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NUMERICAL MODELING OF THE FLOW PAST AN AIRFOIL CHARACTERIZED BY A LAMINAR SEPARATION BUBBLE

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ABSTRACT

This paper discusses the RANS and URANS modeling possibility of a complex three-dimensional flow field forming around an airfoil which is characterized by the presence of a short laminar separation bubble on its suction side and a turbulent separation in the vicinity of the trailing edge. The wing section is placed in a confined computational domain that models the closed test section of a wind tunnel, or also can be interpreted as a duct. The flow is modeled by using the k-ω SST turbulence model with the γ-Re_0 laminar/turbulent transition model that is supposed to be applicable for predicting laminar separation-induced transition which is of major importance in the present case.

1. INTRODUCTION

The investigation of the flow past airfoils is one of the basic topics of the research in fluid dynamics. The main operational area of airfoils is the aircraft industry where wings and other lifting surfaces are usually designed based on two-dimensional flow approaches [1], [2]. Also two-dimensional flow concept is applied for the development of blades used for turbomachinery applications, although most recently, the flow is modeled in 3D space. The flow field, however is becoming three-dimensional in all real circumstances. The origin of three-dimensionality is due to the finite extension of the blades, wing sections or the space in which they are operating. This influences both the operational characteristics and the determination of their theoretical "two-dimensional" aerodynamic characteristics. In case of low angle-of-attack situations, the two-dimensional approach acts as a very good approximation but for higher performances when high lift is needed, the angle-of-attack is increasing and the two-dimensional has to be handled with skepticism. The airfoil of the present investigation is an RAF 6 type low Reynolds number airfoil which was designed mainly for airscrews of old military aircraft and later it was used frequently as the airfoil of fan blades. The airfoil has a flat pressure side and a specially designed suction side that operates with the presence of a short laminar separation bubble which is generated via quick transition in curvature just downstream the leading edge. This laminar separation bubble increases lift and induces boundary layer transition from laminar to turbulence for maintaining attached flow until the trailing edge. The flow field was visualized experimentally and discussed in [6].

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Towards the Application of a Schlieren Measurement Technique in a Wind-Tunnel

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1. INTRODUCTION

A method for real-time monitoring of the velocity distribution in a wind tunnel of large dimensions has already been investigated in [1]. Schlieren measurement technique has also been investigated by many researchers [2-4]. For example, such a Schlieren system can be used for visualization of shockwave in a supersonic tunnel [4-6]. The system is basically adapted for 2D measurements; there are many problems with 3D measurements [3]. The method has also been used for general visualization of heat transport processes [3]. In this work the adaptability of a Schlieren system is investigated, which should be ultimately applicable in a wind-tunnel in order to investigate forced convection flows. An electrically heated circular cylinder was placed perpendicular to the flow in a wind tunnel. The first objective of this work is to determine the relationship between vortices shed by a cylinder and the structure of the instantaneous temperature field, so that a relatively accurate guess can be obtained for the temperature distribution of a heated cylinder as a function of velocity. This research project has been realized within the scope of the DAAD-MOB program. Measurements have been carried out in the Laboratory of Fluid Dynamics, University of Magdeburg in Germany.

2. BASIC SCHLIEREN SYSTEM

The basic optical Schlieren system uses light from a single collimated source shining on, or from behind, a target object. Variations in refractive index caused by density gradients in the fluid distort the collimated light beam. The collimated light is focused on a lens, and a knife-edge is placed at the focal point, positioned to block about half the light. In flow of uniform density this will simply make the photograph half as bright.

Figure 1. Principles of a simple two-lens Schlieren system
However in flow with density variations the distorted beam focuses imperfectly and parts which have focussed in an area covered by the knife-edge are blocked. The result is a set of lighter and darker patches corresponding to positive and negative fluid density gradients in the direction normal to the knife-edge. When a knife-edge is used, the system is generally referred to as a Schlieren system, which measures the first derivative of density in the direction of the knife-edge. Temperature is determined from density (refractive index) [3]. The experiments started with a simple two-lens Schlieren system. Principle of that is shown in Figure 1. The final set-up can be seen in Figure 2.

This simple Schlieren system (Figure 2) has been built up during a diploma thesis [2] in Magdeburg. The system was tested with a single candle flame as described in the thesis. After these successful experiments, the system has been improved to a z-type Schlieren system (Figure 3), in order to be able to carry out measurements in the optically transparent test-section of a wind tunnel.

3. THE Z-TYPE SCHLIEREN SYSTEM

The principle of z-type Schlieren system is similar to that of the simple Schlieren system. The difference between these two systems is that instead of lenses, mirrors are used for the z-type system. Principles of the simple z-type Schlieren system are shown in Figure 3. The symbolical name of the z-type Schlieren system comes from its z-like setup.

4. APPLICATION OF THE SCHLIEREN SYSTEM IN THE WIND TUNNEL

General recommendation for the applications of a z-type Schlieren system according to Settles [3]:

- According to an old rule, the mirror thickness ought to be 12-17% of the mirror diameter for stability.
- To achieve good quality, the ratio of the mirror surface smoothness should be between $\lambda/8-\lambda/10$, where $\lambda$ is the wavelength of the light and the ratio gives the deflection of the wave front, caused by the surface roughness of the mirror.
- A minimum distance between the field mirrors of about $2f$, is required to provide enough space for the test area, where $f$ is the mirror focal length.
- The recommended process to minimize both astigmatism and coma is to limit the offset angles $\theta$ to their minimum practical values. Furthermore, mirrors with $f/n$ with $n$ equal to 6 or greater are strongly recommended. The mirror power in z-type Schlieren systems is usually between $f/6$ and $f/12$, where $f/n$ expresses the ratio of the focal length and mirror or lens diameter.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror thickness</td>
<td>25% of the diameter</td>
</tr>
<tr>
<td>Optical quality of the mirror</td>
<td>$\lambda/8$</td>
</tr>
<tr>
<td>Offset angle</td>
<td>$\theta=7.5^\circ$</td>
</tr>
<tr>
<td>Power of lens</td>
<td>$f/10$</td>
</tr>
<tr>
<td>Distance between the mirrors</td>
<td>$d=3048\ mm$</td>
</tr>
</tbody>
</table>
The Schlieren system is applied here to qualitatively describe the temperature distribution in a flow around a heated cylinder. The measurement system has been adapted according to the available place around the test section of the wind tunnel. The properties of the applied components are detailed in Table 1.

Principle and dimensions of the system are shown in Figure 5. Flow direction is orthogonal to the drawing plain. The measurement setup can be seen in Figure 6.

The built-up Schlieren system has been adjusted with the help of a single candle flame. The candle was placed into the middle of the wind tunnel test section (Figure 7, on the left). The first result of the roughly aligned system can be seen in Figure 7, on the right.

During further experiments the adjusted Schlieren system shall be used to get qualitative information about the temperature distribution behind a heated cylinder. For first tests the cylinder was placed into the measurement section as it can be seen in Figure 8. To eliminate the influence caused by the different refractive index of the wind tunnel windows, the measurement has been carried out without them.

The temperature distribution has been investigated in the wake of a heated cylinder. Temperature of the cylinder has been set to 100, 200 and 300°C respectively. The air flow velocity in the wind tunnel has been set to the minimal value of 0.3 m/s.

5. FIRST RESULTS

The built-up Schlieren system has been adjusted with the help of a single candle flame. The candle was placed into the middle of the wind tunnel test section (Figure 7, on the left). The first result of the roughly aligned system can be seen in Figure 7, on the right.
First results for different temperatures are shown by the Schlieren images in Figure 9. The principle usability of our z-type Schlieren system was confirmed by these results, as with increasing temperature gradients, the contrast of the images increases as well. Now it will be necessary to fine tune the Schlieren system, in order to get more contrasted and fine structured images, by adjusting the light intensity and area, the Schlieren-edge and the recording system. Also coloured Schlieren is planned in this set-up.

First results of Schlieren measurements at 0.3 m/s. Cylinder temperature was 100, 200, 300°C respectively (from left to right).

Comparative measurements have been carried out with the help of a PIV (Particle Image Velocimetry) system. Here the amount of oil fog has been significantly increased, thus making possible the visualization of the flow pattern behind the cylinder (see Figure 10). Similarity between these visualizing measurements with PIV and the pattern in the temperature field recorded with the Schlieren system can be established.

Results of the visualization by means of a PIV-system at 0.3 m/s. Cylinder temperature has been set to 100, 200, 300°C respectively (from left to right).

6. CONCLUSIONS

The measurement results presented in this work confirm that the z-type Schlieren system is in principle suitable to visualize and qualitatively analyze the temperature field in a wind tunnel. However, considerable improvements (such as stable frame for the complete system, digital camera, or knife edge with fine adjustment screws) are still required in the existing system to make more precise and really accurate measurements. In order to analyze the images in a further step, the recording quality must be increased to get more meaningful images. Therefore, the results presented here should only be considered as a first step of this project.

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