FDLV106 - Calculation of added damping in annular flow

Summary:

This test of the fluid field/structure implements the calculation of mass and damping added on a cylindrical structure subjected to an annular flow which one supposes potential. One calculates mass and damping initially added by the flow on the structure for various speeds upstream ($4\,m/s$, $4.24\,m/s$ and $6\,m/s$), this on a model 3D for the fluid and hull for the structure. The structure has a displacement of rotation around a pivot located at the downstream end of the cylinder compared to the flow.

The determined coefficients, one assigns them to a discrete model are equivalent to 1 ddl mass-arise-shock absorber, on which one carries out a modal analysis, in order to determine the complex Eigen frequencies of the system for the various rates of flow:

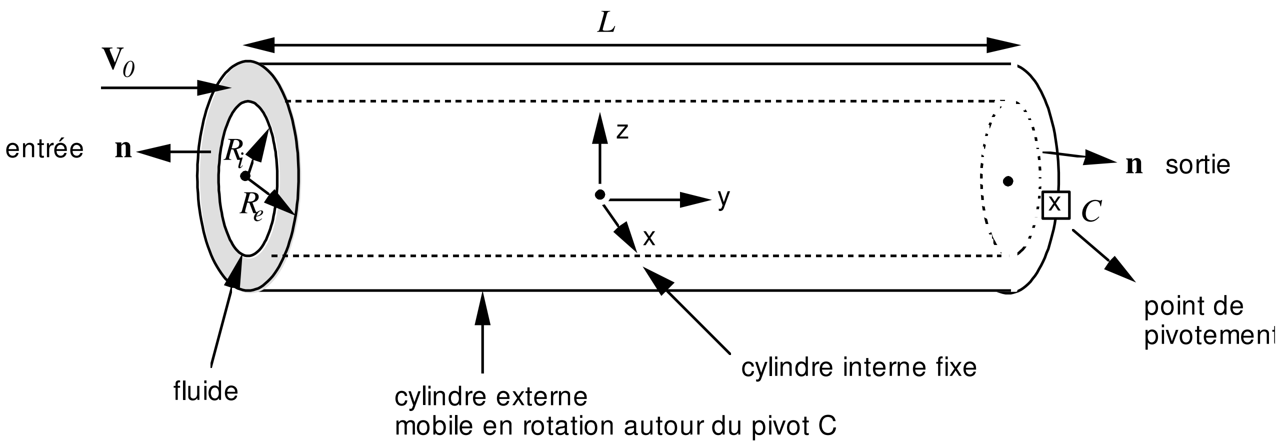
$4\,m/s$: damping,

$4.24\,m/s$: critical velocity, null damping,

$6\,m/s$: negative damping, undulation.

1 Problem of reference

1.1 Geometry



$L=50\,m$

$R_i=1\,m$

$R_e=1.1\,m$

C : not pivot of the external structure

1.2 Properties of materials

Fluid: density $\rho_g=1000\,kg/m^3$ (water).

Structure: $\rho_s=7800\,kg/m^3$; $E=2.10^{11}\,Pa$; $\nu=0.3$ (steel).

1.3 Boundary conditions and loadings

Fluid:

- to simulate steady flow, one forces on the face of entry of the fluid a normal speed of $-4\,m/s$ (by thermal analysis, one imposes a normal heat flow equivalent of – 4),
- to calculate the fluid disturbance brought by the movement of the external cylinder Dirichlet in a node of the fluid.

Structure:

one imposes on the external cylinder a displacement of the type $\vec{X_i}=\left(\frac{L}{2}-y\right)\vec{z}$ with the nodes of the grid of this cylinder.

2 Reference solution

2.1 Method of calculating used for the reference solution

For the calculation of the added coefficients:

it is shown [bib1] that the coefficients of mass and added depreciation depend on the permanent potential fluid speeds $\bar{\phi}$ as well as two fluctuating potentials ϕ_1 and ϕ_2 : these potentials are in the case of written the rotation movement of the external cylinder around the pivot C [bib1]:

$$\begin{cases} \bar{\varphi} = V_0 y \\ \phi_1 = \dfrac{R_e^2}{R_e^2 - R_i^2}\left(r + \dfrac{R_i^2}{r}\right)\left(y + \dfrac{L}{2}\right) \sin\theta \text{ avec } \mathbf{X}_i = \left(\dfrac{L}{2} - y\right) \mathbf{z} \\ \phi_2 = \dfrac{R_e^2 V_0}{R_e^2 - R_i^2}\left(r + \dfrac{R_i^2}{r}\right) \sin\theta \end{cases}$$

However the added modal coefficients projected on this mode of rotation are written:

$$M_a = \rho \int_{\text{cylindre externe}} \phi_1 \mathbf{X}_i \,.\, \mathbf{n}\, dS$$

$$C_a = \rho \int_{\text{cylindre externe}} \left(\phi_2 + \nabla\bar{\varphi}.\nabla\phi_1\right)\left(\mathbf{X}_i \,.\, \mathbf{n}\right) dS$$

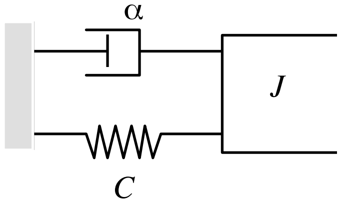
that is to say:

$$C_a = -\rho \frac{V_0 R_3^e \pi}{R_2^e - R_i^2}\left(R_e + \frac{R_i^2}{R_e}\right) L^2$$

$$M_a = +\rho \frac{R_e^3}{R_e^2 - R_i^2}\left(R_e + \frac{R_i^2}{R_e}\right) \frac{L^3 \pi}{3}$$

For the system with a degree of freedom are equivalent:

It is about a system mass-arise-shock absorber representing the rotation movement of the cylinder around the pivot C downstream.



- the inertia of the mechanical system subjected to the flow is written: $J = I + M_a$

  where I is the inertia of the external cylinder swivelling compared to the axis Cx (cf appears Ci - below) in air.

It is shown [bib2] that this inertia is worth:

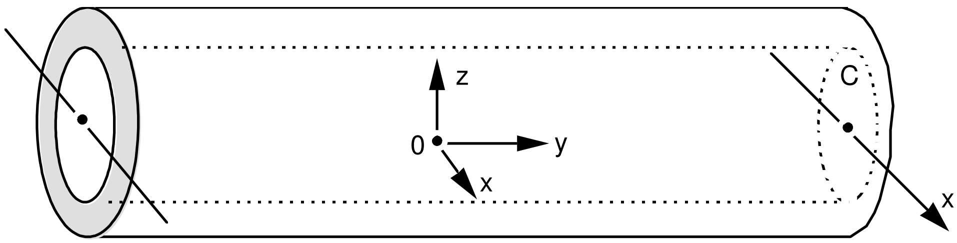
$$I = \frac{m}{6}\left(3 R_e^2 + 2\ L^2\right)$$

where m is the mass of the cylinder:

$$m = 2\,\rho_s\,\pi\,R_e\,e\ L$$

where e is the thickness of the cylinder, L its overall length.

ρ_s is the density of the cylinder.



thus $J = \frac{m}{6}\left(3 R_e^2 + 2\ L^2\right) + \rho \frac{R_e^3}{R_e^2 - R_i^2}\left(R_e + \frac{R_i^2}{R_e}\right)\frac{L^3\pi}{3}$

- the damping of the mechanical system subjected to the flow is written: $\alpha = A + C_a$

  where A is the damping of the mechanical system in air. Usually, A is equal to a few % of the critical damping of the system: $A = 2\xi\sqrt{IK}$.

  where I is the inertia of the cylinder in air calculated above and K the rigidity of the spring at the point of swivelling C . Reduced damping is taken ξ equal to 1%.

  Thus, the total damping of the system under flow is written:

$$\alpha = \xi\sqrt{IK} - \rho\ V_0 \frac{R_e^3\pi}{R_e^2 - R_i^2}\left(R_e + \frac{R_i^2}{R_e}\right) L^2$$

- the rigidity of the mechanical system subjected to flow is written: $K = K + K_a$

  where K is the rigidity of the spring in air. K_a is the rigidity added by the flow. It is shown [bib1] that this one is worthless on this mode of rotation.

$$K_a = 0$$

  Thus the overall rigidity of the system is independent the rate of flow.

$$K = K$$

- One calculates then the complex modes of this mechanical system under flow (damped free vibrations):

$$J\ddot{\theta} + \alpha\dot{\theta} + C\theta = 0$$

The complex Eigen frequencies of this system are written [bib3]:

$$\Omega^R_{1ou2} = -\xi\,\omega \pm i\,\omega\sqrt{1-\xi^2}$$

with $\xi = \frac{\alpha}{2J\omega}$ et $\omega = \sqrt{\frac{K}{J}} = \sqrt{\frac{K}{I+M_a}}$

ξ : reduced damping of the system

ω : own pulsation.

- Digital applications:

One did three calculations of damping added correspondent to three rates of flow which involve three behavior vibratory of the structure:

speed with $4\,m/s$
speed with $4.24\,m/s$
speed with $6\,m/s$

The values of the mechanical system are:

$e=2.10^{-2}m$ $L=50m$ $R_i=1\ m$ $R_2=1{,}1\ m$

$I=4.5\ 10^7 kg\ m^2$

$A=4.24\ 10^8\ N.m\ rad^{-1}s$

$K=10^{13}\ N.m\ rad^{-1}$

The added mass and damping brought by the flow are worth:

$I_a=1.66\ 10^{10} kg\ m^2$ (independent of the value rate of flow)

According to the speed of entry of the fluid, one a:

$V_0=4\ m/s$	$C_a=-4.00\ 10^8\ N.m\ rad^{-1}s$
$V_0=4.24\ m/s$	$C_a=-4.24\ 10^8\ N.m\ rad^{-1}s$
$V_0=6\ m/s$	$C_a=-5.94\ 10^8\ N.m\ rad^{-1}s$

Depreciation of the fluid system/structure is written:

- with $V_0=4\ m/s\ :\ \alpha=0.24\ 10^8\ N.m\ \ rad^{-1}s$

  The flow does not amplify the vibrations. Structural damping interns is sufficiently important to dissipate the energy brought by the flow to the structure. The system is still deadened.

- with $V_0=4.24\ m/s\ :\ \alpha\approx 0$ (vitesse d'écoulement critique)

  The damping of the system is cancelled.

- with $V_0=6\ m/s\ :\ \alpha=-1.5\ 10^8\ N.m\ \ rad^{-1}s$ (l'écoulement amplifie les vibrations)

The damping of the system at this last speed is negative: the system enters then in **instability of undulation**.

Corresponding reduced depreciation is written:

$V_0=4\ m/s$	$\xi=1.1\ 10^{-4}$
$V_0=4.24\ m/s$	$\xi=0$ (en théorie) $\xi=1.380\ 10^{-5}$ (avec les erreurs d'arrondi)
$V_0=6\ m/s$	$\xi=-6.6\ 10^{-4}$

The own pulsation remains as for it unchanged: $\omega=12.5\,Hz$.

2.2 Results of reference

Analytical result.

2.3 References bibliographical

1) ROUSSEAU G., LUU H.T. : Mass, damping and stiffness added for a vibrating structure placed in a potential flow - Bibliography and establishment in *Code_Aster* - HP-61/95/064

2) BLEVINS R.D: Formulated for natural frequency and shape mode. ED. Krieger 1984

3) SELIGMANN D, MICHEL R: Algorithms of resolution for the quadratic problem [R5.01.02], Manuel de Référence *Aster*.

3 Modeling A

3.1 Characteristics of modeling

For the system 3D on which one calculates the added coefficients:

For the fluid:	480 meshs QUAD4 elements of hulls MEDKQU4
For the solid:	480 meshs QUAD4 elements thermics THER_FACE4 on cylindrical surfaces
	360 meshs QUAD4 thermal elements THER_FACE4 on the faces of entry and exit of fluid volume
	720 meshs HEXA8 thermal elements THER_HEXA8 in fluid annular volume

3.2 Values tested

Identification	Reference
N°1 mode with $V_0 = 4 m/s$ frequency reduced damping	12.5 Hz 1.1 10^{-4}
N°1 mode with $V_0 = 4.24 m/s$ frequency reduced damping	12.5 Hz 1,380 10^{-5}
N°1 mode with $V_0 = 6 m/s$ frequency reduced damping	12.5 Hz – 6.60 10^{-4}

4 Summary of the results

The computational tool of damping under flow (potential assumption) was validated on the mode of rotation of a cylindrical structure subjected to an annular flow. It should however be noted [bib1] that the very good agreement between the semi-analytical model suggested for comparison and digital calculation is obtained only if the cylinder is sufficiently long.

Indeed, the semi-analytical model is in fact only one approximate solution of the posed problem.