Attenuation of Shock Waves using Perforated Plates

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Abstract. The shock/blast waves generated due to explosions cause wide spread damage to the objects in its path. Different techniques have been used to attenuate shock wave over pressure, to reduce the catastrophic effects. Perforated plates can be used effectively to attenuate the shock wave pressure. In this paper shock wave interaction with perforated plates is simulated using COMSOL multiphysics software. The pressure drop varied from 43.75\% to 26\% for porosity varying from 10\% to 40\%.

1. Introduction

When sharp/abrupt pressure change takes in a narrow/confined region passing through a medium, predominantly air, a shock wave is generated. Shock waves can be generated when explosion occurs or when a body moves faster than speed of sound in the medium. Shock waves other than being part of high-speed aerodynamics are also used in biological science [1], medicine [2] and industry [3]. The blast/shock wave generated due to explosions travels at high speed with large over pressures. It can cause wide spread damage to the objects in its path. Many methods have been used to attenuate the peak pressure of a shock wave. Some of these methods are, employing abrupt changes in the tunnel geometry, inserting rigid barriers along the wave path, using non rigid barriers, interaction of shock front with porous media. Shock waves propagating inside tunnels can be attenuated by forcing it to pass through duct where the geometry changes abruptly. In addition to this, surface roughness of the walls is also increased. When a large intermediate chamber is used, better results are observed due to longer expansion chamber [4]. Shock wave peak pressure reduction can be achieved using solid/dust particles like granular filters. These are the particles of different size and shape which are introduced in the path of travelling shock. The peak pressure got reduced before it travels to the surroundings. A Britain et.al [5] have shown that gap between the end of the granular filter and test section is also a dependency factor. Shock wave attenuation can be high when a foam of greater thickness is used. Beric W Skews [6] have shown that the properties porosity, thickness, permeability, stiffness, pore geometry of foams are important in the attenuation of shock waves. The liquid droplets in the form of a foam suspended in a solid phase act as barriers that reduce the peak pressure. Porosity is the dependency factor for the type of foam. It can be either dry, wet or bubbly aqueous form based on the
value of porosity, Britian et al [7]. The dry aqueous foam structure is discussed by E. Del Prete et al [8]. A dry aqueous foam consists of a plateau border, vertex and face. These plateau border acts as a barrier that absorbs the energy. It breaks down absorbing some energy, similarly the shock wave passes through the plateau borders series, and the resulting wave would be of less magnitude. The aqueous foam material loses its property over the time as borders of plateau gets depleted over time. This problem can be overcome by using granular filters. But it is very heavy to carry or to prepare it compared to aqueous foam materials Britan et.al [9]. Peak pressure reduction can be achieved by using rigid barriers. A porous plate as a rigid barrier is used in a test section where a shock wave is inducted. Porous plates of different shapes and porosities are used. Different shaped pores like circular, square, triangle etc. are used. It was observed that there is a greater peak pressure reduction [4]. Two or more plates are used with some separation distance for higher attenuation. G.S. Langdon [10]. In this paper, they inferred that both blockage ratio and separation distance influences the shock wave attenuation. In another study, ribs punched plate was used which restricted the shock wave, when passed through it, series of vortices are formed behind the ribs and the leading edge where the gas transmitted and the gas present reaches the same pressure M. E. H. van Dongen [11]. Attenuating shock wave peak pressure can also be done by using non rigid barriers. Structures in the form of triangular wedges/baffle plates are installed in the way of shock propagation. F. Ohtomo [12] have used both normal and oblique baffle plates arrangement. When compared, the arrangement used by oblique baffles got more attenuation. In the present work shock have attenuation using perforated plates is studied.

2. Methodology

In the present work, propagation of shock wave through porous plates is simulated using COMSOL Multiphysics software. The shock tube consists of driver and driven sections modelled by patching as shown in figure 1. High Mach number flow module with time dependent study is done. The continuity, momentum and energy equations are solved.

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0
\]

\[
\rho \frac{\partial \mathbf{u}}{\partial t} + \rho (\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \cdot \left( -p \mathbf{I} + \mu (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3} \mu (\nabla \cdot \mathbf{u}) \mathbf{I} \right) + \mathbf{F}
\]

\[
\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u} \cdot \nabla T + \nabla \cdot \mathbf{q} = \mathbf{Q}
\]

where \( \mathbf{u} \) is the fluid velocity, \( p \) is the fluid pressure, \( \rho \) is the fluid density, and \( \mu \) is the fluid dynamic viscosity \( T \) is the temperature.

Solving these equations for a given set of boundary conditions, predicts the fluid velocity, pressure and temperature in a given geometry. Different Mach numbers can be obtained in the shock tube by varying pressures in the driver and driven sections. The shock wave while propagating through the shock tube interacts with perforated plate. The perforated plate is modelled as solid cylinder with holes in it as shown in figure 2. The porosity of the plate is the ratio of area of plate through which flow is allowed to pass unaffected to total area of plate.
For circular perforated plates, the above equation can be written as

$$\text{porosity} = \frac{\text{porous area}}{\text{total area}}$$

Where $n$ is number of holes, $r$ is radius of the each hole and $R$ is radius of circular perforated plate.

3. Results and Analysis

The shock wave propagation through the shock tube is simulated for different initial conditions so as obtain different Mach numbers. The driver side pressure is varied from 3 bar to 13 bar and the driven side pressure is kept constant at 1 bar. The simulated values for primary and reflected shock strengths $P_2/P_1$ and $P_5/P_1$ respectively are compared with theoretical values obtained by using Rankine-Hugoniot relations (equations 1 and 2). Figures 3 and 4 show variation theoretical and simulated values for pressure jump across primary and reflected shock. From these figures it can be concluded that the difference between theoretical and simulated values is negligible. Figure 5 shows a typical pressure trace at two different points in the driven side of the shock tube. It shows the primary and reflected shock. The shock Mach number is calculated by knowing the distance between these points and the time taken for the shock wave to travel between these points.

$$\frac{P_2}{P_1} = \frac{2\gamma_1M^2 - (\gamma_1 - 1)}{(\gamma_1 + 1)}$$  \hspace{1cm} (1)

$$\frac{P_5}{P_1} = \left[\frac{2\gamma_1M^2 - (\gamma_1 - 1)}{(\gamma_1 + 1)}\right]\left[\frac{(3\gamma_1 - 1)M^2 - 2(\gamma_1 - 1)}{(\gamma_1 - 1)M^2 + 2}\right]$$  \hspace{1cm} (2)

Where $\gamma_1$ is the ratio of specific heats, $M$ shock Mach number, $P_1$ is the initial pressure in the driven section, $P_2$ and $P_5$ are primary and reflected shock pressures.
To study the shock wave propagation through the perforated plate, it is modelled as a cylinder with holes and is kept at the end of driven section. The pressure of the shock wave is noted before and after it passes through the perforated plates. Figure 6 shows pressure variation with time in the shock tube with perforated plate in the driven section. It can be observed that there is considerable pressure drop after the shock wave passes through the perforated plate. Figures 7 and 8 show the pressure contours inside the shock tube before and after the shock wave passes through the perforated plate. It can be observed that after the shock wave passes through the perforated plate it loses its momentum and the peak pressure also drops. The simulations are done for different porosity plates. The porosity of the plates is varied by changing the number holes on the plates. The simulations are done for plates with porosities varying from 10% to 40%. Figure 9 shows the variation of pressure drop (%) with porosity (%). It can be seen that as porosity increases the pressure drop decreases. The perforated plates can be used effectively to attenuate shock/blast waves.
4. Conclusions

Shock wave propagation through the shock tube is modelled and the interaction of shock wave with perforated plates is studied. The shock wave pressure drops as it passes through the perforated plates. The percentage pressure drop varied from 43.75% to 26% for porosity variation from 10% to 40%. Hence, the perforated plates can be used to attenuate shock/blast waves.
5. References

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