MULTI-OBJECTIVE OPTIMIZATION IN CRASH SAFETY ANALYSIS USING MODEFRONTIER INTERFACES FOR ANSA AND μETA

[1]**Zhongli Wen*, Alberto Clarich, [3]Dimitris Georgoulas, [4]George Korbetis**
[1,2] ESTECO SpA, Trieste, Italy   [3,4]BETA CAE Systems S.A.,Thessaloniki, Greece.

KEYWORDS –
Multi-Objective Optimization, Bezier Parameterization, Game Theory, Response Surfaces, Crash Simulation.

ABSTRACT –
This paper describes an application to an industrial case of the multi-objective design environment software modeFRONTIER coupled with ANSA morphing and μETA post processor.
In this environment, most common CAE software can be easily integrated in the process flow through the available direct interface nodes, including ANSA and μETA, allowing the automatic update of morphing parameters and execution of the CAE numerical simulations. One of the available multi-objective optimization algorithms, the Game Theory (MOGT) algorithm, is selected to drive the automatic simulations until the optimal design solutions are found, accordingly to the specified objectives. In addition, several tools for pre, post and statistical analysis are available in order to support the engineers in the complete design process.
In this paper an application of modeFRONTIER combined with ANSA and μETA in Crash Safety Analysis is illustrated. In particular, the distribution of spotwelds on a b-pillar is optimized in order to minimize the maximum intrusion during a side impact, maintaining a total number of spotwelds as close as possible to the baseline configuration.
The paper illustrates an efficient parameterization methodology based on Bezier curves, in order to parameterize the spotwelds distribution density curve with the lowest number as possible of parameters and keeping the highest regularity of the curve. An efficient application of the MOGT algorithm is used to obtain optimal results with a small number of simulations.

TECHNICAL PAPER –

1. INTRODUCTION

Multi-objective optimization in an automatic and distributed environment, that allows direct communication between multi-disciplinary simulation software, is more and more becoming a key factor in today's design process.
Traditional design approach ('trial and error') usually requires many attempts to the designers, which every time need to modify their numerical models by hand and run several solvers, especially when it is difficult to know a priori in which direction of the multi-dimensional variables space to move in order to find the best solutions.
Conversely, the multi-objective design environment modeFRONTIER [1] allows to integrate different computational software (any commercial or in-house code) into a common design environment, thus allowing the automatic run of a series of designs proposed by a selected optimization algorithm, until the specified objectives are satisfied.
In this modular environment, each component of the optimization process, including input variables, input files, scripts or direct interfaces to run the software, output files, output variables and objectives, is defined as a node to be connected with the other components.
In this scenario, the ANSA and μETA [2] direct interfaces available in modeFRONTIER play an important role for designers, since all the morphing parameters and responses defined in the model can be automatically recognized by the direct interfaces.

In this way, the complete logic flow from parameterization to performance evaluation is defined by the user who can select among several available optimization algorithms accordingly to the objectives defined. These include, Genetic Algorithms [3], Evolutionary Algorithms, Game Strategies [4], Gradient-based Methodologies, Response Surfaces (used to speed up the convergence of optimization and to approximate the response of the system made by the available Meta-Models), and Robust Design Optimization (optimization under uncertainties on input parameters).

Statistical and Multi-Variate Analysis tools [5] can be applied to find important information about the influence of the parameters in the system, to address problems characterized by a large number of parameters and heavy computational efforts with the highest efficiency.

In the automotive industry and in particular, crash safety analysis, the way that some parts of an assembly are connected with each other can be a great factor influencing the car model behavior. For this reason an optimization of the connection pattern offers an important improvement to specific model characteristics. In this paper the distribution of spotwelds [6] on a b-pillar is optimized, in order to reduce the maximum intrusion during a side crash, keeping at the same the number of spotwelds as close as possible to the baseline design.

2. Crash Safety Analysis: Problem description and ANSA model definition

A car body is subjected to a side impact analysis with a speed of 56 km/hour [6], and the complete model is prepared in ANSA (fig.1). The objective is to find the optimal distribution of the spotwelds along the two b-pillar flanges, in order to minimize the intrusion of the b-pillar into the cabin, at the same time minimizing the difference of spotwelds number from the baseline design. The optimal distribution of the spotweld points is not uniform (baseline design), but it is needed to increase the spotweld density in areas where needed.

The optimization aims therefore to modify the connection lines which can be easily created from 3D curves or pre-existing connection points. In the latter case, all the information of the points regarding the connection type is passed to the connection lines.
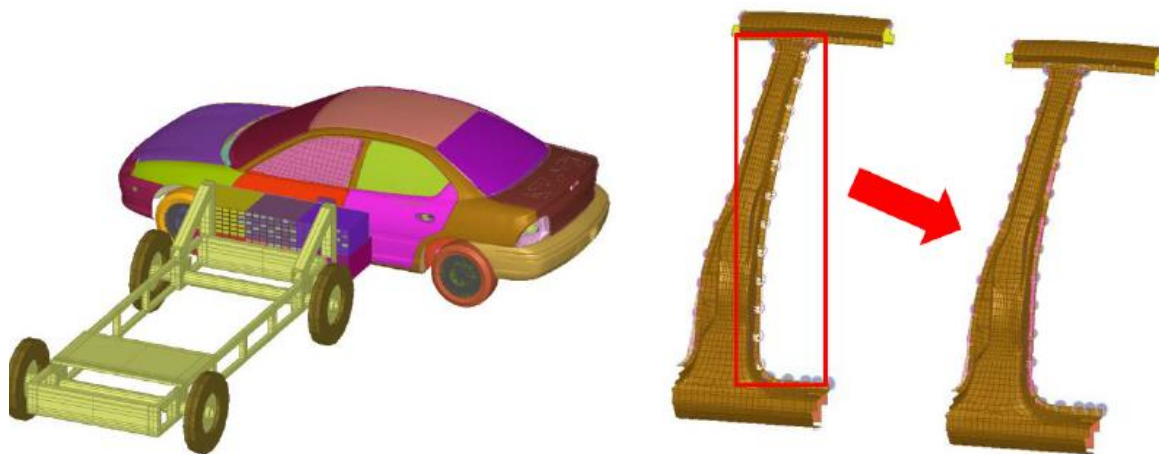

Figure 1 – Crash safety analysis example (left) and spotwelds distribution on a b-pillar (right)

The density curve function represents the spotweld density along the length of a connection line. The X-axis of the function corresponds to the connection line length normalized from 0 to 1, and the Y-axis represents the spotweld density [number of points per unit length].

Spotweld points can at that point be generated accordingly to the specified curve density, using ANSA scripting language. The density curve is then attached to a connection line and the function is mapped to the corresponding connection line length.

The area of the density function represents the total number of spotwelds that will be applied on the line. This information can be extracted in order to be used for the optimization.

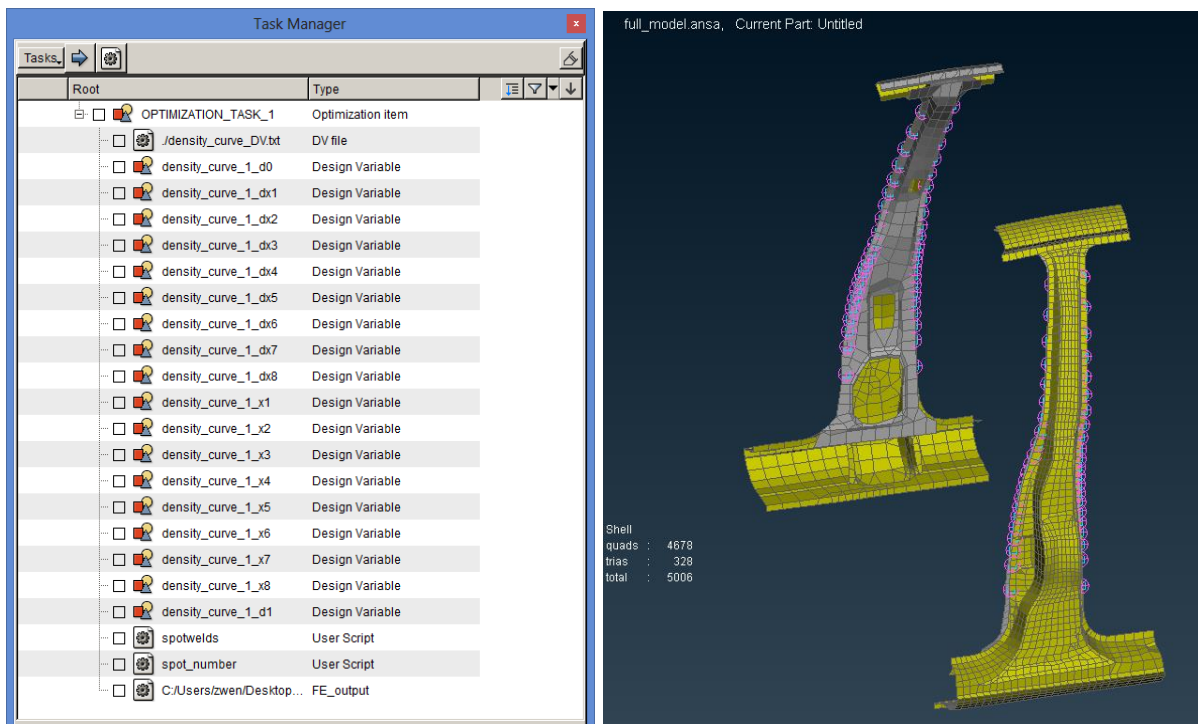The Optimization Task of ANSA is finally used for the optimization sequence setup (fig.2).

Figure 2 - The Optimization Task panel and the model on ANSA

3. Parameterization of spotweld density curve by Bezier curves

The spotweld density curve of the b-pillar described in the previous section is parameterized in the modeFRONTIER workflow by means of Bezier curves [7]. Bezier curves are named after their inventor, Dr. Pierre Bezier, an engineer of the Renault car company who set them out in the early 1960's to develop a simple and efficient parametric curve formulation used in shape design, that could be intuitive enough for designers and stylists, without requiring a background in mathematics.

Parametric curves don't define the y coordinate in terms of the x coordinate, like normal functions do, but they instead link these values to "control" variables also called control points.

Basically a Bezier curve can be defined starting from even 3 control points (degree 2) that are connected with line segments that form a polyline, up to a generic number n of control points (degree n-1). The advantage of the Bezier representation is that the curve mimics the shape of its control polyline. A Bezier curve passes through its first and last control points, keeping itself continuous and regular, and is tangent to the control polyline at those two points.
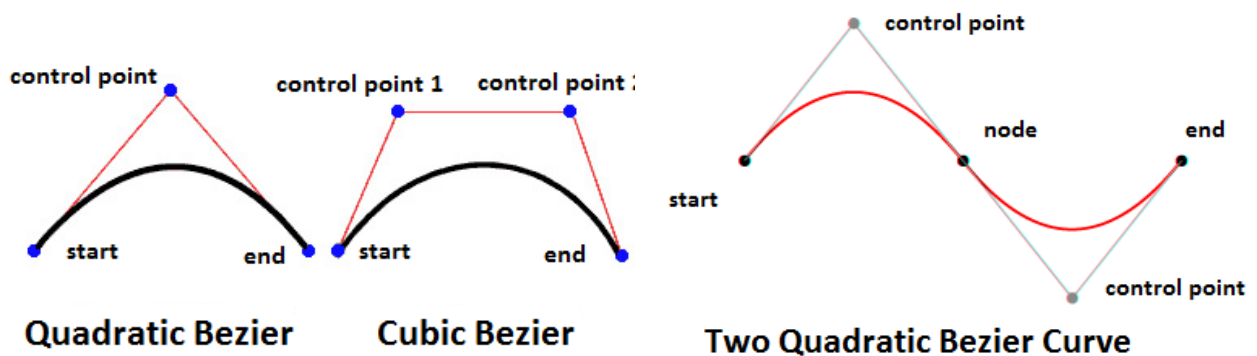

Figure 3 – Examples of Bezier curves

Another advantage of this approach is that complex shapes can be created by using a simple sequence of Bezier curves. Since Bezier curves are tangent to their control polylines, it is possible to join together two or more Bezier curves in such a way that the tangency condition at their extreme points is respected (fig.3).

In this project 4 control points (degree 3) are used to parameterize the spotweld density curve using the Bezier method (fig.4). With this approach it is possible to obtain a very well defined smooth curve with a limited number of control variables: in fact, setting the X-axis coordinates as constant and equally spaced, only the 4 Y-axis variables are free to change within their range. In this way, only 4 input parameters are required for the optimization.
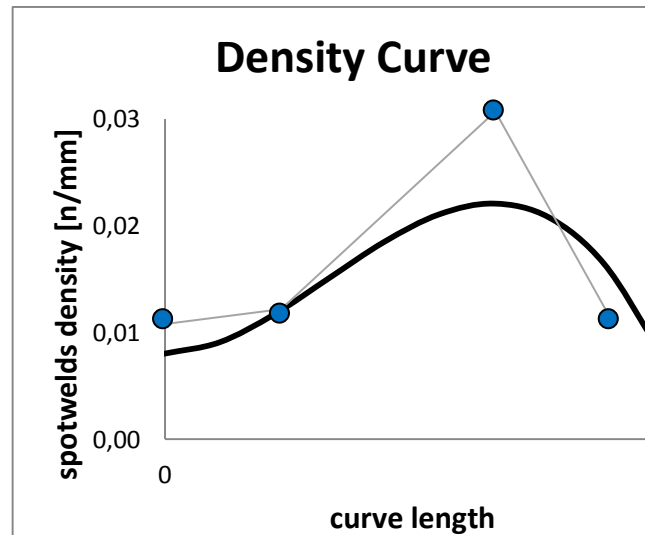

Figure 4 – Parameterized curve of spotwelds density

4. Workflow creation in modeFRONTIER and usage of ANSA/μETA direct interface

The next step needed to setup the optimization process is to define the process workflow in modeFRONTIER (fig.5), which looks as a modular network connecting the different "bricks" of the process design.
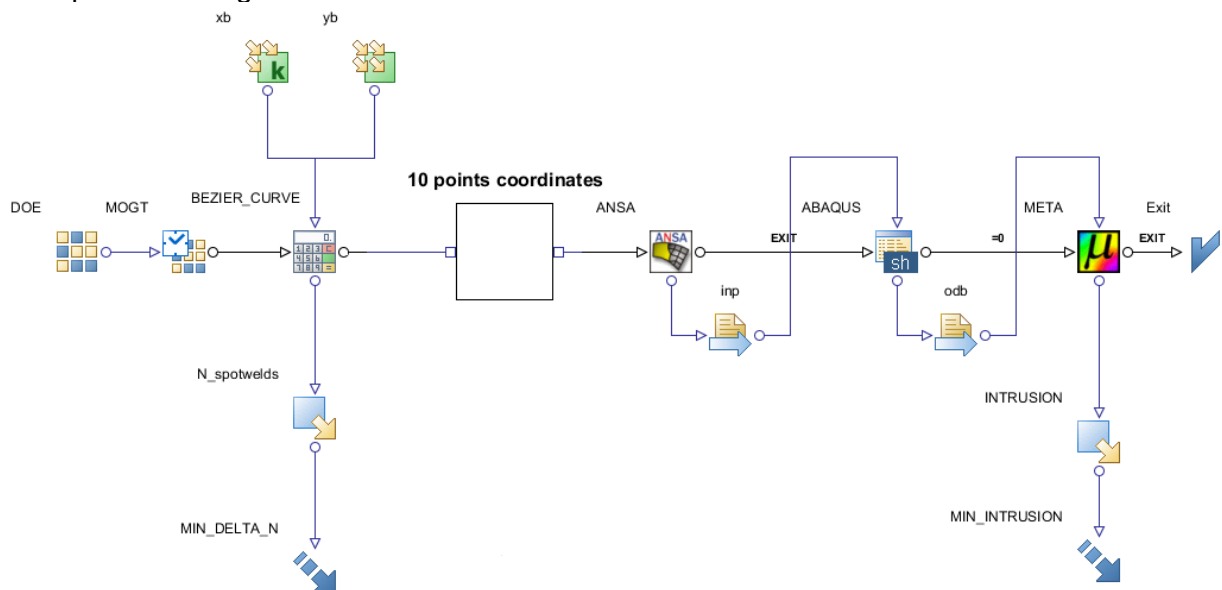

Figure 5 - modeFRONTIER workflow for crash safety optimization

All the Bezier control point parameters (illustrated in the previous section) are defined by dedicated input nodes, which specify their range of variation. In the calculator node we select the available Bezier function to define the curve, and then we extract 10 points coordinates which are considered enough to characterize the curve. The curve is automatically updated for each different configuration proposed by the optimization algorithm MOGT (see section 6) and the coordinates are entered to the ANSA node which executes the corresponding model. The coordinates of the density curve are then used to create the spotwelds points on the b-Pillar and the input file for the crash analysis is thus completed.

The model mesh with the updated design's setting is sent by a transfer node to the following application, in this case the node to execute the crash analysis. The solver for the crash analysis can then be any commercial software or in-house-code, in this case ABAQUS/Explicit is used but for the methodology point of view any other solver like PAMCRASH or LS-DYNA can be applied as well in modeFRONTIER.

About the ANSA direct interface (fig.6), the user has just to indicate the ANSA model file name, the ANSA Design Variable File as defined in the Optimization task (DV file), and the name of the output file to be saved by the ANSA model (in our case, export for ABAQUS). At that point, the morphing variables already existing in the ANSA model are automatically introspected by the node, and it is possible to link each one of them to a design variable defined in modeFRONTIER workflow.

In this way, the integration of the ANSA model in modeFRONTIER is completed: for each design proposed by the selected optimization strategy, the ANSA model will be automatically updated by modeFRONTIER, which will transfer the model output file to the next application (ABAQUS simulation).

The solver is executed by the corresponding script node, which just contains the command line to launch the solver in batch mode.

After the simulation, the results are extracted by μETA direct node: in this case the maximum intrusion, which is the objective to be minimized (fig.7). The results are extracted directly from the IIHS toolbar, a special toolbar available in μETA that automates the post processing of side impact analysis.
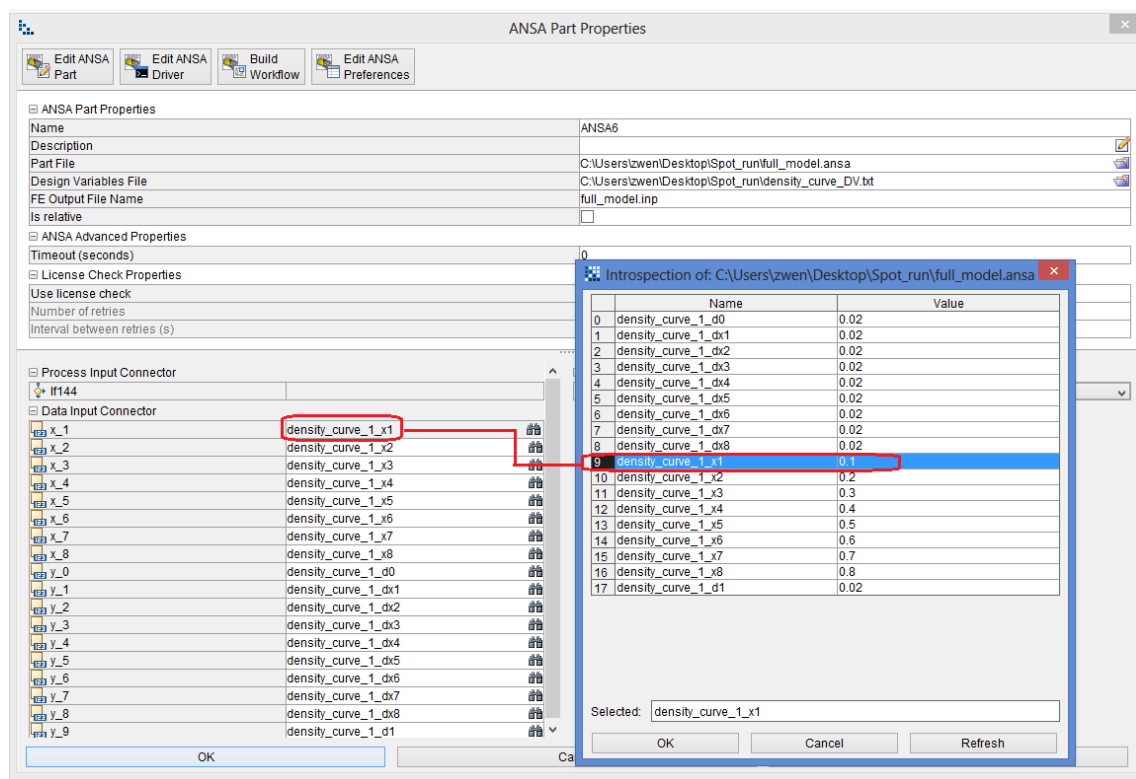

Figure 6 - modeFRONTIER direct interface for ANSA

The second objective is defined by the number of the spotwelds, that can be computed directly considering the density curve. In fact the X-axis of the curve corresponds to the connection line length normalized from 0 to 1, and the Y-axis represents the number of spotwelds per unit length, then multiplying the total area of the density curve by the length, the number of spotwelds can be obtained.

The difference of spotwelds number from the baseline configuration is the second objective to be minimized in the optimization.
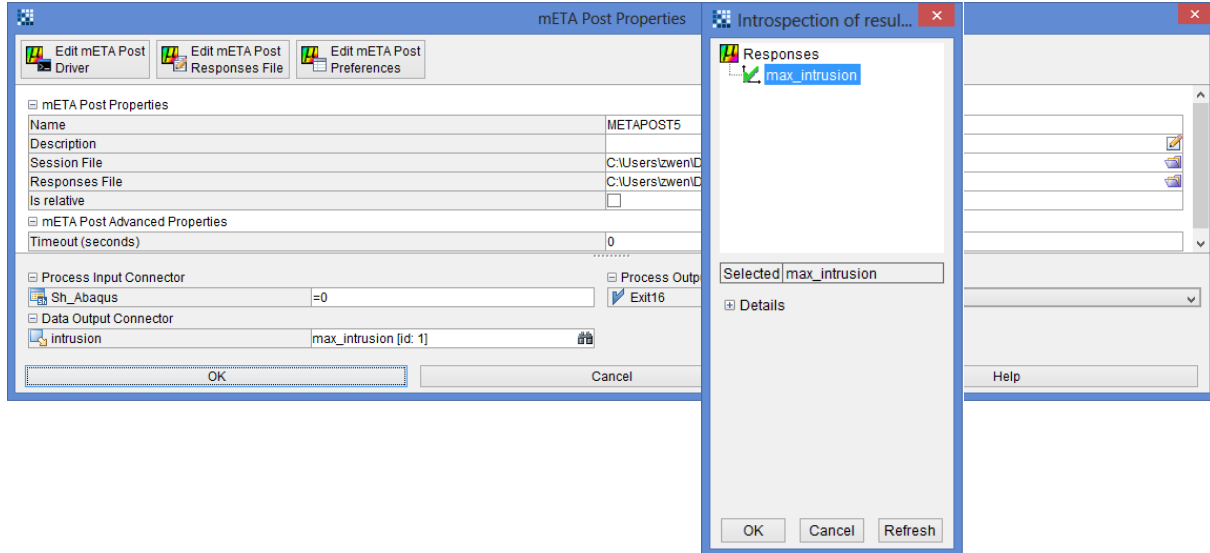

Figure 7 - μETA node in modeFRONTIER

The workflow also includes constraints for the maximum and minimum distance allowed between spotwelds, which is controlled by the density curve:

- Minimum density: 0.008 (corresponds to distance between spotwelds of 125 mm)
- Maximum density: 0.05 (corresponds to distance between spotwelds: 20 mm).

This range can be properly adapted by the engineer according to each specific case.

5. Usage of modeFRONTIER GRID for distributed remote applications

modeFRONTIER allows the possibility to activate the Grid tool [8], which can be used to distribute the simulations of each design (or at least of some application nodes, such as for instance the node which launches ABAQUS/Explicit) on any remote machine available in the network (fig.8).

Jobs are therefore assigned by the system to different grid nodes according to the load balancing policy, excluding nodes that are disabled or can't execute jobs, and therefore fully exploiting the available computational resources of the local network.

As a requirement, a common directory visible from all the nodes of the Grid needs to be mounted. Then the agent should be configured via Grid Manager on each machine that will enter into the Grid.

As soon as the Grid System is activated on each machine, the optimization can be launched by modeFRONTIER, using the algorithm described in the next section.
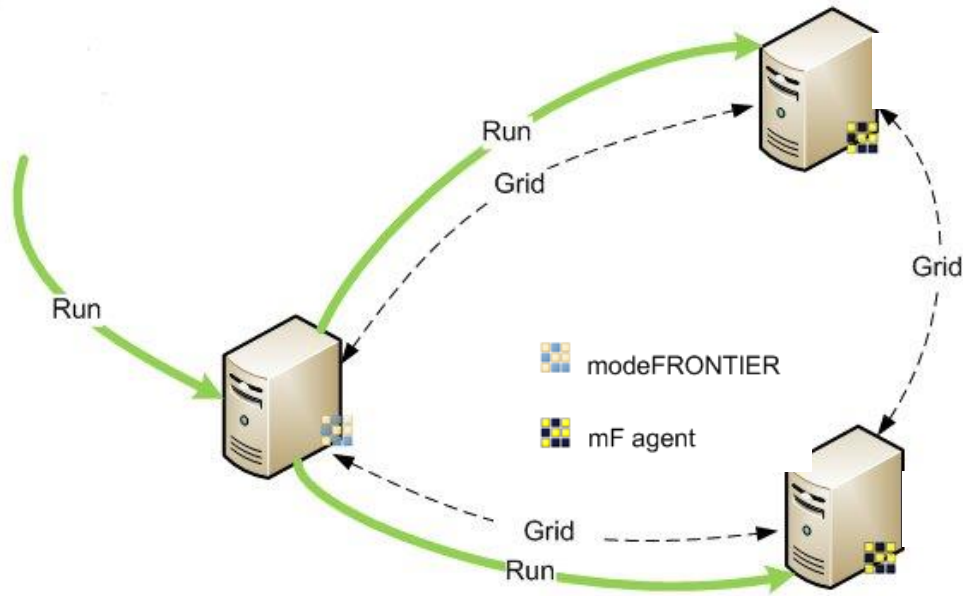
Figure 8 - Grid network launched by modeFRONTIER

6. Optimization setup using MOGT (Game Theory) algorithm

The algorithm selected for this application is MOGT (Multi Objective Game Theory) [9]. This class of algorithms is particular efficient to find by a reduced number of simulations good compromise solutions between contrasting objectives (like in our case), improving efficiently a baseline configuration.

The Competitive Game algorithm implemented in modeFRONTIER follows different steps: first, the variable space is initially decomposed randomly, and then each player, starting from a common original design, launches a mono-objective optimisation algorithm (Downhill Simplex [10]), to improve the objective assigned to it.

After a certain number of Simplex iterations, each player finds the best configuration (and set of variables) for its objective, and then the search continues with a new step, for which each player starts a new Simplex sharing the optimal variables found by the other players.

The problem of the variables space decomposition is very important [11], since it influences the results of the equilibrium point and thus the optimization results. For this reason, an adaptive strategy has been applied in the MOGT algorithm, using statistical analysis and in particular the t-Student coefficient to decide, at the end of each player step, if a variable is statistically significant for the player to which it is assigned or not, and, in the latter case, i.e. if the significance percentage is lower than an assigned threshold, the variable is given to another player in the following step.

As a convergence, not only a (Nash) equilibrium point [12] may be found, but also the optimal variable decomposition between the players; in addition, several not-dominated points can be found by the algorithm during its search, allowing to finally find a set of compromise solutions between the contrasting objectives (Pareto frontier), with a small global number of simulations required, if compared to any other heuristic algorithm like Genetic Algorithm or Evolutionary Strategies.
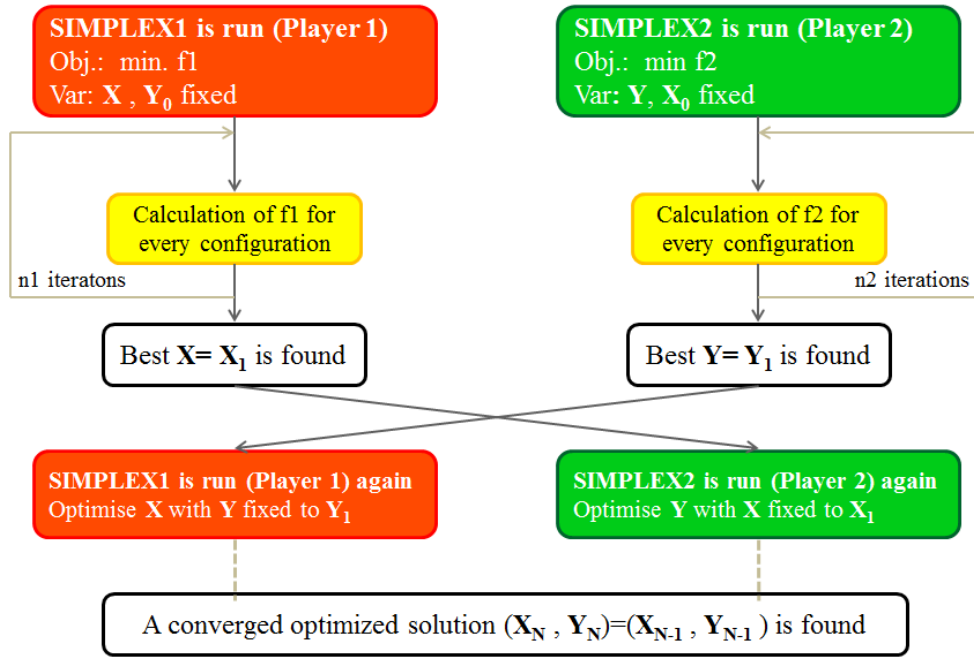
Figure 9 - MOGT: multi-objective game theory algorithm

7. Optimization results

The application of MOGT to the problem defined in this paper allowed to find the results reported in fig.10, with an overall number of required simulation designs less than 40.
MOGT allowed to find a good compromise solution (ID 32 in the chart: 7% of intrusion reduction just adding 2 spotwelds to the original baseline, having 18 spotwelds) with a small number of iterations; a full Pareto frontier was not required in this case.
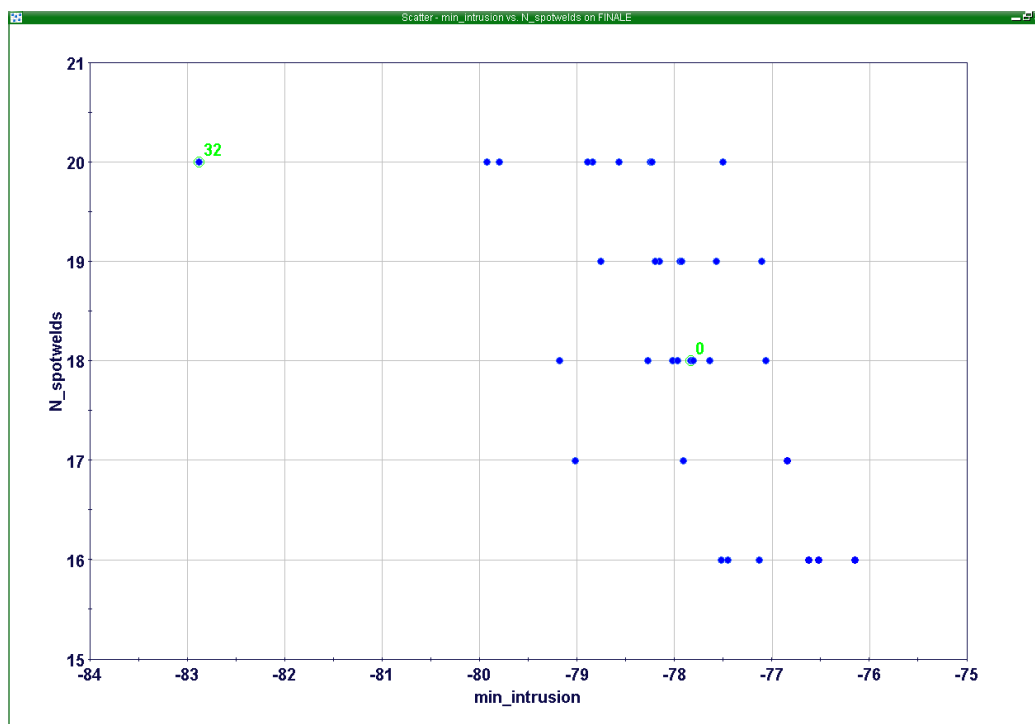

Figure 10 – Optimization results – Pareto chart

The Figure 11 reports the comparison between the baseline configuration (ID_0 in fig.10) for which the spotweld density curve is constant, and the optimal solution (ID_32 in fig.10), having a decreasing spotweld density distribution. Below the corresponding μETA results are reported, with a detail of the b-pillar intrusion.
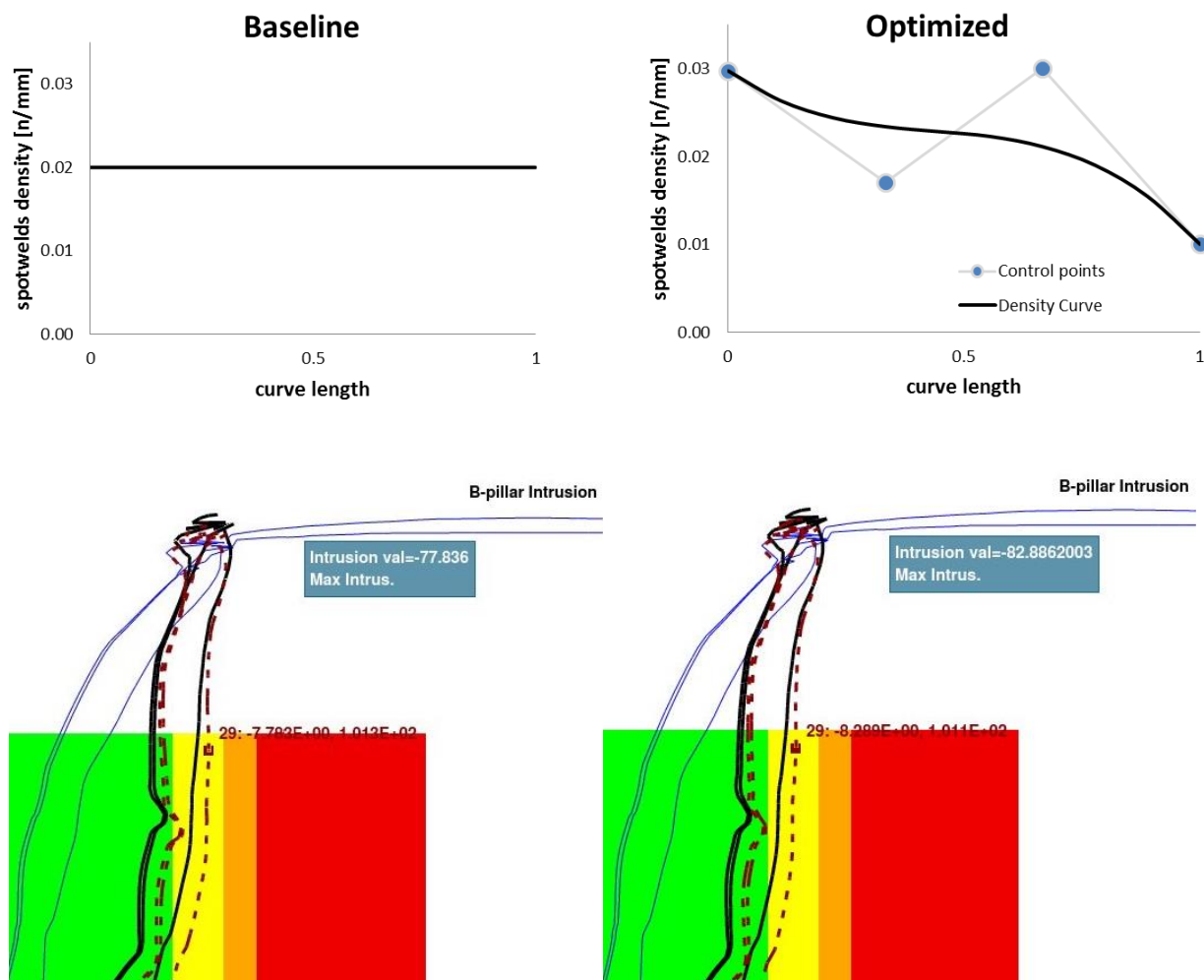

Figure 11 – Details of the μETA results Figure 11 - Comparison between baseline (left) and optimized configuration (right): spotweld density curves and μETA results

8. Conclusions

This paper shows how to integrate ANSA and μETA software in the multi-objective optimization environment modeFRONTIER, through the dedicated direct interfaces, and how to set up and run a multi-objective optimization for an application in crash safety analysis.
Several tools available in modeFRONTIER are used for this optimization: the Bezier curve parameterization which is a valid approach to properly define a smooth and regular density curve, ANSA and μETA nodes (respectively to generate the updated model and to extract the result from the IIHS toolbar), script nodes to launch the suitable solver for the simulation (ABAQUS, but also LS-Dyna, PAM-CRASH, etc.), MOGT algorithm to optimize the two contrasting objectives of the problem with a reduced number of iterations, and Grid tool to distribute the simulations on a set of specified remote machines available in the network.
The optimized solution had significantly improved the baseline configuration, and has been obtained by a reduced overall number of simulation designs.

REFERENCES

(1)   http://www.esteco.com

(2)   http:// http://www.beta-cae.gr

(3)   K. Deb, A. Pratap, S. Agarwal, T. Meyarivan, A fast and elitist multi-objective genetic algorithm: NSGA-II, IEEE Trans Evol Computational Journal, Vol.6, 2002

(4)   A. Clarich, V. Pediroda, C. Poloni, A competitive Game Approach for Multi-objective Robust Design Optimization, AIAA 2004-6511, Chicago, 2004

(5)   Kaufman, L. and Rousseeuw, P. J. Finding Groups in Data: An Introduction to Cluster Analysis. New York, Wiley, 1990

(6)   Spotweld optimization, non-equally distributed spotwelds, ANSA, BETA CAE Systems SA

(7)   Pierre E. Bézier, The First Years of CAD/CAM and the UNISURF CAD System, in Fundamental Developments of Computer-Aided Geometric Modeling, edited by Les Piegl, Academic Press, 1993, pp. 13-26.

(8)   I. Foster; C. Kesselman, S. Tuecke, The Anatomy of the Grid: Enabling Scalable Virtual Organizations, Intl. J. Supercomputer Applications, 2001

(9)   A. Clarich, C. Poloni, Multi-objective optimisation in modeFRONTIER for aeronautic applications, including CAD parameterisation, Evolutionary Algorithms, Game Theory, Metamodels and Robust Design, EUROGEN 2007, Jyvaskyla, 2007

(10)   Nelder, J. A., Mead, R., A Simplex Method for Function Minimization, Computer Journal, 7, 308, 1965

(11)   J.W., Wang, J. Periaux, Search Space Decomposition of Nash/Stackelberg Games using Genetic Algorithms for Multi-Point Design Optimisation in Aerodynamics from Domain Decomposition Methods in Science and Engineering, pp. 139-149, CIMNE,2002

(12)   J.F. Nash, Non-cooperative Games, Annals of Mathematics, (1951)