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Modeling and Designing for Acoustic and Pressure Drop of Perforated Tube in the Path of Unsteady Compressible Flow

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Abstract: Perforated elements are widely used in silencers. Two important parameters in these geometries are their acoustic and hydrodynamic performance. The main purpose of silencers is to reduce the sound, but the pressure drop in them is inevitable. This research presents modeling of a perforated path for unsteady compressible flow to predict acoustic and hydrodynamic behaviors.

Keywords: Perforated element; Acoustic; Hydrodynamic; Compressible Flow; Modelling.

Introduction

In order to estimate the acoustic and hydrodynamic behavior of complex geometries, one must use large and complex computational codes such as Ansys Fluent or convert them into simple geometries using modeling. Many studies have been done on the dynamics of fluid flow in perforated pipes such as [1-3].

The present research aims to model a perforated plate or pipe in the path of unsteady compressible flow so that its acoustic and hydrodynamic behavior can be predicted. Therefore, by simplifying the perforated pipe into a set of independent orifices, an acceptable estimate of its acoustic and hydrodynamic behavior becomes possible.

Assumptions of Governing Equations

The most general description of fluid flow is Navier-Stokes equations in three directions and mass and energy conservation equations. According to the physics and geometry of the problem, equations can be converted from complex to simple forms with using assumptions. Here, the fluid flow equations of unsteady, non-viscous, non-linear, and one-dimensional are considered, and the effect of viscosity is considered as a source term.

Numerical Simulation

Finite difference methods with two-order accuracy of the Lax–Wendroff and MacCormack have been used to solve the equations. Although the response of these methods fluctuates at the location of the shock (or discontinuity). By using oscillatory methods, the solution becomes stable without reducing the accuracy of the method. To reduce the error of the one-dimensional solution method, the appropriate correction length of each geometric discontinuity is considered. Some of the most important geometries are connections, cross-section changes and perforated pipes. In the upstream boundary conditions, the excitation source that induces the wave motion to the system is defined as harmonic disturbance.

Acoustic elements are modeled by the system-tube method, which is a set of series and parallel tubes. The end effect and discontinuities are considered by applying relations related to the modified length with the modeling of the pipe system. Perforated pipes can be found in most mufflers. The perforated pipe is usually placed inside a larger pipe or chamber (Figure 1). The connection between the hole and the chamber and the hole and the inside of the pipe is established through the T branch. In many cases, silencers are made as a combination of reactive and absorption silencers, and it is important to model these components. The absorbing medium consumes sound energy, which is simulated here as a wide or concentrated pressure drop. Two methods of constant pressure and pressure drop are used to analyze multi-pipe branching.

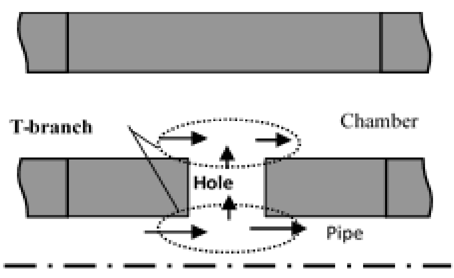

Fig.1: The connection between the hole and the chamber.

Results and Discussion

To validate the modeling performed in this research, it is necessary to compare the simulation results with the experimental results. In Figure 2, the estimated and experimental results of the muffler transmission loss curve are compared. It can be seen that the amplification frequencies and the real transmission loss range have been well detected by the estimation method.

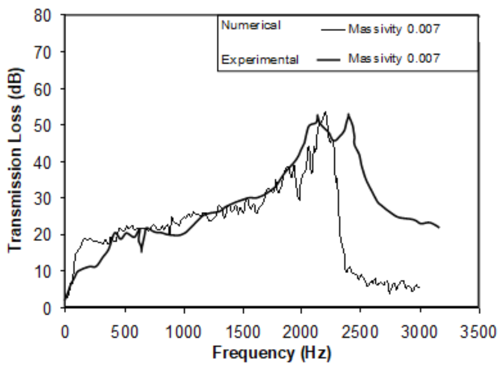

Fig.2: Comparison of estimated TL with experimental results.

The main factor in the pressure drop in the silencer is the diffuser, which is a perforated tube. Due to the importance of the pressure drop in the silencer design, it is also calculated. The diffuser consists of a large number of circular holes so that each circular hole can be considered an orifice. Orifice pressure drop is calculated using mass flow rate and the discharge coefficient. The mass flow rate of the fluid in each orifice is obtained by dividing the mass flow rate of the total fluid by the number of orifices. The discharge coefficient of the orifice can be obtained from the table or diagram according to the diameter of the orifice [4 , 5].

According to Figure 3, the holes are like orifices surrounded by interconnected hexagonal channels. Each hole and hexagon acts as an orifice inside the channel. Therefore, a perforated plate or tube (diffuser) is simulated with an orifice. For hexagons, the equivalent diameter D_{eq} is defined. In Figure 3, the diameter of the holes is shown by d_o and the distance from the center to the center of two adjacent holes is shown by S.

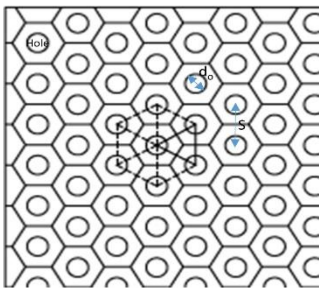

Fig.3: Arrangement of holes and virtual channels.

In the laboratory of Sanat Project Toos Company, three tests were performed on the tube and the perforated plate. The test results are given in Table 1. The result of the test is the calculation of the discharge coefficient C_d of each pipe hole and perforated plate, which is shown in the last column of this table. These results are in good agreement with the reference diagram [4].

Table1: Pressure drop measurement results

Flow Rate [kg/h]	Holes No	d_Orifice [m]	Δp [pa]	C_d
2768	1073	0.004	23000	0.472
2768	283	0.01	1800	0.576
2644	283	0.01	1600	0.584

Conclusions

By simplifying the perforated pipe into a set of independent orifices, the complex geometry of the perforated pipe turns into a simple geometry of series and parallel channels. Based on this, the simplifying assumption of one-dimensionality of the fluid flow in the channels, its numerical solution is simplified and the acoustic and hydrodynamic performance of the perforated pipe is estimated with a good approximation. The results obtained from the performance test of the perforated pipe in the laboratory of Sanat Project Toos Company also confirm the numerical and analytical estimation.

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