Robust Design of Gas Turbine Blades

This article may be found at
http://www.soton.ac.uk/~cedc/posters.html

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UTP for design

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Robust Design

Robust Design is concerned with minimizing the effect of uncertainty in design without eliminating the source of uncertainty. By rationally accommodating uncertainty arising from sources such as manufacturing errors/ tolerances, leading edge erosion and operational wear and damage, robust design methods can improve the performance of compressor and turbine blades. Robust Design focuses on reducing the deviation of performance from a desired nominal performance. It essentially involves a tradeoff between the nominal performance and the deviation from the nominal performance.

Why Robust Design?

The deterministic methods currently in use for product design either tend to over optimize or produce solutions that perform well at the design point but have poor off-design characteristics. There is a need for methods that provide accurate and efficient solutions to nondeterministic design problems. Robust design methods in conjunction with probabilistic analysis can be employed to solve such problems. Figure 1 shows the flowchart employed here for robust design.

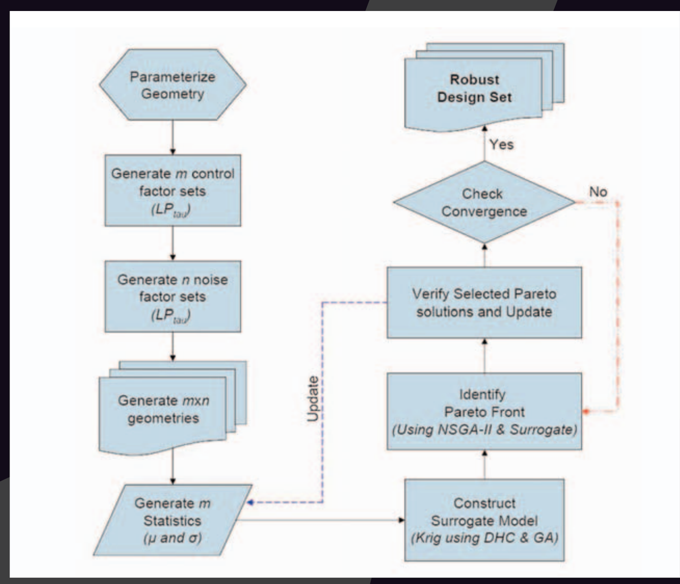

Fig 1

Compressor Fan Blades

The performance of compressor fan blades is central to the behaviour of modern gas turbine engines. During operation, compressor fan blades are exposed to a number of erosion processes that lead to pitting of the leading edges and damage due to foreign objects. Another source of geometry variation can be due to manufacturing errors. Hence there is a need to design compressor fan blades which are robust to erosion, damage and manufacturing uncertainty. Geometric variability in compressor airfoils can cause major aerodynamic losses. These uncertainties have been modeled in the Rolls-Royce code PADRAM. Figure 2 shows a foreign object damage (FOD) model with grids and figure 3 shows manufacturing variation and leading edge erosion models.

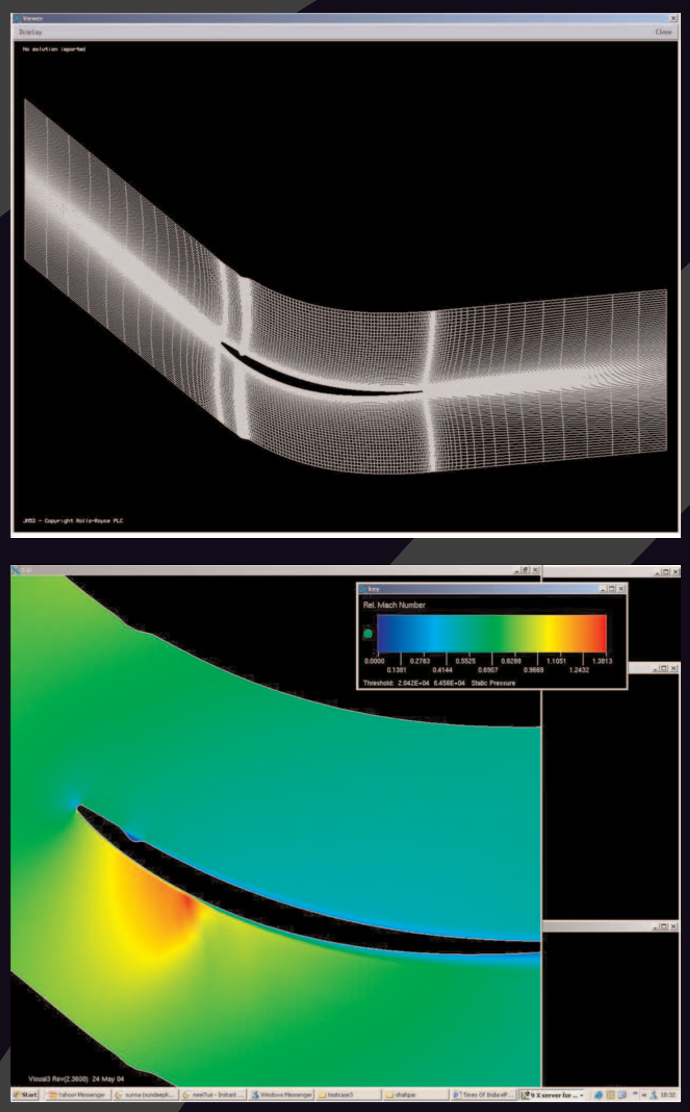

Fig 2

Method

The present work focuses on understanding the effects of FOD, leading edge erosion and manufacturing variations on the performance of compressor fan blades, with the aim of designing blade geometries that are less vulnerable to geometric variability. A probabilistic model of the blades with uncertainty in geometry has been developed. A combination of Hicks-Henne functions, splines and polynomials are used to parameterize the airfoil. The robust design approach employed here combines an efficient multiobjective optimization algorithm with the parametric geometry model, CFD and surrogate models. Design of Experiment (DOE) technique (LPτ) is used to create an initial set of inner control and outer noise arrays. NSGA-II is then employed in conjunction with Krig to search the design space for Pareto optimal solutions. A sequential search strategy is used to update the surrogate model as the optimization proceeds. Figure 4 shows the converged Pareto front.

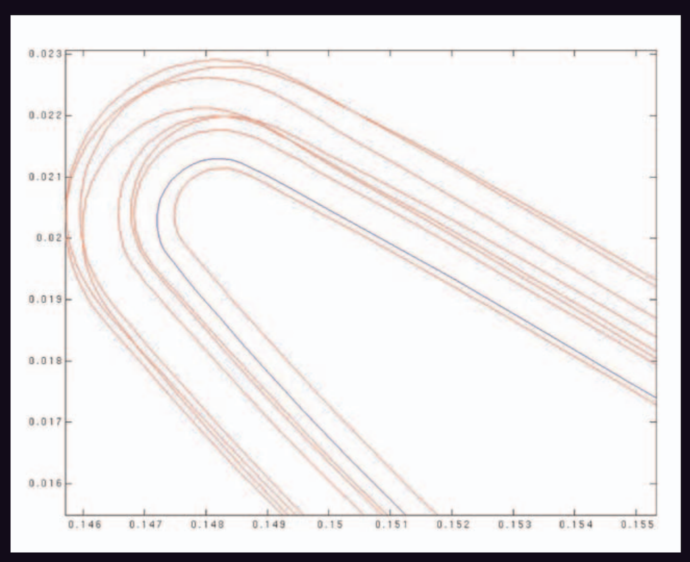

Fig 3a

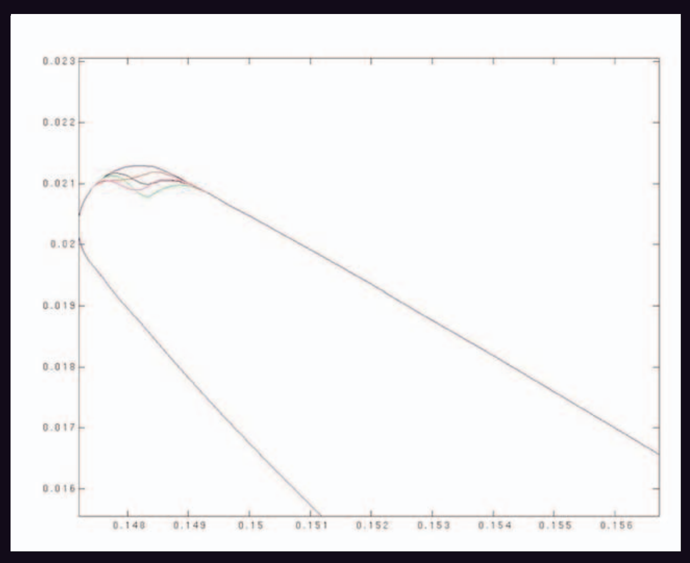

Fig 3b

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Results

A design on the final Pareto front is selected for further analysis and compared with a deterministically optimal design. A 100 point DOE with variations in location, height and width of the erosion is conducted for both the blades. The CFD solutions are used to train Krig models, which are subsequently employed for a 10,000 point Monte Carlo simulation. Figure 5 shows the histograms for the robust optimal design as compared to the deterministically optimal design.

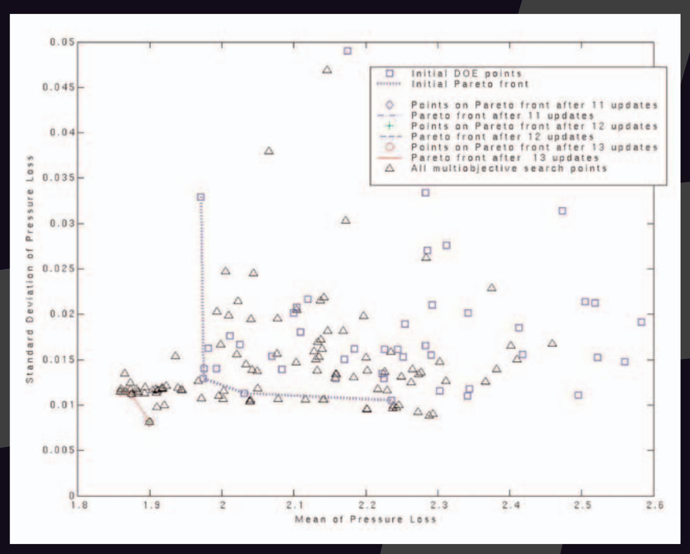

Fig 4

The histogram of the robust geometry shows less variability in pressure loss as compared to the deterministic design. Although the robust design has a slight worse mean performance its variability is greatly reduced. Moreover, the worst case performance of the robust blade is significantly better than for the deterministically designed blade.

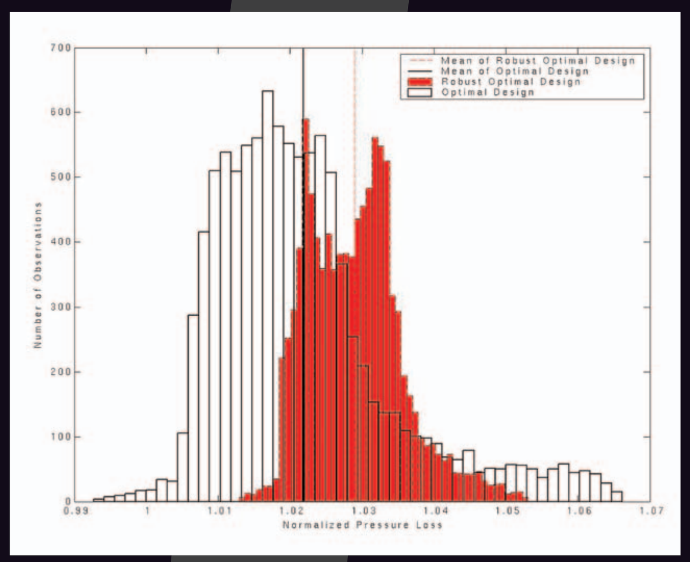

Fig 5

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