COMPREHENSIVE EXPERIMENTAL AND COMPUTATIONAL INVESTIGATIONS OF THE UNSTEADY FLOW IN AN AXIAL FLOW LOW SPEED COMPRESSOR STAGE

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Summary The objective of the study is experimental and computational investigation of unsteady flow in the axial flow low speed compressor stage with the use of three systems based on totally different principles:

- a five hole pressure probe (FHP),
- a 2-sensor fast response straight and 90 degree triple split fiber probes (TSFP) and,
- commercially available three-dimensional Laser Doppler Anemometer (3D-LDA) system.

Using two measurement system, one being intrusive and the other non-intrusive, in the same complex flow field has been given the opportunity for:

- critical comparison of results and opens the view for further improvements. Attention was focused to the rotor blade wake where both measurements are affected by high tangential shear gradients,
- investigation of the influence vane setting angle on the unsteady flow field in the axial flow compressor stage,
- a concerted application of experimental (LDA) and computational fluid dynamics (CFD) calculations as well as basis for verification of computational results. From a comparison of LDA and CFD data, possible improvements in computational technique can be pointed out.

Experimental Facility and Instrumentation

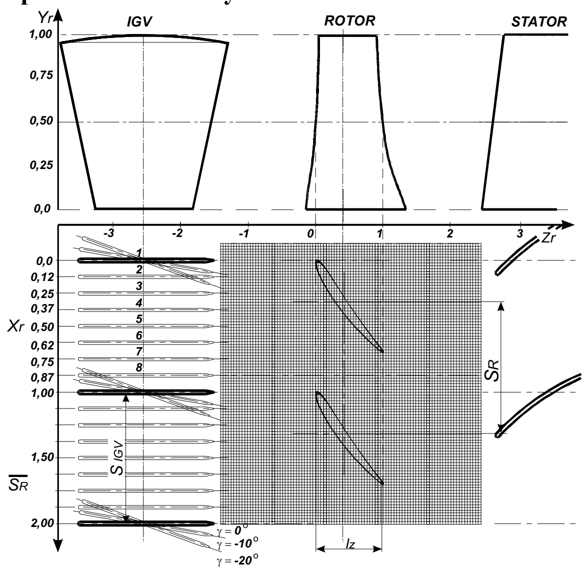


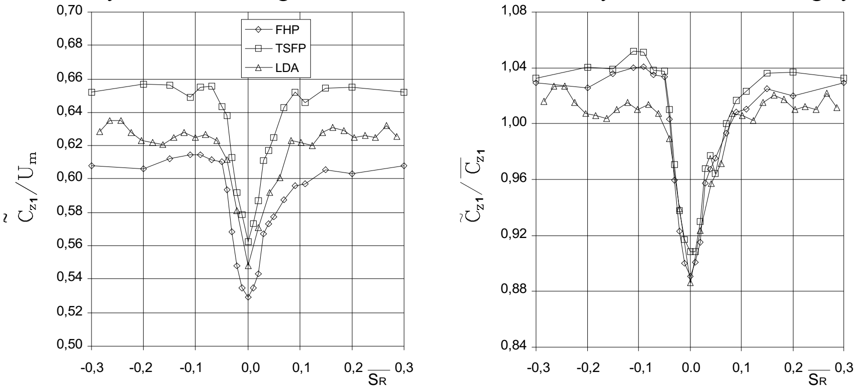
Fig. 1 Measurement locations in spanwise, pitchwise and streamwise direction.

The experiments has been performed in the Axial Flow Low Speed Compressor Stage (AFLSCS) of the Institute of Power Engineering and Turbomachinery at the Technical University in Gliwice which was designed to tests compressor stages over a wide range of parameters and to validate numerical codes [1]. It consists of a rotor with a hub to tip annulus wall diameter ratio 0.56, with outher diameter of 1.0 m, with 16 cambered and twisted blades of British C-4 section, designed for free vortex operation, followed by a 13-vane stator row, and the outflow curvilinear diffuse with the throttling blades. The research compressor stage is connected to the suction side of the measuring collector and consists of a large bellmouth inlet for mass flow measurement. To account for the uniformity of the rotor absolute inlet flow field, measurements have been made at eight tangential locations in the absolute frame equally spaced over one inlet guide vane (IGV) pitch (Fig. 1).

Measurement have been acquired at 40 axial measurement locations from just upstream of the rotor (0.735 chord) to chord downstream of the rotor. Preliminary each measurement location was at midspan. For the measurements with the use of TSFP at each axial or radial location a sequence of 100 real time samples of velocities were recorded over roughly 2 blade passing periods and averaged over 1000 revolutions. In the measurement with the use of LDA system each rotor passage was divided into 50 measurement windows across the rotor pitch. After all instantaneous velocities in both methods were acquired for the particular survey point the velocities is then ensemble averaged and the level of unresolved unsteadiness determined.

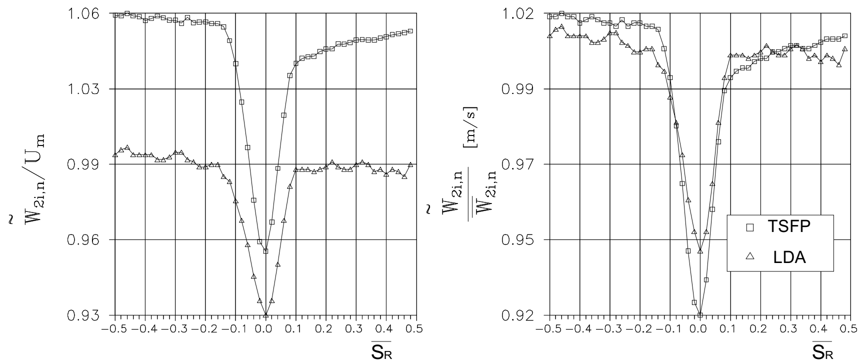
Some Results

In the following figures 2 and 3 the results of different axial positions before (Fig. 2) and behind (Fig. 3) the rotor blades were plotted separately to exhibit differences between the three measurement systems in more details The comparison of the circumferential distribution of the axial component of absolute velocities in the IGV and rotor blade wakes normalized by the mean rotor speed (Figs. 2a, 3a) and by the mean velocity $\overline{C}$ (Figs. 2b, 3b) shows good agreement in the vicinities of the center blade wake, in the free stream region the agreement is not so satisfactory. Larger discrepancies in the ensemble average velocity occurred at the rotor blade wake (Fig. 3), where velocity component value could differ by as much as 7 % at the free stream region. However there is very good agreement in the wakes velocity defect and semiwake width, when the velocity is normalized by the time average velocities $\overline{W}$, determined by the both measuring systems separately.



a) b)

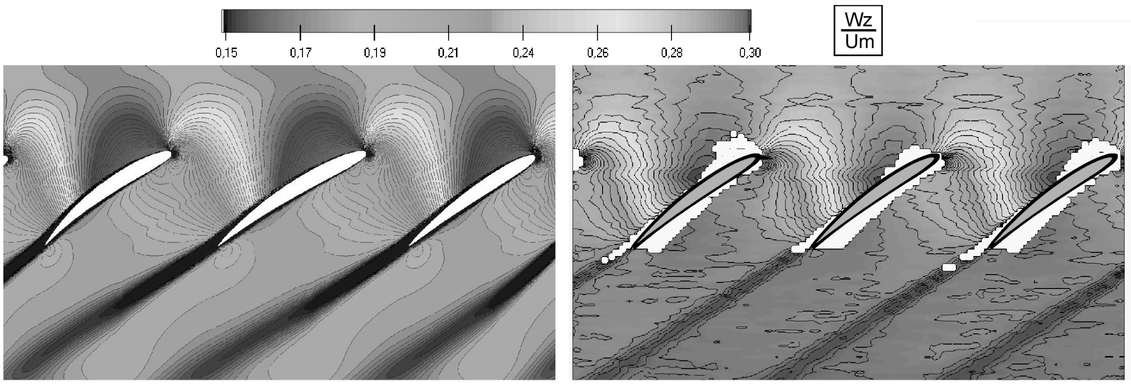
Fig.2 Comparison of the IGV wake velocity profiles normalised by U_m(a) and $\overline{c}_z$(b) [m/s] with the use of the three measurements systems – just downstream of the IGV



a) b)

Fig.3 Comparison of the rotor wake relative velocities profiles just downstream of the rotor trailing edge with the use of different measurement systems

A comparison of the numerically obtained [2] the contour plots of the axial components of the relative velocities on the middle radius with experimental data (LDA) is made in Fig.4. This shows that the predictions give good qualitative agreement. The numerical results show some quantitative differences to the measured data. These differences can be due to the turbulence models as well as the grid resolution.



a) b)

Fig. 4 Contour plots of relative velocities a) CFD data, b) LDA data

Conclusion

- In the present state, the CFD method supplied data giving a fair qualitative characterisation of the flow phenomena in the axial flow compressor stage and pointed out also by the TSFP and LDA measurements.
- In order to obtain a CFD method more capable for simulating flow in compressor stages an improvement must be carried out on the included boundary layer models.
- This comparison of LDA and TSFP technique width CFD method is probably the first on ever made in highly fluctuating and highly turbulent air flow in the axial flow speed turbomachinery channels.

References

[1] Witkowski A., Chmielniak T., Majkut M., Strozik M.: Measurement of the Unsteady Flow Field Due to Inlet Guide Vane Interaction with the Rotor in an Axial Flow Low Speed Compressor Stage., 5 -th European Conference on Turbomachinery, Fluid Dynamics and Thermodynamics, Prague, Czech Republic, 2003.

[2] AEA Technology Engineering Software Lim ited, Waterloo, Ontario, Canada. CFX-TASCflow, User Documentation, January 1999.