

ADLS102 - Meridian oscillator fluidelastic

Summary:

The objective is to calculate the displacement of the piston of a “oscillator meridian fluid-rubber band”. It is about piston-arises coupled with a fluid contained in a channel with rigid and fixed walls; the channel is crossed by a wave of depressurisation.

One considers the problem plan of this meridian model. This two-dimensional problem is brought back to a monodimensional problem by considering by approximation that the rates of transverse flow induced by the movement of the piston are transmitted instantaneously in axial speeds.

Only one modeling is used. The calculation of the modes is in formulation \mathbf{u}, p, ϕ . Elements 2D are thus used; these elements are based on meshes QUAD4 for the fluid and the piston, on meshes SEG2 for the interface between fluid and piston to take into account the fluid interaction structure (PHENOMENE='MECANIQUE', MODELISATION=' 2D_FLUI_STRU').

The boundary conditions of nonreturn of the wave are carried out by modelling a piston shock absorber at each end; the excitation is carried out by applying a depression to the piston of entry.

The fluid which one considers is water (hot), the model schematizing the interaction fluid-structure in annular space between tank and envelope of heart during a fast depressurisation.

An exact analytical solution exists. Its comparison with the results produced by Code_Aster the taking into account of the fluid coupling structure in 2D makes it possible to validate.

1 Problem of reference

1.1 Geometry

One describes below the model of meridian oscillator fluidelastic schematizing the fluid interaction - structure in annular space tank-envelope of heart.

The meridian elastic fluid oscillator is a model of annular space tank-envelope of heart of engine; it consists of an oscillator (piston side-arises appearing a mobile wall) coupled with a compressible fluid contained in a channel with rigid and fixed walls.

The channel is crossed by a wave of depressurisation.

The figure [Figure 1.1-a] below illustrates the model described.

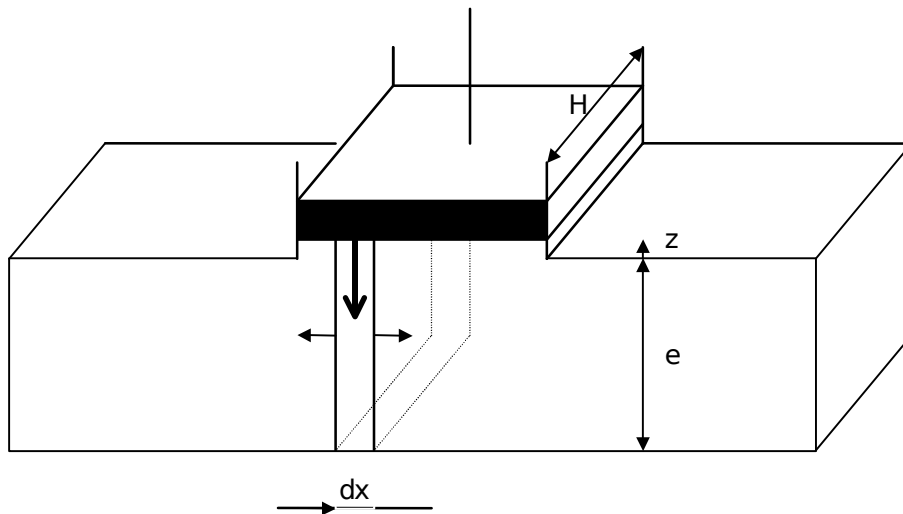


Figure 1.1-a: Total diagram of the oscillator meridian fluid-rubber band

The channel is of section rectangular of dimensions $e \times H$ the rigid side piston moves according to z perpendicular to a wall.

A wave of depressurisation arrives by the left; while moving towards the line (without possibility of return) this wave aspirates the piston which, by its resulting displacement, generates waves being propagated towards the ends of the conduit, supposed infinitely long so that there is no reflection.

One conceives a two-dimensional modeling of this system, represented with figure [Figure 1.1-b] Ci - below:

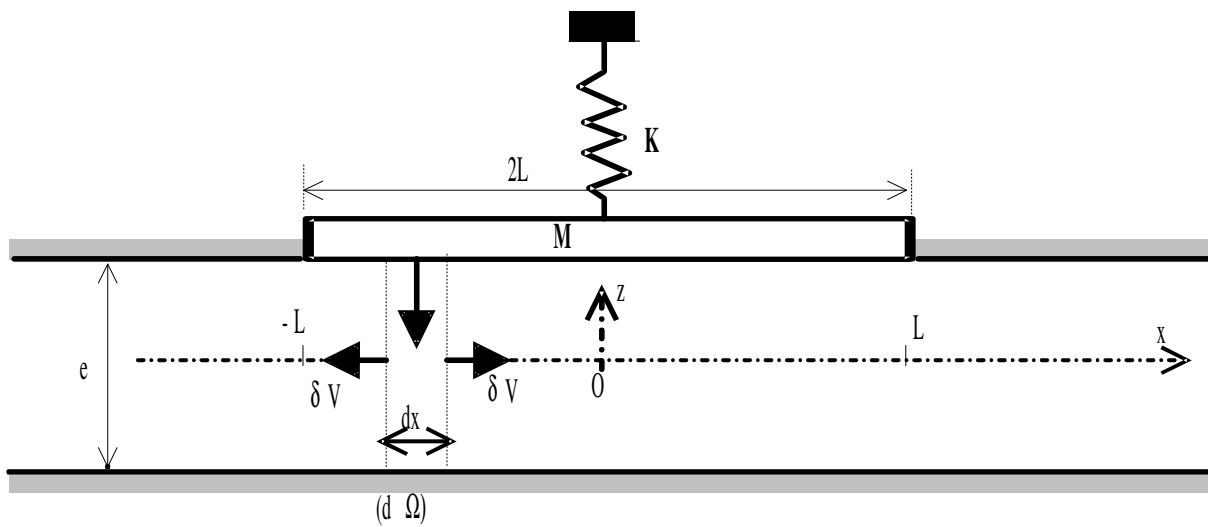


Figure 1.1-b: Theoretical two-dimensional mechanical representation

Its geometrical characteristics are the following ones:

length piston of wall	$2L = 5,0 m$
height of fluid	$e = 0,5 m$
width of fluid	$H = 1,0 m$
section of fluid	$S = e \cdot H$

1.2 Properties of materials

The physical characteristics of fluid material (hot water) in the tube are the following ones:

density $\rho_f = 0.75 \cdot 10^3 \text{ kg/m}^3$,
speed of sound $c_f = 10^3 \text{ m/s}$.

The physical characteristics of materials constituting the piston of wall and the pistons of end play only one formal part in the calculation of *Code_Aster*.

These physical material characteristics are the following ones:

Young modulus $E = 2 \cdot 10^{12} \text{ Pa}$,
Poisson's ratio $\nu = 0.3$,
density $\rho_s = 0 \text{ kg/m}^3$.

1.3 Characteristics of the springs, masses and shock absorbers

The characteristics of the piston of wall as an oscillator are the following ones:

Stiffness $K = 5 \cdot 10^{10} \text{ N/m}$
Mass $M = 200 \cdot 10^3 \text{ kg}$
Damping $A = 0 \text{ Ns/m}$

The characteristics of the pistons of end as oscillators are the following ones:

Stiffness $k = 0 \text{ N/m}$
Mass $m = 0 \text{ kg}$
Damping $a = \rho_f c_f S = 37.5 \cdot 10^4 \text{ Ns/m}$

1.4 Boundary conditions and loadings

Infinitely rigid piston of wall and with displacement only according to the vertical axis.

Infinite length of fluid thus not of reflection of end of the waves: this boundary condition is simulated in the model by a piston at each end, of worthless mass, moving only according to the axis of x and provided with a shock absorber with adequate damping; these pistons are moreover more infinitely rigid.

Total reflection of the waves on infinitely rigid walls of the tube of fluid: realized simply while omitting to model the wall by elements of structure.

2 Reference solution

2.1 Method of calculating used for the reference solution

The goal is to determine temporal displacement $z(t)$ piston of wall.

One considers the problem plan of this meridian model whose geometrical, mechanical and fluid characteristics are described on the figure [Figure 1.1-a]; the side piston is length $2L$.

The two-dimensional problem is brought back to a monodimensional problem by considering by approximation that the rates of transverse flow \dot{z} induced by the movement of the piston are transmitted instantaneously in axial speeds in the channel.

In the volume of control $d\Omega = e dx$ of extent dx under the piston of wall one can write:

$$d(\delta V) = \frac{1}{2e} dx d\dot{z}$$

In the fluid variation speed and variation of pressure in adiabatic evolution are connected by:

$$\delta P = \rho c \delta V$$

Pressure at the moment t in a point of X-coordinate x result from the superposition of the propagation of all the elementary sources distributed on the piston:

The coupling thus consists of this: the movement of the piston of acceleration $\ddot{z}(t)$ armature in the channel a field of pressure $P(x,t)$ whose effort resulting on the extent from the piston itself acts as return on the dynamics of the oscillator.

The geometrical, mechanical characteristics and fluids of the model are presented on the figure [Figure 1.1-b].

It is considered initially that the piston and the fluid are at rest and one carries out to release oscillator at the moment $t=0$ by imposing an initial speed to him.

The expression of the pressure $P(x,t)$ in a point of the channel develops:

$$P(x,t) = \frac{\rho c}{2e} \int_0^t \int_{-L}^x \ddot{z}(\tau - \frac{|x-u|}{c}) du + \int_x^{+L} \ddot{z}(\tau - \frac{|u-x|}{c}) du d\tau$$

However one has $z(0) = 0$ and $\dot{z}(t) = 0$ for t negative, and

$z(-\frac{L-x}{c}) = 0$ since upstream of the piston (x understood enters $-L$ and L) the quantity between

bracket is always negative; for the same reason one has $z(-\frac{L+x}{c}) = 0$.

Finally it comes:

$$P(x,t) = \frac{\rho c^2}{2e} \left[2z(t) - z\left(t - \frac{L-x}{c}\right) - z\left(t - \frac{L+x}{c}\right) \right]$$

One integrates this expression on X in order to obtain the resultant of the compressive forces on the piston:

$$R(t) = -H \int_{-L}^{+L} P(x,t) dx = -2H \int_{-L}^{+L} P(x,t) dx :$$

Indeed $P(x,t)$ is even in x ; it is thus enough to integrate on half of the piston.

From where the expression of the resultant of the compressive forces on the piston on the assumption of the small movements:

$$R(t) = -\frac{H\rho c^2}{e} \left[2Lz(t) - c \int_{-\frac{2L}{c}}^t z(u) du \right]$$

The movement of the oscillator thus obeys the equation:

$$M \ddot{z} + K z + \frac{2HL\rho c^2}{e} z - \frac{2HL\rho c^2}{e} c \int_{- \frac{2L}{c}}^t z(u) du = 0$$

or:

$$M \ddot{z} - F_{\text{int}} - F_{\text{coupl}} = 0$$

if one poses:

$$F_{\text{int}} = -K z - \frac{2HL\rho c^2}{e} z \quad \text{and} \quad F_{\text{coupl}} = \frac{2HL\rho c^2}{e} c \int_{- \frac{2L}{c}}^t z(u) du$$

One now considers the case of the propagation of a wave of decompression to stiff face of amplitude ΔP_0 along the conduit. At the moment $t=0$, this wave still attacks the piston of wall at rest, creating on this piston a force of excitation such as:

$$F_{\text{excit}} = \begin{cases} H c t \Delta P_0 & \text{si } t < \frac{2L}{c} \\ 2 H L \Delta P_0 & \text{si } t \geq \frac{2L}{c} \end{cases}$$

The equation of the movement is written then:

$$M \ddot{z} = F_{\text{int}} + F_{\text{coupl}} + F_{\text{excit}}$$

This equation is solved numerically with the software *Matlab* for the characteristics presented of the meridian oscillator.

2.2 Result of reference

Displacement $z(t)$ piston of wall.

2.3 Uncertainty of the solution

Analytical solution.

2.4 Bibliographical references

- 1) F. STIFKENS: "Transitory calculation in *Code_Aster* with the vibroacoustic elements". Note interns R & D HP-51/97/026/A.
- 2) F. TEPHANY, A. HANIFI, C. LEHAUT: "Elements of analysis of the interaction fluid-structure in annular space tank-envelope of heart in the event of APRP" - Notes intern SEPTEN ENTMS/94.057.

3 Modeling A

3.1 Characteristics of modeling

3.1.1 Vibroacoustic system are equivalent modelling

In order to avoid the waves of return coming from the ends of a modeling inevitably of finished size one provides these ends with systems "piston-shock absorber" as on the figure [Figure 3.1.1-a].

The channel is modelled over an overall length of 28 m sufficient to obtain with certainty, at least the two first extrema of the curve of displacement of the piston without disturbance of a wave of reflection at the ends.

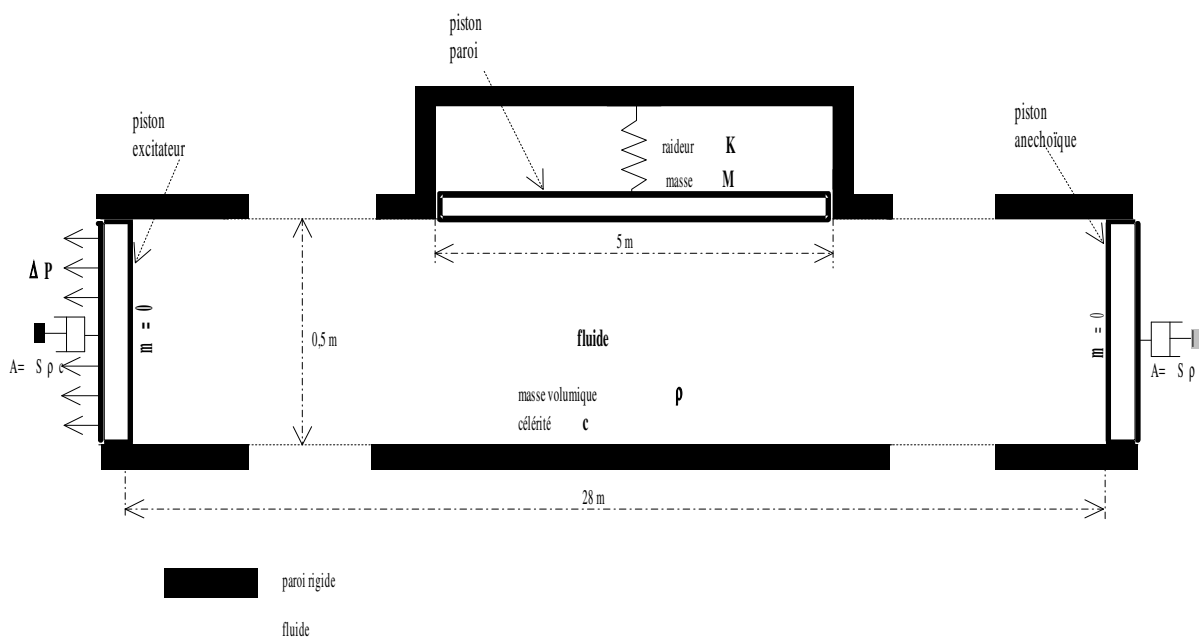


Figure 3.1.1-a: Vibroacoustic system are equivalent

3.1.2 Digital modeling in finite elements of Code_Aster

One chose to model in 2D.

For the fluid : modeling is in formulation p, ϕ .

It is carried out by the assignment on meshes of the type QUAD4 (quadrilaterals with 4 nodes) of elements PHENOMENON = ' MECANIQUE', MODELING = ' 2D_FLUIDE'.

For the structures : modeling is in formulation u .

It is carried out by the assignment on meshes of the type QUAD4 (quadrilaterals with 4 nodes) of elements PHENOMENON = ' MECANIQUE', MODELING = ' D_PLAN'.

For the discrete elements of oscillators : modeling is in formulation u .

It is carried out by the assignment on meshes of the specific type POI1 elements PHENOMENON = ' MECANIQUE', MODELING = ' DIS_T'.

For the interfaces fluid-structure : modeling is in formulation u, p, ϕ .

It is carried out by the assignment on meshes of the type SEG2 (segments with 2 nodes) of elements PHENOMENON = ' MECANIQUE', MODELING = ' 2D_FLUIDE_STRU'.

3.2 Characteristics of the grid

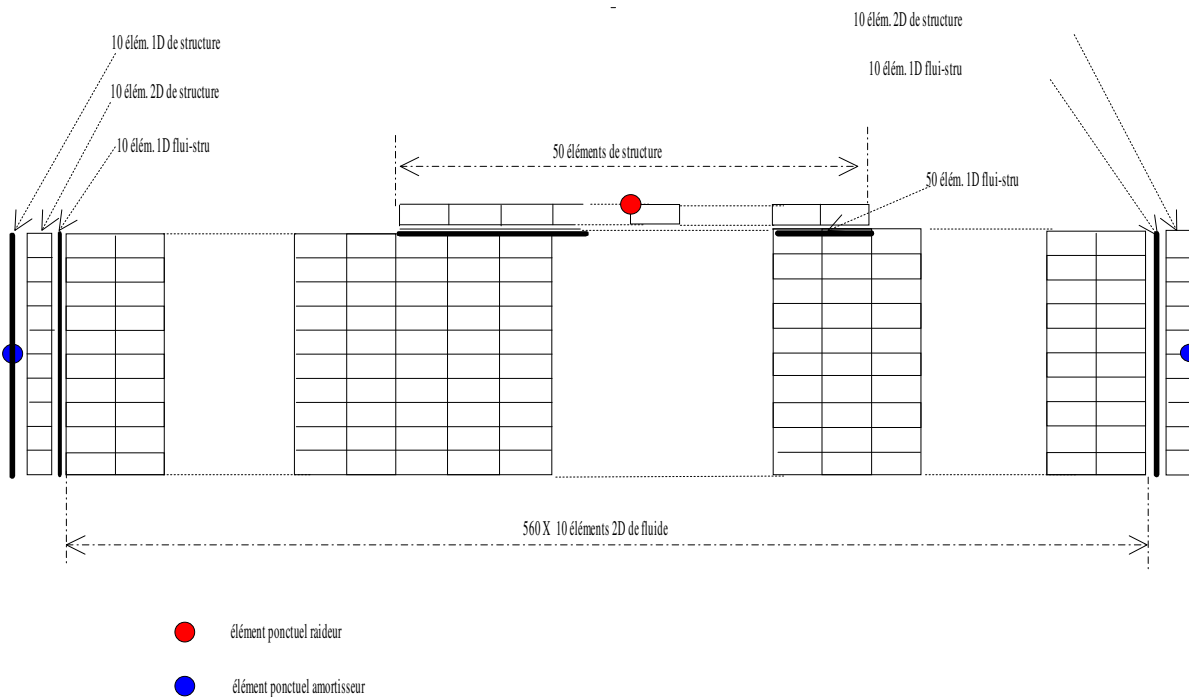


Figure 3.2-a: Two-dimensional grid of the model of oscillator fluidelastic

One gathered in the table hereafter, data characterizing this modeling.

	Type of mesh			Number
	QUAD4	SEG2	POI1	total
Many elements	2870	80	3	2953
Many generated nodes	3164	0	0	3164

Table 3.2-1: Characteristics of the two-dimensional grid of the oscillator fluidelastic

3.3 Calculation

One wishes to validate the elements of interaction fluid-structure in transitory mode by a loading of excitation. One carries out the calculation of the displacement of the piston of wall with the operator `DYNA_LINE_TRAN`.

3.4 Sizes tested and results

Results of calculation with *Code_Aster* are presented graphically on [Figure 4.1-a] in superposition with the "analytical" reference solution.

The curve of *Code_Aster* appears very close to the reference during the first 4 oscillations but the differences, at the same time in amplitude and phase, are increasingly perceptible when T increases.

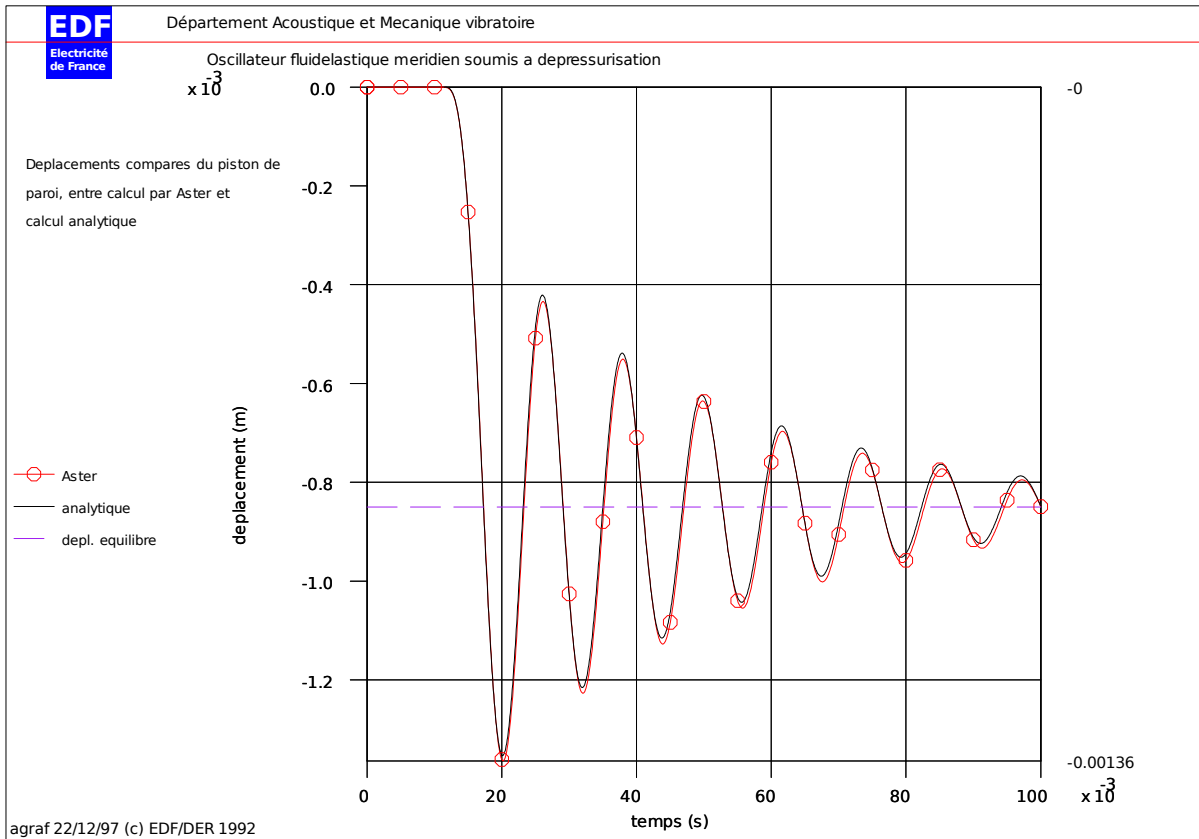


Figure 4.1-a: Comparison between calculation Code_Aster and analytical semi reference

The test relates to the displacement of the piston of wall in two moments given close to the two first extrema.

The table present comparative of the 2 first extrema of the curve of displacement of the piston between analytical points and points calculated by Code_Aster.

The values obtained of the moments of extrema in one and the other case are values considered extracted without interpolation rough computed values: they do not correspond exactly between the analytical curve and the curve of Code_Aster.

One estimates the tolerance of variation relative compared to the analytical value to 1.0%.

	Reference analytical	
	Inst. (ms)	Dépl. (mm)
1 ^{er} Extremum	20.13	- 1.3530
2 ^{me} Extremum	26.05	-0.4210

Test of nonregression of the code:

the tolerance of relative variation compared to the reference is worth 0,1%.

3.5 Notice

The values of reference finally selected are those obtained by Code_Aster during the restitution of the CAS-test, which will thus make it possible to check to it not later regression of the code during its evolution.

4 Summary of the results

Good precision over the first periods then light error in amplitude and phase due to the influence of integration in digital time Newmark $\left(\alpha = \frac{1}{4}, \gamma = \frac{1}{2}\right)$.