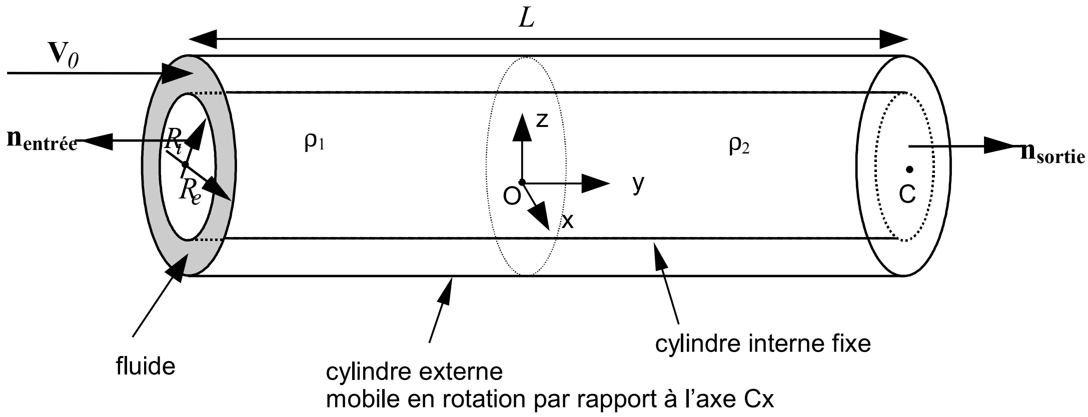
FDLV108 - Computation of damping added out of annular flow (variable density)

Summarized:

This test of the fluid-structure field implements the computation of mass and damping added on a cylindrical structure subjected to an annular flow which one supposes potential. One calculates mass and damping added by flow on the structure for a velocity upstream of $4\,m.s^{-1}$, on a model 3D for the fluid and shell for structure. The structure has a displacement of rotation around a pivot located at the downstream end of the cylinder compared to flow. The interest of the test lies in the taking into account of a fluid field of nonhomogeneous **density**.

1 Problem of reference

1.1 Geometry



$L=50\,m$

$R_i=1\,m$

$R_e=1.1\,m$

C : not pivot of external structure (swivelling around Cx)

1.2 Properties of the materials

fluid: density $\rho_1=1000\,kg.m^{-3}$; $\rho_2=750\,kg.m^{-3}$;

Structure: $\rho_s=7800\,kg/m^3$; $E=2.1\,10^{11}\,Pa$; $\nu=0.3$ (steel).

1.3 Boundary conditions and loadings

Fluid:

1) to simulate steady flow, one forces on the face of entry of the fluid a normal velocity of $-4\,m/s$ (by thermal analysis, one imposes a normal heat flux are equivalent of -4);
2) to model the variation of density, one forces a condition of continuity of the flow on the interface;
3) to compute: the fluid disturbance brought by the motion of the external cylinder one imposes a boundary condition of Dirichlet in a node of the fluid.

Structure:

1) one imposes on the external cylinder a displacement of the type $\mathbf{X}_i=\left(\frac{L}{2}-y\right)\mathbf{z}$ to the nodes of the mesh of this cylinder.

2 Reference solution

2.1 Method of calculating used for the reference solution

For computation of the added coefficients:

one shows [bib1] that the coefficients of mass and added depreciation depend, in each area where ρ is constant, of the permanent potential fluid velocities $\bar{\phi}$ as well as two fluctuating potentials ϕ_1 and ϕ_2 : these potentials are written in the case of the rotational movement of the external cylinder around the pivot C [bib1]:

For the area relating to ρ_1 :

$$\begin{cases} \bar{\phi} = V_0 y \\ \varphi_1 = \dfrac{R_e^2}{R_e^2 - R_i^2}\left(r + \dfrac{R_i^2}{r}\right)\left(y + \dfrac{L}{2}\right)\sin\theta \text{ avec } \mathbf{X}_i = \left(\dfrac{L}{2} - y\right)\mathbf{z} \\ \varphi_2 = \dfrac{R_e^2 V_0}{R_e^2 - R_i^2}\left(r + \dfrac{R_i^2}{r}\right)\sin\theta \end{cases}$$

For the area relating to ρ_2 :

$$\begin{cases} \bar{\phi} = \dfrac{\rho_1 V_0}{\rho_2} y \\ \varphi_1' = \dfrac{R_e^2}{R_e^2 - R_i^2}\left(r + \dfrac{R_i^2}{r}\right)\left(y + \dfrac{L}{2}\right)\sin\theta \text{ avec } \mathbf{X}_i = \left(\dfrac{L}{2} - y\right)\mathbf{z} \\ \varphi_2' = \dfrac{\rho_1}{\rho_2}\dfrac{R_e^2 V_0}{R_e^2 - R_i^2}\left(r + \dfrac{R_i^2}{r}\right)\sin\theta \end{cases}$$

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

$$M_a = \rho\int_{\text{cylindre externe}} \varphi_1 \mathbf{X}_i \,.\, \mathbf{n}\ dS$$
$$C_a = \rho\int_{\text{cylindre externe}} \left(\varphi_2 + \nabla\bar{\phi}.\nabla\varphi_1\right)\left(\mathbf{X}_i \,.\, \mathbf{n}\right)\ dS$$

maybe by separating the integral on two half-cylinders:

$$C_a = -\rho_1 \frac{V_0 R_e^2 \pi}{R_2^e - R_i^2}\left(R_e^2 + R_i^2\right)\ L^2$$

$$M_a = \left(7\rho_1 + \rho_2\right)\frac{R_e^2}{R_2^e - R_i^2}\left(R_e^2 + R_i^2\right)\ \frac{L^3\pi}{3}$$

1) Numerical applications:

One did a calculation of added damping which corresponds for the velocity given to a deadened vibratory behavior of structure:

velocity V_0 with $4\,m.s^{-1}$

the values of the mechanical system are:

$$e=2.10^{-2}m \qquad L=50m \qquad R_i=1\,m \qquad R_2=1{,}1\,m \qquad A=4.24\;10^8\;N.m\;rad^{-1}s$$

The added mass brought by flow is worth:

$M_a=1.614\;10^9\,kg\;m^2$ (independent of the value rate of flow)

The damping added is worth with $V_0=4\,m.s^{-1}$ (it is independent of the change of density):

$$C_a=-0.399\;10^9\;\;N.m\;rad^{-1}s$$

Knowing that the damping of the mechanical system is worth $A=4.24\;10^8\;\;N.m\;rad^{-1}s$, the total damping of the fluid system/structure is written:

1) with $V_0=4\;m/s\;\;:\;\;\alpha=-1.5\;10^8\;\;N.m\;\;rad^{-1}s$

flow does not amplify vibrations. The damping structural intern is sufficiently important to dissipate the energy brought by flow to structure. **The system is still damped**.

2.2 Results of reference

Result analytical.

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 *the Code_Aster* - HP-61/95/064

3 Modelization A

3.1 Characteristic of the modelization

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

For solid:	240 meshes QUAD4 shell elements MEDKQU4
For the fluid:	240 meshes thermal QUAD4 elements THER_FACE4 on cylindrical surfaces
	540 meshes thermal QUAD4 elements THER_FACE4 on the sides of entry, output and interface of fluid volume
	720 meshes thermal HEXA8 elements THER_HEXA8 in fluid annular volume

3.2 Values tested

Identification	**Reference**
added Coefficients	
mass:	1.614 109
damping	– 0.399 109

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 with variable density. It is necessary however to note [bib1] that the very good agreement between the model semi-analytical proposed for comparison and numerical computation are obtained only if the cylinder is sufficiently long, the model semi-analytical being makes of it only one approximate solution of the posed problem.