DESIGN AND AEROACOUSTICAL COMPUTATIONAL ANALYSIS OF MODIFIED GUN SUPPRESSOR

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Abstract:

The study of noise generation through turbulent fluid motion or aerodynamic forces interacting with surfaces is known as aeroacoustics.Flow induced sound can be created by turbulent wakes, detached boundary layer, vortex structures in the flow and flow interaction with solid walls. According to world health organisation (WHO) report, side effects of noise can involve fatigue, stress, hearing loss, and hormonal imbalance. This noise issue is closely associated with gun firing also. Suppressors are an accessory component for firearms that reduces the noise and muzzle flash during gun firing. The suppressors enhance the shooting experience by reducing the risk of hearing damage and noise pollution. In compact mission operation it will protect the shooter's location by suppressing the loud sound from firearms in the same way it will prevent from muzzle flash which causes temporarily blind for shooters or give the shooter's location due to its brightness especially at night. The presented work is about an implementation of porous material to reduce the sound reflection as well as to increase the heat dissipation and there by reduces the sound. Modified gun suppressor is designed and analyzed numerically in this investigation. The transient solver for transonic/supersonic turbulent flow is used in the open source CFD software Open Foam and the solver is rhoPimpleFoam. From the analysis, the pressure fluctuation plot with respect to time is taken and is compared with the results from the paper 'CFD approach to firearms sound suppressor design'.

Key words: Gun Suppressor, muzzle flash, loud sound, porous material, sound reflection, CFD, OpenFoam, rhoPimpleFoam, pressure fluctuation plot.

1. INTRODUCTION:

A strong and sharp sound of the shot is produced by the rapid expansion of the hot gases formed when the gunpowder is burnt. Reducing the speed and temperature of these gases leads to a reduction in shooting noise. In conventional suppressors, special chambers are used in which gases reduce their velocity and temperature. The gases then leave the suppressor without making any loud noise. The first commercially available suppressor is invented by Hiram Percy Maxim, it was a tubular device attached to the barrel of a firearm which reduces noise and muzzle flash when fired. Aeroacoustics is part of the broader topic of acoustics which is centrally concerned with the generation and propagation of sound through a fluid.

Aeroacoustics is a comparatively young subject area. This is mainly because of the fact that it took until 1952, when Lighthill formulated his famous aeroacoustic wave equation and thus founded the field of modern aeroacoustics. With the help of the source terms in Lighthill equation it became possible to physically understand for the first time the origin of sound produced by free turbulence. The derivation of this very equation initiated many developments extremely important for the understanding of aeroacoustic sound generation in general. Aeroacoustics is centrally concerned with the generation and propagation of sound through a fluid Aeroacoustics is part of the broader topic of acoustics, the latter of which can include sound propagation through other types of media, including solids, plasmas, etc. Our research is primarily concerned with the generation, propagation, and minimization of sound produced by gun fire. Through a combination of theory and computation we analyze complex systems from a physics-based perspective, usually solving the two- or three-dimensional compressible Navier-Stokes equations directly.

Acoustics can be divided into two main categories: linear and nonlinear. When sound propagates through a medium it compresses and individuality the medium as a longitudinal wave. When the compression, also known as condensation, reaches certain levels, the sound becomes non-linear. The wave will have greater values of condensation as the sound amplitude increases. Nonlinear effects take place around 200 dB, which is well above the threshold of pain at 130 dB. Typical sources of non-linear effects would be explosions, sonic booms, and other extraordinarily loud events. Additionally, waves of different amplitudes will generate different pressure gradients, contributing to the non-linear effect.

Baffle type suppressor:

Baffle silencers, housed in rectangular or cylindrical enclosures, which include one or more acoustic absorbent baffles. Constructed as a cassette, each baffle contains the absorbent material that converts noise energy into friction heat. Different types of absorbent materials are used dependent upon specifications and noise attenuation. The baffle thickness (spacing and length) has two different functions, the amount of noise attenuation and the frequencies treated. A stacked baffle design can more effectively work the gases and therefore can make a quieter silencer with less length. The increased surface area of the stacked baffle design also helps to pull the heat out of the gases faster, which also aids in reduced decibels. The stacked baffles take a little more precision, supplies, and labor. The baffles must be perfect to ensure that they are aligned straight to avoid baffle strikes, plus the baffles must almost lock into place together to keep them from moving and messing up the alignment.

Porous material for sound suppression:

Flow of liquid or gas into the pores of Porous aluminium is an optimal material for weapon silencers. This material consists of 55-65% of cells connected to each other. Porous aluminium is permeable to gases in all directions. The special shape and structure of the pores give a long contact time between the gas and the porous aluminium matrix. Gas flows follow complex paths with vortices. The combination of different pore sizes makes it possible to control the gas movement very precisely. In addition, products made of porous aluminium can be manufactured in any shape, no matter how complex it is and it will increase the heat transfer and there by decrease the temperature of the hot gas.

2. SUPPRESSOR 3D MODEL DESIGN:

A all new suppressor design is modelled using the Salome software as shown in the fig (1)

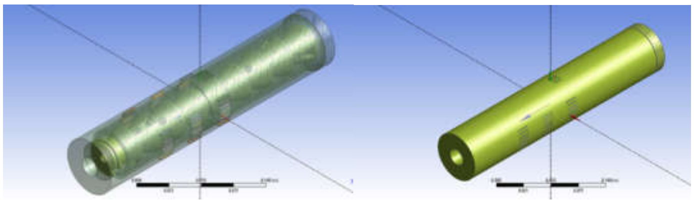

Fig (1). The left model shows the transparent design of the gun suppressor and right model shows the solid design of the gun suppressor

The above model is an assembled structure of three components mainly baffle stack, porous material and outer cover.

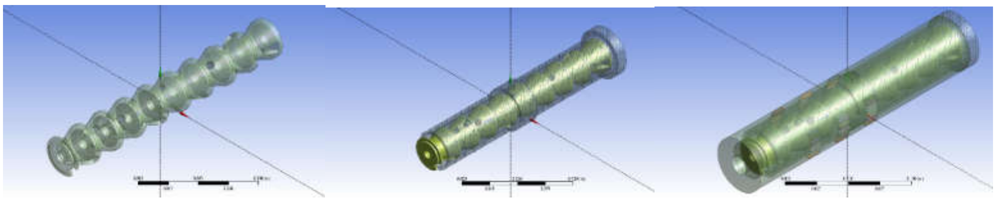

Fig (2). The figure from the left to right shows the assembling sequence of the gun suppressor

From left to right fig (2), first comes the innermost part which is baffle stack then over the baffle stack the porous material is fitted and finally the outer covering.

2.1. Two dimensional model of the design:

The 2D model of the suppressor is modelled by slicing the 3D suppressor design and a domain is also created using Salome as shown in the figure (3)

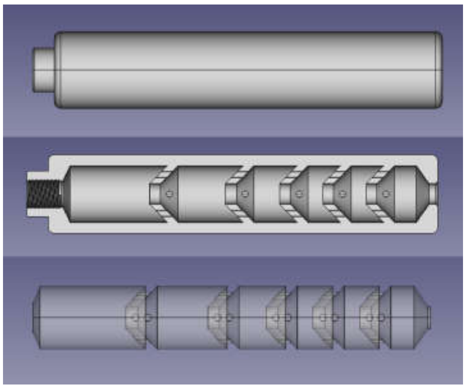

Fig (3). The figure shows the 2D model of suppressor

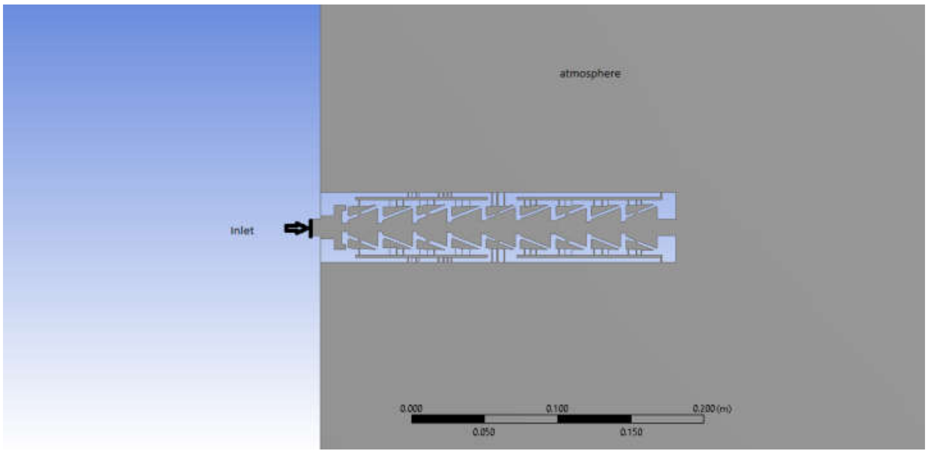

Fig (4). The figure shows the zoomed view of the 2D domain

3. NUMERICAL METHODOLOGY-CFD Approach using OpenFoam:

OpenFOAM is an opensource software, (Open-source Field Operation and Manipulation) it has C++ toolbox for the development of customized numerical solvers, and pre-/post-processing utilities for the solution of continuum mechanics problems, most prominently including computational fluid dynamics (CFD). For suppressor case rhoPimpleFoam solver is used to solve the transient, turbulent and compressible flow.

3.1. Boundary conditions:

For velocity, a no-slip condition is used in the fluid-solid interface. For the temperature, the walls are set to zero Gradient. This boundary condition, applied to temperature, designates that there is no temperature gradient orthogonal to the wall. In other words, it makes the assumption that the walls are adiabatic. Though there will always be some level of heat transfer, this analysis is dealing with the wave reflection so a zero gradient boundary condition can be used. For the pressure, a boundary condition called wave Transmissive was used. This condition is an approximation of the Navier Stokes characteristic boundary conditions (NSCBC) applied to the pressure. This condition was chosen because of its ability to adjust the reflectivity of the walls. This boundary condition requires 4 different pieces of information: gamma, fieldInf, lInf, and value. Gamma refers to the ratio of specific heats, fieldInf refers to far field value to be applied to the pressure, lInf refers to how far away the far-field condition should be, and value is the initial field pressure. These values were set to 1:4, 101325 Pa, 0.5, and 101325 Pa respectively. The reflectivity of the boundary can be adjusted with the lInf value. The smaller the value, the more reactive the boundary will be.

Table 1. Boundary Conditions

	Inlet	**Outlet**	**Wall**	**Front & Back**
P	Uniform Total Pressure	Zero Gradient	Wave Transmissive	empty
U	Pressure Inlet Outlet Velocity	Inlet Outlet	No Slip	empty
T	Zero Gradient	Zero Gradient	Zero Gradient	empty

3.2. Initial Conditions:

The initial field values of the case were selected to mimic typical static atmospheric air conditions. The temperature was set to 300 K, the velocity was set to zero in all directions, and the pressure was set to atmospheric pressure (101325 Pa). It is worth noting that depending on the solver being used, the pressure might be read in kinematic form, which is pressure in Pascals divided by the density of the medium. This unit is used in OpenFOAM purely for mathematical purposes. Incorporating the density into the pressure allows the Navier-Stokes equations to be solved without explicitly showing the constant fluid density. Having used a compressible solver, a constant density cannot be assumed and as such the solver calls for pressure in Pascals. In addition to the key parameters of the problem being set and in order to run an accurate simulation, the thermophysical properties also needed to be defined.

These were set in the thermos Physical Properties dictionary. In this dictionary, the number of moles was set to 1, with a molecular weight of 28.9, according to typical air. Specific heat was set to 1004.9, heat fusion to 2:544E06, dynamic viscosity to 1:846E-05, and a Prandtl's number of 0.707. Once the base characteristics of the fluid were set, a sound impulse was created. To produce a sound impulse, a region at the inlet of the grid was set to have a higher pressure value than the rest of the fluid. To do this, the terminal command setFields was used, which calls the dictionary called setFieldsDict to alter the initial conditions. The dictionary was set to call a function named sphereToCell, which as the name implies allows one to impose new conditions in a specified spherical region. Since the simulation was to be in 2D, the sphere was simply placed on that 2D plane such that a circular slice would be imposed on the plane.

The rest of the sphere would fall outside of the simulation and thus be void. The spherical region to be adjusted was placed at the center of the grid (1.2, 3.1,.05) and given a radius of .03 m. The specified region was given a pressure value of 41368543.8Pa (6000psi) and given a velocity value of 304.8m/s in x-direction.

3.3 Solver:

For the solver, rhoPimpleFoam was chosen and transonic is switched ON. The solver is defined as a transient solver for trans-sonic/supersonic turbulent flow. Because nonlinear acoustics deals with high sound amplitudes, it is not uncommon for this area of acoustics to reach the sonic level. As such it was decided that rhoPimpleFoam would be an appropriate solver.

4. RESULT & DATA ANALYSIS:

A location is chosen as in the paper [1] to capture the pressure variation at that point. The table shows the openfoam results of pressure variation generated at the location with respect to time.

Table 2. Simulation result of pressure and time at different location

Time (unit)	pressure (Pa)	Pressure (atm)
0	101325	1
0.0001	111660.15	1.102
0.0002	111771.6075	1.1031
0.0003	111173.79	1.0972
0.0004	107911.125	1.065
0.0005	106320.3225	1.0493
0.0006	101325	1
0.0007	101183.145	0.9986
0.0008	101102.085	0.9978
0.0009	101325	1
0.001	102307.8525	1.0097
0.0011	101335.1325	1.0001
0.0012	101325	1
0.0013	102267.3225	1.0093
0.0014	102176.13	1.0084
0.0015	100666.3875	0.9935
0.0016	101345.265	1.0002

0.0017	101193.2775	0.9987
0.0018	101325	1
0.0019	101325	1
0.002	101325	1

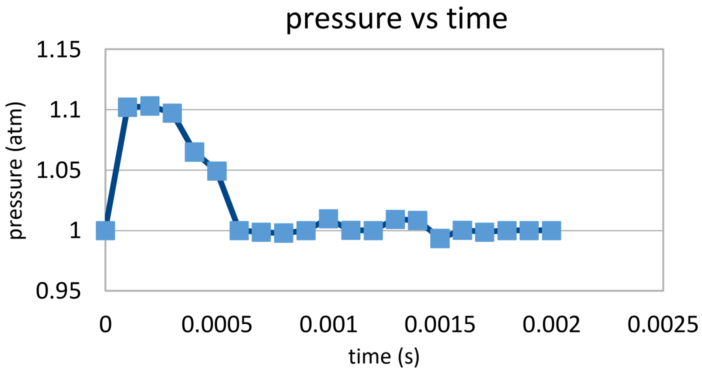

Fig (5)The graph shows the pressure vs time plot from the openFoam data result

The generated graph is compared with the graph from the paper 'CFD approach to firearms sound suppressor design'. The peak value pressure from the graph generated is 1.1031atm fig(5).

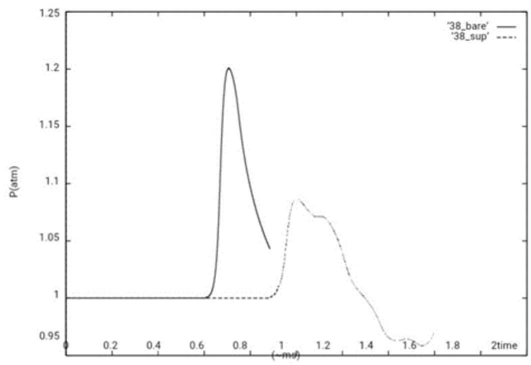

Fig. (6) The figure shows the pressure vs time plot from the paper "CFD approach to firearms sound suppressor design"

From the figure fig(6), The light line shown in the graph represent the pressure variation experienced at the location when suppressor is used and the peak pressure value is 1.0987atm. The bold line represent the pressure variation when suppressor is not used and the peak pressure value is 1.1704atm.

5. CONCLUSION:

The flow-induced sound generated by sudden pressure variation of air is analyzed by OpenFoam. The pressure fluctuation plot is also obtained at a specific location. On comparison of the graph from the paper 'CFD approach to firearms sound suppressor design' the modified suppressor design suppresses the peak pressure fluctuation of about 5.75%. On comparing the suppressor mentioned in the paper with the new design, there is a slight greater value of peak pressure with a difference of 0.0044atm. This may be due to not taking in account of heat transfer effect in our analysis settings.

6. REFERENCES:

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