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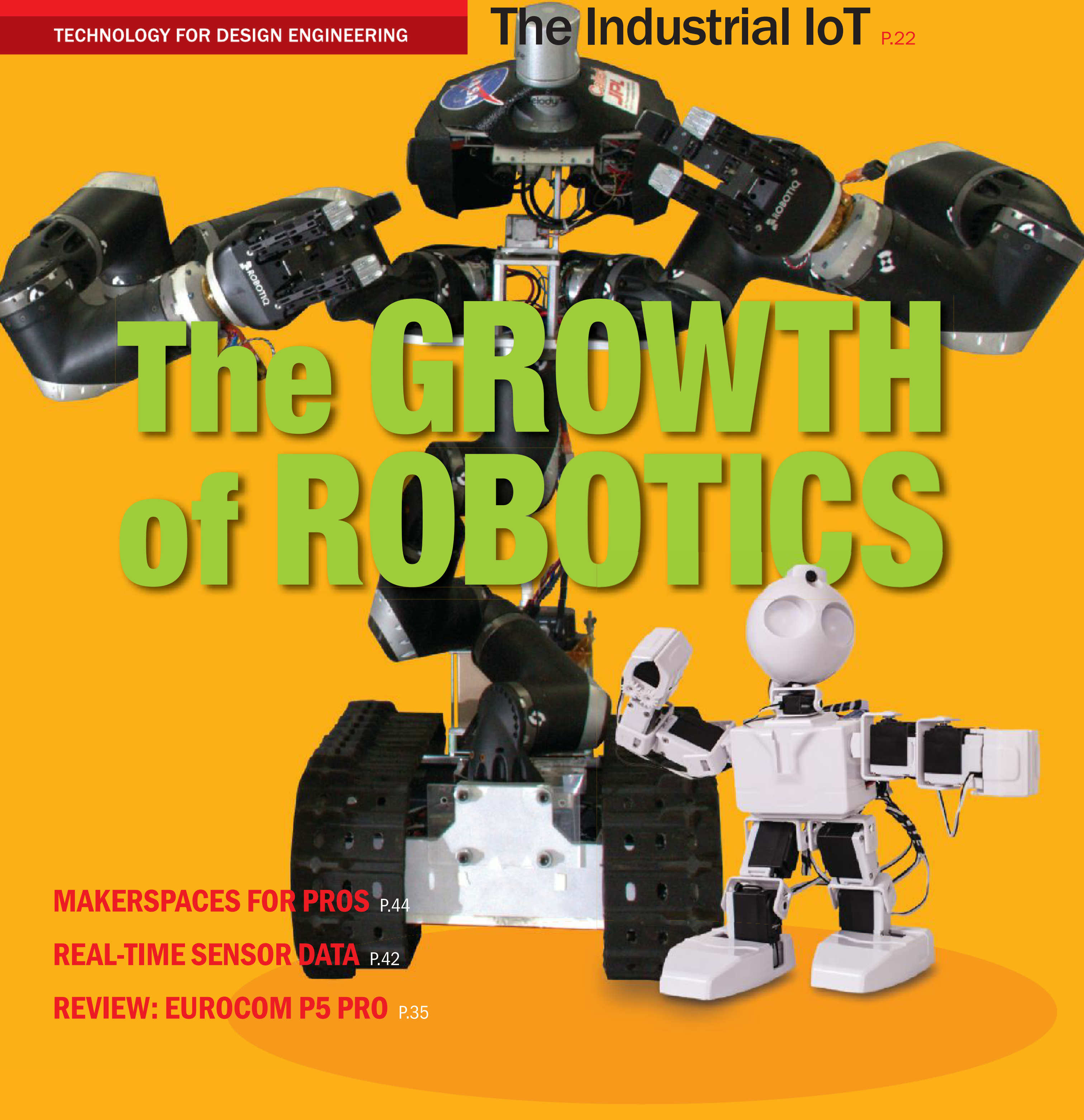

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Real Parts. Really Fast.™

by Jamie J. Gooch

Engineering an Experience

IF your boss walks in one day and tells you that you're no longer designing and engineering products, but are actually creating props to support an experience, there's a good chance he/she has been reading *The Experience Economy: Work Is Theatre and Every Business a Stage* by B. Joseph Pine II and James H. Gilmore. The book was written in 1999 and updated in 2011, but many of the ideas it professes are far older.

The shorthand to the "experience economy" business philosophy goes something like this: In an agrarian economy, consumers often bought the raw ingredients needed to make their own products, then we moved to an industrial economy where consumers bought pre-made products. Many of those products were then transformed into services. Sure, consumers often still paid for a physical product, but in the service economy what they were really buying was a more complete solution to whatever problem the product was intended to help solve.

A product is just part of what your company should be designing.

And now, proponents of the experience economy would say consumers buy experiences, and any company not providing an experience is just selling a commodity that does not acheive maximum profitability.

Products as Props

The name Walt Disney is often invoked when discussing the experience economy. When you buy a ticket to Disney World, it's understood you are really paying for the entire exerience — from the parades to the lighting of Cinderella's castle, to being treated like a guest. Steve Jobs' name comes up almost as frequently thanks to Apple's attention to user experience — not just in the user interface of its software, but in the way its physical products are designed and packaged. A YouTube personality's video unboxing a gold iPhone 5S has more than 3 million views. Further evidence that experience matters more than the actual product: his full review of the 5S' functionality received about a tenth as many views as the unboxing.

If your designs are more along the lines of brackets and braces than Magic Kingdoms and iPhones, do you really need to worry about the experience economy? The short answer is yes, eventually.

Even if the products you're designing are as exciting as an executive-level PowerPoint presentation on accounting best practices, experience still matters. The person buying your products might be just as interested in them as those 3 million YouTubers watching an iPhone being removed from a box. Or, and this is more likely, your customer is comparing your products, services and the entire experience of working with your company to that of your competitors. The product is just one part of what your company is, or should be, designing.

Experience in Design Engineering

I recently attended two industry conferences that reinforced the importance of experience: the COE 2015 Annual PLM Experience & TechniFair and the 2015 Americas Altair Technology Conference (ATC).

COE, a usergroup for Dassault Systèmes software, was focused on experience thanks to 3DEXPERIENCE, Dassault Systèmes' platform to help companies design, collaborate on and track user experiences — from product design to marketing to manufacturing and end use.

"Today we're in the experience economy," decalred Scott Berkey, managing director of Dassault Systèmes North America and CEO of the company's SIMULIA brand in his COE presentation. He was followed by Phillipe Laufer, CEO of the company's CATIA brand, who said CATIA is changing because the economy is changing.

Altair is taking the experience economy to heart by taking a critical look at the how users experience its software. At ATC, Altair Chairman and CEO James Scapa said the company has begun the process of redesigning its HyperWorks software suite's user interface.

"In the past we were designing things so they performed well, but aesthetics were a bit of an afterthought, especially to a lot of engineers," said Scapa. "Companies like Apple have kind of woken everyone up to the importance of human-centered design ..."

Nowadays, design engineers are creating products that have to satisfy a number of different parameters beyond pure functionality — from weight to servicability. In the very near future, the Internet of Things will drastically increase the amount of information design engineers have about how customers use the products they create while advances in high-performance computing and machine learning will help them make use of that data. From there, it's not difficult to imagine user experience dictating design requirements — even for design engineers who don't think of themselves as "Imagineers." DE

Jamie Gooch *is the editorial director of* Desktop Engineering. *Contact him at de-editors@deskeng.com.*

DE June 2015 VOLUME 20/ISSUE 10

ON THE COVER: Design engineers are creating innovative robots in all shapes and sizes. *Images courtesy of EZ Robot (foreground) and JPL-CalTech.*

DEPARTMENTS

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PTC Goes All In with the IoT

At its second annual LiveWorx conference (May 4-7, Boston), PTC inked a $105 million deal to acquire ColdLight, a provider of Big Data machine learning and predictive analytics, filling in a key piece of its IoT (Internet of Things) technology stack. Counting its latest conquest, PTC has doled out $500 million on core IoT technology in the last 18 months, including the $112 million acquisition of ThingWorx, which makes a platform for IoT application development, and last year's $170 million purchase of Axeda, which brought IoT and Machine to Machine (M2M) connectivity services into the PTC fold.

At LiveWorx 2015, PTC demonstrated the concept of a digital twin using an iPad augmented reality app. The speed and turn angles shown on display are real-time data transmitted from sensors. *Image courtesy of PTC.*

ColdLight's automated predictive analytics platform will help users make sense of data streaming off of all of those smart, connected products that PTC and industry watchers project will dominate in every field. While data is the currency of the new IoT era, the data has to be mined for insights that can drive specific actions — say predicting an equipment failure or making a recommendation for a service fix. ColdLight's Neuron platform uses artificial intelligence (AI) and machine learning to automatically and continuously learn from data, helping to discover patterns, build validated predictive models and mash up those findings with any type of application or technology to initiate an action.

PTC sees the ColdLight Big Data capabilities as a natural complement to its IoT-driven after-sales and service application strategy. It plans to use the platform to accelerate creation of predictive analytics applications to support service strategies in such areas as predictive maintenance and system monitoring and rounding out its existing service lifecycle management (SLM) suite.

In fact, one of ColdLight's strengths lies in its ability to simplify predictive modeling and analysis — a discipline that typically requires expert data scientists, which are fast becoming a rare and highly-prized breed. "Analytics are a core part of an IoT solution, and ColdLight democratizes analytics making it approachable by people who are not data scientists," said Jim Heppelmann, PTC's president and CEO, during LiveWorx 2015.

In addition to the ColdLight deal, PTC announced ThingWorx 6.0, which focuses on scalability and security improvements, and ThingWorx Converge, technology that extends the ThingWorx platform with pre-built capabilities to make it easier to integrate the real-time sensor data into existing enterprise applications like ERP (enterprise resource planning) and most importantly, Windchill PLM. Converge includes an out-of-the-box data model and other capabilities that will make it easier to monitor, manage, access and control IoT connected products.

Digital Twins

As part of a technology demonstration, the company showed off its vision of a digital twin, which bridges a physical product — in the case of the demonstration, a sensor-equipped mountain bike — with its digital prototype. Unlike a traditional 3D CAD model, the digital twin displayed in PTC Creo includes everything from sensor data, configuration information, service information, bill of materials (BOM) capabilities and more.

"The 3D digital twin is a broader representation of the digital product," said Mike Campbell, PTC's executive vice president of the CAD division, adding that the digital twin helps engineers and service technicians stay in tune with what's happening to a "thing" or smart, connected product after it is out in the field with a customer. Having that data stream directly integrated with engineering tools like CAD and PLM (think the new ThingWorx Converge), engineers can get direct feedback into how a product is used helping to optimize designs.

In the example PTC showcased, a digital twin of a sensored mountain bike was coupled with augmented reality capabilities to depict a number of factors, including how changes in speed or weight affect performance.

—B. Stackpole

by Kenneth Wong & Beth Stackpole

Growing Lattice in CAD: Additive Manufacturing Inspires Designers

Lilian van Daal wants to bring Nature's engineering methods into people's living rooms. The 2010 graduate of HAN University (Netherlands) created a series of 3D-printed soft seats. The softness comes from her clever use of Nature-inspired lattice structures to create flexibility out of stiff materials. In April, she presented her project to the attendees of the Congress of the Future of Engineering Software (COFES) 2015.

The method let her produce something "in one material [at] one factory, although it has the properties of various materials," she said. Her approach is an alternative to the traditional soft-seat manufacturing, which she pointed out is "normally far from sustainable: it is made from various materials prepared for assembly in different factories."

But van Daal's method also exposes a void in the design software industry. Even though additive manufacturing can produce her lattice structure, the tools to automatically generate such structures based on user-defined geometry are hard to find in the current design software packages.

"I was looking for software that could simulate and generate the most optimal

Lilian van Daal created this soft seat using a single material with varying degrees of stiffness in different regions. She said she manually modeled the lattice structures. *Image courtesy of Lilian van Daal*

[lattice] structures," van Daal said. But she couldn't find any that could do what she wanted. "I had to model all the structures manually — that's the problem," she added.

Historically, design software was developed to produce surfaces and solids — not micro-level structures. So the only way van Daal could model what she had in mind was to model every membrane in the seat. She did it in Rhino.

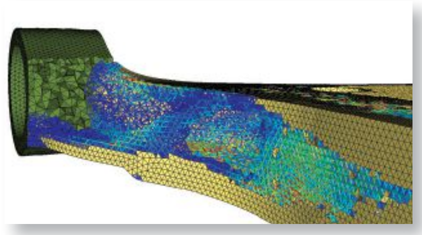
Van Daal found that software in the market can help her get "optimal rigid structures with as little material as possible," but she needs something more. "It's important to have a software where you can apply different properties to a product — for example, for comfort, ventilation, waterproofing, and stiffness," she said.

Since the current stress analysis and simulation software are designed to study geometry with uniform material properties (for example, steel iron, or plastic), she also had a difficult time finding a program to perform analysis on her chair, constructed of a single material but has varying stiffness in different regions. Her analysis, she said, was based on "trial and error."

Lattice Design Help on the Way

Setting aside the lattice structure's aesthetic appeal and flexibility, there's also a more practical need for it in 3D-printed projects. It's an efficient way to generate support structures for designs that must be held up during the printing process. "The current workaround is to fill such gaps with a pattern. That works great for 2D or 2.5D design, but not for 3D," said Dr. Andreas Vlahinos, principal of Advanced Engineering Solutions.

In its 2016 product line, Autodesk introduces Print Studio, which includes the ability to generate support structures for



The latest release of Altair's OptiStruct includes a solver that optimizes lattice structures. ***Image courtesy of Altair Engineering.***

3D printing. Late last year, at Autodesk University 2014, the company also revealed its aspiration to offer algorithm-driven design tools, dubbed Generative Design. It "would automate three types of optimization: topology, lattice-based structures and strut/beam structures," said Jeff Kowalski, Autodesk CTO.

Currently, Project Shapeshifter, Autodesk's Web-based form generator, offers a hint at what Generative Design could do. (Read more: deskeng.com/virtual_desktop/?p=9625.)

In February this year, Altair Engineering also announced it has added a solver to optimize lattice structures in its OptiStruct software. The company states, "OptiStruct now extends topology optimization to assist in the efficient blending of solid-lattice structures with smooth transitional material volume. Lattice performance can be studied under tension, compression, shear, flexion, torsion, and fatigue life."

Due to the limited size of a typical 3D printer's build chamber, van Daal can only print her chair in a miniature size, not at full scale. The best barometer for the performance of a chair, she said, is comfort — something that may elude software algorithms and solvers. "Comfort is a totally different thing than flexibility. It's more complex," she said.

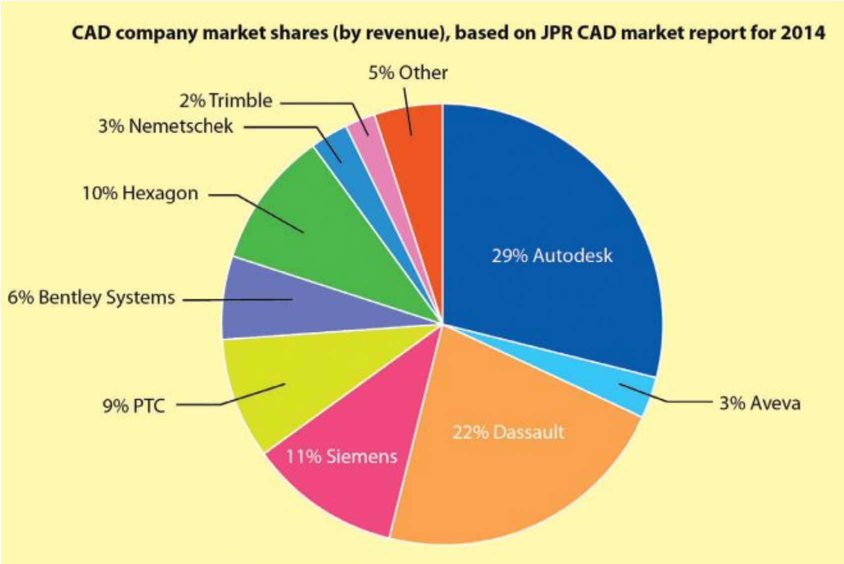
—K. Wong

JPR: CAD Market Growing Again

Jon Peddie Research (JPR), a market watcher that tracks the design software market, has some good news. The CAD market is growing again — to the tune of $8 billion in 2014. JPR estimates the CAD software market to be an $8 billion market with 5.15 million annual users. It writes, "We expect the market to grow to $8.7 billion in 2017 at a CAGR of 4%."

In JPR's market share breakdown, Autodesk leads the pack at 29%. The rest of the pie is divided by Dassault Systèmes (22%), Siemens PLM Software (11%), and PTC (9%).

"We are seeing the industry open up for new players and those new players are bringing new technologies with them," said Kathleen Maher, vice president and editor-in-chief of JPR's Tech Watch. "Most dramatically, of course, are the arrivals of Hexagon and Trimble, who are combining metrology with design and documentation to build location-aware CAD processes. Other companies helping change the face of CAD include SpaceClaim, which has been acquired by ANSYS; and GrabCAD, which has been acquired by Stratasys.



A snapshot of the CAD software market shares according to JPR's data.

—K. Wong

Autodesk Updates Manufacturing Product Line

In mid-April, Autodesk began offering its manufacturing product line for 2016. The portfolio includes Autodesk Product Design Suite, Factory Design Suite and Inventor HSM. Each suite comes with three titles that Autodesk considers essential: AutoCAD 2016, Autodesk 3dx Max and ReCap. The company's flagship drafting and drawing program AutoCAD and its rendering package 3ds Max have long been part of the suites. ReCap, a recent addition, promotes what Autodesk calls "reality computing." With integrated point-cloud handling and photogrammetry, ReCap lets engineers and designers easily digitize real-world objects and environments into editable geometry.

With the release of its 2016 lineup, Autodesk is bolstering its multi-CAD support and adding new tools to bridge CAD design to 3D printing.

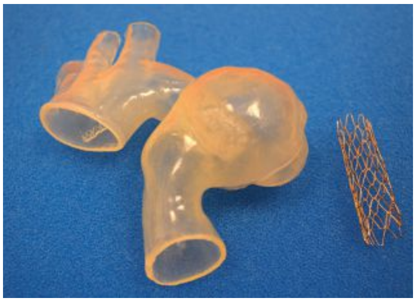
Autodesk Inventor 2016 comes with Print Studio, which generates the necessary support structures for 3D printing projects. ***Image courtesy of Autodesk.***

—K. Wong

Printed Heart Model Guides Surgery

Ariana Smith, a 17-year-old from Taylor, MI, was diagnosed with a large aortic aneurysm in her heart in 2014. The condition, complicated with a tortuous aorta with a distorted shape, can potentially be life threatening.

Because of the complexity of the procedure, doctors at Children's Hospital of Michigan used computed tomography (CT) to create 3D printed models of the girls' heart using the Mimics Innovation Suite software and HeartPrint services from Materialise.



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Rival CAD Vendors Join Microsoft 3MF Consortium

Fierce CAD competitors Autodesk and Dassault Systèmes announced on the same day that they're joining Microsoft's 3MF Consortium as founding members, suggesting a shift away from the use of the STL file format for additive manufacturing. The announcements came from Microsoft's Build Developer Conference.

Currently STL is the most common file format used for 3D printing, but Microsoft seems to think a better alternative is needed. The company has introduced its own format, 3MF (for 3D manufacturing), along with model-repair services (offered in partnership with netfabb) to make 3D printing easier for Windows users. CAD software runs predominantly on Windows; therefore, Microsoft's move could significantly change the CAD-to-print process.

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Printed Parts Will Be Used in Jet Engines

Later this year, Pratt & Whitney will deliver PurePower PW1500G engines to Bombardier that include compressor stators and synch ring brackets that were created via 3D printing powder bed additive manufacturing. The geared turbofan engines are used exclusively in the Bombardier CSeries aircraft.

"Pratt & Whitney has been working with additive manufacturing since the 1980s, and we are looking forward to our upcoming milestone, when the first production PurePower PW1500G engines with parts produced through additive manufacturing will be delivered," said Tom Prete, Pratt & Whitney's Engineering vice president.

According to Pratt & Whitney, the company has saved 15 months in lead time compared to conventional manufacturing processes, and reduced the weight in a single part by up to 50%.

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Stratasys Helps Get the A350 XWB Off the Ground

Airbus is hard at work putting the finishing touches on the A350 XWB aircraft. Some of those final touches include bringing in parts built using 3D printing and, more specifically, parts built using Stratasys systems. According to Airbus, the company used more than 1,000 3D printed parts during the construction of first delivered A350 XWB.

The primary system responsible for cranking out the parts used in Airbus' design was the Stratasys Fortus series, and the material of choice was ULTEM 9085 resin for FDM (Fused Deposition Modeling). ULTEM 9085 has been certified for use by Airbus and provides the aerospace manufacturer with a material that provides high strength-to-weight ratio and is FST (flame, smoke and toxicity) compliant.

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BioBots Offers a New Bioprinting Option

Startup BioBots would like to make bioprinting more affordable by offering a system capable of producing medical quality biomaterials without breaking the bank. The company's prototype was on display at this year's SXSW, and has garnered attention for printing a copy of Van Gogh's ear.

BioBots uses an ink that is a mix of cells and sustaining fluids. It is jetted out in patterns that are then cured by blue light technology to harden into useful biomaterials, such as cartilage and tissue.

It isn't yet possible to build viable replacement "parts" for humans, but biofabrication is valuable in producing bone scaffolding to assist recovery, or to assist medical testing by generating cruelty-free lab materials.

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Overclock and Offload

Overclocking is a safe, effective way to increase productivity.

It's easy to get obsessed with engineering computer specifications when you're trying to boost the speed of product development. The more megahertz, cores and gigabytes the better, right? Not necessarily. While faster hardware is important, it's only part of the solution. The best product design workflow matches the right hardware with the software you use.

Threading Through Design

3D design, simulation, visualization and rendering applications do not equally make use of the same hardware. Think of the tasks you do on your workstation: checking email, rotating a CAD model, changing a simulation parameter and more. All of those tasks are comprised of individual instructions, or threads, that are executed by the processor. Multicore systems are capable of executing different threads concurrently in parallel, but they can't do that if the software itself isn't multi-threaded.

Software for tasks like modeling, animating and texturing are predominantly single threaded, so having more cores won't complete them any faster. For those applications, you want the fastest CPU available. Even a more advanced graphics card won't make up for a slower CPU because the card still needs to wait for instructions from the CPU.

On the other hand, tasks like rendering and simulation visualization are often multi-threaded, so they can take advantage of multiple cores. The more CPU cores you have at your disposal, the shorter your rendering time will be. However, multi-threaded tasks can quickly consume the compute power in a typical multi-core engineering workstation. That not only slows your 3D model interactivity to a crawl, it also, for example, makes it difficult or impossible to adjust a CAD model while running a simulation.

The APEXX line of workstations together with the renderPRO from BOXX Technologies enable a fast overclock and offload oriented design engineering workflow.

Peak Productivity

To overcome these common engineering computing bottlenecks, BOXX Technologies recommends an overclocking and offloading workflow.

A safely overclocked processor, like those available in workstations from BOXX Technologies, allows for peak productivity with single-threaded applications. The company has shipped thousands of safely overclocked systems and guarantees their overclocked performance for the life of the warranty. For example, BOXX overclocks the APEXX 2 Model 3402 and APEXX 4 Model 7402 with 8-core Intel® Core™ i7 processors to 4.125GHz. That provides increased performance in single threaded applications vs. the processor's stock clock speed of 3GHz.

To boost rendering and simulation speeds without compromising your workstation's functionality, you can offload those multi-threaded processes to a BOXX renderPRO. Configurable with up to two Intel Xeon processors for a total of 28 cores (56 threads), the renderPRO enables you to render or simulate without bogging down your other work and without the cost or complexity of a render farm. The renderPRO simply requires power and a network connection. It's small and quiet enough to sit on your desk, yet powerful enough to significantly enhance your workflow when paired with an overclocked workstation.

For more information on the BOXX workflow, visit boxxtech.com/Workflow.

Brett Kennedy, supervisor of JPL's Robotic Vehicles and Manipulators Group, and Max Bajracharya, senior member of JPL's Mobility and Manipulation Group, pose with RoboSimian. *Image courtesy of JPL-Caltech.*

Building Robot First Responders

Behind the scenes at the DARPA Robotics Challenge Finals.

BY MICHAEL BELFIORE

It will be the most ambitious robotics competition in the world. On June 5 and 6, in Pomona, CA, 25 teams from seven countries face off in the DARPA Robotics Challenge (DRC) Finals. At Fairplex, the site of the L.A. County Fair, the machines will walk, roll and drive (in an all-terrain vehicle) their way through challenges that test their ability to work in disaster areas too dangerous for humans.

The machines will have to demonstrate greater autonomy, adaptability and endurance than shown by any robots that have gone before. "We are trying to make the world a little more robust to disasters that are caused either by nature or by man," DARPA Program Manager for the challenge Gill Pratt said on a call with reporters before the event.

Pratt conceived of the DRC in the wake of the 2011 tsunami and subsequent meltdown of the Fukushima Daiichi nuclear power plants on the Japanese coast. The nuclear disaster that ensued as a result of the natural one could have been mitigated — if only workers had been able to get inside the radioactive containment buildings. That's where robots like those being built by the volunteers, professional engineers and students of the DRC teams could have come in handy.

The DRC Finals follow the DRC Trials that took place in Florida in December 2013. The DRC Finals will award a first prize of $2 million, a second prize of $1 million and a third prize of $500,000 to the teams that can best perform simulated disaster recovery operations with minimal human supervision. These tasks include driving a vehicle to the work area, walking over rubble, climbing stairs, turning valves, operating a power tool, removing debris from an entryway and opening doors.

The Challenge

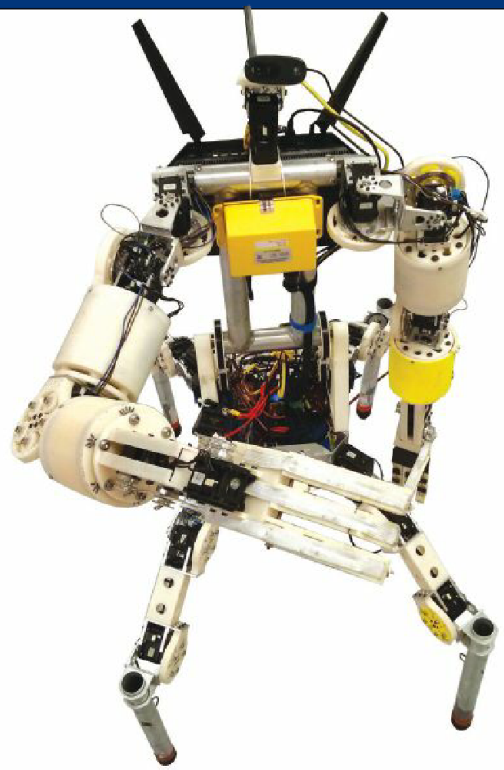
The teams will be presented with significantly more difficult tasks in the finals than in the trials. For starters, the machines will have to operate untethered, without the benefit of external power and safety lines. That means the machines will have to have enough onboard power to make it through the hour that they will have to complete the challenge tasks in one shot. They'll also have to be able to pick themselves up if they fall down and remain intact enough to resume work.

As if that weren't enough, the communications link between each team's operators and their robot will be even more degraded than before. The high-speed data link feeding the operators video and other data from their bot will drop out every minute, for a minute at a time. This is to simulate the spotty communications typically available at the scene of a disaster.

The approaches taken by the teams are as varied as the team members themselves, which range from volunteers working after hours, to the officially sanctioned and funded teams of major corporations, and none other than NASA.

Team Grit

The members of Team Grit are no strangers to DARPA-sponsored competitions. Working on a shoestring budget, the team competed in all three of DARPA's robot car competitions in the 2000s, as well as the DRC Trials — as Team Mojavaton. The team, based in Grand Junction, CO, and led by Karl Castleton, professor of Computer Science at Colorado Mesa University, gets by on limited donations of cash and parts. Merely being accepted into these competitions speaks to the chops and, well, grit, of these volunteers.



Cog-Burn, the robot developed by Team Grit from Colorado Mesa University. *Image courtesy of Team Grit.*

"3D printing was a big part of our previous robot, and it's a big part of our process this time," says Castleton. The team uses LulzBot A0100 and Taz printers to print parts for the robot, including a hypocycloid gearbox that drives its limbs. The gearbox design started on the MakerBot Thingiverse. After modifying the design for its own use, the team uploaded it back into the Thingiverse community as an upgrade. "We plan to take advantage of the open source communities a lot," says Castleton. "I have visions of us going and breaking a leg [at the competition], and then somebody from the audience says: 'Oh, I printed one last night.'" For designing parts, Castleton uses open source OpenSCAD design software.

The robot's CPU runs Linux Ubuntu. Interpretation of the images from the robot's stereo cameras is enabled by OpenCV. To deal with the intermittent connectivity available at competition, the bot will rely on the open source ØMQ messaging library for sending data to and from its operators.

"A lot of the groundwork is already laid for a lot of this stuff," says Michaela Ervin, team software lead. "You don't have to write it all from scratch any more or be a genius like Tesla to come up with something that works." She asserts that just about anyone with the drive and commitment can also work on cutting edge robotics projects, given the low-cost and even free tools available to developers now.

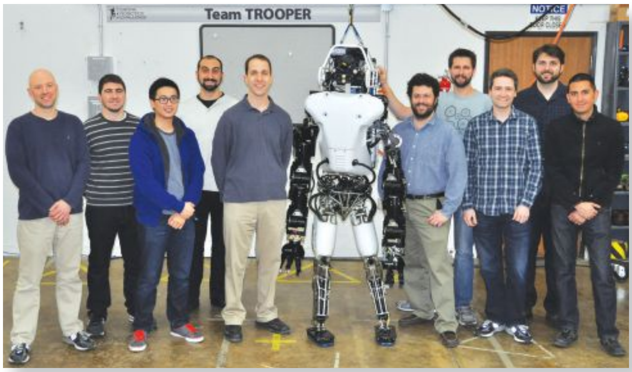
Cog-Burn, the team's robot, stands on four legs, allowing it to conserve energy that has to go toward simply remaining upright in bipedal designs. At just 40 lbs., Cog-Burn may also be the competition's lightest robot, which further maximizes battery life.

Team Trooper

Team Trooper, which also competed in the DRC Trials, is the entry of the Lockheed Martin's Advanced Technology Labs, based in Cherry Hill, NJ. Trooper is one of seven teams that DARPA has given an Atlas robot, specially designed and built by Boston Dynamics for the competition. Relieved of the need to design and build hardware for the competition, Team Trooper can devote its time to the code and the software interfaces needed to run their Atlas.

Team leader Todd Danko, a mechanical engineer at Lockheed Martin, says the DRC is equal parts competition and robotics conference. "The true winner is going to be whoever develops a technology that has longevity beyond this competition," says Danko. "To do that, you need to be working with each other." The members of the various teams have gotten to know each other well, says Danko, and have even exchanged some personnel. "There's a lot of cross pollination in that way," he says.

Team Trooper is working with Rensselaer Polytechnic University, which is contributing expertise in robotic manipulation as well as simulation. Software-driven simulation aids development as well as operations by allowing team members to plan their robot's moves before executing them during the competition. Team members from the University of Pennsylvania are building the code needed for the robot to accurately perceive objects in its environment as well as the algorithms driving the robot's full-body movements.



Team Trooper is using an Atlas Robot from Boston Dynamics to compete in the DRC. *Image courtesy of Team Trooper.*

The open source Robot Operating System (ROS) provides the platform for running the robot. "We consider that the industry standard for this type of robotics project," says Danko. "In one way, it can be viewed as just a communications layer that allows a lot of components of different origins to work closely with each other."

The Atlas robot stands 6 ft. 2 in. tall on two legs and weighs 400 lbs.

Team RoboSimian

Like Team Grit's entry, the NASA Jet Propulsion Laboratory (JPL) team's robot, RoboSimian, is quasi-statically stable. It can either walk on its four limbs or roll around on wheels when it sits down. When height is required to perform one of the tasks, say, to open a door, the machine can rear upright. "RoboSimian's not so much a robot as it is a collection of tech-

Robotics researchers at NASA's Jet Propulsion Laboratory pose with robots RoboSimian and Surrogate. *Image courtesy of JPL-Caltech.*

nologies, including things like the limbs and the software that runs all of that," says Brett Kennedy, team leader and JPL mechanical engineer. This team also competed in the DRC Trials.

The team draws on JPL's experience developing planetary rovers. Kennedy led the team that designed and built the Mars Curiosity rover robotic arm. Given that, cutting the power cord doesn't seem like such a hardship. "We are of the opinion that a robot that needs to plugged into anything — whether it's comm or power — is kind of cheating," says Kennedy.

For hardware design, the team uses SolidWorks. Software, however, all gets developed in-house — for example, a custom simulation environment and the operator interface to go with it. For testing, the operator plans a move, simulates it and then if it looks like it will work in the real world, sends the command to execute. "That development interface is pretty tightly tied to our operator interface so we can seamlessly go between testing ideas of how the robot's going to work to actually running the robot with it." The interface runs on a Linux Ubuntu workstation.

Kennedy says that the ability to gather as many team members in one workspace as possible is a key factor for success. For a complex, time-constrained project like this, says Kennedy: "The less you rely on collaboration tools, the better off you are. Even though people are writing in the same code environment and theoretically don't need to be sitting next to each other to do that, it's just a lot more effective to have everybody in that space."

The DRC, like all DARPA competitions, is designed to jumpstart technologies that didn't exist before, setting them on the path to production. It is expected that the DRC Finals teams will continue development after this last event — just as the teams in DARPA's autonomous car races did to start the self-driving car revolution.

Regardless of what teams take home prizes from the DRC Finals, the real winners will be the beneficiaries of robotic assistance following a future disaster. May the best bots win. **DE**

RoboSimian under construction in a lab at NASA's Jet Propulsion Laboratory, Pasadena, CA.
Image courtesy JPL-Caltech.

Michael Belfiore *is the author of The Department of Mad Scientists: How DARPA Is Remaking Our World, from the Internet to Artificial Limbs (HarperCollins, 2009).*

INFO → **Colorado Mesa University:** ColoradoMesa.edu

→ **DARPA:** DARPA.mil

→ **Dassault Systèmes SolidWorks:** SolidWorks.com

→ **Lockheed Martin:** LockheedMartin.com

→ **LulzBot:** LulzBot.com

→ **MakerBot:** MakerBot.com

→ **OpenSCAD:** OpenSCAD.org

→ **NASA Jet Propulsion Laboratory:** JPL.NASA.gov

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

Shooting for the Moon

Teams competing for the $30 million Google Lunar XPRIZE take novel approaches to engineer their way to victory.

BY MICHAEL BELFIORE

The robot crawls along at a stately 15 centimeters per second at a slag heap in suburban Pittsburgh. The 72-lb. machine moves on four metal wheels, electric motors whining as it climbs over the steel-milling detritus of the last industrial age and into the next one. Twin camera eyes peer out at the surrounding no man's land that closely resembles the moonscape that its flight-ready younger sibling will soon be expected to navigate. Operators in a trailer out of sight receive images on a 2-second delay and issue commands. It takes hours for the machine to clear the 500 meters that will be required to win the Google Lunar XPRIZE (GLXP) on the moon, but in this test, it does so without a hitch.

Welcome to the new moon race, where success is measured in centimeters traveled and the detail of the imagery captured. The technology giant Google has offered a total of $30 million in cash prizes to the first privately funded team that can land a rover on the moon, get it to travel half a kilometer once there and send back high-definition video and social media posts by the end of 2016. The first team to accomplish the main mission stands to win $20 million, with bonus prizes to be awarded for such milestones as finding water and surviving the perilous 14-day lunar night, during which temperatures drop below 200°F.

Astrobotic's Griffin lander comes in for a landing on the lunar surface. ***Rendering courtesy of Astrobotic Technologies Inc.***

Stellar Competition

Sixteen teams are in the running for the race, including Astrobotic Technologies Inc., the Carnegie Mellon University (CMU) spinoff whose mission simulation software and hardware was featured in the April 2013 issue (see "A New Space Race, Fueled by Simulation," deskeng.com/de/?p=12237), and which conducts tests of its rover at a former U.S. Steel dumping ground in West Mifflin, PA.

Astrobotic builds on the expertise of CMU robotics professor Red Whittaker and his team of students and former students who took the first place prize in the DARPA Urban Challenge robotic car race in 2007.

After Whittaker started Astrobotic in 2007, the team spun off as a separate company, also based in Pittsburgh. Now, with former students John Thornton and Kevin Peterson as CEO and CTO respectively, the team divides its engineering focus between the rover, still managed by Whittaker at CMU, and the lander that will take the rover to the lunar surface, which is being developed at Astrobotic.

Also a top contender in the competition is Moon Express, or MoonEx, founded in 2010, led by entrepreneur Bob Richards, and based at the NASA Research Park in Moffett Field, CA. MoonEx started with financing from co-founders and Silicon Valley entrepreneurs Naveen Jain and Barney Pell. The company has designed a lander that's small enough to launch as a secondary payload rather than requiring the purchase of an entire rocket launch to send it on its way to the moon. Moon Express has acquired three former GLXP teams to avoid having to defeat them on the playing field of the moon.

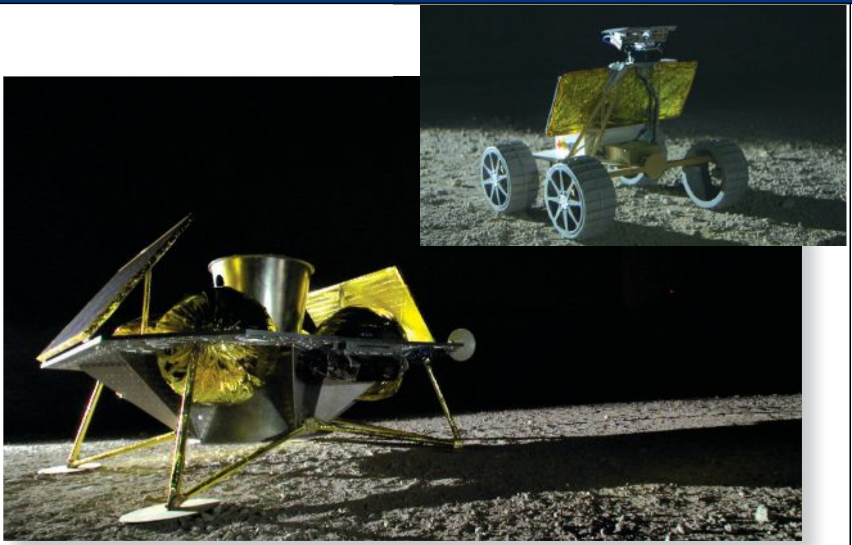
The engineering choices of these top teams competing for the Google Lunar XPRIZE reflect their unique approaches to winning the competition's top prize.

Rideshare to the Moon

Given that Astrobotic founder Red Whittaker and his team's expertise is in autonomous ground vehicles, it made sense to base the team's strategy on a semi-autonomous lunar rover. Andy, the rover, is named after CMU founders Andrew Carnegie and Andrew Mellon.

The communications lag imposed by the 250,000-mile distance to the moon makes direct, real-time control of the Astrobotic spacecraft and rover from Earth impossible. Instead, the machines will have to plot their own courses using machine intelligence and cameras.

"I worked on the Grand Challenges and the Urban Challenge," says Kevin Peterson, chief technology officer of Astrobotic, speaking of DARPA's autonomous vehicle races. "We've taken those approaches and iterated them for landing." Except this time, there's an important difference. "We had to add new software to the computer vision side because all the ground vehicle work relied on GPS," he says. Because there are no GPS satellites in orbit around the moon, both the lander, called Griffin, and the rover must navigate another way. The solution is image processing that can estimate distances between objects based on their changing appearance as the vehicles travel.



Team Astrobotic's Griffin lunar lander and rover (inset) after touchdown on the surface of the moon. *Rendering courtesy of Astrobotic Technologies Inc.*

To ensure they're on the right track as they refine their code, the team working on the lander's software is continuing to run simulations on their HP Z800 workstations with GPU (graphics processing unit) acceleration.

The Astrobotic team is still fine-tuning the design of structural elements of the lander, including its solar panels and legs. For that design work, the team uses Dassault Systèmes' SolidWorks with ANSYS structural analysis software. The ANSYS software simulates launch and landing loads and their effects on the SolidWorks designs.

Rather than acquiring its competition outright in the manner of MoonEx, Astrobotic has taken a rideshare approach to collaborating with other competitors. The company is offering space on board its lander for other GLXP teams or other groups that want a ride to the moon.

Team HAKUTO, which includes members from a startup called iSpace and Tohoku University in Japan, as well as additional volunteers, became the first GLXP team to announce a rideshare agreement with Astrobotic in February 2013. HAKUTO can now focus just on its rover — or pair of rovers — in its bid to win the GLXP. The addition of the HAKUTO rovers to Astrobotic's lander will make this an actual, Grand Prix-style race after all the rovers descend to the lunar surface following touchdown of the lander. If all goes well, the smaller HAKUTO rover, dubbed Tetris, will descend into a collapsed skylight to search for an entrance to a cave at the planned landing site, Lacus Mortis ("lake of death"), while tethered to the larger rover, dubbed Moonraker.

The HAKUTO team, led by Takeshi Hakamada, also relies on SolidWorks for hardware design, including the rover wheels that the team prints on a Stratasys Fortus 450mc 3D printer. "The material is ULTEM," says HAKUTO Lead Engineer John Walker, "an engineering plastic with excellent thermal insulating properties that can withstand temperatures over 200°C."

Members of the public can also get in on the lunar rideshare action through Astrobotic's MoonMail program. Raising money for launch is the main reason for offering ride-along payloads, and not just for the GLXP mission, but also for follow-up missions that the company plans to fly.

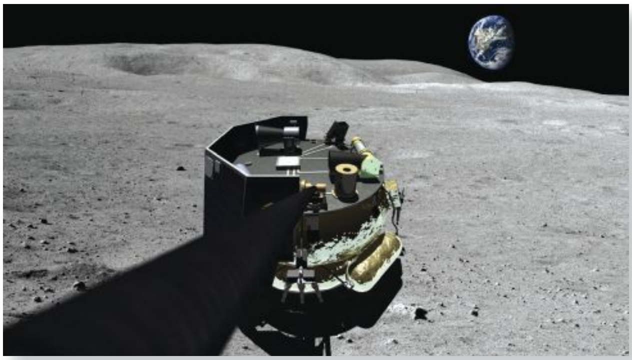
The NASA Sample Return Robot Challenge

The Google Lunar XPRIZE isn't the only way enterprising technologists can get involved in lunar exploration. Since 2012, NASA has sponsored the Sample Return Robot Challenge to foster the development of technologies needed to bring rocks back from other planetary bodies.

On June 8-13, 2015, teams from around the world will run robot rovers in competition for $1.5 million in prize money at the Worcester Polytechnic Institute in Massachusetts.

Prizes will go to the rovers that best drive themselves to a given location, collect simulated geological samples and return to their starting places.

Info: wp.wpi.edu/challenge/



An artist's illustration of the Moon Express MX-1 lunar lander on the surface of the moon. *Image courtesy of Moon Express Inc.*

Leap to Victory

Similar to the approach taken by a team that it acquired in 2012 (Next Giant Leap), Moon Ex has dispensed with rovers altogether. Instead, the team is concentrating on engineering a single craft for its mission: the lander.

After touching down on the surface of the moon, the lander, called the MX-1, will take the required high-definition video, and then fire up its main engines to fly from the surface, traverse the required 500 meters and then touch down again.

With so much riding on the performance of the lander, the coffee table-size vehicle's rocket engines are of critical importance. MoonEx Propulsion Chief Tim Pickens not only has the job of ensuring that the lander's hydrogen peroxide and kerosene fueled main engine and 12 steering thrusters will function reliably, but also that they will deliver the thrust and efficiency needed for a successful mission. Options that Pickens is considering include switching from a pressure-fed propellant design to a higher-speed pump-fed design if initial performance calculations turn out not to match test data.

For designing rocket motors, Pickens starts with NASA's Chemical Equilibrium with Applications (CEA) software to predict propellant performance given environmental factors such as atmospheric pressure (or lack thereof). From there, he can determine the optimal geometry needed for new rocket motor combustion chambers. Pickens and his team also predict such factors as propellant flow rates and heat transfer using C&R Technologies' Thermal Desktop. With all of these calculations in place, the Moon Express team designs hardware for the rocket motors with the help of Autodesk Inventor and other Autodesk design and simulation tools.

Autodesk is an important partner in the Moon Express venture. "Autodesk made a substantial investment in Moon Express during our Series B round and has been supporting us with software, technology and design ideas," says Moon Express CEO Bob Richards.

"Traditionally, design solutions have entailed a hodgepodge of software from different providers of CAD, analysis and CAM tools. Often these tools would have importing and exporting challenges. Autodesk has a cool cloud-based process and software that also allows remote development and monitoring of each project at every step if needed," says Pickens.

Pickens uses a MakerBot Replicator 2x to print rocket motor parts out of ABS (acrylonitrile butadiene styrene) or PLA (polylactic acid) plastic for evaluation by machine shops and other engineering teams working on the project. He finds it invaluable to work closely with machine shop technicians to design hardware that can easily be manufactured. Once rocket motors are ready for real-world testing, Pickens and his team collect test-fire data, including temperatures, flow, strain and acoustics, using National Instruments' LabVIEW.

Like Astrobotic, Moon Express plans to deliver revenue-producing payloads to the moon on its first as well as subsequent missions. Both Moon Express and Astrobotic will rely on a separate launch provider to get their spacecraft into space and headed toward the moon.

Shooting for the moon, as the teams competing for the Google Lunar XPRIZE demonstrate, need no longer be the exclusive domain of big government programs. And now that these small teams of dedicated engineers have the moon within reach — and so does anyone else with the means to hitch a ride. **DE**

Michael Belfiore *is the author of Rocketeers: How a Visionary Band of Business Leaders, Engineers, and Pilots Is Boldly Privatizing Space (HarperCollins, 2007).*

INFO ➜ **ANSYS:** ANSYS.com

➜ **Astrobotic Technologies Inc.:** Astrobotic.com

➜ **Autodesk:** Autodesk.com

➜ **Dassault Systemes SolidWorks:** SolidWorks.com

➜ **Google Lunar XPRIZE:** lunar.XPRIZE.org

➜ **MakerBot:** MakerBot.com

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➜ **National Instruments:** NI.com

➜ **Stratasys:** Stratasys.com

➜ **Team HAKUTO:** team-hakuto.jp/about-hakuto/

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Robotics Software Tools

Engineers create robots with a variety of applications.

BY DAVID GEER

Roboticists, especially those operating in small shops, are free to engineer their designs using the most suitable tools on the market — many of which come in free versions that will do the job without requiring a premium version.

The techniques and processes roboticists employ to bring projects that are both electrical and mechanical to life are as important as the tools they choose. While the design process can appear to be linear, new considerations can crop up at every turn that the roboticist must then input back into the design — perhaps at the very beginning.

Roboticist Derek Scherer used both the SolidWorks and Linkage tools when designing his Brute Golem, pictured here with the Brute Golem skull idea. ***Image courtesy of Derek Scherer, Robot & Automation engineer, The Golem Group LLC.***

Robot Design Tools & Techniques: Mechanical

As a sculptor chooses his own tools, so a roboticist selects his own design platforms. "I use SolidWorks daily for solid modeling. Such mechanical CAD tools are essential for designing systems that are as complex as most robots," says Derek Scherer, Robot & Automation engineer, The Golem Group LLC, who designed robotics for the movies: "The Hobbit: An Unexpected Journey", "Man of Steel" and "Elysium."

SolidWorks brings a deep dimensional and mechanical understanding of surfaces to bear on robot projects. When a desktop engineer cuts a sphere in half in SolidWorks, this platform has the same realization that a human being has of the qualities and characteristics of half a sphere in a 3D space. "SolidWorks produces diagrams, tolerances — everything a shop would need to fabricate the resulting design," says Scherer.

Another tool, Linkage, is a mechanical simulator that enables the user to create links and their connections and move parts inside the simulation to see how these operate collectively. "It's useful in uncovering major design flaws early on," says Scherer.

RobotsLAB, makers of RobotsLAB BOX educational robots uses Autodesk Inventor to design robotic mechanisms. While the capabilities of this design tool are many, the designer must still factor in the limits of fabrication technologies.

"If you want to cut the part out of metal, you have to keep in mind whether the cutter bit can make holes only in one size or can drill a hole on the underside of the part," says Ryan Wood, lead engineer, RobotsLAB. Each building material will have its own fabrication limits.

Blender, a popular physics animation tool, is a popular choice for animation demonstrations and it's free. "Whenever you see a robot animated on YouTube or a company website, chances are that they are using Blender," says DJ Sures, president of EZ-Robot, maker of personal and educational robot platforms.

Blender is a 3D CAD design package that enables the engineer to load design files, animate any design, add effects and visualize robot projects. "Blender uses real physics with animations to simulate your robot so you can verify that it operates as expected," says Sures.

Component Tips

RobotsLAB uses Autodesk Inventor to model components that it doesn't build. When considering how to use a sensor or motor to purchase for their robots, designers will bring a model of that into CAD software to determine its placement and to consider how to place parts and equipment around it. Some companies provide CAD models of the parts they sell. "But we may have to use a mechanical drawing of a unit to model it in our CAD software. Or, we may purchase the part and create a model from that," says RobotLAB's Wood.

If a motor or other component takes up too much space on the robot, a roboticist might try to re-design the other components or the enclosure that everything fits into, or they may try to select a motor in a smaller size, according to Wood. But these component and design choices affect the robot and its capabilities, too.

Integrating Electronics

EZ-Robot, maker of personal and educational robot platforms, uses Altium Designer from Altium's line of PCB (printed circuit board) design products. "I've used some of the free PCB design tools ... but there aren't a lot of free tools that are very good because the paid versions include lots of design samples and templates that the free versions don't," says Sures.

Ben Wirz, president of Element Products, uses the schematic capture tool DxDesigner and the PADS PCB design tool, both from Mentor Graphics. A typical project using these tools starts with a specification to follow.

The design flow starts with a paper design, using spreadsheets, says Wirz. In fact, Microsoft Excel is one of Wirz's most valuable electronics design tools. "I use it to do all the design equations, to calculate the resistor values and capacitor values and to work through all the theoretical calculations," says Wirz.

Microsoft Excel enables Wirz to easily document the electronics design process as design choices change, such as can happen with the ambient operating temperature specification. "If a customer says: 'We told you we wanted to work at 30°C, but we want to work at 20°C', I can change the number in Excel and see how this affects the design," says Wirz.

Wirz does the theoretical design and the mathematical design equations for engineering the circuit and enters the circuit into a schematic capture tool to add the transistors, resistors, and captures. "I make the circuit in DxDesigner, which connects all the pins together," says Wirz.

The Mentor Graphics HyperLynx Analog add-on software that works with DxDesigner Schematic Capture Software comes in handy at this point for simulations. "It lets me do electrical simulations of the circuitry I design. I can simulate analog circuits with it. I find it useful when doing any sort of analog design or filter design," says Wirz.

"Then I export it into the PCB tool to turn the theoretical into the physical, designing the circuit board and determining where the chips and components go down," says Wirz.

Once the circuit board is designed, the desktop engineer will want to integrate the board with the mechanical design. "For that I export the PCB design to Creo, a mechanical 3D design package from PTC," says Wirz. Creo enables the engineer to have a physical object to integrate with the robotics design.

"I can make a 3D model of an enclosure and print it out on my 3D printer to check that my circuit boards fit," he says.

EZ Robot built a robot platform using Blender and Altium Designer. *Image courtesy of EZ Robot.*

Design Considerations

RobotsLAB designers consider the whole robot system, its electronic, computerized and mechanical aspects together and how these affect each other when designing within any of those areas.

"Say you need a robotic arm to pick up a 2-lb. weight. The gripper you design weighs a certain amount too. The base joint of the arm now needs to lift the weight as well as the weight of the arm and gripper. This leads us to question the power abilities of the electronics," says Wood.

More powerful electronics may be necessary if the performance of the robot requires more energy than the electrical specifications support, and to avoid power supply failure, for the safety of others in the robot's environment.

Similarly, to give the end effector more gripping strength, the roboticist may have to consider larger, more powerful gripper motors. Those motors could necessitate stronger motors in the rest of the arm to lift that extra weight, which could again lead to reconsidering which electronics could support the design.

As each robot project is unique and fluid, so too is a roboticist's choice of tools. **DE**

David Geer *is a freelance technology writer based in Northeast Ohio. Send e-mail about this article to DE-Editors@deskeng.com.*

Ben Wirz used DxDesigner and PADS to design the S2 Scribbler Robot. *Image courtesy of Parallax.*

INFO → **Altium:** Altium.com

→ **Autodesk:** Autodesk.com

→ **Blender:** Blender.org

→ **CadSoft:** CadSoftUSA.com

→ **Dassault Systèmes SolidWorks:** SolidWorks.com

→ **DesignSpark:** rs-online.com/designspark/electronics

→ **Linkage:** blog.rectorsquid.com/download-linkage

→ **Mentor Graphics:** Mentor.com

→ **Microsoft:** Microsoft.com

→ **PTC:** PTC.com

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Looking for the Ghost in the Machine

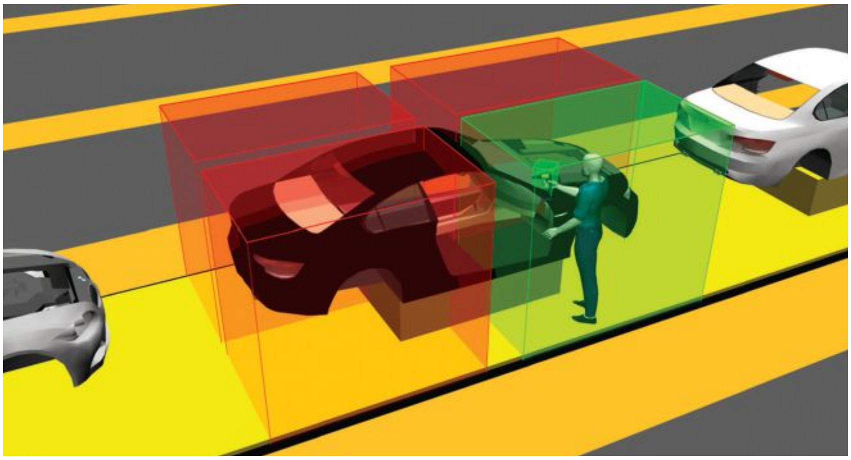
Thinking of the Industrial Internet of Things as just a series of connectivity projects narrows the scope of opportunity.

BY KENNETH WONG

With characteristic English wit, Samuel Taylor Coleridge quipped in a verse that, as a general rule, he would concede, "every poet is a fool … but every fool is not a poet." In light of the current rush to embrace the Internet of Things (IoT), both for its popularity and its legitimate appeal, it's worth making a similar distinction. Every IoT device is connected, but every connected device is not IoT-enabled.

Connecting a vehicle or a thermostat to the Internet doesn't take a lot of effort (or imagination, for that matter). IoT demands something more. An IoT product is greater than the sum of its parts. Streaming weather and traffic data from the cloud to the dashboard doesn't make the vehicle "smart." A thermostat that uploads hourly temperature readings to the cloud isn't adding any value. But if the vehicle can detect potential traffic jams and suggest alternate routes, or if the thermostat can turn itself down when the occupants are absent, you might say the product has been infused with IoT magic.

Strictly speaking, that magic is no sorcery. It's programming logic, pattern recognition and machine learning, aided by sensors and electronics. The ghost in the machine is not in the geometry of the product, the circuits or the lines of code. It's in the intelligent manner in which all these components work in synchronicity to produce the illusion of autonomy.



In its Smart Factory software suite, Ubisense uses RFID tags and sensors to automate and error-proof the factory using location intelligence. ***Image courtesy of Ubisense.***

The emerging IoT technologies featured here suggest the emphasis in product development is shifting from geometry to data acquisition and analysis, and from geometry-based simulation to sensor-driven simulation.

Your Factory is Watching and Listening to You

Adrian Jennings cares about what seems like a ridiculously small amount of time: six seconds. "In a high-volume manufacturing facility, you only get about 60 seconds to 90 seconds to work on a vehicle that comes into your station. So if you have to take six seconds — roughly 10% of the allotted time — to scan the car each time one comes up for work, it adds up," says Jennings, vice president of Manufacturing Industry Strategy at Ubisense.

The point of scanning the product is to identify the vehicle, so you can be sure you're performing the right operation on it. So Jennings and his colleagues at Ubisense developed a technology that could automatically identify the car, reclaiming those precious six seconds.

"Think of it as indoor GPS," Jennings says. "You have active RFID (radio frequency identification) tags that are roughly the size of a deck of cards installed on your assets and tools, and sensors installed along the assembly line. The tags are always pinging, and the factory is listening."

With this setup, the factory knows,

for example, that car 12 has entered workstation 100, and that tool x is present in the same workstation. This location intelligence ensures that you're using the right tool on the right asset, applying the correct torque to perform the designated task. Conversely, if you pick up the wrong tool, it would refuse to complete the operation because the factory knows the tool is inappropriate for the job at hand.

"This eliminates the need to physically fasten tools to a specific workstation with cords. Your tools can be cordless," says Jennings. Up to this point, the technology works to increase efficiency and error-proofing the assembly line, but Jennings has bigger visions. "One of the machine-learning opportunities is in accessing line performance and crisis prediction," he says.

There are telltale signs of impending troubles, detectable in the patterns of delay in workstations. "Assembly lines are like traffic flows. As soon as someone slams on a brake, everyone else behind slams on it a little harder," says Jennings. "So if someone is starting the process a few seconds behind every time, it could be a sign the line is heading for a crisis. That's something an AI-equipped factory can recognize on its own."

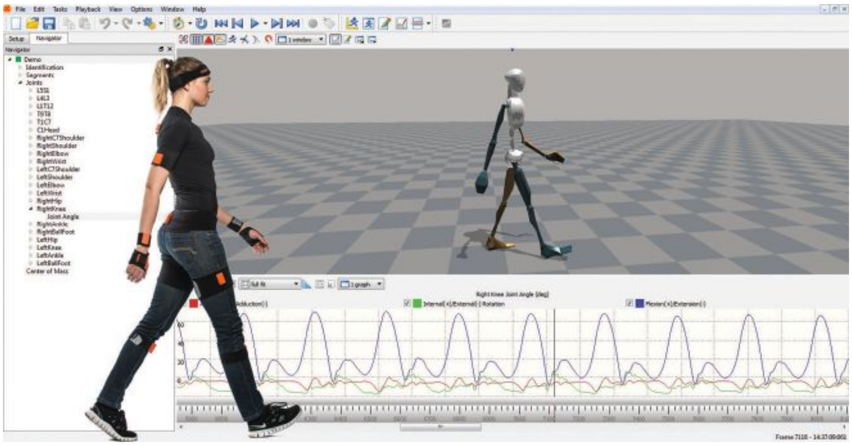
Your Virtual Workers Reporting for Work

Ubisense's Jennings points out that, contrary to what you might have heard, the automotive assembly process is highly manual, driven by humans rather than robots. That's why digital human models like Siemens PLM Software's Jack and Jill, part of the company's Tecnomatix process simulation software, could offer new opportunities.

"Every now and then you see one person who is just way better than everybody else in the assembly line," says Jennings. "Is there something he or she is doing differently from the rest? If you can capture his or her movements, there's a chance it can be replicated."

Replicating real human motions with digital models has been perfected by animators and game developers. The use of motion-capture suits propels the data-acquisition process to new heights. Xsens, a Netherlands-headquartered 3D motion-tracking technology developer, is hoping to improve the process with its gyroscopic suits. Xsens is a partner of Siemens PLM Software. The two work to make it possible to bring movements captured by actors in Xsens MVN BIOMECH suits to Siemens' Jack and Jill.

"The suit from Xsens is a good example of sensor fusion. It involves gyroscopes, accelerometers, and mag-



The use of Xsens suit equipped with gyroscopes allows ergonomists to capture and study human movements for workplace safety and comfort. ***Image courtesy of Xsens.***

netometers. You can put on that suit and start walking around," says Ulrich Raschke, director of Tecnomatix Human Simulation products, Siemens PLM Software. "It's a self-contained tracking system. With motion capture using markers and cameras, you'd have to worry about camera occlusion (the camera's inability to see the subject with markers). With this suit, you don't have to worry about that."

Typical use of Xsens technology may involve, for example, having an actor perform or mimic a particular assembly operation or enter and exit a mockup vehicle. Ergonomists could analyze the movement captured in Siemens' software to understand the stress and strain involved. If needed, the assembly process or the vehicle's doors could be redesigned to allow a much more natural movement.

Ergonomic analysis has emerged as an important part of manufacturing process simulation. "When you're designing something new, you don't know how people will approach it. When planning for wire-harnessing for a plane, you may assume people will hold the wire and use a kneeling posture to do it. But then when you see the subject performing the task, you might realize people have a tendency to do it in differently. The data from the suit can be streamed directly to the Jack software in real time. So while the actor is acting out a task to see if he or she can reach for certain things, the software can calculate if, over a period of time, this action exposes the human employee to injury risks," says Raschke.

The latest enhancement in Ubisense technology adds head tracking, which offers the chance to derive new insights from captured movement. "If somebody is wearing a head-mounted display that includes tracking, we now know where they are, what machine they are standing in front of and what information might be useful to present," says Raschke.

Your Virtual Sensors Ready to Go

Other executives are trying to bring together elements that previously existed in separate spheres. "Imagine a CAD model with sensors in it," says Brian Thompson, senior vice president for PTC Creo.

A CAD model made of pixels and polygons cannot accommodate real sensors, but Thompson and his colleagues have worked out a way to stream real-time data coming from ThingWorx, PTC's IoT application development platform, to a CAD model. By connecting the field data from the sensors to ThingWorx, Thompson and his team accomplish what they set out to do.

"As you start collecting data on a product and learn about it, your PTC Creo model of the product could become the digital twin of the physical prototype," says Thompson. "We think of that as a 3D digital twin [of the physical unit] equipped with virtual sensors."

In an augmented-reality display, the CAD model, the real-time video feed of the product in action (say, a bike in motion with a rider), and the raw data from the experiment (such as speed, forces and pressure) could be consolidated. It may also be possible to incorporate real-time stress analysis results into the same environment, taking the concept of simulation to new heights. "The ability to view the digital twin in conjunction with raw data from a real-time event lets you see instantly whether you've overdesigned or underdesigned something," says Thompson.

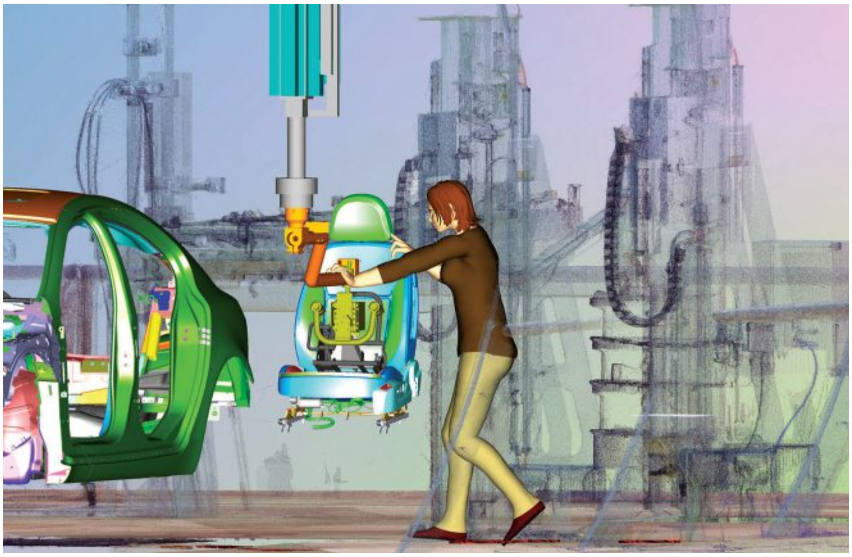
Thompson and his team have also implemented certain software-driven analysis and alerts. For example, the software can recognize from a real-time data feed that a bike's front and rear wheels are spinning at different rates — a potential risk factor. "It's not just about reporting data," he says. "It's meant to give you additional insights."

Thompson and his colleagues said: "We're committed to make this connection [between ThingWorx and PTC Creo] work. How would this manifest in our product? How will our customers implement it or deploy it? That's up for discussion."

The Internet of 'Think'

Machine learning or artificial intelligence (AI) refers to devices that can not only sense and react but "think" and "learn." Through programmed logic, they can act based on what they perceive. Over time, their ability to act without user intervention grows. Zach Supalla, founder and CEO of Spark, has some insights into where the thinking and learning happen.

"You have sensors that are usually



Movements captured in Xsens suits can be imported into Siemens Tecnomatix Jack and Jill software. *Image courtesy of Siemens PLM Software.*

pretty dumb. You also have actuators that are also dumb. Neither of them are usually doing the thinking. Something else provides the logic. Often you don't want that to be in the device, because it's complex, changes all the time and requires lots of resources. So it makes more sense for that to be on the server," Supalla says. In other words: the cloud.

Take, for instance, a farm equipped with weather sensors and sprinklers. The sensors detect conditions, but do not react; the sprinklers can react to command, but do not think. The two enter the realm of IoT when something else provides the logic to activate the sprinklers if the ground is dry and no rain is expected.

"Machine learning happens when you turn that logic into an abstraction, remove it from the hardware, and make it grow in complexity over time," says Supalla. An IoT device like the Nest learning thermostat, he pointed out, would do the learning in the cloud, not on the device itself.

Spark offers IoT development kits — the Spark Core (Wi-Fi), the Photon (Wi-Fi), and the Electron (2G/3G cellular) — for prototyping connected devices. It also offers private cloud solutions, a secure space for your devices to think, as it were.

Since the real-time and historical data collected from sensors serves as the source for the device's thinking and learning, some product designers may have to tackle the Big Data headache. "If you're storing temperatures, the two-digit integer doesn't require a lot of room," Supalla explains. "But if you collect temperature for every second, even though the second-to-second temperature variation is minimal, you could unnecessarily create a Big Data problem. Maybe you just need to know temperatures for every five minutes to make effective decisions." The smart approach, he says, is to identify and collect only meaningful data.

For CAD users who focus on the geometry of the products, Supalla says it is critical to think of making room for sensors and actuators in the products, along with the means to power them. Perhaps less obvious, they may need to consider whether the device's wireless transmission and reception might be hampered by nearby objects. That requires not only thinking about the geometry and shape of the product, but also a good understanding of the field conditions for deployment.

On the Eve of an Evolution

Siemens' Raschke thinks the manufacturing industry is on the cusp of something big. All the technology pieces are in place, awaiting a major transformation. "We already hold much of the information about the machineries in the plant, about the movement of the people, and so on. We're on the doorstep of connecting those data and wearable devices," he says.

Spark's Supalla cautions against a simplistic interpretation of IoT. "AI doesn't necessary need automated robots. Think of Uber, for example. The user transmits their locations and requests cars [from an app on a mobile device]. They don't have to call up a taxi service to order a car. Some part of the system is automated, but that small part makes a huge difference," he says.

The momentum for the IoT and the zeal to deploy it may lead some manufacturers to tunr to autonomous or semiautonomous robots. Such adaptation will surely add speed and efficiency to the operation, but doesn't exploit the full potential of the IoT. Perhaps the inherent paradox in the term "Internet of Things" is that it requires looking at products not as things — but as pieces that produce an overall experience. DE

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. E-mail him at kennethwong@deskeng.com or share your thoughts on this article at deskeng.com/facebook.*

INFO → LiveWorx: LiveWorx.ThingWorx.com

→ **PTC:** PTC.com

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

→ **Spark:** Spark.io

→ **Ubisense:** Ubisense.net/en

→ **Xsens:** Xsens.com

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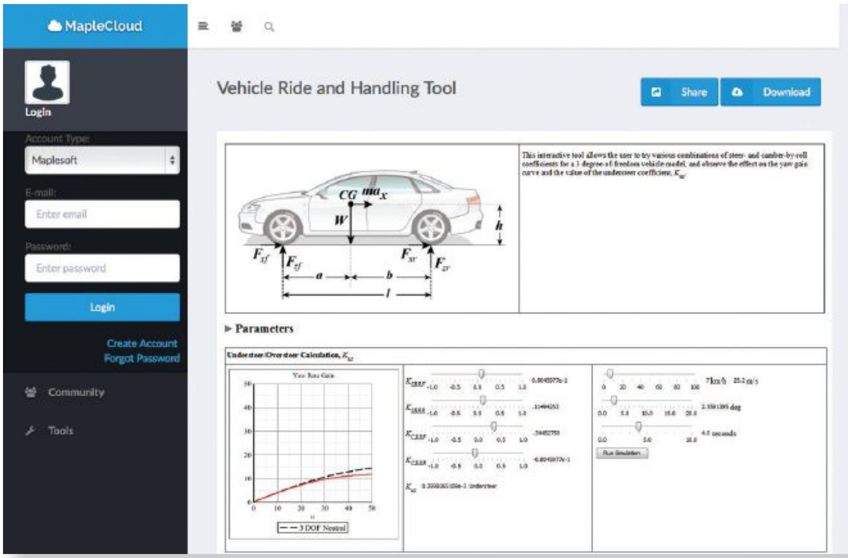
Mainstreaming Math Tools

How the connected community helps make the complex simple.

BY PAMELA J. WATERMAN

I've often thought the keys to life are music, chocolate and air-conditioning, though not necessarily in that order. More recently I've had to add math, engineering and the Internet, definitely in that order because math pretty much comes before all the rest. Whether you're considering the patterns in music, the engineering behind guitar-string manufacturing, the formula for refrigerant chemistry, or the code that drives a communications processor, math is at the core.

However, math as both a language and a tool can be a challenge to implement, so it's a good thing that software developers have embraced the concept of worldwide, 24/7 connectivity to give users at all levels a helping hand.



An interactive vehicle ride-and-handling design tool created with Maplesoft products is shown above. Users can share Maple applications both publicly and privately through the MapleCloud, where they can be accessed through a standard Web browser. *Image courtesy of Maplesoft.*

Today's Watercooler Resources

With the advent of the Internet and particularly the concept of electronic mailing lists, the old concept of comparing notes while standing by the company watercooler moved into the virtual world. The chance of encountering someone who could answer a design or simulation question increased exponentially. Such was the environment in the late '90s when the Mathcad Collaboratory group, under its original Mathsoft ownership, offered an online forum for posting Mathcad software questions. Participants gained an easy way to tap the collective expertise of both developers and users when solving and visualizing math problems in science and engineering fields.

Acquired by PTC in 2006, Mathcad, with its natural "whiteboard" live math notation for numeric and symbolic formulas, saw its support expand even more as it joined the larger online PTC Community in 2010. Users of today's PTC Mathcad Prime 3.1 package now have an number of ways to ask detailed questions and research possible scenarios, whether they are working with the software's improved templates, writing their own APIs (application programming interfaces) or integrating worksheets with PTC Creo design software.

"A good starting place for new PTC Mathcad Community members is ptcusercommunity.com/docs/DOC-3621. This page links to Mathcad worksheets: some for free, some for purchase and some for active Global Support customers," says Brent Edmonds, senior director for Mathcad, PTC.

Topics in the PTC Mathcad Community range from plotting data to designing electro-magnets to optimizing rigid-body dynamics. For example, in the mechanical forum, one member recently asked how to get rid of whatever was causing an "undefined variable" error message. In less than two hours, a helpful fellow member's reply identified a missing multiplication step. And regarding another writer's spreadsheet-conversion dilemma, labeled "Transient Heat Conduction in Cylindrical Geometry" — posted at 10:28 p.m. — a simple formatting solution appeared just 40 minutes later.

Edmonds also points out that his company's general resource page (ptc.com/product/mathcad/resources) gives users access to even more approaches for learning from company experts and tech support staff. Here, users can watch PTC video tutorials, join in live Web demos, explore the customer showcase and navigate to tips-and-techniques blogs. From the number of video views, it's clear that "Using Vectors Instead of Range Variables" (34,162 views) is a hot topic, as is "Solving an Ordinary Differential Equation" (15,212) and learning general "Programming" steps (12,486).

Managing Big Data

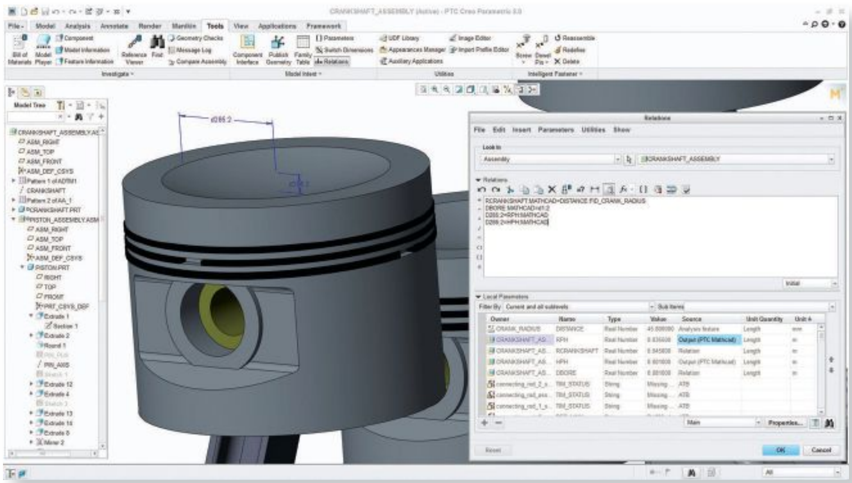
The main webpage for MathWorks notes that its MATLAB product is a programming environment for data analysis, algorithm development, visualization and numeric computations, while Simulink is "a graphical environment for simulation and Model-Based Design of multi-domain dynamic and embedded systems." What you don't see in words, but quickly grasp after a little Web surfing, is the connected, supportive world called MATLAB Central that grew out of FTP swaps and news groups more than a decade ago. Here, experienced users are quick to share programs, solutions, ideas, tips, discussions, and even games. The result is a MathWorks software resource with great depth and a loyal following.

A true sense of helpfulness permeates MATLAB Central. "A large part of our market is people who aren't programmers and may be out of their comfort zone," says Ned Gulley, design lead, MathWorks. A quick search will lead them to detailed solutions of problems similar to their own, plus the chance to post questions and correct puzzling errors. "There are many generous people out there, engineers who figured out a way to solve a problem and were nice enough to write it up and put it out on the Web and are willing to interact with you," says Gulley.

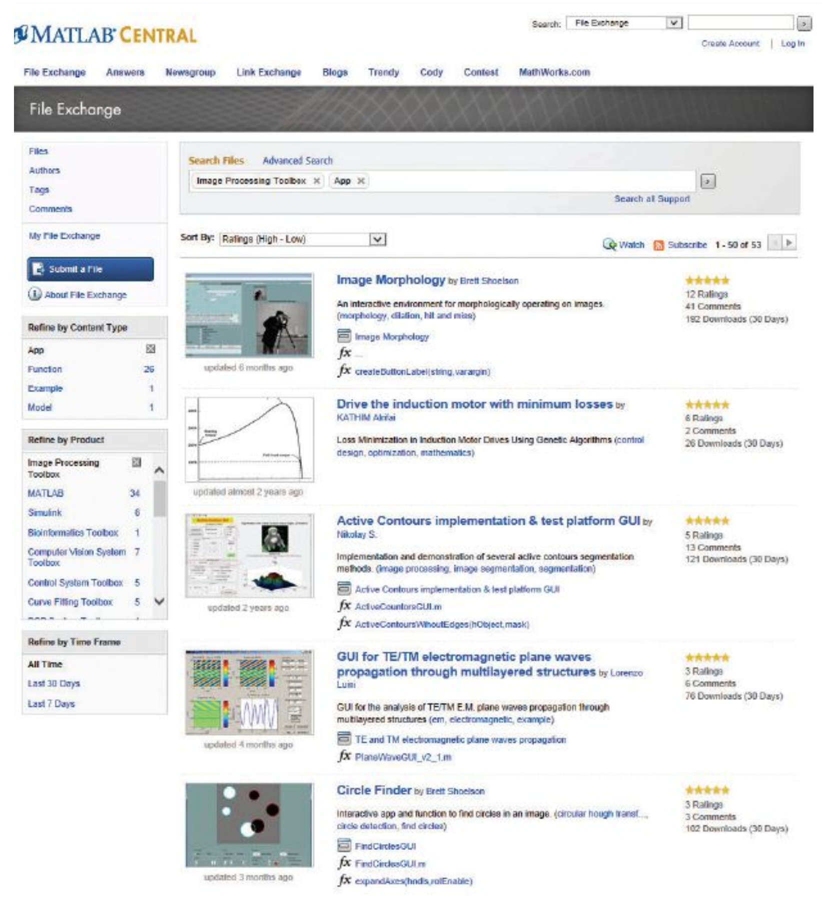
Recently, the File Exchange portion of MATLAB Central listed available downloads for "Calculation of Sphericity of Irregular Objects" and "Visualizing Wave Propagation" — just two possibilities out of nearly 18,000 functions, apps and videos, that can be local or accessed via GitHub. Meanwhile, in the MATLAB Answers section, users have added to the existing database of 145,000+ questions by asking and replying to: "How do I place a number before a decimal point?" and "how can I simulate an antenna array's beamforming in the Phased Array System Toolbox?" The breadth of topics and level of detail is amazing, and users can update existing solutions over many years.

Even more assistance with manipulating files, developing algorithms and analyzing data comes in the form of a MathWorks Link Exchange and the general Newsgroup, as well as a lively "try this" games section. Lastly, MathWorks staff members regularly contribute useful posts through a set of topical blogs.

Maplesoft, the developer of Maple and MapleSim, is another company that recognizes the value of community resources to help make math tools accessible across a spectrum of users. The company's white paper, "From Concept to Deployment," tracks the uses and benefits of Maplesoft products over the past 25 years and comes to some interesting conclusions. No matter the company type or size, math usage fits into three



Users of PTC Creo product-design software can open and use embedded Mathcad parameters, defined within a Relations window, to drive Creo geometry. *Image courtesy of PTC.*



The File Exchange webpage on MATLAB Central from MathWorks. The filters on the left have been set to show only MATLAB Apps that perform image processing tasks, with the highest-rating entries listed first. This is a busy area. Each file visible here shows many comments, ratings and downloads (all free). *Image courtesy of MathWorks.*

categories: advanced analysis, application development and design calculations.

"In large organizations, it's not unusual to find a ratio such as one advanced analyst: five solution developers: 50 end users. Maple captures the knowledge of the analyst working on mathematical concepts and provides a development environment for the solution developer. The Maple-based solution is then deployed to the end users," says Laurent Bernardin, executive vice president, Maplesoft. Supporting both analyst and developers are several online Maplesoft resources that give users a common place to share models and analyses, compare experiences, post comments and download executable code.

At the core of this approach is the Maple Application Center. This online resource features more than 2,350 user- and staff-contributed applications, searchable by dozens of categories including 14 different engineering fields and 31 areas of math. Some files are documents describing an analysis challenge, proposed solution (system of equations) and implementation in Maple or MapleSim. Others are working models that users can adapt to their own needs, such as "Gas Orifice Flow Meter Calculator," "Vehicle Ride & Handling Tool" and "Windshield Wiper Mechanism." The Preview-Before-Downloading feature is very handy.

Additionally, for the past five years, Maple users have been able to share Maple worksheets and apps with fellow users through the MapleCloud. This repository is now accessible from a Web browser, a free Maple Player and from Maple itself, enabling easy collaboration even among non-Maple owners. A public community section within MapleCloud lets users share their applications and examples.

Two other online tools continue to simplify Maplesoft implementations. The MapleNet product lets you share solutions over your own Website through interactive Maple documents, offering more control and features than the basic Maple Player. And because everyone sees the value of user-to-user communications, MaplePrimes hosts the company's active forum for posting comments, asking questions, learning about new features, and exploring tips and techniques.

A Fresh Look at Classic Software

Is it really possible to model, simulate and control nonlinear dynamic systems without coding, i.e., hiding the complexities of the underlying math? That was the challenge taken on 25 years ago by the founder of Visual Solutions; the successful result became VisSim software. Acquired by Altair in 2014, VisSim is a 100% graphical language package that combines the simplicity and clarity of a block diagram interface with a high-performance mathematical engine. A library of functional blocks ranges from simple timers and sine-wave generators to sophisticated sub-systems such as hydraulic components and 6-DOF (Degrees of Freedom) airframe dynamics. Connecting these blocks with virtual wires and hitting "go" sets a simulation in motion.

"We needed to find ways to encapsulate complicated math and describe it graphically. VisSim converts (operational) requirements into plant models, making them available to a broader audience so that they can evaluate different scenarios," says Michael Hoffman, senior vice president, Math and Systems, Visual Solutions. Models of motor controls or gas turbine simulators, for example, can be used for training, for hardware-in-the-loop simulations, or to automatically generate tight, readable controller code that will load directly into a standard control-processor. All of this is done without the originator having to code in C or assembly.

End-users can download the view-only VisSim Viewer software to open, view and simulate VisSim models of any size. The Viewer lets you move sliders, click buttons and change block and simulation parameters to test different design scenarios, all with no knowledge of the math or exposure of company-private algorithms.

Developers can get questions answered through email or online forums focused on modeling, simulation and embedded controllers; reusable models are also shared through an online exchange, addressing such topics as "Controlling Prius Brushless Interior Permanent Magnet Motors" and "Thermal Response of a Large CCD Camera." Adding to the dozens of downloadable tutorials and user guides is a series of mechatronics training videos produced by Richard Kolk, chief technical specialist at Visual Solutions.

Another company that got started in this area 25 years ago is Wolfram Research, developer of Mathematica, now in version 10. Users who are comfortable with equations and coding will appreciate the fundamental Wolfram mathematical language for technical computing, as well as the drag-and-drop component-based modeling and simulation environment found in Wolfram SystemModeler. The latter greatly simplifies connecting a functioning model with the math behind a dynamic system such as a truck-seat suspension or flight dynamics of an aircraft under different flight conditions. Both packages enjoy extensive community support: 89 online discussion groups cover a huge range of topics, from general mechanical engineering (including finite element analysis and computational fluid dynamics) to image processing, control systems, and Raspberry Pi.

The philosophy of the Wolfram language is to automate as many tasks as possible, so programmers can concentrate on defining the end functions. The language automatically solves ODEs and PDEs (partial differential equations) by finding the best algorithm out of thousands in the Wolfram/Alpha Knowledge database. This growing database of information-about-everything already includes 150,000+ examples, including engineering data and computational approaches, plus 10,000 open-code demonstrations.

The new Wolfram Programming Cloud introduces a level of automation that greatly speeds up application/GUI (graphical user interface) creation (*check out wolfram.com/programming-cloud/?source=nav for a good overview*). And with the advent of Mathematica Online, Mathematica interactive notebooks now work directly in a Web browser — letting users seamlessly share documents and resources in the cloud.

Math in Friendly Places

Tapping online resources not only helps demystify math tools but also opens users up to completely new solutions. "We have people coming to the (MATLAB Central) site every morning and afternoon, constantly learning and sharing," says MathWork's Gulley. "It's a really nice way to break out of the isolated world of an engineer at the desktop and make connections with people." **DE**

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

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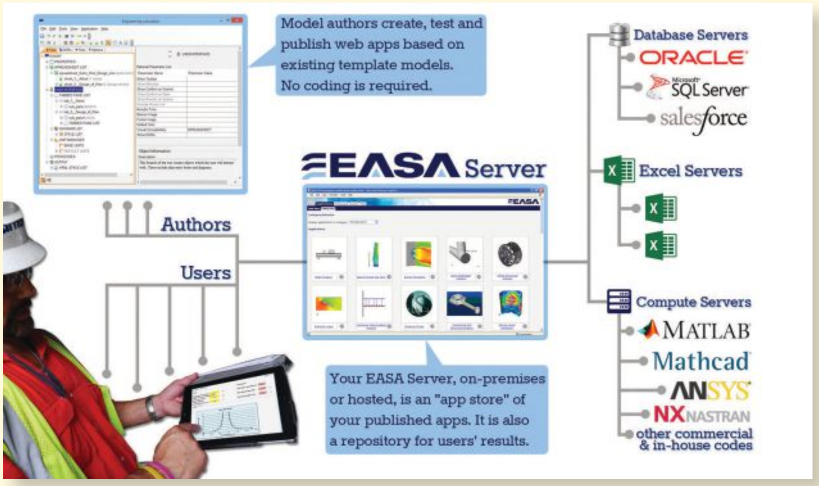
Streamlining Math, Design and Simulation Tasks with EASA Applications

Whether your design "community" is the company or the entire Internet, it's rare that you don't need to share more than one type of FEA or CFD package, along with such tools as Excel spreadsheets, MATLAB applications and Mathcad worksheets. Connecting and smoothing the deployment of these models and legacy applications is the EASA codeless application builder from EASA Software. Installed on a server in a company's network, EASA becomes an internal cloud that hosts the most frequently used simulations, math models and design processes, incorporating expert guidance, all while simplifying and streamlining their access.



Depending on the applications, users don't even need to have local installations of the software they are operating, just browser access to the corporate network. For example, when a model-author opens and selects regions of an Excel spreadsheet from EASA, the EASA Excel Wizard automatically creates GUI objects based on Excel entries, which the author can define as variables. Once the author publishes the application, end users can provide input values for these variables on a laptop, tablet or mobile device; they will not see or need to access the underlying spreadsheet, worksheet or FEA code. Similarly, experts can create a process that lets non-expert users of MATLAB, Mathcad and other CAE programs make guided changes 24/7 across teams, whether local or international, for rapid design evaluations.

Sample Piston Design Application: youtu.be/KdnXp9Pi78Q
Application Creation Tutorial: youtu.be/_5WKLMyhnG0
CFD Software Inspired by EASA: goo.gl/P0RFfF

—PJW

Practical Frequency Response Analysis

This method offers a viable alternative to time-based analysis.

BY TONY ABBEY

Editor's Note: Tony Abbey teaches live NAFEMS FEA classes in the U.S., Europe and Asia. He also teaches NAFEMS e-learning classes globally. Contact tony.abbey@nafems.org for details.

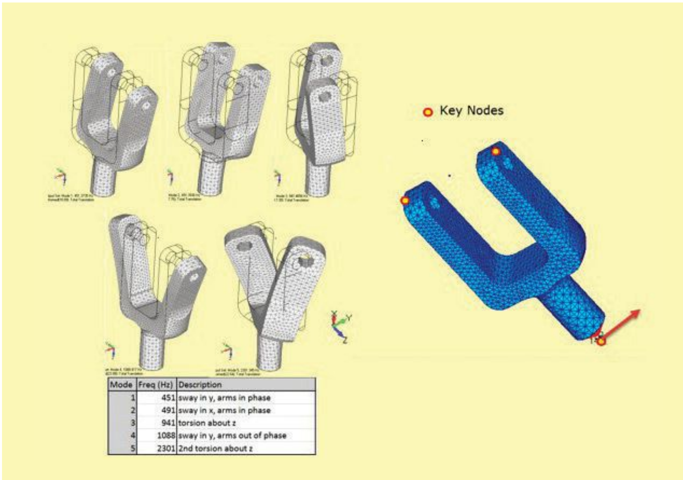
In last month's issue of *Desktop Engineering*, we covered the basics of transient, or time-based analysis (deskeng.com/de/?p=24085). This month's article focuses on the alternative of frequency response analysis.

Frequency-based Response is not as intuitive as Time-based Response. We have to picture a virtual test setup with a shaker table that can be slowly driven through a frequency range. The table is infinitely stiff and our structure is rigidly connected to it at the constrained Degrees of Freedom (DOF).

We crank up the table and monitor as the oscillations are set at around 5Hz. In a non-simulation we have to wait until the response settles down to a steady state. In FEA (finite element analysis), we calculate the steady state directly and throw away the transitory response. At 5Hz we would plot a "frozen" response deformation shape that consists of all the peak amplitudes. We can also plot the peak accelerations, forces, stresses, etc. Having captured all of the results at 5Hz, we move on to 10Hz, capture all these peak responses, then move on to 15Hz and so on. We would go all the way up to the maximum frequency of interest, plus the safety margin we talked about last month.

Our virtual test results are a series of frozen displaced shape plots and all the corresponding peak response data at each frequency step. In a post-processor we can show each frozen plot shape and contour it with accelerations, stresses and more. More useful even, we can plot the peak responses at any DOF as a graph of response against frequency.

We are exploring an envelope of frequency input and plotting it as an envelope of frequency output. In other words, we are looking for trends across a range of excitation frequencies. A typical application would be a structure connected to a bulkhead or similar base structure, which is being shaken harmonically across a frequency range. This does not represent one physical event, but represents an exploration of the steady-state structural responses across a range of possible harmonic input loading that could occur during normal operation.



Mode	Freq (Hz)	Description
1	451	sway in y, arms in phase
2	491	sway in x, arms in phase
3	941	torsion about z
4	1088	sway in y, arms out of phase
5	2301	2nd torsion about z

FIGURE 1: Yoke model; modes 1 to 4 and base driver in y direction.

So far we have talked about shaking through the base of the structure — called "harmonic base motion" and there are many examples including Seismic excitation, a satellite attached to a launcher vehicle, or a car going over rough ground (although that has four independent "bases"). I am going to use the yoke model from last month and drive it laterally through its base, using Fig. 1 to remind us of the mode shapes and frequencies.

Alternatively, we can imagine a real test with point load introduced to the tip of a beam via a "stinger." The stinger oscillates at a set frequency, and when the system settles to steady state, we measure the peak beam response. We change the frequency and repeat the process. This is called harmonic external excitation and we again can do this virtually in FEA.

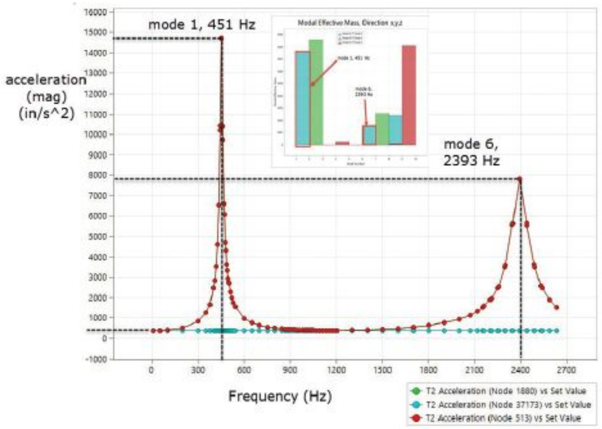


FIGURE 2: Frequency response plots of key nodes (acceleration).

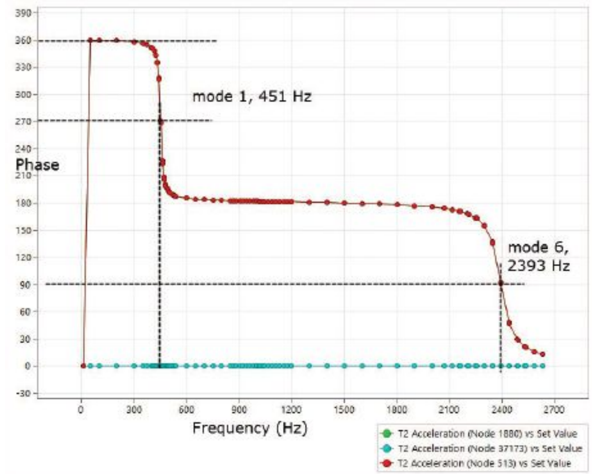


FIGURE 3: Phase response plot at key 3 nodes (acceleration).

The required input motion or loading amplitude versus frequency envelope can be a result of known loading characteristics (like the Seismic input or the satellite input). It can also be a constant amplitude sweep (often called a sine sweep), which explores the response of a structure under a 'neutral' input so as to understand the response characteristics. This latter effectively produces Transfer Functions that can be used in many applications.

This method has been used on the yoke. A unit 1g (386.4 in/s2^2) lateral acceleration is applied as a sine sweep to the base as shown in Fig. 1. The lateral (y) direction acceleration response graphs at the three key nodes are shown in Fig. 2.

Mode 6 response has been included for interest, even though it is outside our 2000Hz limit. Mode 1 and mode 6 were predicted to be the dominant players from the Modal Effective Mass (MEM) plot shown last month and repeated as an inset in Fig. 2. The MEM scale values should match exactly in base-driven Frequency Response analysis and are an important check.

Magnitude and Phase

One major complication in Frequency Response analysis is that in addition to the magnitude of the peak responses at each frequency calculation point, we also have a phase change. To give an idea of phase change, a single spring mass system has a single resonant or natural frequency. A driving harmonic oscillator is used as an input force. Below the resonant frequency the mass responds in phase with the oscillator. Above the resonant frequency the mass opposes the input force by being 180° out of phase. At the resonant point the phasing is 90°.

All this means we have to input a forcing function in terms of magnitude and phase. Equally we have to plot a response in terms of both magnitude and phase. Fig. 2 shows the phase response plot for the yoke.

The two arms of the yoke start with an acceleration response phase of 360° (this is the same as 0°, i.e. in-phase with loading). As they pass through the first mode at 451Hz, they swing through 90° to 270°. Beyond the first mode, they settle at 180° out of phase. The next significant lateral y mode is mode 6 at 2393Hz. There is a further shift and a resultant in phase response beyond this mode.

The base-driven point as node 37173 stays fixed at the 0° phase, as expected.

If we try to plot the corresponding "frozen" response shapes, this can get very tricky. Almost all post processors will plot the response shape as a magnitude. We also need a phase interpretation to fully understand the implications.

Fig. 4 shows four deformed shape plots. Fig. 4a is the first mode shape from the normal modes analysis. These should always be used to understand a response plot as they are a great guide. Fig. 4b shows the phase as a contour at 424Hz – below the resonance. It is all red (360°). This ties up with our key point FR plot in Fig. 3.

Fig. 4c shows phase contour is changing at 451Hz (mode 1) and the arms turn cyan as they change phase to 270°. The base is still red at 360°.

Fig. 4d shows a swing to green (180°) at 500 Hz, beyond mode 1. Notice the response shape is changing and is drifting towards the next dominant y direction mode shape 6 at 2393Hz.

Now to really confuse you, mode 6 is plotted in Fig. 5a. What is going on?

The deformed shape plot can only work with magnitude, and remember this is only half the story. The phase is also plotted as a contour and shows the tips of the arms are blue at the 90° phase, as expected in Fig. 3 at mode 6 (2393Hz). The bottom half is cyan (270°) and there is a null or nodal line half way up at 180°. So, the tip and base of each arm rock about a mid-point, with a correct relative phase of 180°. I have "corrected" the plot in Fig. 5b.

Frequency Response Calculation Points

Last month, I included a short sermon on the two approaches to any dynamic response analysis: direct and modal methods. To recap, a modal-based response analysis can get us answers cheaply, and help us understand the physics of the problem. It requires a normal modes analysis as the first step to generate the required mode shape vectors. The more expensive direct method can confirm the accuracy but strictly speaking doesn't need any calculation of natural frequencies and mode shapes. However, we should do a normal modes (Eigenvalue) analysis anyway to get the natural frequencies and make sure we understand the physics.

We have another consideration in Frequency Response based analysis in that the accuracy of the solution is totally dependent on ensuring we do the response calculations at every natural or resonant frequency. The biggest responses are always at the resonant frequencies. Check mode 1 peak response in Fig. 2 and see how "spiky" it is. If we miss the natural frequency, we get the wrong non-conservative answer — simple as that.

There are various ways we can get the required natural frequency values in Hz into the FEA setup. Some solvers will automatically "slave" the Modal-based Frequency response calculation points using the values from the previous Normal Modes step automatically. Some require a Frequency input table that can be generated during a separate Normal Modes analysis. Another alternative is to use the pre-processor to capture results from a Normal Modes analysis and set up a table that can be included in the subsequent Frequency Response analysis. Getting accurate values into a Direct Frequency response solution can be a challenge.

Imagine the response in Fig. 2 as a pair of "hills" with "valleys" on either side. We have discussed hitting the peaks of these hills accurately. However we must also get a good spread of points around each peak to describe the

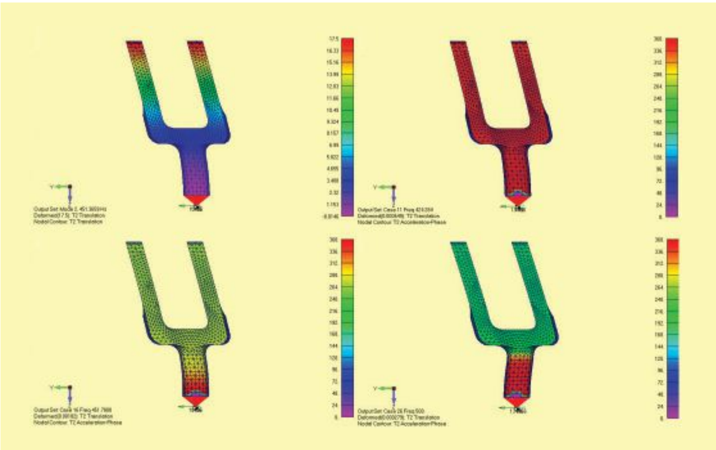


FIGURE 4: Phase change around mode 1 for acceleration response.

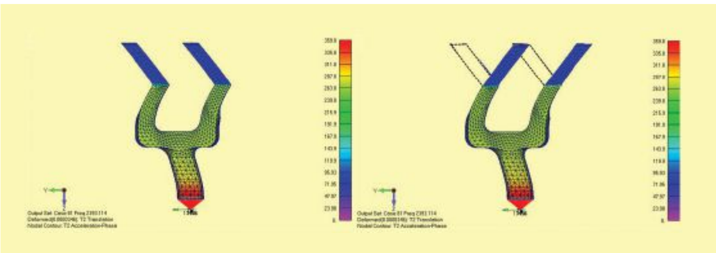


FIGURE 5: Mode 6 acceleration phase plots.

hill accurately, and we must also add points to define the valleys adequately. There are standard schemes to do this. My favorite mix is 10 to 15 points spread +/- 10% around each peak and 10 points across each valley. The first — or left hand slope — is very important and I aim for around 15 there. The typical GUI (graphical user interface) controls are complicated, but I really recommend you master them as the accuracy is entirely dependent on this distribution of calculation points.

The hard way is to type the Frequency values into the input stream manually. This approach is both tedious and error prone, so you will need to find another way around. It may take some effort and guidance to figure out what steps are required for a particular FEA solver/pre-processor combo — but stick with it.

If we really overdo the points then we end up with a more expensive solution. However — it is far better than to have too few points or inaccurate points.

Response Investigation

I recommend two data recovery runs. One run to output a few full plot states to see the "frozen" shapes (maybe one of either side and at each resonance), and a second to output full data at the set of pre-ordained key points. As ever, this can save you a vast amount of data output.

The key dynamic characteristics to investigate are similar to the Transient Analysis.

1. Check input loading.

Enforced motion analysis allows an exact comparison between input and response at the driven point. Fig. 2 shows a constant base response of 1g (386.4 in/s^2) in y. It is easy to make mistakes in acceleration definition (for example 1 in/s^2 instead of 1g). I also failed to constrain my model correctly on the first run and had a gentle rotation towards infinity at low frequency that was spotted by checking the base motion.

2. Check frequency content.

Double check that the natural frequencies you predict at calculation points are still valid. Typical errors include pulling in the wrong set of Normal Mode tables, changing the model between the normal modes run and the Frequency Response run or using fixed instead of simply supported constraints.

Damping levels totally control the magnitude of the response. It is often good practice to run a Frequency Response analysis with two or three damping levels, then to show the sensitivity of the response to damping and ensure everyone is aware there is no "right" answer.

Meeting the Challenge

Frequency Response analysis requires a lot of digging in to fully understand what the analysis can reveal about the dynamic characteristics of your structures. To set the analysis up correctly takes some effort and is very error prone. Finally, the output interpretation can be challenging.

However, once you get the hang of it, it is a very important tool in dynamic analysis investigation. I recommend simple trial models of cantilever beams, two or three DOF spring mass systems and simple plates to get a feel for what is going on. **DE**

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INFO → NAFEMS Dynamic Response Course:
NAFEMS.org/events/nafems/2015/el122

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

Ultimate Speed to Go

The Eurocom P5 Pro mobile workstation offers blazingly fast performance at a premium price.

BY DAVID COHN

We have come to expect a lot from Eurocom. Since 1989, this Canadian company has been delivering long-lifespan, upgradable notebook computers and mobile workstations, such as the Eurocom Racer 3W (deskeng.com/de/?p=101). That system proved that you could have excellent performance and good battery life without spending a fortune. This time around, the company sent us its new Eurocom P5 Pro, a system the company calls a mobile server.

Based on an Intel Xeon CPU and Intel X97 chipset, the $1,635 base configuration includes an Intel Xeon E3-1230 CPU, NVIDIA mobile GPU (graphics processing unit), 16GB of RAM and a 1TB SATA hard drive, but no preinstalled operating system.

The Eurocom P5 Pro comes housed in a sculpted charcoal gray case measuring 15.4 x 10.4 x 1.4 in. and tipping the scales at 7.75 lbs., although the large (7x3.5x1.4 in.) 230-watt power supply adds an additional 2 lbs. to the total package. In this age of thin, light portables, the P5 Pro seems beefy. If only it felt more solid.

INFO → Eurocom: Eurocom.com

Eurocom P5 Pro

- **Price:** $4,489 as tested ($1,635 base price)
- **Size:** 15.4 x 10.4 x 1.4 in. (W x D x H) notebook
- **Weight:** 7.75 lbs. as tested, plus 2 lb. power supply
- **CPU:** 4.0GHz Intel Core i7-4790K quad-core w/ 8MB cache
- **Memory:** 32GB 1866MHz DDR3 SDRAM (32GB max)
- **Graphics:** NVIDIA Quadro K5100M w/ 8GB memory and 1536 CUDA cores
- **LCD:** 15.6-in. diagonal (1920 x 1080), non-glare, IPS
- **Hard Disk:** 256GB M.2 Plextor SSD and 1TB 7200rpm Hitachi HD
- **Optical:** None
- **Audio:** Line-in, S/PDIF (digital), microphone, headphone, line-in, built-in microphone and speakers
- **Network:** Integrated Gigabit Ethernet (10/100/1000 NIC) with RJ-45 port, 802.11b/g/n wireless LAN and Bluetooth 4.0
- **Modem:** None
- **Other:** Four USB 3.0 (one powered), one eSATA/USB 3.0 combo port, 6-in-1 card reader, HDMI-out, two DisplayPorts, 2 megapixel webcam
- **Keyboard:** Integrated 102-key keyboard with numeric keypad
- **Pointing device:** Integrated two-button touchpad and fingerprint reader




1. The Eurocom P5 Pro delivered the fastest performance we've ever recorded for a mobile workstation.

2. Removing the bottom panel reveals space for multiple hard drives and exposes ample cooling ducts and fans that let the system run cool and quiet at all times.

3. The lid on the Eurocom P5 Pro flexes noticeably when adjusting its tilt.

4. The 102-key backlit keyboard has an excellent feel.

Images courtesy of Eurocom.

Mobile Workstations Compared

		Eurocom P5 Pro Mobile 4.0GHz Intel Core i7-4790K quad-core CPU, NVIDIA Quadro K5100M, 32GB RAM	MSI WS60 2.5GHz Intel Core i7-4710HQ quad-core CPU, NVIDIA Quadro K2100M, 16GB RAM	Dell Precision M3800 2.2GHz Intel Core i7-4702HQ quad-core CPU, NVIDIA Quadro K1100M, 16GB RAM	MSI GT70 20LWS 2.4GHz Intel Core i7-4700MQ quad-core CPU, NVIDIA Quadro K4100M, 16GB RAM	Eurocom Racer 3W 2.4GHz Intel Core i7-4700MQ quad-core CPU, NVIDIA Quadro K1100M, 16GB RAM	BOXX GOBOXX G2720 3.6GHz Intel Core i7-3820 quad-core CPU, NVIDIA Quadro K5000M, 16GB RAM
Price as tested		$4,372	$2,600	$2,887	$3,200	$2,172	$5,895
Date tested		2/4/15	1/17/15	3/13/14	11/25/13	11/10/13	5/28/13
Operating System		Windows 8.1	Windows 7	Windows 7	Windows 7	Windows 7	Windows 7
SPECviewperf 12	higher						
catia-04		64.64	21.26	14.74	n/a	n/a	n/a
creo-01		48.70	19.98	13.37	n/a	n/a	n/a
energy-01		2.61	0.32	0.28	n/a	n/a	n/a
maya-04		48.84	17.90	12.79	n/a	n/a	n/a
medical-01		23.93	5.71	3.72	n/a	n/a	n/a
showcase-01		27.86	10.63	8.50	n/a	n/a	n/a
snx-02		58.41	22.05	14.74	n/a	n/a	n/a
sw-03		97.38	32.32	19.43	n/a	n/a	n/a
SPECviewperf 11	higher						
catia-03		80.24	45.66	33.56	72.47	28.97	73.23
ensight-04		86.39	24.09	17.50	50.62	17.38	61.24
lightwave-01		94.51	64.37	58.84	64.39	31.53	78.03
maya-03		178.55	77.78	61.83	112.33	51.20	111.58
pro-5		22.67	18.26	15.37	18.38	9.43	16.06
sw-02		81.17	47.80	39.48	55.00	24.95	63.26
tcvis-02		70.60	36.95	28.69	60.63	27.70	60.91
snx-01		89.35	31.85	23.76	59.76	23.17	63.57
SPECapc SolidWorks 2013	higher						
Graphics Composite		9.00	3.08	2.41	5.27	3.63	2.72
RealView Graphics Composite		10.61	3.23	2.71	6.27	3.97	2.93
Shadows Composite		10.65	3.23	2.34	6.26	3.95	2.93
Ambient Occlusion Composite		21.36	3.51	2.20	13.00	5.35	6.09
Shaded Mode Com-posite		8.88	2.96	2.31	5.78	3.83	2.66
Shaded with Edges Mode Composite		9.12	3.21	2.51	4.80	3.44	2.78
RealView Disabled Composite		4.66	2.55	2.40	2.62	2.55	2.02
CPU Composite		4.25	3.06	2.41	3.74	3.99	3.61
Autodesk Render Test	lower						
Time	seconds	56.88	63.60	71.42	60.33	55.83	79.20

Numbers in blue indicate best recorded results. Numbers in red indicate worst recorded results.

Raising the lid reveals a beautiful 15.6-in. backlit IPS (in-plane switching) display with a non-glare surface and 700:1 contrast ratio. Unfortunately, the lid is quite flexible. Although we were somewhat alarmed at how much the screen bent whenever we adjusted its tilt, this did not appear to cause any actual issues. In addition to the panel in our evaluation unit, Eurocom also offers 4K (3840 x 2160) IPS displays from Samsung and Sharp that add $182 and $391 to the base price, respectively. Eurocom also sells a larger version of the P5 Pro with a 17.3-in. display, but only offers 1080p resolution on those models.

The backlit 102-key keyboard includes a separate numeric keypad that had a nice, crisp feel. A 4.25x2.5-in. touchpad with a pair of buttons and a built-in fingerprint reader is centered below the spacebar, which positions it slightly to the left of the center of the case. A 2-megapixel webcam, centered above the LED, is flanked by a microphone. A pair of 2 watt Onkyo speakers for the Sound Blaster X-Fi sound system are located below a perforated band that extends across the top of the keyboard.

Ample Options

The right side of the case offers a USB 3.0 port, an S/PDIF port, audio ports for headphone, microphone and line-in and a lock slot. The left side provides an RJ-45 network port, three more USB 3.0 ports (including one that is powered), a 6-in-1 card reader, and an eSATA/USB 3.0 combo port. The rear panel hosts a pair of DisplayPorts, an HDMI port and the connection for the external power supply. As is becoming more common, the Eurocom P5 Pro does not include an optical drive bay. For customers who still need this capability, Eurocom offers external USB DVD-RW and Blu-ray drives.

Our evaluation unit came equipped with an Intel Core i7-4790K, a quad-core CPU with 8MB cache, a maximum turbo frequency of 4.4GHz and a thermal design power (TDP) rating of 88 watts, adding $128 to the base price. That CPU also includes Intel HD Graphics 4600. Other CPU options include several Xeon and Core i5 CPUs. Eurocom also equipped our system with an NVIDIA Quadro K5100M mobile GPU, with 1536 CUDA cores and 8GB of dedicated GDDR5 memory, increasing the system cost by an additional $1,955. For those looking to save a bit, Eurocom also offers the NVIDIA Quadro K3100M as well as several other NVIDIA GTX and Radeon boards.

While 16GB of system memory comes standard, you have a choice of configurations. You can also opt for 2133MHz RAM, or increase the total system memory to 24GB or 32GB. Our evaluation unit came equipped with 32GB of 1866MHz memory, installed as four 8GB SODIMMs, which added $382 to the price.

There are also many storage options. While the base configuration includes a 1TB 7200rpm Hitachi Travelstar SATA hard drive, there are actually two 2.5-in. drive bays and Eurocom offers other drives, including solid state drives (SSDs) ranging from 120GB to 1TB and standard drives up to 2TB capacity, with RAID array capabilities. But the P5 Pro also has two internal slots for SSD M.2 card-based drives and offers these in capacities ranging from 128 to 512GB. Our evaluation unit came with a 256GB Plextor M.2 SSD as the primary drive, which added another $272 to the system cost.

An 802.1b/g/n WLAN and Bluetooth 4.0 combo card is included in the base configuration, and Eurocom also offers higher-end network cards. An 8-cell lithium-ion battery and 230 watt auto-switching worldwide power supply are standard.

The last Eurocom mobile workstation we reviewed lasted 3.75 hours. The battery life of the P5 Pro was less robust, powering the system for two hours and 10 minutes. Throughout our tests, the P5 Pro ran cool and remained quiet, averaging 33dB at rest (compared to 29dB ambient background noise) and barely rising above 43dB under heavy compute loads.

Record-breaking Performance

Thanks to its fast CPU, abundance of memory and high-end graphics card, the Eurocom P5 Pro turned in the best performance we have ever recorded for a mobile workstation. On the SPECviewperf test, which focuses solely on graphics performance, the P5 Pro beat all competitors — often by a wide margin — even surpassing the performance of some entry-level and midrange workstations.

Similarly, on the SPECapc SolidWorks benchmark, which is more of a real-world test, the Eurocom P5 Pro beat out every other mobile system that we have tested to date and again surpassed many full-fledged workstations.

We also ran the new SPECwpc benchmark and here again, the Eurocom P5 Pro beat the competition on nearly every aspect of this demanding test.

But the Eurocom P5 Pro would have set us back $4,489 as configured, including the Microsoft Windows 8.1 Professional 64-bit operating system that came preinstalled on our evaluation unit. Eurocom also offers Windows 7 and 8 as well as Microsoft Windows Server. The price also includes a one-year warranty with return to depot service with the option to extend the warranty to two or three years for $159 or $341, respectively.

Eurocom says the P5 Pro is the world's first Xeon-based 15.6-in. lightweight mobile server. It's certainly fast. We think it makes a great mobile CAD workstation, but its price will likely relegate it to users who need the ultimate performance in a mobile form factor. DE

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Impressive New GPUs

The latest cards in NVIDIA's Quadro K-series outperform their predecessors with up to twice the application performance.

BY DAVID COHN

It's been several years since we last looked at workstation-class graphics accelerators from NVIDIA (deskeng.com/de/?p=373). At that time, we reviewed two impressive (and expensive) graphics boards, the high-end Quadro K5000 — the first board based on the company's Kepler-based GPU (graphics processing unit) — and the ultra-high-end Quadro 6000 board.

This past August, at the SIGGRAPH conference in Vancouver, Canada, NVIDIA unveiled its next generation of Quadro GPUs with the introduction of the K5200, K4200, K2200, K620 and K420. The new boards began shipping in the fall of 2014. Offering up to twice the application performance and data-handling capability of the previous generation, the Kepler-based boards let users interact with their designs locally on a workstation or remotely with a Quadro-based workstation from essentially any device, including PCs, Macs or tablets.

We subjected three of the new Quadro boards — the K5200, K4200 and K2200 — to a battery of tests. We also installed several of the previous generation GPUs in the same BOXX APEXX 2 workstation (deskeng.com/de/?p=23627) so we could compare the new generation to the old, seeing for ourselves whether NVIDIA's claims of performance improvement held up.

NVIDIA Quadro K2200

The NVIDIA Quadro K2200 is the company's new mid-range graphics solution, replacing the K2000. This GPU delivers exceptional power-efficient 3D application performance. Yet with a suggested retail price (MSRP) of $599 and a selling price around $429, the K2200 delivers a lot of bang for the buck. The Quadro K2200 features 640 CUDA (compute unified device architecture) parallel processing cores (compared to 384 in the K2000) and includes 4GB of GDDR5 memory, double that of its predecessor. Its 80GB/second memory bandwidth is also considerably greater than the K2000. In addition, an all-new display engine drives up to four displays with DisplayPort 1.2 support for ultra-high resolutions up to 3,840x2,160 at 60Hz with 30-bit color.

The K designation in this board's name is a bit misleading. The K2200 (as well as the entry-level K620 board) is actually based on NVIDIA's next-generation Maxwell GPU architecture — as is the recently announced NVIDIA M6000 board. The reason for the change is really one of timing, with the company having to base its release cycle on both its own internal development and releases from Intel and major workstation vendors.

The mid-range NVIDIA Quadro K2200.

NVIDIA claims floating point performance of 1.3 TFLOPs single precision and 40 GFLOPs double precision. The K2200 has a 128-bit memory interface.

Like its predecessor, the Quadro K2200 provides a dual link DVI connector as well as two DisplayPort 1.2 connectors, and supports up to three monitors using its available connectors or four via a DisplayPort hub. The board uses a single PCIe x16 slot and with a maximum power consumption of 60 watts, the K2200 does not require any additional power connections.

NVIDIA Quadro K4200

The high-end NVIDIA Quadro K4200 is the next step up in price and performance. Because it uses the same chip found in the K5000, it offers a substantial improvement over the previous generation K4000. Yet, with an MSRP of $1,249 and an average purchase price of $789, it is a bit more expensive than its predecessor.

The Quadro K4200 provides 1,344 CUDA cores (compared to 768 in the K4000) and includes 4GB of on-board GDDR5 memory (compared to 3GB in the K4000). Its 256-bit memory interface is also wider than the 192-bit interface in the older board and its 173GB/sec bandwidth is also greater than the 134GB/sec of the K4000.

Floating point performance is nearly double that of its predecessor: 2.1 TFLOPs single precision (compared to 1.2 TFLOPs for the K4000) and 90 GFLOPs double precision.

Again, like its predecessor, the Quadro K4200 provides a dual link DVI connector as well as two DisplayPort 1.2 connectors and supports resolutions up to 3,840x2,160 at 60Hz. You can connect up to three monitors using the on-board ports, or four via a DisplayPort hub. The K4200 uses a single PCIe x16 slot, but its maximum power consumption of 105 watts requires an additional 6-pin auxiliary power connector. The K4200 also supports an optional 3-pin stereo connector on a separate

NVIDIA 2015	NVIDIA K5200 NEW!	NVIDIA K5000	NVIDIA K4200 NEW!	NVIDIA K4000	NVIDIA K2200 NEW!
Manufacturer's Price	$2,499	$2,249	$1,249	$1,199	$599
Average Street Price	$1,899	$1,800	$789	$699	$429
SPECviewperf 11.0 (@ 1920x1200)					
catia-03	130.69	87.52	111.61	54.08	65.18
ensight-04	140.72	77.51	89.32	46.98	52.65
lightwave-01	107.51	106.89	106.52	107.12	107.66
maya-03	239.42	190.23	200.50	144.66	171.09
proe-05	29.06	28.85	28.81	29.14	29.29
SW-02	96.34	90.63	92.90	79.73	86.78
tcvis-02	105.72	81.52	90.64	56.54	57.22
snx-01	131.97	81.30	92.63	53.13	58.26
SPECviewperf 12.0 (@ 1920x1200)					
catia-04	104.25	65.58	72.14	39.48	47.75
creo-01	79.58	52.36	57.97	36.07	42.53
energy-01	3.76	2.93	3.02	0.65	3.26
maya-04	76.88	53.85	58.86	33.62	38.66
medical-01	31.13	21.73	22.70	12.65	15.14
showcase-01	50.57	35.85	38.64	22.94	22.63
snx-02	83.74	57.87	65.15	37.50	34.29
sw-03	134.35	105.42	108.77	75.56	90.98
SPECIFICATIONS					
Bus architecture	PCI Express X16	PCI Express X16	PCI Express X16	PCI Express X16	PCI Express X16
Extra power required	Yes	Yes	Yes	Yes	No
Form factor	4.376 x 10.5 in.	4.38 x 10.5 in.	4.376 x 9.5 in.	4.376 x 9.5 in.	4.376 x 7.97 in.
Slots used	2	2	1	1	1
Max power (watts)	150W	122W	108W	80W	60W
PCIe version	3.0	2.0	2.0	2.0	2.0
Length	full-length	full-length	3/4-length	3/4-length	1/2-length
Processors	2304	1536	1344	768	640
Memory configuration	8GB (GDDR5)	4GB (GDDR5)	4GB (GDDR5)	3GB (GDDR5)	4GB (GDDR5)
Memory interface	256-bit	256-bit	256-bit	192-bit	128-bit
Memory bandwidth	192 GB/sec	173 GB/sec	173 GB/sec	134 GB/sec	80 GB/sec
Number of DVI Dual Link Outputs	2	1	1	1	1
Number of Display Port Outputs	2	2	2	2	2
Stereo 3D Connector (3-pin)	Yes (2)	Yes (2)	Yes (2)	Yes (2)	No
SDI-enabled	Yes	Yes	Yes	Yes	No
Framelock/Genlock	Yes (1)	Yes (1)	Yes (1)	No	No
SLI	Yes	Yes	Yes	No	No
OpenGL version	4.5	4.3	4.5	4.4	4.5
DirectX/Shader model	12/5.0	11/5.0	12/5.0	11/5.0	12/5.0
Maximum Resolution Support (@ 60Hz)	4096 x 2160 (3) 2560 x 1600 (4) 1920 x 1200 (5)	3840 x 2160 (3) 2560 x 1600 (4) 1920 x 1200 (5)	3840 x 2160 (3) 2560 x 1600 (4) 1920 x 1200 (5)	3840 x 2160 (3) 2560 x 1600 (4) 1920 x 1200 (5)	3840 x 2160 (3) 2560 x 1600 (4) 1920 x 1200 (5)

Notes:
1. Requires optional Quadro G-Sync or Quadro Sync card
2. With included expansion bracket
3. Resolution with DisplayPort 1.2
4. Resolution with DVI-I dual link
5. Resolution with DVI-I single link

The high-end NVIDIA Quadro K4200.

bracket, and the board is compatible with NVIDIA's Quadro Sync so you can combine several boards to create a video wall.

NVIDIA Quadro K5200

With an MSRP of $2,499 and an average purchase price of $1,699, the new Quadro K5200 is quite an investment. It uses the same chip as last year's ultra-high-end K6000. As a result, the K5200 features 2,304 CUDA parallel processing cores (compared to 1,536 in the K5000) and 8GB of GDDR5 memory, double that of its predecessor. And like the K5000, the K5200 uses ECC memory, offering protection of data in memory.

The new board features the same 256-bit memory interface as its predecessor, but increases the memory bandwidth from 173GB/sec to 192GB/sec for a significant performance improvement. NVIDIA claims floating point performance of 3.0 TFLOPs single precision (compared to 2.2 TFLOPs for the K5000) and 130 GFLOPs double precision.

The Quadro K5200 supports a maximum resolution of 4,096x2,160 at 60Hz. Video outputs include two DVI connectors as well as a pair of DisplayPort 1.2 connectors, so you can connect up to four monitors to the card. You can use NVIDIA's Mosaic technology to create a video wall of up to 16 monitors. An option is a 3-pin stereo connector on a separate bracket as well as framelock/genlock using an optional Quadro Sync card.

The NVIDIA Quadro K5200 consumes two expansion slots, and requires a 6-pin auxiliary power connection to satisfy its 150 watt maximum power consumption.

Benchmarking the Boards

We tested all three new NVIDIA Quadro GPUs, as well as two previous generation boards in a BOXX Technologies APEXX 2 workstation with a 4GHz Intel Core i7-4790K quad core CPU (over-clocked to 4.5GHz) and 16GB of 1,600MHz memory. We performed all tests running the 64-bit version of Windows 7 and using the same version 347.88 NVIDIA video driver on versions 11 and 12 of the SPEC Viewperf video benchmark.

Based on our results, each of the new generation Quadro GPUs clearly outperformed its predecessor. In fact, each new board equaled or exceeded the performance of the next higher level of the previous generation. For example, the performance of the NVIDIA Quadro K2200 equaled or exceeded the benchmark results of the K4000, and the K4200 beat the older K5000. Essentially, a new mid-range board should yield performance equal or better than what you would obtain from a one-year-old high-end board for a lot less money.

Of course, like all other NVIDIA Quadro boards, the Quadro K5200, K4200 and K2200 are fully certified with most CAD and DCC applications and all of the boards in the Quadro line use the same unified video driver.

The latest NVIDIA Quadro GPUs deliver an unprecedented level of performance. The last time we looked at graphics boards, we wondered when the Kepler GPU technology would become available in the company's midrange boards. With the introduction of the Maxwell technology in the K2200 and the recently released M6000, we will now wait and see when that even newer technology finds its way into the rest of the NVIDIA Quadro line. **DE**

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INFO ➜ BOXX Technologies: BOXXTech.com

➜ **NVIDIA:** NVIDIA.com

Sensor Data Meets Models

NI's InsightCM Enterprise is designed as a real-time monitoring system for rotating equipment. *Image courtesy of National Instruments.*

Real-time monitoring could change the nature of digital prototypes.

BY KENNETH WONG

The Big Brother in Orwell's dystopia "1984" makes us associate monitoring with state-sponsored surveillance and totalitarianism, but today's widespread availability of sensors and electronics is ushering in a different kind of monitoring, one that aims to improve workplace safety and industrial productivity.

At NIWeek 2014, National Instruments (NI) introduced a new product, NI InsightCM Enterprise. The company describes it as "a software solution with tightly integrated hardware options for monitoring critical and ancillary rotating equipment." Siemens PLM Software, another company with strong links to manufacturing, offers a similar tool, dubbed Dimensional Planning & Validation (DPV). It's part of the company's Tecnomatix process planning and simulation suite.

Many large-scale manufacturers possess and maintain 3D models of their production facility and assets. A successful marriage of real-time feedback and digital models could catapult product and process engineering to new heights.

Eyes and Ears of the Plant

NI InsightCM Enterprise is designed to record industrial equipment conditions — such as rotation speeds, acceleration and failures — for trend analysis. The data-visualization environment lets you display the incidents from different devices and machines taken at specific time intervals in waveform, waterfall, full spectrum and other standard data-plotting formats. The method is expected to let facility managers not only see trends and patterns among the equipment but also to predict impending catastrophes and take preventive action.

At LiveWorx 2015, PTC demonstrated the ability to stream sensor-captured real-time data to a ThingWorx interface. *Image courtesy of PTC.*

Siemens describes DPV as "a closed-loop system for the real-time collection of measured quality data, which automates data collection, organization and reporting." With such data, facility operators have a better chance of reducing scrap, rework and preventing losses.

"Real-time collection, analysis and reporting of measured quality data can help manufacturers to reduce their overall cost of quality," writes Siemens' press office. "Software tools like Tecnomatix DPV can be used to identify and resolve quality issues before they adversely affect product quality, operational productivity and warranty costs." The company's offering benefits from integration with its CAD software, which enables data and geometry to be displayed in the same environment.

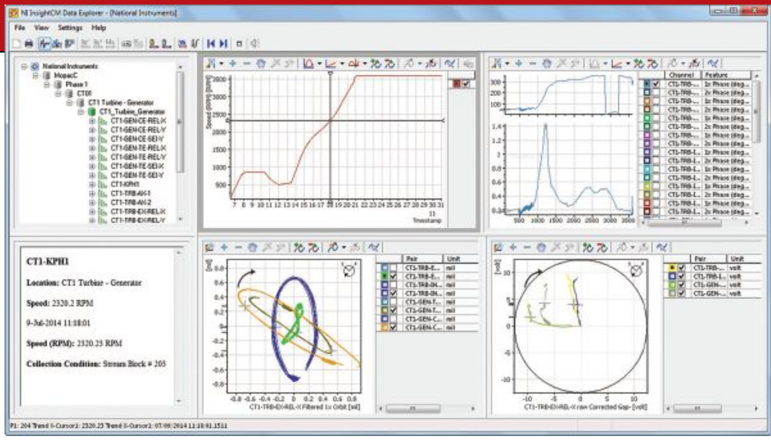
Digital Avatars

In the last few years, CAD and PLM (product lifecycle management) vendor PTC has refashioned itself as an IoT (Internet of Things) product development company. In late 2013, the company acquired ThingWorx, a platform for building and running IoT applications. In late 2014, it also bought Axeda, which offers solutions to connect sensors to the cloud. The technology stack PTC received from these purchases has since become the cornerstone of the company's IoT offerings.

"Very little about what happens in the physical world ever makes it back to the digital world. It's been this way for decades … If you ask questions about your product like, 'I wonder how it's used' or 'I wonder how it's working,' there's just silence," said Jim Heppelmann, president and CEO of PTC, at the PTC LiveWorx 2015 conference in May.

That silence is about to be broken. The company has begun working to stream sensor-acquired data to the ThingWorx interface. A live demonstration took place on stage at LiveWorx. Mike Campbell, PTC's executive vice president of CAD products, demonstrated what he called "the concept of a virtual twin, a product avatar," using a mountain bike from Santa Cruz Bicycles. The sensors mounted on the bike were measuring the "wheel speed, cadence of the paddles, compression on different suspension mechanism and steering angle," he says.

The real-time data from the sensors was fed into a ThingWorx dashboard for display, overlaid on the CAD model of the bicycle (Santa Cruz Bicycles uses PTC software for product design). The movements of the physical bike — its wheel spins, handlebar turns and frame tilts — were faithfully replicated by the 3D CAD model in the software. Furthermore, the demonstration showed sensor data could be projected into a live video feed of the bike in motion, in an iPad augmented reality app.



The Data Explorer in NI's InsightCM Enterprise displays collected sensor data.
Image courtesy of National Instruments.

Finding Insights in Big Data

The desire to monitor and track manufacturing assets may force owners and operators to confront Big Data issues. "As intelligent industrial systems scale in number and complexity, the amount of data coming off of each sensor increases as well," says Kamalina Srikant, senior project manager at NI.

Finding meaningful patterns and insights in the collected data is next to impossible with the naked eye. It requires algorithm-driven operations. "NI's goal is to continue evolving and adding to the analytics that we have within the platform to provide more sophisticated and meaningful insights to users. Additionally, users have the option of integrating with third-party tools or tools like the Watchdog Agent (an NI tool on the LabVIEW Tools Network) to perform advanced predictive analytics or prognostics. With the emergence of the IoT, new technologies like smart sensors, the cloud, mobile devices and embedded intelligence are growing more prolific, meaning dependable data management, systems management and data analytics tools are more important than ever," says Srikant.

Combining Data with Models

Also on the rise is the interest to create virtual counterparts of manufacturing facilities, driven by software that lets you create detailed 3D replicas of factories and plants as well as the content within. The use of photogrammetry and laser scanning makes it easy to create such models. Owners and operators often use the digital factory and plant replicas — usually constructed with CAD geometry, point cloud, or a mix of the two — to experiment with different manufacturing processes, identify possible clashes and collisions, or to verify ergonomic feasibility in the workflow.

The incorporation of real-time sensor-captured data into virtual factories and plants could elevate the type of process simulation possible to new heights. Displaying equipment health data that usually exists as pie charts, bar graphs, and spreadsheets in an immersive 3D environment could yield new insights into manufacturing processes. For now, however, the handshake between 3D models and real-time sensor data is not straightforward or easy. 3D models were initially developed to record geometric dimensions, not intended as the hub for real-time equipment data. However, the IoT movement and the resulting desire to harness the power of data in product development may change that. **DE**

Kenneth Wong *is* Desktop Engineering's *resident blogger and senior editor. E-mail him at kennethwong@deskeng.com or share your thoughts on this article at deskeng.com/facebook*

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→ **National Instruments:** NI.com

→ **PTC:** PTC.com

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

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Introductory Instrumentation

Some companies with vested interests in the test and measurement sector are hoping to expand the art of sensor and signal processing through introductory hardware kits, designed specifically for education and training. Keysight's ME3200 courseware — a complete set of instruments, instructor's guide, training kits and lab worksheets — targets first or second year undergraduates. The company says the program is "for first-year students to gain exposure on how to operate basic instruments such as power supplies, functions generators, oscilloscopes, and multimeters."

NI's Educational Laboratory Virtual Instrumentation Suite — abbreviated as ELVIS — is described as a "modular platform delivers a hands-on lab experience for engineering curriculum." The hardware included is augmented with textbooks, software and add-on boards. The single device offers functions found in oscilloscopes, digital multimeters, function generators, dynamic signal analyzers and more. It may be coupled with add-on boards from Emona, Freescale and Quanser to teach additional courses.

Makerspaces Carve Out a Niche with Pros

These organizations provide technology, advice and collaboration opportunities for startups and corporations alike.

BY BRIAN ALBRIGHT

Square, the mobile payment company that first gained notice with those little credit card swipe accessories for smartphones, has come a long way since founders Jack Dorsey and Jim McKelvey walked into TechShop, a California-based makerspace. Leveraging the tools and community members in the facility, they were able to quickly develop a prototype of their first credit card reader. The company now has a nearly $6 billion market valuation.

While makerspaces have been a boon for students, hobbyists and artists, they've also become an invaluable resource for professional engineers and designers. Whether they were designed that way from the start or have evolved and expanded their services, makerspaces are acting as hands-on manufacturing incubators for startups of every stripe. They also offer a place for engineers to add to their training, tinker with new ideas outside of their day jobs and even provide facilities for large, established companies to brainstorm and prototype.

Square is probably the most well-known example, but there are plenty of others. DODOcase, another TechShop alum, sold its first $1 million in product 90 days after founder Patrick Buckley walked through the door. "Our best bet is about 2,000 jobs have been created through our facilities, along with $2 billion in annual sales and $200 million in salaries created from our members developing and launching companies," says TechShop CEO Mark Hatch. The organization now has eight locations across the country, with more in the works.

At the Columbus Idea Foundry in Columbus, OH, a host of professionals have called the makerspace home, including local 3D printer company IC3D, and 3D scanner maker Knockout Concepts. Having just moved into a 65,000 sq. ft. warehouse space in 2014, the Idea Foundry offers a traditional tool-laden makerspace on its ground floor. It is in the process of raising funds to add more professional services upstairs, including space for graphic artists, Web developers and trademark attorneys.

"The idea is that you use the first floor to build your widget, and then go upstairs and get the professional help you need on the business and legal side to launch a company," says Alex Bandar, founder. "It's really a one-stop-shop, creative ecosystem."

These spaces can help startups create prototypes via 3D printing and other fabrication methods. *Image courtesy of Joseph Schell.*

Artisan's Asylum in Somerville, MA, was originally launched by a group of engineers who wanted to have access to the same fabrication equipment in their personal lives that they did at work, says Derek Seabury, president and executive director. As the facility grew, so did the appeal for professionals.

"The value proposition emerged for a cabinet maker or a contractor, or for someone doing prototyping," Seabury says. The space's most well known startup is probably the 3Doodler, a 3D printing pen that went on to a successful Kickstarter-funded launch.

The appeal is clear: Makerspaces offer, for a nominal membership fee, access to equipment and expertise that would require thousands (or hundreds of thousands) of dollars to obtain for traditional product development. Inventors can launch a product with a relatively small amount of disposable income rather than taking out a large loan or raising capital.

Expanding Professional Services

Makerspaces have made their facilities more hospitable to professional engineers, even as they continue to offer space for amateurs and hobbyists. Most, for example, even offer institutional memberships for companies that want their employees to have access to these less formal workspaces.

"The original appeal was around some newer technologies," Seabury says. "Not every company was able to invest in a 3D printer or a laser cutter, so this gave them a way to access the equipment without the big upfront cost."

Sometimes these services evolve organically. At TechShop's original Menlo Park location, members asked to rent some empty office space that happened to be vacant; now every TechShop offers office space for engineers and startups.

Makerspaces also provide relatively unfettered access to pro-level software tools (see Supplying Software on page 46). TechShop, for instance, actively pursued a relationship with Autodesk to provide software on their in-house workstations. "Some of their executives came for a tour, and they got excited about the concept," Hatch says. "Within a few weeks [TechShop founder] Jim Newton and I were sitting down with their CEO and we struck a deal right there."

Because many of the professional members are doing work after hours, TechShop recently opened its locations 24/7. "That was in direct response to our heavy use members, which tend to be startups and engineering firms," Hatch says. "There was no real reason we had to kick them out at midnight. If someone needs to use the computer in the middle of the night, they should be able to do it."

While the core appeal of makerspaces to engineers is access to tools, most also provide other types of services that can be helpful to startups and inventors. TechShop has developed a relationship with the Patent and Trademark Office that has helped put members in touch with an actual patent examiner to determine if an idea is patentable. Regular meetups also provide instruction on website design and financial services, among others.

"We've become something of a hotbed for service companies that are interested in taking care of startups, and we're a conduit for enabling that," Hatch says.

In some instances, makerspace staff can be hired for light engineering or manufacturing services, and the facilities can be used for small production runs. New companies can also get help from other members in different specialties to help with logo designs, marketing or manufacturing. In many cases, members wind up hiring each other.

"The community itself has become quite a gathering of experts," says Seabury at Artisan's Asylum. "You can network and get advice, and it's a different experience than you would have in an incubator. It's a more collaborative space. Part of our membership charter is that you will share your skills and describe processes with other members, and accept feedback gracefully. We've had folks come in who spent time in a traditional incubator and told us that they got more answers in two weeks here than in two years at an incubator."

At Artisan's Asylum, the makers of the 3Doodler received unexpected help from an artist operating in the building. "Not only were they able to find an electrical engineer to help debut some issues with the power driver, but we had a wire artists here that showed them they types of amazing things she could achieve with the product," Seabury says.

Makerspaces, such as TechShop, give designers and engineers access to professional-grade machines that would be expensive to purchase otherwise.

The company was able to use the wire frame art pieces created with the pen to show investors what it was capable of doing.

Once a company has reached the tipping point where they need to move thousands instead of hundreds of units, the makerspace can help find that manufacturing capacity. Other members from different industries may also provide help with identifying contract manufacturing facilities.

By fostering engineers, makerspaces have been able to have an impact beyond their own four walls. At the Idea Foundry, Bandar has worked with the city of Columbus to turn the makerspace into an economic development engine. The Foundry sits in an economically fragile area near downtown, and is actively working to create jobs and development opportunities that can benefit the surrounding community while allowing the city to plant a flag as a destination for maker culture. Some of the companies that have spun out of the Foundry have followed suit.

Big Companies, Small Spaces

Large existing companies have also discovered that makerspaces can serve as outsourced skunkworks or prototyping facilities. While it seems odd that a multi-national company would join a co-op style studio, many have found that it is more efficient to let designers knock out models and prototypes at a makerspace than trying to carve out time in their own production facilities.

"Xerox uses our local facility's waterjet cutter because they don't have one and it's faster to come down and cut something out here," TechShop's Hatch says. "Mercedes uses our Palo Alto facility to build displays for their software research group. We have corporate members with a wide array of large and small companies that use us as a support mechanism for their own product development."

Supplying Software

To best serve their members, makerspaces need access to professional-grade tools, equipment and software — much of it coming through the largest of vendors and suppliers.

"It's an upside down business model, in that a makerspace is a very capital intensive operation, and our market is inventors, artists and engineers who don't have deep pockets," says Alex Bandar, founder of the Columbus Idea Foundry, a makerspace in Columbus, OH. "We rely on vendors to help us out with discounts, payment programs or donations."

Major design software companies have been generous supporters of these facilities. Autodesk, for one, is a frequent sponsor of makerspaces, and you can find its software (AutoCAD, Alias, Inventor, etc.) loaded on workstations at the Columbus Idea Foundry, TechShop and others.

By making their products available in makerspaces, software vendors are able to tap into a nascent market of up-and-coming inventors, engineers and entrepreneurs who (they hope) will purchase new licenses once they outgrow the makerspace and expand into their own offices and facilities.

The software vendors also gain other benefits from working with makerspaces. According to Paul Kassebaum, product marketing manager at MathWorks and a board member at Artisan's Asylum in Boston, MathWorks became involved as a sponsor of that makerspace after a visit by the company's vice president of Marketing.

"We were their first corporate sponsors, and we provided them with funds and we received memberships as HR benefits from our own employees," Kassebaum says. "MathWorks has for a long time tried to do good in society by giving funds to institutions that focus on education and STEM, both outreach-based programs and more formal education programs. We also try to engage the public in science. Makerspaces hit the middle point on those two extremes."

Artisan's Asylum members can now access MathWorks' software and training, while MathWorks' employees also gain a valuable benefit.

"Having those tools available lets our members work at a higher level," says Derek Seabury, president and executive director. "We have this fantastic relationship now where we can make the facility available to MathWorks employees, and our members have great software tools to work with."

In addition to getting MathWorks' tools into the hands of new users, the corporate membership has also paid dividends for the MathWorks team. Kassebaum, for example, has taken classes at the Asylum to expand his own training. "Many pro engineers come in to learn new skills," he says. "I met a computer programmer in a woodworking class, for example. I'm a theoretical physicist, and she was a veteran software person, and we were both there to get satisfaction out of building something with our hands."

Ford, in fact, brought TechShop to Detroit specifically for that reason. "They brought us so that engineers who weren't directly involved in R&D could build prototypes," Hatch says.

In Columbus, local Idea Foundry sponsor VSP Global (which operates a high-tech optical lab in the city), uses the facility for "intrapreneurship." "They can send their employees offsite to work in a judgment-free zone, rather than having to build their own innovation center," Bandar says. "These larger companies want their engineers to be able to keep an ear to the ground in a place where the other members are up on the latest trends."

Those relationships also provide access to experienced engineers for the startups and hobbyists in the space. "You have this multi-layered environment of very large corporations and new startups operating under the same roof," Bandar says. "It's a huge value-add for them to go over to a guy from a big company and talk to them about an idea. It's rare to see that type of intermingling outside of a makerspace."

All of this begs the question: Do these startups risk their IP (intellectual property) in an environment where prototypes are quite literally being passed around a room full of other inventors and startups? So far, the answer seems to be no.

"You have all this amazing work going on in every room, and it's not generally felt that being secretive or first to market is as important as excellence," Seabury says. "I guess we could be ripe for corporate espionage, but I think that the ability to execute on the plan is more important than the plan these days."

What has mitigated that type of competitive elbowing seems to be that most of the members are working with established technology, and often developing products in different markets. "Some of our members might go head-to-head for some business opportunities, but the space to achieve is really vast," Seabury says. "We have four different people right now working on 3D printers, and none of them feel the need to throw a sheet over things at the end of the night. They aren't threatened by other inspired, passionate people. The bigger threat would be an uncreative entity that can take that idea away and execute on it, and we don't have many of them stumbling around a makerspace." DE

Brian Albright *is a freelance journalist based in Columbus, OH. He is the former managing editor of* Frontline Solutions *magazine, and has been writing about technology topics since the mid-1990s. Send e-mail about this article to DE-Editors@deskeng.com.*

INFO → **Artisan's Asylum:** ArtisansAsylum.com

→ **Autodesk:** Autodesk.com

→ **Idea Foundry:** ColumbusIdeaFoundry.com

→ **MathWorks:** MathWorks.com

→ **TechShop:** TechShop.ws

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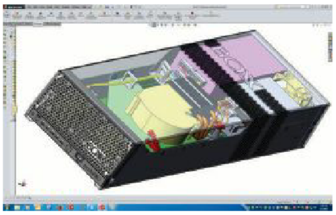
Advancing Specialized Workstation Development

By implementing SolidWorks, BOXX Technologies decreased product development time.



BOXX Technologies Inc. manufactures specialized workstations and rendering systems for visual effects (VFX), film, television, game development, architecture, engineering, product design, simulation, higher education, government, defense, science, medical and general business industries. According to Tim Lawrence, founder and vice president of Engineering and Operations, BOXX needed a 3D design platform to advance development of the custom chassis and enclosure designs required for its systems.

"We started out using AutoCAD 2D design tools," Lawrence said. "While 2D initially allowed us to get the job done, it was difficult, slow, and costly to develop systems in 2D. We foresaw challenges as we continued to develop and advance our technology — including sheet metal fabrication; design branding; advanced cooling systems development; unique shipping requirements; and electromagnetic shielding, safety and international certifications — that we could better tackle in 3D. As a systems manufacturer, we need to continually develop custom chassis and enclosures that not only embody our brand but also satisfy a range of requirements that are unique to high-performance systems."

BOXX consulted with manufacturing partners before standardizing on SolidWorks Premium design software. The systems manufacturer implemented SolidWorks software in 2004 because it's easier to learn and use, provides robust sheet metal and simulation capabilities, and supports both industrial design and mechanical engineering.

"I sat down with SolidWorks software, was able to design right away and decided to utilize SolidWorks software for chassis and enclosure development," Lawrence said.

Designing More Sophisticated Systems in Half the Time

Since implementing SolidWorks Premium software, BOXX has realized dramatic reductions in the length of its development cycles, while simultaneously increasing system complexity, improving quality and boosting performance. "SolidWorks software has enabled us to cut our development process by more than half," Lawrence says.

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Creating Life-like Robots

MapleSim provides the advanced solvers that can tackle the difficult equations used to develop Byrun's motion algorithms.

In movies, robots can walk, talk and even pretend to be human. Their real-life counterparts are considerably more limited. But this gap is closing, and Engineered Arts, a UK robotics company, is seeking to bring reality closer to fiction.

Engineered Arts' current flagship product is RoboThespian, the robotic actor. It is used by research and education centers to inform, entertain and investigate new developments in robotics.

Maplesoft technology was used in the design and modeling of balancing and talking RoboThespian robots. MapleSim, the system-level modeling and simulation platform from Maplesoft, helped design the biologically analogous humanoid robot leg integrating a novel actuator, studying its stability, and building the designed leg to determine strategies for its control.

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Editor's Picks

by Anthony J. Lockwood

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.

Proto Labs Expands Materials Portfolio

The company has added low-alloy steel options for metal injection molding.

If your gig involves automotive, consumer electronics, medical device or industrial manufacturing, you probably know that traditionally, MIM (metal injection molding) has been seen as cost-effective only for large production runs, definitely not prototyping. That no longer happens to be the case.

In late March, Proto Labs announced three new low-alloy steel material options for their MIM service. Two are nickel steel materials and the other is a chrome-moly material. You can use the materials in most applications requiring low-alloy steel materials.

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Touchscreen Oscilloscopes Simplify Zone Triggering

The new 3000T X-Series sports an 8.5-in. touch user interface.

Keysight Technologies has launched the InfiniiVision 3000T X-Series digital storage and mixed signal oscilloscopes for the mainstream scope-using market.

The device offers multiple firsts for its class, including an 8.5-in. touchscreen and an update rate of 1 million waveforms per second.

Furthermore, say you spot a signal anomaly that you want to isolate. On the instrument display you can draw a box around the signal anomaly and create a zone trigger using your finger. You can then select what sort of zone trigger to use by tapping an option from a pull-down menu.

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TurboCAD Pro and TurboCAD Pro Platinum 2015 Ship

Release implements improvements for productivity and usability.

Both TurboCAD Pro and TurboCAD Pro Platinum are professional-level 2D/3D modeling, mechanical design engineering, general-purpose drafting and AEC (architectural, engineering and construction) toolsets.

Version 2015 offers a lot of productivity and usability enhancements. For example, a key new feature called the Conceptual Selector lets you customize any visual and editing parameters in the application. Using the new Contact Manager and File Sharing functionality, you can build and maintain contact lists and send files to people within TurboCAD.

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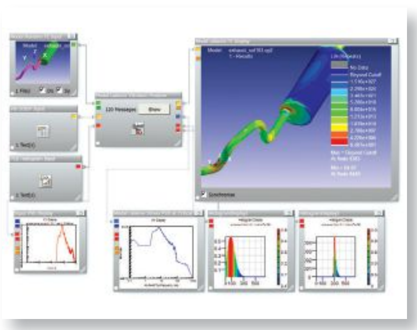

HBM nCode 11.0 Available

Platform now has multiple Power Spectral Densities and Sine on Random loading.

Version 11.0 of nCode focuses on new and enhanced capabilities for designing and validating components subjected to vibration. DesignLife, which handles high to low cycles, crack initiation, crack growth and so on, sees improvements to its plasticity model and its automatic analysis selection methods.

Frequency analyses now have new pre-defined processes for auto-correlation and cross-correlation of input data with various lags/scaling options. Other new features include a waterfall analysis method and the ability to generate Campbell plots.

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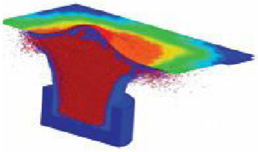
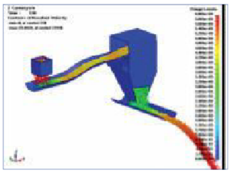
Livermore Software Technology Corporation

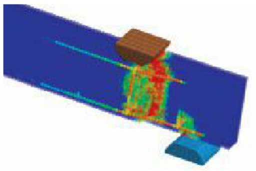


Four New Solvers for Multiphysics Purposes



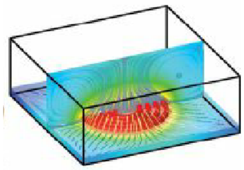
Discrete Element Sphere (DES)

The DES (Discrete Element Sphere) is a particle-based solver that implements the Discrete Element Method (DEM), a widely used technique for modeling processes involving large deformations, granular flow, mixing processes, storage and discharge in silos or transportation on belts. In LS-DYNA, each DE particle is a FEM node, making it easy to couple with other rigid or deformable structures by using penalty-based contact algorithms. The DE is highly parallelized and is capable of simulating systems containing over several hundred-million particles.



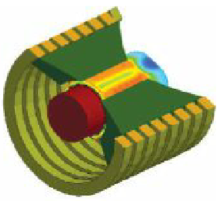
Here are some distinct features of the bond model:

1. The stiffness of the bond between particles is determined automatically from Young's modulus and Poisson's ratio.
2. The crack criteria are directly computed from the fracture energy release rate.
3. The behavior of bond particles is particle-size independent.



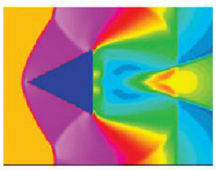
Incompressible CFD

The incompressible flow solver is based on state of the art finite element technology applied to fluid mechanics. It is fully coupled with the solid mechanics solver. This coupling permits robust FSI analysis via either an explicit technique when the FSI is weak, or using an implicit coupling when the FSI coupling is strong.



Electromagnetics

The Electromagnetism solver calculates the Maxwell equations in the Eddy current (induction-diffusion) approximation. This is suitable for cases where the propagation of electromagnetic waves in the air (or vacuum) can be considered as instantaneous. Applications include magnetic metal forming, welding, and induced heating.



CESE/Compressible CFD

The CESE solver is a compressible flow solver based upon the Conservation Element/Solution Element (CE/SE) method, originally proposed by Dr. Chang in NASA Glenn Research Center. This method is a novel numerical framework for conservation laws.

Upcoming Classes in Michigan

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- **June 22** Intro to LS-PrePost
- **June 23-26** Intro to LS-DYNA

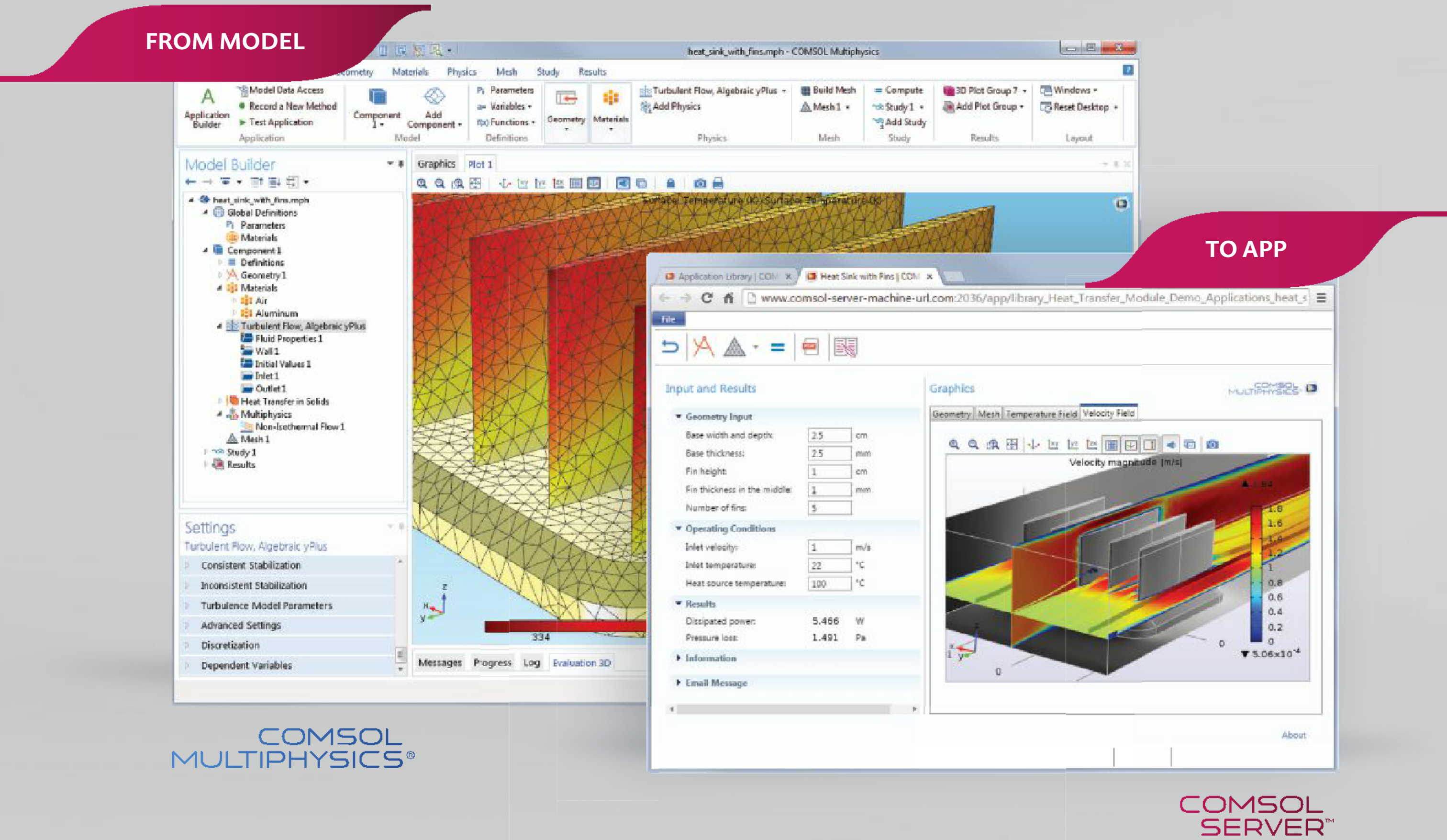
Upcoming Classes in California

- **July 7-8** Composite LS-DYNA
- **July 9-10** Implicit
- **July 16-17** Umat LS-DYNA
- **July 28-29** Blast in LS-DYNA
- **July 30-31** Penetration in LS-DYNA
- **Aug 3** Intro to LS-PrePost
- **Aug 4-7** Intro to LS-DYNA
- **Aug 11-12** Advanced Impact Options in LS-DYNA
- **Aug 13-14** Contact LS-DYNA
- **Aug 17-19** ALE/Eulerian & FSI in LS-DYNA

LSTC Livermore Software Technology Corp.

For more information email: sales@lstc.com or visit www.lstc.com

Livermore Software Technology Corporation, 7374 Las Positas Road, Livermore, CA 94551, USA



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