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Response surface models for design optimisation

UTC for Computational Engineering

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Introduction

Expensive 3D Computational Fluid Dynamics (CFD) solvers are finding increasing use in the design process of aerospace components. In addition, rapid production of computational grids for components with complex geometries is becoming possible through the use of robust, generic parametric geometry definition in combination with rapid meshing tools. This emerging technology provides greater flexibility in the design of components for fluid flow by allowing for a vastly increased design space. Composed of thousands of degrees-of-freedom, the larger design space enables a wider range of possible component geometries to be assessed. An example of this capability is shown in **Fig. 1** where a parametric rotor blade geometry is deformed via 90 controlling parameters.

Large Design Spaces

The aim of this research project is to enable large design spaces defined by parameterised geometry to be searched effectively and efficiently. This will involve the development of improved surrogate-based optimisation methods using design space reduction, parallel multi-objectives, multi-fidelity and Hermite response surface models (RSM). Component design optimisation requires repeated calling of expensive 3D CFD solvers during the design search. In addition, each function call requires the execution of pre-processing software for geometry creation and meshing, setting boundary conditions and multi-grid levels, and post-processing software for extracting and consolidating flow field information. The overall workflow for each function call is complex, and involves a number of data management and authentication issues.

Workflow

A recent collaboration between Microsoft, Rolls-Royce and University of Southampton involved a Proof-of-Concept (PoC) exercise for 'High productivity computing for engineering design optimisation'. The basis of the PoC work was to demonstrate an end-to-end Rolls-Royce design scenario, utilising aspects of Microsoft technology which prove of value individually, but also as integration points and components for the existing workflow solution. The example design scenario chosen was a high fidelity CFD flow field solution for a compressor rotor blade defined by a parametric geometry, as shown in **Fig. 2**. The complex workflow included an optimization package, several pre-processing stages, high fidelity CFD solution calls invoking parallel CFD solvers running on the Windows CCS multi-core processors, and several post-processing steps, as shown in **Fig. 3**.

The workflow solution involved several specific technologies: Windows Forms for presentation technology, Windows Workflow Foundation and Visual Studio, Microsoft SQL Server, and Windows CCS including interoperability with Linux compute resources. The solution was able to demonstrate workflow version control, nested workflows, dynamic allocation of tasks to processors and flexible modification of the workflow. As a result of this work, the PoC technology is currently being assessed for use in the CEDC as a robust, yet flexible framework for design optimisation using mixed fidelity solution methods contained within complex workflows. The system will assist the current project in the research and development of improved surrogate-based optimisation methods.

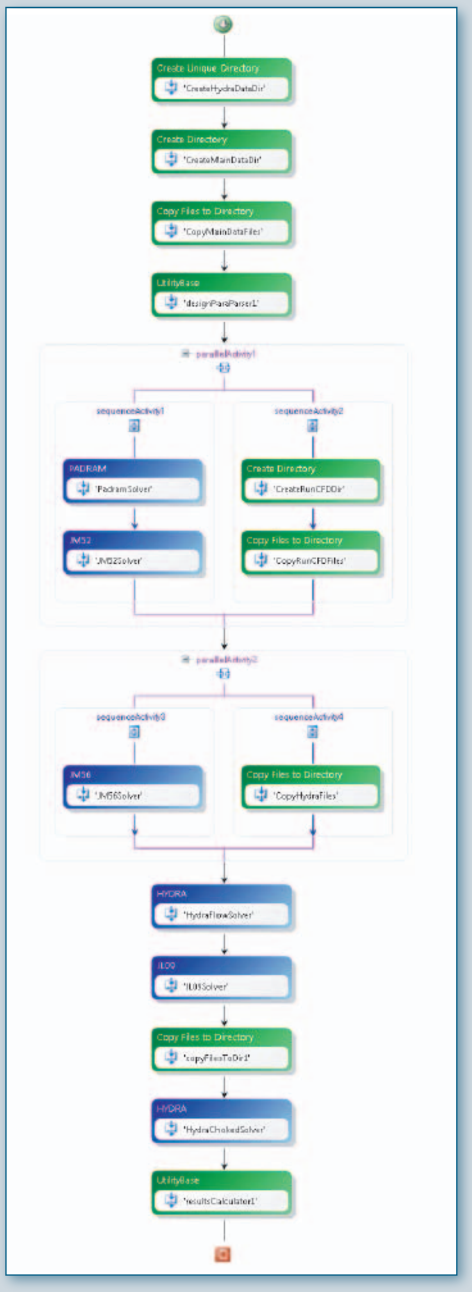
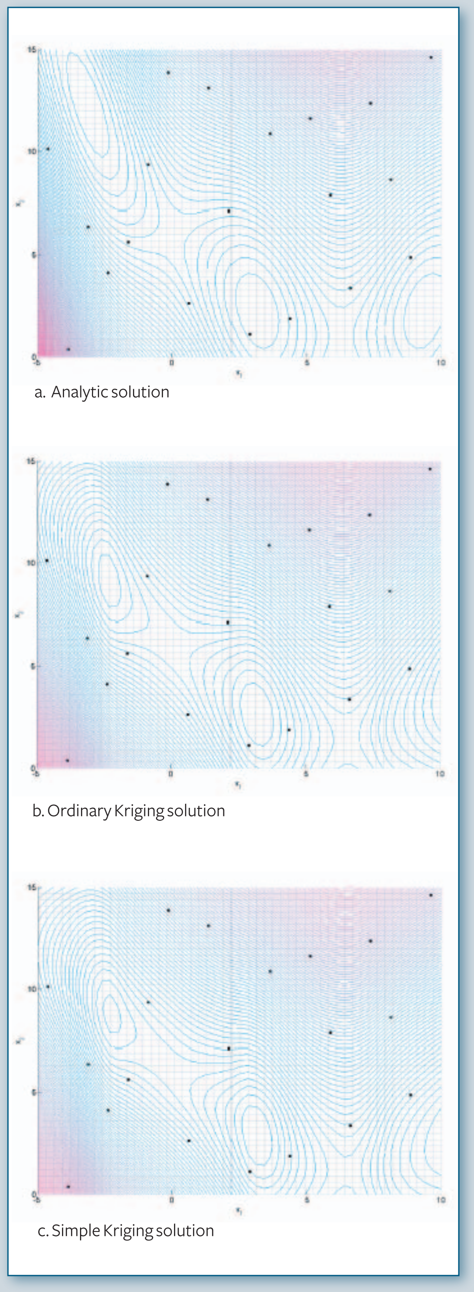


Fig.3 An example workflow for obtaining a high fidelity CFD flow solution for the NASA compressor rotor 37.



a. Analytic solution

b. Ordinary Kriging solution

c. Simple Kriging solution

Fig.4 Kriging predictions of the 2D Branin function using 20 sample points.

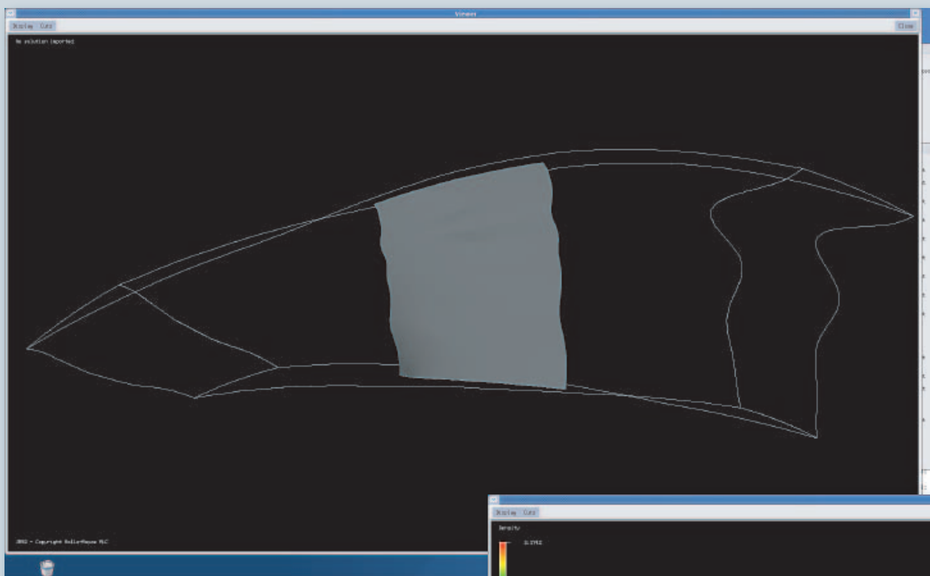


Fig.1 Parametric geometry definition for NASA compressor rotor 37.

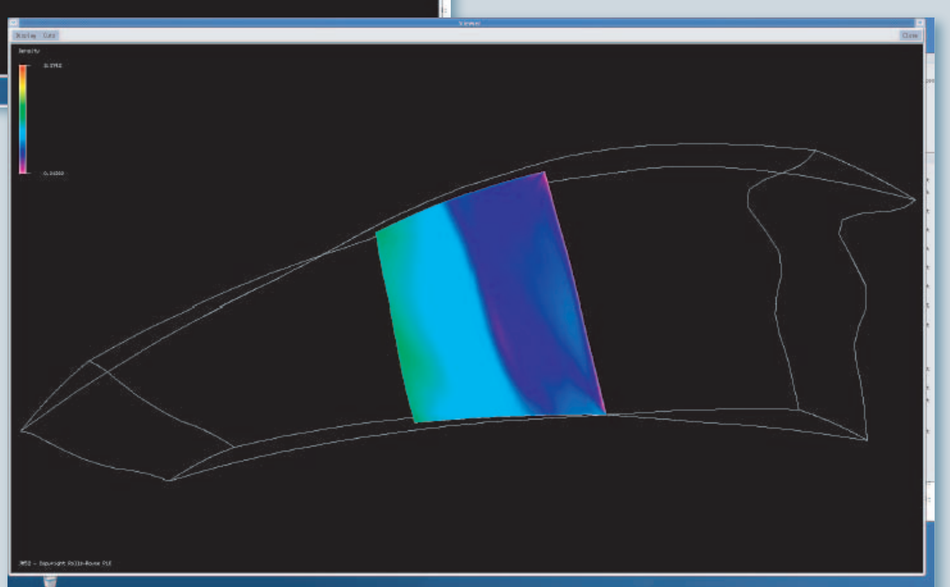


Fig.2 Contours of surface static pressure for NASA compressor rotor 37.

Ongoing Work

Work is currently focussed on building and validating appropriate data structures for storing CFD results for use in future research. The generation of CFD results is currently managed by scripting, but the PoC technology is being assessed for this purpose. Design of Experiment (DoE) methods such as optimised Latin hypercubes, are used to build a series of data sets of multi-fidelity, adjoint, or finite differenced solutions. The results can then be used in research for Hermite, multi-fidelity and other search schemes. A scheme currently being investigated is the use of ordinary (interpolating) and simple (regressive) Kriging models, example solutions of which are shown in **Fig. 4**. Simple Kriging requires fewer matrix-vector multiplications than ordinary Kriging. Kriging prediction for large data sets for design problems with very large degrees-of-freedom rapidly becomes intractable due matrix inversion and difficulties in hyperparameter tuning. Methods to address these problems are being investigated such as pre-conditioned conjugate gradient methods for inverse matrix-vector multiplications, parallel matrix inversion, N-body approach, and hyperparameter tuning using gradient information.

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