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Optical Tools for Aerodynamics

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***Abstract*:** Visualization of flows has a special meaning in aerodynamics. Unsteady three dimensional flow fields need a visual display of experimental as well as theoretical results. Especially in experiments optical visualization techniques often lead to completely new insights into flow phenomena. Some discoveries which have been made this way are described in this review. Topics considered in detail are vortex obstacle interaction, Particle Image Velocimetry, long range Laser Doppler Velocimetry and Pressure Sensitive Paint.

***Keywords*:** optical tools, aerodynamics, fluid mechanics, Pressure Sensitive Paint (PSP), Particle Image Velocimetry (PIV), Laser Doppler Velocimetry (LDV).

1. Introduction

The following examples of optical flow measurement illustrate the increased inside in special problems of the aerodynamics of aircraft. Especially the areas of flow noise and flow separation need detailed experimental investigation to understand the physical background of the phenomena and to find suitable modeling.

2. Vortex Obstacle Interaction

A field of peculiar flow effects where the high speed optical methods and the flow visualization as well as computational methods let to a great increase in knowledge and understanding is the field of vortex obstacle interaction (Meier et al., 1990; Obermeier and Schürmann, 1993). These interactions are of special importance for the problem of rotor noise especially in case of helicopters and many other unsteady encounters of vortex filaments with boundaries. The chosen method of generating plane vortices for experiments is an experimental arrangement of a rectangular cylinder in an especially designed duct in which vortices are separated in distance in an accelerating nozzle (see Fig. 1).

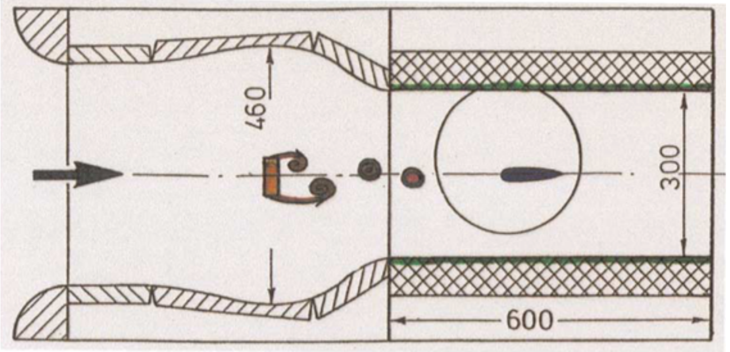

Fig. 1. Experimental arrangement for generating vortexes for the interaction with an airfoil.

The vortices interact downstream for the experiment with an airfoil section under variation of relative position and strength. Interferograms show the interaction of the vortices shed from the rectangular cylinder with an OLS airfoil section. Two phenomena have been detected by the optical visualization and observation of these flow fields. The first is the so-called compression wave. The vortex passing underneath the airfoil section generates an unsteady compression wave propagating upstream from the stagnation area of the airfoil. This compression wave is an unsteady analogon to the bow-shock which may be present in case of a permanently supersonic flow around the airfoil nose. Another phenomenon is the generation of the so-called transonic waves which are due to the decomposition of supersonic pockets on the airfoil which are existing only in the time of interaction of the vortex and the airfoil flow (see Fig. 2).

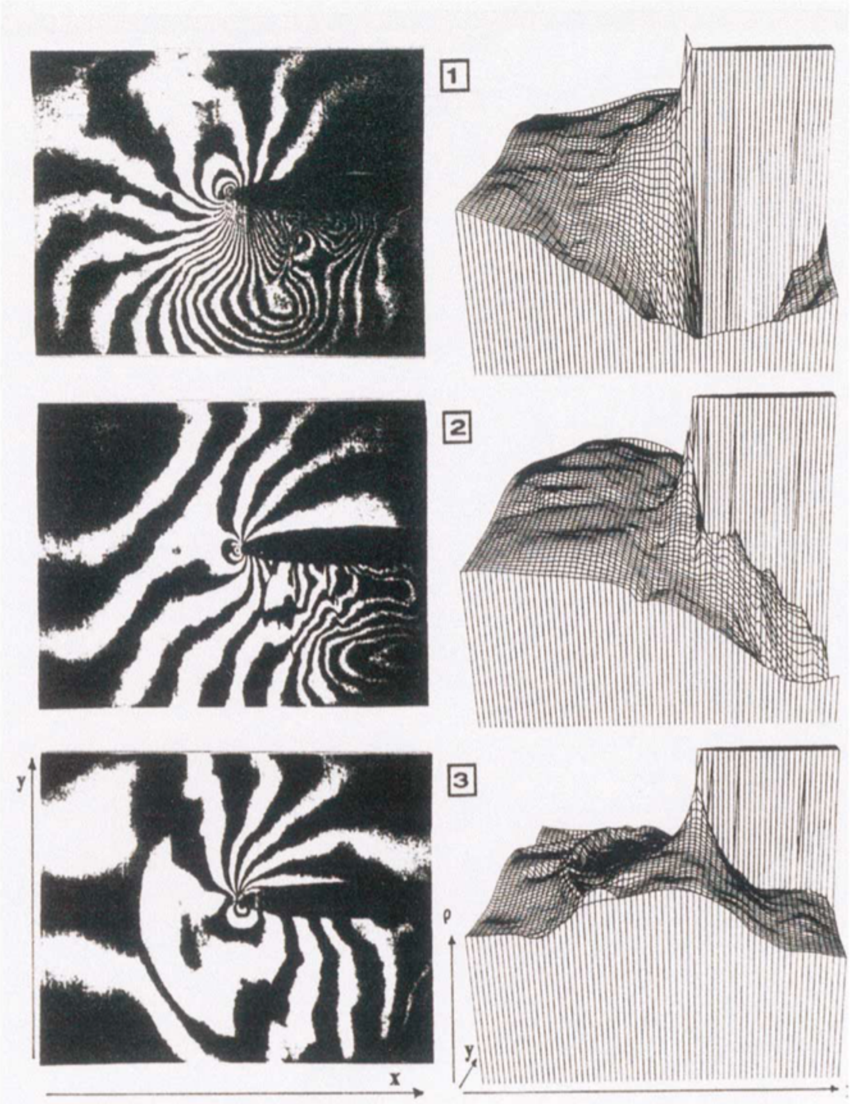

Fig. 2. Example for generation of a compression wave (left side) and a transonic wave (right side). The frames are recorded with the mach Zehnder Inferometer and a high speed camera.

3. Flow Structures Measured by Particle Image Velocimetry (PIV)

The Particle Image Velocimetry (Raffel and Kompenhans, 1994; Raffel et al., 1995; Raffel et al., 1998) which was formerly only developed as a tool for instantaneous flow speed measurement developed later also to a method of flow visualization in some applications. In the set-up for PIV the particles are illuminated twice with the help of a laser light sheet so that by the registration of the two particle images the flow velocity and the flow direction can be determined from the recordings on photographic material or with CCD-cameras (see Fig. 3).

The instantaneous velocity map of the vortices in the wake of a rotating helicopter rotorblade shows not only the velocity vectors of the instantaneous structure of the flow field but the colors of the arrows show also the magnitude of the velocity so that a really clear impression of the complicated wake is achieved (see Fig. 4). So with this type of measurement not only a visual impression of the inflow conditions for the following rotating blade is given but also an exact set of data for validation of numerical calculations with respect to vortex structure and especially the core size of the vortices is achieved.

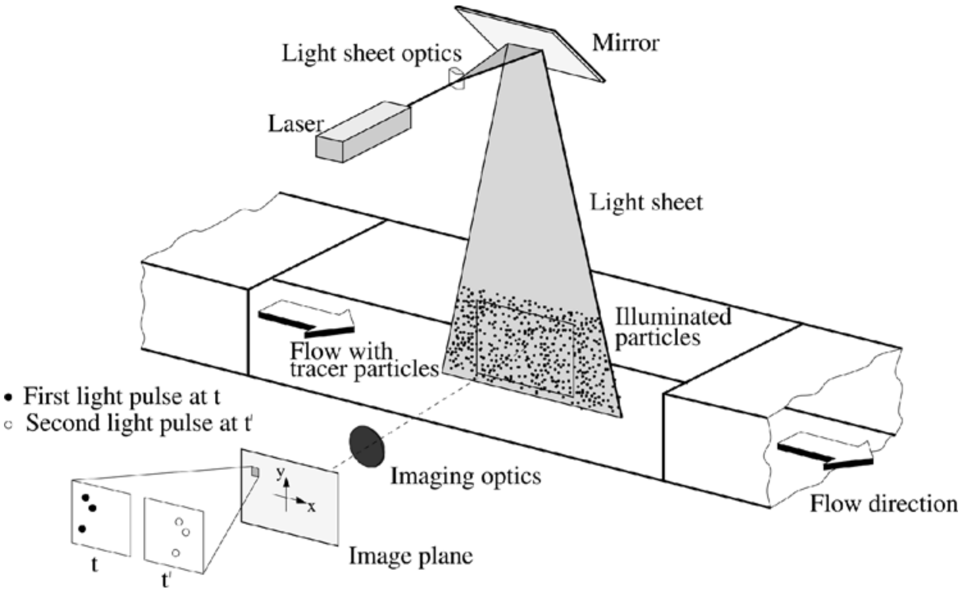

Fig. 3. Set-up for a PIV system for velocity measurement in a duct flow.

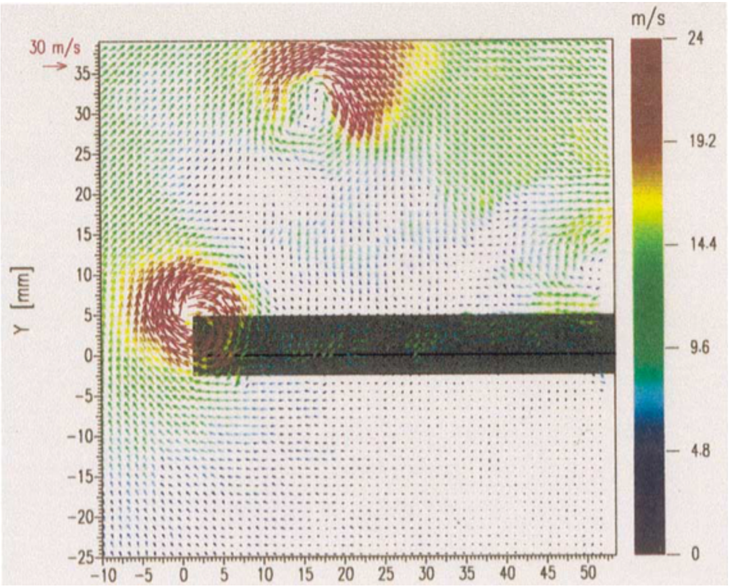

Fig. 4. Instantaneous flow field in the wake of a helicopter rotor blade.

In case of a transonic flow field around airfoils one can get by PIV an impression about the shape of the supersonic flow regime in a real test and also the local turbulence in the flow field. The time resolution of this measurement technique is extremely high and sequences of recordings can also provide the time history of unsteady flows (see Fig. 5a). Another use of the Particle Image Velocimetry can be made in boundary layers where not only the velocity fields can be measured. Also as an surprise also the flow structure can be made visible by a certain unexpected demixing effect of the tracer particles by the shear of the boundary layer flow (see Fig. 5b).

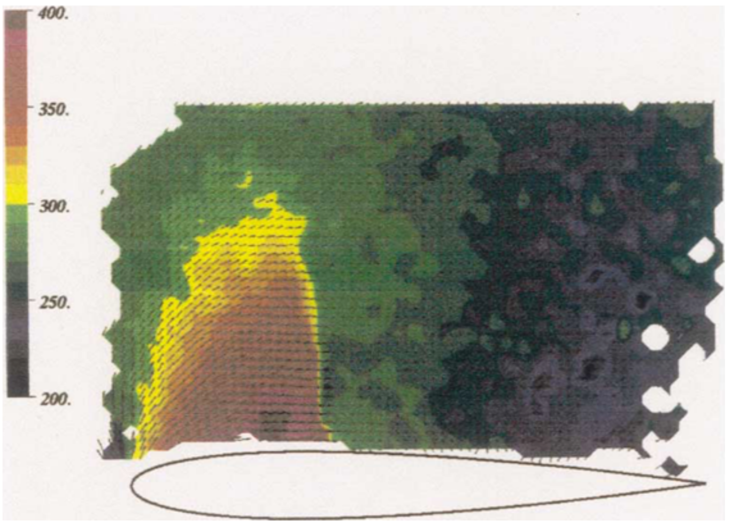

Fig. 5(a). Transonic flow field of an airfoil visualized and measured by PIV.

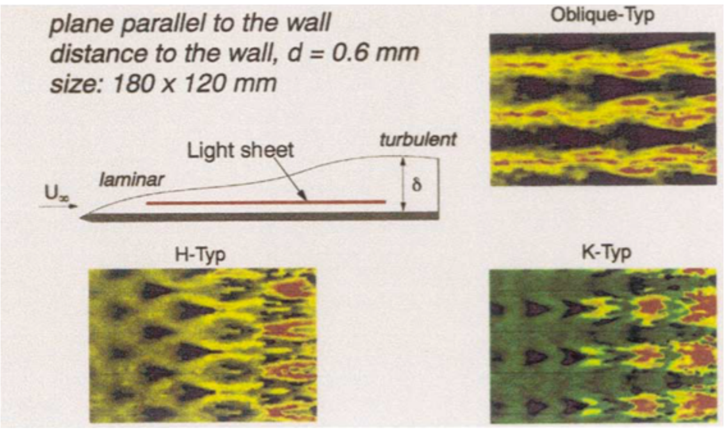

Fig. 5(b). Instability pattern of a boundary layer recorded by Particle Image Velocimetry.

4. Long Range LDV as a Tool for Flow Diagnostics

Especially in large wind tunnels a non intrusive flow measurement is always a difficult problem especially for three-dimensional configurations. So for instance the flow in the gap regions of slats or flaps of airfoils is a very delicate and difficult measurement problem. Especially for this purpose we have designed a long range LDV (Bütefisch, 1989; Seelhorst et al., 1995) which has a maximum measurement distance of five meters and is able to measure 3 components of velocity simultaneously (see Fig. 6).

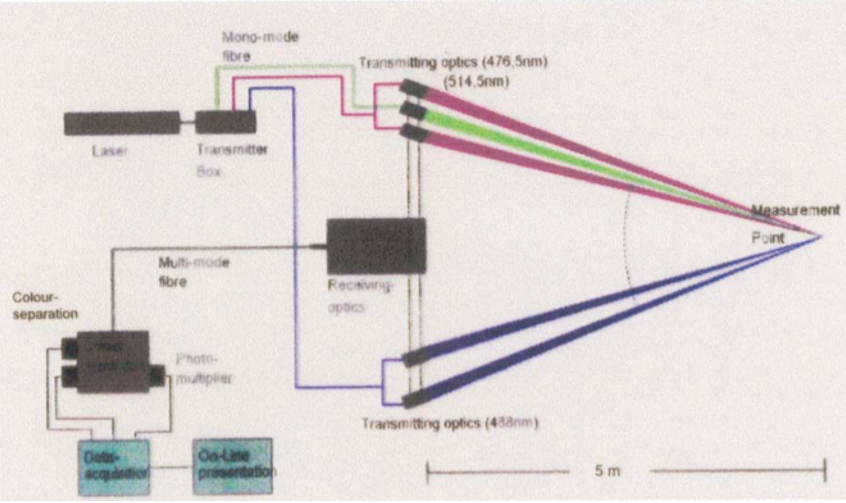

Fig. 6. Set-up of a long range LDV with a measuring distance of 5 m.

With the help of this instrument we have performed measurements in the DNW Wind Tunnel where the distance from the point of measurement was about 5 m. The wake of a slat in operation was measured with respect to all velocity components. From these velocity measurements also the fluctuation velocities can be deduced. A typical result shows in the upper part the configuration of the separated flow with the internal vortices and the point of reattachment. For the estimate of the fluctuations and the production of turbulence inflow to the airfoil also the curl and the velocity fluctuations are calculated from the data (see Fig. 7).

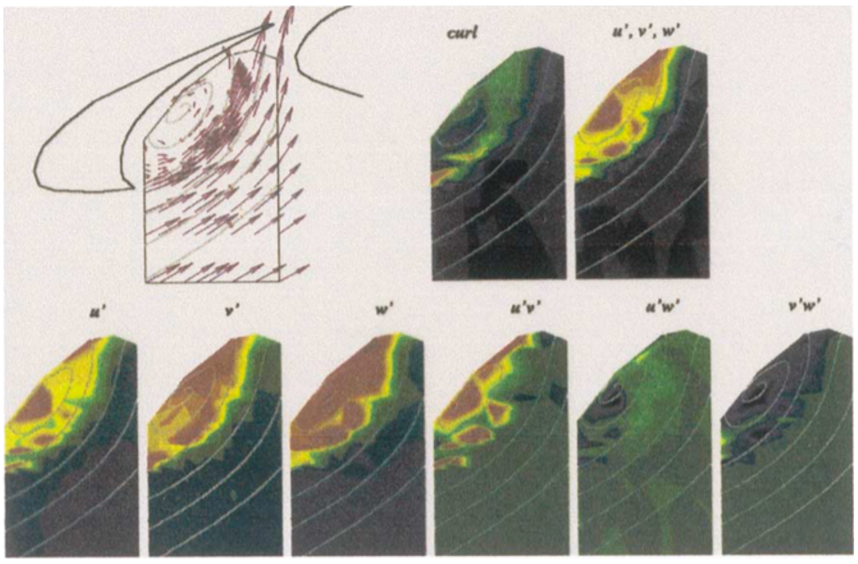

Fig. 7. Velocity measurement with a long range Laser Doppler Velocimeter at a high lift configuration in the DNW Wind-Tunnel.

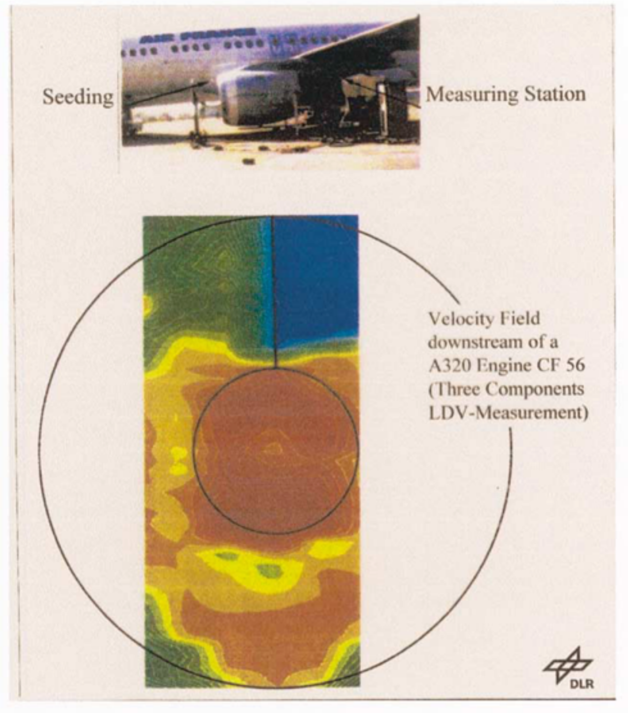

Fig. 8. Velocity field of the jet of a running engine measured with the long range LDV.

Another example of a peculiar application is the use of the LDV on an airfield behind the engine of a transport aircraft. The purpose of this test was to investigate the structure and the velocity field of the jet from a running engine. The velocities in the jet are unexpectedly unsymmetric with a clear preference of high speeds in the upper and lower part of the jet. Also a certain skewness of the jet flow can be observed. This example shows that new measurement techniques often result in an increased knowledge about the performance of existing devices (see Fig. 8).

5. Surface Pressure Measurement with Pressure Sensitive Paint (PSP)

As a very recent development the application of Pressure Sensitive Paint (PSP) (Engler and Klein, 1997; Fonov et al., 1998) let to some extraordinary results in our windtunnel tests with models of reentry vehicles in the supersonic flow regime. For this method the surface of a model is coated with a number of special layers of paint one of which contains a fluorescent substance with an optical activity depending on the partial pressure of oxygen. So after a illumination with the special exciting light source the pressure dependent fluorescence can be recorded by a CCD-camera of high sensitivity. From these recordings pressure distributions on the surface of the model can be achieved in a complicated process of calibration and evaluation (see Fig. 9).

The pressure distribution for a reentry model at a high angle of attack in false colors is achieved from the fluorescence intensity pattern. How detailed this information is can be seen also from the extracted pressure values along a line which is crossing the model at the indicated position. A surprising finding on these maps of pressure was a periodic structure on the rear end of the side wings which indicated a special oscillatory behavior of the streamwise vortices. This periodic oscillation is even more pronounced on another evaluation of this intensity picture in a type of contour plot. Here one can see how accurate the method gives details of the pressure distribution and also the cellular structure of the flow in the central part of the model. By certain techniques of pixelwise calibration the accuracy of the pressure measurement is at present in the order of 1%. To obtain such an amount of information on surface pressure in a classical approach the model would have been otherwise equipped with about 100 000 separate pressure transducers (see Fig. 10).

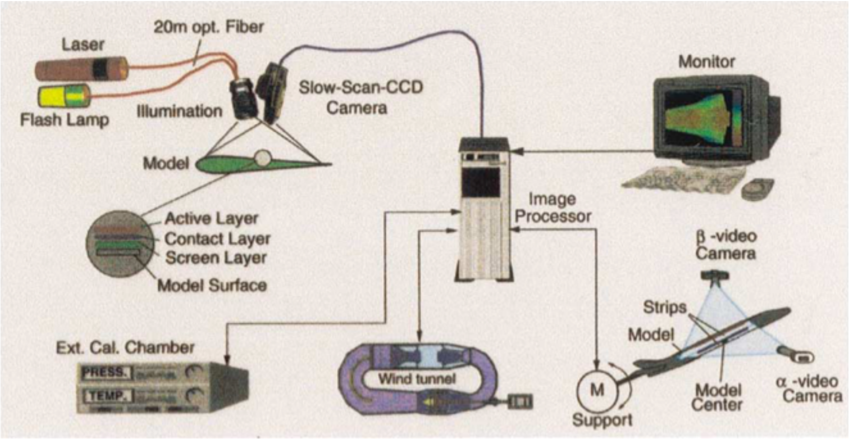

Fig. 9. Set-up of a pressure sensitive paint (PSP) measuring system.

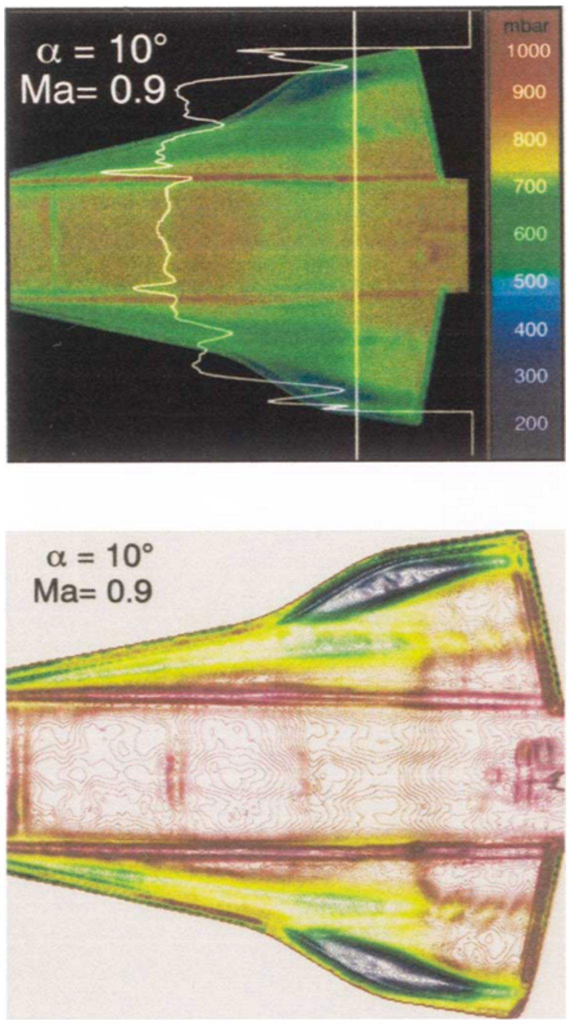

Fig. 10. Pressure distribution on a model of a reentry vehicle. Upper figure pressure indicated by color lower figure pressure indicated by contours of constant pressure.

6. Conclusion

Beside accurate information about the flow fields with an uncomparable high resolution for all possible details optical flow diagnostics and imaging gives sometimes more information than expected. Because of the richness in details information on minor or side effects which are often overlooked with classical integrating or pointwise measuring methods can be easily achieved by a modestly experienced experimentalist. The content of information is so rich because modern methods of data visualization and data processing provide easy access to the physical effects which are to be detected and understood finally.

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He issued approximately 200 publications etc. on Unsteady and Steady Transonic Flow and he has edited three books on Fluid Dynamics Topics. He is currently the Co-editor of some scientific Journals, organized more than 10 conferences in the field of Fluid Mechanics and he is a member of the congress committees of IUTAM and EUROMECH.