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TECHNICAL NOTE

On the RR→MR transition of asymmetric shock waves in steady flows

Z. M. Hu · M. S. Kim · R. S. Myong · T. H. Cho

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Abstract In this paper, RR → MR transition of asymmetric shock waves has been theoretically studied. The transition can occur between the sonic-point and maximum-deflection criteria due to the the effects of expansion fans which are inherent flow structures. Comparison shows a better agreement among experiments and the analytical results. Some discrepancies reported in previous studies among experiments and theory have also been explained based on the threshold for RR → MR transition.

Keywords Regular reflection · Mach reflection · Transition · Asymmetric · Shock waves

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1 Introduction

It is well known that more than one global solution is compatible with the conservation laws and the applied boundary conditions for shock wave reflection in a steady flow at sufficiently high Mach number. This leads to the so-called dual-solution problem. In the dual-solution domain, both regular and Mach reflection patterns are locally stable with a given time history. Intensive analytical, experimental, and numerical investigations have been conducted to illuminate the physics underlining reflection of asymmetric shock waves in the last decades [1–5]. However, the effects of the expansion fans which are inherent flow structures were neglected in most of the previous studies as the theoretical transition criteria were referred to.

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Z. M. Hu · M. S. Kim · R. S. Myong (✉) · T. H. Cho
Research Center for Aircraft Parts Technology,
School of Mechanical and Aerospace Engineering,
Gyeongsang National University, Jinju 660-701, South Korea
e-mail: myong@gnu.ac.kr

Z. M. Hu
e-mail: bighumin@126.com

2 RR → MR transition

The wave configurations of an overall regular reflection (RR) and an overall Mach reflection (MR) for the interaction of two asymmetric shock waves of opposite families are schematically shown in Fig. 1a and b, respectively. An overall RR wave configuration consists of two incident shock waves (i_1 and i_2), two reflected shock waves (r_1 and r_2), one slipstream (s), and two Prandtl–Meyer expansion fans (pm_1 and pm_2). The above discontinuities except pm_1 and pm_2 meet at a single node (R). In an overall MR wave configuration, there is a Mach stem (m) bridging two triple points, T_1 connecting i_1, r_1 and s_1, and T_2 connecting i_2, r_2 and s_2, respectively. The overall MR wave configuration is locally stable and then theoretically admissible if and only if the two slipstreams, s_1 and s_2, assemble an overall converging–diverging stream tube.

In Fig. 1c, the shock polar combination represents the process of RR↔MR transition and the hysteresis phenomena for the wedge assembly. The polar R_1' corresponds to r_1 for the upper wedge with a fixed angle θ_1. The sequential polars R_1 to R_5 correspond to r_2 as θ_2 increases. Li et al. [2] hypothesized the hysteresis that with increasing θ_2 RR → MR transition occurs near the detachment point ‘d’ (θ_2^D) while with decreasing θ_2 MR → RR transition occurs at the von Neumann point ‘b’ (θ_2^{vN}).

In the RR → MR transition process, there is a critical wedge angle, $\theta_2 = \theta_2^S$, at which the intersection is the sonic point of polar R_S as shown in Fig. 2a. Beyond θ_2^S the flow