Name cas_test - Thermal shock in a tube

Summary

The objective of this CAS-test is to validate this methodology on the one hand and to check its to facilitate of implementation on the other hand. In this CAS-test, one models a tube in which a fluid carrying a thermal shock circulates. Then one calculates the mechanical answer by using same methodology.

Four modelings carried out are the following ones:

- **Modeling A** : axisymmetric modeling or one calculates the transitory thermal answer for the thermal shocks $(\Delta T=50°C;\Delta T=100°C;\Delta T=200°C)$ and the associated mechanical answer.
- **Modeling B** : axisymmetric modeling or one calculates the transitory thermal answer for the thermal shocks $(\Delta T=50°C;\Delta T=100°C;\Delta T=200°C)$ starting from the unit thermal shock $(\Delta T_U=1°C)$ via MedCoupling and the associated mechanical answer.
- **Modeling C** : voluminal modeling or one calculates the transitory answer for the thermal shocks $(\Delta T=50°C;\Delta T=100°C;\Delta T=200°C)$ and the associated mechanical answer.

Modeling C : voluminal modeling which calculates the transitory answer for the thermal shocks $(\Delta T=50°C;\Delta T=100°C;\Delta T=200°C)$ starting from the unit thermal shock $(\Delta T_U=1°C)$ via MedCoupling and the associated mechanical answer.
To reduce the time necessary to the installation of thermomechanical calculations in the linear field, a new methodology is proposed. This methodology consists in determining the temperature in a structure starting from calculation of a unit thermal shock by using a chaining Code_Aster → MedCoupling → Code_Aster.

1 Problem of reference

Geometry

The structure consists of a tube in which a fluid carrying the thermal shock circulates.

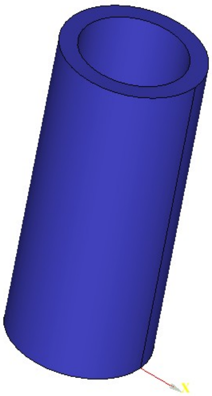
- Section of right tube
- Length of the tube: $L=0.1\,m$
- Diameter external of the tube: $\varphi_{ext}=0.048\,m$
- Thickness of the tube: $e=0.006\,m$

1.1 Material properties

$\lambda=15\,W/m\,°C$	Coefficient of conductivity thermics
$C_P=500\,J/Kg\,°C$	Specific heat
$a=3.8\,x\,10^{-6}\,m^2/s$	Thermal diffusivity
$E=200\,000\,MPa$	Young modulus
$\nu=0.3$	Poisson's ratio
$\alpha=15\,x\,10^{-6}/°C$	Thermal dilation coefficient

1.2 Boundary conditions and loadings

The thermal shock is transmitted to the tube by the fluid via a convectif exchange. Four thermal shocks are studied:



Thermal shock	Under-surface	
$\Delta T=1\,°C$	$T_{fluide}=1\,°C$ $h=20000\,W/m^2/°C$	
$\Delta T=50\,°C$	$T_{fluide}=70\,°C$ $h=20000\,W/m^2/°C$	
$\Delta T=100\,°C$	$T_{fluide}=120\,°C$ $h=20000\,W/m^2/°C$	
$\Delta T=200\,°C$	$T_{fluide}=220\,°C$ $h=20000\,W/m^2/°C$	$T_{imposée}=20\,°C$

The thermal shock corresponds to the difference between the initial temperature of the tube and that of the fluid.

Flow is null in the axial direction of the tube ($\frac{\partial T(x,t)}{\partial z}=0$).

For the mechanical analysis the tube is blocked at its base in the axial direction.

1.3 Initial conditions

- $T(x,t=0)=20\,°C$ for the shocks $(\Delta T=50\,°C\,;\Delta T=100\,°C\,;\Delta T=200\,°C)$
- $T(x,t=0)=0\,°C$ for the unit shock $\Delta T_U=1\,°C$

1.4 Precise details concerning modelings

To define the discretization in time one uses the time-constant $\tau=\frac{e^2}{(a\pi^2)}=1\,s$ who gives us a thermal shock in the case of the moment with beyond which the thermal behavior becomes almost stationary in the tube. The duration of the thermal shock is fixed at $10.^{-1}s$. We chose the following discretization in time:

10	not for	$[0.0, 0.1]$	that is to say	$\Delta t=0.01\,s$
10	not for	$[0.1, 0.5]$	that is to say	$\Delta t=0.04\,s$
10	not for	$[0.5, 3.0]$	that is to say	$\Delta t=0.25\,s$
5	not for	$[3.0, 5.0]$	that is to say	$\Delta t=0.4\,s$
2	not for	$[5.0, 10.]$	that is to say	$\Delta t=2.5\,s$

2 Reference solution

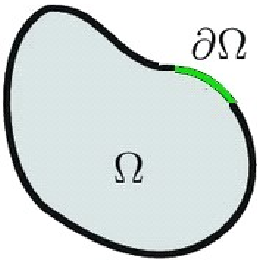
3

4

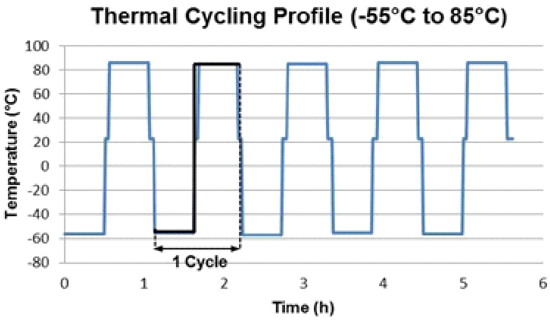
5 Method of calculating used for the reference solution

To reduce the time necessary to the installation of thermal calculations in the linear field, a new methodology is proposed.

A structure Ω is considered. A thermal shock is imposed on part of the structure $\partial\Omega$. The following figure presents an example.



The thermal shock is defined like an increment of temperature significant and instantaneous. Figure 2 presents an example of several consecutive thermal shocks.



5.1 The law of Furrier décr

5.2 ivant heat exchange applied to this structure subjected to a thermal shock can be written in this form:

$$T(x,t)=\begin{cases} T(x,t_0) & \text{pour t} < t_c \\ T(x,t_0)+\int_{t_c}^{t} a\dfrac{\partial^2 T(x,t)}{\partial x^2}dt & \text{pour t} \geq t_c \end{cases}$$

Where $T(x,t_0)$ is the initial of the structure, known state, and t_c the moment of the thermal shock. For various thermal shocks, it is thus necessary to solve this problem and thus to obtain, for each shock the solution $T(x,t)$.

5.2.1 Case of the unit shock

If a unit shock ΔT_U (shock of $\Delta T=1$ degree) is imposed on $\partial\Omega$ at the moment $t=t_c$, the problem is written:

$$T_U(x,t)=\begin{cases} T_U(x,t_0) & \text{pour t} < t_c \\ T_U(x,t_0)+\int_{t_c}^{t} a\dfrac{\partial^2 T_U(x,t)}{\partial x^2}dt & \text{pour t} \geq t_c \end{cases}$$

With $T_U(x,t_0)$ the initial state of the structure before the unit shock. The solution with this problem can be numerically given using the finite element method, in particular the operator `THER_LINEAIRE` of Code_Aster if the parameters materials are independent of the temperature. Once the solved problem, the solution $T_U(x,t)$ is known.

As one is interested that with the differential of temperature, a simplified notation is proposed:

$$\tilde{T}_U(x,t)=T_U(x,t)-T_U(x,t_0)$$

One thus has

$$\tilde{T}_U(x,t)=\begin{cases} 0 & \text{pour t} < t_c \\ \int_{t_c}^{t} a\dfrac{\partial^2 \tilde{T}_U(x,t)}{\partial x^2}dt & \text{pour t} \geq t_c \end{cases}$$

5.2.2 Case of a shock unspecified

A thermal shock, always on $\partial\Omega$, but of unspecified intensity β is this time imposed. This problem is written in the form:

$$T_\beta(x,t)=\begin{cases} T_\beta(x,T_0) & \text{pour t} < t_c \\ T_\beta(x,T_0)+\int_{t_c}^{t} a\dfrac{\partial^2 T_\beta(x,t)}{\partial x^2}dt & \text{pour t} \geq t_c \end{cases}$$

With $T_\beta(x,t_0)$ the initial state of the structure before the thermal shock. By taking again the simplified notation, one obtains:

$$\tilde{T}_\beta(x,t)=\begin{cases} 0 & \text{pour t} < t_c \\ \int_{t_c}^{t} a\dfrac{\partial^2 T_\beta(x,t)}{\partial x^2}dt & \text{pour t} \geq t_c \end{cases}$$

Compared to the preceding unit problem, only the intensity of the thermal loading was modified: $\Delta T=\beta\,\Delta T_U$. Indeed, the shock is always on $\partial\Omega$, it is simply amplified scalar β . Consequently:

This last equation is valid only for one problem of linear thermics and thus β independent of the position. The solution of the unspecified thermal shock is thus:

$$\tilde{T}_\beta(x,t)=\begin{cases} 0 & \text{pour t} < t_c \\ \int_{t_c}^{t} a\,\beta\dfrac{\partial^2 \tilde{T}_U(x,t)}{\partial x^2}dt & \text{pour t} > t_c \end{cases}$$

Moreover, by considering that the scalar β is independent of time, which is coherent with a thermal shock, one a:

$$\int_{t_c}^{t} a\,\beta \frac{\partial^2 \tilde{T}_U(x,t)}{\partial x^2} dt = \beta \int_{t_c}^{t} a \frac{\partial^2 \tilde{T}_U(x,t)}{\partial x^2} dt$$

The integral present in this equation problem is actually the solution obtained before for the unit shock:

$$\int_{t_c}^{t} a \frac{\partial^2 \tilde{T}_U(x,t)}{\partial x^2} dt = \tilde{T}_U(x,t) \qquad pour\, t \geq t_c$$

The solution with the problem of the unspecified thermal shock on $\partial\Omega$ solution obtained for the unit thermal shock:

$$\tilde{T}_\beta(x,t) = \beta\,.\,\tilde{T}_U(x,t)$$

It is considered here that the unit thermal shock takes place at the same moment as the thermal shock Δt_c. If the shock takes place at another moment, it is simply enough to shift the solution:

$$\tilde{T}_\beta(x,t) = \beta\,.\,\tilde{T}_U(x,t-(t_c-t_{c2}))$$

Where t_{c2} is the moment of the unit shock. Consequently, by choosing the unit shock of kind so that t_{c2} maybe at the moment $t=0\mathrm{s}$, the solution becomes:

$$\tilde{T}_\beta(x,t) = \beta\,.\,\tilde{T}_U(x,t-t_c)$$

It is thus possible to determine the field of temperature of the structure while proceeding as follows:

- To define a uniform field of temperature initial on the structure $T_\beta(x,t_0)$

To set up a thermal analysis of a unit shock at time $t=0\mathrm{s}$ on the structure and to obtain the solution of the unit problem and to determine $\tilde{T}_U(x,t)$. It can prove judicious to impose a worthless initial temperature of kind so that $\tilde{T}_U(x,t) = T_U(x,t)$.

- To calculate the solution (in space and time) starting from a linear combination of the initial situation $T(x,t_0)$, intensity of the shock β as well as solution of the problem of the shock unit $\tilde{T}_U(x,t)$.

5.3 Results of reference

5.3.1 Thermic analyses

The thermal behavior is axisymmetric. Several points through the thickness and two moments are selected to test the answer in temperature. The results of references were got by Code_Aster and with a linear axisymmetric grid four time plfine custom. The geometrical coordinates of the points of reference are the following ones:

Points	Ray (m)
Under-surface	0,018
With	0.0185
B	0,019
C	0,020
D	0,022
Suction face	0,024

Temperature (°C)		Under-surface	With	B	C	D
$\Delta T=1°C$	0.1 S	0,392	0,117	0,040	0,001	0.0
	3.0 S	0,856	0,756	0,683	0,498	0,218
$\Delta T=50°C$	0.1 S	39,605	25,867	22,011	20,056	20,000
	3.0 S	62,818	57,822	54,157	44,919	30,891
$\Delta T=100°C$	0.1 S	59,211	31,734	24,022	20,112	20,000
	3.0 S	105,636	95,644	88,315	69,838	41,782
$\Delta T=200°C$	0.1 S	98,422	43,467	28,044	20,225	20,000
	3.0 S	191,272	171,287	156,629	119,675	63,564

5.3.2 Mechanical analyses

One tests the constraints in several points through the thickness for one moment. The results of references were got by Code_Aster and with a quadratic axisymmetric grid four time plfine custom.

Constraint (Pa) with t=0.1s							
Temperature	size	Under-surface	With	B	C	D	Suction face
$\Delta T=1°C$	SIXX	-11,145	-2.464E4	-2.847E4	-2.288E4	-9.917E3	6,984
	SIYY	-1.574E6	-4.416E5	-4.391E4	9.800E4	1.043E5	1.043E5
	SIZZ	-1.574E6	-4.171E5	-1.545E4	1.209E5	1.143E5	1.043E5
	VMIS	1.574E6	4.053E5	2.501E4	1.338E5	1.195E5	1.043E5
$\Delta T=50°C$	SIXX	-5.572E2	-1.232E6	-1.424E6	-1.144E6	-4.958E5	3.492E2
	SIYY	-7.868E7	-2.208E7	-2.195E6	4.900E6	5.217E6	5.217E6
	SIZZ	-7.868E7	-2.086E7	-7.723E5	6.043E6	5.713E6	5.217E6
	VMIS	7.868E7	2.026E7	1.251E6	6.689E6	5.976E6	5.217E6
$\Delta T=100°C$	SIXX	-1.114E3	-2.464E6	-2.847E6	-2.288E6	-9.917E5	6.984E2
	SIYY	-1.574E8	-4.416E7	-4.391E6	9.800E6	1.043E7	1.043E7
	SIZZ	-1.574E8	-4.171E7	-1.545E6	1.209E7	1.143E7	1.043E7
	VMIS	1.574E8	4.053E7	2.501E6	1.338E7	1.195E7	1.043E7
$\Delta T=200°C$	SIXX	-2.229E3	-4.928E6	-5.694E6	-4.576E6	-1.983E6	1.397E3
	SIYY	-3.147E8	-8.831E7	-8.781E6	1.960E7	2.087E7	2.087E7
	SIZZ	-3.147E8	-8.343E7	-3.089E6	2.417E7	2.285E7	2.087E7
	VMIS	3.147E8	8.105E7	5.002E6	2.676E7	2.390E7	2.087E7

5.4 Uncertainty on the solution

Digital solution.

Modeling ACharacteristics of modeling

5.5 Results of modeling A

Temperature (°C) $\Delta T=50°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	39,605	1.
	With	`'AUTRE_ASTER'`	25,867	1.
	B	`'AUTRE_ASTER'`	22,011	1.
	C	`'AUTRE_ASTER'`	20,056	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	62,818	1.
	With	`'AUTRE_ASTER'`	57,822	1.
	B	`'AUTRE_ASTER'`	54,157	1.
	C	`'AUTRE_ASTER'`	44,919	1.
	D	`'AUTRE_ASTER'`	30,891	1.

Temperature (°C) $\Delta T=100°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	59,211	1.
	With	`'AUTRE_ASTER'`	31,734	1.
	B	`'AUTRE_ASTER'`	24,022	1.
	C	`'AUTRE_ASTER'`	20,112	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	105,636	1.
	With	`'AUTRE_ASTER'`	95,644	1.
	B	`'AUTRE_ASTER'`	88,315	1.
	C	`'AUTRE_ASTER'`	69,838	1.
	D	`'AUTRE_ASTER'`	41,782	1.

Temperature (°C) $\Delta T=200°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	98,422	1.
	With	`'AUTRE_ASTER'`	43,467	1.5
	B	`'AUTRE_ASTER'`	28,044	1.1
	C	`'AUTRE_ASTER'`	20,225	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	191,272	1.
	With	`'AUTRE_ASTER'`	171,287	1.
	B	`'AUTRE_ASTER'`	156,629	1.
	C	`'AUTRE_ASTER'`	119,675	1.
	D	`'AUTRE_ASTER'`	63,564	1.

Constraint (Pa) $\Delta T = 50\,°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-5.57E2	1700.
		`SIYY`	`'AUTRE_ASTER'`	-7.868E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-7.868E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	7.868E7	1.%
	With	`SIXX`	`'AUTRE_ASTER'`	-1.23E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-2.208E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-2.086E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	2.026E7	1.%
	B	`SIXX`	`'AUTRE_ASTER'`	-1.42E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-2.195E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-7.723E5	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.251E6	1.1%
	C	`SIXX`	`'AUTRE_ASTER'`	-1.14E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	4.900E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	6.043E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	6.689E6	1.%
	D	`SIXX`	`'AUTRE_ASTER'`	-4.96E5	1.%
		`SIYY`	`'AUTRE_ASTER'`	5.217E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	5.713E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	5.976E6	1.%
	Suction face	`SIXX`	`'AUTRE_ASTER'`	3.49E2	1100.
		`SIYY`	`'AUTRE_ASTER'`	5.217E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	5.217E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	5.217E6	1.%

Constraint (Pa) $\Delta T=100°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-1.114E3	3400.
		`SIYY`	`'AUTRE_ASTER'`	-1.574E8	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-1.574E8	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.574E8	1.%
	With	`SIXX`	`'AUTRE_ASTER'`	-2.464E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-4.416E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-4.171E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	4.053E7	1.%
	B	`SIXX`	`'AUTRE_ASTER'`	-2.847E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-4.391E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-1.545E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	2.501E6	1.1%
	C	`SIXX`	`'AUTRE_ASTER'`	-2.288E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	9.800E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	1.209E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.338E7	1.%
	D	`SIXX`	`'AUTRE_ASTER'`	-9.917E5	1.%
		`SIYY`	`'AUTRE_ASTER'`	1.043E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	1.143E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.195E7	1.%
	Suction face	`SIXX`	`'AUTRE_ASTER'`	6.984E2	3000.
		`SIYY`	`'AUTRE_ASTER'`	1.043E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	1.043E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.043E7	1.%

Constraint (Pa) $\Delta T=200°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	SIXX	'AUTRE_ASTER'	-2.229E3	7000.
		SIYY	'AUTRE_ASTER'	-3.147E8	1.%
		SIZZ	'AUTRE_ASTER'	-3.147E8	1.%
		VMIS	'AUTRE_ASTER'	3.147E8	1.%
	With	SIXX	'AUTRE_ASTER'	-4.928E6	1.%
		SIYY	'AUTRE_ASTER'	-8.831E7	1.%
		SIZZ	'AUTRE_ASTER'	-8.343E7	1.%
		VMIS	'AUTRE_ASTER'	8.105E7	1.%
	B	SIXX	'AUTRE_ASTER'	-5.694E6	1.%
		SIYY	'AUTRE_ASTER'	-8.781E6	1.%
		SIZZ	'AUTRE_ASTER'	-3.089E6	1.%
		VMIS	'AUTRE_ASTER'	5.002E6	1.1%
	C	SIXX	'AUTRE_ASTER'	-4.576E6	1.%
		SIYY	'AUTRE_ASTER'	1.960E7	1.%
		SIZZ	'AUTRE_ASTER'	2.417E7	1.%
		VMIS	'AUTRE_ASTER'	2.676E7	1.%
	D	SIXX	'AUTRE_ASTER'	-1.983E6	1.%
		SIYY	'AUTRE_ASTER'	2.087E7	1.%
		SIZZ	'AUTRE_ASTER'	2.285E7	1.%
		VMIS	'AUTRE_ASTER'	2.390E7	1.%
	Suction face	SIXX	'AUTRE_ASTER'	1.397E3	4500.
		SIYY	'AUTRE_ASTER'	2.087E7	1.%
		SIZZ	'AUTRE_ASTER'	2.087E7	1.%
		VMIS	'AUTRE_ASTER'	2.087E7	1.%

6 Modeling B

6.1 Characteristics of modeling

Axisymmetric modeling is carried out on a slice of the tube.

6.1.1 Thermal analysis

ON tests the unit thermal shock $(\Delta T_U = 1\,°C)$ and 3 thermal shocks $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$ by using methodology suggested, with modeling "`AXIS_DIAG`".

Unit case $(\Delta T_U = 1\,°C)$

Limiting conditions:

- Suction face: $T_{imposée} = T_{Initiale}$
- Under-surface: Convection $h = 20000\,W/m^2/°C$ $\quad T_{EXT} = T_{Fluide} = T_{Initiale} + \Delta T_U$

Initial conditions: $T_{Initiale} = 0.\,°C$

Case $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$

Limiting conditions:

- Suction face: $T_{imposée} = T_{Initiale}$
- Under-surface: Convection $h = 20000\,W/m^2/°C$ $\quad T_{EXT} = T_{Fluide} = T_{Initiale} + \Delta T$

Initial conditions: $T_{Initiale} = 20.\,°C$

6.1.2 Mechanical analysis

One tests the mechanical answer for the unit shock $(\Delta T_U = 1\,°C)$ and 3 thermal Shocks $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$ by using methodology suggested, with modeling "`AXIS`".

- Limiting conditions: dimensioned EF : $DY = 0.$
- Temperature of reference: $T_{Référence} = 0.\,°C$
- Thermal loadings: $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$

6.2 Characteristics of the grid

The grid is identical to that used in modeling A.

6.3 Results of modeling B

6.3.1 Unit case

Temperature (°C) $\Delta T=1°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	0,392	1.
	With	`'AUTRE_ASTER'`	0,117	2.5
	B	`'AUTRE_ASTER'`	0,040	4.
	C	`'AUTRE_ASTER'`	0,001	10.
	D	`'AUTRE_ASTER'`	0,000	1E-06
3.0 S	Under-surface	`'AUTRE_ASTER'`	0,856	1.
	With	`'AUTRE_ASTER'`	0,756	1.
	B	`'AUTRE_ASTER'`	0,683	1.
	C	`'AUTRE_ASTER'`	0,498	1.
	D	`'AUTRE_ASTER'`	0,218	1.5

Constraint (Pa) $\Delta T=1°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-11,145	35.
		`SIYY`	`'AUTRE_ASTER'`	-1.574E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-1.574E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.574E6	1.%
	With	`SIXX`	`'AUTRE_ASTER'`	-2.464E4	1.%
		`SIYY`	`'AUTRE_ASTER'`	-4.416E5	25.
		`SIZZ`	`'AUTRE_ASTER'`	-4.171E5	1.%
		`VMIS`	`'AUTRE_ASTER'`	4.053E5	1.%
	B	`SIXX`	`'AUTRE_ASTER'`	-2.847E4	1.%
		`SIYY`	`'AUTRE_ASTER'`	-4.391E4	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-1.545E4	1.%
		`VMIS`	`'AUTRE_ASTER'`	2.501E4	1.%
	C	`SIXX`	`'AUTRE_ASTER'`	-2.288E4	1.%
		`SIYY`	`'AUTRE_ASTER'`	9.800E4	1.%
		`SIZZ`	`'AUTRE_ASTER'`	1.209E5	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.338E5	1.%
	D	`SIXX`	`'AUTRE_ASTER'`	-9.917E3	1.%
		`SIYY`	`'AUTRE_ASTER'`	1.043E5	1.%
		`SIZZ`	`'AUTRE_ASTER'`	1.143E5	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.195E5	1.%
	Suction face	`SIXX`	`'AUTRE_ASTER'`	6,984	1.1%
		`SIYY`	`'AUTRE_ASTER'`	1.043E5	1.%

		SIZZ	'AUTRE_ASTER'	1.043E5	1.%
		VMIS	'AUTRE_ASTER'	1.043E5	1.%

6.3.2 Thermal shocks $(\Delta T=50\,°C\,;\Delta T=100\,°C\,;\Delta T=200\,°C)$

These results were got with the following MedCoupling script and coefficients:

$$T(x,t)_{\Delta T}=\beta.\tilde{T}_{\Delta T_U}(x,t)+T_{initiale}$$

Thermal shock	β	$T_{initiale}(°C)$
$\Delta T=50\,°C$	50.	20.
$\Delta T=100\,°C$	100.	20.
$\Delta T=200\,°C$	200.	20.

Temperature (°C) $\Delta T=50\,°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	'AUTRE_ASTER'	39,605	1.
	With	'AUTRE_ASTER'	25,867	1.
	B	'AUTRE_ASTER'	22,011	1.
	C	'AUTRE_ASTER'	20,056	1.
	D	'AUTRE_ASTER'	20,000	1.
3.0 S	Under-surface	'AUTRE_ASTER'	62,818	1.
	With	'AUTRE_ASTER'	57,822	1.
	B	'AUTRE_ASTER'	54,157	1.
	C	'AUTRE_ASTER'	44,919	1.
	D	'AUTRE_ASTER'	30,891	1.

Temperature (°C) $\Delta T=100\,°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	'AUTRE_ASTER'	59,211	1.
	With	'AUTRE_ASTER'	31,734	1.
	B	'AUTRE_ASTER'	24,022	1.
	C	'AUTRE_ASTER'	20,112	1.
	D	'AUTRE_ASTER'	20,000	1.
3.0 S	Under-surface	'AUTRE_ASTER'	105,636	1.
	With	'AUTRE_ASTER'	95,644	1.
	B	'AUTRE_ASTER'	88,315	1.
	C	'AUTRE_ASTER'	69,838	1.
	D	'AUTRE_ASTER'	41,782	1.

Temperature (°C) $\Delta T=200°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	98,422	1.
	With	`'AUTRE_ASTER'`	43,467	1.5
	B	`'AUTRE_ASTER'`	28,044	1.1
	C	`'AUTRE_ASTER'`	20,225	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	191,272	1.
	With	`'AUTRE_ASTER'`	171,287	1.
	B	`'AUTRE_ASTER'`	156,629	1.
	C	`'AUTRE_ASTER'`	119,675	1.
	D	`'AUTRE_ASTER'`	63,564	1.

6.3.3 Mechanical analyses

Constraint (Pa) $\Delta T=50°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	SIXX	`'AUTRE_ASTER'`	-5.57E2	1700.
		SIYY	`'AUTRE_ASTER'`	-7.868E7	1.%
		SIZZ	`'AUTRE_ASTER'`	-7.868E7	1.%
		VMIS	`'AUTRE_ASTER'`	7.868E7	1.%
	With	SIXX	`'AUTRE_ASTER'`	-1.23E6	1.%
		SIYY	`'AUTRE_ASTER'`	-2.208E7	1.%
		SIZZ	`'AUTRE_ASTER'`	-2.086E7	1.%
		VMIS	`'AUTRE_ASTER'`	2.026E7	1.%
	B	SIXX	`'AUTRE_ASTER'`	-1.42E6	1.%
		SIYY	`'AUTRE_ASTER'`	-2.195E6	1.%
		SIZZ	`'AUTRE_ASTER'`	-7.723E5	1.%
		VMIS	`'AUTRE_ASTER'`	1.251E6	1.1%
	C	SIXX	`'AUTRE_ASTER'`	-1.14E6	1.%
		SIYY	`'AUTRE_ASTER'`	4.900E6	1.%
		SIZZ	`'AUTRE_ASTER'`	6.043E6	1.%
		VMIS	`'AUTRE_ASTER'`	6.689E6	1.%
	D	SIXX	`'AUTRE_ASTER'`	-4.96E5	1.%
		SIYY	`'AUTRE_ASTER'`	5.217E6	1.%
		SIZZ	`'AUTRE_ASTER'`	5.713E6	1.%
		VMIS	`'AUTRE_ASTER'`	5.976E6	1.%

	Suction face	SIXX	‘AUTRE_ASTER’	3.49E2	1100.
		SIYY	‘AUTRE_ASTER’	5.217E6	1.%
		SIZZ	‘AUTRE_ASTER’	5.217E6	1.%
		VMIS	‘AUTRE_ASTER’	5.217E6	1.%

Constraint (Pa) $\Delta T=100\,°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	SIXX	‘AUTRE_ASTER’	-1.114E3	3400.
		SIYY	‘AUTRE_ASTER’	-1.574E8	1.%
		SIZZ	‘AUTRE_ASTER’	-1.574E8	1.%
		VMIS	‘AUTRE_ASTER’	1.574E8	1.%
	With	SIXX	‘AUTRE_ASTER’	-2.464E6	1.%
		SIYY	‘AUTRE_ASTER’	-4.416E7	1.%
		SIZZ	‘AUTRE_ASTER’	-4.171E7	1.%
		VMIS	‘AUTRE_ASTER’	4.053E7	1.%
	B	SIXX	‘AUTRE_ASTER’	-2.847E6	1.%
		SIYY	‘AUTRE_ASTER’	-4.391E6	1.%
		SIZZ	‘AUTRE_ASTER’	-1.545E6	1.%
		VMIS	‘AUTRE_ASTER’	2.501E6	1.1%
	C	SIXX	‘AUTRE_ASTER’	-2.288E6	1.%
		SIYY	‘AUTRE_ASTER’	9.800E6	1.%
		SIZZ	‘AUTRE_ASTER’	1.209E7	1.%
		VMIS	‘AUTRE_ASTER’	1.338E7	1.%
	D	SIXX	‘AUTRE_ASTER’	-9.917E5	1.%
		SIYY	‘AUTRE_ASTER’	1.043E7	1.%
		SIZZ	‘AUTRE_ASTER’	1.143E7	1.%
		VMIS	‘AUTRE_ASTER’	1.195E7	1.%
	Suction face	SIXX	‘AUTRE_ASTER’	6.984E2	3000.
		SIYY	‘AUTRE_ASTER’	1.043E7	1.%
		SIZZ	‘AUTRE_ASTER’	1.043E7	1.%
		VMIS	‘AUTRE_ASTER’	1.043E7	1.%

Constraint (Pa) $\Delta T=200°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-2.229E3	7000.
		`SIYY`	`'AUTRE_ASTER'`	-3.147E8	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-3.147E8	1.%
		`VMIS`	`'AUTRE_ASTER'`	3.147E8	1.%
	With	`SIXX`	`'AUTRE_ASTER'`	-4.928E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-8.831E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-8.343E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	8.105E7	1.%
	B	`SIXX`	`'AUTRE_ASTER'`	-5.694E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-8.781E6	1.%
		`SIZZ`	`'AUTRE_ASTER'`	-3.089E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	5.002E6	1.1%
	C	`SIXX`	`'AUTRE_ASTER'`	-4.576E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	1.960E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	2.417E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	2.676E7	1.%
	D	`SIXX`	`'AUTRE_ASTER'`	-1.983E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	2.087E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	2.285E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	2.390E7	1.%
	Suction face	`SIXX`	`'AUTRE_ASTER'`	1.397E3	4500.
		`SIYY`	`'AUTRE_ASTER'`	2.087E7	1.%
		`SIZZ`	`'AUTRE_ASTER'`	2.087E7	1.%
		`VMIS`	`'AUTRE_ASTER'`	2.087E7	1.%

6.4 Remarks

- For standard modeling A (without MedCoupling), one accepts a tolerance of 1%, which passes from 1.1% to 1.5% in two points for the thermal shock 200°C
- For modeling B, one notes more important relative variations for the unit case (max 10%). This variation is much weaker for 50°C, 100°C and 200°C. The origin of these values is mainly due to the presence of the not-worthless initial temperature for 50°C, 100°C and 200°C.

  Example: That is to say two values T1= 1 and T2=1.1, the relative error is:

  - from 10% with an initial temperature of 0°C
  - from 0.47% with an initial temperature of 20°C

7 Modeling C

7.1 Characteristics of modeling

Voluminal modeling is carried out on ¼ tube.

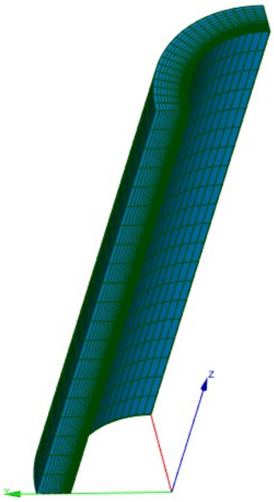
7.1.1 Thermal analysis

ON tests the 3 thermal Shocks $(\Delta T=50\,°C\,;\Delta T=100\,°C\,;\Delta T=200\,°C)$ with modeling `"3D_DIAG"`.

Limiting conditions:

- Suction face: $T_{imposée}=T_{Initiale}$
- Under-surface:
  Convection $h=20000\,W/m^2/°C$
  $T_{EXT}=T_{Fluide}=T_{Initiale}+\Delta T$
- Null flow on the level of the symmetry planes

Initial conditions: $T_{Initiale}=20.\,°C$



7.1.2 Mechanical analysis

ON tests the mechanical answer for the 3 thermal Shocks $(\Delta T=50\,°C\,;\Delta T=100\,°C\,;\Delta T=200\,°C)$ with modeling `"3D"`.

- Limiting conditions: plan principal XOY : $DZ=0.$
- Conditions of symmetry:
  - Plan principal XOZ: $DY=0.$
  - Plan principal YOZ: $DX=0.$
- Temperature of reference: $T_{Référence}=20.\,°C$
- Thermal loadings: $(\Delta T=50\,°C\,;\Delta T=100\,°C\,;\Delta T=200\,°C)$

7.2 Characteristics of the grid

For a good taking into account of the thermal shock on the internal wall of the tube a refinement was imposed.

For mechanical modeling one uses the same grid but with quadratic meshs.

- Many nodes: 10,584
- Many meshs and types: 9,200 HEXA8 (analyzes thermal)
- Many meshs and types: 9,200 HEXA20 (analyzes mechanical)

7.3 Results of modeling C

7.3.1 Thermic analyses

Temperature (°C) $\Delta T=50°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	'AUTRE_ASTER'	39,605	1.
	With	'AUTRE_ASTER'	25,867	1.
	B	'AUTRE_ASTER'	22,011	1.
	C	'AUTRE_ASTER'	20,056	1.
	D	'AUTRE_ASTER'	20,000	1.
3.0 S	Under-surface	'AUTRE_ASTER'	62,818	1.
	With	'AUTRE_ASTER'	57,822	1.
	B	'AUTRE_ASTER'	54,157	1.
	C	'AUTRE_ASTER'	44,919	1.
	D	'AUTRE_ASTER'	30,891	1.

Temperature (°C) $\Delta T=100°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	'AUTRE_ASTER'	59,211	1.
	With	'AUTRE_ASTER'	31,734	1.
	B	'AUTRE_ASTER'	24,022	1.
	C	'AUTRE_ASTER'	20,112	1.
	D	'AUTRE_ASTER'	20,000	1.
3.0 S	Under-surface	'AUTRE_ASTER'	105,636	1.
	With	'AUTRE_ASTER'	95,644	1.
	B	'AUTRE_ASTER'	88,315	1.
	C	'AUTRE_ASTER'	69,838	1.
	D	'AUTRE_ASTER'	41,782	1.

Temperature (°C) $\Delta T=200°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	98,422	1.
	With	`'AUTRE_ASTER'`	43,467	1.
	B	`'AUTRE_ASTER'`	28,044	1.
	C	`'AUTRE_ASTER'`	20,225	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	191,272	1.
	With	`'AUTRE_ASTER'`	171,287	1.
	B	`'AUTRE_ASTER'`	156,629	1.
	C	`'AUTRE_ASTER'`	119,675	1.
	D	`'AUTRE_ASTER'`	63,564	1.

7.3.2 Analyses mechanics

Constraint (Pa) $\Delta T=50°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-5.57E2	20000.
		`SIYY`	`'AUTRE_ASTER'`	-7.868E7	1.8%
		`SIZZ`	`'AUTRE_ASTER'`	-7.868E7	2.%
		`VMIS`	`'AUTRE_ASTER'`	7.868E7	2.%
	With	`SIXX`	`'AUTRE_ASTER'`	-1.23E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-2.208E7	1.8%
		`SIZZ`	`'AUTRE_ASTER'`	-2.086E7	2.%
		`VMIS`	`'AUTRE_ASTER'`	2.026E7	2.%
	B	`SIXX`	`'AUTRE_ASTER'`	-1.42E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-2.195E6	2.5%
		`SIZZ`	`'AUTRE_ASTER'`	-7.723E5	1.%
		`VMIS`	`'AUTRE_ASTER'`	1.251E6	2.5%
	C	`SIXX`	`'AUTRE_ASTER'`	-1.14E6	1.5%
		`SIYY`	`'AUTRE_ASTER'`	4.900E6	2.%
		`SIZZ`	`'AUTRE_ASTER'`	6.043E6	2.2%
		`VMIS`	`'AUTRE_ASTER'`	6.689E6	2.%
	D	`SIXX`	`'AUTRE_ASTER'`	-4.96E5	1.%
		`SIYY`	`'AUTRE_ASTER'`	5.217E6	2.%
		`SIZZ`	`'AUTRE_ASTER'`	5.713E6	2.2%
		`VMIS`	`'AUTRE_ASTER'`	5.976E6	2.%
	Suction face	`SIXX`	`'AUTRE_ASTER'`	3.49E2	4000.
		`SIYY`	`'AUTRE_ASTER'`	5.217E6	2.%
		`SIZZ`	`'AUTRE_ASTER'`	5.217E6	2.2%
		`VMIS`	`'AUTRE_ASTER'`	5.217E6	2.%

Constraint (Pa) $\Delta T=100°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance
0.1 S	Under-surface	SIXX	'AUTRE_ASTER'	-1.114E3	40000.
		SIYY	'AUTRE_ASTER'	-1.574E8	2.%
		SIZZ	'AUTRE_ASTER'	-1.574E8	2.%
		VMIS	'AUTRE_ASTER'	1.574E8	2.%
	With	SIXX	'AUTRE_ASTER'	-2.464E6	1.%
		SIYY	'AUTRE_ASTER'	-4.416E7	2.%
		SIZZ	'AUTRE_ASTER'	-4.171E7	2.%
		VMIS	'AUTRE_ASTER'	4.053E7	2.%
	B	SIXX	'AUTRE_ASTER'	-2.847E6	1.%
		SIYY	'AUTRE_ASTER'	-4.391E6	2.5%
		SIZZ	'AUTRE_ASTER'	-1.545E6	2.%
		VMIS	'AUTRE_ASTER'	2.501E6	2.5%
	C	SIXX	'AUTRE_ASTER'	-2.288E6	1.2%
		SIYY	'AUTRE_ASTER'	9.800E6	2.%
		SIZZ	'AUTRE_ASTER'	1.209E7	2.2%
		VMIS	'AUTRE_ASTER'	1.338E7	2.%
	D	SIXX	'AUTRE_ASTER'	-9.917E5	1.%
		SIYY	'AUTRE_ASTER'	1.043E7	2.%
		SIZZ	'AUTRE_ASTER'	1.143E7	2.2%
		VMIS	'AUTRE_ASTER'	1.195E7	2.%
	Suction face	SIXX	'AUTRE_ASTER'	6.984E2	7500.
		SIYY	'AUTRE_ASTER'	1.043E7	2.%
		SIZZ	'AUTRE_ASTER'	1.043E7	2.2%
		VMIS	'AUTRE_ASTER'	1.043E7	2.%

Constraint (Pa) $\Delta T=200°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-2.229E3	80000.
		`SIYY`	`'AUTRE_ASTER'`	-3.147E8	2.%
		`SIZZ`	`'AUTRE_ASTER'`	-3.147E8	2.%
		`VMIS`	`'AUTRE_ASTER'`	3.147E8	2.%
	With	`SIXX`	`'AUTRE_ASTER'`	-4.928E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-8.831E7	2.%
		`SIZZ`	`'AUTRE_ASTER'`	-8.343E7	2.%
		`VMIS`	`'AUTRE_ASTER'`	8.105E7	2.%
	B	`SIXX`	`'AUTRE_ASTER'`	-5.694E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	-8.781E6	2.5%
		`SIZZ`	`'AUTRE_ASTER'`	-3.089E6	1.%
		`VMIS`	`'AUTRE_ASTER'`	5.002E6	2.5%
	C	`SIXX`	`'AUTRE_ASTER'`	-4.576E6	1.5%
		`SIYY`	`'AUTRE_ASTER'`	1.960E7	2.%
		`SIZZ`	`'AUTRE_ASTER'`	2.417E7	2.2%
		`VMIS`	`'AUTRE_ASTER'`	2.676E7	2.%
	D	`SIXX`	`'AUTRE_ASTER'`	-1.983E6	1.%
		`SIYY`	`'AUTRE_ASTER'`	2.087E7	2.%
		`SIZZ`	`'AUTRE_ASTER'`	2.285E7	2.2%
		`VMIS`	`'AUTRE_ASTER'`	2.390E7	2.%
	Suction face	`SIXX`	`'AUTRE_ASTER'`	1.397E3	40000.
		`SIYY`	`'AUTRE_ASTER'`	2.087E7	2.%
		`SIZZ`	`'AUTRE_ASTER'`	2.087E7	2.2%
		`VMIS`	`'AUTRE_ASTER'`	2.087E7	2.%

7.4 Remarks

The axis of the tube is according to there of axisymmetric and following Z in 3D. It to compare the results in constraints it is necessary to permute axes Y and Z

8 Modeling D

8.1 Characteristics of modeling

Modeling voluminal is carried out on ¼ tube.

8.2 Thermal analysis

ON tests the unit thermal shock $(\Delta T_U = 1\,°C)$ and 3 thermal shocks $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$ by using methodology suggested, with modeling `"3D_DIAG"`.

Unit case $(\Delta T_U = 1\,°C)$

Limiting conditions:

- Suction face: $T_{imposée} = T_{Initiale}$
- Under-surface: Convection $h = 20000\,W/m^2/°C$ $T_{EXT} = T_{Fluide} = T_{Initiale} + \Delta T_U$
- Null flow on the level as of symmetry planes

Initial conditions: $T_{Initiale} = 0.\,°C$

Case $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$

Limiting conditions:

- Suction face: $T_{imposée} = T_{Initiale}$
- Under-surface: Convection $h = 20000\,W/m^2/°C$ $T_{EXT} = T_{Fluide} = T_{Initiale} + \Delta T$
- Null flow on the level of the symmetry planes

Initial conditions: $T_{Initiale} = 20.\,°C$

8.2.1 Mechanical analysis

One tests the mechanical answer for the unit shock $(\Delta T_U = 1\,°C)$ and 3 thermal Shocks $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$ by using methodology suggested, with modeling `"3D"` .

- Limiting conditions: plan principal XOY : $DZ = 0.$
- Conditions of symmetry:
  - Plan principal XOZ: $DY = 0.$
  - Plan principal YOZ: $DX = 0.$
- Temperature of reference: $T_{Référence} = 20.\,°C$
- Thermal loadings: $(\Delta T = 50\,°C\,;\Delta T = 100\,°C\,;\Delta T = 200\,°C)$

8.3 Characteristics of the grid

The grid is identical to that used in modeling C.

8.4 Results of modeling D

8.4.1 Unit case

Temperature (°C) $\Delta T=1°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	0,392	1.
	With	`'AUTRE_ASTER'`	0,117	3.
	B	`'AUTRE_ASTER'`	0,040	4.
	C	`'AUTRE_ASTER'`	0,001	6.
	D	`'AUTRE_ASTER'`	0,000	0,001
3.0 S	Under-surface	`'AUTRE_ASTER'`	0,856	1.
	With	`'AUTRE_ASTER'`	0,756	1.
	B	`'AUTRE_ASTER'`	0,683	1.
	C	`'AUTRE_ASTER'`	0,498	1.
	D	`'AUTRE_ASTER'`	0,218	2.

Constraint (Pa) $\Delta T=1°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`SIXX`	`'AUTRE_ASTER'`	-11,145	400.
		`SIYY`	`'AUTRE_ASTER'`	-1.574E6	2.0
		`SIZZ`	`'AUTRE_ASTER'`	-1.574E6	2.0
		`VMIS`	`'AUTRE_ASTER'`	1.574E6	2.0
	With	`SIXX`	`'AUTRE_ASTER'`	-2.464E4	1.0
		`SIYY`	`'AUTRE_ASTER'`	-4.416E5	2.0
		`SIZZ`	`'AUTRE_ASTER'`	-4.171E5	2.0
		`VMIS`	`'AUTRE_ASTER'`	4.053E5	2.0
	B	`SIXX`	`'AUTRE_ASTER'`	-2.847E4	1.0
		`SIYY`	`'AUTRE_ASTER'`	-4.391E4	2.5
		`SIZZ`	`'AUTRE_ASTER'`	-1.545E4	1.0
		`VMIS`	`'AUTRE_ASTER'`	2.501E4	2.5
	C	`SIXX`	`'AUTRE_ASTER'`	-2.288E4	1.2
		`SIYY`	`'AUTRE_ASTER'`	9.800E4	2.0
		`SIZZ`	`'AUTRE_ASTER'`	1.209E5	2.2
		`VMIS`	`'AUTRE_ASTER'`	1.338E5	2.0
	D	`SIXX`	`'AUTRE_ASTER'`	-9.917E3	1.0
		`SIYY`	`'AUTRE_ASTER'`	1.043E5	2.0
		`SIZZ`	`'AUTRE_ASTER'`	1.143E5	2.2
		`VMIS`	`'AUTRE_ASTER'`	1.195E5	2.0
	Suction face	`SIXX`	`'AUTRE_ASTER'`	6,984	75.
		`SIYY`	`'AUTRE_ASTER'`	1.043E5	2.0
		`SIZZ`	`'AUTRE_ASTER'`	1.043E5	2.2

		`VMIS`	`'AUTRE_ASTER'`	1.043E5	2.0

8.4.2 Thermal shocks $(\Delta T=50°C;\Delta T=100°C;\Delta T=200°C)$

8.4.2.1 Thermic analyses

Temperature (°C) $\Delta T=50°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	39,605	1.
	With	`'AUTRE_ASTER'`	25,867	1.
	B	`'AUTRE_ASTER'`	22,011	1.
	C	`'AUTRE_ASTER'`	20,056	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	62,818	1.
	With	`'AUTRE_ASTER'`	57,822	1.
	B	`'AUTRE_ASTER'`	54,157	1.
	C	`'AUTRE_ASTER'`	44,919	1.
	D	`'AUTRE_ASTER'`	30,891	1.

Temperature (°C) $\Delta T=100°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	59,211	1.
	With	`'AUTRE_ASTER'`	31,734	1.5
	B	`'AUTRE_ASTER'`	24,022	1.
	C	`'AUTRE_ASTER'`	20,112	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	105,636	1.
	With	`'AUTRE_ASTER'`	95,644	1.
	B	`'AUTRE_ASTER'`	88,315	1.
	C	`'AUTRE_ASTER'`	69,838	1.
	D	`'AUTRE_ASTER'`	41,782	1.

Temperature (°C) $\Delta T=200°C$				
Time	Localization	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	`'AUTRE_ASTER'`	98,422	1.
	With	`'AUTRE_ASTER'`	43,467	1.
	B	`'AUTRE_ASTER'`	28,044	1.
	C	`'AUTRE_ASTER'`	20,225	1.
	D	`'AUTRE_ASTER'`	20,000	1.
3.0 S	Under-surface	`'AUTRE_ASTER'`	191,272	1.
	With	`'AUTRE_ASTER'`	171,287	1.
	B	`'AUTRE_ASTER'`	156,629	1.

	C	`'AUTRE_ASTER'`	119,675	1.
	D	`'AUTRE_ASTER'`	63,564	1.

8.4.2.2 Mechanical analyses

Constraint (Pa) $\Delta T = 50\,°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	SIXX	`'AUTRE_ASTER'`	-5.57E2	20000.
		SIYY	`'AUTRE_ASTER'`	-7.868E7	1.8%
		SIZZ	`'AUTRE_ASTER'`	-7.868E7	2.%
		VMIS	`'AUTRE_ASTER'`	7.868E7	2.%
	With	SIXX	`'AUTRE_ASTER'`	-1.23E6	1.%
		SIYY	`'AUTRE_ASTER'`	-2.208E7	1.8%
		SIZZ	`'AUTRE_ASTER'`	-2.086E7	2.%
		VMIS	`'AUTRE_ASTER'`	2.026E7	2.%
	B	SIXX	`'AUTRE_ASTER'`	-1.42E6	1.%
		SIYY	`'AUTRE_ASTER'`	-2.195E6	2.5%
		SIZZ	`'AUTRE_ASTER'`	-7.723E5	1.%
		VMIS	`'AUTRE_ASTER'`	1.251E6	2.5%
	C	SIXX	`'AUTRE_ASTER'`	-1.14E6	1.5%
		SIYY	`'AUTRE_ASTER'`	4.900E6	2.%
		SIZZ	`'AUTRE_ASTER'`	6.043E6	2.2%
		VMIS	`'AUTRE_ASTER'`	6.689E6	2.%
	D	SIXX	`'AUTRE_ASTER'`	-4.96E5	1.%
		SIYY	`'AUTRE_ASTER'`	5.217E6	2.%
		SIZZ	`'AUTRE_ASTER'`	5.713E6	2.2%
		VMIS	`'AUTRE_ASTER'`	5.976E6	2.%
	Suction face	SIXX	`'AUTRE_ASTER'`	3.49E2	4000.
		SIYY	`'AUTRE_ASTER'`	5.217E6	2.%
		SIZZ	`'AUTRE_ASTER'`	5.217E6	2.2%
		VMIS	`'AUTRE_ASTER'`	5.217E6	2.0%

Constraint (Pa) $\Delta T=100\,°C$					
Time	Localization	Constraint	Standard Reference	Reference	Tolerance (%)
0.1 S	Under-surface	SIXX	‘AUTRE_ASTER’	-1.114E3	40000.
		SIYY	‘AUTRE_ASTER’	-1.574E8	2.%
		SIZZ	‘AUTRE_ASTER’	-1.574E8	2.%
		VMIS	‘AUTRE_ASTER’	1.574E8	2.%
	With	SIXX	‘AUTRE_ASTER’	-2.464E6	1.%
		SIYY	‘AUTRE_ASTER’	-4.416E7	2.%
		SIZZ	‘AUTRE_ASTER’	-4.171E7	2.%
		VMIS	‘AUTRE_ASTER’	4.053E7	2.%
	B	SIXX	‘AUTRE_ASTER’	-2.847E6	1.%
		SIYY	‘AUTRE_ASTER’	-4.391E6	2.5%
		SIZZ	‘AUTRE_ASTER’	-1.545E6	2.%
		VMIS	‘AUTRE_ASTER’	2.501E6	2.5%
	C	SIXX	‘AUTRE_ASTER’	-2.288E6	1.2%
		SIYY	‘AUTRE_ASTER’	9.800E6	2.%
		SIZZ	‘AUTRE_ASTER’	1.209E7	2.2%
		VMIS	‘AUTRE_ASTER’	1.338E7	2.%
	D	SIXX	‘AUTRE_ASTER’	-9.917E5	1.%
		SIYY	‘AUTRE_ASTER’	1.043E7	2.%
		SIZZ	‘AUTRE_ASTER’	1.143E7	2.2%
		VMIS	‘AUTRE_ASTER’	1.195E7	2.%
	Suction face	SIXX	‘AUTRE_ASTER’	6.984E2	7500.
		SIYY	‘AUTRE_ASTER’	1.043E7	2.%
		SIZZ	‘AUTRE_ASTER’	1.043E7	2.2%
		VMIS	‘AUTRE_ASTER’	1.043E7	2.%

9 Synthesis of the résul

10 tats

Methodology suggested consists in determining the thermal answers and mechanics in a structure starting from calculation of a unit thermal shock and by using a chaining Code_Aster → Salome_Meca/MedCoupling → Code_Aster. This chaining was tested and implemented, it:

- Allows to reduce the time necessary to the installation of thermal and mechanical calculations in the linear field,
- Is easy to set up.

One thus could check that one could determine the temperature of a structure subjected to a shock ΔT, starting from a unit thermal shock $(\Delta T_U = 1°C)$ and an initial temperature $T(x, t_0)$ by carrying out the following linear combination:

$$T(x,t)_{\Delta T} = \Delta T . \tilde{T}_{\Delta T_U}(x,t) + T(x,t_0)$$

This methodology was also tested within the framework of a thermomechanical analysis. Starting from unit the thermics results one calculated the "Unit" constraints and by using a chaining Code_Aster → Salome_Meca/MedCoupling, one determined the constraints for the shocks $(\Delta T = 50°C, \Delta T = 100°C, \Delta T = 200°C)$.

The noted maximum departures are in:

- Axisymmetric of 1.5% in thermics and 1.2% in mechanics with the reference solution,
- Three-dimensional of 1.5% in thermics and 2.5% in mechanics with the reference solution,

On figures Ci below, one represents the change of the temperature and the constraints for the thermal shock $(\Delta T = 50°C)$:

- According to the thickness for several moments,

In several points in the thickness.

Macro-order CALC _THERMECA_MULT

Goal :

Macro-order CALC_THERMECA_MULT makes it possible to produce the results of thermic and of linear mechanics of an unspecified thermal shock without projecting the field systematically of a grid linear with a quadratic grid thanks to the multiplication of a single unit calculation. It implements a methodology for thermomechanical calculations in the linear field.

This macro-order produces with the choice a concept of the type *evol_elas* or *evol_ther* .

Contents

11 Syn tax

```
resu_out [evol_elas ] = CALC_THERMECA_MULT (

                ◆  TEMP_END = temp_end,                [R]
                ◆
                ◆  TEMP_INIT = temp_init,              [R]
                ◆
                ◆  RESU_SUPL_THER = /'OUI',            [TXM]
                ◆                                      /'NON'
                ◆  RESU_MECA _LINKS= reslin,           [evol_elas]

If RESU_SUPL_THER = 'YES'
                ◆  RESU_THER_UNIT = resther,           [evol_ther]
                ◆  RESU_THER = resthermult             [CO]

)
```

12 General informationS

This macro-order aims to determine the thermal and mechanical state of one structure following a thermal shock. By employing properties of linearity, it is possible to determine the solution of an unspecified shock starting from a “different” shock, most of the time unit. This approach has the advantage of calculating the solutions finite elements only once for the unit shock, then to generate the solutions for the other shocks.

Since properties of linearity are employed, this operator is valid only for calculations thermoemcanic where thermics and mechanics are linear.

13 Operands and Keywords

13.1 Operand TEMP_END

TEMP_CIBLE is a reality giving the value of the temperature different from the temperature of rest creating the thermal shock. Typically if one studies UN pipe crossed periodically and quickly by a fluid at nonambient temperature, TEMP_END corresponds to difference between temperature of the fluid and the temperature of reference TEMP_INIT of the pipe.

13.2 Operand TEMP_INIT

It is about **temperature of reference** studied solid. In the model of this macro-order, it is **too** the temperature of the system **front** the thermal shock.

13.3 Operand RESU_SUPL_THER

Operand to be informed in ‘YES’ when the user wishes to also produce the calculation of linear thermics of the studied thermal shock. The concept is then produced on the right of the macro-order in keyword RESU_THER.

13.4 Operands RESU_MECA_UNIT and RESU_THER_UNIT

It is about concepts results of unit calculations respectively mechanical and thermal.
LMBOU_THER_UNIT is to be provided only when one requests from the macro-order a thermal result (i.e. RESU_SUPL_THER = ‘YES’).

13.5 Keyword RESU_THER

The concept result produced on the right by the macro-order contains when it is asked.

14 Examples

An example of use of the macro-order for a calculation of shock thermal of 50°C on the surface of a cube of temperature of reference of 20°C is in the CAS-test hslv303a.