Design Development of a New Consumer Personal Care Product Pack Driven by Optimization

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Abstract

Packaging designers must constantly inject innovations to attract consumers in a constantly evolving and highly competitive market. Keeping ahead of the competition by bringing new and exciting products to market fast, and at the necessary level of quality, presents a major engineering challenge. A new deodorant pack development process is described, which introduces advanced simulation and optimization technology into the concept development phase. Detailed predictions of interacting parts in a mechanism assembly are made possible through use of advanced simulation technology. Design optimization is then employed using the modelling as a virtual testing ground for design variants. The approach provides clear design direction and helps to improve performance and reduce uncertainty in the development process.

Keywords: Optimization, Packaging Design, LS-DYNA, HyperWorks

1.0 Introduction

Unilever’s 400 brands span 14 categories of home, personal care and foods products. The brand portfolio makes Unilever leaders in every field in which they work. It ranges from much-loved world favourites including Lipton, Knorr, Dove and Omo, to trusted local brands such as Blue Band and Suave.

Unilever aims to constantly enhance its brands through investment in innovation. Unilever invests €1 billion every year in cutting edge research and development, and have five laboratories around the world that explore new thinking and techniques to help develop their products.

Consumer research plays a vital role in the Unilever brands' development. Constantly developing new products and developing tried and tested brands to meet changing tastes, lifestyles and expectations. Strong roots in local markets also mean we can respond to consumers at a local level.

Unilever create and share wealth, invest in local economies and develop people's skills – both inside its organisation and in the surrounding communities. Today Unilever employs 206,000 people in 100 countries worldwide, and supports the jobs of many thousands of distributors, contractors and suppliers.

The health and personal care category at Unilever comprises a wide range of leading brands including the Lynx male grooming brand discussed in this paper. Domestos, Lux and Mentadent are other leading brands in the category.

The Lynx brand **(Figure 1)** has established itself as the world's top male grooming brand by coming up with a constant stream of new ideas to attract consumers. Each year, for example, Lynx launches a new deodorant fragrance. The brand has also ventured into a number of new areas, including shower and hair gels. Award-winning ads and marketing are equally adventurous. First launched in France in 1983, it now holds the number one position in several European and Latin American markets, plus has an increasingly powerful presence in Asia and the US, where it was launched in 2003.

As part of the brand improvement initiative, advanced computer aided engineering (CAE) and optimization was introduced into the latest packaging design development programme.

Figure 1: Unilever Lynx Personal Care Product

CAE has become increasingly widely used in the packaging industry to assist in design. In the past, CAE was used as a forensic tool to assess problems arising in final designs. The automotive industry has lead the way in employing CAE early in the design process to help direct the development and even to generate new concepts. This approach has been adopted on the Unilever project and has included advanced non-linear CAE to accurately predict concept performance and derive new design concepts with optimization.

To employ CAE in the design process, a thorough review of the existing process was required. As already discussed, the design of injection moulded parts for consumer packaging requires satisfaction of a diverse range of often conflicting demands. Structural design, the focus of the CAE work, is only a part of the picture. Structural performance is however, critical to the success of the product. The level of understanding offered by CAE in the process and the added efficiency of reducing prototype generation and testing can often facilitate more freedom in development of innovative products. The challenge for this project was defining aspects of the wider design process where CAE could be employed to enhance structural performance and integrate with the fast paced concept development. Two general application areas were defined:

- Stiffener layout optimization for load carrying structure (e.g. button, cap)
- Top Load performance and optimization of the assembly

Once these CAE processes are defined and tested, the level of expertise required to use them can be drastically reduced by creation of process tools, designed to put the technology in the hands of the wider design community.

The application of CAE in the design process has provided new detailed insight of the system performance, reduced the need for expensive prototypes and made a significant contribution to the quality and success of the design. Through application of the technology, it has been identified that better and more comprehensive material data libraries are required. The availability of this data before a project commences will significantly enhance the efficiency and accuracy of the CAE predictions.

2.0 The Lynx Product Development Challenge

Unilever uses CAE early and throughout the development of Lynx, since the advantages of the technology had been seen in assessment of previous pack designs **[1]**. To make maximum use of the CAE advantage early in the process, topology optimization was employed to derive stiffening concepts for the button and sleeve. Through the rest of the development, detailed models of the cap assembly were developed and used to test and enhance the robustness and quality of the design.

To get maximum value from the technology in the dynamic development process, a good appreciation of the manufacturing, assembly usage and aesthetic requirements for the pack was required. Once understood, all of these design drivers needed to be accounted for in any geometric changes. Manufacturing, for example, places constraints on how material can be added to the walls (stiffening) by virtue of tooling draw and slide directions.

To accurately capture the loading response of the pack as the design developed, advanced non-linear analysis was required. Material characterisation and contact between parts in the assembly were both required to achieve correlation with real world response. These virtual models could be used for a range of loading assessments from topload to usage cases.

3.0 CAE Inside the Design Process

3.1 Design Optimization for Concept Development

The CAE technology suitable for free form optimization early in the design process is provided in Altair OptiStruct **[2]**. A range of conceptual design optimization tools are available which allow derivation of structure from very limited information available at the early development stage. Topology optimization is one of the tools available in OptiStruct and was used in the Lynx development to derive stiffener layout concepts for the cap and sleeve.

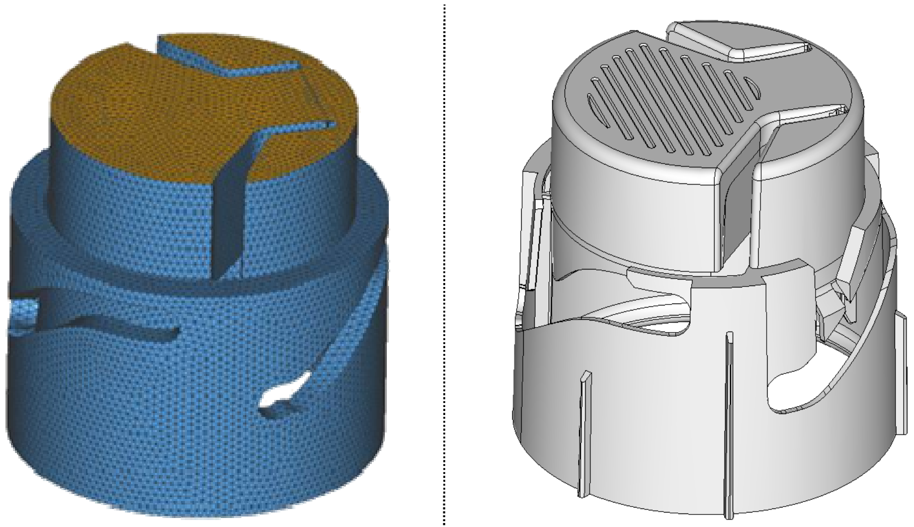
3.1.1 Overview of topology optimization

Topology optimization was performed using Altair OptiStruct. OptiStruct provides a method for free form concept definition given only a design space, loading and optimization formulation (usually to minimise mass whilst respecting stress or stiffness constraints). Topology optimization works well early in the design process and provides a scientific method for concept definition.

For the Lynx cap, topology optimization was used to define material layouts for stiffening the button and optimizing the load path through the side walls. For the Lynx sleeve, topology optimization was used to define an optimum stiffening arrangement around the circumference, given total freedom of design.

3.1.2 Design Space Definition

The design space was generated to encompass the original design concept for the cap and to expand the useable volume into zones unobstructed by the mechanism or functional requirements for the pack. The design space was modelled in CAD and then meshed using 3D tetrahedral elements. Refinement of the mesh was defined to provide sufficient resolution for derivation of thin stiffening features.



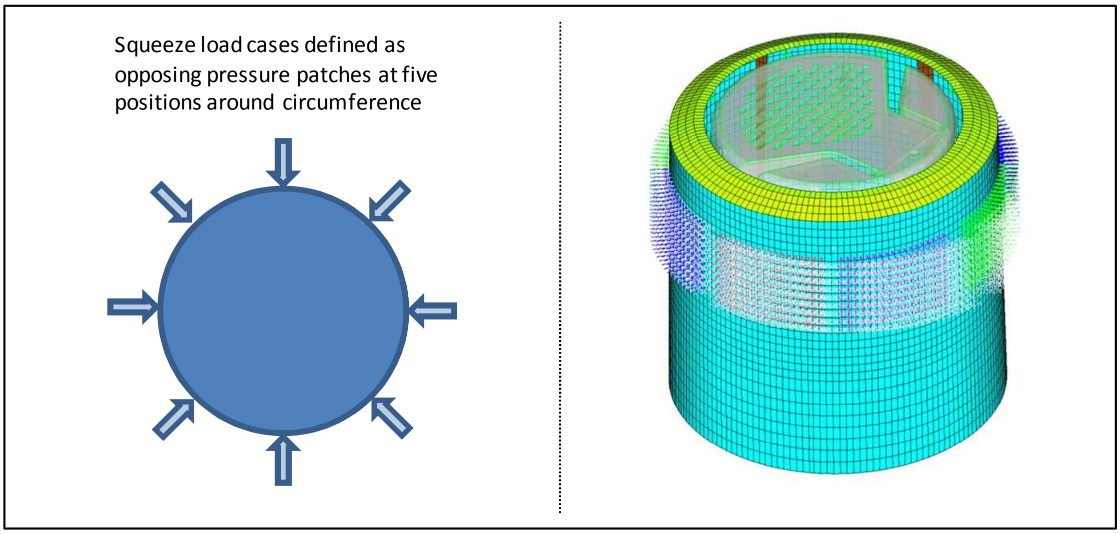
Design Space Model

CAD Model of Cap

Figure 2: Comparison of Cap Topology Design Space with Concept Design Loading definition

Cap loading was defined as a uniform pressure over the top face of the cap to represent load from pallet cases during transit. This type of loading is the main design driver for strength performance. Constraints were defined as an annulus of pinned constraints in the vicinity of contact between can and cap.

For the Sleeve, squeeze load cases **(Figure 3)** were defined to derive designs which would improve the consumer perception of high stiffness and hence quality during usage.



Squeeze load cases defined as
opposing pressure patches at five
positions around circumference

Figure 3: Example Loading and Boundary Condition Set-Up for Upper Squeeze Load Case on Lynx Sleeve

3.1.4 Topology optimization set up and parameters

Topology optimization was set up to minimise the mass of the design material subject to constraints on stiffness and stress. Draw direction constraints were imposed for the button portion of the cap design space to constrain rib growth in the vertical direction.

3.1.5 Topology results

Topology results are presented as isosurface contours of density **(Figure 4)**. Initial interpretations of the designs and descriptions of the suggested features are also provided. The topology results provided a free form idealistic design geometry which had to be studied and interpreted to derive features suitable for production.

The topology optimization identified stiffening layouts for the button which were carried over directly into the design. In addition to providing a stiff button structure, the optimization solution was constrained to facilitate minimal modification for manufacturing feasibility. Initial prototypes confirmed that stiffening of the button improved not only the feel of the button itself but also the stability of the locked button on the support lugs.

The topology results for the rest of the cap were used to help identify areas where additional thickness could be added in the mould and where material could be removed.

3.2 Design Development and Sensitivity Assessment

Once the general layout requirements had been derived using OptiStruct, a more detailed parametric model was developed to investigate a series of 'what-if' scenarios derived from Failure Mode Effects Analysis (FMEA).

CAD data was supplied by Unilever for each structural part in the assembly. Altair HyperMesh **[2]** was used to read this data and develop combined solid and shell element models. These models were developed to provide a high level of geometric fidelity so that stress gradients could be captured and load could be transferred appropriately through contacting components. LS-DYNA **[3]** was used to solve the CAE problem and the implicit solution sequence was chosen to suit the static loading requirements.

Design sensitivity analysis was performed to assess the effects of different loading scenarios, geometry changes and material options. The different top loading scenarios identified areas for reinforcement in the support pins, the button and the sleeve. The effects of different material properties on global stiffness and stress could be measured and ranked against cost. This provided strong metrics for material selection decisions.

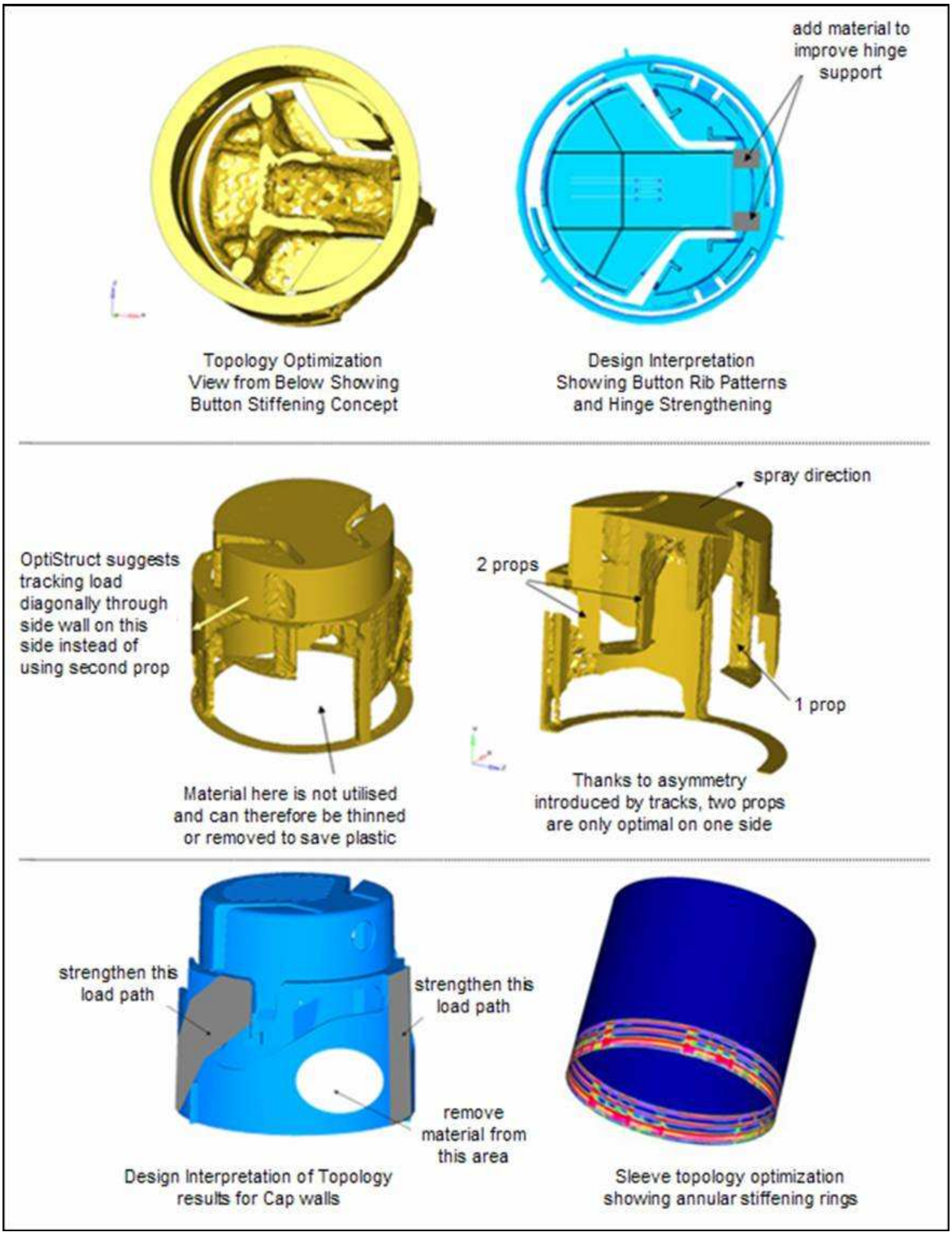
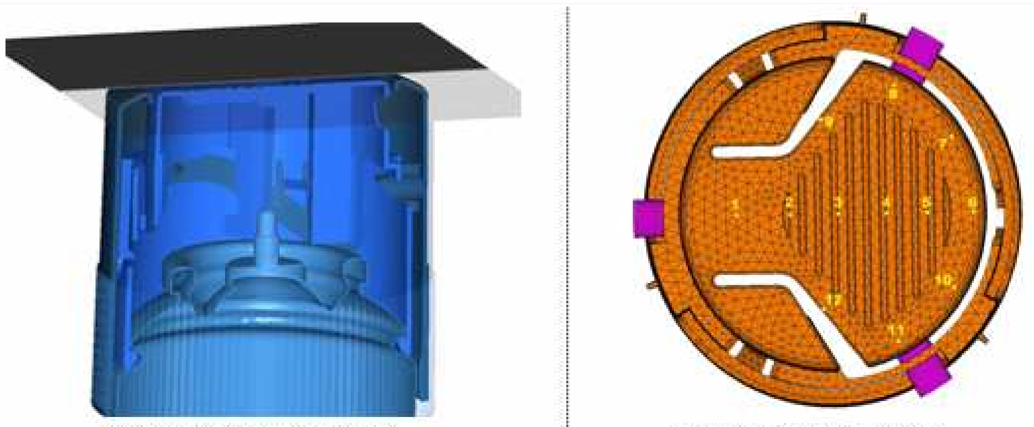


Figure 4: Topology Optimization Results for Stiffening of Button and Sleeve

3.2.1 Lynx Cap

For the Lynx Cap, the objective of building detailed models was: to understand the sensitivity of the design performance to variations in loading **(Figure 5)**; and to use the CAE environment to make changes and improve performance. As noted in the introduction to this section, all suggested modifications were checked against down-stream production requirements.



Detailed Top Load Analysis CAE Model

Array of Point Load Locations for Button Sensitivity Analysis

Figure 5: Illustration of Uniform Topload Test on Full Lynx Assembly

3.2.2 Lynx Sleeve

For the Lynx Sleeve, less structural design freedom was available as the geometry was predominantly dictated by the pack styling. There were also further issues relating to cycle times and manufacturing practicalities which prevented direct implementation of the OptiStruct annular stiffening concept **(Figure 4)**. Available sleeve design modifications for consideration were:

- Thickening of the walls
- Changing the number of vertical stiffening ribs
- Replacement of the sleeve material

3.2.3 Results and Correlation

The sensitivity studies could only be performed after correlation of the baseline model response with real world testing. The cap assembly exhibited complex behaviour, which was driven by contact of interacting components and non-linear material response. A detailed comparison of the global and local response of the system was made. The best measure of the accuracy of the modelling was provided by the force deflection behaviour under top load. A comparison of real world test measurements and analysis results for this response type is provided **(Figure 5)**. The plots demonstrate good correlation between general characteristics of the curves, initial stiffness and collapse capacity.

i) Lynx Cap

The sensitivity of the cap top load capacity to the position of the load **(Figure 5)** for the initial design concept was extremely high **(Figure 7)**. This was largely due to the flexibility of the button initially and its tendency to slip off the supporting sleeve lugs. After incorporation of the stiffening suggested in the topology optimization, the sensitivity was reduced and the robustness of the design greatly improved. Further improvement was then introduced through local design changes in the cap, which could be understood and verified by the CAE analysis.

ii) Lynx Sleeve

A matrix of runs was set up using design of experiments (DoE) technology in HyperStudy **[2]** to explore sensitivity to the variables defined in **Section 3.2.2**. The factorial DoE provided a thorough method for quantifying and recording the effects of each parameter.

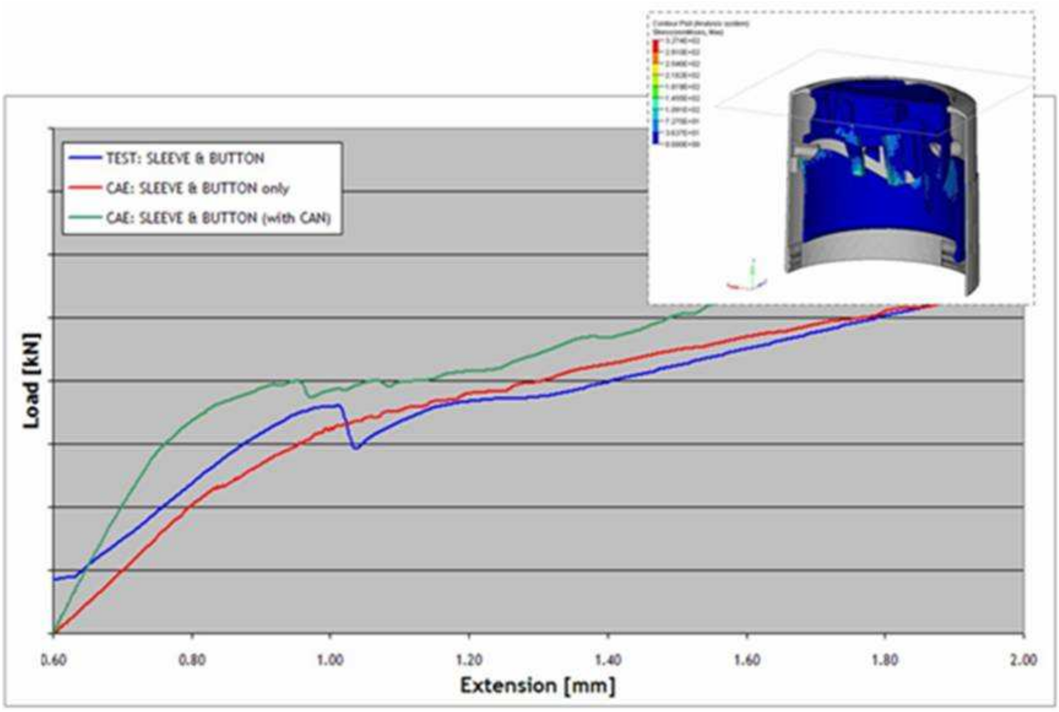


Figure 6: Lynx Uniform Topload Test - Correlation between CAE & Test Data

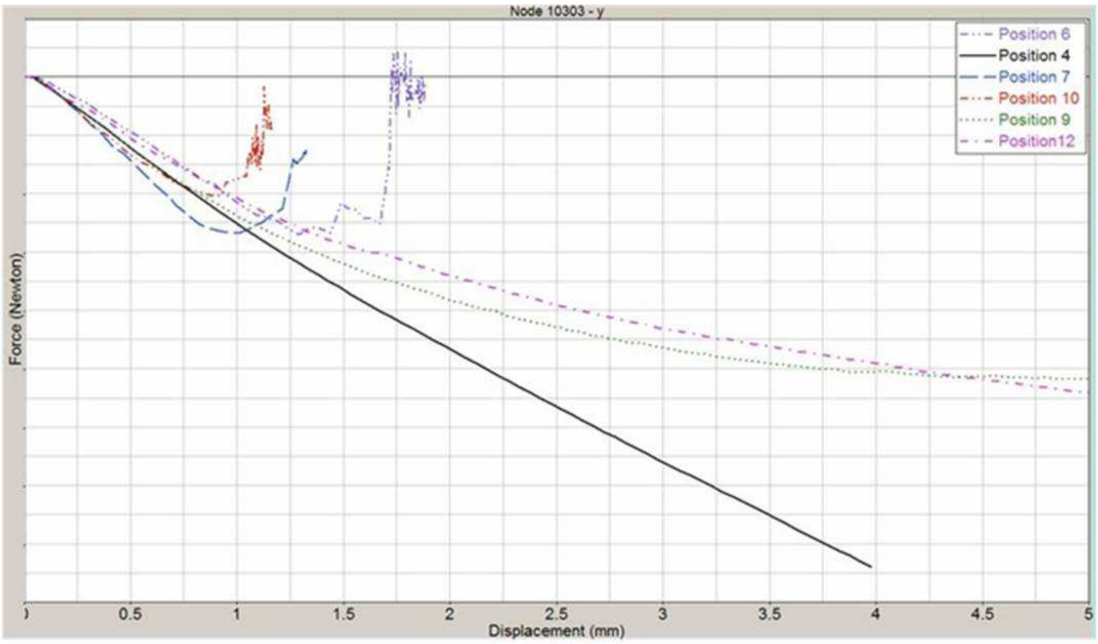


Figure 7: Investigation of effects of concentrated button loads

Sensitivity results are presented for vertical rib count and material change options **(Figures 8 and 9)**. Structural performance characteristics were quantified along-side mass and cost variation. A linear relationship between wall thickness and stiffness was confirmed. There were other issues associated with cost and manufacturing efficiency for the thicker wall options, which lead to rib count and material options gaining higher priority.

The key characteristics found from the vertical rib count studies were:

- A significant drop-off in stiffness improvement above more than 4 vertical ribs
- The maximum feasible stiffness increase (with a full set of 9 vertical ribs) was a factor of 1.2 greater than the stiffness of the sleeve without ribs

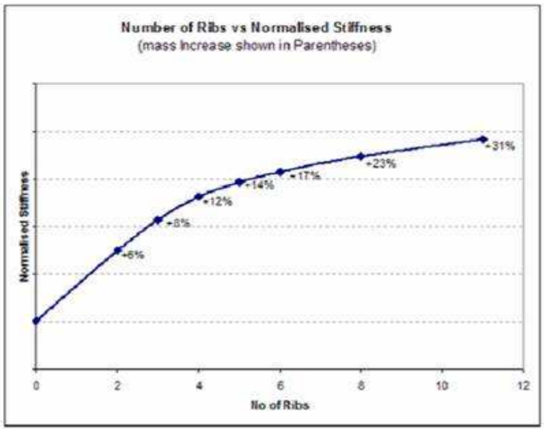


Figure 8: Stiffness Sensitivity versus Number of Ribs

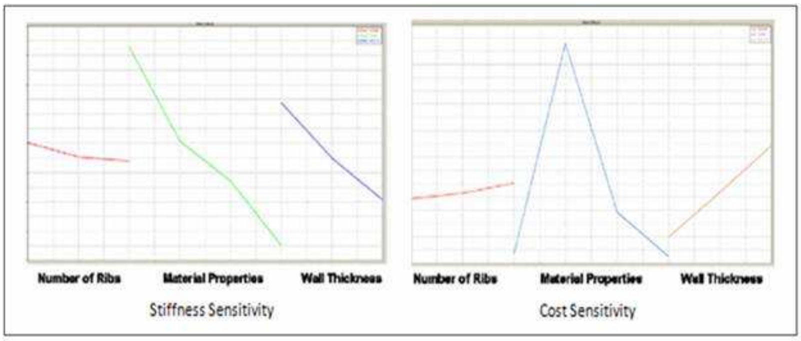


Figure 9: Main Effects Plots for Compliance Response (small numbers equate to higher stiffness) and Cost Response

The sensitivity plots demonstrated that the stiffness of the sleeve was most sensitive to material change and least sensitive to the number of vertical ribs. This was consistent with the topology findings for the sleeve, which clearly defined annular stiffening rings as the optimum solution. Vertical ribs were however the only practical option.

Greatest cost sensitivity came from material change. Notably, the most expensive material did not have the best mechanical properties for squeeze stiffness. Wall thickness and number of ribs drove similar sensitivity to that found for mass.

3.2.4 Summary of final design and conclusions

The design optimization and sensitivity studies fed into definition of a final cap assembly design **(Figure 10)** which provided robust performance. The topology optimization derived structure which could offer high stiffness with minimal additional material, whilst the sensitivity studies provided guidance on final design modifications which improved the feel of the rotating sleeve and improved the button locking mechanism.

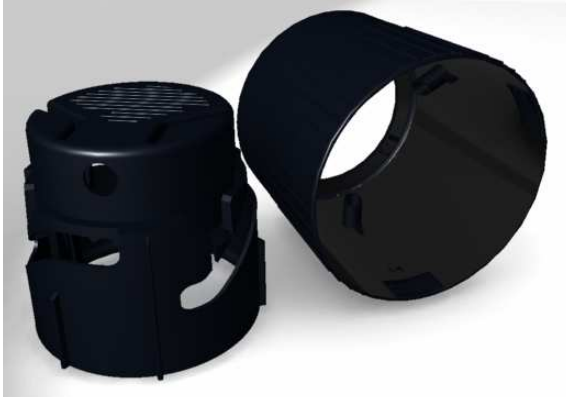


Figure 10: Final Design Geometry

The final Lynx design represents a significant departure from traditional consumer care deodorant products. The innovative locking mechanism provides strong aesthetic and functional appeal to consumers. The design represented many major challenges typical of new product development. Advanced analysis provided a relatively low cost option for exploring unknown design options and assisting in finding ways of introducing efficiency and robustness into the final design. Through a combination of geometric enhancements and careful choice of materials, the multi-functional system was developed to a high level of quality, proved to be highly cost-effective and demonstrated strong shelf appeal.

4.0 Bringing the Capability to the Design Community

4.1 Process definition

Once the CAE analysis process has been defined, correlated and completed, it can be mapped out and automated for use by a wider, less specialised user base. This can only be successful if a specific activity with known scope is chosen and fully specified. Once this has been done, the process can be developed into a software system which integrates with HyperWorks and the solvers to guide the user through the problem set-up with a simple Graphical User Interface (GUI).

The automated process tool developed on completion of the Lynx development process guides the user through the standard CAE workflow process for the set up of a Top Load analysis. Automation of the process brings many advantages to the design function including

- Standardisation and repeatability of the CAE process
- Controlled non-expert GUI so that the wider design community can access the technology
- Corporate wide deployment with centrally controlled compute resource

The workflow process followed for the set-up of a TopLoad analysis has five main stages **(Figure 11)**. Original part geometry must be converted to CAE models in the first stage. Fully descriptive material properties must then be defined for all of the parts in the assembly. Top load platen kinematics are then introduced and the simulation submitted to the server. Once the simulation has completed automatic reporting of a subset of the wealth of analysis results can be executed.

This mapping of the process is the first step in implementing a software system which guides a non-expert user through the process. The next step is construction of the GUI and supporting routines. Emphasis was given to producing a simple, familiar Microsoft Windows style interface **(Figure 12)** with access to a specific set of analysis tools relevant to the top load set-up process. A high level of graphical content was introduced in the GUI to communicate in simple terms to the user the objective of each stage in the process. Detailed documentation in the form of an on-line help system, visible and dynamically updating as the user proceeds was also included.

4.2 Example automated process

To show how the automated process is executed using the GUI, an example of a Lynx top load analysis is provided **(Figure 12)**. Description of each of the main stages outlined in section 4.1 is provided together with snap-shots of the user interface at each stage. The analysis set up process from CAD import to CAE simulation submission can generally be completed in less than one hour. The wall clock time to complete the simulation itself varies from problem to problem and server workload, but typically completes in 1 to 2 hours.

The process fully implements a complete non-linear collapse load analysis with non-linear materials and contact between assembly components. The key reporting capability is a force-deflection trace, which has been shown to correlate with physical test for a range of different assemblies (e.g. **Figure 6**).

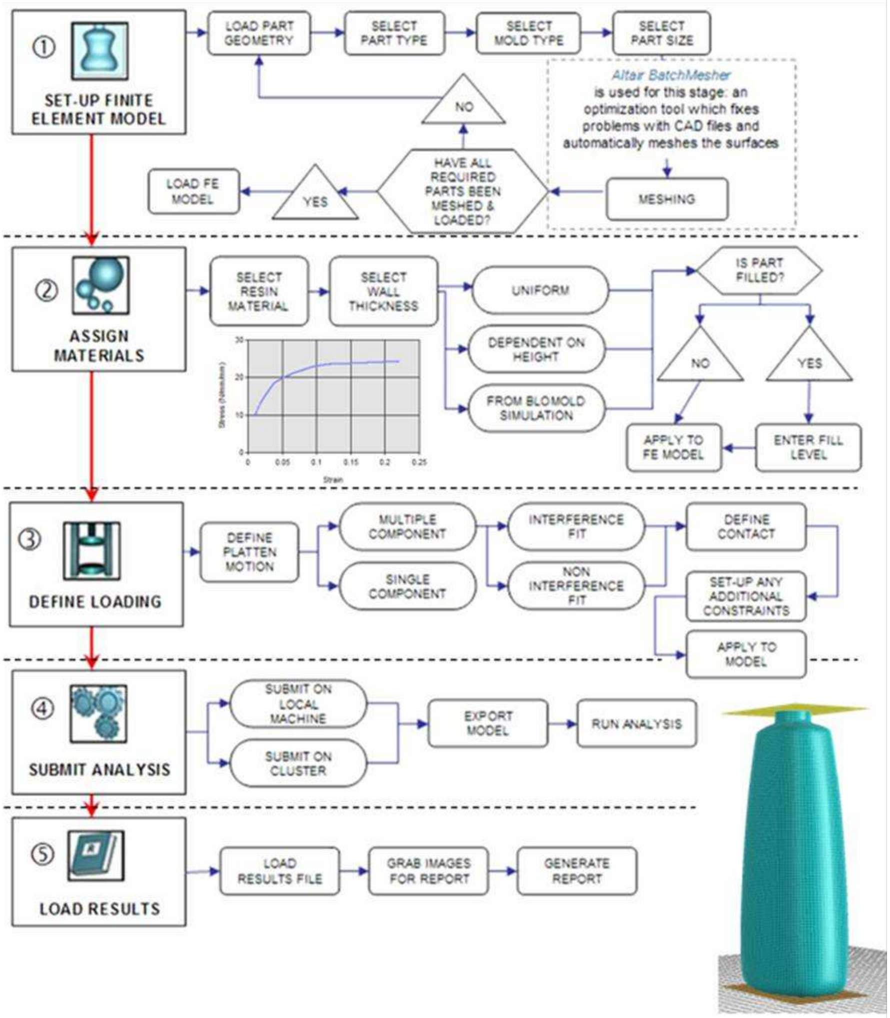
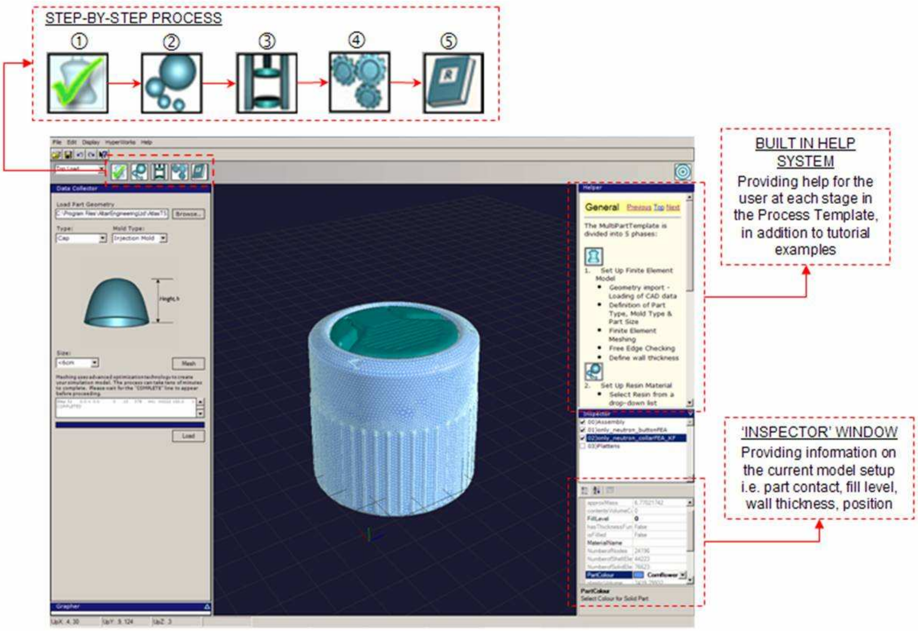


Figure 11: Workflow Process Involved in Setting up a CAE TopLoad Analysis



BUILT IN HELP SYSTEM
Providing help for the user at each stage in the Process Template, in addition to tutorial examples

'INSPECTOR' WINDOW
Providing information on the current model setup i.e. part contact, fill level, wall thickness, position

Load Part Geometry: C:\Program Files\AltairEngineering\Ltd\AltairT1

Type: Cap

Mold Type: Injection Mold

Size: <6cm

Meshing uses advanced optimization technology to create your simulation model. The process can take tens of minutes to complete. Please wait for the "COMPLETE" line to appear before proceeding.

The MultiPartTemplate is divided into 5 phases:

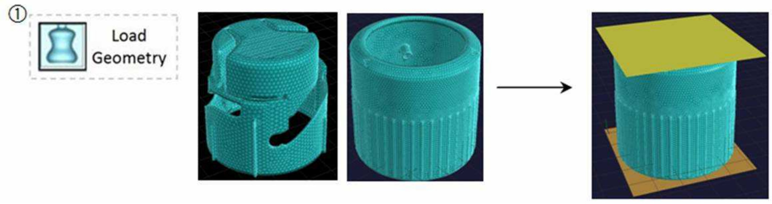
1. Set Up Finite Element Model
    - Geometry import - Loading of CAD data
    - Definition of Part Type, Mold Type & Part Size
    - Finite Element Meshing
    - Free Edge Checking
    - Define wall thickness
2. Set Up Resin Material
    - Select Resin from a drop-down list

☑ 00)Assembly
☑ 01)only_neutron_buttonFEA
☑ 02)only_neutron_collarFEA_KF
☐ 03)Plattens

FillLevel 0

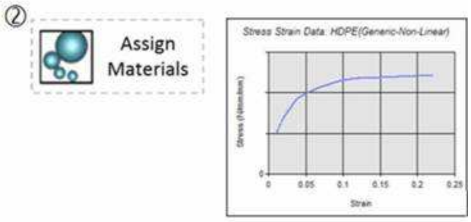
Figure 12: Illustration of the Process Template GUI

STAGE 1:



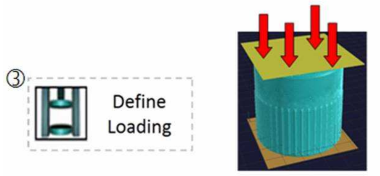
Part geometry is imported into the template, and an FE model is created using Altair BatchMesher. This process is repeated until all parts are loaded and fully meshed. The template automatically imports loading plattens which surround the FE model, to create a topload assembly.

STAGE 2:



Resin material is selected from a comprehensive list within the template, and applied to each selected part. The Stress-Strain curve for any selected material can also be reviewed on-screen.

STAGE 3:

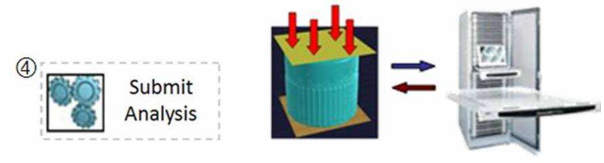


Platten motion is defined by selecting the relevant assembly type from a drop-down menu. The type of assembly dictates the platen kinematics for the simulation. Assembly types are:

1. Single Component
2. Filled Packs & Multiple Components (Interference Fit)
3. Multiple Components (no Interference Fit)

Contact is also set up by selecting options for part-to-part contact pairs within the template.

STAGE 4:

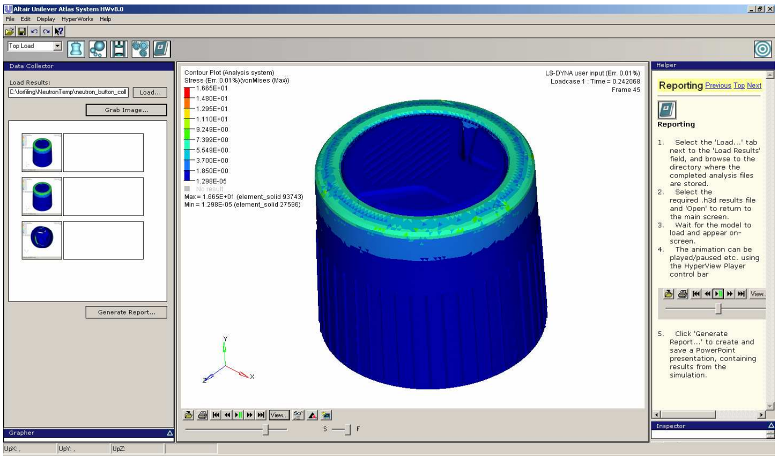


The CAE Top load model is ready to be saved and exported. The Topload analysis can be submitted on a local machine or on a cluster (e.g. an Altair OptiBox).

STAGE 5:

On successful completion of the analysis stage, the Reporting section of the Process Template **(Figure 13, 14)** allows the user to create and save a PowerPoint file containing results and animations from the simulation.

A HyperView results (.h3d) file is automatically created upon completion of the analysis, and this file is then loaded into the Process Template. Once loaded into the template these results can be viewed (played/paused etc.) on screen using animation controls, and the user can grab screen images to add into the PowerPoint report which can be saved after this simple post processing exercise.



Load Results: C:\forfiling\NeutronTemp\neutron_button_coll Load...

Contour Plot (Analysis system)
Stress (Err. 0.01%)(vonMises (Max))
1.665E+01
1.480E+01
1.295E+01
1.110E+01
9.249E+00
7.399E+00
5.549E+00
3.700E+00
1.850E+00
1.298E-05
No result
Max = 1.665E+01 (element_solid 93743)
Min = 1.298E-05 (element_solid 27596)

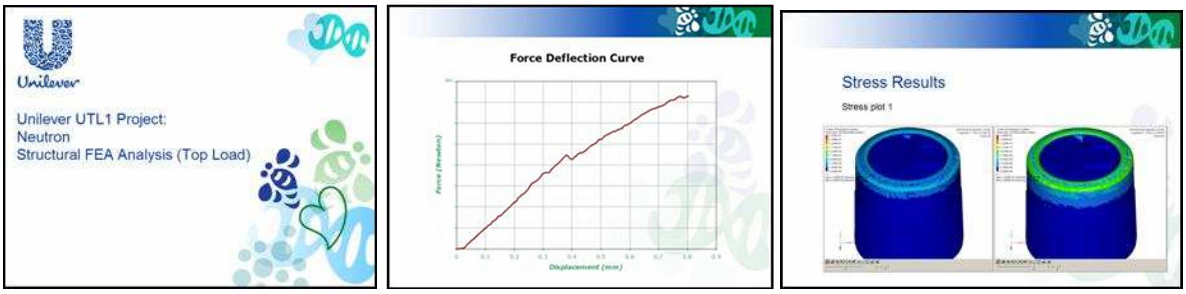
LS-DYNA user input (Err. 0.01%)
Loadcase 1 : Time = 0.242068
Frame 45

Reporting Previous Top Next

Reporting

1. Select the 'Load...' tab next to the 'Load Results' field, and browse to the directory where the completed analysis files are stored.
2. Select the required .h3d results file and 'Open' to return to the main screen.
3. Wait for the model to load and appear on-screen.
4. The animation can be played/paused etc. using the HyperView Player control bar
5. Click 'Generate Report...' to create and save a PowerPoint presentation, containing results from the simulation.

Figure 13: Illustration of the Reporting section of the Process Template



Unilever UTL1 Project:
Neutron
Structural FEA Analysis (Top Load)

Force Deflection Curve

Stress Results

Stress plot 1

Figure 14: Example of an automatically generated PowerPoint presentation

6.0 Conclusions

The Lynx cap development programme has demonstrated how the combination of creative design and advanced analysis can combine to provide innovation, efficiency and highly marketable products. It has been demonstrated that advanced CAE can keep pace with the design development process and that a strong contribution to up-front concept definition can be made.

As design optimization and detailed analysis were deployed on the project, deeper understanding of new designs was obtained. Sensitivity of the robustness and tactility of the product was derived through highly efficient re-analysis with parametric changes. The design optimization and detailed analysis process has allowed exploration of unknown design options and reduced the need for expensive prototypes.

Having demonstrated the process and advantages during the development programme for Lynx, an automated process was developed with Unilever to allow analysis by non-specialist users. Automation of the process also allowed increased efficiency in problem set up and results extraction. The automation was generated so as to be user friendly for CAD users and integrated with the Unilever Compute resources.

Material characterisation was identified as a key requirement for furthering the use of CAE methods in the Unilever design process. Correlation of top load response with predicted results was carried out throughout, but further testing of materials to fully characterise the models used in the analysis was defined as a key area for further study.

7.0 References

[1] **'An Advanced Method For Optimizing Packaging Design'**, Rich McNabb, Unilever and Martin Kemp, Altair, Altair Engineering Technology Conference, 2002.

[2] **'HyperWorks Version 8.0'**, Altair Computing Inc., 2006.

[3] **'LS-DYNA Version 971'**, LSTC, 2006.

[4] **'Unilever Atlas Process Automation System'**, Altair Engineering Ltd & Unilever UK Ltd, 2007