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INVISCID HYPERSONIC FLOW

INTRODUCTION

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The theory of inviscid hypersonic flow has been dominated in the past by two distinctive lines of development, one of which is for the flow around blunt nosed bodies. A number of approximate theories have been proposed; e.g., the Newton-Buseman theory, thin shock layer theory, etc. Purely numerical calculation procedures have also been developed of which Van Dyke's scheme for the inverse problem and Dorodnitzyn's method of integral relations are probably the most successful. The general features of the flow around a simple blunt shape like the hemispherical nose are now quite well known, and the flow properties can be predicted quite accurately, at least for a perfect gas.

The other line of development has been concerned with small disturbance theory. This line started with the general hypersonic similitude principle introduced by Hayes , which states that a small disturbance hypersonic flow is equivalent to an unsteady flow in one less space dimension. The subsequent analysis by Van Dyke showed that hypersonic small disturbance theory, which is basically nonlinear, is generally more accurate than the corresponding theory for moderate supersonic speeds. The solutions to small disturbance theory that have been worked out have been almost exclusively of the self-similar type; i.e., the perturbation velocities and the thickness of the body are assumed to be proportional to some power of the free stream coordinate.

Self-similar solutions have been considered by a several investigators, both in the West and in the Soviet Union. It was found that solutions exist only for the exponents higher than two-thirds in the two-dimensional case and one-half in the axisymmetric case. In the limiting cases the body is found to have zero thickness with a finite shock layer thickness. These cases correspond physically to infinitesimally thin blunted

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flat plate and blunted cylinder, respectively. The corresponding analogy in the unsteady case is a point explosion at the origin at time $t = 0$ (corresponding to the blunted nose at $x = 0$).

Practically all these methods are restricted in their applications to very special classes of simple bodies. The only exception is the Newton-Buseman theory which, however, becomes quite complicated when applied to a general three-dimensional body and, furthermore, generally gives rather poor agreement with experiment. In this chapter two of the papers --namely, those of J. D. Cole and J. J. Brainerd, and of R. E. Melnik and R. A. Scheuing--are concerned with the extension of thin shock layer theory to more complicated three-dimensional shapes than axisymmetric bodies.

Even for the case of axisymmetric flow the present status of the theory is not quite satisfactory, however. For example, there exists no completely rational method to analyze the complete flow field around a blunt nosed slender body. The blunt body solution applies near the stagnation point and small disturbance theory far downstream where perturbation velocities diminish. However, it has become very difficult to treat analytically the transition region between these two extreme types of flow. An attempt is made in the paper by N. C. Freeman, starting from the simple concepts of Newtonian theory. The paper is concerned with how the "free layer solution given by Newtonian theory joins the small disturbance solution far downstream from the nose."

Although small disturbance theory gives solutions also for slightly blunted slender bodies it is not valid for the whole flow field. The strong perturbations due to the blunted nose creates a region of high entropy gas near the body in which the small disturbance equations, and hence the hypersonic similitude principle, fail to apply. The entropy layer has lately been studied rather extensively. It is similar to the boundary layer in that the pressure is essentially constant across it and the velocity perturbations are large. Like the boundary layer the entropy layer also has a displacement effect on the flow. Calculations by Sychev in the Soviet Union showed that this effect can be very large. In the paper by J. K. Yakura an analytic solution is given, in which the entropy layer is taken into account, for the asymptotic flow field far downstream from a shock of prescribed shape.