FORMA21 - Thermomechanical adaptive mesh on a fissured cylinder head

Summarized:

In this case, it is a question of making sure of **the NON-regression of the TP n°2 associated with the course "Error indicators and mesh adaptation; Establishment and state of the art in *Code_Aster* "** of training "nonlinear Static analysis with *Code_Aster* ".

One "abuses" **a thermoelastic computation on a metal cylinder head fissured** in modelization plane stress (for the mechanical part) and lumped (for the thermal part). In accordance with the "good practices" of standard quality of the studies, one uses two distinct meshes: linear in thermal and quadratic in mechanics.

One carries out (modelization A) first of all the thermal computation on which one makes converge freely the mesh P_1 with a coupling spatial card of error indicator (`CALC_ERREUR + "ERTH_ELEM"`) /raffinement-coarsening (`MACR_ADAP_MAIL + "RAFF_DERA"`).

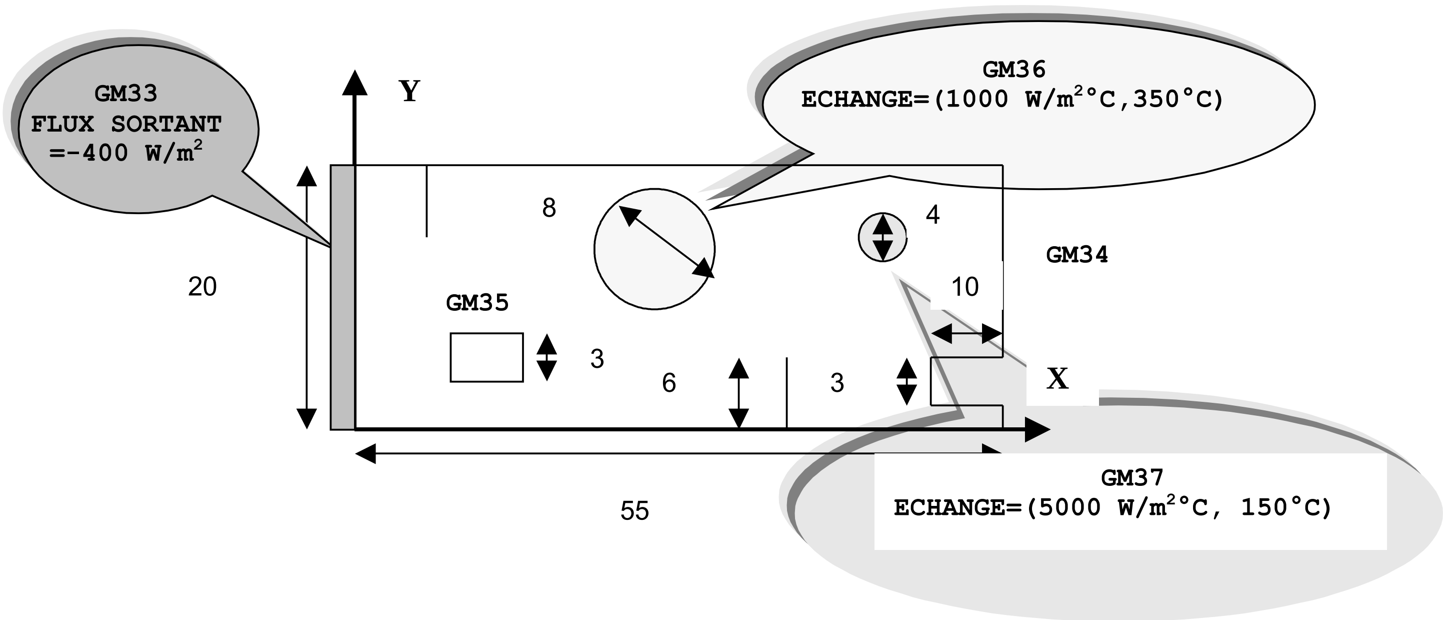
In the second modelization (B), the two meshes are adapted jointly according to the same process during a chained thermomechanical computation. For the free adaptation of the mechanical mesh, one has resorts to the indicator in pure residue "`ERME_ELEM`".

This case test makes it possible to test the NON-regression of different coupling computations from card of errors/procedure of refinement-coarsening into thermomechanical, and the options the "pre one and postprocessings" of these computations.

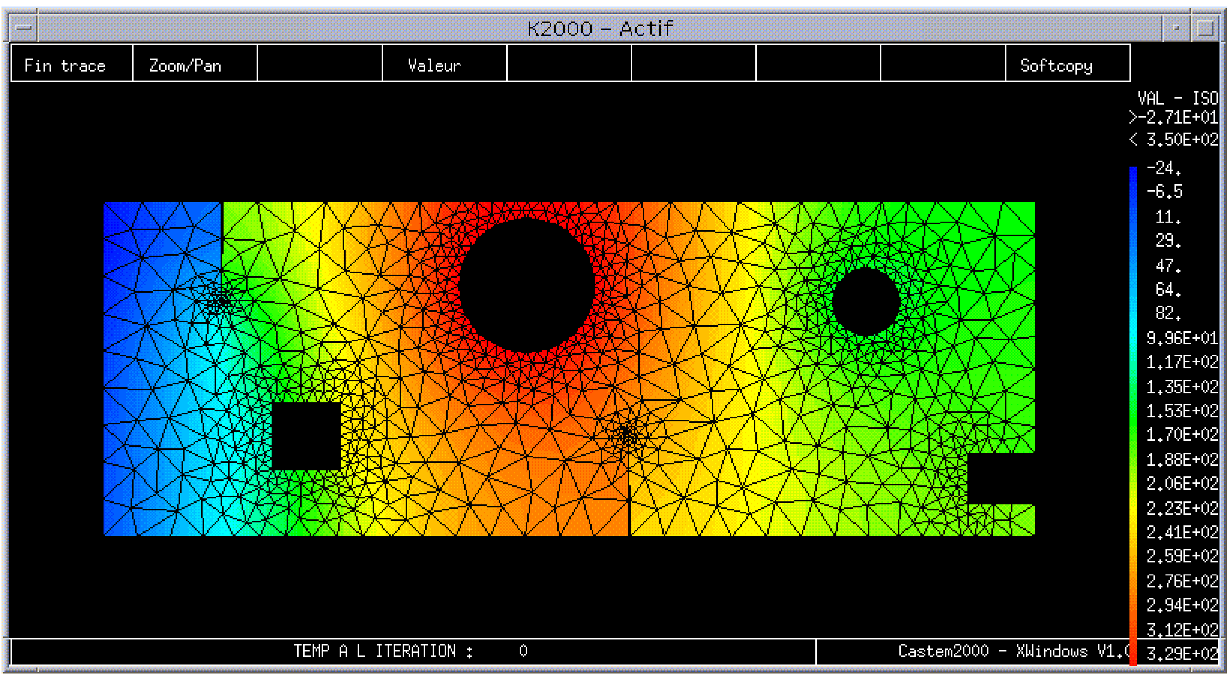
The entirety of the text of the TP is available on the website:
`http://www.code - aster.com/utilisation/formations`.

1 Problem of reference

1.1 Geometry



Appears 1.1-a: Diagram of the thermal loadings and the geometry (modelizations A and B)

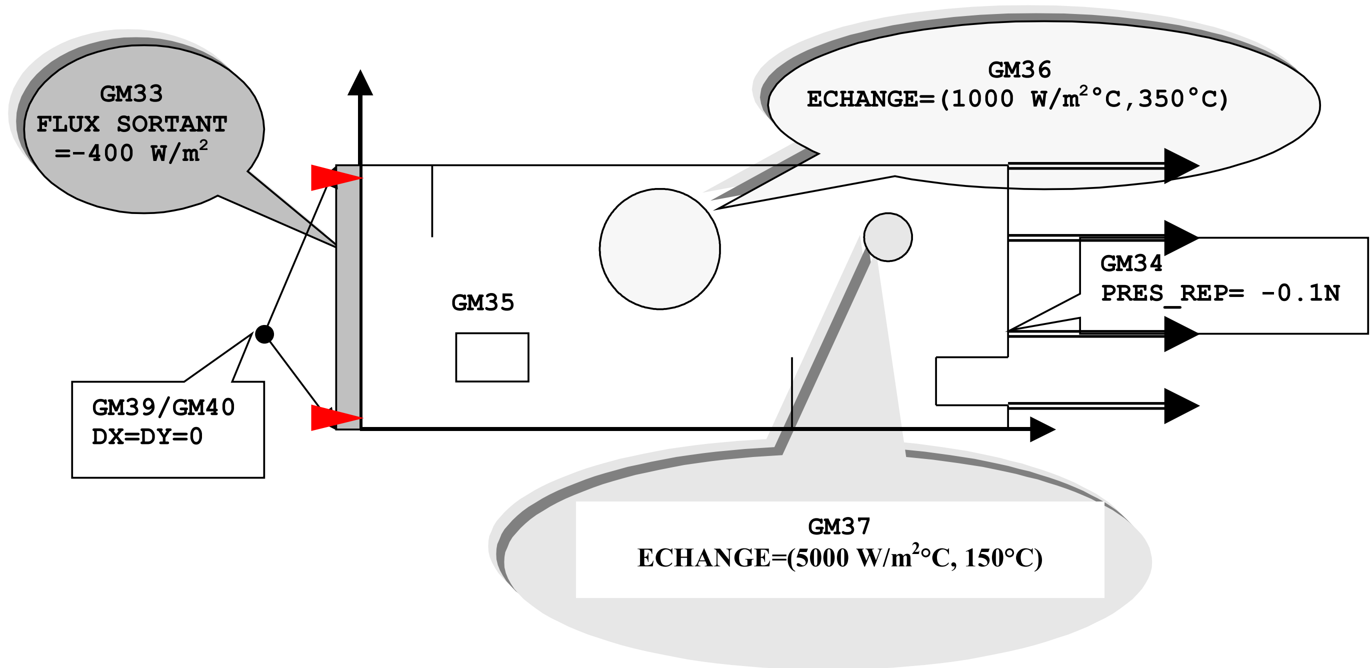


Appears 1.1-b: Isovaleurs of the thermal field on the initial thermal mesh (modelizations A and B)

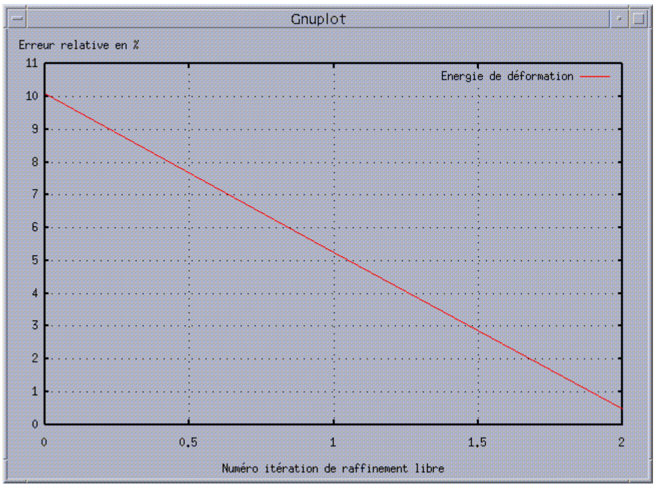
It acts of a fissured metal “cylinder head” (steel 16MND5 $E=210.10^3 Mpa$ $\nu=0.2$ $\rho C_p=526{,}10^4 J/m^3 °C$, $\lambda=33{,}5 W/m°C$).

In the two modelizations (A and B), one carries out an isotropic transitory linear thermal computation (THER_LINEAIRE or THER_NON_LINE) in lumped modelization (PLAN_DIAG) on a thermal mesh TRIA3/SEG2.

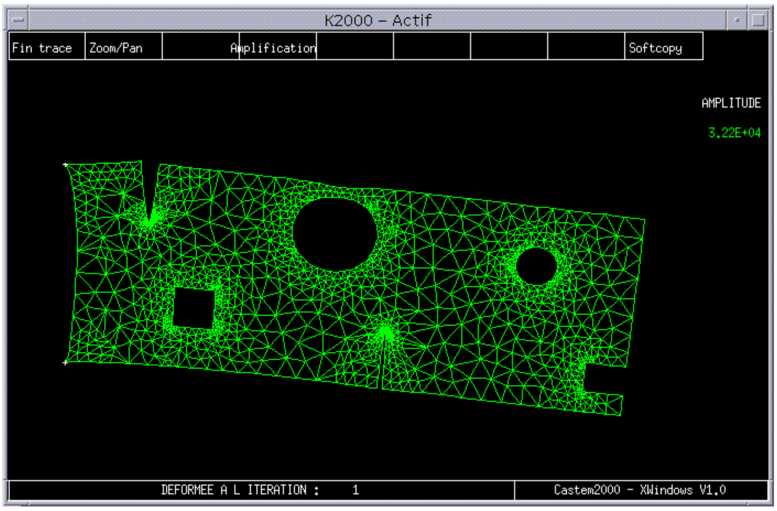
In the second modelization, this computation is chained with an elastic design (MECA_STATIQUE or STAT_NON_LINE) in modelization plane stresses (C_PLAN) on a mechanical mesh in TRIA6/SEG3.



Appear 1.1-c: Diagram of the thermomechanical loadings and the geometry (modelization B)



Appears 1.1-d: Decrease of the potential energy of déformationau course of the process of adjustment free of the meshes (modelization B)



Appears 1.1-e: Deformed mechanical mesh (modelization B)

the various key zones of computation are indicated: `GM38` for all the voluminal part `SORTED some`, `GM33` for outgoing heat flux, `GM36/37` for the conditions of exchange, `GM39/40` for the fixed support, `GM34` for the distributed pressure and `GM35` on the level of which one will measure the integral of the temperature.

1.2 Material properties

On all 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	ECHANGE COEF_H = $1000\,W/m^2\,°C$ TEMP_EXT = $350\,°C$
GM37	ECHANGE COEF_H = $5000\,W/m^2\,°C$ TEMP_EXT = $150\,°C$
GM39/40	DDL_IMPO DX = DY = 0.
GM34	PRES_REP NEAR = $-0.1\,N$

2 Reference solution

2.1 Méthode de calcul 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 the integral of the temperature of GM35 (modelization A) and on the potential energy of strain (modelization 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 operator MACR_ADAP_MAIL option UNIFORME.

2.2 Result of reference

Modelization a:

Potential energy of strain (purely thermal) = $-2016.80291\,J$

Integral of the temperature on GM35 = $4080\,°C\,m$

Modelization b:

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

2.3 Uncertainty on the solutions

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

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. “Error indicators spatial in residue for the transient thermal”. [R4.10.03], 2001.

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

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

3 Modelization A

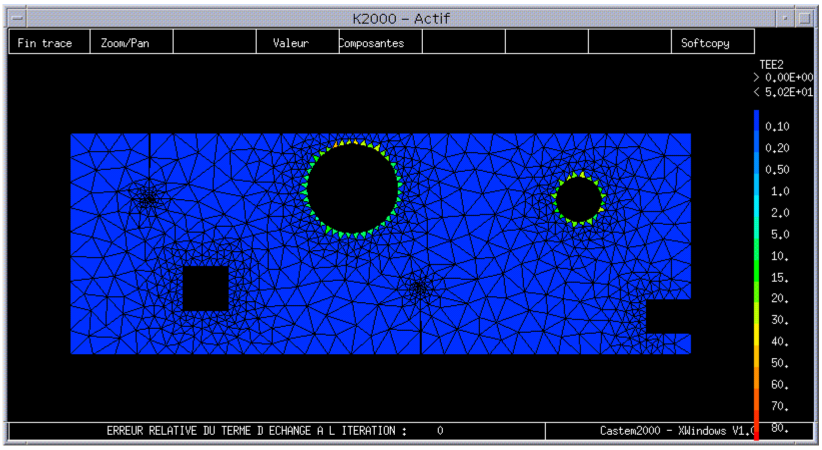
3.1 Characteristic of the modelization

The mesh is carried out with elements of the type TRIA3. The computation is made in isotropic steady linear thermal with operator THER_LINEAIRE into lumped (modelization PLAN_DIAG).

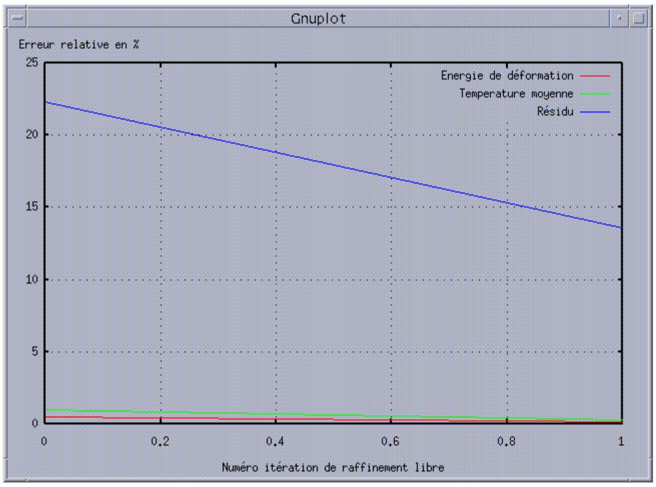
One calculates the cards of spatial errors of the indicator in pure residue (ERTH_ELEM). Beforehand it is necessary to have smoothed heat flux of Gauss points with nodes (FLUX_ELNO) and, post-to treat the card of error (via GIBI), it should be transformed of a CHAM_ELEM by element with a CHAM_ELEM with the nodes by element. One determines also the value of the integral of the temperature on GM35 (POST_RELEVE_T) and that of the potential energy of strain (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 card of error exhumed beforehand. One controls this process by component ERTREL of ERTH_ELEM (component relative 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 structure), the variations of the indices of effectiveness of the indicator and his good checking of the assumption of saturation.

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



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



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

3.2 Characteristic of the mesh

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 Quantities tested and results

One tests the values of the relative errors in integral of the temperature and potential energy of strain compared to the reference solutions (cf [§2.2]). And this, on the initial mesh and after four free refinements. The 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	Toleranc e	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
$T(0)$	0.921819%	idem	$10^{-6\%}$	2.42 10-12 | 0%	ERRETM0	ertm0
$T(4)$	0.208827%	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, fixed support, shock…). It is thus necessary to begin a process of adjustment (UNIFORME or LIBRE), with a mesh refined already a little by the user close to the zones of discontinuities (materials, geometrical…).

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

As in mechanics, **the sequence “operators thermique/MACR_ADAP_MAIL OPTION “LIBRE”” makes it possible to make converge optimalement the mesh**.

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

4 Modelization B

4.1 Characteristic of the modelization

The mesh thermal (resp. mechanics) is carried out with elements of the type TRIA3 (resp. TRIA6). One chains a computation of steady linear thermal isotropic (via THER_LINEAIRE in modelization PLAN_DIAG) and a computation in linear elasticity (via STAT_NON_LINE in modelization C_PLAN).

One calculates the cards of spatial errors of the indicators in thermal and mechanical pure residue (ERTH_ELEM and ERME_ELEM). Beforehand it is necessary to have smoothed heat flux and the stress field of Gauss points with nodes (FLUX_ELNO and SIEF_ELNO) and, post-to treat the card of error, it should be transformed of a CHAM_ELEM by element with a CHAM_ELEM with the nodes by element. One determines also the value of the potential energy of strain (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 card of error exhumed beforehand. This process is controlled:

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

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 computation one of course projects the field of temperature of the thermal mesh on the mechanical mesh (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 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 thermal

mesh Mesh

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 Mesh

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 Quantities tested and results

One compared to the tests the relative error values in potential energy of strain reference solution (cf [§2.2]). And this, on the initial mesh and after two free refinements. The 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	Toleranc e	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

Into **thermomechanical, various strategies of mesh adaptation** are offered to the user:

to adapt the mesh 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 this TP),
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 mesh, 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 computation being to use the lumped P_1 elements in thermal and in P_2 mechanics, that led to use two meshes (as in this TP) and to interpolate the thermal field linear solution on the quadratic mechanical mesh (via `PROJ_CHAMP`).

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

5 Summary of the results

In this case, it acts to make sure of **the NON-regression of the TP n°2 associated with the courses "Error indicators and mesh adaptation; Establishment and state of the art in *Code_Aster*"** of training "nonlinear Static analysis with *Code_Aster*".

In fact, one "abuses" **a thermoelastic computation on a metal cylinder head fissured** in modelization plane stress (for the mechanical part) and lumped (for the thermal part). In accordance with the "good practices" of standard quality of the studies, one uses two distinct meshes: linear in thermal and quadratic in mechanics.
One carries out (modelization A) first of all the thermal computation on which one makes converge freely the mesh P_1 with a coupling spatial card of error indicator (CALC_ERREUR + "ERTH_ELEM") / raffinement-coarsening (MACR_ADAP_MAIL "RAFF_DERA").
In the second modelization (B), the two meshes are adapted jointly according to the same process during a chained thermomechanical computation. For the free adaptation of the mechanical mesh, one resorts to the indicator in pure residue "ERME_ELEM".

The purposes of this TP are multiple, it acts:

- to familiarize and put into practice the two dual problems: computation of card of error indicator and strategies of mesh adaptation. On standard cases, but also on pathological cases and for sequences of computations,
- to detail the various parameter settings of the accused operators (CALC_ERREUR, MACR_ADAP_MAIL) and operators related who can appear particularly interesting for these problems (INFO_MAILLAGE, MACR_INFO_MAIL, PROJ_CHAMP…),
- to hammer advice 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, mesh itself and standard of finite elements. One is not delayed here on the problems of time step, calibration of parameters numerical 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, display, computation, personal macro-command, interactivity…). The official benchmarks being gauged to function in batch, some of these aspects "were thus commentarisés" in the command file.

From a data-processing **validation point of view**, this case test of course makes it possible to test the NON-regression of various couplings computations of card of errors/procedure of refinement-coarsening into thermomechanical, but also the options the "pre one and postprocessings" of these computations (lissage of the stresses and heat fluxes with the nodes, transition of an error per element with an error with the nodes by element).

Each modelization is associated with question TP and one retranscribed **of it the main part of the elements of correction**. Entirety of the text of the TP being available on the website:
http://www.code-aster.com/utilisation/formations.