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STUDY REGARDING VEHICLE ENGINE NOISE ANALYSIS

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Abstract: This paper emphasis on the possibilities to analyze sound propagation with the help of partial differential equations solved by the finite element method, using the MATLAB programming environment.

1. INTRODUCTION

As sound pollution had become an important issue in present days society, a large number of scientific papers are emphasizing on the analysis of noise and vibration generated by vehicles engines. This noise plays a major role not only in city traffic sound pollution, but in the comfort of car drivers and passengers. Related studies are mainly focused on the following issues:

- how noise is generated by the engine;
- how the sound propagates in the engine casing;
- what are the measures that can be taken in order to reduce the noise.

To achieve these goals some theoretical and experimental methods had been developed. These methods and algorithms can be used in a large number of applications, although theoretical studies must be verified in practice.

Experimental methods [4],[6] are focused on the more and more accurate measurement of noise, using high-tech microphones and computerized data acquisition. Signal processing algorithms are then applied to study the components of the measured sound waves in order to find new designs and new materials for sound absorbent engine covers [5].

The theoretical methods [1],[2],[3] are mainly focused on numerical modeling and simulation, both of the sound source and of it's environment (the engine casing).

This paper emphasis on the possibilities to analyze sound propagation with the help of partial differential equations solved by the finite element method, using the MATLAB programming environment.

2. ANALYSIS OF EIGENFREQUENCIES.

Resonance is a well known phenomenon in physics. It can also be a problem in vehicle acoustics. The low bass notes may shake the windows, and make the car plastic parts vibrate. This happens only for certain frequencies the so called eigenfrequencies of the interior of the car or engine casing. It's only in the lower registers that the eigenfrequencies are well separated. In the middle and high registers they are packed so closely, with less than a halftone between them, that the individual resonance are insignificant for natural sounds.

When designing a car interior it's therefore important to take the resonance into account.

Eigenmodes can be studied either by boundary element or by finite element methods. The eigenmodes show the sound intensity pattern for its associated eigenfrequency. From the characteristics of the eigenmodes we can draw some conclusions as how the interior of the car or engine casing have to be designed. Sound propagating in free air is described by the wave equation

$$-\Delta p + \frac{l\partial^2 p}{c^2 \partial t^2} = 0 \qquad (1)$$

where p is the pressure, and c is the speed of sound. If the air is brought into motion by a harmonically oscillating source (which can hapen also with the car engine), only one dominant frequency f will be present. For that reason it makes sense to look for a time-harmonic solution on the form:

$$p = \hat{p} e^{i.2.\pi.f.t} \qquad (2)$$

The wave equation then simplifies to Helmholtz's equation for $\hat{p}$ the amplitude of the acoustic disturbances:

$$\Delta\hat{p} + k^2 \hat{p} = 0 \qquad k = \frac{2\pi f}{c} \qquad (3)$$

Begin with letting all boundaries be perfectly rigid. This means that the normal velocities vanish everywhere. From the basic linearized equations of hydrodynamics we have the relationship:

$$\nabla p = -\rho \frac{\partial u}{\partial t} \qquad (4)$$

where ρ is the density and v is the velocity. So the boundary condition on the pressure is the Neumann condition $n \cdot \nabla p = 0$.

This analysis method can be successfully applied to study the design of car interiors and engine casing in order to find designs, which are free of resonance. The method is implemented in FEMLAB (a finite element engine running under MATLAB) and can be adapted for automotive applications.

3. ANALYSIS OF SOUND WAVE PROPAGATION.

This example studies how sound generated by vibrating car engine propagates in still air. Suppose the source is a car engine that has a main frequency of 15 Hz, equivalent to an angular frequency of $\omega = 2\pi \cdot 15$ *rad/sec*.

The model geometry is presented in figure 1 and 2 with the engine (a rectangular body) in the center and the casing (3 walls) around the engine.

The inertia of pistons and also the ignition generates vibrations which are exciting the engine outer casing enough for the deformity's periodic movement to excite at their turn pressure waves. Assuming the engine remains balanced, the lowest mode of vibration be transmitted to the engines outer surface. In this model, *a* represents the speed of sound, ρ gives the density of air, *k* is the wave number, and *d* describes the amplitude of the deformation. Additionally, *n* is the outward pointing unit normal. The sound pressure *p* satisfies the Helmholtz equation (3). To model excitation of pressure waves on the solid's boundary you can apply the Neuman condition

$$\frac{\partial p}{\partial n} = -\rho \frac{\partial u_n}{\partial t} \tag{5}$$

where u_n is the normal component of the velocity. In this case:

$$\frac{\partial p}{\partial n} = -\rho d\, 4\omega^2 e^{2i\Phi} \tag{6}$$

where Φ is the polar angle. If we also assume that there are no incoming sound waves, the generated field approximately satisfies the *Sommerfeld radiation condition*. The condition at the outer computational boundary is chosen to allow waves to pass without reflection. As |*x*| approaches infinity, *p* approximately satisfies the one-way wave equation

$$\frac{\partial p}{\partial n} + c\xi \nabla p = 0 \tag{7}$$

which allows waves moving in the positive ξ-direction only (ξ is the radial distance from the object). For simplicity reasons, we will let the outward normal of the computational domain approximate the outward ξ-direction. With the time-harmonic solution, this turns into the generalized Neumann boundary condition

$$\frac{\partial p}{\partial n} = -kip \tag{8}$$

When modeling sound waves, we want to make sure that there are enough mesh points to resolve the waveform sufficiently. To achieve this, a minimum of 4 mesh points per wavelength is recommended for quadratic elements. The generated mesh is presented in figure 3. The Neumann boundary condition for a reflecting walls (engine casing) is:

$$\frac{\partial p}{\partial n} = 0 \tag{9}$$

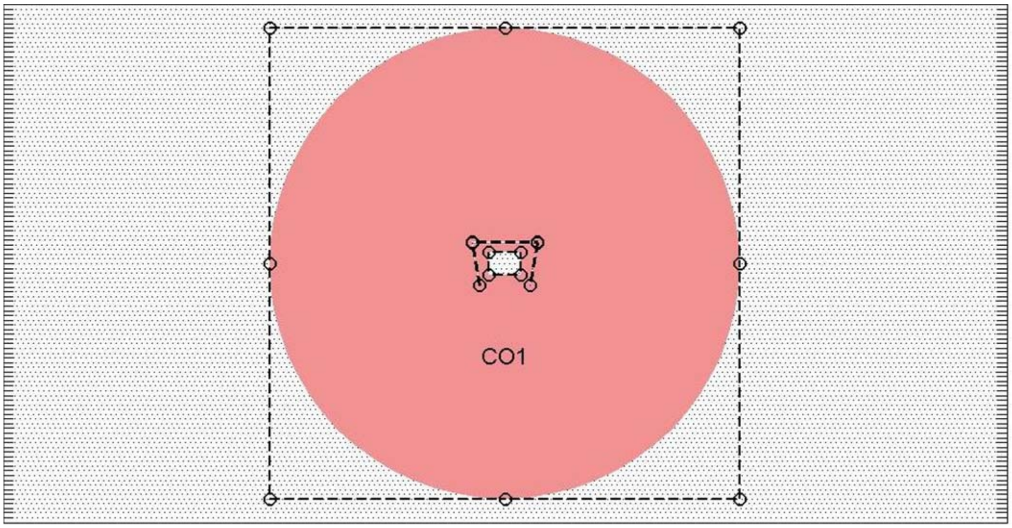

Fig. 1. Geometry of engine and casing model.

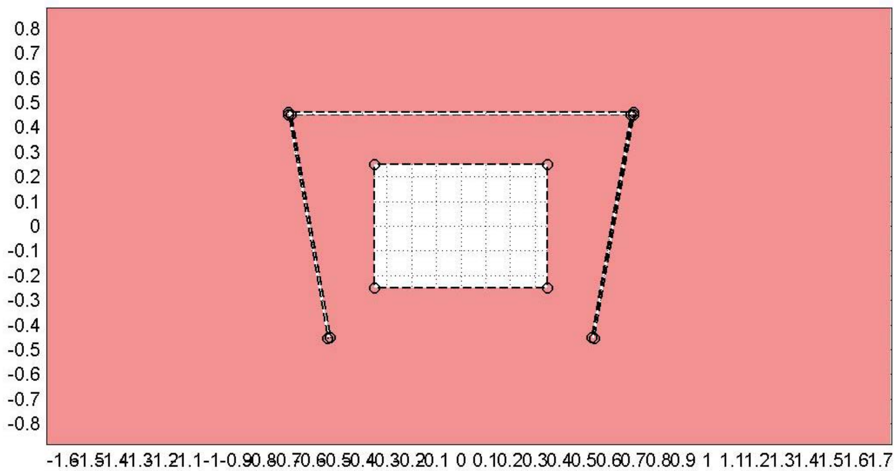

Fig. 2. Geometry detail.

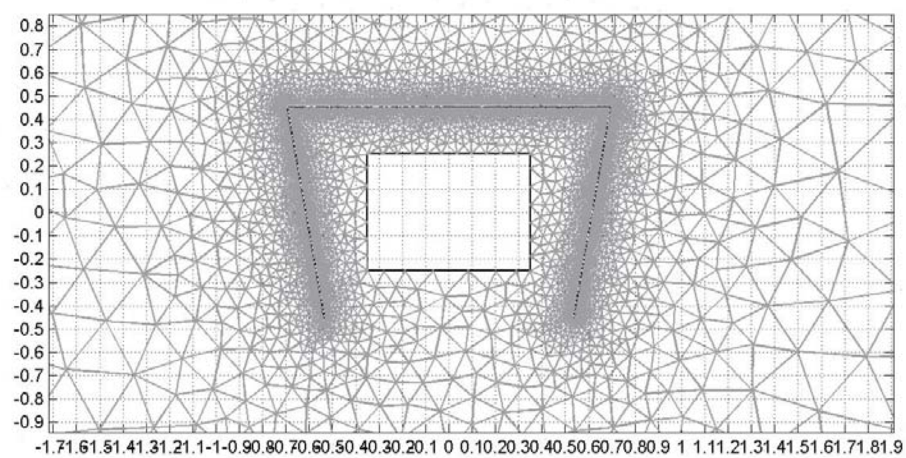

Fig. 3. Model meshing.

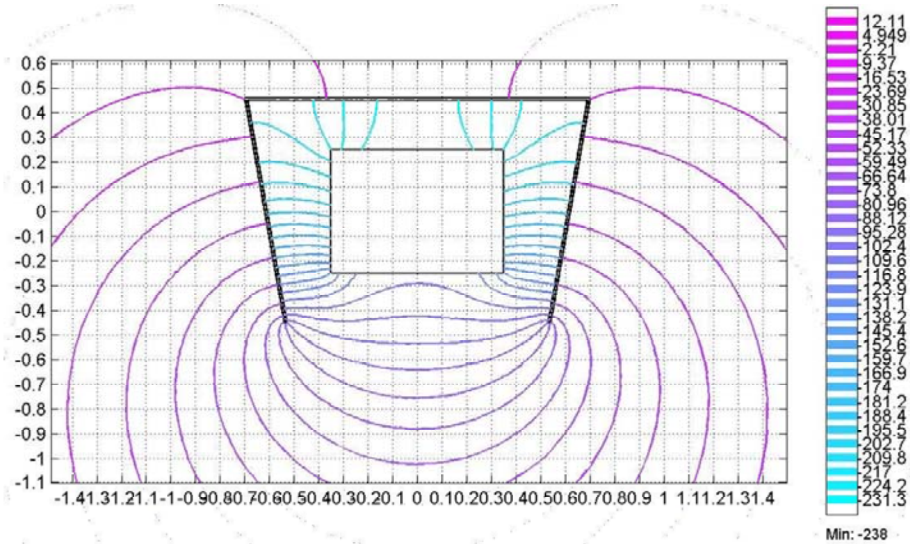

Fig. 4. Contour plot of velocity field.

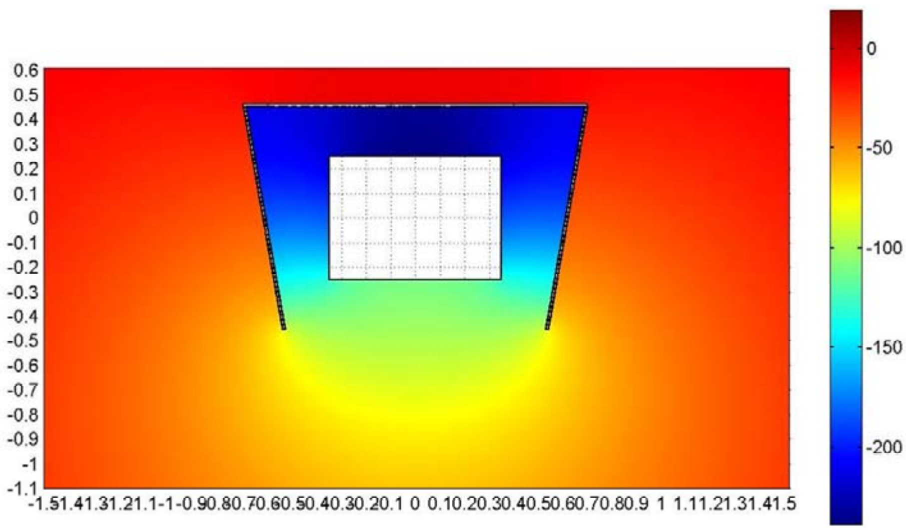

Fig. 5. Colormap plot of the velocity field.

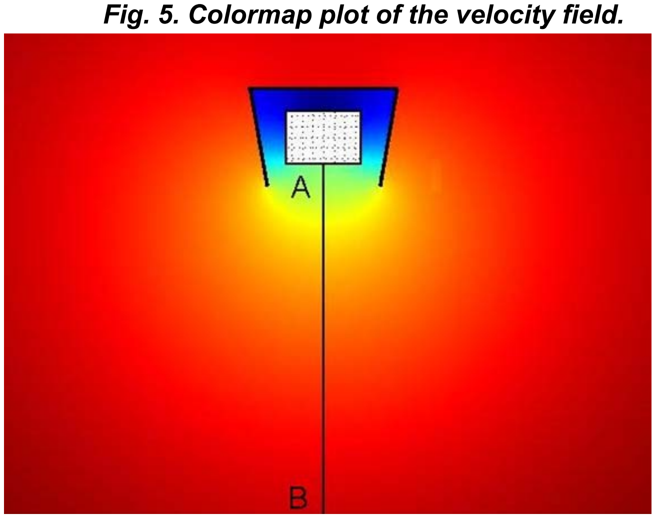

Fig. 6. Resulted velocity field enlarged view.

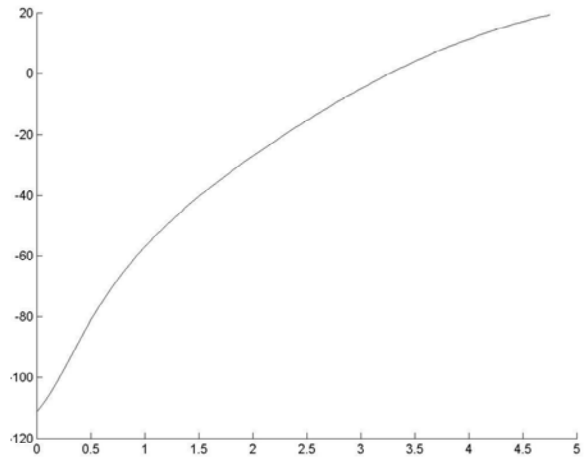

Fig. 7. Resulted velocity graph along A-B line in figure 6.

The results are presented in different forms in figures 4-7. The engine casing can be designed in different shapes in order to analyze the optimal shape for noise reduction.

4. CONCLUSIONS.

Studying the possibilities offered by finite element analysis, we can conclude that both presented methods can be used to develop cat interior and engine casing geometries, which can reduce the impact of engine noise on drivers and passengers. These methods must be further studied and correlated with measured data in order to obtain optimal designs.

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