MTC DEVELOPS SIMULATION APP TO REVOLUTIONIZE DESIGN FOR ADDITIVELY MANUFACTURED PARTS

The Manufacturing Technology Centre takes a new approach to part design and interdisciplinary research, using simulation and computational apps to support teams across the company.

By **LEXI CARVER**

ONE OF THE GREATEST CHALLENGES IN DESIGNING high-precision parts is being able to quickly fabricate them in a repeatable way to meet very tight specifications. If you're designing aircraft engine fuel injectors, for instance, you need precisely measured parts in order for airplane machinery to perform properly and for passengers to entrust their safety to the airline. In order to achieve this, engineers must often optimize not only a specific part, but the manufacturing process itself.

Additive manufacturing, also known as 3D printing, has been on the rise in recent years as a novel and promising way to create parts with less material waste and even to build shapes that were previously impossible to fabricate through more traditional methods.

The Manufacturing Technology Centre (MTC) in Coventry, UK, researches additive manufacturing techniques and supplies designs and prototypes to part producers in the aerospace industry. One additive manufacturing method they employ frequently is called laser powder bed fusion, which uses powder layers tens of microns thick to build parts layer by layer using a laser. The system follows a predefined toolpath to fabricate a part with very fine geometrical details.

In order to verify the quality and performance of their additively manufactured parts, the MTC has used COMSOL Multiphysics® software for virtual design testing, validation, and performance prediction. Over the past couple of years, they began building apps from COMSOL models that allowed them to share their analysis capabilities among different teams exploring a variety of projects for their customers.

I interviewed the MTC team early on in the app-building stage (see page 5 of *COMSOL News* 2015). A couple of years later, we checked back in to find out how their use of simulation and computational apps have impacted their design process and their interdepartmental work.

A NEW APPROACH TO PART DESIGN

BORJA LAZARO TORALLES, TEAM LEADER of MTC's Physics Modelling team, tells me that laser powder bed fusion has certain advantages over other methods of fabrication. Deposition rates are slower than shaped metal deposition processes, but higher accuracy and resolution can be achieved.

One downside is that as the metal cools, deformations can occur after a few layers have been built. Thermal cycling due to the high temperature gradient and quick cooling can cause residual stresses during deposition. This slowly alters the microstructure, which causes distortions in the final part, such

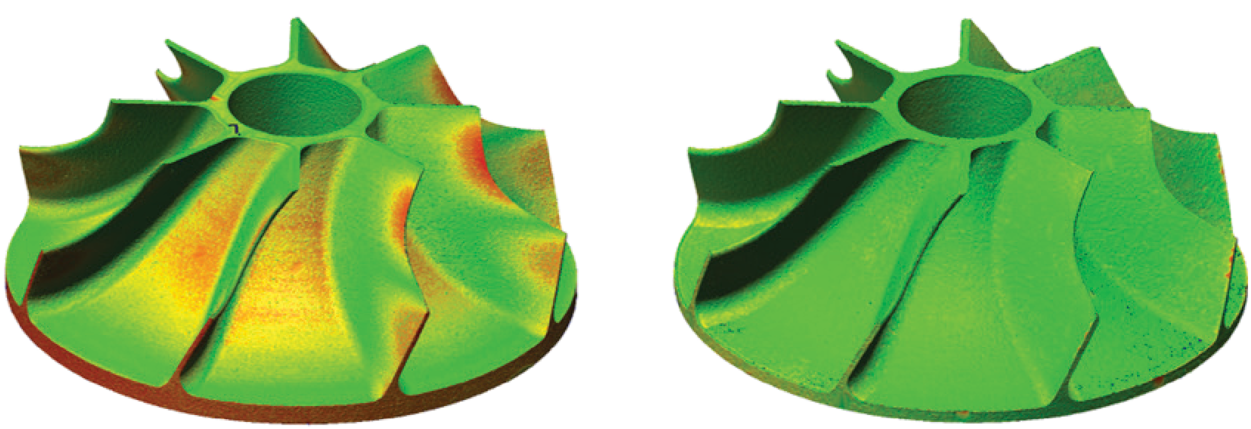

Figure 1. Left: Example of a distorted part, where the blades of an aircraft impeller have warped due to residual stresses. The red color indicates regions of high relative distortion. Right: The final impeller design after adjustments for distortion.

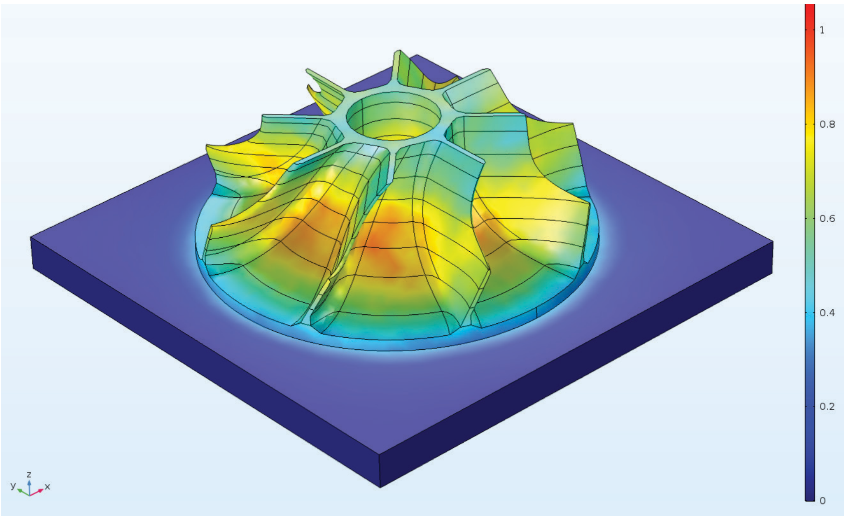

Figure 2. Simulation results showing displacement in the impeller to predict the final part shape.

as those shown in Figure 1 (left).

In certain cases these deformations are negligible, but in other cases a difference of just 100 microns (0.1 mm) can be too far off specification and make the part unusable. For these situations, the MTC team needed a way to get around the effects of thermal cycling.

Since they couldn't remove the thermal cycling and the evolution of the microstructure, they approached it another way: "We created a simulation that predicts the stresses and deformation during a part build to give us a clear understanding of how it will distort during printing," Lazaro Toralles begins. "Once we have this information, we can 'invert' the distortion in the part's design, which allows us to account for the warping ahead of time so that the final product distorts into the shape we actually want."

This clever way of working backward from errors and building them directly into the designs has helped them create parts within the required tolerances more efficiently, knowing that the predictive model will guide them to a shape that results in minimal error (Figure 1, right).

Adopting multiphysics simulation has also opened up new lines of communication with the MTC's design for additive manufacturing team. Lazaro Toralles' team built an app around their COMSOL model for predicting distortions, which allows their colleagues to run the simulation and see where designs need to be changed without having to completely understand the original model.

Before sharing an app with their part designers, the team of course needed to build the high-fidelity model the app would be based on.

» MODELING FOR COMPLEX AND VARIED PARTS

HOW WOULD YOU CREATE A SIMULATION that allows you to test any shape made from any metal? The range is extreme. To build a model that gives design engineers the information needed to make appropriate design adjustments, Lazaro Toralles and his team first defined a new modeling process that would predict the final shape of large parts.

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"Traditional additive manufacturing models are very detailed, down to the microstructure. But these are not suitable for simulating large part builds because of the computational cost," he tells me. "They take forever. But we still need to understand how an entire part will behave during printing. To circumvent this, we 'lump' the layers of the print build and impose an analytical temperature field based on experimental data. This reduces solving time but still gives an accurate solution."

Since the MTC works with a variety of metals, from aerospace grade titanium to stainless steels, they parameterized inputs in the COMSOL model such as material properties, lumped layer thickness, build plate fixturing on the part, and mesh element size so that they could use the model to test parts of many shapes, sizes, and materials.

Within the COMSOL® software environment, they used the structural mechanics functionality to define a linear elastic material with temperature-dependent plasticity and thermal expansion, using the analytical temperature field. The app also performs several automated CAD operations to prepare the geometry for suitable 'lumped' layering.

The simulation then generates a grid to represent an approximate toolpath, given that the lumping of layers makes it impractical to use the real one. The temperature field is imposed on the grid points. The software then computes the stresses generated during deposition and predicts the final shape of the part (Figure 2).

» SPREADING PREDICTIVE CAPABILITIES

WHEN THE SIMULATION PREDICTS the errors in a particular part, getting the information to the design team in a clear and concise way is another

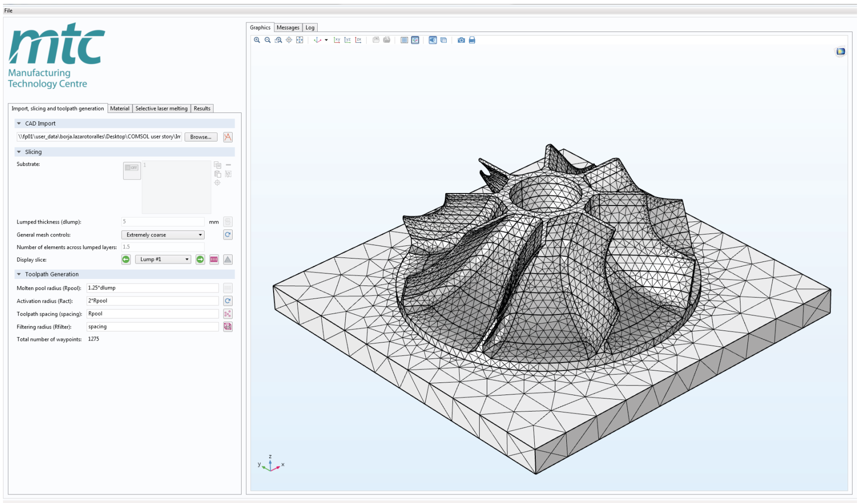

Figure 3. The MTC app enables the user to make design adjustments and test changes in the simulation, but without showing the underlying multiphysics model.

matter. Many companies have broken down their modeling groups into design and simulation, benefiting from employees who specialize in one or the other. But this leaves a gap between part design and part analysis.

Apps bridge this gap by allowing simulation specialists to package their models into user-friendly interfaces, which designers use to run their own tests without needing to understand all the complexities of the simulation underneath. This allows design engineers to make adjustments more easily and saves the simulation experts from running an analysis every time a new part's performance needs to be evaluated.

The design team creates lots of complex parts using a wide range of CAD platforms, so the COMSOL model and corresponding app needed to be quite robust. It includes CAD import features so that any shape can be tested. This is especially important for organic shapes — those based on natural features like plants, animals, and land formations — such as those drawn in a program like Rhino.

The app, created with the Application Builder available in COMSOL Multiphysics, displays the simulation results — final shape, deformation, and stress levels for a given part, in this case an aircraft impeller (Figure 3).

"We [the simulation team] often use the app ourselves," Lazaro Toralles adds. "Once we built it, it was easier to make a few input changes in the app rather than go back to the original model. But the design team doesn't work on simulations. The app was built for them because it allows them to import part models and check the prediction of how it will warp during printing."

The Application Builder included in COMSOL Multiphysics allowed Lazaro Toralles to have full control over what was available to the app user. As the app has evolved based on new needs from the company, he's been careful to build in the necessary outputs and displays, as well as locking certain inputs and conditions so that app users cannot inadvertently create errors. The underlying model setup remains hidden from the user, but the simulation capabilities have spread.

» SOLIDIFYING NEW COLLABORATION

LAZARO TORALLES DEPLOYS THE APP through the COMSOL Server™ product for distributing, managing, and running simulation apps. Hosting the app online makes it available for colleagues who have been given access, anywhere in the company.

Simulation has changed the way teams work together at the MTC. Now they have an established routine where designers and simulation engineers are able to communicate quickly, test designs easily, and make changes that result in the desired prototypes for their customers to manufacture on a wide scale.

Lazaro Toralles admits that there was skepticism when they first began offering simulation apps to other departments. "We had to earn their trust. But since the model consistently provided good results, everyone has found it helpful. The app contains everything: it slices the print geometry, shows the mesh, guides engineers through the distortion analysis, and provides feedback." Their simulation work has been an important part of helping the MTC establish a workflow that improves communication between the physics modeling team and the design team. This, ultimately, has changed the way they approach part design. ◎

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