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Water tunnel for testing the measurement methods of local flow parameters

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Abstract

A configuration of the water tunnel with two independently controlled concurrent streams is presented. Two important zones of the flow, namely: an inner layer with even parameter profiles and a mixing layer between two streams, can be observed. The numerical simulation results obtained by means of the CFX-TASCflow code are compared with the experimental investigation results measured by a Pitot probe in the velocity range from 1.7 to 16 m/s.

Keywords: Water tunnel, Probe calibration

1 Introduction

Turbomachinery design engineers are constantly working towards achieving increased machine efficiency, decreasing weight and number of parts, which leads to more compact machines, with a simultaneous reduction in manufacturing costs.

These efforts are aimed at better understanding of complex 3D flow phenomena in real machine stages, which will allow the designer to estimate and optimise their hydrodynamic performance through numerical simulations.

A water tunnel was constructed to model conditions of a flow through real turbomachinery channels, to test measurement methods, to calibrate measurement devices (multi-hole pressure probes or thermoanemometric probes) and to verify numerical 3D codes for viscous flows.

In the water tunnel, an essentially different measurement opportunity occurs in comparison to air tunnels due to a high fluid density as well as to a significant

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difference between the measured velocities and the speed of sound. It is possible, for instance, to carry out measurements at high Re numbers without an influence of Ma numbers and at very low Re numbers for higher pressures that are easier to measure. At the same time, water electrical and heat conductivity, as well as a possible occurrence of the gas phase impose very serious constraints on measurement techniques, whereas a high liquid density leads to significant energy consumption.

The experimental investigations in wind tunnels for probe calibration [1] and in cascades [2] have been carried out at the Institute of Turbomachinery, Technical University of Łódź, for a long time. A water tunnel allows one to increase significantly the range of experiments and to verify the calibration of probes in air tunnels by means of measurements in water.

2 Water tunnel design

The water tunnel is used to calibrate multi-hole pressure and thermonemometric probes, as well as to model and investigate experimentally flows of very high velocity gradients. The test section is supplied by two concentric streams: the main one ($\dot{m}_{in}$) from the inner nozzle of the diameter of $D_{in} = 30$ mm and the auxiliary one ($\dot{m}_{out}$) from the outer nozzle of the diameter $D_{out} = 80$ mm (Fig. 1). The results of experimental investigation for similar systems used for other purposes [3,4] show that such a configuration is useful for the aims presented in this paper. The test stand scheme is depicted in Fig. 2. Each stream is supplied by a separate pump and can be controlled independently. A test section of the tunnel is preceded by a straight section of inner and outer pipes, which is longer than 3 m. A set of valves upstream and downstream of the channel enables one to control pressure in the test section.

The above-mentioned configuration of the channel is characterised by a stable flow with the central region of constant parameters and the annular region of an adjustable velocity gradient at the high pressure-gradient layer between the streams. The flow conditions in the high pressure-gradient layer are fundamentally different from commonly modelled flows with velocity gradients near the wall. A large tank (28 m^3) allows one to keep the constant liquid temperature during the experiment for a long time.

Mass flow rates of both the streams, values of pressures in many points on the walls of inner and outer pipes, as well as probe holes can be measured and recorded by the measurement system. Pressure measurements can be recorded in 48 points. All pressures are measured with respect to the chosen reference pressure. An application of two differential pressure transmitters (MOBREY, accuracy class 0.075) with a high overload capacity makes it possible to measure

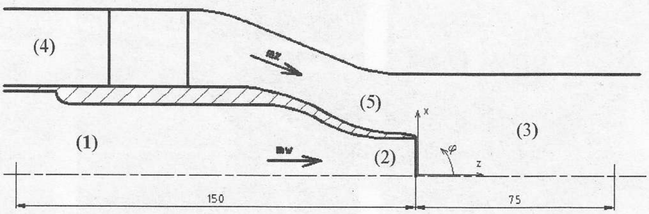

Figure 1. Main parts of the water tunnel: 1 – inner channel; 2 – inner nozzle; 3 – test section; 4 – outer channel; 5 – outer nozzle.

pressures in a broad range with a high accuracy. Two probe supports can be used to insert the probes into the test section from opposite sides, which enables one to determine precisely their positions.

3 Flow investigations in the water tunnel

The numerical simulations of the flow on the test stand were carried out by means of CFX-TASCflow [5]. A miniature Pitot probe (d_p = 0.5 mm) was used in the experimental investigations. Four values of the mass flow rate from the inner nozzle and one mass flow rate from the outer nozzle were considered. The most important flow parameters are presented in Table 1.

Table 1. Flow parameters.

	Outer stream		Inner stream			
No.	$\dot{V}_{out}$	C_{outav}	$\dot{V}_{in}$	C_{inav}	Re_{Din}	Re_{dp}
	dm^3/s	m/s	dm^3/s	m/s		
1	5.64	1.30	1.20	1.70	$5.0 \cdot 10^4$	$8.5 \cdot 10^2$
2			2.57	3.60	$1.1 \cdot 10^5$	$1.8 \cdot 10^3$
3			7.15	10.1	$3.0 \cdot 10^5$	$5.0 \cdot 10^3$
4			11.30	16.0	$4.8 \cdot 10^5$	$8.0 \cdot 10^3$

The numerical simulations were carried out for a section of the channel which spread 150 mm upstream and 75 mm downstream of the outlet plane of the internal nozzle. The 45°C sector of the channel was considered due to eight ribs which fastened the inner channel (Fig. 1), under periodicity conditions at the side surfaces. Such a configuration led to a significant reduction of the task size without any essential, negative influence on the solution quality. The computational mesh, presented in Fig. 3, was generated by means of ICEM Hexa. Refinements

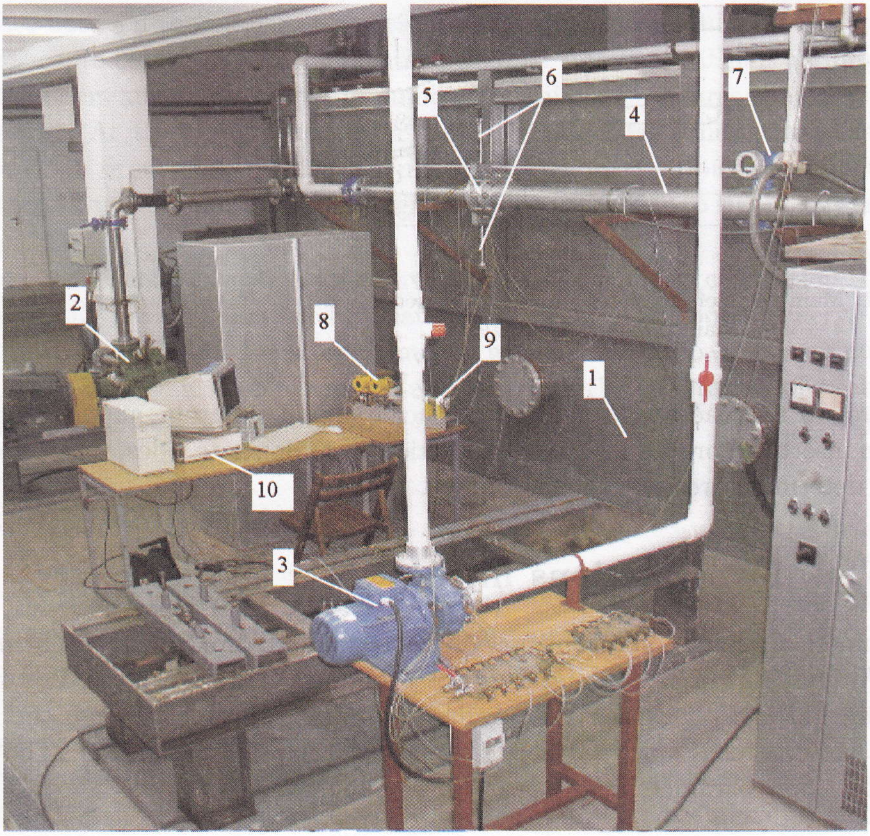

Figure 2. General view of the test stand: 1 – water tank; 2 – main pump; 3 – auxiliary pump; 4 – piping system; 5 – test section; 6 – probe supports 7 – electromagnetic flowmeter; 8 – differential pressure transmitters; 9 – pressure signal hydraulic commutator; 10 – Keithtey KDAC measurement system.

of the mash are visible in the regions of significant velocity gradients, i.e., in the mixing layer and in the wall boundary layer.

The velocity profiles were imposed at the inlets of the computational domain. They were obtained from the numerical solution of the flows in three-meter-long sections of the inner and outer pipes. Additionally, the turbulence intensities were imposed. The mean value of static pressure was assumed. The periodic conditions were applied along the circumferential direction. The walls were treated as smooth.

Many different factors which influence the flow, especially in the stream connection region, were investigated during the numerical simulations. The turbulence model, governing equation discretisation schemes, velocity profiles and turbulence intensities at the inlets and modifications of the advection terms by

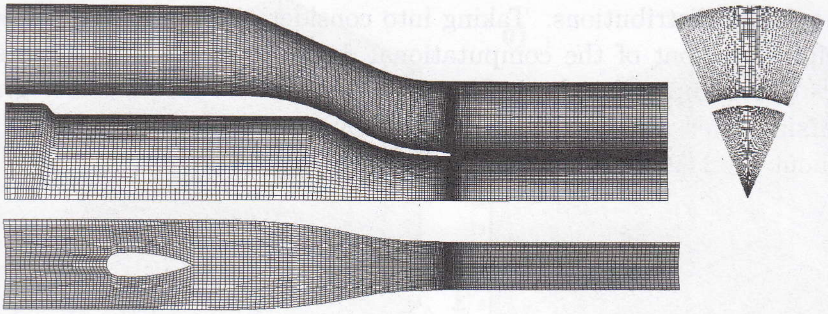

Figure 3. Computational mesh on the side (periodicity) surface.

means of the PAC “Physical Advection Correction” model were considered.

The comparison of velocity profiles in the cross-section 15 mm downstream of the nozzle obtained from the numerical investigations is presented in Fig. 4 for test case 3. The velocity profiles obtained from three-meter-long pipes and 1% turbulence intensity were imposed in this case. An influence of two different turbulence models as well as of the PAC advection model on the solution can be easily seen.

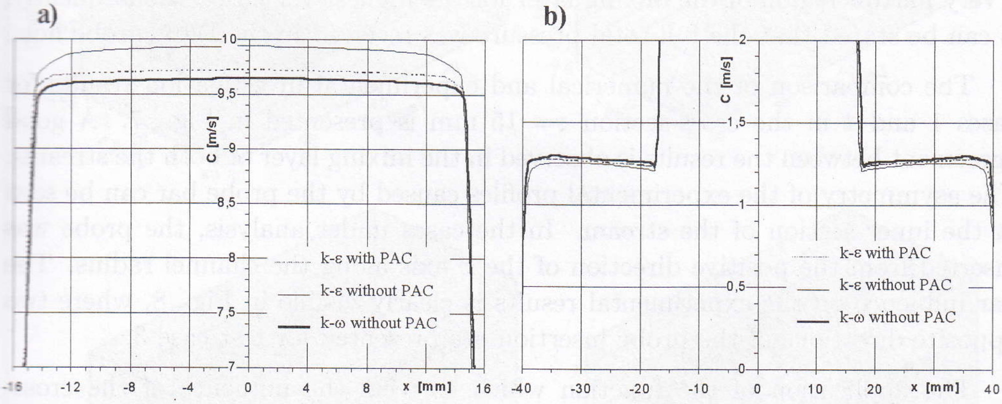

Figure 4. Comparison of numerical simulation velocity profiles for different models (test case 3, Tu = 1%, velocity profiles at the inlets)
a) – inner section of the stream; b) – outer section of the stream.

The analysis of the preliminary computation results led to the conclusion that the best agreement with the experimental data was reached for the solution with second order discretisation model (Linear Profile Skew) of the governing equations and with the k-ε turbulence model. Additionally, the application of velocity profiles at the inlets of the channel section showed their advantage over uniform velocity distributions. Taking into consideration long, straight sections of the piping in front of the computational domain, low turbulence intensities (Tu = 1%) were imposed at both the inlets. Due to very high velocity gradients in the mixing layer, the main part of the computations was carried out for the case without the PAC modification of the advection terms.

4 Investigation results

The velocity profiles obtained from the numerical simulations for the maximal and minimal flow rates (cases 1 and 4 from Tab.1) are presented in Fig. 5. The z axis is collinear with the channel axis and has its origin in the inner nozzle outflow cross-section.

The yaw angle characteristics of the Pitot probe used for the experimental investigations (Fig. 6) shows that changes of the signal do not exceed 0.25% for the angles lower than 10°C , whereas for 15°C they are lower than 1%. The calculations revealed that the advection angles are significantly below 10°C except for a very narrow region of the mixing layer for the highest velocities. Consequently, it can be stated that the full total pressure was received in the Pitot probe hole.

The comparison of the numerical and experimental investigation results for cases 1 and 4 in the cross-section $z=$ 15 mm is presented in Fig. 7. A good agreement between the results is observed in the mixing layer of both the streams. The asymmetry of the experimental profiles caused by the probe bar can be seen in the inner section of the stream. In the cases under analysis, the probe was inserted from the positive direction of the x axis along the channel radius. The bar influence on the experimental results is clearly visible in Fig. 8, where two opposite directions of the probe insertion are presented for test case 3.

The application of the function which corrects the influence of the cross-section blank off by the probe bar leads to a very good agreement between the numerical simulations and the experimental results for the whole region and for all velocities (Figs. 7c and 8). The pressures presented in both the figures were related to the pressure p_{to} (total pressure in the channel axis obtained from the numerical simulations).

The differences between the computational and experimental results for the outer section of the stream presented in Fig. 7d result from the probe bar influence as well as from the presence of two holes (7 mm diameter) in the channel wall where the probe is inserted.

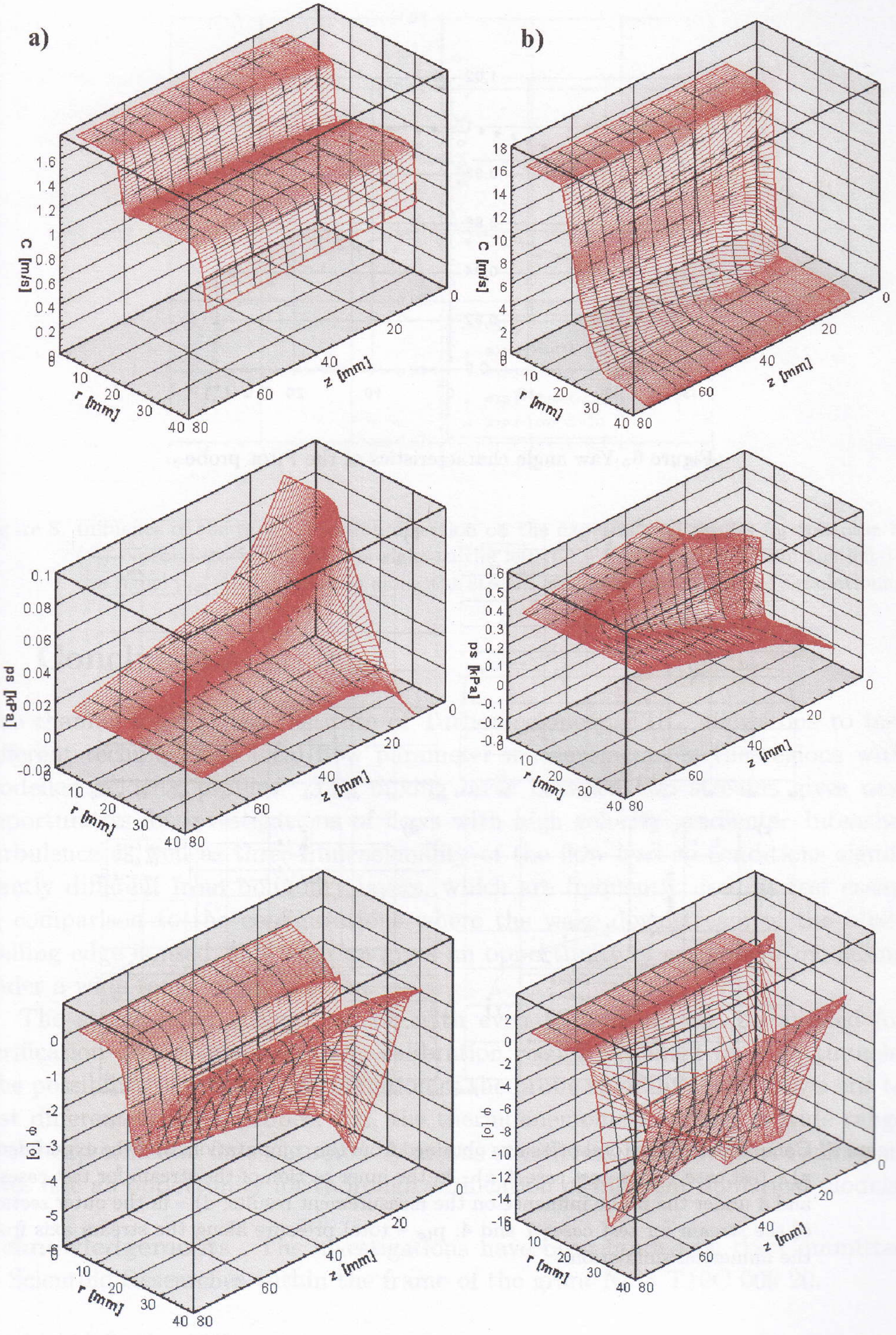

Figure 5. Numerical simulations results: a) – test case 1; b) – test case 4.

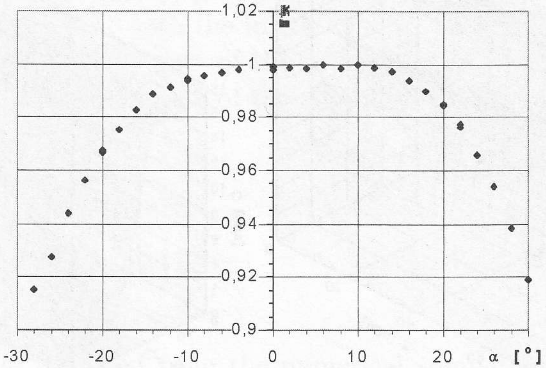

Figure 6. Yaw angle characteristics of the Pitot probe.

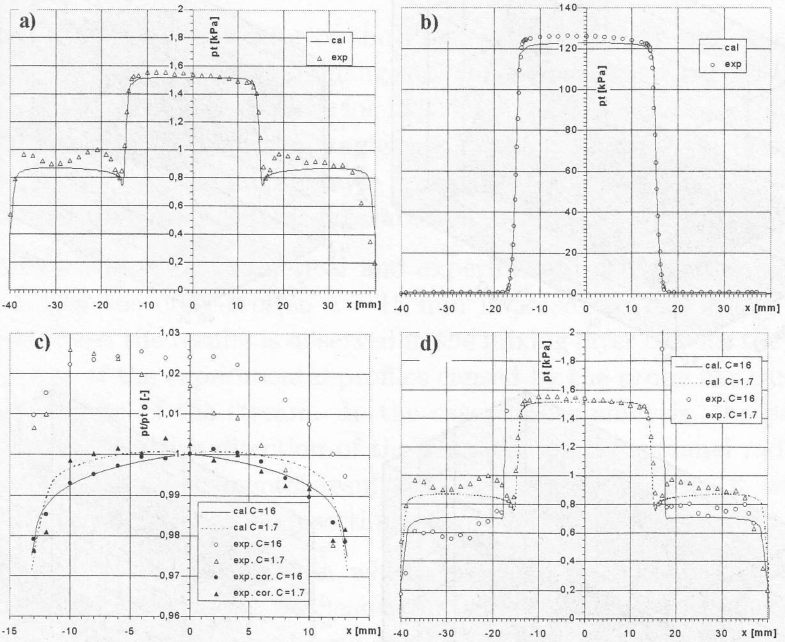

Figure 7. Comparison of the total pressures obtained from the computations and the experiment: a) – test case 1; b) – test case 4; c) – in the inner section of the stream for test cases 1 and 4 under the probe influence on the measurement results; d) – in the outer section of the stream for test cases 1 and 4; p_{to} – total pressure along the stream axis from the numerical simulations.

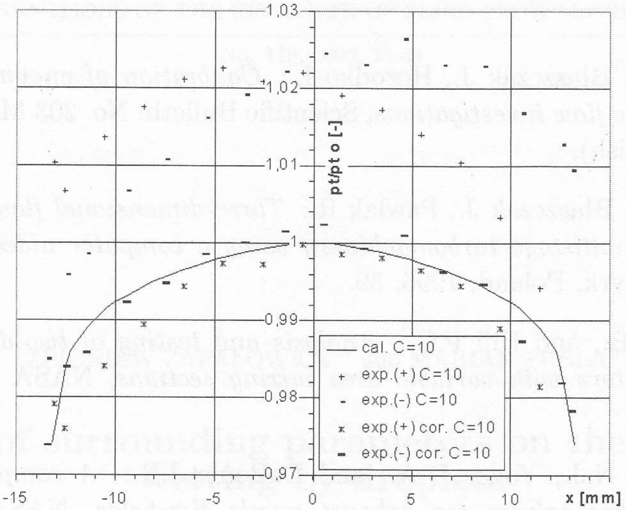

Figure 8. Influence of the probe insertion direction on the experimental results for test case 3. (+) – probe inserted from the right to the left; (-) – probe inserted from the left to the right; p_{to} – total pressure along the stream axis from the numerical simulations.

5 Conclusions

The channel built at the Institute of Turbomachinery, TUL, allows one to test different techniques of local flow parameter measurements in the regions with modelled velocity profiles. The mixing layer between two streams gives new opportunities for investigations of flows with high velocity gradients. Intensive turbulence as well as three-dimensionality of the flow lead to conditions significantly different from boundary layers, which are frequently used as test cases. In comparison to the configurations where the wake downstream of the blade trailing edge is used, this solution gives an opportunity of easier flow modelling under a wide range of parameters.

The stable inner stream section with even parameters can be applied for verification of the pressure probe calibration results obtained in wind tunnels. The possibility of precise determination of the probe stem influence allows one to test different types of probes, e.g., the thermoanemometric ones. A wide range of the experimental data obtained by means of different measurement techniques gives one an opportunity for thorough verification of different numerical models.

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