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# On the Effect of Dense Fluid on Structures During Impact

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Abstract

The dynamical behaviour of impacting structures may be affected by the presence of a dense fluid. This paper investigates the forces exerted by the fluid based on a simple analytical model which refers to a liquid film squeezed by a pair of parallel flat and rigid surfaces. The forces are then introduced in a computer code for calculating the motion of impacting structures. Such calculations will be compared to experimental tests. At this respect encouraging preliminary results were obtained.

## 1. Introduction

Vibrating structures under varied sollicitations may undergo impacts, provided that the gaps between them is sufficiently small. These shocks modify the vibratory behaviour of structures and may cause wear or damage. Typical examples of such problem concern the tubes of steam generators with their support plate and fuel elements under a seismic event.

The effects of shocks may be very different when they occur in air or in the presence of a liquid, due to the fluid forces exerted by the squeezed film. The aim of this paper is to describe the first results of a research program made at CEA/DEMT, in order to analyze the behaviour of a squeezed fluid film separating two structures. Attention is focused here on the characterization of the forces exerted by the fluid during the shock. This includes [1] :

- an analytical formulation of the problem for a simplified geometry,
- the introduction of that model in a computer code for the calculation of the dynamic motion in different conditions,
- and an experimental validation on a simple apparatus.

## 2. Analytical Formulation

The analytical approach of the problem was carried out for a structure having an undeformable flat surface. This surface is squeezing uniformly a fluid film against a rigid wall (Fig. 1). The fluid is assumed to be incompressible and viscous.

The transient flow induced in the films by the transverse motion X(t) of the impacting surface is derived using the Navier Stokes Equations. However at this step the following simplifying hypotheses are introduced.

It has to be pointed out that fluid induced forces are important only when the film is becoming sufficiently thin, i.e. $X/L \ll 1$ where L is a typical dimension of the impacting surface. Hence flow velocity W parallel to the surface is much higher than the transverse velocity U (see Fig. 1). Consequently the mean value of W, as averaged along the transverse direction is simply given by the continuity equation:

$$\overline{W} = \frac{UL}{X} = \frac{\dot{X}L}{X} \qquad (1)$$

Concerning this lateral flow velocity profile W(x) two distinct hypotheses were investigated.

Provided $\overline{W}$ or $\dot{X}$ is sufficiently low, we may assume a parabolic profile in agreement with steady laminar flow. Fluid forces are then for an axisymetrical geometry:

$$F(t) = \frac{-\pi L^4}{8} \rho_f \left( \frac{\ddot{X}}{X} + 12\nu \frac{\dot{X}}{X^3} - \frac{12}{5} \frac{\dot{X}^2}{X^2} \right) \qquad (2)$$

The first term in eq.(1) represents the inertial fluid effect (added hydraulic mass). The second term represents the viscous dissipative effect and the third one take into account the dissipative effect occuring at the edge of the impacting surface due to the head loss. Here it is simply assumed that head loss corresponds to the dissipation of fluid kinetic energy at the surface edge.

When $\overline{W}$ is sufficently high, flow through the film is assumed to be fully turbulent and a uniform flow velocity profile is assumed across most of the film depth. Fluid force are then:

$$F(t) = \frac{-\pi L^4}{8} \rho_f \left( \frac{\ddot{X}}{X} - \frac{1}{2} \frac{\dot{X}^2}{X^2} \right) \qquad (3)$$

In this model dissipation occurs at the surface edge due to the head loss mecanism.

Actually it is expected that fluid forces will verify a relationship of the following general form:

$$F(t) = - \alpha\rho_f \left[ \frac{\ddot{X}}{X} + \beta \left( \frac{X\dot{X}}{\nu} \right) \frac{\dot{X}^2}{X^2} \right] \qquad (4)$$

where $\alpha$ is a coefficient depending only on the geometry of the problem, $\rho_f$ is the fluid density, $S_1 = \frac{X\dot{X}}{\nu}$ is a Stokes number characterizing the transient flow regime, and $\beta$ is a function of that Stokes number $S_1$.

## 3. Implementation in EVICHOC Code

The EVICHOC code allow the calculation of the dynamical behaviour in the linear or non-linear domain of structures [3] . The problem is projected on a model basis, and the motion is calculated using an explicit algorithm of De Vogelaere type [4]. As in all the explicit algorithms, the inertial term ($\ddot{X}$) of the structures is a pivot of the method, which introduces numerical instabilities when the inertial term due to the fluid become compartively high. This fact necessitates the introduction of a special treatment for the fluid shock case. It consists on a permanent correction, at each time step, of the pivot by the diagonal part of the projection of fluid inertial term.

## 4. Results of First Calculation

Two typical cases were analyzed by calculation. The first one concerned an undeformable projectile with an initial velocity $V_o$. During the compression of the film, fluid inertial ($\ddot{X}$) and quadratic dissipative ($\dot{X}^2$) forces reach their extreme values when the film depth X is of the order of magnitude of $\lambda = \alpha/M$ (M: mass of the projectile). The viscous ($\wp\dot{X}$) forces intervene at lower depths, dissipate few energy, but enough to stop the projectile at a critical depth (see Fig. 2):

$$X_c \sim \lambda_\nu \sqrt{\frac{8\nu\lambda}{V_o}} \quad (5)$$

The second case concerns the forced oscillating motion of a spring-mass projectile. When the amplitude $\tilde{X}$ of the oscillations is small compared to the film depth X, the energy dissipation by the fluid is predominantly due to viscousity. Typical damping ratio can then be evaluated as:

$$\varepsilon_v = \frac{1}{2} \frac{Ma}{M+Ma} \sqrt{\frac{2\nu}{\omega_o X^2}} \quad (6)$$

where $Ma = \alpha/X$ is the added mass due to the fluid. When $\tilde{X}$ increases, the quadratic dissipation become important, which means that the forced oscillating motion is no more sinusoidal. The importance of this effect and the equivalent damping ratio can be characterized by a stokes number associated to $\tilde{X}$: $S_2 = \omega_o \tilde{X}^2/\nu = S_1 \frac{\tilde{X}}{X}$ (see Fig. 3).

## 5. Experimental Validation

A special apparatus was realized in order to validate the model (Fig. 4). It consists of a circular stiff disc compressing a fluid film against a rigid wall. The uniformity of the compression is achieved by a set of flexible triangular blades supporting the rod holding the disc. The connection between the rod and the disc is made by a force transducer which measures the forces induced by the fluid.

Experiments with sinusoïdal excitations at different levels were carried out. The first results compare fairly well with the calculation for the inertial and the non linear effects of fluid (Fig. 5). They allow to adjust the boundary conditions chóosen in the derivation of equations (2) and (3).

## References


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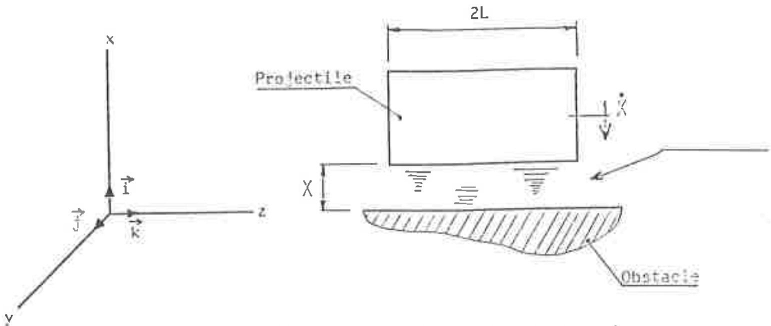


Figure 1 - Scheme of the simplified geometry of the problem

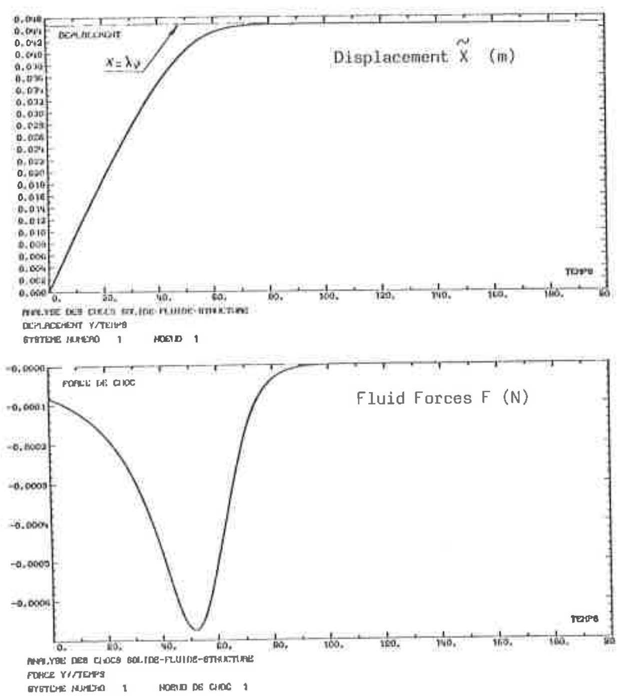


Figure 2 - Fluid-shock of a rigid projectile against an obstacle (Results of calculation with EVICHOC Code)

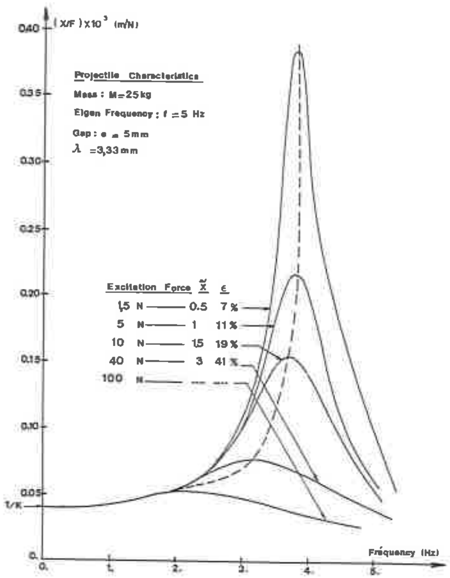


FIGURE 3 - Typical transfer function of a spring-mass system with squeezed film effect (calculation, evolution with the excitation level)

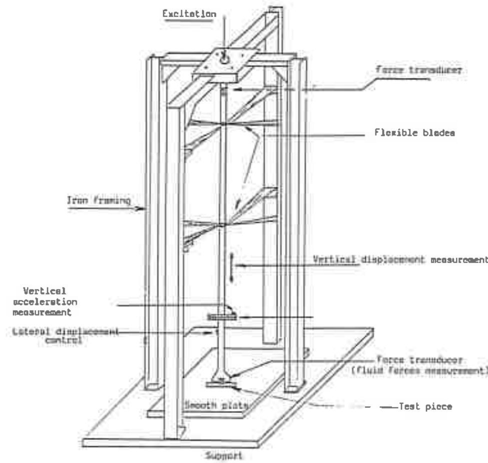


FIGURE 4 - Scheme of the test facility

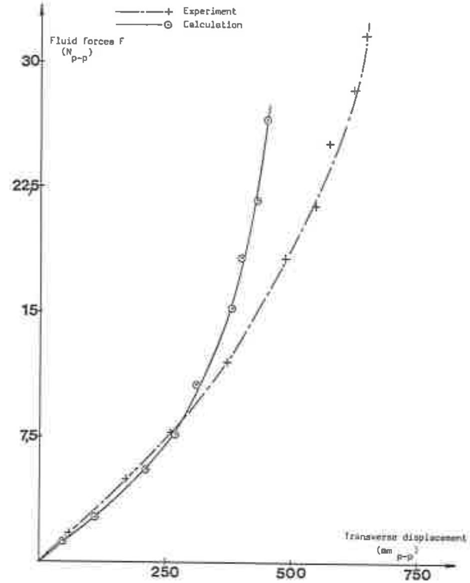


FIGURE 5 - Comparison between calculation and experiment