FORMA21 - Thermomechanical adaptive grid on a fissured cylinder head

Summary:

One realize one **thermoelastic calculation on a fissured metal cylinder head** in plane forced modeling (for the part mechanical) and lumpée (for the thermal part). In accordance with the “good practices” of standard quality of the studies, one uses two distinct grids: linear in thermics and quadratic in mechanics.

One carries out (modeling A) first of all the thermal calculation on which one makes converge freely the grid P_1 with a coupling map of indicator of space errors (CALC_ERREUR + 'ERTH_ELEM') /raffinement-déraffinement (MACR_ADAP_MAIL + 'RAFF_DERA').

In the second modeling (B), the two grids are adapted jointly according to the same process during a chained thermomechanical calculation. For the free adaptation of the mechanical grid, one has resorts to the indicator in pure residue 'ERME_ELEM'.

This case test makes it possible to test the not-regression of different coupling calculations from map of errors/procedure of refinement-déraffinement into thermomechanical, and the options the “pre one and postprocessings” of these calculations.

1 Problem of reference

1.1 Geometry

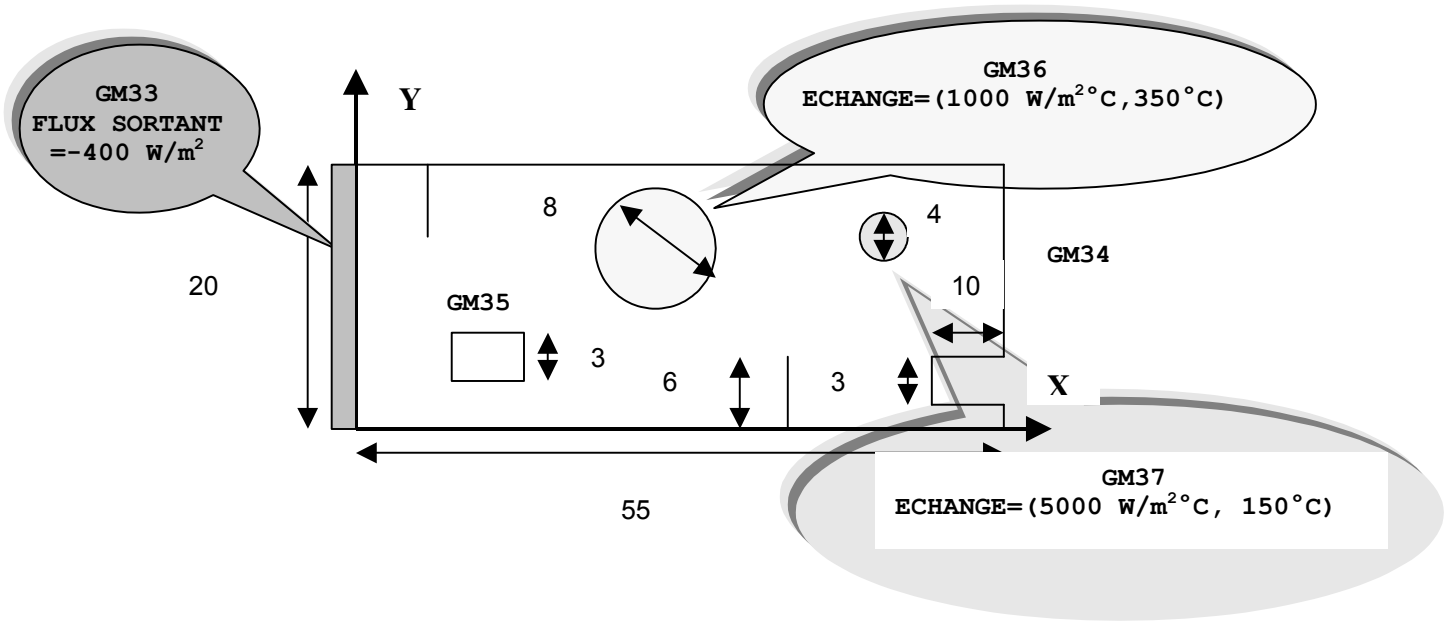

Figure 1.1-a: Diagram of the thermal loadings and the geometry (modelings A and B)

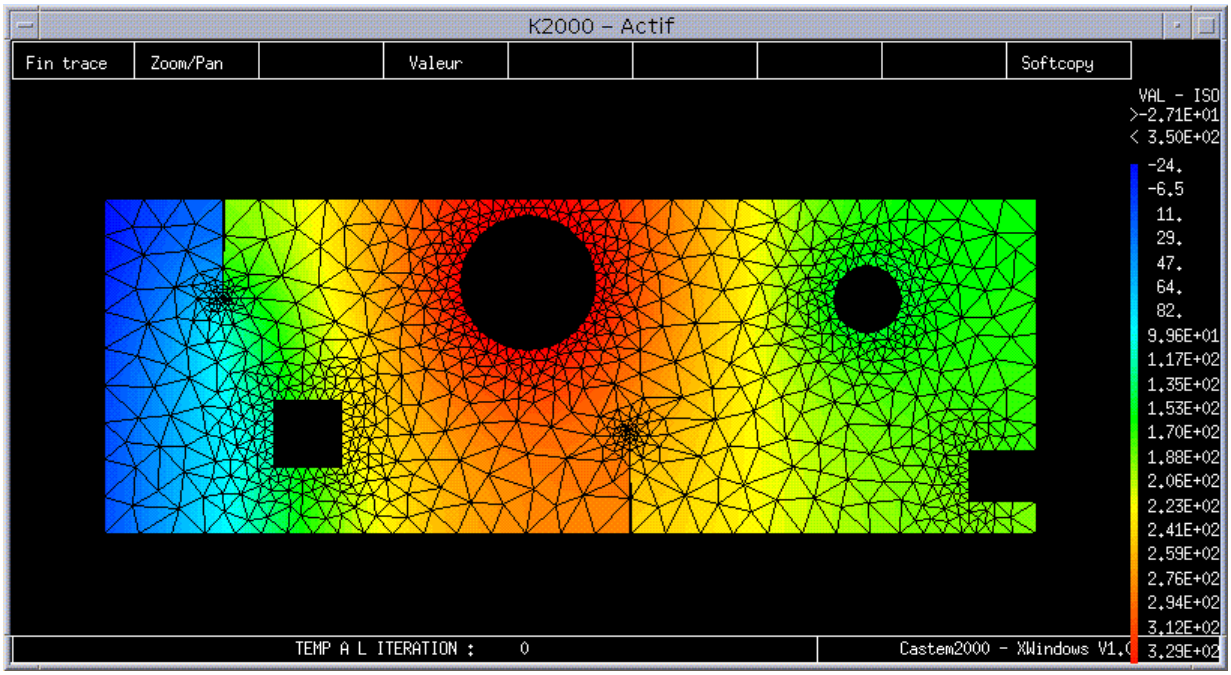

Figure 1.1-b: Isovaleurs of the thermal field on the initial thermal grid (modelings A and B)

It is about a fissured metal "cylinder head" (steel 16MND5, $E=210.10^3 Mpa$, $\nu=0.2$, $\rho C_p=526,10^4 J/m^3°C$, $\lambda=33,5 W/m°C$).

In two modelings (A and B), one carries out an isotropic transitory linear calculation thermal (THER_LINEAIRE or THER_NON_LINE) in lumpée modeling (PLAN_DIAG) on a thermal grid TRIA3/SEG2.

In the second modeling, this calculation is chained with an elastic design (MECA_STATIQUE or STAT_NON_LINE) in modeling forced plane (C_PLAN) on a mechanical grid in TRIA6/SEG3.

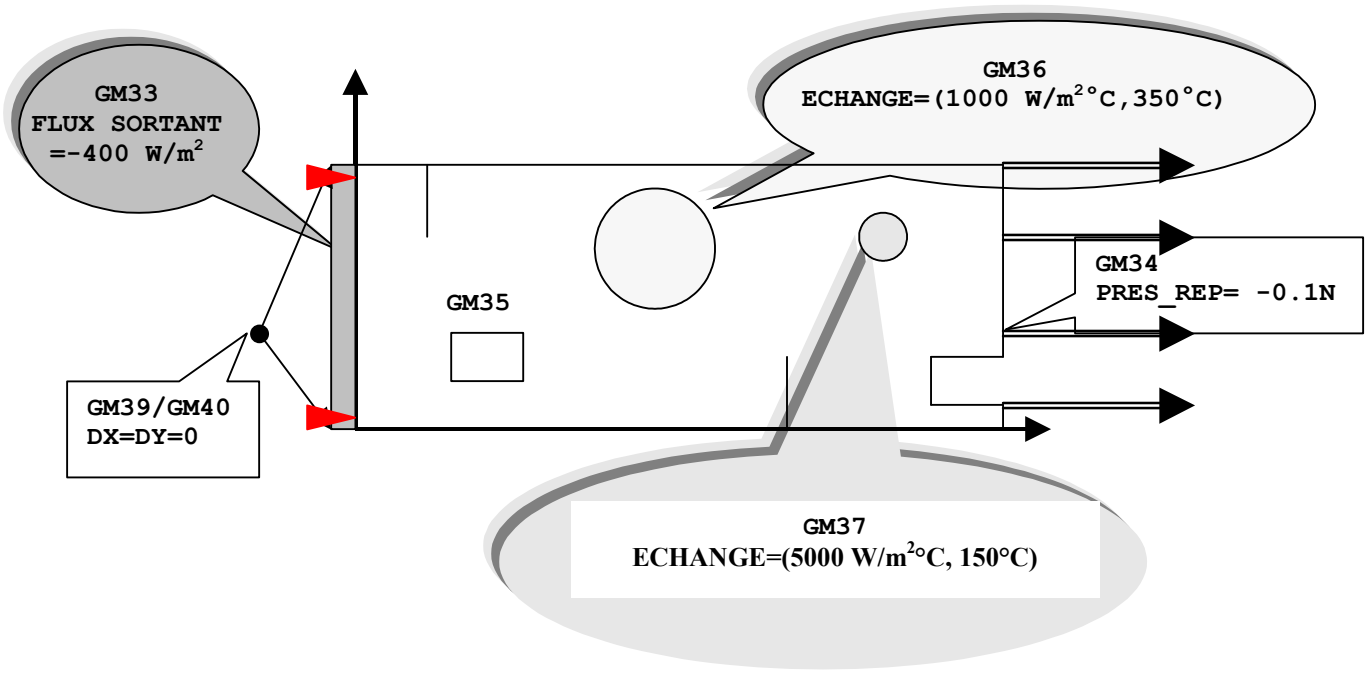

Figure 1.1-c: Diagram of the thermomechanical loadings and the geometry (modeling B)

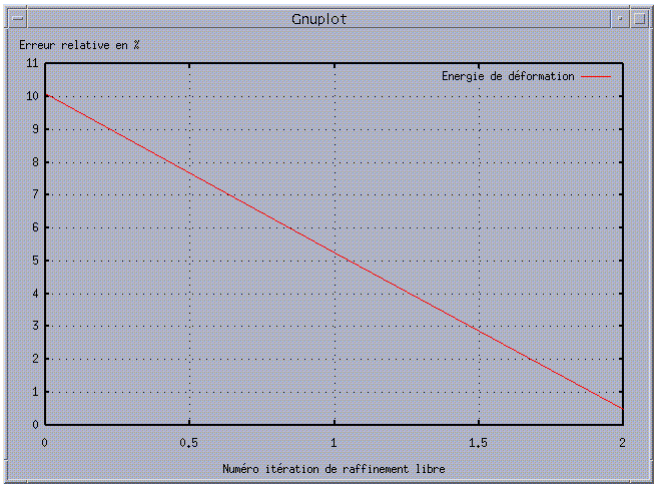

Figure 1.1-d: Decrease of the potential energy of deformation during the process of adjustment free of the grids (modeling B)

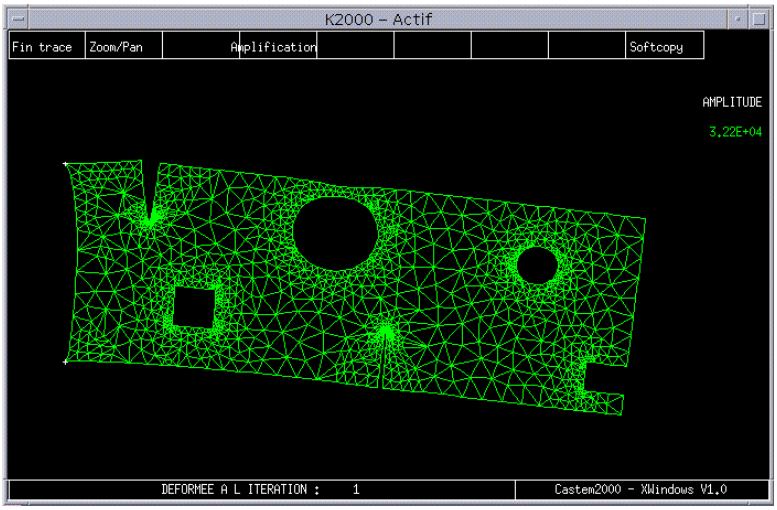

Figure 1.1-e: Deformation of the mechanical grid (modeling B)

The various key zones of calculation are indicated: GM38 for all the voluminal part in SORTED, GM33 for the outgoing heat flux, GM36/37 for the conditions of exchange, GM39/40 for embedding, GM34 for the pressure distributed and GM35 on the level of which one will measure Lhas average temperature.

1.2 Material properties

On all the structure (GROUP_MA GM38), the following characteristics material are applied:

$$E = 21000\,MPa$$
$$\nu = 0.2$$
$$\rho\,C - p = 52610^{4}\,J/m^{3}\,°C$$
$$\lambda = 33{,}5\,W/m\,°C$$

1.3 Boundary conditions and loadings

One can synthesize the decomposition of the loadings by zone in the shape of the following table:

Geometrical zones (GROUP_NO/GROUP_MA)	Loadings
GM33	FLUX_REP FLUN = $-400\,W/m^{2}$
GM36	EXCHANGE COEF_H = $1000\,W/m^{2}\,°C$ TEMP_EXT = $350\,°C$
GM37	EXCHANGE COEF_H = $5000\,W/m^{2}\,°C$ TEMP_EXT = $150\,°C$
GM39/40	DDL_IMPO DX = DY = 0.
GM34	PRES_REP CLOSE = $-0.1\,N$

2 Reference solution

2.1 Method of calculating used for the reference solutions

On such a case, it is not possible to exhume an analytical solution! The reference solution used for error analyses on Lhas average temperature of GM35 (modeling A) and on the potential energy of deformation (modeling A and B), is in fact an approximate solution obtained after a series of three uniform refinements. This procedure of uniform refinement can be controlled by a loop PYTHON and the operator MACR_ADAP_MAIL option UNIFORM.

2.2 Result of reference

Modeling a:

Potential energy of deformation (purely thermal) = $-2016.80291\,J$
Average temperature on GM35 = $170.2\,°C\,m$

Modeling b:

Potential energy of deformation (thermomechanical) = $6.75073756.10^{-}5\,J$

2.3 Uncertainty on the solutions

They acts only of approximate solutions obtained on a “quasi-converged” grid.

2.4 Bibliographical references

1) X.DESROCHES. “Estimators of error of Zhu-Zienkiewicz in elasticity 2D”. [R4.10.01], 1994.

2) X.DESROCHES. “Estimator of error in residue”. [R4.10.02], 2000.

3) O.BOITEAU. “Indicating of space error in residue for transitory thermics”. [R4.10.03], 2001.

4) O.BOITEAU. “Course and TP Indicateurs of error & Adaptation of grid; Establishment and state of the art in *Code_Aster* ”. http://www.code - aster.com/utilisation/formations, 2002.

5) O.BOITEAU. “FORMA04: Mechanical adaptive grid on a beam in inflection”. [V6.03.119], 2002.

3 Modeling A

3.1 Characteristics of modeling

The grid is carried out with elements of the type TRIA3. Is calculated in isotropic stationary linear thermics with the operator THER_LINEAIRE in lumpé (modeling PLAN_DIAG).

One calculates the cards of space errors of the indicator in pure residue (ERTH_ELEM). Beforehand it is necessary to have smoothed the heat flux of the points of Gauss to the nodes (FLUX_ELNO) and, post-to treat the map of error (via GIBI), it should be transformed of one CHAM_ELEM by element with one CHAM_ELEM with the nodes by element. One determines also the value of Lhas average temperature on GM35 (POST_RELEVE_T) and that of the potential energy of deformation (POST_ELEM).
The whole is placed in a loop PYTHON allowing the installation of a free procedure of refinement in nb_calc=4 levels (via MACR_ADAP_MAIL option LIBRE=' RAFF_DERA') coupled on the map of error exhumed beforehand. One controls this process by the component ERTREL of ERTH_ELEM (relative component of the indicator in residue). With like criteria CRIT_RAFF_PE=0.2 and CRIT_DERA_PE=0.1 (one refines 20% of the worst elements and one déraffine 10% of best).

One can thus note the convergence of the values of the temperature and energy, the increase of their errors relative compared to the errors provided by the indicator (they same into relative and on all the structure), the variations of the indices of effectiveness of the indicator and his good checking of the assumption of saturation.

In order to illustrate advices of “good practice” for the quality of the studies, on the aspects geometry with a grid, grid itself and standard of finite elements, one uses the options adhoc LIRE_MAILLAGE, MACR_ADAP_MAIL and MACR_INFO_MAIL.

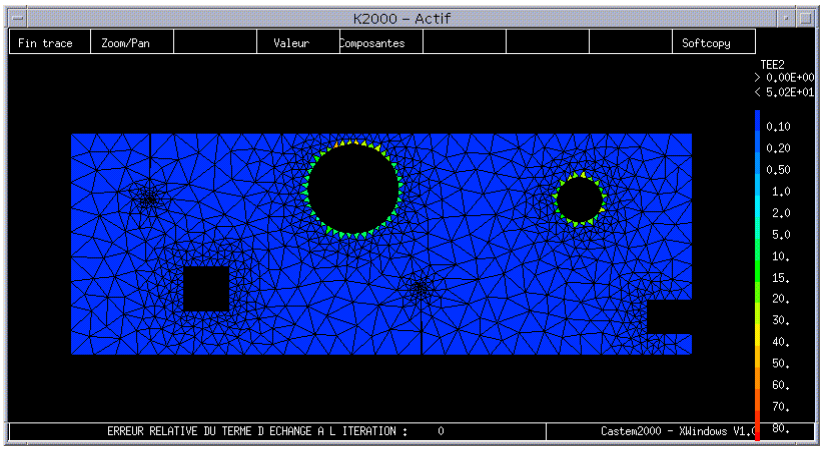

Figure 3.1-a: Isovaleurs of the component of exchange (TERME2) indicator of error

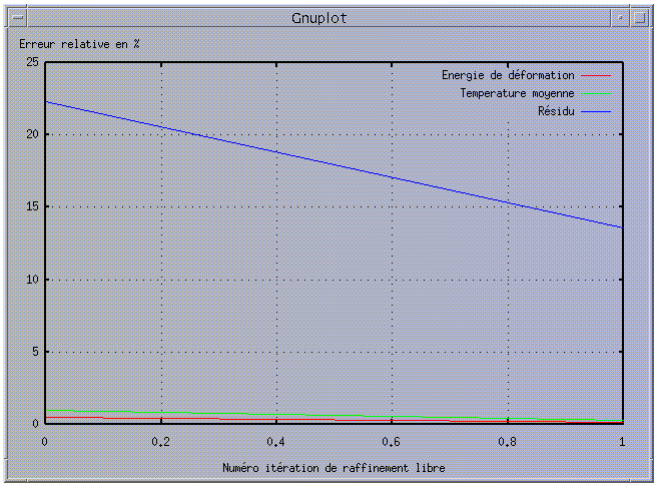

Figure 3.1-b: Decreases of the relative errors of the deformation energy and of the average temperature compared with that of the total component relative of the indicator (ERTREL)

3.2 Characteristics of the grid

Initially: 1619 TRIA3, 102 SEG2, 911 nodes
After a free refinement: 3088 TRIA3, 134 SEG2, 1681 nodes
After two free refinements: 6105 TRIA3, 180 SEG2, 3253 nodes
After three free refinements: 12345 TRIA3, 245 SEG2, 6462 nodes
After four free refinements: 25063 TRIA3, 347 SEG2, 12962 nodes

3.3 Sizes tested and results

One tests the values of the relative errors in average temperature and in potential energy of deformation compared to the reference solutions (cf [§2.2]). And this, on the initial grid and after four free refinements. Tests having to be multi-platforms, the relative tolerance, which on the initial errors is fixed at 10^{-6} %, is voluntarily slackened on the errors after four refinements: 10^{-4}%.
These tests are carried out on variables PYTHON (via TEST_FONCTION) inserted beforehand in functions ASTER (via FORMULA).

Identification	Values *Code_Aster*	Values of reference	Tolerance	Relative variation (in %)	Variable ASTER	Variable PYTHON
$E_p(0)$	0.491819%	idem	10^{-6} %	1.1010^{-11} | 0%	ERREEN0	eren0
$E_p(4)$	0.016287%	idem	10^{-4} %	$3.05\ 10^{-12}$ | 0%	ERREEN4	eren4
$T(0)$	4.797588 %	idem	10^{-6} %	$2.42\ 10^{-12}$ | 0%	ERRETM0	ertm0
$T(4)$	0.042547 %	idem	10^{-4}%	$-6.65\ 10^{-13}$ | 0%	ERRETM4	ertm4

3.4 Remarks

It is necessary well to keep in mind, that as a “simple postprocessing” of the mechanical problem thermo -, **the indicator cannot unfortunately provide more reliable diagnosis in the zones where the resolution of the initial problem stumbles** (crack, corners, multi-material, embedding, shock…). It is thus necessary to begin a process of adjustment (UNIFORM or FREE), with a grid refined already a little by the user close to the zones of discontinuities (materials, geometrical…).

MACR_ADAP_MAIL do not have process of regularization, therefore a bad initial grid will produce, even coupled to an indicator, probably a bad adapted grid!

As in mechanics, **the thermal sequence “operators 'FREE' MACR_ADAP_MAIL OPTION” converge optimalement the grid makes it possible to make**.

One can, moreover, **“to juggle” with the components of the thermal indicator** and of the limiting, “fictitious” conditions or not, for **to direct the construction of a grid refined or die-refined by zones** (cf [§6.3] [R4.10.03]).

4 Modeling B

4.1 Characteristics of modeling

Thermal grid (resp. mechanics) is carried out with elements of the type TRIA3 (resp. TRIA6). One chains a calculation of stationary linear thermics isotropic (via THER_LINEAIRE in modeling PLAN_DIAG) and a calculation in linear elasticity (via STAT_NON_LINE in modeling C_PLAN).

One calculates the cards of space errors of the indicators in thermal and mechanical pure residue (ERTH_ELEM and ERME_ELEM). Beforehand it is necessary to have smoothed the heat flux and the stress field of the points of Gauss to the nodes (FLUX_ELNO and SIEF_ELNO) and, post-to treat the map of error, it should be transformed of one CHAM_ELEM by element with one CHAM_ELEM with the nodes by element. One determines also the value of the potential energy of deformation (POST_ELEM).

The whole is placed in a loop PYTHON allowing the installation of a free procedure of refinement in nb_calc=2 levels (via MACR_ADAP_MAIL option LIBRE=' RAFF_DERA') coupled on the map of error exhumed beforehand. This process is controlled:

- by the component ERTREL of ERTH_ELEM (relative component of the indicator in residue) for the thermal grid,
- by the component NUEST of ERME_ELEM (relative component of the indicator in residue) for the mechanical grid.

With like criteria CRIT_RAFF_PE=0.2 and CRIT_DERA_PE=0.1 (one refines 20% of the worst elements and one die-refines 10% of best).

After each thermal calculation one of course projects the field of temperature of the thermal grid on the mechanical grid (via PROJ_CHAMP).

One can thus note the convergence of energy, the increase of his error relative compared to the errors provided by the indicators (they same into relative and on all the structure), the variations of the indices of effectiveness of the indicators and their good checking of the assumption of saturation.

4.2 Characteristics of the grid

Thermal grid

Initially: 1619 TRIA3, 102 SEG2, 911 nodes
After a free refinement: 3088 TRIA3, 134 SEG2, 1681 nodes
After two free refinements: 6105 TRIA3, 180 SEG2, 3253 nodes

Mechanical grid

Initially: 1619 TRIA6, 102 SEG3, 3443 nodes
After a free refinement: 2881 TRIA6, 152 SEG3, 6065 nodes
After two free refinements: 5319 TRIA6, 180 SEG3, 11097 nodes

4.3 Sizes tested and results

One tests the relative error values in potential energy of deformation compared to the reference solution (cf [§2.2]). And this, on the initial grid and after two free refinements. Tests having to be multi-platforms, the relative tolerance, which on the initial errors is fixed at 10^{-6} %, is voluntarily slackened on the errors after two refinements: 10^{-4}%.

These tests are carried out on variables PYTHON (via TEST_FONCTION) inserted beforehand in functions ASTER (via FORMULA).

Identification	Values *Code_Aster*	Values of reference	Tolerance	Relative variation (in %)	Variable ASTER	Variable PYTHON
$E_p(0)$	10.077761%	idem	10^{-6}%	4.79^{-12} | 0%	ERREEN0	eren0
$E_p(2)$	0.459330%	idem	10^{-4}%	$-1.03\ 10^{-12}$ | 0%	ERREEN2	eren2

4.4 Remarks

In **thermomechanical, various strategies of adaptation of grid** are offered to the user:

- to adapt the grid only according to one thermal criterion,
- idem according to a mechanical criterion,
- to adapt initially according to a thermal criterion, then according to a mechanical criterion (two separate loops of adaptation).
- to adapt jointly according to a thermal criterion then mechanical (a loop as in it CAS-test),
- to adapt according to a thermomechanical criterion.

In *Code_Aster*, one does not have access to explicitly thermomechanical indicators, although the mechanical indicators can comprise a thermal dependence incidentally.

According to the needs for the study (rather thermal or rather mechanical, to make converge a grid, better taken overall into account of certain boundary conditions…) one can set up in the code, one of the first four strategies.

The good practice during a thermomechanical calculation being to use the elements P_1 lumpés in thermics and them P_2 in mechanics, that led to use two grids and to interpolate the thermal field linear solution on the quadratic mechanical grid (via PROJ_CHAMP).

Nevertheless, if one wishes to work only with one grid, one can easily decline one of the first four strategies via the option MAJ_CHAM of MACR_ADAP_MAIL. That allows, while adapting the grid according to a thermal criterion (resp. mechanics), to update the complementary, mechanical field (resp. thermics), on the new adapted grid.

5 Summary of the results

ON " realize " one **thermoelastic calculation on a fissured metal cylinder head** in plane forced modeling (for the mechanical part) and lumpé (for the thermal part). In accordance with the "good practices" of standard quality of the studies, one uses two distinct grids: linear in thermics and quadratic in mechanics.
One carries out (modeling A) first of all the thermal calculation on which one makes converge freely the grid P_1 with a coupling map of indicator of space errors (CALC_ERREUR + 'ERTH_ELEM') /raffinement-déraffinement (MACR_ADAP_MAIL 'RAFF_DERA').
In the second modeling (B), the two grids are adapted jointly according to the same process during a chained thermomechanical calculation. For the free adaptation of the mechanical grid, one resorts to the indicator in pure residue 'ERME_ELEM'.

Objectives of it CAS-test are multiple, it acts:

- to familiarize and put into practice the two dual problems: calculation of map of indicator of error and strategies of adaptation of grid. On standard cases, but also on pathological cases and for chainings of calculations,
- to detail the various parameter settings of the accused operators (CALC_ERREUR, MACR_ADAP_MAIL) and related operators who can appear particularly interesting for these problems (INFO_MAILLAGE, MACR_INFO_MAIL, PROJ_CHAMP…),
- to hammer advices of "good practice" for the quality of the studies and the use of the tools already available on the subject. One is interested only in the aspects geometry with a grid, grid itself and standard of finite elements. One is not delayed here on the problems of step of time, calibration of digital parameters and on the aspects sensitivity with respect to the data,
- to illustrate the formidable potentialities and facilitated which allows the coupling "language ASTER/PYTHON " in the command file of a study (test, buckles, posting, calculation, personal macro-order, interactivity…). The official CAS-tests being gauged to function in batch, some of these aspects "were thus commentarisés" in the command file.

From a point of view **data-processing validation**, this case test of course makes it possible to test the not-regression of various couplings calculations of map of errors/procedure of refinement-déraffinement into thermomechanical, but also the options the "pre one and postprocessings" of these calculations (smoothing of the constraints and heat fluxes with the nodes, passage of an error per element with an error with the nodes by element).