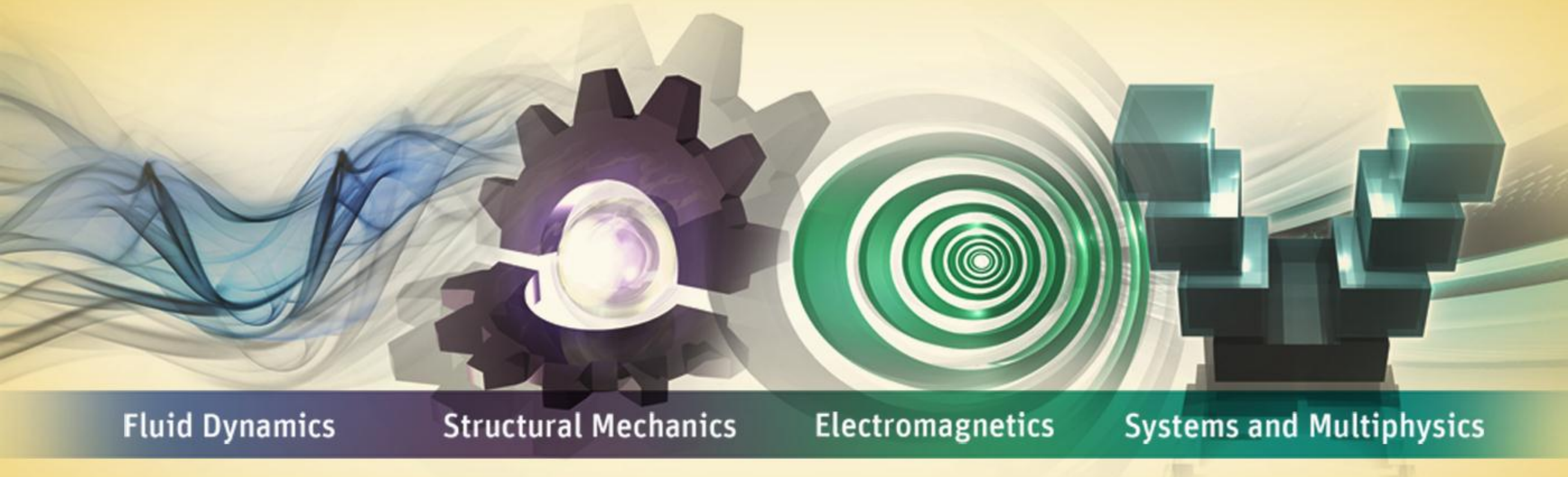
Realize Your Product Promise™

A Simulation Driven Built Environment



Presented by Dr. Mike Slack

With contribution by Wirth Research

Engineering Drivers

Presentation Content

Market Trending

- **Productivity**
- **integrity**
- **& Bottle necks**

Getting the balance right

- **Optimising CFD a sparse matrix**
- **Direct optimisation methods**

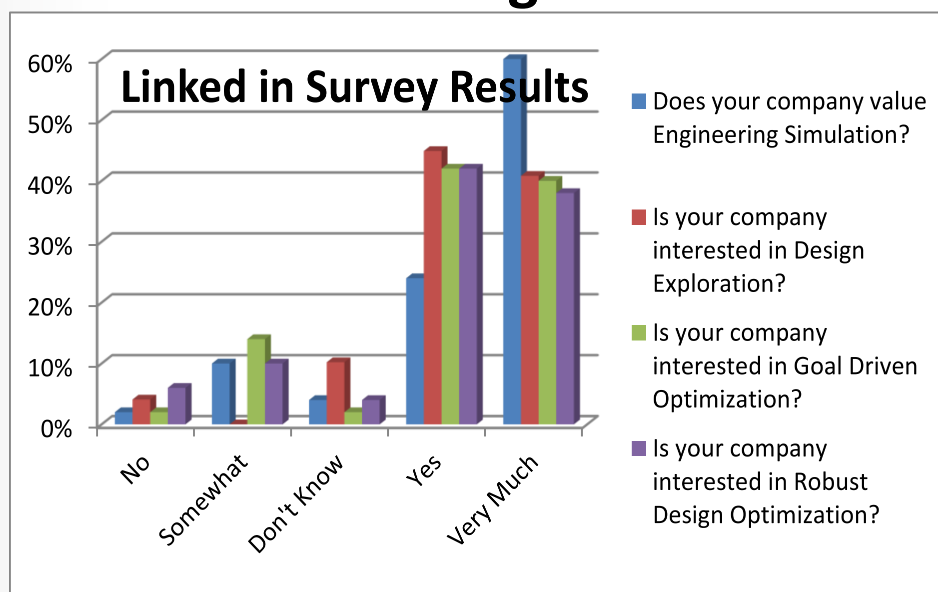
Modelling the small scales

- **Large scale HPC example from Wirth Research (VWT)**

Summary

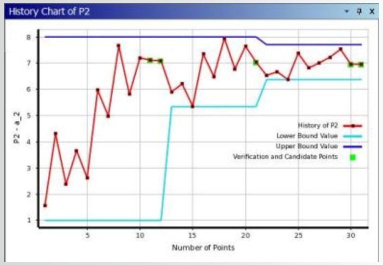
Accuracy and Robust Design

- "Good enough" is NOT good enough anymore.
- Market leaders are making products which outperform rivals.
- Penalty for making mistakes has never been higher.



The tools

Optimisation

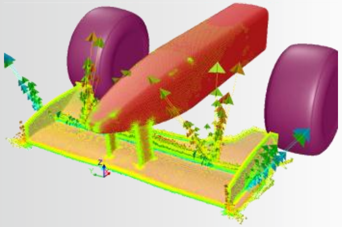


High performance computing

Direct optimisation

Larger more detailed models

Adjoint optimisation

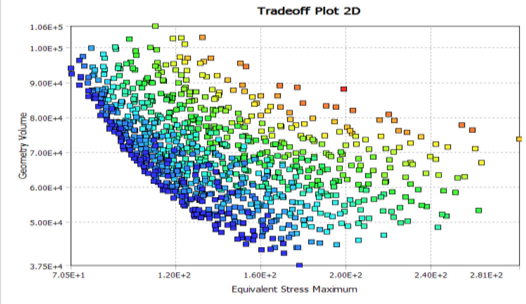


Smaller models can be run faster

Response surface

assessment in parallel of multiple design points.

Morphing

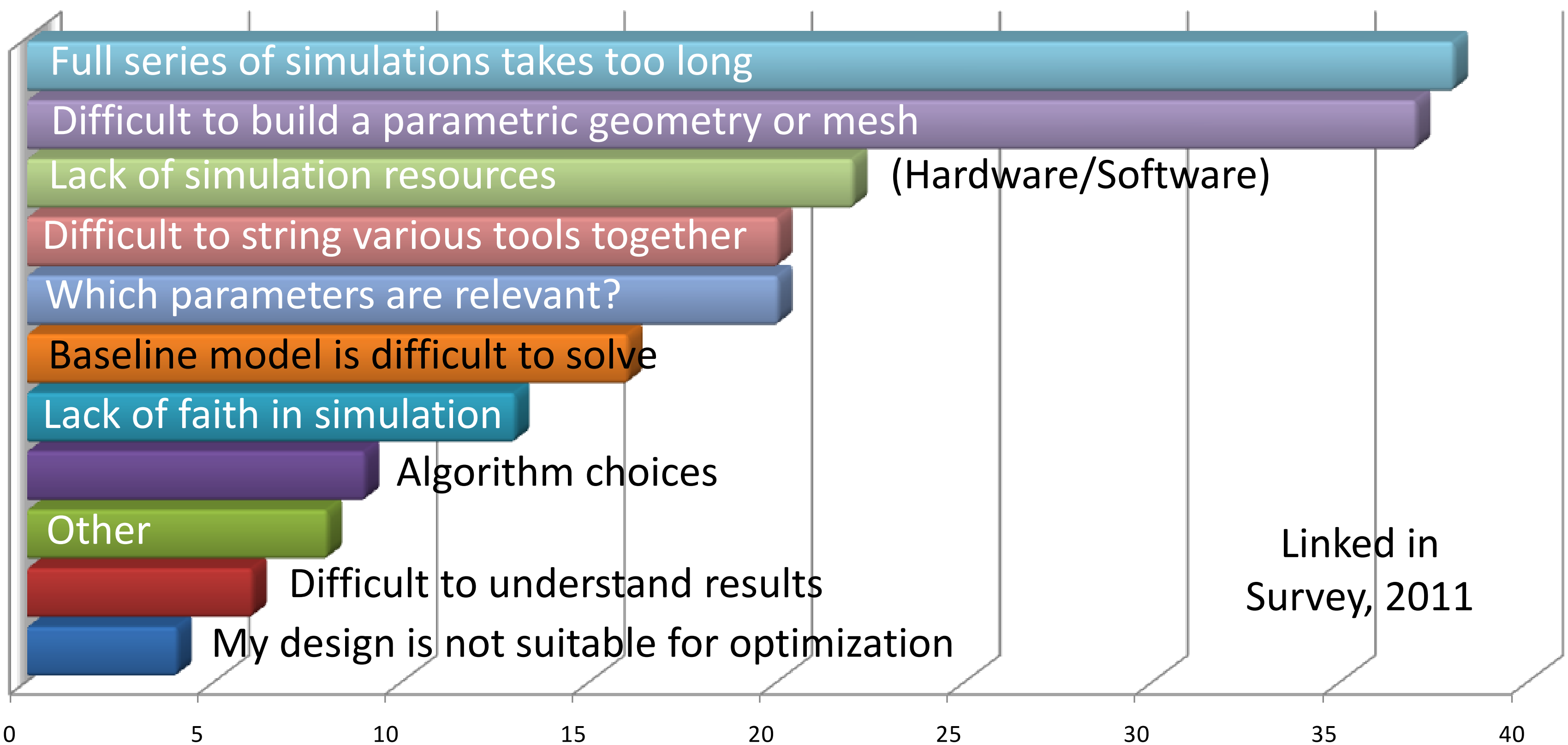


ANSYS

Obstacles

When simulation experts are asked about obstacles…

Main obstacles to design exploration and optimization?



Optimisation

Adjoint+ Geometry morphing
Parametric design exploration

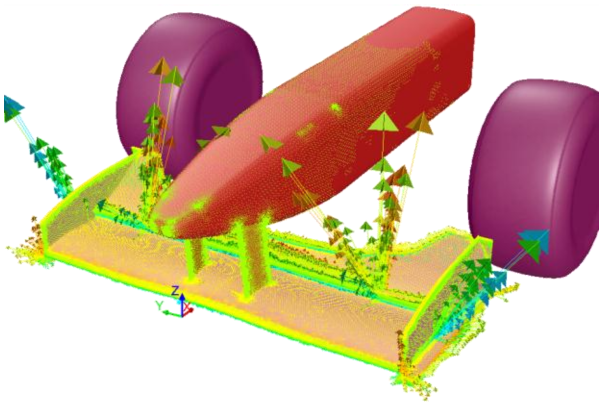
What is the Adjoint Solver?

$$\left[\frac{\partial q_i}{\partial c_j}\right]$$

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.

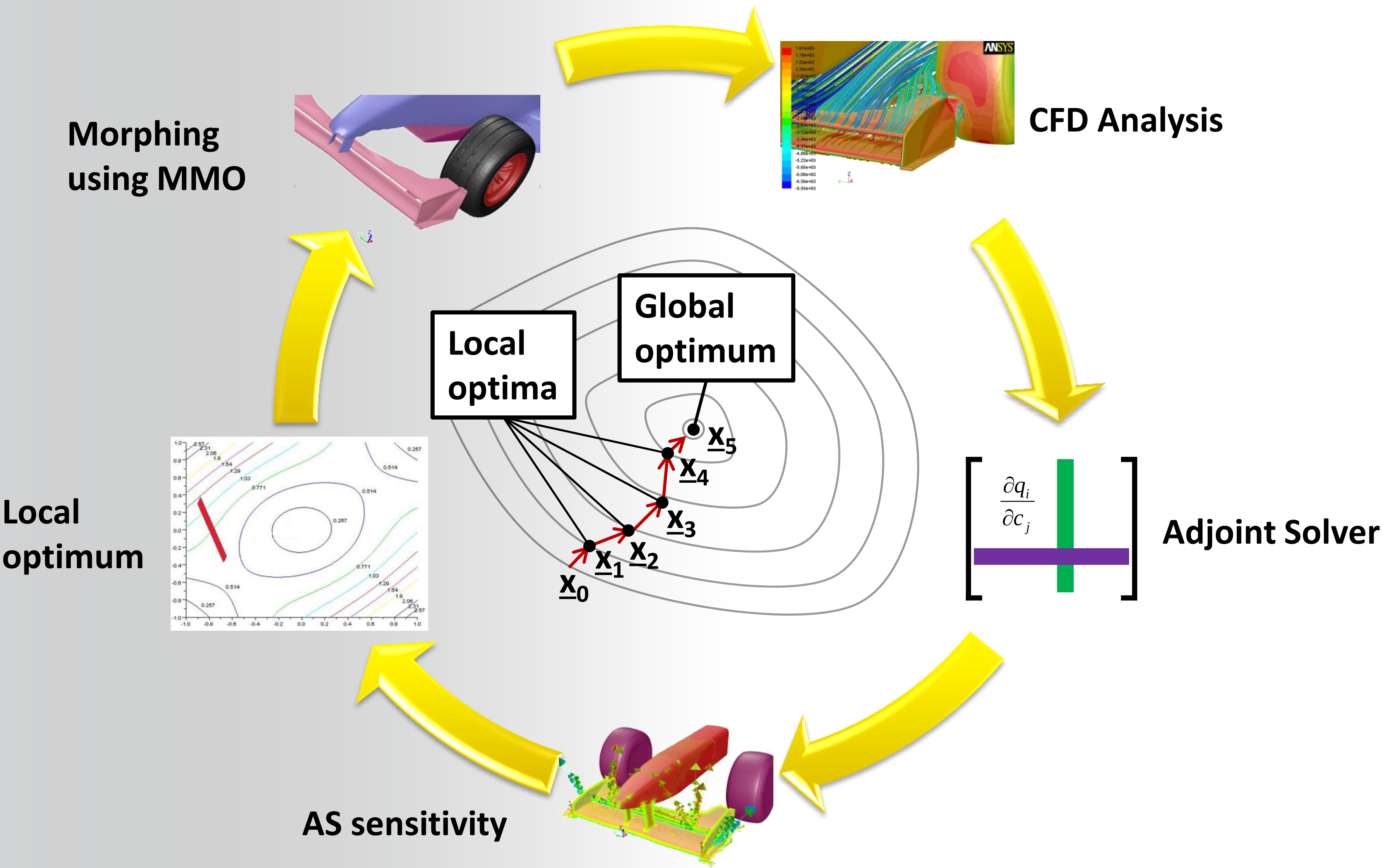


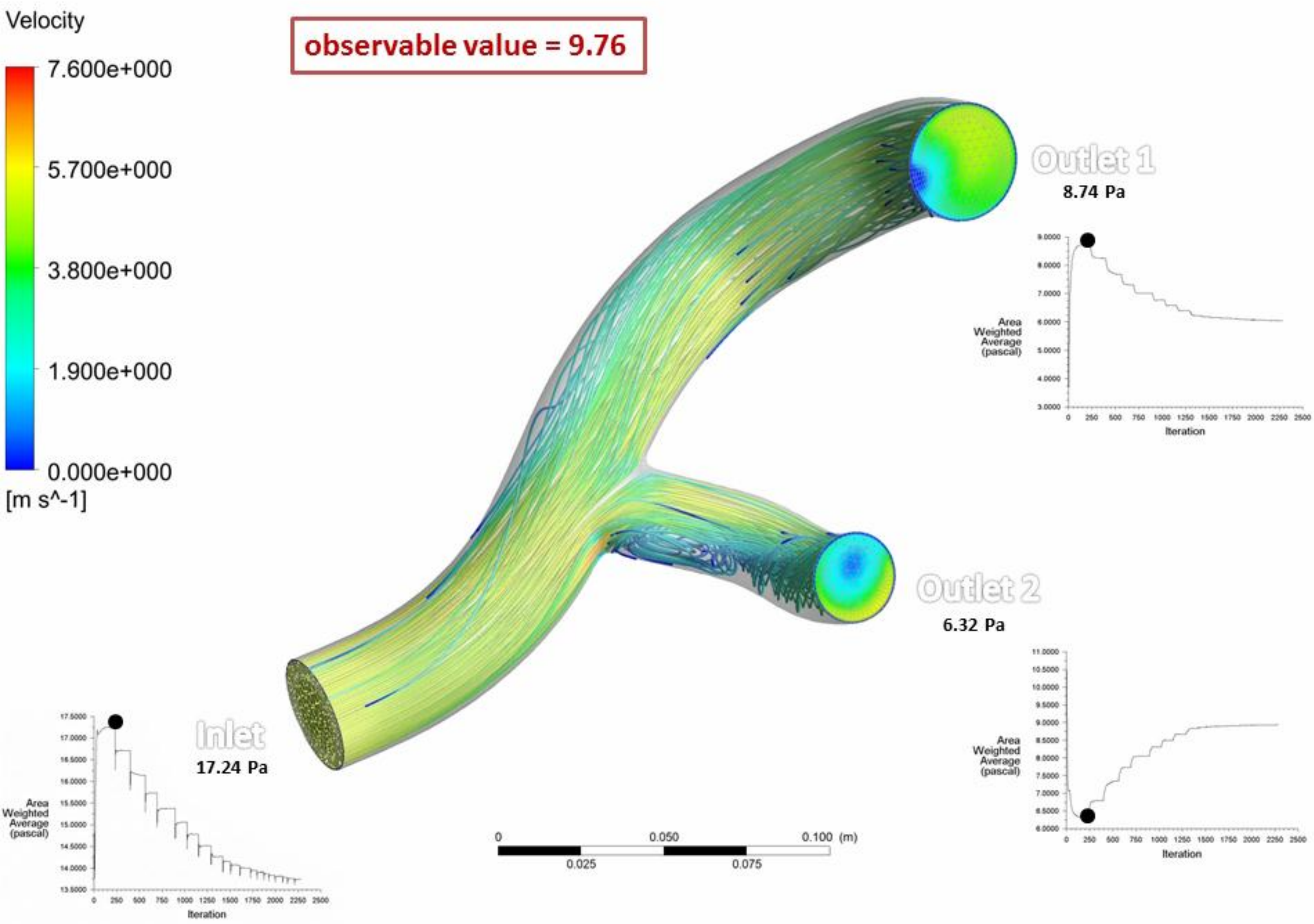
These derivatives/sensitivities can be used to

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

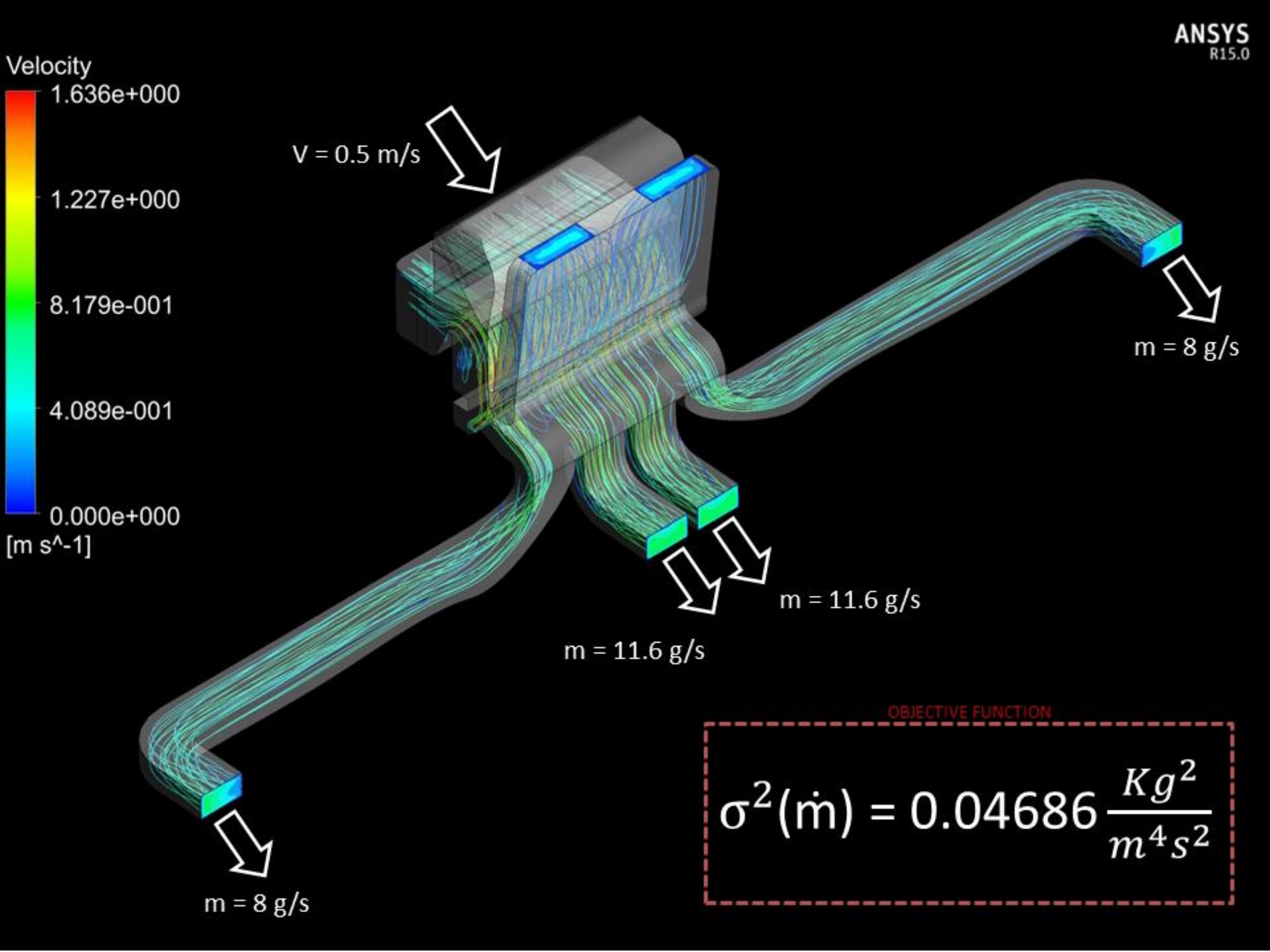
Once the adjoint solution is computed it can be used to guide intelligent design modifications to a system by a simple gradient algorithm for design optimization.

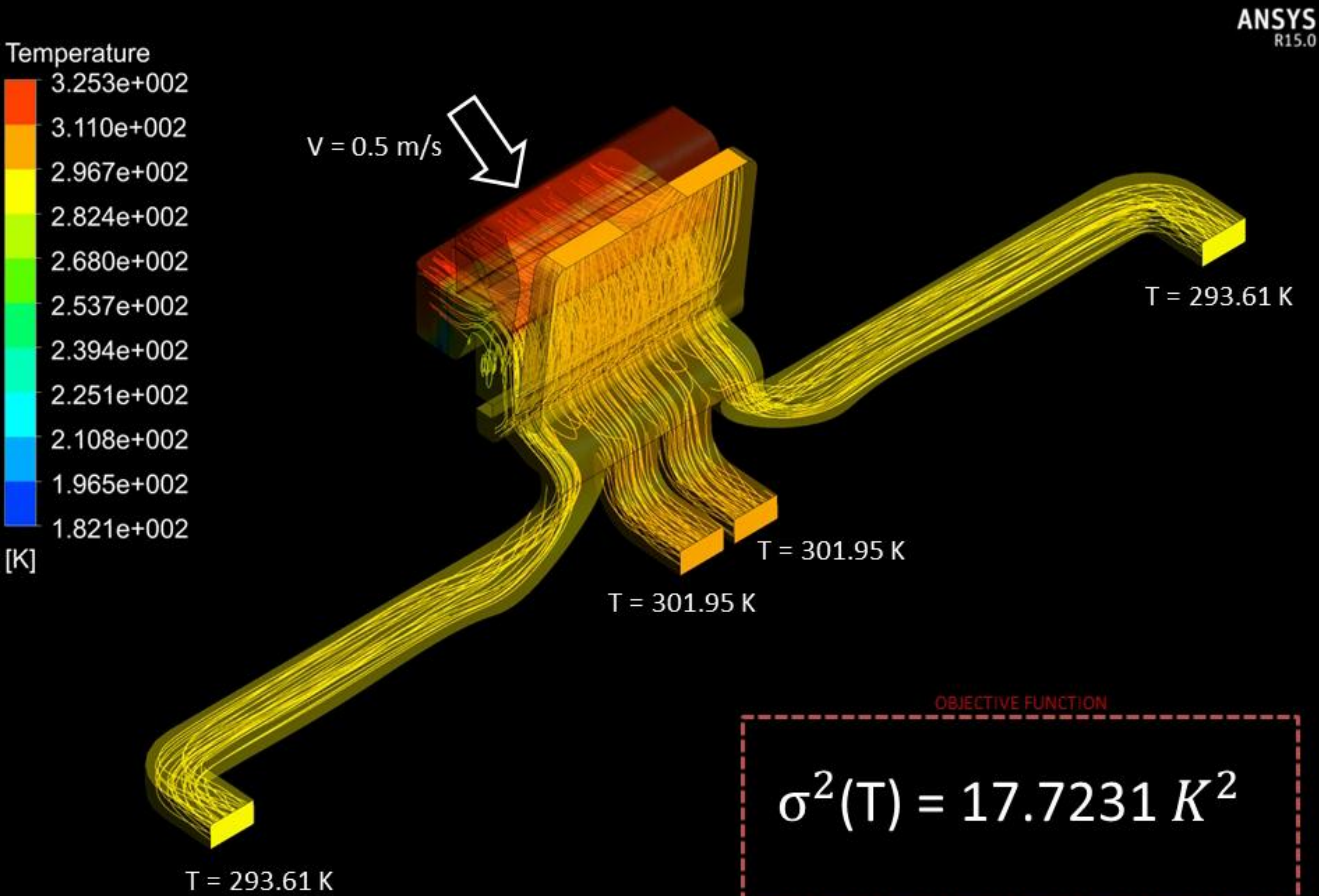
Adjoint driven optimisation





Velocity
7.600e+000
5.700e+000
3.800e+000
1.900e+000
0.000e+000
[m s^-1]
observable value = 9.76
Outlet 1
8.74 Pa
Area Weighted Average (pascal)
Iteration
Outlet 2
6.32 Pa
Area Weighted Average (pascal)
Iteration
Inlet
17.24 Pa
Area Weighted Average (pascal)
Iteration
0
0.050
0.100 (m)
0.025
0.075


ANSYS
R15.0
Velocity
1.636e+000
1.227e+000
8.179e-001
4.089e-001
0.000e+000
[m s^-1]
V = 0.5 m/s
m = 8 g/s
m = 11.6 g/s
m = 11.6 g/s
m = 8 g/s
OBJECTIVE FUNCTION
$\sigma^2(\dot{m}) = 0.04686 \frac{Kg^2}{m^4 s^2}$



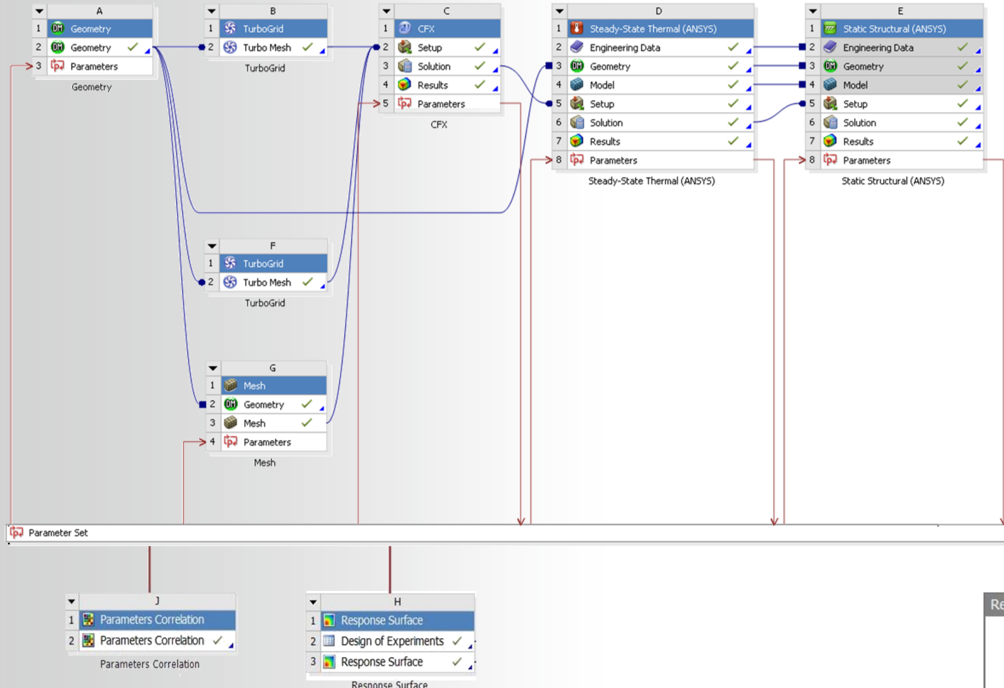
OBJECTIVE FUNCTION

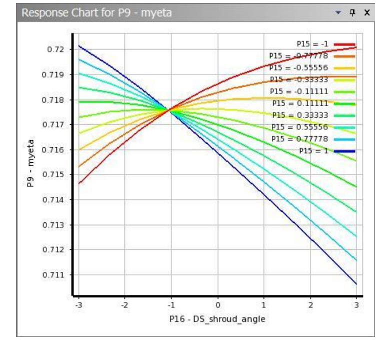
$$\sigma^2(T) = 17.7231\,K^2$$

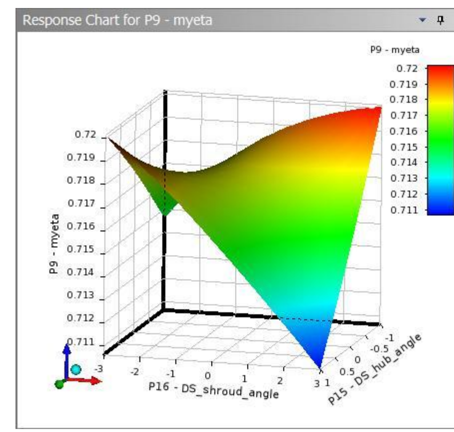
Design Exploration

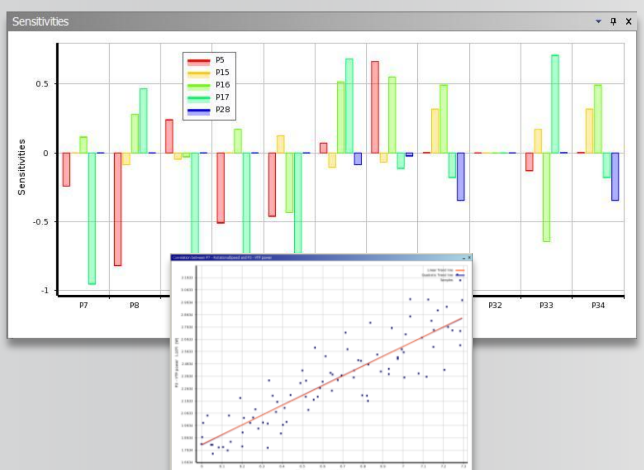
⊟ Design Exploration

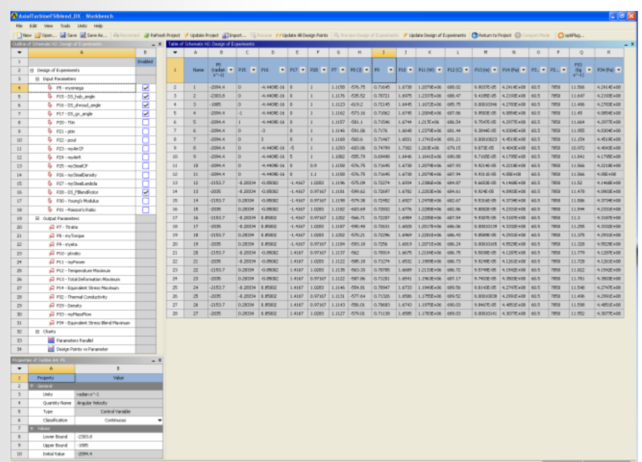
- Direct Optimization
- Parameters Correlation
- Response Surface
- Response Surface Optimization
- Six Sigma Analysis





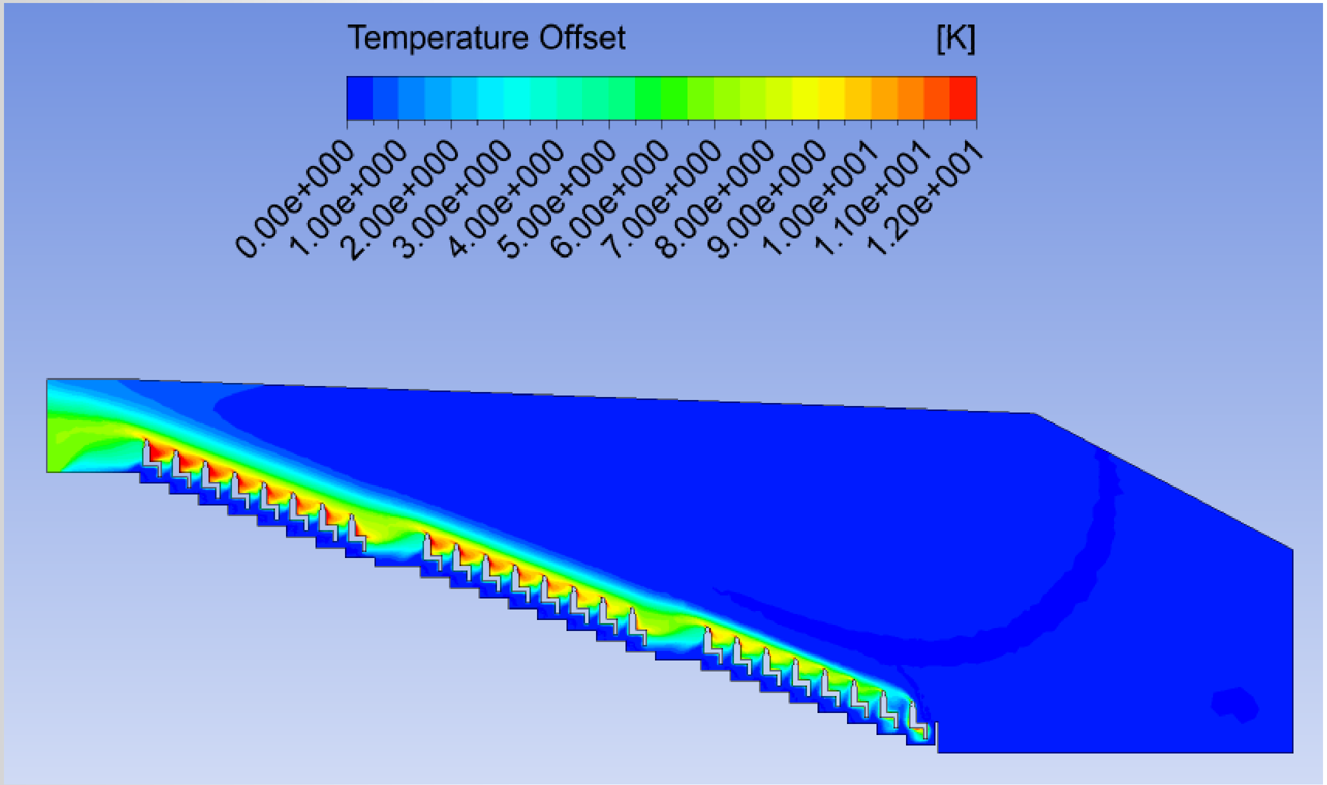






Problem description

- 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

	B
1	Response Surface Optimization
2	Design of Experiments
3	Response Surface
4	Optimization

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

Properties of Outline A2: Design of Experiment

	A	B
1	Property	Value
2	Design Points	
3	Preserve Design Points After DX Run	☐
4	Failed Design Points Management	
5	Number of Retries	0
6	Design of Experiments	
7	Design of Experiments Type	Central Composite Design
8	Design Type	

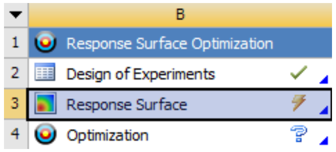
- Central Composite Design
- Optimal Space-Filling Design
- Box-Behnken Design
- Custom
- Custom + Sampling
- Sparse Grid Initialization
- Latin Hypercube Sampling Design

Table of Schematic B2: Design of Experiments (Central Composite Design : Auto Defined)

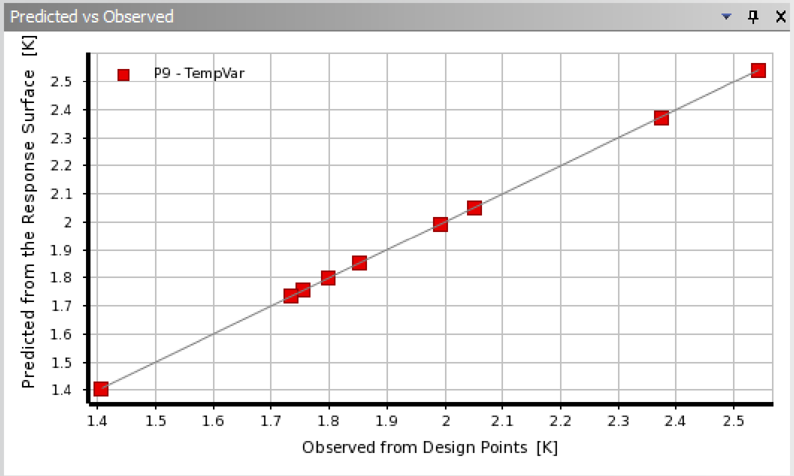
	A	B	C	D
1	Name	P7 - StepFrontBias	P8 - TierFrontBias	P9 - TempVar (K)
2	1	0.5	0.65	⚡
3	2	0	0.65	⚡
4	3	1	0.65	⚡
5	4	0.5	0.3	⚡
6	5	0.5	1	⚡
7	6	0	0.3	⚡
8	7	1	0.3	⚡
9	8	0	1	⚡
10	9	1	1	⚡

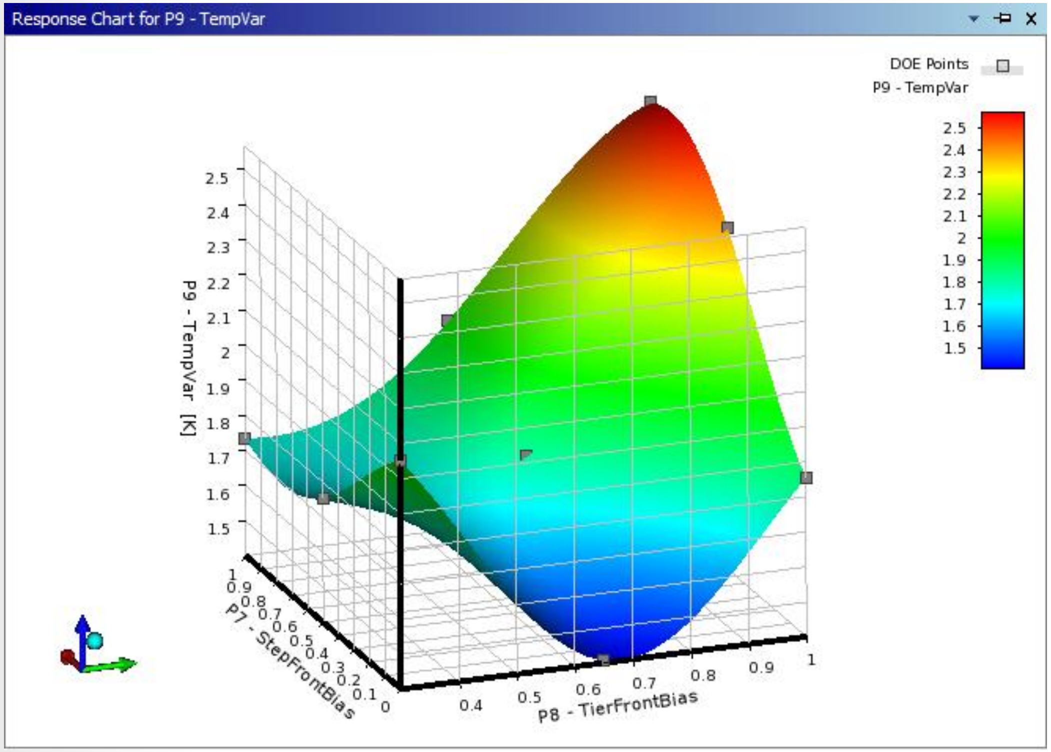
Data analysis can then be submitted to compute cluster in parallel

Response surface



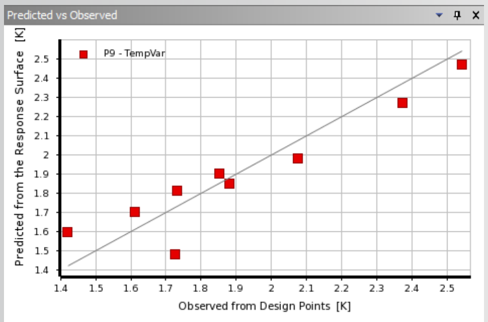
- A response surface is fitted to the design point data
- Goodness of fit reporting displays how well the response surface fits the data (None parametric regression)
- Plot response surface against up to 2 selected parameters at a time.

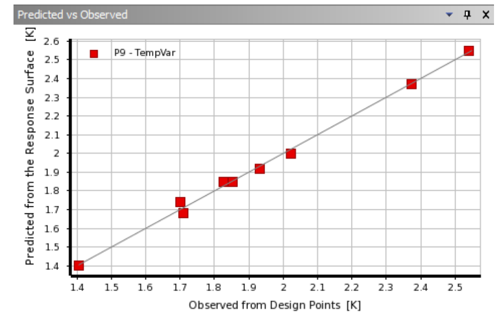


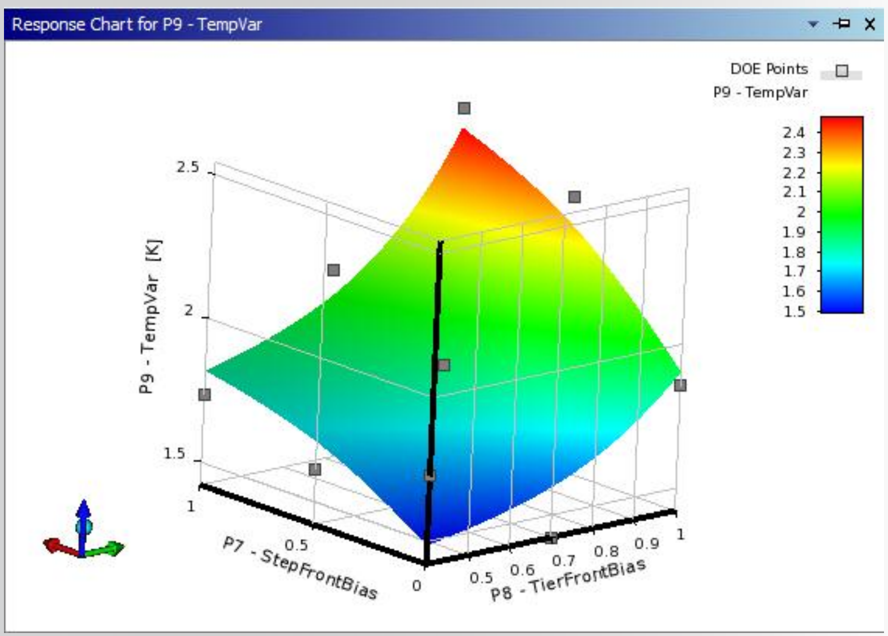


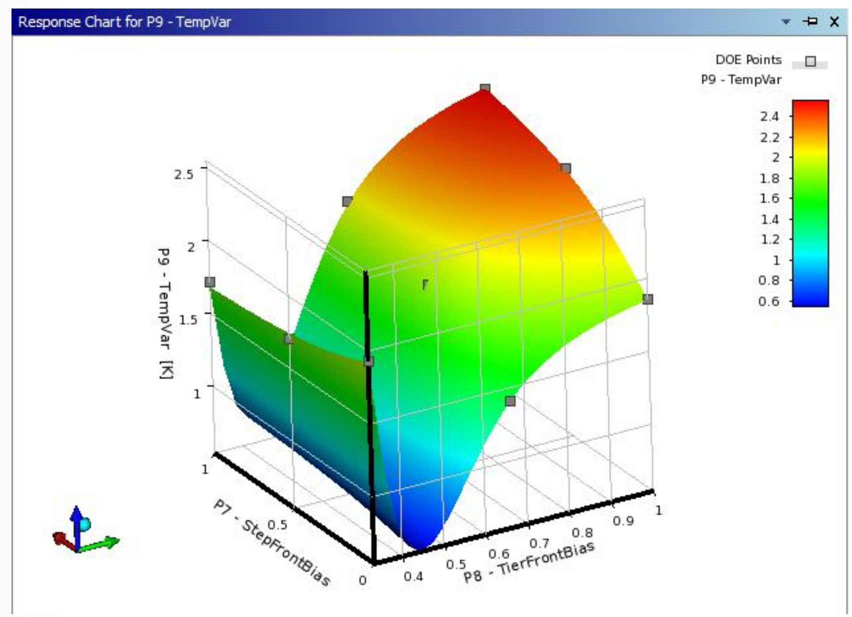
Working with Response Surfaces

Example of poor fit of standard response surface to design points









Optimisation

	B
1	Response Surface Optimization
2	Design of Experiments
3	Response Surface
4	Optimization

- Optimiser cell is used to specify objectives and constraints

Outline of Schematic B4: Optimization

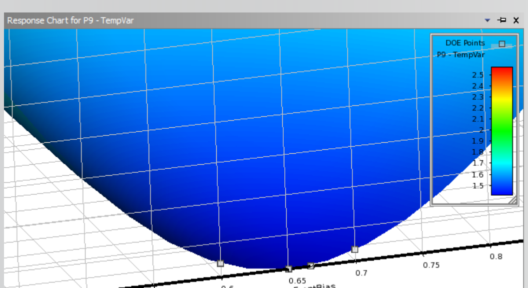
	A
1	
2	Optimization
3	Objectives and Constraints
4	Minimize P9

Table of Schematic B4: Optimization

	A	B	C	D	E	F	G
1	Name	Parameter	Objective		Constraint		
2			Type	Target	Type	Lower Bound	Upper Bound
3	Minimize P9	P9 - TempVar	Minimize		No Constraint		
*		Select a Parameter	No Objective Minimize Maximize Seek Target				

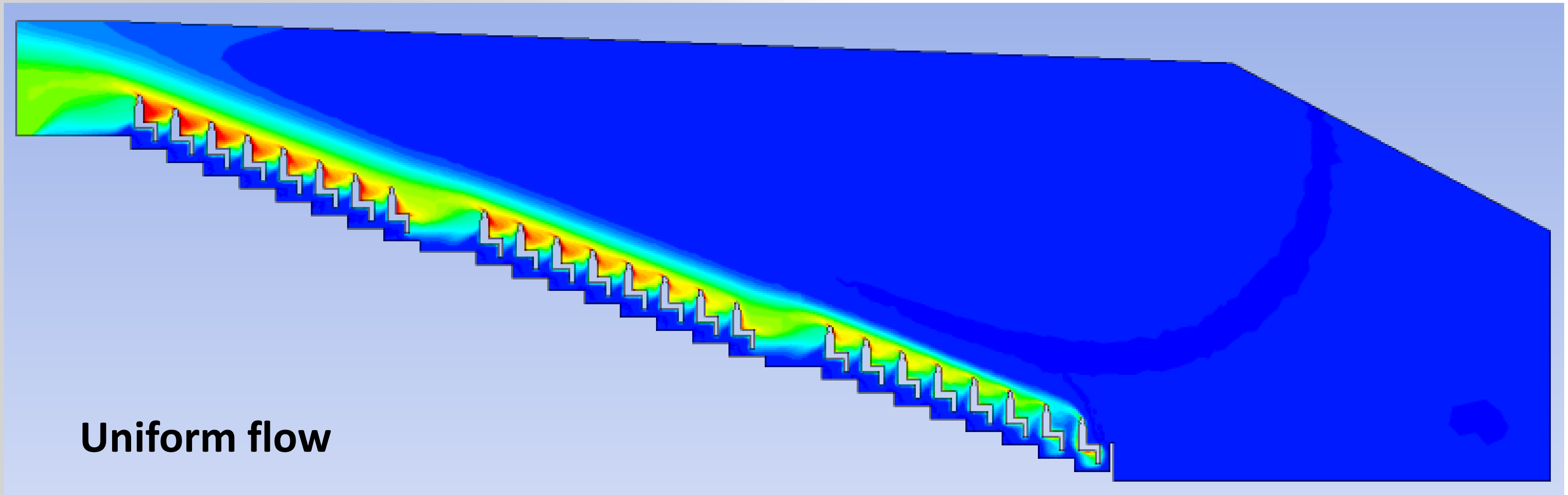
- Optimiser samples response surface and makes suggestions for optimum location

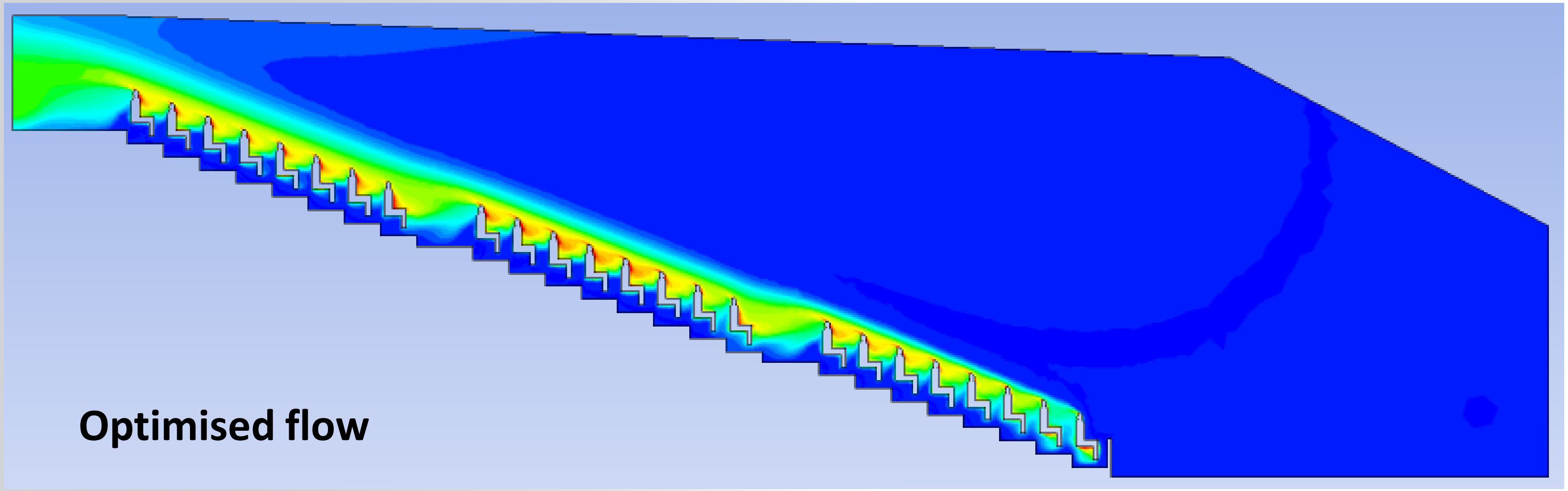
- Can feed back suggestion as a refinement point for the response surface to verify and improve the fit
  - Repeat until the predicted and calculated optimum have sufficiently converged. For Kriging this can be automated.



Candidate Points	Candidate Point 1	Candidate Point 2	Candidate Point 3
P7 - StepFrontBias	0	0.1135	0.2225
P8 - TierFrontBias	0.68088	0.68863	0.63668
P9 - TempVar (K)	1.4013	1.4595	1.5331

Comparison

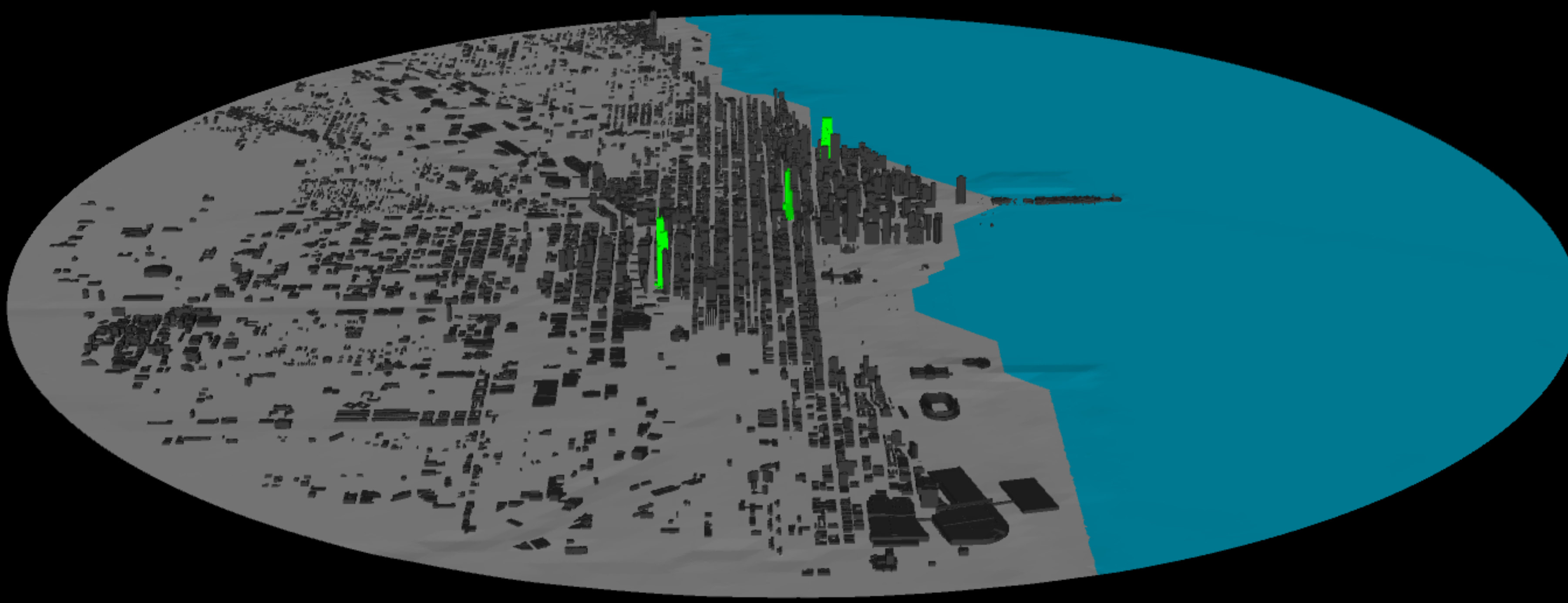




High end HPC example
High resolution Architectural CFD
Courtesy of Wirth Research

IBSPA 2014

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

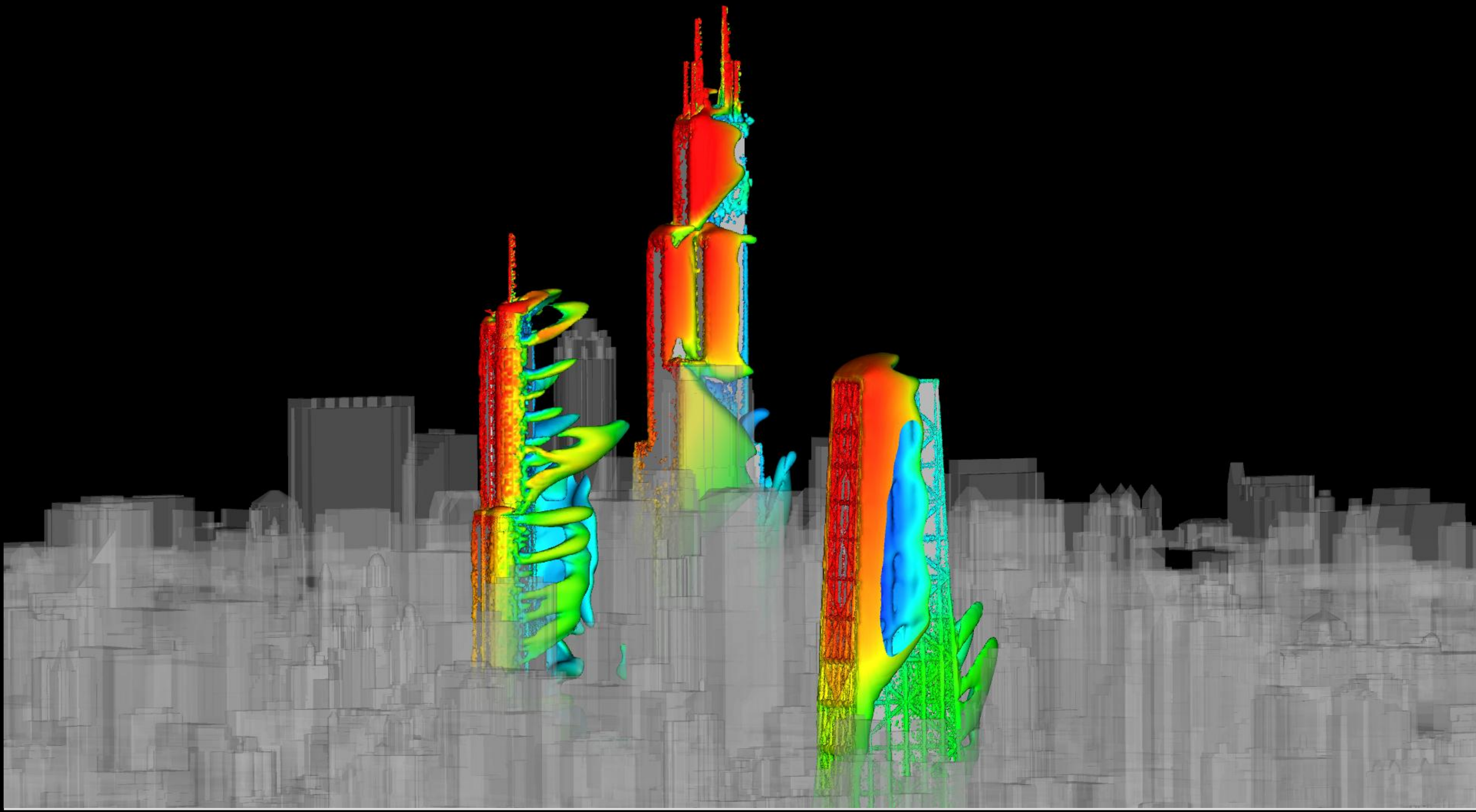


IBSPA 2014

- 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, co could solve approx. 10 jobs similar to this simultaneously.

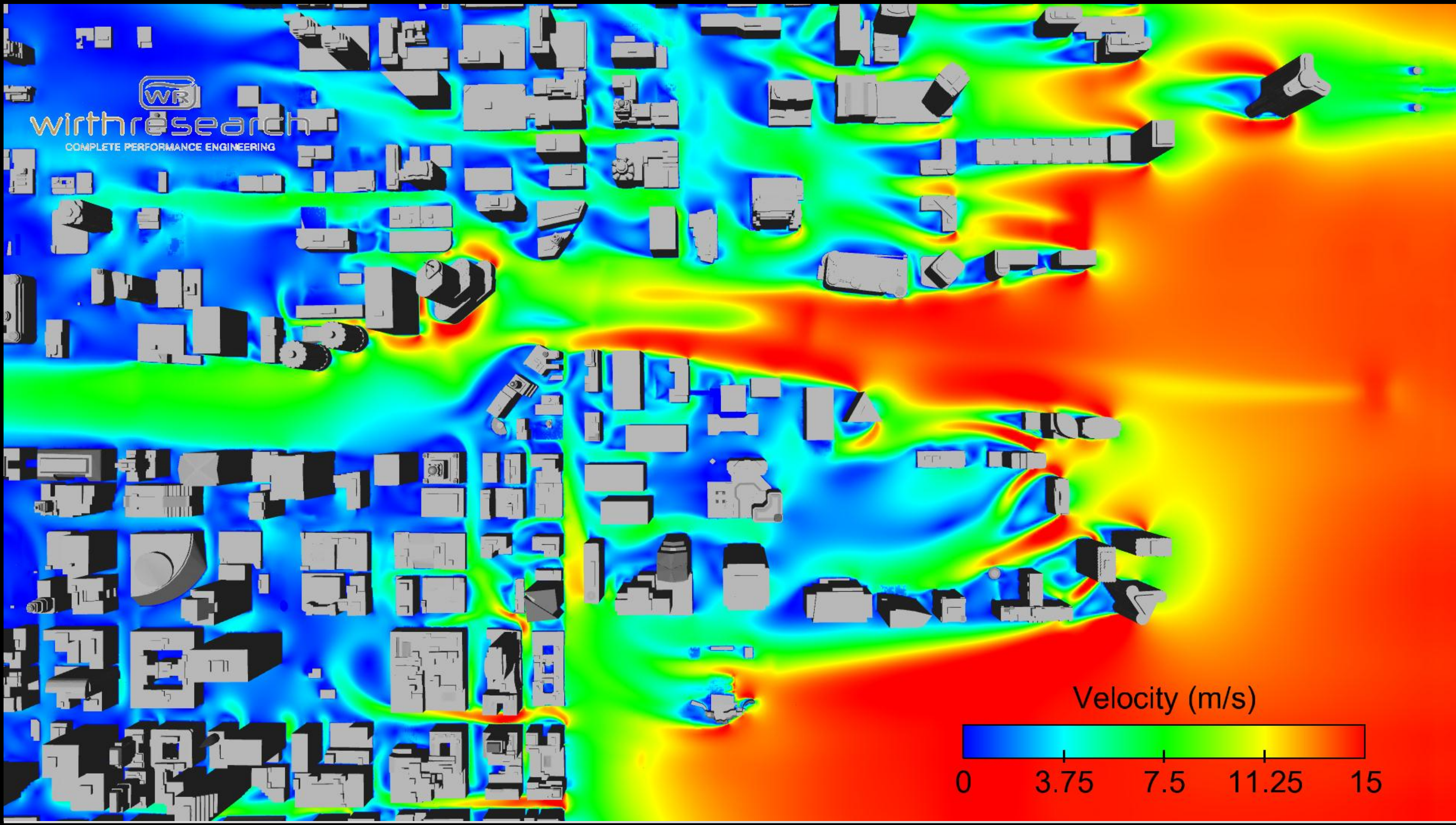
IBSPA 2014

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

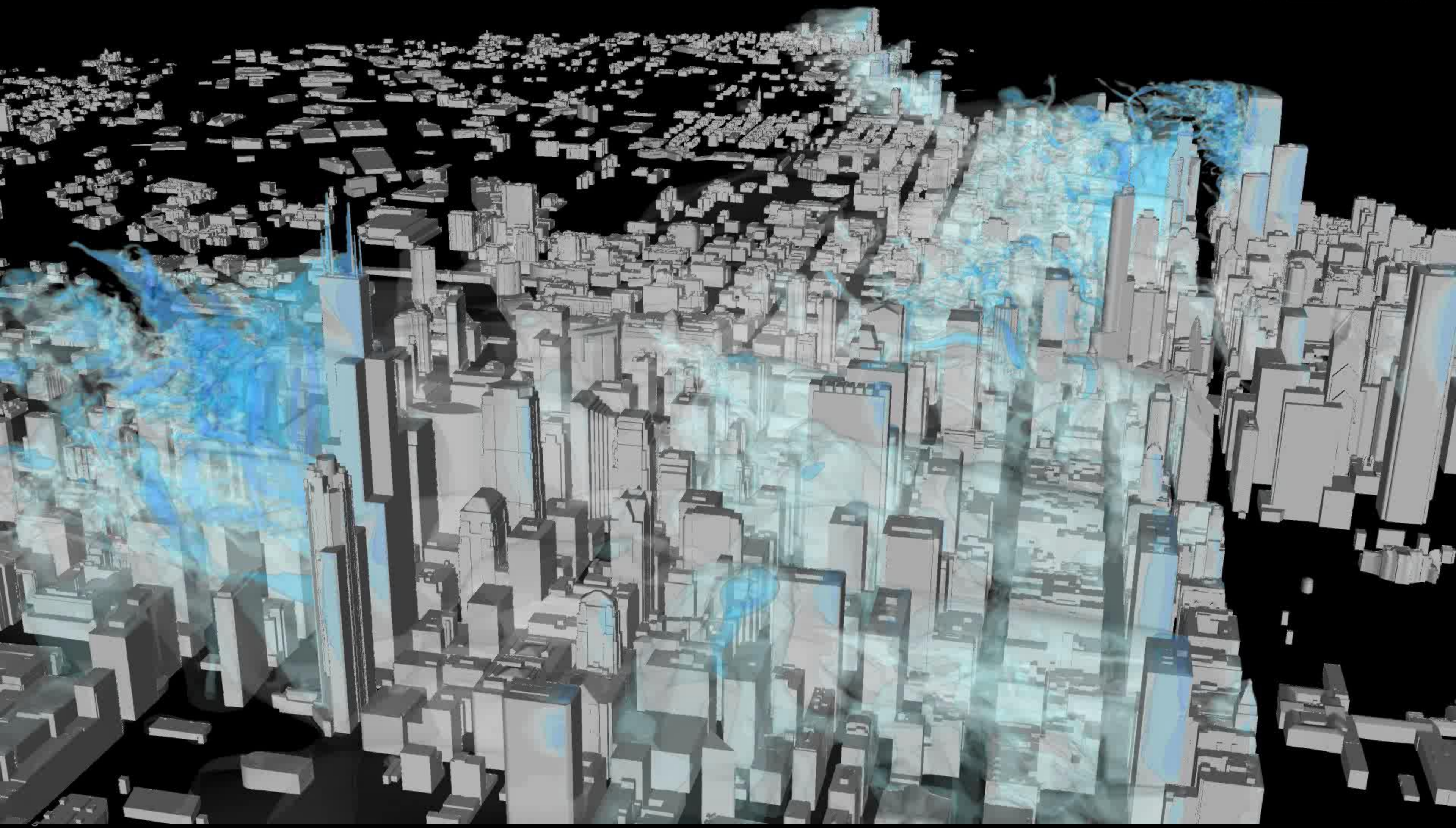


IBSPA 2014

- 10m high slice coloured by velocity



IBSPA 2014



Summary

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.