RELIABILITY BASED ROBUST DESIGN OPTIMIZATION OF A FREE-FALL-LIFE-BOAT (FFLB)

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KEYWORDS –
Optimization, Reliability, ships and offshore, FSI

ABSTRACT –
The FFLBs are fully enclosed vessels, used for emergency evacuation from ships and offshore structures. They are launched from a specifically designed tilted platform on which they slide and then free fall, until entry to the seawater. It is of great importance to predict the behavior of such vessels at the early design stages and assure the proper function in hazardous conditions. Critical parameters such as occupants' acceleration, vessel's strength and successful clearance from the accident area, have to be considered during the design and verification process.
Combined CFD and FEA algorithms are used to analyze vessel's behavior, where numerous iterations are needed to reach convergence, including interpolation of the dynamic loads from the CFD to the FEA. However, the use of a FSI algorithm can produce results much faster and thus the design optimization can become a feasible and cost effective approach.
In addition, the fluctuations and uncertainties of operational and geometrical parameters, such as boat position, angle and initial velocity, have to be taken in account in the design process, since they influence the definition of design objectives (in particular, % of samples respecting limits on occupants' acceleration and clearance distance): the optimization under uncertainties process is also called Reliability-based Robust Design Optimization.
In this paper, a case study of the FFLB optimization is presented using a FSI solver. ANSA software is used to morph the FFLB mesh by editing its shape and its initial position, and modeFRONTIER software is used to automate the simulations and perform the optimization under uncertainties using a proper optimization algorithm. The results lead to important conclusions regarding the proper FFLB shape and operational parameters, which guarantee an optimal motion pattern of the vessel.

TECHNICAL PAPER -

1. INTRODUCTION

Multi-objective optimization in an automatic and distributed environment, that allows direct communication between multi-disciplinary simulation software, is becoming more and more a key factor in today's design process.
Traditional design approach ('trial and error') usually requires many attempts where the designers iteratively modify their numerical models manually and run several solvers. The iteration number grows 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 execution of a series of designs proposed by a selected optimization algorithm (including Genetic and Evolutionary Algorithms, Game Strategies, Gradient-based Methodologies, Response Surfaces and Adaptive and Automatic methodologies), 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, including ANSA and μETA [2], output files, output variables and objectives, is defined as a node to be connected with the other components.

In addition, in industrial practice, there are several operational and geometrical parameters which are not known or defined in a deterministic way, but they are rather defined in a probabilistic way, due to the presence of uncertainties or fluctuations. In such scenario, it becomes fundamental in the design phase to consider the performances of the system in a probabilistic way, in order to obtain optimal solutions which are stable at the variation of the uncertain parameters: this process is defined as Robust Design Optimization, and in presence of probabilistic constraints or objectives defined on a given percentile of the performance distribution, it is also called as Reliability-based optimization. modeFRONTIER has a dedicated module, based on Polynomial Chaos theory [3], to solve efficiently problems of this kind.
In this paper, a reliability-based optimization problem is defined to increase statistically the safety of free fall lifeboats, which are typically used to evacuate passengers in oil platforms and large transport vessels (fig.1).

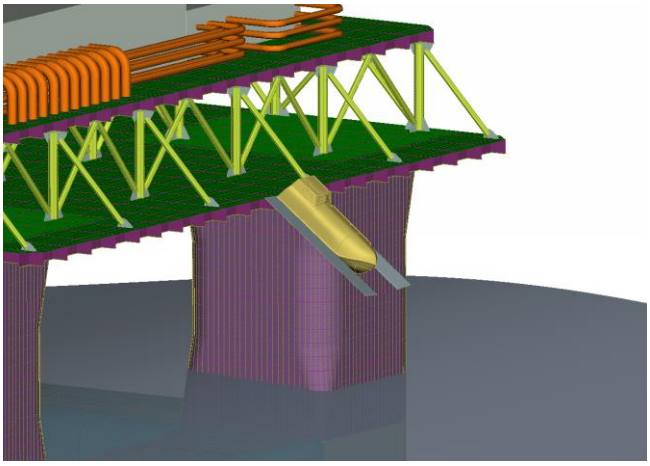


Figure 1 – Free fall lifeboats

2. SIMULATION OF A FREE-FALL-LIFE-BOAT (FFLB)

Free fall lifeboats are used to instantly evacuate the workforce and transport them away from the host vessel in case of an accident, in a fast and safe way [4].
These lifeboats are designed to free fall from up to 60 meters from sea level and they are fully enclosed since, during their fall, they submerge almost completely into the sea, and emerge away from the host structure.
The free lifeboat studied in this work is 10.2 meters long and 3.4 meters wide, weighing 9,517 kg, made of GFRP (Glass Fiber Reinforced Plastic) and able to carry up to 30 people.
The model pre-processing has been done in ANSA applying mixed quad/tria mesh of 40,636 shell elements (fig.2, left). An extra weight of 3750 kg, which represents the weight of passengers, auxiliary machinery, shafts, propeller, engine and tanks, is added to the model through the special ANSA tool Mass Balance, which is able to distribute the desired mass as lamped mass on models nodes while reaching a specified CoG.
The material for the lifeboat is defined as a Rigid material, as the structural integrity of the lifeboat was not considered in this work.
In order to simulate the interaction of the boat with the fluids (fig.2, right), the Arbitrary Langragian Eulerian method is applied: solid HEXA elements are used to represent the air and seawater domain, which define the Eulerian part, while a Shell life boat model represent the Langragian part of the ALE interaction. The interaction between the Langrangian and Eulerian parts is controlled by a specific constrain of the LS-DYNA FSI solver.
About mesh creation in ANSA, the hexa mesh has been easily defined using the *hexablock* tool. This tool uses modifiable boxes in order to define the domain and then automatically meshes the volume of the boxes with pure hexa elements. The element length can be defined per “Row” of boxes and remeshing a defined volume is an easy and rapid task.

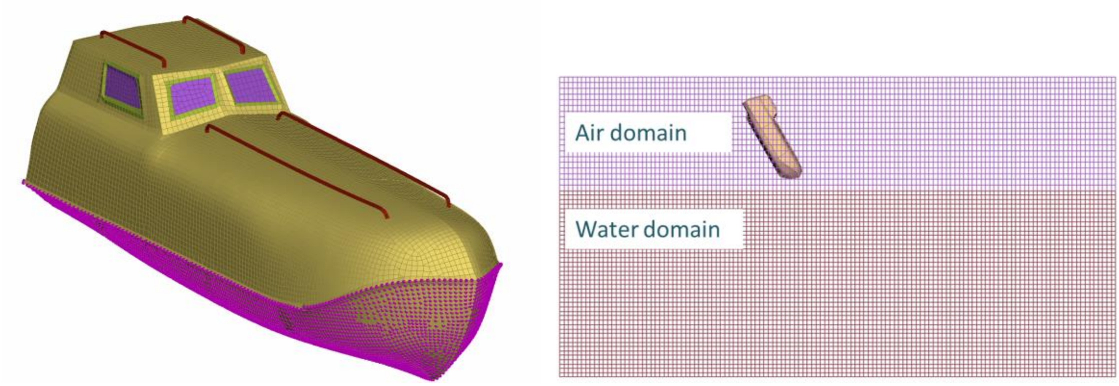


Figure 2 – Shell mesh on boat surface (left) and ALE interaction of the fluid domains with the solid object

The sliding and free fall phase of the boat during the pre-processing phase is simulated by a built-in kinematic solver in ANSA.
In order to do this, two kinematic bodies are defined: the boat and the launch platform (fig.3 left). A kinematic contact pair was also defined between the two bodies, to simulate the sliding phase. The sliding contact surfaces are defined by nylon blocks so a relative friction coefficient (equal to 0.15) was defined.
With gravity defined as the only load, the solver calculated the sliding and the free fall motion taking into account the contact, mass and center of gravity of the lifeboat.

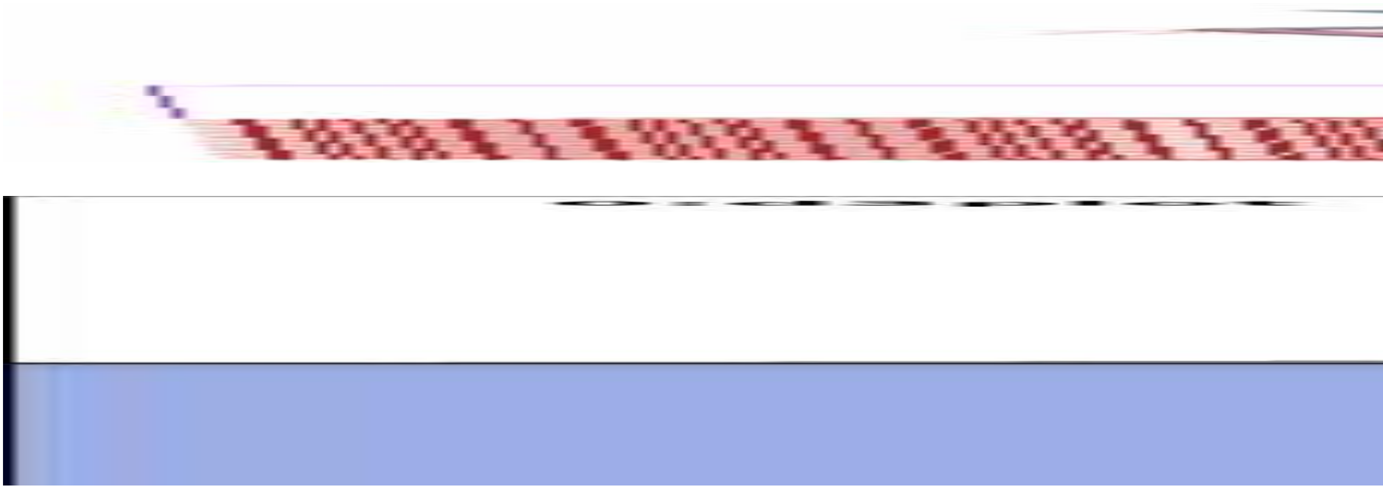


Figure 3 – Kinematic bodies to simulate sliding phase (left) and drowning phase (right)

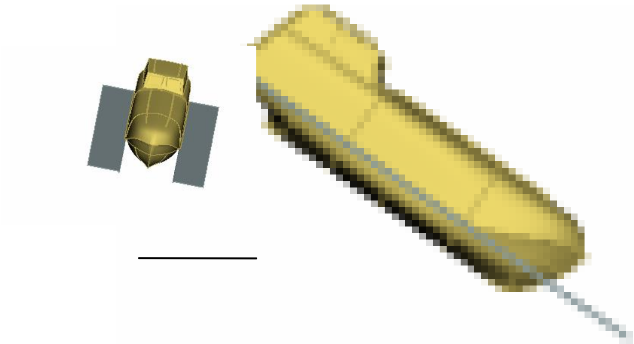
The trajectory of the lifeboat is calculated and can be visualized by a dedicated tool. A kinematic sensor is defined a few centimeters before the sea-level, in order to stop the lifeboat from entering the water domain.
At this position, the velocity calculated from the kinematic solver is applied as initial velocity on the lifeboat and the model is ready for the analysis with the FSI solver. At the end of the analysis, position, velocity and acceleration information of the boat are available as results in function of every time step.

3. UNCERTAIN PARAMETERS AND OBJECTIVES OF RELIABILITY-BASED OPTIMIZATION

Many factors affect the balance of the host structure at the time of the evacuation, which makes the determination of the initial position of the lifeboat an uncertain parameter. The structure may be damaged, weather conditions may be harsh and the load/weight of the host vessel may varies, which affects the distance of the deck from the sea level.

For this reason, three position parameters related to initial position of boat on launching platform are defined, using the morphing tool of ANSA. To quantify their uncertainty, a Normal distribution around their nominal value is defined, with the following values of standard deviation:

- Trim rotation of boat on platform: Standard deviation = 2.8°
- List rotation of boat on platform: Standard deviation = 2.8°
- Height of boat on platform w.r.t. sea-level: Standard deviation = 1.6m



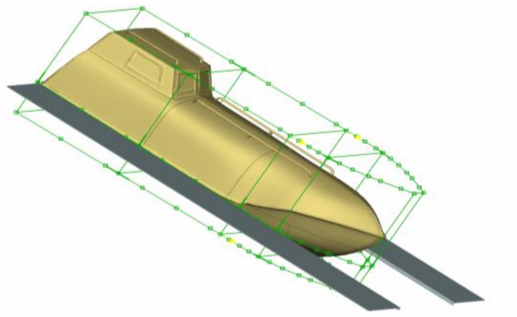


Figure 4 – Trim and list rotation (left) and morphing boxes on the boat

Using morphing functionality, two other shape parameters are introduced in the optimization problem. In particular, through the movements of selected control points, nose (bow shape) and rear (stern shape) shape of the lifeboat can be controlled.
The purpose of the Reliability-based optimization is therefore to find the optimal combination of these two shape parameters, in order to optimize the objectives and satisfy the constraints, which are defined under the probabilistic variation of the three uncertain position parameters considered above.
More in detail, the responses which are of interest in this problem are two: the distance from the host structure reached by the boat when it emerges out of the water, and the CAR or *combined acceleration ratio* (fig.5), which is defined in function of the nodal accelerations at selected measurement points, by the following expression:

$$CAR = \max\sqrt{\left(\frac{a_x}{18g}\right)^2 + \left(\frac{a_y}{7g}\right)^2 + \left(\frac{a_z}{7g}\right)^2}$$

where *ax*, *ay*, and *az* are the in-to-seat acceleration components and *g* is the gravity.

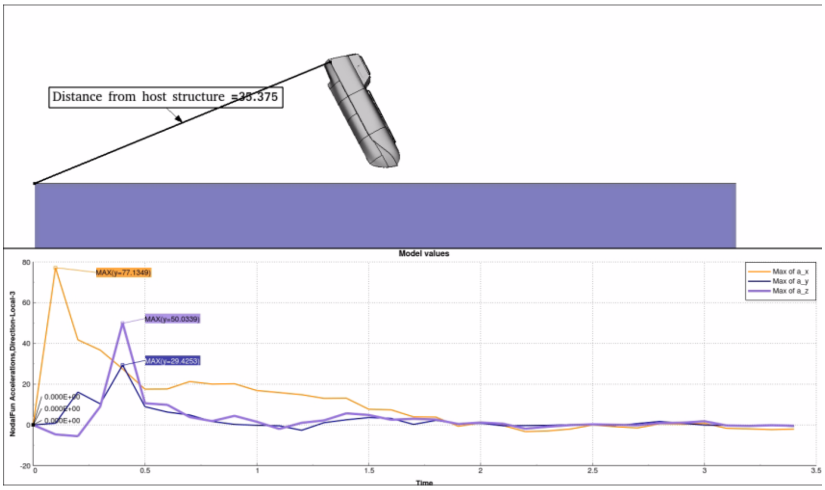


Figure 5 – Objectives of optimization: distance from host structure and CAR acceleration

CAR acceleration is to be minimized in order to reduce the impact effects on the evacuated passengers, and distance from host structure should be greater than 40m, to consider the evacuation successful.
Since the position parameters are uncertain and defined by a probabilistic distribution, the objectives/constraints cannot be defined on the deterministic value of the responses, but they must be defined accordingly to the distribution function of the responses. More in detail, it has been decided to define the following criteria:

- Objective 1: Minimize 99.97 %-ile of CAR distribution
- Objective 2: Maximize 0.03 %-ile of Host distance distribution
- Constraint 1: Mean value of Host distance distribution > 40m

The two objectives above guarantee respectively that the highest or worst CAR value (approximated to 99.97 percentile of its distribution queue) is minimized, and that the lowest or worst distance value (approximated to 0.03 percentile of its distribution queue) is maximized; in addition, we must guarantee that the mean value of the host distance is highest than the required distance, to accept the solution as feasible.
modeFRONTIER optimization platform has a dedicated tool to deal with Robust Design and Reliability-based Optimization problems: applying Polynomial Chaos expansion methodology [3], by the execution of a small set of sampling points, defined by the variation of the uncertain parameters accordingly to their statistical distribution, the response of the system can be accurately and analytically obtained, allowing in this way the accurate definition of objective/constraint in function of a given %-ile of their distribution.

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.6), which looks as like as a modular network connecting the different “bricks” of the process design.

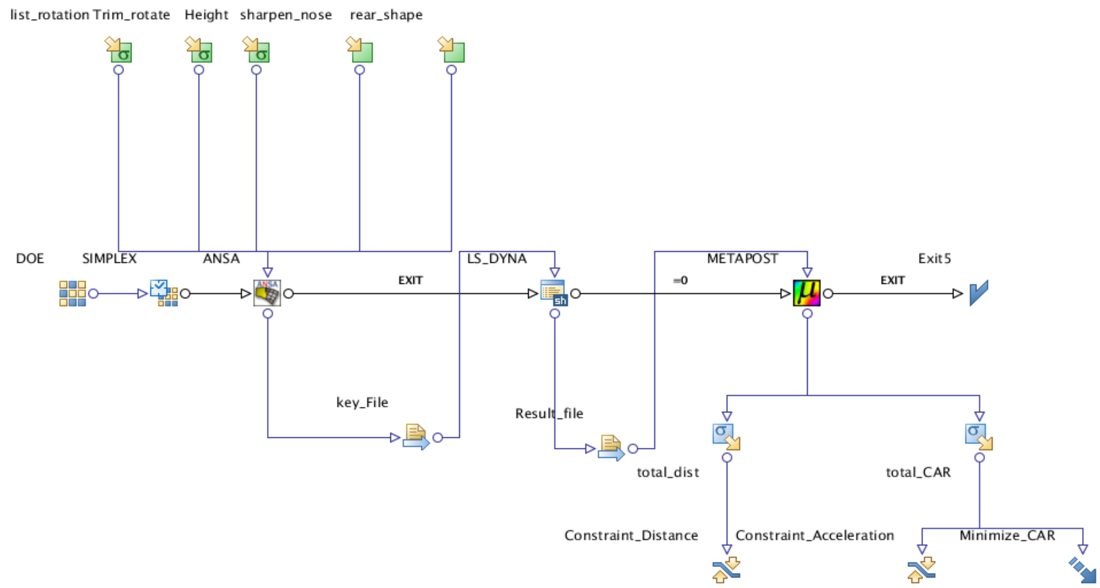


Figure 6- modeFRONTIER workflow for the lifeboat reliability optimization

All the parameters which control the shape (deterministic) and position (uncertain) of the boat are defined by dedicated input nodes, which specify their range of variation and in the case of the uncertain parameters, also the distribution type and details (standard deviation).
The ANSA model including the original mesh can be automatically updated for each different configuration proposed by the optimization algorithm accordingly to the values of the input variables, and the updated mesh model (.key file) is then transferred to the following application, a shell script which launches the LS-DYNA simulation for the stress analysis.

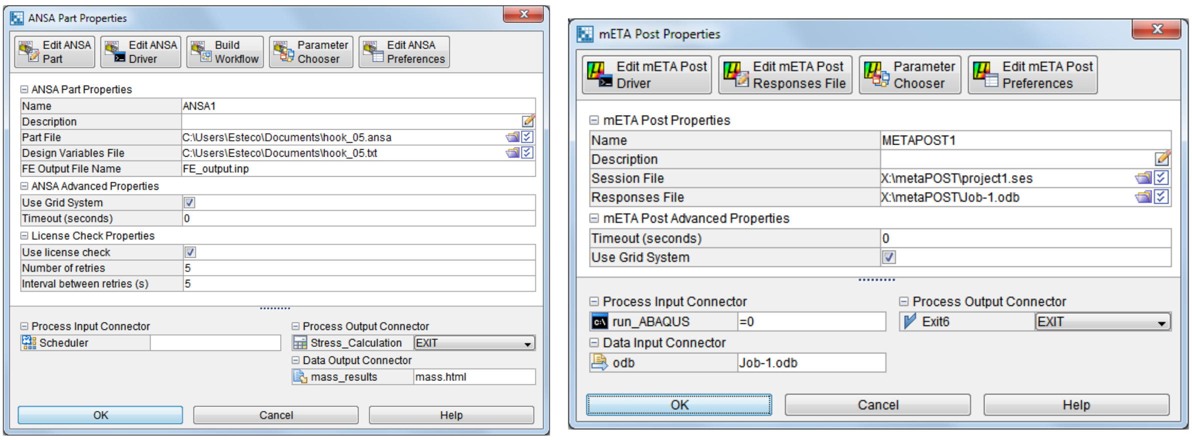


Figure 7 – Example of modeFRONTIER direct interface for ANSA and META.

About the ANSA direct interface (fig.7 left), 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 to LS-DYNA). At that point, all the morphing variables defined in the ANSA model are automatically introspected by the node, and (by using the Parameter Chooser tool) it is possible to link each one of them to a proper design variable node defined in modeFRONTIER workflow.
The LS-DYNA simulation is then automatically repeated for each model proposed by the optimization, accordingly to the instructions defined in the .key file produced by ANSA.
The distance/acceleration results needed to define the objectives and constraints of the optimization problem are instead obtained by the direct interface of mF with μETA (fig.7 right), which automatically list all the available responses of the selected model (in this case a text file containing the maximum values of ax, ay, az read accelerations for several selected history, and the distance of the rear end of lifeboat from host structure when the cog

of the lifeboat is above the sea-level). The user can then link the needed responses to the corresponding objective/constraint of the mF workflow (Parameter chooser tool).
The optimization process is at this point ready to be executed, launching automatically each simulation which is required by the optimization algorithm (MOGA-II genetic algorithm [5]).

5. OPTIMIZATION RESULTS

The application of MOGA-II algorithm [8] to the problem defined in this paper allowed to find the results reported in fig.8 with an overall number of required simulation designs equal to 150. For each configuration, 10 sampling points have been evaluated, in order to compute accurately the distribution of the response parameters and therefore the objective functions.

Fig.8 reports a scatter chart illustrating in abscissa and ordinates the values of the objective and constraint functions, respectively CAR 99.97 percentile, and mean value of distance. In addition, colour scale indicates the value of the second objective, 0.03 percentile of distance.
Among the feasible designs, the best one which has been selected as final design, is the one highlighted in green in the top left corner (ID 130).

Table 1 below reports then the improvements achieved for the optimal lifeboat configuration, with respect to the baseline configuration: the constraint is respected, with a significant reduction of highest percentile of CAR acceleration (29%), and an increase of 10% of the mean distance, and an increase of even 31% relatively to the lowest percentile, confirming the robustness of the solution.

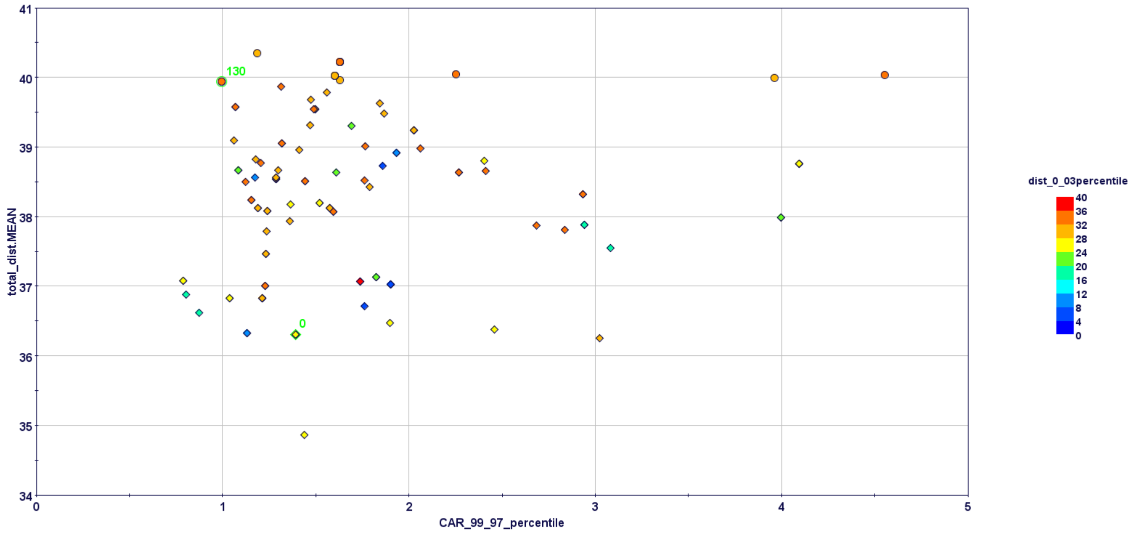


Figure 8 – Optimization results: bubble chart.

Table 1 – Optimization results: best results vs baseline

	mean distance	**0.03%-ile distance**	**99.97 %-ile CAR**
baseline	36.3m	25.5m	1.39 m/s^2
best design (ID 130)	40.0m **(+10%)**	33.6m **(+31%)**	0.99 m/s^2 **(-29%)**

6. CONCLUSIONS

This paper has illustrated 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 reliability based multi-objective optimization of a free fall lifeboat.
Several tools available in modeFRONTIER have been used for this optimization: ANSA and μETA nodes (respectively to generate the updated model and to extract the result od the

simulation), script nodes to launch the suitable solver for the simulation (LS-DYNA), and reliability-based optimization algorithms to optimize the model, taking into account the effects of the uncertainties.
The optimized solution had significantly improved the baseline configuration, within a small overall number of design simulations.

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