Response Surface Model Evolution

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UTP for design

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Traditional RSM optimisation

Aerodynamic shape design may be optimised by simulating the flow over a number of geometries throughout a design space so as to construct a response surface model (RSM) on which searches for the optimum are performed. A RSM (see Figure 1) has been constructed in this manner for the optimisation of the Euler (inviscid) calculated lift/drag ratio (L/D) of a flap-track fairing (FTF) on a commercial airliner wing with respect to its yaw angle and overhang behind the trailing edge. The total CPU time for the 62 CFD simulations was 280 hours.

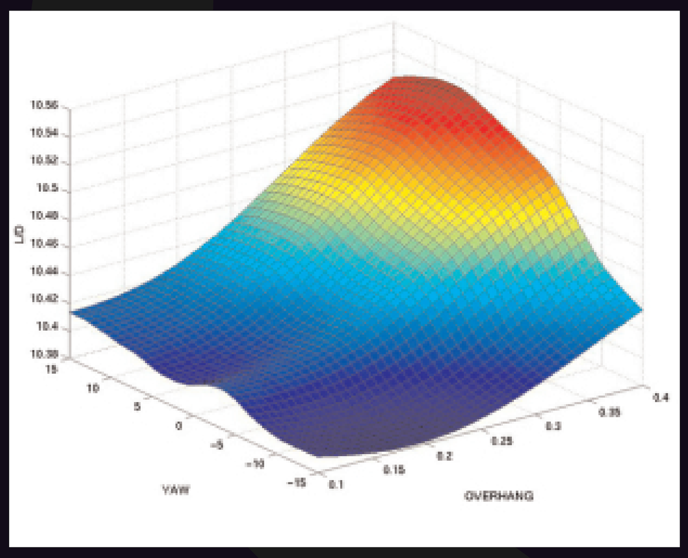

Figure 1 Response surface model of L/D for a FTF and wing

Since the shape of the RSM is not known a priori, the same amount of computing effort has been applied to all points. However, its relatively simple shape suggests significant time savings could be achieved if more effort were to be directed at finding the optimum rather than modelling regions of poor designs.

Evolution

When RSMs are constructed at intervals throughout the convergence history of the CFD simulations, it is seen that all design points converge at a similar rate and information about the nature of the design space can be obtained early in the iterative process. The complete evolution of the FTF RSM is shown in Figure 2 with a contour plot for every 10 CFD iterations. The same scale is used throughout to show the gradually increasing magnitude of the L/D.

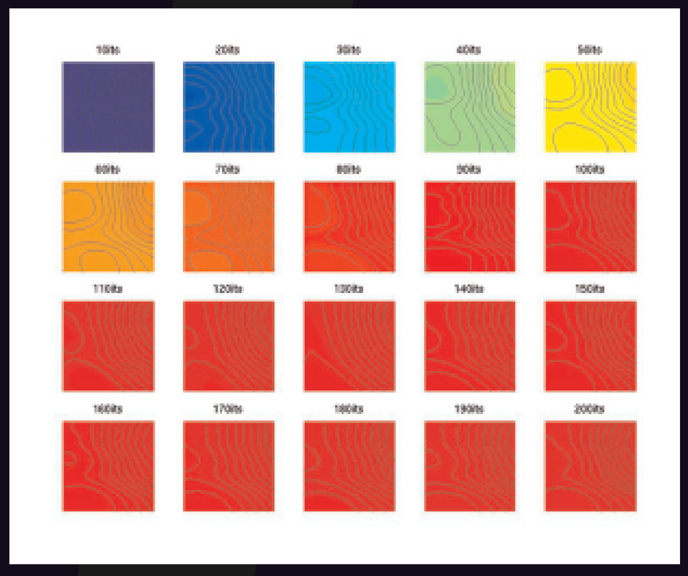

Figure 2 RSM evolution of L/D

The gradients of the RSM are used to ascertain whether the surface has 'stabilised' and whether we can be confident in predicting the region of the optimum. The x and y components (for this 2D surface) of the gradient are calculated by finite differencing at 21x21 points across the surface. As the solution converges, the difference between the gradients of the surface in question and the previous surface are calculated for each component. The root mean square of these differences (the gradient residual) is taken as a global measure of the stabilisation of the shape of the surface. This information can be exploited in the strategy shown in Figure 3.

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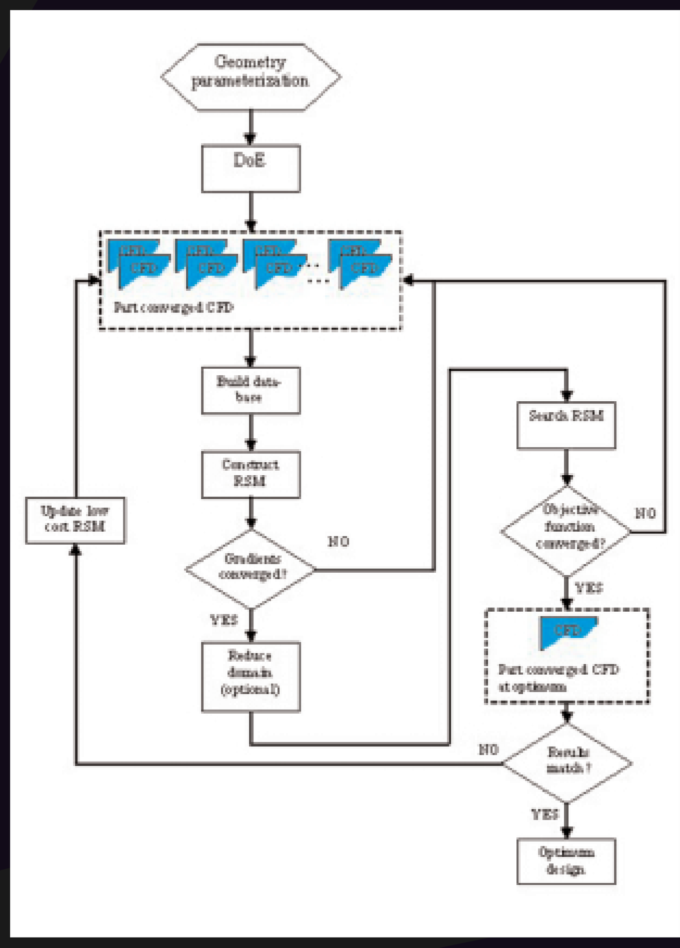

Figure 3 RSM evolution strategy

Monitoring the objective function residual, i.e. the global convergence of the objective function value, may seem logical but, in fact, after initial convergence it becomes noisy (after 110 iterations in this case – see Figure 4) as the CFD approaches convergence. The objective function convergence is instead monitored by searching the RSM for the optimum. Since this is a time consuming process it is only started after the gradient residuals have converged. Such a procedure may be combined with an update strategy on the RSM at successive optima.

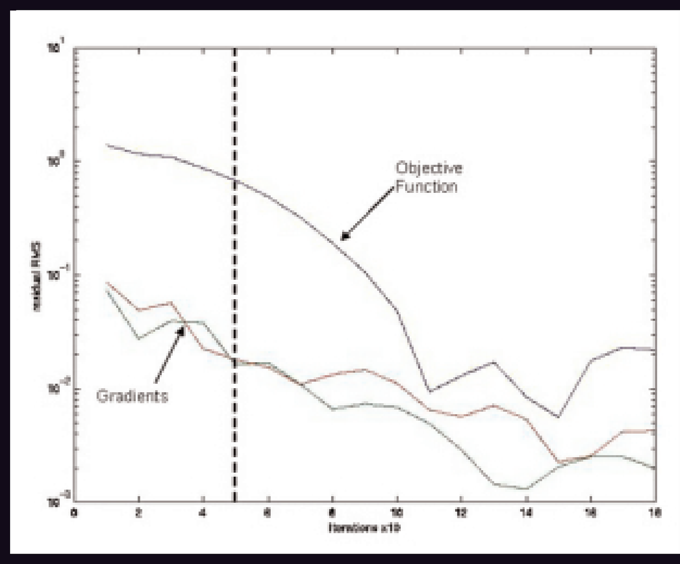

Figure 4 RMS of residuals

Using the strategy outlined, the FTF design space has been reduced after 50 iterations to yaw angles from 0-15° and overhang from 25-40%. This reduced domain is continued until 200 iterations have been completed (see Figure 5) when a final search gives an optimum of 10.52 at 10.74° yaw and 40% overhang. The time taken for this optimisation was 134 CPU hours, representing a 52% time saving over the original case that had full convergence across all design points.

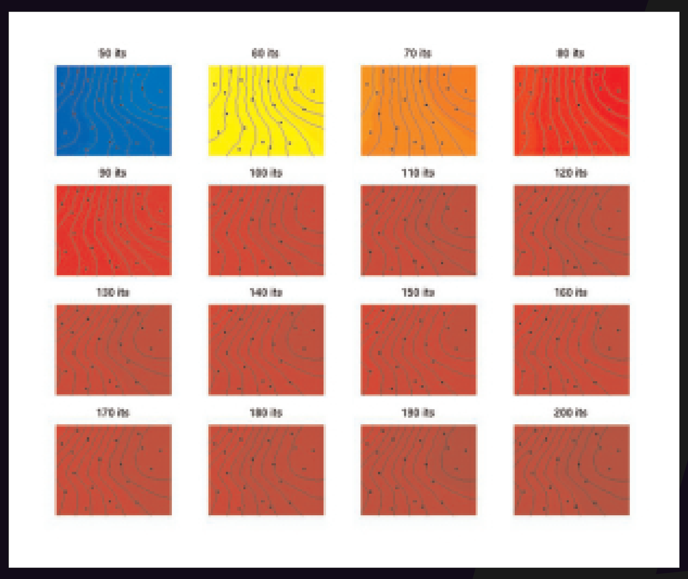

Figure 5 Reduced domain evolution

Summary

Direct optimisation using expensive CFD simulations is infeasible given the long run times involved. RSM techniques can greatly reduce the time required to find a global optimum, but still require a large number of simulations to be run. RSM evolution is a method of quickly homing in on the area of the optimum by taking advantage of the iterative nature of CFD simulations. This allows unnecessary design points to be eliminated and facilitates early updating of the surface. Significant time savings have been demonstrated for the flap-track fairing problem relative to traditional RSM techniques.

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