Speeding the Route to Quality

Rolls-Royce uses Isight for simulation process automation and design optimization of aircraft engine turbomachinery

Designing a jet engine is one of the most difficult engineering challenges there is. The intake, fan, compressor, combustion chamber, turbines and exhaust must all operate in tandem throughout a vast range of altitude, weather and temperature conditions. Further complicating the design task is that important, invisible player: aerodynamics. How do you get power efficiently out of the system by controlling the speed and direction of the air that moves through such a complex structure?

The engineers at Rolls-Royce, whose core product is the gas turbine engine, understand the intricacies of this challenge well. The company is a world-leading provider of power systems and has established a strong position in global markets—civil aerospace, defense aerospace, marine and energy. In the civil arena alone, their engines can be found on 30 types of commercial aircraft, with more than 13,000 engines in service for 650 airlines. A Rolls-Royce powered aircraft takes off or lands every 2.5 seconds.

While it once took up to ten years to develop a new aircraft engine, the industry average has now shrunk to about two. And Rolls-Royce is working to condense that time even further. "Our customers expect consistent performance, fuel-efficiency, and short delivery cycles," says Dierk Otto, design systems engineer at Rolls-Royce

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*Design Systems Engineer,
Rolls-Royce*

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Deutschland Ltd & Co KG. "On our side of the equation we are looking to ensure quality and reliability while keeping design, manufacturing and maintenance costs low."

The solution for Rolls-Royce has been its "robust design" program which emphasizes the leading role of design as the entry point into the company's Six Sigma program. This focus on the impact of early design on quality has led Rolls-Royce to employ powerful engineering resources from the fields of CAD, CAE, CFD, FEA and more, in the pursuit of optimum product performance. "We are continuously evaluating new design concepts by integrating analysis tools from different disciplines," says Otto. "Our experts

and teams rely heavily on Isight software for process integration and automation, as well as optimization, to accelerate problem solving in this complex design environment."
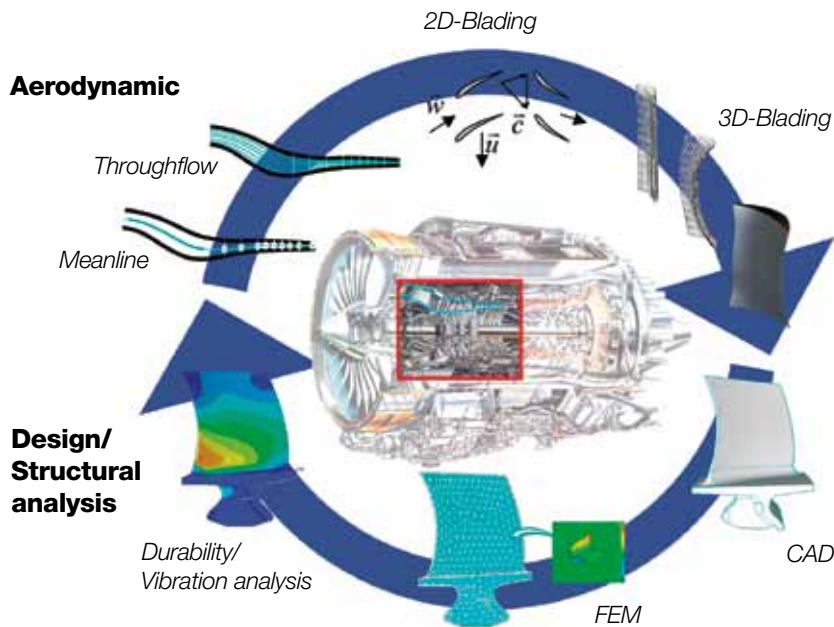
Isight was introduced at Rolls-Royce more than a decade ago and is now employed throughout the company. The software's drag-and-drop capability for creating simulation process flows (known internally at Rolls-Royce as 'workflows') lets engineers link—and automate—all the steps in a particular design process, allowing the simultaneous integration of multidisciplinary simulations (like aerodynamics plus stress plus weight plus cost). Design exploration with DOE or Monte Carlo methods or a variety of powerful optimization techniques (like genetic, gradient-based, or deterministic algorithms) can be performed automatically, and then linked back into an ongoing workflow. Any number of design parameters and analysis types can be included in the workflow, and the design can be further optimized through material trade-off studies, tolerance reviews and manufacturability assessments.

Robust design of an engine compressor

As an example of the Isight toolkit in action, consider the design of an aircraft engine compressor. It all begins with the aforementioned challenge of aerodynamics. A large aircraft wing and an individual engine blade are actually both airfoils—their shape and orientation affect the direction, lift and thrust of the air that passes by them. But a wing is a passive airfoil, while a blade is an active part of the propulsion system. Air entering through the engine fan into the low-, intermediate- (in a three-shaft engine), and then high-pressure compressors is pulled through a gauntlet of hundreds of blades— some spinning (rotors), some not (stators). The airfoil cross-section, number and layout of these blades are determined by how much pressure is required at each stage of the compressor.

The first compressor task is meanline prediction. Starting from an existing design, the engineer must find the optimum form of the annulus—the donut-shaped area of rotating "blade exits" through which the air flows—for the desired new configuration. The meanline is calculated halfway between the hub (base of the blades) and the tip (outer end of blades) of the annulus. The total area of the annulus determines exit velocity and pressure rise for each stage. This is the principal determinant of the size and cross-sectional layout of the compressor, how many stages it should have and what

The design iteration loop for an aircraft engine compressor blade. Process automation and optimization with Isight can be applied at any stage of the cycle.

the inner and outer diameters of each stage will be.

At this point the design engineer is not thinking about blade shape; he is only conducting a thermodynamic and fluid flow exercise to determine the overall flow of air that results from different diameters of annulus at different compressor stages. Yet it's a very complex exercise already: Aerodynamic parameters that have to be taken into account in meanline prediction include pressure ratios, efficiency, surge margins, form factors and so forth. Running these analyses manually would be immensely time-consuming. But by using Isight, the engineer can integrate all the meanline tasks into an automatic process flow that works through each task sequentially, evaluating the data and applying any relevant external programs, to arrive at the optimum solution.

Isight components decrease design process complexity

Although the typical Isight user at Rolls-Royce is an expert who can set up such complex simulation flows quickly, not everyone on the design team needs to work at these deepest levels of expertise. For example, a CFD analyst might want to use an Isight workflow of a meanline prediction to measure the feasibility and consequences of his own design ideas and changes. To support these more casual users of Isight, Otto and his colleagues created customized Isight components of calculation routines, data mapping, program controls and bundles, and dynamic link libraries. The casual users can

now call upon whatever component they need and drop it into their own simulation flows to speed up and simplify their work, generating the same solutions that an expert would without having to work through all the subroutines.

"This user-friendly component approach gives our team a number of advantages," says Otto. "Information can be shared easily—even with worksites in other locations—and we can standardize our process build-ups more readily as well as speed up our runtimes."

Multidisciplinary optimization drives design

The next step in the development of the engine compressor requires the engineering team to move from one-dimensional meanline analysis to throughflow (optimizing streamlines of predicted air movement inside the annulus). The final step is actual blade design. Starting with two-dimensional blade geometries (profile sections) that produce the flow angles and conditions predicted by the meanline and throughflow analyses, designers use CFD solvers within Isight to automatically optimize the geometry of every single blade, the cross-section profile of which is the familiar airfoil shape.

By stacking multiple airfoil profile sections on top of each other, connecting them with linear filaments, adjusting the lean of the resulting structure and giving it a root and a platform to sit on, the engineers arrive at the first 3D shape of a blade. Using an in-house Rolls-Royce blade generator tool, these blade profiles can be modified via

different design parameters like maximum thickness, blade angles, camber style, etc. The goal is to find the airfoil design that best meets performance requirements and structural criteria as well as the previously determined, all-important aerodynamics.

In aircraft engines, lighter weight is always at a premium. Arriving at a CAD model of a blade where the geometry and orientation have been optimized for weight, the designers still need to prove that the blade will survive under real-world conditions. This is where static and dynamic (FEA) are brought into the optimization loop to perform stress analysis, study vibration and resonance behavior, and examine material creep and lifetime wear. When critical issues are identified, the engineers can modify the sections and rerun the stress analysis. Here Isight is an integral tool for accelerating the identification of the best design solution.

This automatic blading design process has a great deal of external input-output data flow, so selecting the correct design parameters is very important to avoid error. Taking a page from their experience with creating custom components for meanline prediction, the Rolls-Royce team decided to create a series of templates for blading as well. Again, the casual user (perhaps an FEA analyst this time) can now select just the required design parameters, set upper and lower boundaries for the desired parameters, and include DOE or optimization runs to refine constraints against performance goals. "While templates help speed up our process build-ups and reduce error-sources, they are also designed to preserve process flexibility," says Otto.

Evaluating more design options— faster

Using components and templates together in a single design iteration loop—modify airfoil, run 2D CFD calculations, do 3D optimization with FEA, and finally evaluate results—now takes only 13 minutes, whereas previously it would need about a day. "We have noticeably less redesign work now, which leads to better control over manufacturing costs," says Otto. "Overall this allows faster response to our customers' demands while adhering to the strictest quality standards of the aircraft industry."

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