Study on Internal Supersonic Flows with Pseudo-shock Wave Using Liquid Crystal Flow Visualization Method

WANG Dong-ping[1], ZHAO Wen-zhong[1], SUGIYAMA Hiromu[2], TOJO Akira[2]

(1. College of Mechanical Engineering, Dalian Jiaotong University, Dalian 116028, China)

(2. Department of Mechanical Systems Engineering, Muroran Institute of Technology, Muroran, Hokkaido 050-8585, Japan)

Abstract: The flow visualization technique using shear-sensitive liquid crystal is applied to the investigation of a Mach 2 internal supersonic flow with pseudo-shock wave (PSW) in a pressure-vacuum supersonic wind tunnel. It provides qualitative information mainly concerning the overall flow structure, such as the turbulent boundary layer separation, reattachment locations and the dimensionalities of the flow. Besides, it can also give understanding of the surface streamlines, vortices in separation region and the corner effect of duct flow. Two kinds of crystals with different viscosities are used in experiments to analyze the viscosity effect. Results are compared with schlieren picture, confirming the effectiveness of liquid crystal in flow-visualization.

Key words: surface flow visualization; turbulent boundary layer separation; pseudo-shock wave; shock wave/turbulent boundary layer interaction; shear-sensitive liquid crystal; corner effect

液晶流动可视化方法研究拟似冲击波的内部超声速流动. 王东屏, 兆文忠, 杉山弘, 东条启. 中国航空学报(英文版), 2005, 18(2): 102-107.

摘 要: 在一个压力-真空超声速风洞中, 剪切应力敏感液晶流动可视化技术被应用来研究方管内马赫数 2 拟似冲击波(pseudo-shock wave) 的超声速流动。它主要提供关于整个流动的定性信息, 诸如湍流边界层分离、再附着位置以及流动的维数等。而且液晶也反映了表面流线, 分离区内的涡流和管道流动的角效应。使用两种不同黏度的液晶分别进行实验, 分析黏度对结果的影响。液晶实验的结果与纹影照片所得结果比较吻合, 说明了液晶是一个非常有效的流动可视化工具。

关键词: 表面流动可视化; 湍流边界层分离; 拟似冲击波; 冲击波/湍流边界层相互作用; 剪切敏感液晶; 角效应

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The use of the liquid crystal flow visualization technique has increased greatly over the past few years. Selective reflection of a particular wavelength is one of the most significant characteristics of liquid crystals. When a beam of white light is incident on the liquid crystal material, changes in the color of the reflected light are seen as the result of heating or shear stress advanced.

The shear-sensitive liquid crystal coating (SSLCC) method can provide area visualizations of instantaneous shear stress distributions on surfaces in dynamic flow fields[1]. It is useful for visualizing subtle flow features of boundary-layer separation, which are otherwise difficult to detect.

In the early 1980's, scientists at NASA Langley investigated the use of liquid crystals for qualitative illustration of surface flow features. Since then, many researches have been done, but obtaining satisfactory results at high dynamic pressure remains one of the significant challenges to be resolved for the liquid-crystal technique[2]. Moreover, most of the researches done mainly is on the outer flow field, and not on the internal flow field[3]. So far, the research paper about surface flow visualizations of the pseudo-shock wave (PSW) by liquid crystal has seldom appeared.

When a supersonic flow is decelerated to subsonic in a confined channel, PSW appears due to

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the interaction between a boundary layer and a shock wave. The PSW significantly affects the performance and efficiency of various flow devices, such as scramjet engine, supersonic wind tunnel diffuser and supersonic ejector. Its most important feature is the interaction of shock waves with boundary layer. The present understanding of the complex boundary layer flows of PSW is rather limited and many physical aspects are not well understood. Therefore, a careful study of this phenomenon is of practical and fundamental value.

The purpose of the present investigation is to obtain qualitative information concerning the boundary layer flow in Mach 2 with PSW supersonic wind tunnel experiment by using shear-sensitive liquid crystal. It provides information concerning the turbulent boundary layer separation, reattachment locations and the dimensionalities of the flow. Besides, it can also give an understanding of the surface streamlines, vortices and the corner effect of the duct flow.

1 Experimental Apparatus

The experiments are carried out in a pressure-vacuum supersonic wind tunnel of Muroran Institute of Technology of Japan.

By adjusting the size of the second throat (shock generator), the PSW is positioned at the desired locations. The structure of the PSW is visualized *via* a high speed color schlieren system, and the light source is a nanospark flash (30 ns).

Experimental condition: free-stream Mach number $Ma_\infty \doteq 2.0$; Reynolds number based on unit length $Re_\infty / m = 2.5 \times 10^7$; the ratio of the undisturbed boundary layer thickness to the duct half height $\delta_\infty / h = 0.25$.

When the liquid crystal experiments are done, one sidewall window of the tunnel is removed and replaced with a solid metal insert as the experimental surface. It has the size of 300 mm long and 80 mm high, and is positioned directly on one side of the off-centerline window ports and can thus be uniformly illuminated from the light outside the tunnel.

The liquid crystal coating is illuminated with a white light source mounted outside of the tunnel. Digital video and high-resolution camera are used to record the liquid crystal color change while the tunnel runs. When determining the shear stress change from the color changes of liquid crystals, the lighting and viewing angles are important. These angles are chosen on the basis of that they give the greatest color change in this experiment as shown in Fig. 1. By comparison, a shallow lighting angle and nearly perpendicular viewing angle produce intense color change, which is agreed with the result of Ref. [2].

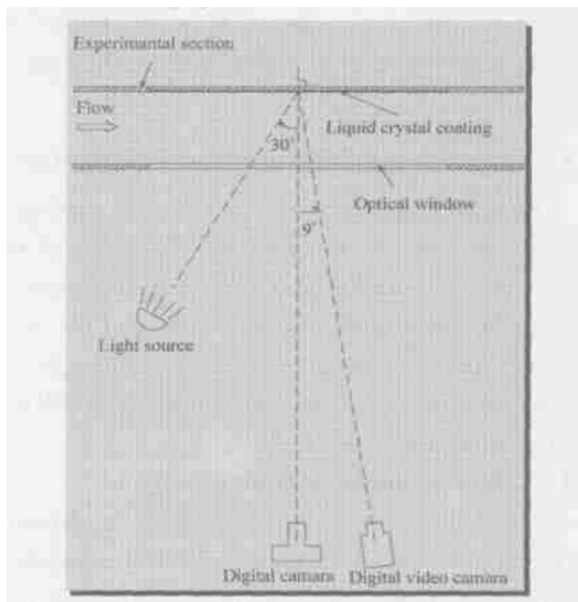

Fig. 1 Diagrammatic sketch of the lighting and viewing angles

The run time of the tunnel is approximately 10.5 s. The experiment is done presence and absence of PSW.

2 Flow Visualization Method

Liquid crystals have properties of both liquid-phase and solid-phase materials. Although appearing fluid-like, liquid crystals exhibit optical properties of solid crystals. The chemical structure of the liquid crystals is not affected, so the liquid crystal coating can respond rapidly and reversibly and be repeatable to these external effects. Many different experimental conditions can be studied with one application, which is an advantage over other tech-