European Journal of Mechanics B/Fluids 59 (2016) 115–123

Contents lists available at ScienceDirect

European Journal of Mechanics B/Fluids

journal homepage: www.elsevier.com/locate/ejmflu

Shock wave mitigation by different combination of plate barriers; a numerical investigation

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ARTICLE INFO

Article history:
Received 3 September 2015
Received in revised form
22 March 2016
Accepted 9 May 2016
Available online 19 May 2016

Keywords:
Shock mitigation
Shock interaction with barriers

ABSTRACT

Propagation of shock waves through a set of plate barriers is studied numerically. It is found that the studied barrier sets are very effective in attenuating transmitted shock waves. All transmitted shock waves through the proposed barrier sets are reduced to mild compression waves upon exiting the sequence of inclined or vertically placed barrier plates.

1. Introduction

In the search for protection from sudden and unexpected explosions that result in traveling shock/blast waves through underground mine channels, or in industrial complexes where large amounts of combustible material is stored, a variety of underground shelters were proposed during the 70s and 80s of the previous century. An important feature in designing such protection is knowledge of shock/blast wave propagation in ducts leading to the shelter and what type of obstacles could reduce the strength of such waves. Additional usage of the proposed barriers system is for reducing the exit pressure prevailing in the jet plume of a rocket launched from a silo or other confined space. Another application in which employing a barrier system is of help is in a blow down super/hypersonic wind tunnel. In design of such tunnels a nozzle is employed behind the test section; in some cases if the nozzle throat is not correctly configured the flow leaving it might still be supersonic. By installing a barrier system downstream of the nozzle or instead of it, will ensure that the flow emerging out of the wind tunnel has the desired reduced pressure.

An overview of shock propagation in tunnels is given in chapter 10 of the Handbook of Shock Waves [1]. When a planar shock wave propagates into a uniform cross-section duct it slowly attenuates due to momentum and energy dissipation via friction and heat transfer. A faster decay can be achieved by applying roughness to the duct walls, and/or introducing quick changes in the flow direction by inserting a bend in the conduit, or by introducing abrupt area enlargement in the duct cross-section. The effectiveness of using these methods is described in [2,3]. In such cases the main mechanism responsible for reducing the shock wave strength is multiple shock wave diffraction and reflections initiated by altered geometry of the duct. A different suggestion proposed for attenuating shock/blast waves in a **straight** conduit is by introducing plate barriers in the shock/blast wave direction. Among publications offered for attenuating shock waves propagating inside a straight conduit one should mention the work of Mataradze et al. [4]. They proposed introducing additional phase into the gas in order to reduce the harmful effect of a transmitted shock/blast wave. Chauvin et al. [5] also investigated the usefulness of introducing a cloud of water droplets into the gaseous phase for attenuating the passing shock wave. Another option is to combine two methods such as a double bend duct and dust as described in [6].

The simplest way of obtaining attenuation of a shock/blast wave propagating inside a straight duct is by introducing rigid plate barrier(s). Britan et al. [7] conducted experimental and numerical investigation of the flow resulted from head-on collision between a planar shock wave and a single plate barrier. In [8,9] an investigation of a single and double barrier is presented. An experimental study with 4 barriers of different sizes and locations inside the shock tube is described in [10].

A detailed review of different suggestions proposed for shock/blast attenuation appears in [11]. It is the purpose of the

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http://dx.doi.org/10.1016/j.euromechflu.2016.05.002
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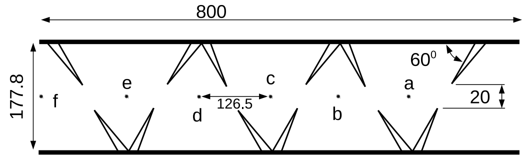

Fig. 1. Schematic description of the inclined barrier geometry tested in [12]. All distances are in mm.

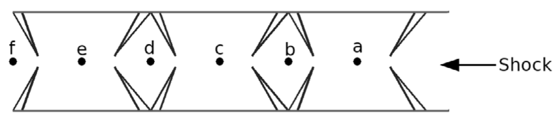

Fig. 2. Alternative plate barrier configuration.

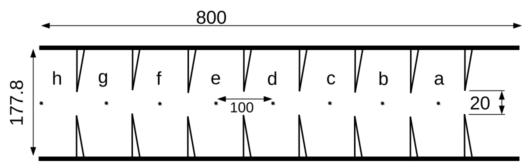

Fig. 3. Schematic description of the straight barrier geometry tested in [12]. All distances are in mm.

present paper to check numerically the usefulness of employing several plate barriers in a straight conduit for obtaining significant shock/blast wave attenuation. We begin our study with computing the experimental results of Ohtomo et al. [12]. It should be noted that a numerical solution is also given in Ohtomo et al.; however there are no details regarding the used scheme, and it is conducted for only one value of the incident shock wave Mach number, Ms = 1.47.

2. Numerical scheme

The computational domain is two dimensional. Computations were performed using a compressible inviscid flow model, and then solving the Euler equations listed below.

$$\frac{\partial U}{\partial t}+\frac{\partial F}{\partial x}+\frac{\partial G}{\partial y}=0 \tag{1}$$

$$U=\begin{Bmatrix}\rho\\ \rho u\\ \rho v\\ \rho E\end{Bmatrix},\qquad F=\begin{Bmatrix}\rho u\\ \rho u^2+p\\ \rho uv\\ u\left(\rho E+p\right)\end{Bmatrix},\qquad G=\begin{Bmatrix}\rho v\\ \rho uv\\ \rho v^2+p\\ v\left(\rho E+p\right)\end{Bmatrix} \tag{2}$$

$$e=E-\frac{1}{2}\left(u^2+v^2\right) \tag{3}$$

$$p=\left(\gamma-1\right)\rho e \tag{4}$$

where ρ and p are density and pressure respectively. E and e are total and internal specific energies and u, v are velocity components in the x, y directions respectively. γ is the specific heat capacity ratio. The ideal gas equation of state (Eq. (4)) was employed in the numerical simulations. Simulations were conducted using the commercial FLUENT code, with the coupled (density based) solver based on a second order AUSM upwind scheme. The solver is second order in both space and time. The AUSM (Advection Upstream Splitting Method) is a flux vector splitting scheme. This scheme separates the flux to convective and pressure parts. First an interface Mach number is computed based on velocities from neighboring cells. This interface Mach number is then employed to compute the convective and pressure fluxes, further details are available in [13].

The grid is composed of quadrilateral cells. In these cells the flow was solved using a finite volume scheme. The conservation equations of mass, momentum and energy were solved in each cell for unsteady flow. A grid sensitivity study is presented in the Appendix. Number of grid cells varied between 130,000 and 184,400 depending on the barrier geometry.

3. Results and discussion

As a first step in finding a good barrier configuration for achieving quick shock wave attenuation the available experimental studies were simulated; specifically, the work of Ohtomo et al. [12] was numerically simulated. During each numerical simulation pressures were computed at various locations, ahead of the barriers and between barriers. Locations of the "pressure gauges" are shown by black dots and circles for the various barriers shown Figs. 1–4 that are investigated in the current paper. Performance of two different pointed plate barriers were computed in [12], are shown in Figs. 1 and 3.

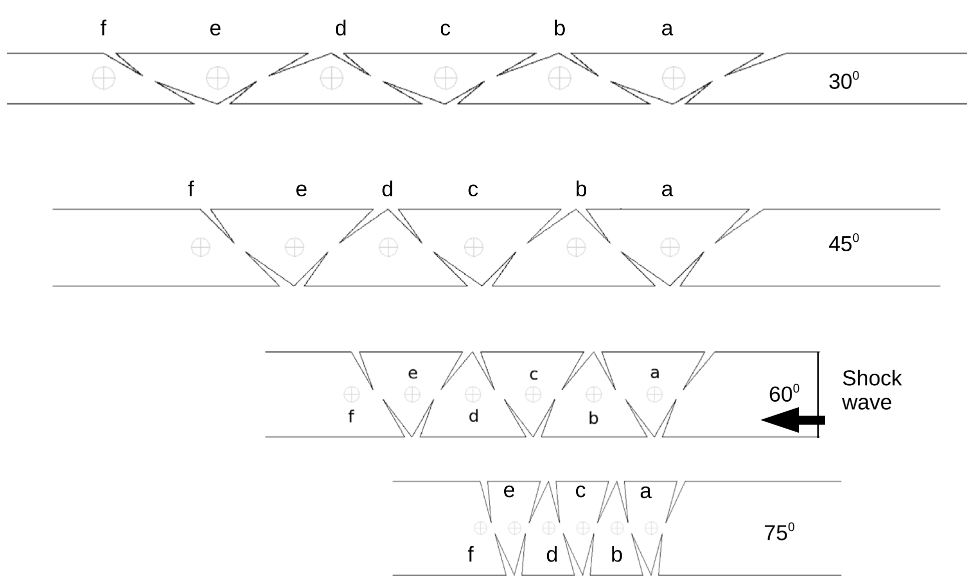

Fig. 4. Geometry of barriers installed at different orientation inside a straight duct.