Measurements and Modeling of the Transient Acoustic Field at Impacted Plates

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Abstract: A comparison is made between measured and simulated transient acoustic fields generated by impacted plates. The initial vibration and the radiation of the plate are modeled in the time-domain and discretized using appropriate numerical techniques. Optical measurements are obtained by using an interferometric comparison of two holographic recordings, captured before and after the impact. This yields a 2-D projection of the acoustic pressure field which can be compared to the simulations. A high degree of similarity is observed between measured and simulated sound fields, except in the close vicinity of the impact point.

INTRODUCTION

A number of sound sources are due to mechanical impacts against structures. The impact forces are often characterized by a large magnitude and a small duration and give rise to transient sound fields of particular relevance for our hearing. The complexity of sound fields generated by mechanical impacts makes it necessary to use time-domain methods rather than frequency domain methods for investigating them. The purpose of this paper is to investigate the nearfield of a cantilever steel plate (330x30x1 mm) impacted by an air-gun bullet at different instants of time shortly after the impact.

First, a numerical modeling of the plate vibration and radiation is conducted using finite difference methods. The sound pressure is calculated on a spatial grid near the plate at successive instants of time. A non-contacting optical technique based on pulsed holographic interferometry is used for measuring the sound field. In these experiments, a double exposed hologram obtained with the two-reference-beam technique yields an interference pattern which can be directly related to the spatial distribution of the sound pressure.

PLATE MODELING

It is assumed that the transverse displacement \( W(x, y, t) \) of the thin rectangular undamped isotropic steel plate of thickness \( h \) and density \( \rho \) is governed by the equation:

\[
\rho h \frac{\partial^2 W}{\partial t^2} = -D \nabla^4 W + q(x, y, t) \quad \text{with} \quad D = \frac{h^3 E}{12(1 - \nu^2)}
\]

where \( E \) is the Young's modulus and \( \nu \) is the Poisson's ratio of the plate. The plate is set into vibration through the loading \( q(x, y, t) \) which represents the impact of a lead bullet. The plate is clamped at \( x = 0 \) and free at the three other edges (see Fig. 1). The numerical simulation of the initially vibrating plate is conducted by using an explicit central finite difference scheme of 4th-order in space and 2nd-order in time. This scheme has proven to be a particularly good compromise between stability, frequency warping and computational burden [1]. The acoustic problem is assumed to be decoupled from the vibration. As a consequence, the pressure radiated by the plate is obtained through a time-domain formulation of the Rayleigh integral:

\[
p(\vec{r}, t) = -\frac{\rho_a}{2\pi} \int \frac{1}{||\vec{r} - \vec{r}_a||} \frac{\partial^2}{\partial t^2} W\left(\vec{r}_a, t - \frac{||\vec{r} - \vec{r}_a||}{c_a}\right) dS
\]

where \( \rho_a \) is the air density and \( c_a \) the speed of sound. Eq. (2) is put into a numerical form using a standard trapezoidal rule for approximating the integral. In order to allow direct comparison between numerical and experimental results, the pressure field is calculated in a number of planes perpendicular to the plate and averaged over its width.
A 0.5 g lead bullet (B) with velocity about 100 m/s is fired towards the cantilever plate (CP) (see Fig. 1). Just before the impact, a laser pulse emitted from the ruby laser (RL) yields a recording of the undisturbed air surrounding the plate on the holographic plate (HP). A second laser pulse is emitted a few fractions of a millisecond after the impact giving a second recording of the pressure disturbance on the same holographic plate [2]. The interference fringes can be related to the change in density along the optical path. The pressure is derived from density through classical thermodynamic relations. The holograms (see Fig. 2) yield two-dimensional projections (pressure maps) of the sound pressure field radiated by the plate. A high-speed camera has been used in order to investigate the impact process. This experiment indicates that the duration of the impact force is nearly equal to 35 μs. Since the exact shape of the force impulse is not known, this force is modeled as a cosine wave (Hanning window) in the simulations.

**FIGURE 1.** Geometry of the plate (left) and optical set-up (right). BS: beam splitter, M: mirror, NL: negative lens, O: object beam, R: reference beam.

**EXPERIMENTS**

**FIGURE 2.** Comparison between simulated (left) and measured (right) sound field of the impacted plate.

**DISCUSSION**

Fig. 2 shows a comparison between simulated (left) and measured (right) pressure distribution, about 140 μs after the impact. The plate edge is shown as a vertical line in the middle of the figures. Bright and dark regions indicate positive and negative sound pressure, respectively. In both figures, trace-matched acoustic waves are seen. These are radiated by the flexural bending waves in the plate. The dispersive character is clearly seen on the figures, the wavelength and the radiating angle becoming smaller further away from the impact point. The restrictions in the numerical model (baffled plate) imply that there is no interaction of sound between the left and right side of the plate. Therefore, comparisons above the upper edge are not relevant. The lead bullet impact involves plastic deformation and nonlinear effects due to its high velocity. These effects are not taken into account in the model. However, measured and simulated sound field agree well around the impact point although detailed comparisons should be performed with care. In conclusion, both the experimental and numerical methods have proven their efficiency in a simple case and should be extended in the future for the analysis of more complex transient acoustic fields.

**REFERENCES**
