Data Driven Design Optimization Methodology Development and Application

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Rutgers University
Mechanical and Aerospace Engineering

Outline

- Collaborators
- Objectives
- Optimization
- Methodology
- Application
- Conclusions
- Future Work

Collaborators

- Rutgers University
  - Profs. J. Jaluria and N. Langrana, Dept Mech & Aero Engr
- University of Georgia
  - Prof. K. Rasheed, Dept Computer Science
- University of Illinois
  - Prof. G. Elliott, Dept Aero & Astro Engr

Objectives

- Develop a Data Driven Design Optimization Methodology (DDDOM) incorporating experiment and simulation in a concurrent *integrated* software system to achieve better designs in a shorter time
- Demonstrate advantages of the Dynamic Data Driven Application Systems approach to engineering design

  “The novel capabilities to be created are application simulations that can dynamically accept and respond to ‘online’ field data and measurements and/or can control such measurements.”

March 8-10, 2000 NSF-sponsored Workshop on Dynamic Data Driven Application Systems —
"*Creating a Dynamic and Symbiotic Coupling of Application/Simulations with Measurements/Experiments*”

Optimization

- General statement of problem

  Given the set of design variables

  $$\mathbf{x} = (x_1, x_2, \ldots, x_n)$$

  find the Pareto Set of designs to minimize the objectives

  $$\mathbf{f} = (f_1, f_2, \ldots, f_m)$$

  subject to the constraints

  $$d_k \leq 0 \quad \text{for } k = 1, l$$

Optimization

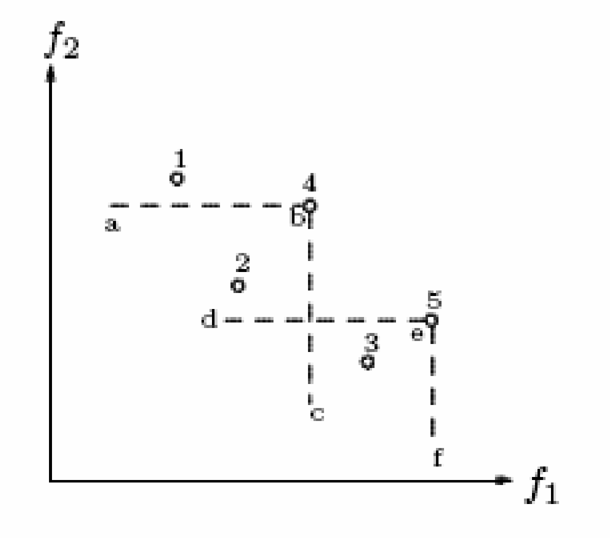
- Consider two designs $\mathbf{x}_a$ and $\mathbf{x}_b$
- Design *a* is dominated by design *b* if

$$f_i(\mathbf{x}_a) \geq f_i(\mathbf{x}_b) \quad \text{for all } i = 1, \ldots, m \quad \text{except } i = k$$
$$f_k(\mathbf{x}_a) > f_k(\mathbf{x}_b) \quad \text{for } i = k$$

- The Pareto Set is the set of non-dominated designs $\mathbf{x}_\alpha$, $\mathbf{x}_\beta$ … of non-dominated designs

Optimization

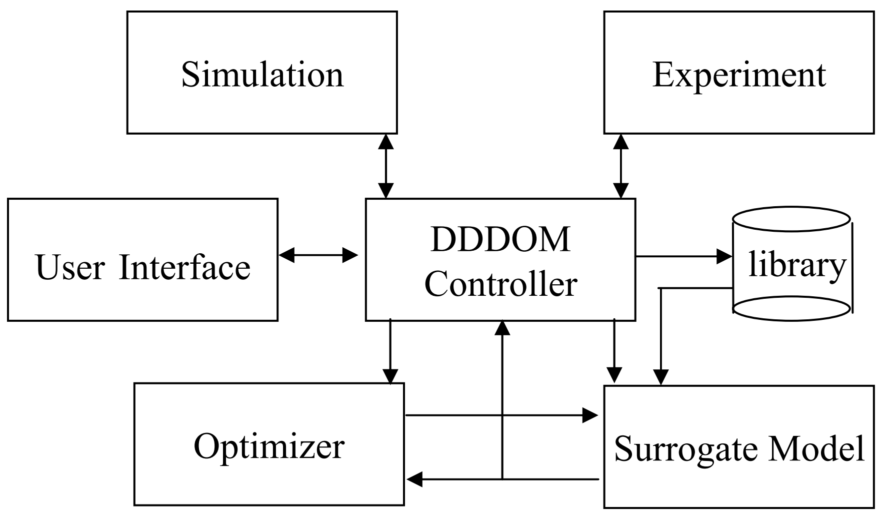
- Example for minimizing f_1 and f_2



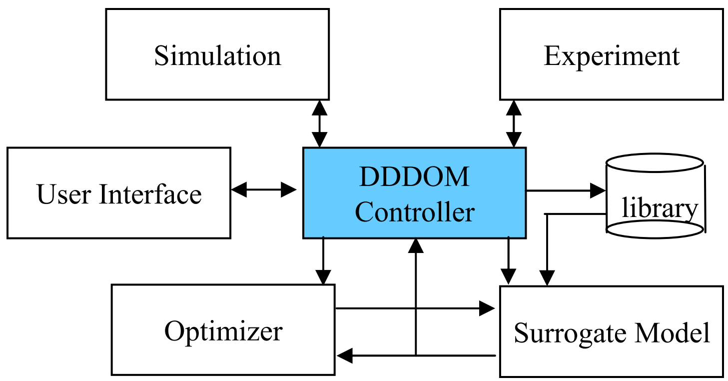
Designs 1, 2 and 3 are the Pareto Set

Methodology

- Data Driven Design Optimization Methodology (DDDOM)



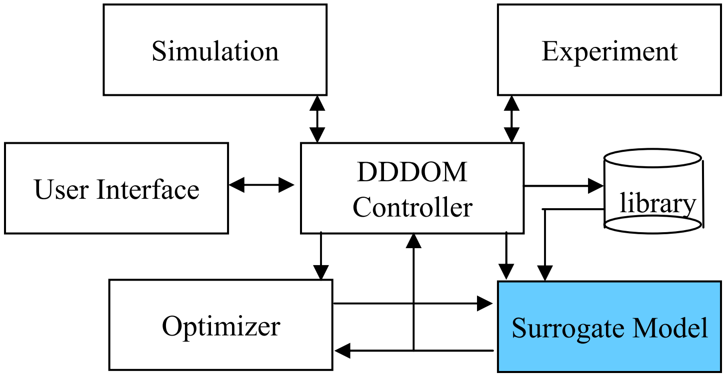
Methodology



- Controller

Overall control of design optimization
Determines new experimental and simulation data required for optimization
Controls training of Surrogate Model
Written in Perl and therefore platform independent

Methodology



- Surrogate Model

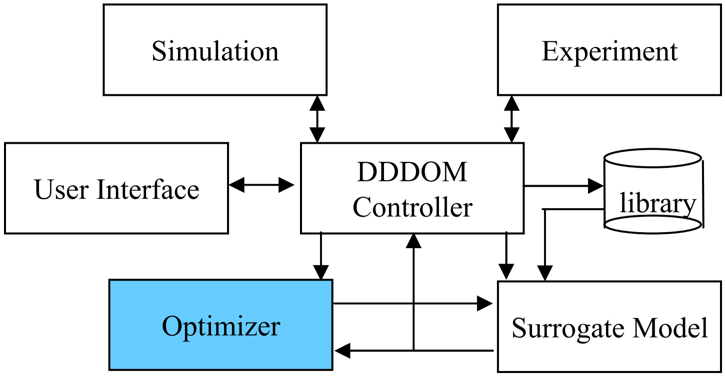
Trained on experimental and simulation data

Periodically updated during optimization as determined by Controller

Variety of Surrogate Models including Artificial Neural Network, Polynomial Response Surface, etc

Used by Optimizer to determine approximation to Pareto Set

Methodology



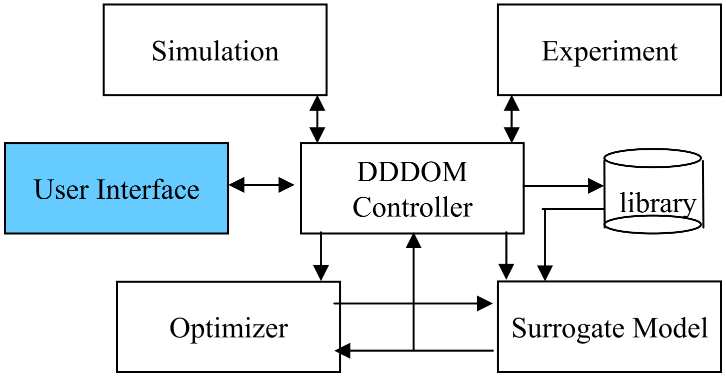
- Optimizer

Multi-criteria Design Optimization (MDO)

Gradient-based (*e.g.*, CFSQP) or Evolutionary (*e.g.*, GADO)

Uses Surrogate Model to determine approximation
to Pareto Set

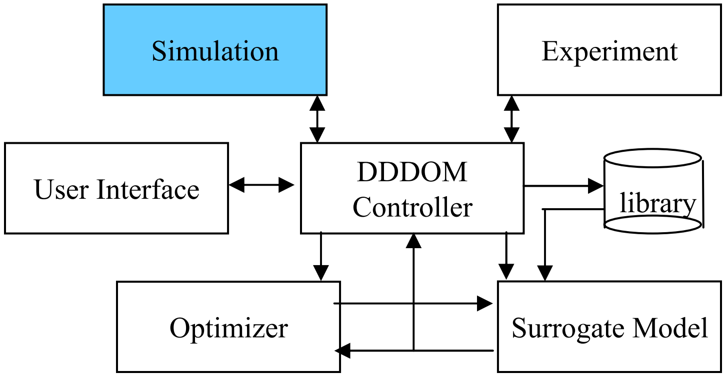
Methodology



- User Interface

Graphical User Interface for problem definition, monitoring and evaluation
Written in Perl/Tk and therefore platform independent

Methodology



- Simulation

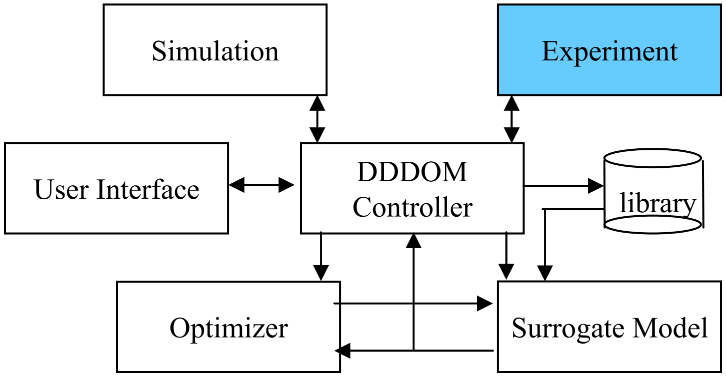
Use existing simulation codes

Specific configuration for each simulation is selected by Controller

Uses existing GUI of each simulation code

Simulation codes may be executed on remote computer systems (*e.g.,* NCSA using Globus)

Methodology



- Experiment

  Focus on experiments wherein Rapid Prototyping may be used to fabricate models in approximately 2 days

  Specific configuration for each experiment is selected by Controller

  Experiment requires human intervention for instrumentation and installation

Application

- Design of cooling system for electronic components
- Within the last 10 years:

Heat dissipation at chip level has increased from 30 to 150 W/cm^2

Number of devices at chip level has increased from thousands to millions

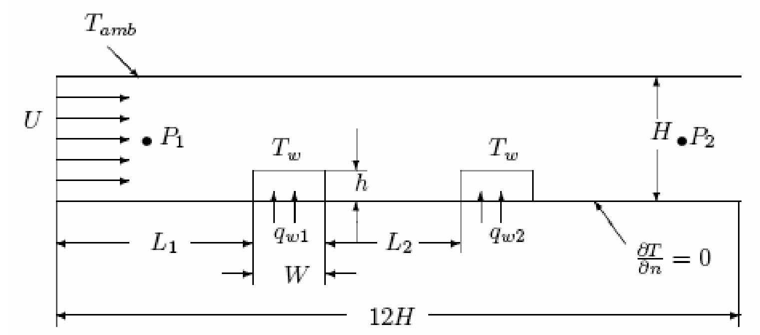
Chip sizes have decreased from 100μm to less than 1μm

Approximately 50% of chip failures attributed to excess temperature

Maximum surface temperatures must be maintained below 90 °C

Application

- Design optimization
  - Design variables:
    - L_1 , L_2
  - Design objective
    - Maximize heat transfer St
    - Minimize pressure drop Dp
  - Constraint
    - $\Delta T_w \leq \Delta T_{w_o}$ where ΔT_{w_o} = 60 ^oC
  - Reynolds number Re = 2.1×10^3
  - Grashof number Gr = 1.4×10^6
- Flow conditions correspond to unsteady flow

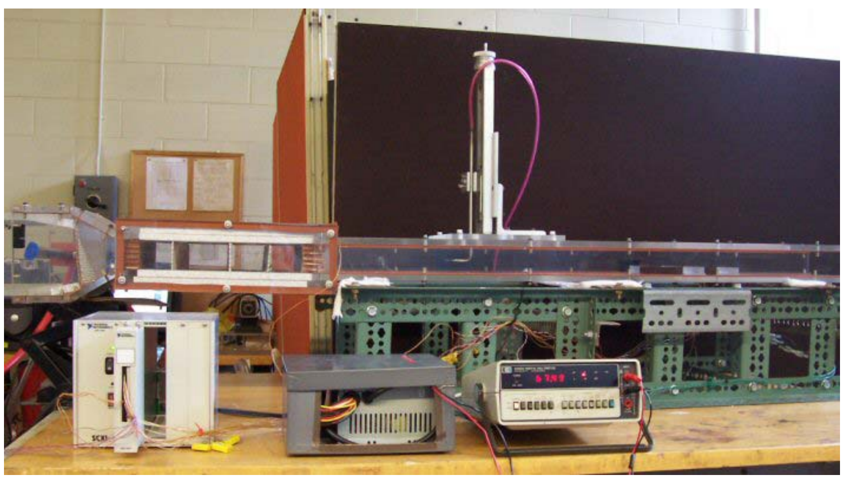


Flow Configuration

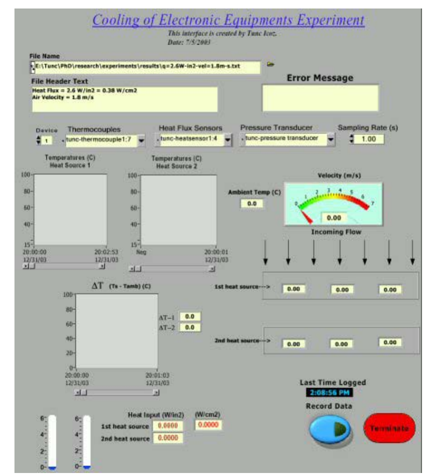
$$St = \frac{(q_{w_1} + q_{w_2})}{\rho c_p U_m \Delta T_{w_o} L_s}, \quad Dp = \frac{(p_1 - p_2)}{\frac{1}{2}\rho U_m^2}$$

Application

- Experiment
  - Copper heat sources
  - Measured pressure drop, heat flux and surface temperature
  - LabView interface
  - Selected 13 designs not considered by simulation



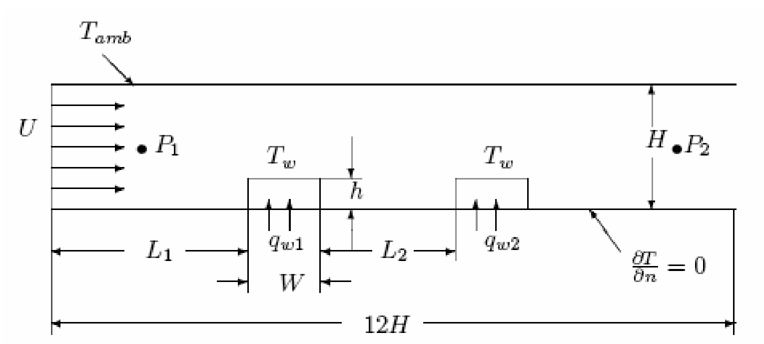
Experimental Configuration



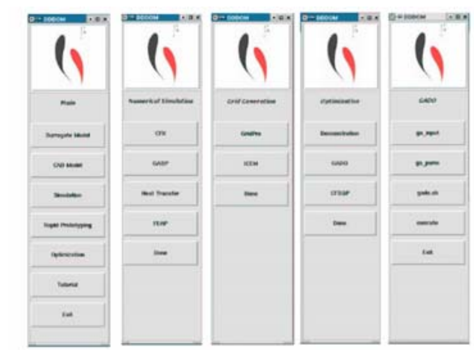
LabView Interface

Application

- Simulation
  - Fluent© software
  - Selected 25 designs (using Gosset technique) not considered by experiment except for overlap in 2 cases



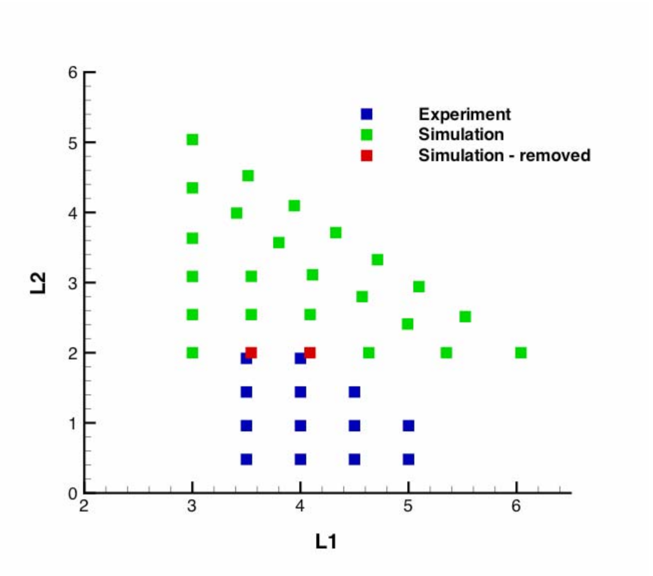
Flow Configuration



DDDOM Interface

Application

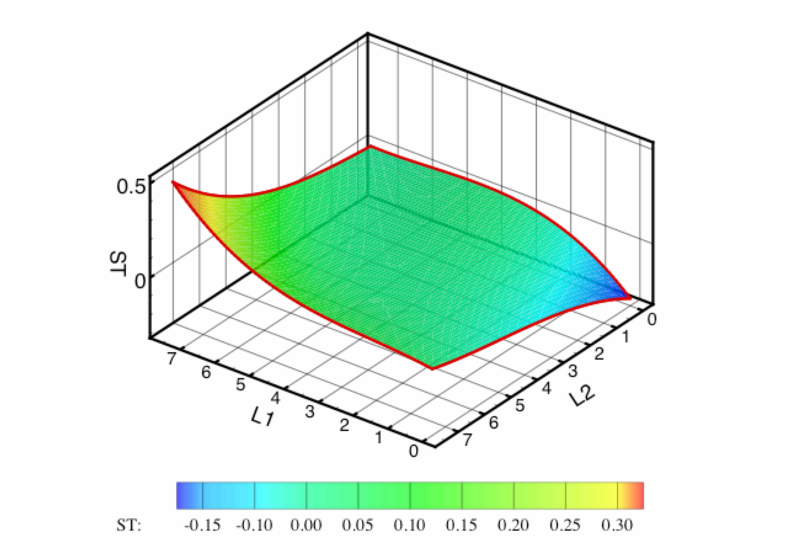
- Response Surface
  - Experiment defined 13 points
  - Simulation defined 25 points
  - Experimental results chosen over simulation in region of overlap
  - Third order response surface generated with RR = 0.78 and 0.62 for St and Dp.
- Optimization
  - CFSQP using ε-constraint



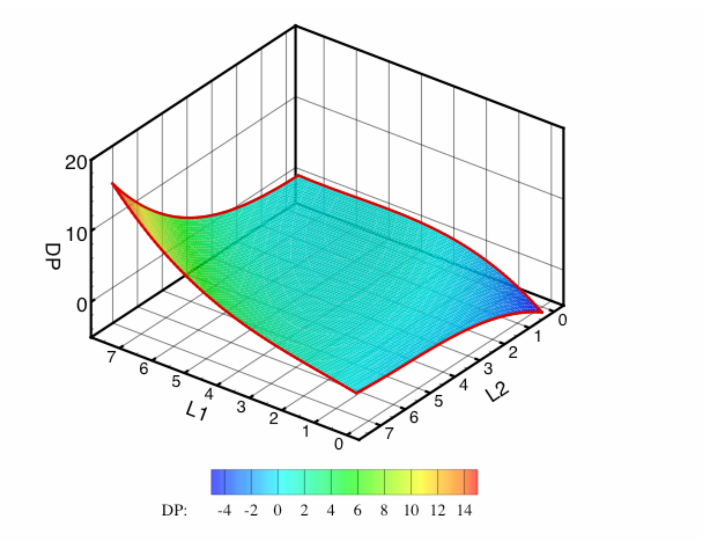
Datapoints Used for Response Surface

Application

- Response Surfaces (3rd Order)



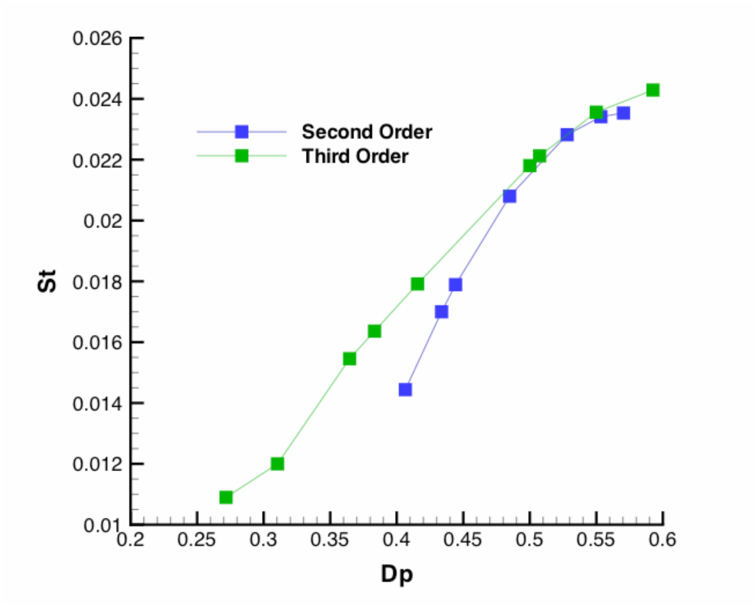
Heat Transfer



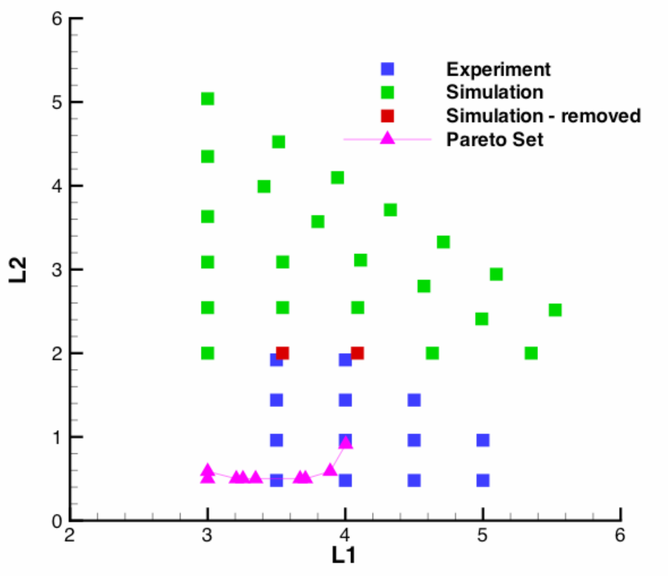
Pressure Drop

Application

- Pareto Set



Pareto Sets Obtained Using
2nd and 3rd Order Response Surfaces



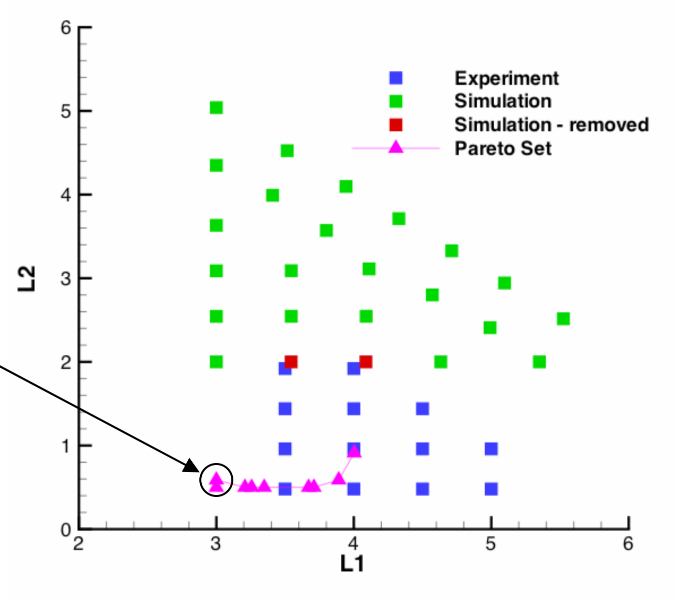
Pareto Surface in (L1, L2) design space
for 3rd Order Response Surface

Application

- How did the Dynamic Data Driven Application Systems concept improve the design ?

A region of low Dp and moderate St was identified which can be further examined in new experiments

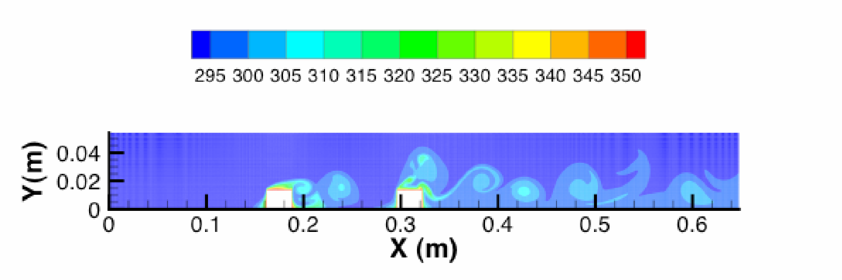
St = 0.12, Dp = 0.31



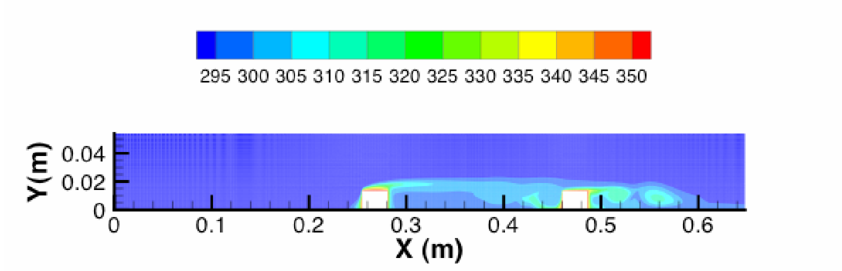
Thus, the initial Pareto Set obtained using experiment and simulation *drives* the next set of experiments

Application

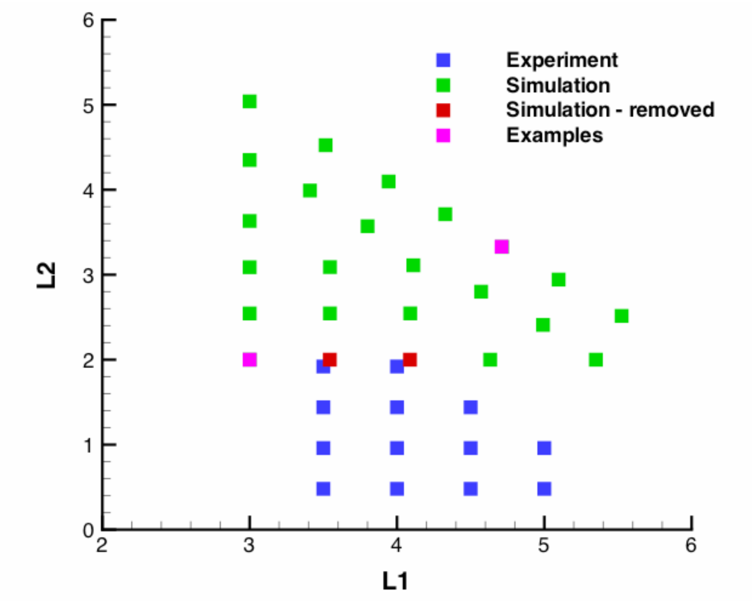
- Instantaneous temperature contours for two designs



L1 = 3.0, L2 = 2.0, St = 0.017, DP = 0.597



L1 = 4.71, L2 = 3.33, St = 0.015, DP = 0.707



Location of designs in L1, L2 domain

Conclusions

- Developed Data Driven Design Optimization Methodology (DDDOM) using Dynamic Data Driven Applications Systems (DDDAS) approach
- Application to design of cooling for electronic components using experiment and simulation
  - Determined initial Pareto Set of optimal designs, based on minimizing pressure drop and maximizing heat transfer, using experiment and simulation
  - Identified promising designs for further experiment, thus the experiment + simulation drives the next set of experiments
  - Thus, the DDDOM is an application system that "… can dynamically accept and respond to 'online' field data and measurements and/or can control such measurements."

Future Work

- DDDOM Methodology
  - The DDDOM software development is 95% complete
  - Additional DDDOM software development
    - Incorporate MDO Genetic Algorithm, developed by Prof. Khaled Rasheed, in DDDOM
- DDDOM Application
  - Additional applications of the DDDOM will be performed to demonstrate the effectiveness of the Dynamic Data Driven Application System concept
    - Optimal design of lumbar vertebral support
    - Optimal design of subsonic submerged inlet
  - Preliminary design optimizations have already been performed for these cases