Air Intake Module optimization from multiphysical analyses

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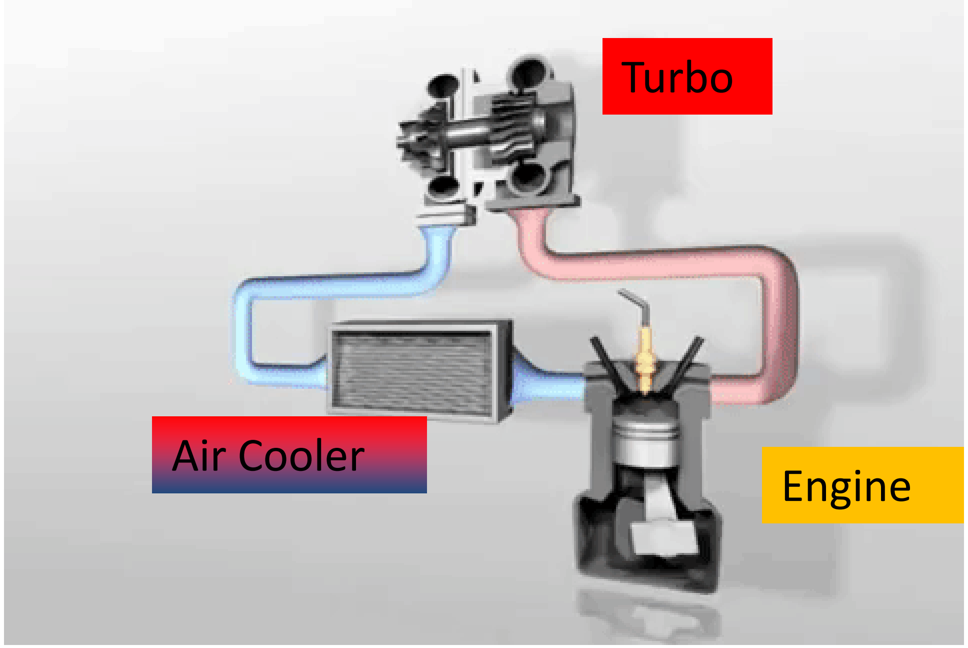
Introduction

Running of a charged engine

A charged engine allows a better efficiency adding more air in the engine by compressing air. Compressing air increases temperature of inlet air from ambient temperature to almost 150 - 220°C.



Introduction

Typical architecture for Charge Air Cooler is

- behind bumper - or bext
- below engine hood
- In wheel arch

Most of charge air cooler use external air as cold source , named as Air charge cooler

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Introduction

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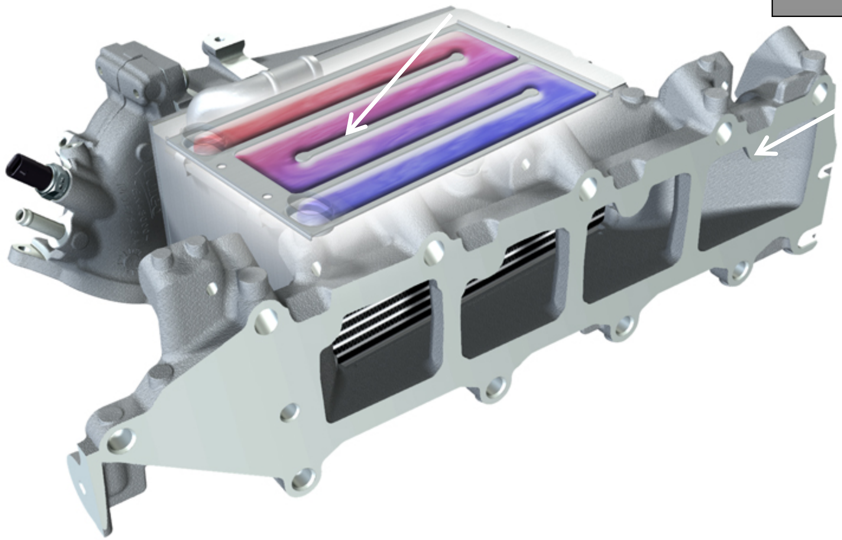
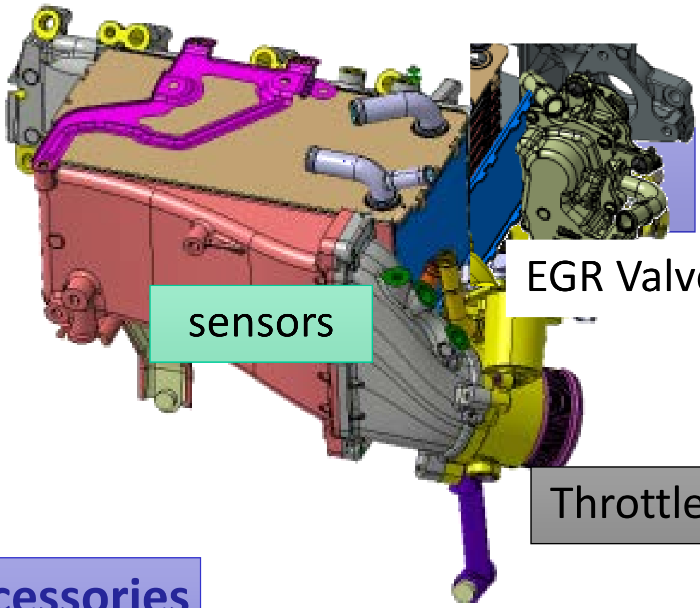
The Air Intake Module integrates different functions in ONE component

2 main functions integrated in one component

Water charge air cooler

Air intake manifold





EGR Valve

sensors

Throttle

& support for many accessories

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Introduction

→ **This new concept thanks to cooling charge air with engine coolant allows**

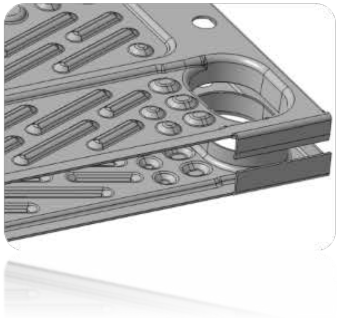
- Better efficiency within
- Smaller packaging
- To integrate different sensors, valve (EGR, throttle)

Advantages	
Comfort	**Engine**
Turbo delay response ↘	Better efficiency ↗
More driving comfort ↗	Nox ↘
	CO2 ↘
	Management engine inlet T° ↗
	Range of using EGR BP ↗

Introduction

→ **As AIM is**

- A quite new component
- Complex component
  - CFD &
  - Structural aspects (pressure, thermo mechanical, vibration, process)
  - Materials datas
  - Large range of temperature
  - Large range for frequency (0- 2000 Hz)
  - Very thin (0.15- 0.50 mm), for 90- 200 mm in other dimensions , small detail of 0. 5mm !!



→ **Simulation is complex to perform keeping reasonable simulation size !**

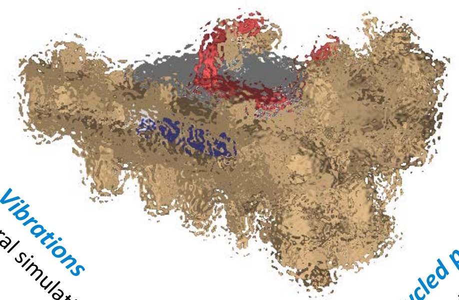
Introduction

Since the last conference

Users' Conference 2016	Users' Conference 2018
Multimodal optimization (one load)	**Multimodal optimization (multiple loads)**
Loads : - Simplified thermal shock	Loads : - Thermal field in a context of thermal shock **from CFD simulations** - Cycled pressure - Vibrations
Design areas : - Inlet box (TOPO) - Dimples (PARAM)	Design areas : - Inlet box (TOPO) - Dimples (PARAM) - Brazing region at the back of the system (TOPO)
	Fatigue (*via* submodelling)
	Reliability (*via* submodelling)

Model
Unique and complex

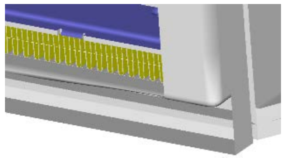
A unique complex model for the various planned studies

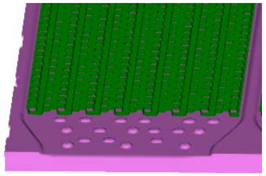


Unique complex model

An indispensable complex model:
Details must be finely meshed :
- To get a consistent rigidity
- To show the physical behaviour.

The highest stresses develop in finer geometries of model.
→ Need for a detailed model for best results, and to optimize decision making.





Complex geometries

Mesh statistics

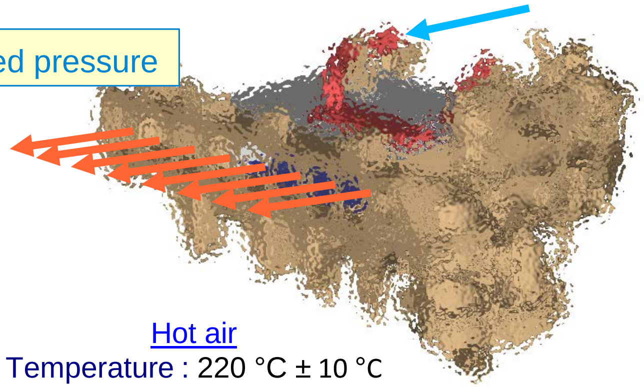
	Elements	Nodes
« Structure » model	~13 millions	~19 millions
« Internal fluid » model	~19 millions	~22 millions
« External fluid » model	~05 millions	~06 millions

Multimodal optimization

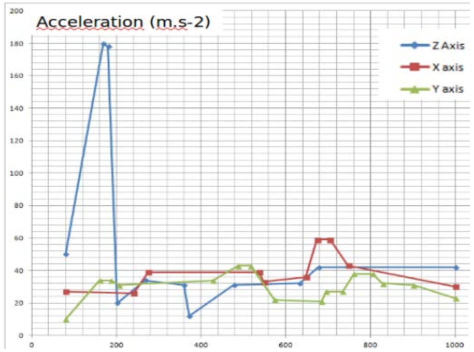
Multiphysical loads

Cold fluid
Static pressure : 2.4 bar (abs)

Cycled pressure



Hot air
Temperature : 220 °C ± 10 °C
Pressure : 2.5 bar (abs)
Number of cycles : 1 000 000 – 1 200 000



Acceleration towards each direction, function of the excitation frequency

Vibrations

Thermal shock

A spécific and new method has been built, validated and applied during this project to compute the thermal field to which is submited the system under the conditions of thermal shock.

Main idea : Take into account at once time the effect of fins on the cinematic of the external fluid.

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Multimodal optimization

Thermal shock simulation : innovating method

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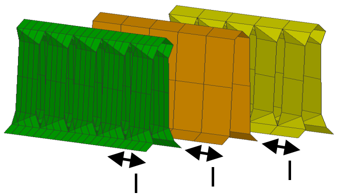
Step 1 : Model building

3 different models :

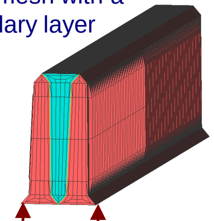


- Detailed model : finely meshed, with louvers
  → used for a « CFD general » calculation on lone fin.
- Simplified model : coarse, without louvers,
  → used for a « CFD thermal » calculation on the complete model.
- Structural model : coarse, with louvers,
  → used for a « Structure » calculation on the complete model.

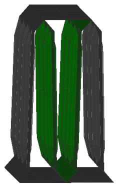
Step 2 : « CFD general » calculation on lone fin

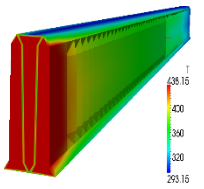
Fluid mesh with a boundary layer

Shape of a fin studied in particular (modeled by a double skin)



Meshing of neighboring fins to take into account their effect.





Exemple of a resulting thermal field on a lone fin.

Step 3 : Extraction of a function $h(x,y,z,V_i)$

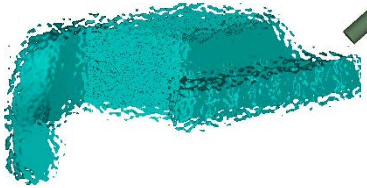
x	y	z	V_i	h
x_1	y_1	z_1	V_{i1}	$h(x_1,y_1,z_1,V_{i1})$
x_2	y_2	z_2	V_{i2}	$h(x_2,y_2,z_2,V_{i2})$
x_n	y_n	z_n	V_{in}	$h(x_n,y_n,z_n,V_{in})$

From results obtained after the previous step, building of a tabular which permits to link the value of convection coefficient h to the position of considered element in the fin and to the input speed of fluid.

Step 4 : Determination of « h » values for others interfaces

For each fluid, some thermal simulations are computed with a steady-state hypothesis to define the value of the convection coefficient on interfaces which are not concerned by the homogeneization.

Used model for the external fluid



Used model for the internal fluid

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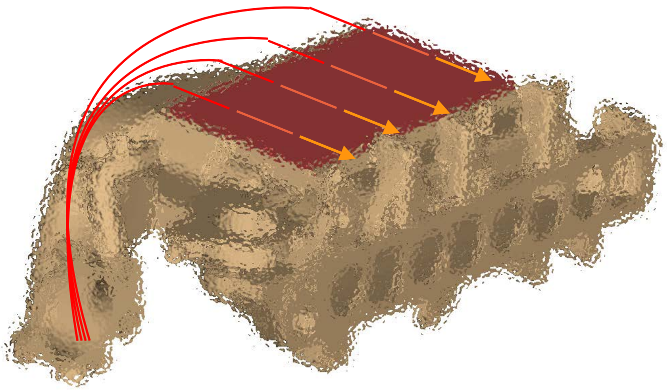
Multimodal optimization

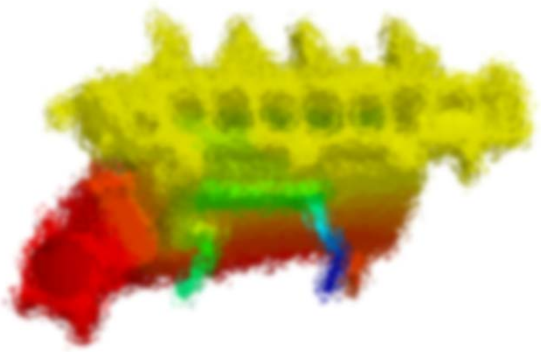
Thermal shock simulation : innovating method

Step 5 : Definition on an ambient temperature field

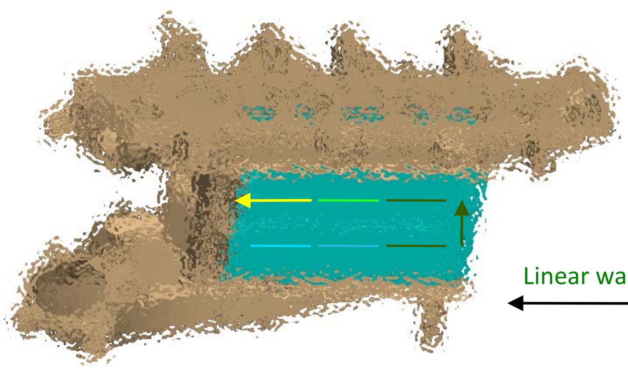
Linear refreshing throughout fins.

Pressurized hot fluid (air) as input :



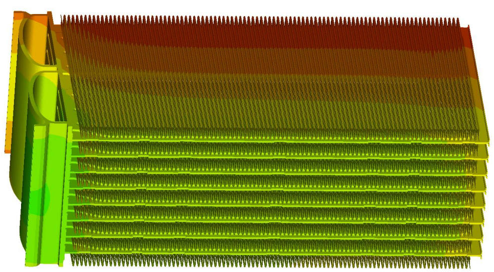


View of an ambient temperature field



Cold water-glycol mix as input :

Linear warming during the way in the pair of plates.



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Thermal shock simulation : results

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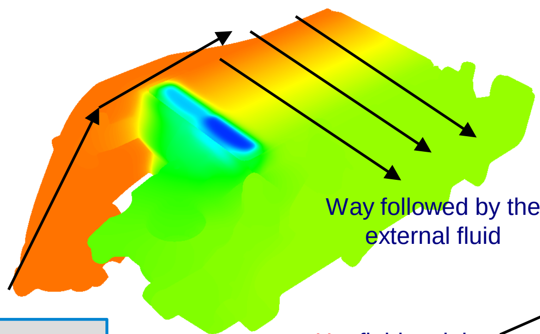
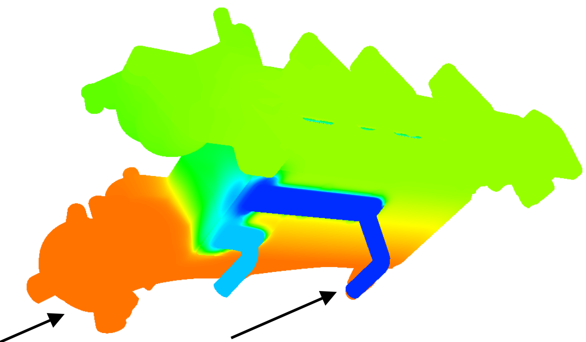
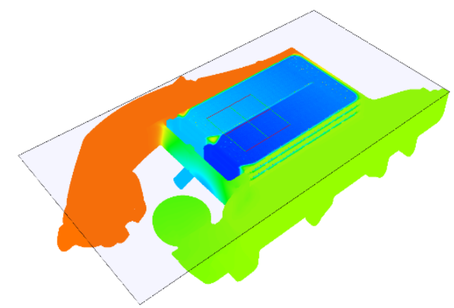
Final step : use of PERMAS to compute the thermal field evolution in the model.







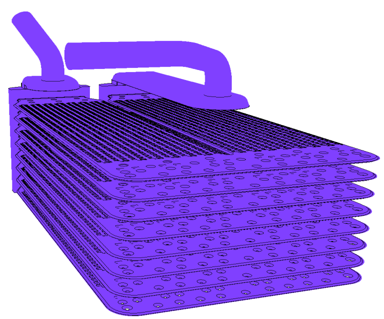
Steady-state

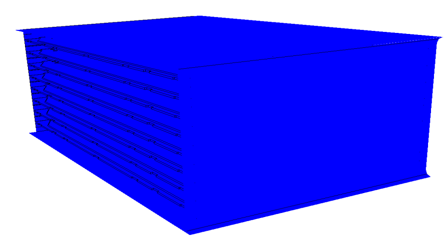
Hot fluid on inlet

Cold fluid on inlet

Structure bathed by the external fluid.

→ The internal fluid is too convective to see transient or 3D effect.





→ The transient effect is more significant with the external fluid, and a 3D effect is viewable too along the height of the system (with a symmetry compared to the central plate).

Transient

Structure bathed by the internal fluid.

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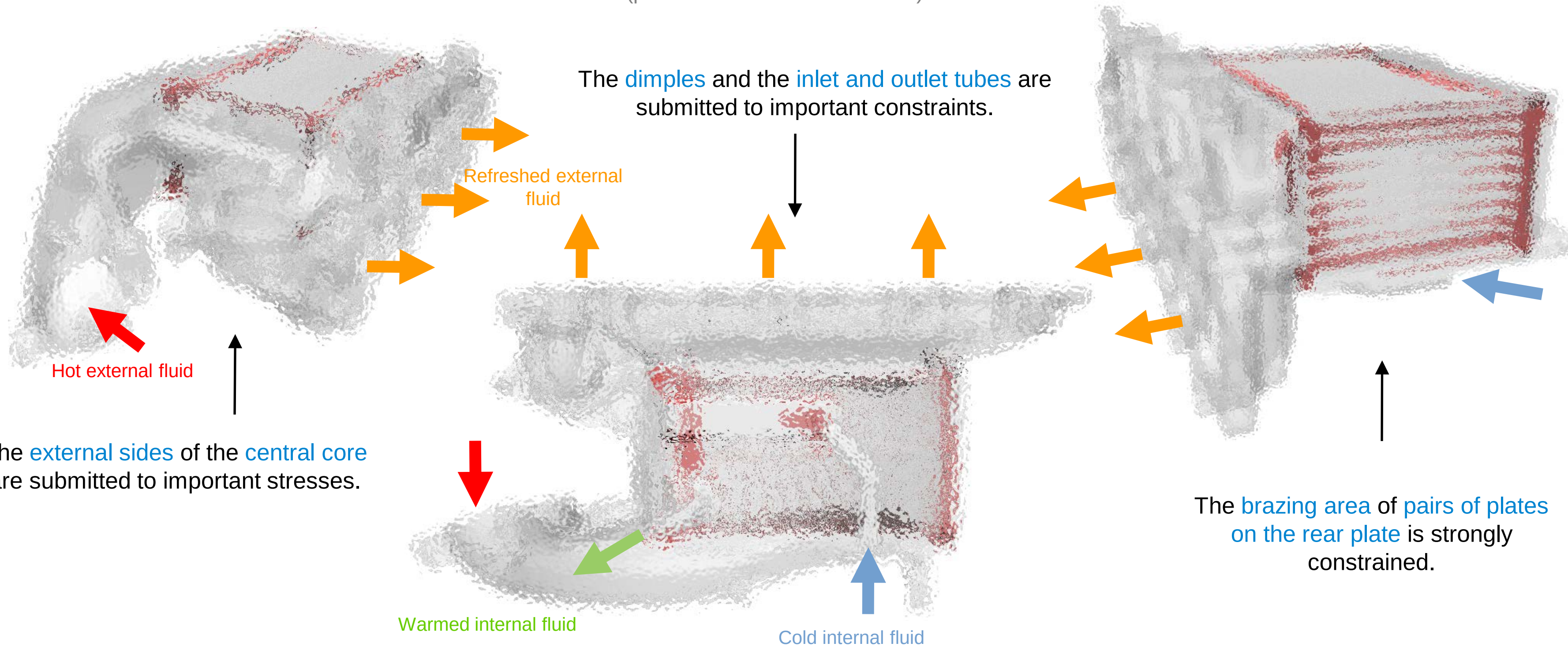
Multimodal optimization

Thermal shock simulation : results

Simulation of the mechanical stresses applied to the system by the thermal field previously computed.

(pictures taken at the time t=6s)

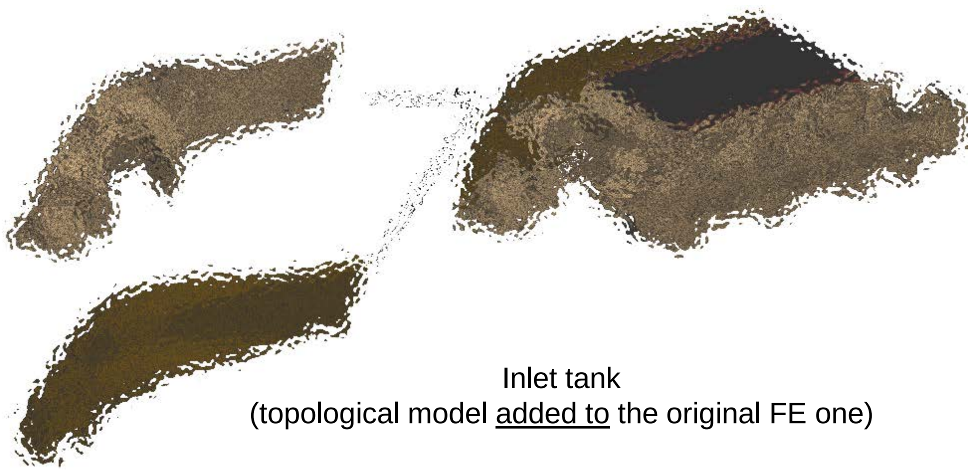


The most constrained areas of the WCAC are colored in red.

Multimodal optimization

Additional models and optimization scenario

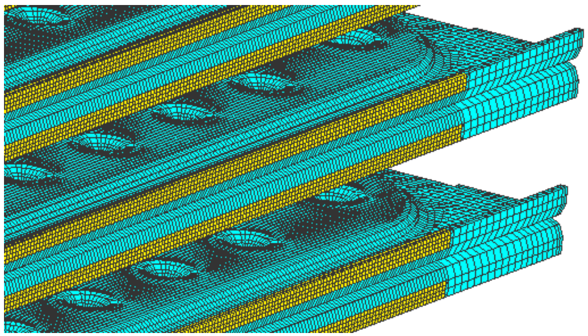
Additional models



Inlet tank
(topological model <u>added to</u> the original FE one)

622 000 cubic elements, with a side equal to 1 mm.

35 000 hexaedral elements, with a side equal to 0,3 mm.



Brazing area at the rear side of the AIM
(topological elements <u>instead of</u> original ones)

Optimization scenario

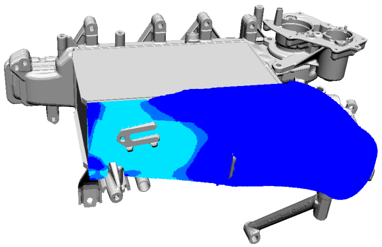
<u>Objective :</u> Minimization of the maximal constraint on dimples.

<u>Constraints :</u> - on the mass and the compliance of the complete system,
- on the eigenfrequency linked to the most important effective mass.

<u>Loads :</u> Thermal field, cycled pressure and vibrations.

Multimodal optimization

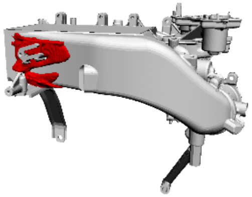
Results of topological optimizations



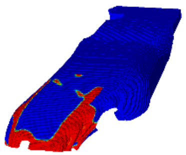
The difference with the result previously obtained (with a linear thermal load) is significative.

The enforced area is more localized, although located in the same region.

Optimization result obtained with a :

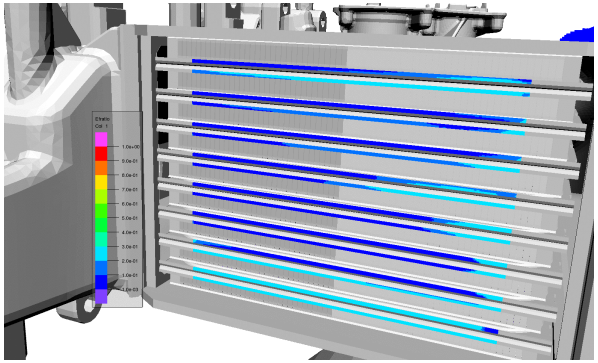


- thermal load **from thermal shock simulation**



- **linear** thermal load

The optimization process underlines an area to enforce by an adding of material.
This area is located on the rear region of the box (near to the rear plate) on which are concentrated most of constraints.



The optimization process clearly shows a possibility of material suppression on the brazing area.

Only the pairs of plates located near to the extremities and the part of the brazing area located on the side of the inlet of external fluid keep some material.

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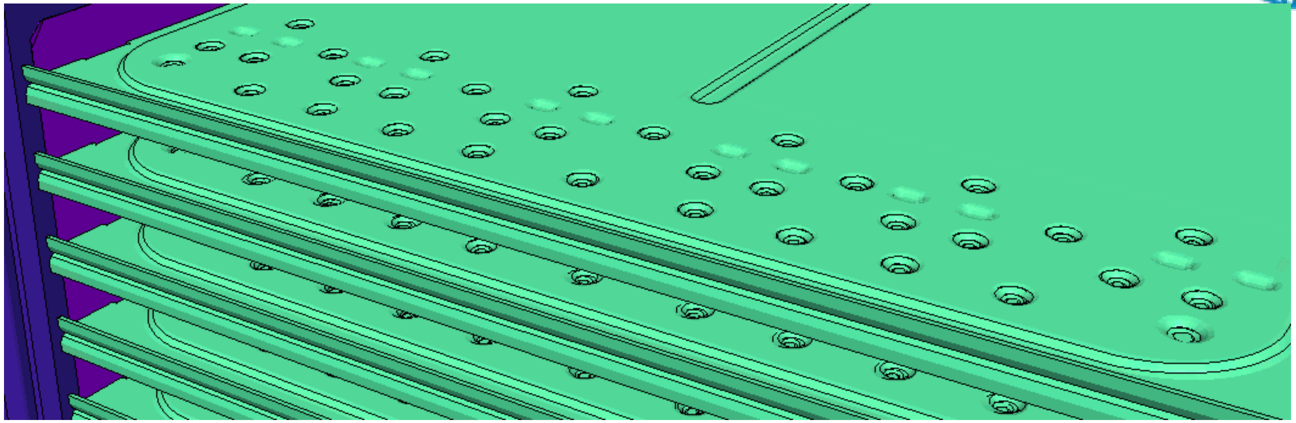
Multimodal optimization

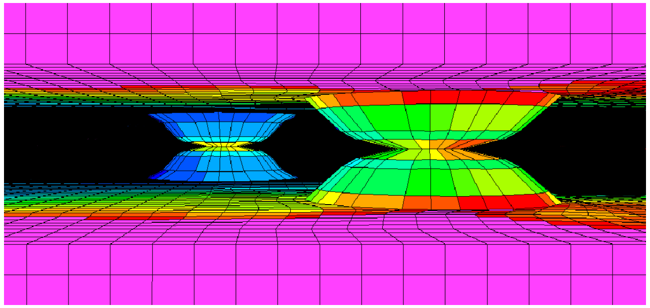
Results of parametric optimization

Parametric optimization effect on dimples **position**



The parametric optimization applied to dimples leads to a displacement of those towards the center of pairs of plates.

Moreover, locally, a swelling of these dimples is observable.



Parametric optimization effect on dimples **shape**

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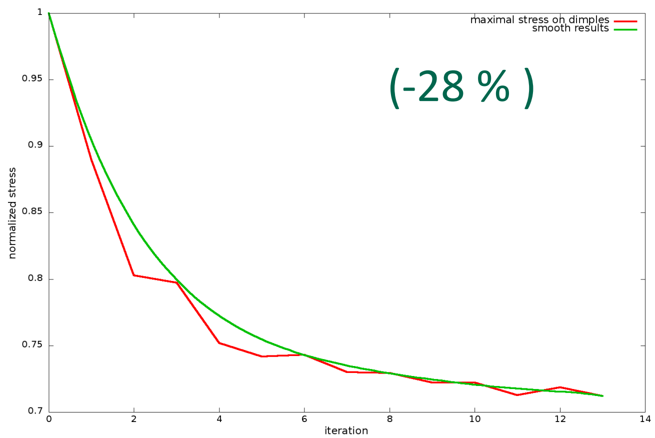
Multimodal optimization

Evolution of objectives and constraints

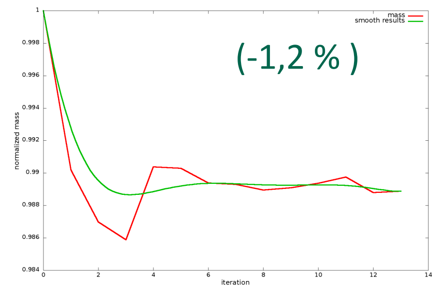
The red curves represent exact normalized results, while green ones are smoothed ones drawn to underline the evolution of the quantities.

Objective

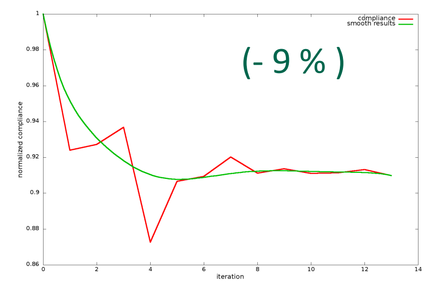
Maximal stress on dimples



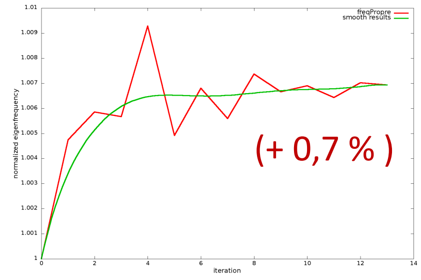
Constraints



Mass



Compliance



Eigenfrequencies

Statistics (13 loops)

Processor	2*14 cores Intel Xeon CPU E5-2697 v3 @ 2.60 GHz
Cores number	28
RAM	450 GB
XPU	GPU - Nvidia Tesla K40m
Scratch	RAID-0 (6x) SSD disks
PERMAS version	v16.00.221

Model	
Elements	14 millions
Nodes	20 millions
Degrees of freedom	61 millions
Design variables (TOPO)	660,000
Design variables (OPT)	2,208
Thermal field calculation	
Duration	3 hours
DMS	682 GiB
Multimodal optimization	
Duration (for each loop)	10 hours
DMS	6.0 TiB

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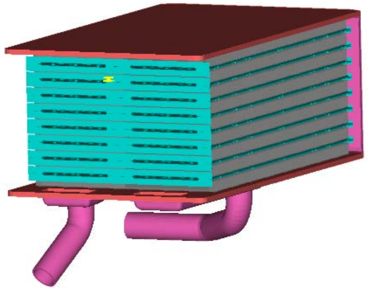
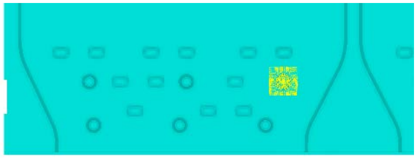
Fatigue

Choice of the studied area and additional model

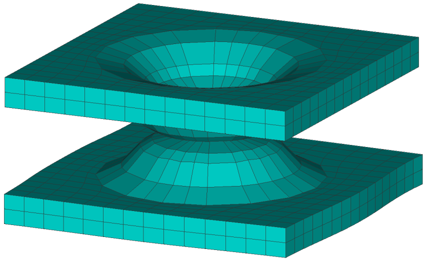




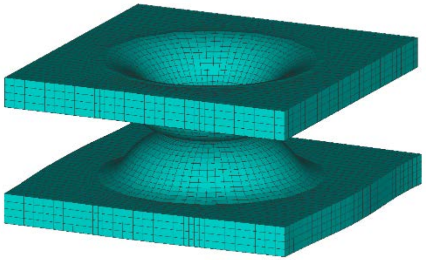
The chosen region for this study is a pair of dimples located in the passage of the cold fluid, on the second pair of plates from the top.

Exact position of the studied pair of dimples, shown on the central core and on the concerned pair of plates.

The original model of this pair of dimples is too coarse for this kind of study, a finely meshed one is then built. It will permit to evaluate robustness of such a structure facing many loading cycles.



Coarse model of studied dimples, from complete model of AIM



Finely meshed model of studied dimples

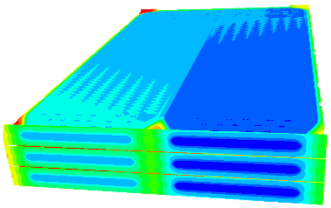
	Coarse model	Finely meshed model	Ratio
Elements	1456	16384	11,25
Nodes	2275	20713	9,10

Mesh statistics

The size of the finely meshed model is significatively bigger than the coarse model one, but it implies a better correspondence with the given geometry.

Fatigue

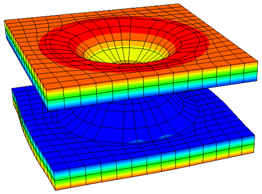
Loads



Thermal field applied to the pairs of plates surrounding the considered one, at the time t = 6 s.

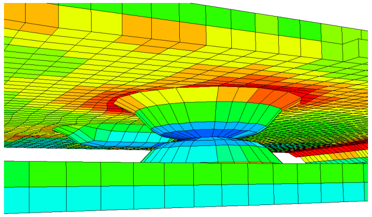
A thermal transient load, obtained from CFD simulations, is applied to the system.

This load implies thermomechanical deformations of the structure, particularly on the dimples, which are submitted to important temperature gradients.

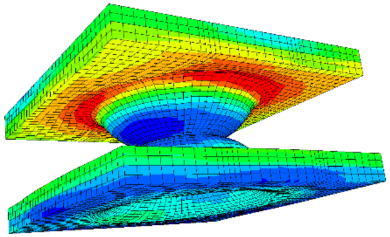


Thermal field applied to the studied pair of dimples, at the time t = 6 s.

The maximal stress implied by this thermal load is located at the junction between the plate and the geometry of the dimple.



Calculated stresses on the studied pair of dimples, from a simulation on complete model of AIM, at the time t = 6 s.



Calculated stresses on the studied pair of dimples, from a simulation on the finely meshed model, during the first load cycle, at the time t = 6 s.

These stresses are used to evaluate the good correlation between the coarse model and the finely meshed one.

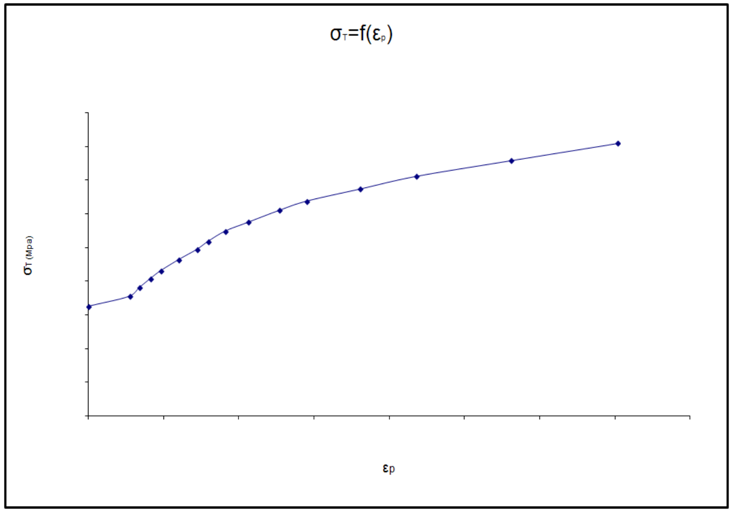
The transmitted datas are the temperature and the displacements. The thermal field and the displacements from the coarse model are applied respectively to all the points of the finely meshed one and to the boundaries of it.

Fatigue

Thermo-elastic law and load cycles

The objective is to repeat the load cycles applied to the dimples, to simulate the behaviour of a such a system in a long-term situation.

Each load cycle have to start and finish with the same load to avoid numerical singularities.
→ A « unload » second is added to the 6 seconds evolution of the thermal field obtained from CFD simulation. The resulting load (7 seconds) is cycled 1 000 times.



Thermo-elastic law for the Aluminium used in AIM

To precisely simulate the behaviour of such a structure, a thermo-elastic law is needed.

This law (represented by the curve on the left) links the plastic deformation to the level of stresses. It permits to define the elastic (or plastic) behaviour of the structure, facing the encountered sollicitations.

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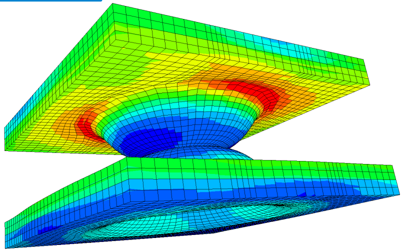
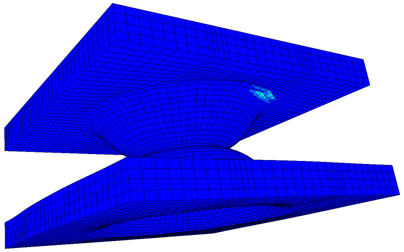
Results

First cycle



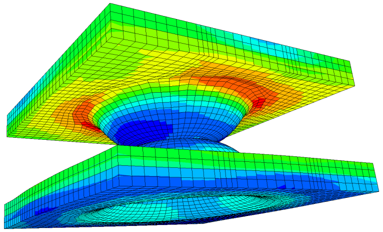
Stress field evolution during the first loading cycle, with one picture every second from t = 1 s to 6 s.



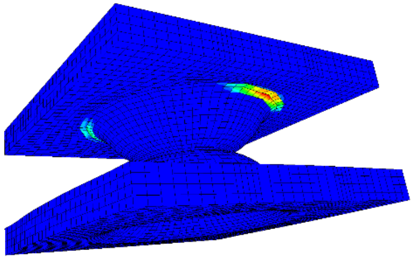
Plastic deformation evolution during the first loading cycle, with one picture every second from t = 1 s to 6 s.

The results obtained after the first loading cycle underline two regions with plastic deformations, even if the level of deformation is not important (< 0,1 %).

1 000th cycle



Stress field evolution during the 1000th loading cycle, with one picture every second from t = 1 s to 6 s.



Final plastic deformation during the 1000th loading cycle, at t = 6 s.

The plastification observed after one cycle and the repetition of loading cycles does not modify significantly the stress field evolution.

Consequently, the plastic deformation does not change anymore.

INTES

Valeo

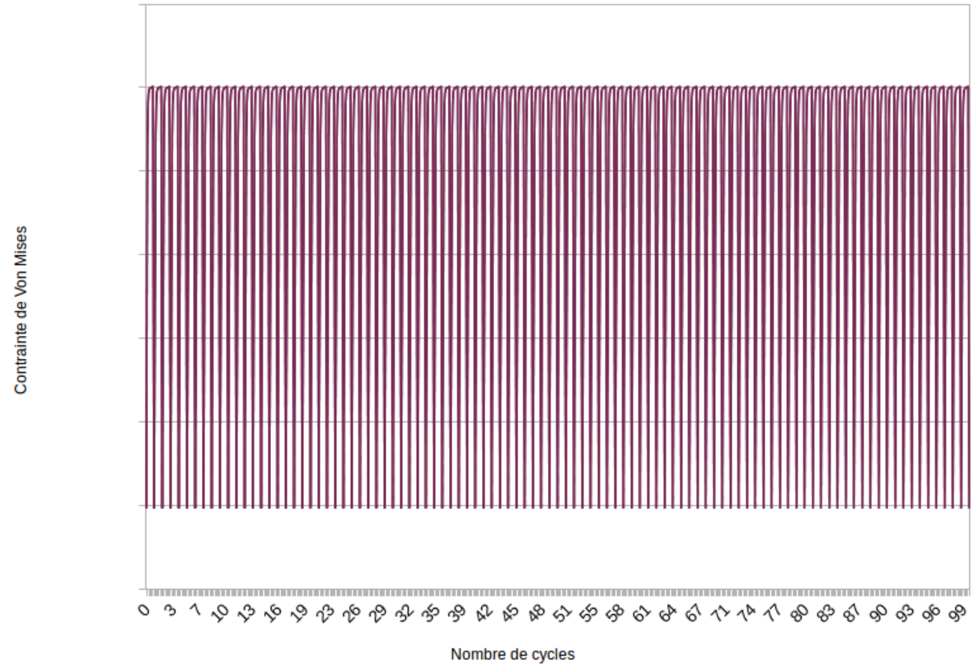
Fatigue

Results (Von Mises)

The Von Mises stress evolution on the most constrained element, located in the lastification region, shows that the stresses does not vary significantly during the process.

To obtain more accurate results and consequently improve the knowledge about such a system facing the repetition of loading cycles, a more detailed thermo-elastic law, with a temperature dependency, should be useful.

However, this study has underlined a plastification area, according to the calculated stress field.



Von Mises stress evolution function of loading cycles, taken on the most constrained element located in the plastification region.

Reliability

Parameters

A reliability analysis is performed to evaluate the effect of inaccuracies in the building process of the dimples.

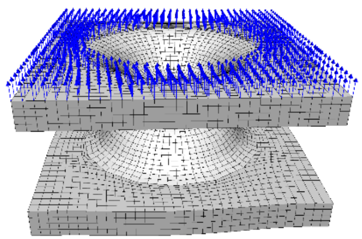
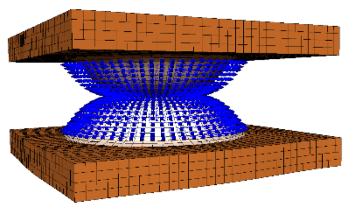
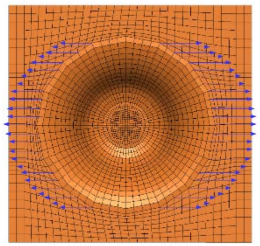


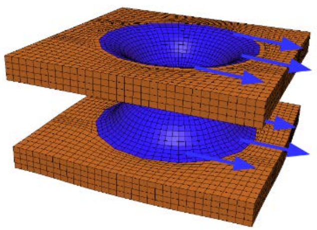
Plate thickness



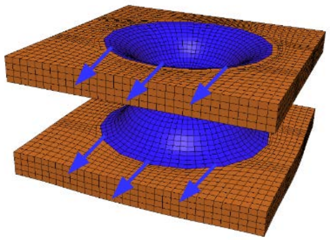
Rounding of the stamped



Ovalization



X-motion of the dimple



Y-motion of the dimple

Parameters definition

→ Moreover a tolerance is applied to the Young modulus.

CASCADE

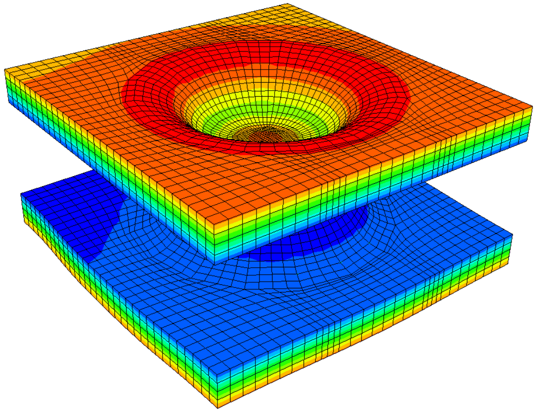
Reliability

Methodology and load

Objective : to apply variations on the parameters, and to estimate the relative importance of each one in the building process reliability (for a fixed set of tolerances).

Methodology : a surface method is used, computing the stress field at each iteration and comparing it to a critical value, given by VALEO.

Load : a thermal load, from the CFD simulations on the complete model of the AIM. By a submodelling method, this load is transmitted to the finely meshed model of the pair of dimples. The time chosen to extract the thermal field is the one at which the stresses are the highest, so t = 6 s.



Thermal field applied to the studied pair of dimples

An isostatic blocking is also applied to the pair of dimples to permit a thermal deformation.

CASCADE

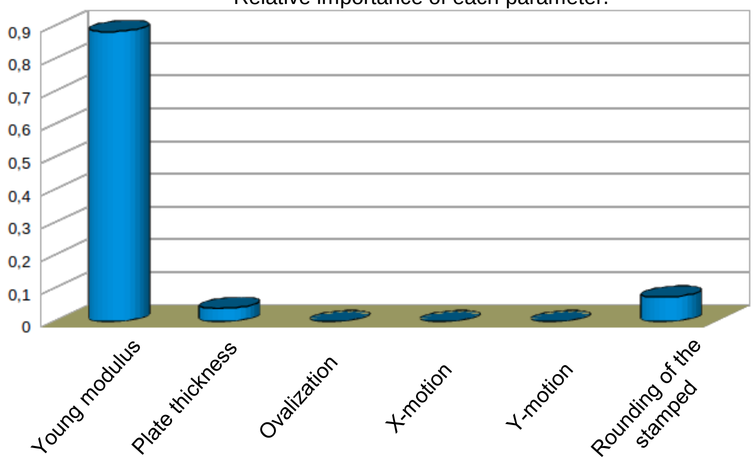
Reliability

First scenario

Standard deviation applied to each parameter.

Parameters	Moment	Standard deviation	Influence of dispersion
Young modulus	Initial value	5 %	0,8847
Plate thickness	Initial position	10 %	0,4057e-01
Ovalization	Initial position	10 %	0,3500e-25
X-motion	Initial position	10 %	0,8524e-05
Y-motion	Initial position	10 %	0,1256e-04
Rounding of the stamped	Initial position	10 %	0,7468e-01

Relative importance of each parameter.



- The dominating parameter is the Young modulus.
- The dispersions of the plate thickness and the rounding of the stamped are significative too.
- On the other hand, the motions of the dimple and its ovalization have a negligeable effect.

Failure probability : 0,17740

INTES Valeo

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INVESTISSEMENTS D'AVENIR

Reliability

Second scenario

According to the previous results, the standard deviations applied to the most influent parameters have been diminuated and are now equal to 1 %.

The concerned parameters are : the Young modulus, the plate thickness and the rounding of the stamped.

Parameters	Moment	Standard deviation	Influence of dispersion
Young modulus	Initial value	**1 %**	**0,9770**
Plate thickness	Initial position	**1 %**	**0,1194e-01**
Ovalization	Initial position	10 %	**0,1013e-23**
X-motion	Initial position	10 %	**0,2485e-03**
Y-motion	Initial position	10 %	**0,3643e-03**
Rounding of the stamped	Initial position	**1 %**	**0,1049e-01**

Failure probability : 9,11e-07

Young modulus
Plate thickness
Ovalization
X-motion
Y-motion
Rounding of the stamped

The use of tolerance values in agreement with those found in the industry permits to obtain acceptable failure probabilities.

It is possible to obtain more accurate results using the exact set of tolerances values (if it is communicated by the manufacturer), but these results are significative and improve the knowledge about such a system and its reliability.

Conclusion

The AIM has been studied, optimized and validated by fatigue and reliability calculations. The knowledge about this kind of thermal systems has been significantly improved and will help designers to conceive future ones.

Moreover, the study of this complex system has led to improve and validate numerical methods, and to confirm the performance of PERMAS calculations facing such complex analysis. The builts numerical methods are now constituting a toolbox to the study of complex thermal systems, particularly with a strong coupling between fluid and structure.