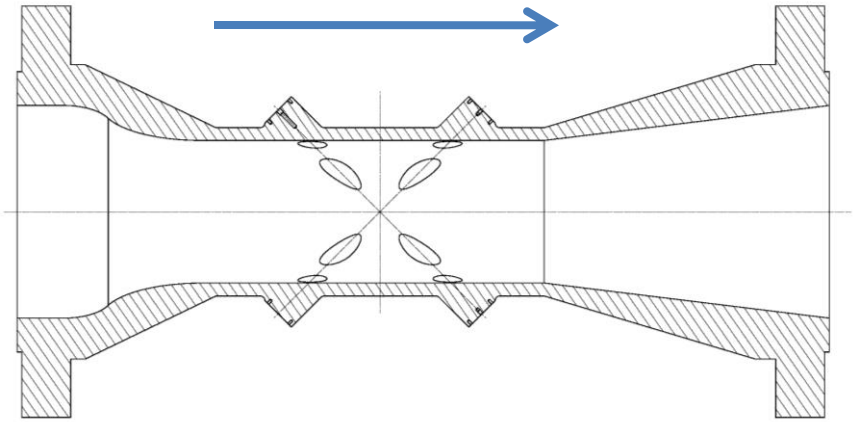


Caldon meter with reducing nozzle

- 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

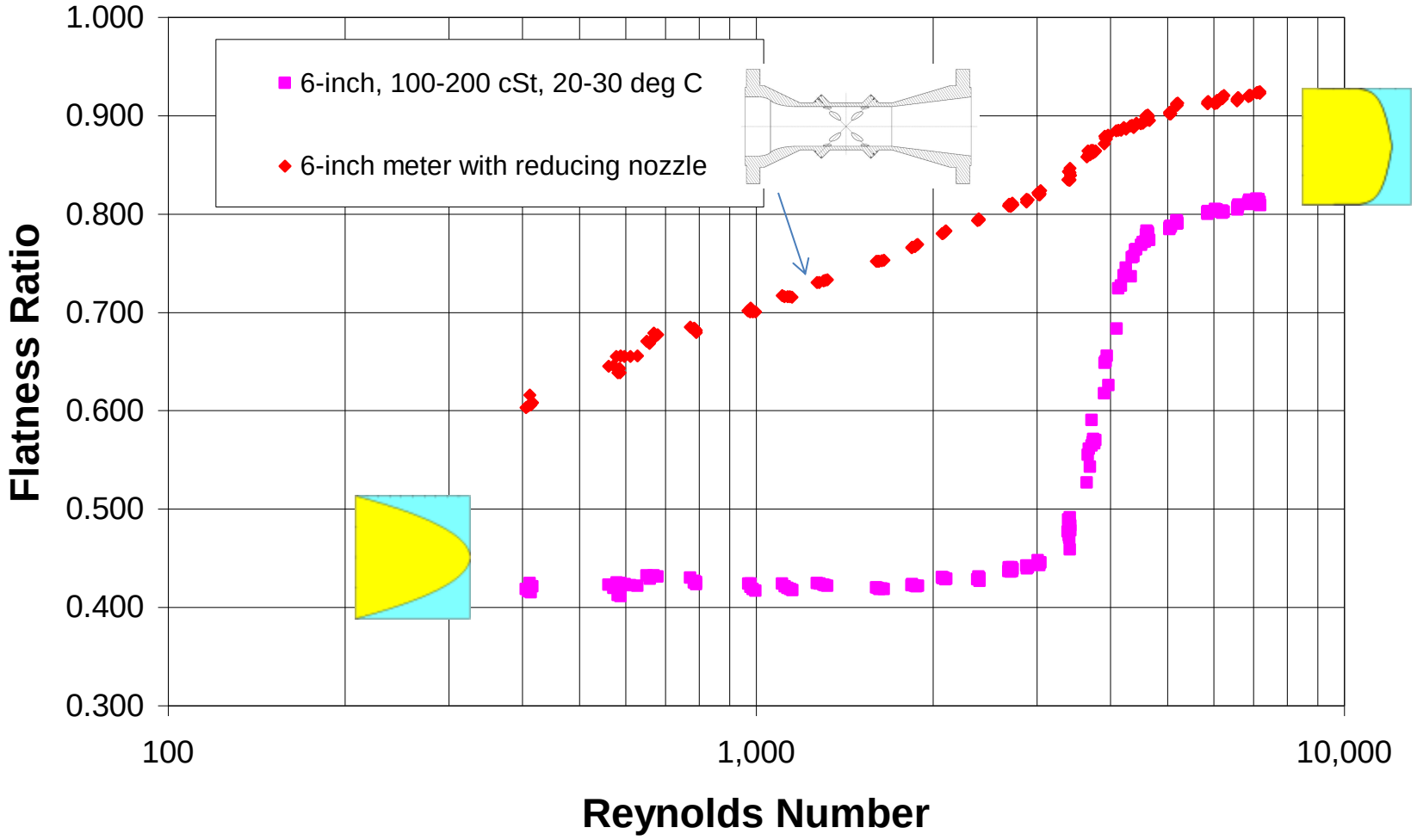
- Reducing **elliptical nozzle shaped** inlet
- **<u>Substantial</u> diameter/area reduction**
- **Beta < 0.64, area ratio < 0.41**
- Downstream pressure recovery cone



What does it do?

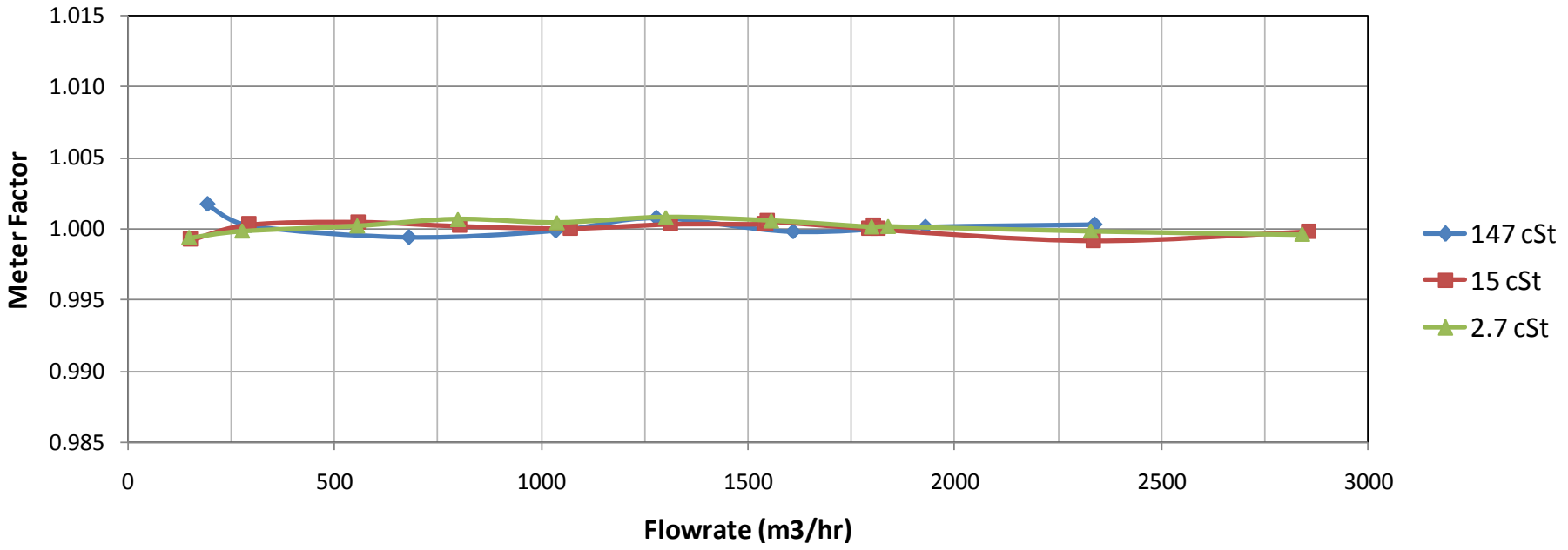
- The reducing nozzle works by:
  - Increasing the Reynolds number in the throat
  - **Flattening the velocity profile and smoothing out the transition between laminar and turbulent flows**
  - Reducing the relative magnitude of the non-axial velocities

Modified velocity profile behaviour



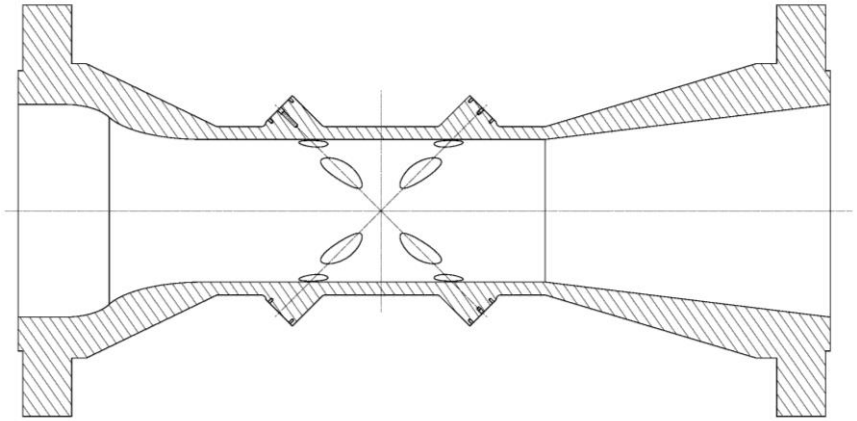
Caldon meter with reducing nozzle

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

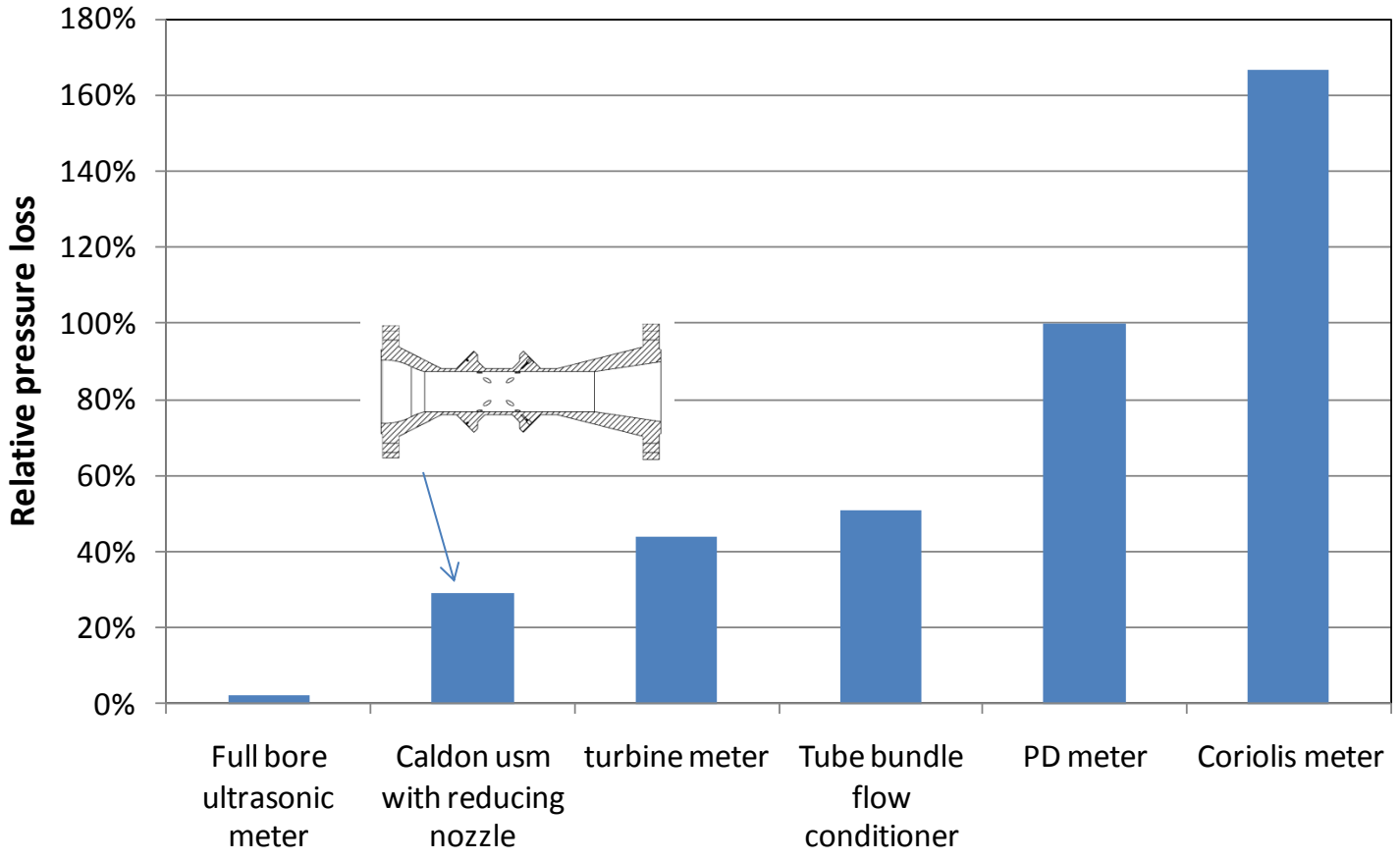


Pressure loss

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

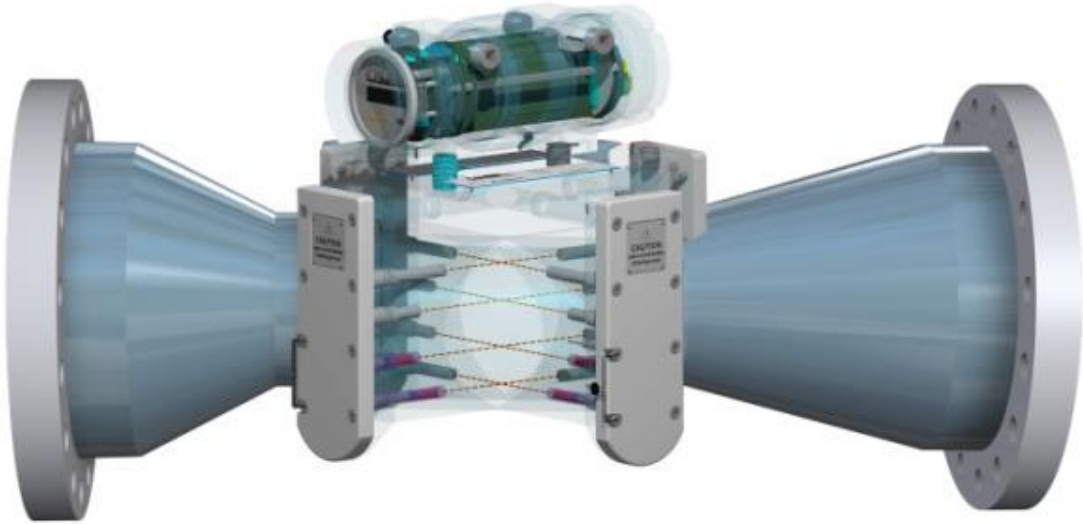


Relative pressure loss



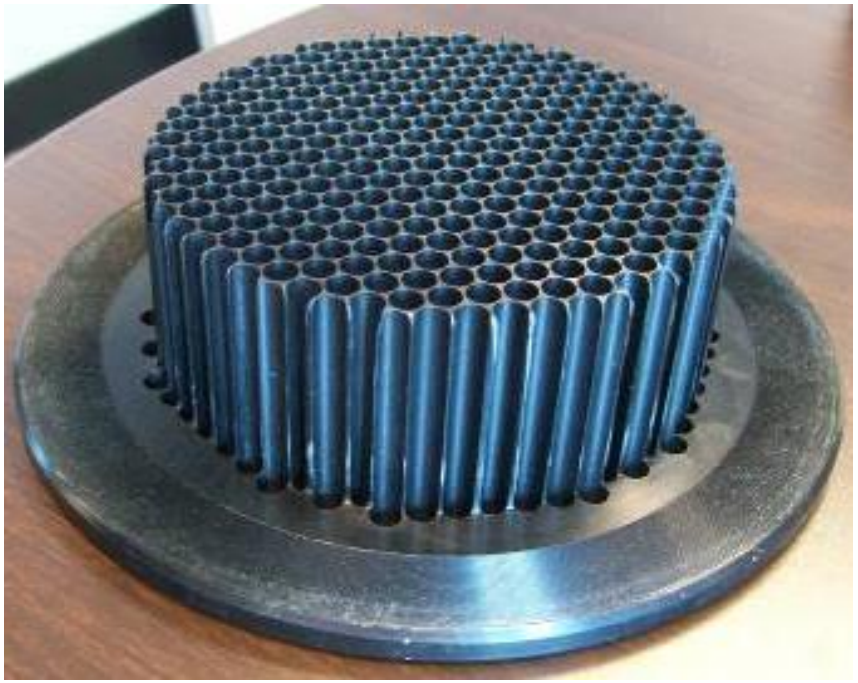
Caldon 280CiRN meter with reducing nozzle

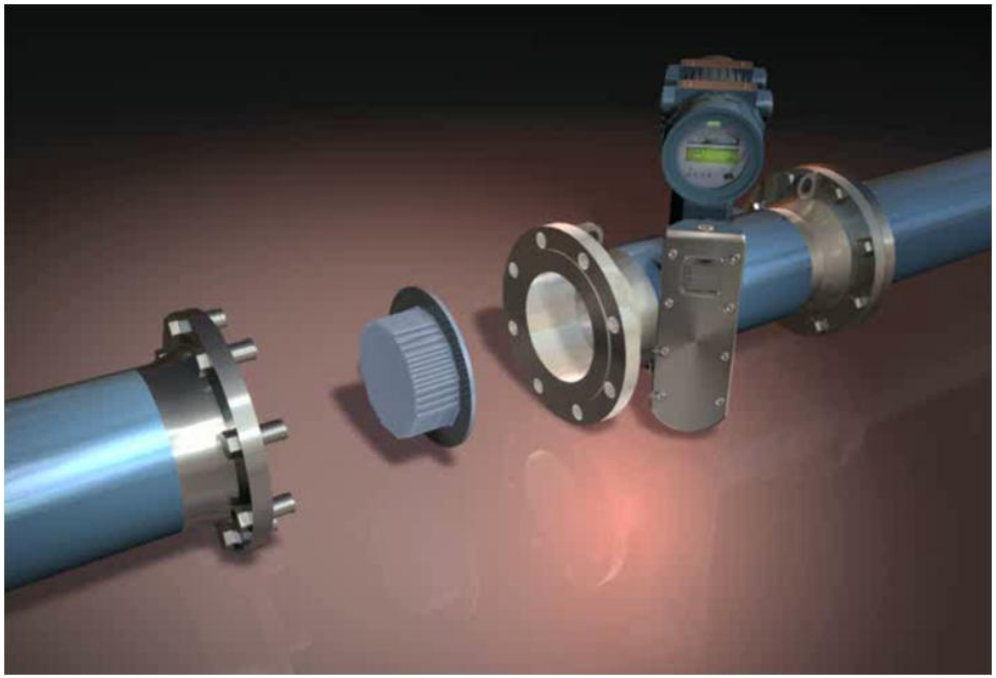
- Rapid acceleration of the flow via the smooth contour of the nozzle increases the axial velocity at the measurement section and reduces the relative magnitude of the turbulent features in the flow
- This results in a significant improvement in repeatability



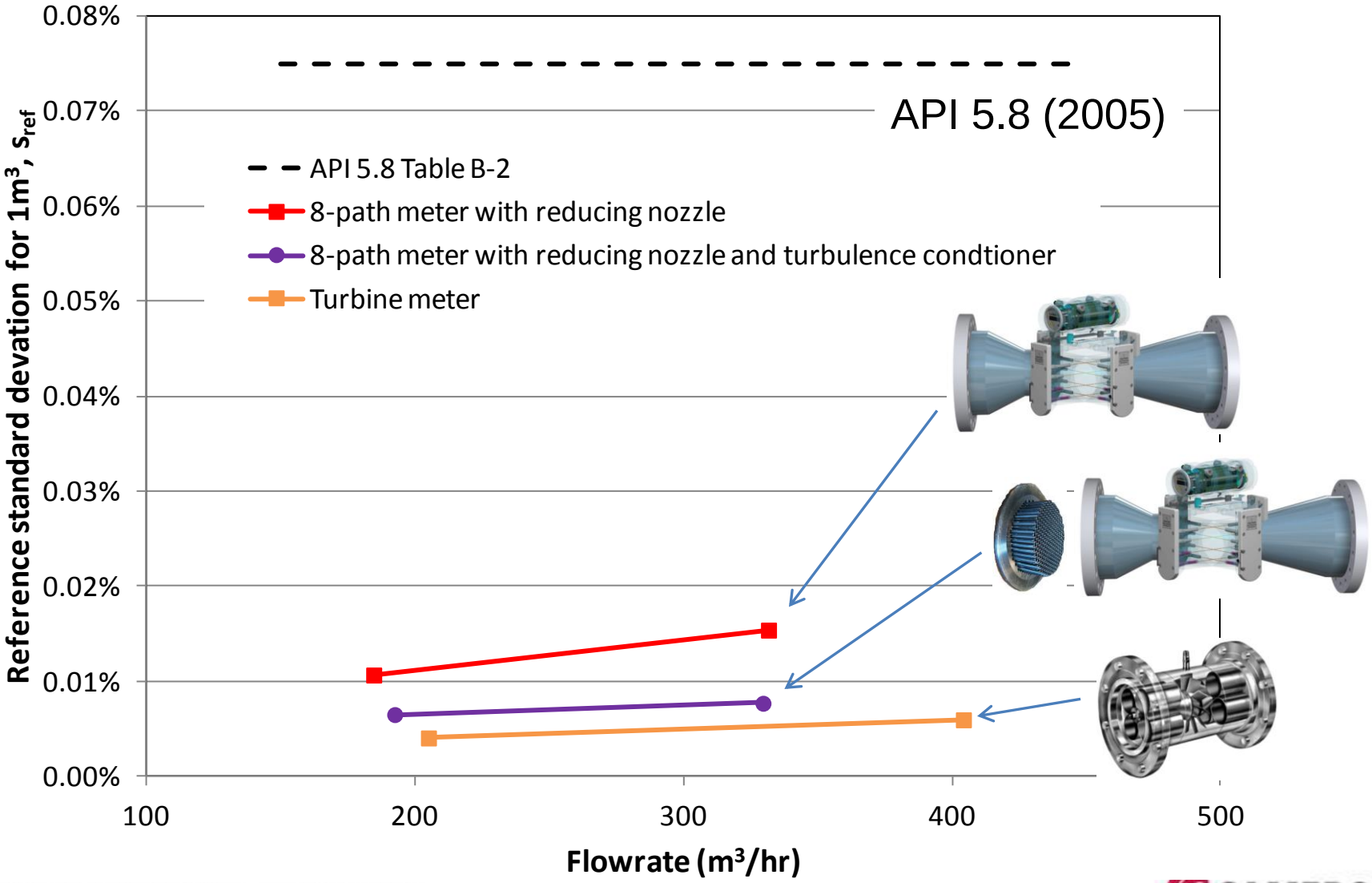
Turbulence conditioner

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



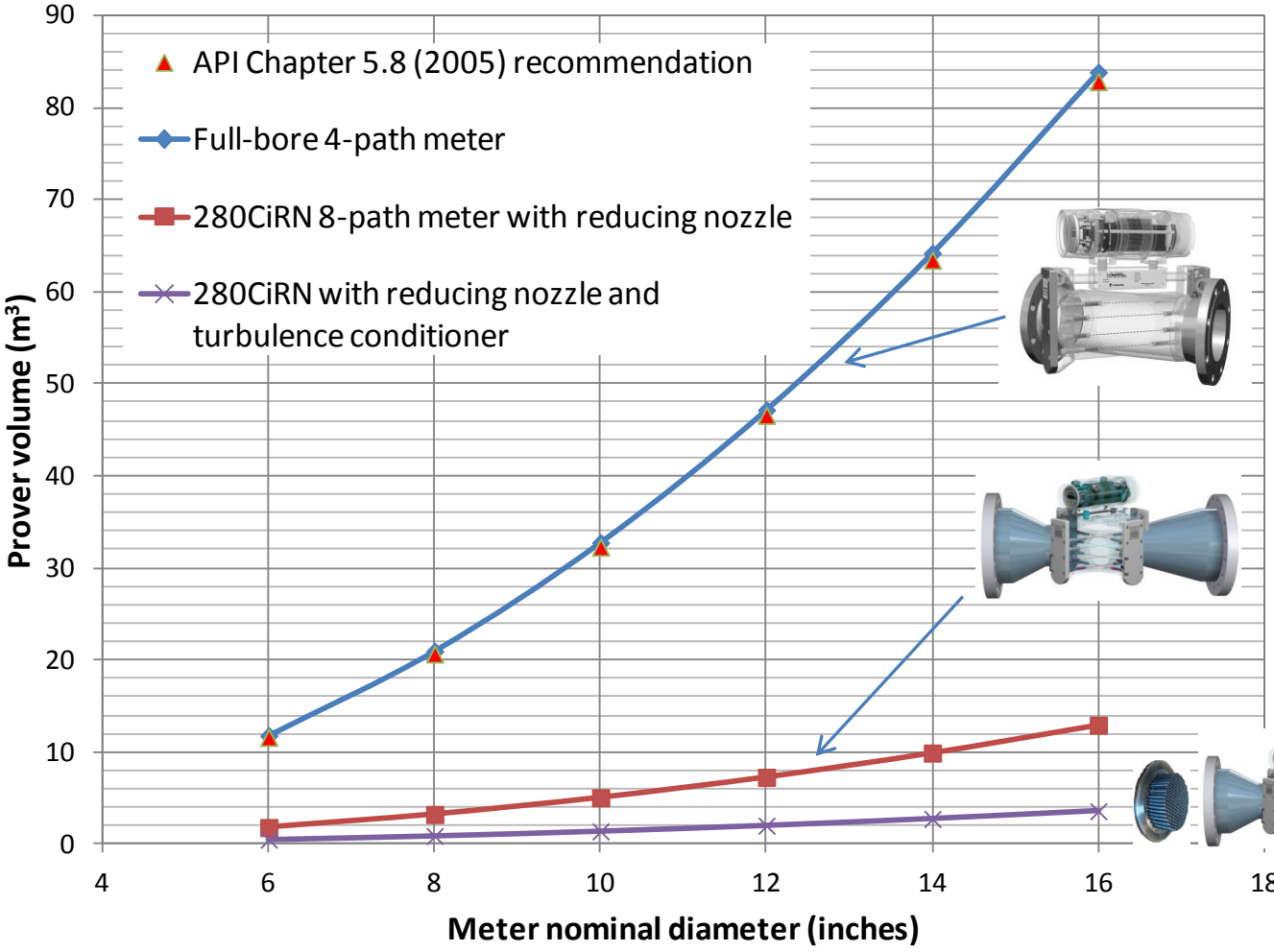


Reducing nozzle & turbulence conditioner



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

NMi

Evaluation Certificate

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 **Measurement sensor** (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) 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	**NMi Certin B.V.** 2 August 2010

C. Oosterman
Head Certification Board

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3314 EG Dordrecht
The Netherlands
T +31 78 6332332
certin@nmi.nl
www.nmi.nl

Custody transfer certification

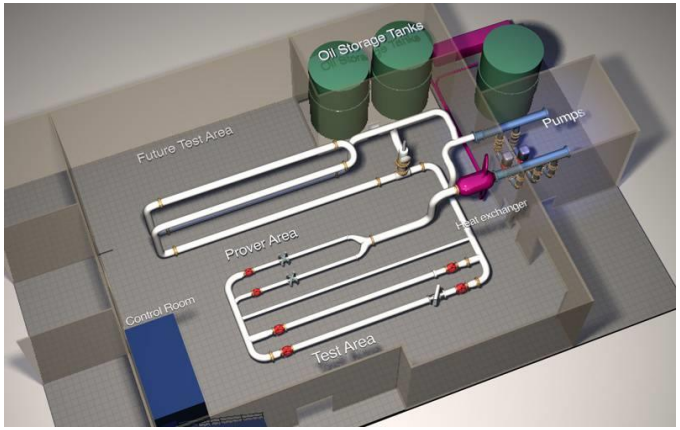
- Broadest range of certification in the market
- Highest available accuracy class (0.2 % MPE)
- Covers 4 and 8 path meters, full bore and reducing nozzle variants
- Meter diameters from 4 to 24 inch
- Viscosity range 0.1 to 3000 cP
- Temperature from -200 °C to +110 °C
- Turndown of 50:1 possible

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 ULTRSONICS
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^3/hr

Chosen route for certification/accreditation

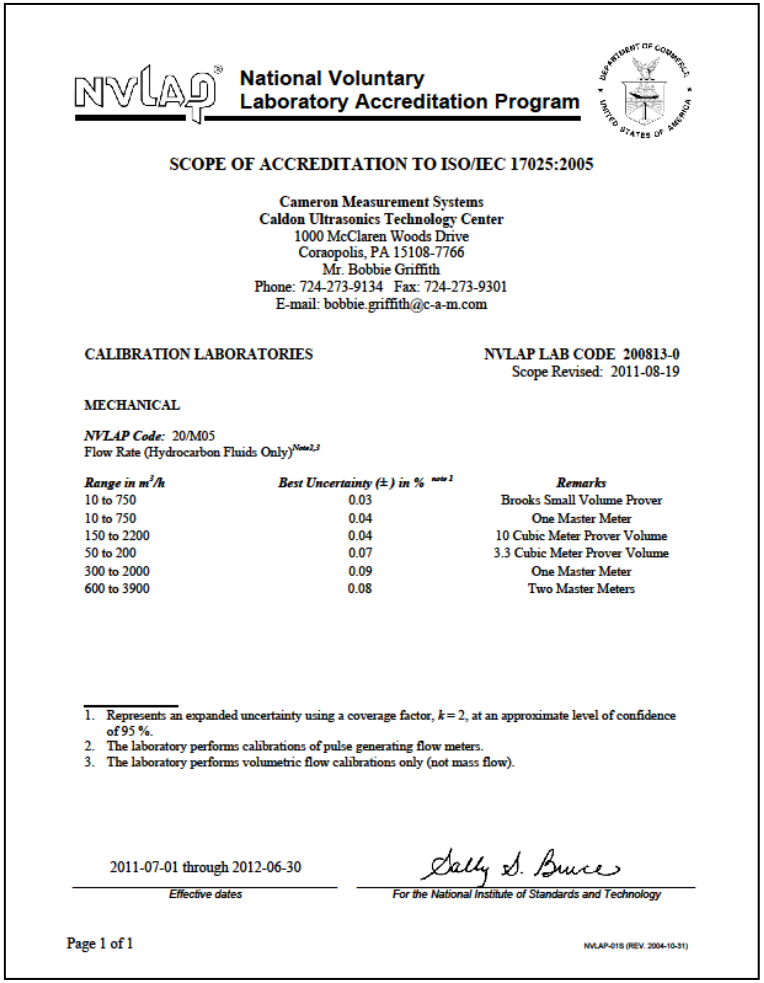
- NEL, Trapil and SPSE are all accredited to ISO17025 by the recognised authority in their respective countries (UKAS, COFRAC)
- Equivalence required that the Caldon laboratory should also have ISO17025 accreditation
- Various providers in the USA
- Caldon chose to use the National Voluntary Laboratory 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^3/hr
  - Small volume prover 0.03%
  - Turbine master meter 0.04%
- 150 to 2200 m^3/hr
  - Ball prover 10 m^3 0.04%
  - Ball prover 3.3 m^3 0.07%
  - One master meter 0.09%
- 600 to 3900 m^3/hr
  - Two master meters 0.08%



NVLAP® National Voluntary Laboratory Accreditation Program

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)Note2,3

Range in m^3/h	*Best Uncertainty (±) in %* note 1	*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

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

2011-07-01 through 2012-06-30 — *Effective dates*

Sally S. Bruce — *For the National Institute of Standards and Technology*

Page 1 of 1 NVLAP-01S (REV. 2004-10-31)

Calibration Process

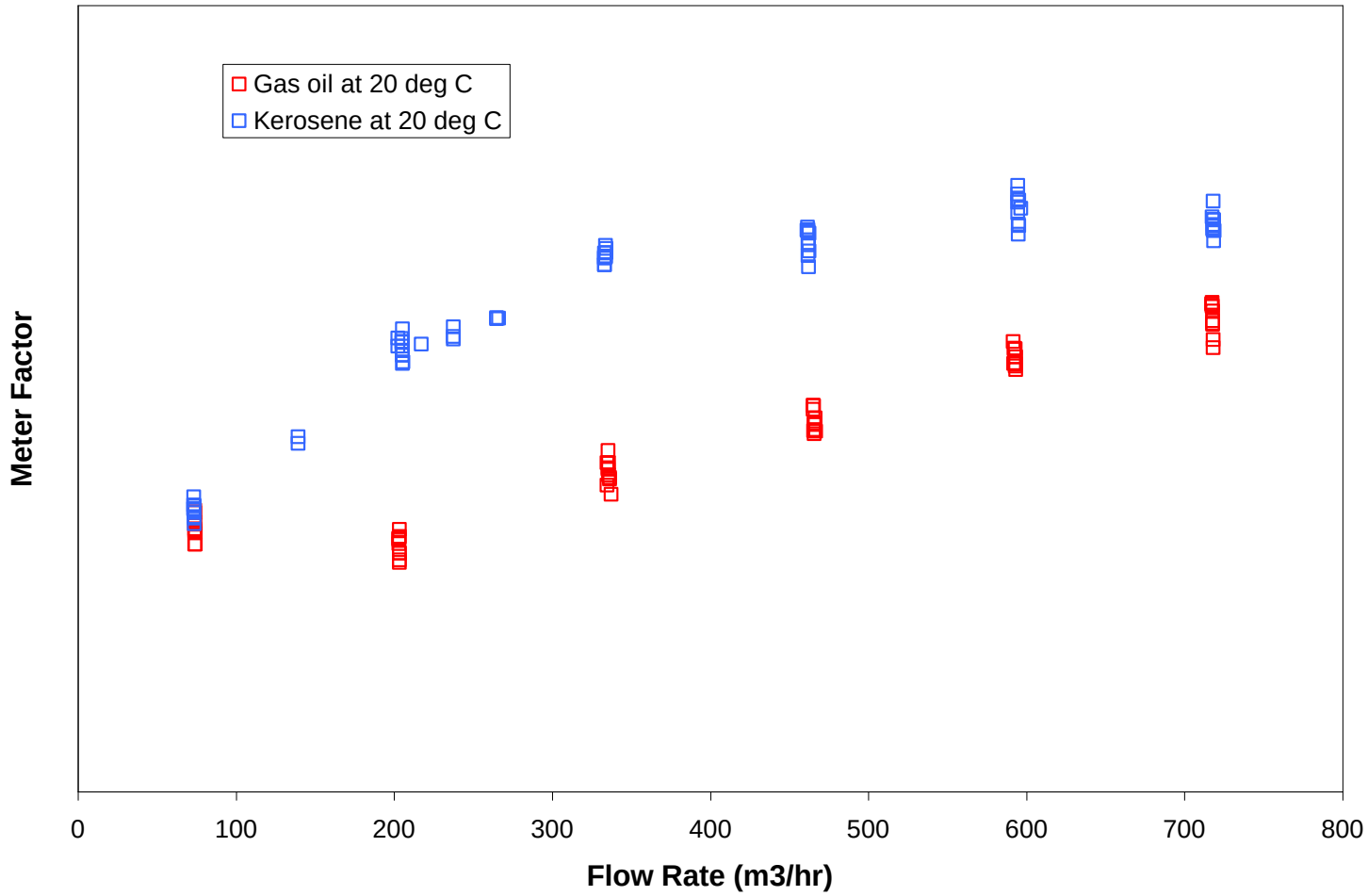
- For Caldon meters the calibration process typically involves tests on multiple fluid viscosities and entry of the resulting data in a look up table in the meter's electronics
- This creates a meter that is insensitive to changes in viscosity/Reynolds number over the range covered by the test fluids

Reynolds number

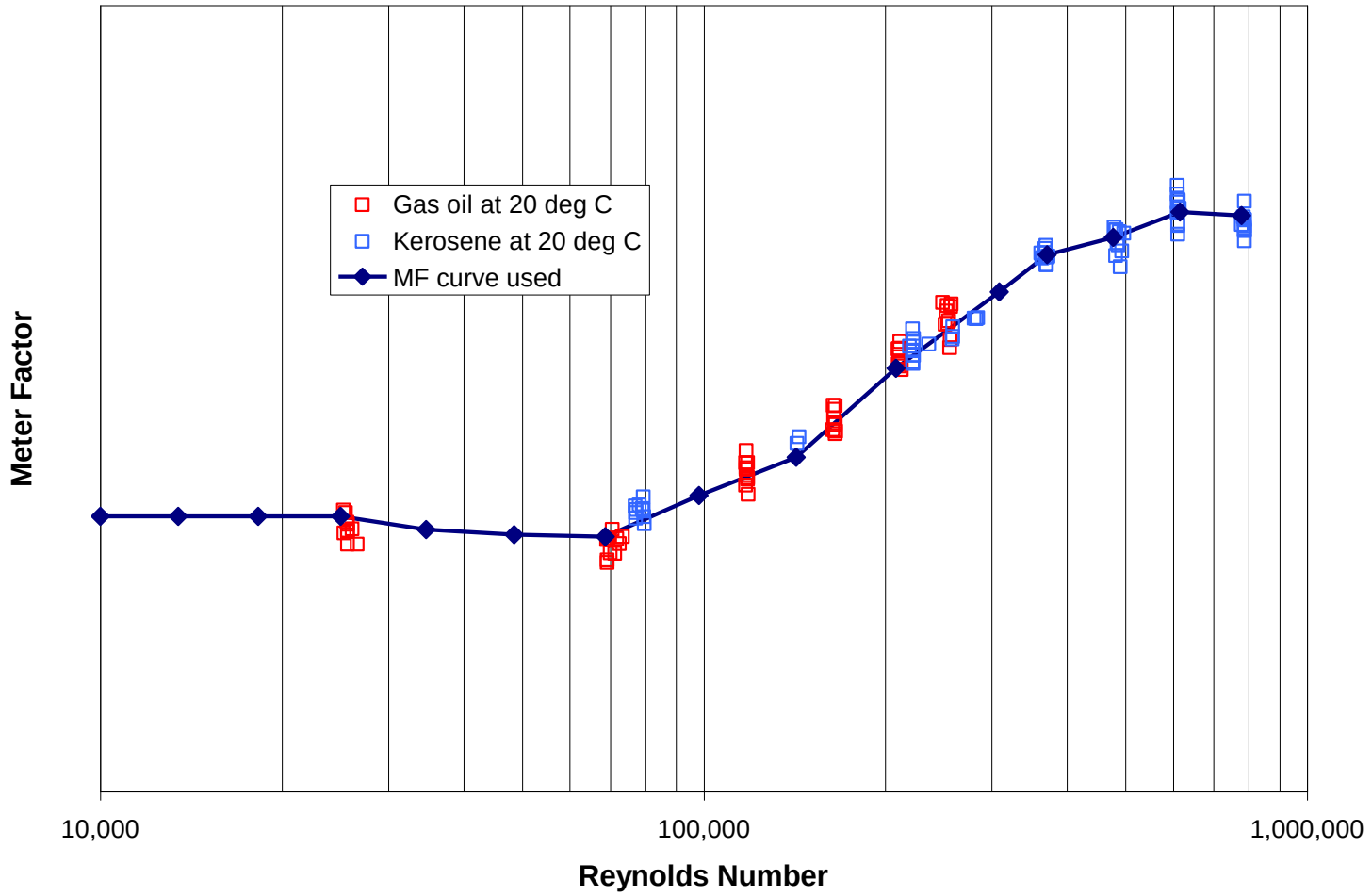
- Reynolds number describes the flow conditions in terms of velocity, pipe diameter and viscosity, and essentially defines the flow velocity profile characteristics of importance to ultrasonic meters

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

Raw Calibration vs Flow Rate



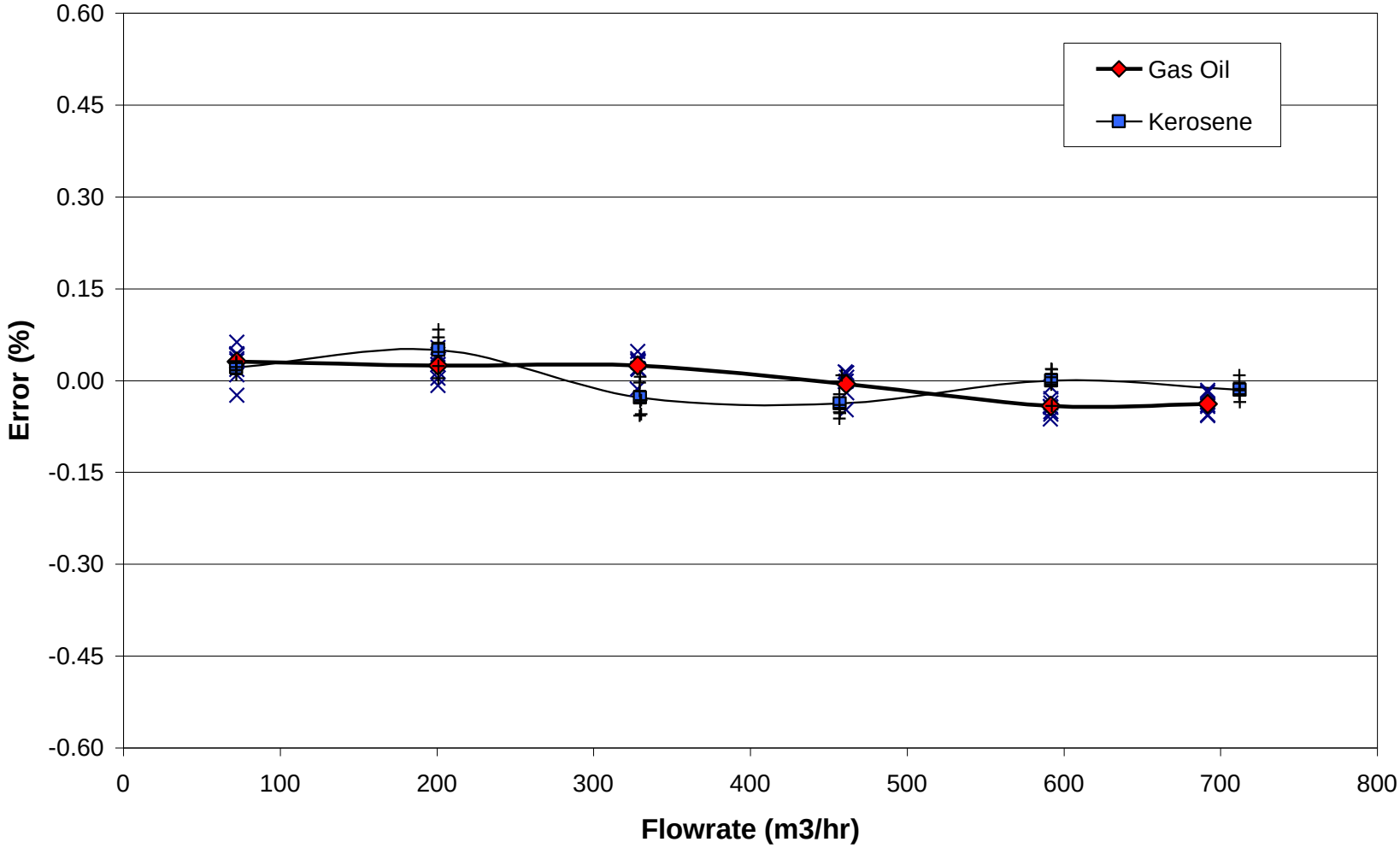
Raw Calibration vs Reynolds Number



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.”

NMi

Evaluation Certificate

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 **Measurement sensor** (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) 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	**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 6332332
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 BV as Notified Body can be verified at http://ec.europa.eu/enterprise/newapproach/nando

Parties concerned can lodge objection against this decision, within six weeks after the date of submission, to the general manager of NMi (see www.nmi.nl).

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INSPECTION RvA I 122

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

Yùum K'ak'Náab 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


M14
FISCAL METERING SKID

Proving with portable provers

Sunoco Toledo refinery, 8-path meter


SUNOCO PIPELI
TOLEDO REFIN

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	0.036%
MF	1.0012
MF Variation	0.0010

Liquid Properties at Metering Conditions for CMF

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

	RUN	Accepted?	IMF
64	1	Yes	1.00114
86	2	Yes	1.00125
71	3	Yes	1.00146
17	4	Yes	1.00110
99	5	Yes	1.00112
5074			1.00121

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

Liquid Properties at Metering Conditions for CMF

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

	RUN	Accepted?	IMF
12	1	Yes	1.00114
12	2	Yes	1.00096
16	3	Yes	1.00139
11	4	Yes	1.00104
15	5	Yes	1.00098
0512			1.00110

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	

	RUN	Accepted?	IMF
607	1	Yes	1.00095
940	2	Yes	1.00107
029	3	Yes	1.00085
817	4	Yes	1.00105
867	5	Yes	1.00098
9.4120			1.00098

6-inch 280CiRN – SVP, DIRECT proving

[redacted]

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		Mesurement 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 BPH		
3	78.8	63.5	79.2	467.5	473.5	1,897.060	2,010.57	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	1,897.230	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	x	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
1,896.8700	/	2.000	=	0.948440		0.95480		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

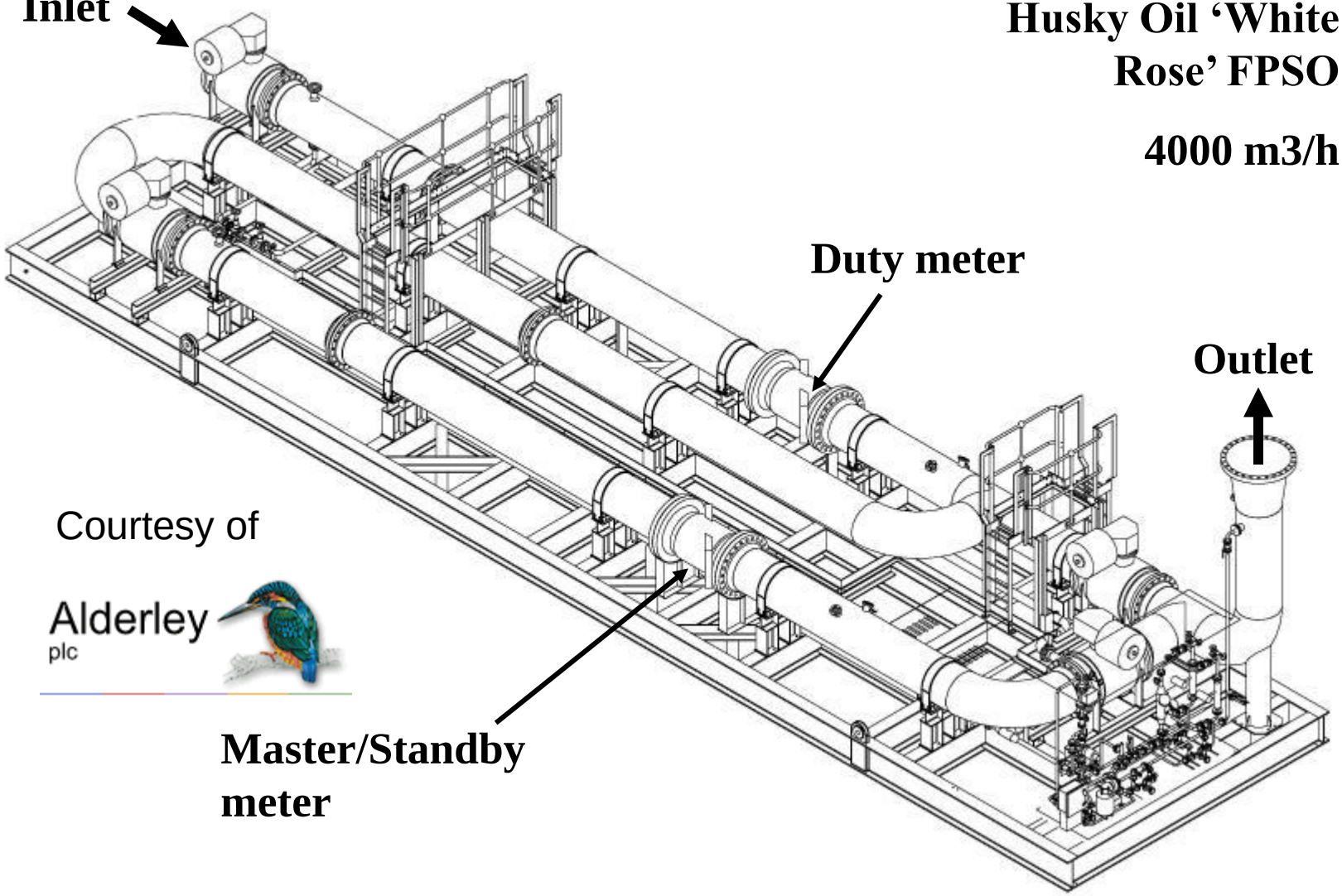
Comments:

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

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	

Master/Duty or Pay/Check installations

Tullow Oil, 4-path pay and check


Inlet
Husky Oil 'White Rose' FPSO
4000 m3/h
Duty meter
Outlet
Courtesy of
Alderley plc
Master/Standby meter

Ultrasonic Flow Meters – Multipath Liquid

FPSO Aoka Mizu, Nexen/Bluewater, UK North Sea

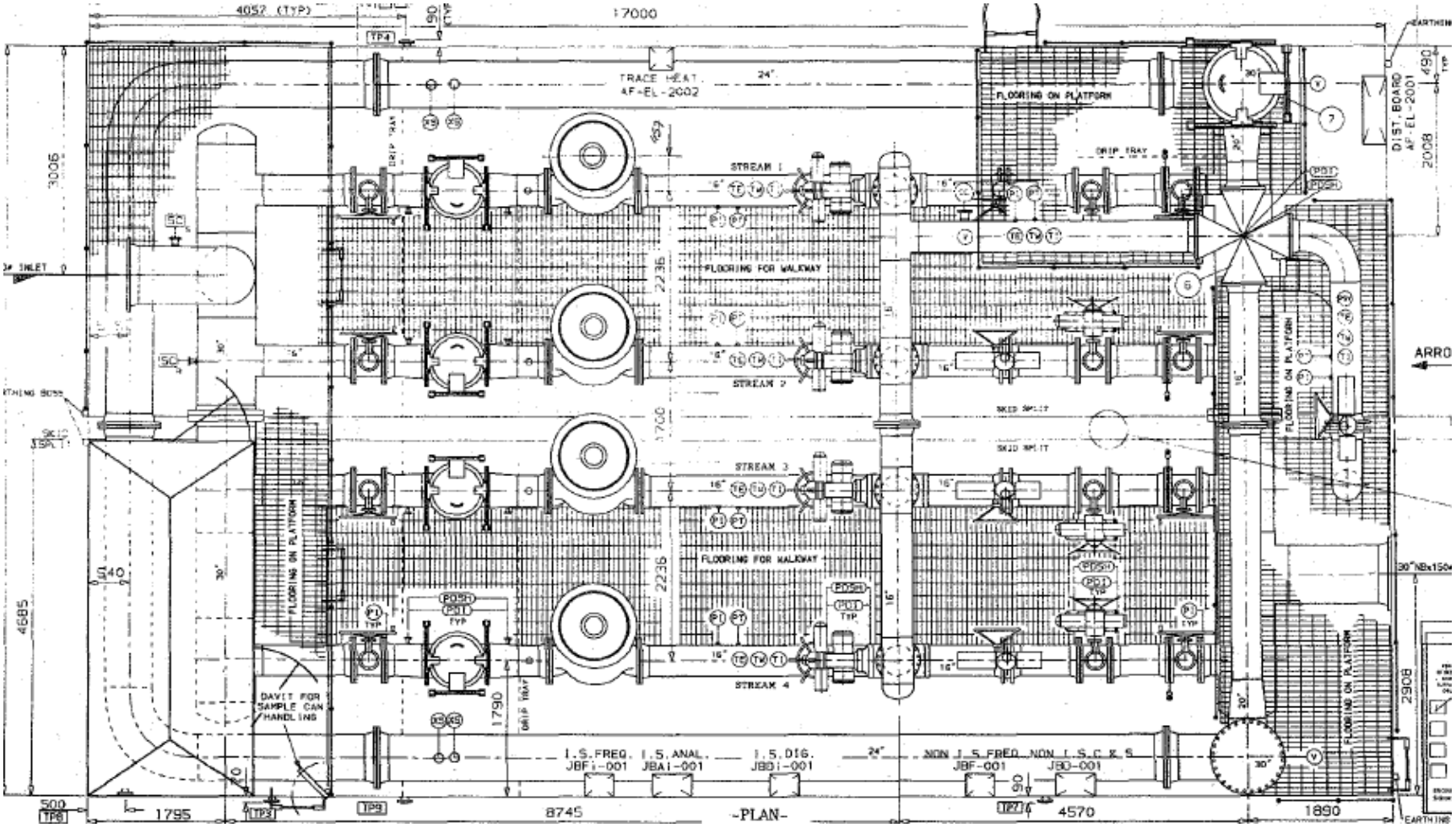
- Design Capacity 6500 m3/h
- Configuration: 2+Master Meter
- 14” LEFM 240C
- Master Meter Proving

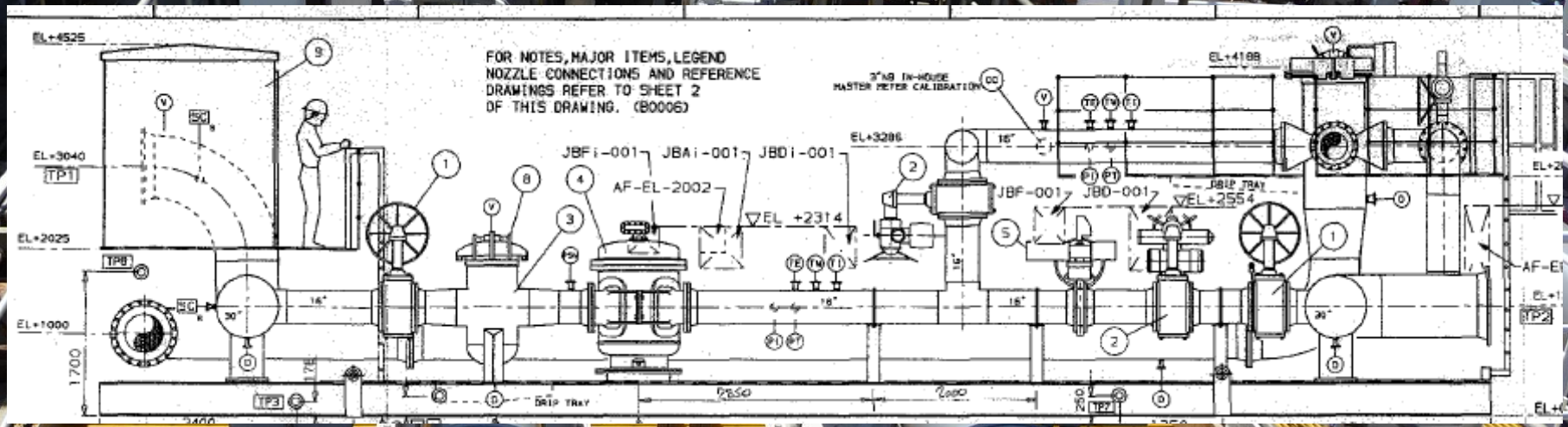
Retrofit/replacement of traditional mechanical meters

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




FOR NOTES, MAJOR ITEMS, LEGEND
NOZZLE CONNECTIONS AND REFERENCE
DRAWINGS REFER TO SHEET 2
OF THIS DRAWING. (B0006)
EL+4525
EL+3040
TP1
EL+2025
TP8
EL+1000
TP3
1700
JBFi-001
JBAi-001
JBDi-001
AF-EL-2002
EL +2314
EL+3286
3"NB IN-HOUSE
MASTER METER CALIBRATION
EL+4188
JBF-001
JBD-001
EL+2554
DRIP TRAY
2850
2000
TP7
TP2


FOR NOTES, MAJOR ITEMS, LEGEND
NOZZLE CONNECTIONS AND REFERENCE
DRAWINGS REFER TO SHEET 2
OF THIS DRAWING. (B0006)
EL+4525
EL+3040
EL+2025
EL+1000
1700
JBFi-001
JBAi-001
JBDi-001
AF-EL-2002
EL +2314
EL+3286
EL+4188
JBF-001
JBD-001
EL+2554
DRIP TRAY
TP1
TP2
TP3
TP8

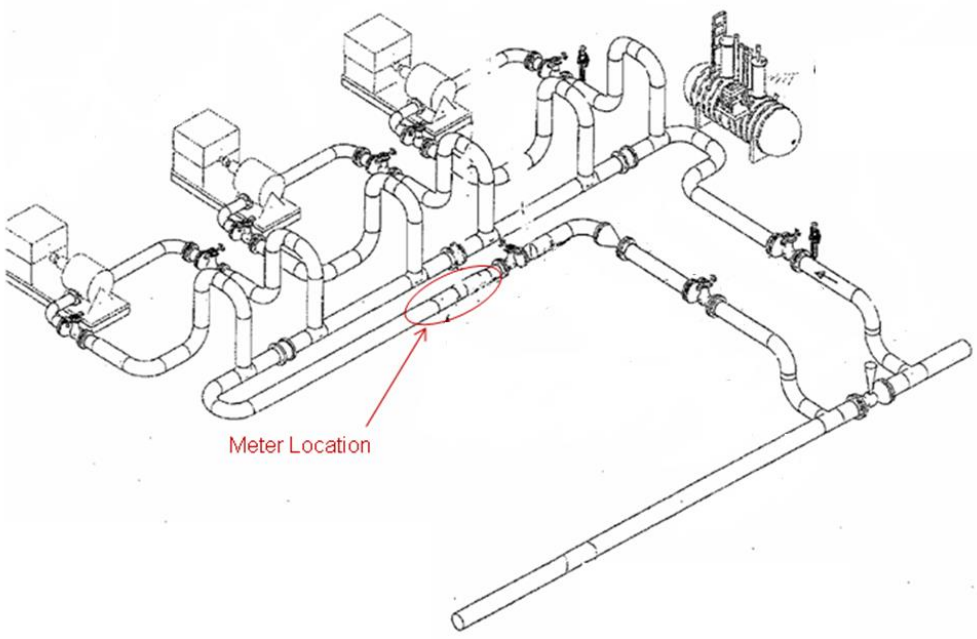
Pipeline Leak Detection

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

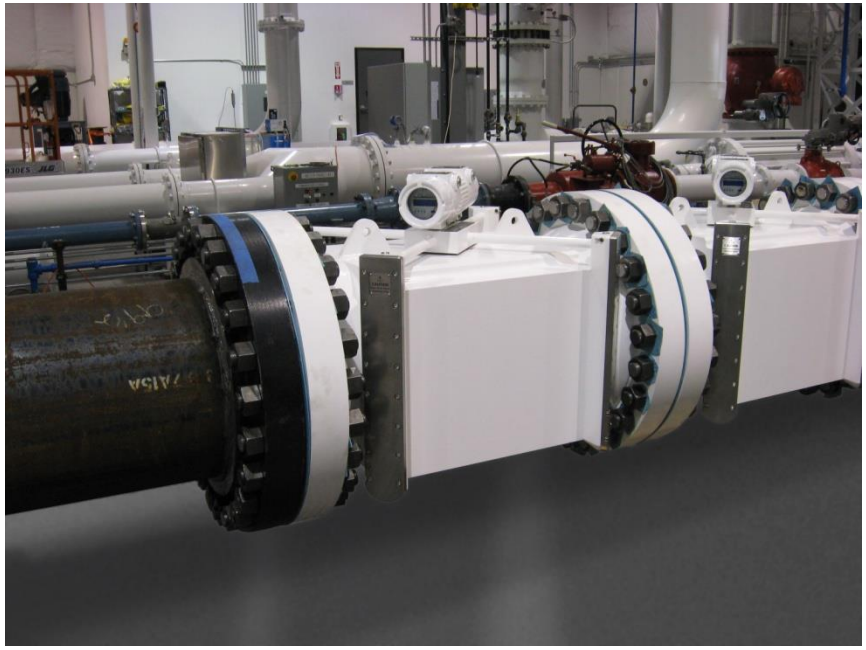


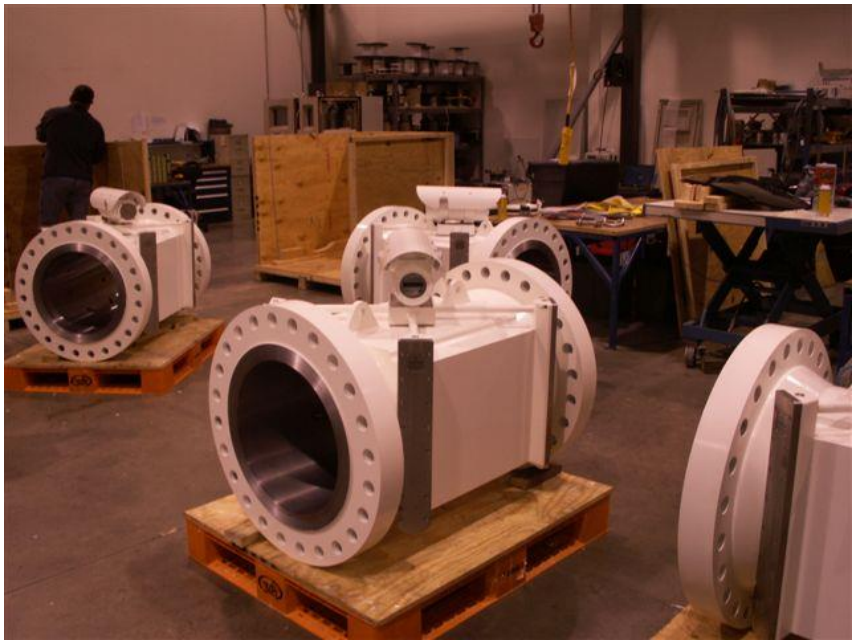
Pumping Cost

- 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

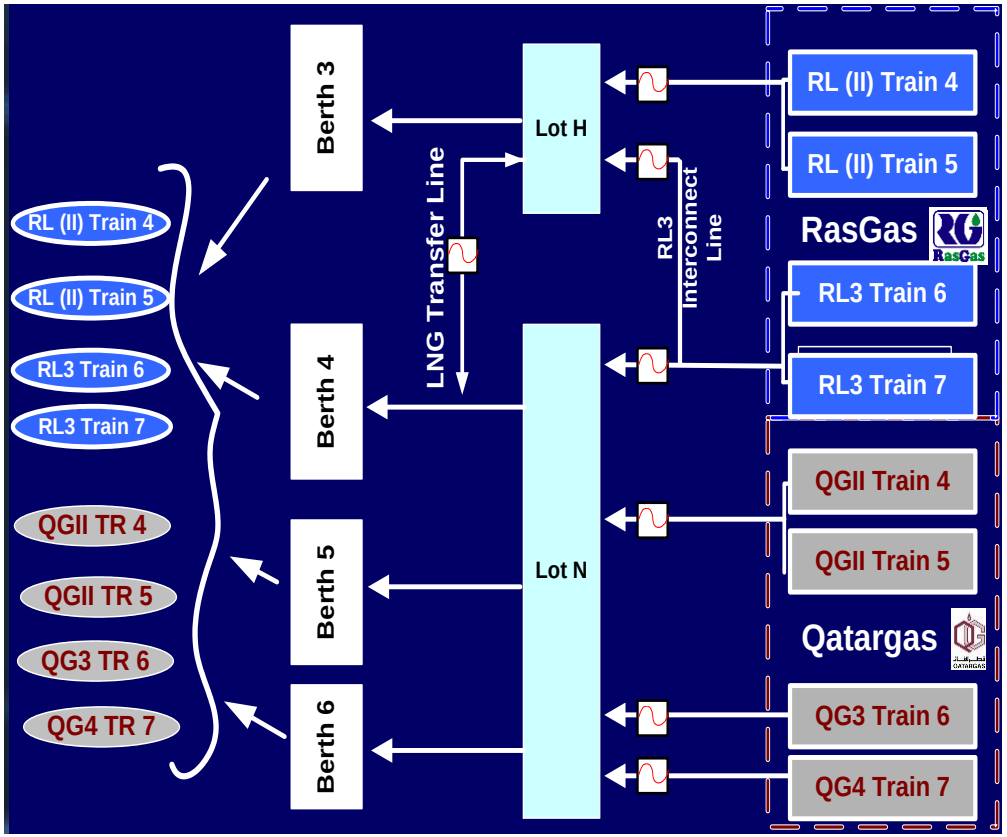




LNG Allocation and Custody Transfer

Qatar Common LNG Facilities

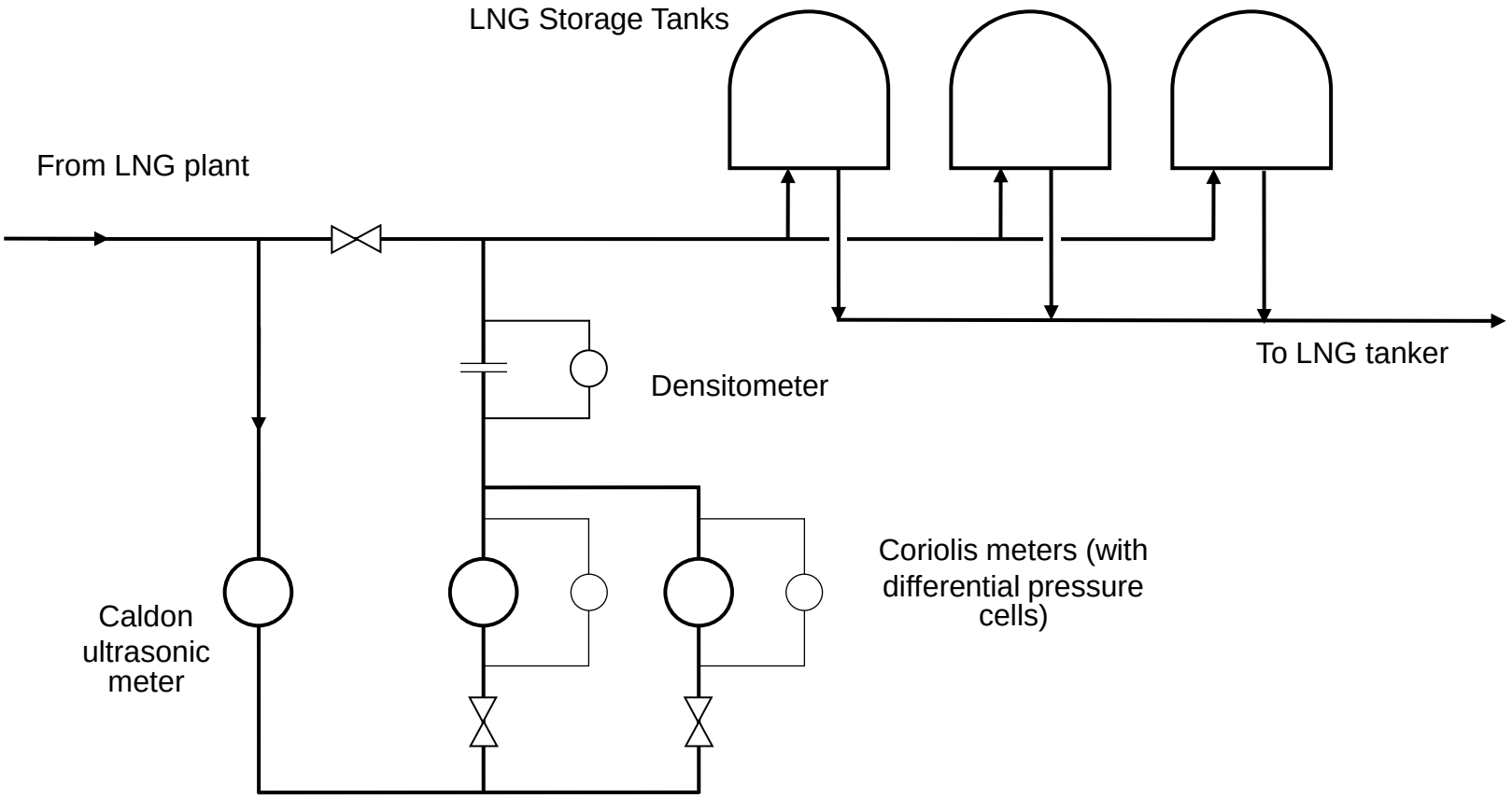
- Common storage and shared offloading for multiple production joint ventures
- Massive cost savings (estimated 1 billion $ us)
- Allocation metering is a key enabling technology



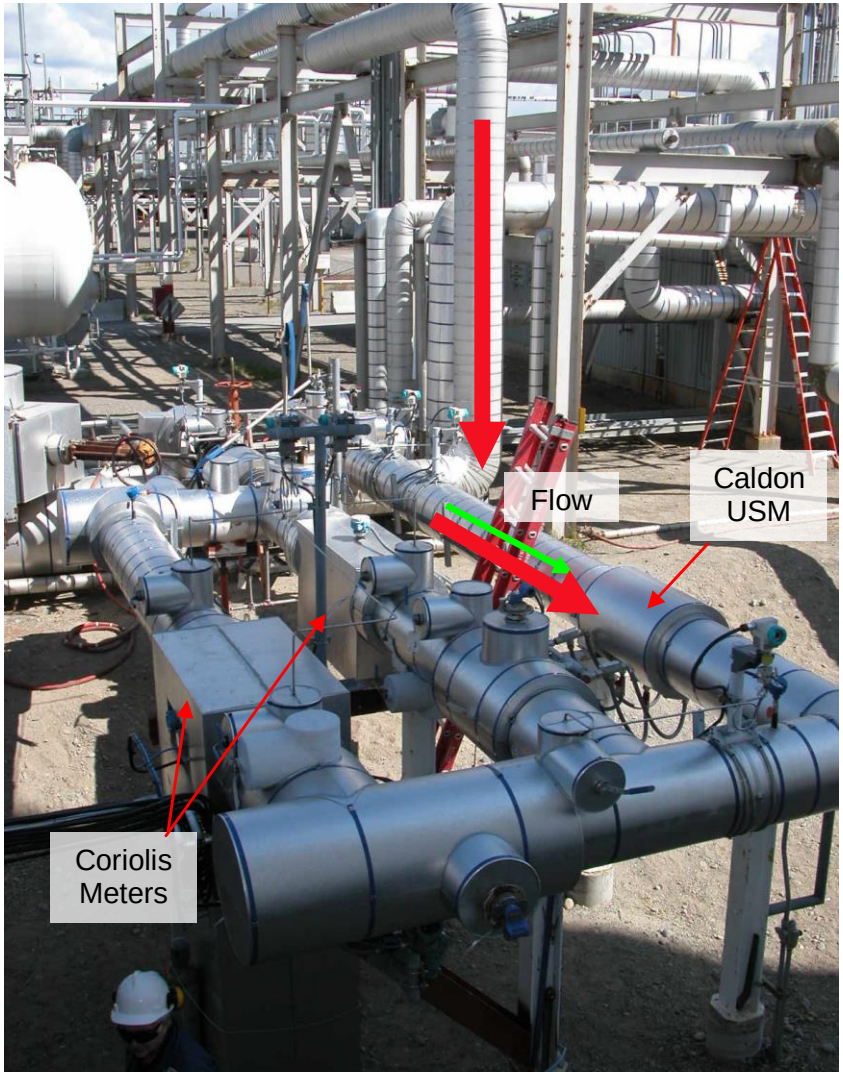
Field tests

- 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

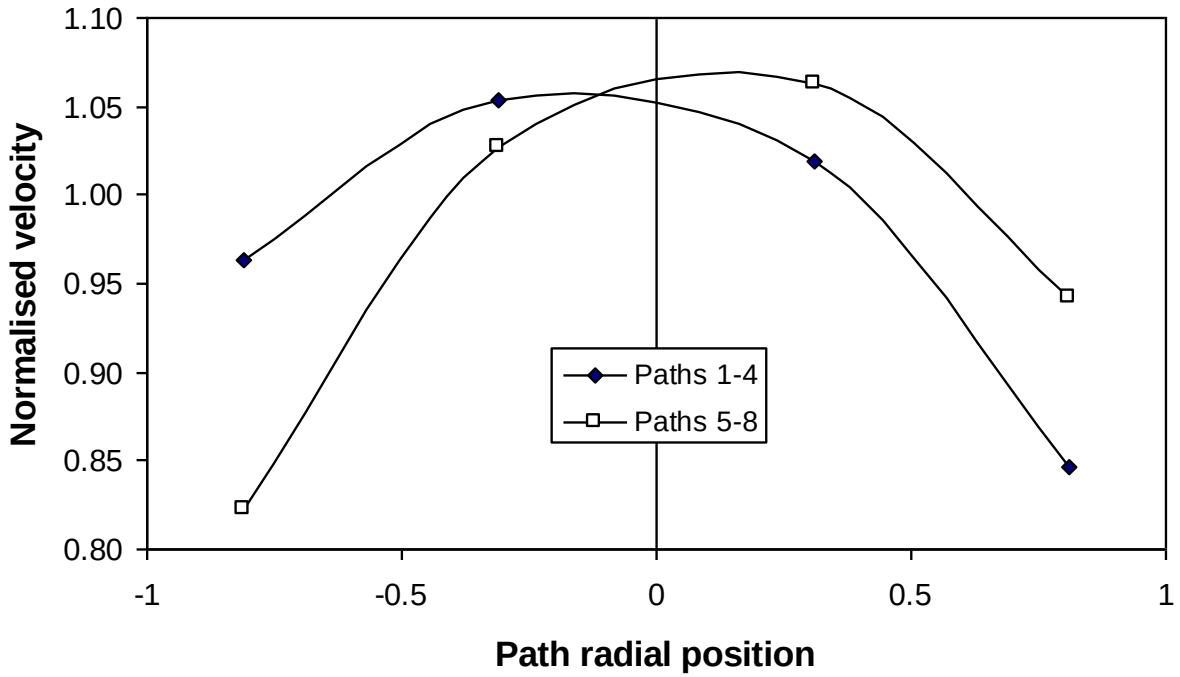

LNG Storage Tanks
From LNG plant
To LNG tanker
Densitometer
Coriolis meters (with differential pressure cells)
Caldon ultrasonic meter

Out-of-Plane Bends



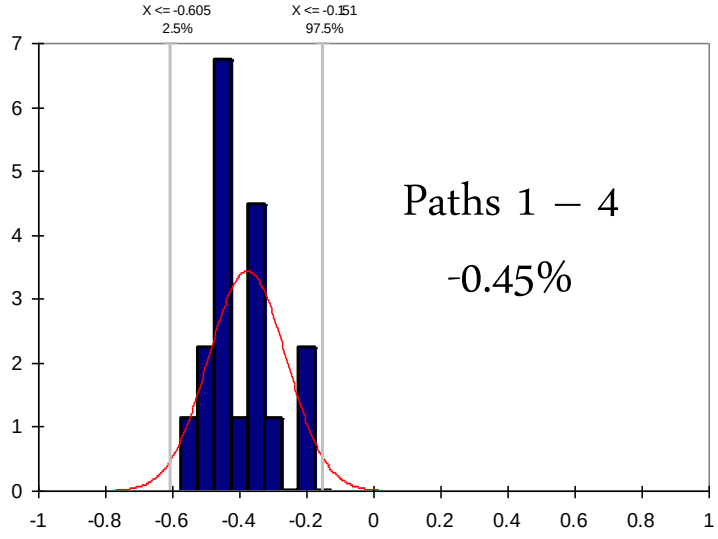
37 diameters of straight pipe upstream

Path Velocities Confirm Swirl



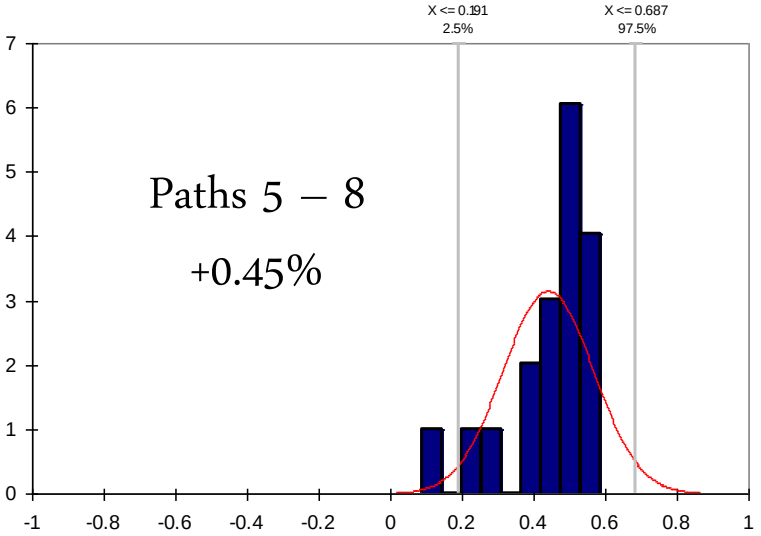
- Max swirl angle of approx 5 degrees (or one full rotation every 48 pipe diameters)

A and B Outputs



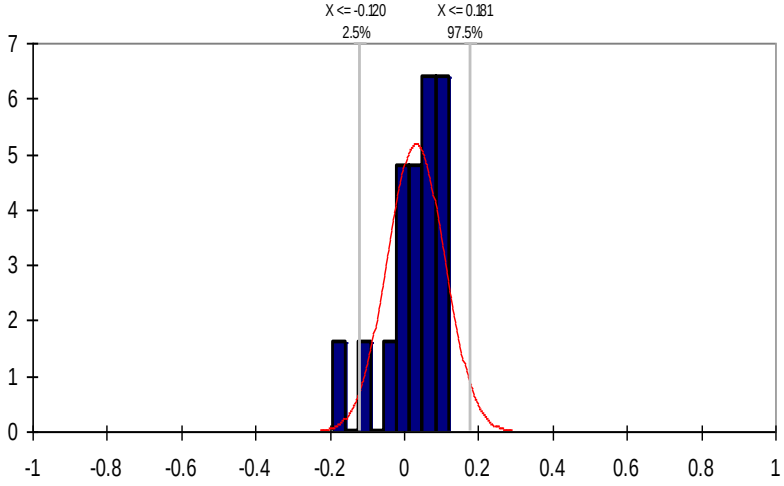
Paths 1 – 4

-0.45%



Paths 5 – 8

+0.45%



8-Path result

<0.1%

Test Outcomes

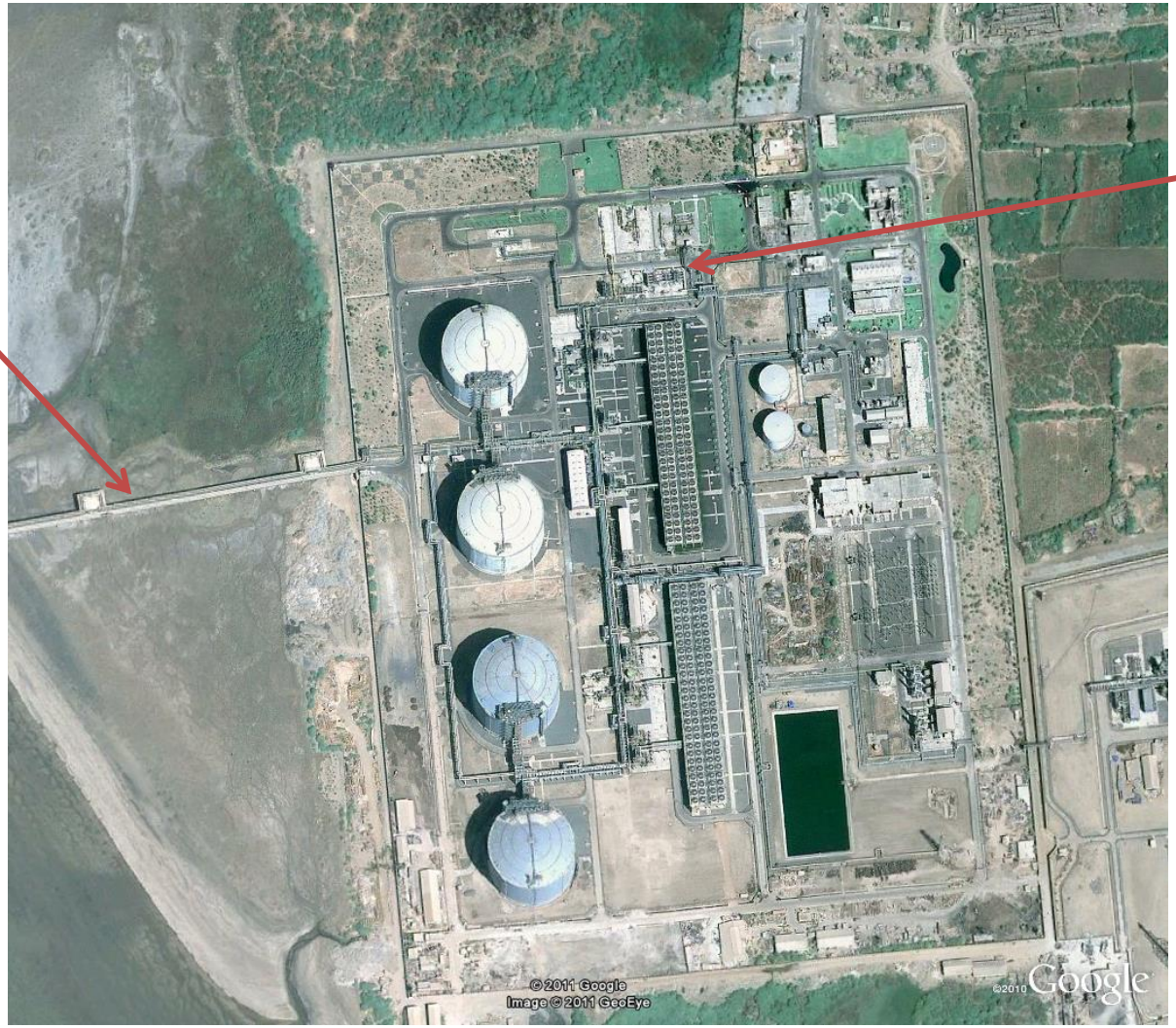
- 22 Caldon LEFM 280C-LT flow meters employed for allocation metering at Ras Laffan
- Same technology selected for custody transfer of LNG at the Dajeh receiving facilities in India

Dahej Re-Gasification Plant, India

Dahej Re-Gasification Plant, India

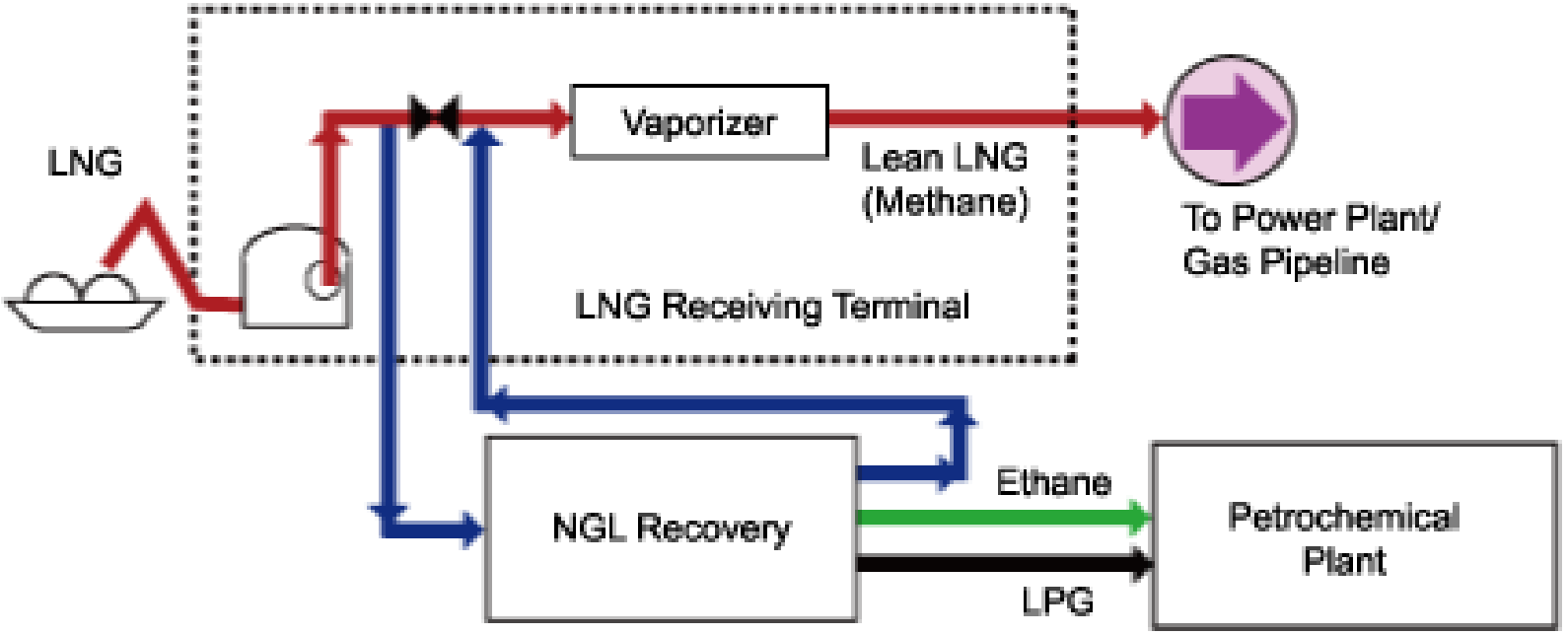
- Expansion project includes new storage facility and new jetty
- New Jetty will be able to dock Q-Flex and Q-Max tankers
- Contract with Qatar to receive 7.5 MTPA LNG
- Dynamic measurement of LNG to Gas using LEFM 280C meters

Dahej Re-Gasification Plant, India



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