Visualization of Design Space
-What is MODE?

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Outline

- **Background**
  - Flow Visualization
  - Multidisciplinary Design Optimization (MDO)
  - Self-Organizing Map (SOM)
  - Rough Set
  - Multi-Objective Design Exploration (MODE)
- **Application to Regional Jet Design**
  - Wing-Nacelle-Pylon-Body Configuration
  - Analysis of Sweet-Spot Cluster
- **Conclusion**

Flow Visualization -1

Flow transition: Reynolds number

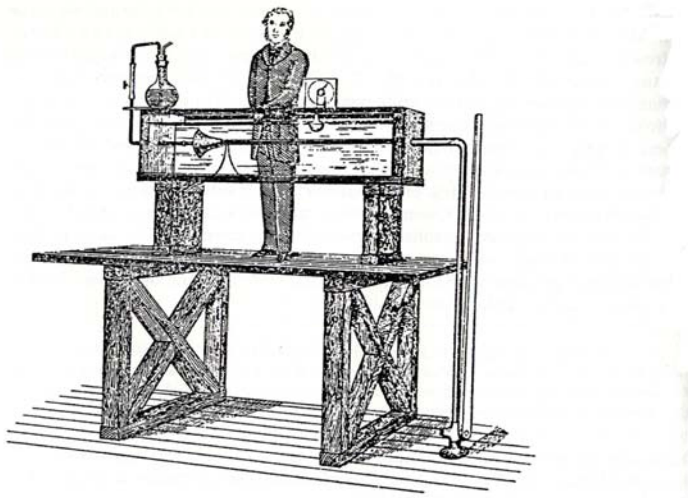
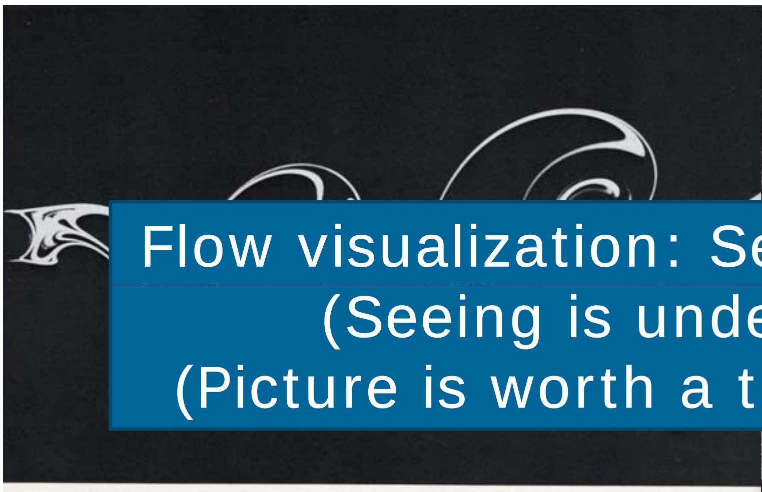


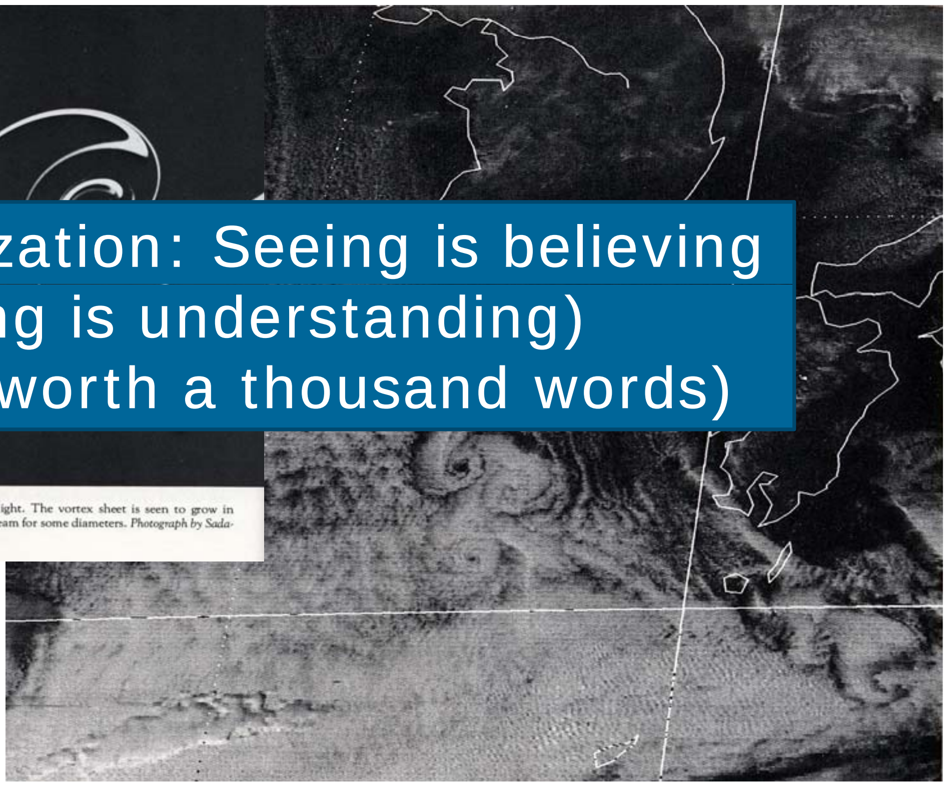
Figure 4.49 Osborne Reynolds's apparatus for his famous pipe-flow experiments. This figure is from his original paper, referenced in the text.

103. Repetition of Reynolds' dye experiment. Osborne Reynolds' celebrated 1883 investigation of stability of flow in a tube was documented by sketches rather than photography. However the original apparatus has survived at the University of Manchester. Using it a century later, N. H. Johannesen and C. Lowe have taken this sequence of photographs. In laminar flow a filament of colored water introduced at a bell-shaped entry extends undisturbed the whole length of the glass tube. Transition is seen in the second of the photographs as the speed is increased; and the last two photographs show fully turbulent flow. Modern traffic in the streets of Manchester made the critical Reynolds number lower than the value 13,000 found by Reynolds.

Flow Visualization -2



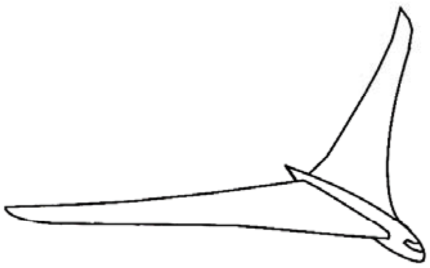
94. Kármán vortex street behind a circular cylinder at $R=140$**.** Water is flowing at 1.4 cm/s past a cylinder of diameter 1 cm. Integrated streaklines are shown by electrolytic precipitation of a white colloidal smoke, illuminated by a sheet of light. The vortex sheet is seen to grow in width downstream for some diameters. *Photograph by Sadatoshi Taneda*



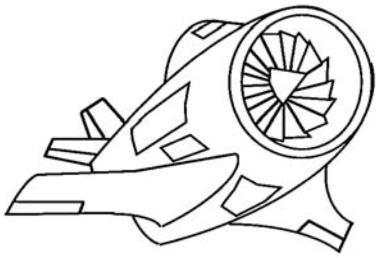
Flow visualization: Seeing is believing
(Seeing is understanding)
(Picture is worth a thousand words)

Karman Votex

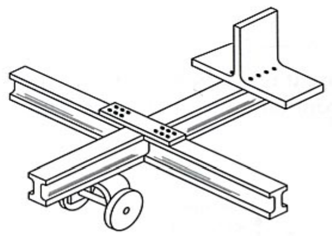
Aircraft Design



Aerodynamics



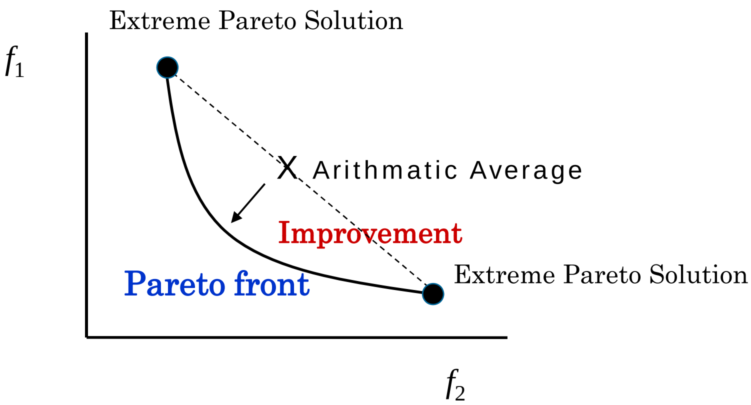
Propulsion

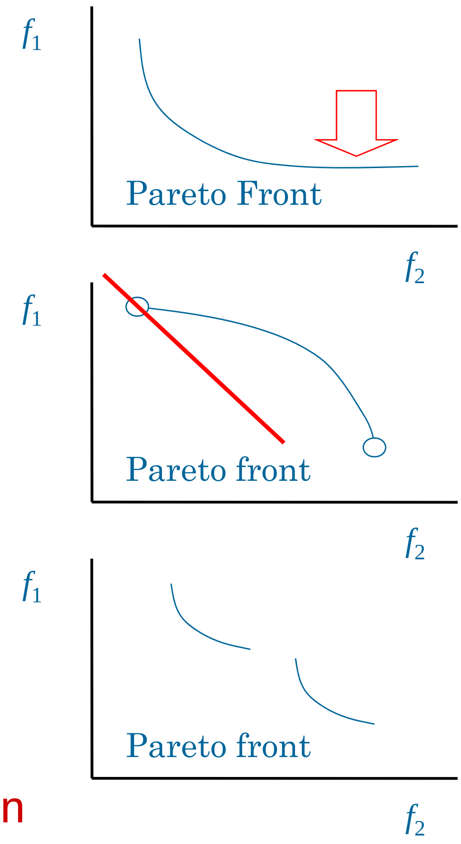


Structure

- Compromise of all disciplines
- Multidisciplinary Design Optimization (MDO) as Multi-Objective Optimization (MOP)

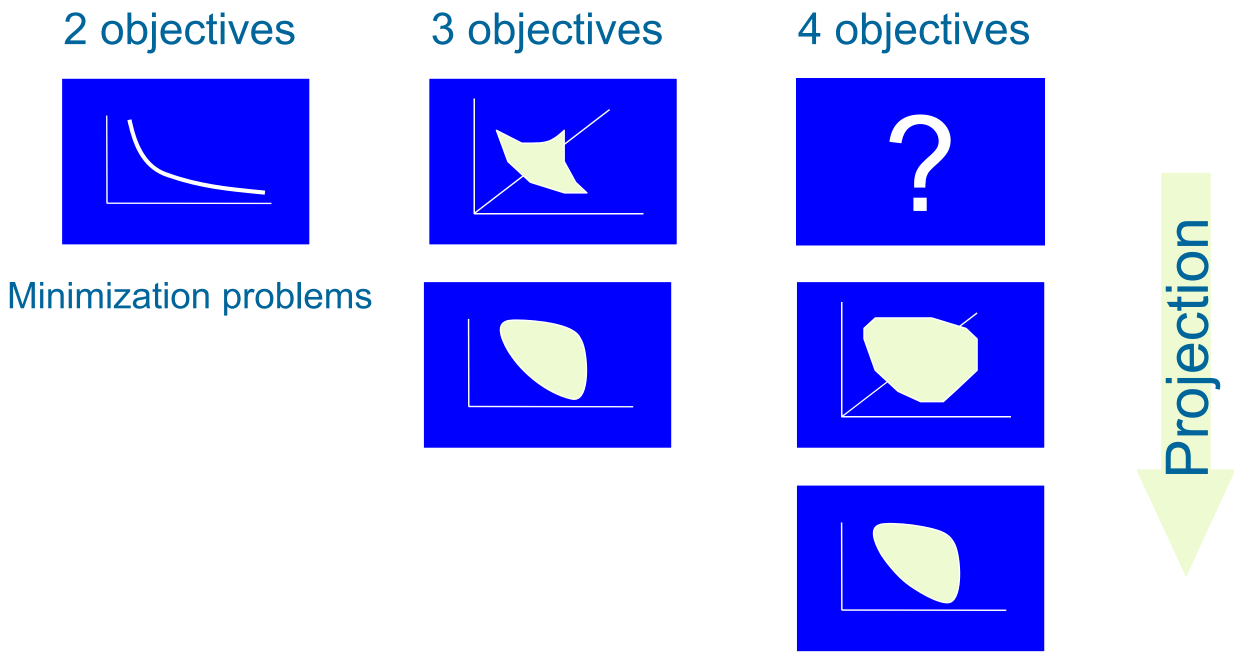
How to Understand MOP





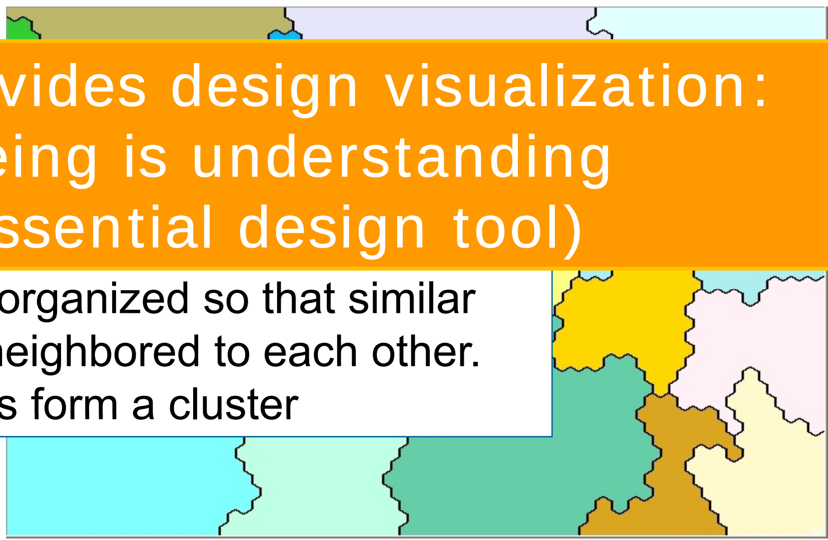
- Global optimization is needed
- Visualization is essential!
- Data mining is required
- Design optimization→Design exploration

Visualization of Tradeoffs



Self-Organizing Map（SOM）

- Neural network model proposed by Kohonen
  Unsupervised, competitive learning
- High-dimensional data → 2D map
- Qualitative description of data

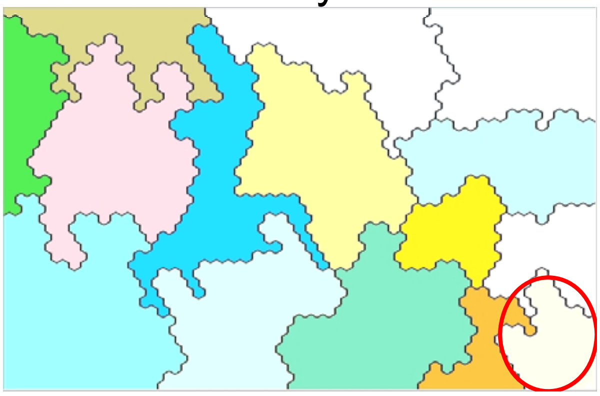


SOM provides design visualization:
Seeing is understanding
(Essential design tool)

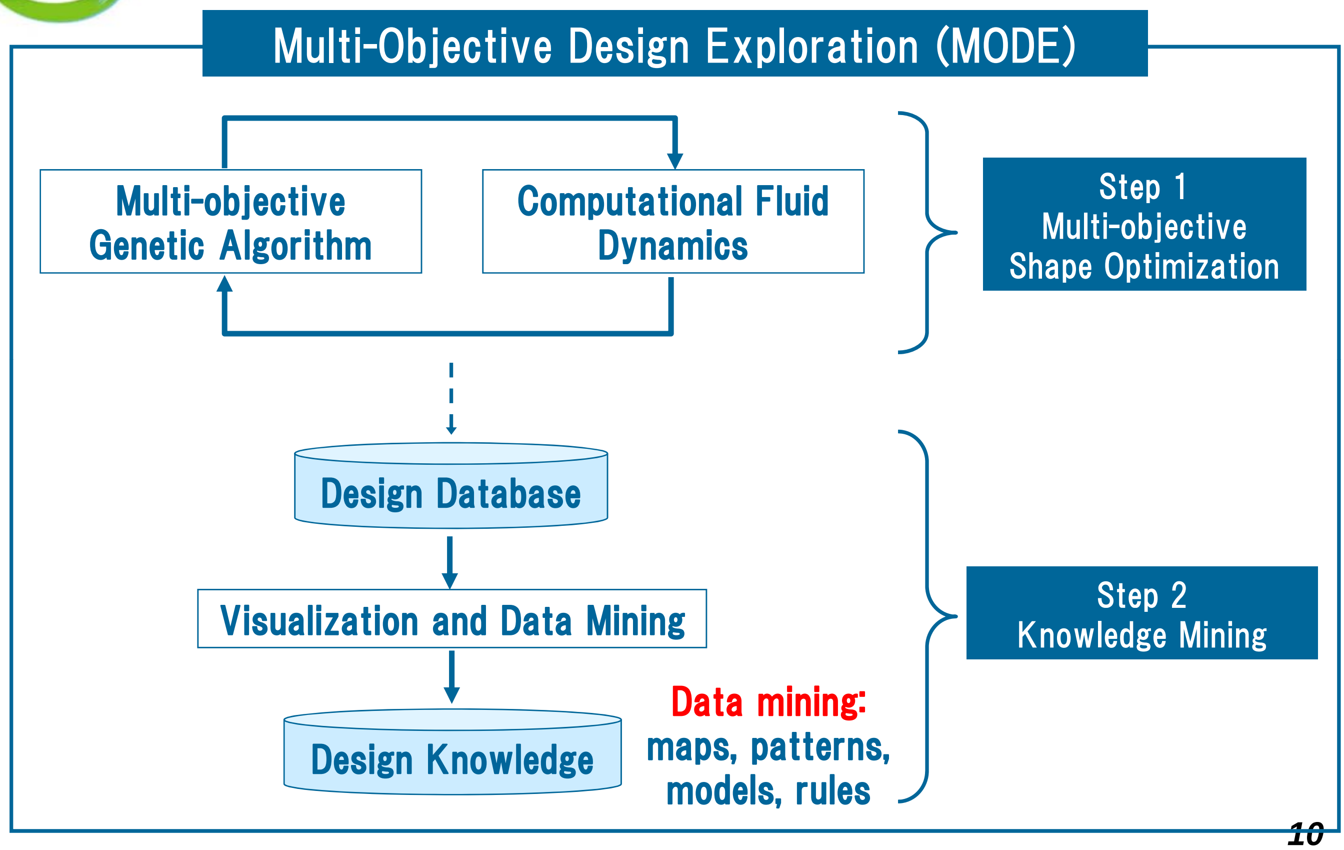
•Neuron is self-organized so that similar neurons are neighbored to each other.
•Similar neurons form a cluster

How to understand SOM better?

- Colored SOMs identify the global structure of the design space
- Resulting clusters classify possible designs
  - If a cluster has all objectives near optimal, it is called as sweet-spot cluster
  - If the sweet-spot cluster exists, it should be analyzed in detail
    - Visualization of design variables
    - Data mining, such as decision tree and rough set



What is MODE?



Small Jet Aircraft R&D Project

R&D Organization

New Energy and Industrial Technology Development Organization (NEDO)

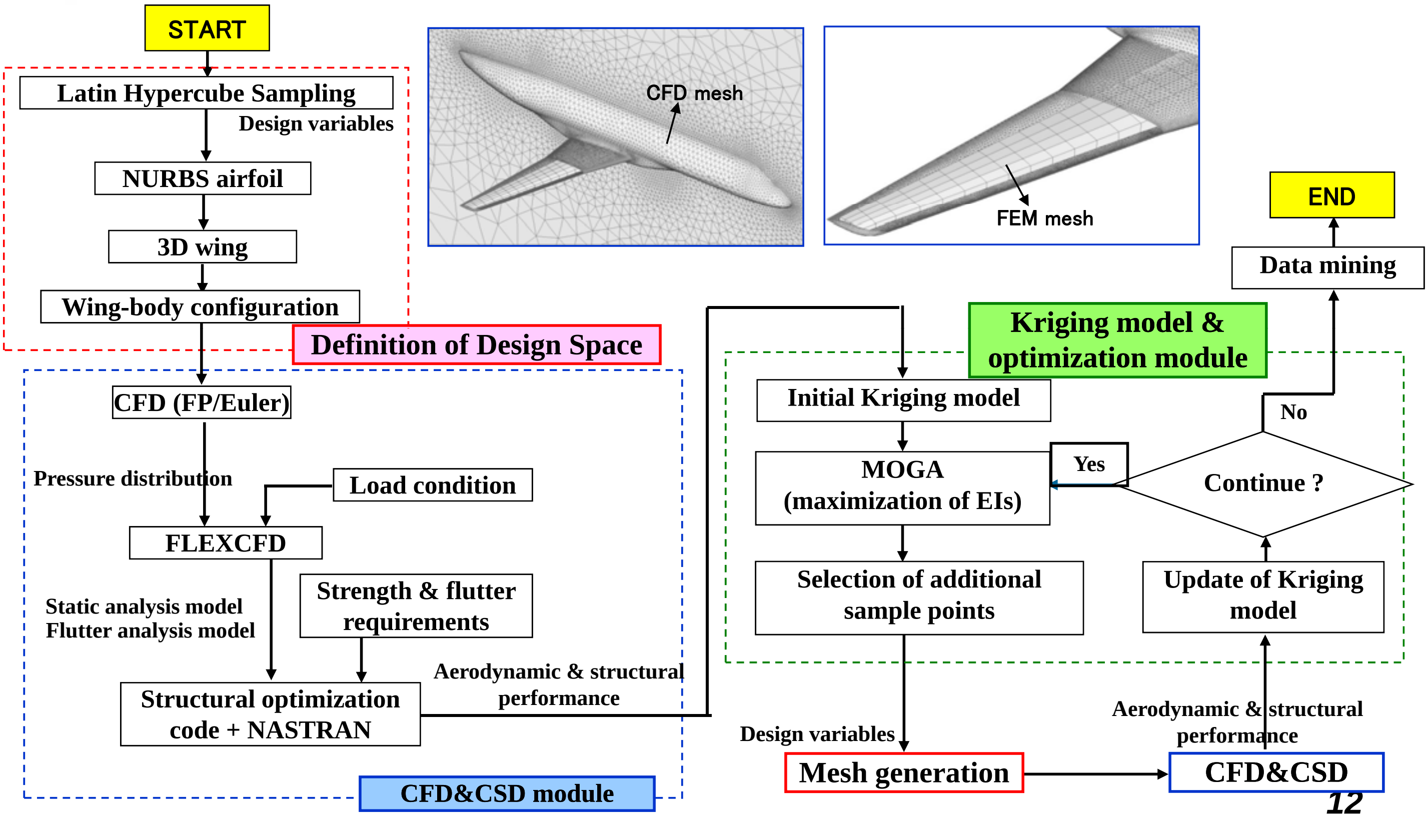
R&D Activities

- Mitsubishi Heavy Industries
- Fuji Heavy Industries
- Japan Aircraft Development Corporation (JADC)

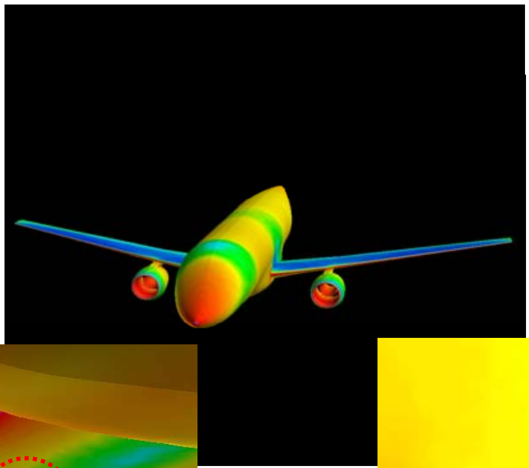
Research Collaboration

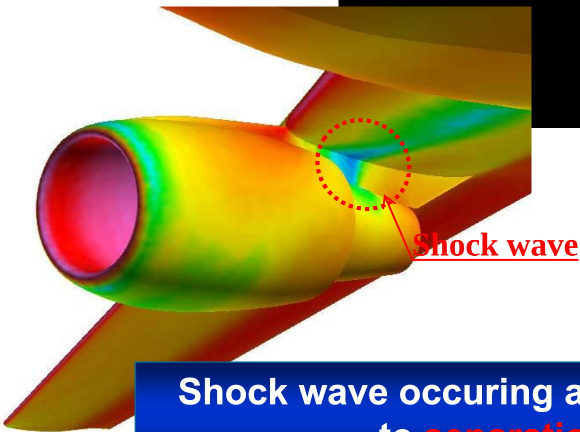
- Japan Aerospace Exploration Agency (JAXA)
- Tohoku University

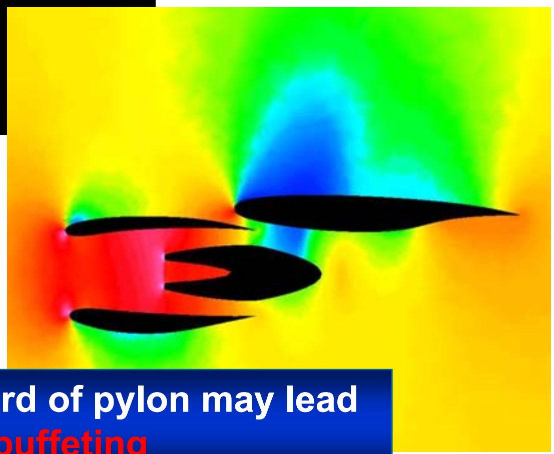
Present MODE System



Optimization of Wing-Nacelle-Pylon-Body Configuration







Shock wave occuring at inboard of pylon may lead to separation and buffeting

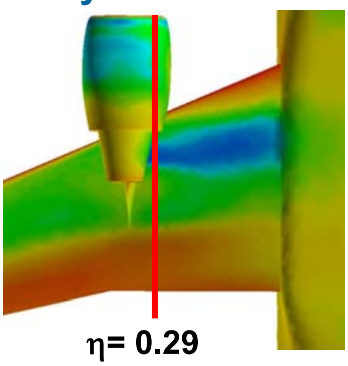
Definition of Optimization Problem -1 - Objective Functions -

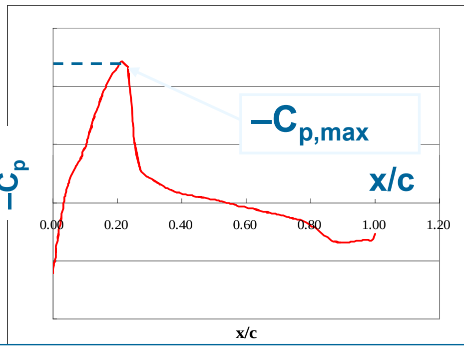
Minimize

1. Drag at the cruising condition (C_D)
2. Shock strength near wing-pylon junction ($-C_{p,max}$)
3. Structural weight of main wing (wing weight)

✓ Function evaluation tools

- CFD : Euler code (TAS-code)
- CSD/Flutter analysis : MSC. NASTRAN



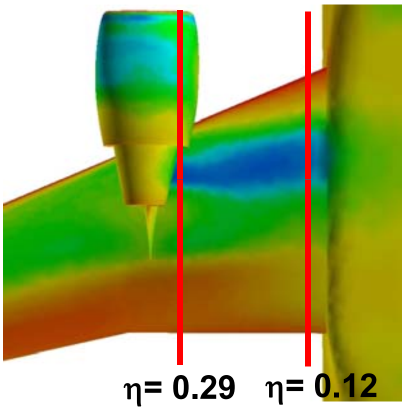


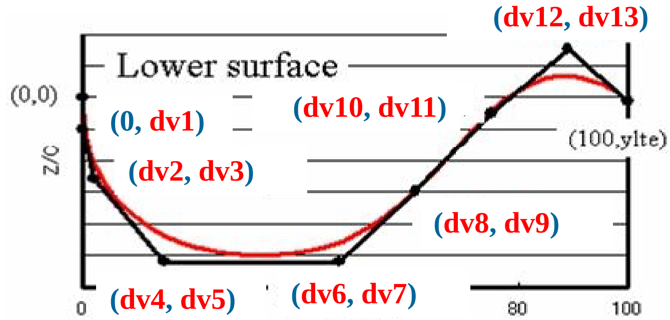
$-C_P$ distribution of lower surface @η=0.29

Definition of Optimization Problem -2
- Design Variables -

- Lower surface of Airfoil shapes at 2 spanwise sections (η= 0.12, 0.29)
  → 13 variables (NURBS) × 2 sections = 26 variables
- Twist angles at 4 sections = 4 variables

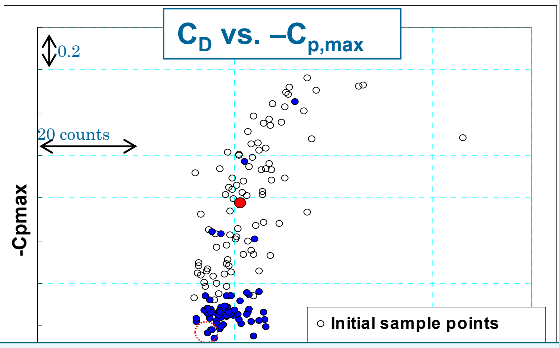
<u>30 variables in total</u>

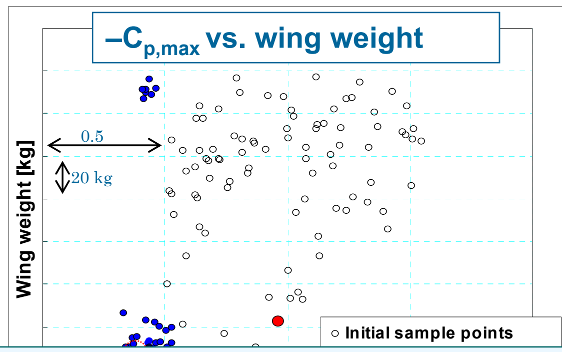




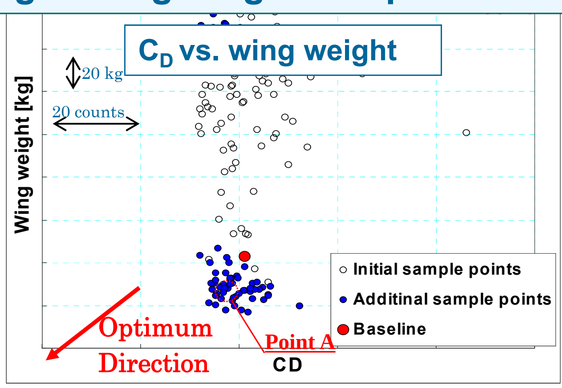
NURBS control points

Performances of baseline shape and sample points

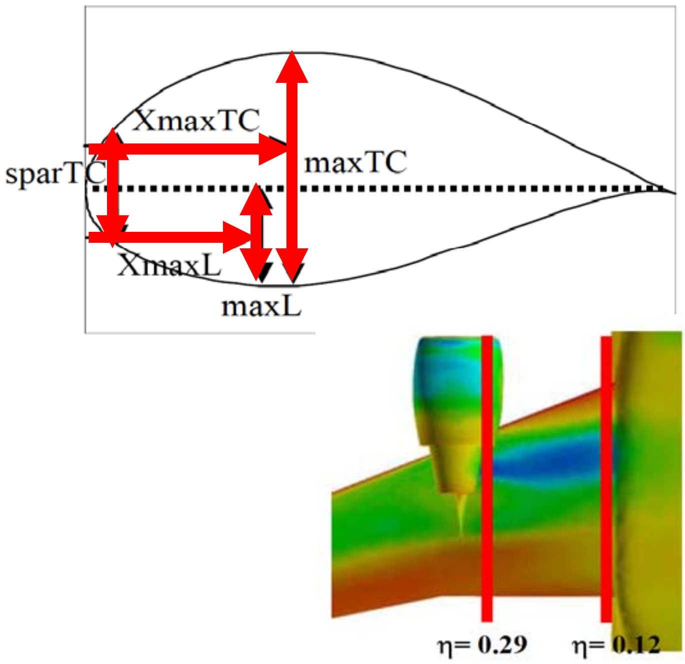




Point A is improved by 6.7 counts in C_D, 0.61 in $–C_{p,max}$, and 12.2 kg in wing weight compared with the baseline



Definition of Configuration Variables for Data Mining



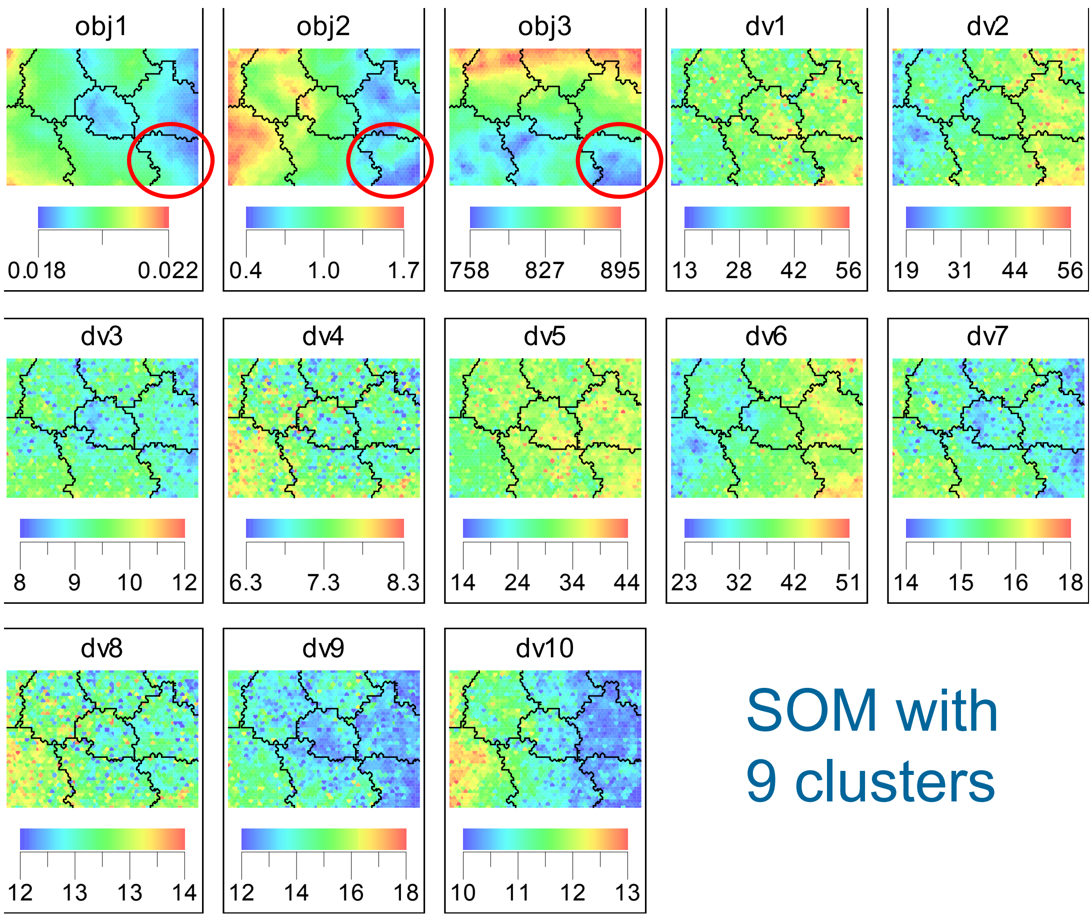
- XmaxL
- maxL
- XmaxTC
- maxTC
- sparTC

At wing root and pylon locations

↓

10 variables

Visualization of Design Space

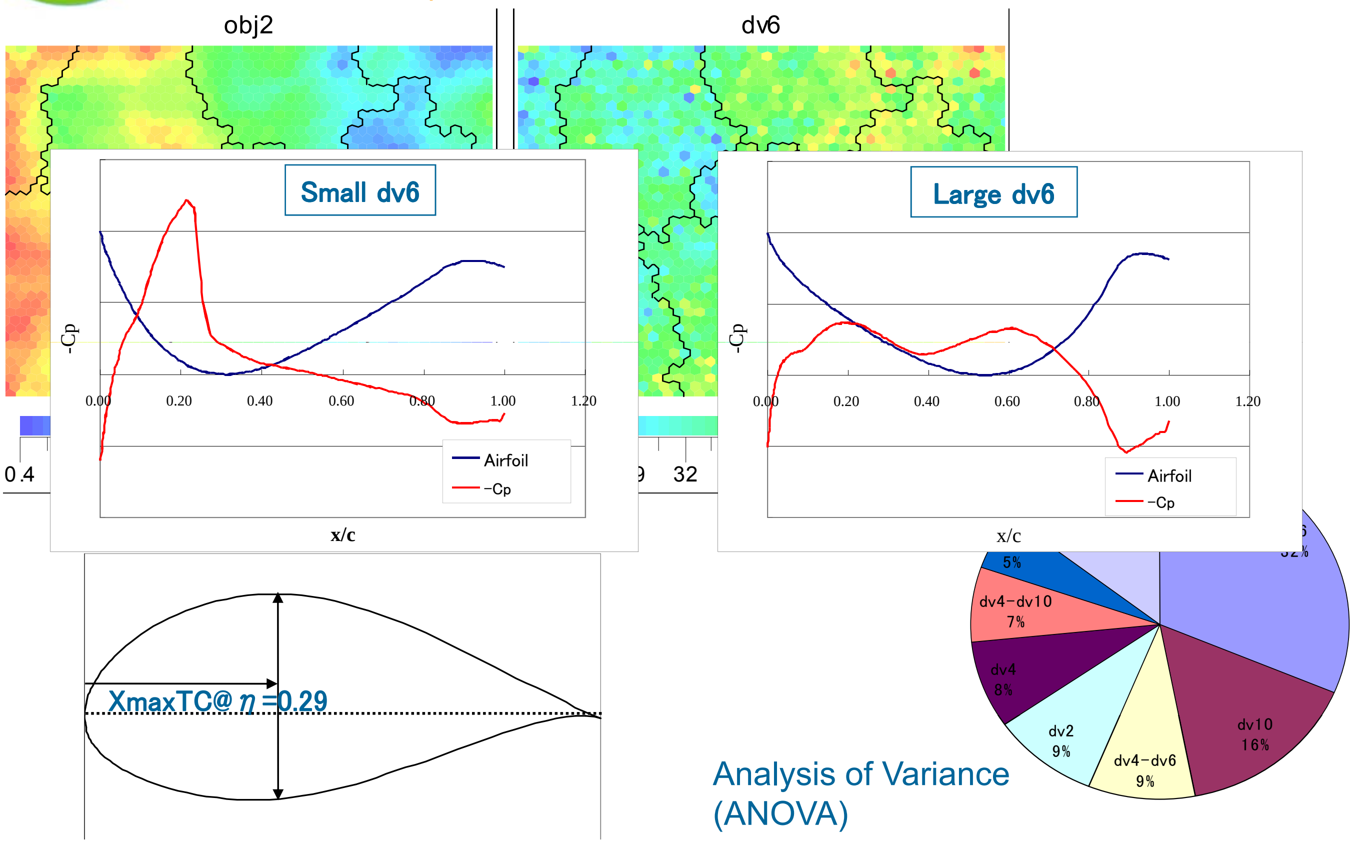


SOM with
9 clusters

Analysis of Sweet–Spot Cluster

- Handpick
- Parallel coordinates
- Extraction of design rules by discretization of configuration variables
  - ✓Visualization
  - ✓Rough set

Handpick
$-C_{p,max}$ and dv6 (XmaxTC at pylon)



Data Mining Results from Rough Set

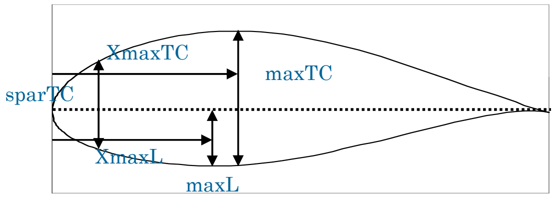
	Sweet	Cd	Cp	WW
dv1	11	1	1	5
dv2	9	2	6	3
dv3	8	5	6	4
dv4	10	3	5	11
dv5	13	8	1	7
dv6	7	6	3	3
dv7	9	5	6	5
dv8	2	4	3	2
dv9	9	2	2	3
dv10	14	9	8	8

large

small

No large dv10

Number	Airfoil parameters
dv1	XmaxL @ η= 0.12
dv2	XmaxL @ η= 0.29
dv3	maxL @ η= 0.12
dv4	maxL @ η= 0.29
dv5	XmaxTC @ η= 0.12
dv6	XmaxTC @ η= 0.29
dv7	maxTC @ η= 0.12
dv8	maxTC @ η= 0.29
dv9	sparTC @ η= 0.12
dv10	sparTC @ η= 0.29



Conclusions

- Multi-Objective Design Exploration (MODE) has been proposed
  - Visualization and data mining based on SOM
- Regional-jet design has been demonstrated
  - Wing-nacelle-pylon-body configuration
    - ✓SOM reveals the structure of design space and visualizes it
    - ✓Analysis of the sweet-spot cluster leads to design rules

Acknowledgements

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