3D-MEASUREMENTS IN AN ADVERSE-PRESSURE-GRADIENT TURBULENT BOUNDARY LAYER OVER SMOOTH AND RIBBED SURFACES

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Summary 3D-PIV and 2D-LDA measurements in a fully turbulent boundary with adverse pressure gradient have been performed. Two types of surfaces were investigated: a smooth surface and a surface with riblets aligned in main flow direction. Particle image velocimetry was used to determine the influence of the surface structure on large-scale structures in the near wall region whereas profiles of mean and fluctuating velocity inside the boundary layer were acquired by laser Doppler anemometry. Significant changes of size and location of near-wall vortex structures were found ongoing with a deformation of the mean-velocity profile due to the riblet surface.

INTRODUCTION

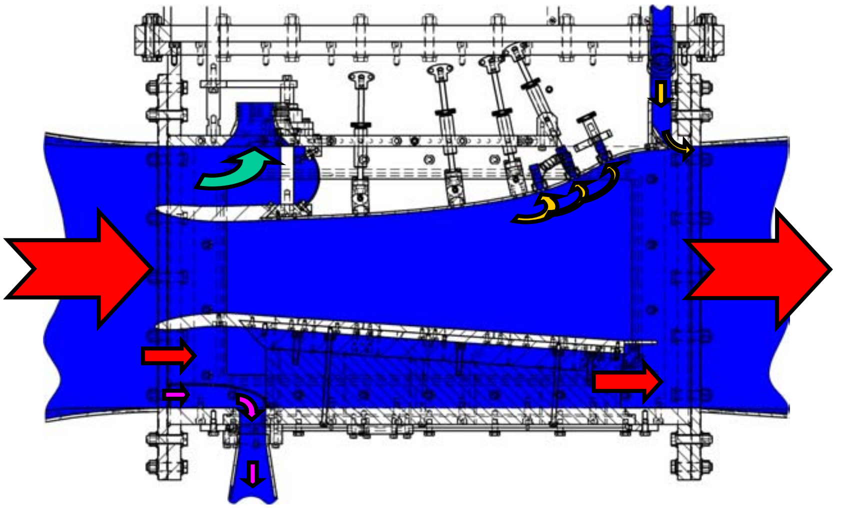
E. g. for optimal efficiency of turbo machines a strong deceleration of boundary layer flow is required which promotes, however, the tendency of the boundary layer to separate. Turbulent boundary layers are known to be less likely to separate than laminar ones. The main disadvantage of turbulent boundary layers are higher friction losses. Passive devices to reduce these losses resulting are so-called riblets, microscopic grooves aligned with mean-flow direction. Numerous investigations showed their properties and have helped to design optimal shapes and dimensions [1]. A yet unsolved issue is their influence on an adverse-pressure-gradient turbulent boundary layer.

The presented research has two objectives. First, beneficial the determination of vortex structure, mean and fluctuating velocity distributions inside a turbulent boundary layer over differently rough surfaces subjected to a pressure gradient, in order to examine the influence of riblets on the attached and separated flow. Second, the verification of a new method of particle image velocimetry (PIV) which is well-suited for measuring three-dimensional flows [2].

DISCRIPTION OF TEST FACILITY AND MEASUREMENT TECHNIQUES

The experiments have been carried out in a closed circuit water channel with a special designed test section, described in detail below. The medium water has been selected since the comparably large riblet dimensions facilitate manufacturing. Also, the developed boundary layer has a sufficient thickness for high resolution PIV and LDA measurements.

Test section of closed circuit water channel

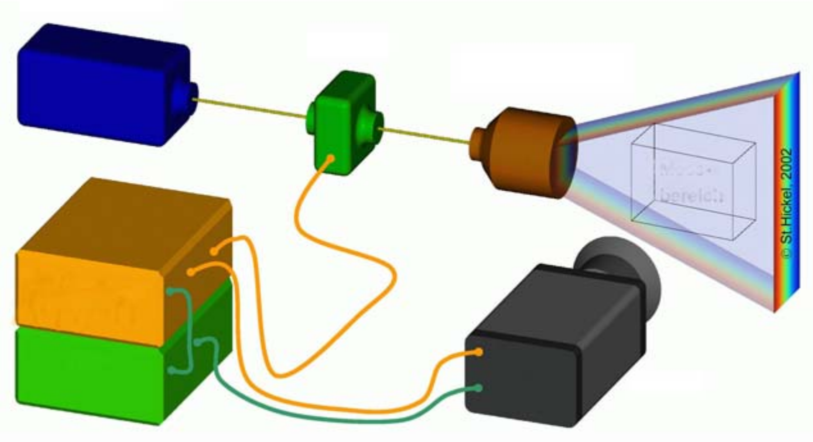


The test section made of stainless steel has a cross section of 0,4 x 0,4 m² and an overall length of 0,8 m. Installed is a flat plate of 0,725 m length with elliptical leading edge which allows to be lined with exchangeable surfaces. The reference surface is mirrored polished glass which improves measurements in the near wall region. The riblet surface has been manufactured by wire-cut EDM of a master and cloning by a silicon-vacuum-casting process. Based on previous investigations trapezoidal grooves were selected with a height to spacing ratio h/s = 0,5 and a tip angle of 30°. On the trailing edge of the plate an additional flap was installed in order to prevent back flow. To obtain a constant adverse pressure gradient in mean-flow direction a flexible and adjustable ceiling made from special plastics is installed. This contour is also translucent for optical access from top. For an controlled boundary layer development within the measurement section three additional suction taps are installed. Suction-tap one is located near the leading edge to avoid blockage and to control the stagnation point flow. A second tap is used for removing the entire flow above the upper wall. This is necessary because channel is of closed-circuit type without open surface. A third tap is located at the upper contoured wall in order to avoid separation due to curvature effects. Optical access is possible through a Plexiglas window on each side of the test section.

Conventional measurement techniques
Mean-velocity profiles were measured by a commercial LDA system by DANTEC Dynamics. Because of coincidence problems in the standard 2D-configuration a simple 1D-setup has to been used. Therefore three independent measurements at each location in streamwise direction were necessary in order to obtain profiles of all mean and fluctuating velocities.

To measure the pressure gradient 12 static pressure holes are installed on the flat plate. Wall shear stress was measured by means of a Preston tube. A reference point was defined right at the beginning of flow deceleration. At this location the velocity can be evaluated by a Prandtl tube, the free-stream turbulence level by a 1D-CTA probe.

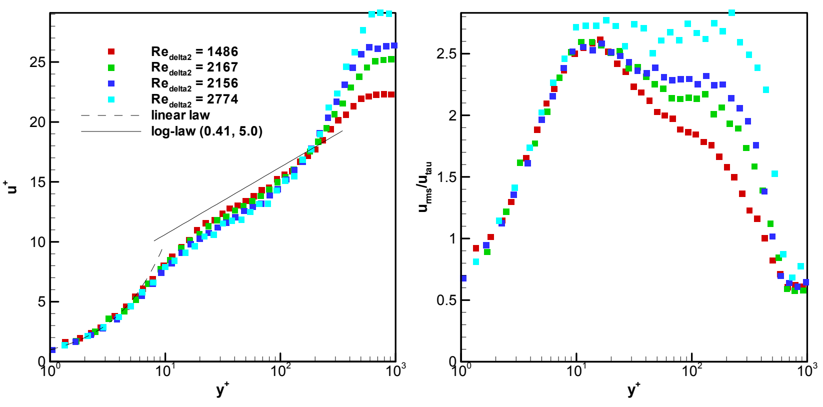
Fully 3D-PIV System



A newly developed 3D-PIV technology combines classical PIV with a color-coded light-sheet and with a new principle of three-dimensional cross-correlation of probability-density fields. To achieve a high-resolution measurement of three coordinates of position and displacement, a multi-color light sheet with a typical thickness of 1 up to 10 centimeters is used. The local wavelength is a (quasi-) continuous and invertible function of the coordinate in perpendicular direction across the light sheet. The particles which move with the flow scatter light elastically. So the frequency noted by the PIV colour camera permits the allocation of the particle to a certain plane in the light sheet. On the basis of the functional characteristics of the light sheet, the most probable position of each particle, visible on the color photographs, can be determined from the frequency of the scattered light. The probability density in the surrounding three-dimensional area of this point can not be calculated exactly, so we assume a log-normal distribution depending on luminance and the size of the particle's image. The superposition of the probability densities of all available particles results in a three-dimensional scalar field, which forms the data base for the cross-correlation instead of the usual two-dimensional black-and-white pictures. These fields are decomposed into cubical parts called "interrogation cubes". The 3D cross-correlation of corresponding partitions performed in frequency domain is the core of the interrogation process and yields three components of displacement directly. Because the data base was cut into several layers of interrogation cubes not only in x and y direction but also in z direction, we obtain a true 3D measured field.

RESULTS

Mean-velocity profiles and profiles of root-mean-square fluctuating velocities for different Reynolds numbers obtained by LDA measurements (smooth surface) are shown in the figures on the right. The pressure gradient parameter β is 0.93 (red), 2.18 (green), 3.30 (blue) and 6.49 (turquoise), respectively. Whereas the linear part of the mean velocity profile is well recovered, the values of the von-Kármán constant κ and the integration constant C deviate from their zero-pressure-gradient values.



Results of the boundary layer quantities over the riblet surface and 3D-PIV measurements of coherent structures for both surface cases will be presented during the oral session of the meeting.

References

[1] Walsh, M. J.: Riblets, in: Viscous Drag Reduction in Boundary Layers, Bushnell, D. M., Hefner, J. N. (Editors), Progress in astronautics and aeronautics (Vol. 123), 1990

[2] Hickel, S.: Entwicklung einer neuen echt dreidimensionalen Particle Image Velocimetry, Thesis (in German), Brandenburg University of Technology, Cottbus, 2003.