DE
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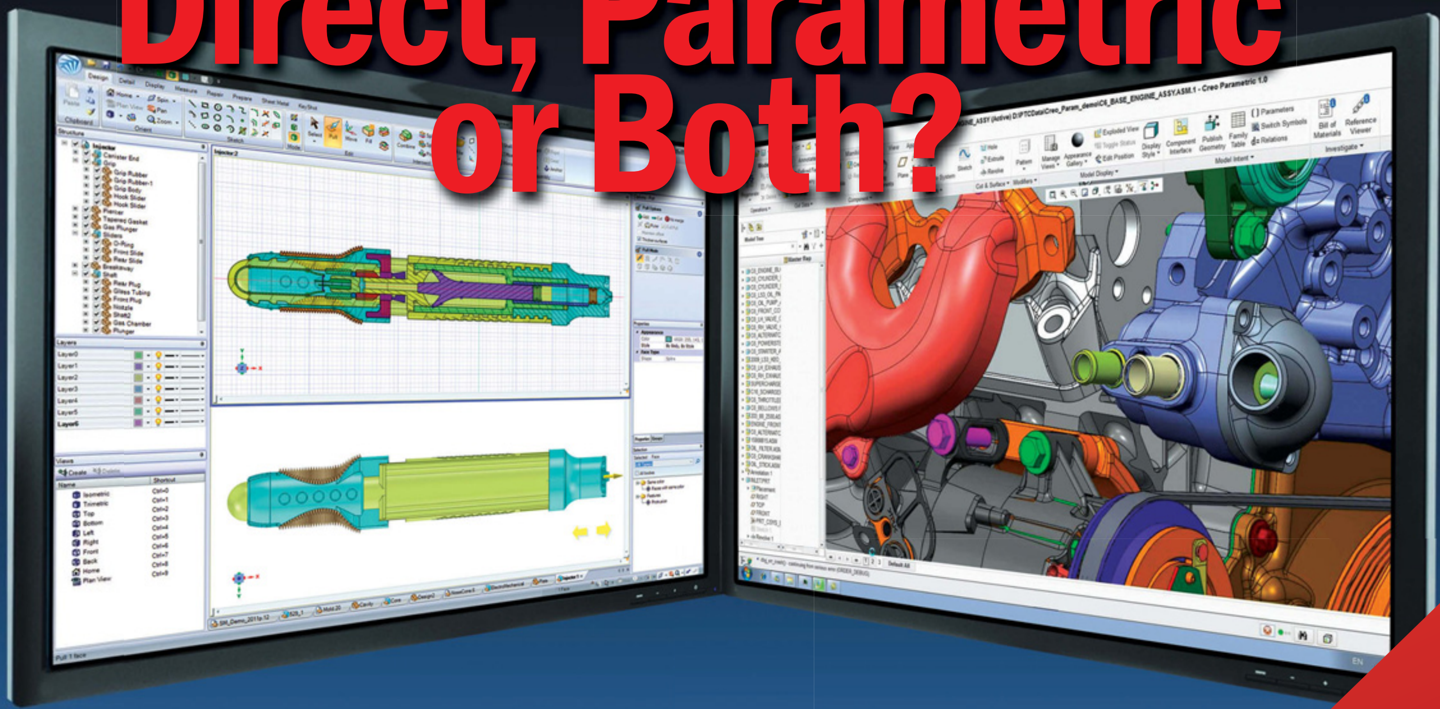
SPECIAL SECTION: Test and Measurement

Direct, Parametric or Both?



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Degrees of Freedom

by Jamie J. Gooch

Get Ready for Rapid Tech

Rapid is a relative term. What was once fast now seems slow. The horse and buggy gave way to steam power, and steam power to internal combustion, just as hand-written letters gave way to email. Now even email takes too long for my text-happy daughter and her friends.

Manufacturing speed has increased as well, but that speed increase has largely relied on economies of scale. The assembly line was a triumph of manufacturing efficiency in 1908, and has since allowed companies to quickly turn out everything from Model Ts to computer workstations in massive quantities with great efficiency. Nowadays, robotic arms can pick hundreds of parts from a high-speed conveyor belt each minute. But, when you add in the time it takes to place a part order, get it queued

Our goal is to get you ready for the hardware, software, materials and services that allow you to make digital designs physical.

onto a production line, build a widget and ship it to a customer, that's still too slow for many people today.

At first, those hurried people were mainly design engineers who wanted a few quick prototypes. They didn't need 1,000 widgets, just a few to test a design. Computer numerical control (CNC) machines and 3D printers filled the gap between fast, extremely short run prototyping and assembly line manufacturing. But that's just the beginning.

Momentum Achieved

Some technologies take time to really get up to speed. The computers we rely on so heavily today, for instance, stem from roots in the 1940s. The term "personal computer" was coined more than 35 years ago. Now they're ubiquitous.

It's easy to postulate that the same thing will happen with rapid technologies, such as 3D printers and even personal CNC machines. Progress has made the equipment faster and cheaper, and the basic software free and easy to use. Visionaries have predicted personal manufacturing machines in every office for decades. Could 2012 be the year we look back on as rapid tech's big breakthrough?

Desktop Engineering has covered rapid technologies for more than 15 years. It's exciting for us to see articles about 3D printing in mainstream media like *The New York Times* and read comments of disbelief under YouTube videos showing 3D printing in action. We can feel a shift in the wind, both from engineering firms whose eyes have opened to the benefits of rapid technologies and from an eager and vast consumer market.

To support an even wider acceptance and use of rapid technologies, we've launched a new site called Rapid Ready Technology (rapidreadytech.com). The site is designed to provide insights and information on different additive manufacturing technologies, materials and types of equipment — from entry-level 3D printers used by hobbyists to 3D production systems used by leading global manufacturers. But we will not ignore other tools that can help quickly create physical prototypes, parts and products from digital files, including custom subtractive manufacturing, 3D scanning and reverse engineering software. Our goal is to get you ready for the hardware, software, materials and services that allow you to rapidly make digital designs physical.

A Bright Future

Perhaps the most amazing thing about rapid tech is that, despite how impressive the technology already is, it still has a lot of room to grow. More and more companies are realizing the value of rapid prototyping, and consumers' imaginations have already been captured by the idea of downloading and printing their own products. Direct manufacturing is a long way from displacing mass production, but it is making a real difference in speed and cost savings for certain applications.

Rapid manufacturing is already being used to rebuild bones on an individual patient basis. Creative people are exploring 3D printing as a new medium for everything from sculptures to jewelry to gourmet meals. Global manufacturers are using it to create specialized jigs needed for mass production. Other manufacturers who sell a few hundred or a few thousand high-end products per year are realizing they can use rapid tech to replace some traditional manufacturing methods.

These are just a few examples of prototyping and low-volume manufacturing scenarios that are perfect for rapid technologies. You can find more examples on page 14 and on rapidreadytech.com.

We hope you'll share some of your own stories on how rapid prototyping and manufacturing is changing the way you work, and let us know what you'd like to see on the site. You can contact us at de-editors@deskeng.com. It may not be as fast as a text message, but we'll respond rapidly. **DE**

Jamie Gooch *is the managing editor of* Desktop Engineering. *Send comments about this subject to DE-Editors@deskeng.com.*

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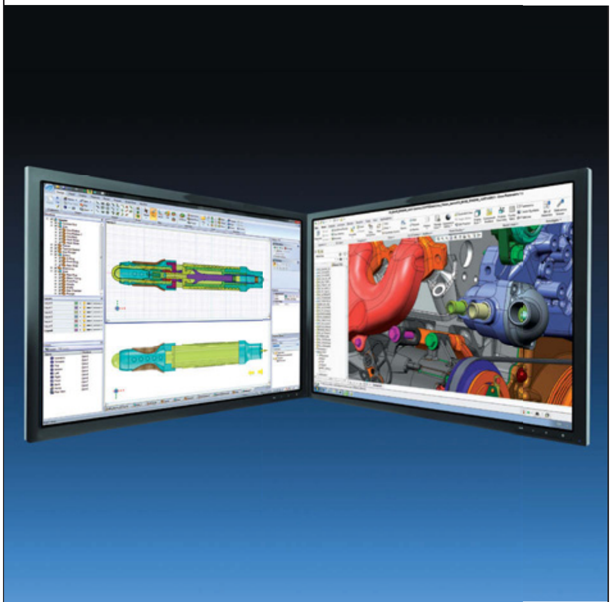

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Direct, Parametric or Both?

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ON THE COVER: SpaceClaim (on the left) ushered in the popularity of direct modeling. PTC (on the right) includes some direct-modeling functions inside its Creo Parametric.

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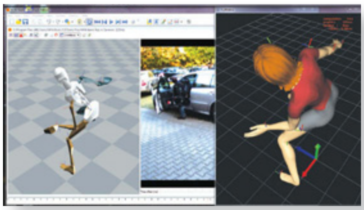

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A LEVEL 5 COMMUNICATIONS PUBLICATION
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ADVERTISING, BUSINESS, & EDITORIAL OFFICES
***Desktop Engineering*® magazine**
Level 5 Communications, Inc.
1283D Main St., PO Box 1039 • Dublin, NH 03444
603-563-1631 • Fax 603-563-8192
E-mail: DE-Editors@deskeng.com
www.deskeng.com

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***Desktop Engineering*® magazine**
PO Box 677 • Northbrook, IL 60065-0677
847-559-7581 • Fax 847-564-9453
E-mail: den@omeda.com

***Desktop Engineering*®** (ISSN 1085-0422) is published monthly by Level 5 Communications, Inc., 1283D Main Street, P.O. Box 1039, Dublin, NH 03444, 603-563-1631. Periodicals postage paid at Dublin, NH, and at additional mailing offices. Desktop Engineering® is distributed free to qualified U.S. subscribers.

SUBSCRIPTION RATES: for non-qualified; U.S. $108 one year; Canada and Mexico $126 one year; all other countries $195 one year.

LIST RENTALS: For information on list rentals, contact Statlistics, Danbury, CT: 203-778-8700.

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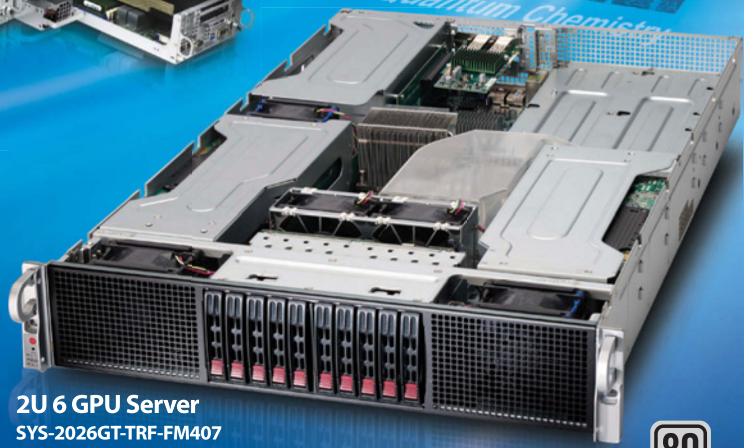

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by Kenneth Wong

IMSI/Design to Build Mobile EcoSystem with SDK

IMSI/Design (IMSIdesign.com) is laying the groundwork for a mobile app ecosystem. It will revolve around the company's TurboViewer app, which is currently available for iOS and Android devices. To entice other developers to come on board, IMSI/Design plans to offer a free software developer kit (SDK) for TurboViewer, beginning next month.

In June 2011, IMSI/Design released TurboCAD Viewer, a free 2D/3D DWG viewer for iOS mobile devices. It was quickly followed by the releases of TurboViewer X ($6.95) and Pro (introduced at $9.99, now selling for $24.99). Last month, TurboViewer and TurboViewer X ($3.99) for Android devices made their debut on Android Market. The free viewer displays a banner populated with rotating ads. Upgrading to commercial versions eliminates the banner.

IMSI/Design uses a similar strategy with its drafting and drawing software, DoubleCAD XT. It gives away a free version, complemented by a Pro version selling for $695. The free TurboViewer SDK will be "generous and robust" in offerings, according to Bob Mayer, IMSI/Design's COO. For those who desire additional features and functions, IMSI/Design plans to offer commercial versions of the SDK.

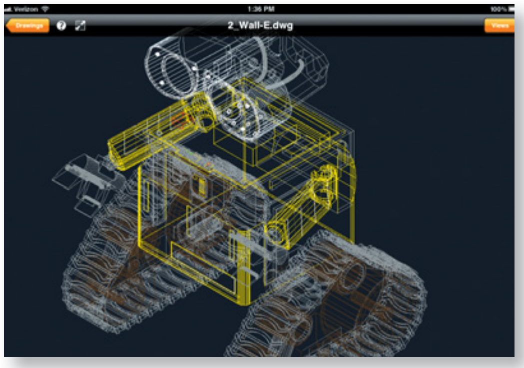
In releasing the SDK for TurboViewer, IMSI/Design is borrowing a page from the playbook of one of its biggest competitors, Autodesk. The success of AutoCAD, observed Mayer, is due to "its most enviable asset—the software developers creating a wonderful ecosystem around AutoCAD."

IMSI/Design hopes to duplicate the same success with its mobile viewer series. "We believe we can be a foundation for Mobile CAD going forward and can't wait to see what apps the smart phone and tablet generation creates," said Royal Farros, the company's chairman and CEO.

The ubiquitous presence of mobile tablets and smart phones has prompted many 2D/3D design software makers to launch their own mobile viewers. The growing list includes Autodesk's AutoCAD WS, Dassault Systèmes' 3D VIA Mobile, and Lattice Technology's iXVL View.

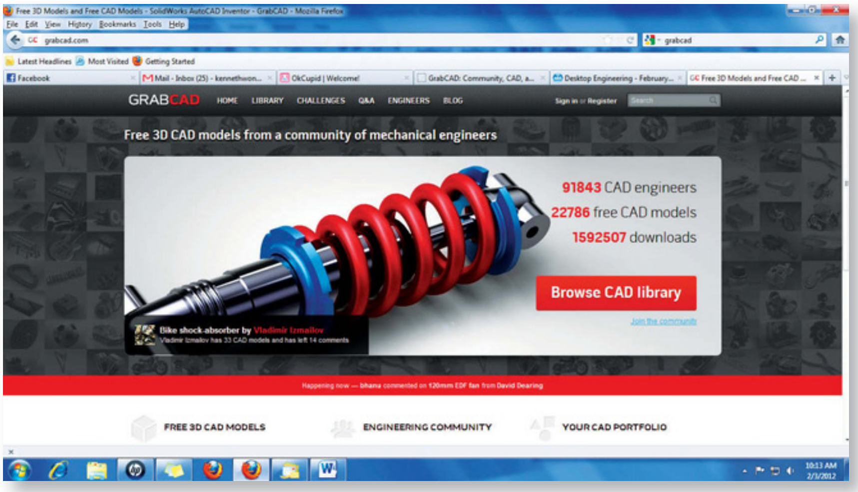
Running on Android OS and equipped with multi-touch screens, leading e-readers like Amazon's Kindle Fire and Barnes & Noble's Nook Color also contribute to the thriving app commerce. For about $225, e-readers can stand in as cheaper alternatives to those unwilling to spend $500 to $900 for a full-fledged mobile tablet.

In a recent blog post, the AutoCAD WS blogger (who goes by Daniel) pointed out that AutoCAD WS is available to Kindle Fire owners through the Amazon marketplace. It may be only a matter of time before we begin to see TurboViewer and other 2D/3D viewers on e-readers as well.



IMSI/Design's TurboViewer, shown here displaying a 3D model of Wall-E in wireframe mode.

GrabCAD: Community, CAD and Goodwill Prove to be a Winning Formula



GrabCAD, cofounded by Hardi Meybaum, combines social media with 3D model hosting services. (The stats represent a snapshot on Feb. 3, 2012.)

On Jan. 5, GrabCAD's (GrabCAD.com) status showed 1.229 million downloads, 19,000 CAD models and 72,000 engineers using the portal. On Feb. 3, the counter had risen to 1.592 million downloads, 22,000 CAD models and 91,000 engineers. That's a growth of more than 363,000 downloads, 3,000 models and 19,000 engineers in less than a month.

GrabCAD was cofounded by Hardi Meybaum, an immigrant from Estonia, a Baltic state that regained independence from the USSR in 1991. In October 2010, Meybaum landed in Boston Logan International Airport with his wife and 9-month-old daughter in tow. His most immediate concern at the time was to find a place to live, a home for his family.

In August 2010, Meybaum wrote—and rewrote—what would become GrabCAD's debut blog post. He found the right words in his fourth attempt: "We're live!"

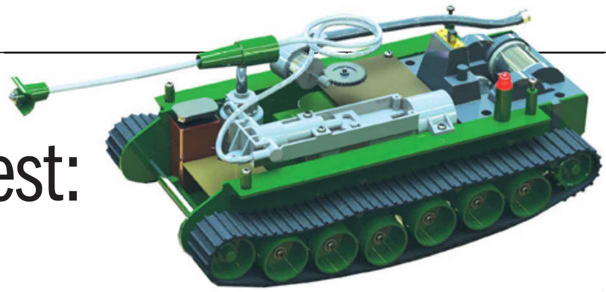
For the first 12 months, the site struggled to find an audience, but in mid-2011, it began to see meteoric rise. On Dec. 15, Christmas came early for Meybaum and his partners: They saw their 1 millionth download.

"We saw inefficiencies in engineering—in the way services are provided and how engineers share knowledge," he said. "The idea [for the site] has evolved a lot since the start, but one thing has not changed—we are there to make engineers' life easier."

GrabCAD embodies some of the best characteristics found on social media sites. Just like you can publish video clips on YouTube, you can publish 3D models to GrabCAD. Like Facebook, you can identify and befriend 3D software users with similar interests (for example, those specializing in architecture modeling or alien monsters). You can swap comments and follow those whose work you admire, like you would on Twitter. Like LinkedIn, you can harvest your social connections for potential assignments and job leads.

The outlook for 2012 is bright. GrabCAD has just secured $4 million in a new round of fundraising.

DE Cubicle Toy Design Contest: We Have a Winner!



Mark Norwood's water-spraying Sherman tank, with its top cover removed to reveal the internal mechanism.

Last December, *DE* invited readers and fans to submit their ideas for a fun, playful, inventive cubicle toy. The honorary judges (Kenneth Wong, senior editor, *DE*; Tony Lockwood, editor-at-large, *DE*; and Josh Mings, blogger, SolidSmack) narrowed the choices to the final three:

- Jason Cox's remote-controlled mouse, detailed in Google SketchUp;
- Ray Kelley's bottle cap blaster, designed in SolidWorks; and
- Mark Norwood's water-spraying tank, designed in SolidWorks.

Despite this being his initiation into 3D modeling, Cox managed to convey his idea in solid form in Google SketchUp, along with exploded views showing how internal subcomponents would fit together. Kelley's detailed SolidWorks assembly gives you a clear idea how the internal mechanism would work. Norwood's renderings and transparent views show how he plans to fit the water-carrying tube inside the tank's shell.

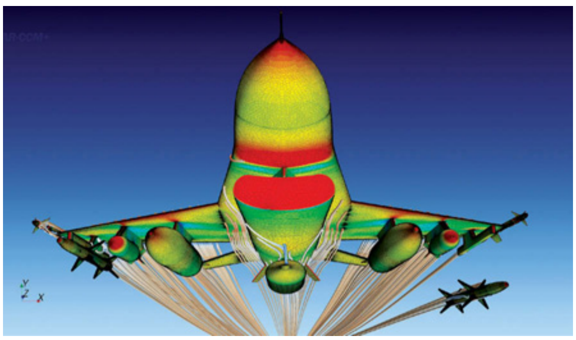
In the end, the sheer amount of CAD and visualization efforts that went into the project, along with a fully assembled physical prototype, tipped the scale in Norwood's favor.

"Each gentleman is a winner in my book," Lockwood said. "All have proven themselves disruptive technologists, impish pranksters and ingenious beyond compute … In the end, however, the polling station must close, and I can choose but one. So, with my hat off and a deep bow to the other finalists, I check Mark Norwood's name on my ballot. When I tally up his doggedness in making an 8-year-old workstation execute his CAD models, his snagging a demo version of SolidWorks Premium 2012, his learning PhotoView 360, buying and adapting components to fit his design, his wife's complaints, and his bringing wondrous new meaning to a toy from the Land of Abandoned Toys, I get a number too big to ignore."

Voting for the three finalists that took place on *DE* Facebook fan page also agreed with judges' decision. So with pleasure and delight, we introduce you to the winner of our inaugural *DE* cubicle toy design contest: Mark Norwood and his water-spraying Sherman tank. He wins a Dell Precision workstation equipped with AMD FirePro graphics—with a retail value estimated at more than $5,000.

STAR-CCM+ v7.02 with Replay Option

CD-adapco (CD-adapco.com) is updating its STAR-CCM+ engineering simulation package. In v7.02, released in February, the company expanded its 3D CAD reading features. The software now imports tessellated formats, along with PLMXML data. Other improvements in CAD interaction include curvature retention in hole fillings, new gradients, and line projection. A new meshing technology introduced in this version lets you generate thick polyhedral prism layers. The software also lets you perform thermal coupling of one STAR-CCM+ simulation to another.



CD-adapco's STAR-CCM+ v7.02 features, among other things, the option to record and replay simulation results as a history file.

The Solid Shell element available in this version lets you simulate thin solids that are subjected to in-plane thermal conductivity. To deal with the explosion of simulation data—and the headaches associated with archiving and managing it—STAR-CCM+ v7.02 gives you the option to record and compare results from different configurations, or different meshes, and animate results over time (for transient analysis). According to the company's presentation, "Results from multiple simulations may be recorded in a single simulation history file, and easily replayed."

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by Kenneth Wong

The Return of Adobe 3D PDF

In 2007, when Adobe released Acrobat 3D Version 8, it hailed a new CAD translator and its ability to "convert virtually any CAD file into a highly compressed 3D PDF file." Squarely targeting the manufacturing crowd, the brochure said, "Use the de facto PDF standard for more secure, reliable electronic information exchange as the foundation of the release process of your CAD data to your customers and suppliers."

Then, for some reason, Adobe ceased pushing 3D PDF for design collaboration. Fortunately, the company didn't kill the format. 3D PDF just retreated into a corner, like a neglected puppy.

But the format may have finally found a new home at 3D PDF Consortium (3DPDFconsortium.org), formally incorporated this January. In its announcement, the consortium described itself as "a group of end users, software vendors, systems integrators, developers and software toolkit providers whose mission is to encourage the continued development and adoption of 3D PDF as a truly open standard for visualization, collaboration, data exchange and the long-term archiving of 3D data across multiple industries and disciplines."

"Forming the 3D PDF Consortium is a crucial step in keeping this high-value standard strong and responsive to industry needs," said Phil Spreier, manager of Translation Products for Tech Soft 3D.

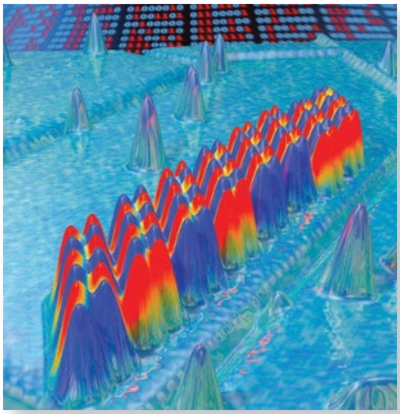
With proper industry and user support, 3D PDF could emerge as a rival to other lightweight formats like JT (from Siemens PLM Software) or 3D XML (from Dassault Systèmes).

Founding members include Adobe, the originator of 3D PDF; Anark, which specializes in 3D CAD reuse; Aras Corp., maker of open source product lifecycle management (PLM); Lattice Technology, which specializes in 3D CAD reuse; TechSoft 3D, which provides a 3D software developer kit; and tetra4D, which develops 3D PDF convertor software. Membership in the consortium is open to all organizations, regardless of size and industry focus.

Many members will come together in the group's first annual meeting in May, scheduled to take place at the same time as the 3D Collaboration and Interoperability Conference (3DCIC), May 21-23 in Denver. **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. You can send him e-mail to DE-Editors@deskeng.com.*

IBM Researchers Create Nanotech Memory



Researchers at IBM may have found a way to fundamentally boost digital storage capacity. As part of a five-year drive to devise a new angle on data storage, the team turned to nanotechnology.

Using a scanning tunneling microscope, the researchers experimented with what amount of atoms could be used to store information like a machine. Twelve was the magic number. These 12 atoms were able to store a digital 0 or 1. The best information storage technology currently available requires nearly 1 million atoms to achieve the same result.

The catch in all of this is that the experiments were conducted at 1 K (-457.87° F), and the information became unstable at around 5 K (-450.67° F). Researchers believe their results would require 100 to 150 atoms to retain stability at room temperature, but even that creates a technology that is 10,000 times more efficient than current drives.

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Engineering An Interactive Skateboard

You won't be skipping across water like McFly on his hoverboard in Back to the Future Part II, but the interactive skateboard developed by Chaotic Moon has some neat tricks engineered into it. By combining a skateboard, a Windows 8 tablet and Xbox Kinect controller, Chaotic Moon created a device that responds to speech and gesture recognition while processing localization data, accelerometer data, and more.

The amalgamation allows a user to pilot what the developers are calling "the Board of Awesomeness" just by movement. While few people may be interested in commuting to work on this new device, it does open up some possibilities for designing other hands-free technologies and maybe making people rethink how mobile devices can interact with home, work and play.

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Using Simulation to Prevent Battery Fires

With headlines trumpeting the potential for battery fires in GM's Chevy Volts, the company announced engineering changes to the structure around the battery pack, as well as the addition of a sensor to observe battery coolant levels.

No Volts have caught fire outside of testing by the National Highway Traffic Safety Administration, and GM has not issued a recall. The fires occurred days or weeks later in testing, and could pose a hazard for technicians working on the cars who might not follow proper safety procedures. The enhancements were incorporated into the Volt manufacturing process when production resumed in January.

Because no manufacturer wants to see their product's safety questioned, *DE* asked Sandeep Sovani, manager of Global Automotive Strategy at ANSYS Inc., how simulation and testing might be used to avoid such problems before production.

"Cell and pack makers perform a considerable amount of testing during the development process to investigate the impact of these variables, but there is never enough time to come anywhere close to investigating the complete design space," Sovani told us. "Simulation with tools such as computational fluid dynamics (CFD) and thermal analysis can fill the gap by enabling battery makers to evaluate a large combination of design variables under extreme conditions to determine their propensity to produce thermal runaway. With simulation, the cooling system can be extensively characterized over a wide range of scenarios, so that the battery management system can be programmed to take effective countermeasures for any scenario."

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Spider Robots in Outer Space: Biomimicry, B-Movie, or Both?

NASA turned to nature for the inspiration for its Spidernaut, a robot designed for constructing and maintaining large on-orbit structures in space. The robot's eight legs help it disperse its mass over a large area without imparting any torque when it moves. The extra-vehicular robot (EVR) is under development at NASA's Johnson Space Center.

Because these robots can move "lightly," they are being looked at for constructing and maintaining fragile space science platforms and vehicles. According to NASA's website, these eight-legged robots can spread climbing loads evenly across a structure, carrying large payloads or transporting structural materials across a solar array.

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3D Printers Head Home

The Thing-O-Matic, MakerBot's first offering in the field of personal manufacturing, is now joined by the Replicator. It shares the same rough-and-ready look of the Thing-O-Matic, but can be purchased with what MakerBot is calling a "Dualstrusion" option. Dualstrusion allows for two-color products and printing of objects up to 8.9 x 5.7 x 5.9 in. The going price for the Replicator with the Dualstrusion option is $1,999, and the single-color version sells for $1,799.

3D Systems' upcoming personal 3D printer is named the Cube. Unlike MakerBot's offerings, it is sleek and stylish. It can print objects up to 5.5 X 5.5 X 5.5 in., and offers the ability to print in 10 different colors (only one color per object). The retail price for 3D Systems offering is $1,299.

MORE ➜ rapidreadytech.com/?p=40

Additive Manufacturing Goes Big in Africa

South African manufacturer AeroSud is thinking big. With the aid of government investments, AeroSud has launched Project Aeroswift. The end goal of

the project is to create an additive manufacturing machine capable of printing out parts as large 6.5 x 1.5 ft.

The South African National Laser Center has pitched their aid to the project by creating a 5 kW IPG single-fiber diode laser to use in the laser sintering machine. The primary material used will be powdered titanium. By using AM to create aerospace parts, AeroSud says it can use variable-density printing to reduce the overall weight of parts, which in turn will reduce the amount of fuel consumed.

MORE ➜ rapidreadytech.com/?p=345

Win a 3D Printer

Who doesn't want their very own 3D printer? Engineers, educators and designers can enter *DE's* Rapid Ready sweepstakes for a chance to win a uPrint 3D Print Pack from Stratasys. The deadline is March 23.

The uPrint package contains a uPrint SE 3D printer, a WaveWash support cleaning system, EcoWorks cleaning agent, ABSplus ivory print material, build support material and modeling bases. All of that works out to a complete 3D printing solution right out of the box. If you find yourself needing something to print, check out Rapid Ready's 3D model files section (rapidreadytech.com/rapid-resources/3d-files/) for inspiration.

TO ENTER ➜ deskeng.com/3Dprinter

The Doctor is Into Additive Manufacturing

A number of institutes around the world are experimenting with bioprinting. The process uses inkjet-based 3D printers and an "ink" made of human cells (as with cloning, using the patient's own cells are the best bet) mixed with a dissolvable gel, often cellulose. From there, the process is similar to other additive manufacturing techniques. The printer puts down a layer, which is then cured with heat, chemicals or UV light, before moving on to the next layer. Finally, the printed part is placed in a bioreactor, where it is subjected to the processes it is meant to facilitate (blood is pumped through heart valves, liquid through a liver, etc.).

As well as helping ensure transplanted organs won't be rejected, bioprinting can help to overcome a general shortage of organ donors. As long as the patient has enough of the proper cells to be harvested, no donor is required. Even in cases where this isn't possible, a donated organ could theoretically be used multiple times to produce a number of organs, instead of providing for a single patient.

The process isn't limited to the creation of internal organs. Researchers at Washington State University have used bioprinting to make new bones. Doctors at University College in London designed and printed a polymer scaffold that was used for a trachea transplant. Even skin can be produced through this method, which will have a serious impact on the treatment of burn victims.

MORE ➜ rapidreadytech.com/?p=83 and rapidreadytech.com/?p=421

Details Announced for RAPID 2012

The Society of Manufacturing Engineers (SME) will host RAPID 2012, one of North America's largest additive manufacturing (AM) conventions, in Atlanta May 22-25.

Speakers for the event will include Terry Wohlers, president of Wohlers Associates, Michael Mock of INUS Technology, Andreas Berkau of citm GmbH and many others. Wohlers will speak about the state of additive manufacturing, Mock will discuss 3D scanning and Berkau will cover using AM as an alternative to aluminum casting.

SME will offer concurrent workshops at the show covering the areas of the fundamentals of AM, reverse engineering and 3D data capture, and the use of AM to create metal parts.

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A Mouse That Roars

Team leader Danny Ellis leverages the 3D mice family and six degrees of freedom control for robot design and flight manipulation.

When Danny Ellis was first introduced to CAD in high school with a course in Autodesk Inventor, little did he know he would someday be designing and flying aerial robots. As Ellis advanced into the engineering program at the University of Michigan, he was introduced to the powerful capabilities of CATIA, and it was there he also discovered 3Dconnexion 3D mice.

"In between my freshman and sophomore years, I became irritated at how cumbersome it was to rotate a model using a traditional mouse in CATIA," says Ellis. "I thought, 'I bet I could get a trackball mouse and program it so when I rotate the mouse, it rotates the part. I did a Google search to see if it had been done before, and that's when I came across 3Dconnexion. It was exactly what I had been looking for. I ordered the SpaceNavigator right away, and haven't stopped using it since."

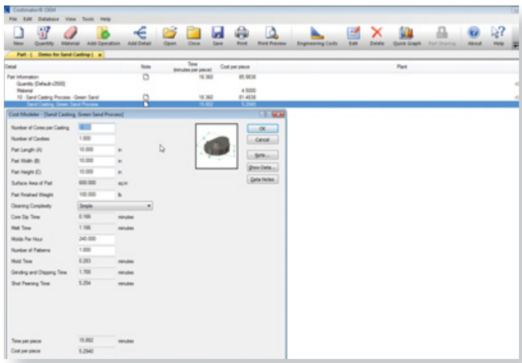
In 2009, during his senior year, Ellis began researching an aerial robot competition he could undertake at the university. Five days later, he started the

Michigan Autonomous Aerial Vehicles (MAAV) team, with 15 members ranging from freshman to graduate students studying aerospace, computer, electrical and mechanical engineering. Within a week, the team kicked off its first quadrotor design for the International Aerial Robotics Competition (IARC). And at the end of the first year, MAAV successfully built two quadrotor vehicles capable of manual flight.

MORE → deskeng.com/articles/aabect.htm

Pedal to the Metal

Costimator gives one manufacturer speed and accuracy in its estimating projects



MCG of Portugal recently selected Costimator, MTI Systems' flagship software estimating tool, to help increase its cost-estimating speed and enhance the accuracy of its quotations.

MCG is a 60-year veteran of the metallic component manufacturing industry, with a laser focus on ethics and sustainability. The machining, fabricating and assembly company fuses its cutting-edge technologies, a robust engineering department and forward-thinking research and development processes, all dedicated to making waves in the automotive, solar, laser and tooling markets. However, when traditional cost estimating practices on archaic spreadsheets consumed vast amounts of financial and human resources, MCG knew it was time for a change.

"What we used for cost estimating was the typical spreadsheet for every kind of process. So if, for example, you had a part with five processes, we would use five different spreadsheets. This dispersion, over thousands of spreadsheets, was time-consuming and error-prone," explains MCG Sales and Marketing Director Pedro Sousa. "With Costimator, we are seeing a reduction in cost estimating lead time, and an increase in accuracy through a more simplified estimating process."

"We are finding that more and more overseas manufacturers are seeking out cost estimating software to help them improve the quality and timeliness of their cost estimating process," notes David LaJoie, vice president of sales for West Springfield, MA-based MTI Systems. "In fact, our international sales of Costimator have more than tripled in the last two years."

Costimator cost estimating, quoting and process planning software has, for the past three decades, served as a platform helping to make cost estimating more effective for part suppliers. Whether estimating machining, fabricating or assembled parts, it helps manufacturers, like job shops, contract manufacturers, precision machining shops and others quickly and accurately estimate cycle times and determine the manufacturing cost for parts and assemblies. Today, the software is also being used by many of the world's largest original equipment manufacturers (OEMs) in a variety of industries, including defense, aerospace, medical, heavy equipment, automotive and consumer product.

→ For the complete application stories visit deskeng.com/fastapps

Testing, Testing, 1-2-3

Test & measurement are what separate the designer from the engineer. Without the constraints of validation, design concepts exist only on the screen. Through virtual and physical testing, the concept becomes reality.

Digital simulation and analysis can go a long way toward ensuring a design will meet its intended purpose. It can help reduce material use due to costly over-engineering, find design flaws earlier in the product devlopment cycle and make trying various "what-if" scenarios easy and affordable. We cover the amazing advancements of simulation software each month in *DE*. But any simulation expert will tell you that simulation alone is not enough.

For firms just getting more comfortable with simulation, it can actually lead to more testing. Just as email created more printouts, simulating various design scenarios often leads to more phyisical prototypes and testing before the visualizations on the screen can be trusted. As engineers become more familiar with the strentghs and weaknesses of simulation, it allows them to do fewer physical tests than ever before.

In the end, rather than supplant testing, simulation and testing go hand in hand. Simulation became a credible tool because testing validated it, and now fewer tests make each one even more critical.

Test & Measurement Tech

Luckily, the technology behind test & measurement has kept pace with the demand for more accuracy and faster results when validating product designs. Just as simulation has ridden the wave of increasingly faster computer processors to improve results, so too has test equipment.

Virtual instrumentation consolidates dozens of specialized pieces of hardware into windows on your workstation monitor, modular hardware and industry standards allow you to mix and match until you have the right tests for each prototype, and data acquisition devices are capable of collecting more results from smaller, more precise (sometimes wireless) sensors. Handheld scanners bring thousands of data points into your workstation, no calipers required. You can even load an oscilloscope app on your iPad.

Keeping Up with Complexity

The state of the art is a constantly moving target. Look no further than the proliferation of our ever-shrinking electronics or the gradual shift toward hybrid vehicles. Each technological innovation seems to add to the complexity of the final product.

Design engineers are charged with incorporating the latest and greatest technology into their products. The whole is greater than the sum of its parts because design engineers make sure each new part — each new technology — fits into the overall design without breaking anything else. From testing the sensitivity of a tiny accelerometer in the thinnest new smart phone to ensuring an electric motor will take over for a gas-powered one when needed, today's product technologies have become increasingly integrated.

Such complex, integrated systems are shifting the responsibilities of engineers. For example, mechanical engineers were once content to deal with the "nuts and bolts" of a product and send it off to an electrical engineer to add in the necessary electronics and worry about voltages and heat exchange. But now engineers are becoming multi-disciplinary. Easy-to-use test software is allowing designers to become more adept at including electronic systems in their mechanical products.

DE is excited by the advancements in test & measurement that are enabling new innovations to come to market. It's the reason we've renewed our focus on test & measurement with dedicated monthly magazine coverage, daily online updates and four special sections like this one. If you have a test & measurement story to tell, we're listening. Contact us at de-editors@deskeng.com.

In This Special Section on Test & Measurement:

17 Convert Design Intent to the Inspection Plan
18 The Battery Battle
22 Testing the F-35
23 New Test & Measurement Products

Convert Design Intent to the Inspection Plan

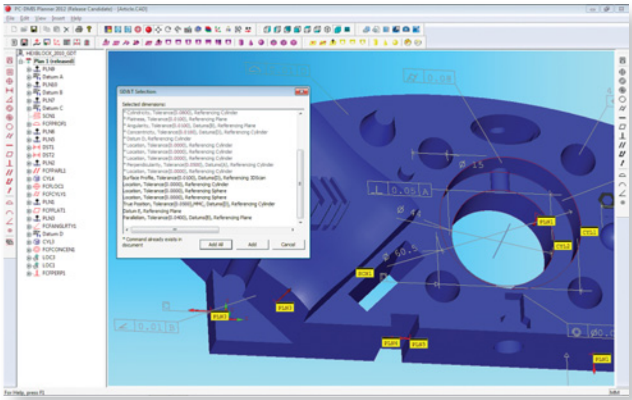
BY JIM ROMEO

Hexagon Metrology offers a complete Enterprise Metrology Solution (EMS) suite of software and hardware. One of the EMS solutions is PC-DMIS Planner, which allows the CAD designer to convert design intent into an inspection plan regardless of measurement device. PC-DMIS, the EMS flagship software, supports a wide array of measurement devices. The software can import the inspection plan from PC-DMIS Planner and automatically create an efficient, collision free part program. The results can be sent automatically to DataPage+, a statistical process control (SPC) software within EMS with statistical analysis tools and graphical reports. Finally, Web Reporter allows users to view those statistical reports on the web without proprietary software or extensive training.

Joe Zink works with Hexagon Metrology for its CAD and dimensional reporting products and specifically PC-DMIS Planner. We spoke to him to understand the application.

DE: Can you explain how your product is used by Chrysler?
Joe Zink: Chrysler has written an in-house software package called eTool. It resides as a module inside their Unigraphics CAD software system. It outputs an inspection plan, just like PC-DMIS Planner, in the same inspection plan file format. PC-DMIS can import this file and automatically create a part program. The inspection plan philosophy allows the engineer to manage only one measurement routine per product as PC-DMIS automatically accounts for the specific hardware platform when the plan is imported. This means the same inspection routine will run on virtually any device with minimal operator input.

DE: How can designers to test and assess their products?
Joe Zink: One of the highlights of PC-DMIS Planner is that it reads in the CAD file directly, displays the part geometry, and shows the Geometric Dimension and Tolerancing (GD&T) notes added by the designer to indicate the critical dimensions and their tolerance values. PC-DMIS Planner is very intuitive and easy to operate. The user just clicks on a GD&T note, and the commands defining the datums, features, and dimensions for that note are automatically added to the inspection plan. This simple step removes any ambiguity in the interpretation of the GD&T note. The user can add all dimensions indicated by all of the GD&T notes on the CAD model by clicking just one icon, or selecting one menu item.



PC-DMIS Planner can convert designs into inspection plans.

DE: What is the relationship between Hexagon's product and other proprietary engineering software?
Joe Zink: We have licensing partnerships with all the major CAD software companies. PC-DMIS and PC-DMIS Planner directly access CAD data from CATIA, Pro/Engineer, SolidWorks and Unigraphics through a Direct CAD Interface. Additionally, both products come standard with the ability to import data in a variety of generic CAD file formats; including, DXF, IGES, JT and STEP to name a few. Both products are very CAD-centric.

DE: Do you see any trends in engineering design software?
Joe Zink: The EMS strategy is a trendsetting approach to software development with its big picture focus on design-to-quality solutions. NIST is in the process of creating an industry standard that in many ways mimics the EMS strategy. It is called the Quality Information Frameworks (QIF). Specific standards will be derived from QIF's umbrella of capabilities. One of these standards will be called QMplans, and its purpose is to define the flow of information from design to quality. For example, this will allow a product like PC-DMIS Planner to create an inspection plan in an industry standard format, so that any measurement software that subscribes to this standard will be able to read the plan. Hexagon Metrology is an active participant in the development of this standard. DE

INFO → Hexagon Metrology: hexagonmetrology.us

For more information on this topic, visit deskeng.com.

The Battery Battle

Optimizing battery run-time calls for a real-time capable SMU.

BY EDWARD BROREIN, *AGILENT TECHNOLOGIES*

There is a worldwide revolution taking place: All kinds of things in our daily lives are becoming wireless—not only our mobile phones and the Wi-Fi for our laptops, but our home's climate monitoring and controls, our utility meters, our medical health monitors, and even sensors in the bridges we drive over are examples of this.

Most of these devices are battery-powered. Some devices, like mobile phones, are rechargeable—and they usually make it through a day before needing a recharge. Other devices, however, like a wireless outdoor thermometer, can run for a year or longer on its disposable battery.

Whether the device runs for a day, a month or a year, one thing that has not kept up with the rapid rate of wireless innovation is the battery. There is a clear need to optimize all these devices to get the maximum possible run time from their batteries.

A precision source measure unit, or SMU, would seem like an ideal instrument for powering a variety of battery-powered devices and accurately measuring their respective battery drains. However, in practice this turns out not to be the case. The critical difference is the use-model for which traditional SMUs are tailored: powering and characterizing functionally passive devices. In contrast, when you optimize battery run time, you are powering and characterizing a functionally active device. This is a very different use-model calling for a different kind of SMU, one having real-time sourcing, measurement and operational capabilities to address this need.

Real-time Battery Emulation

A battery is a non-ideal energy source. Its output voltage varies with loading, temperature, charge, time and even its history. The basic real-time behavior of a battery is usually modeled as a variable voltage source with series impedance. The battery voltage instantaneously drops in proportion to the current drawn as a result.

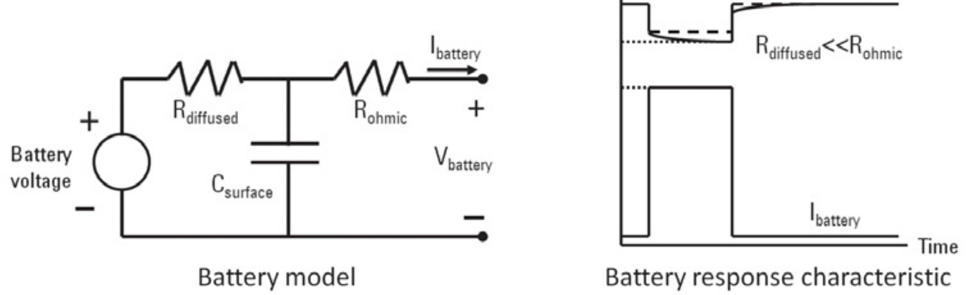
A little more elaborate, real-time model also includes the resistor–capacitor (RC) stage, simulating the slight voltage droop and recovery effects many batteries exhibit during heavy loading and unloading. This is governed by the charge more immediately available vs. that which exists deeper in the battery's structure. This battery model and its response characteristics to pulsed loading are shown in Figure 1. Because of a battery's non-idealities, it interacts with and influences the performance of the device it is powering.

A traditional SMU strives to be as precise of a static direct-current (DC) voltage as possible. Delay time is used to let it settle acceptably close to its set level before a measurement is taken. While this is good for powering functionally passive devices, it is not as well suited for battery-powered devices, thanks to the devices' dynamic loading and interdependency with their non-ideal batteries.

A traditional SMU often has excessive transient under- and overshoot voltage at load transitions, and lacks the battery's voltage drop response in proportion to the load current. This alters the performance and current draw of many battery-powered devices. For some devices, a large enough transient drop can even trigger the low battery voltage shutdown.

In comparison, SMUs tailored for battery-powered devices incorporate extremely fast transient voltage response and programmable series output resistance to provide basic, real-time battery emulation. An example of this is shown in the oscilloscope screen captures of a mobile phone's input power in Figure 2. The SMU output response behavior is similar to the bat-

Figure 1: Real-time battery model and load response characteristics.



tery, providing more realistic device performance and comparable current drain—and thus more accurate test results.

Volume vs. Range

To conserve energy, most battery-powered devices transmit or otherwise operate in short bursts of activities. They then drop down to an extremely low power idle or sleep state between these periodic activities. The resulting current drain is pulsed. The minimum- and average-to-maximum ratios often span as much as four decades, depending on the device and how deeply it powers down between its bursts of activities.

Because most battery-powered devices spend most, if not all, of their time operating in a power savings mode, it is important you optimize these modes. Real-time, high-speed digitized measurement of the minimum and maximum values, and everything in between, is essential for you to get the detailed insights needed for optimizing the battery run-time.

A traditional SMU has a multitude of measurement ranges, usually spaced just a decade apart, allowing it to accurately measure from femtoamps to amps. While this is an extremely wide range, it is a static capability. It can only use one range at a time when making a measurement. While this is excellent for characterizing functionally passive devices drawing static currents, it is not as well suited for battery-powered devices drawing pulsed currents. A measurement range has a typical error of 0.03% of reading plus 0.03% of range. The percent of range offset error limits the dynamic range of measurement accuracy. For example, for 0.03% offset error, to achieve up to 3% accuracy for a pulsed signal's floor level, the signal cannot span more than two decades.

What is instead needed for battery-powered devices drawing pulsed currents is an extremely wide dynamic range of measurement having low offset error. However, measuring the floor for a signal spanning four decades with 3% accuracy calls for just 0.0003% offset error. This performance is not available in traditional SMUs. You sometimes can adopt workarounds to get past this inherent limitation, but not without suffering significant consequences as a result.

In Figure 3, we measured the pulsed current drain on a wireless temperature transmitter. On the left, you can see it transmits every 4 seconds, drawing a peak current

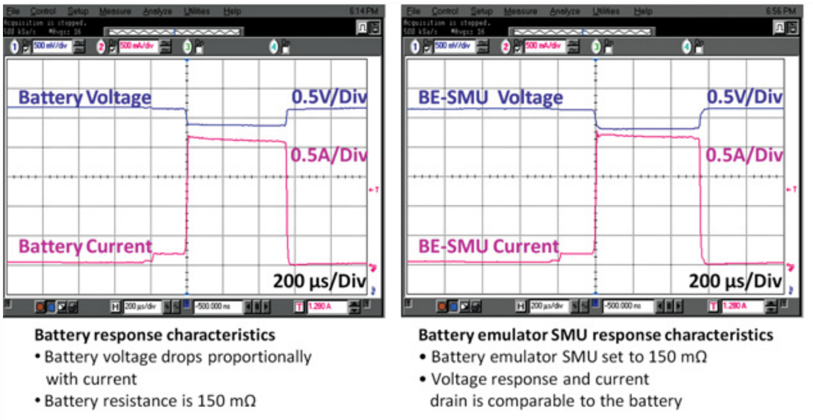


Figure 2: Actual battery and battery emulator SMU voltage response characteristics.

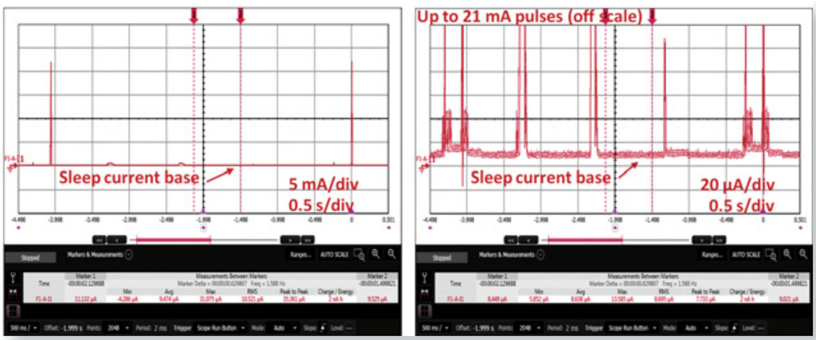


Figure 3: Pulsed current drain measurement on a wireless temperature transmitter.

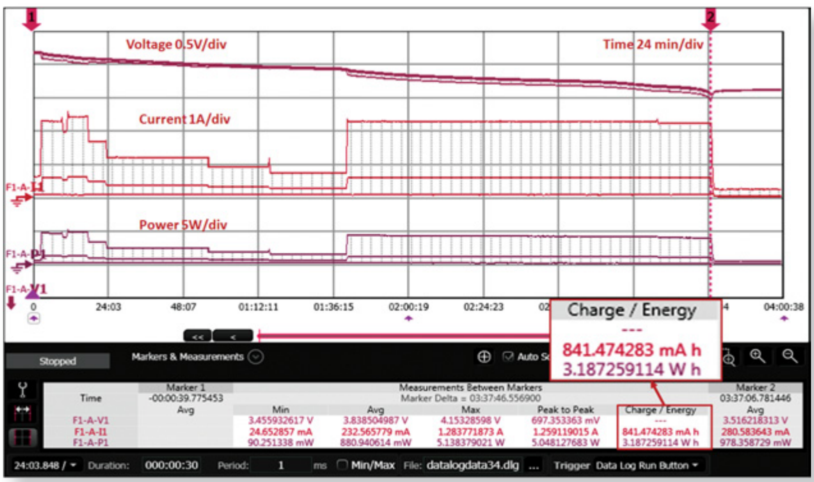


Figure 4: Battery run-down test on a GSM mobile phone.

of about 21 mA. On the right, we expanded the amplitude scale to 20 µA/div. Together with measuring the peaks, we were also able to observe and accurately measure the overall average current of 53 µA, as well as the sleep current of just 8.7 µA. We used an Agilent N6781A SMU and related software, tailored for battery-powered devices. The N6781A has conventional 1 mA, 100 mA and 3 A measurement ranges. However, unlike traditional SMUs, the N6781A seamlessly selects its most accurate range in real-time, based on the instantaneous level of the signal, to provide a high-speed, wide dynamic range, continuous measurement in just one pass.

Parametric vs. Time-based Measurement

One key aspect of testing battery-powered devices is measuring and evaluating the current and voltage over short and long time periods, sampled at high rates, to provide the insights for optimizing run time.

Traditional SMUs are tailored for generating I-V parametric curves of functionally passive devices by forcing a series of voltage or current settings, and making the corresponding current or voltage measurements independent of time. The SMU and device, in turn, wait upon the other to be ready at each setting. While some traditional SMUs support higher sampling rates for short time-based measurement acquisitions, they lack all the operational capabilities useful for battery-powered device testing.

SMUs for testing battery-powered devices need to operate like an oscilloscope, for fast dynamic waveform acquisitions, and similar to a data logger, for long-term acquisitions, capturing and displaying voltage, current and power against time. They should compute area-under-the-curve amp-hour capacity and watt-hour energy values, key for assessing and optimizing runtime of battery-powered devices. They should also have configuration flexibility to allow logging their own voltage and current when directly powering the device, as well as remotely logging the output of an actual battery when performing a run-down test. Figure 4 shows the results of a battery run-down test performed on a mobile phone together with its battery. These capabilities greatly simplify the task of battery drain measurement and analysis.

Final Thoughts

There is indeed a revolution taking place, with all kinds of new wireless devices being innovated. It's imperative we get the most out of the batteries available. While a traditional SMU would at first seem to be a logical choice for powering and measuring current drain for battery-powered devices, we have learned here that this turns out not to be the wisest choice. Optimizing battery-powered devices is instead better served by using SMUs having real-time sourcing, measurement, and operational capabilities tailored specifically for this task. **DE**

Edward Brorein *is an engineer at Agilent Technologies. Contact him via de-editors@deskeng.com.*

INFO ➜ Agilent Technologies: Agilent.com

For more information on this topic, visit deskeng.com.

Tadiran Introduces New Batteries

Tadiran Batteries (tadiranbat.com), the company that promises 25 years of operating life for some of its products, has introduced a new high-voltage/high-rate AA-sized lithium battery, the TLM 1550, as well as TLM Military Grade Batteries, a new family of high-energy lithium metal oxide batteries developed for military and aerospace applications.

The AA-sized TLM 1550 features an open circuit voltage of 4.0 volt, and the ability to handle pulses of up to 15A, with 5A maximum continuous load. According to the company, the TLM offers very long life in extreme environmental conditions, including a self-discharge rate of less than 3% per year at room temperature, and a temperature range of (-40°C to +85°C).

TLM Military Grade cylindrical batteries feature an open circuit voltage of 4V, with a discharge capacity of 500 mAh (20 mA at 2.8V RT), capable of handling 5A continuous pulses and 15A maximum high current pulses. They feature low self-discharge and an operating temperature range of -40°C to 85°C. The batteries comply with various MIL-STD 810G specs and UN 1642 and IEC 60086 standards for ruggedness.

Testing the F-35

New stealth fighter illustrates importance of real-world testing.

BY JAMIE J. GOOCH

New product introductions often have cost over-runs, but when your new product costs $90 million each and multiple governments are footing the bill, the consequences are multiplied through the lens of public debate.

Take, for example, the Lockheed Martin F-35 Lightning II. It's a fifth-generation fighter plane that incorporates stealth technology. The family includes three models: a conventional takeoff and landing (CTOL) variant, a short take off/vertical-landing (STOVL) variant, and a carrier-based variant. The U.S. plans to spend about $379.4 billion on 2,400 of the jets. Turkey, Italy, Britain, Denmark, Norway, the Netherlands and Canada have also placed orders.

But the jet development was planned with a concurrent production strategy that emphasized simulation and modeling upfront, then conducted testing as planes were being produced. Intended to get the aircraft up and flying faster, the strategy led to several planes being delivered before critical issues were found via testing.

Public Fallout

The man responsible for buying weapons for the U.S. military recently called the strategy "acquisition malpractice" and said it should not have been done.

Frank Kendall, the Pentagon's Acting Undersecretary of Defense for Acquisition, Technology and Logistics, explained the flaws in the "optimistic" concurrent strategy during a speech at the Center for Strategic and International Studies.

"The optimistic predictions, when we started the production of the F-35, that we now had good enough design tools and good enough simulations and modeling that we wouldn't have to worry about finding problems in test was wrong," he said.

"So we're finding problems with all three of the variants that are the types of things that are historically in a state-of-the-art, next-generation fighter aircraft you're going to find, OK, where our design tools are not perfect and we didn't model everything as precisely as we thought we had. So we're working our way through that," Kendall continued.

Production on the aircraft began in 2003. The first official test flight took place in December 2006.

"The hardest part of any acquisition program is the transition from development to production," Kendall said. "And that's where the concurrency arguments come in. You know, when should you start? And I think there's been a tendency to start too early in some cases. And the F-35 is probably an extreme example of that."

Congressional Consequences

That speech last month wasn't the first time F-35 production issues made headlines. In 2010, then Secretary of Defense Robert Gates testified before the House Appropriations committee about "unacceptable delays and cost overruns" in the program, and how it was being restructured.

"We reduced the number of aircraft being purchased concurrent with testing and development," he said. "While delaying full-scale production was not a welcome development — to put it mildly — it was important to avoid a situation where a problem discovered in testing would lead to expensive retrofits of aircraft."

He went on to explain how the program's manager had been replaced, more aircraft had been added to the testing program and that more than $600 million in performance fees had been withheld from the lead contractor.

The F-35 SDD flight test program plan calls for the verification of 59,585 test points through developmental test flights by Dec. 31, 2016. Through 2011, the flight test team had accomplished 12,728 test points, which exceeded the goals for 2011.

While developing a new military aircraft is a massive undertaking full of technical complexities and political wrangling, most design engineers can relate to the pressure to get a product out quickly. Though modern modeling and simulation technologies are capable of amazing things, the F-35 serves as a public example of the importance of testing early in the design phase. **DE**

Jamie J. Gooch *is managing editor of* Desktop Engineering. *Contact him via de-editors@deskeng.com.*

The F-35 Lightning II by the Numbers

Crew: 1

Length: 51.4 ft.

Wingspan: 35 ft.

Height: 14.2 ft..

Wing area: 460 ft.^{2}

Empty weight: 29,300 lbs.

Loaded weight: 49,540 lbs.

Powerplant: 1 × Pratt & Whitney F135 afterburning turbofan

Thrust with afterburner: 43,000 lbf

Internal fuel capacity: 18,480 lbs.

Maximum speed: Mach 1.6+ (1,200 mph)

Service ceiling: 60,000 ft.

1 Acquire, Analyze and Present Test Data

NIational Instruments' (ni.com) LabVIEW Signal-Express provides an interactive measurement workbench for acquiring, analyzing, and presenting data from hundreds of data acquisition devices and instruments, with no programming required. It features a drag-and-drop environment to acquire data, perform analysis, and create custom reports. Support for hundreds of data acquisition, modular, and stand-alone instruments is included.

Tektronix Expands, Upgrades High Voltage Probe Offerings

Tektronix, Inc. (tek.com) has announced four new high-voltage probes and upgrades to three existing probe offerings. New models include the THDP0100, THDP0200 and TMDP0200 probes. The P5202A is another new model that offers lower attenuation and improved signal to noise ratio. The upgraded probe models include the P5200A, P5205A and P5210A probes. Tektronix says power measurement requirements are becoming increasingly challenging, requiring probes that can measure both the high and low voltage components of signals.

2 Calibration Management Software Released

Fluke Calibration (flukecal.com) has released version 8.0 of its MET/CAL Plus Calibration Management Software. It adds an expanded Procedure Editor with a more flexible user interface, more functions for editing, testing, and storing procedures, increased security, and the ability to automate a wider variety of references including power sensors, RF power meters, and National Instruments PXI systems. MET/CAL Plus consists of two applications: MET/CAL for automated calibration and MET/TRACK for test and measurement asset management.

Kistler Releases Quartz High-Pressure Sensor

Kistler North America (kistler.com) has released the Type 6215 quartz-based, high-precision pressure sensor, designed for meeting the application demands of internal ballistics; closed bomb testing; weapons discharge and cartridge chamber testing; and other extreme high-pressure measurement requirements. The design of the Kistler Type 6215 incorporates a quartz crystal sensing element and front sealed diaphragm, packaged together within a stainless steel housing.

Module Serves as a Base System for Airbag Testing

The Keithley Instruments Inc. (keithley.com) Model 2790-H is a single-module system designed for both low current and high voltage ohms (10MΩ to 1GΩ) applications. The company says the system provides all the capabilities needed for electrical testing of either single- or dual-stage inflators in single position test stands. With the addition of a Model 7702 40-channel differential multiplexer module, the Model 2790-H + Model 7702 opens the door to higher channel count applications.

3 HBM's MX1601 Boosts QuantumX Flexibility

HBM's (hbm.com) MX1601 is a 16-channel amplifier that can work together with a large number of different sensors. According to the company, all physical measurements via standardized voltages or currents can be acquired. Current-fed, piezoelectric transducers (IEPE/ICP) can also be connected. The new amplifier module supports TEDS, the Transducer Electronic Data Sheet that enables connected sensors to be automatically identified and configured.

New Accelerometers Made for Weapons Testing

Meggitt Sensing Systems (meggittsensingsystems.com) now offers the Endevco model 7280 series, a family of lightly damped single axis high-g piezoresistive shock accelerometers designed to support pyroshock, weapons testing, high-shock data recorders, missiles, munitions and other demanding requirements. According to the company, the sensors offer survivability to four times over-range, minimum shift after shock, higher impedance and lower power consumption than legacy models.

Omega Introduces DPGM409 Pressure Gauge

Omega Engineering (omega.com) has released the DPGM409 pressure gauge. According to the company, the gauge covers the full spectrum in pressure measurement with Gage, Sealed Gage, Absolute, Compound Gage, Vacuum, and Barometric pressure ranges. Its core is a micromachined silicon sensor with a 0.08% accuracy. Each unit is supplied with a 5-point NIST traceable calibration certificate and is tested to industrial CE standards. DE

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Pass the SULSA

Laser sintering is used to design and build what's being hailed as the first 3D-printed unmanned airplane.

BY SUSAN SMITH

Reminiscent of model airplanes with their snap-together features, the Southampton University Laser Sintered Aircraft, or SULSA, is the first of its kind: a 3D printed airplane created using an EOS Eosint P730 nylon laser sintering machine. SULSA is part of the EPSRC-funded Decision Environments for Complex Designs (DECODE) project, which consists of a team of students and staff of the University of Southampton who design, build and fly sub-20kg state-of-the-art unmanned air vehicles (UAVs) outfitted with full autonomous control systems and on-board cameras. These include morphing wings and tiperon control surfaces.

Currently, they are using manufacturing techniques such as laser sintering to demonstrate their use in the design of UAVs. These SULSA aircraft are small, fly and have "useful payload," notes A.J. Keane, professor of Computation Engineering at University of Southampton and a Fellow of the Royal Academy of Engineering (FREng). He and Jim Scanlan, professor of Aerospace Design, are both project leads from the Computational Engineering and Design Research group.

"I guess it's more than a model, though not being made in a production fashion, since we are not a commercial operator (yet)," Keane says.

The entire structure is 3D printed from a SolidWorks 3D CAD model, with conventional servos, batteries, avionics, motor and propeller that clip into place without screws. The design process was streamlined with complete optimization, design and manufacturing work flow.

Designed by the University of Southampton, the 3D printing additive layer manufacturing specialist company 3T RPD Ltd., based in Berkshire, assisted in the process. Skycircuits created the autopilot capability. EOS Eosint P730 was chosen because there are only two companies who offer nylon sintering, and the aircraft needed the strength of nylon.

In addition to research projects like this one from the University of Southampton, 3T RPD applies its technology to various projects, such as creating specialist aerospace components, medical implants and architectural design elements for the construction industry.

Snappy Structure

The aircraft boasts a four-part structure, including main fuselage, rudder fins, nose cone and two outer wings. The aircraft itself has a pusher engine, v-tail design and elliptical wing form. The fifth nylon part is the instrument tray that clips inside the main fuselage.

All the fasteners are printed in the nylon, with no bolts, screws or nuts. Hinges are also 3D printed, and all hinges and parts are printed in place.

All the equipment is clipped into place including four servos, the engine, and the equipment tray that has clips for and houses all the additional equipment, which includes two batteries, avionics and the autopilot. The front fuselage is attached using a bayonet.

The maximum engine power for the aircraft is 400 w. Cruise range is nearly 28 miles at 38 knots. The electric-powered aircraft has a 6-ft., 6-in. wingspan and can fly at a top speed of nearly 100 mph. When it's in cruise mode, it's almost silent. It is also equipped with a miniature autopilot. The weight of the plastic parts is less than 5 lbs. The aircraft employs a catapult launch with a belly landing.

"Aerodynamicists have, for decades, known that elliptical wings offer drag benefits," Scanlan points out. "But laser sintering removes the manufacturing constraint associated with shape complexity—and in the SULSA aircraft, there is no cost penalty in using an elliptical shape."

Scanlan says that the laser sintering process is so flexible, it allows the design team to explore ideas that would have been extremely expensive using traditional manufacturing methods. One of these ideas involves the use of a geodetic structure, which is stiff and lightweight, but also complex. To create this type of structure traditionally would require numerous, individually constructed parts that would have to be fastened together—at great expense. This type of structure was initially developed by Barnes Wallis, and used on the Vickers Wellington bomber that first flew in 1936.

Because the design is parametric, it can be stretched and resized. Although this design is small, it can be made larger to accommodate larger aircraft designs.

"This could revolutionize the economics of aircraft design," Keane predicts. "The cost of structural design complexity is effectively zero."

Keane adds that because there are no tooling costs and you can print when you need to, mass customization will be not only possible, but desirable. Scanlan agrees.

The only time-consuming ele-


All equipment is clipped into place, no screws required.

ment of the process is the powder cleaning, but otherwise designs can be upgraded and spare parts printed in 96 hours or less.

When the aircraft goes into production, the team plans to combine 3D printing with numerically cut foam techniques it's been pioneering to make large wings. The two materials are linked with carbon fiber tubes as spars.

Keane and Scanlan say that they see observation studies such as for shorelines, oceanography or forests as potential uses for the aircraft. Farming also will be a big user, they predict, "once air regulations catch up." **DE**

Susan Smith *is a contributing editor for* Desktop Engineering *magazine. She has been an editor and writer for the technology industry for more than 15 years and resides in Santa Fe, NM. Send e-mail about this article to DE-Editors@deskeng.com.*

INFO ➜ University of Southampton DECODE: SoTon.ac.uk/~decode/index.htm

➜ **Skycircuits:** Skycircuits.com

➜ **3T RPD:** 3TRPD.co.uk/

➜ **EOS:** EOS.com

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Autodesk, the Simulation Company

BY VINCE ADAMS

Based in San Rafael, CA, Autodesk has long been known as a CAD powerhouse. After some recent high-visibility acquisitions in the simulation domain—including Algor, Blue Ridge Numerics and Moldflow—Autodesk's commitment to computer-aided engineering (CAE) became clear.

This alone isn't remarkable. Most major CAD companies have integrated simulation solutions in different degrees through acquisition. It's a familiar story, in fact: A CAD company purchases a finite element analysis (FEA) tool and offers a CAD-embedded version of the traditional analysis process.

However, Autodesk wasn't prepared to accept the status quo. Per Scott Reese, the company's senior director of Simulation Solutions, after exhaustive research with customers and across the market, Autodesk chose a different approach that it expects to be a game changer.

Autodesk's View of Simulation

Reese says that Autodesk believes the simulation market is bigger than the current industry offering can address. Conversations with customers helped it realize that every design and manufacturing company needs simulation. What's driving development at Autodesk is that established paradigms won't work with the diverse cultures, cost structures or engineering processes at non-traditional simulation users.

Autodesk recognized that previous investments and commitments to simulation—at Autodesk, its partners and its competitors—have not made simulation as prolific as industry gurus predicted it should be. Reese and Autodesk were convinced that a "one-size-fits-all" simulation tool would never succeed in these companies.

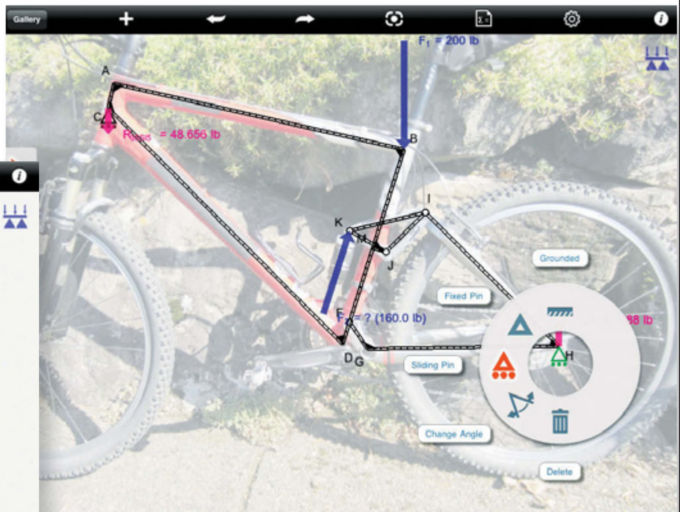
"They need the right simulation tool for each person in the process at the proper time," Reese says.

Autodesk has responded to this view on market need with acquisitions, as mentioned previously, as well as investments in internal R&D and customer support for simulation. Reese estimates that Autodesk has invested more than $500 million on simulation in the last 4 to 5 years.

The strategy developed in San Rafael is built upon three key areas of development, each predicated on the mantra that "one size fits all" won't succeed, and that companies need the right simulation for each person at the right time.

1. Mobile Simulation

Feedback from customers was that many engineers are being issued mobile computing devices such as the iPad to augment or even replace their laptops. Because this is an emerging technology, the full potential has yet to be understood—but Autodesk wants to remain ahead of the curve. Thus, its mobile computing strategy is in full swing. Its first simula-



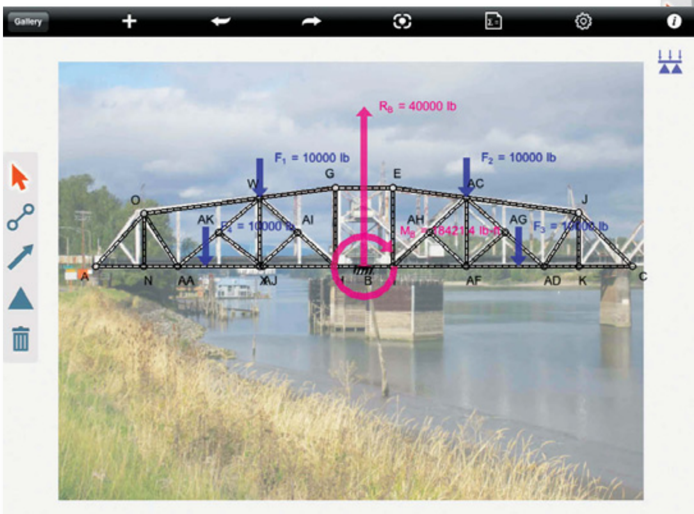


Figure 1, above: Autodesk ForceEffect restraint options.
Figure 2, left: Autodesk ForceEffect calculations on bridge loading.

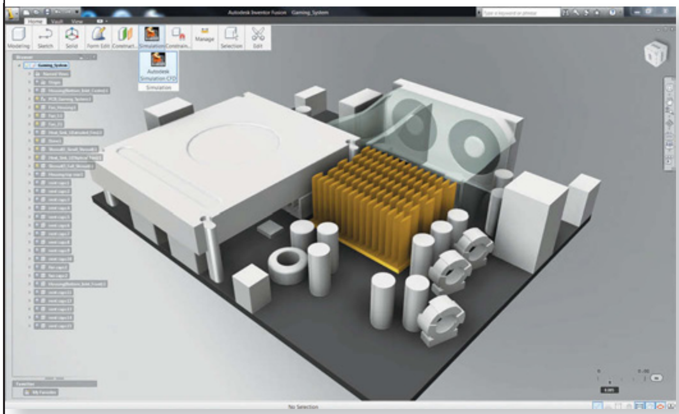


Figure 3: Autodesk SimCFD in Autodesk Fusion.

tion product for mobile devices is ForceEffect, an interactive free-body diagram calculator. It is currently available on iOS devices (*see Figure 1*).

ForceEffect offers freehand sketching of members with intuitive access to dimensioning. Autodesk has provided a full palette of loads and restraints, and reaction forces solve instantaneously as changes are made. Models can be saved in a gallery for later reuse (*see Figure 2*).

2. "Always-on" Simulation

Reese notes that design engineers want insight as early in the design process as possible on relative value of design alternatives, trending data and how much better/worse a change makes a design. Traditional simulation tools require these engineers to switch gears, both mentally and in their software interface, to pose a structured problem to a solver, then to interpret the results before returning to actual design activities.

Autodesk's vision is to provide instant feedback on design choices without interrupting the workflow. Think of a GPS unit that automatically updates arrival time and route information based on driving decisions.

Autodesk's Moldflow Adviser Design Plug-In is a CAD add-in for Autodesk Inventor, as well as competing products such as Pro/Engineer. This tool is always working in the background and recognizes when an engineer is working on a plastic part. It begins to offer immediate input on mold filling, feature placement, draft, manufacturability and cost-effectiveness utilizing on-screen gages. The color and fill level of each gage indicates the status of various manufacturability parameters, and can be queried when a problem is noted.

First developed for the Alias platform, Project Falcon provides quick feedback on air flow-related phenomena such as drag. It provides insight on trends and design direction. All simulation is local (vs. cloud) and uses STL files for geometry input. Once a concept is fleshed out, a user might choose to refine details in a full-featured computational-fluid dynamics (CFD) code like Autodesk CFDesign.

3. Cloud Computing

More rigorous simulation users are still burdened by long run times, resource/CPU bottlenecks, and the need to iterate in designs that haven't been fully fleshed out.

Autodesk is counting on the cloud to make simulation more accessible. Moldflow Insight WS (Web Service) is a pay-as you go simulation experience that performs all computations and post-processing remotely. Going back to Autodesk's belief that all companies need simulation, but on their terms, this allows companies with infrequent needs that can't justify a deep investment to access simulation only when required. WS customers receive full access to reports, screen shots and animations to make design decisions.

SIM Squad

With the acquisition of Moldflow, Algor, CFDesign and others, Autodesk found itself with a team of hundreds of simulation experts that had both those factors with their established user base and more than 1,000 man-years of diverse simulation experience. This resource was forged into a cohesive, cross-functional group and dubbed the SIM Squad. This team acts as the "public face" of Autodesk Simulation. They appear at trade shows, user conferences and web events. They publish articles, technical papers, training and best practices documents, as well as offering and e-support for both Autodesk customers and prospects.

Autodesk says it is focusing on tools that fit within the engineering workflow. This allows designers to focus on design, not simulation. In the past, companies hoped simulation would ensure that only viable designs would go to test. Autodesk is expanding this vision to ensure that only viable designs will make it to more rigorous and costly simulation. **DE**

Vince Adams, *currently an account manager for LMS, is a longtime simulation educator, consultant and speaker. He has authored three books on finite element analysis and numerous magazine articles. Contact him via de-editors@deskeng.com.*

INFO → Autodesk: USA.Autodesk.com

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We Gather Here Today **to Reconcile** Direct and Parametric

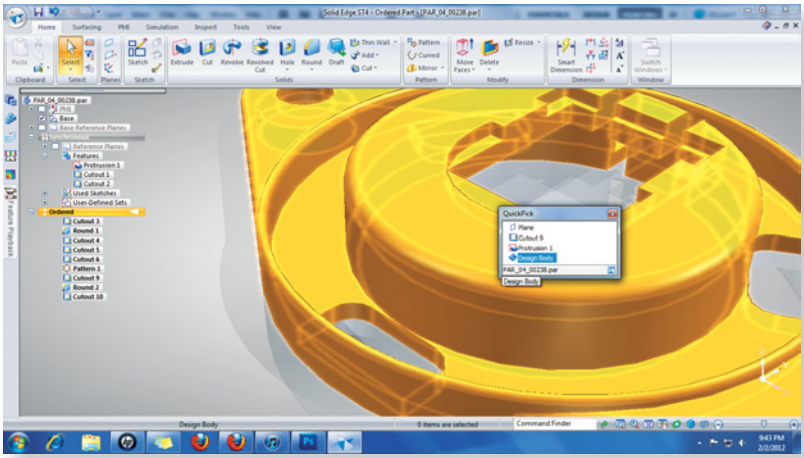
You can't have one without the other, but in time the two may become one.

BY KENNETH WONG

About five years ago, direct modeling drove into an old engineering town in a red sports car, with the top down. She got everyone hot and bothered with her push-pull action. She was simple, uncomplicated and easy to get along with. You could get to know her in just a day or two—sometimes in less than a few hours. You didn't have to invest several years to know how to push her buttons. After a few sidelong glances, even some old-timers had to admit they were tempted to abandon their faithful parametric workhorses.

But here's the kicker. Direct modeling is not new. She the ex-girlfriend who's lost a lot of weight and returned to conquer her old territories. Having shed the excess menus in previous interfaces, she's now proudly flaunting her faster, leaner form. She has already captured the hearts of new users. Hobbyists, enthusiasts, and 3D dabblers are waiting in line.

There is, however, a delicate dance she needs to perform: While winning fans with ease, she must figure out a way to get along with parametric modelers, who view her as a rival. If she wants to exert her influence over established communities, she can't afford to alienate the history-based camp.



Solid Edge with Synchronous Technology 4 is shown here with a model that incorporates features built in a traditional history-based approach (Ordered) and history-free approach (Synchronous).

Fundamentally Different Approaches

Direct modeling—the direct manipulation of geometry—is a departure from classic history-based, feature-based, parametric CAD modeling. In a parametric modeler, you rely on a series of steps to parametrically build your geometry. Want a cylinder with a hole? You sketch a circle in 2D, extrude the profile into a solid cylinder, sketch a circle on the top face of the cylinder, then use the circle to punch a hole through your solid. The information about the resulting shape is preserved in the history of steps you took to build the shape. Therefore, if you need to change something (say, adjust the diameter of the cylinder), you'll need to retrace your steps to the point its parameter was first defined (in this case, the initial sketch), then make the edit there. That, more or less, is how parametric modeling works.

In direct modeling, the emphasis shifts from modeling steps to geometry. In many direct modelers, you'll probably still start off the same way you do in a parametric modeler. In fact, how you create your initial design in a direct modeler may even be identical to how you might do it in a parametric modeler. But when you need to make changes, direct modeling shines. Because the software treats your geometry as, well, just geometry, you don't need to rely on the feature history to edit your design. Want to adjust the diameter of your cylinder? You just select the base or top, then enter a new numeric value. If the software provides a dynamic dragging handle with real-time preview, you can simply push or pull on your geometry to widen its diameter. With this approach, you can execute a lot of complicated changes (like repositioning the location of a hole or rotating a surface) after the fact, with little or no regard for the modeling steps you've taken.

The Push-Pull Era

Kubotek's KeyCreator, a direct-modeling pioneer, has been around since 2003. (Kubotek's acquisition of the technology asset of CADKEY gave birth to the KeyCreator brand.) Explaining its approach, the company writes, "Kubotek uses the intelligence inherent in geometry to power its Direct Editing. We call it Face Logic technology, a unique foundation for our advanced face selection capabilities. This means we are able to provide smart-editing tools that offer a very different approach to creating or changing a model. No history tree is needed to find features and manipulate the model geometry."

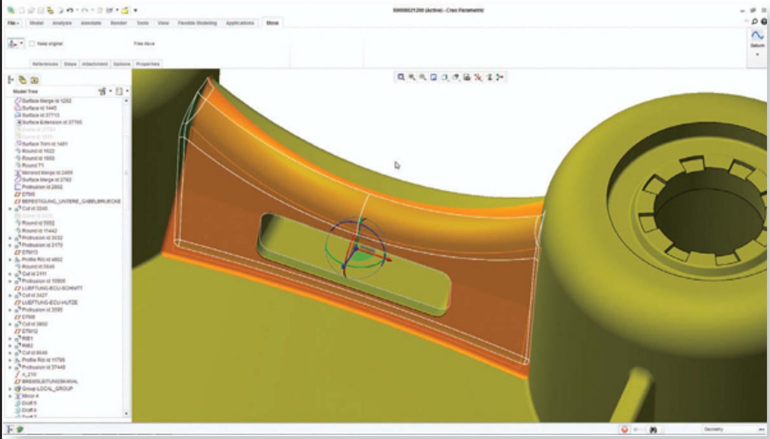
But the watershed moment may have been SpaceClaim's arrival on the scene in 2009. Previous direct-modeling programs relied heavily on dropdown menus and dialog boxes. By contrast, SpaceClaim's push-pull approach made direct modeling much more direct. Want to move the location of a hole? Simply select the hole by its center axis, drag it along an axis, and release it at its new position.

Directly pushing and pulling on features and faces to edit or adjust their parameters is now the standard mode of operation in most direct-editing software packages. With some variations, this method is now employed by Autodesk Inventor Fusion, PTC Creo Direct, PTC Creo Elements/Direct Modeling, Solid Edge with Synchronous Technology, and others. Though known by different names, the move-and-rotate handles in these programs are nearly identical. It invariably appears as three arrows pointing at the X, Y and Z directions, encircled in a rotation arc. Even some parametric packages that have been sitting on the sideline—for instance, Alibre Design and SolidWorks—employ methods that mimic the push-pull editing found in direct modelers.

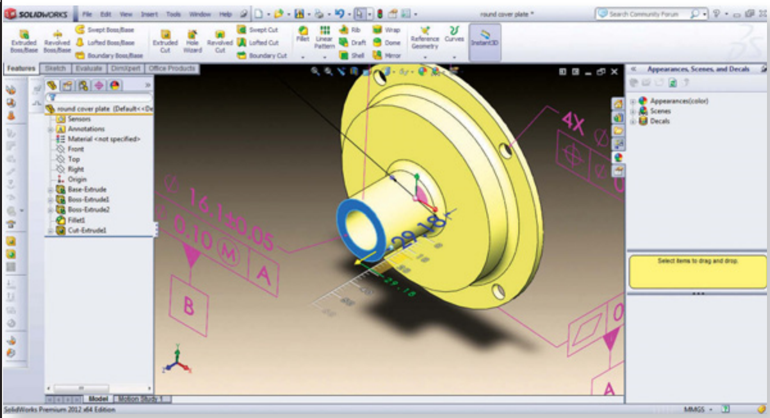
Hybrid Aspirations

Two direct modelers with deep roots in history-based modeling—Autodesk Inventor Fusion and Solid Edge with Synchronous Technology—have been gradually bolstering features that let you move back and forth between direct modeling and parametric modeling. Inventor Fusion serves as a companion program to Autodesk Inventor, Autodesk's classic parametric software for mechanical modeling. Over time, Autodesk plans to merge direct and history-based modeling into a single program, allowing you to work in both direct and history-based modes in a single program window.

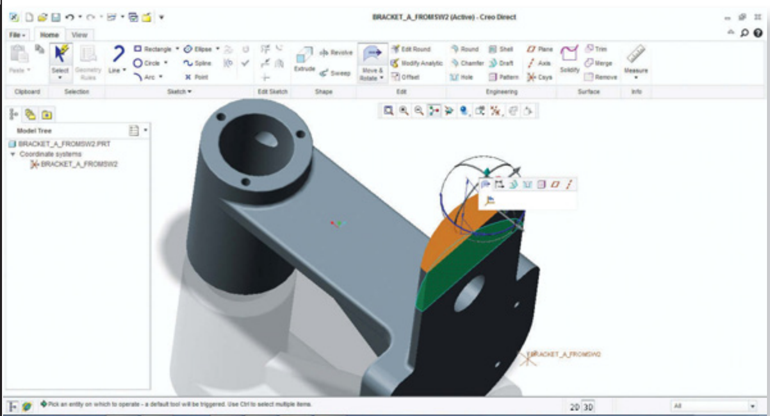
At present, Inventor Fusion still remains a separate installation (it's included at no charge when you buy Autodesk Inventor). But the company has put in significant efforts to convert direct edits made in Fusion into history-based fea-



PTC's Flexible Modeling Extension puts direct-modeling functions inside Creo Parametric, a traditional history-based modeler (and the successor to Pro/ENGINEER).



Though still a history-based modeler, SolidWorks offers you the choice to use Instant3D's push-pull editing, which mimics direct-modeling operations (demonstrated here in SolidWorks Premium 2012). Instant3D is turned on by default.



Creo Direct 1.0 from PTC, is a history-free direct modeler built from scratch, according to PTC. The software is aimed at casual users who would like work with 3D, but don't need the full power and complexity of a full-blown CAD system.

tures. In other words, if you execute a direct edit on your geometry in Fusion, once imported to Inventor classic, you could treat the feature as a parametric feature and continue to edit it using parametric editing methods. From the other direction, if you feel the need to make a direct edit while using Inventor classic, clicking on the Fusion button brings you right into Inventor Fusion.

With the option to work in Ordered (history-based) and Synchronous (history-free) modes in the same program window, Solid Edge with Synchronous Technology can justifiably claim to be the most advanced of the bunch in marrying the two modeling paradigms. The software's robust feature-recognition technology and built-in algorithm (called Live Rules) let you identify and preserve parallel faces and matching curvatures. Live Rules may also be temporarily suspended, so if you choose to break the inherent parallelism (such as extruded shapes on left and right that mirror each other), you can. These capabilities give the software a combination of flexibility and precision previously unseen in mechanical modeling programs.

A Break from History

In remaking its software titles into faster, lighter, nimbler apps, parametric powerhouse PTC introduced two direct-editing programs as part of its Creo 1.0 lineup. Creo Elements/Direct Modeling is derived from its previous product, CoCreate. Creo Direct is a brand-new app, developed from scratch. At present, the company promotes Creo Elements/Direct Modeling as a professional-class software, and Creo Direct as a product for hobbyists, enthusiasts and 3D dabblers. It's unclear how PTC plans to reconcile the two in the future.

In modeling strategy, PTC's approach is closer to SpaceClaim than Solid Edge with Synchronous Technology. When confronted with imported geometry, Solid Edge with Synchronous Technology makes certain assumptions about the inherent relationships in its geometry. For instance, if the imported geometry contains a series of holes that are aligned, the software will, in most cases, preserve the alignment. By contrast, PTC's Creo Direct and Creo Elements/Direct Modeling treat geometry as a collection of solids and surfaces. If you'd like to preserve alignments and parallel structures in your geometry in these packages, you'll have to explicitly tell the software to treat them as such. (One simple approach is to select and edit related features as a group.)

Is one approach better than the other? The answer depends on your modeling preferences and the type of mechanical designs with which you routinely work. If you specialize in designs that include significant parametric constraints (geometric features that mirror each other on the left and right, surfaces that must remain parallel or coincident, patterned features that must remain aligned, and so on), you may prefer a direct modeler that can deduce and preserve these relationships as you work. On the other hand, if you'd like to explore design alternatives with little or no concern for parametric constraints, you'd prefer the freedom of a direct modeler that treats geometry strictly as solids and surfaces.

New Markets for Direct Takeover

In the last several years, the do-it-yourself (DIY) movement picked up steam, fueled by tradeshows like Maker Faire and subscriber-supported manufacturing facilities like TechShop. Driven to build one-of-a-kind artwork and prototypes, those in the DIY community are now turning to affordable 3D printing service bureaus to literally solidify their ideas. These hobbyists, inventors, craft-makers, self-taught designers and weekend engineers represent a new market for 3D software makers. Parametric CAD vendors like Autodesk, SolidWorks and Alibre Software are carefully watching the trend.

The time and effort required to master a traditional parametric CAD modeler is more than what a DIY-er may be willing to spare. What these users need is a general-purpose direct modeler with a low learning curve, packaged in a novice-accessible interface like Google SketchUp. Recognizing this, Autodesk began pushing a new direct-modeling software titled 123D, based on Inventor Fusion, to the DIY market. Similarly, Solid Edge recently launched a subscription service through a partnership with Local Motors, an online community that practices crowd-sourced automotive design.

Another market, one that SpaceClaim is vigorously pursuing, is the analysis users. Though well versed in simulation disciplines, finite element analysis (FEA) and computational fluid dynamics (CFD) specialists may not necessarily be proficient CAD users. Yet, they must routinely engage with CAD models to inspect them and sometimes edit them—to remove rounded edges, blends, and holes on a solid block, for example.

For these users, a parametric CAD program's feature history is often a stumbling block. It prevents them from making the type of edits they need to do with efficiency. (Most likely, they can make these changes in a parametric program, but they'd have to dissect the history tree to understand the model's structure first—no picnic for someone with limited CAD experience). A direct modeler like PTC's Creo Direct or SpaceClaim that presents a design as a history-free collection of surfaces and solids, on the other hand, makes the simulation specialist's job a lot easier.

In the long run, the distinction between direct modeling and parametric modeling will probably disappear. User demand is bound to result in the incorporation of more direct-modeling operations into existing parametric CAD packages, blurring the line between the two. Furthermore, increased computing horsepower in engineering workstations allows forward-thinking software developers to let their software infer and predict what a user wishes to do, which can lead to simpler, cleaner interfaces with fewer menus and dialog boxes.

Once history-based modeling was the best alternative. Today, it remains an important part of design and engineering, but it's no longer the only alternative. **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. Contact him via de-editors@deskeng.com, at deskeng.com/virtual_desktop or via Twitter @KennethwongSF.*

INFO ➔ **Autodesk:** Autodesk.com

➔ **Kubotek:** KubotekUSA.com

➔ **PTC:** PTC.com

➔ **Siemens PLM Software:** Siemens.com/PLM

➔ **SpaceClaim:** SpaceClaim.com

➔ **TechShop:** TechShop.ws

For more information on this topic, visit deskeng.com.

Expand Your FEA Skills

A wealth of resources can help designers use meaningful analysis techniques.

BY PAMELA J. WATERMAN

As a mechanical designer, you probably have a fairly solid background in finite element analysis (FEA). You learned the theory in college, and you may have some years of experience using a commercial software package. But unless you set up and perform daily finite element analyses, there's probably room for improvement.

Because no one argues with the theory of "garbage in, garbage out," how can you zero in on the areas to refine, from preparing the CAD geometry to properly defining elements? And where will you find resources to do so?

DE asked seasoned FEA users, developers and educators for their best tips and pointers on learning actual FEA, as opposed to manipulating FEA software. With the variety of in-person, online, short-term, extended and even completely free resources available, you should find a learning opportunity that fits your needs, your time and your budget.

Advice from the Trenches

Some FEA missteps arise because GUI developers have actually done such a good job. Jeff Crompton, principal at AltaSim Technologies, an Ohio consulting company for simulated engineering solutions, knows this all too well.

"Commercial FEA programs have become increasingly easy to use," he points out. "It is now relatively simple for anyone with limited experience and expertise to set up a problem, solve the problem and get a believable, but absolutely wrong answer."

Crompton's company is experienced in analyses for applications ranging from large-scale shipbuilding to small-scale implantable medical devices, specializing in COMSOL, Abaqus and LS-Dyna software. He has steered users onto the right path when their engineering problem exhibited some or all of the following issues: ill-conceived in the first place, set up with incorrect boundary conditions, inadequately meshed or not validated.

"Material properties may not be as well-known as you suppose," he offers as an example. "Just because the properties are tabulated in the FEA program doesn't mean they are applicable to your problem."

Pierre Theiffry, ANSYS lead product manager, structural mechanics, offers an additional consideration for problem setup: "Even supplier data is (based on) nominal models. The CAD model differs from the actual part due to manufacturing differences. Everyone can get a result, but you need to know what is really important: What is really influencing your data?"

Users are advised to do a series of parametric analyses to investigate results for a range of values across the material properties, and across tolerance spreads.

Groups, Forums and Online Goldmines

To first identify what you need to know, the deciding factor—the "big one," according to Mitch Muncy, Sr., engineering manager at NEi Software—is asking which analysis type you need.

"If I need to run linear statics or I need to run modal, do I know everything I need to know about modal analysis? The same goes with buckling or non-linear: How do I know what I need?" he says. "That will always be difficult, so what's the quick and easy way to learn that?"

Many companies, including NEi Software, offer company-neutral materials, but first take a look at these outside sources.

If you're not familiar with the UK-based professional organization NAFEMS, the International Association for the Engineering Analysis Community, you owe it to yourself to check them out. Vendor-neutral and dedicated to promoting every aspect of FEA (as well as computational fluid dynamics, or CFD), this group has been a pioneer in offering

New and Classic Books on FEA

- ***Applied Mechanics of Solids***, A. Bower (revised ed. 2009; free online – solidmechanics.org)
- ***Building Better Products with Finite Element Analysis***, V. Adams (1999)
- ***The Finite Element Method for Engineers***, K. Huebner, D. Dewhirst, D. Smith, T. Byrom (4th ed. 2001)
- ***Finite Element Procedures***, K.J. Bathe (revised ed. 2007)
- ***A First Course in Finite Elements***, J. Fish, T. Belytschko (2007)
- ***Introduction to Finite Element Analysis***, B. Szabó, I. Babuška (2011)
- ***A Practical Guide to Reliable Finite Element Modelling***, A. Morris (2008)
- ***Practical Stress Analysis with Finite Elements***, B. J. Mac Donald (2007)
- ***Roark's Formulas for Stress and Strain***, W. Young, R. Budynas (7th ed. 2002)

educational materials across many levels of end-user, from designer to analyst to manager. Its Benchmarks, Reports, "How To" and "Why Do" Guides are classics.

Although most NAFEMS in-person classes are presented in the UK, the organization's e-learning programs are timed to work well for US-based participants. Eight code-independent e-courses address different levels of FEA use, from Practical Introduction to FEA and Basic FE Analysis sessions to Non-Linear and Dynamic FE Analysis, to name a few. Tony Abbey, NAFEMS' principal trainer, has created and taught FEA training classes for more than 15 years; his e-classes generally run 2.5 hours/week for four weeks, allowing time to put the information into practice and line up more questions.

Other fee-based options include earning professional development hours (PDH) through PDHOnline, with courses such as "Introduction to Finite Element Methods" and "Basic Applied Finite Element Analysis" (prices vary), and taking the occasional FEA class from ASME (founded as the American Society of Mechanical Engineers).

On the free side, MIT OpenCourseWare is an increasingly popular approach to self-guided, online learning. Among many engineering subjects, it offers lecture notes, assignments, exams and study materials for the courses "Finite Element Analysis of Solids" and "Fluids I, II and III." In addition, "Finite Element Procedures for Solids and Structures" is an MIT OCW classic video series presented by Dr. Klaus Jürgen-Bathe, the founder/developer of ADINA nonlinear analysis software.

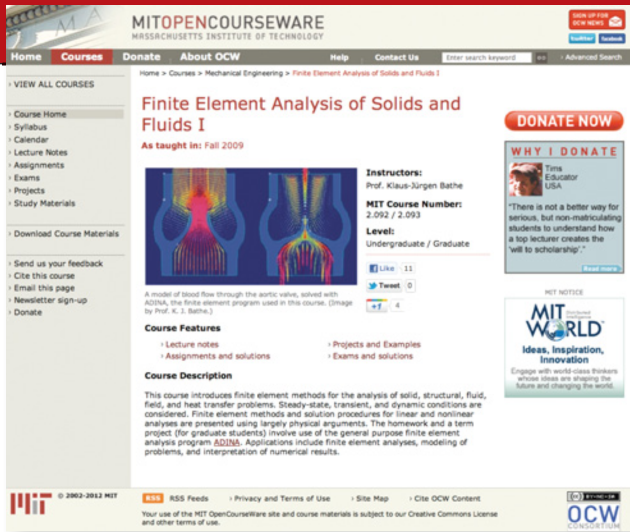
Two other options go deep into this topic. LearnersTV, a source of free online courses, offers the 30-lecture video series "Advanced Finite Element Analysis," presented by Dr. R. Krishna Kumar, Department of Mechanical Engineering, IIT Madras. And the website of the University of Colorado at Boulder is home to a highly readable set of texts and slides for the course "Introduction to Finite Elements," given by Dr. Carlos Felippa, Department of Aerospace Engineering Sciences.

Company Fare

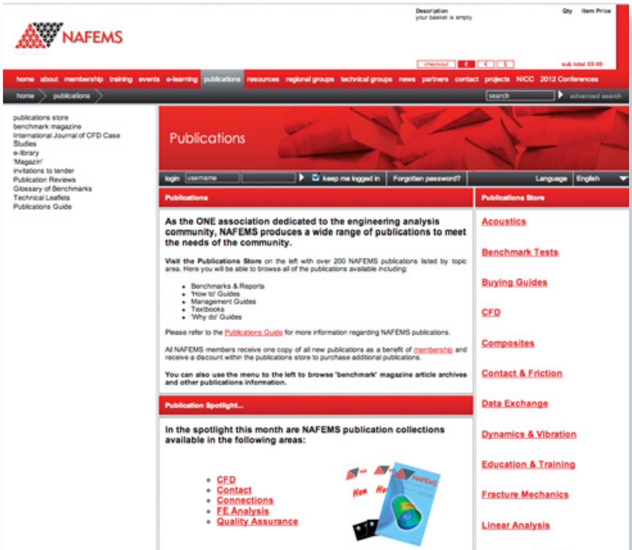
Software vendors are also reaching out to users with an amazing variety of educational approaches, including traditional training (their location or yours), customized training, webinars, online courses and user groups. They generally cover a mix of software-specific and general-FEA topics. Many are free, so there's almost no excuse for holding back. Here is a sampling with a media type for every taste:

• ANSYS offers dozens of webinars that its customers can download to learn at their own pace, such as "Ask the Expert — Structural Nonlinear Diagnostics in ANSYS 12.0," and white papers such as "Incorporating Nonlinear Analysis into Routine Engineering Processes for Better Accuracy." Customers can also phone in technical questions.

• MSC.Software lists 125 different free training videos, interactive tutorials and webinars, mostly with no registration necessary. Examples include "MSC Nastran Dynamics



MIT OpenCourseWare provides self-guided, online learning.



NAFEMS offers e-learning programs via its website.

NEI and other vendors offer FEA training.

It May be Time to Expand Your FEA Knowledge When You ...

- Are using an unfamiliar material with nonlinear properties.
- Realize the model is behaving with sliding contacts/friction effects.
- Need to account for thermal effects, such as expansion during high-temperature operation.
- Want to include the details of weld behavior in the analysis.
- Believe that using a different element type may improve your mesh.
- Want to learn more about the durability of a living hinge.
- Need to allow for real-world differences in manufacturing, especially casting and molding.

Solution Setup and Result Processing using Patran," "Marc Adaptive Mesh Refinement" and "MD Nastran Essential Skill: Selecting What Dimension Finite Elements to Use."

• NEi Software presents general and customized training classes; a distance learning program "FEA On-the-Go"; non-software-specific white papers and webinars in its online Knowledge Base Center (online under Support—sign-up is free); guides ("Composites Compendium" and "When Analysis Goes Nonlinear," for example); and extensive Nastran. TV presentations ranging from five to 60 minutes (including "Tips for Complex Models" and "Explicit FEM Analysis").

• SIMULIA gives dozens of introductory and advanced-application training classes for Abaqus software, plus access to the SIMULIA Learning Community (free, just register) with videos and how-to tips.

• SolidWorks produces seminars, blogs, tutorials and the lively SolidWorks Forums.

Consultant Power

Never underestimate the power of a consultant. Dedicated simulation companies have the experience and time to focus on FEA, and are in a great position to share knowledge through training classes.

George Laird, principal at Predictive Engineering, lives and breathes high-end mechanical analyses and knows the deep nuances of practical FEA—with more than 25 years' experience on projects ranging from satellites and drilling platforms to engines and medical devices. Ask him for his opinions on self-training in FEA techniques, or take one of his in-depth courses, such as the two-day classes on "Foundations of (or Advanced) FEA Modeling with Femap and NX Nastran."

Operating in the Real World

Good engineers know to explain their assumptions. J. Ben Deaton is a Ph.D. candidate in structural engineering at the Georgia Institute of Technology who writes about numerical models in his blog, "Only a Model," at JBDeaton.com. He sets out a thoughtful checklist in the post called "How to Learn a New Finite Element Code," then comments on the realities of presentations involving numerical (usually FEA) conclusions: "When all you say is, 'We built a model and here is what we learned,' you might as well say, 'We got these numbers from our crystal ball!'"

Deaton suggests addressing the issue head-on, saying one could state, "We simulated the response using an [algorithm name] approach in [software name] with special attention given to [key components of the model]. Our simulation neglected [key things you forgot neglected] but was validated against [other accepted numerical methods or experimental data] and shown suitable within [whatever bounds]." Now you're covered.

Acknowledging the potential for problems is definitely an important step. SolidWorks Simulation Product Manager Stephen Endersby sums up the learning process: "The thing to do when you are just starting out is to be a cynic. At first, assume some of the mistakes made are yours. Validate your assumptions before and after you run the simulation."

Don't forget the Keep It Simple, Stupid (KISS) rule, he adds: "Initially simplify the problem as much as possible, so you could almost get a textbook solution to the problem." DE

Contributing Editor **Pamela J. Waterman**, *DE's simulation expert, is an electrical engineer and freelance technical writer based in Arizona. You can send her e-mail to DE-Editors@deskeng.com.*

INFO → **ADINA:** ADINA.com

→ **AltaSim Technologies:** AltaSimTechnologies.com

→ **ANSYS:** ANSYS.com

→ **ASME:** ASME.org

→ **University of Colorado at Boulder:** Colorado.edu/engineering/CAS/courses.d/IFEM.d

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→ **MIT OpenCourseWare:** ocw.MIT.edu

→ **NAFEMS:** NAFEMS.org

→ **NEi Software:** NEiSoftware.com

→ **PDHOnline:** PDHonline.com

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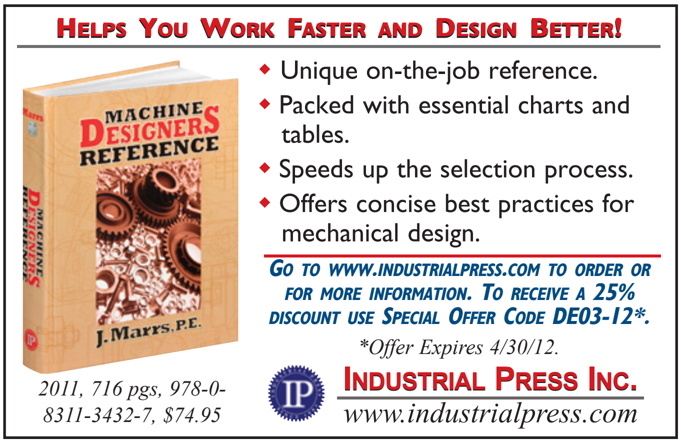
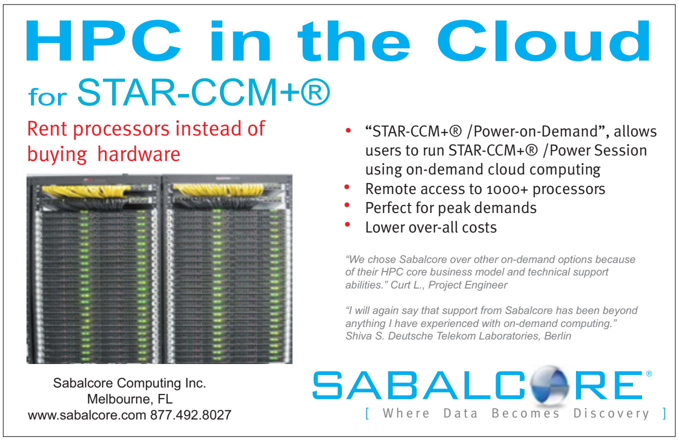
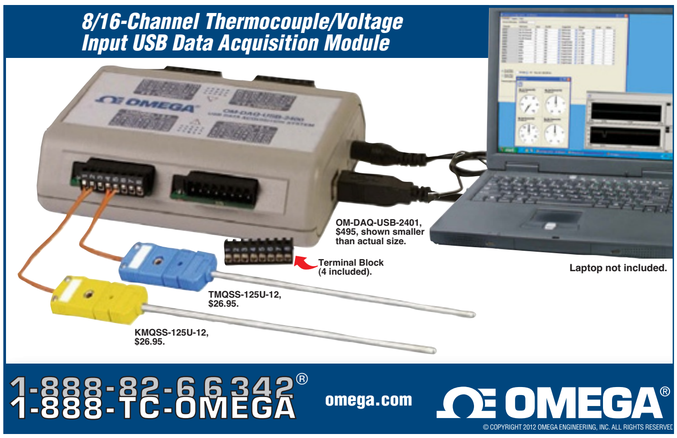
SPOTLIGHT

Directing your search to the companies that have what you need.







GPU Programming in MATLAB

The graphics processing unit promises higher computational performance.

BY JILL REESE AND SARAH ZARANEK

Originally used to accelerate graphics rendering, graphics processing units (GPUs) are increasingly applied to scientific calculations. Unlike a traditional CPU, which includes no more than a handful of cores, a GPU has a massively parallel array of integer and floating-point processors, as well as dedicated, high-speed memory. A typical GPU comprises hundreds of these smaller processors.

The greatly increased throughput made possible by a GPU, however, comes at a cost. First, memory access becomes a much more likely bottleneck for your calculations. Data must be sent from the CPU to the GPU before calculation, and then retrieved from it afterward. Because a GPU is attached to the host CPU via the PCI Express bus, the memory access is slower than with a traditional CPU. This means that your overall computational speedup is limited by the amount of data transfer that occurs in your algorithm.

Programming for GPUs in C or Fortran requires a different mental model and skill set that can be difficult and time-consuming to acquire. In addition, you must spend time fine-tuning your code for your specific GPU to optimize applications for peak performance.

This article demonstrates features in Parallel Computing Toolbox that enable you to run your MATLAB code on a GPU by making a few changes to your code. We illustrate this approach by solving a second-order wave equation using spectral methods.

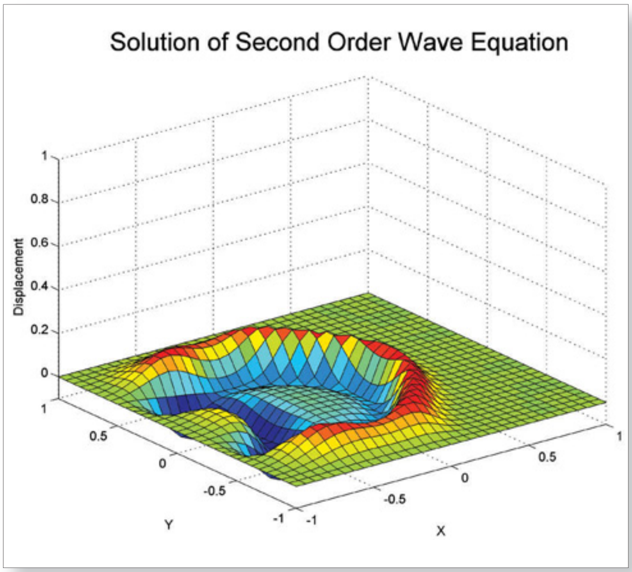


Figure 1: A solution for a second-order wave equation on a 32x32 grid. See animation here: http://goo.gl/Aj61z.

Why Parallelize a Wave Equation Solver?

Wave equations are used in a wide range of engineering disciplines, including seismology, fluid dynamics, acoustics and electromagnetics, to describe sound, light and fluid waves.

An algorithm that uses spectral methods to solve wave equations is a good candidate for parallelization, because it meets both of the criteria for acceleration using the GPU:

1. **It is massively parallel.** The parallel fast Fourier transform (FFT) algorithm is designed to "divide and conquer," so that a similar task is performed repeatedly on different data. Additionally, the algorithm requires substantial communication between processing threads and plenty of memory bandwidth. The inverse fast Fourier transform (IFFT) can similarly be run in parallel.
2. **It is computationally intensive.** The algorithm performs many FFTs and IFFTs. The exact number depends on the size of the grid and the number of time steps included in the simulation (*see Figure 1*). Each time step requires two FFTs and four IFFTs on different matrices, and a single computation can involve hundreds of thousands of time steps.

Applications that do not satisfy these criteria might actually run slower on a GPU than on a CPU.

GPU Computing in MATLAB

Before continuing with the wave equation example, let's quickly review how MATLAB works with the GPU.

FFT, IFFT and linear algebraic operations are among more than 100 built-in MATLAB functions that can be executed directly on the GPU by providing an input argument of the type GPUArray, a special array type provided by Parallel Computing Toolbox. These GPU-enabled functions are overloaded—in other words, they operate differently depending on the data type of the arguments passed to them.

For example, the following code uses an FFT algorithm to find the discrete Fourier transform (DFT) of a vector of pseudorandom numbers on the CPU:

```
A = rand(2^16,1);
B = fft (A);
```

To perform the same operation on the GPU, we first use the gpuArray command to transfer data from the MATLAB workspace to device memory. Then we can run fft, which is one of the overloaded functions on that data:

```
A = gpuArray(rand(2^16,1));
B = fft (A);
```

The fft operation is executed on the GPU rather than the CPU because its input (a GPUArray) is held on the GPU.

The result, B, is stored on the GPU. However, it is still visible in the MATLAB workspace. By running class(B),we can see that it is a GPUArray:

```
class(B)
ans =
parallel.gpu.GPUArray
```

We can continue to manipulate B on the device using GPU-enabled functions. For example, to visualize our results, the plot command automatically works on GPUArrays:

```
plot(B);
```

To return the data back to the local MATLAB workspace, you can use the gather command; for example:

```
C = gather(B);
```

C is now a double in MATLAB and can be operated on by any of the MATLAB functions that work on doubles.

In this simple example, the time saved by executing a single FFT function is often less than the time spent transferring the vector from the MATLAB workspace to the device memory. This is generally true, but is dependent on your hardware and size of the array. Data transfer overhead can become so significant that it degrades the application's overall performance, especially if you repeatedly exchange data between the CPU and GPU to execute relatively few computationally intensive operations. It is more efficient to perform several operations on the data while it is on the GPU, bringing the data back to the CPU only when required.

Note that GPUs, like CPUs, have finite memories. However, unlike CPUs, they do not have the ability to swap memory to and from disk. Thus, you must verify that the data you want to keep on the GPU does not exceed its memory limits—particularly when you are working with large matrices. By running gpuDevice, you can query your GPU card, obtaining information such as name, total memory and available memory.

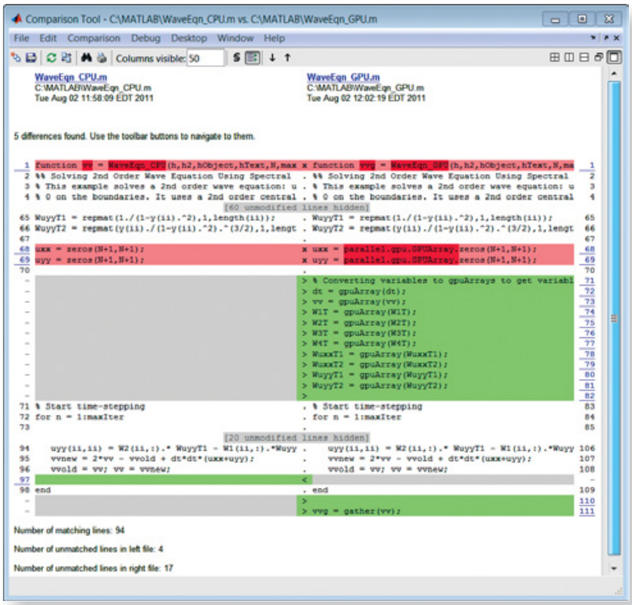


Figure 2: The Code Comparison Tool shows the differences in the CPU and GPU versions of the code. The GPU and CPU versions share over 84% of their code in common (94 lines out of 111).

Implementing and Accelerating the Algorithm

To put the above example into context, let's implement the GPU functionality on a real problem. Our computational goal is to solve the second-order wave equation, with the condition u = 0 on the boundaries:

$$\frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}$$

We use an algorithm based on spectral methods to solve the equation in space, and a second-order central finite difference method to solve the equation in time.

Spectral methods are commonly used to solve partial differential equations. With spectral methods, the solution is approximated as a linear combination of continuous basis functions, such as sines and cosines. In this case, we apply the Chebyshev spectral method, which uses Chebyshev polynomials as the basis functions.

At every time step, we calculate the second derivative of the current solution in both the x and y dimensions using the Chebyshev spectral method. Using these derivatives together with the old solution and the current solution, we apply a second-order central difference method (also known as the leapfrog method) to calculate the new solution. We choose a time step that maintains the stability of this leapfrog method.

The MATLAB algorithm is computationally intensive, and as the number of elements in the grid over which we compute the solution grows, the time the algorithm takes to execute increases dramatically. When executed on a single CPU using a 2048x2048 grid, it takes more than a minute to complete just

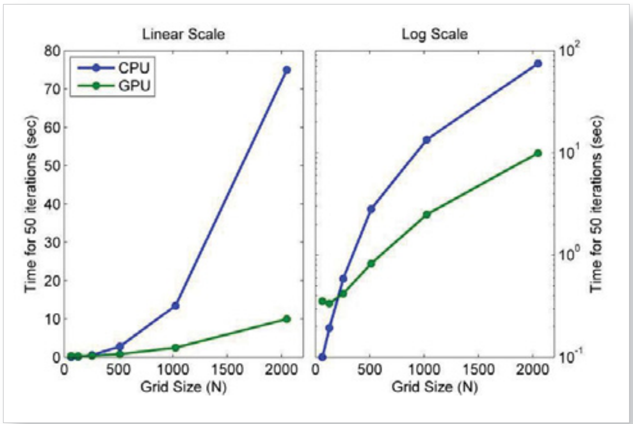


Figure 3: The linear scale plot (left) and log scale plot (right) of the same benchmarks results show the time required to complete 50 time steps at different grid sizes.

GPU Glossary

• **Central processing unit (CPU).** The central unit in a computer responsible for calculations and for controlling or supervising other parts of the computer. The CPU performs logical and floating point operations on data held in the computer memory.

• **Compute unified device architecture (CUDA).** A parallel computing technology from NVIDIA that consists of a parallel computing architecture and developer tools, libraries and programming directives for GPU computing.

• **Core.** A single independent computational unit within a CPU or GPU chip. CPU and GPU cores are not equivalent to each other; GPU cores perform specialized operations whereas CPU cores are designed for general-purpose programs.

• **Graphics processing unit (GPU).** A programmable chip originally intended for graphics rendering. The highly parallel structure of a GPU makes it more effective than general-purpose CPUs for algorithms where processing of large blocks of data is done in parallel.

• **Host.** The CPU and system memory.

• **Kernel.** Code written for execution on the processor. Kernels are functions that can run on a large number of threads. Parallelism arises from each thread independently running the same program on different data.

50 time steps. Note that this time already includes the performance benefit of the inherent multithreading in MATLAB. Since R2007a, MATLAB supports multithreaded computation for a number of functions. These functions automatically execute on multiple threads without the need to explicitly specify commands to create threads in your code.

When considering how to accelerate this computation using Parallel Computing Toolbox, we will focus on the code that performs computations for each time step. *Figure 2* illustrates the changes required to get the algorithm running on the GPU. Note that the computations involve MATLAB operations for which GPU-enabled overloaded functions are available through Parallel Computing Toolbox. These operations include FFT and IFFT, matrix multiplication, and various element-wise operations. As a result, we do not need to change the algorithm in any way to execute it on a GPU. We simply transfer the data to the GPU using gpuArray before entering the loop that computes results at each time step.

After the computations are performed on the GPU, we transfer the results from the GPU to the CPU. Each variable referenced by the GPU-enabled functions must be created on the GPU or transferred to the GPU before it is used.

To convert one of the weights used for spectral differentiation to a GPUArray variable, we use:

```
W1T = gpuArray(W1T);
```

Certain types of arrays can be constructed directly on the GPU without our having to transfer them from the MATLAB workspace. For example, to create a matrix of zeros directly on the GPU, we use:

```
uxx = parallel.gpu.GPUArray.zeros(N+1,N+1);
```

We use the gather function to bring data back from the GPU; for example:

```
vvg = gather(vv);
```

Note that there is a single transfer of data to the GPU, followed by a single transfer of data from the GPU. All the computations for each time step are performed on the GPU.

Comparing CPU and GPU Execution Speeds

To evaluate the benefits of using the GPU to solve second-order wave equations, we ran a benchmark study in which we measured the amount of time the algorithm took to execute 50 time steps for grid sizes of 64, 128, 512, 1024, and 2048 on an Intel Xeon Processor X5650, and then using an NVIDIA Tesla C2050 GPU.

For a grid size of 2048, the algorithm shows a 7.5x decrease in compute time from more than a minute on the CPU to less than 10 seconds on the GPU (*see Figure 3*). The log scale plot shows that the CPU is actually faster for small grid sizes. As the technology evolves and matures, however, GPU solutions are increasingly able to handle smaller problems.

Advanced GPU Programming with MATLAB

Parallel Computing Toolbox provides a way to speed up MATLAB code by executing it on a GPU. You can change the data type of a function's input to take advantage of the MATLAB commands that have been overloaded for GPUArrays. A list of built-in MATLAB functions that support GPUArray is available in the Parallel Computing Toolbox documentation.

To accelerate an algorithm with multiple simple operations on a GPU, you can use arrayfun, which applies a function to each element of an array. Because arrayfun is a GPU-enabled function, you incur the memory transfer overhead only on the single call to arrayfun, not on each individual operation.

Finally, experienced programmers who write their own compute unified device architecture (CUDA) code can use the CUDAKernel interface in Parallel Computing Toolbox to integrate this code with MATLAB. The CUDAKernel interface enables even more fine-grained control to speed up portions of code that were performance bottlenecks. It creates a MATLAB object that provides access to your existing kernel compiled into PTX code (PTX is a low-level parallel thread execution instruction set). You then invoke the feval command to evaluate the kernel on the GPU, using MATLAB arrays as input and output.

Engineers and scientists are successfully employing GPU technology, originally intended for accelerating graphics rendering, to accelerate their discipline-specific calculations. With minimal effort and without extensive knowledge of GPUs, you can now use the promising power of GPUs with MATLAB. GPUArrays and GPU-enabled MATLAB functions help you speed up MATLAB operations without low-level CUDA programming. If you are already familiar with programming for GPUs, MATLAB also lets you integrate your existing CUDA kernels into MATLAB applications without requiring any additional C programming.

To achieve speedups with the GPUs, your application must satisfy some criteria, among them the fact that sending the data between the CPU and GPU must take less time than the performance gained by running on the GPU. If your application satisfies these criteria, it is a good candidate for the range of GPU functionality available with MATLAB. **DE**

Jill Reese *is a senior software engineer and* **Sarah Zaranek** *does MATLAB product marketing at MathWorks. Contact them via de-editors@deskeng.com.*

INFO → **CUDA:** NVIDIA.com/object/cuda_home_new.html

→ MATLAB: MathWorks.com/products/matlab

Can You Believe Your Eyes?

How companies use rendering software to present products.

BY JOSH MINGS

Okoqu uses rendering to gain concept approvals. *Image courtesy of Luxion.*

We uncover an idea, visualizing it in our mind—relishing with anticipation the discovery of each step. Throughout the product development process, using tools and software to form our idea, we play in the iteration of the design, causing the idea to come alive. Designing products has always been a visual process. At the core, it's an exercise in tweaking edges, surfaces and perspective, optimizing and illustrating each iteration from concept through manufacturing and on to marketing.

Increasingly, the "product" may be displayed in the catalog or on the website storefront long before an engineering drawing has been created, die has been machined or a pattern cut. The most phenomenal part of iterating and visualizing the design process is that one, many or even an entire community can do it.

Quirky Designs Socially

For those with ideas, a community of creators now exists at the industrial design firm Quirky. The website is home to tens of thousands of online members, ordinary people using ordinary consumer products with a few ideas on how make them safer, less wasteful or just easier.

Renders are posted to the Quirky website to foster member discussion. *Image courtesy of Luxion.*

Within the site, product ideas are discussed and voted on as consumer mavens from around the world contemplate the subtleties of designs. Quirky then pays members for their innovations (if chosen for development) and for the product design feedback they post on other projects. Quirky differs from conventional product design firms, leveraging social media for consumer preferences and delivering new, marketable designs at an unbelievable rate.

"We can build two products per week," says Quirky's head of engineering, John Jacobsen. "It may seem radical, and it is. The designs are not fully developed, but we are taking the community ideas to a certain level of refinement."

These almost-finished designs don't immediately go off to production, but instead incubate as rendered images on the Quirky website for further community design review. The photorealistic previews spread through the member's social networks, and also attract shoppers for cool gear through Quirky's catalog page.

"The visual feedback is definitely a necessary component. The better the imagery and higher the fidelity, the more compelling the product is to consumers," says Jacobsen. "People can appreciate the idea behind the innovations, but it is really the image of the design that gets the customer excited enough to follow through with a purchase."

For many products, Quirky posts the virtual image before a product demonstration photo shoot is scheduled. Quirky's ability to present a convincingly real product before the product is real—and do it faster than many other firms—lies in Jacobsen's computer.

"What we are working with now is lightning fast. I have a laptop equipped with multiple processors, and I am able to get high-resolution images from an engineering model in a matter of seconds. For our group, time is of the essence, so this kind of capability is crucial," he says. "I don't think we would be able to do what we doing at Quirky without these tools."

Pensa Evaluates Renders Before Prototypes

"In the past, rendering required you to have the skills of both a photographer and a computer expert," recalls Marco Perry, principal and co-founder of Pensa. "Like a photographer, you had to understand the physics of lighting to get the right angle, shadow and reflectivity. Then you had to be computer expert, because you had to translate this understanding into numbers. You had to know what levers to pull and push inside the program to get the effects."

New advances in software have eliminated this need for specialized expertise. Common materials like soft plastic or brushed aluminum are pre-programmed to reflect light naturally. Designers simply drag them from palettes and drop them onto a surface of a model, like a game of 3D paint-by-numbers. Rendering experts used to slave over the subtle shadows that give objects the right illusion of depth. Now the shading appears perfectly on every render.

Perry says the core purpose of rendering for designers is the same as it has been in years past: "We can view CAD data as realistically as possible before getting prototypes of it. In some cases, when we work on very large-scale equipment, like vending machines, to get a prototype is no small feat. We need to evaluate the product before it gets that far in the process."

Okoqu Test Markets with Renderings

As many in product development are discovering, rendering isn't just for designers anymore. Photorealistic previews are now playing a much broader role that extends beyond the engineering process. Russell Beard, head of Okoqu (pronounced "oh-koh-koo"), found out the visuals are also good at communicating business potential, even for a simple product called the NUT, an iPhone case made of durable hard-shell plastic.

"Very early on, we needed to get a measure from the biggest distributors and central retailers whether or not we should continue to develop a product to manufacture," Beard explains. "I rendered the model to produce some really powerful visuals. Because of these renderings, the product concept received traction with people before it became a reality."

The rendering technology offers the advantage of product photography well before the item is manufactured, he notes.

"Much of the instant output from high-speed rendering applications comes out with the same studio lighting that consumers are used to seeing in magazine ads and catalogs," Beard says. "Pictures speak louder to merchandisers in the larger arena of business development."

Beard says the imagery helped across the entire process. He could show his intent to manufacturing engineers, make a pitch to investors, and even connect with potential customers.

Pensa uses renders to evaluate products before prototyping them. *Image courtesy of Luxion.*

"We are still using the visuals that we created early in the process on our website and product demos," he says. "That's how powerful the visuals are to this project.

"The way technology has sped up communication on the business end has been phenomenal," he adds. "For the NUT, it just helped massively."

Rapid Rendering

Rendering used to be an afterthought to the process, a time-consuming task after design and before physical prototyping. As the technology has become more interactive, designers are looking at product components in a photo-real environment early and often, which ultimately gives you more time to design better products.

Visualizing the product development process with realistic images is becoming another means of evaluating the design itself, a way to judge the forms, materials and finishes. Where those decision used to be made internally, 3D renderings are now making it possible to visualize the completed product throughout the entire lifecycle. **DE**

Josh Mings *is web marketing manager at Luxion. He is also editor at SolidSmack.com, covering 3D design, product development and related technology. Contact him via KeyShot.com.*

INFO ➜ Luxion: KeyShot.com

➜ **Okoqu:** okoqu.com

➜ **Pensa:** pensanyc.com

➜ **Quirky:** quirky.com

For more information on this topic, visit deskeng.com.

Tools of the Month

New Products for Engineers

Adept PDM Provides SolidWorks, SharePoint Integration

Synergis Software's (synergissoftware.com) Adept 2011 product data management (PDM) system integrates with SolidWorks 2012 and Microsoft SharePoint. With the 2011 upgrade, Adept delivers advanced vault replication and two classes of web clients. It is designed to improve global enterprise collaboration on engineering projects while providing a unified view of data and documents to all stakeholders.

Shares Data Between Inventor and PTC Crew View

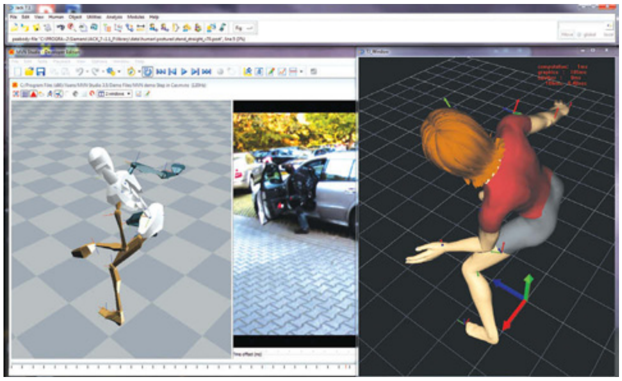
Theorem Solutions' (theorem.com) latest visualization products can help resolve the issue of sharing data between the Autodesk Inventor and PTC Creo View formats. Theorem's Autodesk Inventor Adapter for Creo View (formerly ProductView) publishes 3D mechanical design geometry parts, assemblies and 2D drawings, together with attribute information to the compact format used by the Creo View application.

Geometric Introduces Glovius

Geometric Limited (geometricglobal.com) has launched its new extensible and customizable 3D visualization tool, Glovius, for consumption of product design data on Windows, iPad/iPhone and Android systems. Glovius for Windows is a free viewer with an add-on based architecture, and operates on the JT file format. Its add-ons allow users to import CAD files from multiple platforms like CATIA V5, NX, Pro/ENGINEER, Creo, SolidWorks, Autodesk Inventor, STEP and IGES.

ESI Releases New Versions of PAM-RTM and PAM-FORM

ESI Group (esi-group.com) has released PAM-RTM and PAM-FORM 2012, two numerical simulation applications dedicated to the manufacture of composite parts. This composites manufacturing simulation suite defines and optimizes manufacturing processes of dry textiles and prepregs, with the objective of achieving better part quality and lower production time cycle and cost. PAM-FORM is a virtual manufacturing solution dedicated to non-metallic forming processes. PAM-RTM is a simulation software application for resin injection or infusion of composite preforms with or without inserts and core materials.



Xsens Ads Motion Capture to Siemens Tecnomatix Software

3D tracking solutions provider Xsens (xsens.com) has joined the Siemens (plm.automation.siemens.com) Solution Partner Program to provide its motion capture solution (pictured above) for the Jack software ergonomics package, a part of the Tecnomatix software family of digital manufacturing solutions. The company's human motion data capture solution will be integrated with the Jack software package. Jack allows manufacturers to address the ergonomic aspects of products and production processes in the early stages of design and development, thus improving safety, efficiency and comfort. According to the company, the use of Xsens sensor fusion algorithms and biomechanical models results in accurate 3D human motion reproduction. DE

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by Anthony J. Lockwood

Editor's Picks

Each week, Tony Lockwood combs through dozens of new products to bring you the ones he thinks will help you do your job better, smarter and faster. Here are Lockwood's most recent musings about the products that have really grabbed his attention.

Lease a Complete 3D Printing System

Monthly lease said to cost less than a typical outsourced job.

Stratasys has come out with what it calls 3D Print Packs. The short of it is that 3D Print Packs are a leasing program that enable you to install a 3D printer in-house cost-effectively. So, what does a 3D Print Pack get you?

Well, 3D Print Packs start with your choice of a Stratasys uPrint SE (Special Edition) or uPrint SE Plus 3D printer. (The uPrint SE and SE Plus machines are the company's new generation of this product line.) You also get a system for cleaning out support materials, software to convert your STL files for 3D printing, and a start-up kit with some ABS *plus* modeling material, support material, cleaning agent, and six modeling bases.

MORE ➜ deskeng.com/articles/aabdfn.htm

Contex Introduces New Wide Format Scanners

Company also releases version 2 of its Nextimage imaging software.

Contex recently announced the availability of two new Energy-Star compliant wide-format scanners, the HD Ultra series and the SD3600, as well as version 2 of its Nextimage imaging software for scanning, copying, and printing. These devices seem fast, easy to use, and arrayed with features that should make you appreciate just what you've been missing with your old scanner.

Both the HD Ultra and SD3600 are available as multi-function products so that they can connect with most office printers, copiers, or large-format inkjet and LED printers. Nextimage is available in three versions, one of which surely will cover your needs.

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National Instruments Releases Six New PXI Products

New releases include embedded controller and high-speed data storage.

National Instruments, considered the leader in PXI solutions, alone offers over 450 products, a number that includes six new PXI-based devices it recently introduced.

PXI stands for PCI (peripheral component interconnect) eXtensions for Instrumentation. It is an open standard for high-performance PC-based platforms for test, measurement, and automation systems. (NI defined then released the standard, which is now overseen by a governing body of manufacturers.) PXI enables you to mix and match a variety of hardware and software to create scalable systems that address engineering challenges.

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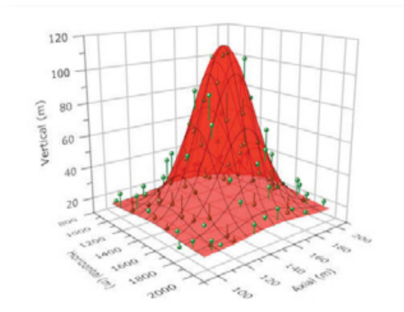

Graphing and Data Analysis Software Upgraded

Advanced statistics and tools highlight Origin and OriginPro 8.6 release.

OriginLab's Origin and OriginPro 8.6 enhancements range across all major areas of the software from memory access to graphing and worksheets to importing and data analysis. And, to support their users working with oversized data sets, the company has come out with a 64-bit version, which means that your only memory size limitation is in your hardware. A cool new plot type called a Spider/Radar Chart helps you display and compare multivariate data.

The Pro version of Origin now offers four new multivariate analysis tools: principal component analysis, K-means cluster, hierarchical cluster, and discriminant analysis.

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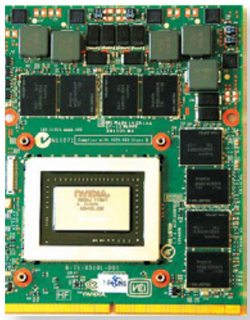
Cool Tools

Eurocom Neptune Mobile Workstation

Upgrade Options

1 The Eurocom Neptune is a 17.3-in. notebook that is designed to be upgraded. It supports Intel Core i5 and i7 processors up to the Intel Core i7 2960XM Processor Extreme Edition with 8MB of L3 cache. It can be equipped with two drives — mechanical or solid-state — for up to 2TB of storage. It features a 9-in-1 card reader and up to 32GB of memory.

Advanced Graphics



2 Eurocom's Neptune Mobile Workstation is capable of supporting NVIDIA 3D Vision with NVIDIA GeForce GTX 580M and 560M GPUs through a built-in emitter, 3D active shutter technology, a 120Hz display and supported NVIDIA graphics cards. It also supports NVIDIA Quadro and AMD graphic processing units.

Computing in Three Dimensions

3 The Eurocom Neptune comes with an NVIDIA 3D Vision Kit, which consists of one pair of 3D Vision glasses and USB cables. Each lens of the glasses operates at 60Hz, and alternate to create a 120Hz 3-dimensional experience.

→ DO YOU HAVE A COOL TOOL? *Desktop Engineering* editors are always on the hunt for great tools to share with our readers. Send us your ideas at de-editors@deskeng.com.

TECH SPECS

- Display: 17.3-in. full HD 1920-by-1080 backlit LED display with glossy/matte surface.
- Memory: up to 32GB; 4x RAM sockets, DDR3 1333/1600 MHz.
- VGA: Modular design supports both NVIDIA GeForce, Quadro and AMD GPUs, single VGA operation.
- Processor: Intel Core i5 and i7 processors; up to Intel Core i7 2960XM Processor Extreme Edition with 8MB of L3 cache.
- Storage: up to two physical drives, SSD, hybrid or mechanical, up to 2TB of storage.
- Ports: 2x USB 3.0; 2x USB 2.0; DVI-DL; 1x IEEE1394a; 1x eSATA; 1x HDMI out; 1x Headphone jack; 1x Microphone jack; 1x S/PDIF out; 1x Line-in; 1x RJ45 for LAN
- Communications: 1Gb LAN on-board; optional WLAN N or Bluetooth + WLAN Combo and/or 3.75G Mini Card UMTS/HSDPA
- Weight and Dimensions: 6.82lbs; 15.04x10.24x1.4-1.72 in.

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