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Design Space Exploration with Behavioral Modeling

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Acknowledgments

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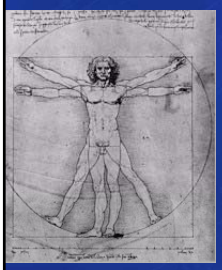
BMX what is that?

Pro/ENGINEER Behavioral Modeling Extension (BMX) is a design space exploration and optimization software that :

1. Defines analysis features



- Pro/E measures (distance, curvature, volume, UDA)
- Excel (drag and drop bi-directional associativity)
- MDX measures (max acceleration)
- MDO measures (max reaction)
- External programs (FEA, CFD, Cost, etc)

BMX what is that?

- Pro/ENGINEER Behavioral Modeling Extension (BMX) is a design space exploration and optimization software:
  - Using these analysis features perform:
    - Sensitivity Analysis
    - Feasibility / Optimization
    - Multi-objective Design Studies

  - Generates optimization features that extend the Pro/E associativity to product attributes and drives the design from engineering requirements (not dimensions)

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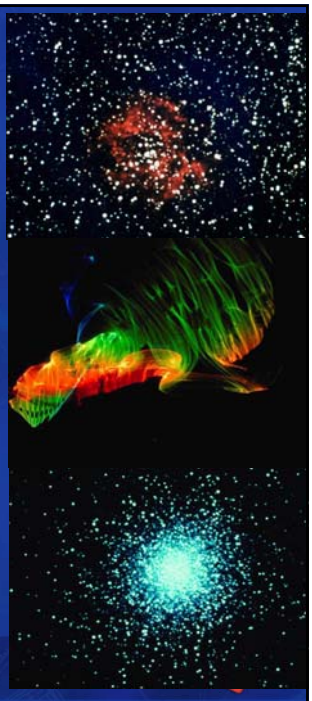
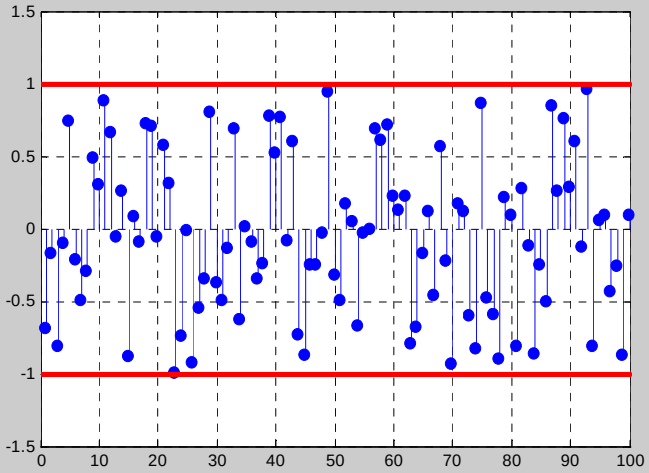
Tools for Robust Design

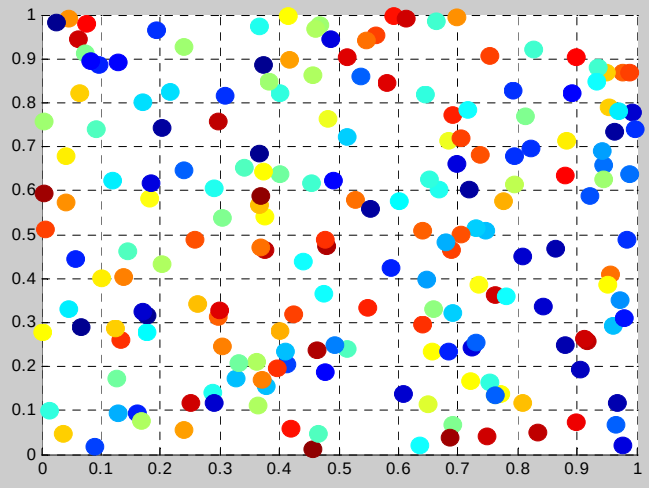
- Design Of Experiments
  - Exploits nonlinearities and interactions between noise & control parameters to reduce product performance variability
  - full factorial, fractional factorial, Monte-Carlo, LHC
- Response Surface Methods
  - Central Composite Design
  - Box-Behnken Design
- 6-sigma design
  - Identifying & qualifying causes of variation
  - Centering performance on specification target
  - Achieving Six Sigma level robustness on the key product performance characteristics with respect to the quantified variation



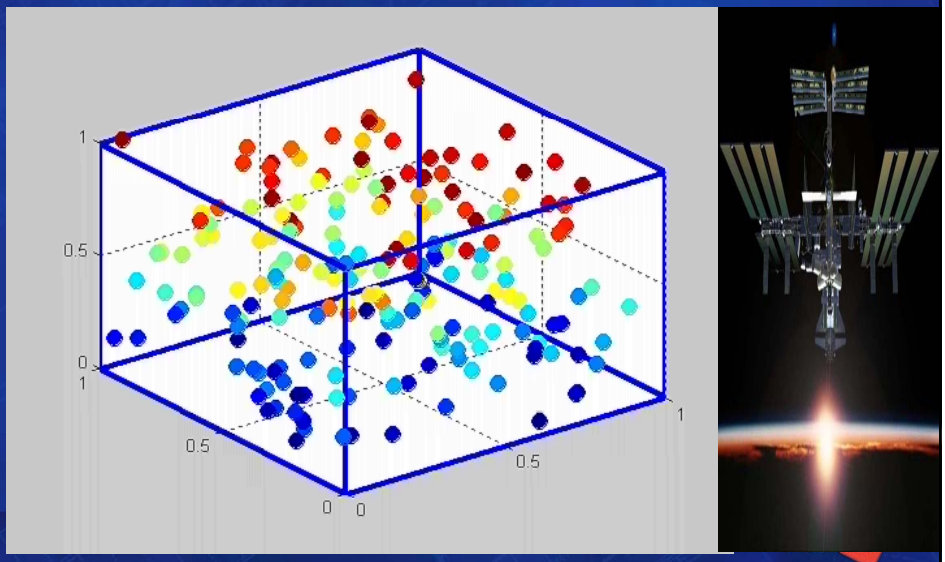
Design Exploration 1 Variable



Design Exploration 2 Variables



Design Exploration 3 Variables

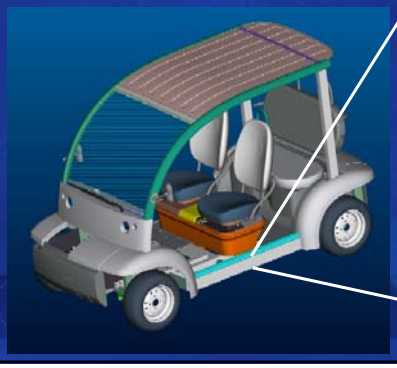


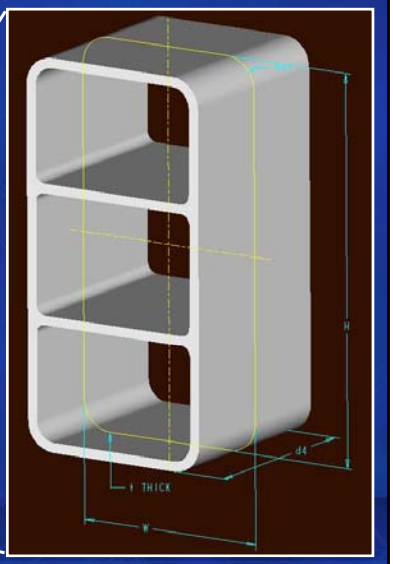
Example - Live Demonstration

Fundamentals of Designs Of Experiments

Problem Statement:

Find the lightest section that meets the Design requirements ($I_{xx} > I_{req}$) for the aluminum extruded section shown in 5 min.





Problem Statement in ProE terms

- Find the dimensions (Pro/E parameters W, H, t) that minimize the cross sectional area (Min Weight - cost) and meet all the strength, manufacturing and stability requirements

  $80 < W < 120$

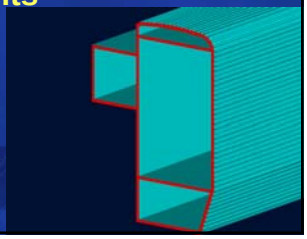
  $160 < H < 240$

  $4 < t < 6$

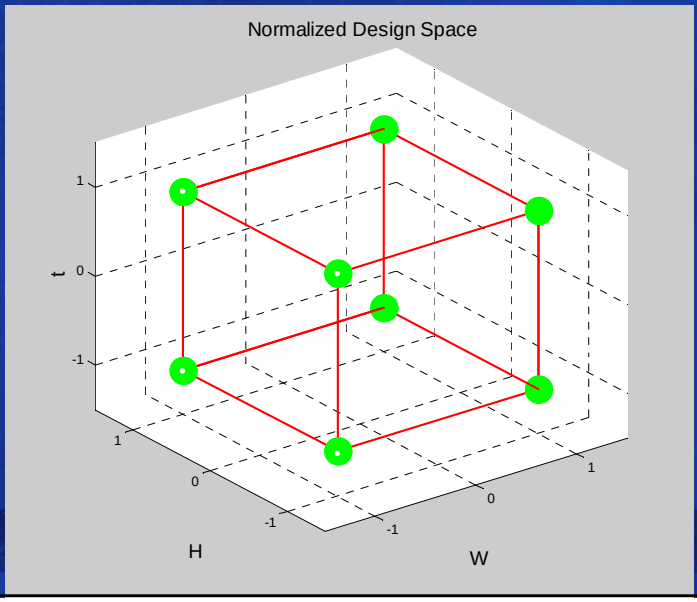
- Action: Perform a multi-objective design study to identify the most economical section that satisfies the strength requirements.

Behavioral Modeling of the Rocker Section

- **All sections have the same moment of Inertia**
- **Find the one that minimizes the cross sectional area (Min Weight) and meets all the manufacturing and stability requirements**
- **Not a dimension driven CAD model**
- **Requirement driven design (I_{req})**



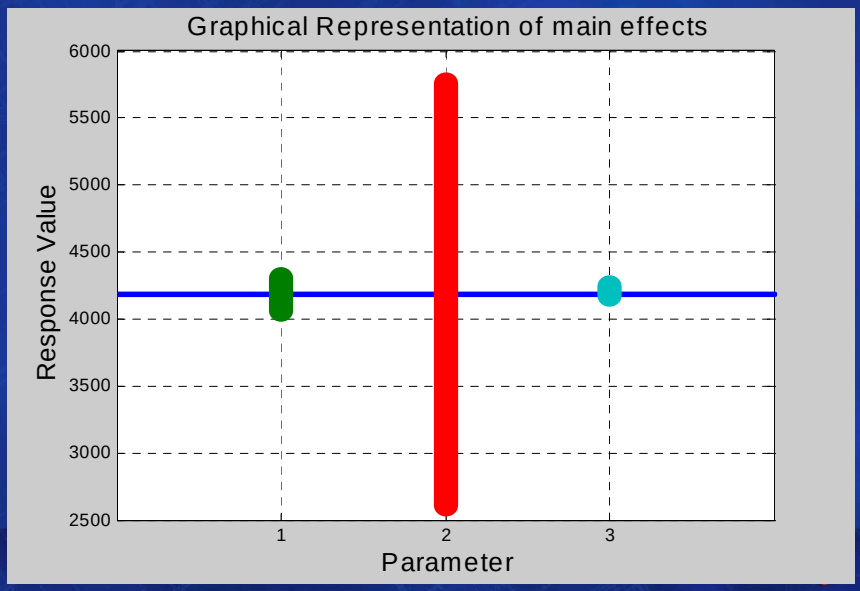
Typical Design Exploration (without BMX)
Full Factorial, 2 level - 3 factor design



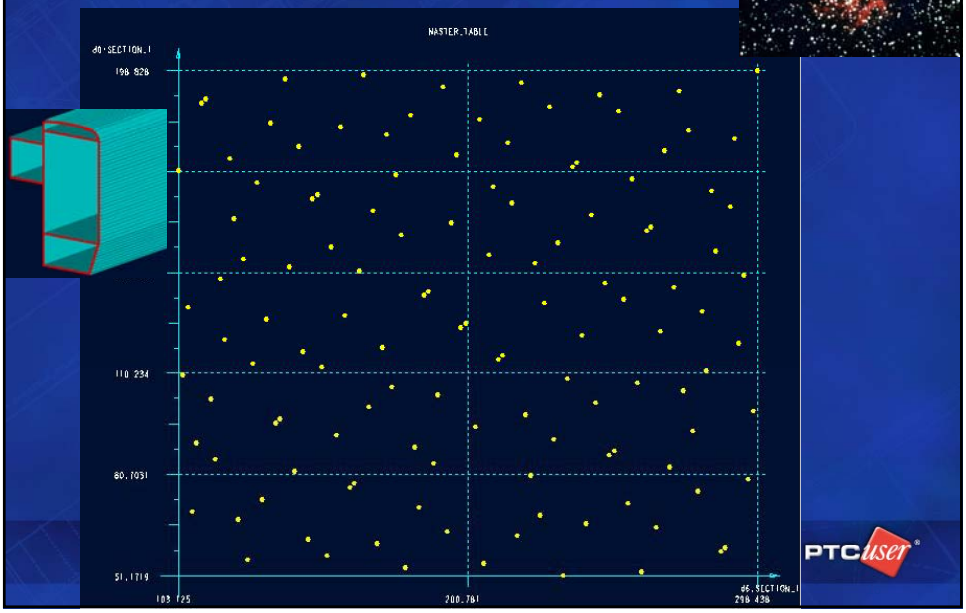
Response Table for Three-factor Experiment

Experiment Number	Response Value	W (Width)		H (Height)		t (thickness)	
		min 80	max 120	min 160	max 240	min 4	max 6
1	R1	R1		R1		R1	
2	R2	R2		R2			R2
3	R3	R3			R3	R3	
4	R4	R4			R4		R4
5	R5		R5	R5		R5	
6	R6		R6	R6			R6
7	R7		R7		R7	R7	
8	R8		R8		R8		R8
AVERAGE	R	W1	W2	H1	H2	t1	t2
EFFECT		W2-W1		H2-H1		t2-t1	

Graphical Representation of Main Effects



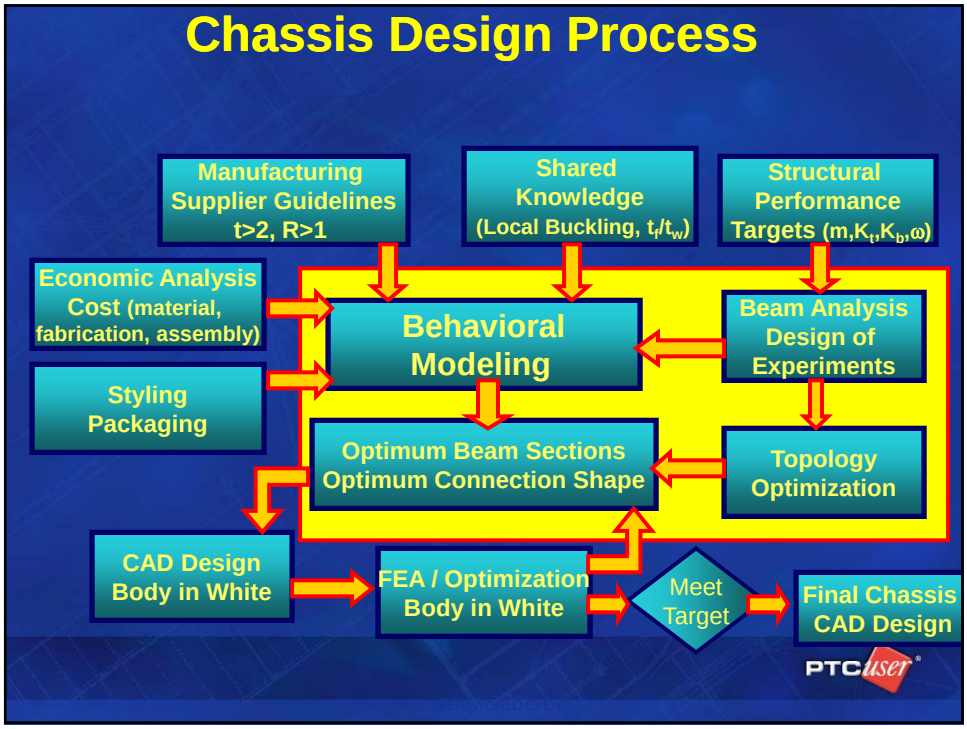
Design Exploration with BMX
Scatter Plot for two of Design Variables



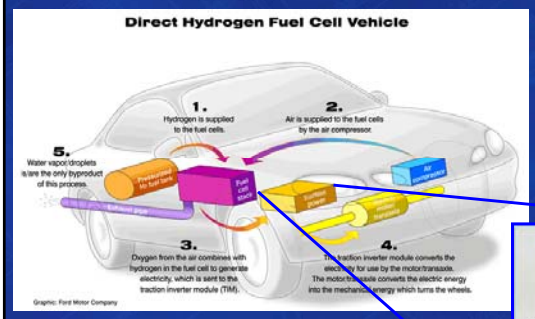
Scatter Plot of Ixx versus Area

Live Demonstration

Chassis Design Process



BMX Example on Power Electronics Cooling



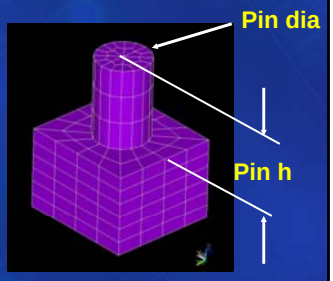
Project Goal :
Develop a heat exchanger design to efficiently remove heat from the power module and reject it into the vehicles coolant loop with uniform cooling, minimum cost, volume and pressure drop

Problem Statement

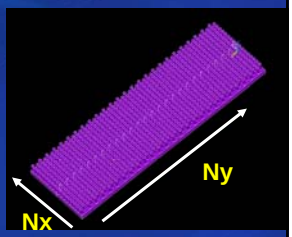
F find the optimal pin-fin geometry that:

Minimizes **dT**

Where:



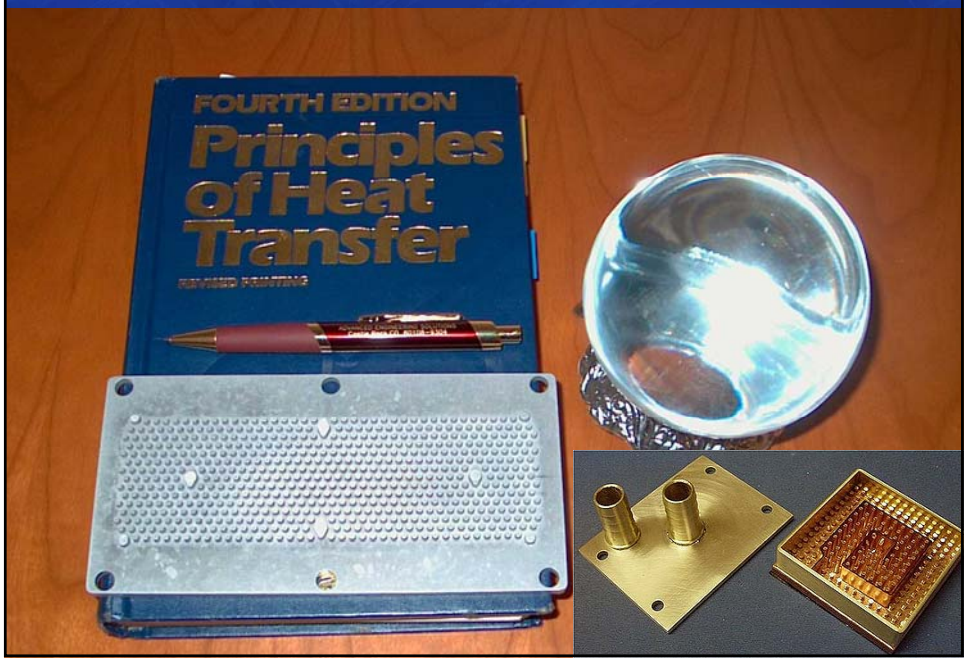
1 mm	<	Pin_dia	<	10 mm
1 mm	<	Pin_h	<	5 mm
1	<	Nx	<	15 (integer)
2	<	Ny	<	50 (integer)



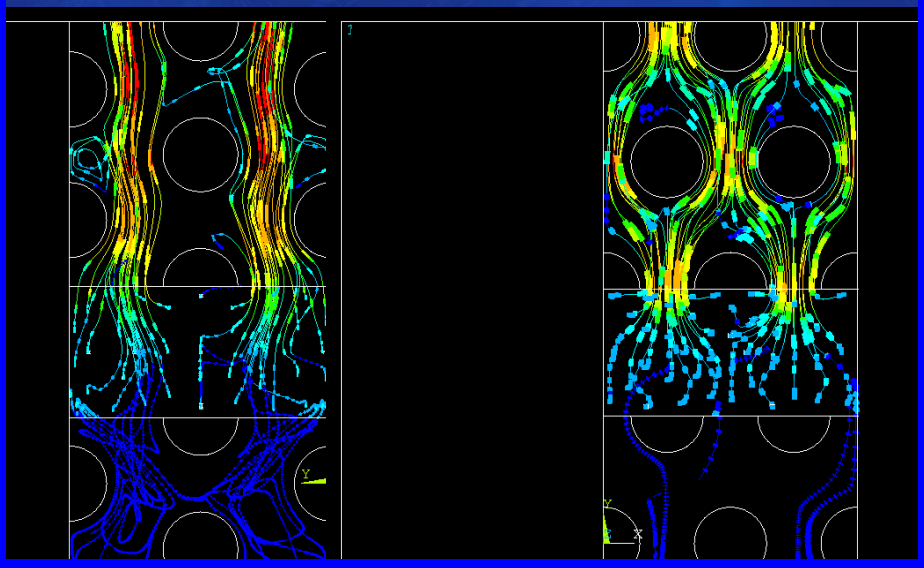
Subject to:

maxT	<	125 °C
dP	<	20000 Pa
(Lx-Nx*Pin_dia)/Nx	>	0.5 mm (no interference in x)
(Ly-2*Ny*Pin_dia)/(2*Ny)	>	0.5 mm (no interference in y)

Design Aids: Experiments, CFD, FEA, BMX, CB

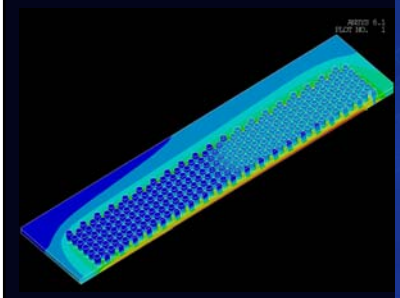


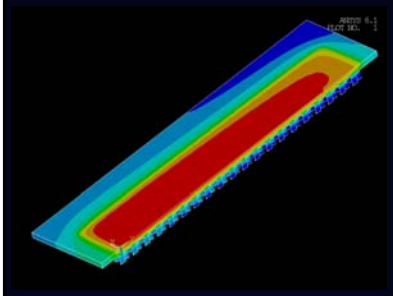
CFD Analysis of Staggered vs. In-Line Flow



Thermal Analysis

Classical Determination of Film Coefficients for BMX Implementation





Reynold's number for flow around pin fins

$$\mathrm{Re}_D = \frac{U_{\max} D}{\nu}$$

Nusselt number

- laminar

$$Nu_D = 0.9\,\mathrm{Re}_D^{0.4}\,\mathrm{Pr}^{0.36}$$

- transitional

$$Nu_D = 0.35\left(\frac{St}{Sl}\right)^{0.2}\mathrm{Re}_D^{0.6}\,\mathrm{Pr}^{0.36}$$

- turbulent

$$Nu_D = 0.022\,\mathrm{Re}_D^{0.84}\,\mathrm{Pr}^{0.36}$$

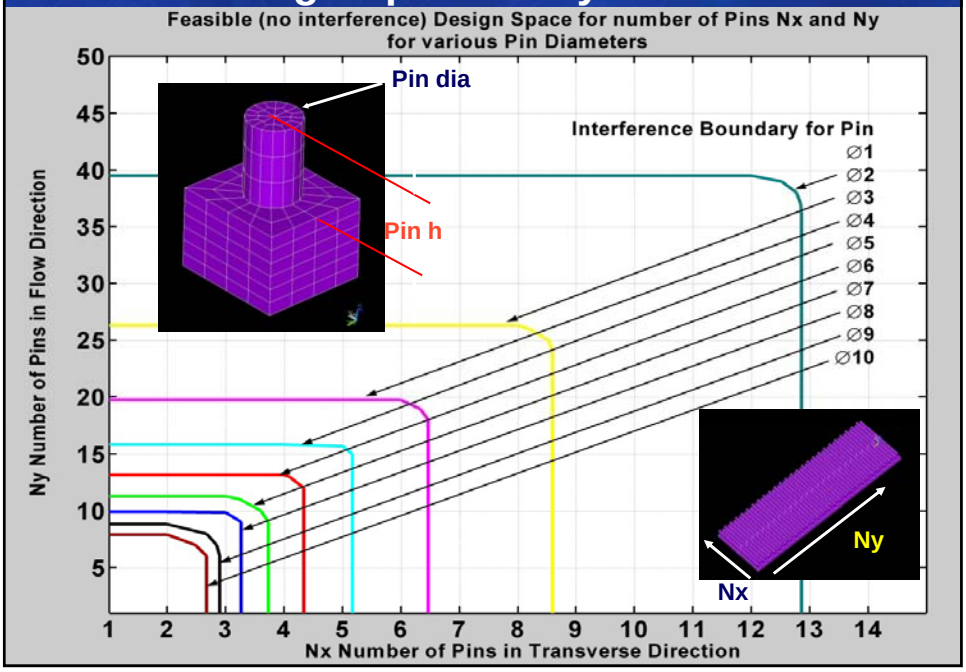
Heat transfer coefficient

$$h = \frac{Nu \times k}{D}$$

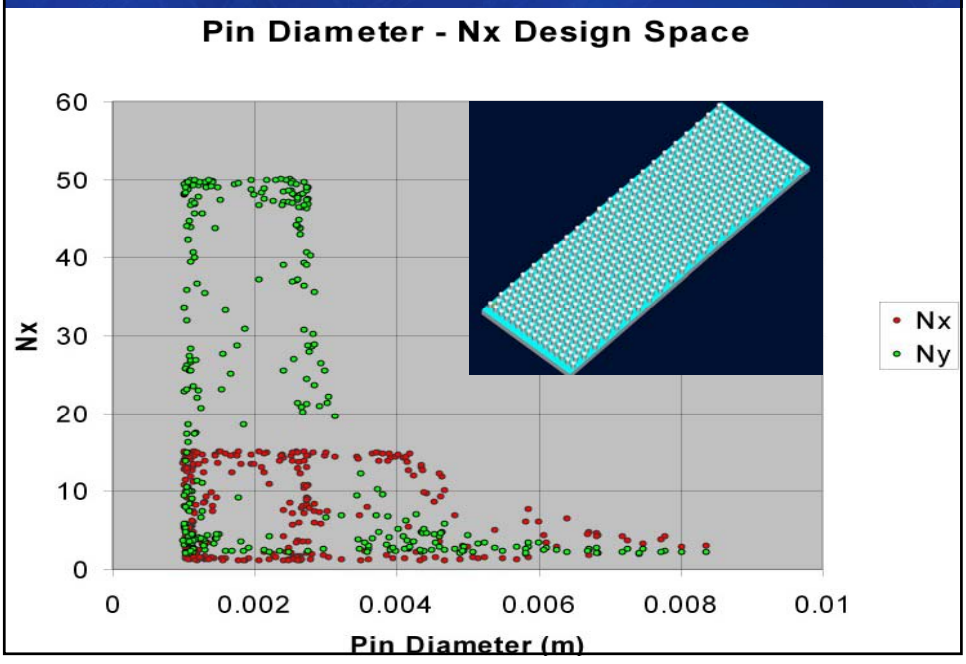
Pressure Drop

$$\Delta P = f\,\frac{\rho U_{\max}^2}{2}\,N$$

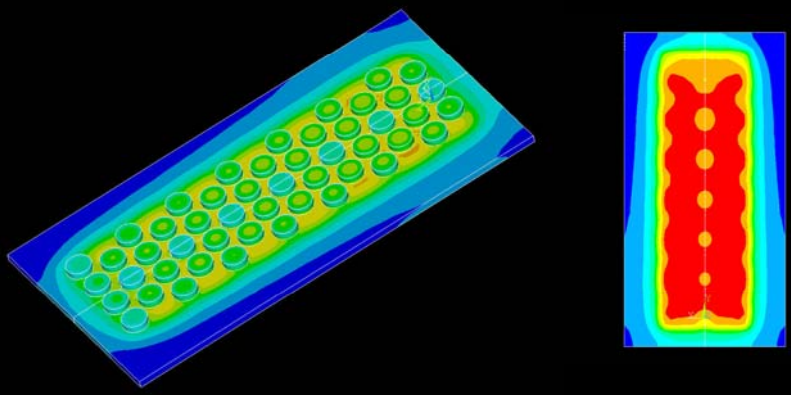
Feasible Design Space of Ny versus Nx



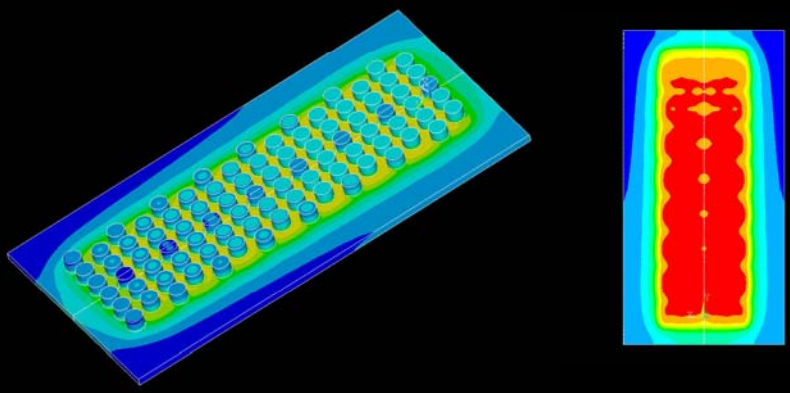
Feasible Design Space of Pin diameter versus Nx



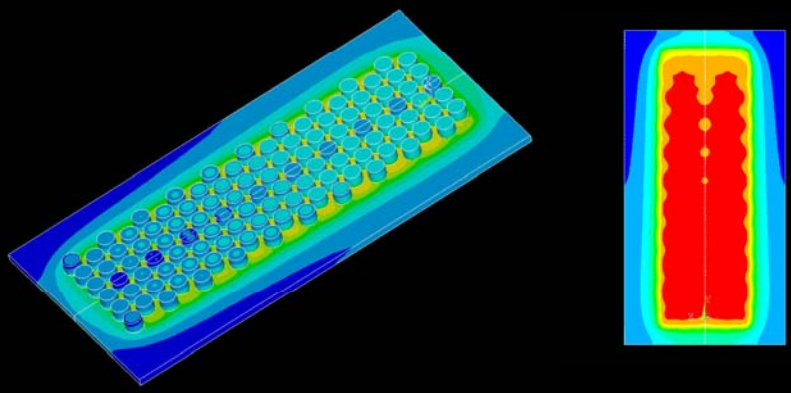
Design Option A



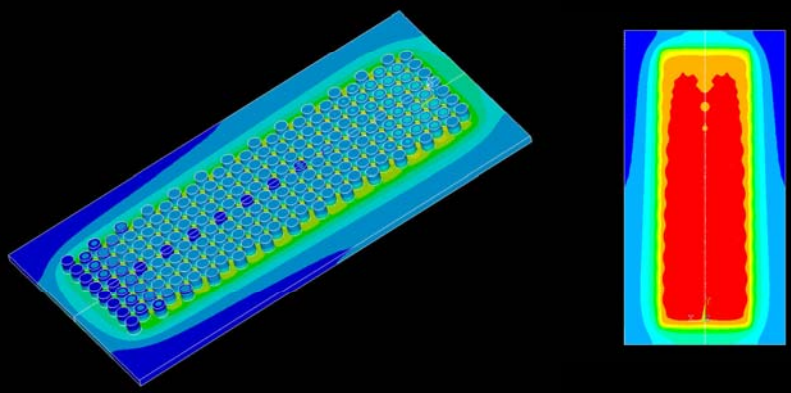
Design Option B



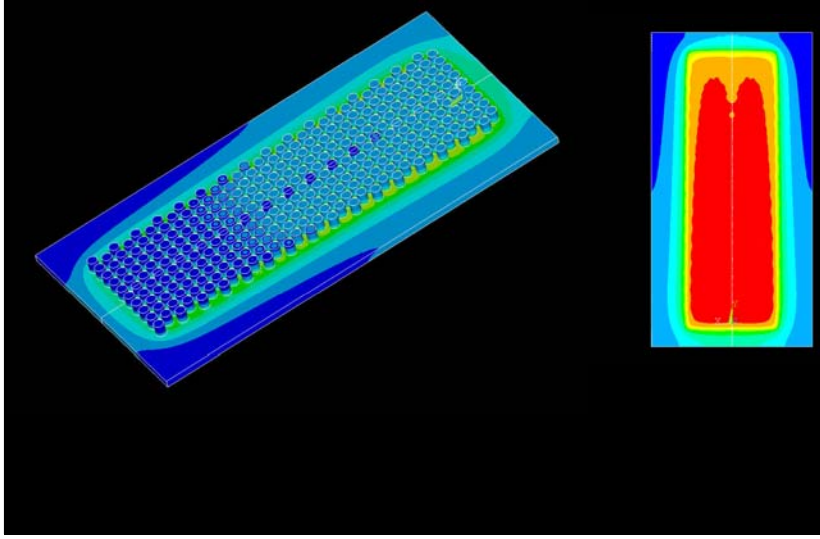
Design Option C



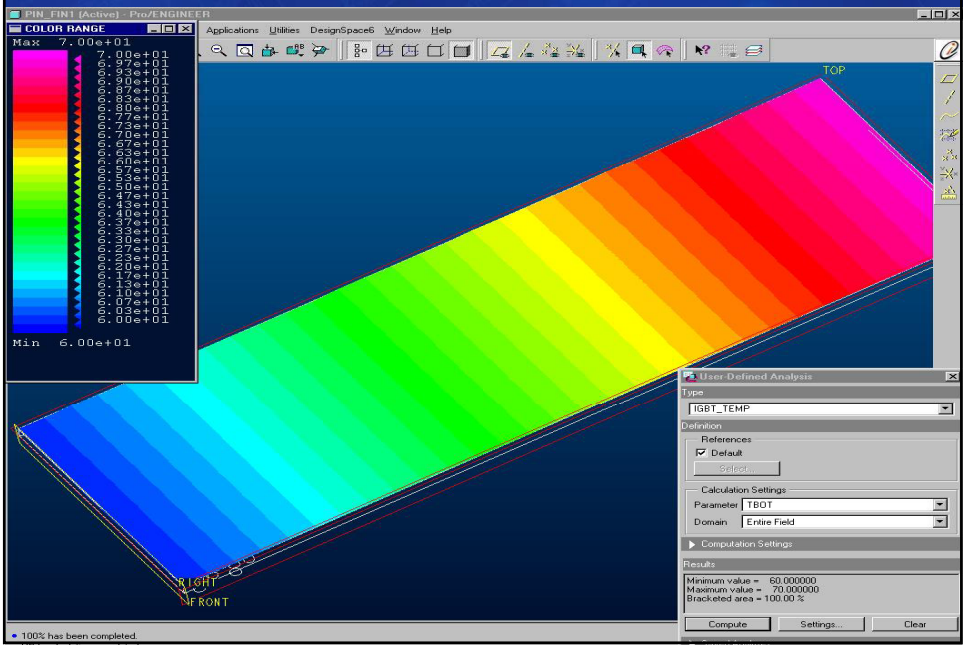
Design Option D



Design Option E

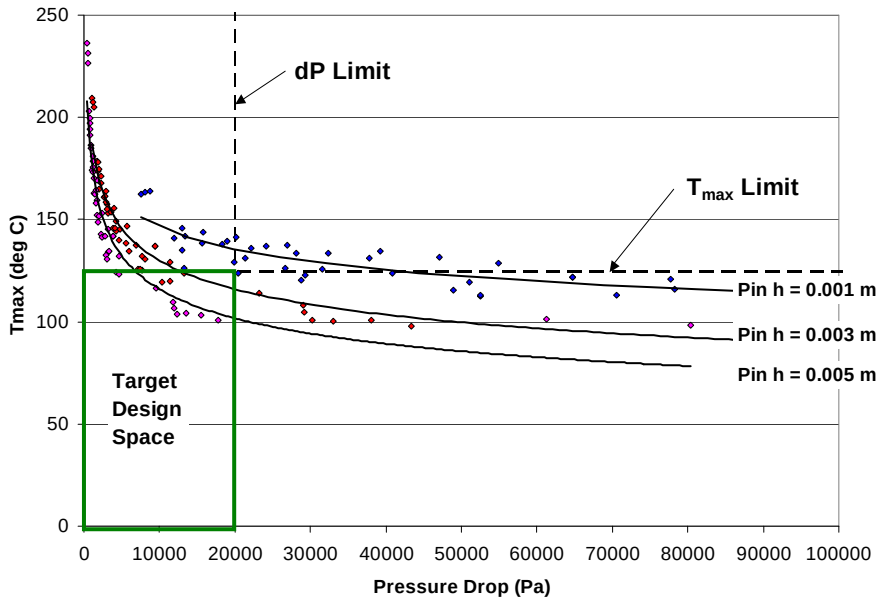


Temperature Distribution with BMX's UDA



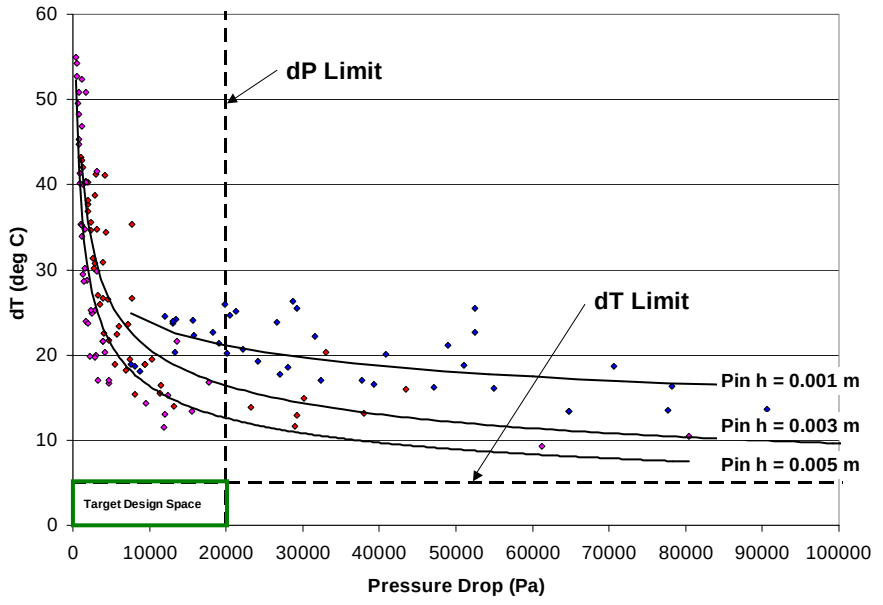
Design Space Exploration *(pin h, pin dia, spacing)*

Maximum Temperature vs. Pressure Drop

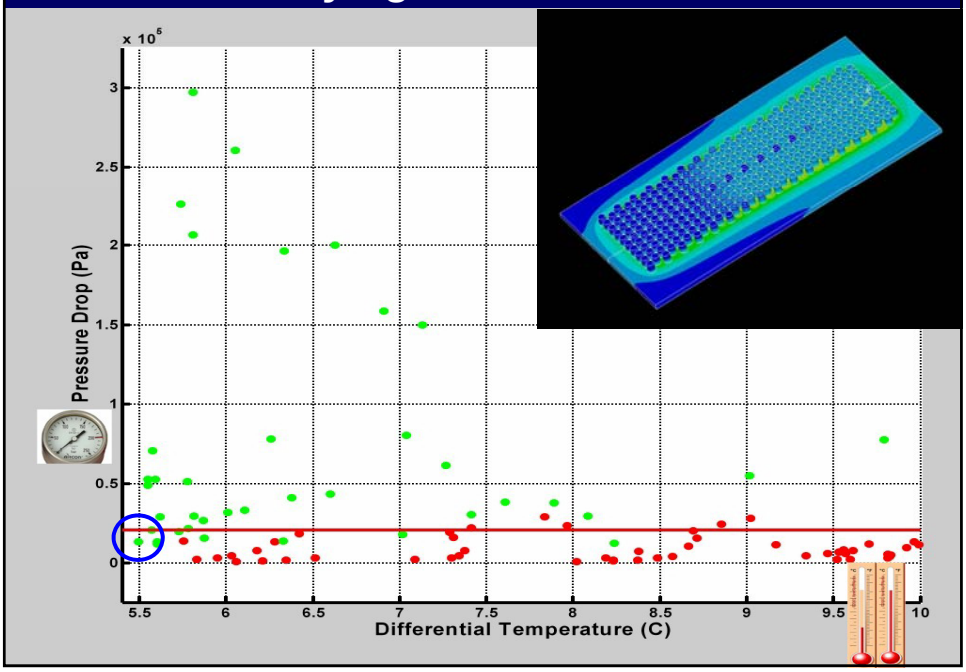


Design Space Exploration *(pin h, pin dia, spacing)*

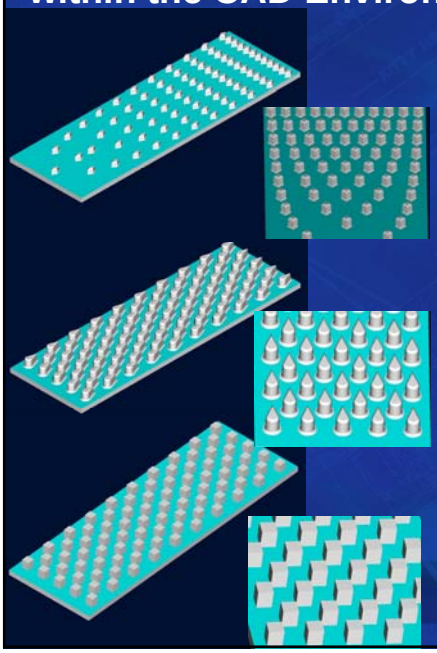
Temperature Differential vs. Pressure Drop



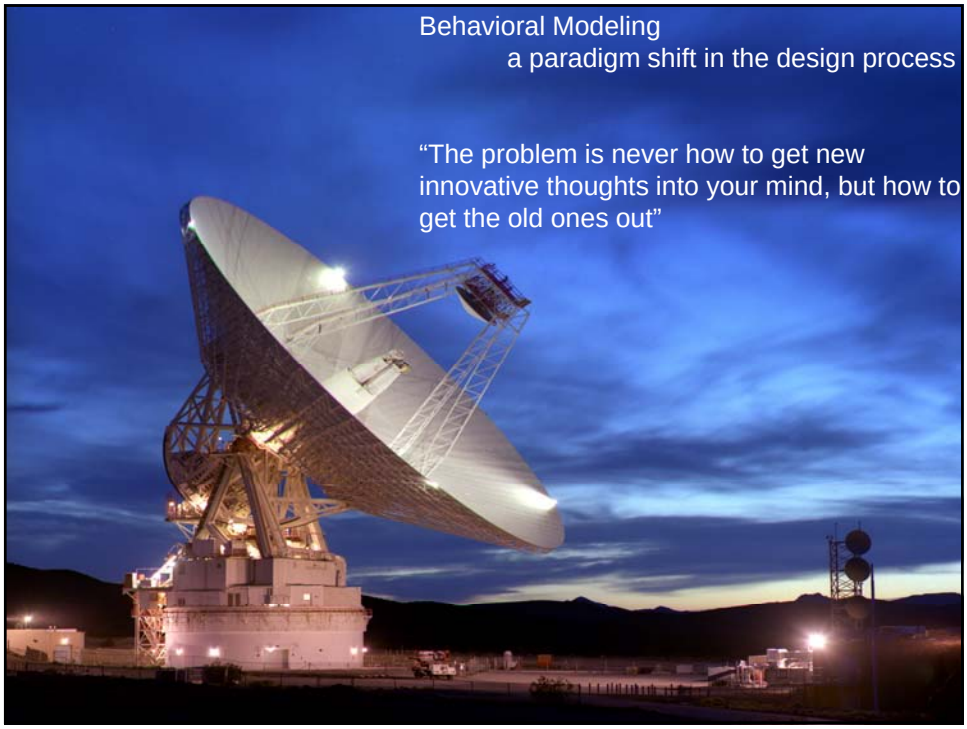
Identifying the Best Solution



Achieving Design Requirements
within the CAD Environment



- Attribute driven Parametric modeling (dP, Tmax, dT)
- Automated optimization at the design stage
- Very fast solutions and flexible geometry
- Requires closed form solutions or link to other analysis tool (CFD, FEA, etc.)


Behavioral Modeling
a paradigm shift in the design process
“The problem is never how to get new innovative thoughts into your mind, but how to get the old ones out”