Applied Research Group

Seeking Answers, Deploying Solutions

A Lesson for Small Manufacturers: CFD + HPC add up to deliver competitive advantage, business success

ARG-13-01

ZIPP
SPEED WEAPONRY

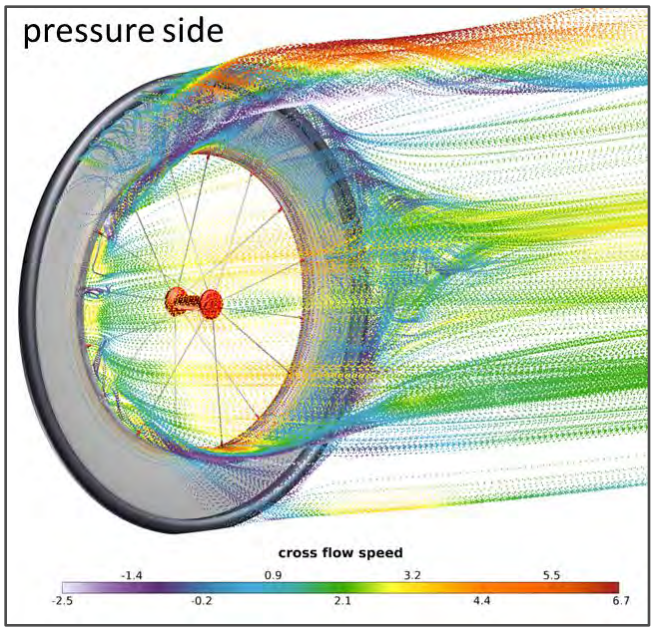
Intelligent Light

Advanced CFD and HPC Technology for Small Manufacturers

Overcoming obstacles to achieve success, gain competitive edge

The advent of digital manufacturing – advanced modeling, simulation and analysis using high performance computing (HPC) systems – has transformed the global manufacturing landscape, becoming fundamental to the success and competitiveness of large organizations in industries such as automotive and aerospace.

But for small-to-medium sized manufacturers (SMMs), the benefits of digital manufacturing have for the most part been out of reach. Often referred to as the 'missing middle' by the established HPC community, these companies – roughly 300,000 manufacturers in the U.S. (two million globally) that employ fewer than 500 people – provide the production, process, and design that underpin the operations of the big corporations. They are also responsible for an ever increasing share of the work of innovation as the largest corporations cut back internal R&D funding. Currently, SMMs account for 60 percent of R&D investment, up more than 40 percent since 1983.[1]



SMMs and Digital Manufacturing

- 55% of HPC usage is at companies with more than 10,000 employees.
- Only 8% of the companies with fewer than 100 employees use HPC.
- 56% of SMMs who are maxed out at 2D drawing have 20 or fewer employees.
- 72% of those at the desktop modeling level believe adoption of advanced methods would provide them a competitive advantage
- 82% of those at the desktop modeling level want to test new technologies at lower cost and lower risk.

Source: Intersect360 Research and National Center for Manufacturing Sciences, "Modeling and Simulation at U.S. Manufacturers: The Case for Digital Manufacturing," 2011.

Advanced digital manufacturing technologies offer SMMs the tools to meet these demands, but the barriers to adopting them – time, talent, cost, risk – are high. The majority of SMMs are still reliant on traditional physical prototyping to design and test their product designs – a time-

[1] "The Invisible Innovators: What Is the Missing Middle? And Why Do We Need Them?" Jon Riley & Matt Sakey, *Digital Manufacturing Report*, June 15, 2011

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consuming and expensive approach. The end result is that most SMMs are working on the periphery of modern manufacturing practices at a time when their production and innovation is needed most.

"Intelligent Light has essentially taken what would have taken us three years to learn, and in three months made it turnkey."
Josh Poertner, Zipp Speed Weaponry

Those SMMs who have taken the leap into digital manufacturing are finding success and a highly profitable competitive advantage. In this paper, we'll look at one engineering-driven manufacturing company whose use of HPC-enabled simulation led to 100% category revenue growth, created 120 new U.S. manufacturing jobs, and extended its industry leadership and reputation for technical innovation.

Barriers & benefits: taking a new approach

SMMs interested in adopting advanced digital technology face a myriad of decisions. Purchasing hardware and software, developing the in-house expertise (or adding new staff) to implement and run the system, and validating simulation results against existing methods all require significant time and effort. New tools and processes must be introduced and integrated with existing ones so past investments are not lost and production doesn't suffer.

The obstacles are even greater in computational fluid dynamics (CFD), a complex engineering domain that uses numerical methods and algorithms to solve and analyze problems of fluid and air flows. Due to its technical demands and intensive compute requirements, CFD has long been seen as the exclusive province of experts. Today's HPC systems and user-friendly software packages have made CFD more accessible to large engineering organizations, but for the majority of SMMs, CFD modeling and simulation is a high hurdle to jump.

The benefits of digital manufacturing technologies like CFD are numerous – reduced time and cost; faster time to market; increased productivity and throughput; and greater innovation at lower risk, to name a few. To reap the rewards and benefits, SMMs need a low cost, low risk, value added way to knock down the barriers.

Intelligent Light is successfully taking a services-based approach to solving the problems SMMs face in adopting and implementing digital technologies. As a market leader in CFD, the company has tools and methodologies that make CFD more accessible to all users, no matter the size of the organization or level of skill. Leveraging the power of FieldView®, its best in class CFD post-processing software, and the power of HPC, Intelligent Light enables its customers to streamline the CFD workflow. Powerful automation, data management, and visualization capabilities enable them to quickly become productive in this complex domain, where timely, accurate answers and results are mission critical.

At Zipp Speed Weaponry, the only remaining U.S. manufacturer of advanced high performance cycling components, Intelligent Light is rapidly developing a well-engineered, highly automated CFD workflow and integrating it into Zipp's wheel design process. In three months, Intelligent Light has created a highly

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productive CFD workflow that Zipp believes would have taken at least three years to create on its own.

Already, Zipp engineers are driving through more CFD data, evaluating a larger number of design concepts and doing so faster, and increasing the quality of designs taken to the wind tunnel. Using automation and on-demand HPC, the company is getting results cost-effectively and quickly enough to meet tough product schedules. With HPC resources running 24/7 and automatically providing reports, new wheel designs are being reviewed on a daily basis, leading to greater insights and deeper understanding at lower risk.

The project's success to date illustrates how a services-based approach can help SMMs overcome, at lower cost and reduced risk, the obstacles inherent in implementing digital manufacturing technologies. While easier access to HPC resources and powerful, specialized software tools are essential to the task, they alone are not enough to pull SMMs out of the gap. Achieving that requires value-added expertise and guidance, as the Intelligent Light-Zipp case outlined here clearly demonstrates.

The revolutionary Zipp 808 Firecrest® wheel.

Zipp's Firecrest revolution: CFD delivers market-changing product

Firmly established as the producer of the world's most advanced bicycle racing wheels, Zipp Speed Weaponry has a long history of innovation, introducing the first tri-spoke wheel design, carbon fiber disc wheel, and deep section carbon rim to the market. Along with its pioneering work in wind tunnel testing protocols and rapid prototype models, Zipp has set industry standards for years.

In 2010, Zipp once again took the cycling world by storm, introducing Firecrest®, the first wheel rim design to marry incredible speed with superior handling stability. Representing a 30% performance improvement over previous products, Firecrest was both a technological breakthrough and a corporate success, delivering 100% category revenue growth and the addition of more than 120 new manufacturing jobs in Indiana in just two years. Firecrest quickly gained market dominance – at the Ironman Triathlon World Championships, competitors chose Firecrest wheels by a margin of 8:1 over the next most common brand.

In an industry that had for decades been focused on aerodynamic drag, the ability to simultaneously design for handling stability was a game-changer, and it was a unique CFD research study that made the breakthrough possible.

CFD wheel study revolutionizes design

Looking to develop a highly efficient, robust modeling methodology and CFD workflow with FieldView, Intelligent Light's Matthew N. Godo, Ph.D., FieldView product manager, performed a CFD analysis on a rotating bicycle wheel in

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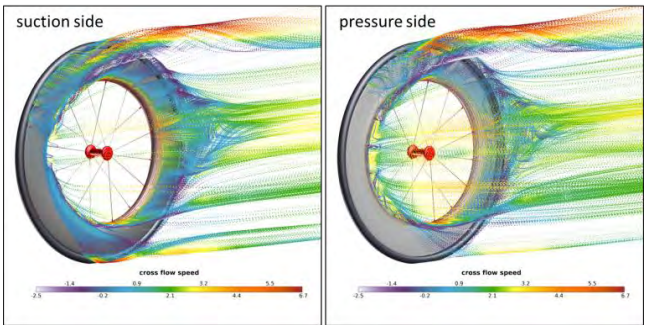
contact with the ground. An avid cyclist and CFD practitioner, Dr. Godo brought personal passion to the work. Leveraging FieldView's automation capabilities, large data handling, and advanced visualization tools, he created a highly productive workflow that was repeatedly put to the test as the study progressed.

Godo's studies found revealing glimpses into wheel aerodynamics, clearly demonstrating much of what was unexplainable in the wind tunnel, and previously unreported force phenomena. The study found that rim depth and shape affects vortex shedding behavior, with significant impacts on drag and handling.



Streamlines in steady-state flow calculations show cross flow patterns for two different wheel prototypes.

When Josh Poertner, technical director at Zipp, read the findings, it was a revelation. "The big moment was seeing that Dr. Godo was measuring steering torque, a value not measurable in any wind tunnel at the time. Side force and steering torque were always closely related, but we assumed that they couldn't be decoupled."

Using CFD to calculate center of pressure and torque (steering force) makes it possible to move beyond drag as the driving element in wheel design. "We learned that there are three elements of aerodynamic stability, and that they could be optimized through rim design, as well as measured and validated in the wind tunnel," Poertner continues. "In trying to solve the stability problem, we ended up solving the drag issue we've looked at for 20 years – turns out we just had to solve them together. We knew then, this is the future."

"Intelligent Light's bike wheel study... beautifully explains much of the 'why' – it instantly made sense to us, and recharacterized our approach to designing wheels." Josh Poertner

Breaking down the barriers

The success of Firecrest made Zipp eager to incorporate CFD into its design process, but the familiar barriers of time, money, and expertise loomed. Another obstacle, Poertner says, was simply knowing where to start. "For someone from the outside, nothing here [in CFD] is intuitive."

Intelligent Light teamed with other industry leaders to help Zipp be successful with the expansion of their CFD use (see page 10). CD-adapco, maker of the CFD solver STAR-CCM+®, and R Systems, a provider of flexible HPC resources, collaborated with Intelligent Light and Zipp to meet several goals:

- Deliver actionable information that would be quickly understood by and immediately useful to Zipp engineers with a high level of expertise in wheel design and an introductory level of experience with CFD.
- Build a reliable set of protocols and tools to enable Zipp engineers to quickly

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iterate on many wheel designs and decide which designs will be taken into the wind tunnel.

- Ensure the methodology works seamlessly with Zipp's established CAD environment and is flexible enough to accommodate current and anticipated compute needs and resources.

Working closely with Zipp engineers, the Intelligent Light Services team identified several quantitative and qualitative post-processing requirements, taking into account the need for simplicity and portability. Automated scripts had to run locally, on Zipp's existing in-house compute cluster, as well as at external HPC sites, such as those available through R Systems, with little or no modification.

Engineering a productive workflow

To manage the solver tasks, scripts were developed using Java®, the scripting language native to STAR-CCM+. Best practices for mesh generation, selection of turbulence model, and standardized naming conventions were built into the script, which generates a 'ready-to-run' STAR-CCM+ solver file. The script works with Zipp's existing Microsoft Excel® macros to gather CAD parts and assemble them, and at the end of the run, saves figures of merit and automatically exports files into FieldView for post-processing.

For the post-processing tasks, FieldView FVX-based[2] scripts were developed to automatically generate quantitative and qualitative output in the form of spreadsheet-compatible files, images, and animations. The quantitative results gave Zipp engineers immediate access to the most critical design information:

- summary results for resolved forces (drag, side and vertical), aerodynamic torque, power, center of pressure and turning moment;
- component results for the wheel, rim, spokes and hub in row and column format;
- circumferential averaged results for the pressure and suction side of the wheel for the resolved forces, aerodynamic torque and power.

Streamlines are very useful in illustrating flow structures which in turn can be used to understand and characterize differences between designs. Intelligent Light created FieldView FVX scripts to simplify and automate the task of creating streamlines and starting emitter seed locations used in both steady and unsteady analyses.

To speed interactive, qualitative post-processing, which allows for a more detailed visual interrogation of the simulation results, a FieldView FVX script was developed to generate FieldView XDB (eXtract Data Base) files. XDBs, which capture objects such as geometry surfaces, cutting planes, iso-surfaces and streamlines, are typically 10X to 100X smaller than the solver files, yet retain the solver fidelity so that quantitative calculations match whether working with the full solver data or the XDB extract.

[2] FieldView FVX is a powerful yet easy to learn scripting tool for automation.

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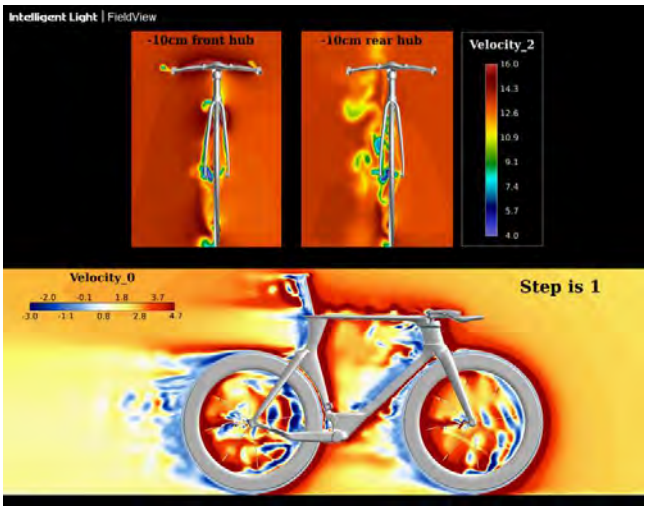


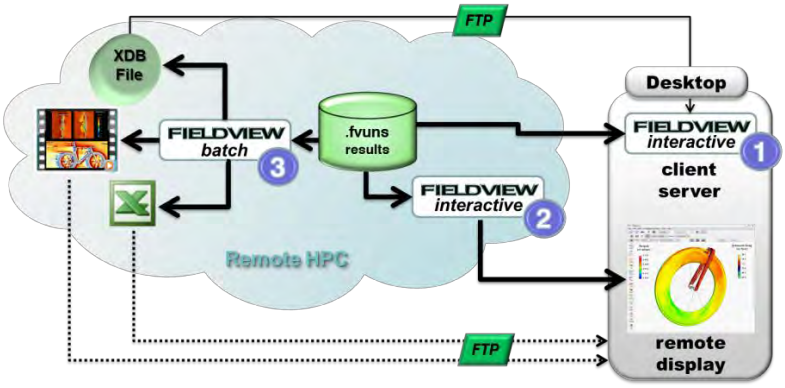
Scott Plasma racing bicycle frame with Zipp Firecrest 808 wheels. DES simulation performed with STAR-CCM+, three cutplanes showing relative air velocity.

The script was designed to generate three different XDB files for each time step. The first of these contains the geometry for the moving parts of the wheel. The second contains a series of coordinate planes saved at different locations within the data volume, and with several scalars stored on each plane. The third contains the q-criterion iso-surface, again saved with several different scalars. In one case, compared to the size of the solver file at 6.8GB, these three XDBs were 6MB, 95MB, and 106MB, respectively.

FieldView XDBs are particularly useful in transient, or unsteady, analyses, which are more complex, generate massive amounts of data and require significantly more (greater than 100-fold) compute time and disk space. Since the decision to conduct a transient analysis is usually made when the results from steady analyses require further interrogation, Intelligent Light incorporated the ability to switch from steady to unsteady as a standard capability in Zipp's workflow.

One of the greatest bottlenecks to productivity with CFD is the time and effort spent on copying and moving large data. FieldView XDBs minimize this burden. To give Zipp maximum computing flexibility, Intelligent Light enabled three different options:

- Running FieldView on local desktops connected to a server process (or processes if running in parallel) on Zipp's in-house cluster or on R Systems' HPC resources. (1)
- Running FieldView directly on the compute cluster where FieldView exports are located, sending a remote display back to the local desktop. (2)
- Running FieldView as a batch process directly on the compute system, creating XDBs, spreadsheets and animations that are sent via FTP to the local desktop. (3)



Three options maximize computing flexibility.

To handle batch post-processing, a FieldView FVX script collects all the export files for a given design, runs the analysis and automatically outputs three spreadsheet-compatible files with numbers of merit and component breakdowns. Another script

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outputs circumferential averaged results for all yaw angles studied. Information is split out to show the results on the pressure and suction side of the wheel separately, helping Zipp engineers determine how well the flow stays attached around the entire wheel, and how this flow behavior changes as a function of yaw angle.

CFD + HPC + Services = A Winning Equation for Zipp Speed Weaponry

- Productive CFD workflow in 3 months
- Studying 30x more design concepts
- Higher quality, more refined design iterations
- Greater performance improvements gains from one product generation to the next
- Rapid expansion of knowledge base
- Innovation, competitive advantage secure

With the new workflow in place, Intelligent Light and Zipp engineers performed CFD analyses on six Zipp rim designs, including two Firecrest production rims. Reviewing the performance predictions for these baseline cases, Zipp engineers found good agreement with their wind tunnel data – another key step in confidently adopting advanced simulation technology.

Accelerating the pace of development

Just months into the project, Zipp is already reaping the benefits of their HPC-enabled CFD workflow, testing significantly more concepts without the time and cost risks associated with physical prototyping.

Automation is enabling faster design iteration, more refined designs, and larger incremental improvement gains. “On average, we’re studying a new design every 18 hours,” Poertner says, “and the level of refinement is remarkable. From 100 ideas, we can narrow down to 20 and take 12 of those to the wind tunnel. From a throughput perspective, it’s fantastic. More good ideas emerge and we have more good late-stage design candidates.”

One of Zipp’s primary motivations for developing its CFD capability and making it a core part of their wheel design process was the ability to see and understand the ‘why’ questions that wind tunnel testing can’t answer. “In the tunnel,” Poertner says, “no matter what I put in there, I get a single drag value and no insight into the interactions. The tunnel doesn’t provide the ability that CFD does to analyze a system and get values on the subcomponents.”

CFD is rapidly expanding Zipp’s knowledge base, enabling bigger performance improvements with each product generation. New insights and best practices are captured and embedded into the workflow through automation, saving time and effort and accelerating the development cycle.

The robust CFD workflow is complementing and maximizing the time and financial investment that Zipp has made in its wind tunnel testing regime by improving the quality of the designs selected for testing. In the past, Poertner explains, by the time they’d locked onto a rim shape to take into the tunnel, they’d already have spent thousands of dollars and significant time building physical prototypes, making it impractical to add a newer design iteration to the wind tunnel schedule. Now, with the

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ability to iterate and optimize upfront, Zipp is able to identify the most promising design ideas for wind tunnel testing.

The project has provided some surprises for the Zipp team. Poertner finds it interesting "how much more data we're driving out of FieldView – graphs, data points, spreadsheets, etc. When we started this project, defining what we wanted out of FieldView, we had 30 image descriptions and five data points. Now we probably have 50 data points and 10 images. The system kicks out all the forces, center of pressure location, coordinates, and more – and right there we have more data about a run than almost anyone I know in the bike industry is collecting. At the end of the day, the data is what's supercritical."

Other unexpected findings during the project, such as FieldView's usefulness in debugging models, are proving helpful in numerous small ways. As for the project itself, Poertner says, "We couldn't have done any of this without Intelligent Light," he says. "I truly don't know if it could have happened. Like so many others, we could easily have spent three years just starting to get proficient. That's an inevitability for SMMs trying to do this without this level of support. Especially in a small shop like ours, where everyone wears six hats, the prospect of losing even a year of one person dedicated to such a task is really hard to justify."

"Intelligent Light has essentially taken what would have taken us three years to learn, and in three months made it turnkey," Poertner states. "Without Dr. Godo and Intelligent Light's services, we'd be reading tutorials and trying to look at the flow over a sphere. This is a totally different level of support, and knowing what we do today, it's worth it."

Maximizing ROI, reaping rewards of CFD

With this automated, HPC-enabled, production CFD workflow, Zipp has the tools it needs to capitalize on its market leadership and maximize its return on investment in CFD. Faster design iterations, higher quality concepts for wind tunnel testing, and greater understanding at lower risk provide the company with a definite, sustainable competitive advantage.

Closing the digital technology gap for SMMs requires leveraging analytical capabilities, HPC resources, and customized automation and data management tools. The goal of the process is a sophisticated CFD workflow that is immediately productive and delivers actionable information for critical design decisions. The rewards of that workflow – higher productivity, reduced time and costs, improved and innovative products, an expanded knowledge base – deliver a powerful ROI and a sustainable market advantage for small manufacturers in any industry. ■

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PROJECT COLLABORATORS

Intelligent Light — Project lead; provider of FieldView post-processing software and customized CFD workflow solutions.

CD-adapco — Providing Zipp with the capability to accurately model their physics through their STAR-CCM+ solver suite. Power on Demand licenses complement Zipp's standard license and allow large simulations to be run on HPC systems without per-processor license fees that can render some other CFD solutions unaffordable. Dedicated support engineer provides continuity and responsiveness as well as a path to all of the company's experts.

"It is clear that the combination of STAR-CCM+ and FieldView have afforded Zipp engineers a distinct advantage in their race to build better wheels. The results speak for themselves. Zipp wheels are widely recognized as 'best in class' in the market and, more importantly, on the road. We at CD-adapco are proud to be a small part of this winning team."
Bill Clark, Ph.D., Executive Vice President

RSYSTEMS powering innovation — On-demand HPC allows SMMs to easily and affordably utilize the latest-generation HPC capability when they need it, removing the limitations of in-house compute capacity without requiring new capital investments in IT infrastructure. This cloud computing capability is a tremendous enabler for SMMs when combined with FieldView and STAR-CCM+ which are efficiently run both locally and remotely by Zipp engineers.

"R Systems' HPC resources combined with Intelligent Light's FieldView post-processing software provides clients an innovative tool suite for maximum productivity. We see FieldView as an key enabler for CFD users wishing to leverage cloud-based resources."
Brian Kucic, Business Principal

intel — Provider of advanced compute processors that are the engine behind the CFD work performed by Zipp. Their latest processors are always readily available at R Systems, where they are combined with high-performance system architectures and interconnects to deliver maximum performance and throughput.

"Intel has supported Intelligent Light in a case study with Zipp Speed Weaponry. Intelligent Light's simulation of the airflow around Zipp's wheels led to the understanding of how to improve their handling and Zipp was able to build this knowledge into their latest wheel design.This product has changed the wheel industry, giving Zipp a product that is fundamentally better than their competition. This in turn has led to a significant increase in sales and a large return on their investment that could not have been done any other way. This case study is an excellent example of how CFD can be brought to smaller manufacturers, showing how they can also 'make the leap' into this technology."
Bill Feiereisen, Senior Scientist and Corporate Strategist, High Performance Computing

"Looking back now, it's shocking, but of all the problems that had to be solved in this project, the CFD was really the easiest one. Quite frankly, that was the most straightforward. All the other workflow design, data management, and process stuff has been much harder."
Josh Poertner, Zipp Speed Weaponry

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