TTLV01 – Sphere: heat transfer by convection

Summarized:

This test is resulting from the validation independent of version 3 in linear transient thermal.

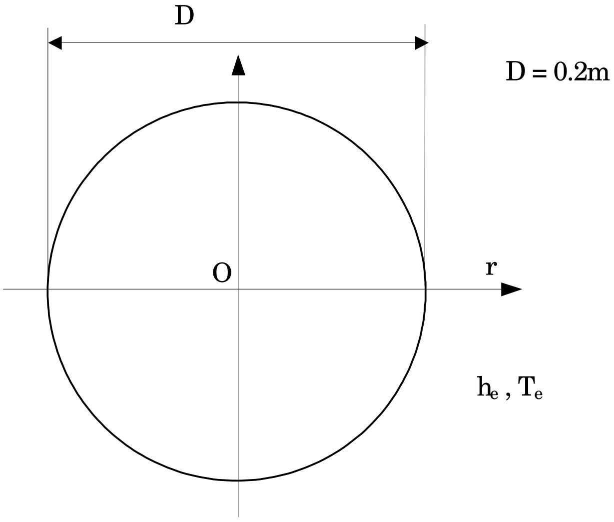
It is about a three-dimensional problem represented by four modelizations, one voluminal, three the other axisymmetric ones.

The features tested are the following ones:
- voluminal thermal elements,
- axisymmetric thermal elements,
- algorithm of transient thermal,
- conditions limiting: convection.

The results are compared with those provided by VPCS.

1 Problem of reference

1.1 Geometry



1.2 Properties of the thermal

$\lambda=48.822\,W/m\,°C$ material conductivity
$c_p=669.0\,J/kg\,°C$ specific heat
$\rho=7200\,kg/m^3$ density

1.3 Boundary conditions and loadings

Convection on external surface with air:

- $h_e=232.5\,W/m^2\,°C$
- $T_e=1000\,°C$.

1.4 Initial conditions

initial Temperature: $T(t=0)=20\,°C$

2 Reference solution

2.1 Method of calculating used for the reference solution

the reference solution is that given in file TTLV01/89 of guide VPCS.

- computation of the coefficients,
- reading on abacus of Gurney-Lurie.

2.2 Results of reference

Temperature on the surface and in the center of the sphere for t understood enters $400\,s$ and $2400\,s$

2.3 Uncertainty on the solution

< 2%

Below $600\,s$, uncertainty increases (difficult reading of the abacuses).

2.4 Bibliographical references

- Guides validation of the software packages of structural analysis. French company of Mechanics, AFNOR 1990 ISBN 2-12-486611-7

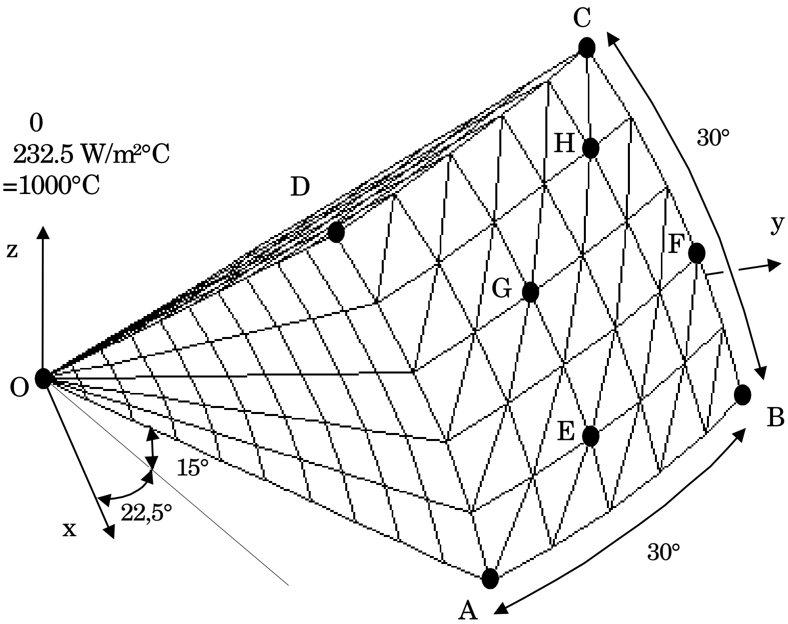
3 Modelization A

3.1 Characteristic of the modelization

3D (PENTA6 and TETRA4)

Conditions limites:

- faces OAB, OAD, ODC, OBC $\varphi = 0$
- face ABCD $h = 232.5\ W/m^2°C$
  $T_{ext} = 1000°C$



Point	Noeud
O	N291
A	N292
B	N345
C	N234
D	N179
E	N254
F	N133
G	N5
H	N198

3.2 Characteristic of the mesh

Many nodes: 361
Number of meshes and types: 450 PENTA6, 50 TETRA4 (and 50 TRIA3)

3.3 Remarks

One takes, for voluminal heat $CP=\rho c_p=4816800.0\,J/m^3\ °C$.
The limiting condition $\varphi=0.$ is implicit on free edges.
Discretization of time: 36 intervals

from	0 to	100 seconds:	8 intervals from	$12.5\,s.$
	100 to	300 seconds:	8 intervals from	$25.0\,s.$
	300 to	700 seconds:	8 intervals from	$50.0\,s.$
	700 to	1400 seconds:	7 intervals of	$100.0\,s.$
	1400 to	2400 seconds:	5 intervals of results	$200.0\,s.$

4 of the modelization A

4.1 Values tested

Identification	Reference	Aster	relative Variation (%)		absolute Deviation (°C)	
			difference	tolerance	difference	tolerance
Temperatures:						
In the center ($O:N291$)	$T(°C)$					
T = 400 S	334	340.56	1.965%	5.%	6.56	20.
T = 600 S	500	493.15	~ 1.371%	5.%	~ 6.85	20.
T = 800 S	618	610.27	~ 1.252%	5.%	~ 7.73	20.
T = 1000 S	706	700.18	~ 0.824%	5.%	~ 5.82	20.
T = 1200 S	774	769.35	~ 0.600%	5.%	~ 4.65	20.
T = 1400 S	828	822.57	~ 0.656%	5.%	~ 5.43	20.
T = 1600 S	872	863.33	~ 0.994%	5.%	~ 8.67	20.
T = 1800 S	902	894.73	~ 0.806%	5.%	~ 7.27	20.
T = 2000 S	923	918.91	~ 0.443%	5.%	~ 4.09	20.
T = 2200 S	942	937.54	~ 0.474%	5.%	~ 4.46	20.
T = 2400 S	956	951.89	~ 0.430%	5.%	~ 4.11	20.

Identification	Reference	Aster	relative Variation difference	relative Variation tolerance	absolute Deviation difference	absolute Deviation tolerance
On the surface ($A:N292$)	$T(°C)$					
T = 400 S	461	474.82	2.998%	5.%	13.8	20.
T = 600 S	608	596.37	~ 1.913%	5.%	~ 11.6	20.
T = 800 S	696	689.64	~ 0.914%	5.%	~ 6.36	20.
T = 1000 S	774	761.24	~ 1.648%	5.%	~ 12.8	20.
T = 1200 S	828	816.33	~ 1.410%	5.%	~ 11.7	20.
T = 1400 S	868	858.70	~ 1.071%	5.%	~ 9.30	20.
T = 1600 S	902	891.16	~ 1.202%	5.%	~ 10.8	20.
T = 1800 S	923	916.17	~ 0.741%	5.%	~ 6.83	20.
T = 2000 S	942	935.42	~ 0.698%	5.%	~ 6.58	20.
T = 2200 S	956	950.26	~ 0.601%	5.%	~ 5.74	20.
T = 2400 S	962	961.69	~ 0.033%	5.%	~ 0.314	20.

4.2 Remarks

the relative variations are higher than 2% for $t=400.s$, inferiors for $t\geq 600.s$

On the surface, the results calculated by *Code_Aster* are symmetric compared to the diagonal AC . The maximum variation observed, into relative as in absolute, is of 0.29% is $1.4°C$, between the point A ($N291$) and the point D ($N179$) at time $t=400.s$. These variations decrease in absolute value when time increases.

5 Modelization B

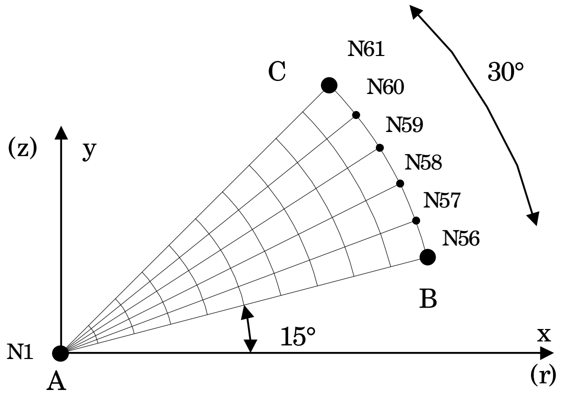
5.1 Characteristic of modelization

AXIS (TRIA3, QUAD4)

Conditions limites:

- coté AB, AC $\varphi =$ 0
- coté BC h = 232.5 W/m²°C
  T_{ext} =1000°C

Point	Noeud
A	N1
B	N56
C	N61



5.2 Characteristic of the mesh

Many nodes:	61
Number of meshes and types:	45 QUAD4, 5 TRIA3 (and 5 SEG2)

5.3 Remarks

One takes, for voluminal heat $CP = \rho c_p = 4816800.0 J/m^3\ °C$.

The limiting condition $\varphi = 0.$ is implicit on free edges.

Discretization of time: 36 intervals

from	0 to	100 seconds:	8	intervals from	$12.5 s.$
	100 to	300 seconds:	8	intervals from	$25.0 s.$
	300 to	700 seconds:	8	intervals from	$50.0 s.$
	700 to	1400 seconds:	7	intervals of	$100.0 s.$
	1400 to	2400 seconds:	5	intervals of results	$200.0 s.$

6 of the modelization B

6.1 Values tested

Identification	Reference	*Aster*	relative Variation (%)		absolute Deviation (°C)	
			difference	tolerance	difference	tolerance
Temperatures:						
In center (a: N1)	$T(°C)$					
T = 400 S	334	339.95	1.780%	5.%	5.95	20.
T = 600 S	500	492.47	1.506%	5.%	7.53	20.
T = 800 S	618	609.59	1.361%	5.%	8.41	20.
T = 1000 S	706	699.55	0.914%	5.%	6.45	20.
T = 1200 S	774	768.78	0.675%	5.%	5.22	20.
T = 1400 S	828	822.05	0.718%	5.%	5.95	20.
T = 1600 S	872	862.88	1.046%	5.%	9.12	20.
T = 1800 S	902	894.34	0.849%	5.%	7.66	20.
T = 2000 S	923	918.58	0.479%	5.%	4.42	20.
T = 2200 S	942	937.26	0.503%	5.%	4.74	20.
T = 2400 S	956	951.65	0.455%	5.%	4.35	20.

On the surface (N: N56)	$T(°C)$					
T = 400 S	461	475.14	3.068%	5.%	14.1	20.
T = 600 S	608	596.46	1.899%	5.%	11.5	20.
T = 800 S	696	689.58	0.922%	5.%	6.42	20.
T = 1000 S	774	761.11	1.666%	5.%	12.9	20.
T = 1200 S	828	816.15	1.431%	5.%	11.8	20.
T = 1400 S	868	858.51	1.093%	5.%	9.49	20.
T = 1600 S	902	890.97	1.223%	5.%	11.0	20.
T = 1800 S	923	915.99	0.760%	5.%	7.01	20.
T = 2000 S	942	935.26	0.715%	5.%	6.74	20.
T = 2200 S	956	950.11	0.616%	5.%	5.89	20.
T = 2400 S	962	961.56	0.046%	5.%	-0.441	20.

6.2 Remarks

the relative variations are higher than 2% for $t=400.s$, inferiors for $t \geq 600.s$
the maximum variation observed between two nodes on surface, into relative as in absolute, is of 0.012% is $0{,}055\,°C$, between the point B ($N56$) and the point C ($N61$) at time $t=400.s$. These variations decrease in absolute value when time increases.

7 Modelization C

7.1 Characteristic of modelization

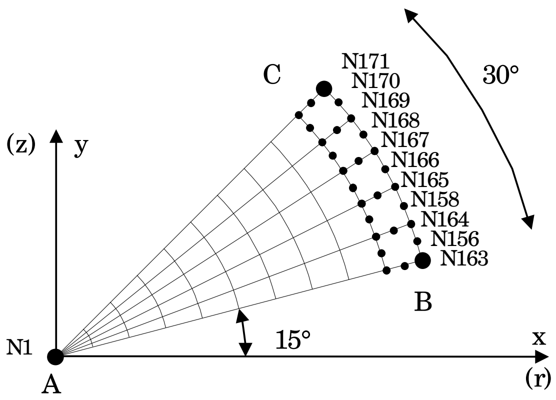
AXIS (TRIA6, QUAD8)

Conditions limites:

- coté AB, AC $\varphi = 0$
- coté BC $h = 232.5\ W/m^2°C$

$T_{ext} = 1000°C$

Point	Noeud
A	N1
B	N163
C	N171



7.2 Characteristic of the mesh

Many nodes: 171
Number of meshes and types: 45 QUAD8, 5 TRIA6 (and 5 SEG3)

7.3 Remarks

One takes, for voluminal heat $CP = \rho c_p = 4816800.0\ J/m^3\ °C$.
The limiting condition $\varphi = 0.$ is implicit on free edges.
Discretization of time: 36 intervals

from 0 to	100 seconds:	8	intervals from	$12.5\,s.$
100 to	300 seconds:	8	intervals from	$25.0\,s.$
300 to	700 seconds:	8	intervals from	$50.0\,s.$
700 to	1400 seconds:	7	intervals of	$100.0\,s.$
1400 to	2400 seconds:	5	intervals of results	$200.0\,s.$

8 of the modelization C

8.1 Values tested

Identification	**Reference**	***Aster***	**relative Variation (%)**		**absolute Deviation (°C)**	
			difference	**tolerance**	**difference**	**tolerance**
Temperatures:						
In center (a: N1)	$T(°C)$					
T = 400 S	334	341.10	2.126%	5.%	7.10	20.
T = 600 S	500	493.15	1.370%	5.%	6.85	20.
T = 800 S	618	609.65	1.303%	5.%	8.05	20.
T = 1000 S	706	699.70	0.893%	5.%	6.30	20.
T = 1200 S	774	768.80	0.672%	5.%	5.20	20.
T = 1400 S	828	822.00	0.725%	5.%	6.00	20.
T = 1600 S	872	862.78	1.058%	5.%	9.22	20.
T = 1800 S	902	894.22	0.863%	5.%	7.78	20.
T = 2000 S	923	918.45	0.493%	5.%	4.55	20.
T = 2200 S	942	937.14	0.516%	5.%	4.86	20.
T = 2400 S	956	951.54	0.467%	5.%	4.46	20.

On the surface (N: N163)	$T(°C)$					
T = 400 S	461	474.78	2.989%	5.%	13.8	20.
T = 600 S	608	596.02	1.971%	5.%	12.0	20.
T = 800 S	696	689.12	0.989%	5.%	-6.88	20.
T = 1000 S	774	760.65	1.725%	5.%	13.3	20.
T = 1200 S	828	815.72	1.483%	5.%	12.3	20.
T = 1400 S	868	858.12	1.138%	5.%	-9.88	20.
T = 1600 S	902	890.63	1.261%	5.%	11.4	20.
T = 1800 S	923	915.69	0.792%	5.%	7.31	20.
T = 2000 S	942	935.00	0.743%	5.%	7.00	20.
T = 2200 S	956	949.90	0.639%	5.%	6.10	20.
T = 2400 S	962	961.37	0.065%	5.%	0.625	20.

8.2 Remarks

the relative variations are higher than 2% for $t=400.s$, inferiors for $t\geq 600.s$
the variations observed between the results calculated by *Code_Aster* on two nodes of external surface, are lower than $0{,}011\,°C$ (either 0.002%).

9 Modelization D

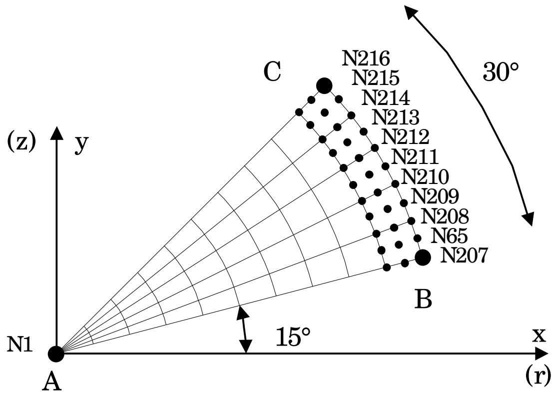
9.1 Characteristic of modelization

AXIS (TRIA6, QUAD9)

Conditions limites:

- coté AB, AC $\varphi =$ 0
- coté BC $h =$ 232.5 W/m²°C
  T_{ext} =1000°C

Point	Noeud
A	N1
B	N207
C	N216



9.2 Characteristic of the mesh

Many nodes: 216
Number of meshes and types: 45 QUAD9, 5 TRIA6 (and 5 SEG3)

9.3 Remarks

One takes, for voluminal heat $CP=\rho c_p=4816800.0 J/m^3\ °C$.
The limiting condition $\varphi=0.$ is implicit on free edges.
Discretization of time: 36 intervals

from	0 to	100 seconds:	8	intervals from	$12.5 s.$
	100 to	300 seconds:	8	intervals from	$25.0 s.$
	300 to	700 seconds:	8	intervals from	$50.0 s.$
	700 to	1400 seconds:	7	intervals of	$100.0 s.$
	1400 to	2400 seconds:	5	intervals of results	$200.0 s.$

10 of the modelization D

10.1 Values tested

Identification	Reference	*Aster*	relative Variation (%)		absolute Deviation (°C)	
			difference	**tolerance**	**difference**	**tolerance**
Temperatures:						
In center (a: N1)	$T(°C)$					
T = 400 S	334	341.10	2.125%	5.%	7.10	20.
T = 600 S	500	493.14	~1.371%	5.%	~6.86	20.
T = 800 S	618	609.95	~1.303%	5.%	~8.05	20.
T = 1000 S	706	699.70	~0.893%	5.%	~6.30	20.
T = 1200 S	774	768.79	~0.673%	5.%	~5.21	20.
T = 1400 S	828	821.99	~0.726%	5.%	~6.01	20.
T = 1600 S	872	862.78	~1.058%	5.%	~9.22	20.
T = 1800 S	902	894.22	~0.863%	5.%	~7.78	20.
T = 2000 S	923	918.45	~0.493%	5.%	~4.55	20.
T = 2200 S	942	937.13	~0.516%	5.%	~4.87	20.
T = 2400 S	956	951.54	~0.467%	5.%	~4.46	20.
On the surface (N: N207)	$T(°C)$					
T = 400 S	461	474.78	2.989%	5.%	13.8	20.
T = 600 S	608	596.01	~1.971%	5.%	~12.0	20.
T = 800 S	696	689.12	~0.989%	5.%	-6.88	20.
T = 1000 S	774	760.65	~1.725%	5.%	~13.4	20.
T = 1200 S	828	815.72	~1.483%	5.%	~12.3	20.
T = 1400 S	868	858.12	~1.138%	5.%	~9.88	20.
T = 1600 S	902	890.63	~1.261%	5.%	~11.4	20.
T = 1800 S	923	915.69	~0.792%	5.%	~7.31	20.
T = 2000 S	942	935.00	~0.743%	5.%	~7.00	20.
T = 2200 S	956	949.89	~0.639%	5.%	~6.11	20.
T = 2400 S	962	961.37	~0.065%	5.%	~0.626	20.

10.2 Remarks

the relative variations are higher than 2% for $t=400.s$, inferiors for $t\geq 600.s$
the results calculated by *Code_Aster* on the nodes of external surface are almost identical (maximum: $5.10^{-5}°C$ maybe 10^{-7} into relative).

11 Summary of the results

the got results are satisfactory. The maximum change obtained (3%) is on surface external of the sphere for weakest time the T. This variation decreases when time T increases.

Whatever the modelization, the results are increasingly more precise in the center than on the surface external of the sphere.

A identical cutting the results between the linear and quadratic elements are appreciably the same ones.