AERODYNAMIC HEATING IN THE REGION OF SHOCK AND TURBULENT BOUNDARY LAYER INTERACTION INDUCED BY A CYLINDER

Tang Guiming (唐貴明)  Yu Hongru (俞鴻儒)
(Institute of Mechanics, Chinese Academy of Sciences, Beijing 100080, China)

ABSTRACT: Detailed distributions of heat flux in the region of shock wave and turbulent boundary layer interaction induced by a cylinder were measured in the shock tunnel. Oil flow patterns and Schlieren photographs were taken. Empirical relations were given for determining separation shock angle, peaks of heat flux and their locations on both cylinder leading edge and flat plate surface, and other characteristic parameters of the interaction region.

KEY WORDS: shock wave, boundary layer, aerodynamic heating

I. INTRODUCTION

In high speed vehicle design, the shock-turbulent boundary layer interaction heating augmentation induced by protuberance is one of the most severe problems. For three-dimensional protuberance the inviscid-viscous interaction flow makes the analytical prediction very difficult, even though the flowfields have been described by several authors.[1-5] Experimental data on protuberance interaction heat flux are very limited particularly for hypersonic turbulent flow. Lack of heat flux measurements and its practical importance promoted this study. Besides measurements of heat flux, a new oil flow technique for short duration facilities was developed to observe the direction of the flow on the model surface. The data obtained from these tests and other investigations were used to form the relations for calculating the peaks of heat flux and their locations on both the leading edge of cylinder and the surface of flat plate, and other characteristic parameters in the interaction regions.

II. EXPERIMENTAL TECHNIQUE

The 1.2m Shock Tunnel The tests were conducted in the 1.2m shock tunnel at Institute of Mechanics, Chinese Academy of Sciences. The tunnel consists of a shock tube, a nozzle, a test section and a vacuum tank as shown in Fig.1. In these tests, the free stream Mach number ranged from 5 to 9, the corresponding Reynolds number ranging from 2 to $6 \times 10^7$/m with the test time of about 5 to 7ms.

Model A flat plate, 30cm wide by 70cm long, was mounted near the test section axial line. The boundary layer on the model surface starts upstream far from separation initiation to transform to turbulence. The cylinder was mounted on the plate surface at 50cm from the

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plate leading edge. The height of the cylinder may be adjusted from 12 to 20 cm and the cylinder may be inclined with an angle from 0° to 30°. The disc of 15 cm diameter was inlaid with a series of thin film thermometer arranged in a column, which was a part of the flat plate, and could rotated around the cylinder center. Thus the heat flux distributions at any azimuth can be measured conveniently.

**Heat Transfer Instrumentation** Thin film resistance thermometer in the form of a strip approximately 0.2 mm wide by 2 mm long was used as the heat flux measuring element. During the tests a constant current of 20 milliampere passed through the gage. The value of the heat flux was obtained from the film response processed by RC analogue network \( t_6 \). The test data were recorded with an A/D converter and processed with the microcomputer.

**Flow Visualization on Model** Oil flow patterns and Schlieren photographs were taken for typical models. The oil flow technique has been extensively applied to the test in the long duration facilities \( \text{[2,3]} \). A new oil flow technique for transient flow was developed to observe the flowfield on the model surface. The oil mixture was made of titanium dioxide dust and silicon oil. The models were painted black and small mixture dots were spread on the surface of the flat plate to visualize the direction of shear force.

**III. RESULTS AND DISCUSSION**

1. **Heat flux distribution and flow pattern on the symmetric plane**

   The heat flux distributions on the symmetric plane of interaction region for \( M_1 = 5.2 \) are shown in Fig. 2a. The heat flux data on the leading edge of the cylinder and on the surface of the flat plate are normalized by the undisturbed value on the cylinder leading edge \( q_s \) and the local plate value \( q_l \) respectively. The oil flow pattern (Fig. 3) show that the interaction of the bow shock induced by the cylinder with the turbulent boundary layer on the plate causes widespread upstream and lateral separations. The impingement of separation shock on the bow shock (Fig. 4) results in a lambda shock. The heat flux on the surface of the plate ahead of the cylinder starts to rise at \( X_s = 1.9d \), reaches a plateau value \( q_{p1} = 2.8q_l \) at \( X_{a1} = 0.8d \), goes through a large dip at about \( X_{s1} = 0.58d \) and then rises sharply to a higher peak \( q_{pk} = 25q_l \) at \( X_s = 0.12d \), after which rapidly drops to a low value \( q = 8.9q_l \) at the foot of the cylinder. The heat flux distribution along the cylinder leading edge from the foot to \( Z_s = 0.22d \) decreases from \( q = q_s \) to 0.4\( q_s \), after which rises to a short plateau at \( Z_r = 0.5d \), and then increases steeply.

![Fig. 2 heat flux distributions (a) and imaginary scheme (b) of vortices on the symmetric plane](image-url)