The Propagation of Weaks Shocks in Non-Uniform Flows

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Abstract
A new theory of the propagation of weak shocks into non-uniform, two-dimensional flows is introduced. The theory is based on a description of shock propagation in terms of a manifold equation together with compatibility conditions for shock strength and its normal derivatives behind the shock. This approach was developed by Ravindran and Prasad (1993) for shocks of arbitrary strength propagating into a medium at rest and is extended here to non-uniform media and restricted to moderately weak shocks. The theory is tested against known analytical solutions for cylindrical and plane shocks, and against a full direct numerical simulation (DNS) of a shock propagating into a sinusoidal shear flow. The test against DNS shows that the present theory accurately predicts the evolution of a moderately weak shock front, including the formation of shock-shocks due to shock focusing. The theory is then applied to the focusing of an initially parabolic shock, and to the propagation of an initially straight shock into a variety of simple flows (sinusoidal shear, vortex array, point-vortex array) exhibiting some fundamental properties of turbulent flows. A number of relations are deduced for the variation of shock quantities with initial shock strength M_{S0} and the Mach number of the flow ahead of the shock M_U (e.g. separation of shock-shocks and maximum shock strength at a focus). It is found that shock-shocks are likely to form in turbulent flows with $M_t/M_{1N} > 0.14 - 0.25$, where M_t is the average Mach number of the turbulence and M_{1N} is the Mach number of the shock in a flow at rest. The shock moves up to 1.5% faster in a two-dimensional vortex array than in uniform flow.