Eighth Australasian Fluid Mechanics
Conference, University of Newcastle,
N.S.W., 28 November/2 December 1983.

A SIMPLE TOMOGRAPHIC TECHNIQUE TO STUDY THREE-DIMENSIONAL FLOW FIELDS

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SUMMARY This investigation was initiated to test the feasibility of using a simple tomographic technique to study complex three-dimensional flow-fields. A 90° transparent wedge (2 perspex plates) at -10° angle of attack was used as a model in a Ludwieg Tube operating at Mach 6. A tomographic study of the wedge flowfield was achieved by rotating the model in 2° to 5° degree increments through 90° and taking colour differential interferograms at each rotation position.

1 INTRODUCTION

The experimental investigation was performed in a Ludwieg Tube at the D.F.V.L.R./A.V.A. in Göttingen. This facility is fully described in Ludwieg *et al* (1970). The stagnation pressure was maintained at 20 bar and the stagnation temperature was between 220°C and 240°C. With these conditions and the Mach 6 nozzle placed in the B Channel, a freestream Mach number of 5.98 was obtained in the test section.

A 90° wedge model was constructed from two identical Perspex (5 cm x 15 cm x 1 cm) plates, each having an external 15° chamferred leading edge. The model was fixed to a stainless steel sting at -10° angle-of-attack, see Figure 1. This model sting was then inserted into the integral support sting of the B Channel Ludwieg tube.

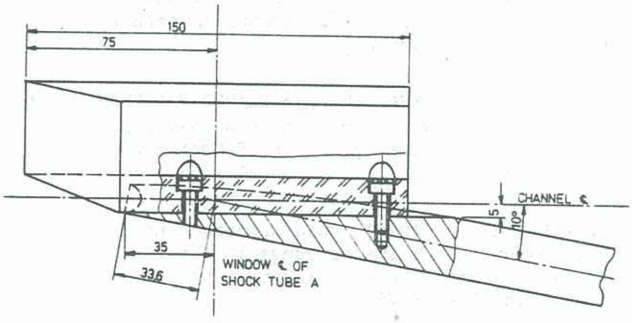

Figure 1 Construction of 90° Perspex wedge model and sting

A differential interferometer, using a tungsten light source and a Contax 35 mm camera, was the only piece of measuring equipment employed in this study. The interferometer was adjusted to give infinite fringes along the 5 cm width of the wedge plates. By taking a colour interferogram at each angle of model rotation, a tomographic study of the wedge flowfield was obtained. The model was rotated in 2° increments from 0° to 40°, in two 2.5° steps between 40° and 45°, in 5° increments from 45° to 80° and in one 10° step from 80° to 90°. The infinite fringe setting was focussed on Plate 1 for the model rotation of 0° to 28°, on both Plates 1 and 2 for 22° and for 30° to 60° and on Plate 2 for 65° to 90°. Three interferograms were taken for each angle of model rotation: (i) the no flow (valve closed) condition; (ii) near the start of the constant-flow test run; and (iii) near the end of the test run where flow features were more developed.

2 GENERAL OBSERVATIONS

Two shocks were visible in all constant-flow interferograms. These were named the *corner* shock, because it appeared to emanate from the inside corner of the wedge, and one of the two plate *leading edge* shocks. The corner shock was thicker and more distinct than either of the leading edge shocks. Both shocks appear to be coincident at a section 5 cm downstream of the wedge leading edge when the model was in the 0° position; i.e., when Plate 1 was vertical (perpendicular to the light beam) and Plate 2 was horizontal. This apparent crossover point moved away from the inside corner of the wedge and in the downstream direction as the angle of model rotation increased to 36°. At 40° rotation, the leading edge shock is outside or "above" the rear portion of the wedge. At 45°, the leading edge shock is totally "above" the wedge. This situation then went in the opposite direction as the model rotation angle was increased. When the model was in the 90° position, with Plate 2 vertical (perpendicular to the light path) and Plate 1 horizontal, the two shocks again appeared coincident 5 cm downstream of the wedge leading edge. The wedge flowfield was essentially symmetrical through 45 degrees of rotation.

At angles near 0° and 90°, the corner shock appeared blue near the front of the visible portion (4 - 15 cm from the leading edge) of the wedge. At the angles of 20° to 25°, the trailing portion of the corner shock was blue on the interferograms. These blue areas may indicate stress waves where a shock is touching the inside surface(s) of the wedge plate(s).

A parabolically-shaped "vortex" line was visible near the outer edge of the uppermost plate for all interferograms. In the rear portion of the wedge, a double set of parallel lines were near the inside corner of the wedge; these lines were also parallel to the corner shock.

3 ANALYSIS OF THE INTERFEROGRAMS

An enlarger was used to project the individual interferograms onto translucent paper. Tracings were made of the wedge boundaries and the flowfield features. At low angles, both the flow features and the inside corner of the wedge are shifted (by refraction through Plate 1) equally. Depending upon the "vertical" section or cutting plane of the model, Plate 2 was between the flowfield and the image plane from 22°- 30° up to 90° of model rotation. Then only the inside corner of the wedge was shifted by the additional refraction through Plate 2.

The necessary correction was determined by measuring the "vertical" distance (perpendicular to the inside corner) between the extension of the image of the inside corner of the wedge and the apex of the two plates at the wedge leading edge. This correction was then added to the distance to any flowfield feature, which was measured perpendicularly from the image of the inside corner of the wedge. The true distance was then plotted on polar coordinate paper. A line drawn perpendicular to the plotted point represented the locus, or line-of-sight, along which the particular flowfield feature existed at the given angle of rotation.

In this manner, it was found that the so-called *corner* shock was actually a cusp at any given section and was a conical shock emanating from the apex of the inside corner of the wedge. The classical diagonal or 45° corner shock, see Figure 2, as found by Kipke (1973a,b; 1974) at Mach 15.8 was not found in this investigation.

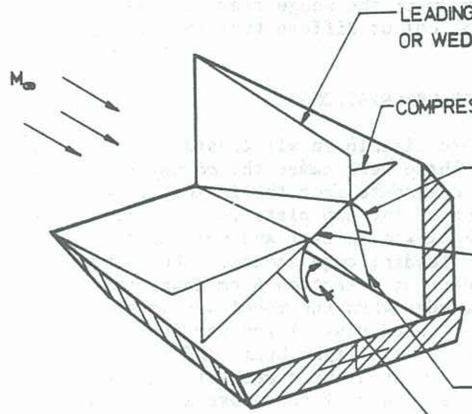

Figure 2 Schematic of 3D flowfield in a corner model, from Kipke (1973b)

A closer representation is shown in Figure 3. If one continued the curved secondary shock to replace the straight corner shock, the conical "corner" shock (found in this investigation) would be obtained. In this study, the flowfield was too weak to be able to discern compression waves or entropy lines from the interferograms. The leading edge or wedge shocks intersect the conical shock at 30°- 35° and 55°- 60° of azimuth. These straight shocks extend to the edge of each plate and then curve outwards around the 1 cm thickness of each plate.

4 CONCLUSIONS

This simple tomographic technique has been shown to be effective in locating shocks in three-dimensional flowfields. The Mach 6 flow condition appears to be too weak to produce a straight corner shock or to distinguish features such as flow separation regions, straight secondary shocks or compression waves. A bigger model, particularly with a larger plate width than 5 cm, tested at a higher Mach number should permit flowfield features which are weaker than shocks to be observed.

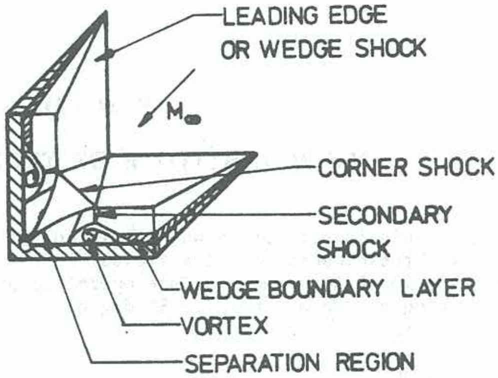

Figure 3 Schematic of 3D flowfield in corner model, from Schepers (1976)

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6 ACKNOWLEDGEMENT

This work was performed while the author was at the Institute for Experimental Fluid Mechanics, Göttingen, West Germany.