

AN ADVANCED METHOD FOR OPTIMIZING PACKAGING DESIGN



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Abstract: Consumer product packaging designers are faced with conflicting requirements throughout the development process. Good pack aesthetics are vital for the success of the product, whilst unit costs must be minimized and suitability for stacking and transportation maintained. This paper describes, by example, how design optimization technology can be used to enhance the design process. It is demonstrated that the technology can be employed to provide clear design information for the pack designers, facilitating definition of an attractive shape incorporating features to meet the structural and manufacturing requirements whilst minimizing cost.

Keywords: *Geometry Cleanup, Automesh, Packaging Design, Design Optimization, Process Automation*

1.0 INTRODUCTION

Consumer product packaging designers are faced with conflicting requirements throughout the development process. Good pack aesthetics are vital for the success of the product, whilst unit costs must be minimized and suitability for stacking and transportation maintained.



Figure 1: Bottle Design

A significant improvement in the design process can be gained if design information can be clearly communicated to the product designers early in the design process. This paper describes how design optimization and advanced CAE can be used to deliver this. The resulting design process facilitates the early definition of an attractive pack shape incorporating features which will meet the structural and cost requirements.

The design optimization process requires input in the form of a series of alternative shapes for the pack,

definition of a design objective (cost or weight) and constraints (structural, manufacturing). An automated series of structural assessments are then performed, and design sensitivity information and an optimum shape defined. This output information can be communicated clearly to the product designer in two distinct ways:

- (i) Pack geometry, with highlighted zones indicating where shape changes should be avoided.
- (ii) Optimum geometry.

To facilitate efficient definition of the design optimization problem, advanced automated modelling and morphing tools (Altair® HyperMesh® [1]) are employed, together with advanced simulation technology (LS-DYNA [2]). The optimization process is automated and set up through an intuitive user interface (Altair® StudyWizard® [1]), which produces focused sensitivity information automatically.

The technology demonstrates a route to sharing information throughout the development team which can be used to accelerate the design process. By improving the early screening process, a starting point to the design can be defined which is well positioned to pass the down-stream requirements, reducing the need for costly trial-and-error.

2.0 DESIGN TOOL OVERVIEW

The design tool's primary objective is to facilitate provision of clear information to the product design team about how to choose a shape, which will be economical to produce, manufacturable, and capable of withstanding the design loads. It is extremely important that this information is generated in a timely manner. Automation of the process is therefore required wherever possible.

The design tool comprises five major components (**Figure 2**). The model generation process includes importing CAD data, automated CAD cleanup and automated meshing. The deliverable from this process is a baseline simulation model of the pack.

The parameterisation process provides advanced morphing technology to apply complex changes to 3D shapes (shape variables), and thickness linking to allow weighted variation through the height of the bottle (size variables). The shape variables can be reviewed interactively and animated in 3D, making this complex information easily accessible to all members of the design team. At the end of the parameterisation process, a series of pack geometry variations are available for use in the optimization phase.

The simulation environment (LS-DYNA) incorporates advanced solver technology to capture the non-linear collapse of the pack under the enveloping design condition (top load). This provides a means of understanding in a very short time frame (less than 1 hour) how the proposed geometry will perform, without the need for testing.

Optimization is a two-stage process, which uses as input the baseline model and shape variables plus additional specification of the optimization objective and constraints. To start the process a Design of Experiments (DoE) study is performed using StudyWizard. This yields a summary of

the sensitivity of the design performance to the shape changes. This is followed by a full non-linear optimization to define the optimum shape.

On completion of the DoE and Optimization studies, geometry extraction technology in Altair® HyperMesh® can be used to produce CAD data.

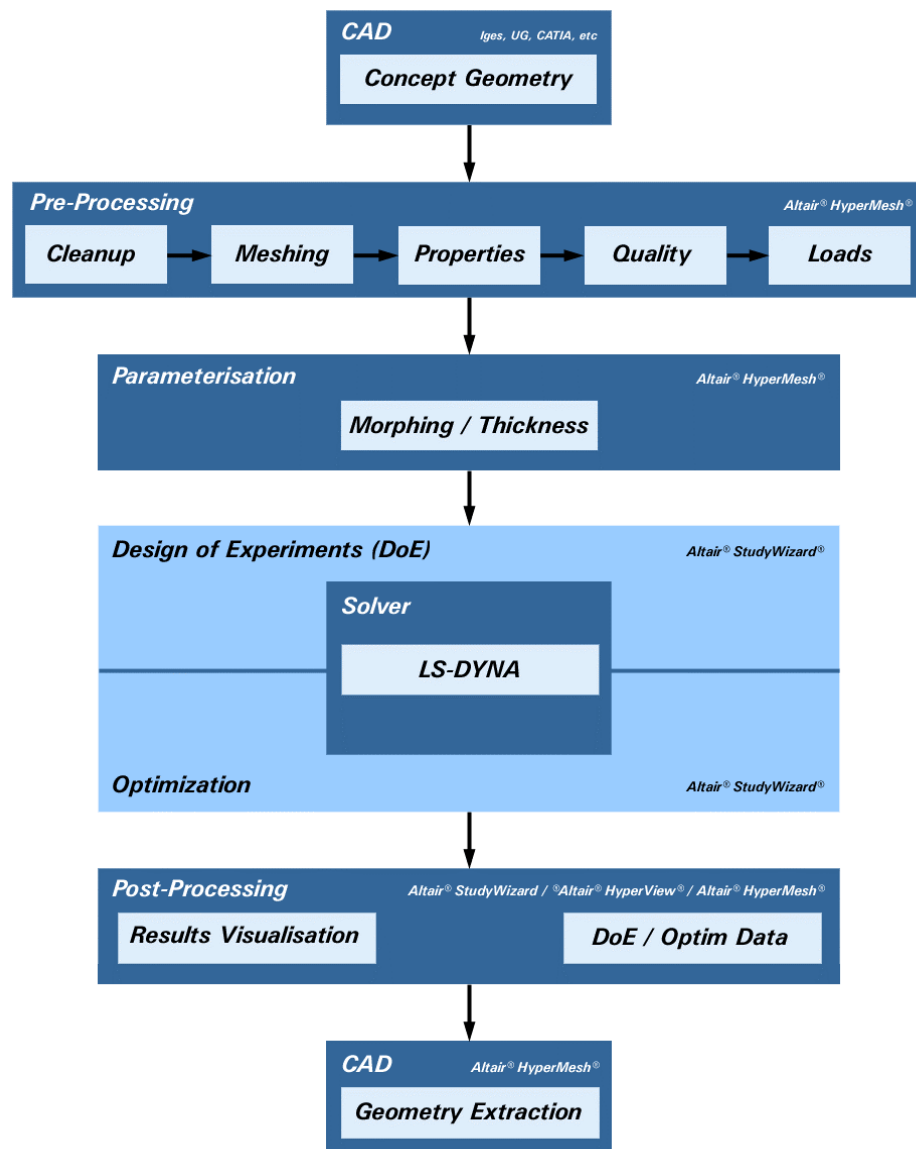


Figure 2: Design Tool Process Flow

The process is demonstrated by application to a real world pack design developed by Lever Fabergé.

3.0 MODEL GENERATION PROCESS

The model generation process (Pre-Processing, **Figure 2**) commences with import of CAD geometry of the baseline design. The geometry is then cleaned or modified to make it suitable for finite element meshing (**Figure 3**). Intuitive 'Geometry Cleanup' functionality in Altair® HyperMesh® streamlines this process, and produces geometry suitable for meshing in less than one hour.

Meshing of the model is also performed in HyperMesh. Provision is made at the mesh boundaries to accommodate morphing of the geometry without introducing significant element quality issues (**Figure 3**). The completed finite element mesh is subjected to automated element checks and interactive adjustments made where necessary to meet the quality requirements.

Non-linear material properties representing the plastic behaviour are specified (**Figure 4**) and thickness is assigned to represent the manufacturing distribution (**Section 4.2**). The baseline thickness distribution is based on a simple estimation of the thickness resulting from the blow moulding manufacturing process.

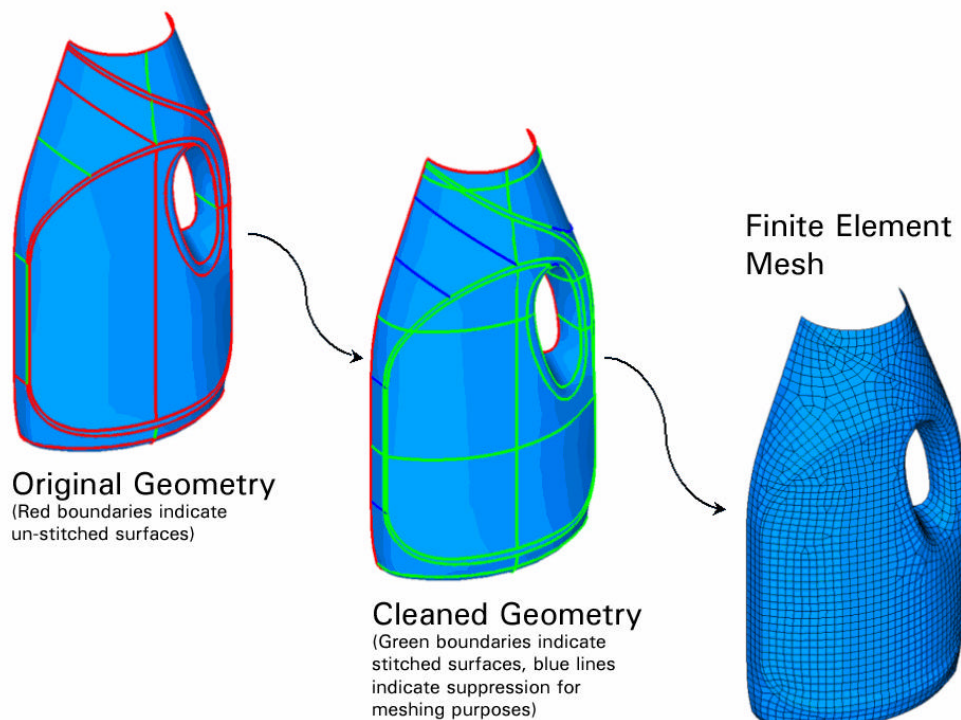


Figure 3: Model Generation Process

The simulation environment is completed by addition of rigid planes at the base for support and at the top for application of top load.

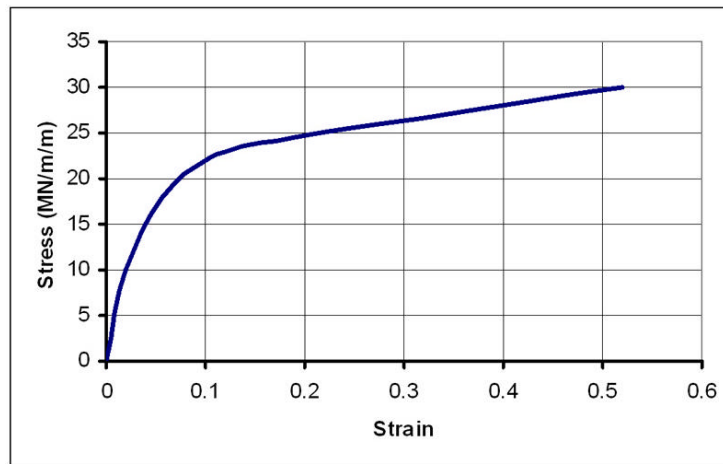


Figure 4: Material Curve for Bottle

4.0 PARAMETERISATION

Two types of parameterisation are used for the bottle design. Shape variables or general changes to the bottle geometry are defined using morphing technology in HyperMesh. Size variables, or changes to the bottle wall thickness, are also defined in HyperMesh. The definition of the shape variables requires input from the design team to ensure that the look and feel of the pack is maintained and that none of the variables will cause manufacturing problems. Size variables are defined based on knowledge of the manufacturing process.

4.1 Shape Variable Definition

The completed baseline model is subjected to modifications using HyperMesh mesh morphing technology. This is a highly interactive and accurate toolset for generating modifications to the geometry for use at the design optimization phase. Shape variables are defined with input from the aesthetic designers to find a range of possible “morph targets” which generate various possible shapes for the product.

All of the morph targets for the example pack are shown in **Figure 5**.

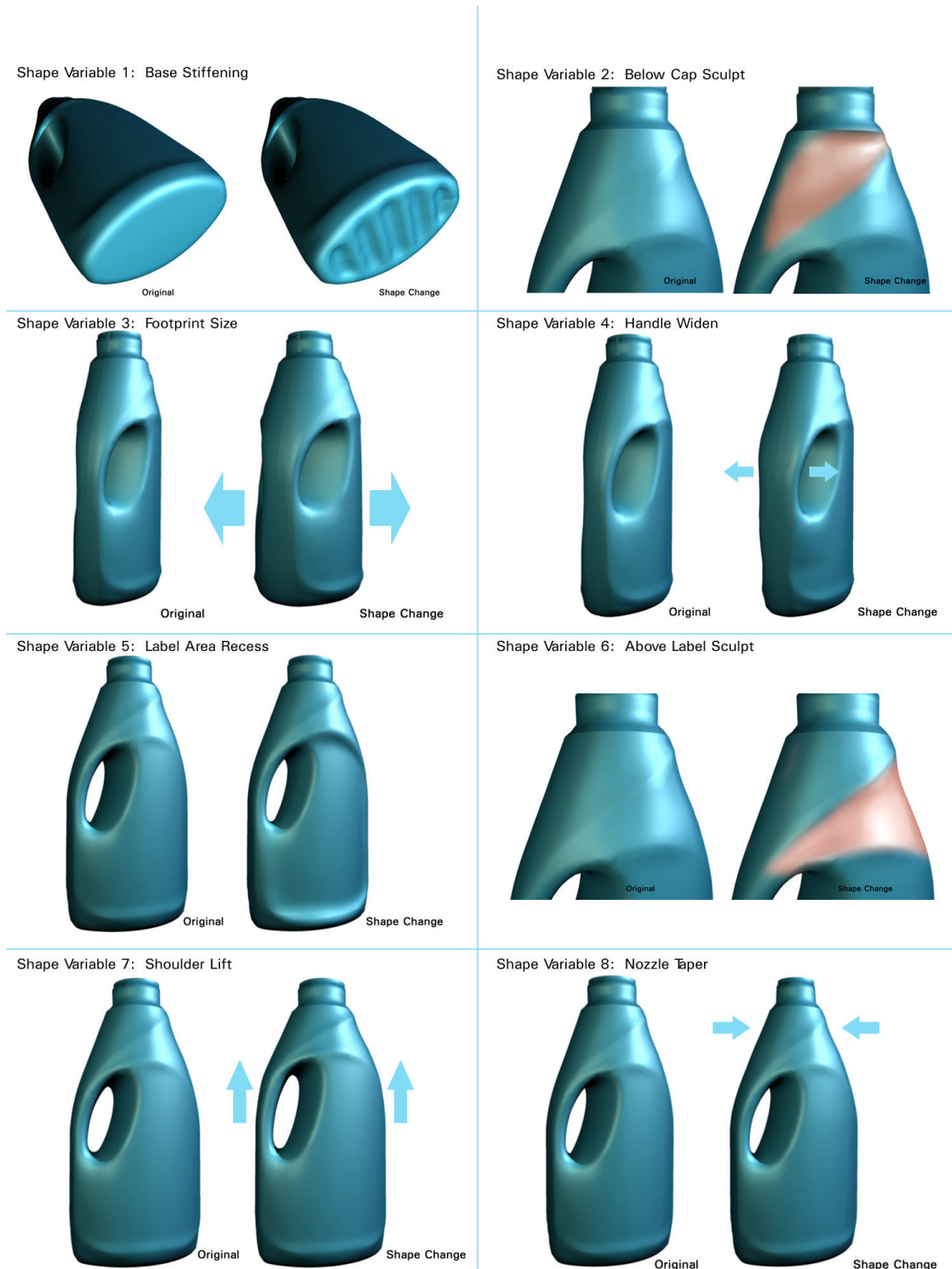


Figure 5: Morph targets for the example pack

4.2 Size Variable Definition

Size variables must be defined to represent potential changes to the parison thickness whilst capturing an approximation of the thinning during the blow moulding operation. To achieve a representative thickness distribution, the nominal parison thickness was multiplied by factors which decrease with increasing deflection of the parison material from the original undeformed state (**Figure 6**).

Control of the parison thickness in practice is limited to changing wall thickness in horizontal bands down the major axis. Design variables were therefore defined to parameterise wall thickness of the pack in achievable bands (**Figure 6**). The wall thickness gradient across the bands remains the same as the baseline design gradients and is maintained through defining equations relating the local thickness to the key thickness (**Figure 6**).

This is a general procedure which can be adopted for a wide range of packs and provides a link to maintaining manufacturing feasibility and capturing the key effects of the forming process in the simulation and optimization.

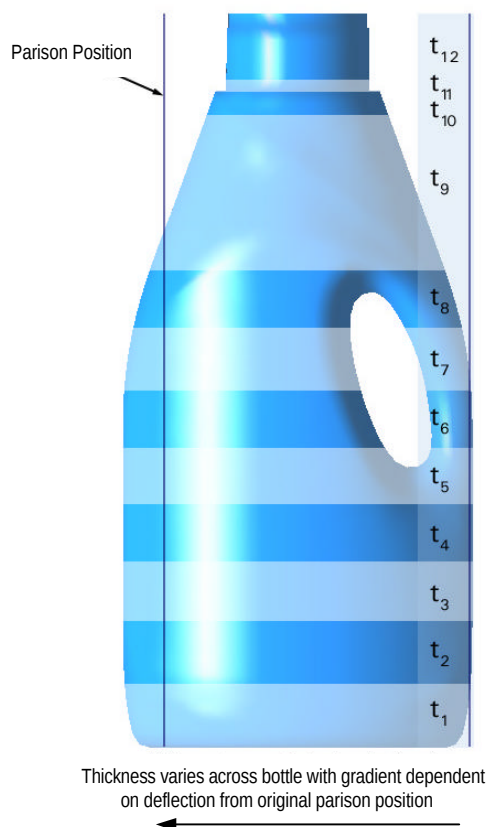


Figure 6: Definition of Size (Wall Thickness) Variables

5.0 BASELINE SIMULATION

Before proceeding with the design optimization process, testing and verification of the simulation procedure on the baseline design is necessary. The top loading surface is moved vertically downwards to capture the peak buckling load and the post buckling behaviour of the pack. Results from the simulation are presented in **Figures 7** and **8**.

The peak load capacity of the pack is influenced by the geometry, the redistribution of load due to contact with the loading platen and base plate, and the non-linear material properties.

The collapse response under top loading (**Figure 7**) demonstrates that buckling first occurs in the neck region. Load is then re-established (**Figure 8**) before the base of the bottle buckles.

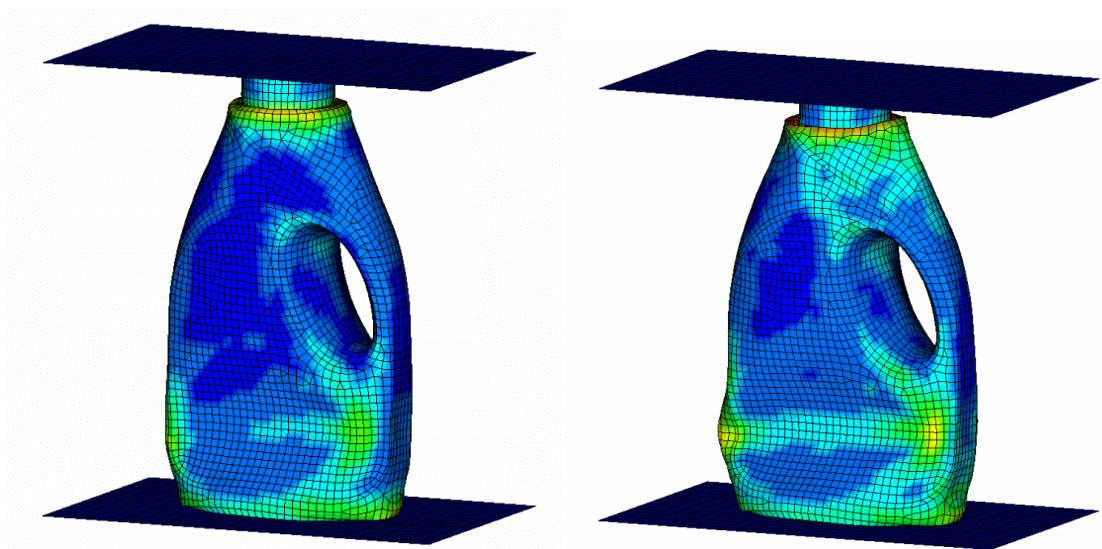


Figure 7: Von Mises stress plot of the baseline bottle during collapse simulation

A comparison of the predicted response with actual test data shows that the simulation environment accurately captures the real world response.

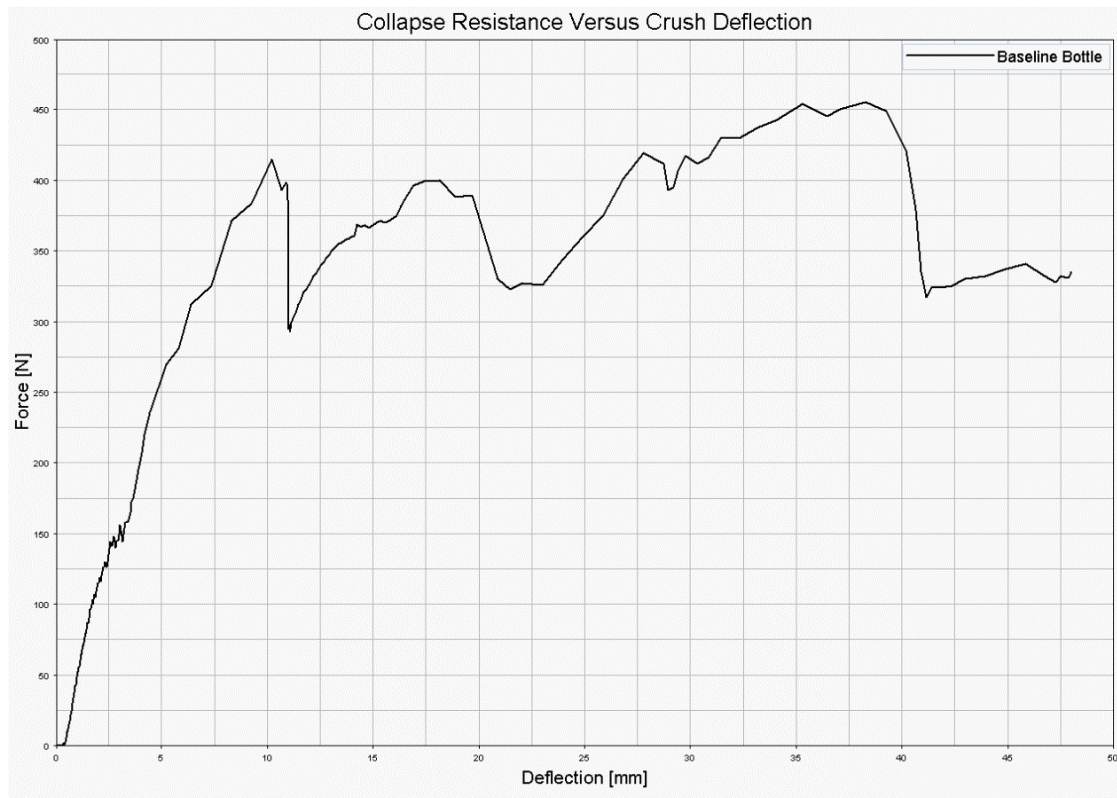


Figure 8: Collapse Force against Crush Displacement for Baseline Case

6.0 DESIGN OPTIMIZATION

The design optimization process is divided into two stages. A DoE study is performed first and then followed by a full non-linear response surface design optimization. The whole process is set up and controlled from StudyWizard, which automates the procedure and simplifies user input.

6.1 DoE Study

The primary objectives of the DoE study are to derive the sensitivity of the response of the structure to the design changes and to provide sample points in the design space. This discretisation of the design space can be used as the starting point for the response surface optimization process.

The DoE study is performed in two passes. The first pass is a screening exercise to reduce the number of design variables (**Table 1**). The design variables, which have least effect on the objective and constraints, (**Figure 9**) are removed to leave the key design variables for the optimization phase.

Variable	Nominal Run Value	Lower Range Limit	Upper Range Limit
Base Thickness (1)	0.95	0.85	1.05
Thickness level 2	0.96	0.86	1.06
Thickness level 3	0.97	0.87	1.07
Thickness level 4	0.98	0.88	1.08
Thickness level 5	0.99	0.89	1.09
Thickness level 6	1	0.9	1.1
Thickness level 7	1.01	0.91	1.11
Thickness level 8	1.02	0.92	1.12
Shoulder Thickness (9)	1	0.9	1.1
Top Thickness (10)	1.4	1.3	1.5
Lip Thickness (11)	0.7	0.6	0.8
Shoulder Top Thickness (12)	0.8	0.7	0.9
Base Ribs	0	0	3
Below Top	0	-3	3
Footprint	0	-3	3
Handle	0	-3	3
Label	0	-3	3
Above Label Sculpt	0	-3	3
Shoulder	0	-3	3
Nozzle	0	-3	3

All Dimensions in mm

Table 1: Design Variable Summary

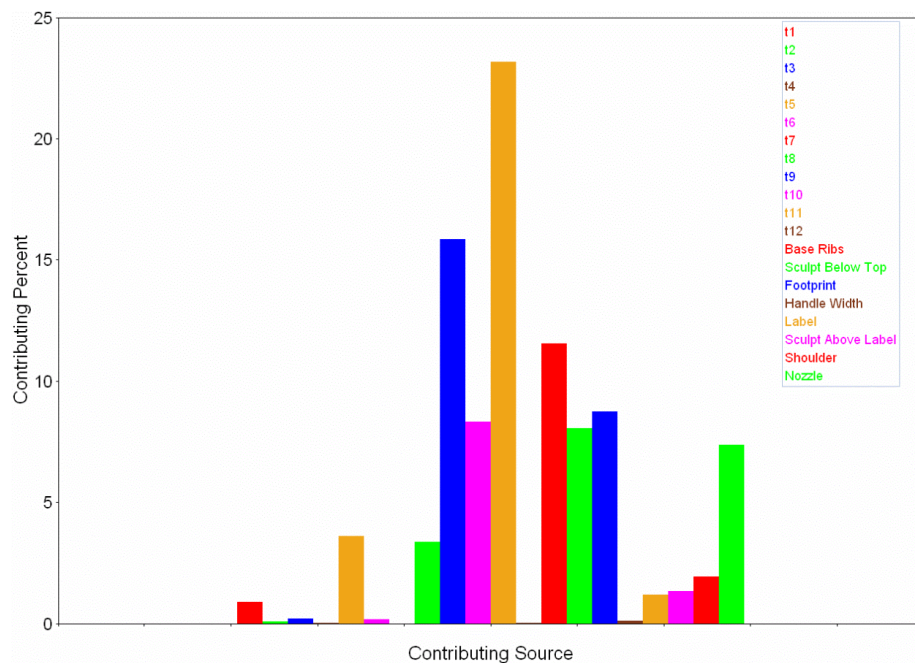


Figure 9: Anova Data from Fractional Factorial DoE

Figure 9 Identifies that the buckling capacity of the bottle is most influenced by the thickness at the top of the bottle. Significant sensitivity is also noted for global and local shape changes including: shoulder slope, footprint size and neck sculpting. A review of the main effects data also indicates how the upper and lower bounds of the design variables affect the response. For example, increasing the thickness variable, t_{11} increases the buckling capacity, whereas increasing the sculpt depth at the neck has the opposite effect.

Seven design variables were selected from the screening DoE and were taken forward for the optimization phase, which commenced with a Box Behnken DoE. This provides a more even sampling of the design space and is well suited to approximating the response surface to initialize the Optimization study. Main effect results from this study are shown in **Figure 10**. A total of 57 designs were generated and analysed to produce this data and discretise the design space.

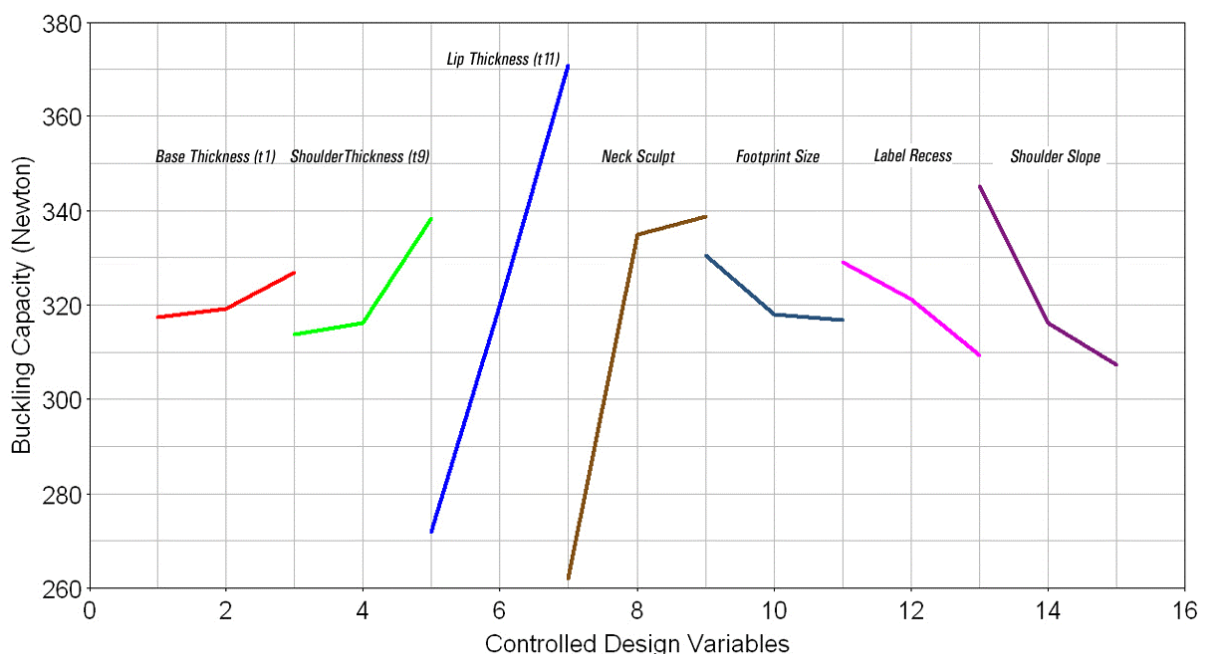


Figure 10: Main Effects on Buckling Capacity from Box Behnken DoE study

6.2 Design Optimization

The design optimization procedure finds an optimum combination of design variables to meet the objective (minimize mass) whilst satisfying the constraints (buckling capacity). This approach uses the discretised design space generated in the Box Behnken DoE study as the starting point.

The optimization generated a bottle design with the parameters summarized in **Table 2**. It is clearly demonstrated that design optimization can automatically provide the right mix of design parameters to save weight and increase performance.

Variable	Value (mm)
Base Thickness (t1)	1.0
Shoulder Thickness (t9)	0.8
Lip Thickness (t11)	1.1
Neck Sculpt (Shape Variable 2)	-0.6 (Pulled out)
Footprint Size (Shape Variable 3)	0.0
Label Recess (Shape Variable 5)	-0.3 (Pulled out)
Shoulder Slope(Shape Variable 7)	-3.0 (Shallower)
Response	Value
Mass	212g (c.f. 223g, reduction of 5%)
Buckling Capacity	490N (c.f. 420N, increase of 20%)

Table 2: Summary of Optimum Design

7.0 CONCLUSION

A clear need has been identified in the packaging industry for reliable design input early in the development process. The drivers for successful packaging design are many and conflicting, but the pack must always remain attractive to the consumer.

A design tool has been described and tested on a real world example, which can help bridge the gap between those involved in defining the right look and feel for the product and those involved in engineering a solution. The design tool generated a reduced mass design concept given a baseline example design already on the market as a starting point. A first pass design optimization yielded a 5% reduction in bottle mass, whilst exceeding the top-load capacity requirement.

The high level of automation in the process facilitates rapid delivery of the design information. Advanced visualization tools and intuitive user interfaces make this information highly accessible to all of the design team.

The marketing team and product designers can get timely information about how to maintain or improve the appearance of the pack without compromising manufacturing or transportation performance. Careful choice of shape changes for the pack becomes a collaborative process between structural, manufacturing and product designers, with the design tool providing independent review. A by-product of the optimization process is readily accessible design sensitivity information, clearly indicating which shapes are beneficial to the pack performance.

Extraction of the best geometry, which meets the requirements of all of the team is the last phase in the process and the resulting CAD data can be taken forward for prototyping.

The tool provides potential for reducing design cycle times, through facilitating definition of strong design concepts early in the design process, which require fewer down-stream modifications. Close team collaboration is forced by the tool: creative, marketing, manufacturing and engineering professionals are all called upon to review the proposed shape changes and understand their impact on the design.

8.0 REFERENCES

- [1] Altair HyperWorks Version 5.1, Altair Engineering Inc., 2002**
- [2] LS-DYNA Version 960, LSTC, 2002**



This technical paper was first presented at an Altair Engineering event.

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