

Keeping Cool While Cutting Costs

Simulation helps keep temperatures and costs down while optimizing refrigerator design.

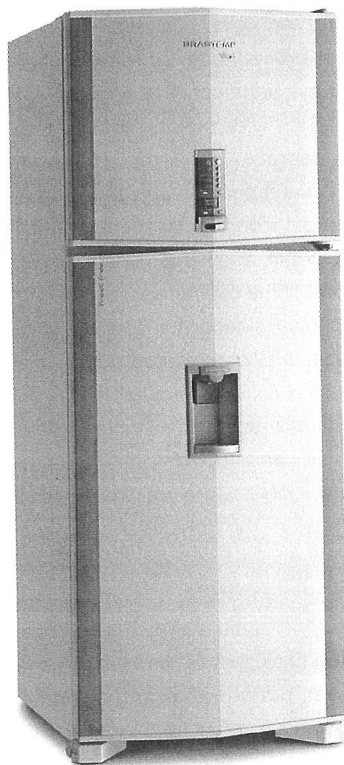
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Global competition in the appliance industry is placing ever-increasing pressure on manufacturers to decrease costs while maintaining high quality. Refrigeration products are especially competitive, and as raw material costs for these appliances continue to rise, manufacturers are forced to take a close look at their product designs.

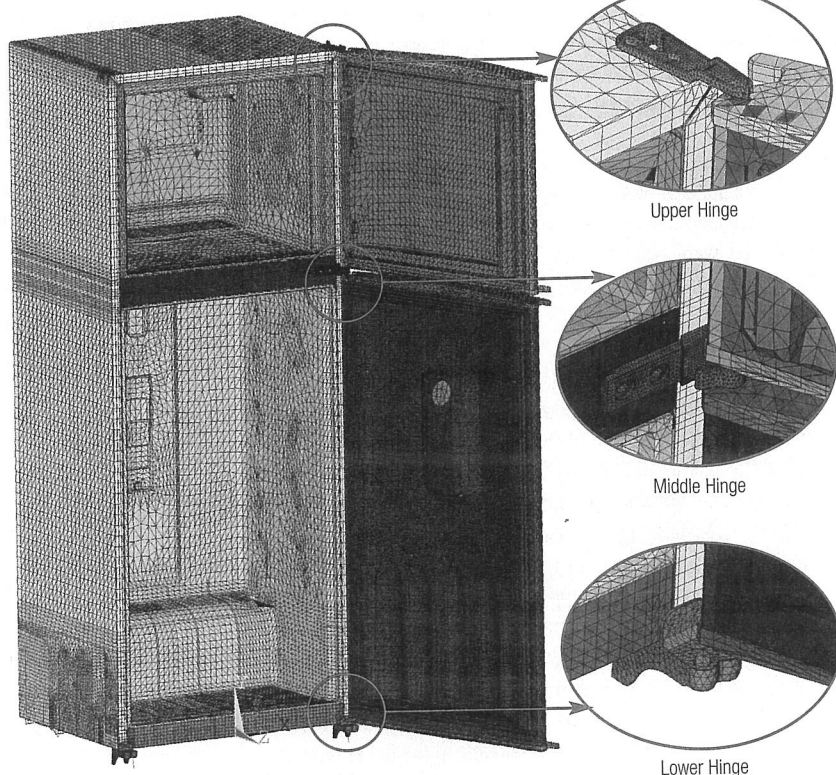
With worldwide industry revenue in 2006 reported at \$6.2 billion and a sluggish market to contend with, the stakes are high.

In an effort to find a competitive edge, Whirlpool Corporation, one of the market leaders in the consumer and commercial refrigeration market, has turned to software from ANSYS.

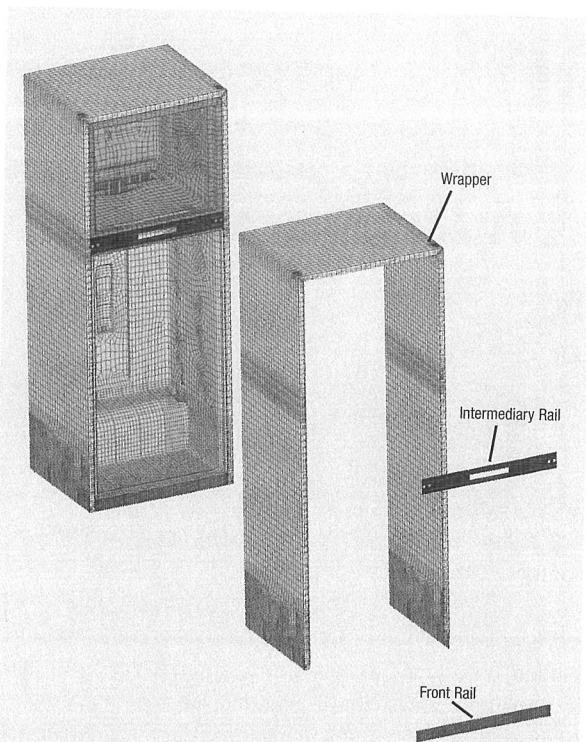
In the past, cost-reduction projects at Whirlpool typically have required that engineers build and test several prototypes, with results then compared with current production cabinets. This trial-and-error approach is costly and time-consuming, leading to only incremental changes. Recently, Whirlpool has enjoyed more substantial benefits



Original design of the Whirlpool refrigerator model used in the cabinet optimization analysis



Finite element model of cabinet and door assembly with close-ups of critical hinges



Simulation Setup

The refrigerators' polyurethane foam, EPS mullion, hinges and levelers were modeled with solid tetrahedron elements (SOLID45). Other parts, basically composed of thin plates, were modeled with SHELL181 elements. For all the connections of clinch joints and screws, the element BEAM188 was utilized.

All of the material properties were considered as linear isotropic, and the input data was derived from laboratory tests and supplier technical specifications. For the polyurethane foam, the elastic properties were evaluated in a laboratory test device, and the elasticity modulus was included as a factor.

In order to adequately represent the real loading conditions, the masses of all cabinet parts were evaluated and included. In addition, the masses corresponding to cabinet ballast and loaded doors were calculated and were then assigned to each location in the model. The acceleration due to gravity was applied as a load boundary condition. At its bottom base, the cabinet was constrained, simulating actual operating conditions.

The door attachments and hinges were modeled with constraint equations, which allowed controlling translations and rotations to be correctly transferred from the doors to the cabinet. As a result, it was possible to impose door support only at the bottom position and release rotations from the hinge pins. In so doing, it was necessary to set two additional constraints at the upper liner of each door to eliminate rigid body motion.

from an approach that utilizes leading-edge simulation combined with experimental tools to assess complex structural behavior.

When Whirlpool recently looked to cut costs associated with producing a three-year-old, 450-liter double-door refrigerator, the model was required to meet the existing specific cabinet deflection and door drop limits of its current design as well as maintain adequate cabinet stiffness. Cabinet deflection and door drop occur when a fully loaded door is opened. When this occurs, the cabinet distorts and the door moves downward, eventually leading to cabinet deformity. Additionally, any redesign that changes cabinet stiffness could negatively impact insulating capabilities as well as aesthetics, which, in the end, can influence consumer-perceived quality.

A refrigerator cabinet is constructed of external sheet metal parts, polyurethane foam filling and internal plastic liners. It is very complicated to evaluate cabinet deflection and door drop since there is significant variation between products of the same model, with variations in both the manufacturing and testing procedures affecting door stiffness. To identify the most significant variables, engineers at Whirlpool used Design of Experiments (DOE) and sequential analysis. Following this process and the compilation of quantitative data describing structural behavior, the engineering team then utilized ANSYS Mechanical software to optimize the refrigerator design.

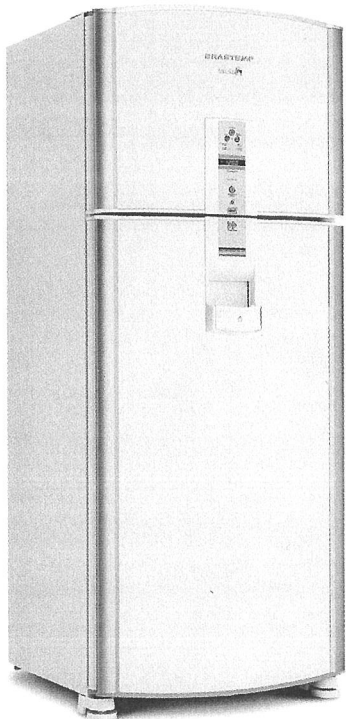
The goal of simulation and analysis was to evaluate the design factors that most significantly affect material costs and door drop. To begin, engineers constructed a finite element model (FEM) of the cabinet using solid and shell elements. (See technical sidebar for details.) All of the finite element analyses (FEAs) executed during this study were performed using ANSYS Parametric Design Language (APDL). The state or response variable used to control the cabinet stiffness was door drop under static load application. The cost function to be minimized was directly related to the mass of the cabinet sheet metal parts.

With the goal of reducing costs by cutting the amount of materials used in manufacturing, the analysis showed that reducing the thickness of the compressor plate, deck reinforcement, bottom deck and front rail (7.8 percent of total mass) would allow for a reduction in materials while having a minimal effect on door drop. The simulation/optimization further determined that the most

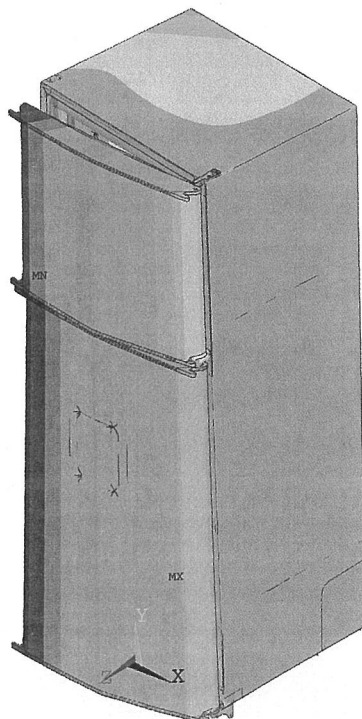
sensitive factor affecting mass was the cabinet wrapper (or outer paneling), but that reducing the wrapper thickness resulted in an increase in door drop. The most significant factor driving door drop was the screw that connected the intermediary rail and cabinet front flange. In order to compensate for the increase in door drop that resulted from reducing the wrapper thickness, designers added two screw connectors, rather than one, between the wrapper front flanges and the intermediary rail, resulting in a 12 percent improvement in door drop. This design change also contributed to cabinet robustness and compensated for polyurethane foam stiffness loss (manufacturing process variation).

In the end, this optimization and the associated design changes resulted in the reduction of overall cabinet mass by 26 percent while maintaining door drop and cabinet displacement at reasonable levels, as defined by Whirlpool quality standards. On the bottom line, material costs were reduced by 15 percent per product, resulting in a cost savings for the company of \$1.2 million per year.

By using ANSYS Mechanical software and Six Sigma tools, analysts at Whirlpool now have the ability to develop complex finite element cabinet models calibrated with real data, enabling the optimization of first-round physical prototypes. This procedure has resulted in a reduction of development time and manufacturing costs, helping Whirlpool meet increasingly competitive market requirements. ■



Whirlpool refrigerator model following a redesign of the doors and some other features but with the same cabinet shape. This model was just launched in the market.



Simulation results quantifying door drop (displacement)

Six Sigma and the Importance of Critical Thinking

In this case study from Whirlpool, Six Sigma tools, including Design of Experiments (DOE) product testing, were used to assess manufacturing process and laboratory test sources of variation affecting cabinet structural behavior. Eventually, engineers gained enough knowledge to act on variation reduction in order to accomplish the finite element model (FEM) calibration.

With the FEM and calibration completed, the first optimization in ANSYS Mechanical software executed a sequential virtual DOE, with factors and levels selection based on Six Sigma tools. The goal was to evaluate the design factors that most significantly affected door drop and material costs.

At Whirlpool, Six Sigma initiatives are used to investigate the impact of sources of variation on key critical outputs of product and process, such as quality or performance, and the initiatives are often lauded for huge reductions in defects. A phrase often associated with Six Sigma philosophy is " $Y = f(X)$ " (Y is a function of X.) This overly simplified equation reflects the observation that behavior in critical product or process performance characteristics (Y) is due to certain process factors or inputs (X). For example, the cabinet wrapper thickness (X) can potentially affect cabinet stiffness and door drop (Y). A crucial part of Six Sigma work is to define and measure variation in Y with the intent of discovering the cause and developing efficient, operational means to control, mitigate or reduce the variation.

In addition, critical thinking based on the scientific method is a very important skill and is used extensively to conduct industrial experiments associated with simulation, which then leads to design optimization. Critical thinking — the process of deduction and induction — implies that the investigator has the wherewithal to develop theories from the initial questions. This wherewithal comprises subject matter knowledge, experience, process knowledge and the ability to reflect critically and engage others. In fact, it has been shown that critical thinking is more important to improvement and development activities than training in a particular tool set.