Fluorescent Oil Film Global Skin Friction Measurement Technique Research Progress

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Abstract Skin friction is an important physical quantity in the research of turbulent boundary layer, turbulence modeling, validating results of numerical simulation and projection. The Oil film skin friction measurement technique, invented by Tanner and Blows, is based on detecting temporal-spatial evolution of a thin oil film thickness to determine skin friction. The global extension of a luminescent oil film skin friction measurement was originally proposed by Liu and Sullivan. The silicone oil doped with luminescent molecules is used as luminescent oil. Since the luminescent intensity is proportional to the oil film thickness for a thin oil film, thickness measurement is converted to luminescence measurement which is much easier and more robust against noise. In order to solve the skin friction from the equation, the oil film governing equation is simplified by Liu et al and then has the same form with the optical flow constraint equation which has been solved by means of integration minimization combined with smoothness constraint condition. In this paper, several research progress on luminescent oil film skin friction measurement would be introduced. A low speed wind tunnel experiment(20m/s) and a subsonic wind tunnel experiment(Mach0.785, Mach0.82) on riblets drag reduction were carried out and the drag reduction effect of micro-riblet film was obtained by global skin friction measurement technique based on fluorescent oil film. Now, this technique is extended to hypersonic wind tunnel test, and some result will be shown here.

Keywords: skin friction; riblets; fluorescent oil film; optical flow

1 Introduction
Skin friction is an important physical quantity in the research of turbulent boundary layer, turbulence modeling, validating results of numerical simulation and projection. In a long term of research history, drag reduction has attracted great interest in fluid mechanics research. Much of this interest has derived from the practical benefits of reducing drag; for example, reduction of the drag on transport vehicles leads directly to decreased fuel consumption and thus lowers operational costs. Analysis shows that, among the skin friction measurement methods, the global skin friction measurement technique based on fluorescent oil film have obvious advantages in precision and spatial resolution with bright prospect.

2 Method of Fluorescent Oil Film Global Skin Friction Measurement Technique
This basic solution was based on the optical flow method, and the differential method is the basic solution of optical flow velocity measurement. Using optical flow constraint equation combined with smoothness constraint condition and spatial and temporal gradients of grayscale, the movement information of each point would be extracted from optical flow field. In global skin friction measurement technique based on fluorescent oil film, the governing equation of fluorescent oil film, which expresses the relationship between the oil film thickness and skin friction, was solved by introducing additional constraint using integral minimization approach and variation approach, which was similar to the solution of optical flow. A delta wing skin friction measurement experiment and other tests were carried out, and high resolution skin friction distributions were acquired and consistent with the theoretical analysis.

3 Wind tunnel experiment result
(1) Riblets drag reduction in low speed wind tunnel(FD-09). The model is NLF0415 airfoil with 0.4m chord length and 1.2m span length, $U_\infty=20m/s$, $Re_C=0.5\times10^6$, $h=0.1mm$, $s=0.125mm$, $h^+=7.6$, $s^+=8.3$.

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Riblets drag reduction in high speed wind Tunnel (FD-12), Mach number 0.785-0.82, \( \alpha = 0^\circ \), \( \text{Re}_C = 4.5 \times 10^6 \), \( h = 0.025 \text{mm}, s = 0.0.030 \text{mm}, h^+ = 12.5, s^+ = 15 \).

Hypersonic wind tunnel test of VG drag reduction (FD-03). In mach 5 hypersonic wind tunnel different vortex generators were used to verify the drag reduction effect compared with plate model, and the height of two lozenge-shaped vortex generators were 2.5mm and 4mm.

4 Conclusion

The fluorescent oil film is used as the surface friction probe to measure the optical flow surface friction, and the prepared fluorescent oil film is coated on the surface of the smooth film or the small rib film downstream to make the shooting measurement. It is found that the relative friction resistance amplitude decreases obviously when the film is applied downstream in both the low speed wind tunnel and the high speed wind tunnel, and agrees with the references results. Now, this technique is extended to hypersonic wind tunnel test. In mach 5 hypersonic wind tunnel different vortex generators were used to verify the drag reduction effect compared with plate model, and a 14% drag reduction rate was obtained at last.

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References


