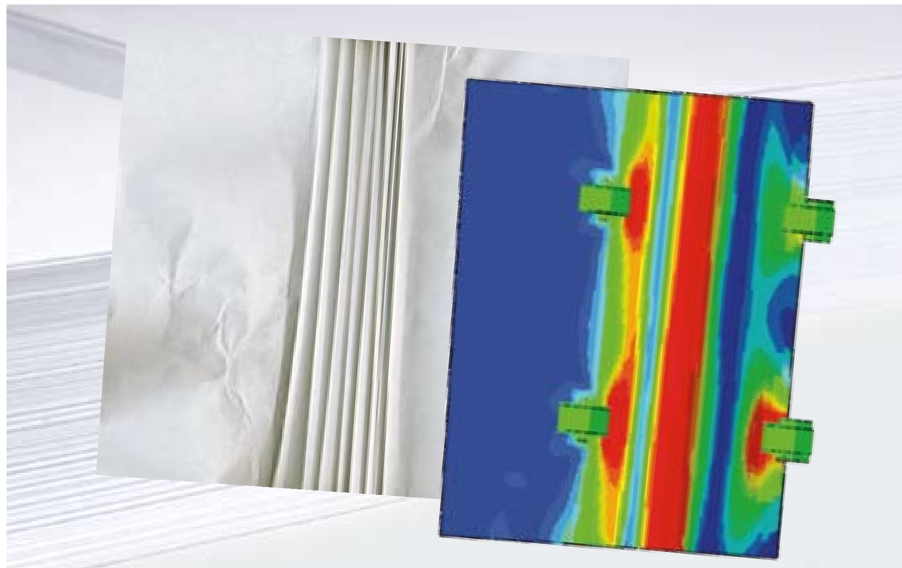
# Designing Your Way Out of a Paper Jam with Realistic Simulation

## HCL Technologies uses Abaqus FEA to help keep high-speed printers on track



Remember how the invention of the personal computer was supposed to do away with the need for paper? We all know how that turned out. Despite the proliferation of digital files, email, online publications, and social media, there are more printers in the home and office than ever before. Early laser printers sold for as much as $17,000 in the 1970s—now a low-end black and white printer costs under $75.

The highest growth rate for printers these days lies in the developing world, where increasing prosperity is fosters strong demand for print-generating PCs. India leads the pack. With a national print market for printing equipment, paper, and supplies predicted to expand more than 70% from 2006 to 2011, according to the Print Industries Market Information and Research Organization (PRIMIR), those printers need to run as smoothly as possible: A paper jam is a no-no in any language.

HCL, India's largest manufacturer of PCs, anticipated the boom in printers and other IT-related equipment by spinning off a software services division in the late 1990s, HCL Technologies Ltd. As the inventors of the Indian computer in 1978—concurrent with Apple and three years before IBM—the parent company has long been aware of the importance of starting from good design to ensure product quality and reliability. HCL Technologies now offers engineering and R&D services from initial concept to validated prototype to a wide variety of IT-related equipment makers in India and abroad. A large portion of their work focuses on those ubiquitous printers.

### It's all about the paper path

The functional bottom line in printer design is the paper path: the route that a sheet takes through a printer from entry to exit. Of course the inner workings of a printer can vary quite a bit: large or small capacity, faster or slower speed, inkjet or laser technology, monochrome or full-color toner, standard prints or copying, scanning and faxing as well. But if the finished product is imperfect, damaged, or never comes out at all (paper jam!), you end up with an unhappy user.

"Paper path design is a challenge no matter what product we are working on," says Thangavel Mayilvaganan (Mayil), Associate Project Manager, CAE Centre of Excellence, responsible for printer projects at HCL Technologies in Chennai, India. "Meeting the final requirements of each printer manufacturer depends on defining, and then designing-in the proper flow of paper through their particular machine."

### Cutting costs with simulation

To make this customization process cost-effective, HCL has been using a variety of CAD and CAE tools for product design and development for more than ten years.

"Real-world verification is always the final proof of functionality, but it is expensive and difficult to develop individual physical paper flow path tests," says Mayil. "Simulation has become the backbone of our R&D process. By using virtual prototyping, starting at the earliest concept stage, we've been able to reduce our product development costs an average of 40 percent."

In a typical computer model used by HCL for a paper flow path analysis—in this case employing Abaqus FEA from SIMULIA, the Dassault Systèmes brand for realistic simulation—the challenge is to accurately represent and analyze the contact and forces that a single sheet of A4 paper encounters on its way from the feeder zone to the outlet tray. The hazards to be avoided are many: the paper can skew out of alignment, flow at the wrong speed, bend and stub (paper jam!), or slip at the roller interface.

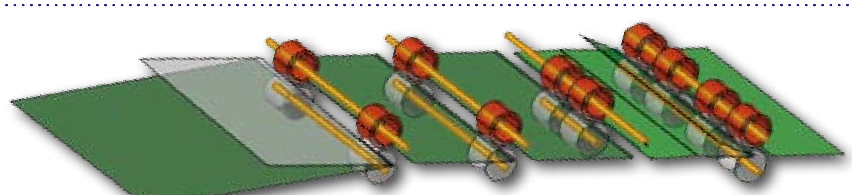


Figure 1. 3D CAD model of a typical printer paper flow path. The paper is pulled into the printer ('nipped') between a rotating upper rubber roller (the drive) and a stationary, spring-loaded lower plastic roller (the driven, or idler). During the printing process the paper is conveyed through a series of these rollers, with baffles and stationary guides (not shown) directing its path.

Simulating the effects of all these variables helps HCL's engineers predict and rectify potential paper flow roadblocks at the earliest stages of design development. Employing Abaqus FEA in a feedback loop with the design department, they can quickly fine-tune and perfect their virtual prototypes before building and validating the final physical prototypes for their customers.

## Geometric simplicity, analytical dynamism

To chart and then analyze the path of a virtual piece of paper, the engineers begin with a CAD model (see Figure 1) of the components of a proposed flow path design, including the paper itself.

The CAD model is then meshed using Abaqus/CAE to prepare for an explicit dynamic analysis in Abaqus. This part of the process is fairly straightforward: Neither a piece of paper, nor the components of the paper path, are geometrically complex. The paper is modeled as beam elements with rectangular section properties when 2D analyses (generally side views of paper movement) are being run, and shell elements for 3D (more detailed problems like buckling and skewing). The paper material is considered to be linear elastic isotropic. The baffles, guides and plastic rollers are considered to be rigid. A hyperelastic Neo-Hooken material model is used for the rubber rollers to capture their deformation.

Straightforward, yes, but when the simulation model is set in motion, it becomes a finely choreographed dance in which the correct function of each component is dependent on the proper operation of the previous step. It's a fast-evolving, highly nonlinear FEA problem that has to account for a host of variables: grade of paper, complexity of flow path, roller pre-loads, roller rotation speed, transport velocity and acceleration, materials, friction, even the effect of gravity—at speeds approaching two meters per second (up to 100 pages a minute). The analysis time is estimated as per flow path length and roller RPM.

## Fixing the virtual paper jam

Within this multifaceted engineering environment, HCL's engineers can focus in on the behavior of a particular piece of paper as it travels along a proposed design flow path configuration (see Figure 2). They can simulate what happens when the paper gets out of alignment (skew), and is corrected again by guides. They can study the effects of paper weight and roller drive on bends (buckle) in the paper that lead to potential stubbing points (paper jam!), and they can measure the amount of slippage at the roller interface.

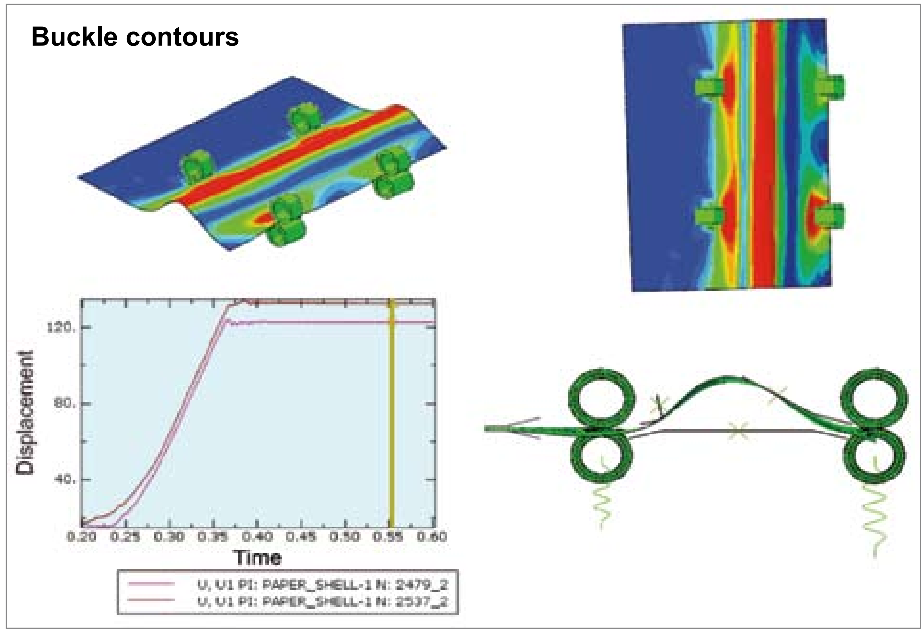



Figure 2. Results from 3D paper buckling contour analysis using Abaqus FEA. When paper flow and roller nip forces are imperfectly balanced, a buckle of paper can rise up, filling the paper path and resulting in paper slip and/or stubbing (paper jam). HCL's engineers use such data to examine the relationship between such forces in different printer designs so they can make modifications that resulting in optimum paper flow.

With their Abaqus simulation results in hand, the engineers can then modify design variables, and combinations of variables, within a flow path. They can vary the distance between rollers, roller positioning, and circumference, the angle of the guides, and so forth—and then run the virtual piece of paper through it all over again. They can also modify the characteristics (weight, thickness, composition) of the paper itself to test the full range of capabilities of each proposed path design.

## Abaqus FEA passes the reality test in record time

"Abaqus' advanced contact algorithm capabilities and extensive material models support our simulations for a broad range of customer needs," says Mayil. "To ensure that our final designs are robust enough for a particular printer configuration, we build and test physical prototypes. When we compare our results against the FEA, we see very good correlations." And they accomplish all this with significant time savings: "We've been able to cut three months off overall project time for designing and validating a typical A4 printer using simulation," says Mayil.

Realistic simulation will continue to play a pivotal role for HCL's global CAE team. Future work will focus on the effects of inducing electrostatic charges on paper (a step inherent to the laser-printing process), and consideration of environmental conditions like humidity and temperature.

"With a constant drive for product innovation, cost and weight reduction, the highly competitive high-tech electronics industry is continuously challenged to update products in a very short design cycle," says Mayil. "Reliable functionality is one of the major goals for information technology and electro-mechanical products. Realistic simulation helps us achieve that for our customers."

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