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ORIGINAL ARTICLE

The influence of radial entrance width of the circular cavity on incident shock wave focusing

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Abstract Despite the achievement of shock wave focusing with certain reflectors, the influence of the radial entrance width of a circular cavity on the flow field has yet to be addressed. In this study, we systematically investigated the effects of the shock wave focusing process in a cavity based on the radial entrance widths. An experimental system was installed to research the evolution of the flow field under conditions with different radial entrance widths of 3.0, 11.1, 19.5, and 33.0 mm. A schlieren system was used to photograph the structures of the flow field in the cavity, and a data acquisition system was used to record the dynamic pressure histories of different points. A numerical simulation was carried out to investigate greater details of the shock wave focusing process. A third-order strong stability-preserving Runge-Kutta method, third-order weighed essential non-oscillation scheme, and an adaptive mesh refinement algorithm were adopted to simulate the shock wave reflection, diffraction, and focus process. Good agreement between the experimental and numerical results was observed. By comparing the evolution process of the flow field under the conditions of four different entrance cavity widths, we found that when the entrance width was 19.5 mm, there was the stronger intensity of the shock wave focusing in the focal region, and the larger pressure value at the apex of the cavity than the other three entrance widths, occur. This study improves our understanding of shock wave focusing.

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Nomenclature

w	width of the radial entrance (unit: mm)
E	total energy per unit volume (unit: J/m^3)
p	pressure (unit: Pa)
p_0	initial pressure (unit: Pa)
T	thermodynamic temperature (unit: K)
T_0	initial thermodynamic temperature (unit: K)
LS	leading shock
R	reflected shock
V	vortex
EF	expansion fan
RC	recompression shock
SL	shear layer
SS	second shock
OS	oblique shock
ES	bow shock
M	Mach stem
FR	reflected shock at the focal area
I	incident shock
J	jet
S	slip line
MR	main reflected shock
InMR	inverse-Mach reflection
MR	Mach reflection
RR	regular reflection

Greek letters

ρ	density of flow (unit: kg/m^3)

1. Introduction

Since the phenomenon of shock wave focusing was first observed in a shock tube by Perry and Kantrowitz [1] in 1951, the phenomenon has been investigated over the past years. The authors found that shock wave focusing in a converging channel produces a region with high pressure and high temperature. After their study, other early studies of the shock wave focusing process obtained many different flow features and discussed the focusing mechanism. Meshkov [2] conducted an experimental study on the reflection of a plane stationary shock wave with different Mach numbers from a cylindrical concave wall. The author compared the influence of the Mach number on the focus process. However, it was pointed out that the flow features are very complex, and thus flow images cannot be simply described analytically. Sturtevant and Kulkarny [3] found the behavior of shock discontinuity under a variety of different types of focus, which was experimentally determined through the same nonlinear gas-dynamic processes. However, the general law of variation of the shock strength along the Mach stem was not determined, particularly near the three-shock intersection, which evidently plays an important role near the focal region.

More flow field details on the shock wave focusing process were later revealed. Shugaev et al. [4] observed that a jet and vortices arise behind a reflected shock wave, which influences the stability of the flow inside a cavity. The length of the jet depends on the depth of the cavity and the strength of the shock wave. Skews et al. [5] established flow patterns of the interaction of shock waves on cylindrical and parabolic surfaces. Kelvin-Helmholtz instabilities on the shear layers were clearly identified. The behavior of an initial planar shock wave propagating into a linearly convergent wedge was investigated by Bond et al. [6] It was found the nature of the focusing in a two-dimensional converging geometry depends on the structure of the reflected waves early in a flow, and the distributed reflections produce a much smoother focusing that better approximates a circular cylindrical shock, whereas the sharper waves from the compact reflections outside this regime yield a poorer approximation to smooth focusing.

In addition, the influences of variable geometry reflectors and the initial conditions on shock wave focusing were investigated. Babinsky et al. [7] compared the different influences on shock wave focusing under four reflector entrance shapes both experimentally and numerically. It was concluded that the peak pressure at the focus, as well as the extent of the high-pressure region, increases with the growing radius of the circular entrance of the reflector. However, the authors mainly studied the influence of bluntness of the reflector entrance shape on the focusing of the reflected shock waves. Skews et al. [8] conducted an analysis of flow photographs. They studied some new interaction patterns influenced by both the cavity shape and shock Mach number. Izumi et al. [9] analyzed the shock wave focusing process for various shapes of a parabolic reflector. They found that the focusing mechanism in a parabolic reflector is independent of the reflector shape and incident shock Mach number. However, some flow feathers differ with the changes in the shock Mach number and the depth of the parabolic reflector. Experiments and a numerical simulation were carried out by Achasov et al. [10] to investigate the radial incident shock wave focusing applied to initiate a gas mixture. Experiments were conducted to obtain schlieren photographs during the use of real gas and cold air, and the pressure data at the apex of the cavity were recorded. The different intensities of a shock wave were shown to change the position of the shock wave focusing area. Meanwhile, the influence of geometrical structures of a concave cavity on the initiation effect was studied, and it was concluded that both a concave cavity depth of less than the concave cavity radius, and an entrance jet with an injection angle, are conducive to detonation. In 2003, Leyva et al. [11] conducted two-dimensional experiments and a numerical simulation of four different geometrical structures of a concave cavity under different jet pressure ratios. The results showed that the

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