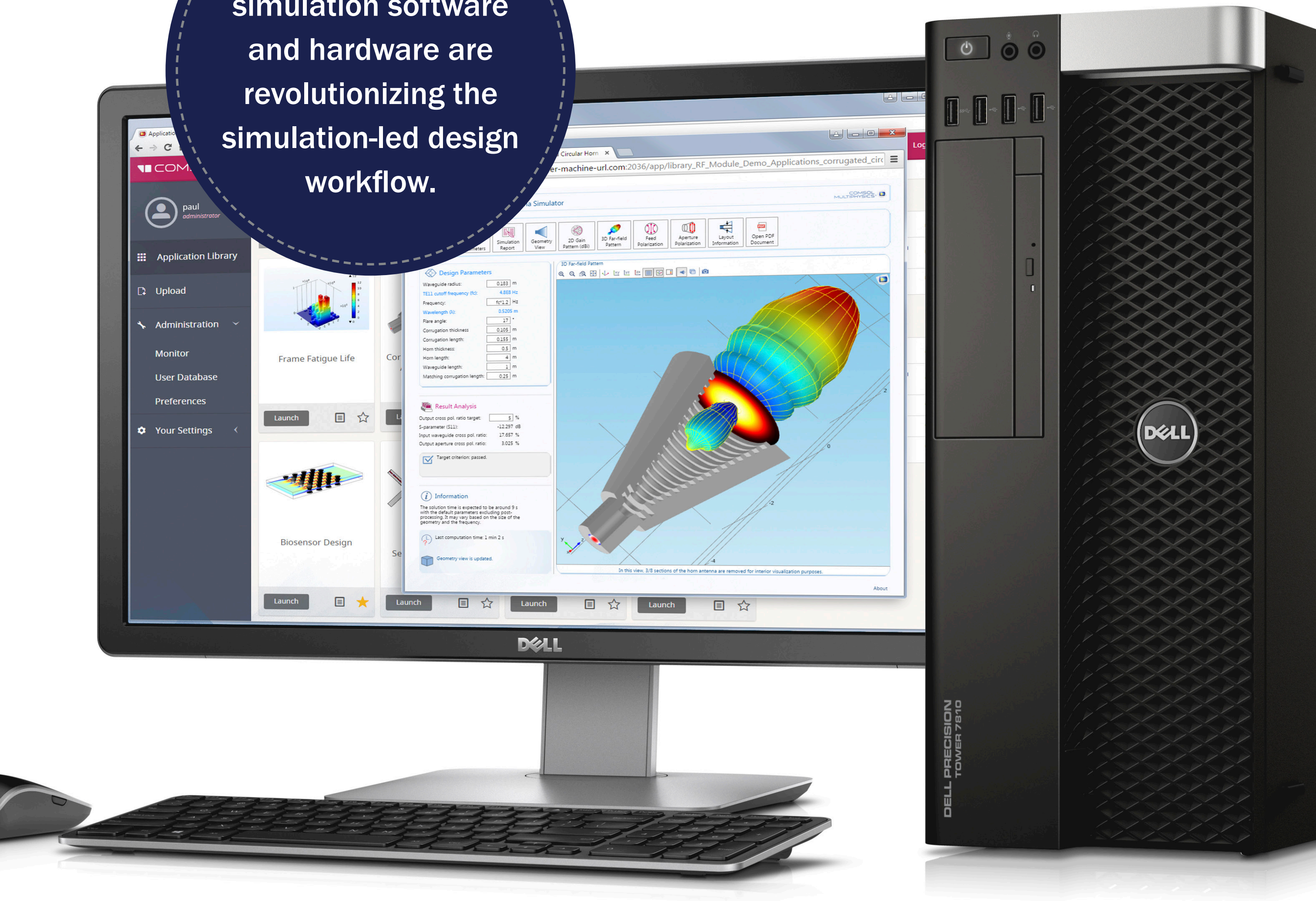
Simulation *for the* Masses

How modern simulation software and hardware are revolutionizing the simulation-led design workflow.



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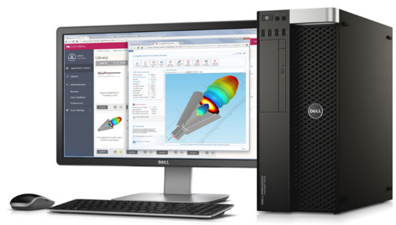
This is the first in a series of benchmarking studies produced by Desktop Engineering *with Intel, Dell and independent software vendor sponsors that is intended to explore the benefits of embracing simulation-led design.*

Executive Summary



Simulation-led design offers many benefits to design engineering teams. Chief among them: Time and cost savings via less physical product testing, the ability to quickly determine the best initial designs to develop and the freedom to digitally experiment with innovative "what-if" scenarios, particularly with designs for new markets. Moving simulation further forward in the design process can give engineering teams a decided competitive advantage, but technological, personnel and cultural challenges have kept many companies from reaping the rewards. Three recent developments explored in this paper promise to change that.

1. Advances in Hardware and Software

As the availability of affordable computing power increases and simulation software is optimized to take advantage of it, more design engineering teams should be able to realize the incredible benefits of a simulation-led design workflow. We put this notion to the test by benchmarking three-year old COMSOL Multiphysics® software on a three-year-old Dell Precision® workstation against their comparable present-day counterparts. We discovered that modern hardware and software can complete some multiphysics simulations 6X faster.

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We also explore licensing options for distributed computing. COMSOL Multiphysics is optimized to support the latest hardware innovations. The software's hybrid modeling feature and Floating Network License allows you to model large simulations on standard workstations that support parallel processing, or on as many cores and nodes as you want on a cluster.

2. Distribution of Simulation Expertise

Moving to a simulation-led design workflow requires more than just the latest hardware and software to prevent bottlenecks. Setting up, running and analyzing simulations requires expertise that is in short supply in most companies. Even with the fastest computers and latest software, design engineers, sales representatives, executives and many others in the wider enterprise could be left waiting for a small group of expert analysts to furnish them with the results they need to do their jobs.

One answer to the problem is to distribute that expertise over a wider user base via an app-based approach. COMSOL's Application Builder and COMSOL Server™ technologies put COMSOL Multiphysics simulation and modeling capabilities into the hands of the entire engineering team. Those who aren't experts can use specialized applications built by simulation specialists, allowing them to adjust variables, run specific simulations and get the answers they need without waiting for the simulation experts. The apps can be loaded into COMSOL Server, a program which allows them to be run in any major web browser or in a dedicated desktop client from anywhere within an organization.

This paper explains how Application Builder and COMSOL Server can help democratize simulation, and provides three real-world examples of organizations that are using them to streamline research & development, empower engineering staff and free up simulation expertise to focus on high-value solutions.

3. Increased Cultural Acceptance of Simulation

As product complexity increases and time-to-market decreases, more engineering teams and business managers are ready to embrace a properly presented workflow change that will help them meet their goal of innovative product design. Still, implementing a simulation-led design workflow is a significant undertaking that requires executive-level buy-in and grassroots acceptance. This paper will explain how to educate management on the benefits of simulation-led design, calculate its return on investment and enlist the support needed to transform your workflow. ●

Simulation-Led Design Gains a Following

Most engineering organizations wouldn't dream of building something as complex as a hybrid-electric vehicle powertrain or as basic as a support bracket without enlisting simulation to explore the validity of designs. Yet while simulation has become essential to the overall development process, complexity has limited its use to pockets within an organization, vastly undermining its potential for transforming design.

With an emphasis on mathematical equations, arcane user interfaces and complex setup procedures, simulation software has traditionally lived on the outskirts of engineering — the domain of a small cadre of R&D specialists who understand tasks like meshing and parameter settings for solvers, and who are trained in the art of model preparation. Not only has simulation software been difficult to use, there have been limits to its functionality, minimizing its utility for the multifaceted problem solving integral to today's complex products.

> With mass adoption of simulation, companies can develop better and higher quality products, ensure faster time to market and, as a result, carve out a clear competitive edge.

Hardware Hurdles

Simulation's reach narrows even further when you consider what it takes to run finite element analysis (FEA), computational fluid dynamics (CFD) or multiphysics software at peak performance. Older workstations cannot be economically equipped with the horsepower to adequately handle the sophisticated models and computationally intensive processing required by multiphysics simulation studies, further restricting the widespread use of simulation.

The combination of the expert analyst bottleneck with the aging workstation bottleneck has prevented organizations from harnessing the full potential of simulation. But those barriers are being removed with outstanding results. Unleashing a few experts to conduct a handful of simulation studies at set intervals pales in comparison to creating an environment that supports simulation by many participants throughout the entire process — particularly in the earliest stages when simulation can have the greatest impact on design outcomes.

The ability to involve more stakeholders — both inside and outside the inner engineering circle and throughout all stages of the design cycle — is where companies can expect to get the greatest return on simulation. Encouraging more widespread use of simulation, particularly in design and development, fosters more iterative workflows and allows organizations to explore a greater number of alternatives. It also reduces reliance on costly, physical prototypes and gives companies a better shot at identifying optimal designs. With mass adoption of simulation, companies can develop better and higher quality products, ensure faster time to market and, as a result, carve out a clear competitive edge.

Taking the Lead

Many vendors and experts have paid lip service to the benefits of simulation-led design and simulation for the masses, but the concepts are just now starting to take hold in organizations thanks to advances on multiple technology fronts and more widespread adoption of best practices.

For example, thanks to powerful processors, additional cores and extras like fast solid state drives (SSDs) and higher capacity memory, modern workstations are equipped to attack large-model problem solving leveraging parallel processing capabilities on a level that just isn't feasible with older workstations.

In addition, with prices on workstations falling over the last few years, companies are now able to secure far more processing horsepower for the same investment as well as make workstations available to a wider audience of users.

For organizations with modeling problems too complex for the average workstation, improvements in high-performance computing (HPC) have made cluster technology more accessible. HPC clusters are now more affordable than ever. In addition, leading simulation software has been certified to run on HPC clusters, and a new generation of management software makes it easier for non-HPC experts to provision hardware and do job scheduling.

Similarly, simulation software has evolved significantly these last few years. New, more intuitive user interfaces are masking some of the complexities of the technology while the simulation solvers themselves have gotten far more powerful and easier to configure. Simulation vendors have also stepped up certification efforts, optimizing their programs to fully exploit new workstation features such as multiple cores, updated instruction sets and faster SSDs. Newly certified simulation applications are also taking advantage of multi-core parallel processing, enabling them to solve larger and more complex multiphysics problems much more quickly and accurately. ●

Benchmarking: Then and Now

> The key to effectively driving new simulation-led design workflows is to marry the latest hardware with the most current simulation software releases.

AT THE THREE-YEAR MARK, the average company will evaluate the possibility of a hardware or software upgrade, many going through a formal return on investment (ROI) analysis to guide their decision making.

Our benchmarking study compared the latest version of COMSOL Multiphysics running on a present-day workstation to a hardware and simulation software configuration that was standard three years ago. Specifically, the study examined the performance of a variety of multiphysics simulation models run on a Dell Precision T3500 workstation and a current generation Dell Precision Tower 7810 workstation.

The three-year-old Dell Precision T3500 workstation sported a single Intel® Xeon® CPU W3505 processor running at 2.53GHz along with two cores, 12GB of RAM, and a 300GB SATA drive. It was outfitted with Windows 7 Pro and ran what was then the most current version of COMSOL: COMSOL Multiphysics 4.2.0.288.

The modern-day Dell Precision Tower 7810 features dual Intel Xeon E5-2687W v3 processors, running at 3.10GHz and using 20 cores. The system was stocked with 64GB of RAM, a 500GB SCSI disk and a 512GB Samsung® SM84 solid state drive (SSD). MPI was also enabled to support cluster-like hybrid parallel processing. For the sake of parity, the system also ran Windows 7 Pro, however, the latest version of COMSOL, version 5.0.1.276, was put to the test.

We selected a variety of model types that showcased COMSOL's multiphysics strengths to see how they would translate to the newer equipment.

- a 3D Fluid-Structure Interaction model that coupled laminar flow and structural mechanics;
- a Tonpilz Piezo-Transducer model that coupled acoustic-structure-piezo interaction as a parametric study;
- an Aluminum Extrusion model, which coupled structural mechanics, laminar flow and heat transfer;
- and an Electrical Switch model , which coupled multiphysics contact, structural mechanics, electrical currents, and heat transfer.

The Hardware

	Dell Precision T3500 workstation (3 years old)	**Modern Dell Precision Tower 7810 workstation**
Processor	Intel® Xeon® CPU W3505, 2.53GHz	A pair of Intel® Xeon® E5-2687W v3, 3.10GHz
Core	2	20
RAM	3x4GB	4x16GB
Storage	300GB SATA drive	500GB SCSI disk, Samsung SM841N solid state drive (SSD)
OS	Windows 7 Pro	Windows 7 Pro
Software	COMSOL Multiphysics 4.2.0.288.	COMSOL Multiphysics 5.0.1.276
MPI		Enabled for hybrid parallel processing

The Results: 6X Faster Simulation

> Benchmarking tests show simulation performance when using modern hardware and software was up to 6X better than on comparable hardware and software from three years ago.

RUNNING MULTIPHYSICS SIMULATIONS on present day workstations compared to three-year-old hardware has a dramatic impact both in terms of the size and complexity of models, as well as the speed of performance.

Thanks to the introduction of far more cores and memory, support for parallel processing, and the hybrid modeling capabilities in the latest version of COMSOL, the study revealed more than six times faster performance running on the present day Dell Precision Tower 7810, depending on the model and the multiphysics coupling.

For example, the 4.23 million degrees of freedom Aluminum Extrusion model took 920 seconds to run in the three-year-old set up, but only 153 seconds in the present-day configuration, resulting in 6X faster processing times.

A 290,000 degrees of freedom 3D Fluid-Structure Interaction model took 4,617 seconds to run on the three-year old Dell Precision T3500 with COMSOL 4.2.0.288 compared to 906 seconds on the Dell Precision T7810 with COMSOL 5.0.1.276 — a 5X increase in speed.

The 115,000 degrees of freedom Electrical Switch model enjoyed a more than 4X boost vs. the current-day configuration, going from 1,028 seconds down to 255 seconds.

The Tonpilz Piezo-Transducer model, at 56,000 degrees of freedom, didn't scale as dramatically as the others because of its small, initial size. Still, its speed more than doubled on the new hardware using the latest COMSOL version in 209 seconds compared to 481 seconds on the three-year-old hardware and software.

3 Reasons Why this Study was Conducted

1. Affordable Technology

Making do with older workstations or past releases of software is a common way for engineering organizations to stretch limited budgets. But in this age of product complexity, companies have more to lose by trying to do realistic simulation with outdated resources that can't possibly accommodate the growing size and sophistication of present-day multiphysics simulations.

2. Parallel Processing

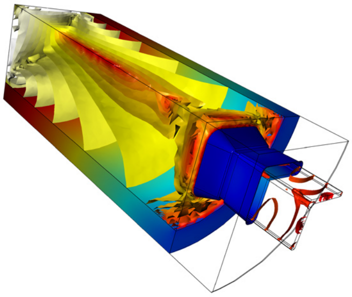
Major advances in hardware over the last three years have had a serious impact on the size and scope of simulations that can be run as well as the speed in which they are processed. Modern day workstations are equipped with many more cores and are architected for parallel processing — capabilities that were commonly only available in clusters three years ago, not in desktop workstations.

3. Optimized Software

Similarly, current simulation software has been optimized to automatically support multiple cores and parallel processing. In older simulation packages, a trained expert would have to manually make adjustments to calibrate software to take advantage of whatever parallel processing capabilities were available on the existing platform.

Because the technology has changed so radically, we decided to see what kind of performance impact could be expected by upgrading hardware and software to the latest release. As a benchmark for comparison, we compared current workstation hardware from Dell and the latest version of COMSOL Multiphysics® with three-year old hardware and this software because three years is typically the time frame in which companies start to consider an upgrade.

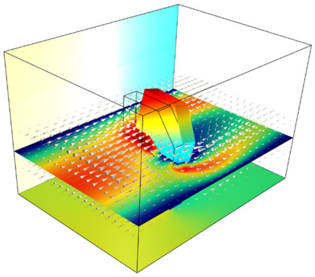
The Results: Model Comparison



Aluminum Extrusion

Degrees of freedom: 4,235,000
Physics: Coupled structural mechanics, laminar flow, heat transfer
Solution time:
3-year-old workstation and software: 920 seconds
Current workstation and software: 153 seconds

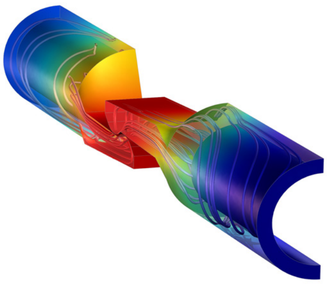
Speedup: 6.01X



3D Fluid-Structure Interaction

Degrees of freedom: 290,000
Physics: Strongly coupled laminar flow, structural mechanics
Solution time:
3-year-old workstation and software: 4,617 seconds
Current workstation and software: 906 seconds

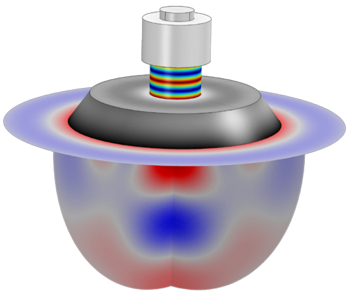
Speedup: 5.10X



Multiphysics Electrical Switch

Degrees of freedom:115,000
Physics: Strongly coupled structural mechanics, electrical currents, heat transfer
Solution time:
3-year-old workstation and software: 1,028 seconds
Current workstation and software: 255 seconds

Speedup: 4.03X



Tonpilz Piezo-Transducer

Degrees of freedom: 56,000
Physics: Strongly coupled acoustic-structure-piezo-interaction, parametric study
Solution time:
3-year-old workstation and software: 481 seconds
Current workstation and software: 209 seconds

Speedup: 2.30X

New Engineering Workflow Drives Simulation for the Masses

COMSOL is driving a revolution in simulation-driven design and simulation for the masses with its Application Builder and COMSOL Server technologies, introduced as part of COMSOL Multiphysics version 5. The Application Builder transforms traditional simulation workflows by making COMSOL Multiphysics simulation and modeling capabilities available to non-simulation experts through the concept of specialized applications. Application Builder apps are built by R&D simulation specialists, but made available to the wider community of users involved in product design, allowing them to participate in the simulation and product optimization process.

Create Simulation Apps

Using the Application Builder's array of tools for designing user interface layouts, and implementing customized commands, specialists leverage their extensive knowledge of physics and simulation software to create highly specialized simulation apps drawing from their own libraries of existing multiphysics models or by creating new apps from scratch.

The simulation app — which could be something like a spring deformation calculator or a battery performance simulator, for example — is then framed up in a customized user interface making it readily accessible to the non-expert, including engineering colleagues, lab technicians, operators, non-engineers as well as customers. With an easy-to-digest simulation app, the simulation engineer is no longer solely responsible for generating simulation results or resolving the same simulations multiple times to accommodate varying requests. Instead, a broader set of users can play an active role in simulation-driven design, contributing their product- or process-specific knowledge without being fluent in modeling techniques and without familiarity with numerical analysis.

COMSOL Multiphysics comes with a wide range of apps, which demonstrate what's possible with the Application Builder. Among them are such targeted apps as a transmission line calculator, biosensor designer, mounted crane analyzer and a heat exchanger optimizer.

Run and Manage Apps

While the Application Builder is the tool for creating the simulation apps, COMSOL Server is the engine for running the apps and the software platform on which they are run, distributed and managed. The apps are uploaded to COMSOL Server, which allows them to be run in any major web browser or in a dedicated desktop client from anywhere within an organization. Moreover, the software supports a worldwide flexible network license that enables customers, clients, vendors and outside partners to run the specialized apps from the same COMSOL Server software license. Furthermore, the apps can be run on just about any device such as a tablet, desktop, workstation or cluster.

To address on-going challenges around security and model management, COMSOL Server supports robust security settings that allow groups to mark apps as public or private. It also features management tools that facilitate easy access to the Application Library, letting users search for apps based on descriptions while also marking options as favorites to facilitate easy access. There are even reporting tools to keep track of what simulation apps are being used most and by whom.

COMSOL's multiphysics software and the Application Builder/COMSOL Server duo go a long way toward democratizing multiphysics simulation, but they further release the potential of simulation in design workflows when paired with upgraded hardware. Many of the new features of COMSOL Multiphysics version 5, including the Application Builder and COMSOL Server, fully utilize the faster processing speeds, multiple cores and parallel processing capabilities of the latest workstation models to deliver their capabilities at peak performance.

Both Hardware and Software Support an Optimized Workflow

The key to effectively driving new simulation-led design workflows is to marry the latest hardware with the most current simulation software releases that have been certified and optimized for those platforms.

To truly understand the potential of simulation-led design workflows and simulation for the masses, you have to go back to traditional trial-and-error design processes. Engineers would typically create a benchmark design, scale it with the requisite features to meet requirements, then validate it by building a physical prototype. If performance problems were identified, the process would start again with a fresh design and a new physical prototype. Given the high cost and manual effort involved in physical prototyping, the scope of design exploration was largely constrained.

The situation improved with the introduction of simulation, even if it was just employed by a handful of R&D specialists. With this scenario, instead of building one-off physical prototypes, experts create simulations aimed at validating designs based on their knowledge and with minimal input from design engineers and other related parties. While it's certainly easier and less expensive than building physical prototypes, putting experts to work on building simulation models is time intensive and doesn't go far enough in democratizing the simulation workload or encouraging more extensive design exploration. As a result, expert-directed simulation remains a barrier to infusing agility and innovation throughout the design cycle.

However, the introduction of new simulation-led design workflows made possible by the latest Dell Precision workstations and new simulation tools, like the Application Builder and COMSOL Server, completely transforms this cycle. With this combination, the R&D engineer or specialist is no longer a bottleneck for simulation. With application creation an integrated part of the design workflow, specialists can create simulations that only include the parameters they want to make available for manipulation by others, and design engineers are empowered to experiment and run their own results.

In this way, modeling power that has traditionally been the sole domain of engineering analysts and specialists can now be distributed across a product design team. Manufacturing engineers or design engineers who are experts in their product category or process domain, but less comfortable with simulation, can now run the simulation apps on their own, providing input and making modifications that reflect real-world product usage or actual constraints more accurately. Limiting the inputs and variables reduces the chance of human error while improving the quality of models. It also vastly accelerates the overall simulation process.

Introducing input from more stakeholders in the design and engineering process has other benefits. Simulation becomes a more integral part of the overall design workflow so it's engaged continuously during the design process. Moreover, widespread adoption of simulation-led design practices results in more realistic simulation, which in turn, leads to improved and optimized product designs and processes. ●

Simulation-Driven Design at Work

To reap the full potential of simulation-driven design, engineering organizations need to prepare to do things differently. More powerful workstations equipped with modern bells and whistles will certainly churn through complex models more quickly, but the real advantage lies beyond simply turbocharging the standard handful of simulation runs.

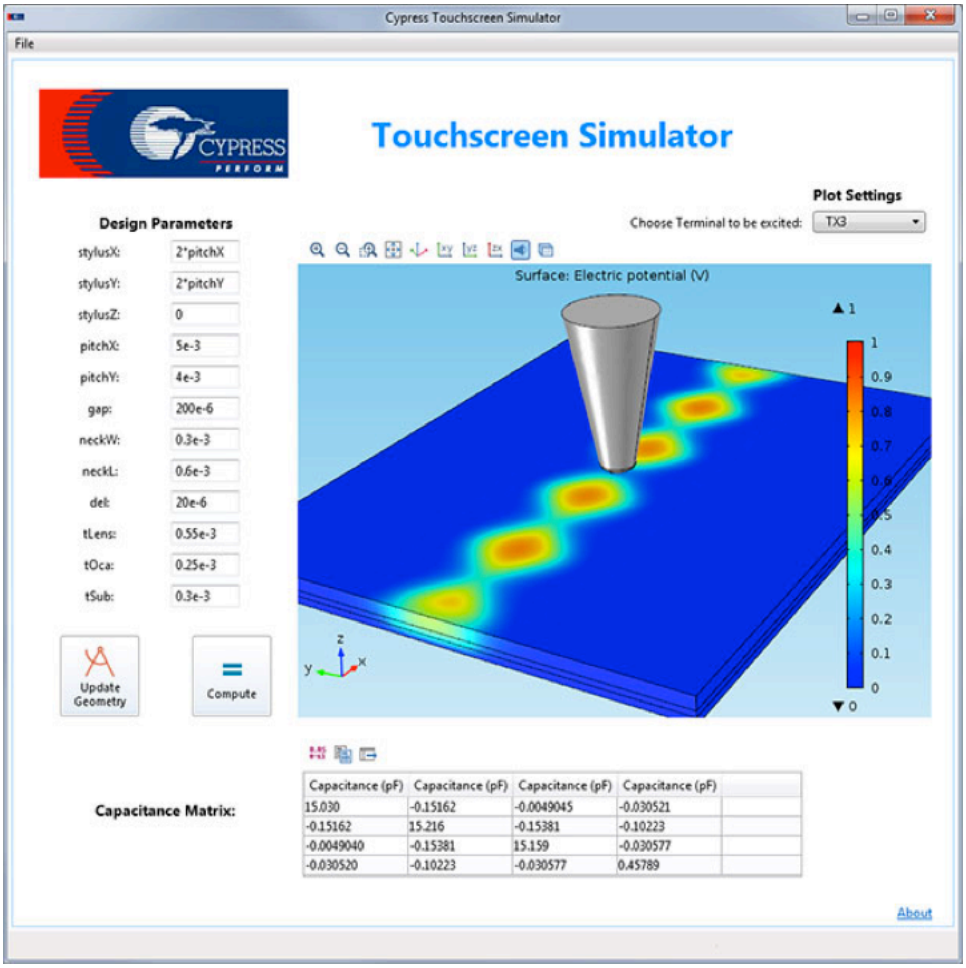
By expanding the existing workforce with simulation know-how, organizations can bring all of their resources and expertise to bear on design problem solving, which is a critical asset in this age of product complexity and heightened competition. The more eyes and sets of experiences channeled toward simulation, the more likely companies can identify and solve more complex, multiphysics problems.

With simulation opened up to more users and with simulation practices incorporated throughout the entire engineering workflow, organizations are also apt to explore more ideas because there is no analyst bottleneck. Unlike traditional workflows where simulation is deployed on a handful of designated best case scenarios, simulation-driven design workflows encourage many users to leverage simulation as an exploration tool on any and all designs, which puts more ideas on the table and inevitably leads to more innovative products.

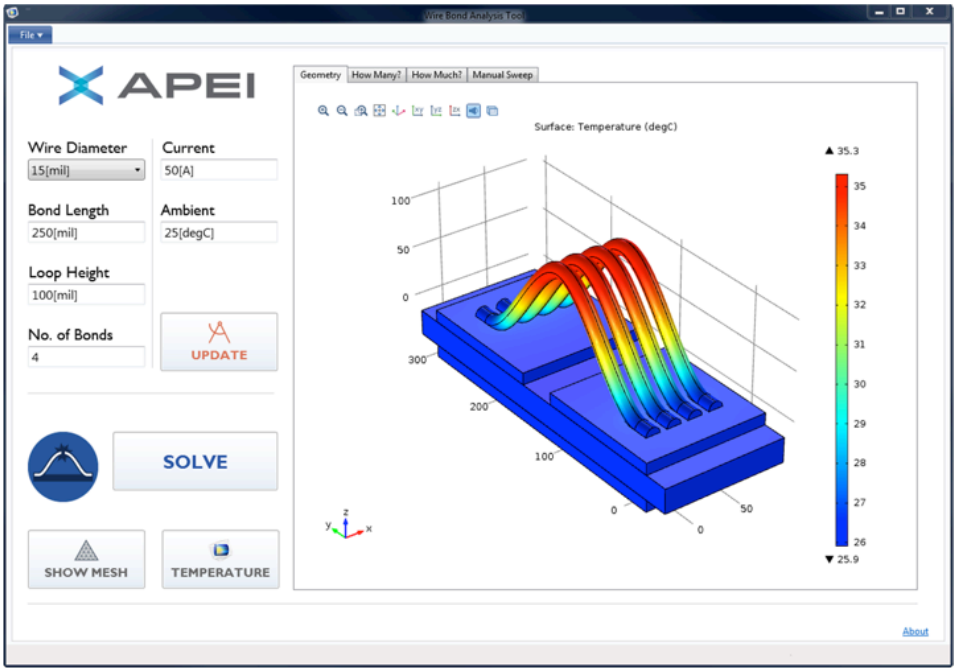
With the added horsepower of current generation workstations and cluster hardware, engineering teams can also move past simulation as a single-point, general predictor to pin-pointed, high-fidelity simulation of all aspects and design detail in a product's lifecycle. With such an approach, which has traditionally only been supported by HPC environments, engineers can rapidly iterate designs to determine how key changes — things like a curved corner or a reduction in material, for example — contribute to meeting key design goals.

Embedding Simulation

At Cypress Semiconductor, a leading manufacturer of touchscreen and embedded systems, simulation engineers have historically tapped COMSOL for research and design initiatives, but the benefits of simulation didn't transcend to other groups essential to product development, including customer support. This group of users, which serves as the key liaison to Cypress Semiconductor's clients deploying its touchscreens as part of phones, MP3 devices, home appliances, and automotive



Cypress Semiconductor has started using COMSOL's Application Builder to streamline its process for touchscreens. Image courtesy of Cypress Semiconductor.



At APEI, any user can select the appropriate values for wire diameter, arc geometry and the number of wires to determine the maximum current without overheating. Image courtesy of APEI.

and industrial applications, was solely reliant on R&D engineers to create simulation models and do development work for their customers' projects.

"In addition to taking up a seat of one of our COMSOL Multiphysics licenses, the R&D team was often asked to help with this process, which took up valuable time for our development staff as well," said Peter Vavaroutsos, a member of Cypress's touchscreen modeling group.

Using the Application Builder and COMSOL Server, Vavaroutsos' team now develops and packages simulation models into apps, allowing the support team to partake in simulation, but with a clean and modified view of the model that only shows them the parameters they need. One such simulation app was developed to support the design of touch-based capacitive sensors. Users can change design parameters ranging from the finger location to the thickness of the different layers in the sensor, but they don't have access to the entire model. The app reports back on the capacitance matrix, which is critical information for capacitive sensor design, and it also depicts the voltage distribution in the sensor. The custom user interface also allows for a drop-down list that makes it easy to select a solution corresponding to the excitation of different sensor traces.

While Cypress Semiconductor creates a general model of the touch screen for consumer products, referred to as a design box, it customizes the app for a wide range of products by allowing users to adjust parameters. With the new simulation apps, the customer support team can easily update the model parameters without having to worry about the underlying complexity of the model or wait for assistance from the R&D engineers. Now, designs can be created on a case-by-case basis, empowering Cypress Semiconductor's design team to be more responsive to customer needs.

"We can create many different apps for a variety of different touchscreen types, which will allow our customer support team to easily and quickly solve complex questions and provide excellent service to our customers," Vavaroutsos said.

Power to the People

At Arkansas Power Electronics International (APEI), a manufacturer of high-power density and high-performance electronics products, the Application Builder is set to expand access to simulation and ultimately, speed up its design processes. Prior to using the software, the engineering group was a bottleneck for simulation, since it was primarily responsible for creating and running simulations — even those requested by colleagues outside of the engineering team.

Today, staff engineers are creating simulation apps that let manufacturing and sales colleagues along with field engineers run the simulation studies on their own, without a learning curve. One of the apps built with the Application Builder is specifically aimed at helping fuse current and ampacity of wire bonds — the small wires used to interconnect semiconductor devices within their packages.

Traditionally, the simulation specialist would have to set up the model and analyze the temperature increase under a variety of conditions. The app uses a parametric sweep to show how the number of wires affects the peak wire temperature at a set current; previously, experts had to look up those values in tables that were generated over time in COMSOL Multiphysics.

"Now we can have a clean, simple application to get that data without requiring an engineer," said Brice McPherson, a senior staff engineer at APEI. "The results are more accurate than what we could have achieved using the tables since the information provided in the app is generated on a case-by-case basis."

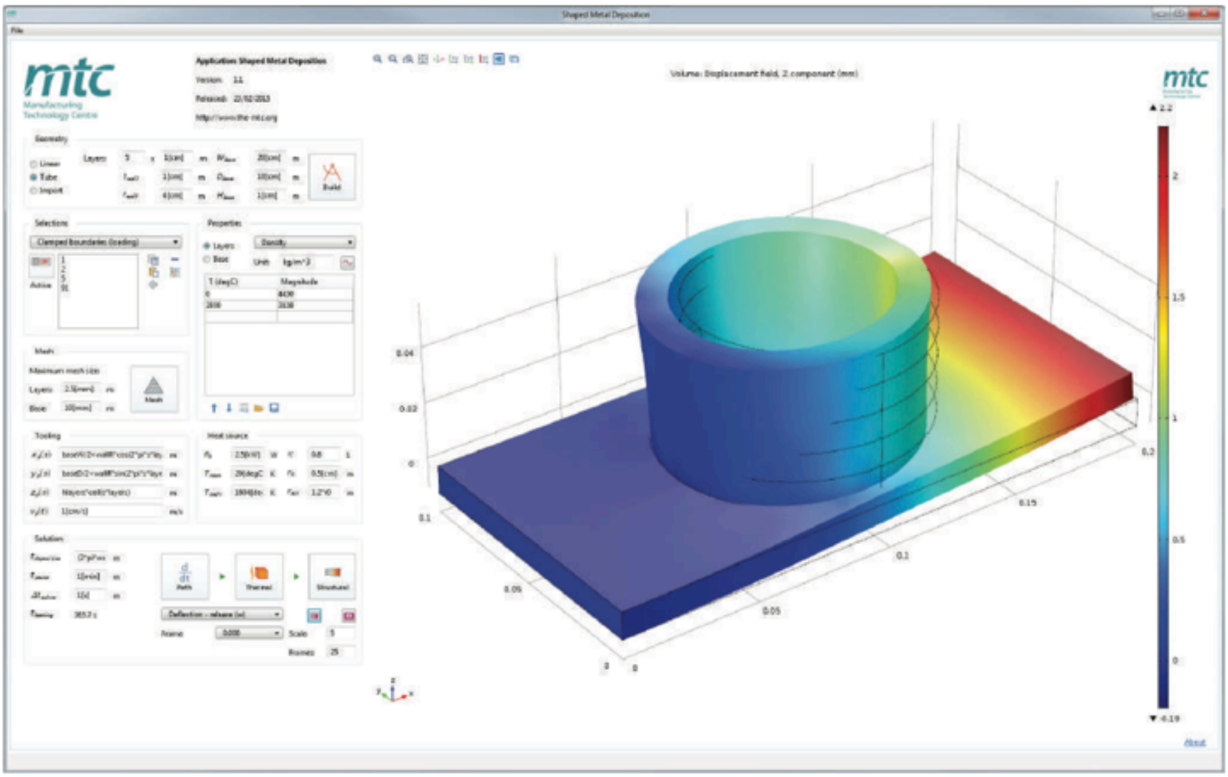
Plans are in place to expand the number of simulation apps built in the Application Builder, including those for package thermal performance, inductor and transformer design, and layout analysis.

Concept to Commercialization

The Manufacturing Technology Centre (MTC) is all about innovation and pushing the limits of design. Its charter is to bridge the gap between concepts and the commercialization of a product. One of its recent projects was to evaluate the potential of an additive manufacturing technique called shaped metal deposition (SMD), which promises advantages over powder-based additive manufacturing technologies, including the use of multiple materials on the same part.

During development, it became clear that thermal expansion arising from the technique sometimes resulted in a final product that was different than anticipated. Using the Application Builder, MTC built a simulation app that solves a time-dependent coupled thermomechanical analysis that predicts residual thermal stresses and deformation arising from SMD thermal cycles. MTC users who don't have experience with simulation are leveraging the app to predict whether the deposition process will produce parts that fall within established tolerances. They are easily able to experiment with geometries, heat sources, deposition paths and materials without having to understand or worry about the underlying model complexities.

"Were it not for the app, our simulation experts would have to test out each project we wanted to explore — something that would have decreased the availability of skilled resources," says Borja Lazaro Toralles, research engineer in MTC's Manufacturing Simulation theme. ●



This shaped metal deposition (SMD) simulation app created using the Application Builder available in COMSOL Multiphysics allows MTC to compute the residual stresses generated during the manufacturing process and predicts the final deflection of the part. Image courtesy of MTC.

Bringing Simulation-Driven Design to Your Company

Now that the software to support simulation for the masses has arrived and affordable, high-performance workstations are well within reach, the next steps are to steer your engineering organization toward a simulation-driven design engineering workflow.

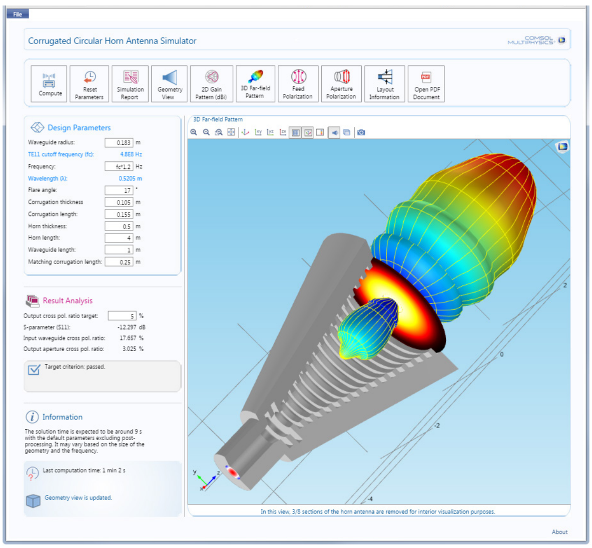
Simulation is a powerful tool, and it can be transformative when it's unencumbered by bottlenecks and made accessible to everyone throughout the design chain. By leveraging updated software and more powerful workstations to democratize simulation, organizations infuse a collaborative spirit into their design workflows, opening the door to greater innovation and improved design agility that's sure to beat the competition.

Step 1: Educate management and users. Explain the benefits of a new, simulation-led workflow by underscoring what's possible when more people are engaged in simulation practices. Firm up a business case that showcases how the new workflow will bolster innovation and design agility.

Step 2: Show the results. Demonstrating the software's ease of use while highlighting the bottlenecks and gaps in traditional design workflows will go a long way in gaining user support for the necessary changes to existing styles of collaboration.

Step 3: Calculate the return on investment. It's one thing to demonstrate that hardware and software can improve your workflow, but management will want hard numbers before making a move. Here you will be looking for the compounded effect of using modern computational hardware as well as introducing specialized simulation apps. You can easily calculate the cost of the hardware and software vs. the expected R&D employee time savings they will produce by using average salaries. The 6X speed up shown in our benchmarking study is a good place to start on the productivity side. However, such an improvement in simulation speed is only part of the story because it does not show the savings a distributed, simulation-led workflow could bring to your larger enterprise. You can easily calculate time savings through the elimination of running repetitive analysis tasks for multiple departments. And with more people performing more simulations in parallel, return on investment for a shorter time to market always provides competitive business advantage.

Step 4: Enlist support. Align with an executive sponsor who can help lead the change management effort. With the help of executive leadership, engineering management can assess the organization's overall readiness for implementing streamlined workflows around simulation-driven design and simulation for the masses.



This application, created with COMSOL Application Builder, allows a circular horn antenna's radiation characteristics, as well as aperture cross-polarization ratio, to be improved by modifying the geometry of the antenna.

Licensing, Software and Hardware Configurations with COMSOL Multiphysics

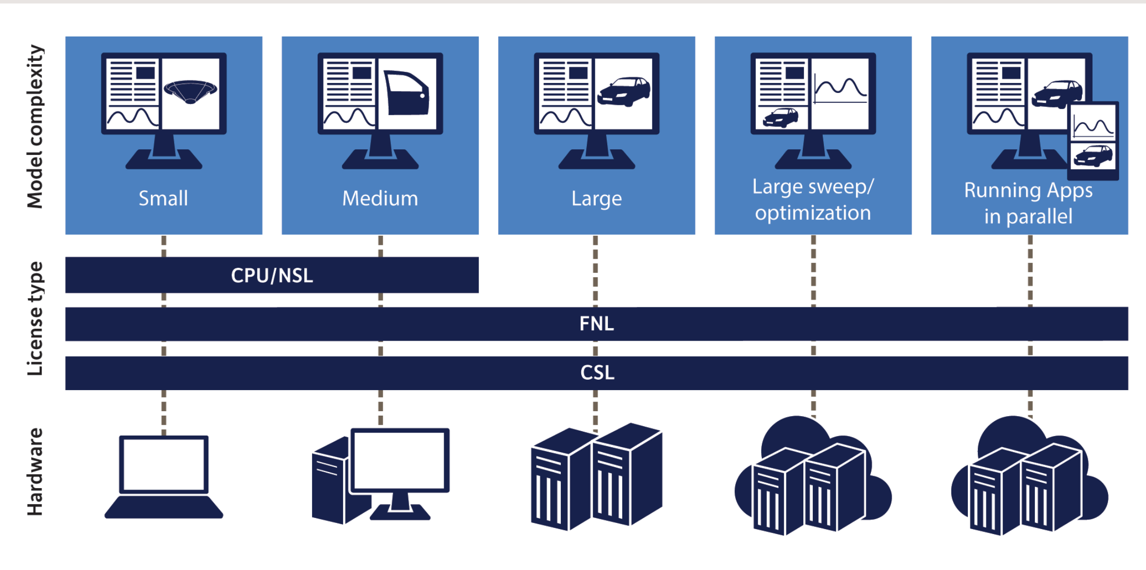
OPTIMAL COMPUTER PERFORMANCE that provides quick simulations is an important factor when choosing appropriate engineering software and hardware. However, a greater need is often how quickly your organization can innovate, design and optimize its products or processes, and how quickly you can get them to market. Finding the right hardware and software configuration for optimal simulation performance that remains flexible for your organization's needs depends on what it is you are trying to simulate.

In many cases, the fundamentals of your products' or processes' behavior need to be investigated and operating ranges established. This usually entails small simulations that use the flexibility of COMSOL Multiphysics to quickly set up models, add and couple physics, and investigate many different scenarios. Such simulations can make use of a simple CPU-locked (CPU) or user-locked (NSL) license that will run on any laptop, PC or workstation.

As you optimize your design, you need to investigate more parameters and, ultimately, introduce complexity to your simulations. COMSOL Multiphysics utilizes both shared-memory and distributed modeling through its hybrid modeling feature when using a Floating Network License (FNL). This allows you to model large simulations on standard workstations that support parallel processing or on as many cores and nodes as you want on a cluster.

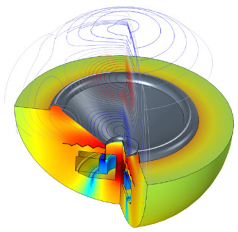
Once most of the operating conditions or design parameters have been decided, you are often required to find optimal values for operation or manufacture. This can involve sweeping through hundreds or thousands of parameters on clusters in your network or in the cloud. Once again, the standard FNL will support you with this modeling, irrespective of the number of processors you run in parallel.

Finally, you may want to utilize the experience and knowledge of your organization through engineers who may know a lot about the product or process, but do not have a background in creating simulations. The Application Builder can be used to create simplified apps where you control the number and range of inputs and outputs for these engineers to manipulate. A COMSOL Server License (CSL) then allows your organization to run these apps from anywhere in the world for a much lower cost than a full version of COMSOL Multiphysics.

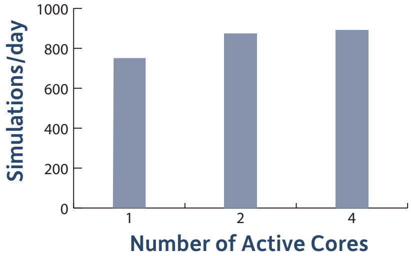


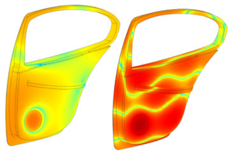
COMSOL offers a number of licensing options. CPU: machine-locked, multiple users. NSL: user-locked, up to four machines. FNL: concurrent-usage controlled, multiple users, unlimited number of nodes. CSL: concurrent-usage controlled, multiple users, worldwide license, unlimited number of nodes. Image courtesy of COMSOL.

Computer Configurations for Different Simulations of Loudspeaker Acoustics in a Car's Interior

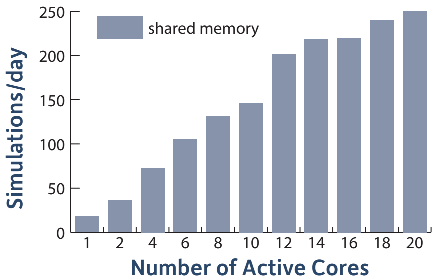


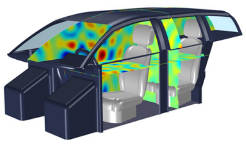
Small
Hardware: Entry-level workstation
Processor: Intel® Core i7-3720QM @2.60 GHz
CPU usage: Shared Memory
Solver: Direct Solver
Memory usage: 2GB RAM (57kDOFs)
Network communication: NA



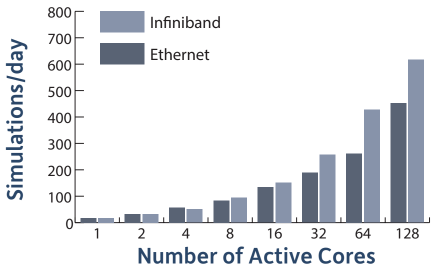


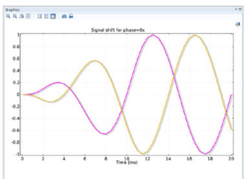
Medium
Hardware: Workstation
Processor: Intel® Xeon E5-2643 @3.3GHz
CPU usage: Shared Memory
Solver: Direct Solver
Memory usage: 33GB RAM (1.3MDOFs)
Network communication: NA



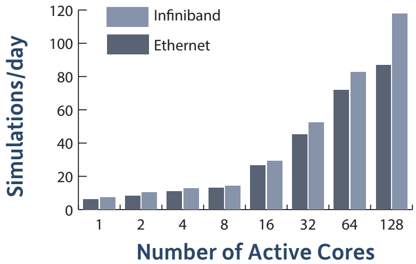


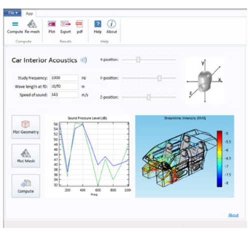
Large
Hardware: Cluster
Processor: Intel® E5-2690v3 @2.6 GHz
CPU usage: Distributed, Hybrid Modeling
Solver: Segregated Solver
Memory usage: 76GB RAM (8MDOFs)
Network communication: Ethernet v InfiniBand



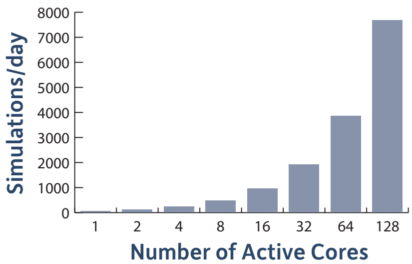


Large sweep/optimization
Hardware: Cluster
Processor: Intel® E5-2690v3 @2.6 GHz
CPU usage: Distributed, Hybrid Modeling
Solver: Direct Solver
Memory usage per parameter: 12GB RAM (712kDOFs)
Network communication: Ethernet v InfiniBand





Running Apps in parallel
Hardware: Cluster
Processor: Intel® E5-2690v3 @2.6 GHz
CPU usage: Distributed, Shared Memory
Solver: Direct Solver
Memory usage per App: 2GB RAM (57kDOFs)
Network communication: Ethernet



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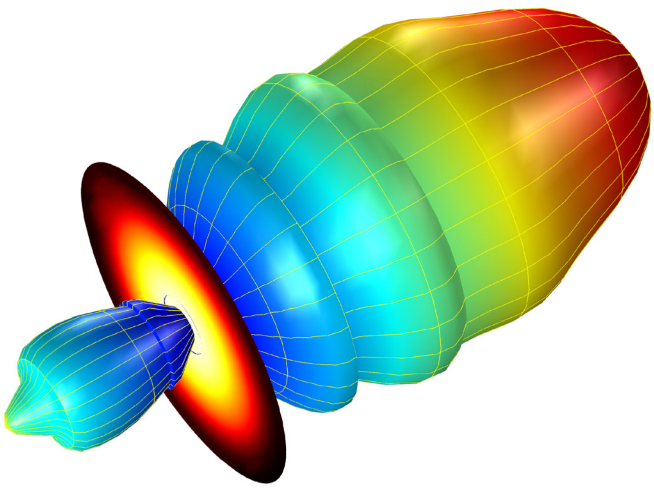

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