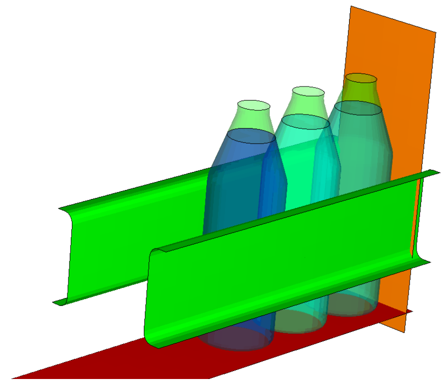
Bottle Conveying System Analysis

Summary

A key factor in the design of bottles and packaging containers is performance during conveying. The ability of a bottle to remain standing while traveling through a conveying plant for production, cleaning, filling, packaging, etc. allows that plant to be automated. If bottles fall or jam during conveying then human intervention is required to correct the situation. Finite element analysis can be used to verify new bottle designs and ensure that changes to current designs will not cause a reduction in conveying performance.



Background

Physical testing to evaluate the performance of bottle designs on conveying systems is expensive and time consuming. Any problems or failures found late in the design cycle can cause large delays in a product release schedule, particularly if the changes needed to remedy the issue are sufficiently large as to require consumer testing of the new design. Simulating the conveying process with the finite element method can allow designers to more quickly make decisions about changes to existing bottle designs, to validate new designs, or to compare performance between designs.

This technology brief describes an example of the analysis of a conveying system for fluid filled bottles. The purpose of the analysis is to determine whether the bottles will remain standing during a surge test. This is a two stage test: first, the bottles impact a closed gate while the conveyer belt is moving, then the gate is opened and the bottles accelerate back up to the speed of the belt.

Finite Element Analysis Approach

The various parts in this model are meshed as separate bodies, with contact definitions defined at the interfacing surfaces. Abaqus/Explicit contains a general contact algorithm, which allows for very simple definitions of the complex contact interactions between many bodies.

Abaqus/CAE is built on the concept of parts, instances and assemblies. With this methodology it is straight forward to create a mesh for one bottle, and then generate an assembly that contains multiple instances of that bottle. Each instance will automatically have the material and section assignments, and the surfaces and sets, which were defined for the original part. Options and tools exist for positioning the instances relative to each other in the assembly, such that the correct initial model configuration can be defined.

Key Abaqus Features and Benefits

- Explicit dynamic solution method for efficient analysis of transient, highly nonlinear problems
- Equation of state models for fluid constitutive behavior
- Automatic adaptive meshing to maintain fluid mesh quality
- Robust contact algorithm
- Part, instance, assembly methodology for simple model set up and expansion

This approach also makes it very straight forward to remove the fluid and perform the simulation on empty bottles. A variety of tests can therefore be performed by making simple, minor changes to the model.

The model used in this technology brief contains one bottle definition and one fluid definition. These parts are then instanced three times each, and each instance is initially translated along the conveyor belt to give the correct starting position. If more bottles were to be added, then additional instances could be simply defined. With this methodology there is no need to have a complete, separate definition for each body in the model.

Shell elements are used for the bottle and the mesh can be seen in Figure 1. The high-density polyethylene (HDPE) of the bottle is represented with an elastic-plastic material model.

Solid hexahedral elements are used for the fluid and the mesh can be seen in Figure 2. Adaptive Lagragian-Eulerian (ALE) meshing is used for the fluid to maintain good element shapes during the large deformations that the fluid experiences. The ALE method can also smooth and improve the initial mesh.

The fluid is represented with an equation of state material model, which can be used to characterize incompressible and inviscid fluid response. The equation of state determines the volumetric strength of a hydrodynamic material and specifies the pressure in the material as a function of density and internal energy. The deviatoric strength of the material is considered separately and can be included if viscous behavior is needed.

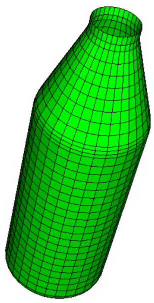


Figure 1: Bottle mesh

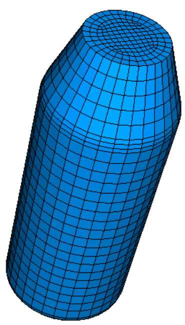


Figure 2: Fluid mesh

Abaqus/Explicit offers alternative kinematic formulations for solid hexahedral elements, and when appropriate for the analysis, choosing a non-default formulation can significantly reduce computational expense. For the elements representing the fluid in the present simulation, an orthogonal formulation is chosen. This formulation provides a good balance between computational speed and accuracy.

If the objective of the analysis was to determine the shape of the fluid free surface with the highest possible accuracy, the default kinematic formulation would be appropriate. However, because the inertial coupling of the fluid and structure is of primary importance, a less computationally expensive formulation can be used.

The conveyor belt, guide rails and gate are considered as rigid for the purpose of this analysis, and are meshed using rigid elements. The undeformed configuration of the full system can be seen in Figure 3.

Contact is defined between the inner surface of each bottle and the outer surface of the corresponding fluid mesh, between each pair of neighboring bottles, between the first bottle and the gate, and between all bottles and the guides and conveyor belt.

This example considers bottles that have been filled, but are not yet sealed. So, no gas pressure or seal are included in the model.

Gravity loads are applied to both the fluid and the container. The conveyor belt is given a constant velocity throughout the analysis. The gate is initially closed, and then it opens once all the bottles have impacted against it, and settled.

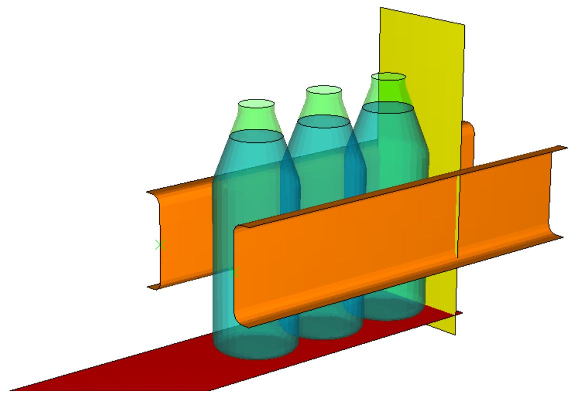


Figure 3: Initial model configuration

Analysis Results and Discussion

Some representative results from the analysis are presented below.

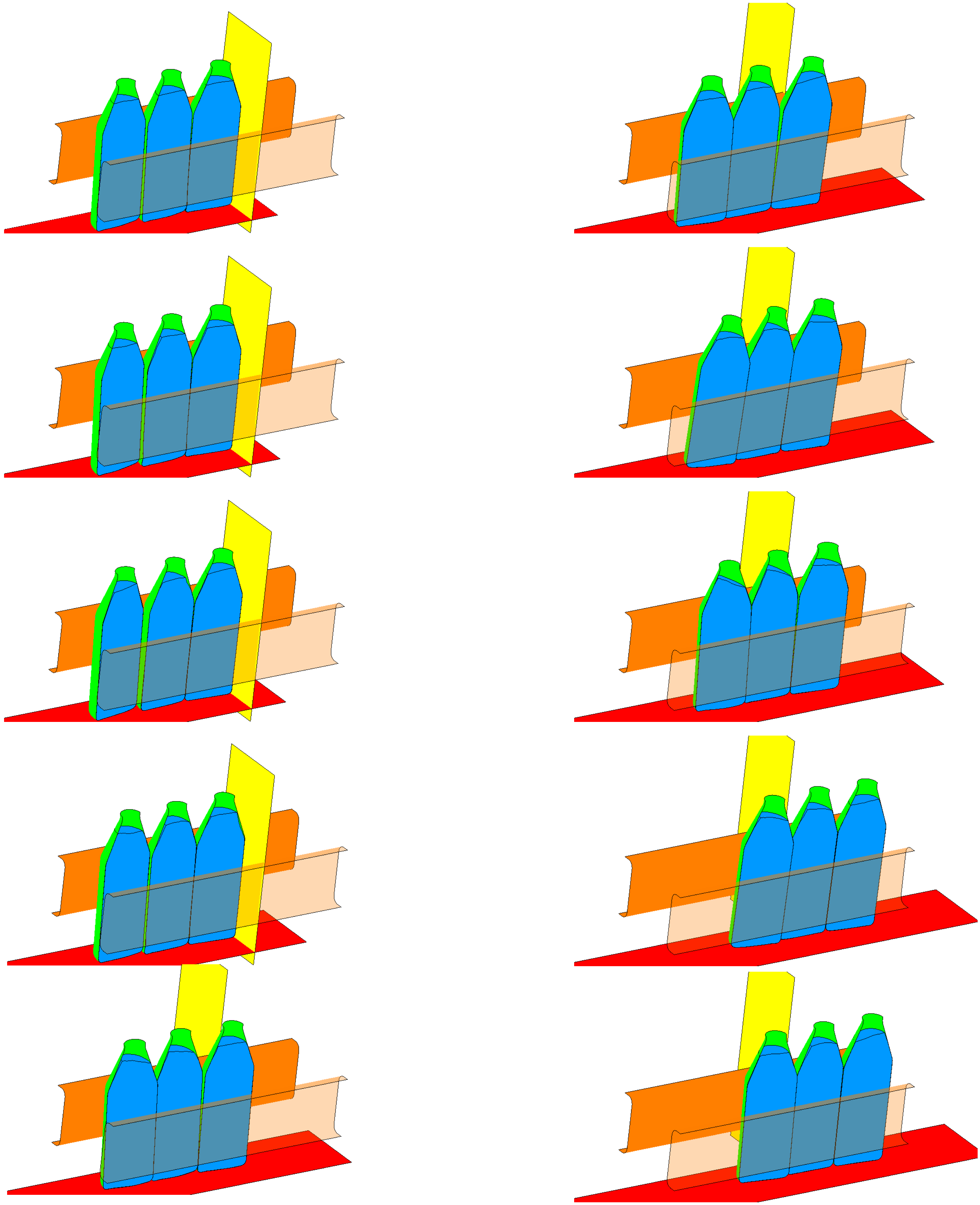
The sequential plots in Figure 4 (next page) show the fluid sloshing in the bottles during impact (left column) and acceleration (right column).

The main purpose of this analysis is to determine whether the bottles remain upright during the deceleration and acceleration caused by the impact with the gate. The deformed shape plots show that this design of bottle would pass this test.

Conclusions

As demonstrated in the above analysis, Abaqus/Explicit can be used to incorporate the effects of sloshing-type fluid-structure interaction into dynamic analyses. While it is generally not possible in Abaqus/Explicit to model complex fluid flow behaviors or phenomena such as free-surface interactions and splashing, inclusion of the inertial loading caused by the fluid deformation allows for a more complete simulation capability.

Figure 4: Sequence showing fluid sloshing in bottles during impact (left) and acceleration (right).



References

1. Consumer Products Simulation with Abaqus webinar, presented jointly between Abaqus and The Procter & Gamble Company. http://www.simulia.com
2. Bottle Conveying Simulation – Henning, D., The Procter & Gamble Company, Stevens, J., Stress Engineering Service, Inc., and Kumar, S., Abaqus Central, Inc. Abaqus Users' Conference 2004.
3. Abaqus for Package Development at Procter & Gamble – Henning, D. B., and Loudin, B. K., The Procter & Gamble Company. Abaqus Users' Conference 2002.
4. Abaqus Technology Briefs: Fluid-Structure Interaction Simulations. http://www.simulia.com/

Abaqus References

For additional information on the Abaqus capabilities referred to in this brief please see the following Abaqus 6.11 documentation references:

- Analysis User's Manual
  - "Explicit dynamic analysis," Section 6.3.3
  - "ALE Adaptive meshing," Section 12. 2
  - "Equation of state," Section 24.2.1
- Example Problems Manual
  - "Cask drop with foam impact limiter," Section 2.1.12
  - "Water sloshing in a baffled tank," Section 2.1.14
- Benchmarks Manual
  - "Water sloshing in a pitching tank," Section 1.12.7