Visual Analytics for High-Dimensional Data Exploration and Engineering Design Optimisation

Timoleon Kipouros

UNIVERSITY OF CAMBRIDGE
Engineering Design Centre

Engineering Design Centre

Research partners

BT

Rolls-Royce

GKN

AgustaWestland

DH Department of Health

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Computational design

Integrated optimisation methods and tools

Geoff Parks

Timoleon Kipouros

Change management

Modelling change in products

John Clarkson

Timoleon Kipouros

Engineering Design Targets and Challenges in Aviation

- Improve the efficiency by means of noise reduction, aerodynamic and thermal performance, weight reduction (structures), fuel consumption, emissions, cost (investment, production, operating, maintenance), flight trajectories, comfort, …
- Subject to hard-to-satisfy physical and functional constraints
- Reduce lead times in product and process development
- Increase capability to follow the market dynamics and customers needs

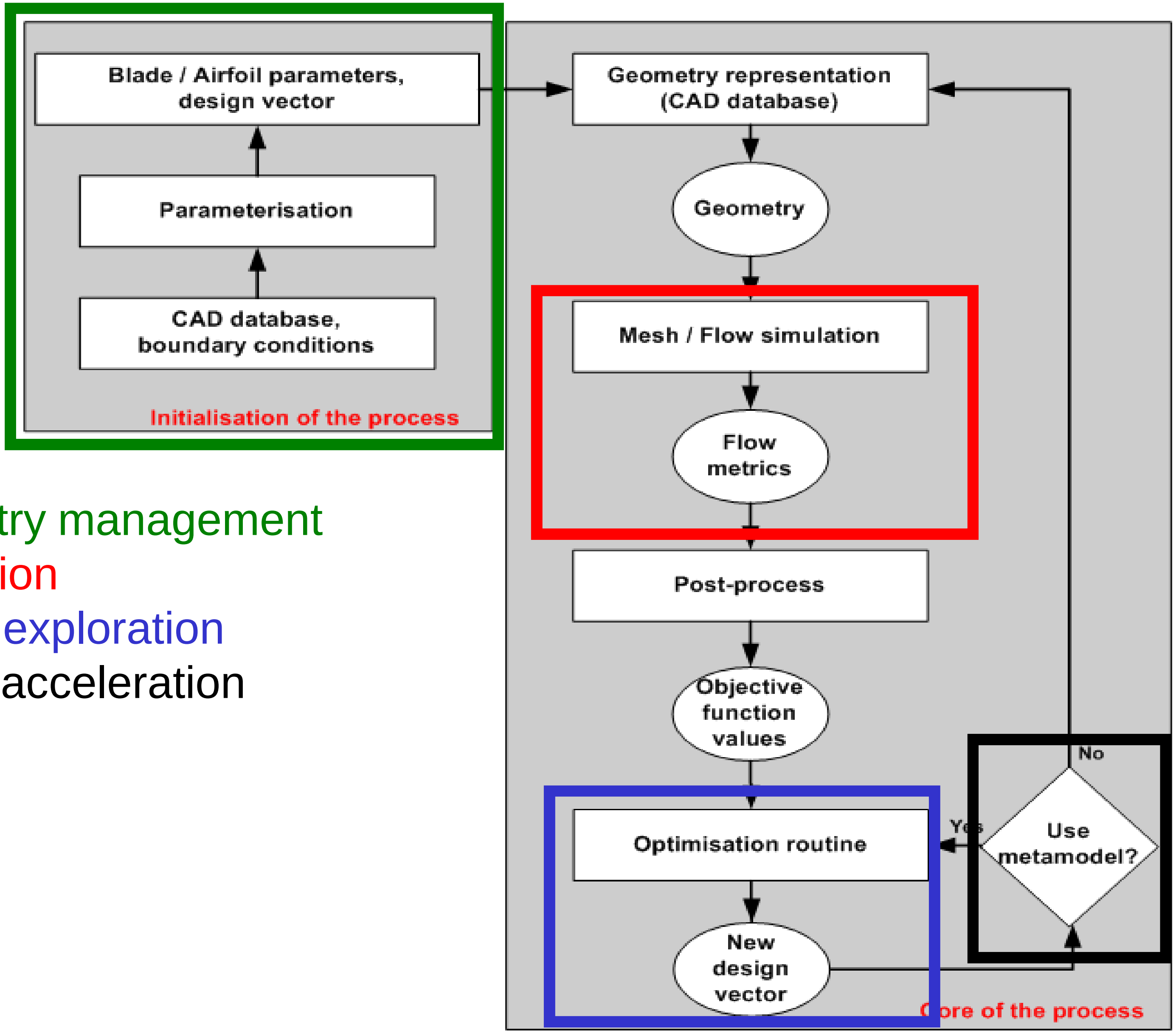
Why Computational Engineering?

- Rapid exploration of high-dimensional design spaces
- Investigation of thousands of different design configurations
- Ability to manage many disciplines at the same time
- The design tools are often modular
- Produce innovative design configurations that couldn’t be explored by any other means
- Identify and reveal a range of optimum solutions that offer insight into the problems and a well informative decision-making
- Offer time to the human designer for creative thinking

Drawback

- It is difficult to do!

Conventional Computational Engineering Design Cycle

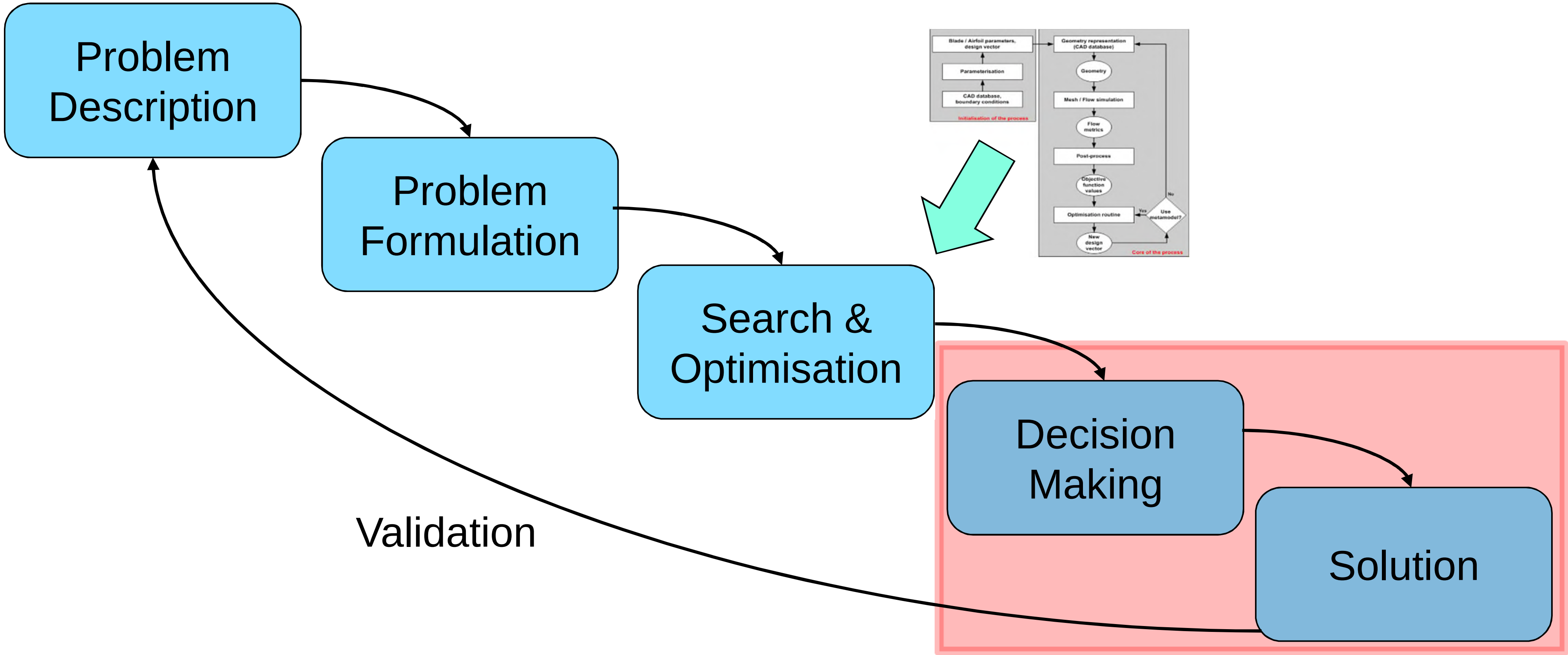


Geometry management
Evaluation
Search exploration
Design acceleration

- Kipouros, T., *et al.,* AIAA Journal, Vol. 46(3), 2008 **and** Kipouros, T., *et al.,* ASME-GT2007-28106

Engineering Design

- Improve products, manufacturing methods or the design process
- Integrated systems with many physical, functional and behavioural links between the different parts
- Is a non-deterministic process and should be tailored to the product under development



Some Data from 4 Computational Experiments…

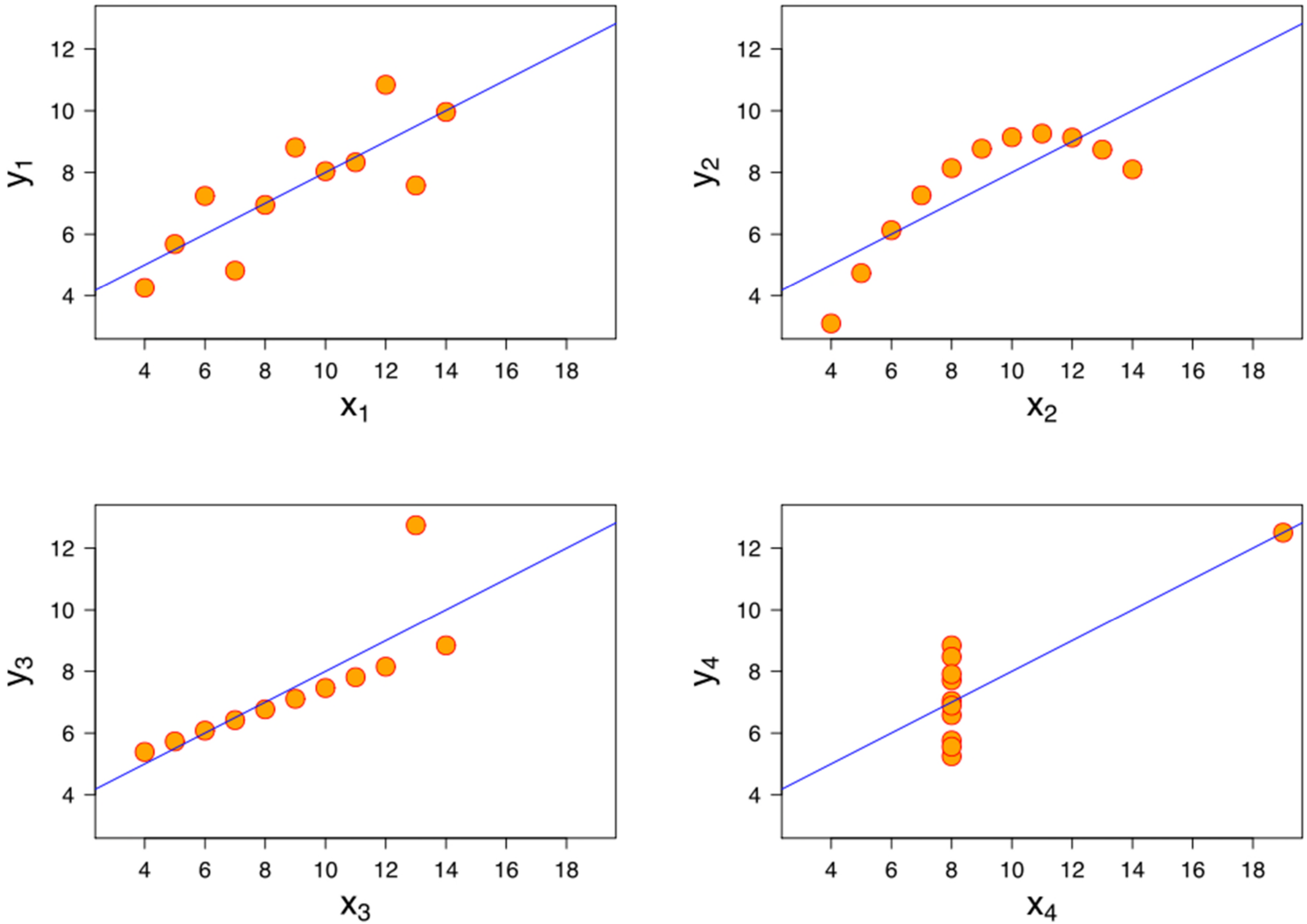
Anscombe's quartet

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

… with same statistics

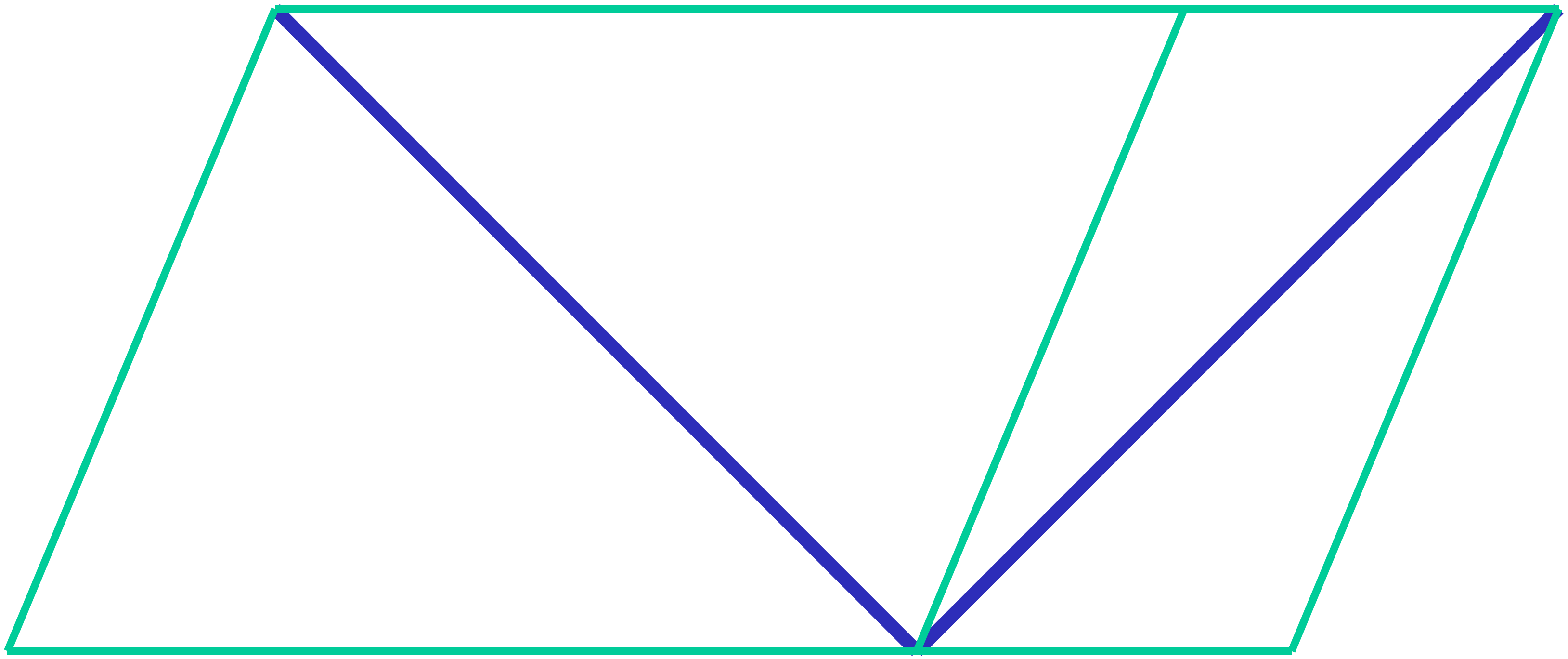
Property	Value
Mean of x	9
Variance of x	11
Mean of y	7.50
Variance of y	4.122 ~ 4.127
Correlation between x and y	0.816
Linear regression line	y = 3.00 + 0.500x

… but look different when visualised; The importance of Visualisation

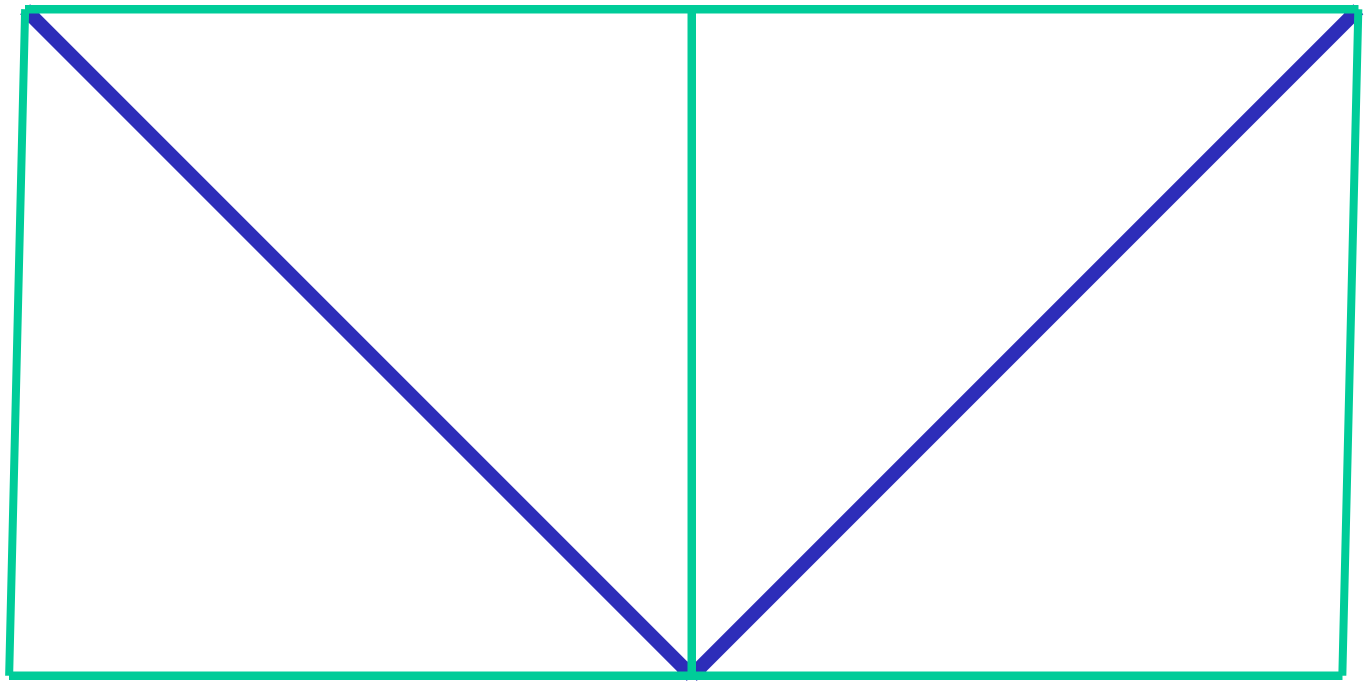


Quick quiz question!

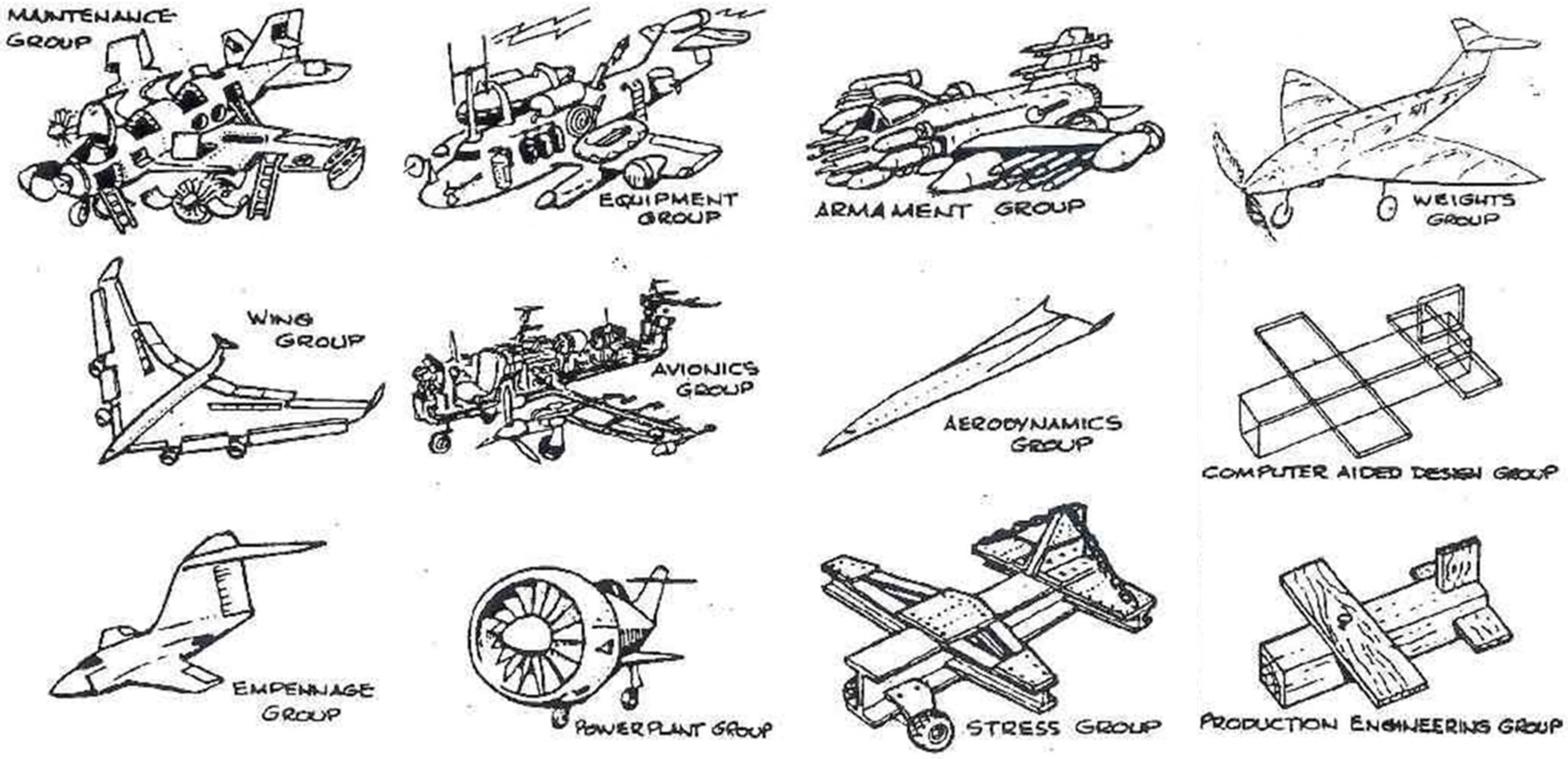
Which of the two blue lines is larger?



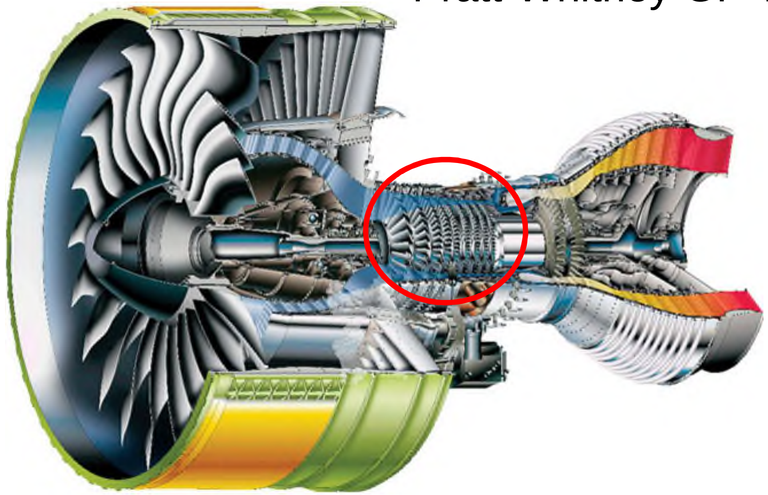
Actually, they are the same!



The context of information visualisation is equally important



Blade Design for Axial Compressors

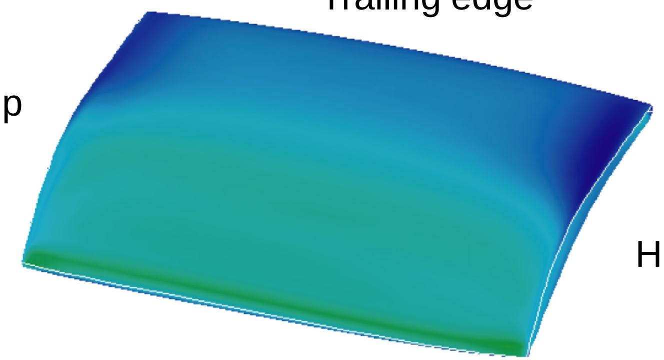

Pratt-Whitney GP-7200

Objectives

- Minimise blockage
- Minimise entropy generation rate
- Minimise profile losses
- Minimise endwall losses

Constraints

- Mass flow (equality)
- Mass-averaged flow turning (inequality)
- Leading edge radius (inequality)
- Tip clearance (inequality)

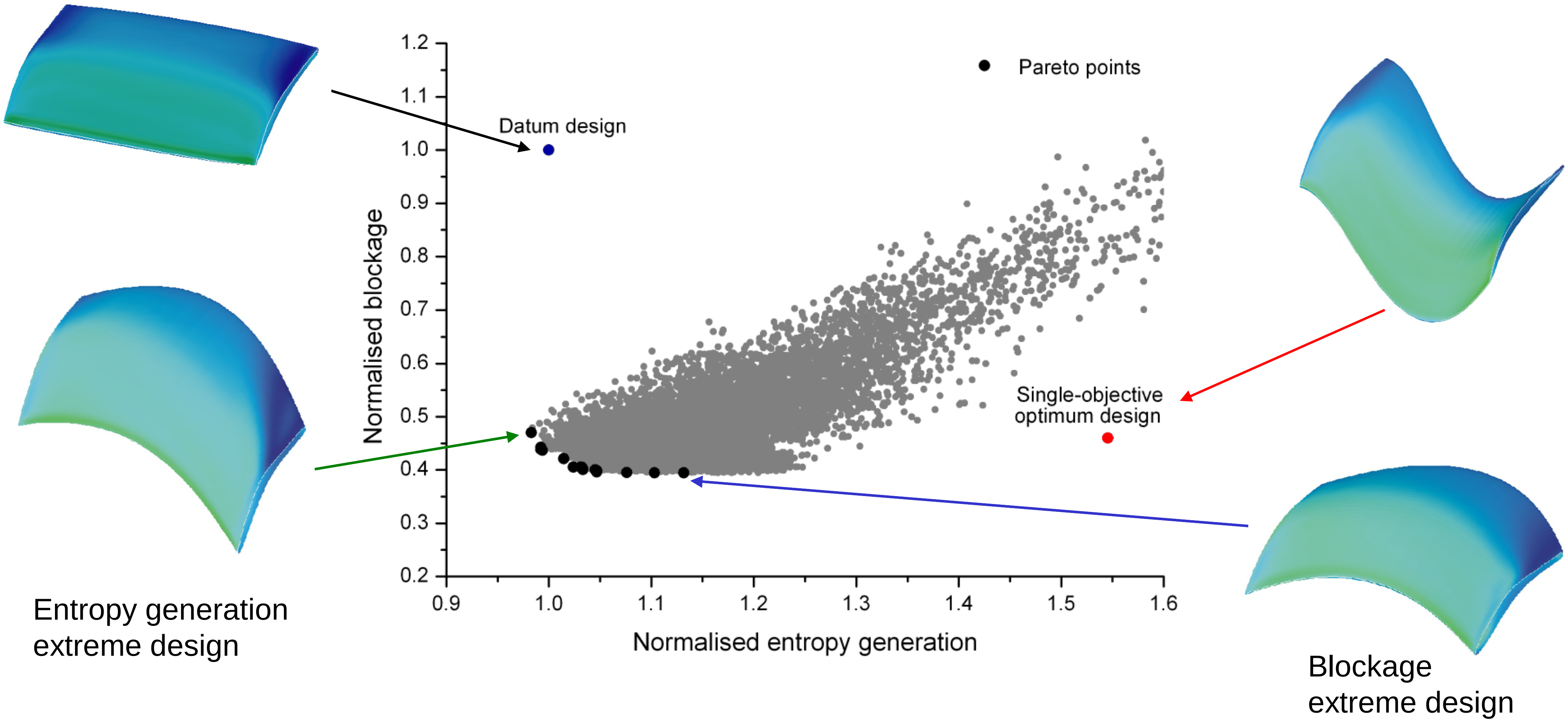


Datum design

Design space

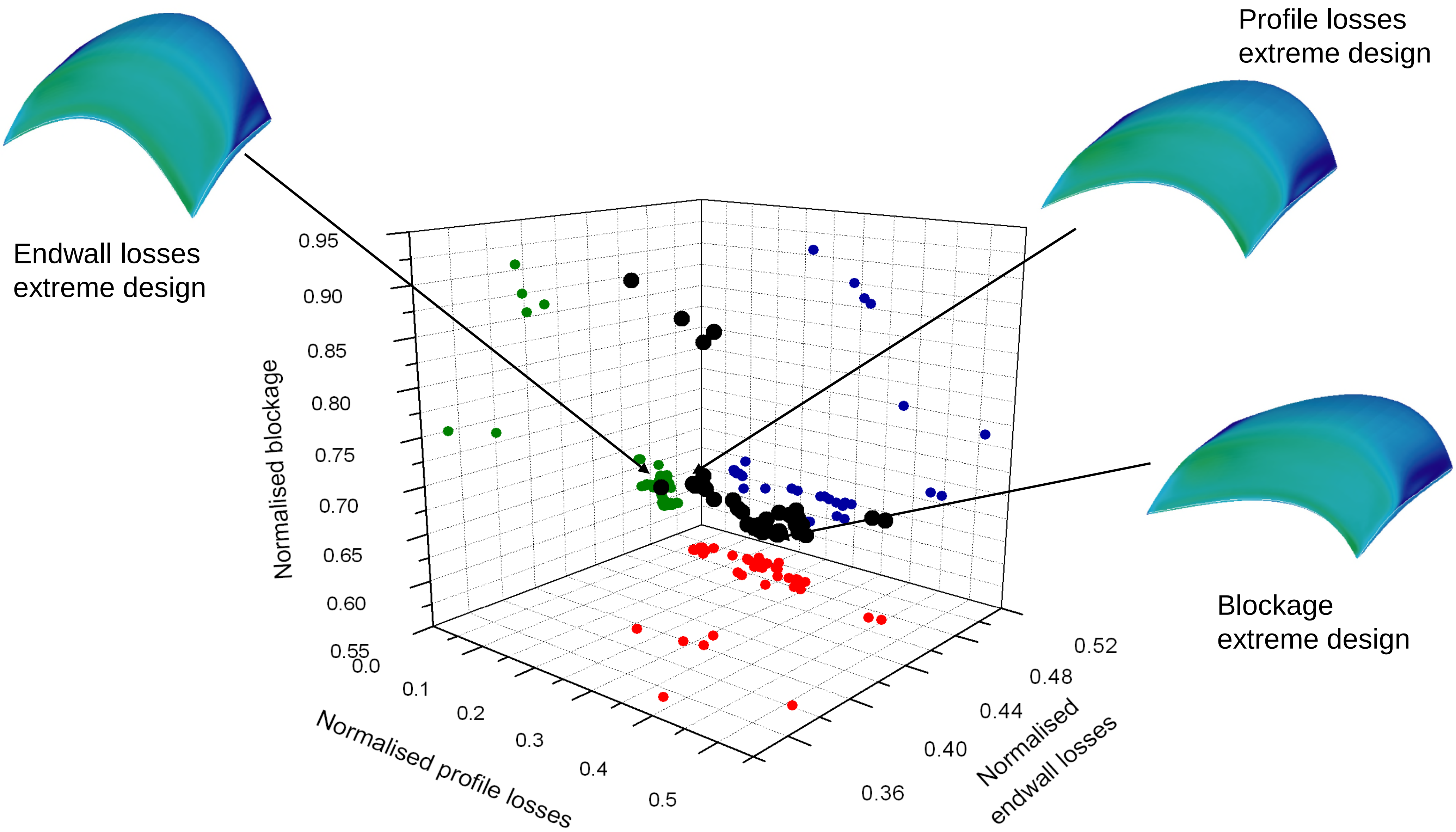
- 26 parameters for 3D geometry management

Single- vs Multi-Objective Optimisation



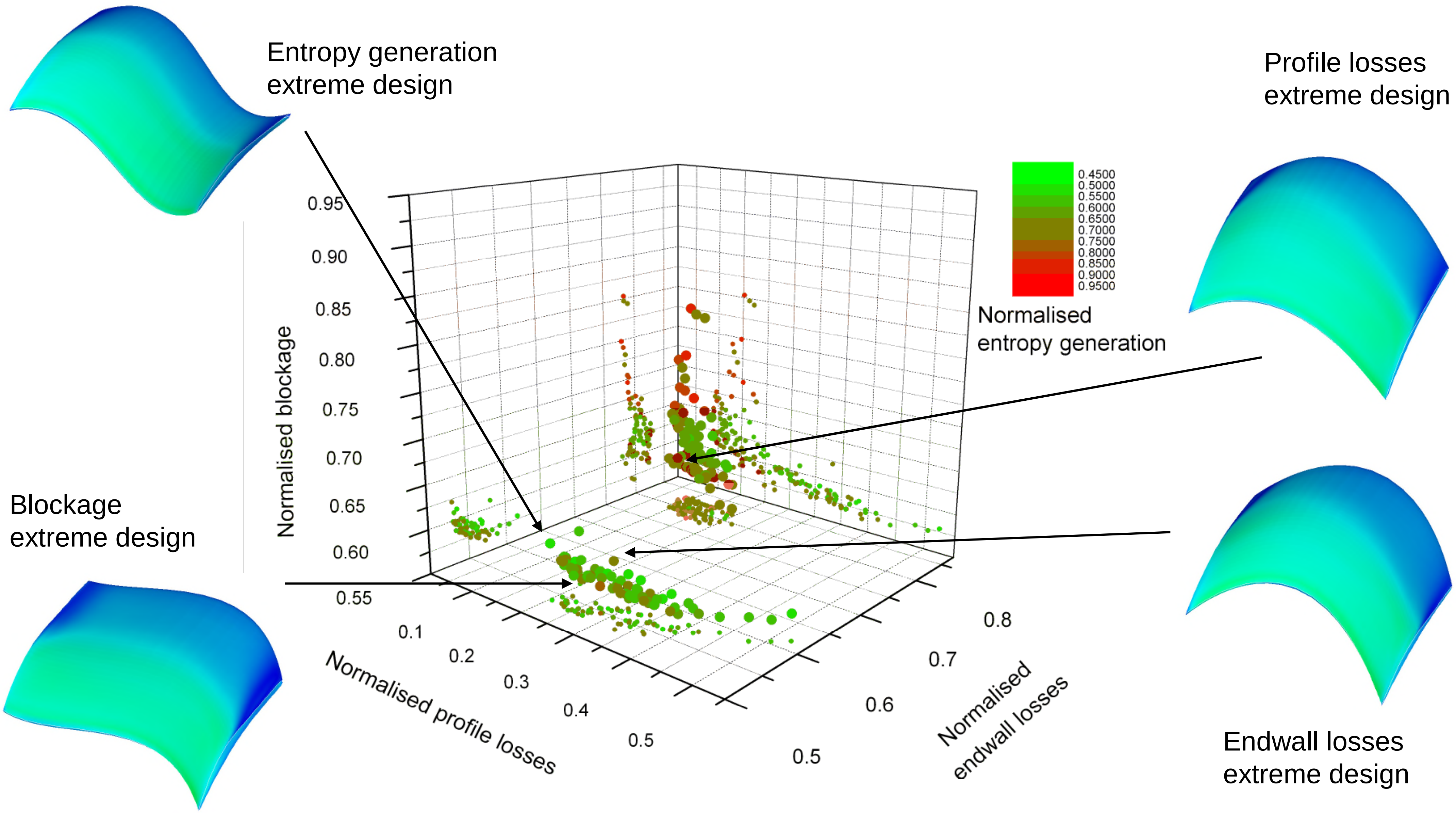
• Kipouros, T. *et al.,* AIAA Journal, Vol. 46(3), 2008

3D Pareto Surface



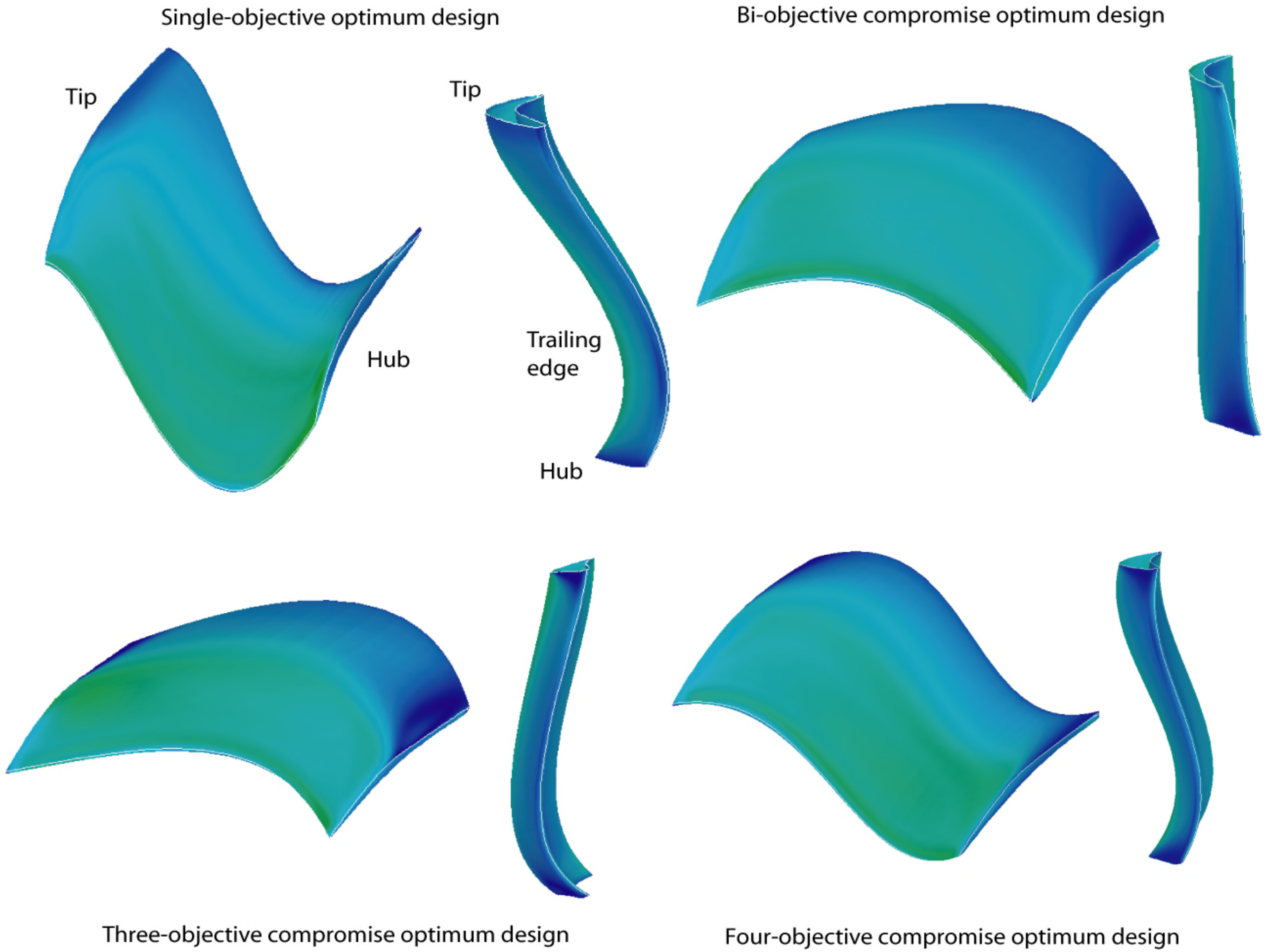
- Kipouros, T. *et al.,* CMES: Computer Modeling in Engineering & Sciences, Vol. 37(1), 2008

4D Pareto Surface



• Kipouros, T., *et al.*, AIAA-2012-1427

Indicative Optimum Blade Geometries

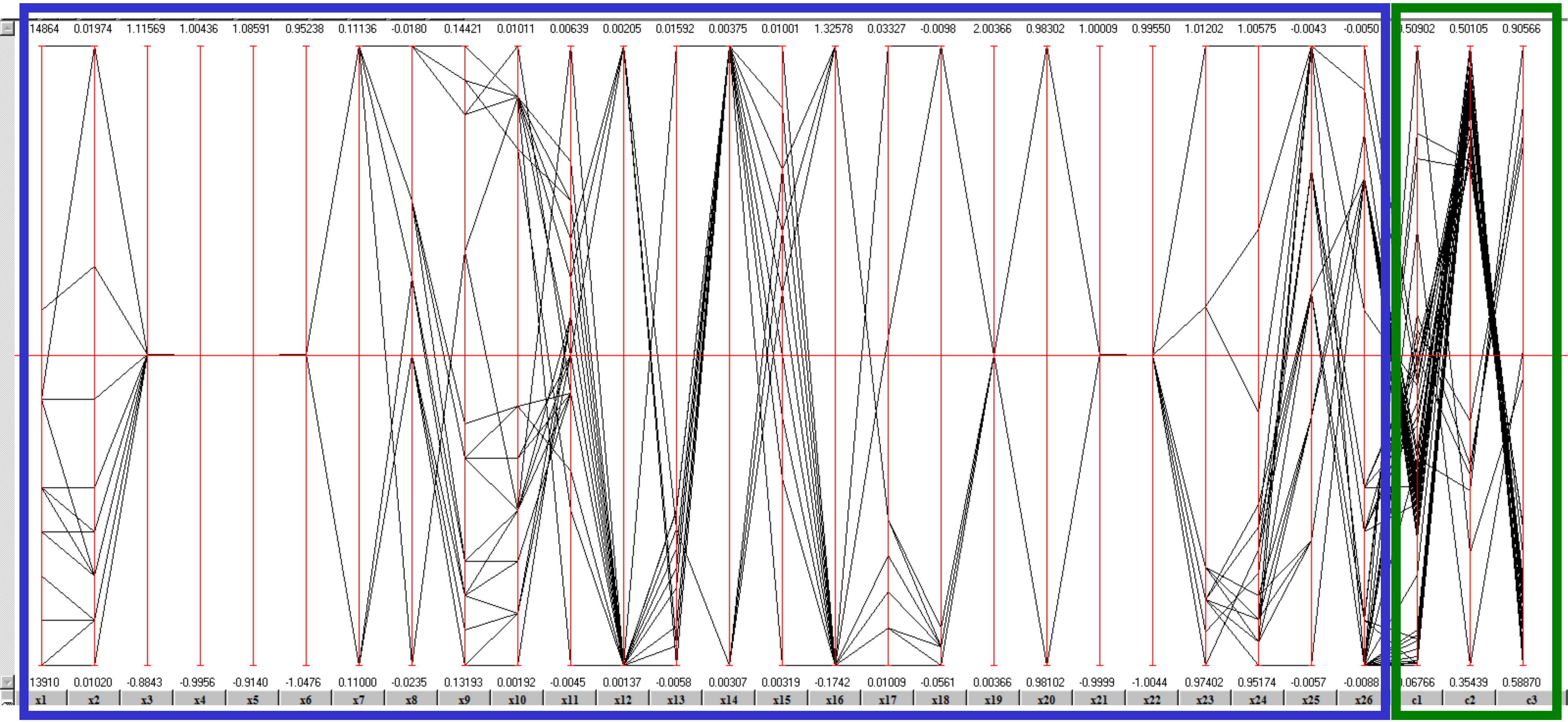


Message…

- Consider all of the critical performance metrics for optimisation at the same time in order to reveal a global picture of the design space

Post-analysis with Parallel Coordinates: Identification of Patterns

- **Full data set**

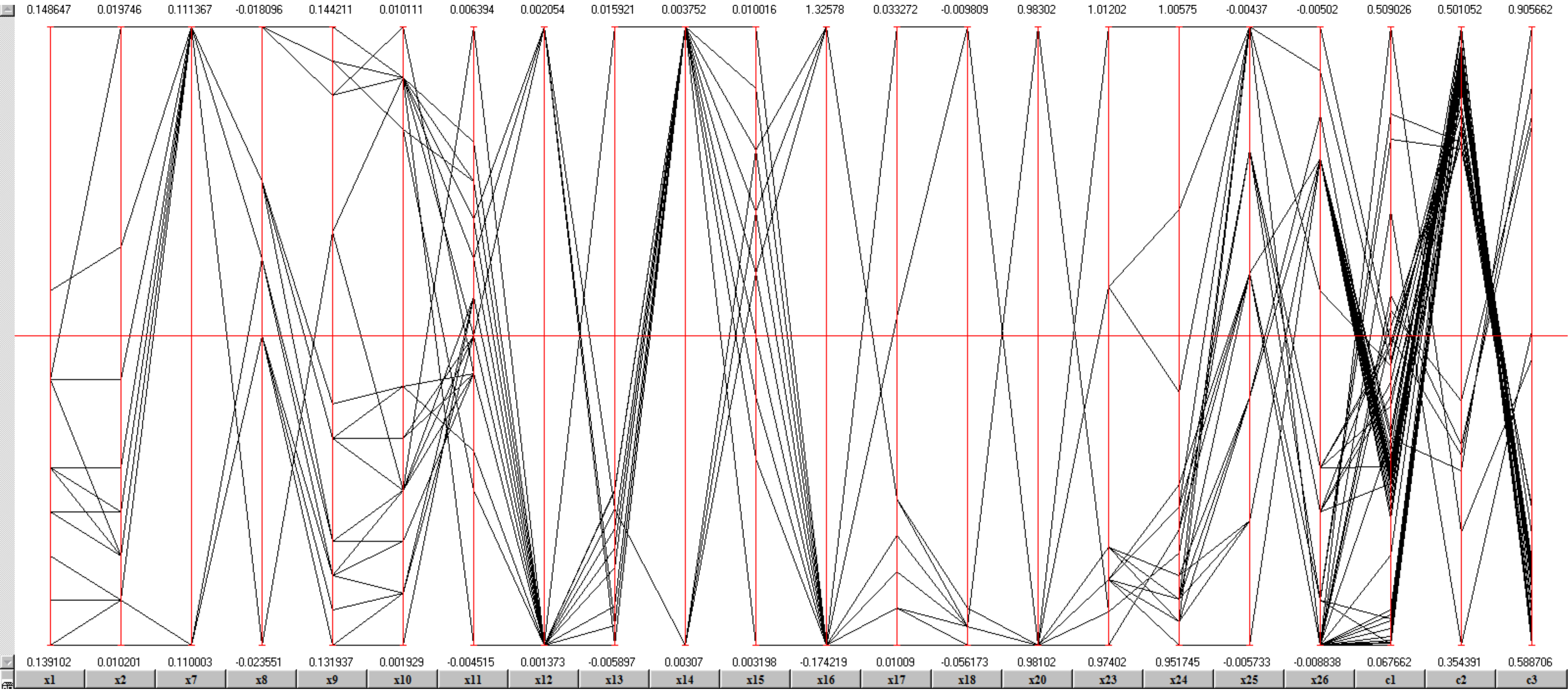


Design parameters **Objective functions**

- Kipouros, T., *et al.,* AIAA-2008-2138 **and** Kipouros, T., *et al.,* AIAA-2013-1750

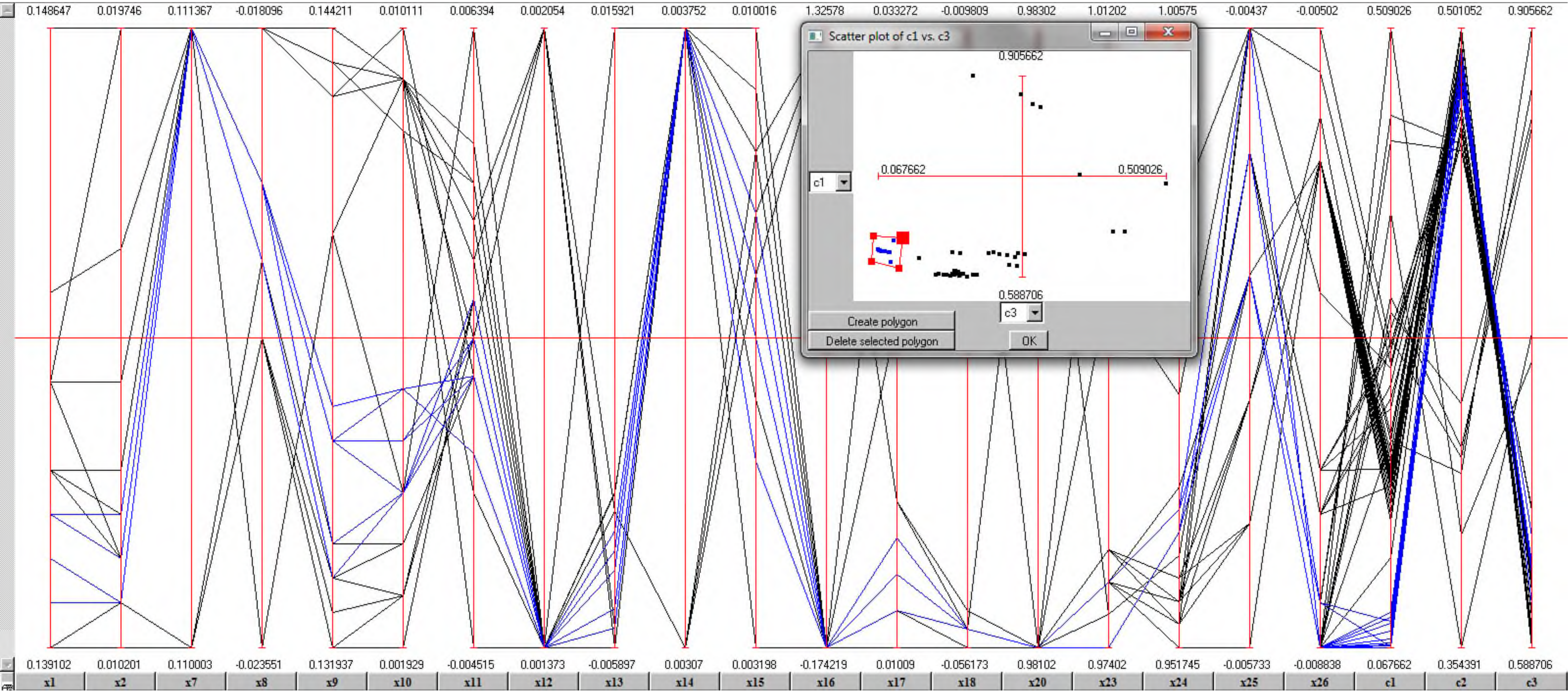
Post-analysis with Parallel Coordinates: Identification of Patterns

- **Eliminating the constants**



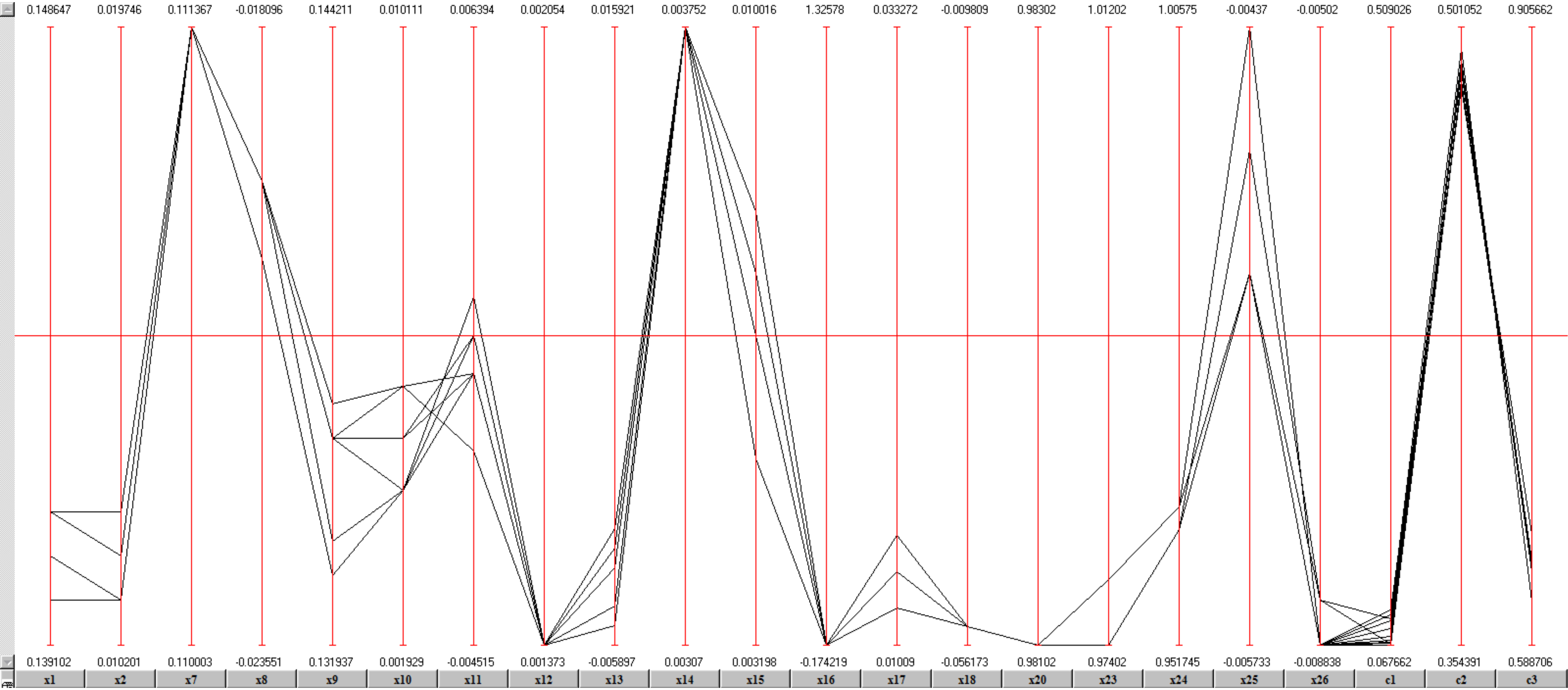
Post-analysis with Parallel Coordinates: Identification of Patterns

- **Selection of a region in the objective function space**



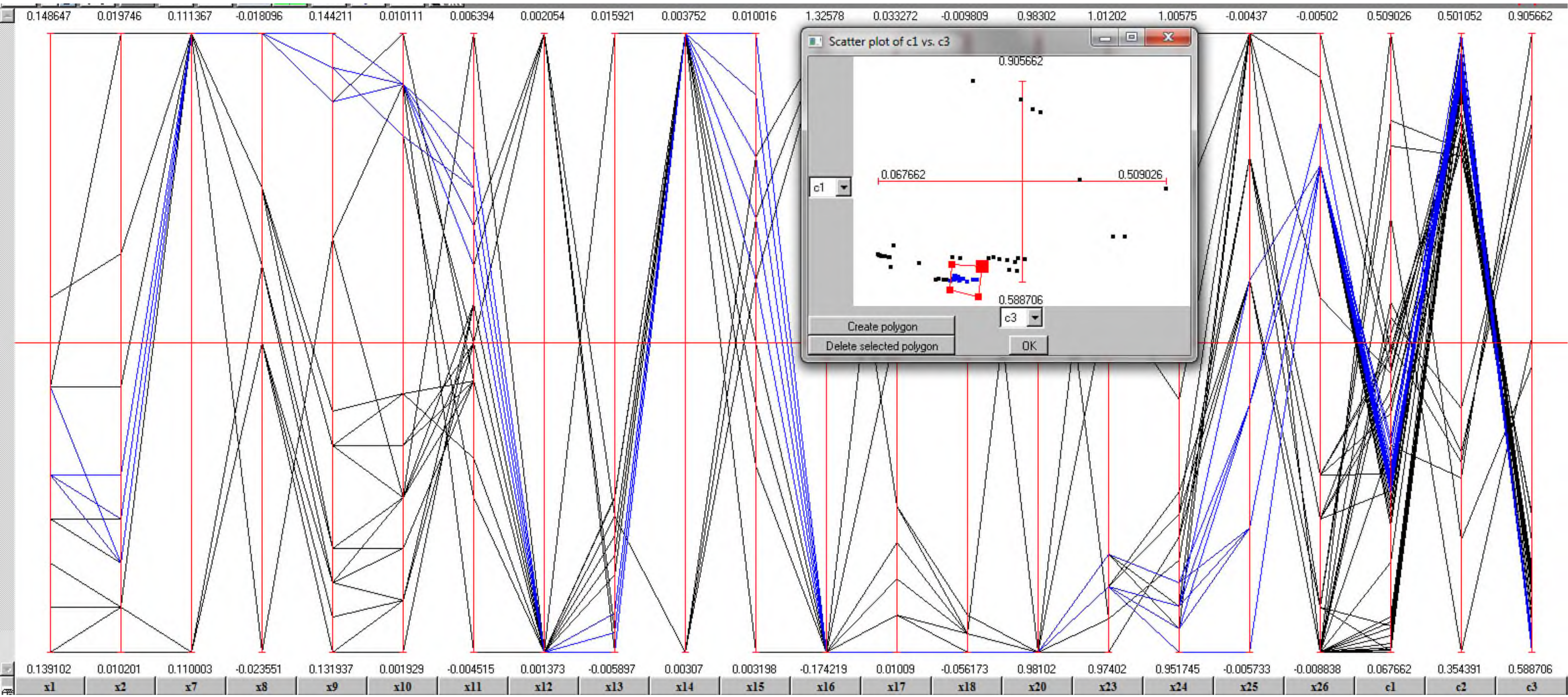
Post-analysis with Parallel Coordinates: Identification of Patterns

- **Pattern comprising the 20% of the Pareto Set**



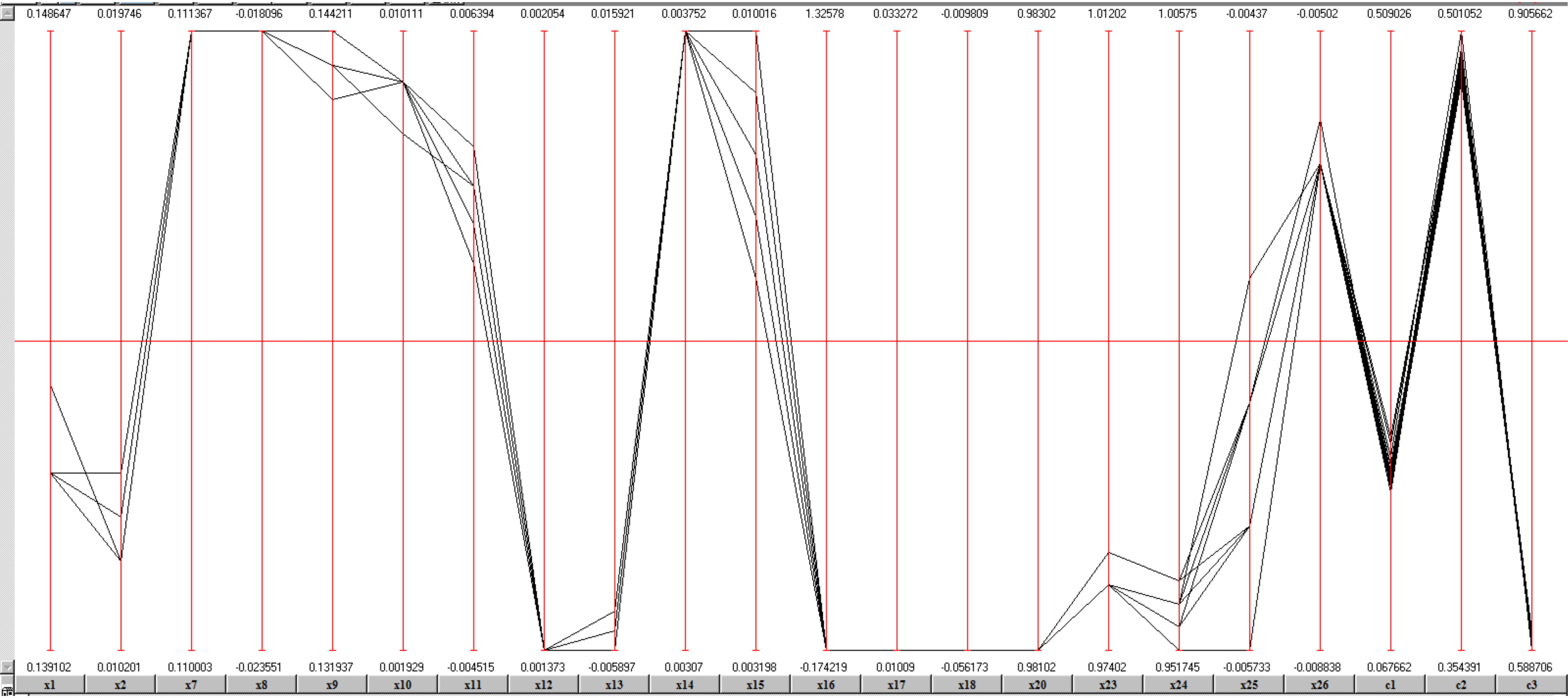
Post-analysis with Parallel Coordinates: Identification of Patterns

- **Selection of a region in the objective function space**



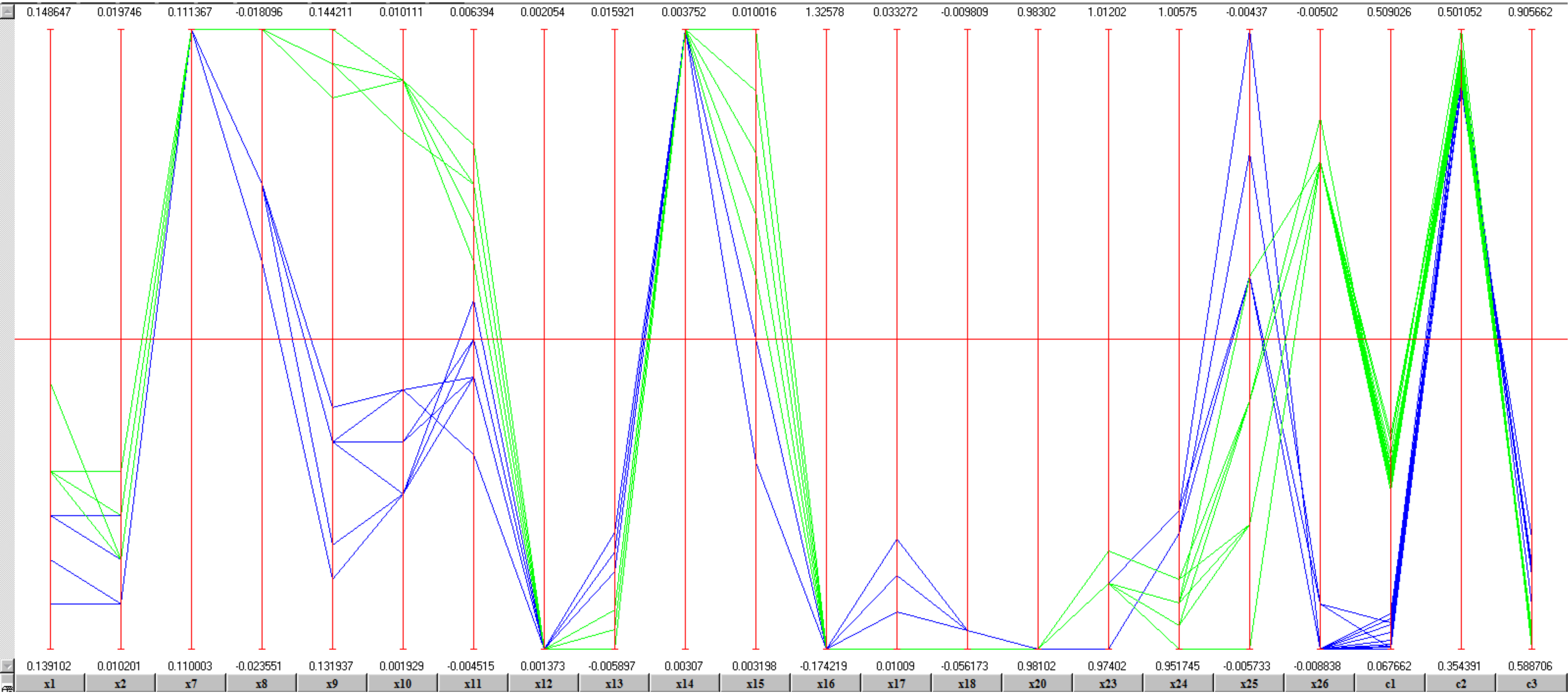
Post-analysis with Parallel Coordinates: Identification of Patterns

- **Pattern comprising the 35% of the Pareto Set**

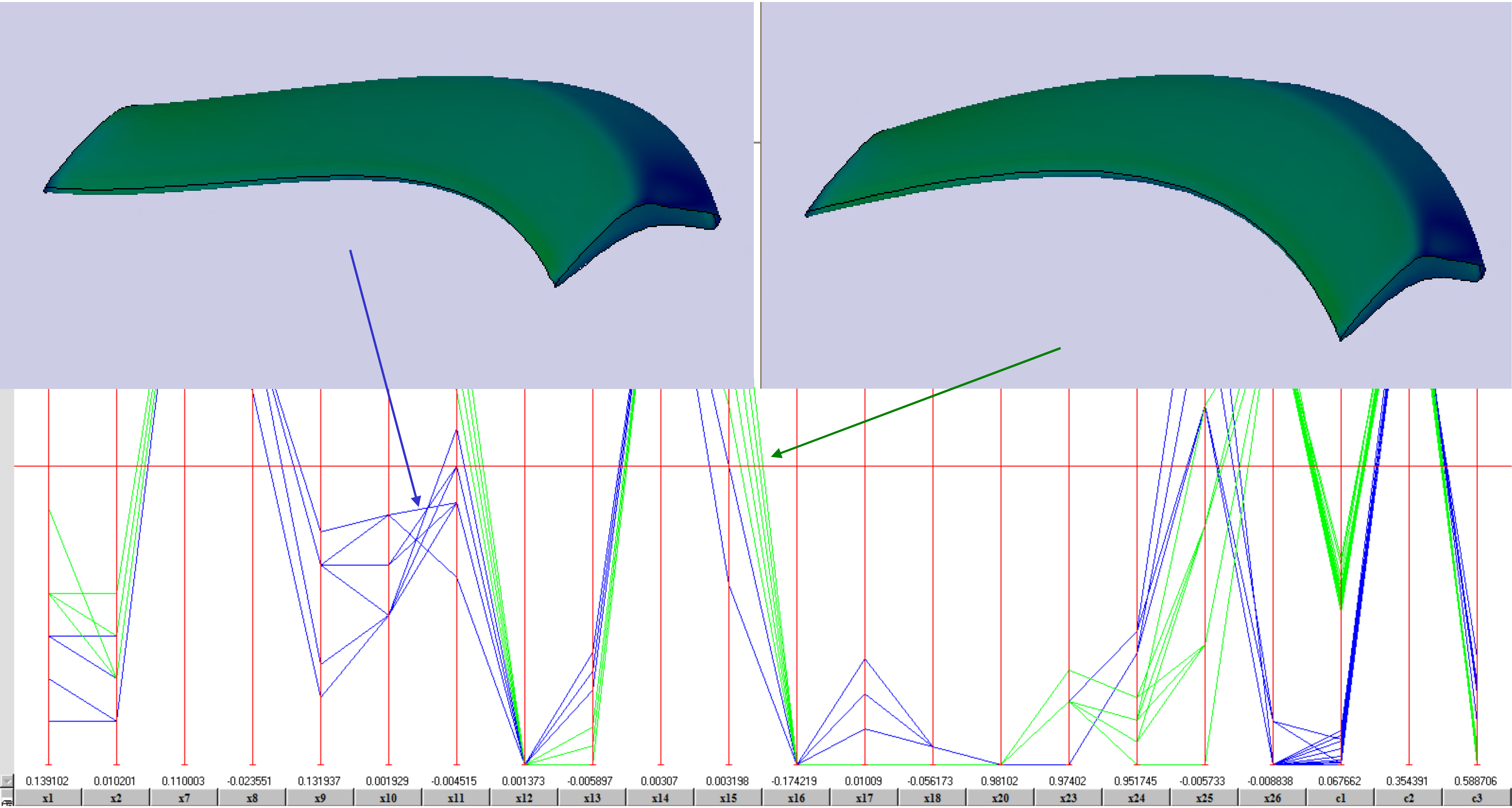


Post-analysis with Parallel Coordinates: Identification of Patterns

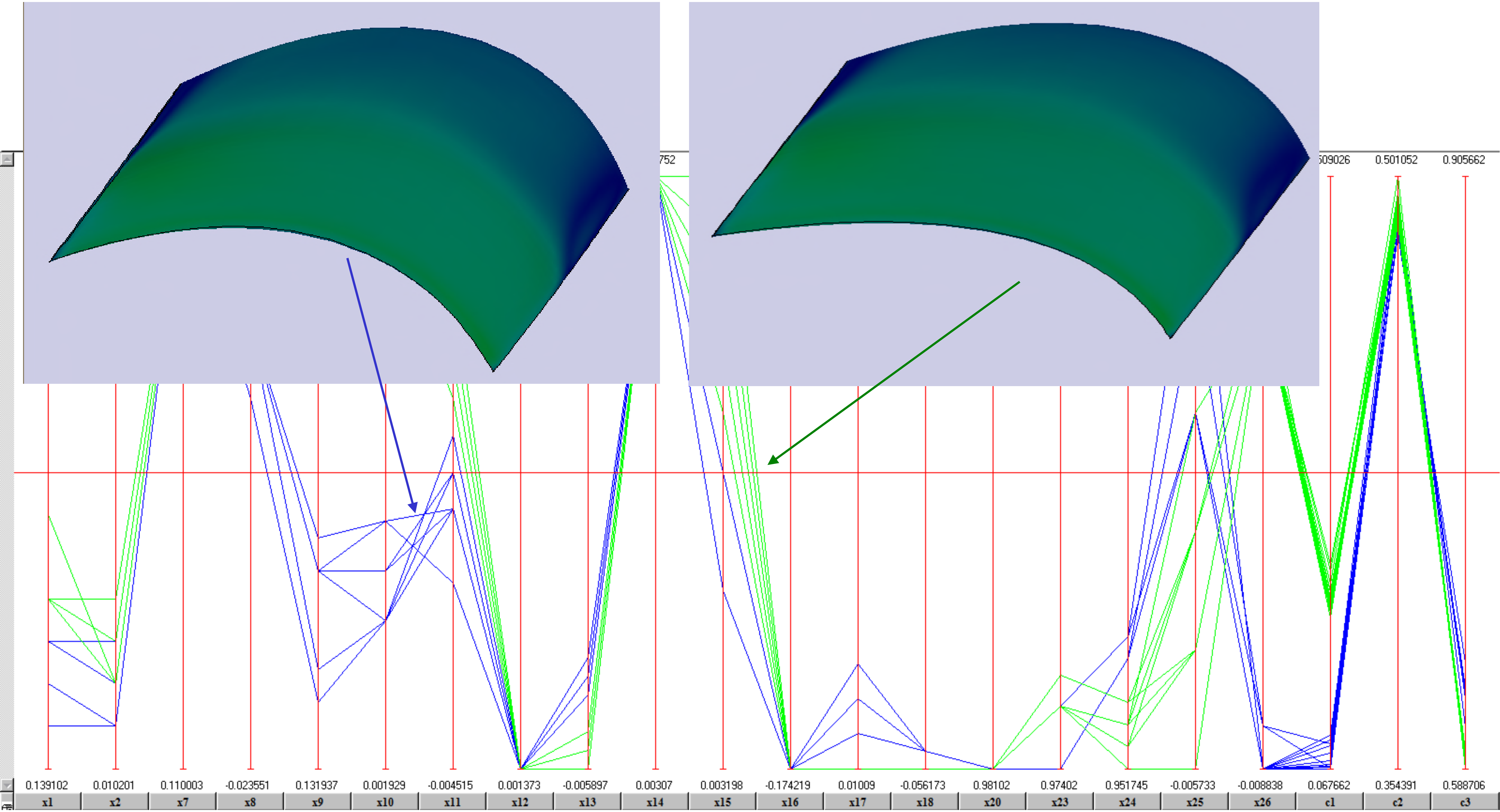
- **Patterns comprising the 55% of the Pareto Set**



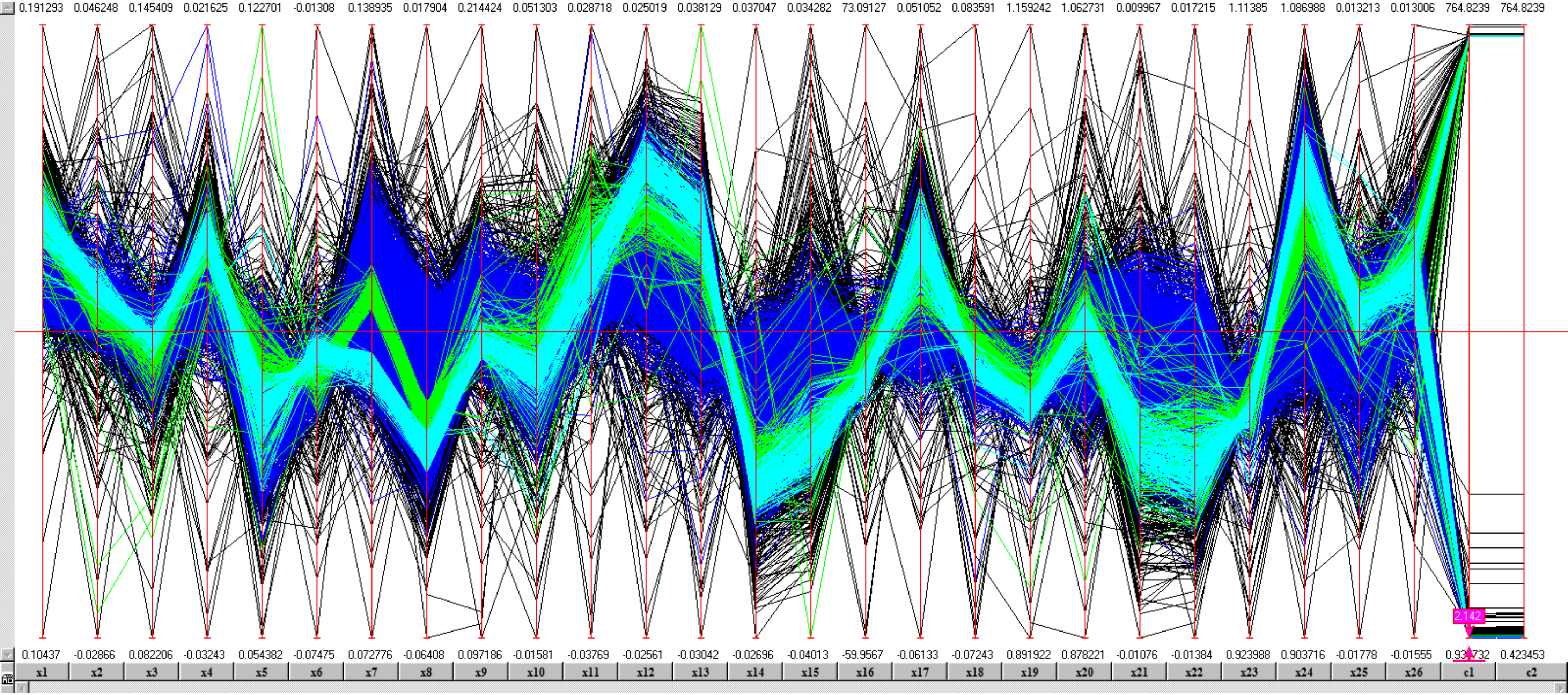
Post-analysis with Parallel Coordinates: Identification of Patterns



Post-analysis with Parallel Coordinates: Identification of Patterns

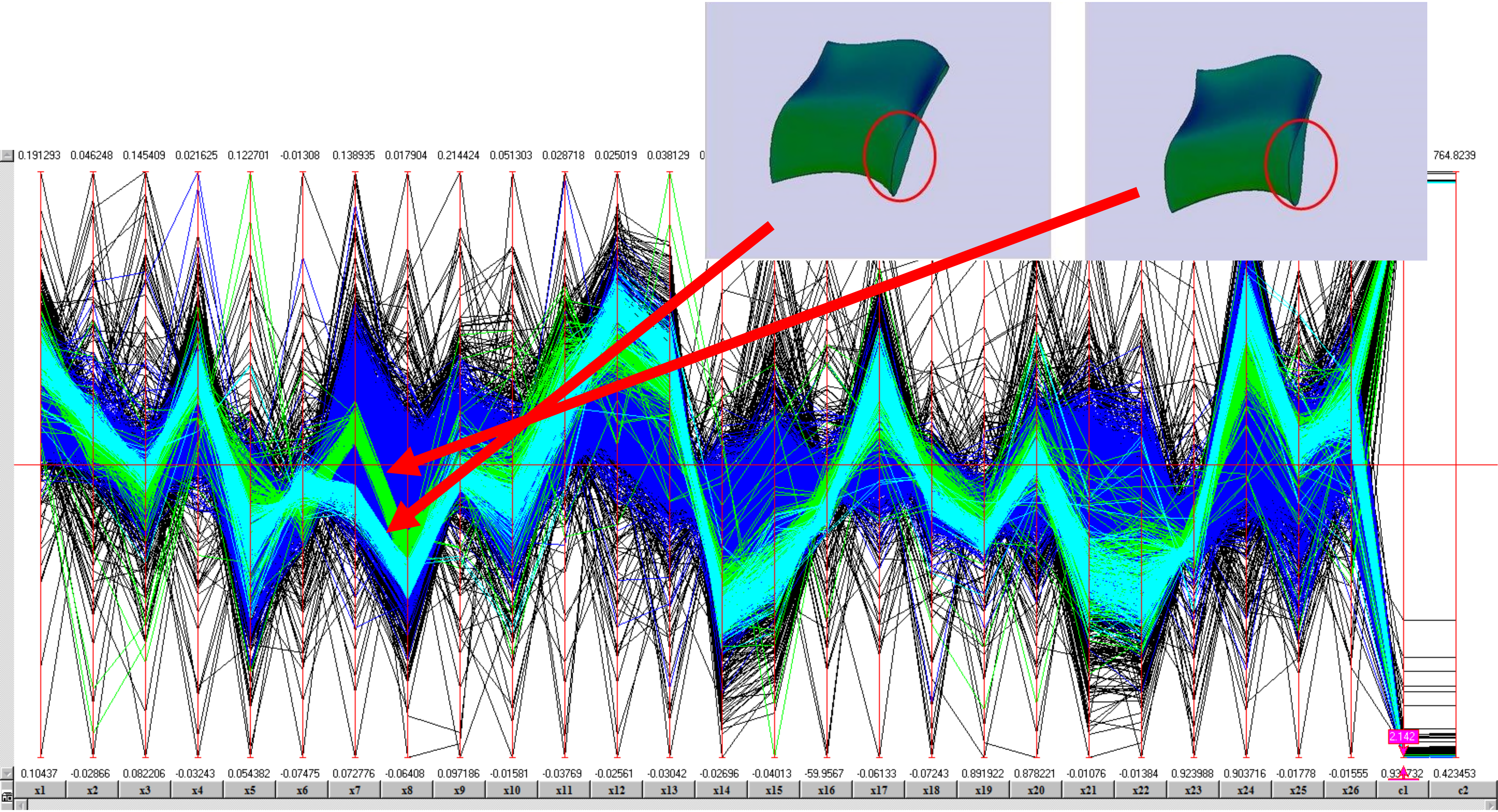


Identifying Feasible and Infeasible Patterns in the Design Space



- Kipouros, T., *et al.*, OPT-i 2014-3090

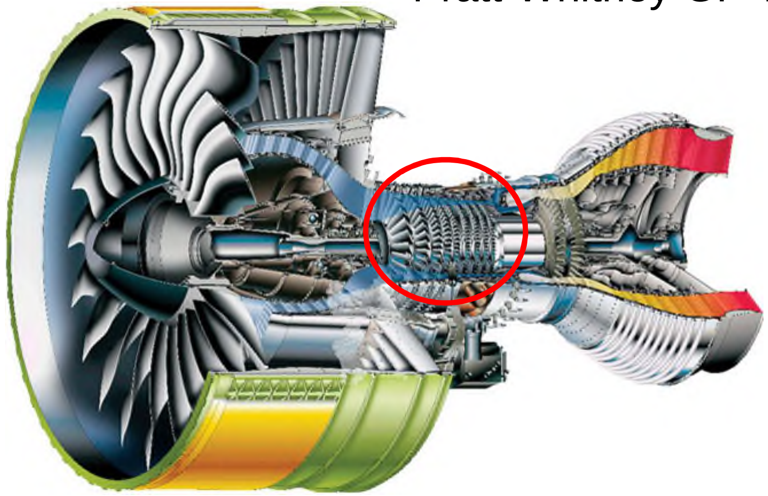
Identifying Causes of Feasible and Infeasible Aerodynamic Behaviour



- Kipouros, T., *et al.,* OPT-i 2014-3090

Preliminary Design for Core Compressor

Pratt-Whitney GP-7200



Objectives

- Maximise isentropic efficiency
- Maximise surge margin

Constraints

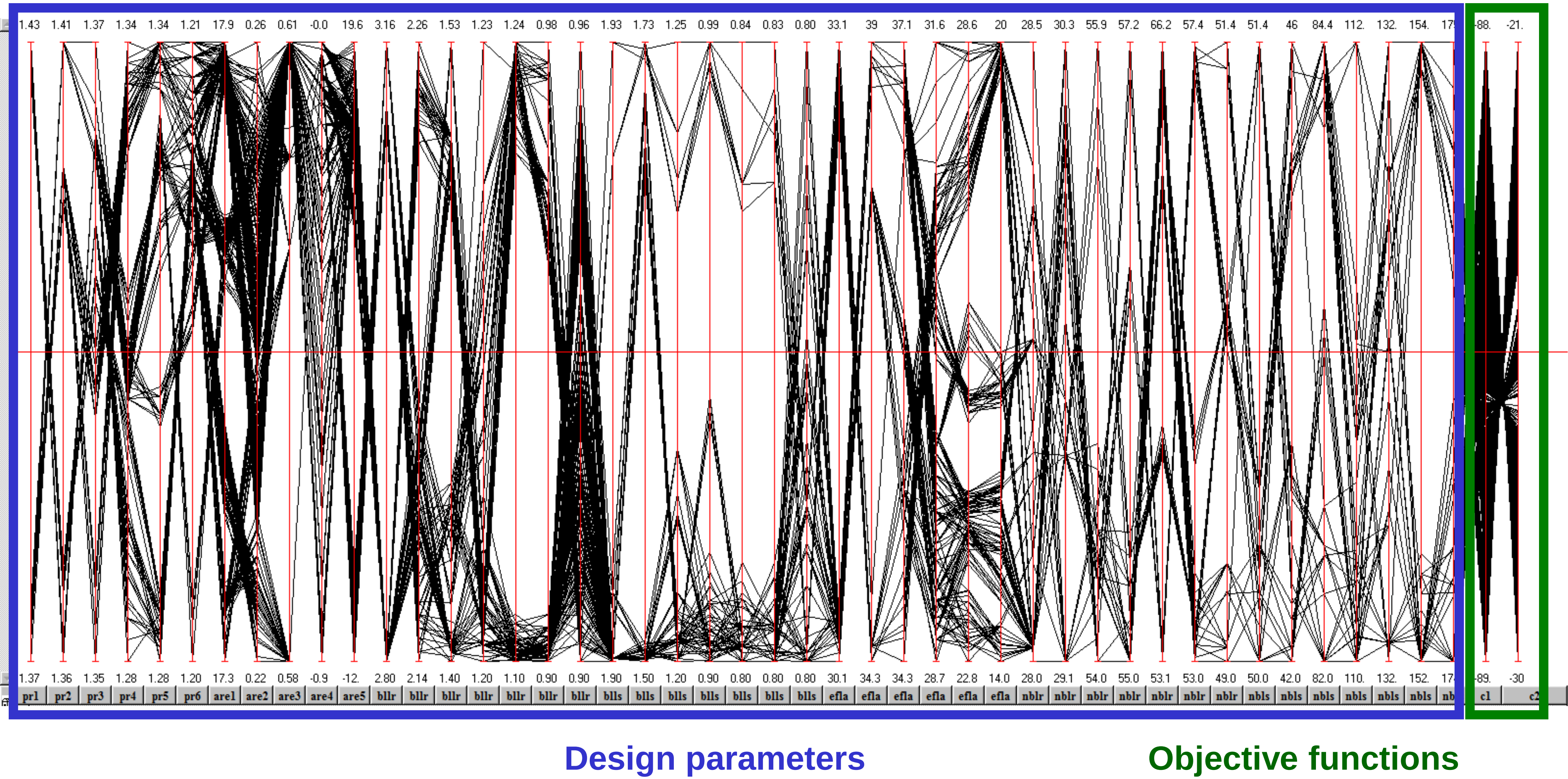
- De Haller number
- Koch factor
- Static pressure rise coefficient

Design space

- 45 design parameters controlling stage pressure ratio, annulus area, flow angles and number of blades

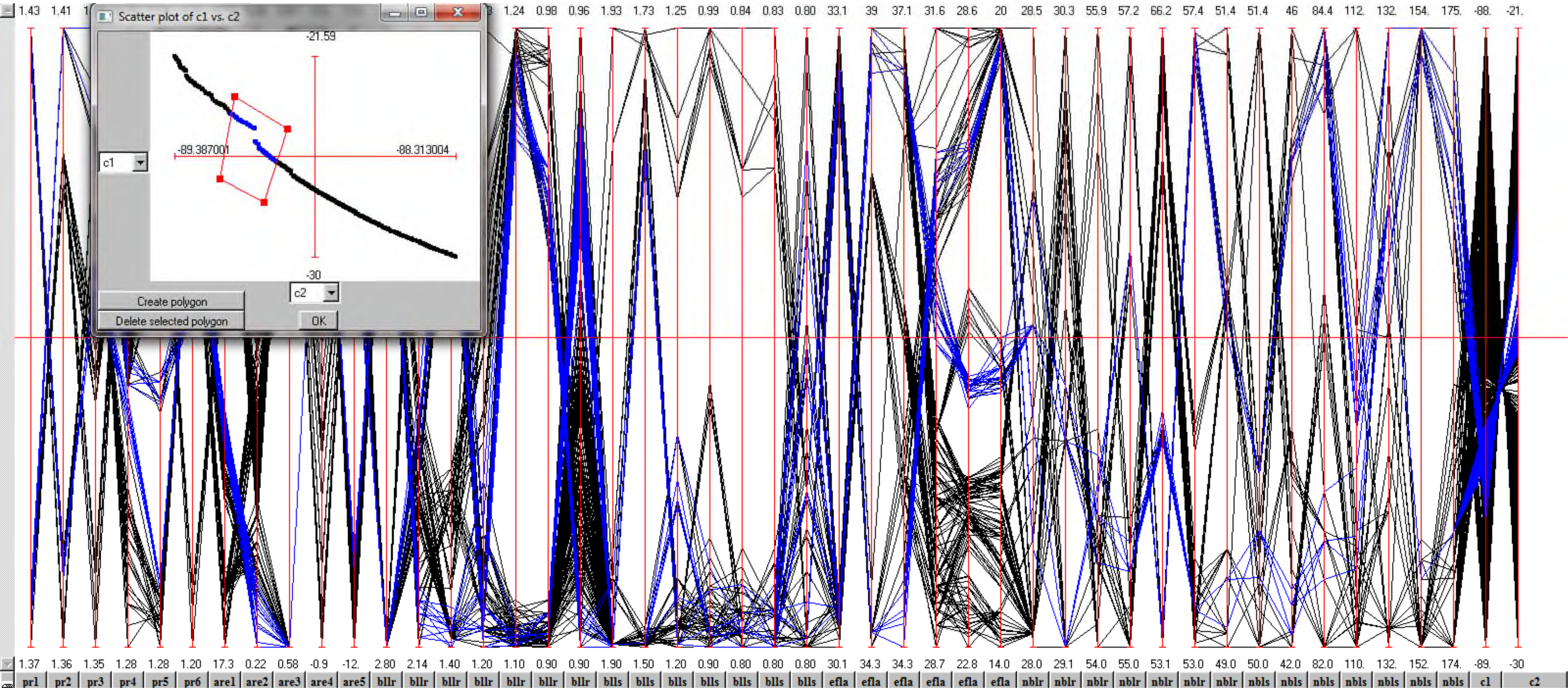
Post-analysis with Parallel Coordinates: Exploration of Discontinuities

- **Full data set**



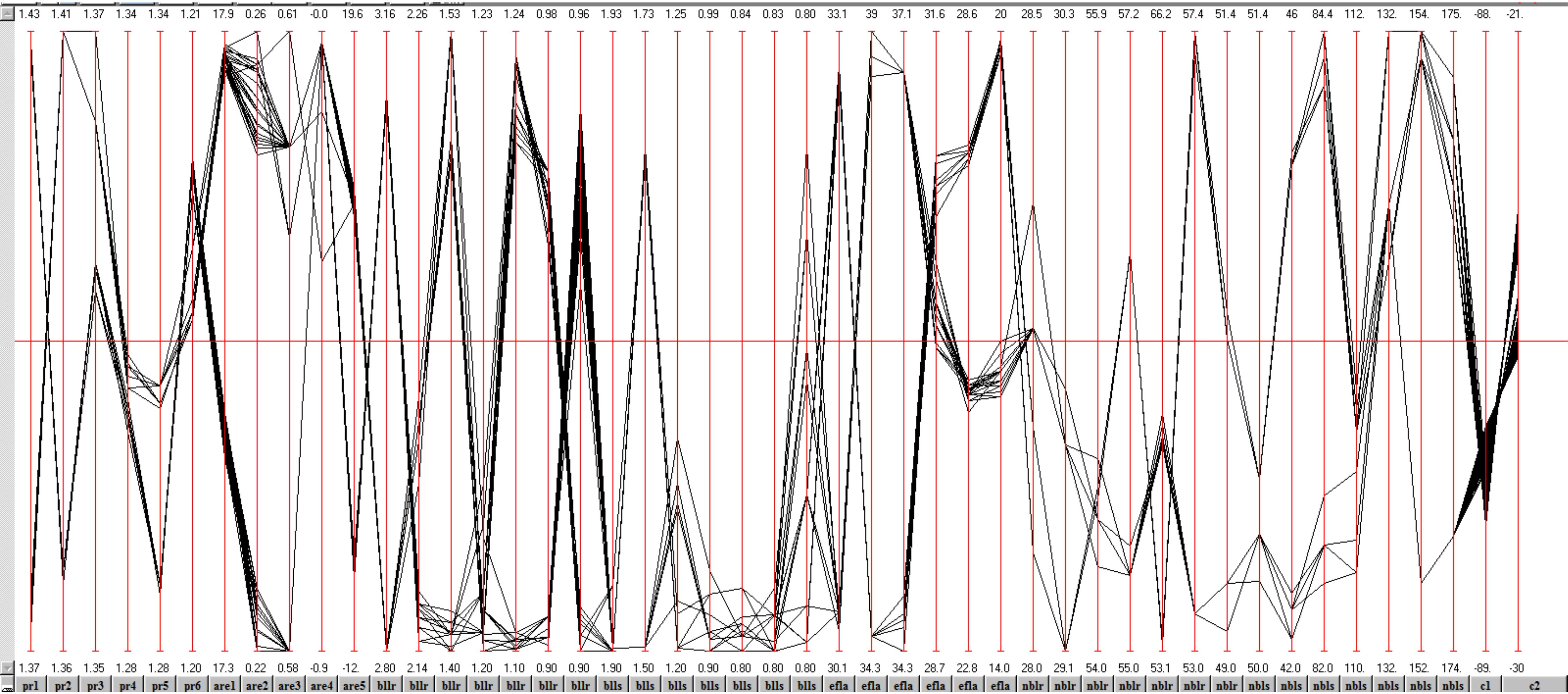
Post-analysis with Parallel Coordinates: Exploration of Discontinuities

- **Highlighting the discontinuous region in the objective function space**



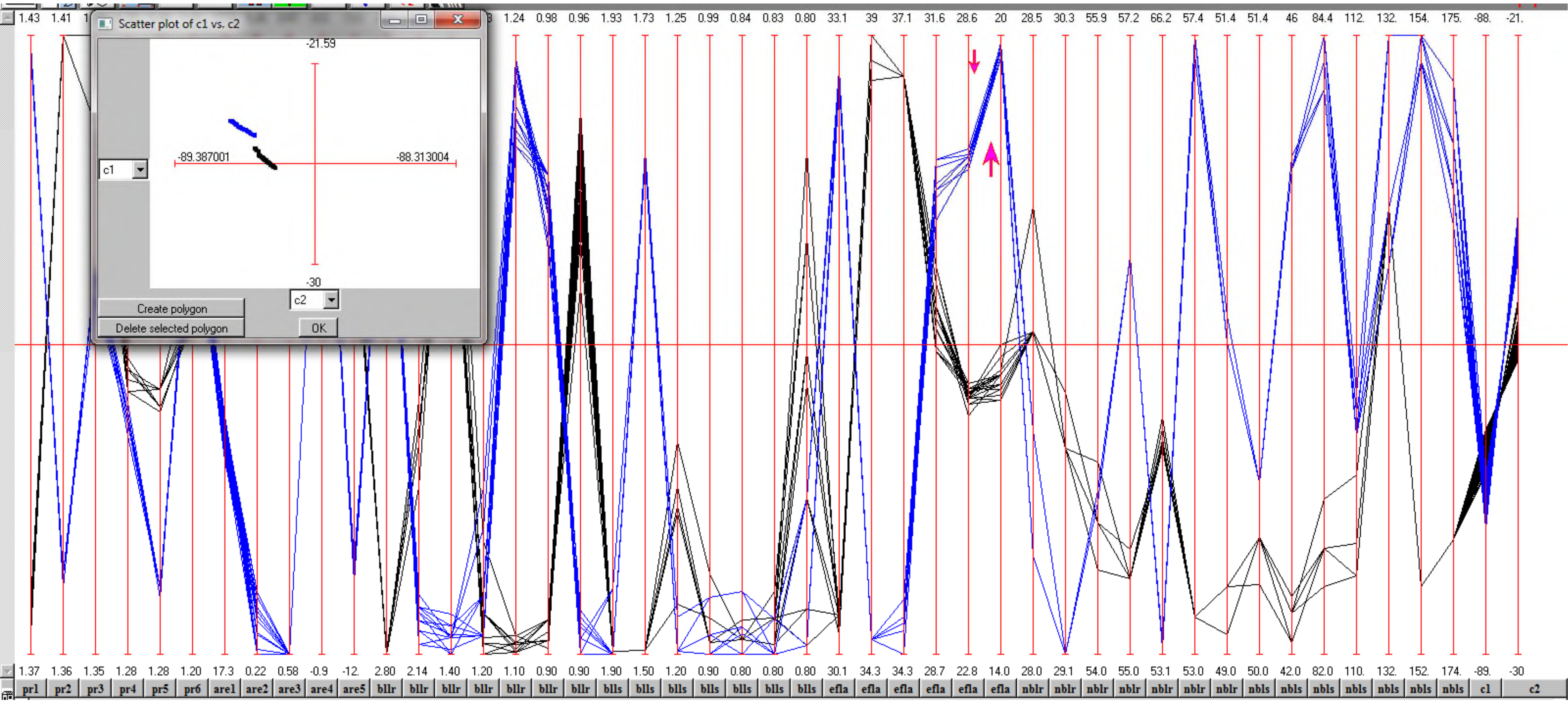
Post-analysis with Parallel Coordinates: Exploration of Discontinuities

- **Display of the selected design configurations**



Post-analysis with Parallel Coordinates: Exploration of Discontinuities

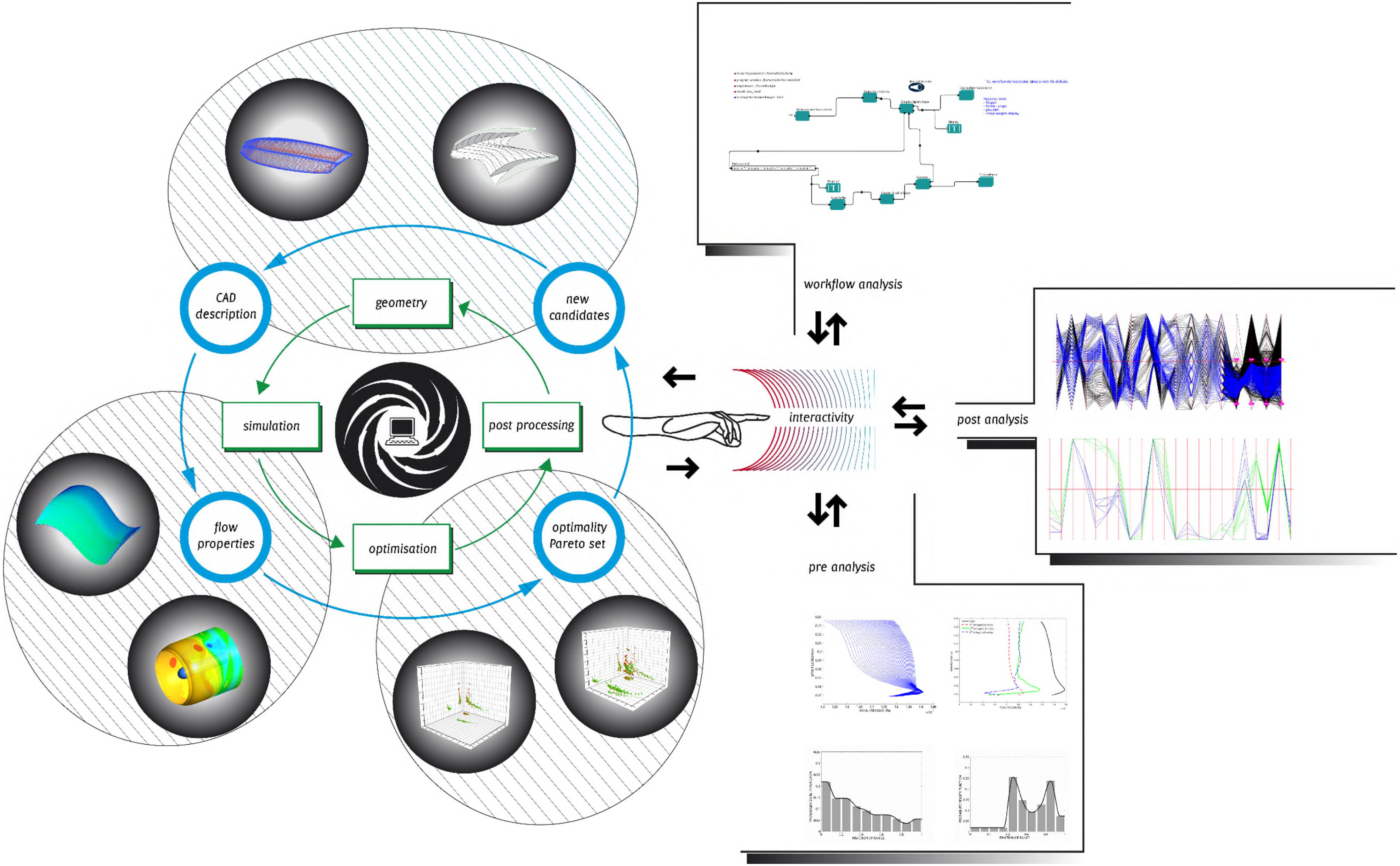
- **Further exploration of the Pareto Set**



Message…

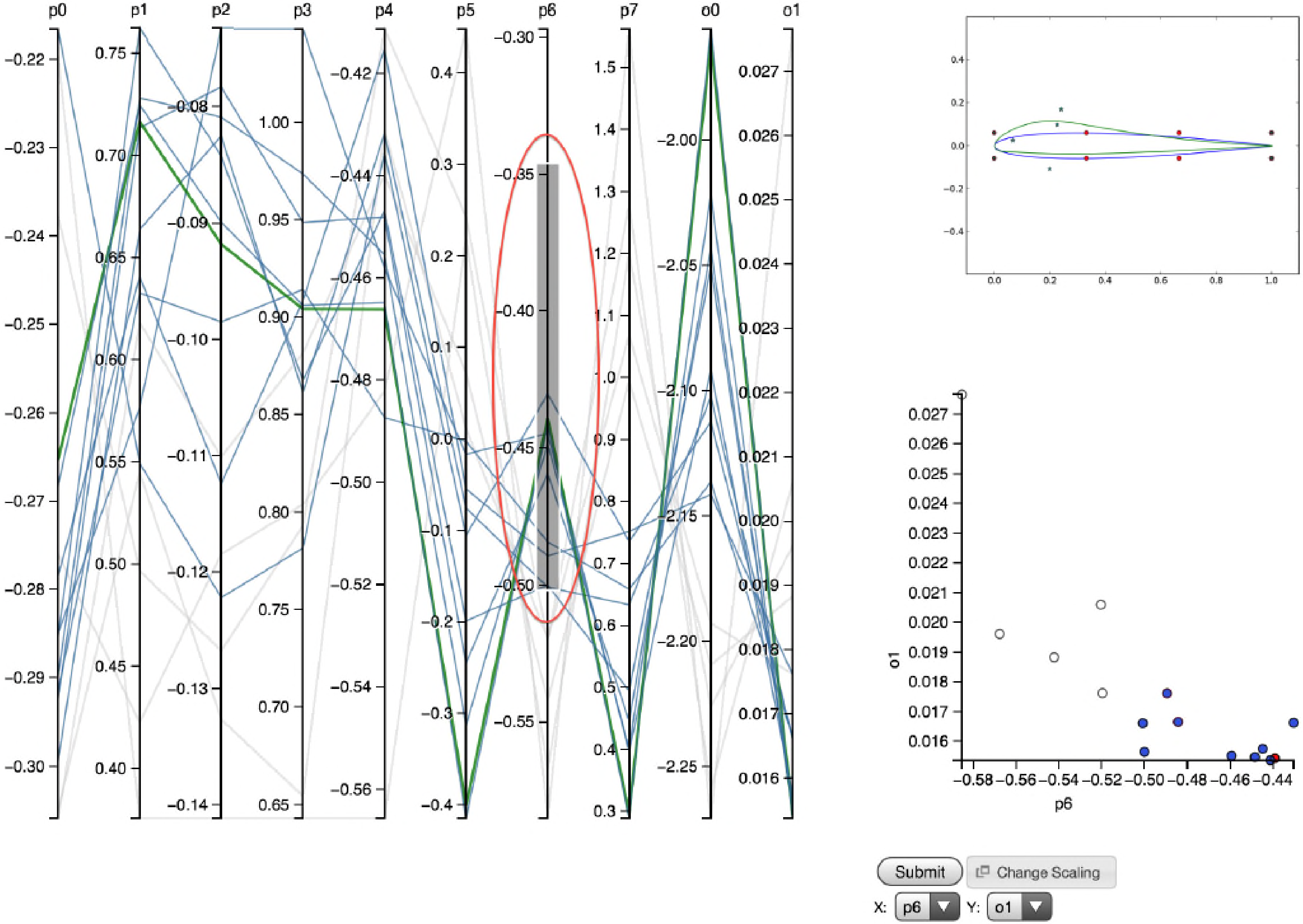
- Visualisation of the whole design parameters and objective functions hyper-space is essential in order to gain understanding of the complexities and morphology of the design space and lead to informative decision making

Human-in-the-Loop
Computational Engineering Design Cycle



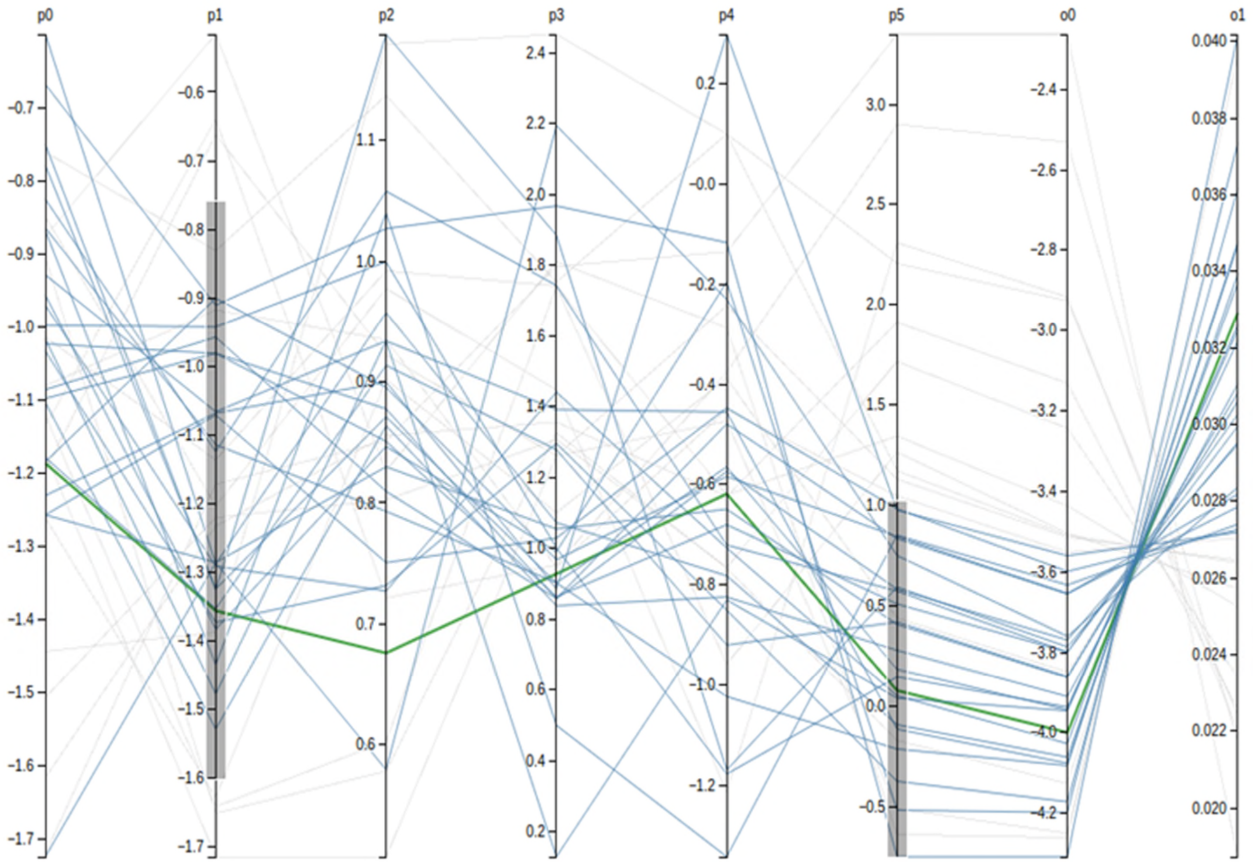
- Kipouros, T., Evolve, 2014

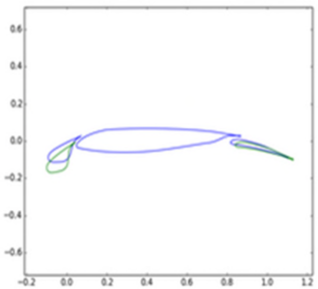
Interactive Design Framework

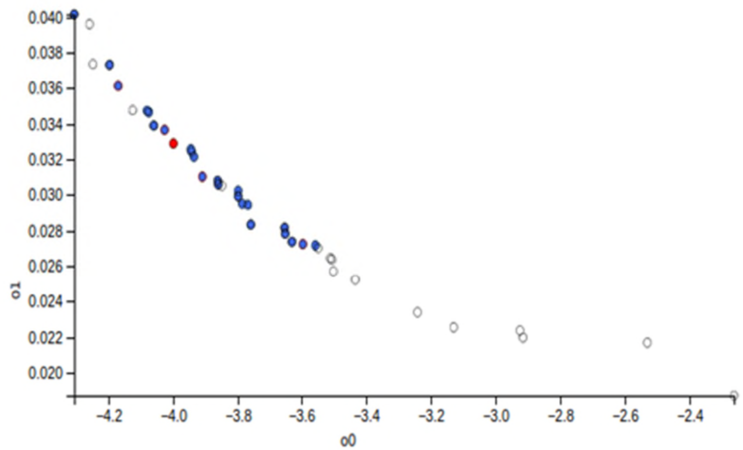


- *with* Kipouros, T., IEEE Congress on Evolutionary Computation, E-1350, 2013

Enhanced Interactive Design Framework





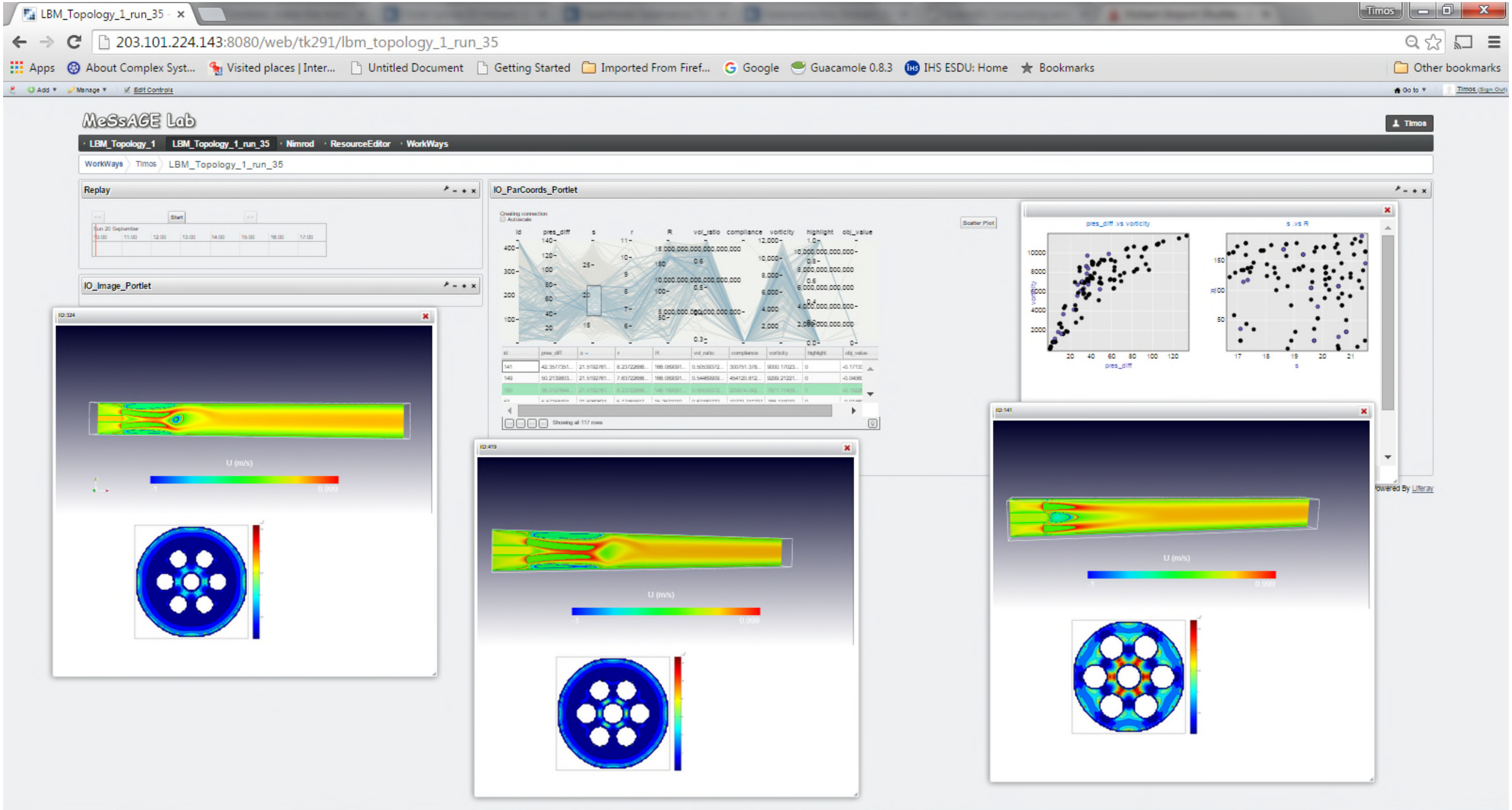


Submit Change Scaling

X: o0 Y: o1

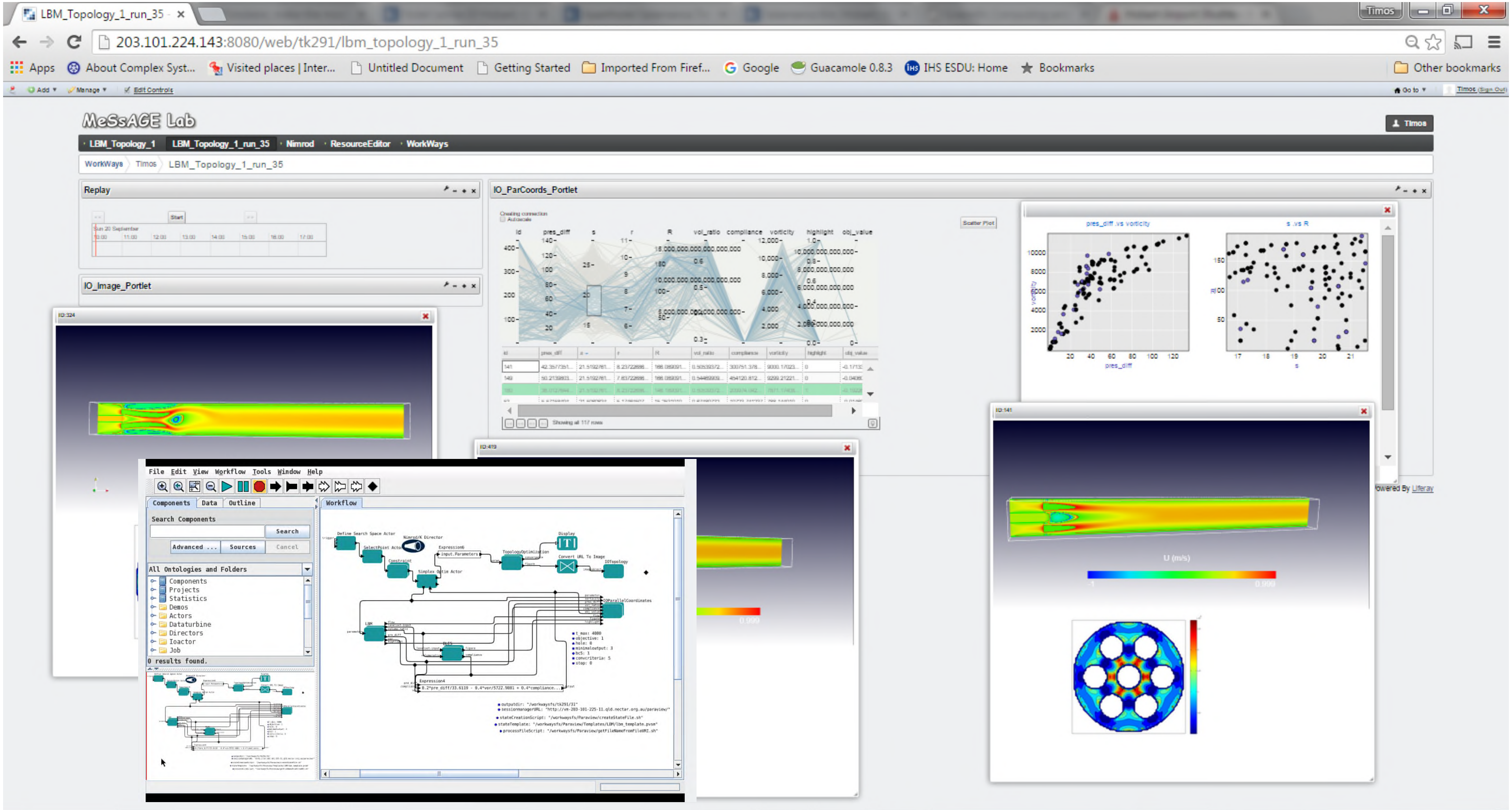
name	min	max
p1	-1.6020723115516275	-0.7578789699721609
p5	-0.746637011321	1.025825700972867

Web-based Interactive Design Workflow



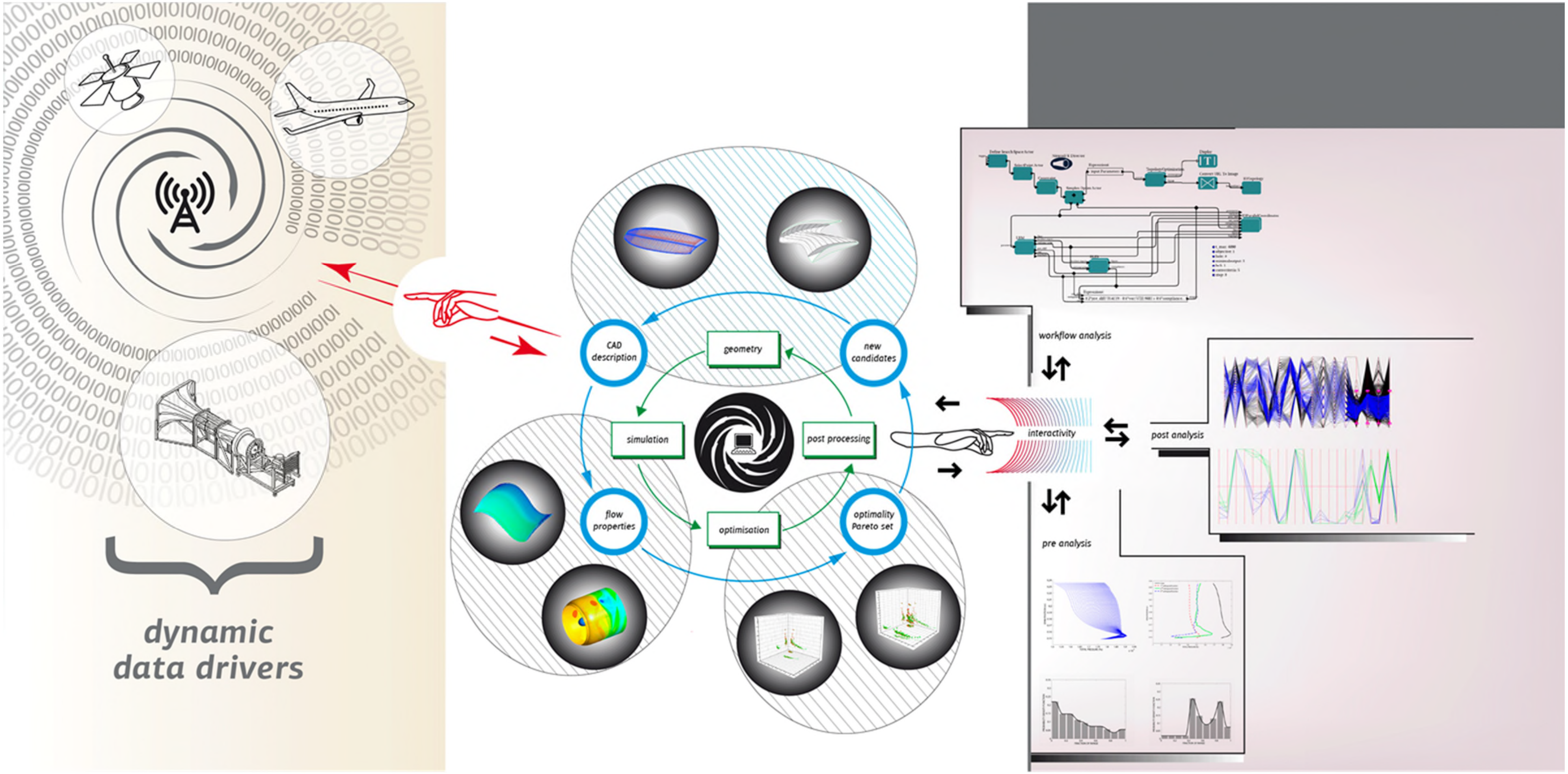
- *with* Kipouros, T., Concurrency and Computation: Practice and Experience, DOI: 10.1002/cpe.3525, 2015

Web-based Interactive Design Workflow



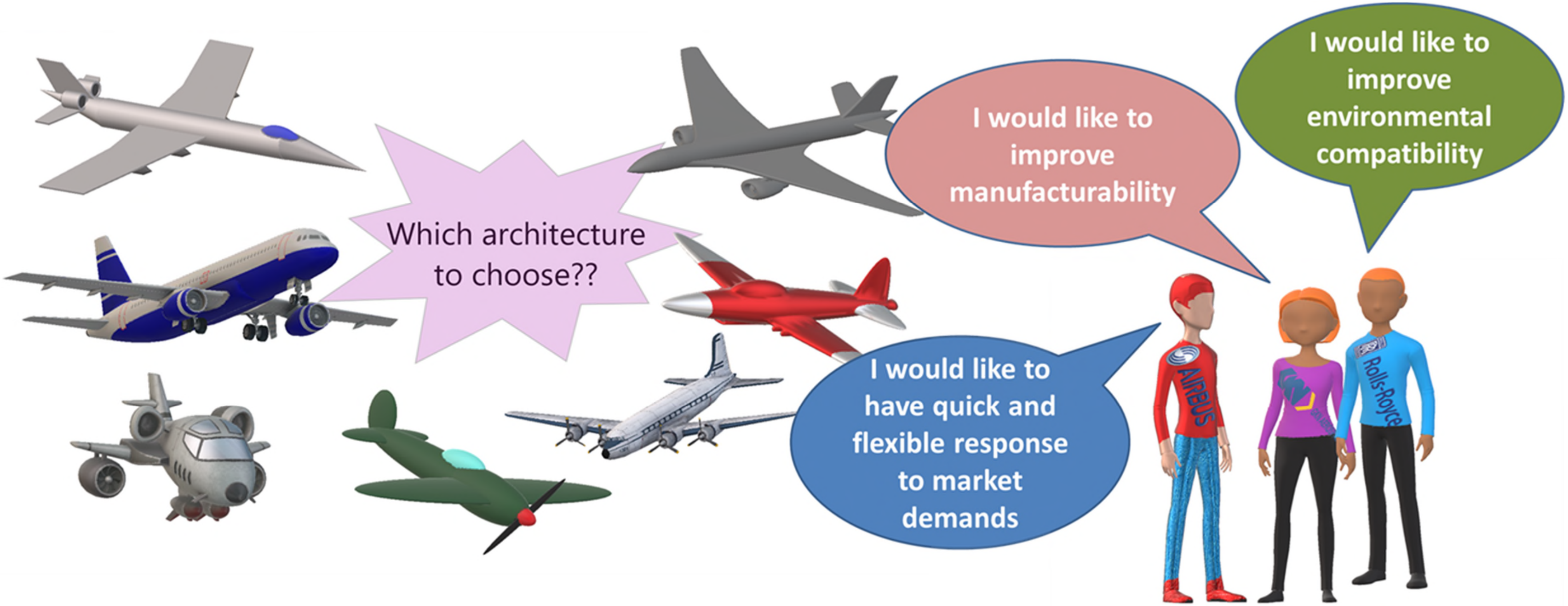
- *with* Kipouros, T., Concurrency and Computation: Practice and Experience, DOI: 10.1002/cpe.3525, 2015

DDDAS supported Human-in-the-Loop Computational Engineering Design Cycle

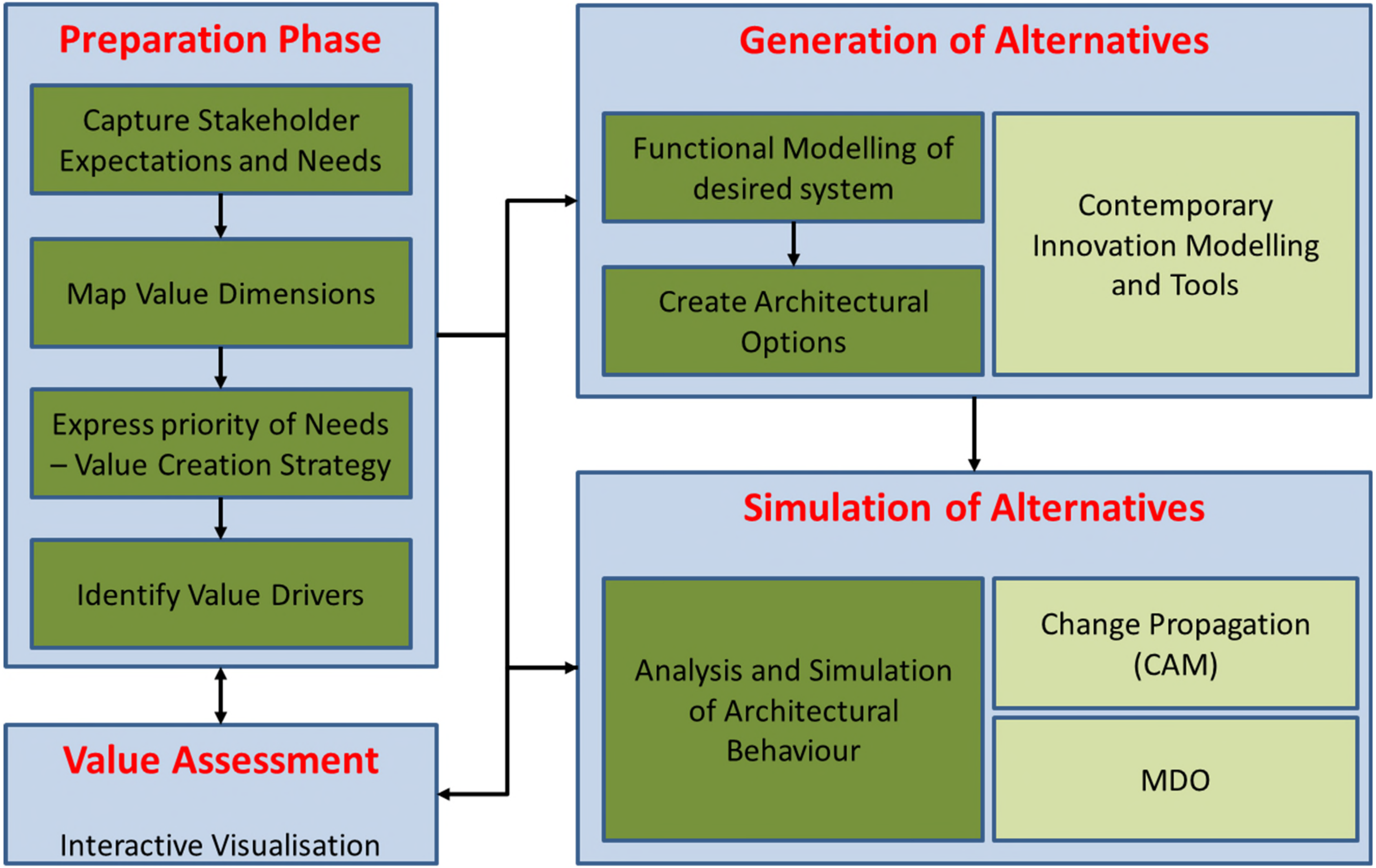


Value Assessment

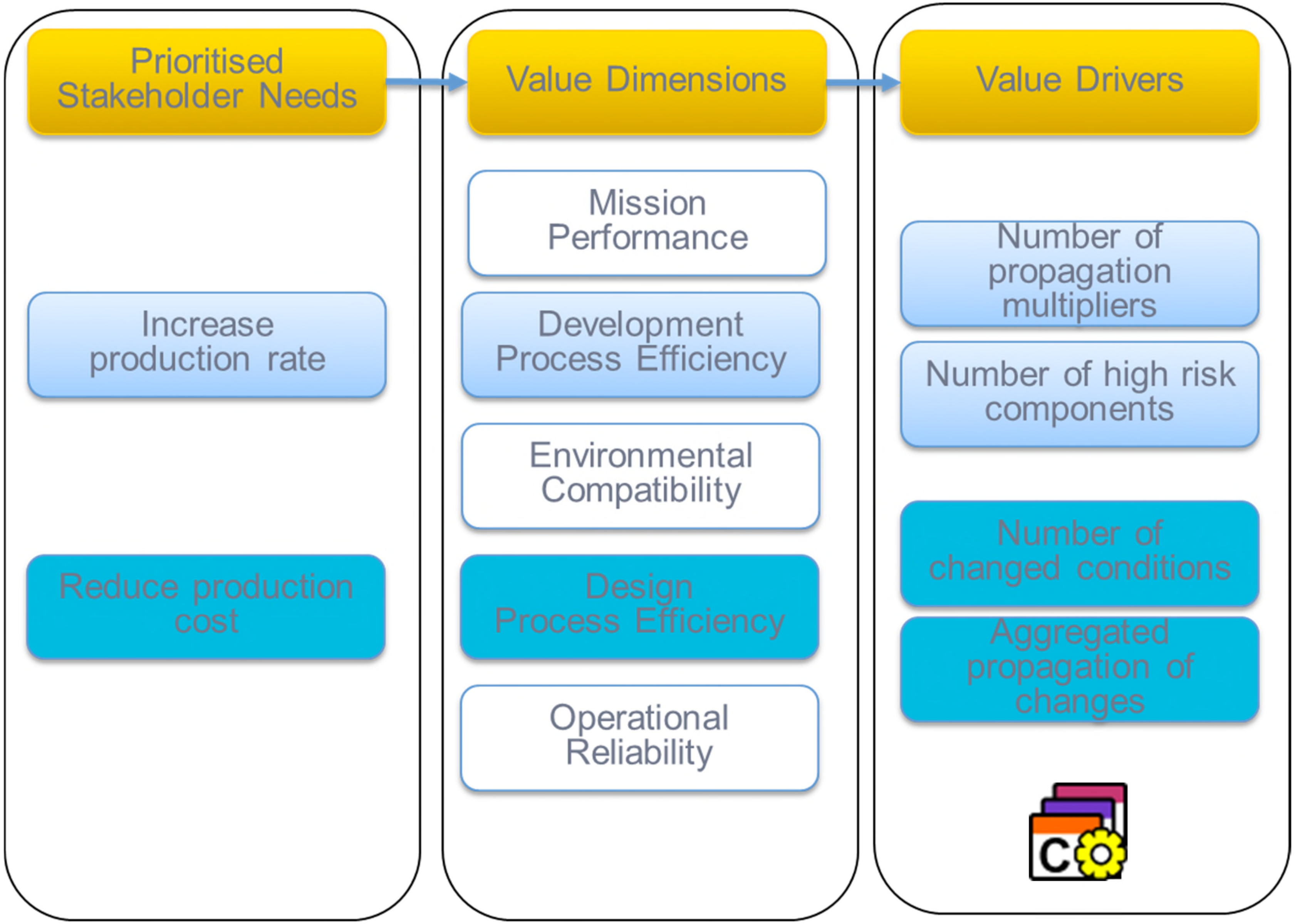
What is Value Assessment?



Value Driven Design process



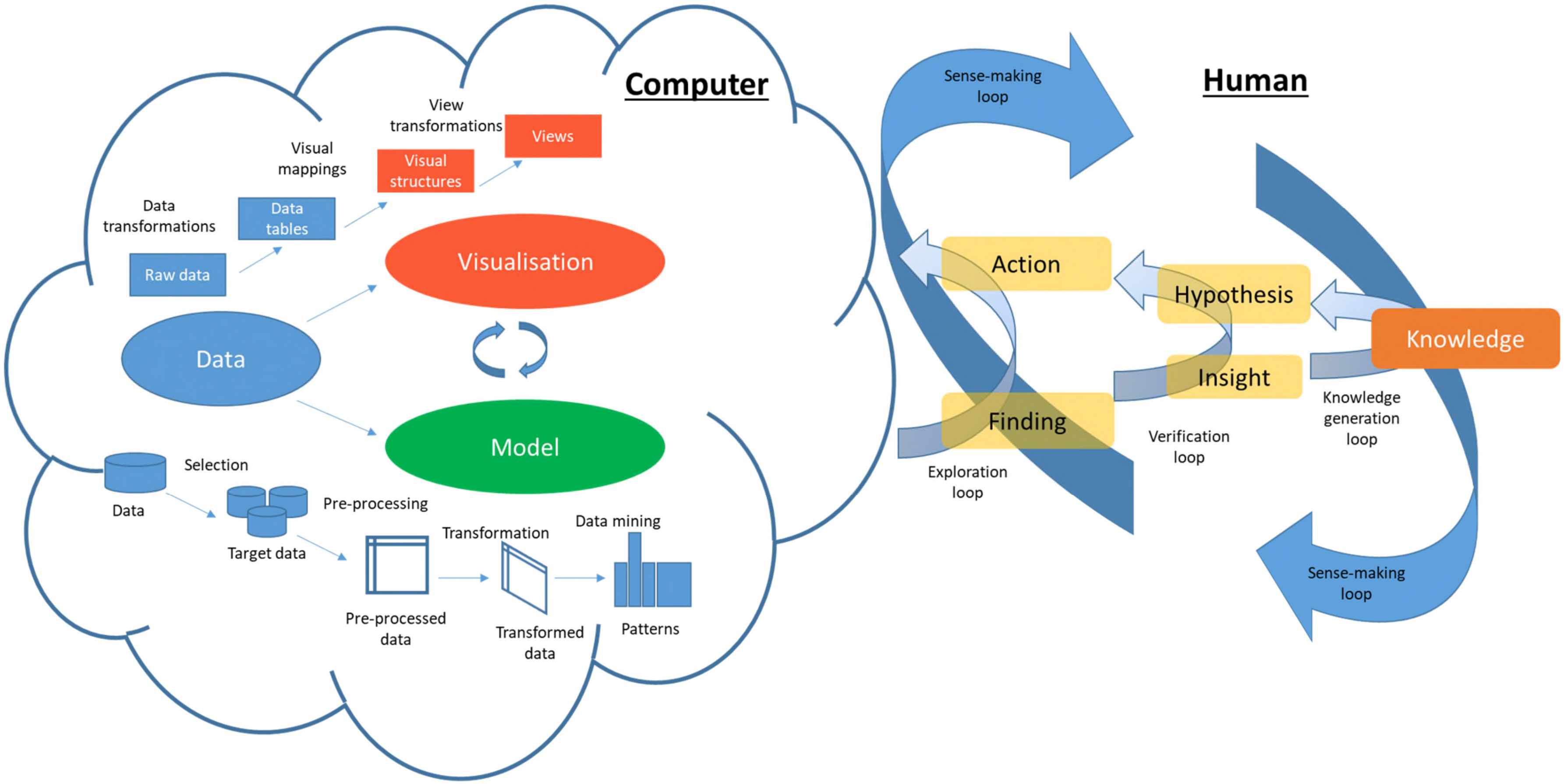
An example


Prioritised Stakeholder Needs
Value Dimensions
Value Drivers
Increase production rate
Reduce production cost
Mission Performance
Development Process Efficiency
Environmental Compatibility
Design Process Efficiency
Operational Reliability
Number of propagation multipliers
Number of high risk components
Number of changed conditions
Aggregated propagation of changes

APROCONE Q7 Progress Report

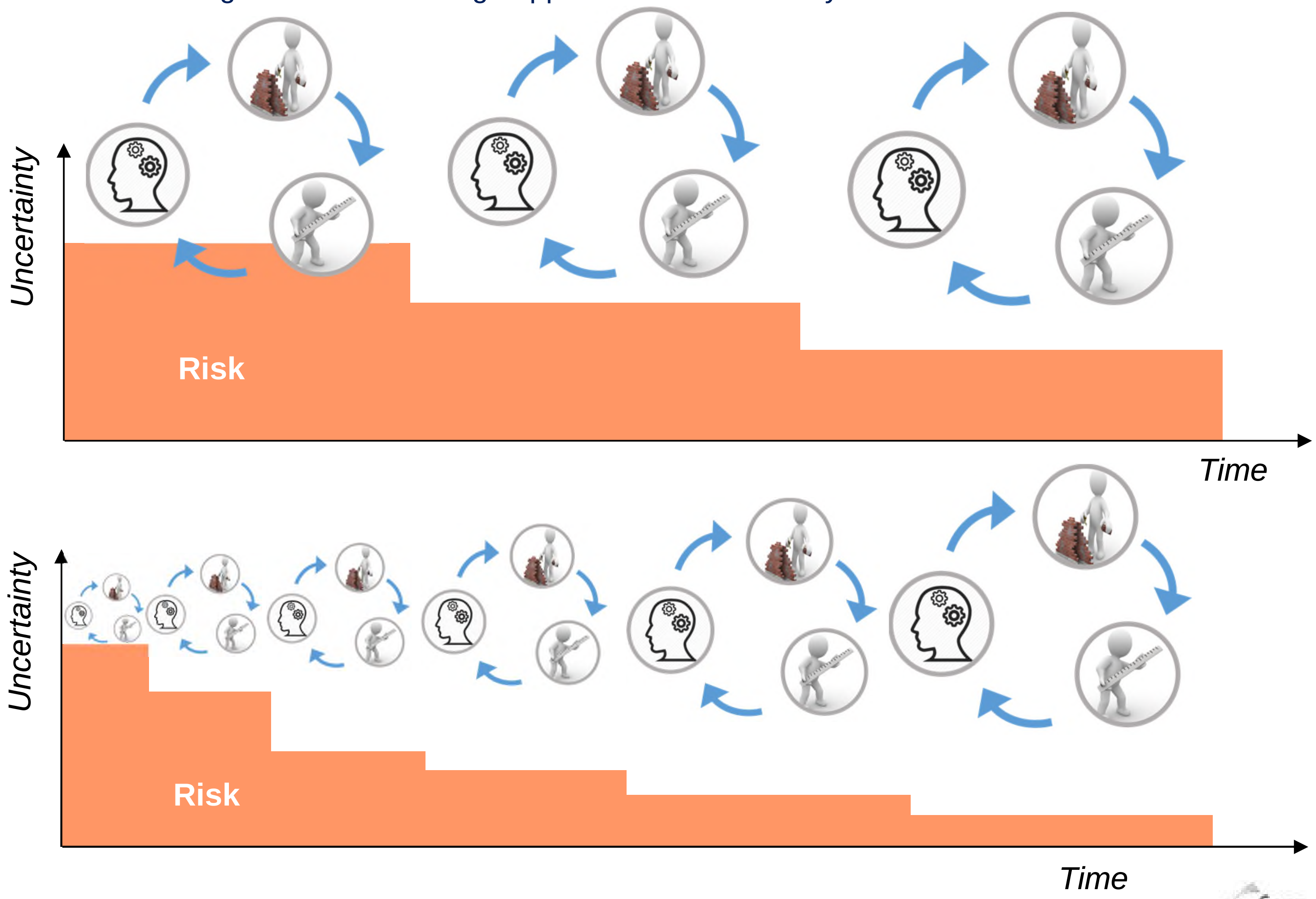
Work Package 4.2 – Novel design approaches & data analytics - CAMBRIDGE

The concept of Visual Analytics



APROCONE IW2

Work Package 4.2 – Novel design approaches & data analytics - CAMBRIDGE



- The faster you iterate, the more you learn and the **faster** you succeed and **meet the stakeholder needs**
- You **reduce risk** and uncertainty more substantially

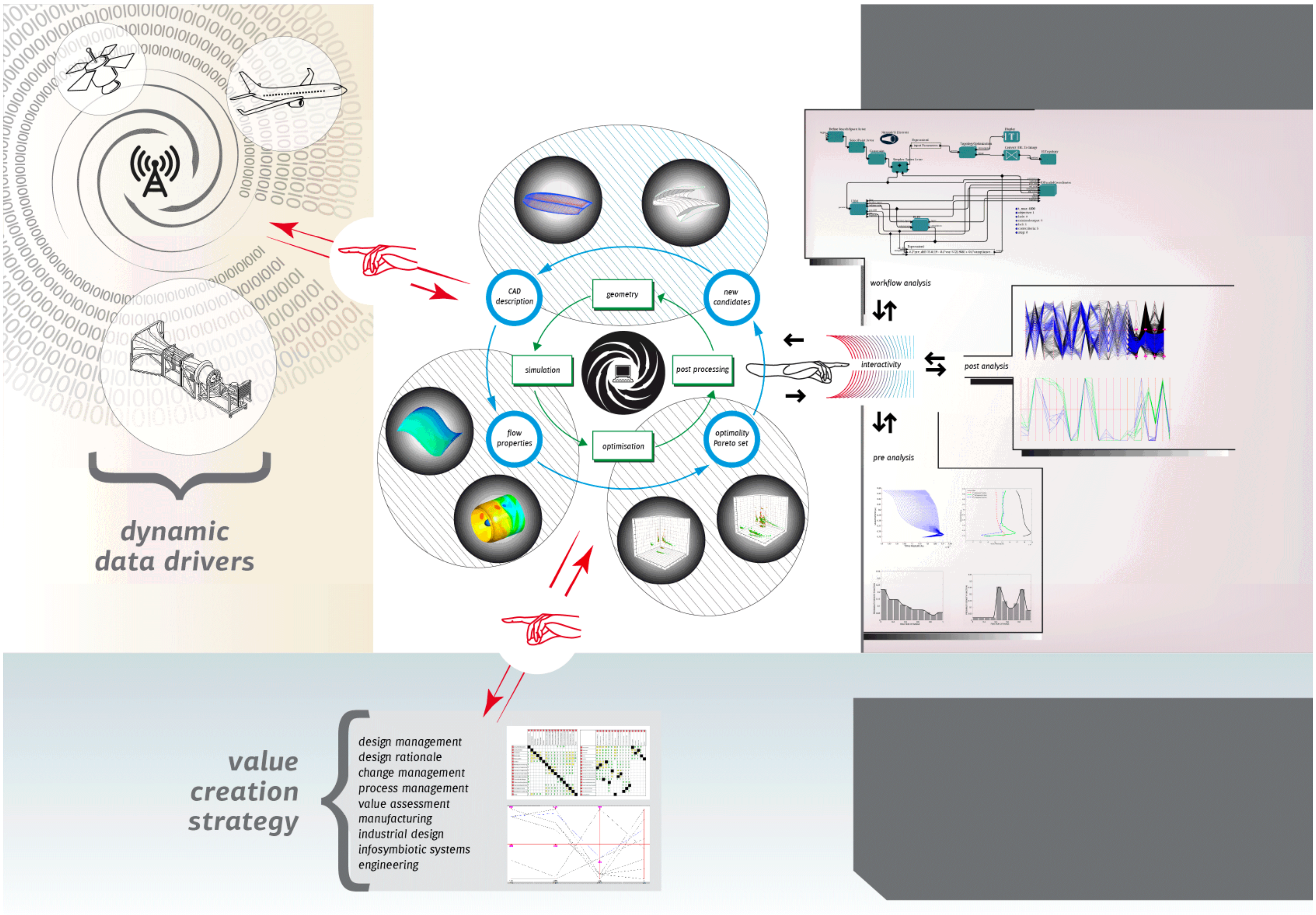
APROCONE IW2

Work Package 4.2 – Novel design approaches & data analytics - CAMBRIDGE

• Demonstration on the design/manufacturing use case - Capturing of Value Assessment data

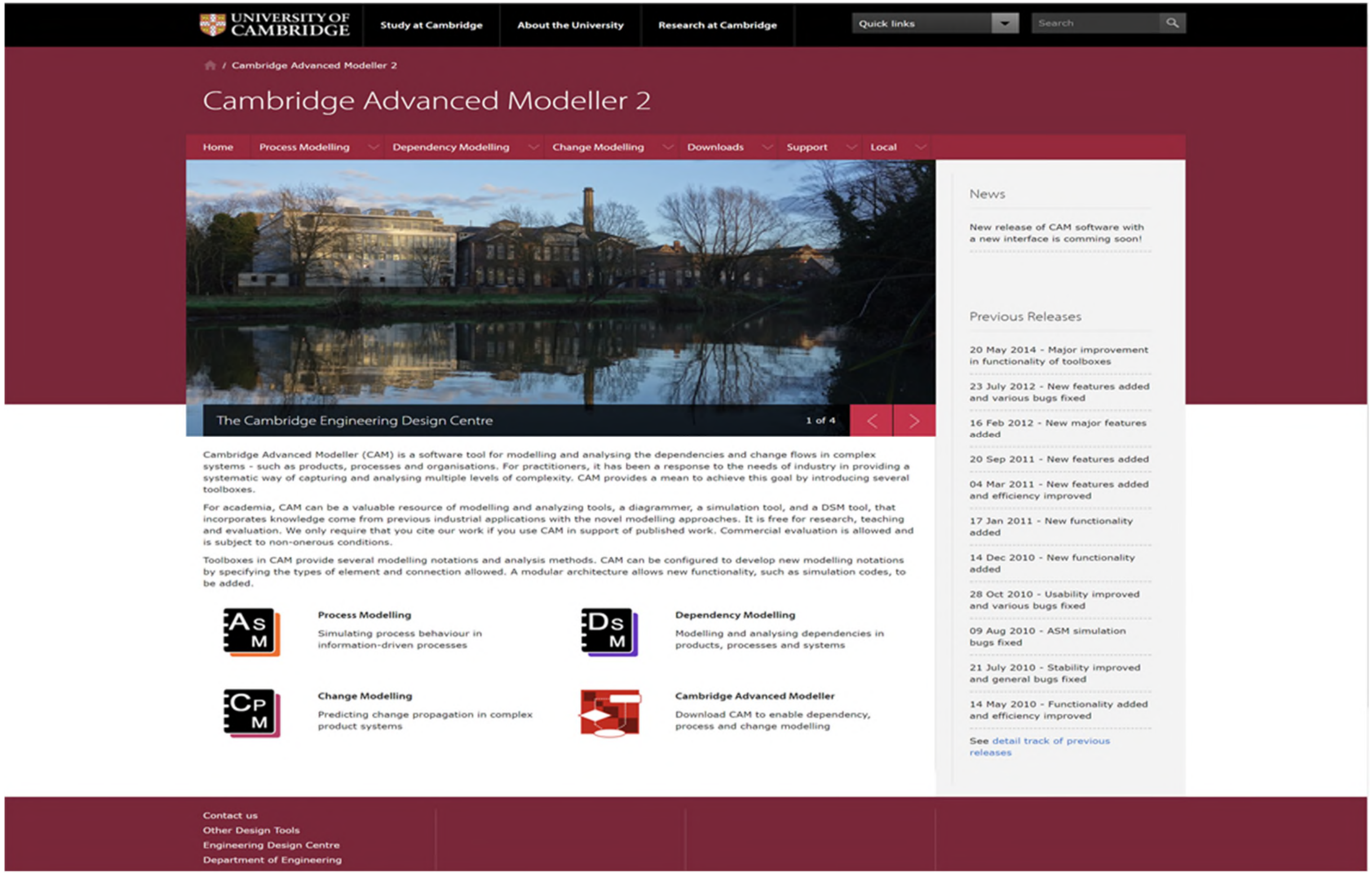
Stakeholder Needs	Constraints	Value Dimensions	Value Drivers
Better performance	$Hbar \leq 2.2$	Mission Performance	$\frac{L}{D}, \Delta(\frac{L}{D})$
Faster production rate		Development Process Efficiency	Number of computations
Model manufacturing process design	$1.33 \leq Cpk \leq 2$	Manufacturability	Price
Reduce manufacturing cost			Manufacturing process
Explore different processes and technologies			

Live Demo – CAM VPM


dynamic
data drivers
CAD
description
geometry
new
candidates
simulation
post processing
flow
properties
optimisation
optimality
Pareto set
workflow analysis
interactivity
post analysis
pre analysis
value
creation
strategy
design management
design rationale
change management
process management
value assessment
manufacturing
industrial design
infosymbiotic systems
engineering

Access to the software tools

- The new open access dedicated website for CAM software is underway…
- Free download of the software and toolboxes for academic purposes
- Tutorials
- Sample case studies



Parallel Coordinates is more fun when performed with friends...