Fast Study of Multiple Sizes Helmets and Design Shape Optimization using LS-DYNA, LS-OPT and DEP MeshWorks

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1 Introduction

For obvious security reasons, wearing a helmet is highly recommended when riding a bike or a skateboard. In order for the manufacturers to design safe helmets some regulations have been established and must be respected before any market release. The process enabling to meet the regulation targets can be quite long considering the numerous impact points and test configurations that have to be repeated for each helmet size. The use of simulation and the appropriate tools can be a real asset to save time and reduce experimental tests while increasing security and comfort. Indeed, the numerical simulation offers the opportunity to explore more designs and test almost an infinite number of impact configurations. Especially when the numerical tools are powerful enough to significantly speed up the product development process.

This paper highlights the relevance of using DEP MeshWorks, LS-DYNA and LS-OPT to design such helmets in an efficient and fast process. After few words on the regulations criteria, the steps enabling to set up helmet numerical models for every size, to run impact analyses and to optimize the helmet geometries will be described. The methodology has been implemented here, for illustration purpose, on a free of copyright helmet but has already been used and proved relevant for real industrial products.

2 Regulation

When designing a helmet, two regulations in Europe have to be considered: the EN 1078:2012+A1 and the EN 960 2006. They describe the tests configurations to take into account, their corresponding impact velocity, the head mass to be used depending on the helmet size and the criteria to meet to be considered safe.

In summary, helmets have to be dropped on a rigid flat plane at 5.42 m/s or on a rigid kerb shape (representative of a sidewalk) at 4.67 m/s. The head, weighting 4,7 kg for a L size or 4.1 kg for a XS size, should never suffers an acceleration over 250 g.

In this paper study, Dynas+ has worked with an additional criterion on the foam residual thickness, considering that it has to stay over 25% of its initial size.

3 Helmet model set up

The software used to mesh the helmet models was DEP MeshWorks. This software offers a wide range of meshing capabilities and is particularly efficient when it comes to mesh complex geometries. But its main asset in this study is its ability to follow a different model set up process than the one traditionally used.

Indeed, most of time, to create a family of helmets, one would create all the sizes CAD models, then mesh them individually. Indeed, the differences between two helmet sizes being more complex than a scale factor, in general, each finite element model is created from its corresponding CAD model. This process requires to repeat the meshing process as many times as there are sizes. DEP MeshWorks is a versatile tool that offers two others possibilities:

- If all the sizes CAD models exist, the first option consists in meshing only one helmet size and then use the others sizes CAD geometrical lines to "map" the first meshed model to new sizes ones. By defining specific target lines, DEP MeshWorks maps the initial model and automatically adapt the mesh to keep it smooth and of good quality.

- If the CAD of only one size has been created, DEP MeshWorks morphing features can be used to apply any useful transformation to the initial finite element model and quickly obtain the others helmet sizes. The corresponding CAD models can then be extracted from the newly created finite element ones.

With any of the two previously described innovative processes (illustrated on the figure below), the user would save quite a lot of time during its meshing process to obtain the finite element models of the entire helmet family. For similar application typical time saving is around 70%.

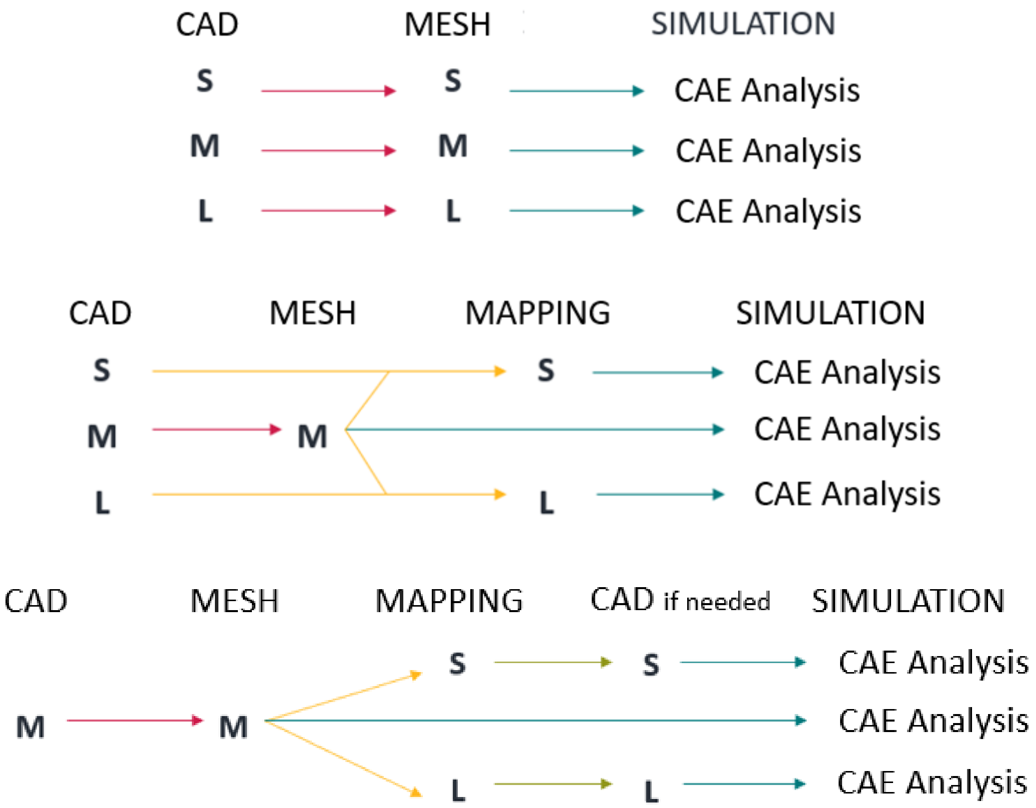

Figure 1: Comparison between the common meshing methodology (top) and the other two used thanks to DEP MeshWorks (middle and bottom)

In this study the second innovative process has been used. Several kinds of morphing are available in the software but the interesting feature in this case is the mapping. By defining the main "origin" lines on the first meshed model and the "target" lines, DEP MeshWorks maps the model and automatically rearranges the mesh. This mapping is of course not a simple scale as some dimensions will be modified (such as the helmet perimeter for example) whereas others will remain unchanged (such as the LED lamp specific attachment hole). As well, some geometrical lines shapes will evolve from one helmet size to another either for security, comfort or aerodynamic reasons.

In this paper study Dynas+ has worked from one helmet free of copyright CAD. The M size has been meshed first and the other sizes have been created using the previously described process. The figures below show the meshes obtained. The outer shell is made of quad elements and the volumetric foam of tetra elements.

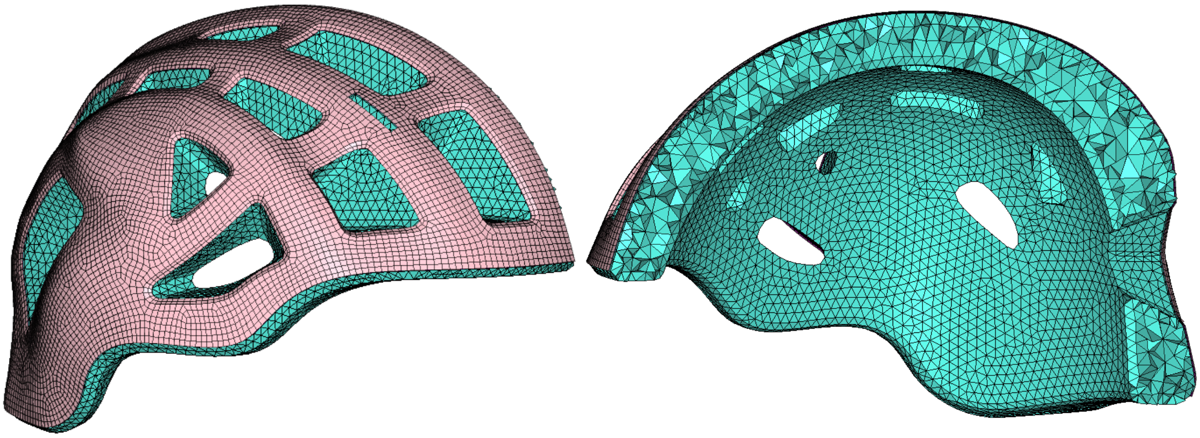

Figure 2: View of the helmet mesh

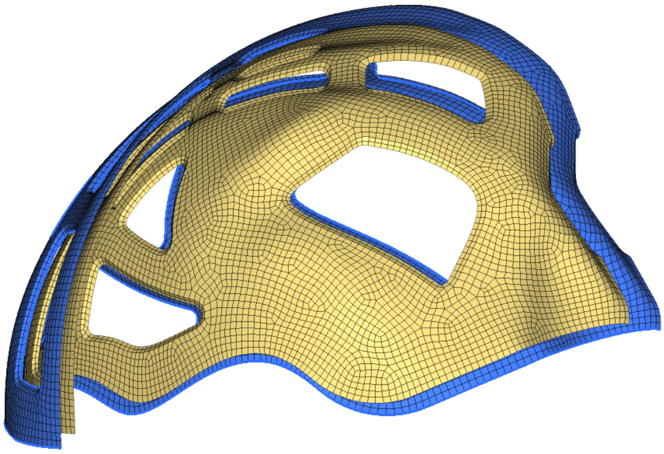

Figure 3: View of the M (blue) and S (yellow) sizes outer shell meshes

DEP MeshWorks morphing capabilities can be used on much more complex structures such as complete vehicle. Indeed, for this application a specific automated tool called “Full vehicle Morphing” exists and enables to create a new finite element model from another one without coming back to the CAD, without remeshing (or only locally), without rebuilding connection elements (such as spotwelds, joints…) since the finite element model automatically adapts to fit the targeted geometry. This technology enables significant time savings during the early design phases of a project. Depending on the project scale, it can reduce timelines by several months for vehicle-level complexity and by several hours or days for helmet-level complexity.

4 Helmet impact analysis

Once the meshing process finished, the models set up has been finalized by adding the appropriate sections, materials, contacts, initial velocity and boundary conditions. The head is always considered rigid. The volumetric foam is tied to the helmet plastic shell on some specific regions using a tied contact.

No matter where the helmet will impact the ground or another object the head always need to be protected. Then, the helmets need to respect the regulations head acceleration criteria for the two impact configurations (flat plan and kerb) for any impact point on the helmet. The position of the helmet in the LS-DYNA model has been parametrized using the *INCLUDE_TRANSFORM keyword and LS-OPT has been used to run all the analyses covering the potential impact zone.

The first model analysed was the M size for which all results were respecting the regulations criteria. Of course, these results were expected since the CAD model used to create the model was coming from a commercialized product that had to respect safety rules before its market release.

Going to the XS size, it also passed the tests with success regarding the acceleration criteria. However, contrary to the M size, the XS size did not always respect the residual foam thickness of 25% minimum that Dynas+ decided to add as a fail/pass criteria in this study. Some impact points were leading to thicknesses close to 10%, as illustrated in the figures below.

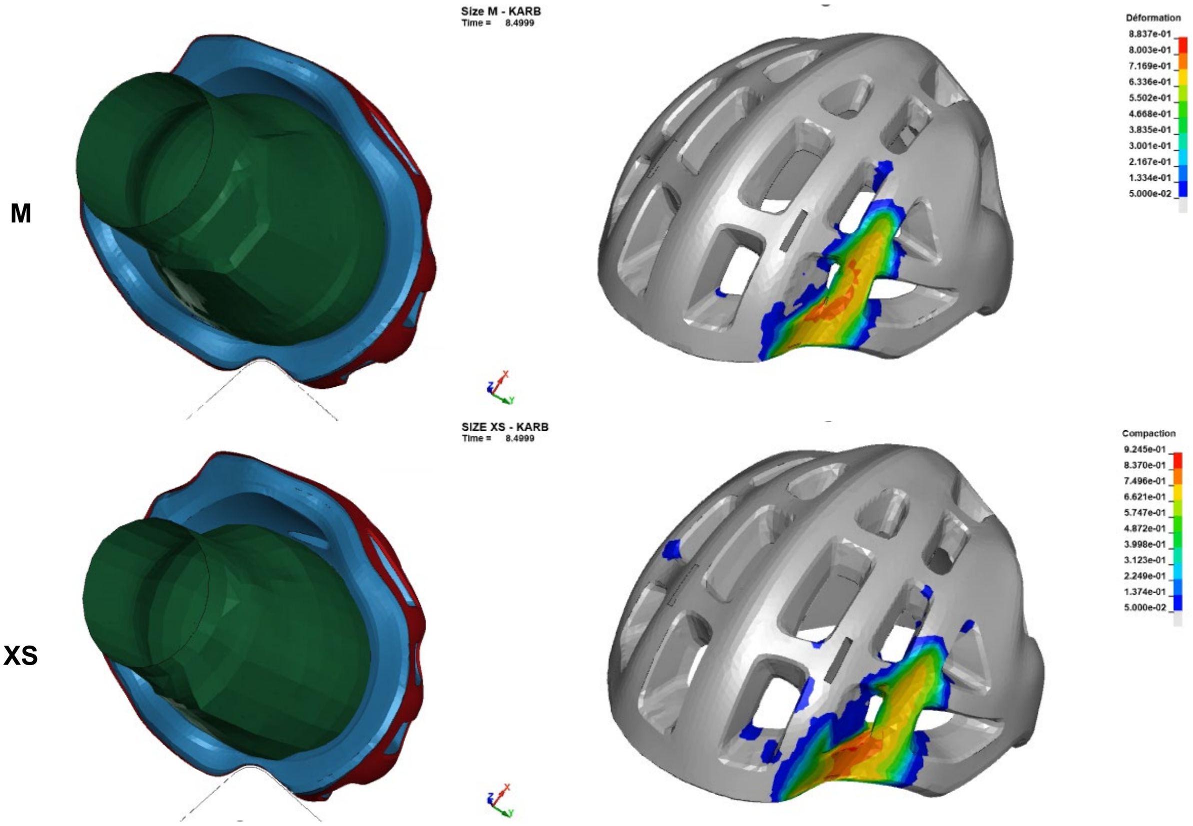

Figure 4: Kerb impact comparison between two helmet sizes (M and XS) – Helmet deformation

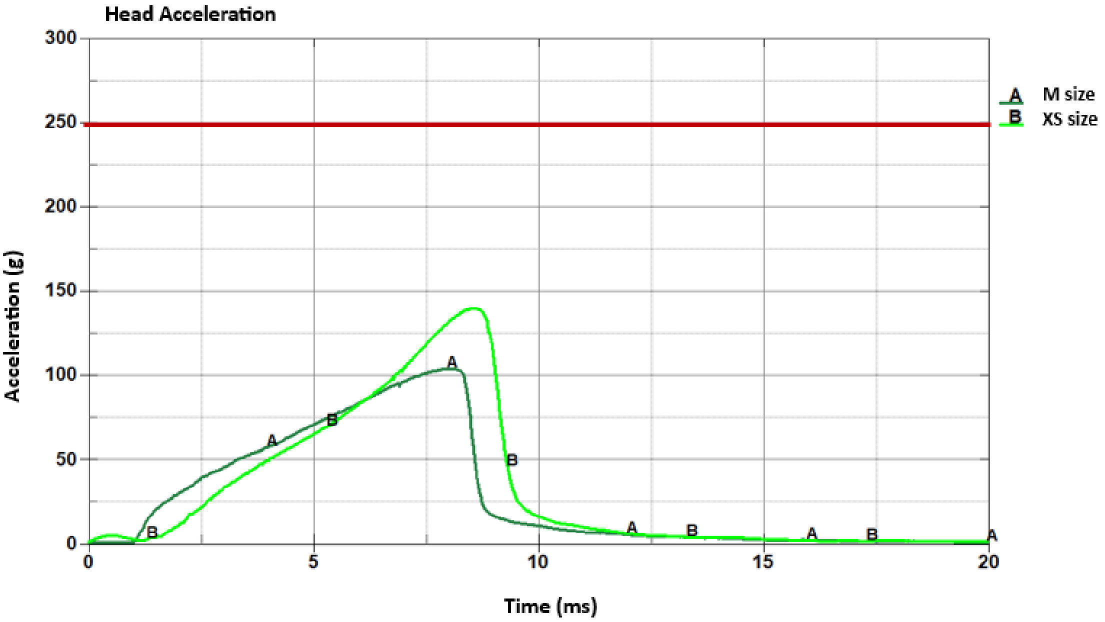

Figure 5: Kerb impact comparison between two helmet sizes (M and XS) – Head acceleration

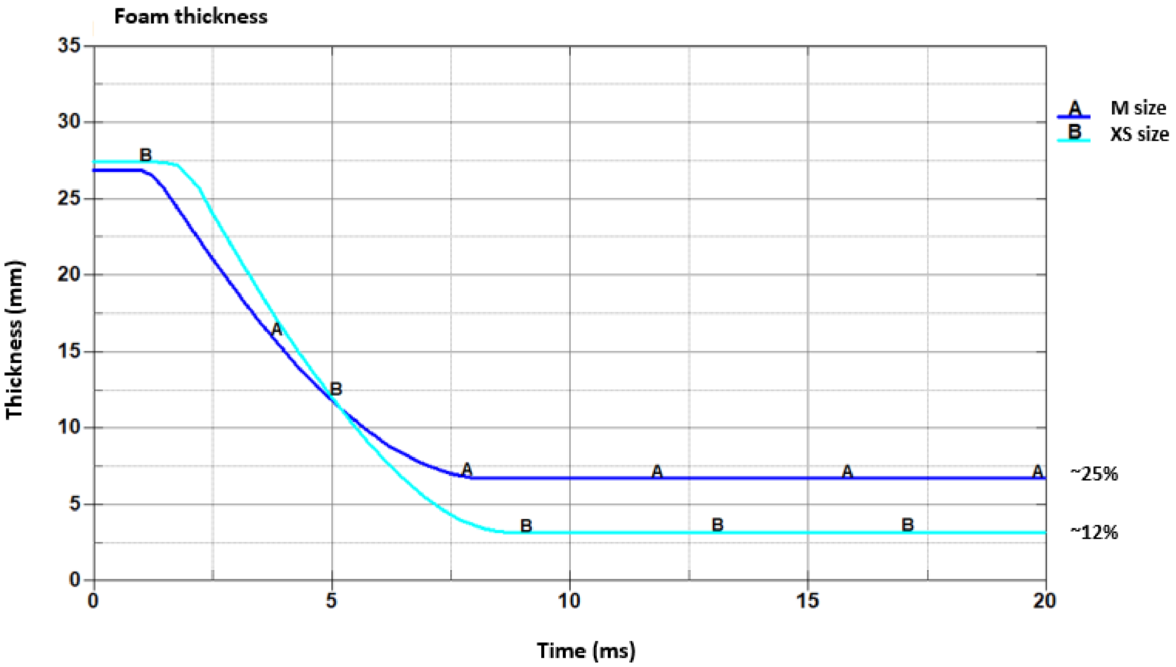

Figure 6: Kerb impact comparison between two helmet sizes (M and XS) – Foam thickness

5 Iterations process

During the product development process, depending on the impact results to ensure the helmet safety, some iterations will be needed to modify its geometry accordingly. Each impact point result will lead to local modifications in order to respect the regulation, while keeping in mind comfort, aerodynamism and cost considerations.

Once again, DEP MeshWorks enables to easily test these modifications without having to go back to the CAD model. The geometry is directly updated in the finite element model and the mesh is adapted automatically. In addition to the significant time saving offered by DEP MeshWorks tools in this iterative process, the software also facilitates the access to the simulation, increasing its use and improving the communication between Design and Simulation teams.

Feedback from real-world industrial applications shows that switching to DEP MeshWorks can reduce the total development process time by up to 70%. For instance, the meshing of a complex helmet design can be cut down from 3 days to just 3 hours, and subsequent modifications can be made in minutes instead of requiring an additional 3 days. Similarly, with the integration of process automation technology, modelling time can be reduced from 4 hours to just 20 minutes. In summary, the annual development cycle for one helmet design, typically taking around 110 days, can be streamlined to just 30 days.

In this study, the XS helmet was modified to pass the residual foam thickness criteria using an optimization study discussed further. Indeed, an optimization tool such as LS-OPT coupled with DEP MeshWorks and LS-DYNA is another efficient way to explore new designs and identify relevant solutions. However, designers' experience often wisely guide their choices and they prefer to control local design modifications iteratively.

In order to illustrate DEP MeshWorks capabilities to locally change the helmet geometry directly in the finite element model, the following modification (see figure 7) has been realised: Adding two holes shaped as cones to lower the mass of the helmet on its back side. In order to do so, the cones have first been created and meshed using tetra elements. Then a Boolean operation subtracting the two volumes (helmet – cones) has automatically led to the new helmet meshed model.

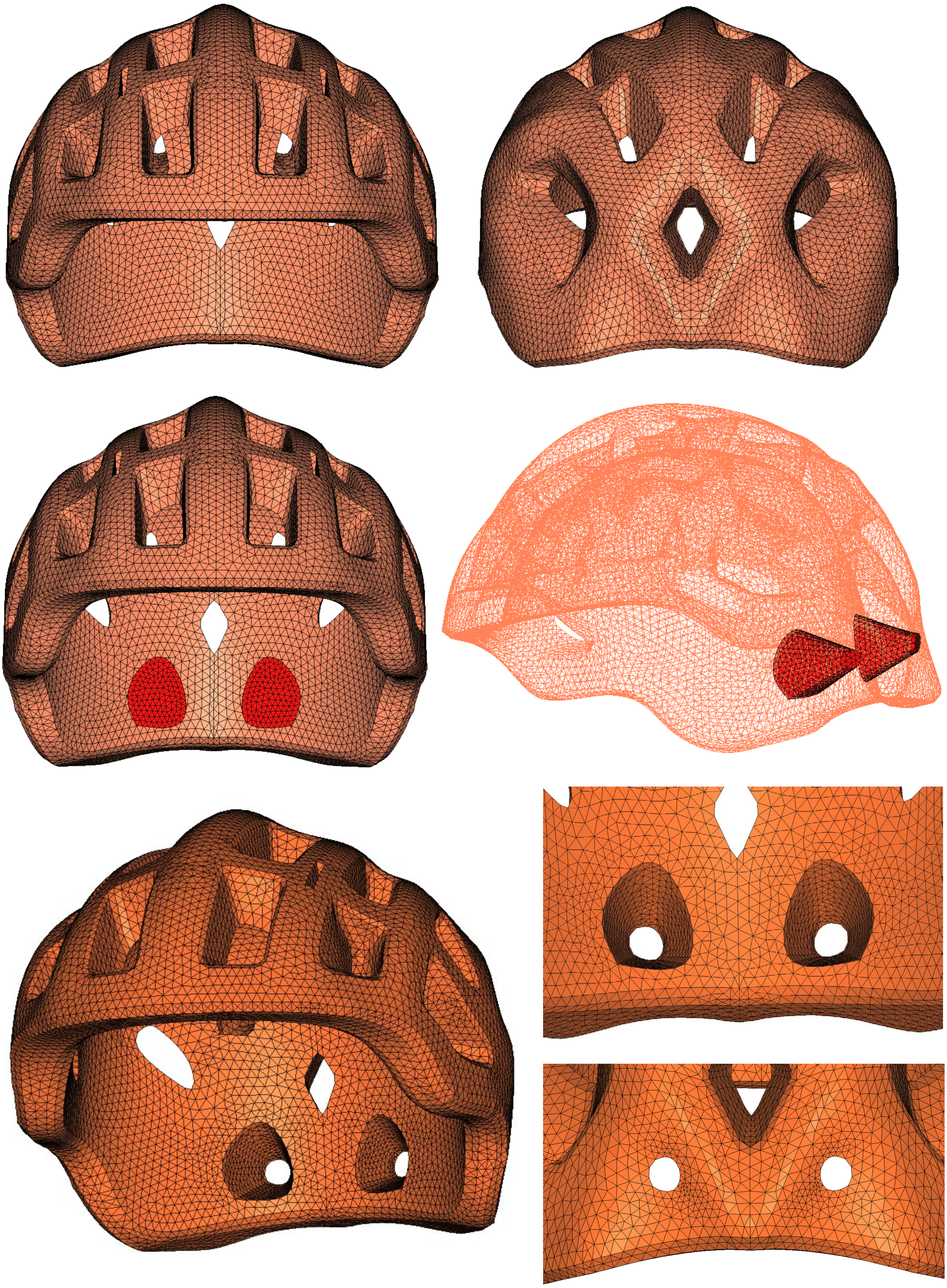

Figure 7: View of the helmet initial (top) and final (bottom) mesh when using DEP MeshWorks boolean operation feature to add a specific shape hole (middle) directly in a volumetric mesh

6 Optimisation study

Going back to our XS size helmet that did not respect our residual foam thickness criteria, an optimization study was set in order to determine the necessary outer shell and foam thicknesses to respect this additional criterion while still satisfying the acceleration one. To make it more relevant the optimization study also had the objective of limiting the helmet mass.

The first step of this work was to parametrize the helmet in order to easily vary the model thicknesses in an LS-OPT study. DEP MeshWorks was used to set up the model as its morphing capabilities would later enable to easily create as many models as necessary, using a Design of Experiment (DoE) generator, with various thicknesses depending on the LS-OPT sampling. Since the helmet did not have a circular shape for which a scale would have been satisfying, the geometry modifications were done using offsets. The inner surface was defined fixed (the head shape does not change) and the modifications used the inner elements normal to offset the geometry. Again, no remeshing was needed and DEP MeshWorks automatically adapted the mesh size and its distribution to keep a homogeneous variation of the thicknesses along the whole helmet surface, as illustrated on the figure below.
Consequently, once the model parametrized, it was then quick and easy to get any new helmet finite element model required by the LS-OPT study by varying the model thicknesses.

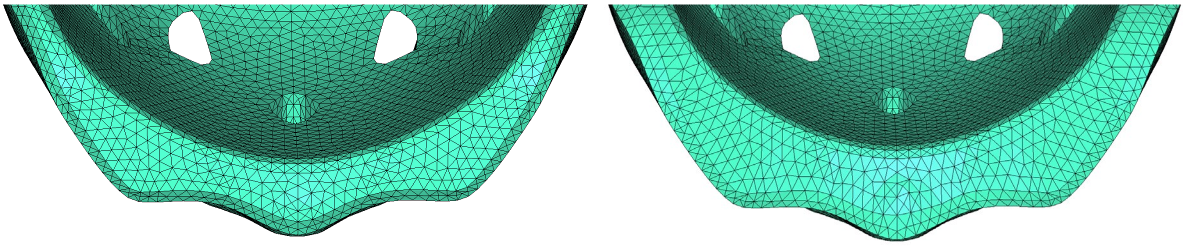

Figure 8: View of the helmet back side mesh when using DEP MeshWorks morphing capabilities to automatically adapt the mesh when increasing the foam thickness

The second step was precisely to set up the optimization process using LS-OPT. This software has the capability to run multi-objectives optimisation on a set of parameters shared by several models considering different load cases. However, the first optimisation run only considered the flat impact configuration and one impact point for which the residual thickness was below the allowed 25%.

A parametric study using LS-OPT has been implemented to optimize the helmet mass, and consequently to reduce the production cost. The input parameters were the shell thickness of the outer shell (from 0.5 mm to 1.5 mm) and the value of the offset to drive the foam thickness. The values were chosen to have a wide range of helmet design. The 250 g for the head acceleration has been implemented as a constraint and the mass reduction has been specified as objective. A space-filling point selection has been chosen to explore the maximum variety of design points.

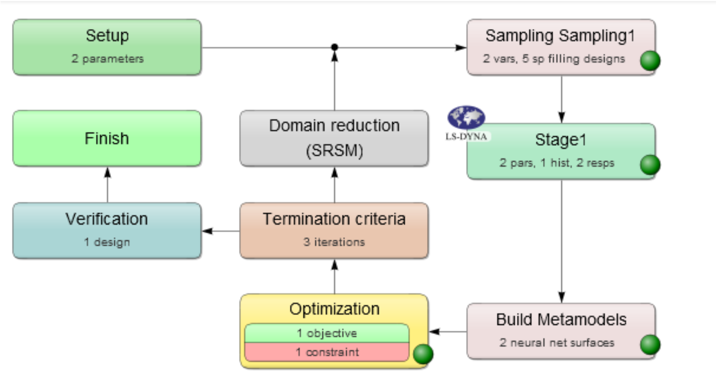

Figure 9: LS-OPT interface

In term of results, the mass of the helmet is mostly impacted by the outer shell thickness. Typically, a shell thickness of 1.5 mm corresponds to a skateboarding helmet and a shell thickness of 0.5 mm corresponds to a bicycle helmet.

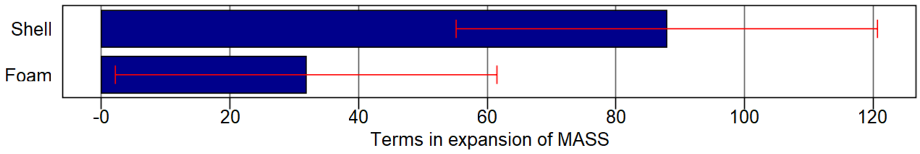

Figure 10: LS-OPT Sensibility of the helmet mass regarding input parameters

Moreover, as shown in Figure 11, it is interesting to note that the greater the foam thickness, the lower the maximum acceleration experienced; however, the greater the shell thickness, the higher the acceleration becomes.

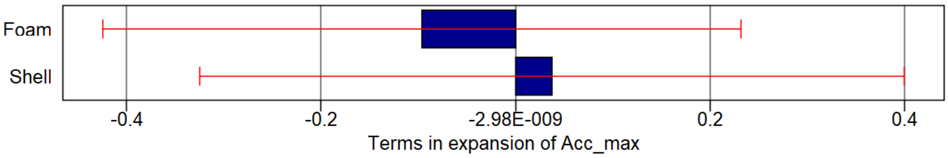

Figure 11: LS-OPT Sensibility of the head acceleration regarding input parameters

As a result, LS-OPT allowed to find that the couple of parameters keeping the head acceleration under 250 g while minimising the mass is: a shell thickness of 0.5 mm and a foam offset of 0.955. The following figure shows the results in term of acceleration for the different configurations. The marked curve highlights the optimal design found, and the colours represent the evolution of the mass.

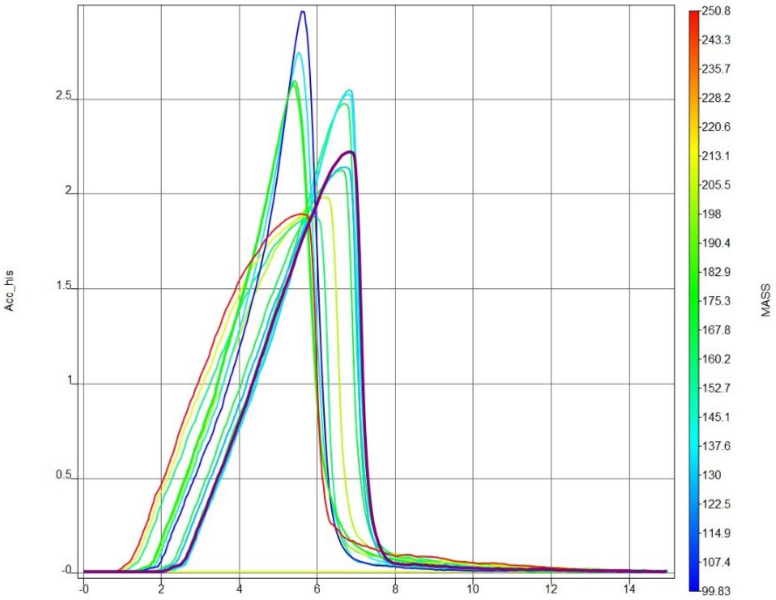

Figure 12: Acceleration versus time curves

Since; the LS-OPT optimization shown has been done only on one impact point and on the flat surface, some verification simulations have also been performed to validate the optimized design on other test configurations.

To vary the helmet thicknesses is not the only possibility to respect the security criteria. Moreover, since the inner shell shape and size are fixed by the head shape and the outer shell surface geometry is often fixed by aerodynamism considerations, increasing the foam thickness directly leads to a significant increase in the helmet mass. Then, another interesting parameter can be to play with the helmet holes number, size or shape. A second LS-OPT study could have been set to investigate this idea.

Once again DEP MeshWorks was used to parametrize the model and make the holes size and shape easily vary. Three parameters were defined: Two for the holes' length and width and one for the curvature angle of the holes' corners. The inserts size and location were also parametrized in this model. DEP MeshWorks was automatically adapting the model mesh to fit the new design dimensions for a new set of parameters. Ideally the parameters should be as simple as possible and their combination should enable all the targeted changes that are to be investigated. The figures below show several views of the helmet design depending on the parameters' variations.

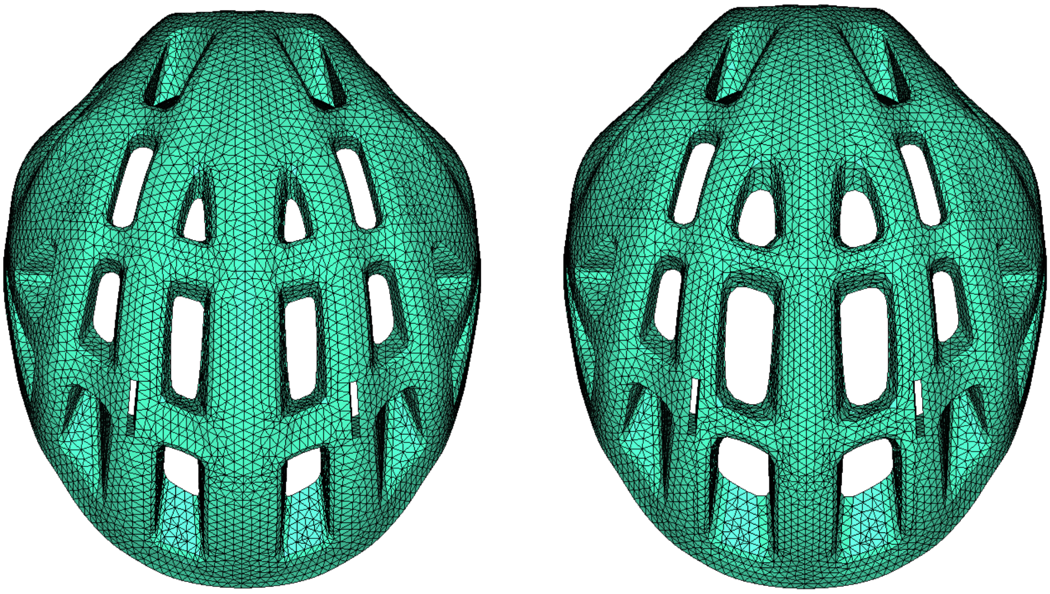

Figure 13: View of a possible variation of the holes size using DEP MeshWorks parametrization and morphing capabilities directly on a meshed model

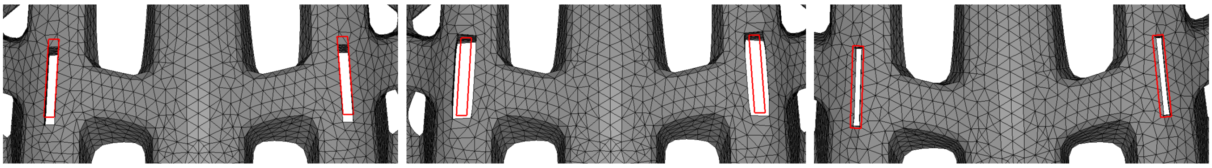

Figure 14 : View of possible variations of the inserts size or location using DEP MeshWorks parametrisation and morphing capabilities directly on a meshed model

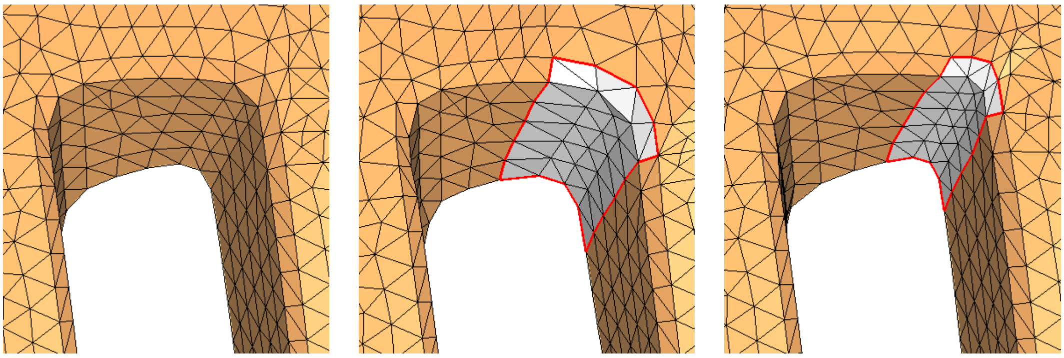

Figure 15: View of possible variations of the holes' corners shape using DEP MeshWorks parametrisation and morphing capabilities directly on a meshed model

Thanks to DEP MeshWorks significantly speeding up the models set up, a second optimisation study could enable to go further in exploiting LS-OPT capabilities. This time, a multi-cases optimisation could be considered: the simulations corresponding to the two impact configurations (flat and kerb) and every targeted head impact positions could be taken into account. Being able to run an optimisation study simultaneously on every impact scenario to get the best possible common set of parameters would lead to particularly relevant design.

7 Conclusion

This paper objective was to demonstrate the relevance of using the simulation to reduce products design cycles, on a general public example. Therefore, the simulation enables to reduce costs. Powerful tools in DEP MeshWorks coupled with LS-DYNA and LS-OPT were highlighted to make quick and efficient mesh modifications and model parametrization in order to create finite element helmet size models, run iterations to locally modify their design and run optimisation studies. Going further in these software capabilities a global optimization could be run considering several configurations study such as the helmet aerodynamic as well. Indeed, as an example, fluid simulations using LS-DYNA ICFD solver can be taken into account in LS-OPT multi cases optimisation to push further the design improvement. In the end, whatever the user goals these versatile tools enable to save time and be more efficient for a very wide range of applications.

8 Literature

[1] Ansys LST, “LS-DYNA User’s Manual”, Vol. I & II, 2023