Forces of fluid blade in transient computation on modal base

Summarized:

This document presents a numerical modelization of the forces of fluid blade which exist when two mechanical systems, plunged in a fluid, vibrate with weak clearances between them.

These nonlinear forces comprise terms of acceleration which require a particular processing for the classical explicit diagrams of integration.

An iterative diagram of type not fixes is proposed. It makes it possible to preserve the architecture of the explicit diagrams of *Code_Aster*. These forces are established in operator DYNA_TRAN_MODAL [U4.54.03].

Contents

1 Introduction

Into the primary education circuit of the power stations REFERENCE MARK the mechanical components are immersed in a fluid. For some of these materials, put in vibrations by the excitation of the primary education fluid, the presence of relatively reduced clearances leads to a more or less important closing of these clearances even to contacts in fluid environment. Numerical works were undertaken in *the Code_Aster* to model the dry contact between mechanical structures. These works were established in an operator of transient computation by modal recombination [bib3] and were validated by comparison with tests carried on model MASSIF [bib4].

Vibrations with contact in fluid environment show characteristics different from those observed in air. When clearance is filled, it creates a all the more important fluid flow as clearance is weak. This flow is at the origin of compressive forces acting on antagonistic structures. Contrary to the configuration in air, where the structures interact by forces of contact, only when clearance is filled; in fluid environment this interaction is permanent and depends in a nonlinear way of the values on clearance, the normal velocity of structures and their acceleration. One will qualify the fluid enclosed in the reduced type font of **fluid blade** ; the forces resulting from the compression of the fluid will be **the forces of fluid blade**.

For materials like the fuel assemblies or the pencils of the control rods these forces of fluid blade induce a modification of the mechanical characteristics of structure in air (mass, damping). The damping induced by the fluid blade can be considerable, and it seems interesting to take it into account in a modelization of these materials.

We present, in this ratio, a simple geometrical configuration, where one can and the integrate flow in the fluid blade realising certain assumptions on the profile of flow pressure losses into edges. We thus determine the compressive forces exerted by the fluid on the structure and release a general form of their statement according to clearance, relative velocity and acceleration norms between structures.

We build benchmarks of reference on a system to a degree of freedom which illustrate the behavior of a mechanical system subjected to a force of fluid blade.

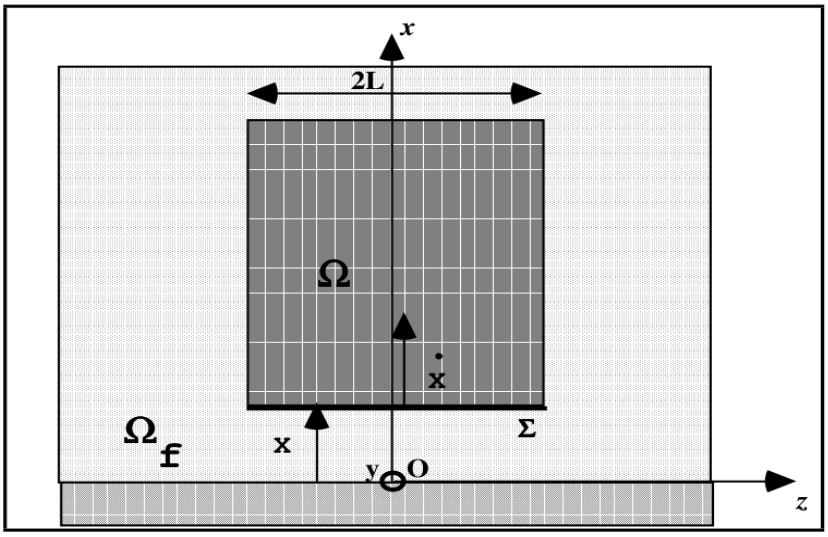
The numerical establishment of these nonlinear forces in *Code_Aster* is then detailed. It requires the use of an algorithm of point fixes to find accelerations generalized.

2 Analytical statement of the forces of fluid blade in a simple geometrical configuration

One proposes to determine in an analytical way here the forces being exerted on a structure vibrating in an incompressible fluid in the vicinity of a motionless wall.

2.1 Geometrical configuration

One places a problem of plane flow in the case of (invariant in the direction y of [fig 2.1-a]). A solid body Ω is plunged in a fluid Ω_f. The solid has a plane face Σ of width $2L$ parallel with the plane yOz and vibrates in the vicinity of a wall fixes parallel with this plane.



Appear 2.1-2.1-a2.1-a : Geometrical configuration of the fluid blade

2.2 Equations governing the behavior of the fluid

the problem is supposed invariant by translation according to the axis y, one is thus brought back to a problem dimensional Bi -.

The velocities in the fluid will be noted:

$$\mathbf{v}(t)=\mathrm{u}(x,z,t).\mathbf{x}+\mathrm{w}(x,z,t).\mathbf{z}$$

One will note x,z, the spatial coordinates eulerian of the fluid, and the $X,\dot{X},\ddot{X}$ variable Lagrangian defining the position, velocity and acceleration of solid.

The incompressible fluid being supposed, the components velocities must check:

$$\mathrm{div}(\mathbf{v})=0 \text{ either } \frac{\partial \mathrm{u}}{\partial x}+\frac{\partial \mathrm{w}}{\partial z}$$

the fluid also checks the Navier-Stokes equations:

$$\rho\frac{\partial\mathbf{v}}{\partial t}+\mathrm{grad}(p)+\rho.\mathbf{v}.\mathrm{grad}(\mathbf{v})-\mu\nabla^2\mathbf{v}$$

In the fluid blade one will suppose that the profile according to x component w of the velocity field east of invariant form compared to z . That amounts supposing that it can be written in the form of a function with separate variables:

$$w(x,z,t)=w(x,z).\varphi(x,t)$$

One in general considers two rather simple assumptions of profile:

- **a uniform profile velocity**,
- **a parabolic profile velocity or flow of One tenth of a poise**, valid for low w speeds,

2.3 Resolution of the flow of fluid blade with uniform profile

flow according to z does not depend on x :

$$w(x,z,t)=w(x,z)$$

One neglects in that the effects of viscosity of the fluid in the blade.

Let us write the relation of incompressibility of the fluid, integrated on the thickness of the fluid blade:

$$.\int_0^X(\frac{\partial\mathrm{u}}{\partial x}+\frac{\partial\mathrm{w}}{\partial z}).dx=0,\quad\mathrm{soit}\quad[u]_0^X+\frac{\partial\mathrm{w}(z)}{\partial z}\int_0^X dx=0$$

The boundary conditions are: $\mathrm{u}(X)=\dot{X}$ and $\mathrm{u}(0)=0$,

one thus obtains $\frac{\partial\mathrm{w}(z)}{\partial z}=-\frac{\dot{X}}{X}$ who gives by integration and by noticing that $\mathrm{w}(0)=0$:

$$w(z)=-\frac{\dot{X}}{X}z$$

One from of then deduced immediately the velocity fields:

$$\mathrm{w}(x,z)=\mathrm{w}(z)=-\frac{\dot{X}}{X}z$$
$$\mathrm{u}(x,z)=\mathrm{u}(x)=\frac{\dot{X}}{X}x$$

By means of the Navier-Stokes equation to describe the behavior of the fluid and by projecting it on the axis z , then by replacing the statements of u and w drawn up higher, and while placing itself on the assumption of a thin fluid blade like by considering assumptions of pressure losses [bib2], one can show [bib5] that the fluid force has two statements different according to the sign from $\dot{X}$

if $\dot{X}<0$:

$$F=-\frac{2}{3}\rho.L^3.Y\left\{\frac{\ddot{X}}{X}\right\}+\frac{4}{3}\rho.L^3.Y\left\{\frac{\dot{X}}{X}\right\}^2$$

if $\dot{X}>0$:

$$F=-\frac{2}{3}\rho.L^3.Y\left\{\frac{\ddot{X}}{X}\right\}-\frac{2}{3}\rho.L^3.Y\left\{\frac{\dot{X}}{X}\right\}^2$$

One can give a general statement of the fluid force for the uniform profile in the form:

$$F=\alpha.\left\{\frac{\ddot{X}}{X}\right\}+\beta.\left\{\frac{\ddot{X}}{X}\right\}^2+\delta\frac{\dot{X}.|\dot{X}|}{X^2}$$

For the uniform profile, one a:

$$\alpha=-\frac{2}{3}.\rho.L^3.Y$$
$$\beta=\frac{1}{3}.\rho.L^3.Y$$
$$\delta=-\frac{2}{3}.\rho.L^3.Y$$

2.4 Resolution of the flow of fluid blade with parabolic profile

One gives at the horizontal speed w a parabolic profile which has as a statement:

$$\mathrm{w}(x,z,t)=a.x.(X-x).\bar{W}(z,t) \quad ,$$

$\bar{W}(z)$ being the mean velocity in the blade and $a=\frac{6}{X^2}$

Let us write the relation of incompressibility of the fluid, integrated on the thickness of the fluid blade:

$\int_0^X\left(\frac{\partial \mathrm{u}}{\partial x}+\frac{\partial \mathrm{w}}{\partial z}\right).dx=0$ that is to say $[\mathrm{u}]_0^X+\frac{\partial \bar{\mathrm{w}}(z)}{\partial z}\int_0^X[a.x.(X-x)]dx=0$.

The boundary conditions give: $\mathrm{u}(X)=\dot{X}$ et $\mathrm{u}(0)=0$, one thus obtains the statement: $\frac{\partial \bar{\mathrm{w}}(z)}{\partial z}=-\frac{\dot{X}}{X}$ who gives by integration and by considering that $\mathrm{w}(0)=0$:

$$\bar{\mathrm{w}}(z)=-\frac{\dot{X}}{X}z$$

One from of then deduced immediately the velocity fields:

$$\mathrm{w}(x,z,t)=a.x.(X\text{-}x).\bar{\mathrm{w}}(z,t)=\text{-}6.x.(X\text{-}x).\frac{\dot{X}}{X^3}z$$

$$\mathrm{u}(x,z,t)=\text{-}\frac{x^2.(3\mathrm{X}\text{-}2\mathrm{x})}{X^3}.\dot{X}$$

By means of the Navier-Stokes equation to describe the behavior of the fluid and by projecting it on the axis z , then by replacing the statements of u and w drawn up higher, and while placing itself on the assumption of a thin fluid blade as well as assumptions of pressure losses [bib2], one can show [bib6] that the fluid force in the case of a parabolic profile has two statements different according to the sign from $\dot{X}$

if $\dot{X}<0$:

$$F=-\frac{2}{3}\rho.L^3.Y\left\{\frac{\ddot{X}}{X}\right\}-\frac{24}{3}\rho.L^3.Y\left\{\frac{\dot{X}}{X^3}\right\}+\frac{24}{15}\rho.L^3.Y\left\{\frac{\dot{X}}{X}\right\}^2$$

if $\dot{X}>0$:

$$F=-\frac{2}{3}\rho.L^3.Y\left\{\frac{\ddot{X}}{X}\right\}-\frac{24}{3}\rho.L^3.Y.\nu\left\{\frac{\dot{X}}{X^3}\right\}+\frac{2}{5}\rho.L^3.Y\left\{\frac{\dot{X}}{X}\right\}^2$$

One can give a general statement of the fluid force in the form:

$$F=\alpha.\left\{\frac{\ddot{X}}{X}\right\}+\beta.\left\{\frac{\dot{X}}{X}\right\}^2+\chi\frac{\dot{X}}{X^3}+\delta\frac{\dot{X}.|\dot{X}|}{X^2}$$

with the formulated assumptions (parabolic profile), the coefficients are worth:

$$\alpha=-\frac{2}{3}.\rho.L^3.Y$$

$$\beta=\frac{3}{5}.\rho.L^3.Y$$

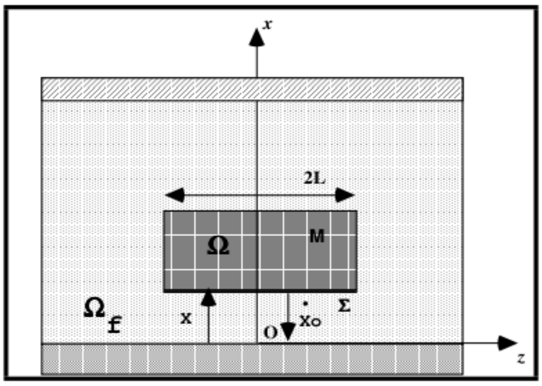
$$c=-\frac{24}{3}.\rho.L^3.Y.\nu$$

$$d=-\rho.L^3.Y$$

The statement of the fluid force above thus represents the most complete form and is that established in *Code_Aster*.

3 Study of the dynamic behavior of a system to a degree of freedom in the presence of a fluid blade

This chapter aims at integrating in an quasi-analytical way a system with fluid blade into a degree of freedom, and is used as references to tests SDND110A [V5.01.110] and SDND111A [V5.01.111].



Appear 3-3-a3-a : Mass damped by a fluid blade

One will consider the system without stiffness above nor external force applied.

The mass has an initial velocity $-\dot{X}_0$, and a position X_0. One seeks to determine the position of stopping of the mass, the evolution of the reaction force. The equation of the system with the 2 assumptions of profile: uniform and parabolic is the following one:

$$\begin{cases} M\,.\,\ddot{X}=\alpha.\left\{\dfrac{\ddot{X}}{X}\right\}+\beta.\left\{\dfrac{\dot{X}}{X}\right\}^2+\chi\dfrac{\dot{X}}{X^3}+\delta\dfrac{\dot{X}\,.|\dot{X}|}{X^2} \\ X(t=0)=X_0 \\ \dot{X}(t=0)=-\dot{X}_0 \end{cases}$$

3.1 To launch of a mass slowed down by fluid blade with uniform profile

For the uniform mode, the differential equation governing the motion of stopping of the mass is written in the following way: $M\,.\,\ddot{X}=\alpha.\left\{\dfrac{\ddot{X}}{X}\right\}+\beta.\left\{\dfrac{\dot{X}}{X}\right\}^2$.

One can find in [bib1] an analytical resolution whose we will point out the principal results here. By integrating once the differential equation, one obtains a form of the velocity of the projectile according to his position:

$$\dot{X}=-\dot{X}_0.\left(\frac{X_0+\lambda}{X_0}\right)^2.\left(\frac{X}{X+\lambda}\right)^2 \quad \text{où} \quad \lambda=\frac{\alpha}{M}$$

While integrating once again compared to time this differential equation it comes:

$$t=\frac{1}{\dot{X}_0}.\left(\frac{X_0}{X_0+\lambda}\right)^2.\left[X_0-X+2\lambda\,.\,Log\left(\frac{X_0}{X}\right)+\lambda^2\left(\frac{1}{X}-\frac{1}{X_0}\right)\right]$$

There is thus an implicit definition of the displacement of the mass in the course of time. One can release the following properties of this motion:

- the solid can touch the obstacle only at the end of an infinite time,
- the solid approaches at infinitely slow velocity of the obstacle.

The total fluid force has as a statement:

$$F_{fluide}(X)=2.\lambda.M.\dot{X}_{0^2}.\left(\frac{X_0+\lambda}{X_0}\right)^4.\frac{X^3}{(X+\lambda)^5}$$

Its maximum value is obtained by cancelling derivative of this function. It is reached in $X_{F\max}=\frac{3}{2}\lambda$ and is worth $F_{Max fluide}=8.\frac{3^3}{5^5}.M.\frac{\dot{X}_0^2}{\lambda}.(\frac{X_0+\lambda}{X_0})^4$.

The numerical values considered for computations are:

M = 1000 kg	$2L$ = 100 mm
X_0 = 6 mm, $\dot{X}_0$ = -0.1 m/s	
ρ_f = 1000 kg/m3	ν = 10-6

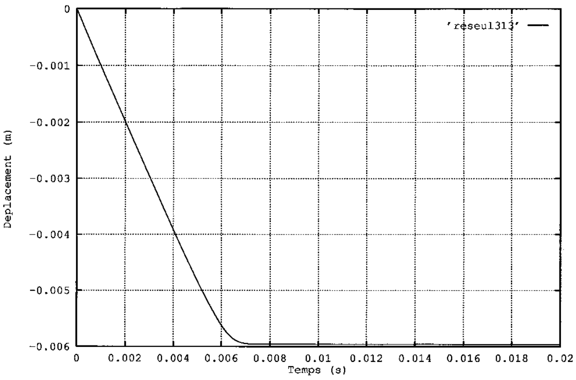
the coefficients α , β are calculated according to the formula of paragraph 2.3 and are worth in this case:

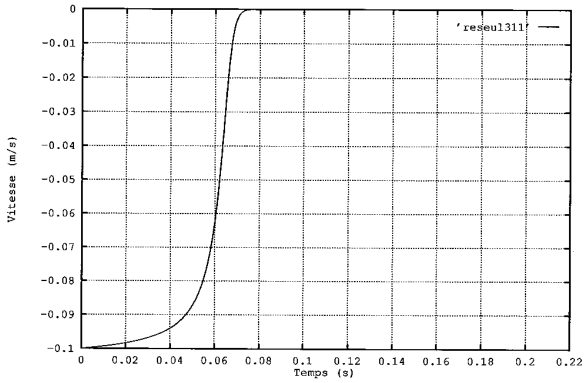
$$\alpha=-0.0833 \quad ,\beta=0.1666$$

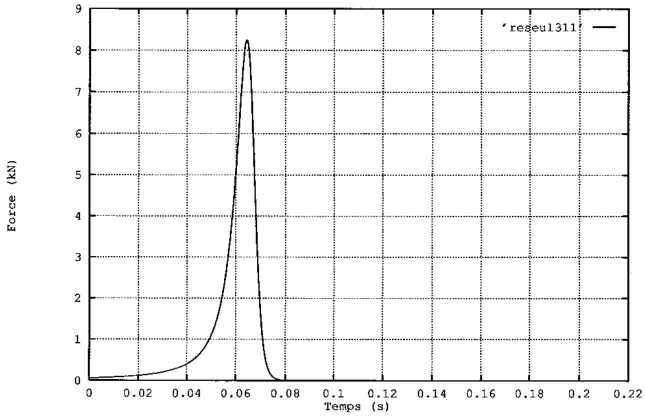
One can observe below displacement, the velocity of the mass and the fluid force which it undergoes. The behavior of the mass is rather similar to that observed for the parabolic mode. The maximum fluid force, given in an analytical way in the preceding paragraph, is worth in this case $8768\,N$. The mass in this case approaches in an asymptotic way of the wall and reaches it only at the end of an infinite time.

Note:

On the graph, at the end of $0,2\,s$ *computation there remains a distance from* $1.\mathrm{e}^{-6}\,m$ *with the wall.*







3.2 To launch of a mass slowed down by fluid blade with parabolic profile

the analytical resolution of the differential equation governing the behavior of the mass is not possible any more. One proposes to determine in an external way with any computer code, the dynamic response of this system with a d.o.f. in the presence of a fluid blade. That caused the development of a dedicated FORTRAN program, developed with this occasion.

As we established in the preceding paragraph, the reaction force of the fluid blade takes the following general shape:

$$F_{fluide}=\alpha.\left\{\frac{\ddot{X}}{X}\right\}+\beta.\left\{\frac{\dot{X}}{X}\right\}^2+\chi\frac{\dot{X}}{X^3}+\delta\frac{\dot{X}.|\dot{X}|}{X^2}$$

The dynamic equation to which this system is subjected is the following one:

$$M.\ddot{X}+K.X=F_{ext}+\alpha.\left\{\frac{\ddot{X}}{X}\right\}+\beta.\left\{\frac{\dot{X}}{X}\right\}^2+\chi\frac{\dot{X}}{X^3}+\delta\frac{\dot{X}.|\dot{X}|}{X^2}$$

We propose a resolution by a temporal diagram of integration of the dynamic problem.

The statement of the second member is not classic because it utilizes acceleration. One proposes to use an explicit diagram of integration, which requires the statement of $\ddot{X}$, according to $X,\dot{X}$. It is thus necessary to rewrite the system in the form:

$$(M-\frac{\alpha}{X_t}).\ddot{X}_t+K.X_t=F_{ext}+\alpha.\left\{\frac{\ddot{X}_t}{X_t}\right\}+\beta.\left\{\frac{\dot{X}_t}{X_t}\right\}^2+\chi\frac{\dot{X}_t}{X_t^3}+\delta\frac{\dot{X}_t.|\dot{X}_t|}{X_t^2}$$

We will use the diagram of Eulerian modified to integrate this equation in time:

$X_{0,}\dot{X}_0$ given to t_0 ,

To repeat

$$\frac{\ddot{X}_i=F_{ext}-K.X_i+\beta.\left\{\frac{\dot{X}_i}{X_i}\right\}^2+\chi\frac{\dot{X}_i}{X_i^3}+\delta\frac{\dot{X}_i.|\dot{X}_i|}{X_i^2}}{M-\frac{\alpha}{X_i}}$$

$$t_{i+1}=t_i+dt$$
$$\dot{X}_{i+1}=\dot{X}_i+dt.\ddot{X}_i$$
$$X_{i+1}=X_i+dt.\dot{X}_i$$

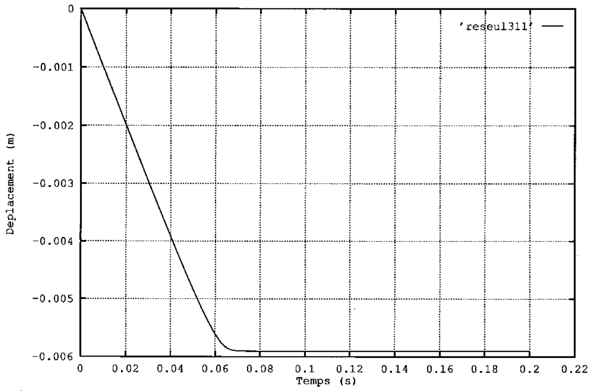
as long as $t_{i+1}<t_{fin}$

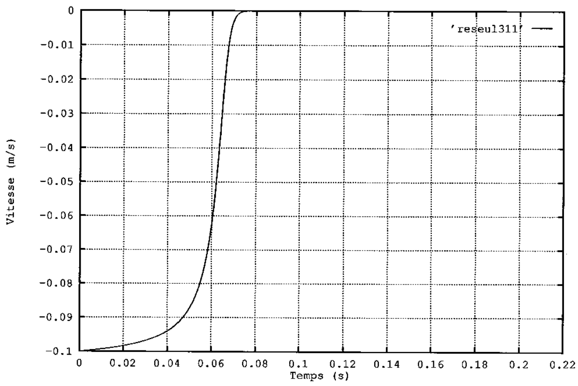
For the type of non-linearities considered, one does not have criterion of stability *a priori* of the diagram of integration. One was thus ensured by a study of convergence while decreasing time step of computation which the got results were stable.

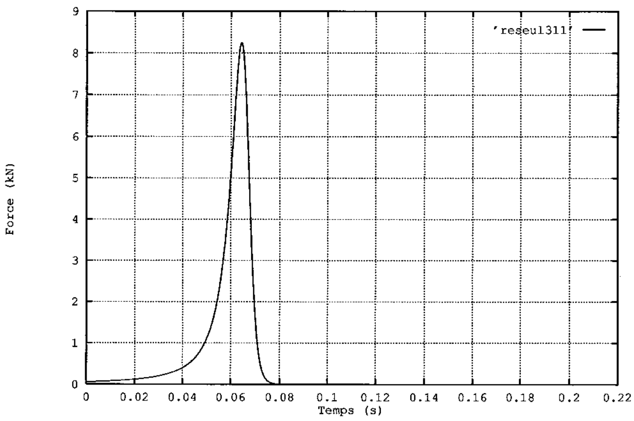
The coefficients α , β and χ are calculated according to the formula of paragraph 2.4 and are worth in this case:

$$\alpha=-0.0833, \beta=0.19992 \quad \text{et}\ \chi=-0.9996.10^{-6} \quad \text{et la masse}\ \mathrm{M}=1000\,\mathrm{kg}$$

One can observe below displacement, the velocity of the mass and the fluid force which it undergoes. It is noted that it preserves a velocity close to that initial before being sufficiently close to the wall. Then it undergoes an important fluid force which dissipates all the kinetic energy of the mass. The mass does not touch the wall, but preserves an asymptotic distance at the wall, which is worth $0.098\,mm$.







4 Computation of a system multi degrees of freedom subjected locally to forces of fluid blade

a layer to simulate the forces of fluid blade is to introduce them like linear forces not - into the algorithm of modal recombination DYNA_TRAN_MODAL [bib3] [U4.54.03], allowing to calculate the dynamics of a mechanical system by carrying out a projection on the basis of its free mode.

The temporal algorithms of *Code_Aster* treating the nonlinear forces are the explicit diagrams of Eulerian and Devogelaere. We saw in the preceding chapter that the intrinsic form of the forces of fluid blade poses a problem for the resolution with an explicit diagram. A modification of algorithm DYNA_TRAN_MODAL allows a suitable processing of the forces of fluid blade.

The direct dynamic problem discretized by finite elements is written:

$$\mathbf{M}\ddot{\mathbf{X}}_{\mathbf{t}}+\mathbf{C}\dot{\mathbf{X}}_{\mathbf{t}}+\mathbf{K}\mathbf{X}_{\mathbf{t}}=\mathbf{F}_{ext}(t)+\mathbf{F}_{fluide}(\mathbf{X}_{\mathbf{t}},\dot{\mathbf{X}}_{\mathbf{t}},\ddot{\mathbf{X}}_{\mathbf{t}})$$

The technique used in operator DYNA_TRAN_MODAL consists in projecting on the basis of linear system and to maintain the forces nonlinear with the second member.

The dynamic system project takes the shape:

$$\boldsymbol{\Phi}^{t}.\mathbf{M}.\boldsymbol{\Phi}.\ddot{\eta}_{t}+\boldsymbol{\Phi}^{t}.\mathbf{C}.\boldsymbol{\Phi}.\dot{\eta}_{t}+\boldsymbol{\Phi}^{t}.\mathbf{K}.\boldsymbol{\Phi}.\eta_{t}=\boldsymbol{\Phi}^{t}.\mathbf{F}_{ext}(t)+\boldsymbol{\Phi}^{t}.\mathbf{F}_{fluide}(\boldsymbol{\Phi}.\eta_{t},\boldsymbol{\Phi}.\dot{\eta}_{t},\boldsymbol{\Phi}.\ddot{\eta}_{t}) \quad \textbf{éq 4-4-14-1}$$

the integration methods explicit require to determine $\ddot{\eta}_t$ knowing $\eta_t,\dot{\eta}_t$ and possibly their former values.

One thus sees in the statement of the system [éq 4-1] above that $\ddot{\eta}_t$ is not given explicitly according to $\eta_t,\dot{\eta}_t$. From this moment, one proposes to use a method of point fixed to obtain generalized accelerations.

This is obtained by applying the following operations:

$\ddot{\eta}_t^0=\ddot{\eta}_{t-1},\eta_t,\dot{\eta}_t$ given

to repeat until convergence:

$$\ddot{\eta}_t^{i+1}=[\boldsymbol{\Phi}^t.\mathbf{M}.\boldsymbol{\Phi}]^{-1}.(\boldsymbol{\Phi}^t.\mathbf{F}_{fluide}(\boldsymbol{\Phi}.\eta_t,\boldsymbol{\Phi}.\dot{\eta}_t,\boldsymbol{\Phi}.\ddot{\eta}_t^i)+\boldsymbol{\Phi}^t.\mathbf{F}_{ext}(t)-\boldsymbol{\Phi}^t.\mathbf{C}.\boldsymbol{\Phi}.\dot{\eta}_t-\boldsymbol{\Phi}^t.\mathbf{K}.\boldsymbol{\Phi}.\dot{\eta}_t)$$

convergence is tested par. $\|\ddot{\eta}_t^{i+1}-\ddot{\eta}_t^i\|<\varepsilon\|\ddot{\eta}_t^i\|$

Unfortunately this technique of iteration of the fixed point is not necessarily convergent. For that, it is necessary that the linear operator reiterated either contractor. However for low thickness of fluid blade, the terms of inertia forces can be very important and thus prevent the convergence of the iterations of fixed point. It is thus not established such as it in operator DYNA_TRAN_MODAL.

We will analyze more in detail the operator $\boldsymbol{\Phi}^t.\mathbf{F}_{fluide}(\boldsymbol{\Phi}.\eta_t,\boldsymbol{\Phi}.\dot{\eta}_t,\boldsymbol{\Phi}.\ddot{\eta}_t)$, to extract the diagonal part and to make it from it pass to the first member.

In a node n comprising an effect of fluid blade, the fluid inertia force will be expressed in the form, linear in acceleration:

$$F_{inertie}=\alpha.\frac{\ddot{X}_n}{X_n}$$

The quantities $\ddot{X}_n, X_n$ are expressed in a local coordinate system. They are thus obtained by an operation of extraction $\mathbf{P}$ of the total assembled vector, followed by a series of rotations $\mathbf{R_n}$ to obtain in the local coordinate system, followed by a extraction $\mathbf{E}_\mathrm{n}$ of the normal component.

One will note these operations in a matric way $\ddot{\mathbf{X}}_\mathrm{n}=\mathbf{E}_\mathrm{n}.\mathbf{R}_\mathrm{n}.\ddot{\mathbf{X}}$.

In a similar way, the local inertia force must be turned over in the physical reference and corresponding to assembled vector, before being projected on the basis $\boldsymbol{\Phi}$. These operations can be noted in a matric way: $\boldsymbol{\Phi}^t.\{\mathbf{F}\}=\boldsymbol{\Phi}^t.\mathbf{P}^\mathrm{t}.\mathbf{R}_\mathrm{n}^{-1}.\mathbf{E}_\mathrm{n}^\mathrm{t}\mathbf{F}_{fluide}$

The vector of the generalized forces representing the component of inertia of the fluid blade is:

$$\boldsymbol{\Phi}^t.\mathbf{F}=\frac{\alpha}{X_n}\boldsymbol{\Phi}^t.\mathbf{P}^\mathrm{t}.\mathbf{R}_\mathrm{n}^{-1}.\mathbf{E}_\mathrm{n}^\mathrm{t}.\mathbf{R}_\mathrm{n}.\mathbf{P}.\boldsymbol{\Phi}.\ddot{\boldsymbol{\eta}}\ .$$

In the general case, one cannot determine once for all the value of this matric product because it thus depends on the local coordinate system of the position of structure compared to the fluid blade. One proposes to use an approximation of this matrix in the form:

$$\mathbf{m}'_t=\frac{\alpha}{X_n^t}.\boldsymbol{\Phi}^t.\mathbf{P}^\mathrm{t}.\mathbf{P}.\boldsymbol{\Phi}$$

To return the operator of point contractor it fixes is enough to modify the mass matrix of the operator of iteration by cutting off the matrix to him $\mathbf{m}'$. That amounts adding to him by way of the mass because α is negative.

One will use in the algorithm of Eulerian modified for the taking into account of the effects of fluid blade, the algorithm of point fixes opposite:

$\ddot{\boldsymbol{\eta}}_t^0=\ddot{\boldsymbol{\eta}}_{t-1}$ to repeat until convergence:

$$\ddot{\boldsymbol{\eta}}_t^{i+1}=\left[\boldsymbol{\Phi}^t.\mathbf{M}.\boldsymbol{\Phi}-\sum_{noeuds\ fluide}\lambda.\mathrm{diag}(\mathbf{m}'_n)\right]^{-1}.$$
$$(\boldsymbol{\Phi}^t.\mathbf{F}_{fluide}(\boldsymbol{\Phi}.\boldsymbol{\eta}_t,\boldsymbol{\Phi}.\dot{\boldsymbol{\eta}}_t,\ddot{\boldsymbol{\eta}}_t^i)-\sum_{noeuds\ fluide}\lambda.\mathrm{diag}(\mathbf{m}'_n).\ddot{\boldsymbol{\eta}}_t^i+\boldsymbol{\Phi}^t.\mathbf{F}_{ext}(t)-\boldsymbol{\Phi}^t.\mathbf{C}.\boldsymbol{\Phi}.\dot{\boldsymbol{\eta}}_t-\boldsymbol{\Phi}^t.\mathbf{K}.\boldsymbol{\Phi}.\boldsymbol{\eta}_t)$$

convergence is tested by $\|\ddot{\boldsymbol{\eta}}_t^{i+1}-\ddot{\boldsymbol{\eta}}_t^i\|<\varepsilon\|\ddot{\boldsymbol{\eta}}_t^i\|$, where ε is an accuracy given for the stop of the iterations.

The parameter λ. selected higher than one, is used to guarantee the character contracting of the iterations of fixed point. In practice, one chooses for value $\lambda=10$ what seems to guarantee convergence in all the cases observed, one can possibly modify this parameter in the event of problems of convergence. It does not exist of result theoretical giving a best alternative for λ . One will be possibly led to modify this value according to the importance of the linear forces not - in the response of the system, to improve convergence of the computation of acceleration.

5 Establishment of the nonlinear forces of specific

5.1 fluid blade Integration for the forces of fluid blade

the forces of fluid blade compatible with the diagram of integration are named "EULER" and "ADAPT" in operator DYNA_TRAN_MODAL. The processing of the forces of fluid blade is activated only when fluid blades are present in the model what guarantees a maintenance of the performances of former algorithms EULER and DEVOGE, and makes it possible to use in the case of a fluid blade, a specific option but preserving nevertheless non-linearities and the existing functionalities of the initial algorithm.

5.2 Use of the forces of fluid blade in DYNA_TRAN_MODAL

the forces of fluid blade are provided to function like non-linearities of shock, i.e., that an effect of fluid blade can act between a point of a structure and a fixed obstacle, or between two points of two antagonistic structures.

The parameters of fluid blade are thus provided in factor key word the CHOC of operator DYNA_TRAN_MODAL. Syntax under this key word will be the following one:

```
◊CHOC  :   (
                   ….

              ♦RIGI_NOR   : KN     [r8]
                   ….

              ◊LAME_FLUIDE :  /   "NON"         [DEFAULT]
                                  /rep             [kN]
              ◊ALPHA    :         /   0.            [DEFAULT]
                                  /   α              [R8]
              ◊BETA     :         /   0.            [DEFAULT]
                                  /   β              [R8]
              ◊CHI      :         /   0.            [DEFAULT]
                                  /   χ              [R8]
              ◊DELTA    :         /   0.            [DEFAULT]
                                  /   δ              [R8]

           )
```

key word LAME_FLUIDE makes it possible to specify if the interaction between the node and the obstacle or the two nodes takes place in the presence of a fluid blade. By default connection is supposed of standard dry contact.

Key words ALPHA, BETA, CHI, DELTA make it possible to describe the form of the linear force not - of fluid blade, their values correspond to the coefficients α,β,χ,δ are mentioned in the chapter [§2]. They make it possible to define in the choice a uniform or parabolic profile.

6 Model transition fluid blade - shock

the studies justifying the development of the forces of fluid blade comprise situations where the structure vibrates in the presence of fluid blade and can even according to certain conditions of excitation outward journey until the dry contact with the obstacle in the event of fluid fracture of film.

This situation is particularly difficult to manage numerically from the nature of the statement of the forces of fluid blade used. In fact, one is obliged to consider a physical limit of validity to the statement of these forces of fluid blade, limiting beyond which it is necessary to forward towards conditions of mechanical contact (dry) between structures.

One thus introduces by the same occasion the notion of **limiting thickness of fluid blade** beyond which the model of fluid blade only is not valid any more, and the blade becomes in fact incompressible.

To preserve by the strength of reaction (fluid blade and contact) a continuous character, we introduced a weight function which makes it possible continuously to forward force of repulsion of fluid blade to a force of repulsion of type dry contact.

$$\mathrm{f}_{\mathrm{ponder}}(d_n)=0 \,\mathrm{si}\, d_n \leq 0$$

$$\mathrm{f}_{\mathrm{ponder}}(d_n)=1 \quad \mathrm{si} \quad d_n^3 \geq \varepsilon$$

$$\mathrm{f}_{\mathrm{ponder}}(d_n) \,\text{de continuité}\; C^0 \,\text{pour}\; d_n \in [0, \varepsilon]$$

In the zone of transition $d_n \in [0, \varepsilon]$, the reaction force is written:

$$F_{\textit{réaction}} = \mathrm{f}_{\mathrm{ponder}}(d_n) \times \mathrm{F}_{\mathrm{fluide}}(d_n, \dot{d}_n, \ddot{d}_n) + (1 - \mathrm{f}_{\mathrm{ponder}}(d_n)) \times Fchoc(d_n - \varepsilon, \dot{d}_n)$$

The boundary layer ε is dynamically given with heuristics according to the formula:

$$\varepsilon = \frac{\mathrm{F}_{\mathrm{fuilde}}(d_n, \dot{d}_n, \ddot{d}_n)}{K_N} \qquad \textbf{éq 6-6-16-1}$$

If this boundary layer is reached or exceeded $d_n \leq \varepsilon$ by the wall of structure one enters a phase of transition towards the shock. The limiting value of thickness is then filed and the model of transition is used until d_n becomes again $\geq \varepsilon$.

One explains physically the choice of the formula [éq 6-1] to determine the thickness of fluid blade by considering that in this situation the force of fluid blade is such as it can deform structure on its stiffness of shock and thus the fluid blade in it even becomes incompressible, from where the need for forwarding towards the model shock force.

Note: Use of the forces of fluid blade with the model of transition

The model from transition fluid - shock was introduced in a systematic way. As soon as a force of fluid blade is introduced, one can forward towards the shock. It is thus necessary systematically to introduce a stiffness of shock K_N (key word `RIGI_NOR`). If one never wishes not to forward towards a dry contact (mainly for benchmarks) it will be necessary to take a value of K_N very large (10^{15}).

7 Conclusion

This document describes the statement of the fluid forces which are exerted when a structure vibrates in the vicinity of a plane wall, in an incompressible fluid at rest (**put out of flow by the motion of structure**). These forces are called **forces of fluid blade**.

For two assumptions of flow profile in the blade, an analytical form of the force is established. The latter depends in a nonlinear way of acceleration, the velocity and the position of structure compared to the obstacle.

For a system with a degree of freedom with initial velocity deadened by a fluid blade, an analytical computation could be carried out with a uniform profile. For the other profile, like for configurations of system masses spring, a numerical integration was necessary. One could analyze on these computations the behavior of the fluid blade, which introduces in particular a strong damping.

The processing of these forces for systems with several degrees of freedom resulted in modifying the explicit algorithm of integration on the basis of DYNA_TRAN_MODAL modal base to correctly integrate the dynamic effect of these forces in *Code_Aster*.

8 Bibliography

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9 Description of the versions of the document

Version Aster	**Author (S) Organization (S)**	**Description of the modifications**
3	G.Jacquart EDF-R&D/AMV	initial Text