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MULTI-PHASE MODERNISATION OF THE SUBSONIC WIND TUNNEL ORIENTED TOWARDS INTEGRATION OF CFD & EXPERIMENT

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Abstract

In applied aerodynamics, an experiment supplementing theoretical or numerical analysis can be conducted in a wind tunnel as it is a basic tool for practical study. It gives a record of how rules of physics apply in the real world and can serve as means of validation. On the other hand, advantageous features of CFD (i.e. low cost, ability to predict 3D flow fields, and relatively short time for obtaining results) cannot be underestimated. Combining both techniques, CFD and experiment, provides full information about aerodynamics of the studied object.

Awareness of the significance of a wind tunnel experiment for the research quality was the mainspring for the wind tunnel modernisation process at Institute of Turbomachinery (IMP) at the Technical University of Lodz (TUL). It was decided to provide IMP with the experimental stand of the high standard. The idea of working on the experimental stand was also inspired by the concept of CFD and EFD integration planned to be developed at IMP (Liśkiewicz et al., 2011). At the early stage of work, a decision was made to adapt formerly operated wind tunnel facility at the Institute of Turbomachinery (IMP WT hereafter) for modern applications. Character of performed actions can be classified as experimental with implementation of basic design. This paper summarizes the initial stage of modernisation process. The comparison of CFD results with experimental data gatherd in the tunnel for flow investigation around NACA 0012 profile will be shown. Additionally, main stages of IMP WT modernisation will be presented focusing on actions aimed at flow improvement and test stand adaption for PIV system installation.

Key words: subsonic wind tunnel, Computational Fluid Dynamics (CFD), Experimental Fluid Dynamics (EFD), Particle Image Velocimetry (PIV)

INTRODUCTION

The major purpose of the modernisation process described in this paper was to supply IMP with a wind tunnel facility equipped with a modern measuring system. A decision was made to revitalise existing experimental stand. A lot of work has been done to rerun the wind tunnel after the years of not being exploited. A summary of works oriented towards IMP WT modernisation, starting from first tunnel restart and ending with preparation of PIV experiment, will be presented in the following sections.

Wind Tunnel Facility

Wind tunnel at Institute of Turbomachinery was designed to operate in lowspeed range ($Ma < 0.3$). Its original application was investigation of turbine blade cascades (Porochnicki et al., 1977). Boundary layer flow and laminar-turbulent transition were tested. The last documented use of the wind tunnel, basing on documentation research, dates to the early 90s.

IMP WT can be described as an open-return, blow-down type wind tunnel. Both original and current designs possess a closed section located at the tunnel outlet. Air leaving the tunnel enters laboratory room in which a flow loop is being closed drawing it back to the inlet channel. Due to the vertical arrangement of inlet channel, access to the wind tunnel is possible from two building floors. Main duct and powering unit are located at the basement level. Fig. 1 shows general layout of IMP WT. Referring to the numbers on the drawing following elements are included in the current IMP WT construction:

- 3000 x 1800 x 1500 mm grid cage for cloth filter (1) (cloth filter currently not in use),
- two rectangular inlet channels (inclined at 120° to each other) with two radiators per each connected in series (2),
- vertical intake suction channel (3) equipped with flap-valve system regulating flow speed (flaps I-IV),
- centrifugal fan (4) of nominal flow rate $Q=6.25m^3/s$ and total pressure $\Delta P_c=6.55kPa$ powered with 55kW asynchronous motor,
- diffuser (5) with flat walls inclined at angles of ~7° for horizontal walls and ~17° for vertical ones,
- suction chamber (6) with two holes located sideways for boundary layer control (currently not in use),
- flow stabilisation section (7) with two grids inside and newly mounted honeycomb flow straightener (outlet channel dimensions: 1360 mm height x 990 mm),
- confusor (8) with contraction ratio around 3.5 increasing airspeed and improving parameters of the flow in test section (outlet channel dimensions: 1360 mm height x 290 mm width.

Old cascade test section and some auxiliary devices are excluded from the description. For construction details of all elements refer to (Porochnicki et al., 1977).

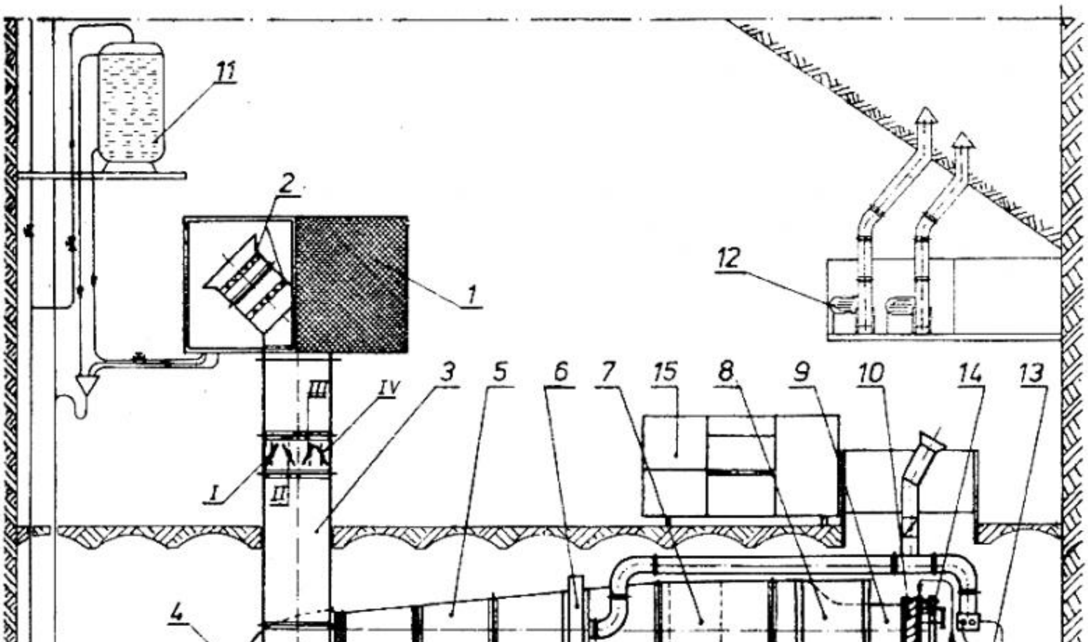


Fig. 1 Scheme of the wind tunnel at Institute of Turbomachinery (original layout)

Current-state pictures of IMP WT can be seen in Fig. 2.

Fig. 2 Present-day overview of IMP WT; from top-left clockwise: 1. diffuser, suction chamber and flow stabilisation section; 2. inlet channels with cooling system; 3. examples of tested blades; 4. powering engine-fan unit; 5 outlet from flow stabilisation section (grids visible)

WIND TUNNEL MODERNISATION

Initial Stage

Installation of the inverter provided the asynchronous motor with possibility of direct control for rotational speed. Such speed control is a convenient solution especially having in mind future automatisation of the facility. This modernisation provides an easy and precise flow speed regulation without use of flap-valves. Flow speed can be regulated now by setting the current frequency in the range of 0-50Hz.

Cooling system check revealed the malfunction of one radiator (system consists of 4 radiators located inside the inlet channels). In order to investigate temperature variation during the run of the engine with no active cooling system a series of measurements were carried out.

New Test Section

Process of modernisation of IMP WT includes test section adaptation for aerodynamic experiments with a new type of measurement equipment. For the initial tests it was decided to use the remains of the previous stand. Confusor and old cascade support were adapted. Narrow outlet from the contraction section seemed a perfect solution for planned experiments with an aerofoil. Closed test section arrangement was chosen. As the nature of PIV measurement requires optical access into the flow, transparent walls were installed. Plexiglass sheets were attached to the steel frame enabling to observe the interior from side, top and bottom. In order to improve optical properties of installed test section walls, plexiglass were polished to remove any surface imperfections. Fig. 3 shows new test section adapted for the experiment with PIV system.

Fig. 3 New test section with plexiglass walls

Honeycomb Flow Straightener

In a wind tunnel it is hard to guarantee a completely uniform and steady airstream. Small eddies and velocity fluctuations are always present. All flow disturbances are referred to as a turbulence of the stream which is one of the most important quantity to be considered in wind-tunnel design (Pankhurst et al., 1952). There are various techniques enabling satisfactory turbulence level and velocity distribution inside the test section. In order to provide a good flow quality in the test section, turbulence should be kept at reasonably low level (values depending on the application).

Reduction of turbulence intensity is obtained by installing honeycombs, coarse mesh screens and contraction. Combination of all these methods results in a much better turbulence reduction factor. This has been already implemented in IMP WT partially. Facility is equipped with flow stabilisation section. Originally, two turbulence reduction grids are located inside.

Screens reduce axial and lateral turbulence at various rates. They are more effective at axial reduction (Scheiman et al., 1981). Total turbulence reduction factor of IMP WT grid arrangement is equal approximately to 0.27 and 0.52 for axial and lateral turbulence respectively. In order to improve flow quality by reducing lateral turbulence more efficiently, a new flow manipulator was introduced into the stabilisation section. Unlike screens alone, honeycomb reduces lateral turbulence more than axial one. It is easy to imagine that any lateral velocity fluctuation larger than its cell size is effectively absorbed. What is more, any smaller turbulence would decay rapidly due to viscosity. On the other hand, axial turbulence is not reduced as effectively as in case of grids because pressure drop for honeycombs is much smaller (basing on IMP in-home analyses honeycomb pressure drop is in the range of few pascals).

PERFORMANCE TESTS

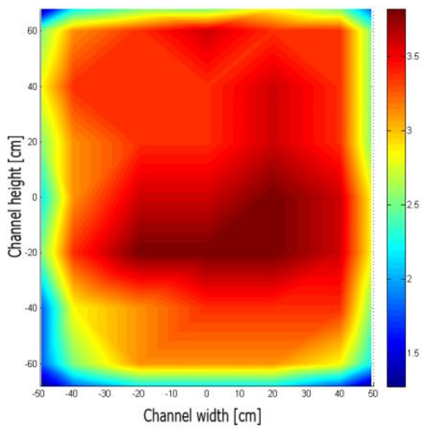
Due to lack of data on IMP WT operating characteristics few basic flow measurements were performed. Examples of acquired data are: maximum achievable airspeed, velocity distribution, turbulence intensity, temperature variations. As a result, knowledge of many parameters and phenomena occurring in IMP WT was gained.

Velocity Distribution

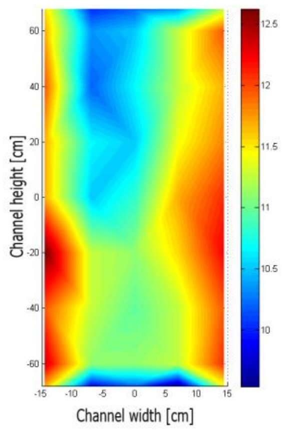
The aim of performed tests was to investigate velocity profile at the wind tunnel outlet and check maximum achievable flow speed.

Airspeed was determined indirectly basing on pressure measurements with a Pitot-static probe. Measurements were taken for channel outlet with and without a confusor at two engine speeds (25Hz & 50Hz inverter frequency, i.e. 50% & 100% of engine rotational speed) which gives 4 independent tests. In order to find velocity profile, pressure was measured at multiple positions across the outlet. Uniform grid of measurement points was used. Vertical grid spacing was 20cm for both cases. Horizontal grid spacing was 20cm for larger outlet and 7cm for the test with confusor. Additionally, each grid for both tests was implemented by pressure measurement taken close to the channel wall (final grid sizes: 7 x 9 and 5 x 9). Since one probe was used during tests, measurements were not taken at the same time. Tests carried out aimed at getting rough results allowing to get general idea of WT performance.

Measurement results are presented in the form of contour plots with velocity distribution across the inlet to the test section (see Fig. 4).



a)



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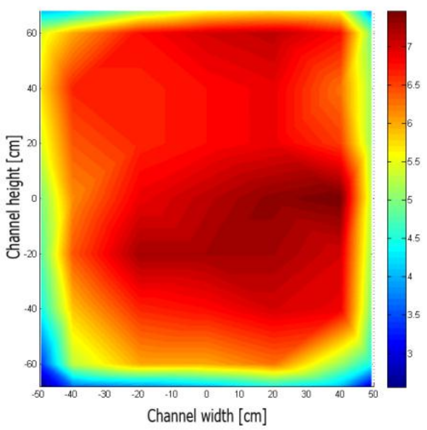

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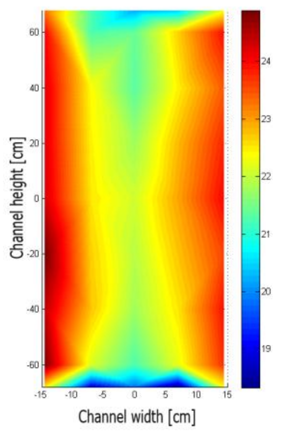


d)

Fig. 4 Velocity distribution across tunnel outlet with and without the confusor for 50% a), b) and 100% of engine power c), d)

Following observations may be pointed out:

- velocity distribution for channel outlet without confusor appeared to be in general agreement with the theory of wall-bounded flows (maximum velocity in the channel centre decreasing while approaching the wall),
- velocity distribution for channel outlet with installed confusor became more uniform (maximum velocity occurs at channels side walls decreasing slightly at the middle),
- velocity peak position for channel without confusor is slightly moved to the bottom-right side,
- significant airspeed drop occurs only at the corners of the channel without confusor and top and bottom walls of the confusor,
- increasing engine speed results in more uniform velocity distribution across the inlet.

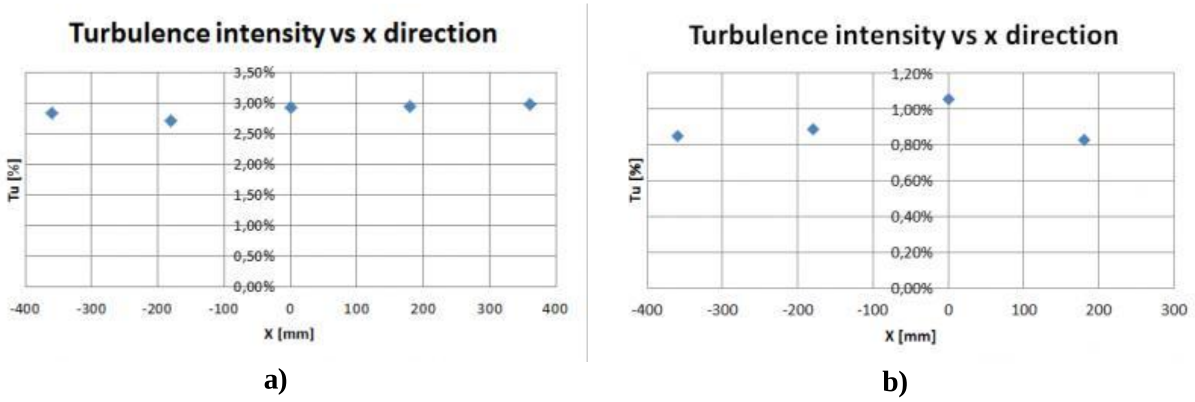
For analysed cases mean velocities across the channel were calculated. Results can be seen in Tab. 1. Bolded values represent maximum possible airspeed obtainable in IMP WT facility. It is an important parameter limiting wind tunnel application that should be included while designing future experiments.

Tab. 1 Values for mean velocity across wind tunnel outlet

	inverter frequency [Hz]	mean velocity	
		[m\s]	[km\h]
confusor	25	11,21	40,37
	50	**22,50**	**81,01**
no confusor	25	2,87	10,32
	50	5,73	20,64

Turbulence Intensity

Together with the maximum achievable airspeed inside the wind tunnel, one of the most common and vital parameter describing its performance is turbulence intensity. For complete definition of IMP WT flow characteristic turbulence levels at particular airspeed were investigated. Measurements were performed by means of a hot-wire anemometry (CTA - constant temperature anemometry). Test was carried out in closed test section channel for the half of the maximum airspeed. Turbulence of the flow is strictly correlated with boundaries of the flow. Obtained results are valid only for analysed case and could vary significantly if tests were performed in test section of a different shape. Placing any kind of obstacle into the flow (tested model, probes, etc.) would disturb the flow and influenced obtained turbulence measurements as well. Measured velocity was based on the single wire reading, which means that only resultant of a velocity was measured. Moreover, such an approach results in knowing nothing more than velocity magnitude. Therefore, it provides no information about direction and nature of velocity variations. Direction of fluctuations cannot be recognised. Velocity variation was measured at different locations (along axes in 3 directions in space). Collected data were processed using calculated calibration trend line equation (voltage vs velocity dependency) and statistic methods. In Fig. 5 exemplary results of calculated turbulence intensity are presented (X direction = axial direction aligned with the flow). Acquired data was used for validating effectiveness of the honeycomb structure as CTA test were performed twice (before and after installation of the flow straightener).



a) b)

Fig. 5 Turbulence intensity measured in axial direction (X axis; (x,y,z)=(0,0,0) - centre of WT test section) without honeycomb straightener a) and after installation of the flow manipulator b)

The objective of the honeycomb installation stated as minimalization of turbulence intensity was fulfilled. Proper combination of flow straighteners - screens and honeycomb provided decrease of the Tu to the ranges around 1% for the half of the maximum IMP wind tunnel speed.

Temperature

IMP WT is of the open return type (i.e. uses a surrounding room to return the air to the inlet). An obvious effect occurring during the tunnel operation is the rise of the flow temperature due to the thermal energy released through the friction of the fluid and radiation coming from the engine. As mentioned before due to cooler malfunction, it is not possible to control the flow temperature. If the original cooling system is not used, too extensive temperature rise could be a problem. In order to check exact temperature changes of the flow and surrounding room, temperature measurements were performed.

Temperature measurements were taken using digital measuring instrument with a thermocouple giving an accuracy of 0.1°C. Wind tunnel was operating during the entire test. Test procedure was realised by taking measurements every 5 minutes. Two rotational speeds of engine (50% & 100%) were investigated for mentioned test. Maximum speed was kept for the first 35 minutes. After that, engine rotational speed was decreased by switching inverter frequency to 25Hz. Locations chosen for measurements was WT outlet - direct flow measurement. Results are shown in Fig. 6.

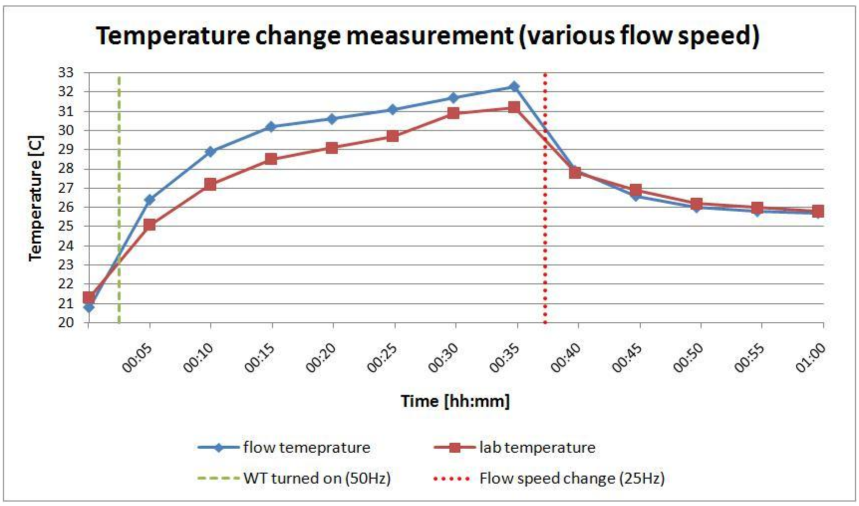


Fig. 6 Temperature changes influenced by engine rotational speed

Analysis of results gives following observations:

- max. absolute temperature change measured was Δt=11°C,
- for 50Hz no full stabilisation was observed for test duration thus max possible temperature can be slightly higher than presented,
- for 25Hz temperature stabilised at the level around 26°C.

Performed temperature test provided a general knowledge about maximum temperatures obtainable during WT operation and rate of change of their variation. In order to ensure stable flow conditions for further experiments in WT constant temperature should be kept. Measurement results shown that with current design of WT at IMP (open return type circuit) and its technical condition it is impossible to ensure such conditions right from the engine start. Relatively long time is required to stabilise flow temperature. Such an experimental strategy could increase operational costs in a long run.

Ability of sustaining constant flow conditions as well as controlling them is a crucial issue considering wind tunnel design. An obvious conclusion is that IMP WT needs to be equipped with efficient cooling system. Alternative solution is to remove coolers and redesign tunnel's duct by moving WT inlet and outlet outside the laboratory changing circuit to non-return type. Both solutions have their pros and cons. Revitalisation of old cooling system is definitely an easier and cheaper option. What is more, it would guarantee easy temperature control of the flow. On the other hand, redesigning facility at IMP would improve its performance. Removing coolers installed in inlet channels would decrease pressure losses thus increasing the maximum available flow speed. At the same time WT would be supplied with the air of a constant temperature from outside the building. With such solution however, flow temperature would be dependent on weather conditions and could not be controlled. That yields for the idea of combining these two concepts. Having in mind the need of temperature control and advantages of duct redesign as well as the fact of unreasonably high inefficiency of current cooling system, switching to non-return type wind tunnel equipped with new cooling system should be considered in the future. Additional improvement worth considering is relocation of coolers from WT inlet to the channel downstream the fan. This would enable direct temperature control of air heated by fan-engine system not possible with current design. Moreover, installing cooler downstream the fan is expected to improve the flow quality by flow stabilisation and turbulence reduction (cooler becomes a part of flow stabilisation section together with grids and the honeycomb).

CFD SIMULATION

In the process of revitalisation of the wind tunnel facility at the Institute of Turobmachinery it was decided to run a series of CFD simulations supporting the design of a new test section. Analyses of a virtual wind tunnel were performed in the ANSYS CFX software. Analysis described below is a part of larger study described fully in (Olasek, et.al, 2011). Aim of the mentioned project was to find proper relation between dimensions of wind tunnel's working section and characteristic dimensions of tested obstacles (focusing on an aerofoil).

Geometry Generation

For simulation simplification, two dimensional analyses were performed. In other words a flow around infinitely long profiles was simulated. In order to run this kind of simulation in the ANSYS CFX software, a thin geometry representing the cross-section of a wind tunnel with an obstacle was meshed with one element layer across its depth. Applying the symmetry boundary condition to the side walls of 2D slice-shaped fluid domain (see Fig. 7) mimics a quasi 3D-flow.

Standardised aerofoil NACA0012 was used for flow simulations. Chord length c=100mm and angle of attack α=10° were chosen.

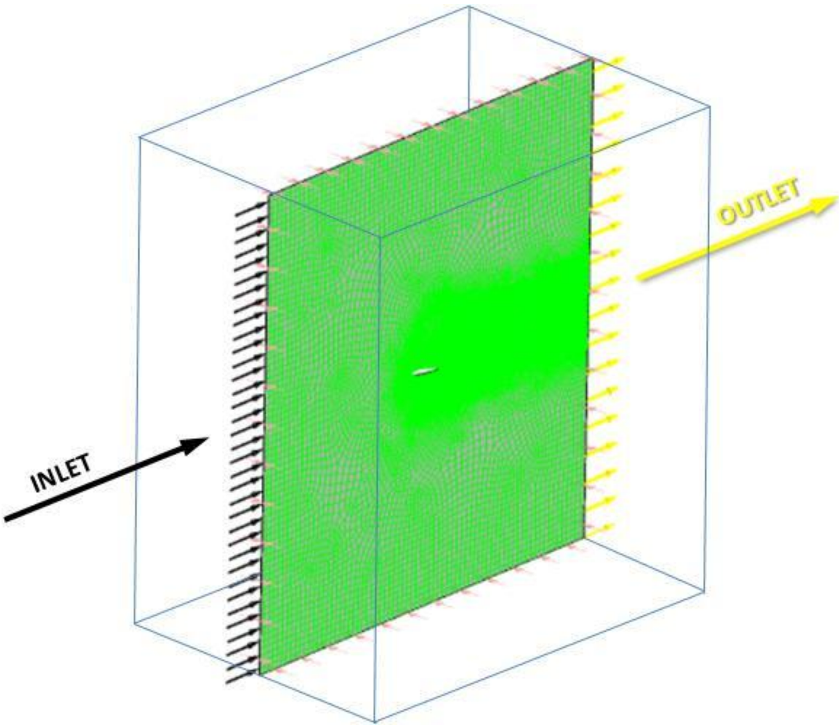


Fig. 7 Numerical domain used for quasi 2D simulations of the flow around aerofoil (NACA 0012) located inside the test section of the virtual wind tunnel

Mesh Generation

A combination of structured and unstructured hexahedral type of a grid was chosen for meshing the geometry. Structured mesh for outer domain and unstructured one for the inner (in the proximity of NACA0012 profile and for wake region). As long as complicated geometries are not being considered hexahedral mesh is a better choice than a tetrahedral grid. It allows to use faster algorithms, and is known to provide more reliable results (Biswas et al. 1998), In Fig. 8 a mesh region around the aerofoil is shown.

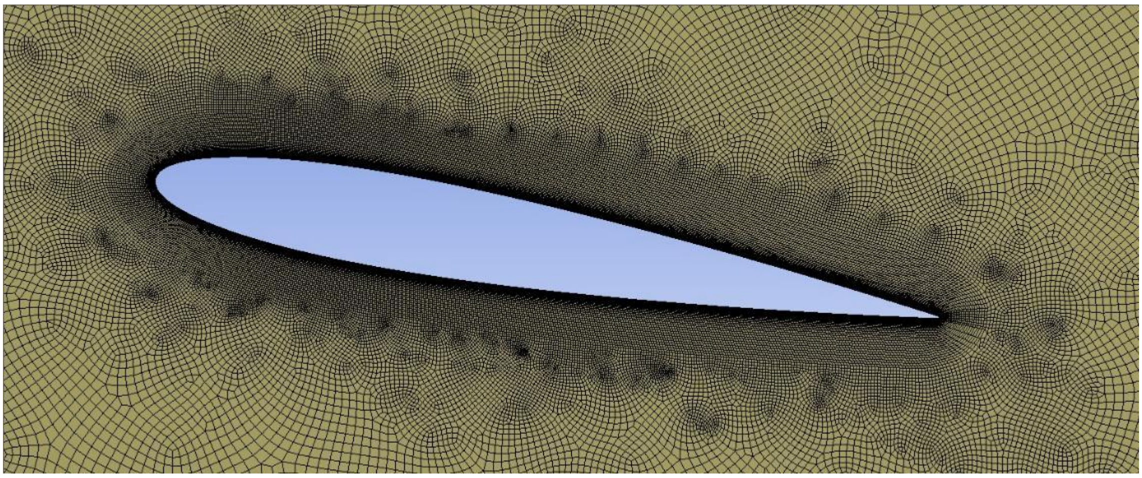


Fig. 8 Mesh around NACA0012 aerofoil

Task Preparation and Pre-processing

Crucial pre-processor parameters as well as initial and boundary conditions are listed below:

Analysis type:

- transient,
- timestep - 0.0005 s.

Domain:

- medium - air at 25°C,
- reference pressure - 1 bar,
- heat transfer - isothermal,
- turbulence model - SST with automatic wall function,
- transitional turbulence - gamma-theta model.

Inlet:

- turbulence option - medium intensity - 5% (due to requirements of the gamma-theta model),
- v = 11 m/s.

Outlet:

- average relative pressure - 0 bar,

Walls:

- no slip and smooth.

Results

Exemplary simulation results will be presented with comparison to PIV measurement.

PIV EXPERIMENT

The last step of initial stage of IMP WT modernisation process was equipping the adapted test section with a PIV measurement system. A decision was made to carry on an experiment analysing the flow around a simple obstacle - NACA0012 profile. Aim of the experiment was to validate CFD simulations with PIV WT measurements results by comparison of velocity fields obtained by means of both techniques and to observe any effect that IMP WT walls and overall arrangement could have on the final results.

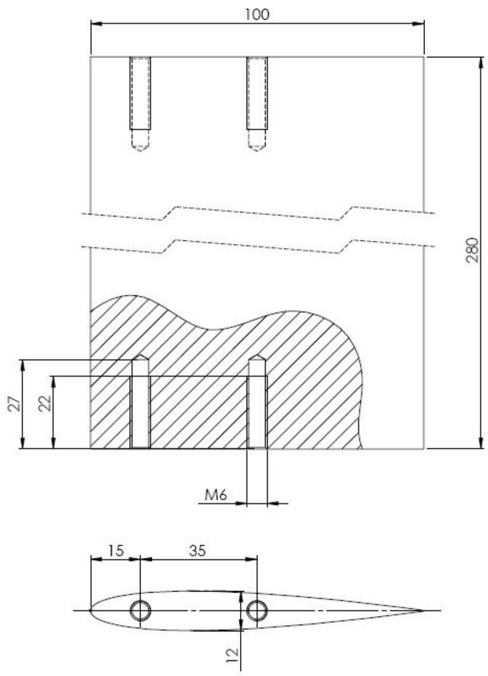
Wing profile for test was manufactured by means of electrical discharge machining (EDM). Proper shape was cut out in aluminium with an electrically energised thin wire. Due to limitation on maximum length of models manufactured by particular device that was used, aerofoil consists of two shorter elements. Fig. 9 shows engineering drawing of a designed part and manufactured model. Two threaded holes were created on side walls of the aerofoil enabling easy mounting to the wall. Span of the profile was adjusted to the width of test section.

Experimental setup

Experimental setup consisted of the following components:

- double-pulse Nd:YAG laser from Litron (1200mJ max output, 4ns pulse duration, 1064/532nm wavelength),
- arm with optical system redirecting laser beam to desired position,
- laser sheet optics (cylindrical lens f=-10),
- two high speed cameras Imager pro x 4M from LaVision (2048x2048 pixels),
- Nikkor camera lenses (24-85mm, f2.8),
- Programmable Timing Unit V9,
- liquid seeding generator,
- mirror (reflectance R=100%) for illuminating bottom part of the aerofoil,

- Davis 7.2 software for image processing.



a)

b)

Fig. 9 NACA0012 aerofoil, a) design, b) manufactured model

The scheme with test section experimental setup is shown in Fig. 10 & Fig. 11. NACA0012 profile was inclined at angle of 10° (the same as in CFD analyses). A 2D measurement method was chosen, i.e. each camera pointing at different flow region (with slight overlapping enabling merging results). Cameras were placed in a vertical arrangement observing top and bottom surface of the aerofoil. Laser sheet optics was illuminating observed area from the top creating a plane parallel to the flow. Mirror located at the bottom of test section was used to reflect laser sheet in order to illuminate bottom of the aerofoil.

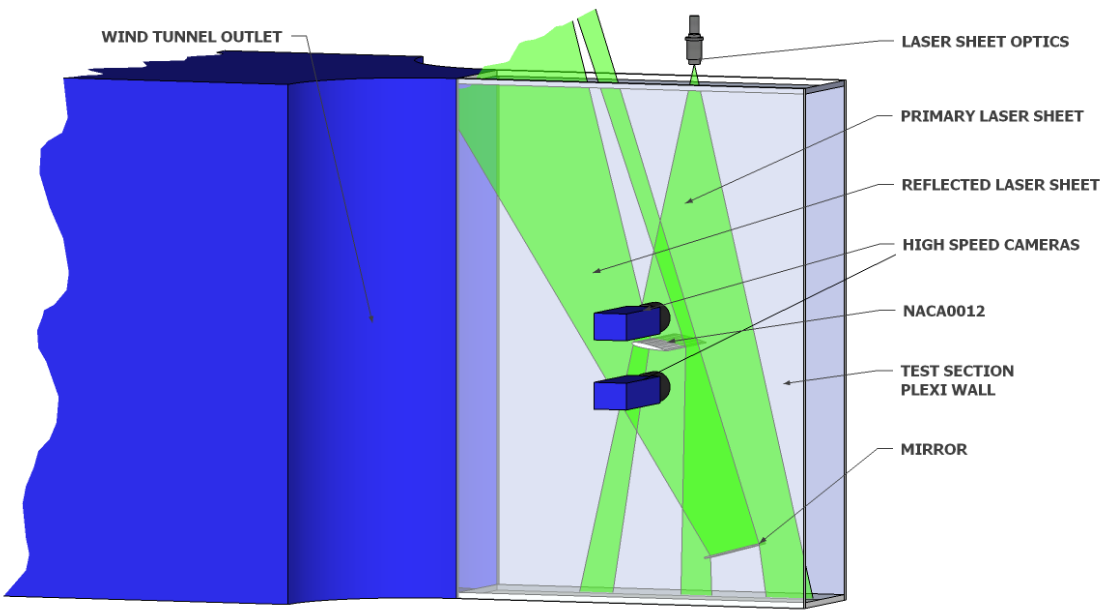


Fig. 10 Scheme of the PIV experimental setup

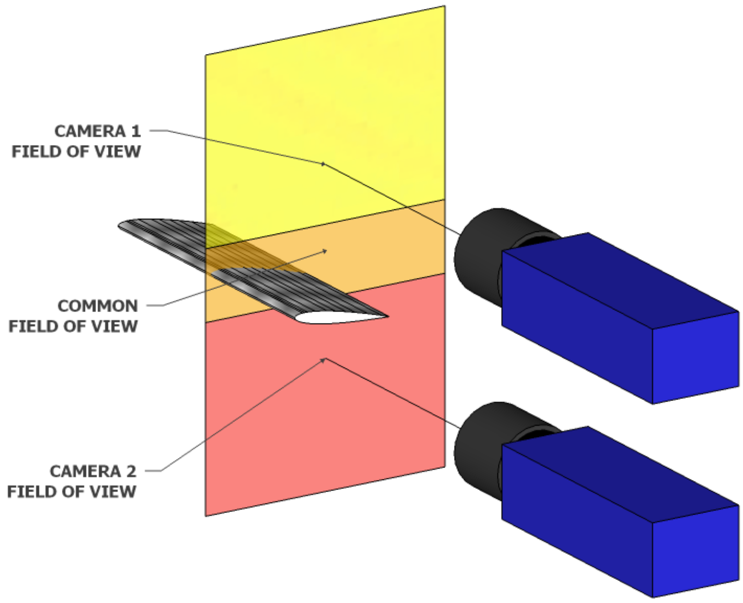


Fig. 11 Field of view of high speed cameras

Measurements and vector processing

Flow images were captured by two 4Mpix high speed cameras (2048x2048pix) in a double frame mode (giving 4 images per one measurement). Maximum available frame rate of 7.26Hz was used for image acquisition. Time delay between two laser shots was set to dt=75μs providing average seed displacement of 7 pixels basing on free stream velocity (11m/s). Measurement plane covered an area of approx. 251x251mm and 237x237mm for top and bottom camera respectively. For vector field calculation cross correlation mode was applied with multi pass iteration procedure:

- 2 initial passes with interrogation window size of 64x64pix and 50% overlapping (second-order correlation function used),
- 3 final passes with interrogation window size of 32x32pix and 75% overlapping (high-accuracy mode for final vector result - Whittaker reconstruction).

After merging vector fields results obtained from two cameras total resultant plane covered area of approx. 251x297mm with 264x314 vectors (ca. 83000 vectors) giving resolution of 0.95mm per vector.

Quality of the measurement

Preparation of the PIV experiment for IMP WT was a time consuming process. Few problems, strongly affecting solution quality, have been encountered. Testing various hardware and software settings during a series of preliminary tests allowed to minimise negative factors disturbing the measurement. Majors steps made to ensure the best measurement conditions are described below.

An attempt of eliminating possible sources of reflections causing reading errors was done. PIV images were taken with a black background installed inside the test section. Additionally various settings of laser power was tried to guarantee best illumination condition. Light intensity needs to be high enough to illuminate all seeded particles. On the other hand, increasing this parameter results in reflections from the aerofoil surface creating bright indeterminable regions disabling correct image postprocessing. This phenomenon was significantly reduced by blackening the aerofoil by fire in order to obtain black matte model surface. Even though a certain amount of light was reflected disabling measurement of velocity in the boundary later what is a known deficiency of PIV experiments.

Two locations of seeding generator were investigated. One in IMP WT inlet channel and the other in the settling chamber. First location provided uniform distribution of particles in the flow. Their concentration, however, was very low. In order to improve it, particles were seeded near the test section. This solution caused non-uniform distribution of highly concentrated particles which was not good as well. What is more, such location of seeding nozzle disturbs the flow entering test section. Finally, usage of different oil medium and tuning of the seed generator guaranteed proper concentration distribution of tracer particles entered through inlet channel. Currently, better location for seeding particles has been introduced. IMP WT diffuser was adapted in a way allowing uniform distribution of particles across the channel (i.e. injection of tracer particles via small holes distributed along circumference of the diffuser just after the fan).

During initial tests, problems with illuminating the bottom of the aerofoil appeared. Too much of light intensity was being lost and area under the aerofoil became indeterminable in terms of PIV measurement. Satisfactory results has been obtained after redirecting the centre axis of the laser sheet onto the mirror. Laser beam passing through the cylindrical lens is not being distributed uniformly. Most of its energy is carried through the middle part of the sheet with maximum intensity at the centre axis. Redirecting most energetic part to the mirror and reflecting it onto the bottom surface solved the problem of under-exposition. Additionally reflections from the top surface of the aerofoil were decreased.

Results

An example of preliminary instantaneous velocity fields can be seen in Fig. 12.

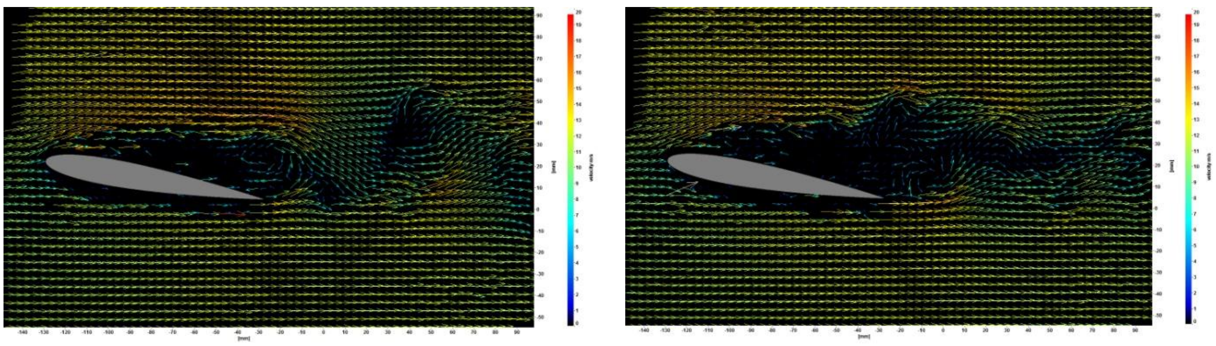


Fig. 12 Exemplary instantaneous velocity fields

For comparison purposes average velocity field was calculated basing on instantaneous PIV velocity fields. 100 independent snapshots has been used for statistical analysis. All PIV results presented below are based on the calculated mean field. A mask has been applied for regions where needed (i.e. region covered by the aerofoil or areas indeterminable in terms of PIV experiment due to poor illumination or lenses vignetting). Separate vector images obtained from two cameras were merged in order to obtain full image of the flow around the aerofoil (see Fig. 13).

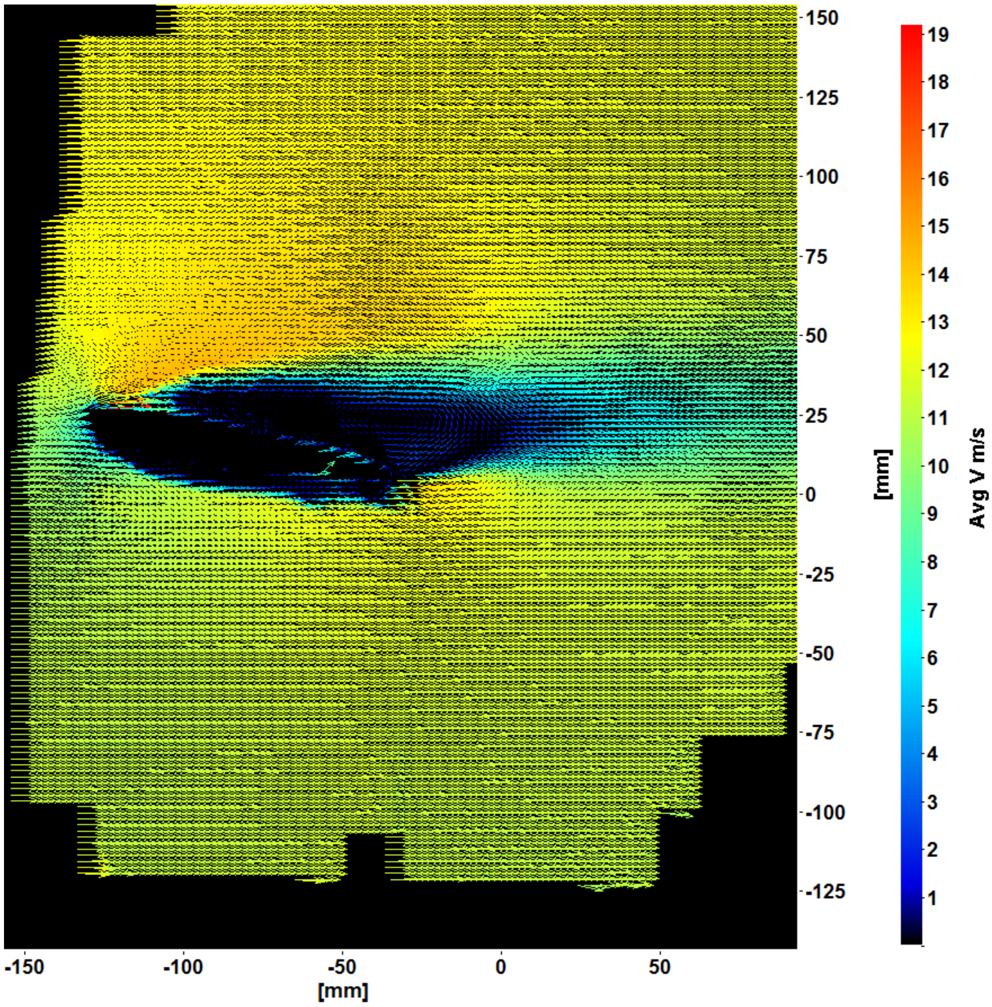


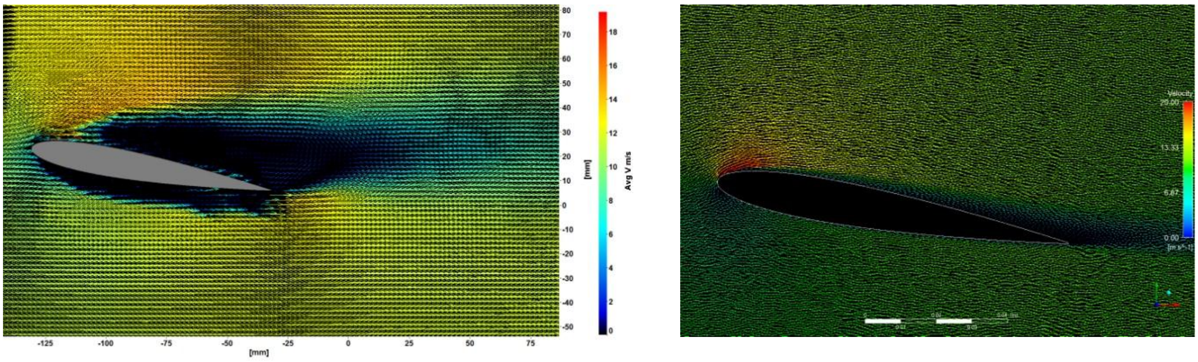
Fig. 13 Full velocity vector field result obtained by PIV measurement

CFD & PIV comparison

In Fig. 14 – Fig. 16 comparison of PIV and CFD results for setup with aerofoil inclined at angle α=10° is presented. As it can be seen the most significant difference is the large area of separation that can be observed in the PIV images. According to the literature data (Jacobs et al., 1932; Scheldal et.al., 1981), phenomenon of static stall, for given flow condition ($Re \approx 10^5$), occur for flow around the aerofoil with angle of attack within the range of 8-10°. Taking the above into account results of the presented PIV measurements confirm this. On the other hand, structures observed in IMP wind tunnel experiment can be exaggerated. If more uniform flow condition was provided it could result in different flow behaviour.

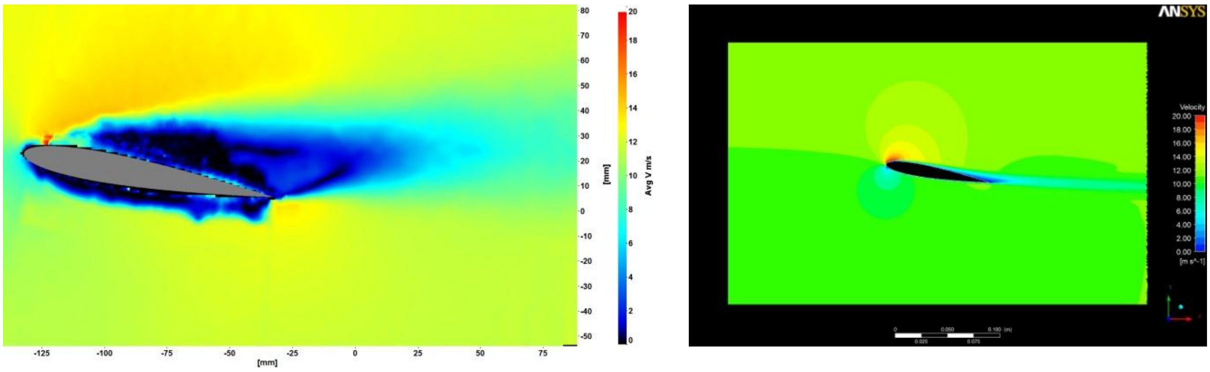
Comparison of results from both techniques should be done carefully at this stage. One should have in mind the following limitations of both studies:

- CFD simulation was performed for quasi 2D geometry with boundary conditions set in a way to mimic the flow around an infinitely long wing profile. This means that no influence from crossflow direction (Z axis) occurs for numerical analyses.
- PIV experiment was performed in a narrow test section where interaction between walls and tested obstacle in directions perpendicular to the streamwise flow can be significant.
- Flow conditions provided by IMP WT are still not uniform and are not fully controlled.



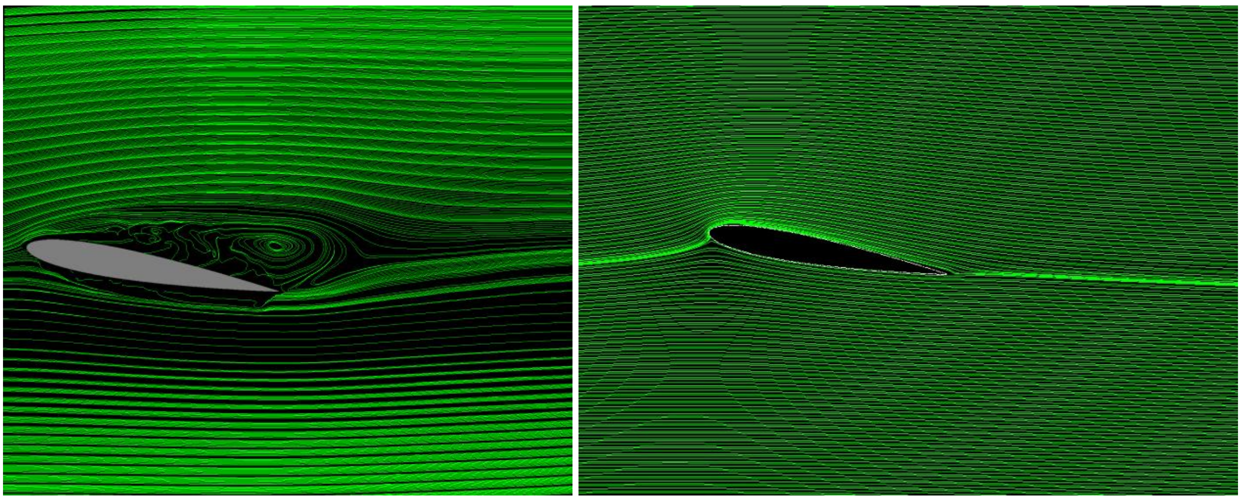
a) b)

Fig. 14 Velocity vectors fields from a) PIV (averaged velocity field) and b) CFD



a) b)

Fig. 15 Velocity contour plots from a) PIV and b) CFD



a) b)

Fig. 16 Streamlines from a) PIV and b) CFD

SUPPLEMENATRY ANALYSES

Due to observed discrepancy of results it was decided to run a series of additional CFD simulations. The aim was to find aerodynamic characteristic of the airfoil for a wide range of angle of attack α in order to find an exact value at which static stall occurs (for CFD analyses with given condition). Angle values within the range of 1-17° were analysed. Results of performed study are shown in Fig. 17. Static stall can be observed after angle of attack α=12°. Obtained characteristic is moved towards higher angles with respect to literature experimental data (Jacobs et al., 1932; Scheldal et.al., 1981). That partially explains difference observed for CFD and PIV experiment results for aerofoil inclined at angle α=10°. The numerical model assumed is not able to correctly reflect the stall for the compared angle α.

Explanation of presented characteristic displacement is the object of current study being performed at IMP. Possible reason could be limitation of applied turbulence model (especially at given low Reynolds Number) and the transition model. In order to understand that issue fully it is planned to continue CFD study analysing various turbulence models as well as expand it for wider range of Re.

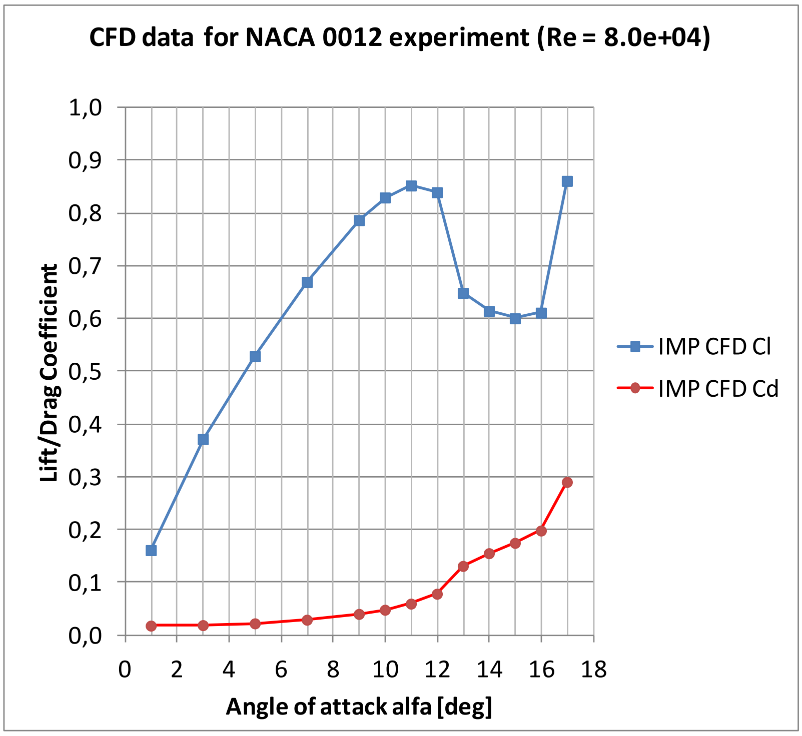


Fig. 17 Aerodynamic characteristic of NACA0012 aerofoil obtained in CFD simulations at IMP

It is suggested to perform similar series of analysis for PIV experiment in the wind tunnel. Obtaining a full aerodynamic characteristic via this technique would be a valuable source for comparison purposes.

Conclusions

Results presented in this paper are the effect of over one year of work related to the wind tunnel facility. Subject area of performed actions is very wide combining research, restoration works, basic design, theoretical analysis, measurements, numerical simulations, and the actual experiment. These are the main outcomes of the work performed at the Institute of Turbomachinery in the frame of wind tunnel modernisation:

- Installation of current inverter provided an easy way of engine rotational speed control increasing wind tunnel flexibility. This enables future possibility for building an automated facility managed with one system responsible for control of all crucial parameters.
- Performance tests provide huge amount of data about IMP WT operating characteristic and potential. Preliminary measurements of max. achievable velocity, velocity

distribution, turbulence level and temperature variations provided information about the current state of the facility. Weak points of the construction were shown.

- Basic design of a honeycomb structure was accomplished. This simple flow manipulator improved significantly flow characteristic of IMP WT. Ensuring stable and uniform flow is a crucial factor needed to perform high quality and reliable measurements.
- PIV system installed into IMP WT significantly improved measurement capability of this device. Adapted test section and high-tech measurement system allows to perform very sophisticated experiments. Preliminary tests provided methodology for future experiments.
- The NACA 0012 experiment and CFD simulation performed showed significant differences. At the given Re number (around 10^5) and angle of attack $\alpha=10°$.
- The difference is most likely attributed to the numerical turbulence model limitations. Additionally WT wall interference from upstream that has not been identified yet can be the reason for excessive flow perturbation. Boundary layer influence should be investigated. Upcoming tests are scheduled to identify the source of instabilities in the test section.
- Nevertheless, the work shows importance of carrying CFD and EFD tests in parallel even during WT design stage. Such approach allows to gain an early access to important data about WT performance at fraction of costs.

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