Practical Examples of Efficient Design Optimisation by Coupling VR&D GENESIS and LS-DYNA

David Salway, GRM Consulting Ltd. UK.

Paul-André Pierré, GRM Consulting Ltd. UK.

Martin Liebscher, Dynamore GMBH, Germany

Summary:

With the ever increasing demand for the efficient use of materials to reduce manufacturing costs and product mass; the use of optimisation techniques have become common place in CAE. The optimisation techniques used for optimising in the non-linear domain, and those used for linear domain problems have until recently been distinctly separate philosophies. For instance topology optimisation would be used with linear static analyses, but could not be applied to non-linear problems.

VR&D GENESIS provides a fully integrated linear static analysis and optimisation solver code. GRM have developed an interface so that GENESIS can be coupled to non-linear problems solved in LS-DYNA. The coupling allows the advanced analysis capabilities found in LS-DYNA to be coupled to the Topology, Topometry and Shape optimisation techniques of VR&D GENESIS.

The paper outlines the processes already developed by GRM Consulting Ltd[1] to allow this coupling, and the most recent developments. These developments allow the analysis methods available in LS-DYNA to be optimised by the optimisation methods available in VR&D GENESIS. The latest developments have taken the method from a research project to a code suitable for use in production level optimisation tasks

The practical examples are intended to show how the use of this method allows non-linear domain optimisation to consider thousands of design variables, non-linear and linear load cases, whilst reducing the number of function calls required to converge.

Keywords:

LS-DYNA, GENESIS, Shape, Sizing, Topometry, Topology, Non-Linear, Optimization, Implicit, Explicit

1 Introduction

The continual need to reduce part mass and cost in modern engineering design, has resulted in the adoption of optimisation techniques in the product development life cycle. The two distinct analysis disciplines have developed distinct optimisation philosophies. In the linear domain it is common to use gradient based optimisers that are integrated into the solver, providing the benefit of determining sensitivities internally and reducing the analysis function calls, thus allowing thousands of variables to be considered. Non-linear domain optimisation tends to be based around design space exploration and stochastic methods. Determining sensitivities in these methods relies on analysis function calls, and because of this the number of design variables is limited.

The key benefit is that by coupling GENESIS and LS-DYNA optimisation tasks that would not be viable using traditional methods can be carried out with a practical number of LS-DYNA function calls and example of this would a topology considering 33000 design variable requiring only 30 LS-DYNA calls. This would not be practical using any other method.

2 Currently Released Code Capabilities

Following the initial proof of concept phase the method has been developed with the intention of being a commercial product and as such robust code and a GUI have been developed. The GUI runs inside Design Studio for GENESIS, which is a pre and post environment for creating analysis and optimisation problems for GENESIS.

A series of steps have been created to take the user through the coupling set-up stage. The process is managed by a control file, which contains user defined variables, examples are things such as path to LS-DYNA executable, path to LS-DYNA input file. In addition to file paths there is also a series of parameters that allow the user to adjust move limits, convergence criteria, and other variables to tune the process[2].

The requirement to start the coupling is a running LS-DYNA simulation and a GENESIS mesh (in NASTRAN format) of the designable part or parts. The LS-DYNA model is run to create a baseline set of results, these results are then read and a number of approximate load cases are created in the GENESIS model. The number of load cases is controlled by the user, the number should be chosen to capture the behaviour of the LS-DYNA model through time.

Following the Create phase a Check phase has been provided in the code. The Check phase runs the GENESIS model as an analysis, the results of this analysis can then be overlaid on the LS-DYNA result in a post processor. The two results should match perfectly, this provides a visual check to ensure that both models are behaving in the expected manner.

The final stage is to run the full coupled optimisation, this can be carried out from the GUI within Design Studio or from the command line. The GUI allows both local and remote submission using the SSH protocol, with live objective/constraint violation graphing. The graphing of the objective and constraint violations allows the user to track the progress of the optimisation as well as check the behaviour at a glance. Figure 1 overleaf shows the GUI with the live graphing, progress dialogue box and coupling set-up UI.

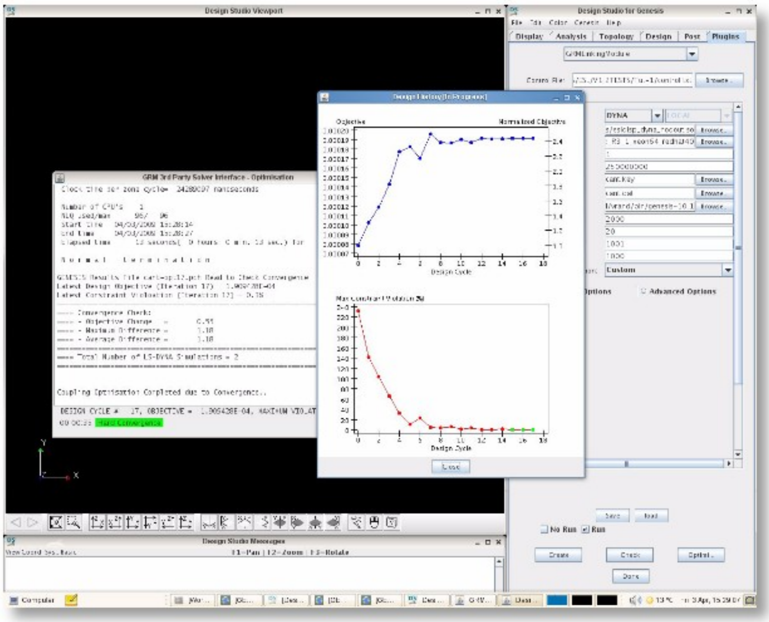


Figure1: Design Studio GUI

The three automated phases and the GUI are now well established, the logic is to automate as much as possible. Automating the process not only allows the process to run unattended, but also allows the process to be repeatable.

Testing and benchmarking of different problems has shown that for implicit problems the coupling is extremely efficient. Implicit coupling currently supports stress and displacement constraints in the release version of the code. The typical implicit topology example can be completed in 5 LS-DYNA calls, this is due in a large part to the similarity between the behaviour of an Implicit problem and the GENESIS analysis allowing more GENESIS design cycles between each LS-DYNA call. Sizing and shape optimisation problems when coupled to implicit LS-DYNA tend to converge in a similar number of function calls, but most importantly there is very little correlation between the number of design variables and the number of non-linear analyses (i.e. larger numbers of design variables do not require more solves).

The coupling can also used to optimise explicit problems, the approximate GENESIS load cases need to be updated more often in this case resulting in more function calls. However the function calls are still not linked to the number of design variables. Sizing and shape have been shown to work very efficiently with explicit type problems, the release code currently is able to support intrusions and force/ acceleration type constraints. Crash topology works well with a constrained mass fraction, but minimising the mass fraction has a tendency to result in local optima problems. Figure 2 shows an example of an explicit topology, the ball impacts the top of the block with an initial velocity. The outside of the block is constrained.

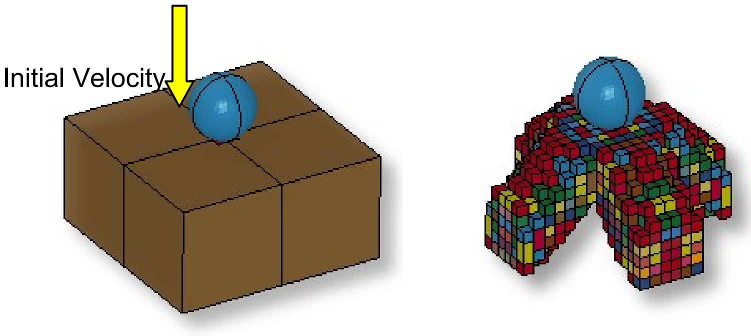


Figure 2: Baseline and Optimised Explicit Topology Result

3 Recent Developments

Due to the infancy of the method developments are continual, with one discovery invariably opening the door to others.
One application that has been requested more than anything else is the ability to optimise for force, accelerations and velocities, bumper beams and knee bolsters were mentioned time and again. Our initial studies showed that it is possible but that out first attempt was not sufficiently robust. The first obstacle was to create a formulation for the optimisation that works well in conjunction with GENESIS. To get a nice smooth input to allow GENESIS to calculate accurate sensitivities it is necessary to provide high frequency time history data. This results in a high number of sub cases and therefore a high number of constraints. The second formulation that has been devised overcomes this problem. Due to the size of the results files needed for large problems it will be necessary to read the LS-DYNA binary files in the future.

In addition to LS-DYNA support of ABAQUS and MSC MARC are currently available. A PAMCRASH interface is currently being developed. LS-DYNA is used for development and testing and because of this the LS-DYNA interface is the most advanced.

4 Benefits of Coupling

The use of traditional non-linear optimisation methods relies on exploration of the design space, this inherently requires LS-DYNA to be called for the optimiser to acquire sensitivity data. By coupling the two codes together this sensitivity can be calculated internally within GENESIS. This internal calculation of the design sensitivities reduces the number of LS-DYNA function calls, and removes the necessity of running LS-DYNA to acquire the sensitivity data. This in turn removes the link between design variables and function calls, and dramatically increases the number of design variables that can be considered. Figure 3 shows a comparison study between RSM approaches and the coupling method to solve the same problem.

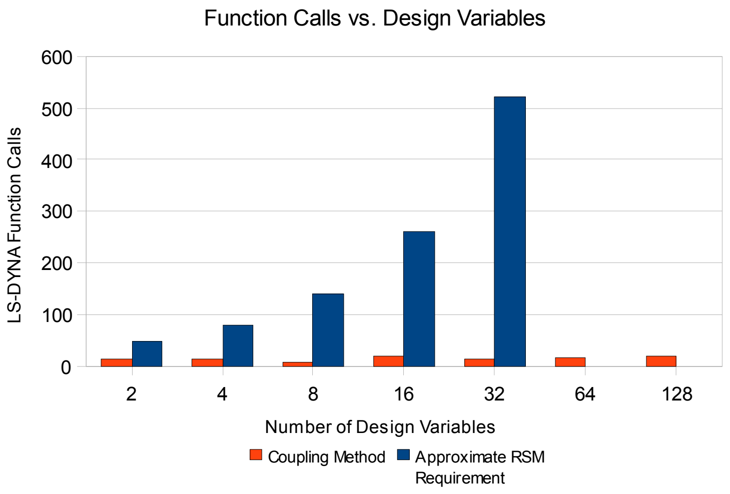


Figure 3: Comparison of Generic RSM and Coupling Method Function Calls

The comparison shown in figure 3 indicates that for the traditional non-linear approaches the relationship between the number of design variables and the number of LS-DYNA runs shows positive correlation, whilst for the Coupling Method there is no obvious correlation at all. The RSM values quoted are quite conservative, so a more aggressive approach may reduce these values.

The largest benefit of the coupling is the availability of the optimisation tools integrated into GENESIS. The coupling has been developed to integrate seamlessly with LS-DYNA, thus the user doesn't need to use the *PARAMETER cards to change the deck. The coupling code prepares the updated LS-DYNA file for each iteration.
Whilst the coupling method provides many benefits it is not able to optimise some of the more advanced safety related problems that software such as LS-OPT has specific routines for.

5 Practical Examples

5.1 Crash worthiness

Crash worthiness is one of the largest areas of use for LS-DYNA around the world and certainly the application that the coupling was first intended for use with. The current formulation is limited to optimising for displacements, but this means that intrusions, acceleration and forces can be considered. The practical example used for this area is a full vehicle crash. The vehicle chosen is the 2001 Ford Taurus model from NHTSA, the model has been set-up to consider the bulkhead intrusions in the full frontal barrier simulation. The objective of the optimisation is to minimise the mass of the BIW. The constraints are the intrusions of three points on the bulkhead. The GENESIS coupling model consists of the BIW, an additional constraint of the torsion mode was applied in GENESIS, this demonstrates that the coupling can also consider linear or modal load cases as this example does. Figure 4. shows both the LS-DYNA model and the GENESIS model. For this example the conversion of the BIW to GENESIS is the single biggest step, the spot welds were converted and all element and node ids had to remain the same.

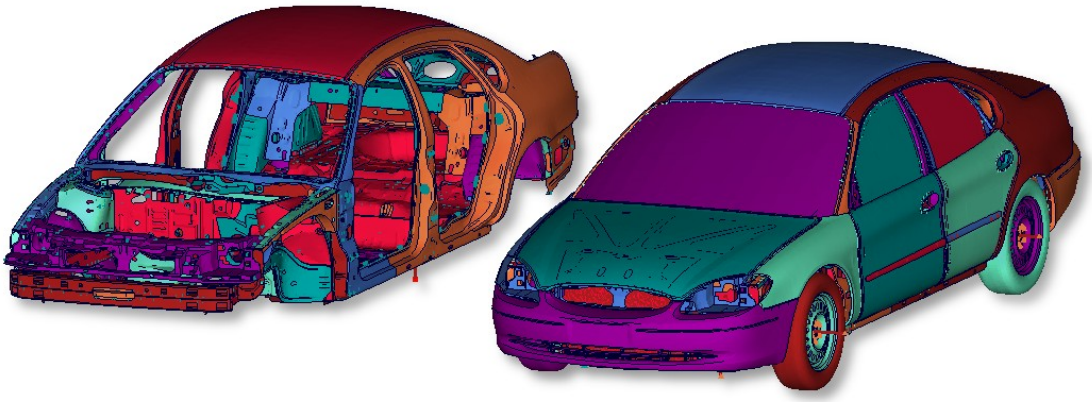


Figure 4: Ford Taurus GENESIS BIW model and LS-DYNA Models.

The optimisation considers 107 independent thickness design variables and a total of 205 design variables. Symmetry has been applied to the common parts on each side of the vehicle. Non-symmetrical parts have been considered individually. The design variables were considered to be continuous, but GENESIS can consider discrete variable sets. Generally the thickness variables have a lower bound value of 0.8mm and an upper bound 5.0mm.

The intrusions of three points on the bulkhead above the tunnel were constrained to 100mm of intrusion through the complete simulation. The objective of the optimisation was to minimise the mass of the vehicle. By considering only the intrusion constraints and the objective the optimiser would have made all parts rear of the bulkhead the minimum material thickness as the sensitivities would have indicated this to the be the best solution. To avoid this happening a target frequency constraint was applied to the first torsion mode of the vehicle. This requires the stiffness of the rear of the vehicle to be considered during the optimisation. Figure 5 shows a graph of the intrusion at the three points in the baseline and optimised model, whilst figure 6 shows the baseline and optimised modes.

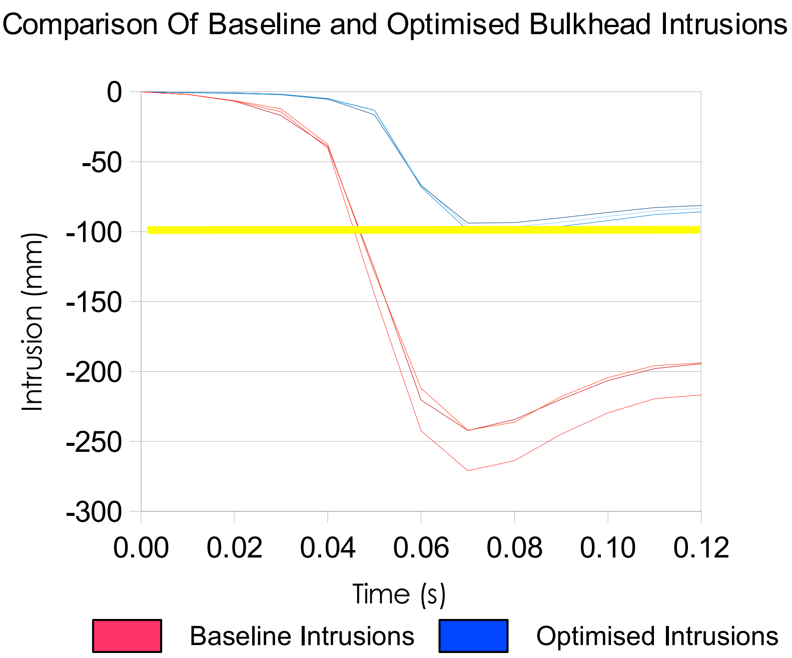


Figure 5 Baseline and Optimised Bulkhead intrusions

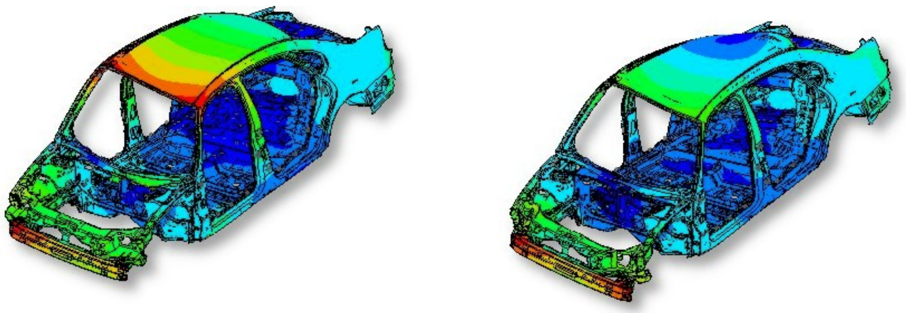


Figure 6 Baseline (20.3Hz) and Optimised (25.9Hz) Torsion Modes

The coupling software is able to adjust the number of GENESIS iterations that are carried out in between each LS-DYNA call depending on its own internal convergence checking routine. This is intended to minimise the number of LS-DYNA calls required and so speed up the process. This optimisation took 32 GENESIS iterations and 22 LS-DYNA calls. As the results shown indicate the intrusion constraints have been met, and the frequency has been increased from 20.3Hz to 25.9Hz, for a modest mass gain of 4.6%. The material at design cycles 0, 15, and 32 are shown in figure 7.

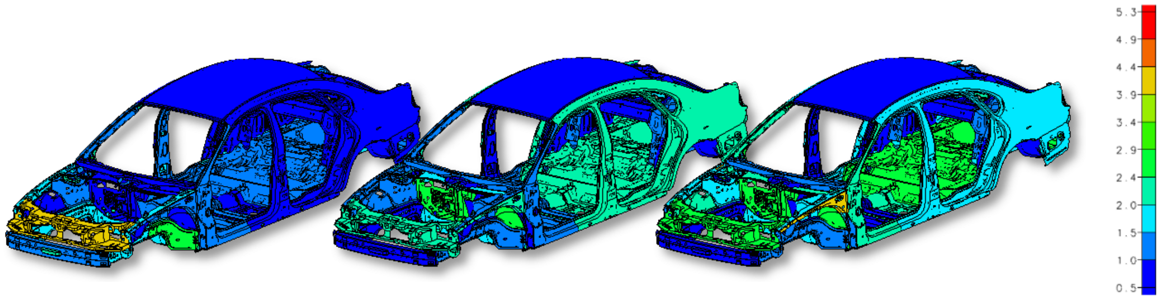


Figure 7: Material thickness at GENESIS design cycle 0, 15, and 31.

At this point it should be noted that the formulation of the optimisation does not consider accelerations, as a result the reduction in intrusion will have caused an increase in acceleration. A formulation to consider acceleration and force is now available. This could be applied to this case and then the accelerations could be constrained to the current value.

The Taurus is a fairly sophisticated model and as such the solve time on the limited LS-DYNA CPUs available meant that it was only practical to consider one LS-DYNA simulation. Given access to a larger cluster of LS-DYNA CPUs it would be possible to consider all of the crash requirements of the development cycle and include these in the optimisation.

5.2 Non-Crash Example

In order to demonstrate that this method is applicable to many of the features of LS-DYNA an example not related to automotive crash analysis has been considered. In this example an ALE simulation of an underwater explosion has been conducted. The LS-DYNA model can be seen in figure 8.

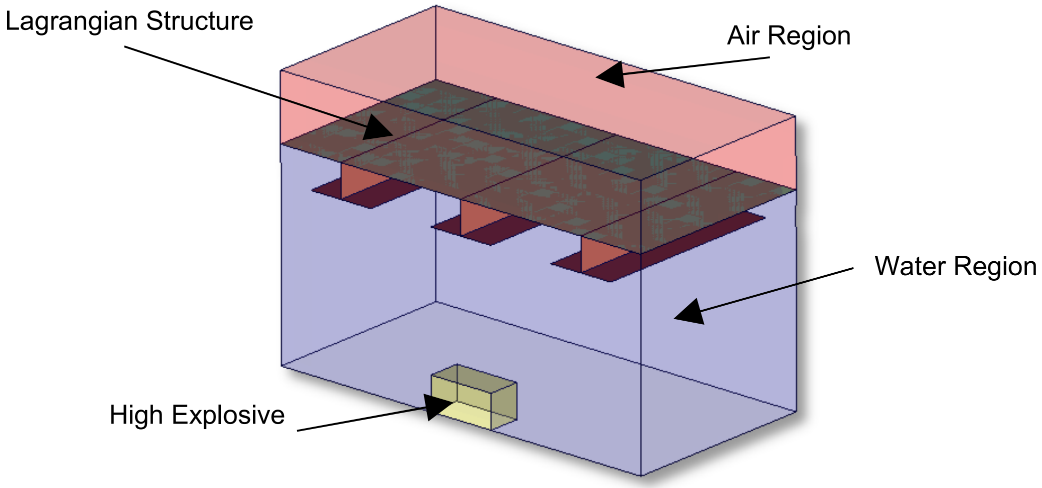


Figure 8: LS-DYNA Underwater explosion ALE Model

The model consists of a Lagrangian structure floating on top of a water region, an air region is also modelled. The detonation causes a pressure wave to move through the water, when this wave hits the structure it first of all deforms and then lifts the structure clear of the water. The deformed shape is shown in figure 9.

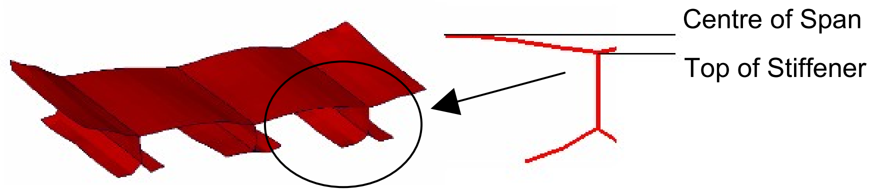


Figure 9: Structure Deformed due to Pressure Wave, showing relative deck heights

The objective of the optimisation is to minimise the mass of the Lagrangian structure. A constraint has been applied on the relative displacement of the deck between a point at the top of the stiffener and a point in the centre of the span.

The GENESIS model is constructed from the Lagrangian mesh, the same symmetry boundary conditions have been added to the GENESIS model as are used in the LS-DYNA model. In addition three linear springs have been applied to the GENESIS model, these allow the mesh to move freely whilst applying a constraint to all of the degrees of freedom. The boundary conditions for both the GENESIS and LS-DYNA Lagrangian models are shown in figure 10.

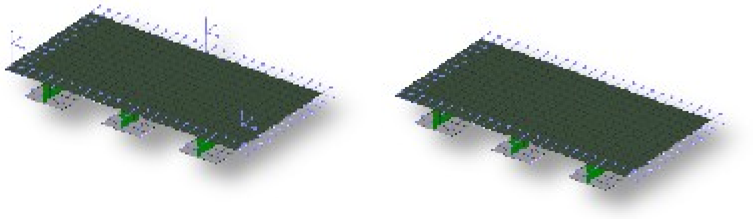
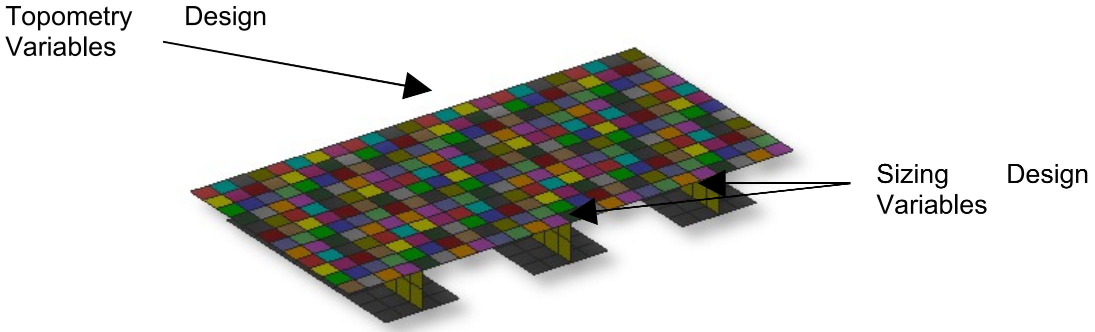


Figure 10: GENESIS and LS-DYNA Lagrangian mesh

The coupled optimisation was carried out as a mix of panel sizing and Topometry (element by element sizing). The top deck of the structure has been optimised using Topometry, whilst the stiffeners have been optimised by sizing complete panels. Both the Topometry and Sizing design variables are shown in figure 11



Topometry Design Variables

Sizing Design Variables

Figure 11: Design Variables.

The optimisation considers 290 design variables and 60 constraints; convergence was reached in 20 LS-DYNA calls. An extrusion manufacturing constraint has been applied to the design variables. This example successfully demonstrates that the method can work in Fluid Structure interaction problems.

It is true to say that the method can be applied to any problem where the LS-DYNA model is deformed by the loads (i.e. by contact, fluid interaction, thermal loading, etc). The optimised material thickness can be seen in figure 12 below.

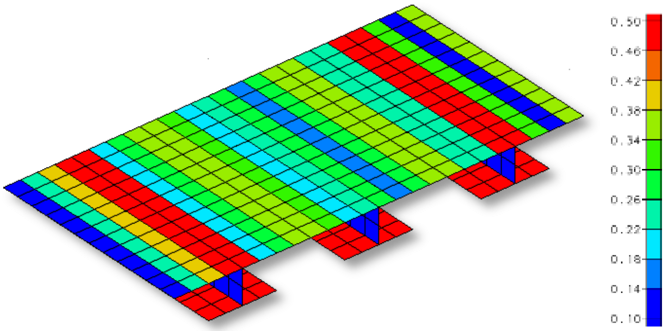


Figure 12: Optimised Material Thickness (cm)

6 Future Developments

Recent developments have progressed the coupling method forward, but there is still so much to learn that development is progressing quickly. The next big development is to be able to consider plastic strain and non-linear stress as constraints. This will mean that the coupling can be applied to many more problems. To consider non-linear stress and strain it will be necessary to pass GENESIS the response from LS-DYNA, to ensure the coupling is as robust as possible this will take time to code, test and tune before it is available for release. This is obviously a big step forward for the method.

Improvements to the optimisation problem formulation and GENESIS model set-up are continually being made. This step is the single biggest source of error and so it makes sense to make it as simple as possible. Various methods have been developed to consider moving objects such as the Taurus front impact or the FSI example. In the linear static code it is necessary to have all degrees of freedom fully constrained, and so this presents a problem. The solution used for the Taurus was three CBUSH[5] elements fixing it to ground. Because of the way the nodal forces are calculated in GENESIS the precise stiffness of the springs is unimportant but they provide a way to fully constrain the model whilst still allowing the whole model to translate as seen in LS-DYNA.

7 Summary and Conclusion

By coupling LS-DYNA and VR&D GENESIS it is possible to take the best features from each code and combine them to provide state of the art analysis and optimisation. The coupled method provides a method to quickly achieve an optimum design. The benefit it has over traditional methods is greatly reduced number of LS-DYNA calls needed to converge; this is because it is able to calculate the gradients internally. The method also has limitations. Whilst the method is available as a commercial product, new applications and methods are being discovered all of the time.

8 References

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