ABAQUS for Package Development at Procter & Gamble

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Abstract: Automation of analysis routines for designing packages has lead to the development of the Virtual Packaging System. Through computer automation, the time required to do virtual testing of product designs can be greatly reduced. Using commercially available software, a customized interface was developed to automate the virtual analysis of bottle geometry. The customized interface guides the analyst through the process while automating the geometry healing, meshing, solution, and reporting steps. The analyst is free to focus on the physical parameters of the design problem rather than the non-value-added steps of setting up analytical solutions. The automated solution results in significant productivity gains while improving repeatability and reliability of the analysis.

1. Introduction

Procter & Gamble, P&G, is a leader in the consumer products industry. Three hundred of the world’s most recognized brands are P&G brands. Tide™, Pampers™, Crest™, Charmin™, Pantene™, Old Spice™, Pringles™, Cover Girl™, and Bounce™ are just a few of these brands. P&G employs over one hundred thousand people world wide with sales of $39 billion in 2001. P&G sells products to 5 billion consumers in over 140 countries. P&G operations exist in more than 70 countries.

A huge diversity of products provides big opportunities for our analysis community. P&G analysts typically model difficult materials. Paper and plastics are the main area of focus with very little emphasis on modeling traditional materials such as steel. The primary exception is the design of custom manufacturing equipment.

The objective of this paper is to share one primary area of P&G analysis, plastic bottle design.

2. History of ABAQUS at P&G

ABAQUS was first used at P&G in 1985 via a leased line to a Boeing super computer. This was the first attempt at using FEA for packaging or anything else at P&G. From that small start, grew a sizable and highly developed system that we called the Integrated Packaging System, IPS. Packaging analysis was first and it has been the cornerstone from which FEA technology has grown within P&G. Previous engineers had the vision to create something from this relatively new technology. Applying FEA to plastics was not commonplace in those days.

Now ABAQUS is widely used in P&G around the globe. Analysts can share results and collaborate with colleagues in all of our technical centers around the world. The biggest growth in ABAQUS has been
within the last few years. P&G has embraced the technology and sees its strategic importance for achieving better solutions and ultimately better products for the consumer in less time.

Business units within P&G are using this technology to solve highly diverse problems from designing bottles and caps to lipstick applicators to Swiffer™ mops and many more. ABAQUS is also used for designing and optimizing production equipment. Many of our products are made on custom designed manufacturing lines. However, the focus of this paper will be on packaging analysis.

3. **Strategy for FEA Use in Packaging Design**

Speed is important. A tremendous number of steps are required to set up a model and it can take many days to complete a design analysis. This is too long. A system that delivers answers in less than 24 hours is required to provide design direction in our development process. Waiting a week for an answer is prohibits rapid innovation of bottle designs. The prevailing strategy in our packaging analysis systems is rapid completion of the work.

Typically, design direction is what the package developer needs. This is key to how the analysis system is designed and used. Since only direction, not precision, is sought, the analysis problem is simplified. Many times package designs are evolved to give a fresh new appearance. In these cases, relative performance to the old design is critical.

To get the work done fast, several factors are key to the design of the analysis system. First, ABAQUS and FEA in general is a complex tool. Second, geometry is always hard to clean up and difficult to mesh. Finally, procedures must be stable and require minimal monitoring and tweaking to make them complete.

Automation is one key answer to overcoming complexity. Considering the focus of this system is to analyze only bottles for structural performance, it works well. Bottles share many similarities. They are thin walled with a single opening, generally at the top, for the liquid to come out or go in. These similarities are a primary reason automation works for packaging analysis.

Given the sameness of the bottles and using standard design and analysis practices, much of the work can be programmed through the programming interface of the preprocessing software.

4. **The Virtual Packaging System**

The bottle analysis system is known as the Virtual Packaging System, VPS. This system automates all the required operations including pre-processing, job submission and post-processing.

The balance of this paper illustrates the use of VPS through an example analysis of a new package design. Last fall, P&G introduced a new brand of corn chips called Torengos™. The development of the package included extensive analysis work.

4.1 **Pre-Processing**

Altair Engineering’s HyperMesh™ is the pre-processing software. HyperMesh™ is our choice primarily because of its capability to import and clean up the complex geometry of our bottles. HyperMesh™ also
has a programming environment that allows for customization. A highly automated version of HyperMesh™ is used for the VPS.

Figure 1 illustrates the VPS custom interface. The buttons on the right side are designed to establish the workflow.

![Figure 1. Customized HyperMesh interface.](image)

4.1.1 Creating a Project and Importing Geometry

The first step in the process is to establish a working directory. All files will be written to this directory. The directory resides on the users local NT workstation until the job is submitted.

After the working directory is established, the user is prompted for the geometry file. Upon import, the software places the geometry in the correct 3D space and automatically cleans it up. Manual tools are also available to further position and clean up the geometry as needed.
Units and symmetry conditions are established next. Geometry comes from many global design sources using various CAD systems. The geometry import operation provides dimensional information that determines whether the bottle units are Metric or English. The user has the opportunity to change the units to work in the system they prefer.

Many bottles are symmetric. Typically it is preferred to work in the base symmetry of the bottle. The symmetry of the geometry is established at this time.

4.1.2 Meshing, Material Selection and Initial Thickness

Creating a mesh is the next step. The base symmetry is meshed through automatic and manual techniques. HyperMesh™ has an extensive set of tools to create, evaluate and modify the mesh. In areas of too much detail, surface edges can be easily suppressed to aid in mesh generation.

The user must select a material. Standard materials are accessed from a built-in materials database. Default information is stored in a preference file for each user. The user specifies the material and an initial uniform shell thickness for the model.

4.1.3 Assigning Non-Uniform Thickness

Manufactured bottles are not uniform in thickness. The process of blow molding creates variation in thickness. The user has three ways to create thickness variation in the shell elements:

- Specifying thickness at the nodes
- Specifying thickness of a group of elements
- Importing a thickness file.

The first technique works well if the bottle already exists. Thickness data can be measured and transferred to the model by entering thickness at the nodes near the measured position.

For bottles not yet manufactured, the other two techniques work better. To get a rough representation of the thickness distribution, groups of elements can be made thicker or thinner.

Blow molding simulations provide the most data for virtual bottles. Thickness data is created in the form of a text file from in-house developed blow molding simulations. This text file consists of 3D coordinates and corresponding thickness values. Custom written procedures read the files and interpolate the thickness values onto the bottle mesh. Elements are assigned colors based on their thickness values to provide visual feedback to the user. The model now looks similar to a contour plot of the thickness.

4.1.4 Reflecting the Model, Checking Normals and Bottle Weight

Symmetric models are reflected to full symmetry. The primary purpose is for post-processing. It is preferred to display results in full symmetry to minimize confusion when sharing results with non-technical audiences. One click reflects the model. The software uses the information provided in a previous step to execute the correct symmetric reflection.
Element normals must be set to face out to facilitate correct contact definition. Normals can be checked and accepted if correctly oriented. If not, a button click will reverse the orientation and the normals will be corrected.

At this point, the bottle weight can also be checked.

4.1.5 Load Case Selection

The Virtual Packaging System currently automates the set up of six standard load cases. Each case is described briefly below. Specifying the load case determines the boundary conditions, contact definitions and analysis procedures used. The user specifies the load case in the dialog box displayed as shown in Figure 2 after clicking the Apply Load button.

- **Top Load Empty** - This model simulates the application of force on top of an empty and vented bottle. This force typically represents the load applied by equipment that contacts the bottle during the filling operation. There is no bottle cap restricting the bottle volume so no internal pressure is considered.

![Figure 2. Load case selection.](image-url)
• Top Load Filled – This model represents forces on top of a bottle due to stacking either on store shelves, in warehouses or in trucks. In this case, the bottles are filled and sealed with a cap. The internal volume can change only through compression of the internal air above the liquid fill level.

• Pressure – The pressure case captures the effect of shipping a bottle from sea level to high altitude regions. The change in atmospheric pressure creates internal pressure that can cause the bottle to bulge. Bottoms of bottles can invert and cause the bottle to sit incorrectly on the shelf. Tracking the change in the volume is also important.

• Vacuum – The vacuum case reverses the pressure load case described above. If you ship from a high to a low altitude, the increase in external pressure can collapse the bottle.

• Hydrostatic – This load case simulates the effect of putting fluid in the bottle. Bottles will bulge due to the weight of the liquid contained. If the bulge is too great, the bottles will not fit into the shipping case.

• Squeeze – The squeeze simulation represents a consumer squeezing the bottle with their hand. The important information in this case is the change in volume with respect to squeeze pressure.

Other load cases are continually being evaluated for addition to these six.

4.1.6 Input Deck Creation

Creating the ABAQUS input deck is the final step in pre-processing. The input deck for the load case selected in the previous step is written out by clicking the Gen ABAQUS button. A dialog box opens indicating the name of the input deck to be saved. The user is prompted for a description to associate with the input deck. This description is written to the database later and is ultimately useful when searching for results. After the description is entered, the deck is written out.

4.2 JobManager

Job submission, job monitoring and automated post-processing is accomplished through an in-house custom application know as JobManager. Interaction with the Unix computer providing the ABAQUS results is facilitated through JobManager. The focus of JobManager is to speed up the process and minimize complexity.

4.2.1 Job Submission

Submitting a job in VPS is accomplished by selecting the Job Submitter text as shown in Figure 3. Population of a database that can be accessed globally is the primary reason to use JobManager to submit the jobs. Input decks are selected through the GUI interface. Additional information stored in the input file is automatically read into the input window. Once all the information is filled in, the job can be submitted by clicking the Submit Job button.
When the job is submitted, all the important data files are uploaded to the mainframe and database. Storing the data in a central location which is accessible thru a database allows the jobs to be easily shared among designers and analysts across the globe for collaboration.

4.2.2 Job Monitoring

JobManager monitors jobs. Jobs are classified as running, completed or failed. Users can check the status of their own or others’ jobs through the GUI interface. Key files such as the status file or the dat file can be viewed and searched without leaving JobManager.

Users can retrieve project files through JobManager. Modifications and additional input decks can be created once the files are back at the user’s local workstation.

JobManager also archives the data. Jobs that have not been accessed within a defined period of time have their results files compressed. Ultimately results files will be automatically removed from the system after
a period of 3 months of inactivity. Input files will always be retained and can be re-submitted to re-create the results data.

4.2.3 Post Processing

Post processing is done in two different ways. The first way generates plot files. Standard views and charts are available for selection in JobManager. The process is highly automated and delivers the plot file back to the user’s workstation for integration into reports and documents. An example of the top load and vacuum load case results are shown in Figure 4 and 5 respectively.

Figure 4. Top load empty results for Torengos™ analysis.
The second alternative creates html-based reports that contain interactive 3D results for visualization using Altair’s H3D file format. Figure 6 shows the visualization window for the H3D file. These reports are created from a button in JobManager. The compact H3D models are an excellent way to display basic information. Communicating the results to others is easy since the data is accessed through standard Internet browsers.
5. Conclusion

Analyzing a packaging design will require many models. Models that need to be repeated often are good candidates for automation. We at P&G have found that automation can help tremendously. When automating a model, a few key points should be emphasized.

First is simplicity. One of the purposes of automation is to make the process simple and easy to accomplish. Simplifying the process of creating an analysis is not easy. Automation is worth the time and effort for the highly repeated tasks that require expertise in complicated software.

Second is speed. Stay focused on making the system fast. Minimize the number of user inputs and interactions. Justify each and every action required by the user and try to eliminate it if possible.

Figure 6. HyperView player showing H3D display of Torengos™ analysis.
Third is programming. Make sure good technical computing resources are available. These resources should be familiar not only with computer technology like programming but also have a background in mechanical engineering. They will be able to embrace the vision and see the purpose.

Finally is maintenance. The work is not over when the automated system is delivered. Keeping the system running will require a big commitment. Automated systems are born and will ultimately die. In between, they require attention and maintenance. Changes in technology will drive the need for this maintenance.

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