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QUANTIFIED COMPARISON OF THE EFFICIENCY OF NEW FLOW CONDITIONERS

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Abstract: The paper reports about the profile measurement downstream of several perforated plates and their evaluation. Five different designs of perforated plates were investigated, which were: modified Zanker, Mitsubishi, two designs by company NOVA and a design by Laws.

Every flow conditioner were tested in three different pipe configurations with different levels of axial profile deformation and swirl. The report focuses on development of the axial velocity profile. The evaluation was done not only by comparing the velocity profiles but also with respect to the error shift of turbine meters.

Keywords: flow conditioner, axial profile, installation effect, LDA measurement, error shift, turbine meter,

1 INTRODUCTION

In the last few years the investigation of installation effects regarding flow meters was the subject of many efforts to improve their accuracy. The scope of investigations was one hand to figure out the relation between flow profile and meter behaviour and on the other hand to find out the most efficient way to minimise these effects.

At the PTB a research project was initiated for systematic investigations of installation effects in gas. The investigations started with the experimental verification of OIML-R-32 [1] by means of flow profile measurement downstream of OIML-pipe configuration. In a second step the evaluation of flow conditioner efficiency came into the scope [2]. Up to now more than 250 velocity profiles and corresponding flow meter readings have been determined for different pipe configurations at several flow rates and well known flow conditioners (Etoile, Zanker, tube-bundle, perforated plates) have been evaluated. This work is going on continuously.

During the last years a number of researcher developed new flow conditioners based on perforated plates, therefore this paper presents some new results of investigations of these flow conditioners.

2 TEST FACILITY

To carry out these experiments an automated two-component LDA test facility for air measurements under atmospheric conditions was used [3] (Fig. 1). This diagnostic test rig takes advantage of the construction of efficient miniaturised LDAs and the use of critical nozzles for the establishment of gas flow rate measurement of highest accuracy and reproducibility. The test rig according to Fig. 1 allows to measure in-situ flow profiles across the cross section in a DN 200 pipe at arbitrary inlet conditions. LDA1 and LDA2 can be traversed perpendicular to the pipe axis x and can be rotated 360 degrees around the pipe axis. It has thus become possible to obtain detailed knowledge of the flow characteristics inside the pipe configurations of interest.

The heart of the facility is the LDA measuring unit. The connection to the piping to be investigated is realised by a special pipe segment (Fig. 1). Eight windows allow four different profiles rotated by 45 ° to be scanned. Inside the pipe, each window is made of a glass film to prevent changes in the diameter and to provide for a smooth inner contour of the pipe. The windows outside of the pipe consist of plane glass plates to block pressure differences.

Two separated LDAs for the two-dimensional measurement of the flow profiles are installed on a rotating mechanism and positioned face to face on both sides of the pipe, see Fig. 2. Each miniature diode LDA is mounted on a precise linear traversing bench and can be operated by a remote control. A linear scan through the pipe diameter is easily done when the moving tables are driven synchronously.

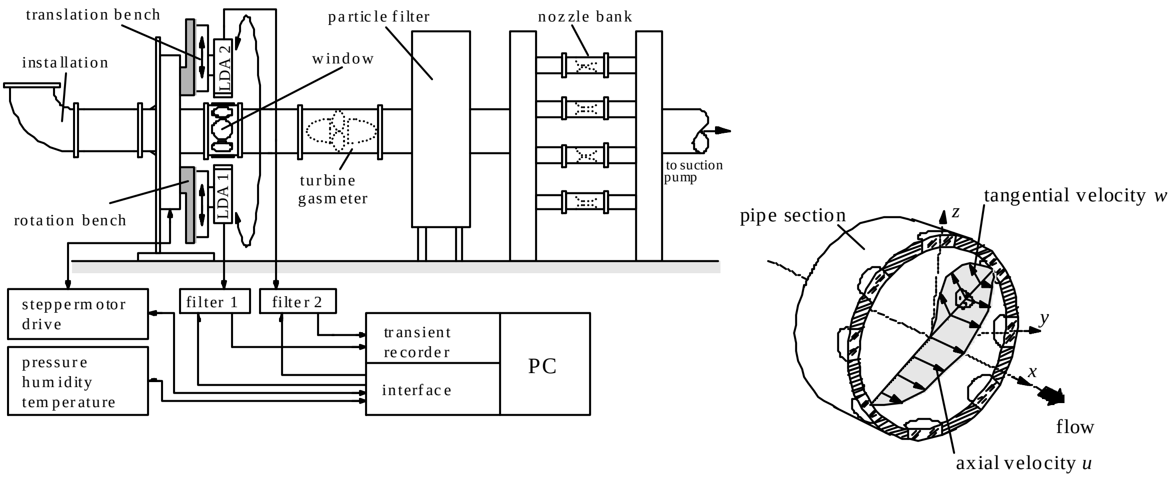
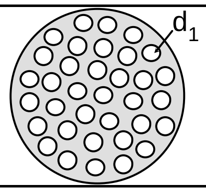
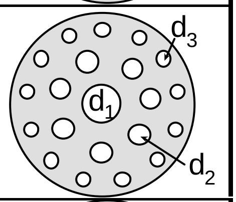
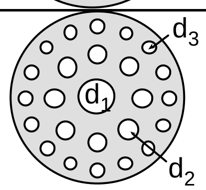
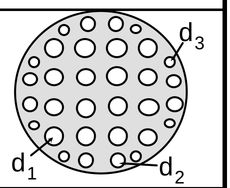


Fig. 1: test facility for investigation of installation effects

3 FLOW CONDITIONERS AND TEST CONFIGURATIONS

A short outline to all five flow conditioners discussed in this report is given in table 1. It contains a sketch and some main characteristics of their perforation. The design of Laws and Mitsubishi conditioner were adapted from publications [4] [5] [6]. The modified Zanker and the NOVA plates we got from the constructors and we thank for this kind support of our work.

table 1: flow conditioners investigated

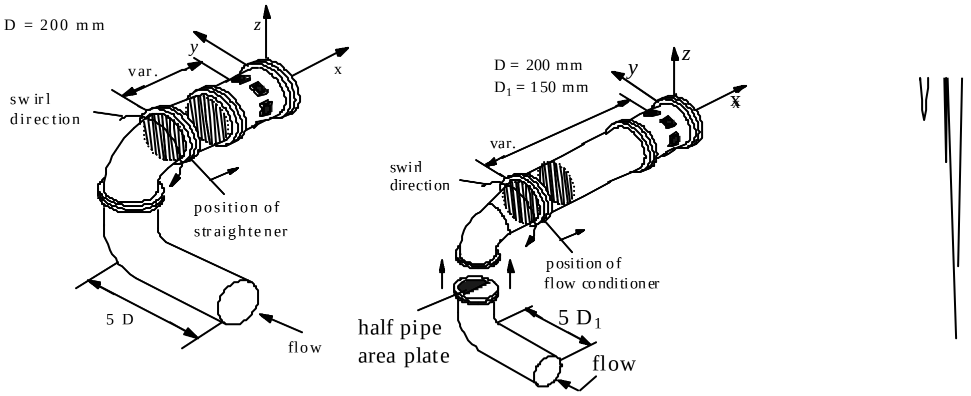
Conditioner	Area covered [%]	Pressure Loss Coef-ficient K_p *)	Thickness (in pipe dia-meters *D*)	diameters (in pipe diameters *D*) and number of wholes	sketch
Mitsubishi	41	2,3	0,135 D	d_1 : 35x0,13D	
Laws	48	2,8	0,19 D	d_1 : 1x0,2D; d_2 : 7x0,175D; d_3 : 13x0,15D (wholes with phased edge)	
short Nova	53	3,9	0,155 D	d_1 : 1x0,19D; d_2 : 8x0,165D; d_3 : 16x0,12D	
long Nova	53	3,9	0,2 D		
modified Zanker	55	4,5	0,125 D	d_1 : 16x0,14D; d_2 : 8x0,11D; d_3 : 8x0,08D	

*) $K_p = \frac{2\Delta p}{\rho u_m^2}$; $u_m = \frac{4Q}{\pi D^2}$;

The configurations used for testing flow conditioners are shown in Fig. 2. Because in Germany the application of turbine meters is very important in measurement of large gas flow rates, our investigations were concentrated on perturbations given by OIML R-32. This recommendation defines perturbation tests of turbine meters to evaluate the meter behaviour. Consequently our aim is to figure out the efficiency of flow conditioners in such situations.

In OIML R-32 two different configurations are used and we choose the High-Level-Perturbation for flow conditioner testing because of the high axial deformation and strong swirl. For moderate level of axial deformation and swirl we use a normal double bend out of plane with bend radius of 1 D.

In Germany short straight pipe length in front of turbine meters are often required because it is a question of space and expenditure. Going out from this we were interested in applications of flow conditioners immediately downstream to the perturbations. We started with test configurations Conf. 1 and Conf. 2 in Fig. 2. In Conf. 2 all flow conditioners could not improve the axial profile in short pipe length, that's why we increased the distance between perturbation and conditioner to 2 D (Conf. 3).



Conf. 1 Conf. 2 Conf. 3

Fig. 2: Test configurations for investigation of flow conditioner behaviour.
Conf. 1: Low-Level-perturbation, double bend out of plane, flow conditioner at exit of double bend
Conf. 2: High-Level-Perturbation according OIML R32, flow conditioner at exit of diffusor
Conf. 3: similar to Conf. B, but flow conditioner with 2 D distance to diffusor.

4 EVALUATION OF FLOW PROFILES AND THE RELATION TO ERROR SHIFT

For the evaluation of the efficiency of flow conditioners it is necessary to compare such different flow profiles as shown in figures 3 to 6. The best way to do that is to quantify the main characteristics of the flow such as flatness, swirl and asymmetry by flow field parameters and to compare the values of these numbers. Accompanying to this, it is possible to describe the installation effects of a flow meter in empirical models, if the parameters are well chosen. This was done for orifice meters by Morrison [7] and inside of this research project for turbine meters by the PTB [3]. Hence, the flow conditioner efficiency expressed by the relation of flow field parameters in pipe configurations with and without flow conditioners is also a statement on the remaining installation effect of the flow meter.

In the research project of the PTB the flow profiles are characterised by defining three parameters:

1. The axial momentum number K_u:

$$K_u = \frac{\iint_A \rho u^2 r \, dA}{\pi \rho u_m^2 R^3} \qquad (1)$$

The closer the location of the flow to the wall, the higher the momentum number of a pipe flow. Hence, a high momentum number indicates a flat axial velocity profile. As a fully developed pipe flow has a certain momentum number K_{uo} but we are interested only in the difference between a disturbed flow and the undisturbed case, the difference $\Delta K_u = K_u - K_{uo}$ indicates the perturbation level. Fully developed flow profiles have a value of K_{uo} = 0,62.

2. The swirl number K_v:

$$K_v = \frac{\iint_A \rho u v r \, dA}{\pi \rho u_m^2 R^3} \qquad (2)$$

The sign of the swirl number is related to the rotating direction of the swirl. Right-hand swirls have positive, left-hand swirls negative numbers. Downstream to double bends swirl numbers of about 0,05 to 0,2 can occur depending on bend radius and diffusers in the pipes. The smaller the bend radius, the higher the swirl number. A diffuser downstream to the double bend increase the swirl number too. But swirl is not a big problem at all, because also perforated plates normally reduce it to a level less than 10 %. Hence, in this paper we concentrates on axial profile.

3. The asymmetry number K_A:

$$K_A = \frac{\sqrt{\left(y_S^2 + z_S^2\right)}}{R} \qquad (3)$$

$$y_S = \frac{\iint_A y \cdot \mathrm{d}\dot{m}}{\dot{m}} \quad \text{and} \quad z_S = \frac{\iint_A z \cdot \mathrm{d}\dot{m}}{\dot{m}}$$

The asymmetry is used to describe the distance of the centroid of the mass flow from the pipe axis. This parameter is illustrating the quality of axial profiles additional to axial momentum number K_u.

After defining the flow field parameters and quantifying the disturbances of the flow profiles it was possible to compare these disturbances with the shift of the calibration curves (error shift) of turbine meters applied downstream of the perturbation [3]. Detailed comparison of the profile catalogue (respective the flow field parameters) with the measured error shift ΔE (measured in percent) led to the empirical model:

$$\Delta E_{model} = a_1 K_v (1 + a_2 K_A) + a_3 \Delta K_u \qquad (4)$$

The model parameters a_1 to a_3 are characteristic for every turbine meter, and they have to be determined by regression from the flow field parameters and error shifts.

The flow field parameters and the error shift model provide a good basis for separating the different components of the error shift due to flatness, asymmetry or swirl. Comparing the flow field parameters in pipe configurations thus the efficiency of flow conditioners can be effective evaluated.

Downstream to flow conditioners investigated here the remaining swirl is negligible. Therefore in eq. (4) only the part $a_3 \Delta K_u$ is responsible for an installation effect downstream to the flow conditioner. Turbine meters tested in PTB had values of 3..7 for the parameter a_3 [3]. If we assume that very sensitive meters have $a_3 = 10$ we can expect an error shift of less than 0,1% if the momentum number K_u is lower than 0,63. This should be kept in mind if we discuss later on the efficiency of flow conditioners.

5 AXIAL FLOW PROFILES AND AXIAL MOMENTUM NUMBERS

All shown profile in Fig. 3 to Fig. 6 were measured at a Reynolds number of $Re = 6.5 \times 10^4$. There were also measurements at higher flow rates, but there was no significant change in the profile shape up to our maximal Reynolds numbers of 2.5×10^5.

In Fig. 7 the axial momentum numbers K_u according to the profiles in Fig. 3 to 6 and for some additional profile measurements are given.

The comparison starts with the axial profiles downstream to perturbations without flow conditioner. Fig. 3A gives the profiles in case of Conf. 1 (double bend out of plane) and Fig. 3B the profiles down to Conf. 2 (High-Level-Perturbation according OIML R-32) in distances of 2.5, 5.5 and 10.5 D (pipe diameters). In both cases the profile shape at the beginning is asymmetric and sattle shaped. The asymmetry for high level perturbation is significant higher than for low level. The asymmetry is decreasing with the pipe length and gets into the same level for both configurations at 10,5 D and the location of maximum velocity is rotating around the axis (due to swirl). At 10.5 D we have in both cases a flat profile. In Fig. 7 one can see the difference in the value of K_u at the beginning and the level of $K_u \approx 0.65$ at 10.5 D for both cases.

If we insert the flow conditioners at the exit of a double bend out of plane (Conf. 1) we will get profiles shown in Fig. 4. The left part of the figure gives profiles at short distances of about 2 D, the right part at longer distances of about 7 D. Independent from the plate design the characteristics of all profiles are the same (Laws conditioner was not investigated in this configuration up to now). The profile shape is improved even at short distances (comparing with Fig. 3A) and at about 7 D the profiles fit nearly into the 5% tolerance band according to the standard of ISO 5167 [8]. Same conclusion comes from the values of momentum number K_u in Fig. 7A. The values are significant decreased comparing to perturbation without conditioner and at about 7 D the value is near to the fully developed flow. The level of $K_u = 0.63$ is reached at 5 D which corresponds with an error shift of turbine meters less than 0.1 %

Fig. 5 shows the application of conditioners at the exit of high level perturbation. In this case the profiles at about 2 D are much more disturbed than without conditioner, what also reflects Fig. 7B with tremendous values of K_u. Here some gradual differences between the different perforated plates exist. The differences in values of K_u are correlated with the covered area of plates. The higher the covered area the lower the value of K_u at short distances. At distances longer than 9 D the profile shapes are well improved. They fit not yet into the 5% tolerance band but the K_u-value is below 0.63.

If a straight pipe length of 2 D is inserted between high level perturbation and flow conditioner (Conf. 3, Fig. 6) the situation becomes more suitable. There is some improvement of axial profile shape at distances of 2 D to the plates or 4 D to the perturbation rsp. Except the Laws conditioner all conditioners show similar profiles. The Laws conditioners differs a little bit at short distances but at longer distances (11 D) all profiles are very similar. The speed of development is not so high as in Conf. 2, hence the level of K_u = 0.63 is reached at about 10 D again.

6 CONCLUSIONS AND OUTLOOK

The first conclusion by comparing the flow profiles is that the differences in profiles downstream to the several perforated plates are less than one can expect. In all measured profiles the main characteristics were the same for same test configuration. Gradual differences at short distances (about 2D to the plates) especially in Conf. 2 (Fig. 5) or Conf. 3, (Fig. 6) decrease and become negligible at longer distances (about 9 to the plates). Hence, the resulting profile shape is not significant influenced by plate design.

Same conclusion can be made about the values of momentum number K_u which is an integral measure of the axial profile shape and which is proportional to the error shift of turbine meters caused by axial profile deformations (Fig. 7). Greater differences for values of momentum number K_u occur downstream of Conf. 2 at short distances but in all cases of Conf. 2 (and also Conf. 3) the values convergence to the same level. To have an error shift of turbine meters less than 0.1 % inlet pipe length of 10 D is recommended in these perturbation levels.

For Low-Level-Perturbation (Conf. 1, Fig. 4) all perforated plates show good results by improving the axial profile shape, what is also to be seen in values of momentum number K_u (Fig. 7). But there are no significant differences in the individual profile shape caused by the plates (Fig. 4). The length recommended to avoid error shifts of turbine meters higher than 0.1 % is for this perturbation level 5 D.

In addition the profile measurements and their relation to error shift via the momentum number demonstrate that the criteria of ISO 5167 for undisturbed axial profiles is also acceptable for applications of turbine meters. If there is no other source of installation effect and if one can assure to fit into the limit of 5 % deviation to fully developed profiles, the error shift of the turbine meter will be less than 0.1 %.

In the next few month investigations of static mixers (adapted from chemical industries) will come into the scope of research work to figure out new ways in flow conditioning. An other important point will be measurements of installations effects and flow profiles in high pressure natural gas to apply the results to high Reynolds numbers (10^7), which we got here at low Reynolds numbers (about 10^5).

We kindly acknowledge Mr. Klaus Zanker from Daniel Cooperation and Mr Blaine Sawchuk from Canada Pipeline Accessories NOVA for supporting our research work.

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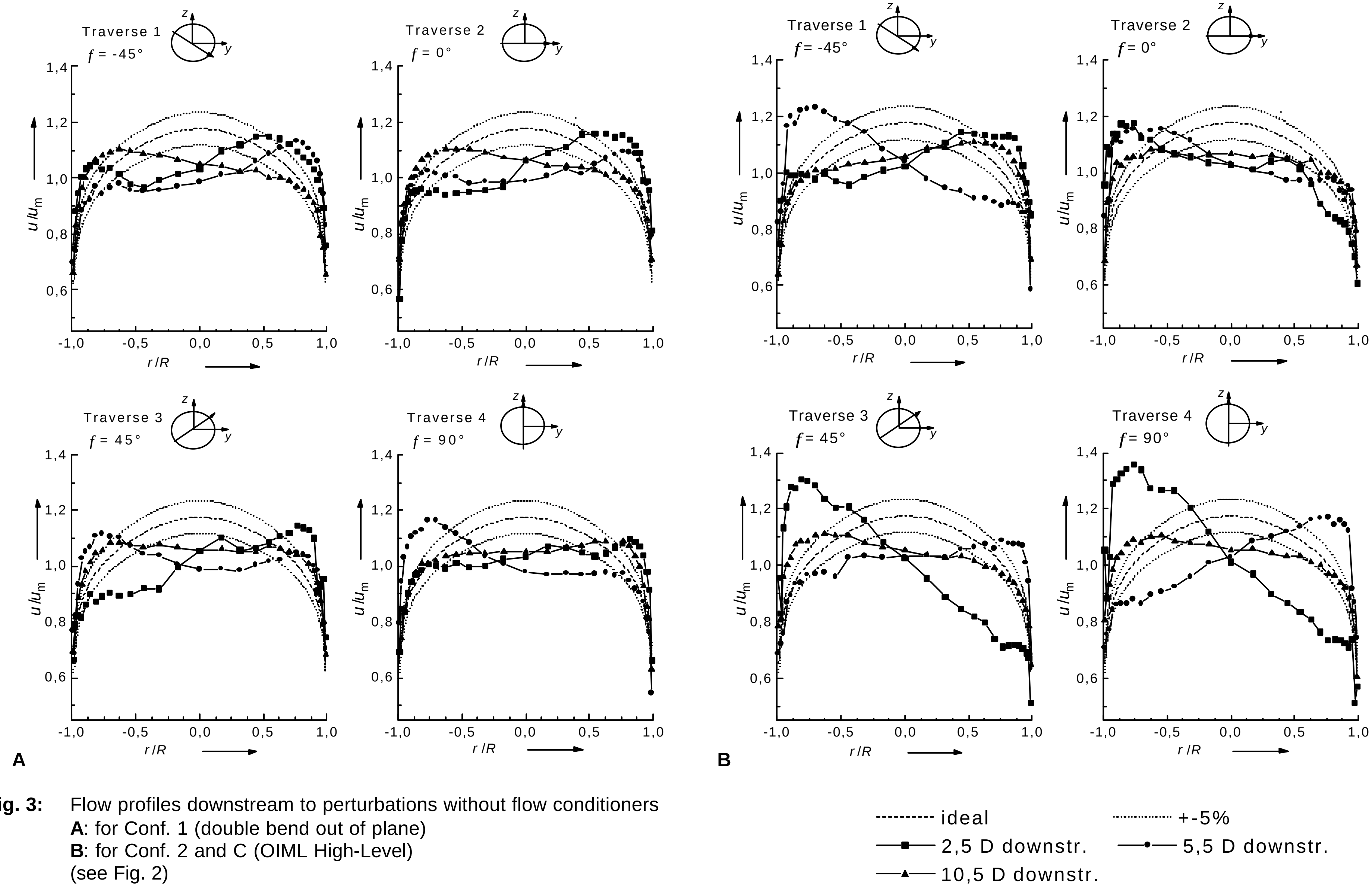


Fig. 3: Flow profiles downstream to perturbations without flow conditioners
A: for Conf. 1 (double bend out of plane)
B: for Conf. 2 and C (OIML High-Level)
(see Fig. 2)

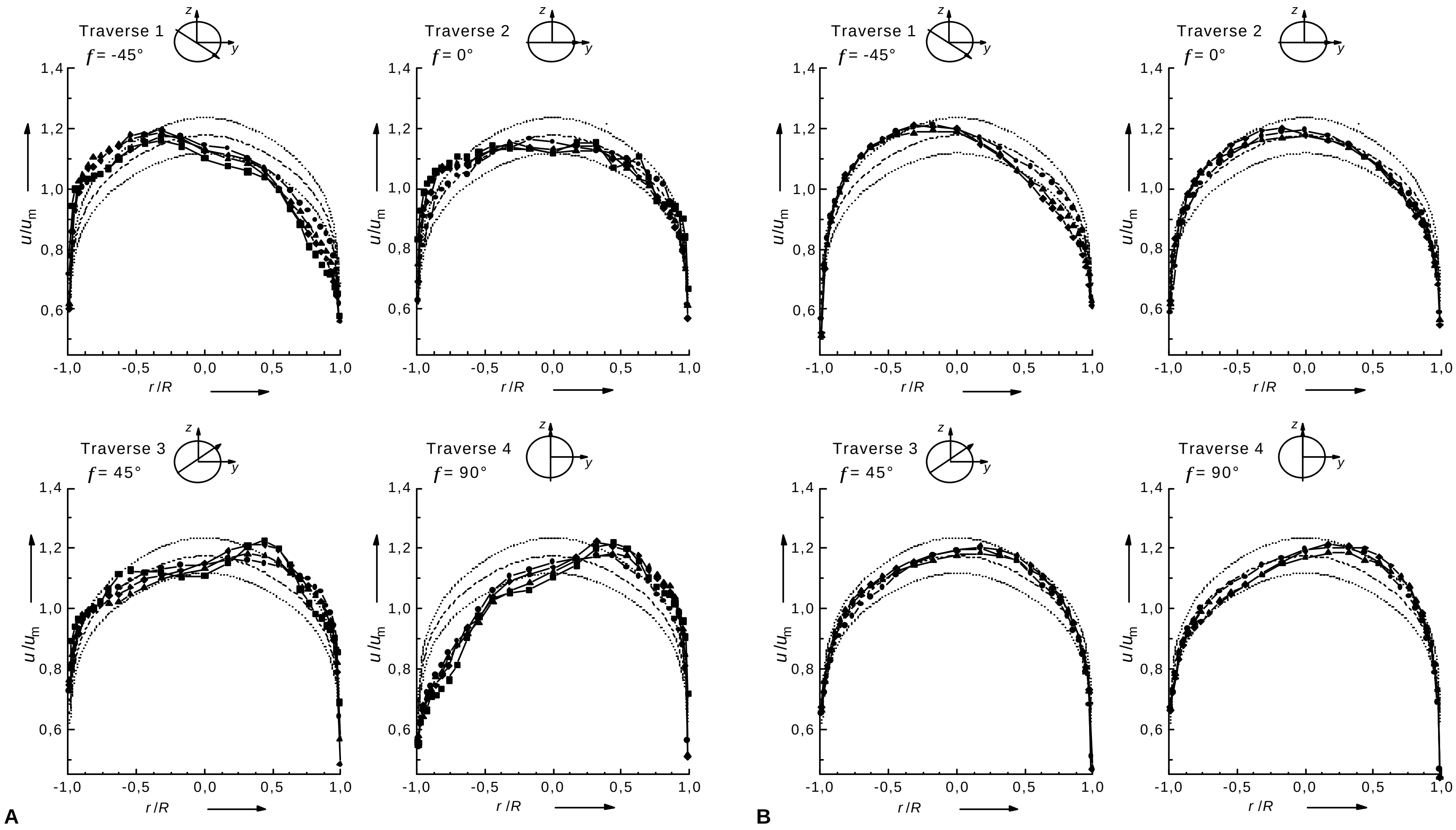


Fig. 4: Flow profiles downstream to **Conf. 1** (Low Level) with flowconditioners (see Fig. 2)
A: short distance to perturbation (about 2 D)
B: long distance (about 7 D)
(see also Fig. 7 for exact distances)

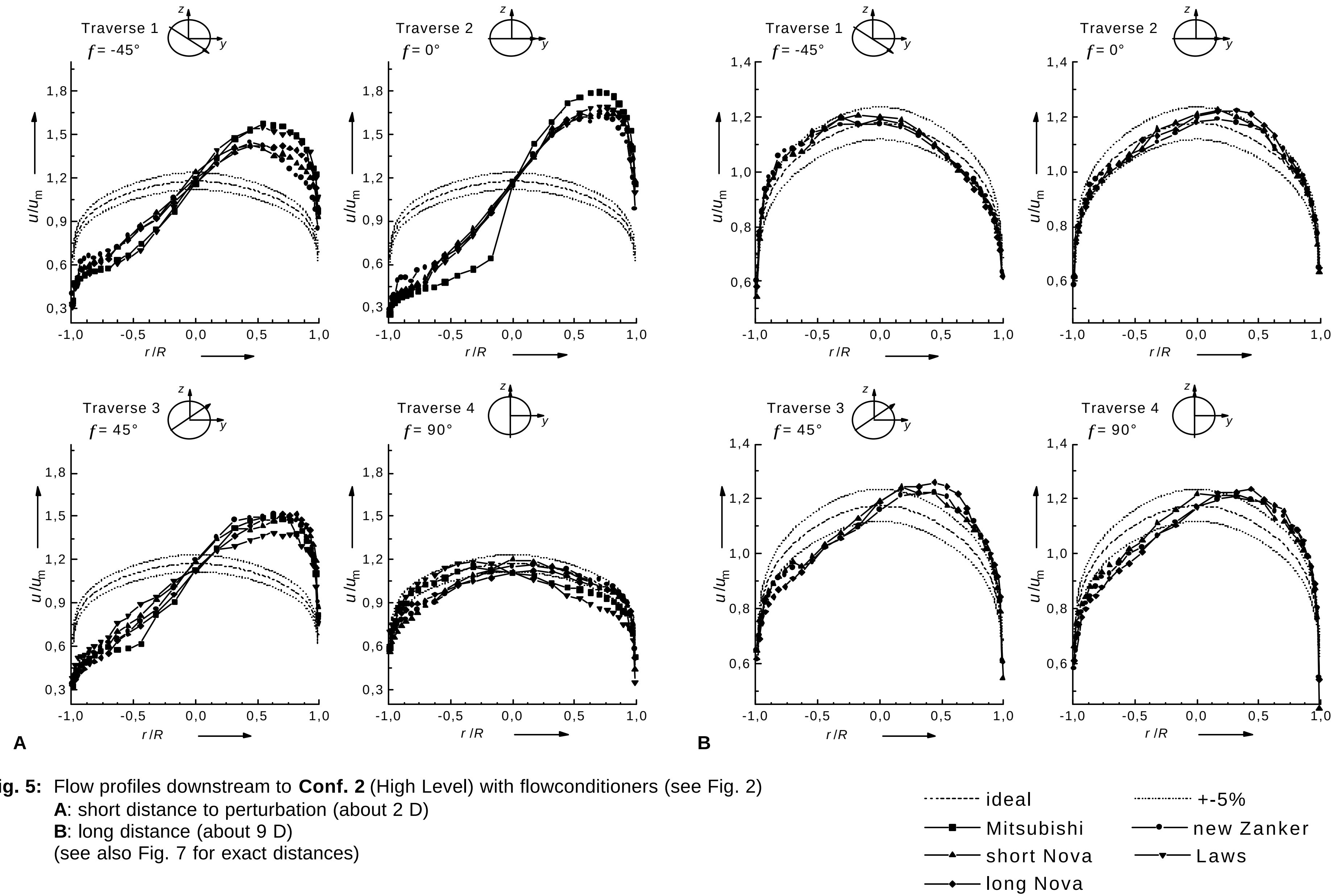


Fig. 5: Flow profiles downstream to **Conf. 2** (High Level) with flowconditioners (see Fig. 2)
A: short distance to perturbation (about 2 D)
B: long distance (about 9 D)
(see also Fig. 7 for exact distances)

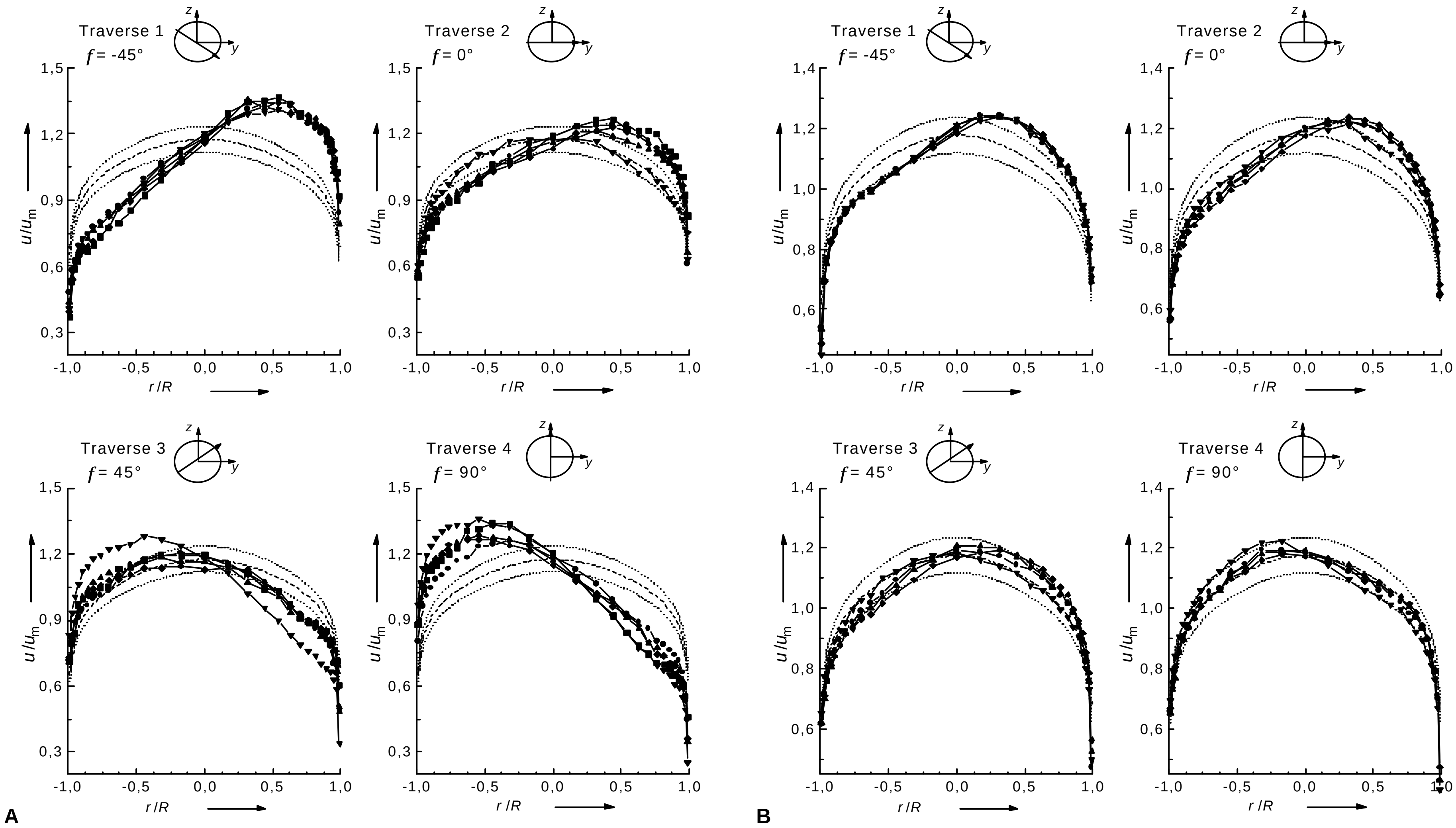
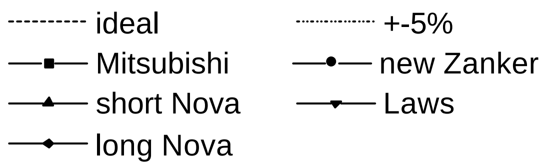
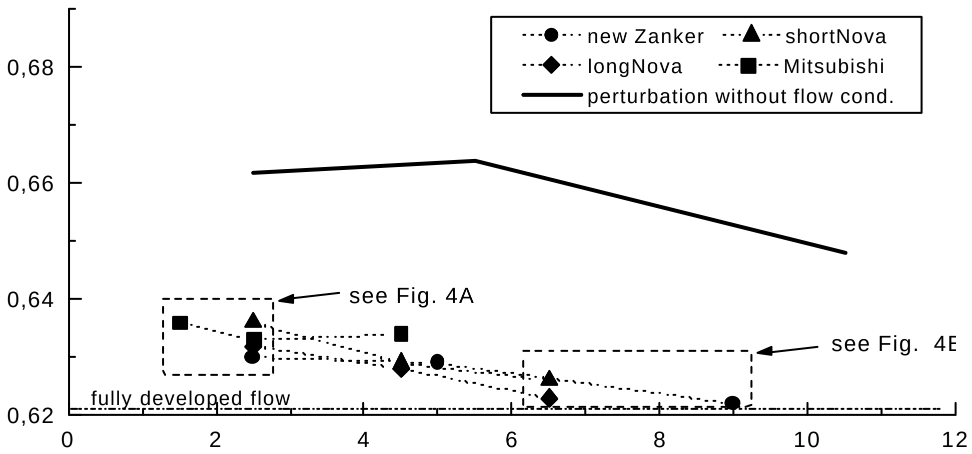
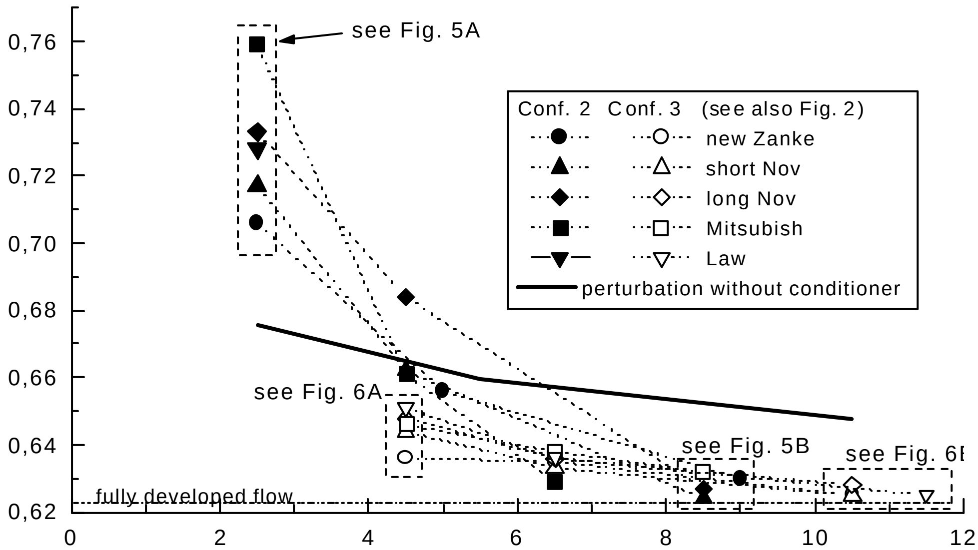


Fig. 6: Flow profiles downstream to **Conf. 3** (High Level) with flowconditioner (see Fig. 2)
A: short distance to perturbation (about 4 D; 2 D to conditioner rsp.)
B: long distance (about 11 D; 9 D to conditioner rsp.)
(see also Fig. 7 for exact distances)





A



B

Fig. 7: Development of Momentum number K_u as function of distance L (distance measured to perturbation)
A: for Conf. 1 Low Level
B: for Conf. 2 High Level (solid symbols) and Conf 3 (open symbols)