Laser Doppler Velocimetry (LDV)

An Accredited Method for On-Site Calibration of Large Flow Meters

In the course of the last three years, the Danish Technological Institute has achieved – as the only laboratory in the world – accreditation for on-site calibration of flow meters using Laser Doppler Velocimetry (LDV). This innovative calibration technique is now accredited to perform on-site calibration of flow meters with diameters of 100 mm up to 1000 mm, and a flow range of 0.25 m^3/h up to 17,000 m^3/h (0.01 m/s to 6 m/s), with an expanded measurement uncertainty of 0.9 %. Two accredited calibrations have already been carried out: a calibration of a 500 mm flow meter at the Danish refuse incineration plant L90, and a calibration of a 1000 mm flow meter at Esbjergværket, a CHP (Combined Heat and Power) plant, both located in Esbjerg/Denmark. The results from both calibrations have been very satisfactory and the Danish Technological Institute expects a rapidly increasing interest in this calibration method in the future.

Background

In district heating networks and other facilities with large amounts of water flow it is a typical problem that large flow meters are difficult – and sometimes impossible – to calibrate once they have been installed and are in operation. In addition to the associated practical and economic problems, it can also be difficult to find a suitable laboratory to carry out the calibration. There are limited facilities in Europe offering calibration of flow meters larger than 200 mm in diameter and at flow rates greater than 400 to 500 m^3/h. The few facilities capable of doing so operate mainly with cold water. In addition, a laboratory calibration will inevitably take place under conditions which do not reflect the normal operating conditions of the installed meter. This is of great importance, as regular meter calibration is the best way of obtaining information about the meters' current measurement ability.

In Denmark alone there are approximately 1000 large meters in the district heating system, and the majority of the heat produced and sold is billed according to these meters. With an annual Danish district heating production of about 90 PJ, metering errors are an important factor with regard to fair billing between the district heat supplier and the district heating companies. In addition to using meter readings for billing purposes, district heating suppliers are interested in using data from the meters to plan heat production relative to a forecasted demand. Any difference between the measured and the true flow values can easily lead to excessive primary energy consumption. Likewise, inaccurate or unreliable measurements can result in incorrect judgement of the efficiency of a heat production plant and of the heat losses in the distribution pipe network.

A solution to this problem is a new application of a well-known optical measurement technique called Laser Doppler Velocimetry (LDV). LDV has origins in measuring flow velocity in air and gasses but more

Matthew Adams Rasmussen (top) M.Sc., *Andy Drysdale* (left) B.Sc. MInstP and *John Frederiksen* B.Sc., Danish Technological Institute in Aarhus/Denmark. *J. Frederiksen* is head of the Institutes Flow Laboratory and *A. Drysdale* was project manager for the project

A BEGINNERS GUIDE TO LDV

LDV is the point measurement of velocity by means of laser light and it is based on the Doppler Effect. A simple illustration of the LDV measurement principle is shown in *figure 1*.

A laser beam is split into two beams, which pass through a focussing lens and subsequently converge again, creating an area of interference, referred to as the measurement volume. Light is reflected when the laser beams illuminate a tiny particle moving with the fluid and passing through the measurement volume. The speed of the particle causes a Doppler shift of the reflected light's frequency and produces a photo detector signal directly related to velocity.

LDV measurements require optical access to the fluid, e.g. a window, so that the incoming laser beams are able to penetrate the medium, and so that the reflected light from moving particles can be received by the photo detector. Ideally, the measurements are carried out on a steady flow and through a number of quickly repeated measurements that are treated statistically in order to obtain a representative mean velocity. By measuring the velocity component in the flow direction in several points over several diameters, a flow profile can be built up describing the flow over a certain cross section of the pipeline, see the example in *figure 2*.

By rotating the laser, different velocity components of a flow can be measured. What normally is of interest is the velocity component in the flow direction, but the perpendicular velocity component can also be relevant: In many cases it can be important to investigate flow conditions, e.g. swirl, after disturbances in the flow arising from tee bends, 90° bends, open valves, etc.

recently LDV has been applied to measuring the velocity of flowing water.

In brief, LDV can be described as a non-contact optical measurement technique for measuring local flow velocity. Measurements do not disturb the flow, as the LDV principle allows measurements to be made without inserting a physical object into the flow. Transparent windows allow optical access to the flowing medium. The operating principle involves focusing two laser beams at the point where velocity is to be measured and then sensing with a photo detector the light scattered by tiny particles carried along with the medium as they pass through the laser focal point. LDV measures point velocities, and these values are converted to a flow rate to make it comparable with the readings from a flow meter. By taking measurements at several points across the diameter of a pipe, a 3D flow profile can be constructed and the flow rate can be calculated.

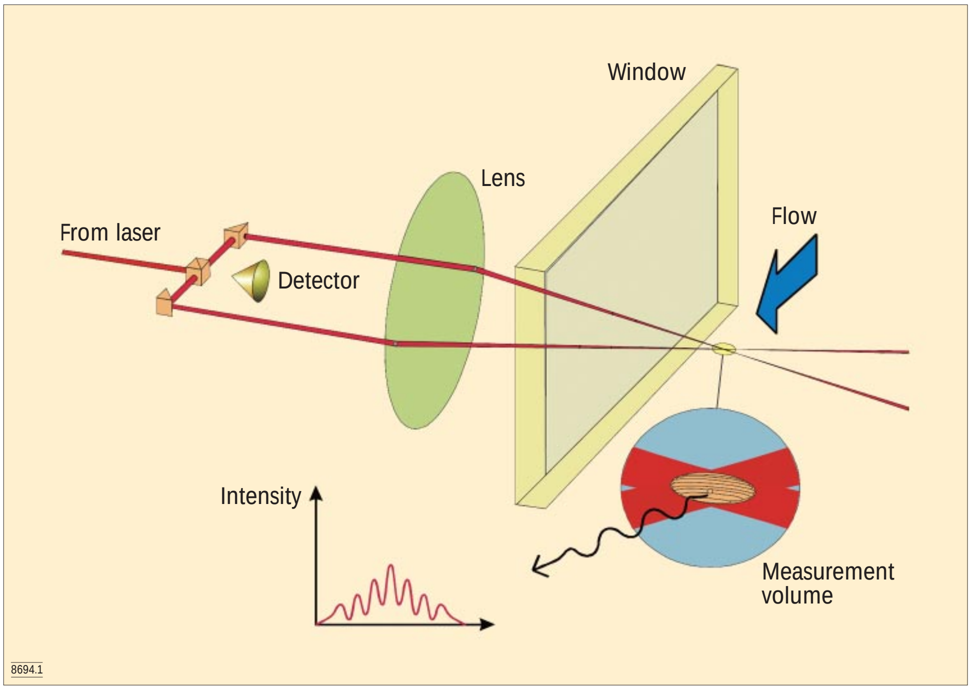

Figure 1. *Simple illustration of the Laser Doppler Velocimetry (LDV) principle*

Pursuing the possibilities of using LDV to characterize flow installations – and inspired in no small part by the work of Dr. *Stefan Frank* from the Technical University of Berlin/Germany and his LDV measurements on district heating installations – the Danish Technological Institute coordinated and managed the project »Improved district heating measurement using Laser Doppler Velocimetry« from 1998 to 2001, with a subsidy of 450,000 DKK from the Danish Energy Agency's R&D programme and the participation of a number of Danish district heating and transmission companies, meter manufacturers, a LDV manufacturer and the Technical University of Denmark. During the process a long list of detailed measurements using LDV were performed at the Danish Technological Institute in Aarhus/Denmark, at the Technical University of Denmark, with Danfoss (now Siemens Flow Division) at their facilities in Nordborg/Denmark as well as field measurements on a 350 mm diameter district heating pipe in service at the »Langelinie« heat-exchanger substation (LAW) in central Copenhagen/Denmark. On the basis of these highly successful measurements, the Danish Technological Institute saw the clear need for accredited, on-site calibration of flow meters. Recognising the potential of LDV as an excellent solution, we set to work to achieve accreditation for this method.

To achieve optical access to the fluid flowing through pipes, several different window constructions have been developed. Laboratory and field installations operate under different temperature and pressure levels, which have resulted in different solutions for these applications. *Figure 3* and *4* show window constructions for laboratory and field measurements respectively.

Accreditation

In order to attain accreditation for this method, two important issues

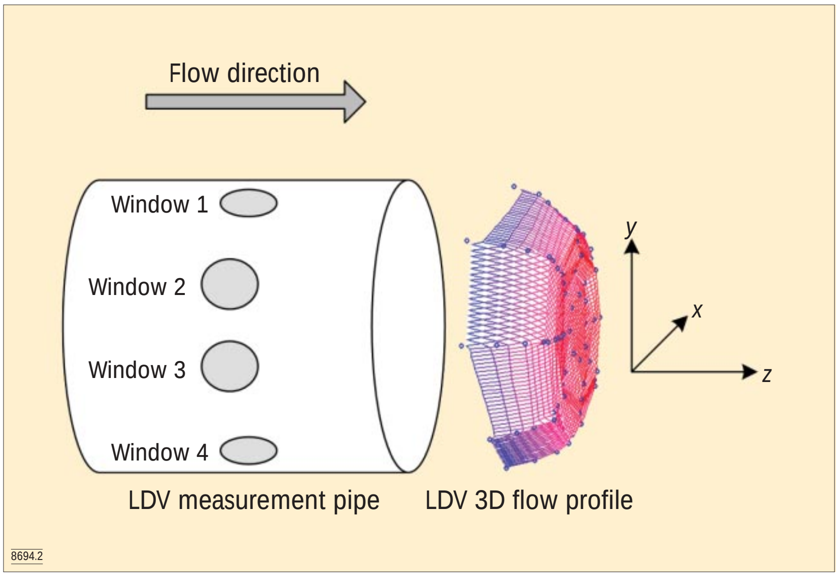

Figure 2. *The generation of a 3D LDV flow profile from measuring point velocities across several pipe diameters*

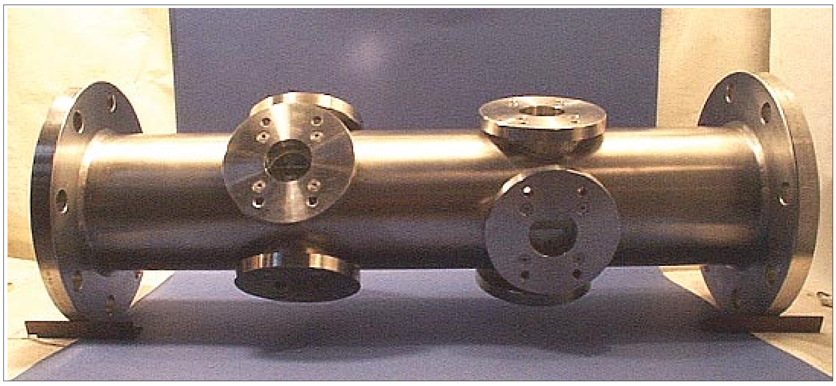

Figure 3. *Window construction for laboratory use*

Type of uncertainty	Uncertainty contribution relative %
Calibration of LDV system and velocity change along measuring volume	0.03
Drift of LDV system	0.03
Refraction index of window and medium	0.06
Velocity variation particle/medium	0.03
Geometrical position of points	0.32
Model for flow rate calculation and short time flow rate fluctuations	0.23
Cross sectional area	0.17
Long time flow rate fluctuations	0.04
Root mean square of uncertainties	0.44
Expanded uncertainty (k = 2)	**0.90**

Table 1. *Uncertainty analysis of LDV method*

had to be resolved: firstly, an accurate evaluation of the total measurement uncertainty of this method had to be determined; secondly, a thorough series of validation tests in the laboratory had to be carried out. From a detailed analysis of all uncertainty contributions, the resulting uncertainty budget is shown *table 1*.

After determining the measurement uncertainty, the laboratory validation tests consisted of comparing the flow measurements of

Figure 4. *Window construction for use in on-site calibration of large flow meters*

the LDV method with a calibrated laboratory reference meter on an installation with a pipe diameter of 150mm, where several kinds of flow disturbances were inserted upstream of the LDV measurement pipe, but downstream from the reference meter. Simply put, the goal was to subject the LDV method to as much flow disturbance as possible, with the accompanying demand that the deviation of every LDV result from the calibrated laboratory reference meter must be less than the overall measurement uncertainty! A wide variety of disturbances were generated: contraction/expansion in the pipe diame-

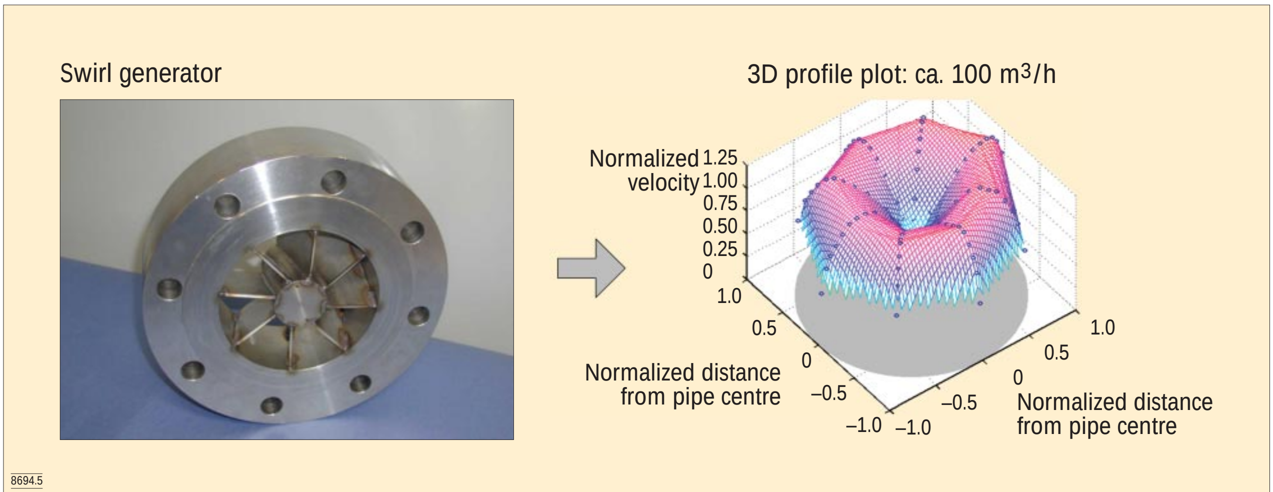

Figure 5. *The applied swirl generator, and the resulting 3D LDV profile plot*

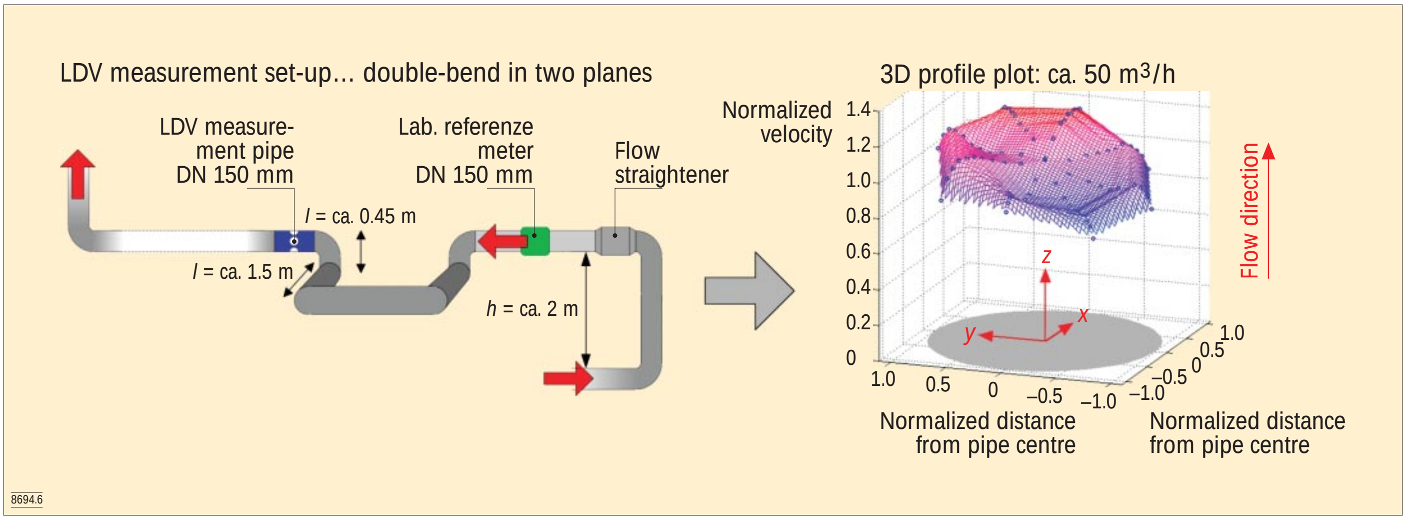

Figure 6. *The installation of a 90° double-bend in 2 planes, and the resulting 3D LDV profile plot.*

ter, forced variation (20 %) of the flow rate during measurement, generation of swirl (up to 35 to 40 %) from a swirl generator, 90° double-bends in one plane, 90° double-bends in two planes, as well as simulation of half-open valves. In all cases, the deviation of the LDV measurement method from the reference flow meter was less than the overall uncertainty. In *figure 5* and *6* are shown the disturbed flow profiles from the swirl generator and the 90° double-bend in two planes respectively.

On-site calibration in Esbjerg

After completing a long list of validation tests and preparing a comprehensive uncertainty budget, the Danish Technological Institute was granted accreditation in 2004 for on-site calibration of flow meters of dimension 100 to 500 mm and flow rates of 0.25 m^3/h up to 6000m^3/h (0.01 m/s to 6 m/s), with an expanded measurement uncertainty of 0.90 %. In 2005 this accreditation has been expanded to pipe dimensions of 100 to 1000 mm and flow rates of 0.25 m^3/h up to 17000m^3/h.

Upon gaining accreditation, two on-site calibrations were performed. The first was performed on a 500 mm flow meter at the Danish refuse incineration plant L90, located in Esbjerg. A diagram and photo of the installation is given in *figure 7*.

The calibration was performed at a flow rate of 1284 m^3/h, giving a deviation of the customer's flow meter from the LDV reference of (-0.55 ± 1.64)%. The larger uncertainty is due to the limitation of only being able to measure over 2 diameters instead of the normally prescribed 4 diameters.

The second calibration was performed on a 1000 mm flow meter at Esbjergværket, a CHP (Combined Heat and Power) plant, also located in Esbjerg. A diagram and photo of the installation is given in *figure 8*.

The calibration results are listed in *table 2*, together with a 3D profile for 1600 m3/h (*figure 9*).

These results have been gladly accepted by the respective district heating plants, but much more: they were each performed in the period of 2 to 3 days, and – apart from installing the LDV measurement pipe beforehand – requiring neither dismantling of equipment nor disruption of plant operation. All that was required was a reasonably steady flow and access to the cus-

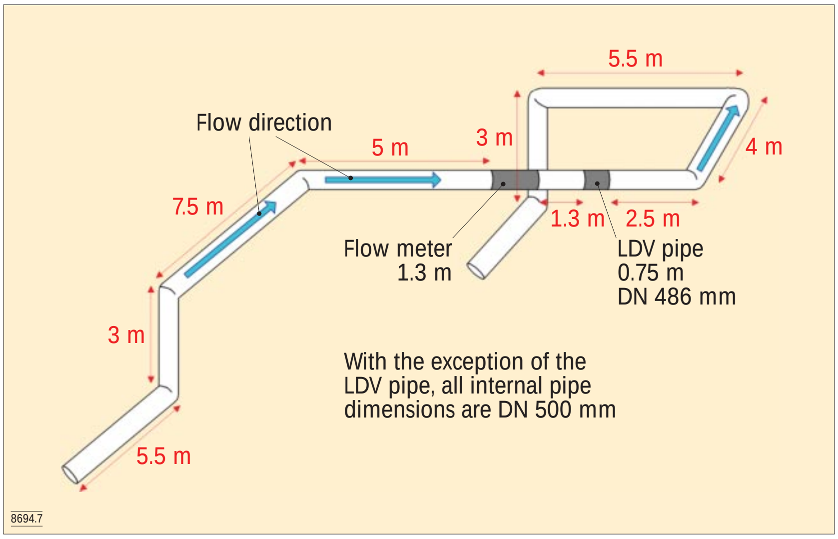

Figure 7a. *Installation diagram of the on-site calibration of a 500 mm flow meter*

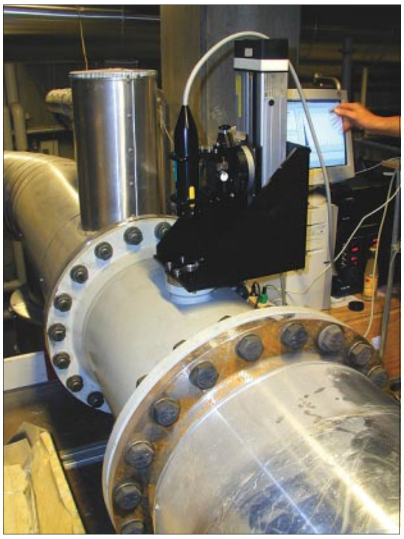

Figure 7b. *Photo of the installation*

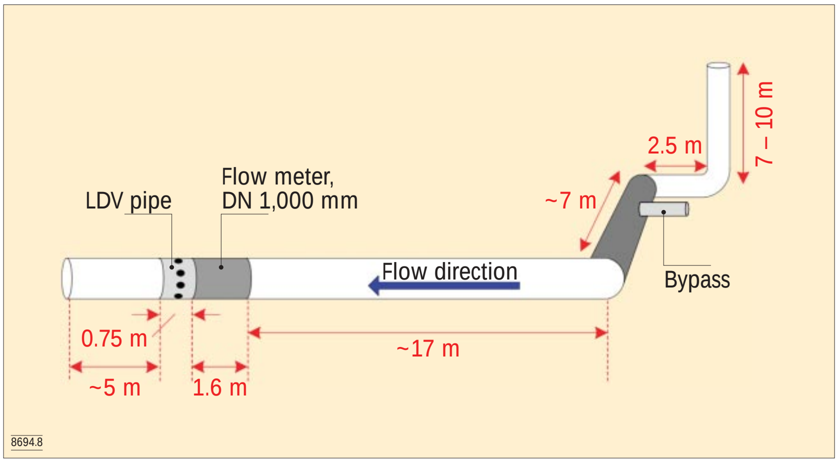

Figure 8a. *Installation diagram of the on-site calibration of a 1000 mm flow meter*

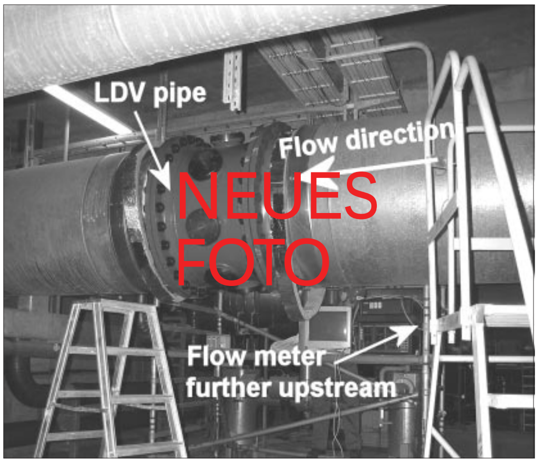

Figure 8b. *Photo of the installation*

tomer meter's data log. Comparing this with the alternative – disrupting plant operation to take down the same meter, sending it away for calibration under dissimilar operating conditions for at least a month at a time at large costs – makes the case for on-site calibration of flow meters even more appealing.

Reference flow (LDV) m^3/h	Customer meter m^3/h	Customer meter deviation from LDV %	Expanded uncertainty k = 2, %
395.15	395.55	0.10	0.90
1482.0	1494.6	0.85	0.90
2869.5	2870.2	0.02	0.90
4692.9	4731.9	0.83	0.90

Table 2. *Calibration results for 1000 mm flow meter*

Conclusions

The Danish Technological Institute is unique in being the only institute in the world that is accredited to perform on-site calibration of flow meters with the Laser Doppler technique known as LDV. However, due to the compactness and transportability of the equipment itself, this is not a service that is only confined to inside Danish borders. This is a truly mobile technology, enabling the on-site calibration of large flow meters on a European scale.

Where to in the future? As the cost of energy and water production increases - and the political focus on conservation and efficiency grows - so too does the necessity for reliable calibration of large flow meters. This growing attention to the use of new measurement technologies to increase production efficiency and pursue sound environmental policies has been demonstrated as lately as a month ago, when a number of leading figures in the Danish district heating industry turned out for the seminar »Accredited on-site calibration of flow meters with LDV« held at the Danish Technological Institute, where great interest was shown for the possibilities that LDV offers. As mentioned at the start of this article, the simple size of the meters in question makes the possibility of sending the meters away for calibration in a laboratory - as one would for smaller meters - a cumbersome and costly affair. Now, with an accredited LDV calibration service, it is possible to bring the laboratory to the flow meter - instead of having to bring the flow meter to the laboratory. ■

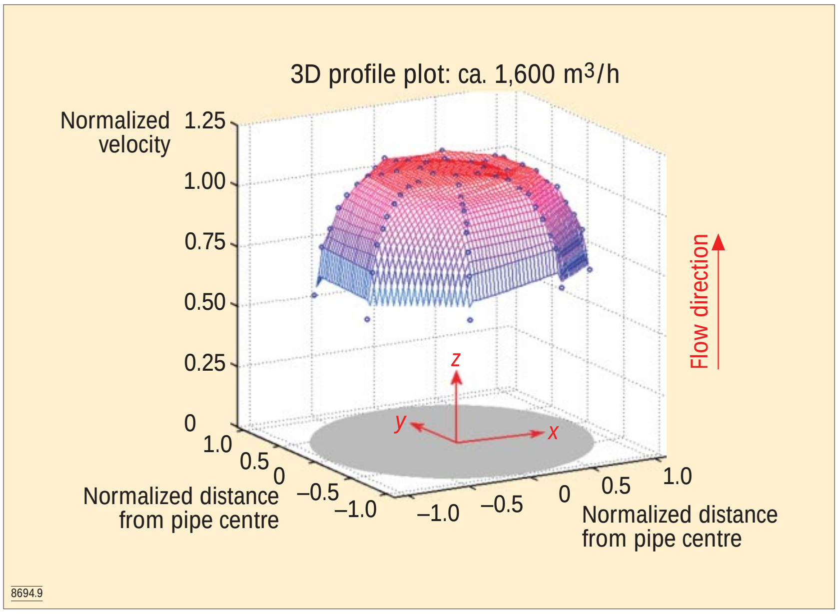

Figure 9. *A 3D LDV profile plot from calibration of a 1000 mm flow meter, showing a fully-developed flow*

matthew.adams@teknologisk.dk
john.frederiksen@teknologisk.dk
andy.drysdale@teknologisk.dk
www.teknologisk.dk