SDLS103 - Coaxial hulls under flow annular: inertial coupling between modes

Summary

One considers a hardware configuration made up of two coaxial cylindrical hulls, in interaction with a fluid running out in annular space separating the hulls.

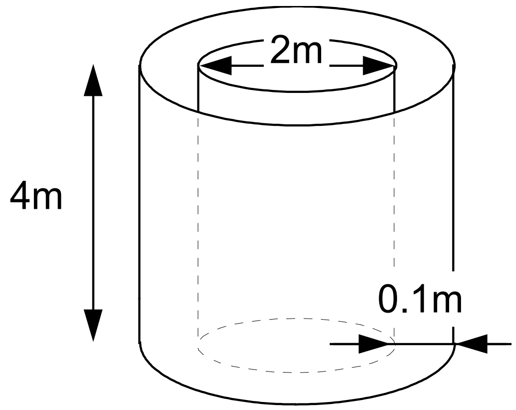
The goal of the CAS-test is to validate the model of coupling fluid-structure developed in the operator `CALC_FLUI_STRU` for this kind of configuration.

One is interested here more particularly in the taking into account of the inertial coupling between modes, obtained out of water at rest (mean velocity of flow worthless). The reference solution is provided by a calculation carried out with *Code_Aster* implementing the operator `CALC_MATR_AJOU`.

1 Problem of reference

1.1 Geometry

The studied configuration consists of two 4 meters height coaxial cylindrical hulls:



The internal hull has an average radius of $1\,m$ and a thickness of $1\,cm$.

The external hull has an average radius of $1{,}10\,m$ and a thickness of $1\,cm$.

1.2 Properties of material

The material constituting the two hulls is steel. Its physical characteristics are:

$$\rho=7800\,kg/m^3 \qquad E=2.10^{11}\,Pa \qquad \nu=0{,}3$$

1.3 Boundary conditions and loadings

The conditions of self-supporting quality are the same ones for the two hulls: embedded ends partly lower ($z=0$) and free partly higher ($z=4\,m$).

2 Reference solution

2.1 Method of calculating used for the reference solution

The reference solution is provided by a calculation carried out by means of *Code_Aster* implementing the operator CALC_MATR_AJOU.

With this intention, one uses a grid on which are defined the elements of the structure (hulls internal and external), the voluminal elements of fluid (annular space) and the elements of fluid interface - structure. This method is described completely in [bib1].
On the elements of interface, the condition normal speed limit worthless is imposed, translating the condition of nonpenetration of the fluid in the hulls.
On the sections of entry and exit of annular space, the limiting condition of null potential is imposed, translating the condition of worthless disturbed pressure at the ends.

One carries out the first modal calculation of the structure in air. The operator CALC_MATR_AJOU then allows to calculate the matrix of mass added by the fluid, projected on the basis of modal structure in air. One can then recombine this matrix of mass added with the matrix of mass generalized of the structure in air, then to solve a new modal problem which leads to the characteristics of the water system at rest. **The results got for the Eigen frequencies of the water system at rest constitute the reference solution.**

Characteristics of the grid:
17 nodes on a vertical generator
60 nodes on a crown

960 meshs QUAD4 on each hull
=> 1920 meshs for the interface fluid-structure

2880 meshs HEXA8 for the fluid field
180 meshs QUAD4 for the section of entry of annular space
180 meshs QUAD4 for the section of exit of annular space

2.2 Results of reference

N° of the mode	1	2	3	4	5	6	7	8	9	10	11	12
Fréq. (Hz)	5.65	5.65	6.48	6.48	9.34	9.34	20.82	20.82	28.22	28.22	31.48	31.48

2.3 Uncertainty on the solution

In the studied case, the half-thicknesses of hull represent 10 % of the dimension of the annular game. In the calculation of reference realized by the operator CALC_MATR_AJOU, the half-thicknesses are neglected for the definition of the fluid field. One thus expects a systematic error of about 5 % on the frequencies, because of this approximation.
Moreover, differences of modeling and resolution between the digital method put in work in the operator CALC_MATR_AJOU and the analytical model developed in the operator CALC_FLUI_STRU induce an additional variation.

2.4 Bibliographical references

1. G. ROUSSEAU: “Specifications and principle of realization of the calculation of stiffness and damping added in *Code_Aster*“, HP-51/96/005/B.

2. L. PEROTIN, “Note of principle of the model MOCCA_COQUE“, HT-32/95/021/A.

3 Modeling A

3.1 Characteristics of modeling

The geometry of the structures and the characteristics of material constituting the hulls were presented before.

Concerning the absolute roughness of wall of the structures, one takes a value of 10^{-5} meter.

The surrounding fluid is water. The values taken for the density and kinematic viscosity are respectively

$$\rho_f = 1000\, kg/m^3 \qquad \nu_f = 10^{-6}\, m^2/s$$

One considers the flow not confined upstream and downstream from the structures.

The problem of coupling fluid-structure is solved by the model analytique MOCCA_COQUE [bib2] integrated in *Code_Aster* (operator `CALC_FLUI_STRU`), for a mean velocity of flow worthless : one thus obtains the modal characteristics of the water system at rest, by taking into account of the effects of added mass.

3.2 Characteristics of the grid

Compared to the calculation of reference, the characteristics of the grid are similar, with the difference close the fluid field is not represented any more. In order to make the two hulls interdependent one of the other, one adds a group of meshs connecting the nodes to the level of embedding.

One a: 17 nodes on a vertical generator,

60 nodes on a crown,

960 meshs QUAD4 on each hull,
60 meshs QUAD4 to solidarize the two hulls (bases embedded).

3.3 Stages of calculation

The definition of the characteristics of a hardware configuration made up by two coaxial cylindrical hulls for a calculation of coupling fluid-structure is given via the operator `DEFI_FLUI_STRU` keyword factor `COQUE_COAX`.

The resolution of the coupling fluid-structure for a configuration of the type “hulls coaxial” and calculation of the modal parameters (reduced frequencies and depreciation) and deformed modal out of water at rest are carried out with the operator `CALC_FLUI_STRU`.

4 Results of modeling A

4.1 Values tested

The comparisons relate to the water frequencies at rest of the first 12 modes of the system.

Numbers of the modes	CALC_FLUI_STRU ($H=9\text{cm}$)	CALC_MATR_AJOU ($H=10\text{cm}$)	variation
1 and 2	5.30 Hz	5.65 Hz	6,2%
3 and 4	6.12 Hz	6.48 Hz	5,5%
5 and 6	8.69 Hz	9.34 Hz	6,9%
7 and 8	21.96 Hz	20.82 Hz	– 5,5%
9 and 10	29.34 Hz	28.22 Hz	– 3,9%
11 and 12	33.75 Hz	31.48 Hz	– 7,2%

One gives, for information, the values of the frequencies of these modes in air:

Numbers of the modes	Hull moving	Order of hull	Order of beam	Frequency
1 and 2	external	3	1	25.15 Hz
3 and 4	intern	3	1	26.12 Hz
5 and 6	external	4	1	31.91 Hz
7 and 8	intern	2	1	36.85 Hz
9 and 10	intern	4	1	37.42 Hz
11 and 12	external	2	1	39.49 Hz

4.2 Remarks

The results are in conformity so that one could wait. One observes indeed:

- a systematic error of about 5 %, because not taken into account thicknesses of hull for the definition of the fluid field in the calculation of reference;
- a residual variation due to the differences of modeling and resolution between the two operators CALC_MATR_AJOU and CALC_FLUI_STRU.

Modes 1 to 6 are modes for which the structure is strongly coupled with the fluid. In practice, these modes correspond to movements of the hulls internal and external overall in opposition of phase. For these modes, the terms of added mass are theoretically proportional to $\frac{\rho_f \pi R^3}{H}$, where R indicate the average radius and H the thickness of annular space.

For these the first six modes, results provided by CALC_FLUI_STRU lead to Eigen frequencies lower than those calculated by CALC_MATR_AJOU. Indeed, H being weaker, the terms of added mass are larger.

Modes 7 to 12 are modes for which the structure is slightly coupled with the fluid. In practice, these modes correspond to movements of the hulls internal and external almost in phase. Thus, the terms of added mass are theoretically proportional to the trained water mass, i.e. with $\rho_f \pi R H$.

In this case, it is normal that the results provided by CALC_FLUI_STRU lead to Eigen frequencies higher than those calculated by CALC_MATR_AJOU. Indeed, H being weaker, the terms of added mass are smaller.

5 Summary of the results

The comparison of the water frequencies at rest calculated with the operators CALC_FLUI_STRU and CALC_MATR_AJOU is satisfactory. The variations met between these two operators are explained by the fact why they use a different modeling.