A Simulation Driven Built Environment

Presented by Dr. Mike Slack
With contribution by Wirth Research
Engineering Drivers

Bridgewater Place ‘wind tunnel caused Leeds injuries’
Market Trending

Productivity

integrity

& Bottle necks

Getting the balance right

Optimising CFD a sparse matrix

Direct optimisation methods

Modelling the small scales

Large scale HPC example from Wirth Research (VWT)

Summary
Accuracy and Robust Design

• “Good enough” is NOT good enough anymore.

• Market leaders are making products which outperform rivals.

• Penalty for making mistakes has never been higher.

Linked in Survey Results

- Does your company value Engineering Simulation?
- Is your company interested in Design Exploration?
- Is your company interested in Goal Driven Optimization?
- Is your company interested in Robust Design Optimization?
The tools

**Optimisation**

Direct optimisation

Adjoint optimisation

Response surface

Morphing

**High performance computing**

Larger more detailed models

Smaller models can be run faster

assessment in parallel of multiple design points.
Obstacles

When simulation experts are asked about obstacles...

Main obstacles to design exploration and optimization?

- Full series of simulations takes too long
- Difficult to build a parametric geometry or mesh
- Lack of simulation resources
- Difficult to string various tools together (Hardware/Software)
- Which parameters are relevant?
- Baseline model is difficult to solve
- Lack of faith in simulation
- Algorithm choices
- Other
- Difficult to understand results
- My design is not suitable for optimization

Linked in Survey, 2011
Optimisation

Adjoint+ Geometry morphing
Parametric design exploration
What is the Adjoint Solver?

In a Nutshell

It can tell you from a single run how you should change a geometry in order to improve it

An Adjoint Solver can be used to compute the derivative of an engineering quantity with respect to all of the inputs for the system.

These derivatives/sensitivities can be used to

- provide extremely valuable engineering insight
- optimize system performance
- detecting areas in the flow where discretization errors can potentially have a strong effect

Once the adjoint solution is computed it can be used to guide intelligent design modifications to a system by a simple gradient algorithm for design optimization.
Adjoint driven optimisation

Morphing using MMO

Local optimum

Global optimum

AS sensitivity

CFD Analysis

Adjoint Solver

\[
\frac{\partial q_i}{\partial c_j}
\]
observable value = 9.76

Inlet: 17.24 Pa

Outlet 1: 8.74 Pa

Outlet 2: 6.32 Pa
\[ \sigma^2(\dot{m}) = 0.04686 \frac{K g^2}{m^4 s^2} \]
$\sigma^2(T) = 17.7231 \, K^2$

$V = 0.5 \, m/s$

$T = 293.61 \, K$

$T = 301.95 \, K$

$T = 301.95 \, K$

$T = 293.61 \, K$
Design Exploration

- Direct Optimization
- Parameters Correlation
- Response Surface
- Response Surface Optimization
- Six Sigma Analysis
Problem description

- Flow in a theatre, 3 tiers of seating
- Fresh air inflow at steps under seats
- Uniform flow produces non uniform temperature distribution
Problem description

• Fit 2 linear velocity profiles: one profile for within a tier and one for between tiers

• Parameterise each profile with respect to ratio of minimum velocity to maximum velocity

• Seek to optimise these parameters to minimise the temperature variation over a range of monitor locations
Optimisation set up

- DOE tool will generate a set of design points to sample
- Various sampling strategies are available

Data analysis can then be submitted to compute cluster in parallel
Response surface

- A response surface is fitted to the design point data
- Goodness of fit reporting displays how well the response surface fits the data (None parametric regression)
- Plot response surface against up to 2 selected parameters at a time.
Working with Response Surfaces

Example of poor fit of standard response surface to design points
Optimisation

- Optimiser cell is used to specify objectives and constraints

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- Optimiser samples response surface and makes suggestions for optimum location
- Can feed back suggestion as a refinement point for the response surface to verify and improve the fit
  - Repeat until the predicted and calculated optimum have sufficiently converged. For Kriging this can be automated.
Comparison

Uniform flow

Optimised flow
High end HPC example
High resolution Architectural CFD
Courtesy of Wirth Research
IBSPA 2014

- Chicago, 10km diameter model.
- 3 interesting buildings highlighted which are focussed on in following slide.
The Chicago cityscape model

- Refined down to 10cm on key details of the three key buildings, with general resolution on those building's of ~30cm, with prismatic layers everywhere.

- The whole domain came to ~600million cells.

- Solved on 432 cores over 36 nodes. The RANS runs take ~10hrs, and the DES ~5days, using Fluent v15.

- A typical study would involve RANS wind angles with some DES dependent on objective.

- Wirth Research have 3500 cores in their compute cluster, so could solve approx. 10 jobs similar to this simultaneously.
IBSPA 2014

- Iso-surfaces of vorticity, coloured by total pressure, showing different type of vortical structures seen around different designs of tall buildings.
IBSPA 2014

- 10m high slice coloured by velocity
Engineers are facing many challenges and simulation can play a significant part in this.

Increasing realism and detail is being captured using high fidelity tools.

There is increasing adoption of robust design methods driven by both software developments and hardware availability.