Recent Developments of Image Based Measurement Methods for Application to Transonic Flows in Industrial Wind Tunnels

J. KOMPENHANS, J. AGOCS, Y. EGAMI, R. ENGLER, U. FEY, H. FRAHNERT, K. de GROOT, U. HENNE, T. KIRMSE, C. KLEIN, F. KLINGE, R. KONRATH, L. KOOP, H. MATTNER, D. OTTER, D. PALLEK, W. SACHS, A. SCHRÖDER, B. STASICKI

(*German Aerospace Center (DLR), Institute of Aerodynamics and Flow Technology 37073 Göttingen, Bunsenstrasse 10, Germany*)

Abstract: The experimental investigation of unsteady complex flow fields in wind tunnels requires advanced measurement techniques. The most important of such image based measurement techniques are those for the measurement of planar flow velocity fields, planar pressure distribution, model location and deformation, model temperature and quantitative high speed flow visualization. The applications as carried out by DLR range from low speed flows to transonic flows, from high lift configurations to propellers and rotors, from wake vortex investigations in catapult facilities and water towing tanks to investigations of vortex break down phenomena on delta wings. The capability to use image based measurement techniques in transonic flows requires dedicated technical developments and experienced scientists due to the special environment of a transonic wind tunnel. In this paper an overview of the state-of-the art of the application of image based measurement techniques in transonic flows as performed by DLR's Institute of Aerodynamics and Flow Technology will be given.

Key words: industrial wind tunnel; transonic flow; image based measurement techniques; pressure sensitive paint; particle image velocimetry; model deformation measurement techniques; thermography; non-standard video techniques

基于图像的测量方法在工业风洞跨声速流测量中的最新进展. J. KOMPENHANS, J. AGOCS, Y. EGAMI, R. ENGLER, U. FEY, H. FRAHNERT, K. de GROOT, U. HENNE, T. KIRMSE, C. KLEIN, F. KLINGE, R. KONRATH, L. KOOP, H. MATTNER, D. OTTER, D. PALLEK, W. SACHS, A. SCHRÖDER, B. STASICKI. 中国航空学报(英文版), 2006, 19(2): 114 - 125.

摘 要:风洞中非定常复杂流场的实验研究要求先进的测量技术。基于图像的测量技术中最重要的是测量平面流速度场、平面压强分布、模型位置和变形、模型温度以及定量的高速流可视化等技术。DLR(德国宇航研究院)对这些技术的应用包括从低速流到跨声速流、从增升装置到螺旋桨和旋翼、从弹射装置和水塔储水罐尾迹流旋涡到三角翼上涡破裂现象等的研究。由于跨声速风洞的特殊环境,将基于图像的测量技术用于跨声速流要求专门的技术开发和有经验的科学家。给出了DLR空气动力学和流动技术研究所将基于图像的测量技术应用于跨声速流研究的最新进展。

关键词:工业风洞; 跨声速流; 基于图像的测量技术; 压强敏感涂料; 粒子图像测速仪; 模型变形测量技术; 温度记录法; 非标准视频技术

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During the last ten years several advanced non-intrusive image based measurement techniques such as Particle Image Velocimetry (PIV) for large field and instantaneous velocity measurements, Pressure Sensitive Paint (PSP) for pressure measurements on the complete surface of a model in the wind tunnel, Infrared Techniques (IR) and Temperature Sensitive Paint (TSP) for transition line

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detection *via* temperature measurement and various methods for model location and deformation measurement have been developed. Non-standard video techniques support qualitative visualization as well as the application of the image based quantitative measurement techniques at high speed or periodic events. Due to the fast progress made in the field of computers, lasers, electronics, video technique *etc*. in the past decade it was possible to set up reliable, modular and mobile advanced measurement systems for use in industrial test facilities such as large wind tunnels. Today PIV and PSP are the most advanced and mostly used of these techniques in industrial wind tunnels. The qualitative and quantitative improvements achieved during the past few years will be demonstrated in the following chapters by presenting results of industrial wind tunnel tests at transonic flow.

PIV allows the recording of a complete velocity field in a plane of the flow within a few microseconds. Thus, PIV provides information about unsteady flow fields, which is difficult to obtain with standard non-optical and intrusive experimental techniques. PSP provides planar information about the pressure distribution on the surface of the model, not just at a few locations as possible with conventional sensors. Thus, PSP is a very attractive method for application in wind tunnels for aerodynamic investigations and also for providing data for comparison with the results of numerical calculations. The short acquisition time and fast availability of data obtained by the advanced experimental techniques reduce the operational time, and hence cost, in large-scale test facilities.

The main areas of application of PIV, PSP, and model location and deformation techniques in aerodynamics at DLR are at present: wake vortices, high lift configurations, propellers, delta wings (in rotation) and turbulent and transitional boundary layers. The main problems involved with all these techniques are limited optical access in the closed test section of wind tunnels, reflections from the model under investigation and the time required for setting up and adjusting the equipment and for the calibration of the imaging conditions. Due to its physical properties PSP works better at high speed transonic flows (low pressure) and PIV works better at low speed flows (no problem of velocity lag of tracer particles).

Another problem receiving more and more attention today is that the application of non intrusive optical measurement techniques such as PIV, PSP *etc*. requires the transmitting and receiving optics to be located far away from the object under investigation in order not to disturb the flow. This has the consequence that the instrumentation cannot be rigidly attached to the object under investigation. Especially, if measuring close to the surface of the object the exact position of the area under observation by means of the chosen optical measurement technique and the location of the object are required simultaneously. In addition, models in a wind tunnel to be investigated at high-speed flows will deform under the loads of the flow. This means that the location of a model in the wind tunnel as well as its deformation have to be determined carefully during the measurement, especially, when applying optical diagnosis tools. In addition, such information is also absolutely required when utilizing these experimental data for validation of numerical calculations. The need to perform model location and deformation measurements in different wind tunnels for different aerodynamic investigations requires developing a modular and mobile system for model deformation measurements as well.

The application of image based measurement techniques in transonic flows is more difficult than in low speed flows due to different problems such as: closed test section with limited optical access for transonic wind tunnels, noise and vibration, no access to equipment such as cameras and lasers during the measurement, time consuming alignment and calibration of recording set up due to limited space and access, difficulty to seed large volumes with tracer particles for PIV, aero-optical effects due to varying and non-homogeneous density (shocks) *etc*. For many of these problems solutions have been developed in the Institute of Aero-