Assessing Variability to Achieve Robust Design

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One of the most complex mechanical systems relied on everyday is an aircraft engine. The engineers who design the gas turbines that power today's huge commercial jets must master a myriad of details in these highly-integrated, fine-tuned machines. The turbine, the compressor, the combustor, the casing, the rotors and bearings, the inlet and exhaust—all must work in tandem in extreme conditions of temperature, pressure, and stress, not to mention high forces on the rotating components.

Designing an aircraft engine puts many engineering disciplines into conflict: aerodynamics, mechanical stress, noise and vibration, heat transfer, material properties, reliability, life prediction, and more. And the finished product had better be robust; aircraft manufacturers demand efficient operation, long life, and short delivery cycles (it used to take about 10 years to develop a new aircraft engine but the industry now aims for an average of only two).

At the same time, aircraft engine makers are targeting low design, manufacturing and maintenance costs. So it's no surprise that the business of making all this possible can be competitive, demanding—and expensive.

Yet over the past eight years at Rolls-Royce, we have arrived at a roadmap for managing the multidisciplinary complexity of gas turbine design that enables us to work together with maximum efficiency, keep our customers happy and achieve our goals on time. And we've even saved money doing it. The underlying concept for this method is what we call "robust design."

Robust design is a 360-degree assessment of variability in the early design phases. We use this term often because it grabs the attention of designers and engineers by underscoring the pivotal role of design as the entry point into a complete Six Sigma program.

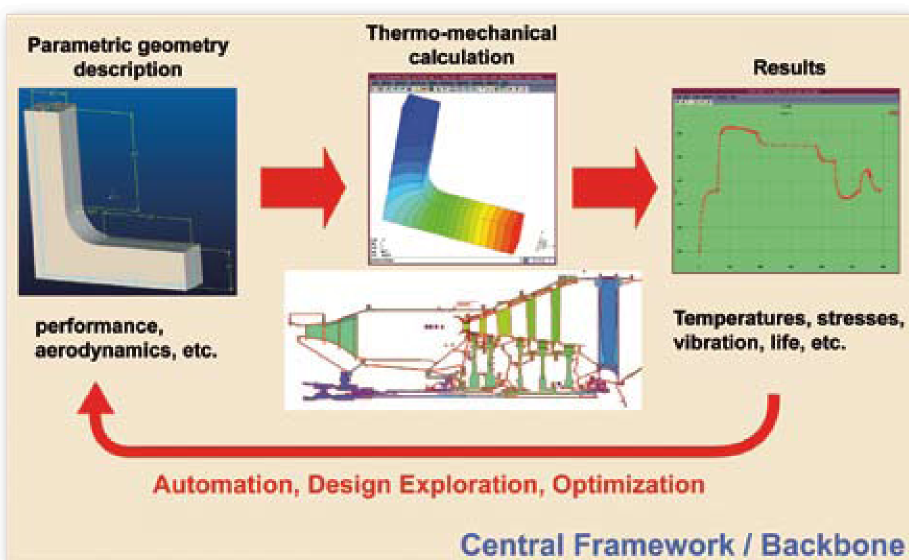
The aim of robust design is to deliver consistent product performance to the customer—so that every engine they buy runs predictably, copes with the extremes in its operating environment and even survives certain unexpected events. Building robustness into our products from the earliest design stages has far-reaching effects down the supply chain: less redesign work, reduced development times, and better control over manufacturing costs.

The aircraft turbine is an extremely complex mechanical system. This photograph is reproduced with the permission of Rolls-Royce plc, copyright © Rolls-Royce plc 2009.

The robust design process enables us to incorporate customer requirements—and even changes—quickly and flexibly, while cost-effectively adhering to the strict quality standards demanded by the aircraft industry.

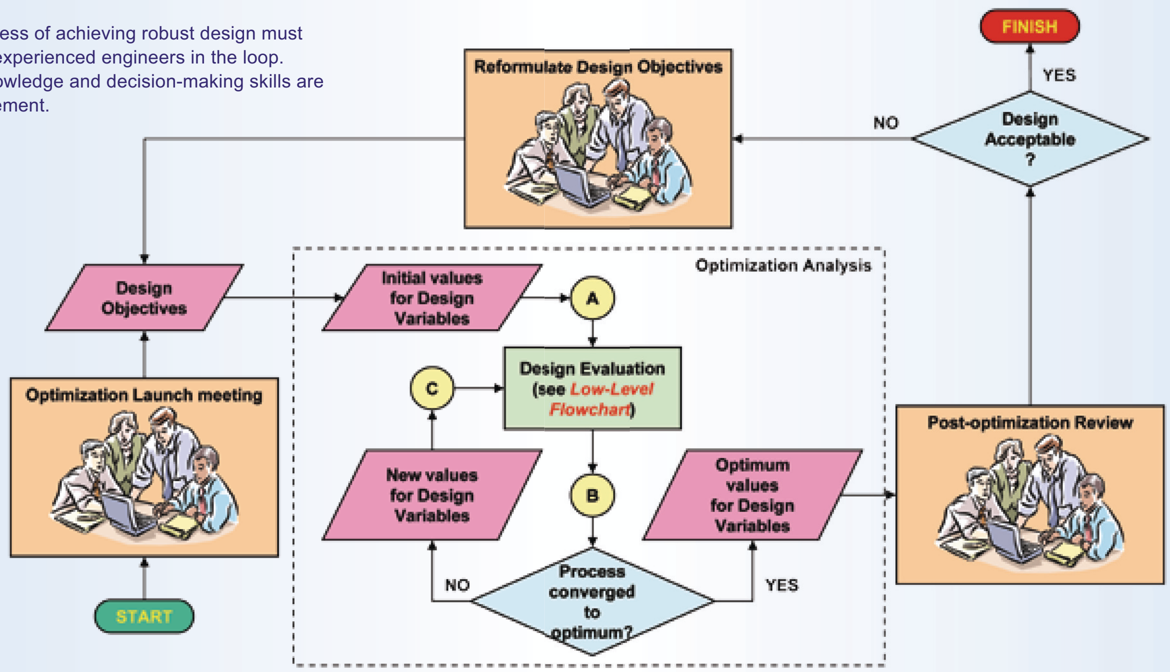
Why did we implement robust design at Rolls-Royce? Because we realized, early on, that the sheer size and complexity of the aircraft engine design and development "problem" could only be mastered through a combination of simulation, process automation and optimization. We have been using Isight software as our main toolkit for robust design for almost a decade.

At first, our management approached this new technology with caution, but our early successes with it convinced them of the value of standardizing on a single solution



The robust design process assesses variability in the early design phases and uses automation and optimization to deliver consistent performance to the customer.

The process of achieving robust design must include experienced engineers in the loop. Their knowledge and decision-making skills are a key element.



instead of growing lots of different solutions. Once it was realized that process integration and automation could be a cost driver for manufacturing, everyone was on board. Launching with pilot programs in Germany and the U.K., we now use this software throughout the company.

Our five steps to achieving robust design are:

- Automate the Process – execute design and analysis without human intervention
- Process Integration – build up integrated processes between the various disciplines
- Design Exploration – understand the full design space
- Optimization – achieve the best compromise regarding all requirements
- Achieve Robust Design – ensure that the design performs across variable conditions

We now have the complete toolkit to coordinate these steps. In order to thoroughly assess variability (which is what robust design is all about), we first must automate the design simulation process. The software's easy drag-and-drop capabilities help coordinate this automation through the creation of simulation flows, which enable simulations to be executed 'hands-free.' Next, we integrate the results of our multidisciplinary analyses so that we simultaneously look at aerodynamics and stress and thermal and cost and weight, etc. Then we run any necessary design explorations (with Design of Experiments or Monte Carlo methods, for example), and finally we optimize the entire problem in order to achieve our goals.

Of course, with a highly complex gas turbine engine we are running a vast series of such robust design exercises, starting at the system level (whole engine cycle optimization and turbine preliminary design), through sub-systems (turbine thermo-mechanical analysis, secondary air system analysis, etc.) and finally focusing on components (turbine blade, discs, casings and so forth). Our process automation and integration software is a key part of driving and integrating this entire robust design workflow forward through materials tradeoffs and tolerances all the way to optimum manufacturability.

Because none of this can be accomplished without a great deal of simulation data, we also use integrated frameworks to link our simulation tools and achieve speed-up of simulation tasks, achieve multidisciplinary processes across teams and business units, and lock in standardization of the simulation processes we use over and over again.

While automating all of these tasks is essential, we cannot achieve robust design without the continued input of a full cadre of highly experienced engineers, which is why I focus so much on training these days. It is critical to keep our people in the loop as their knowledge and decision-making skills remain a key element in the process.

By empowering our people to apply these software tools as broadly—or as narrowly—as needed along the way, we have reduced our development costs and cycle times and reaped a competitive advantage much greater than what we spend on software.

The lessons we have learned, and the techniques we are using, can be applied by other design and development organizations who need to assess a range of variables that impact overall performance and costs. I encourage you to participate in industry groups dedicated to sharing experience and knowledge related to robust design technology and methods. And investigate the use of process integration and automation as part of your design simulation process. It is almost certain that, like Rolls-Royce, you can achieve efficiency gains and cost savings while improving the performance of your product.

Dr. Karl is the lead of Robust Design for Rolls-Royce and is based in Indianapolis, Indiana. He recently chaired the NATO AVT-167 conference in Montreal, Canada, on Strategies for Optimization and Automated Design of Gas Turbine Engines. He holds a Ph.D. in Aerospace Technology from the University of Stuttgart.