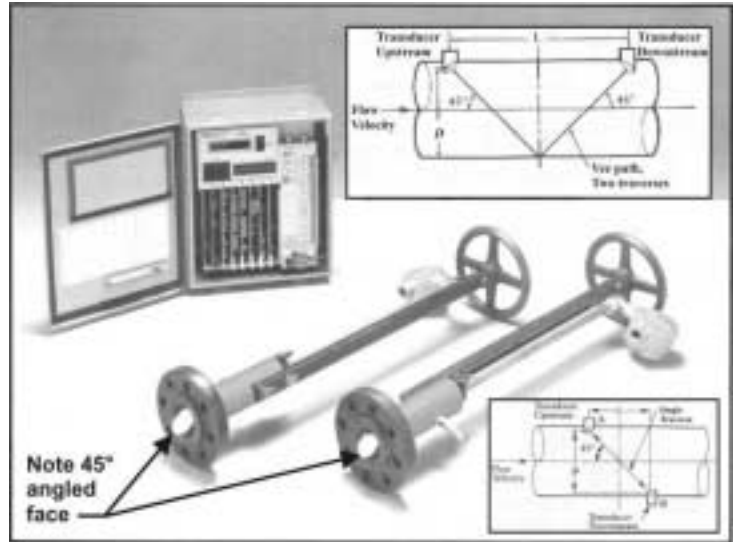


## PART 3 OF 5 PARTS\*

### (C) Applications in Natural Gas (Wetted Transducers)

We base our current design for a custody transfer ultrasonic flowmeter for high-pressure natural gas on a multipath quadrature (Chebyshev) solution. Quadrature solutions have been used for a long time to achieve an answer that is largely independent of flow profile conditions, including substantial immunity to the various upstream disturbances found in practice (elbows, bends, diameter mismatches, partially-open valves, etc.). Earlier suggestions to use quadrature include [21, 30, 51, 33]. Midradius [3, 27] and midradius + diameter solutions also exist [10]. Tomographic solutions, which offer image reconstruction, have been investigated [19] but are not yet available commercially. Again, a comparison of many of these approaches is given in Table 2. A single-path gas flowmeter, developed nearly twenty years ago, primarily the work of Pedersen [34], is shown in Figure 6.



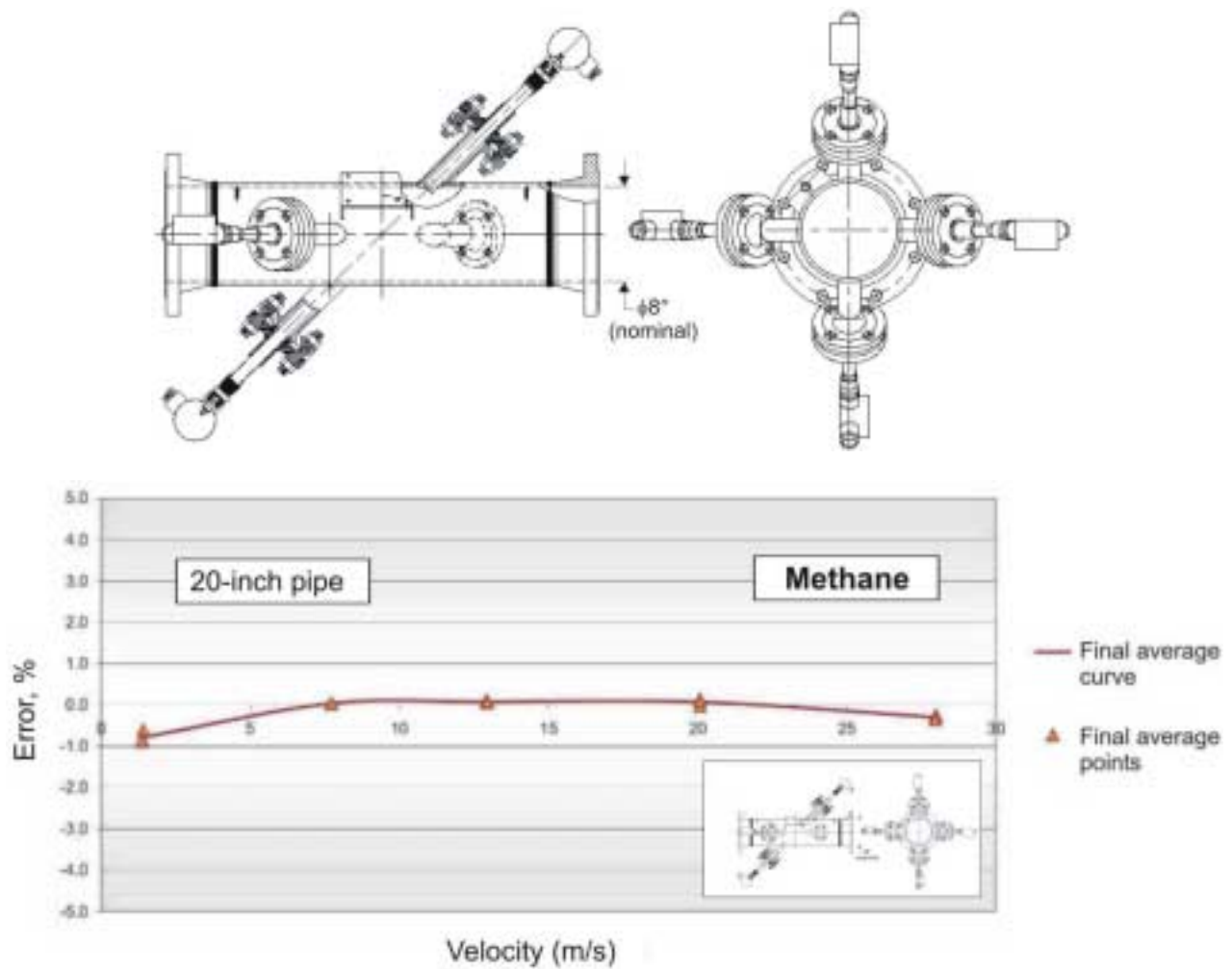
**Figure 6.** Example of early gas flowmeter single path 45° transducers, and gas-driven insertion mechanisms used in 1983-1986 field test program to determine performance in a variety of natural gas pipeline installations. Insets: path and face geometry for transducers installed perpendicular to pipe wall. [34(c)]

Referring now to Figure 7(a), we see for a three-plane Chebyshev quadrature spoolpiece solution that the basic chord locations are along the diameter and the edges of an inscribed square, as projected in an end view. A practical implementation is shown in the two photos comprising Figure 7(b). The T11 transducer used in each of this spool's twelve ports is shown in Figure 7(c). Test data for this design and/or earlier systems comprise Figure 7(d-j).

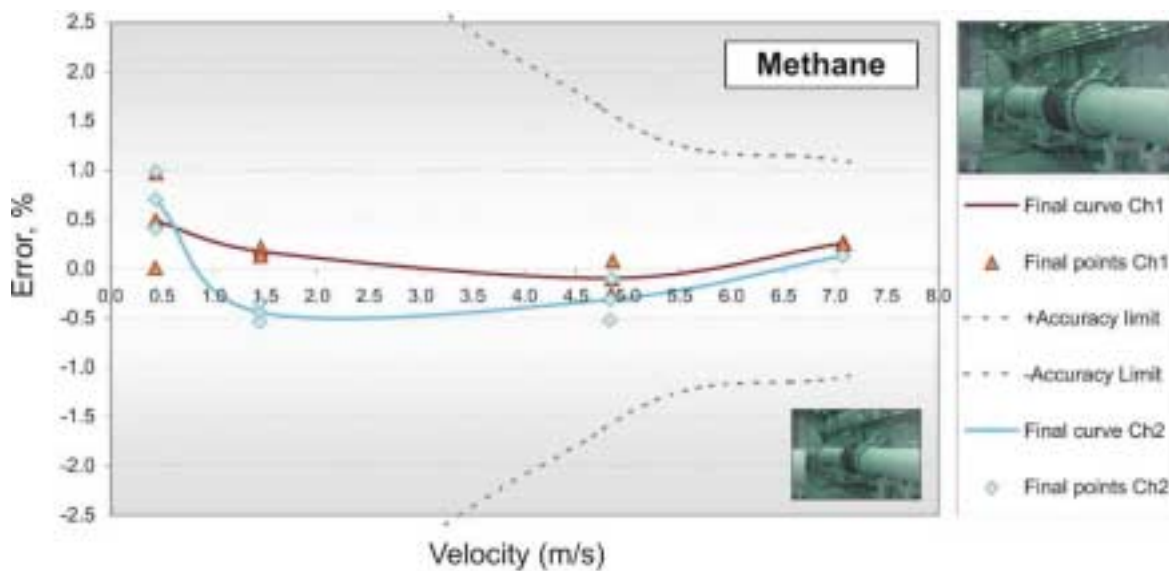
More complete calibration data of three-plane Chebyshev systems will be reported elsewhere [17].



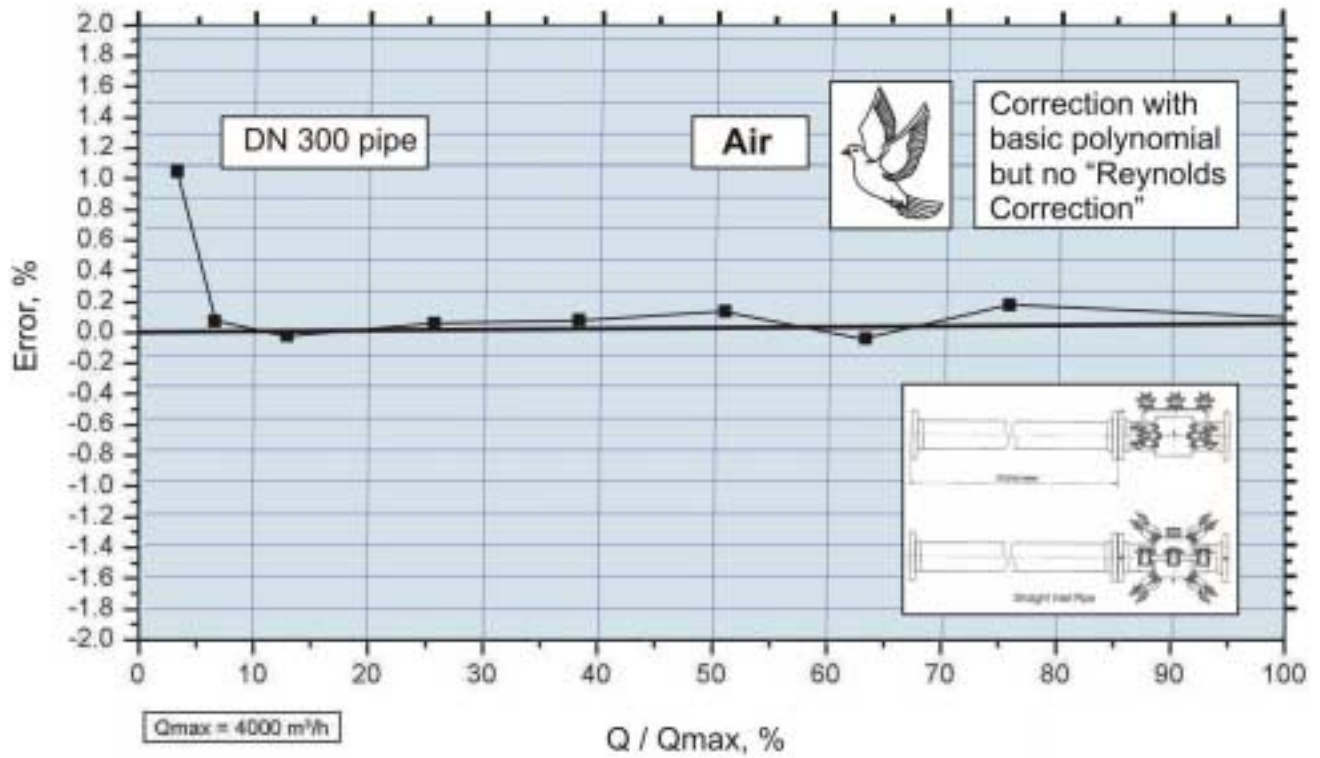
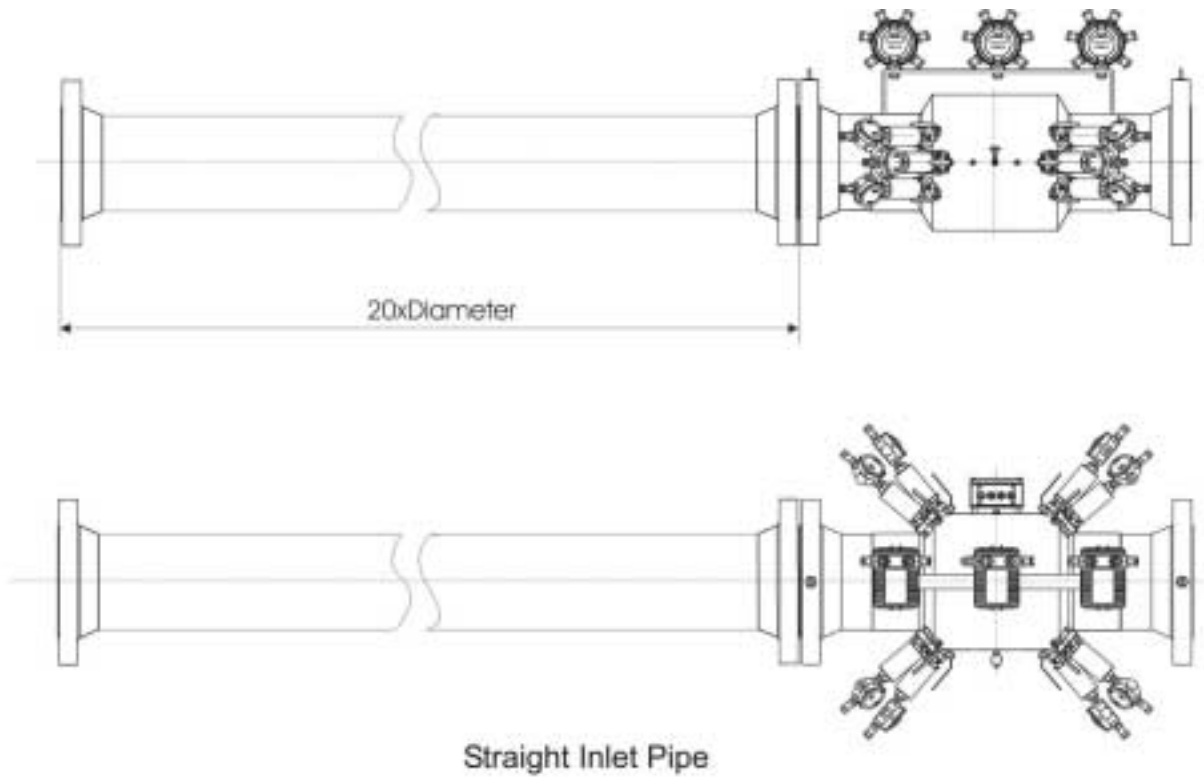
**Figure 7.** (a) Schematics show planes of measurement in end view, and the crossed paths in a three-dimensional SolidWorks rendition. (b) Photos of a spool piece manufactured by RMG and corresponding to the schematics. (c) Example of a T11 transducer. It is Ti-housed, internally quarter-wave matched, and twelve of them are used in (b).



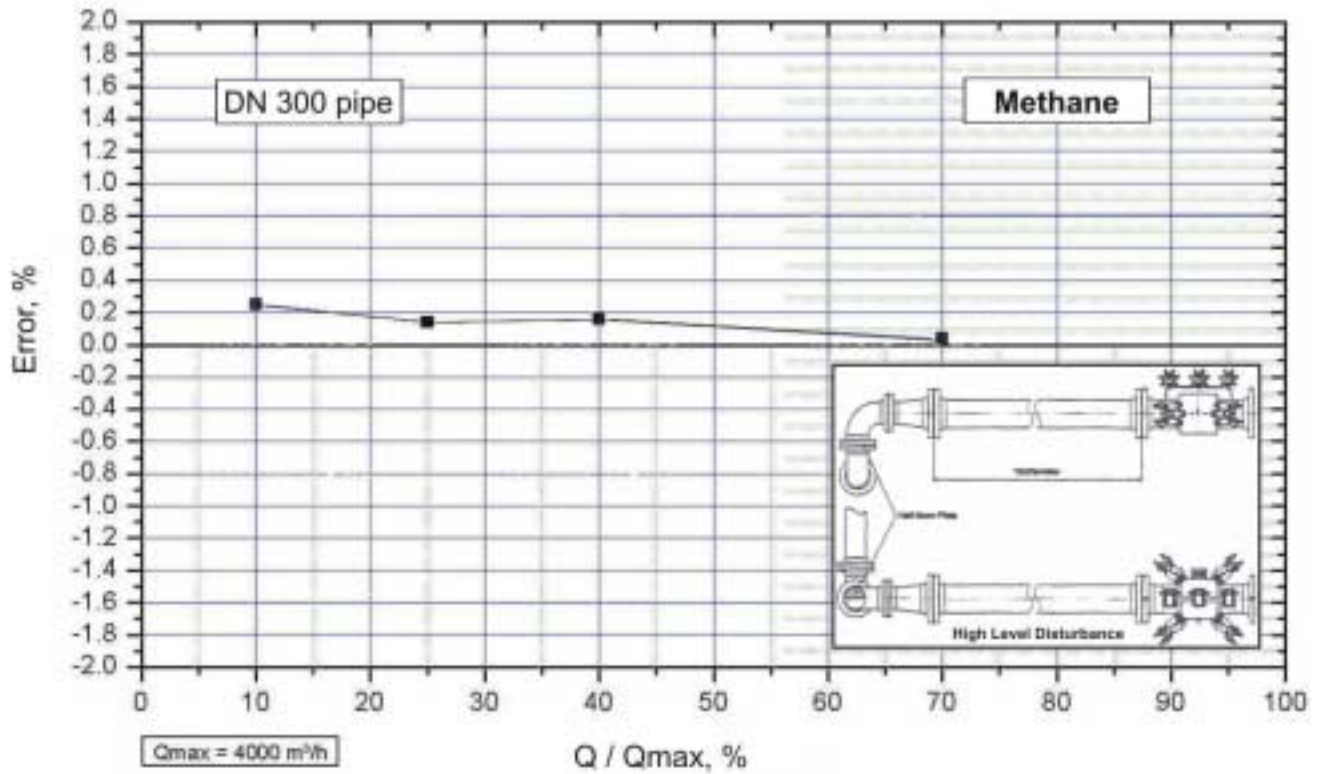
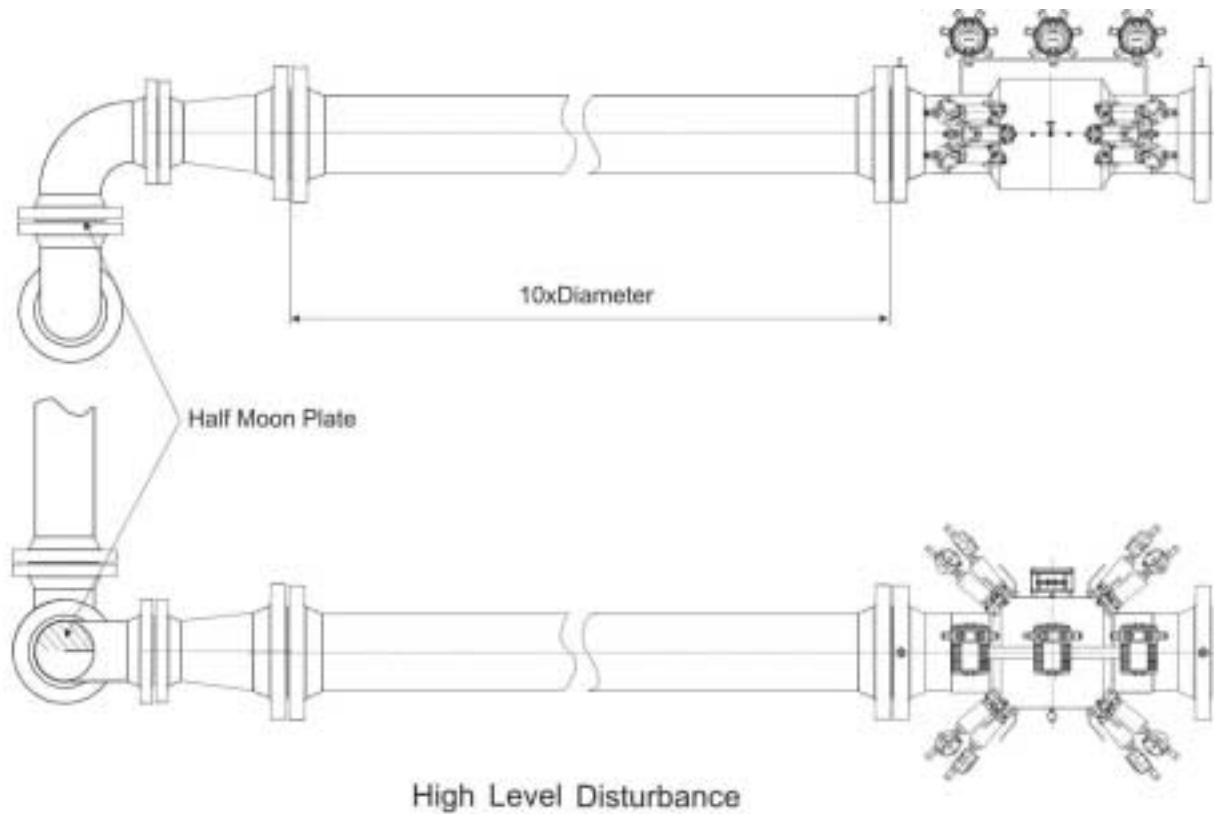
**Figure 7. (d)** Methane calibration (final average curve after determining meter factor  $K$ ), for the  $\phi 8''$  spoolpiece as illustrated. Details: calibration final results @ Pigsar Dorsten, Germany; June 2001, 8-inch, 600# - 2 crossed diameter paths, natural gas at  $P = 24.7$  bar &  $T = 14.85\text{C}$ , 2 channel XGM868 with 2-path averaging and FTPA BWT transducers. Data and illustration supplied by Jacob Freeke and Paul Ceglia.



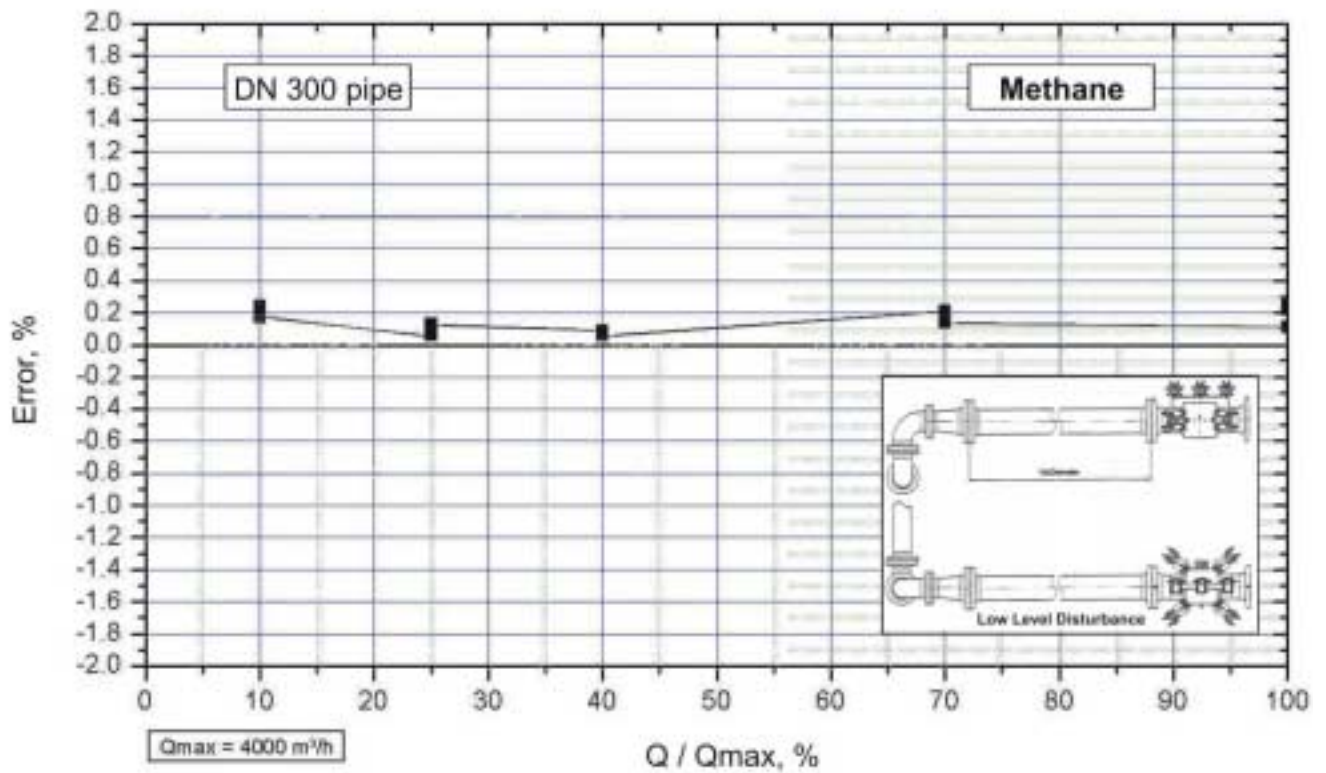
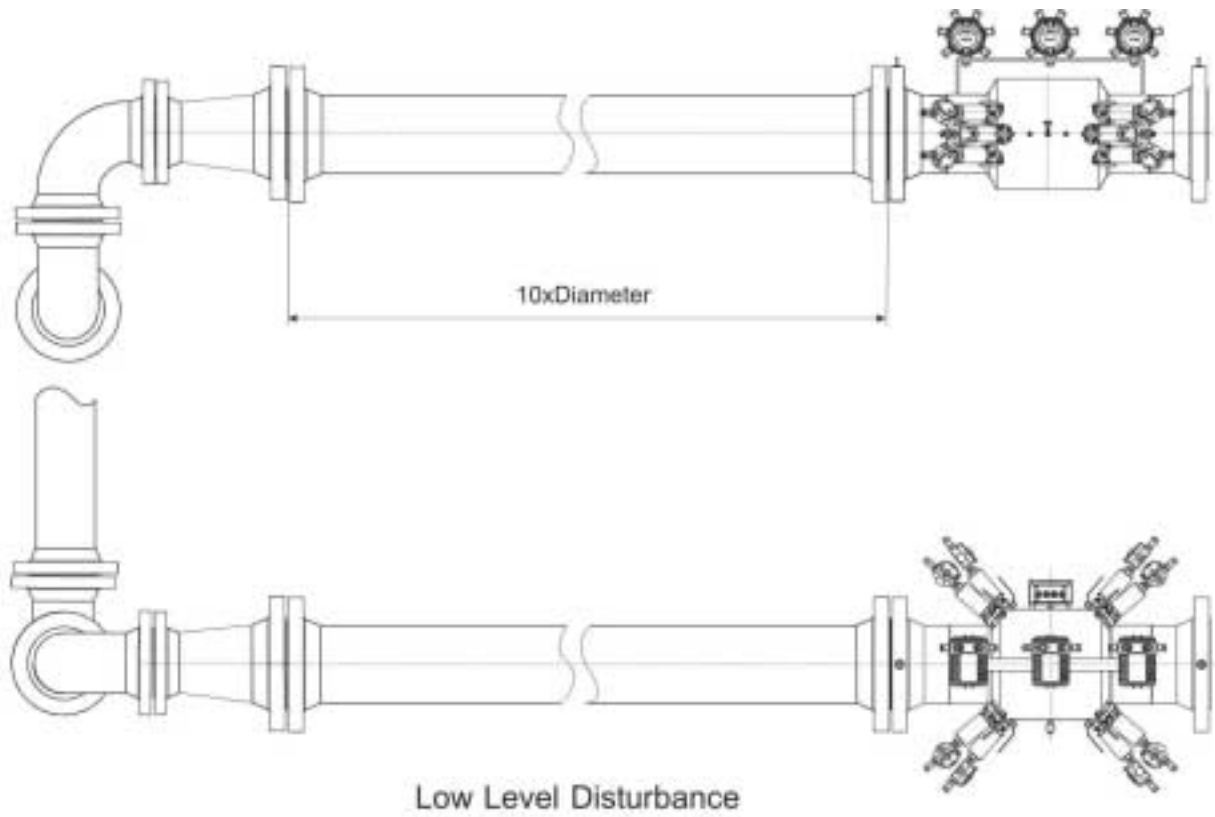
**Figure 7. (e)** INITEC calibration @ TCC calibration, Winnipeg, Canada, TAG FT-03001, 30-inch, 300# - Bias 90. Data and illustration supplied courtesy of Jacob Freeke and Paul Ceglia.



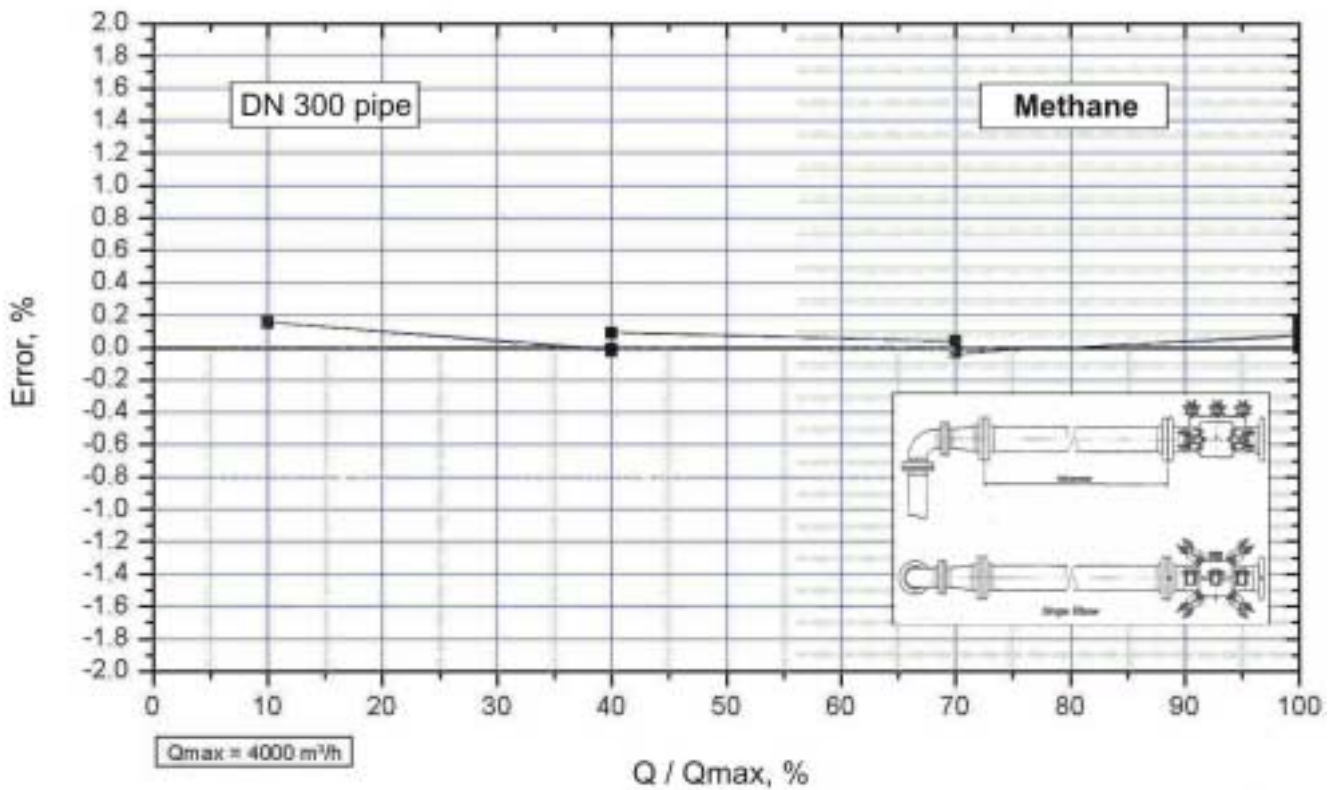
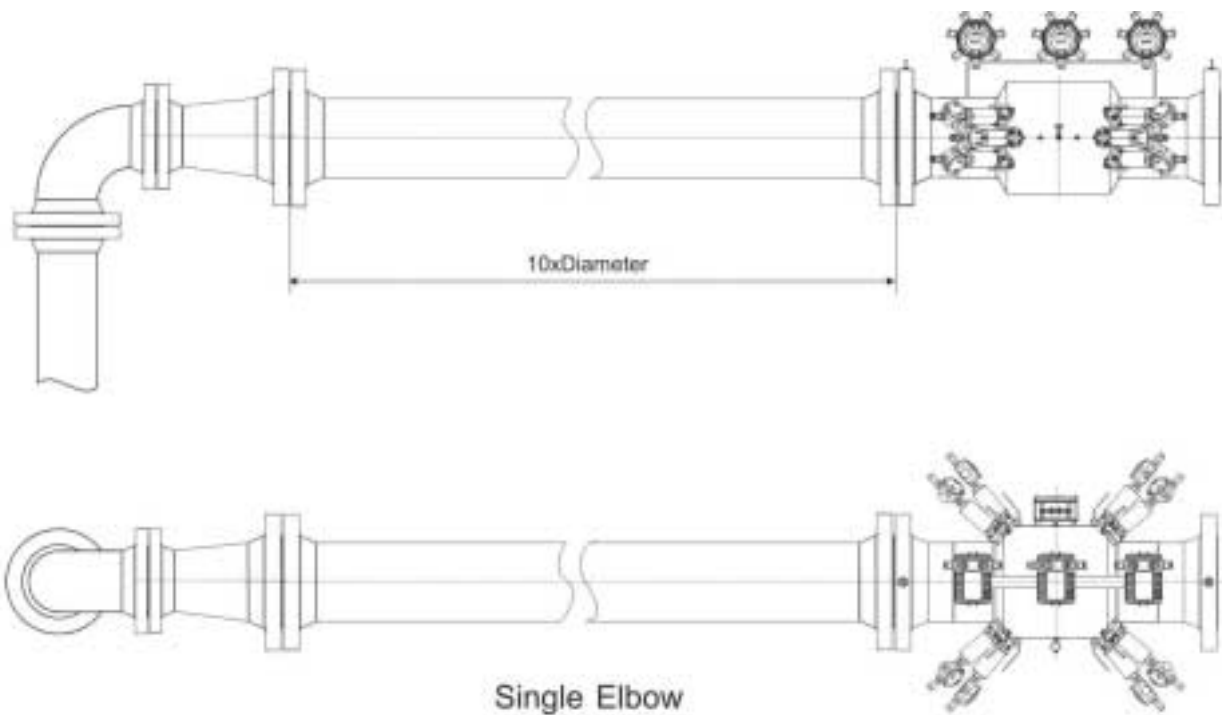
**Figure 7. (f)** USZ 08-6P / DN 300 No.: 0001 20 DN inlet pipe test under atmospheric pressure **air**. Illustration courtesy of Andreas Weber and Hans Kastner of RMG, Butzbach, Germany.



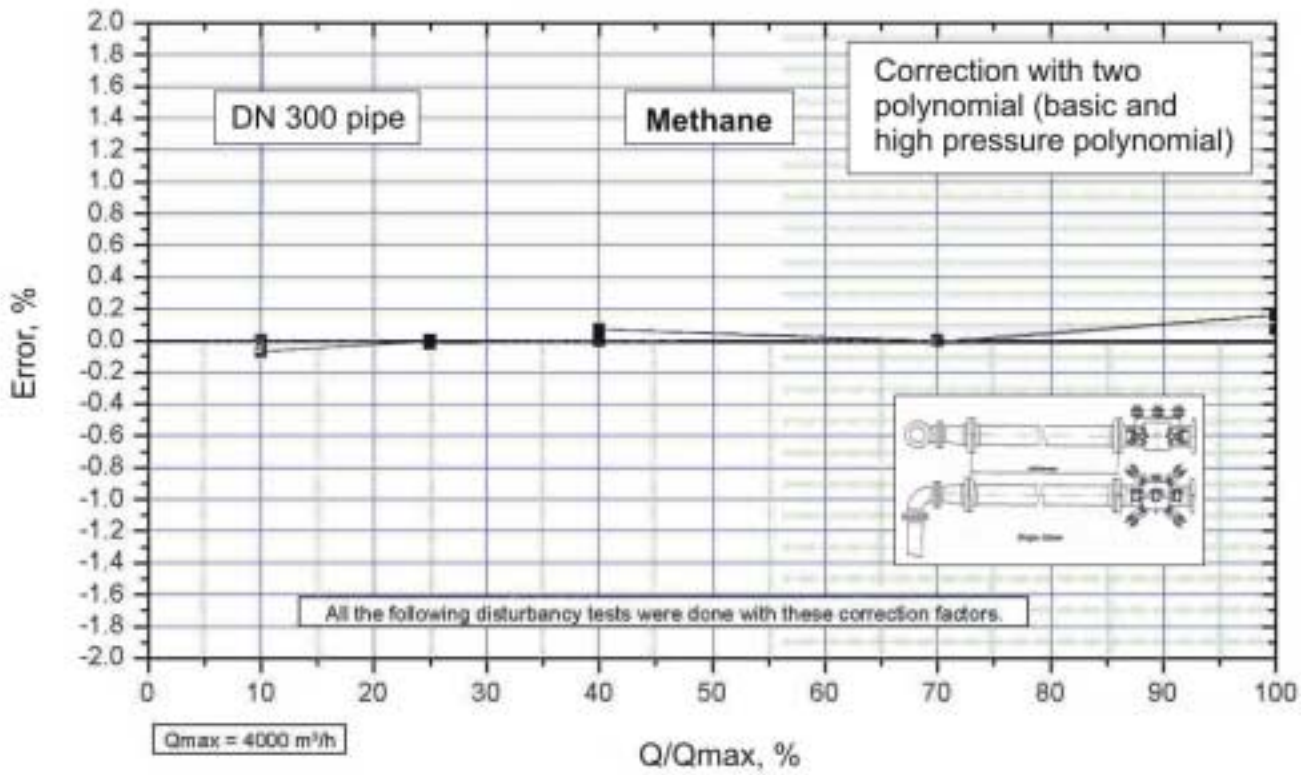
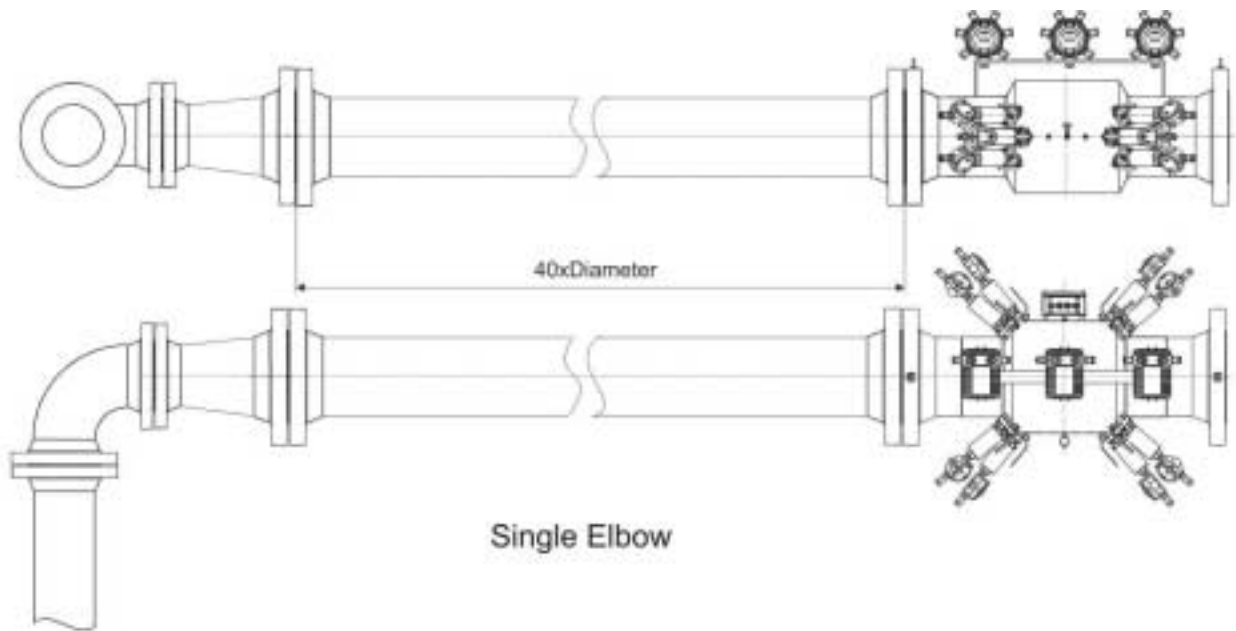
**Figure 7. (g)** USZ 08-06P / DN 300 No.: 0001 10 DN inlet pipe high-level disturbances, 90° turned, **methane** pressure: 10 bar. Illustration courtesy of Andreas Weber and Hans Kastner of RMG, Butzbach, Germany. Test date: 12 Oct. 2001.



**Figure 7. (h)** USZ 08-06P / DN 300, No.:0001 10 DN inlet pipe low-level disturbances, 90° turned, **methane** pressure: 10 bar. Illustration courtesy of Andreas Weber and Hans Kastner of RMG, Butzbach, Germany. Test date: 11 Oct. 2001.



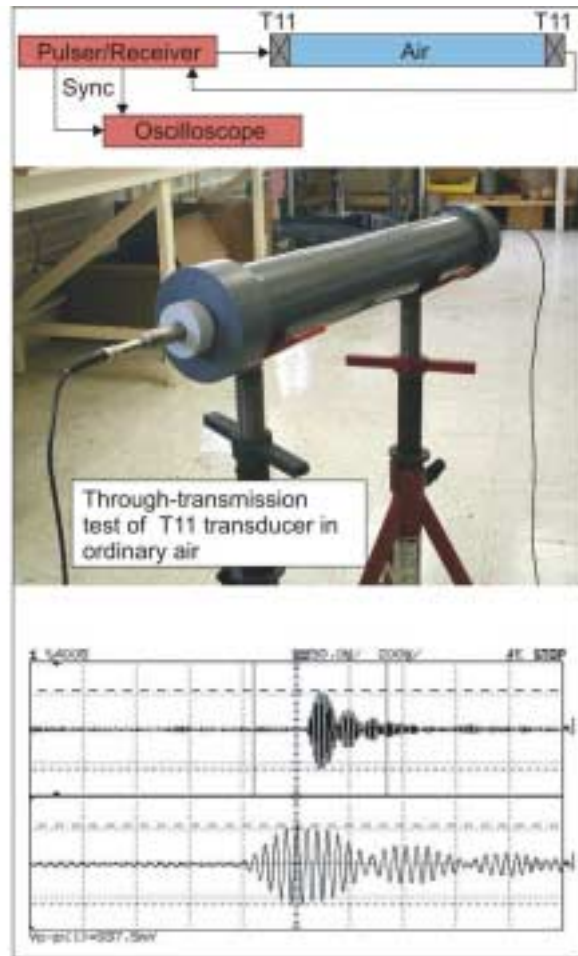
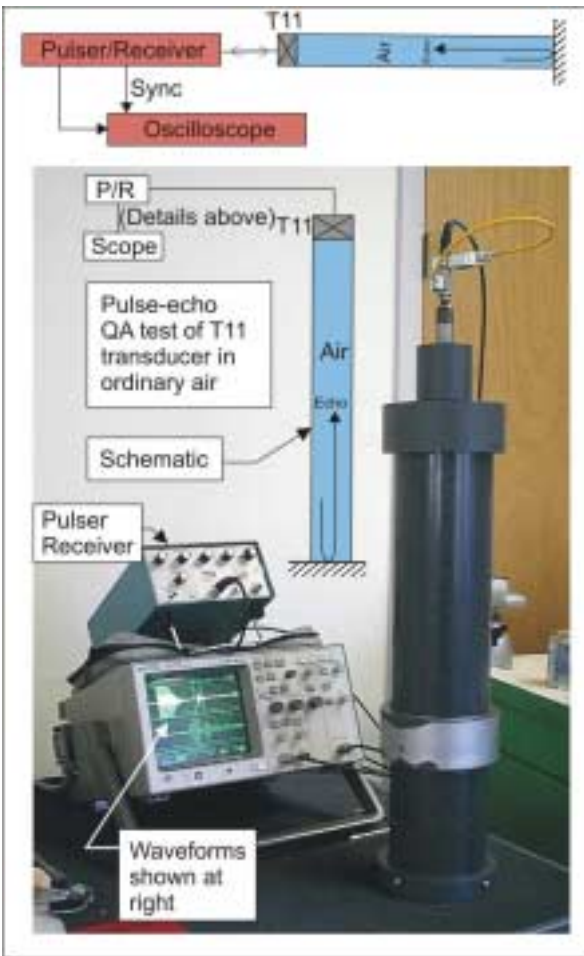
**Figure 7. (i)** USZ 08-06P / DN 300 No.: 0001 10 DN inlet pipe disturbancy: single elbow, 90° turned, **methane** pressure: 10 bar. Illustration courtesy of Andreas Weber and Hans Kastner of RMG, Butzbach, Germany. Test date: 26 Sept. 2001.



**Figure 7.** (j) USZ 08-06P / DN 300 No.: 0001 40 DN inlet pipe disturbancy: single elbow pressure; 10 bar methane. Illustration courtesy of Andreas Weber and Hans Kastner of RMG, Butzbach, Germany. Test date: 24 Sept. 2001.



Forty (40) T11 transducers, twenty per crate, being prepared for shipment from Waltham, Massachusetts to Butzbach Germany in April 2002. Photo of T11 (below) photographed 30 April 2002 by Tracey Russell. Each T11 transducer looks like this:



**Figure 7. (k)** Quality control testing of T11 transducers in air. (Work of Toan Nguyen and David Hesketh). © 2002 Panametrics