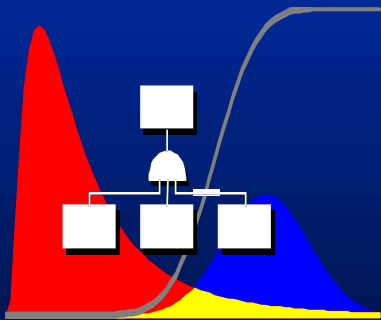


# Fast Discovery of the Best Designs



by

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# Learning Outcomes

- Understand the basics of designed experiments and robust design
- Enable designs to be driven by their product specifications
- Know how to use simple graphical techniques to analyze multi-objective study data
- Perform automated design space exploration
- Optimize automatically the design for a set of performance attributes
- Design for Six-sigma quality levels

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# Application Activity # 1

Identification of the most influential  
Pro/E parameters (DOE)

## Application activity #1:

# Identification of the most influential Pro/E parameters

- **Problem Statement:**

Using 2 level 3 factor design of experiments determine the Pro/E parameters  $W$ ,  $H$ ,  $t$  that are the most influential on the performance attribute ( $I_{xx}/A$ ) for the aluminum extruded section shown.

where:

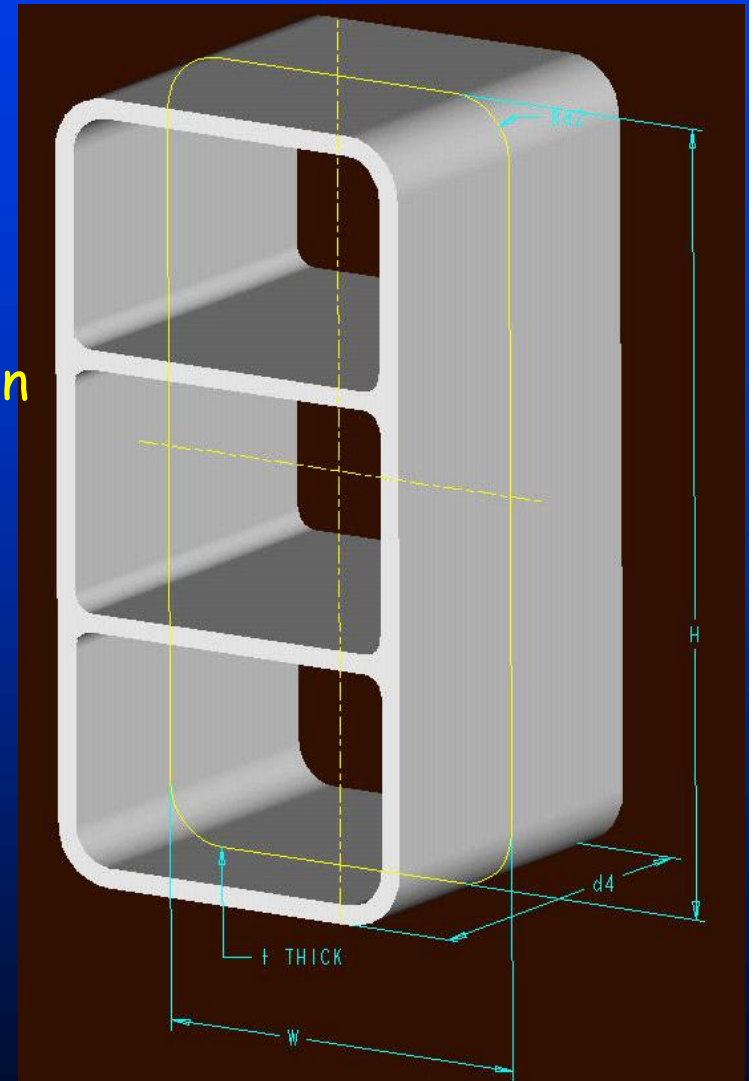
$$80 < W < 120$$

$$160 < H < 240$$

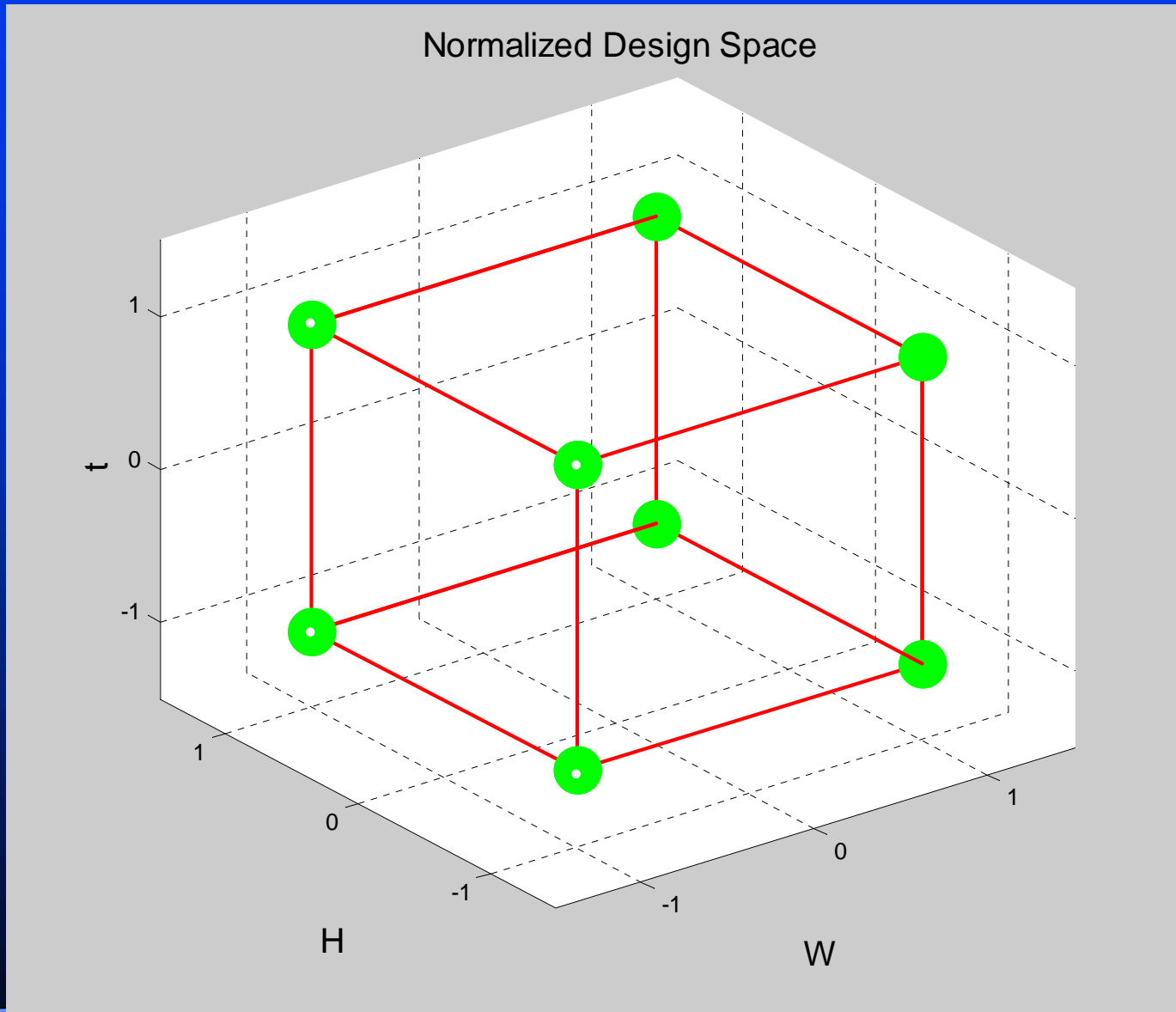
$$4 < t < 6$$

- **Learning Goals:**

- Understanding the fundamentals of Designs Of Experiments



# Design Exploration for Full Factorial, 2 level - 3 factor design



# Multi-Objective Design Study - Full Factorial

**Master Table**

Sampling Method: **Manual**

Run Experiments on:  All Combinations  One Per Row

Design Variables

	W:EX1	H:EX1	tEX1
1	80.000000	160.000000	4.000000
2	120.000000	240.000000	6.000000
3			
4			
5			

Design Goals

XSEC\_AREA:ANALYSIS1  
XSEC\_IXX:ANALYSIS1

Select Goals

OK Cancel

**Multi-Objective Design Study**

File Setup Table Record Tools Options

Study Name: DS2

Table Tree

Table	Records
MASTER_TABLE	8

Table Data

Name: MASTER\_TABLE Records: 8

Record #	Goals	Variables
0	2385.645996 610311...	80.000000 160.000000 4.000000
1	3471.309705 877479...	80.000000 160.000000 6.000000
2	3025.645996 169383...	80.000000 240.000000 4.000000
3	4431.309705 246167...	80.000000 240.000000 6.000000
4	3025.645993 827841...	120.000000 160.000000 4.000000
5	4431.309702 119649...	120.000000 160.000000 6.000000
6	3665.645993 219069...	120.000000 240.000000 4.000000
7	5391.309702 319584...	120.000000 240.000000 6.000000

# Response Table for Three-factor Experiment

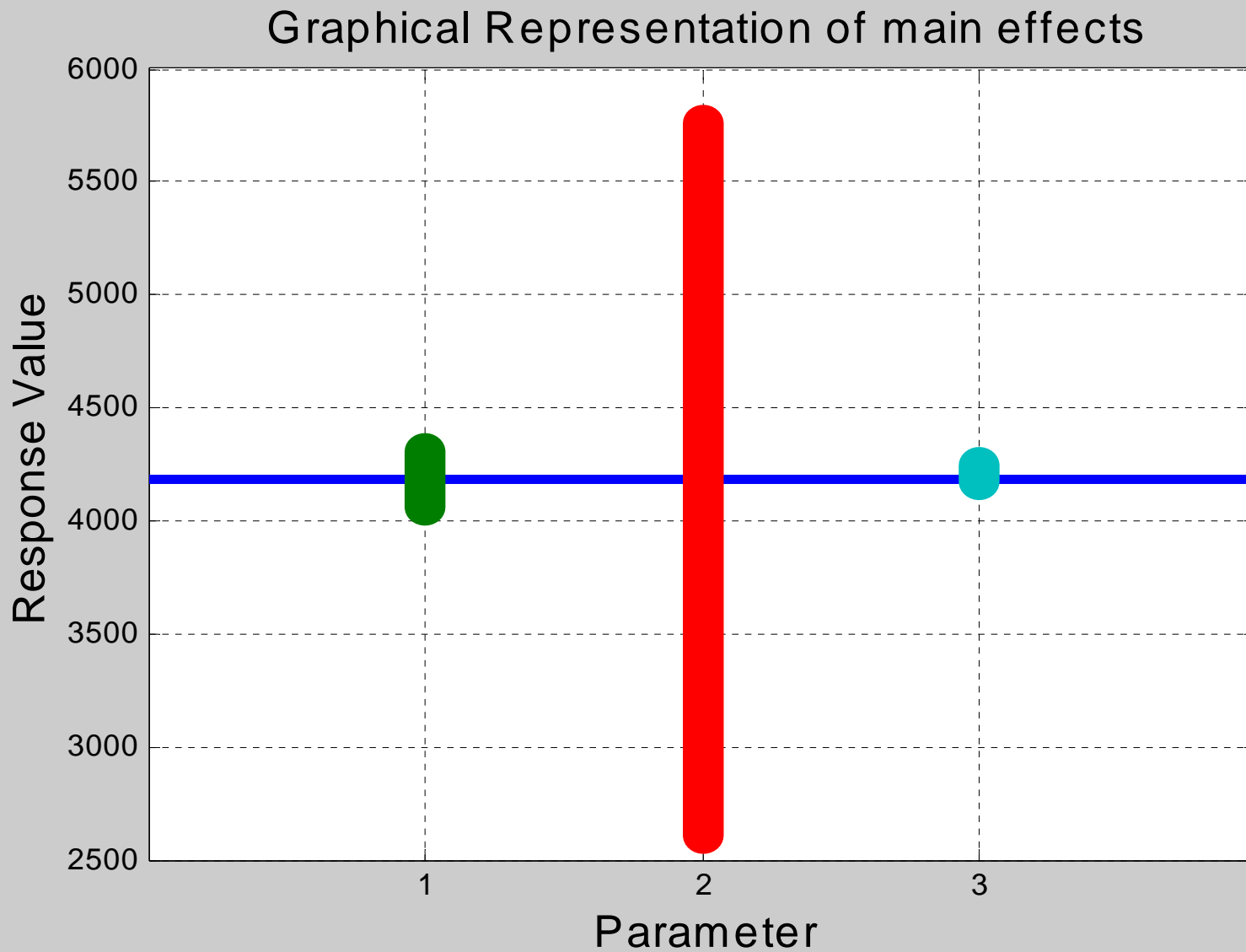
Experiment Number	Response Value	W (Width)		H (Height)		t (thickness)	
		min 80	max 120	min 160	max 240	min 4	max 6
1	R1	R1		R1		R1	
2	R2	R2		R2		R2	
3	R3	R3		R3		R3	
4	R4	R4		R4		R4	
5	R5		R5	R5		R5	
6	R6		R6	R6		R6	
7	R7		R7	R7		R7	
8	R8		R8	R8		R8	
<b>AVERAGE</b>	<b>R</b>	<b>W1</b>	<b>W2</b>	<b>H1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

# Response Table for Three-factor Experiment

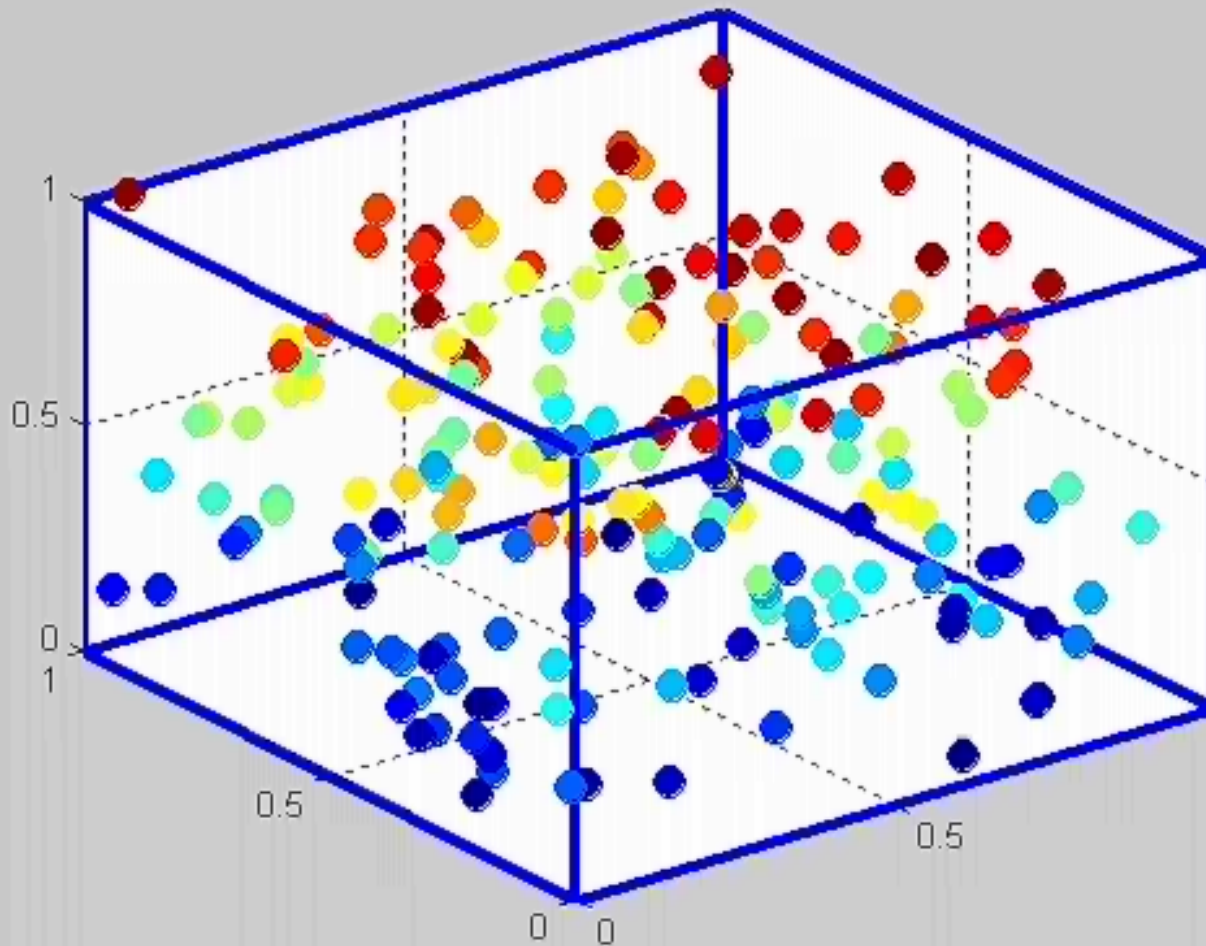
Experiment Number	Response Value	W (Width)		H (Height)		t (thickness)	
		min 80	max 120	min 160	max 240	min 4	max 6
1	2558	2558		2558		2558	
2	2527	2527		2527			2527
3	5598	5598			5598	5598	
4	5555	5555			5555		5555
5	2636		2636	2636		2636	
6	2700		2700	2700			2700
7	5976		5976		5976	5976	
8	5927		5927		5927		5927
<b>AVERAGE</b>	<b>4184.6</b>	<b>4059.5</b>	<b>4309.8</b>	<b>2605.3</b>	<b>5764.0</b>	<b>4192.0</b>	<b>4177.3</b>
<b>EFFECT</b>		<b>250.25</b>		<b>3158.75</b>		<b>-14.75</b>	



# Graphical Representation of Main Effects



# Automatic Design Exploration



**Master Table** [X]

Sampling Method: Automatic [v]

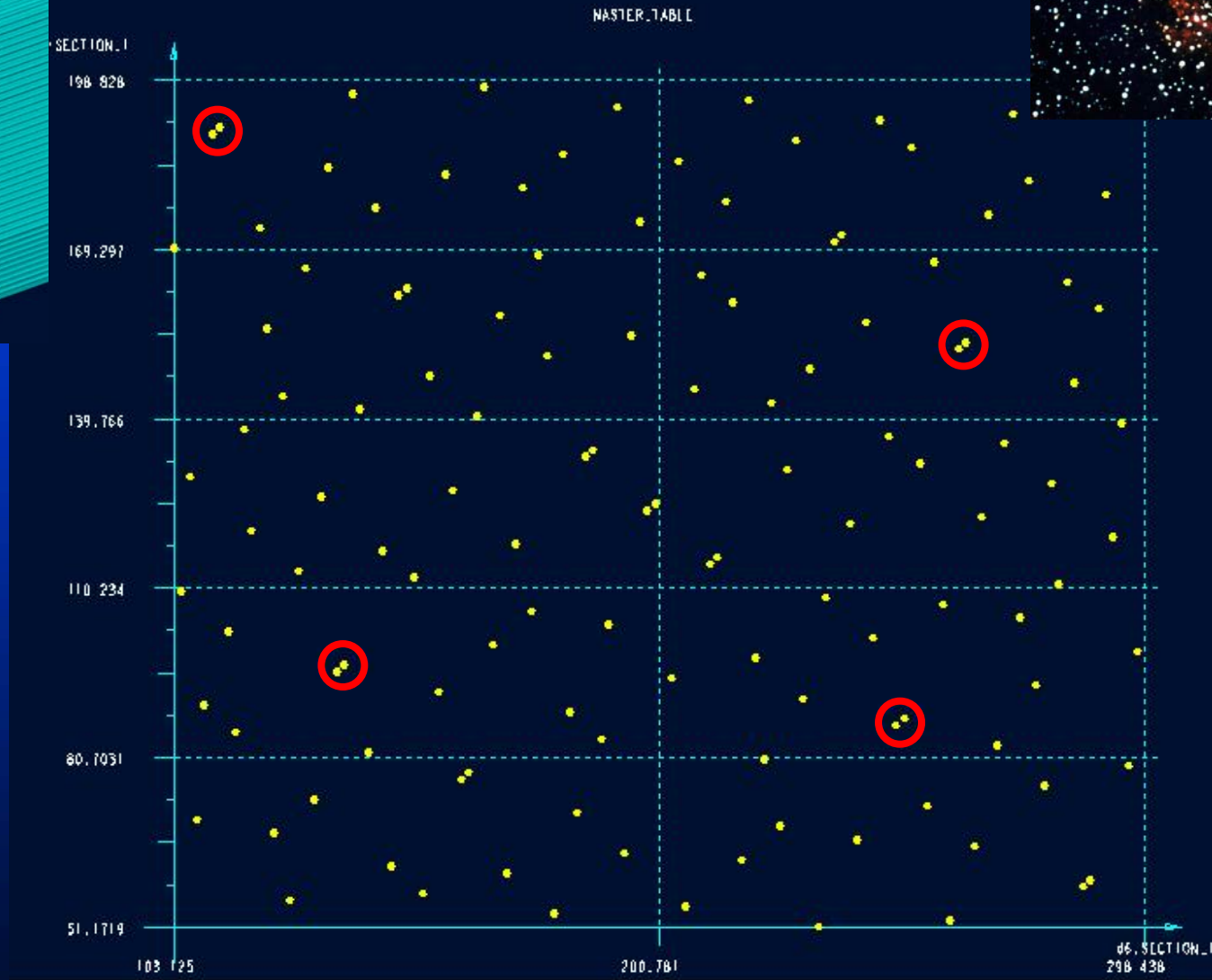
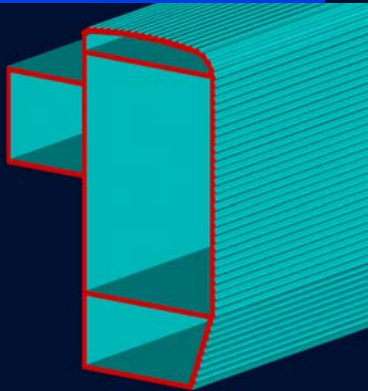
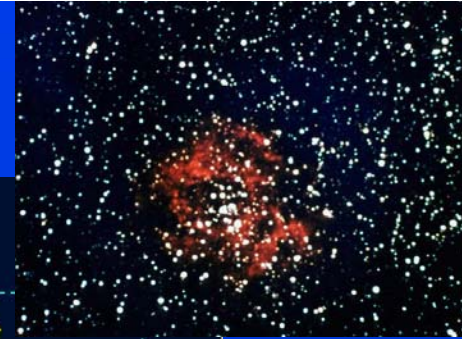
Design Variables:

Variable	Min	Max
W:EX1	108.000000	132.000000
H:EX1	216.000000	264.000000
tEX1	5.400000	6.600000

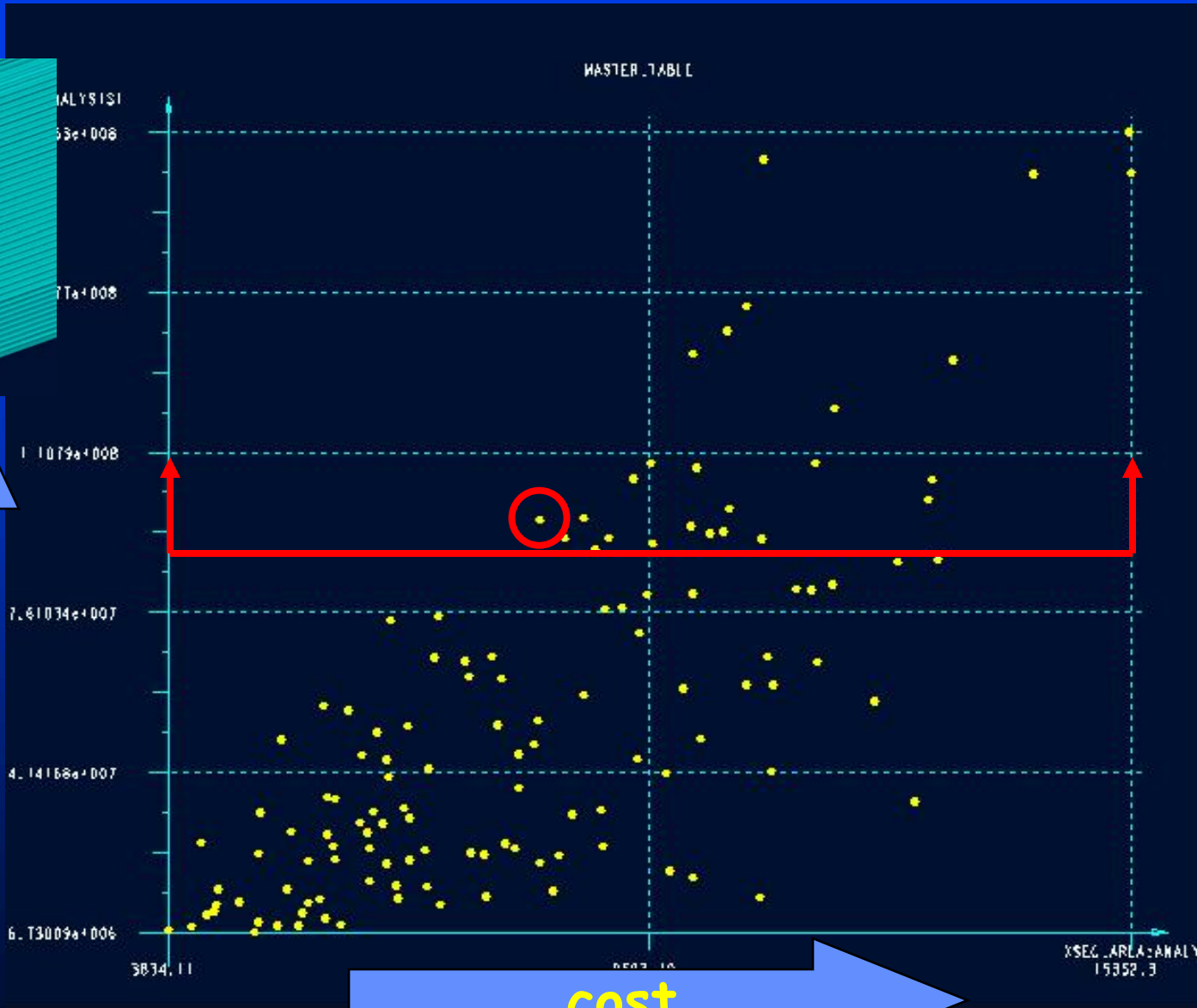
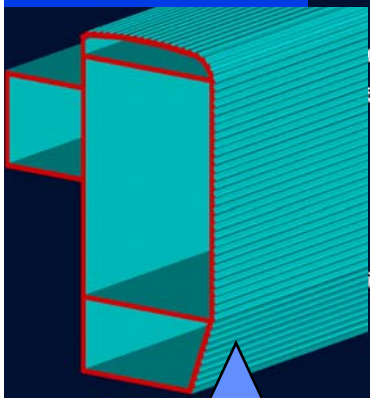
Design Goals

XSEC\_AREA:ANALYSIS1  
XSEC\_IXX:ANALYSIS1

# Scatter Plot for two of Design Variables



# Scatter Plot of Ixx versus Area



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Application activity # 2

Minimum Cost Container

# Application activity # 6

## Minimum Cost Container

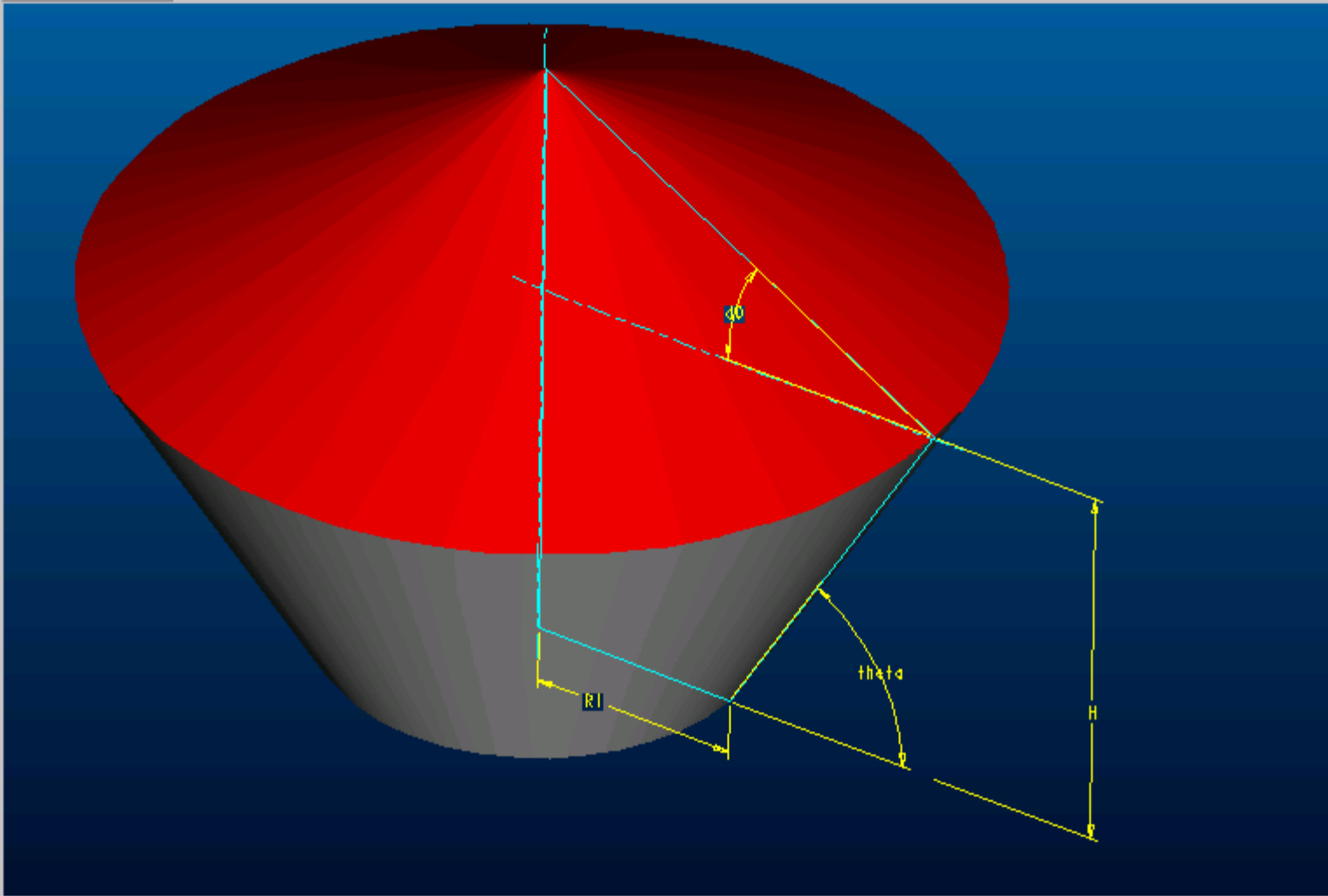
---

### Problem Statement:

Consider the open top circular storage bin container shown. Choose the height  $h$ , the width  $d$ , and the slope  $\theta$  such that the bin holds a prescribed volume  $V = 10 \text{ m}^3$  and it is of a minimum cost. The cost of the base per unit area is  $C_1 = 1.00 \text{ \$/m}^2$  and the cost of the side per unit area is  $C_2 = 1.50 \text{ \$/m}^2$

### BMX Learning Goals:

- Create an optimization study that holds a prescribed value constant and minimizes a cost function.



➤ Select FEATURE or DIMENSION.  
➤ Enter symbol text: H



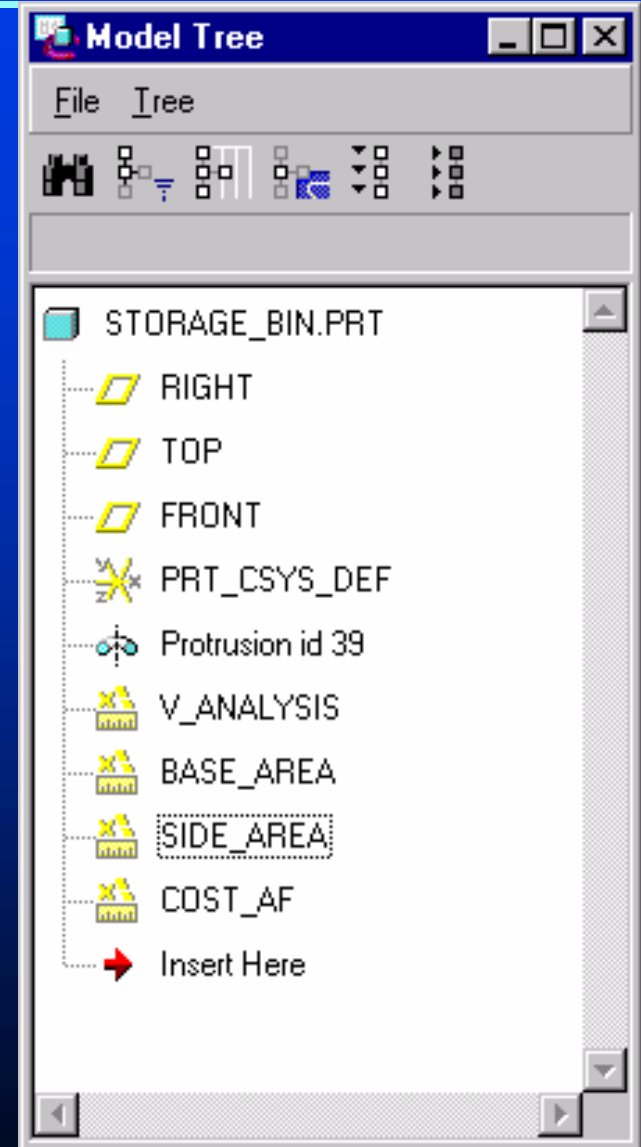
# Volume, Area and Cost Analyses Features

- Insert a model analysis feature to compute the volume
- Insert a measure analysis feature to compute the base area
- Insert a measure analysis feature to compute the side area
- Insert a Relation Analysis Feature to compute the cost:

cost=

$1.00 * \text{AREA:FID\_BASE\_AREA} +$

$1.5 * \text{AREA:FID\_SIDE\_AREA}$





# Optimization of storage container

- Goal:
  - Minimize cost
- Constraints:
  - Volume = 10
- Design Variables:
  - $0.5 < \text{RADIUS} < 3$
  - $0.5, \text{HEIGHT} < 3$
  - $10 < \text{ANGLE} < 90$
- Optimum Solution:
  - $\text{RADIUS} = 1.63$
  - $\text{HEIGHT} = 0.50$
  - $\text{ANGLE} = 53.35$

Optimization/Feasibility

File Run Options

Study Type/Name

Optimization  Feasibility

Name OPTIM2

Goal

Minimize COST:COST\_AF

Design Constraints

Parameter	Op	Value
VOLUME:V_ANALYSIS	=	10.000000

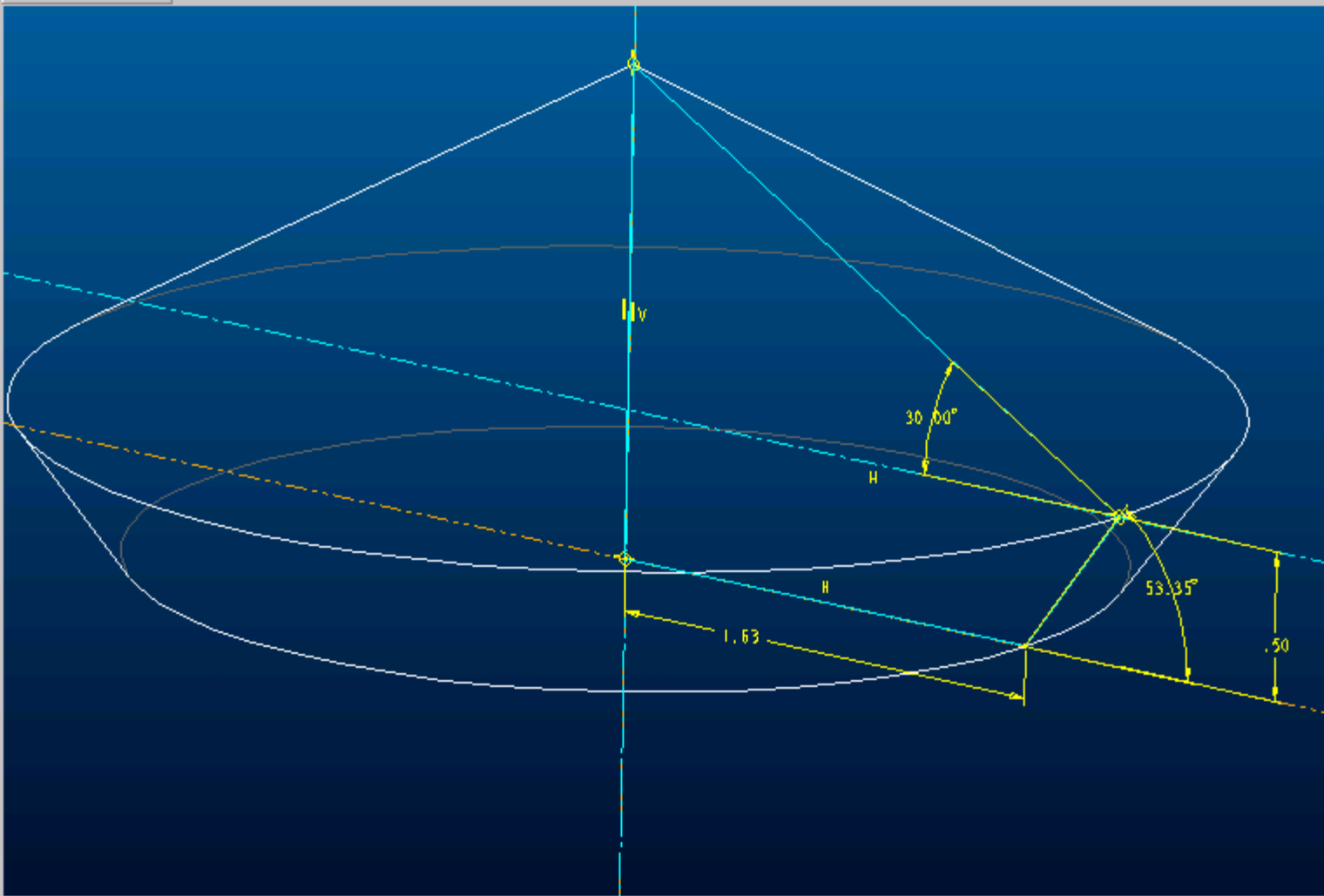
Add... Delete

Design Variables

Variable	Min	Max
R1:STORAGE_BIN	0.500000	3.000000
H:STORAGE_BIN	0.500000	3.000000
theta:STORAGE_BIN	10.000000	90.000000

Add Dimension... Add Parameter... Delete

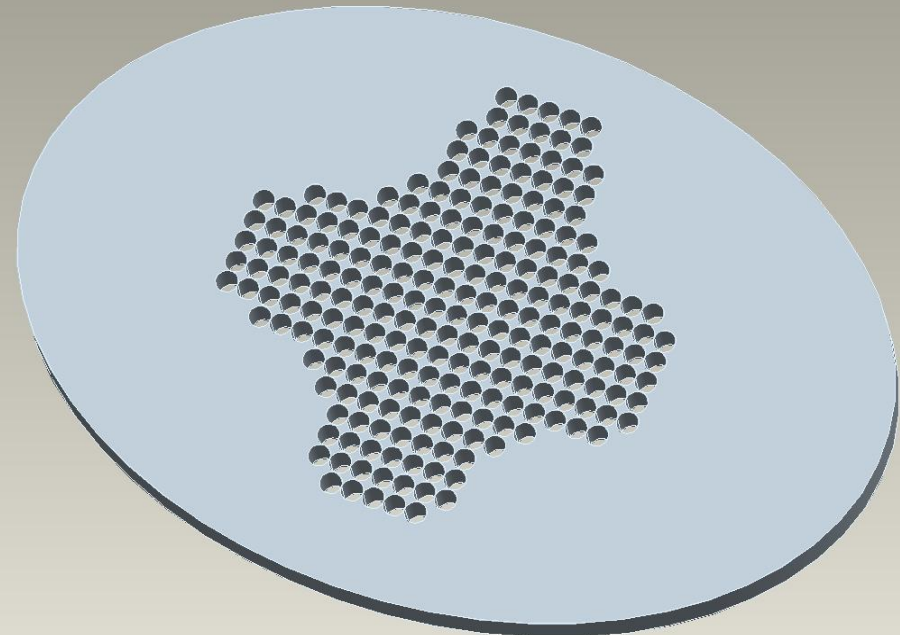
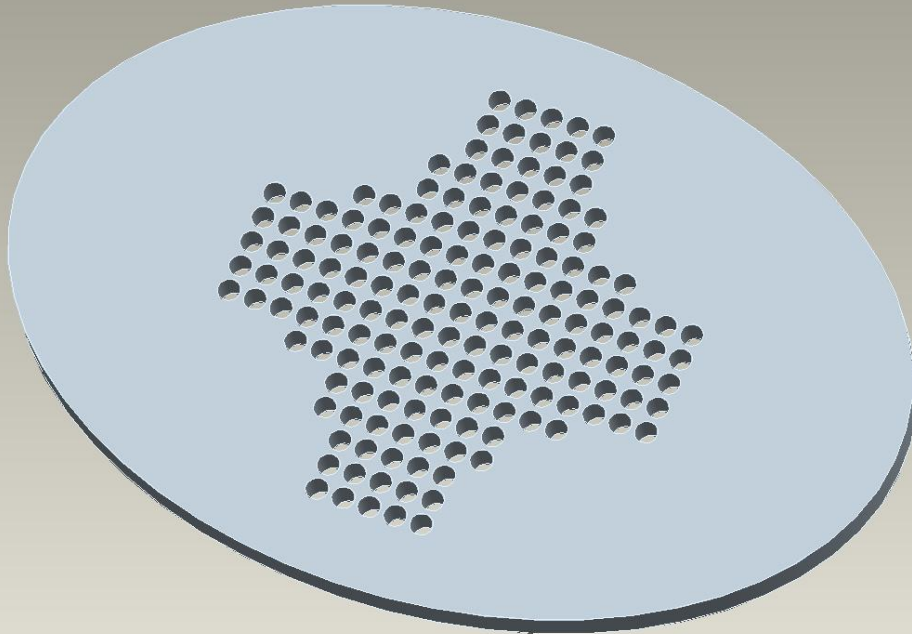
Compute Undo Close



- Doing preliminary Mass Props calculation.
- Mass properties calculation of part 'STORAGE\_BIN' is 100% complete.
- Mass Properties calculation completed.

# Application activity # 3

## Cell Phone speaker - Spacing Sensitivity



# Spacing Sensitivity on Area Ratio



# Robust Design Using Multi Objective Design Study

The screenshot shows the ANSYS Pro/ENGINEER software interface. The main window displays a 3D model of a part with a dense grid of sampling points. Two dialog boxes are open:

- Multi-Objective Design Study**: Shows the study name 'DS2' and a table tree with 'MASTER\_TABLE' and 'Records'.
- Master Table**: Shows the sampling method 'Manual' and the design variables table.

Design Variables	
d9:PHONE	
1	0.151365
2	0.148613
3	0.151090
4	0.152856
5	0.149139

Run Experiments on:  All Combinations  One Per Row

Design Goals

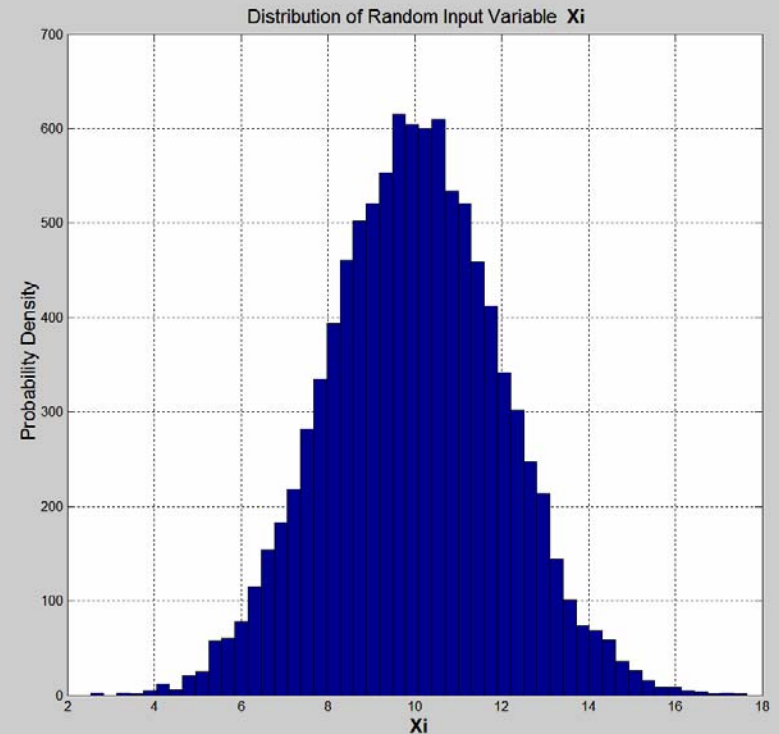
TARGET:ANALYSIS4

Select Goals

OK Cancel

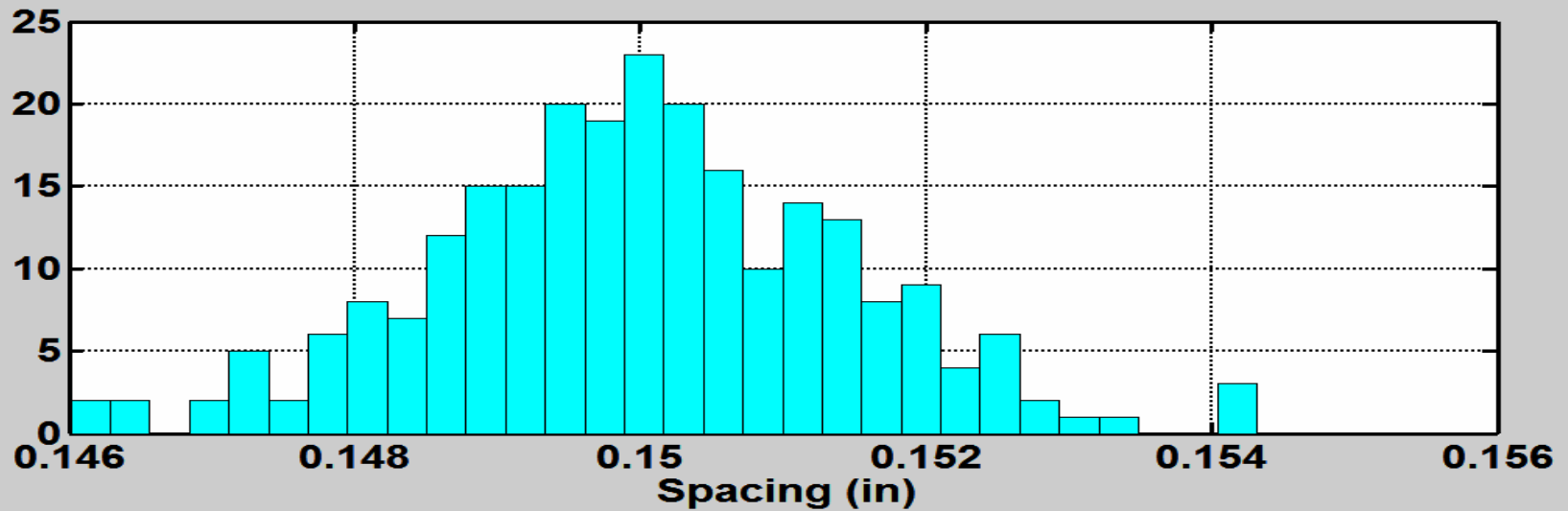
# Random Number Generation

- Random numbers for common distributions can be obtained using Box-Muller method in Excel and the equations:
  - Standard Normal Distribution
  - $X_i = \mu + \sigma * R_n$
  - Where:
    - $R_n = \sqrt{-2 * \ln(R_u)} * \cos(2\pi R_u)$
    - $R_u$  a uniform random number generator
    - In Excel =SQRT(-2\*LN(RAND()))\*COS(2\*PI()\*RAND())
  - Distribution of 10,000 random input variables generated in Excel with a mean of 10 and standard deviation of 2

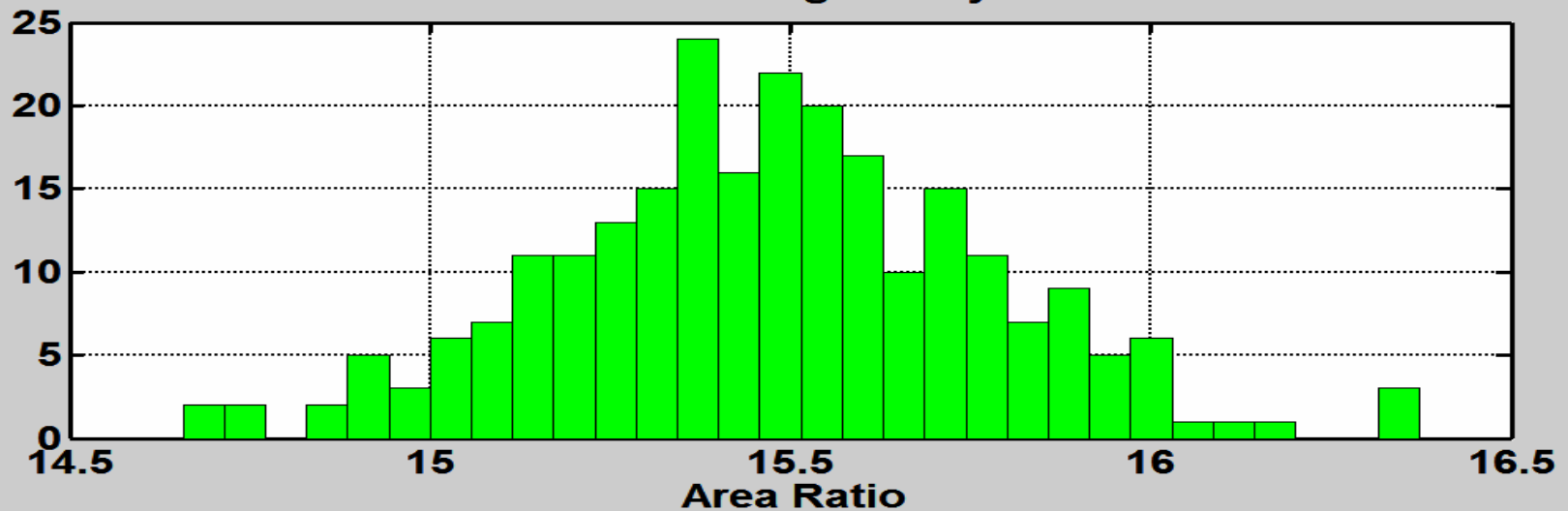




# Random spacing Input and Area Ratio Output



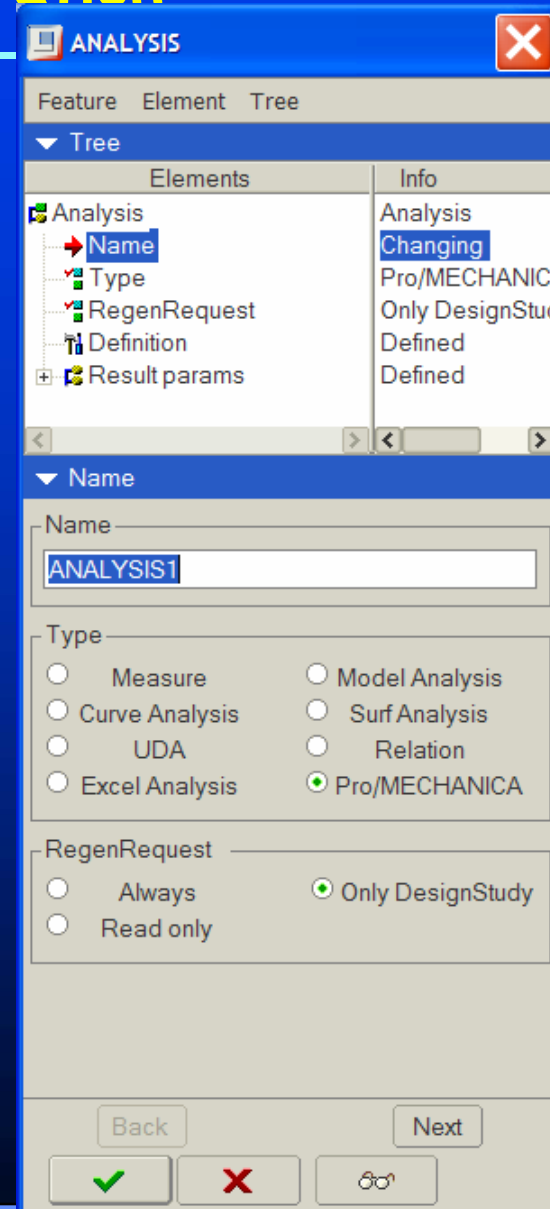
## Robust Design Analysis



# Application activity # 4

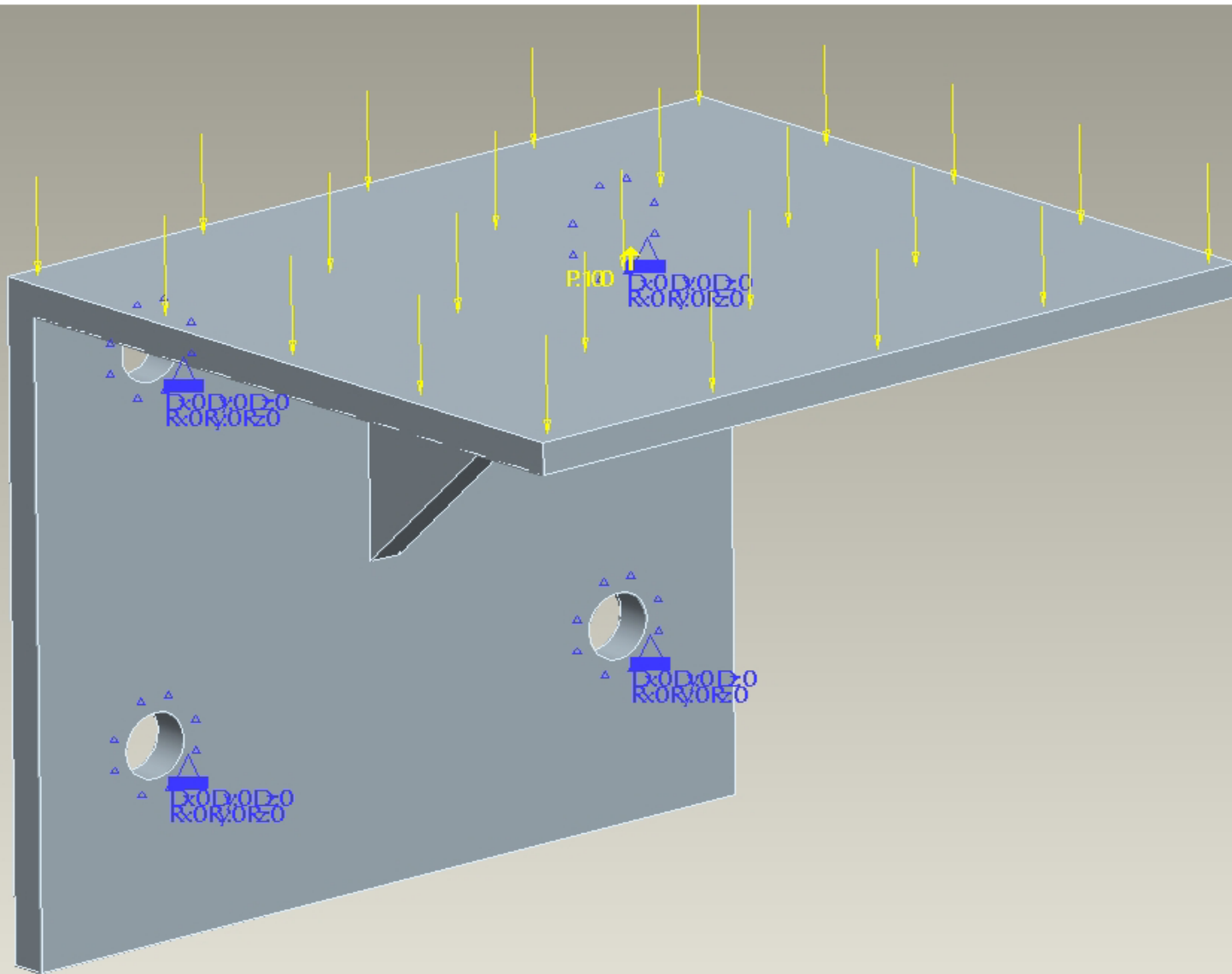
## BMX - Pro/MECHANICA Integration

- Set up an analysis in Pro/MECHANICA,
- Set up a BMX Analysis feature.
  - tag the list of quantified results from the Mechanics analysis as a computed parameter.
- Use these computed parameters for relations, Sensitivity, Global Optimization and Multi-Objective Design Studies.





# Set up an analysis in Pro/MECHANICA



# Tag the list of quantified results from the Mechanics analysis as a computed parameter

The image shows three sequential screenshots of the Pro/ENGINEER software interface, illustrating the process of tagging analysis results as a computed parameter.

**Left Screenshot:** The 'ANALYSIS' dialog box is open. The 'Name' field is set to 'ANALYSIS1'. The 'Type' is set to 'Pro/MECHANICA'. The 'RegenRequest' is set to 'Only DesignStudy'.

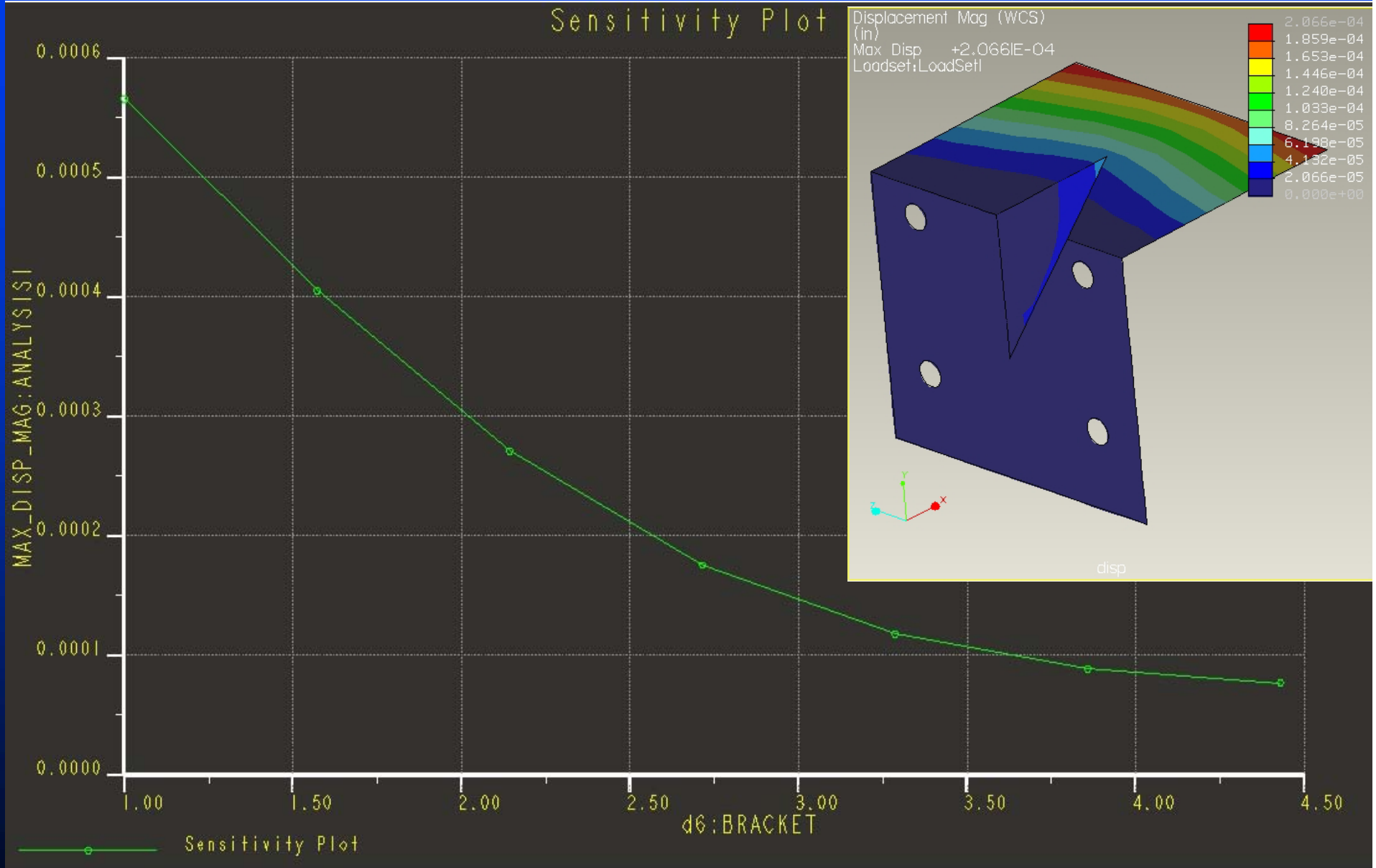
**Middle Screenshot:** The 'Pro/MECHANICA' dialog box is open. The 'Type' is set to 'Structure'. The 'Definition' is set to 'Analysis1'. The 'Results' list is displayed, with 'max\_stress\_vm: 90468.8' highlighted.

**Right Screenshot:** The 'ANALYSIS' dialog box is open. The 'Result params' section is expanded, showing a table of parameters:

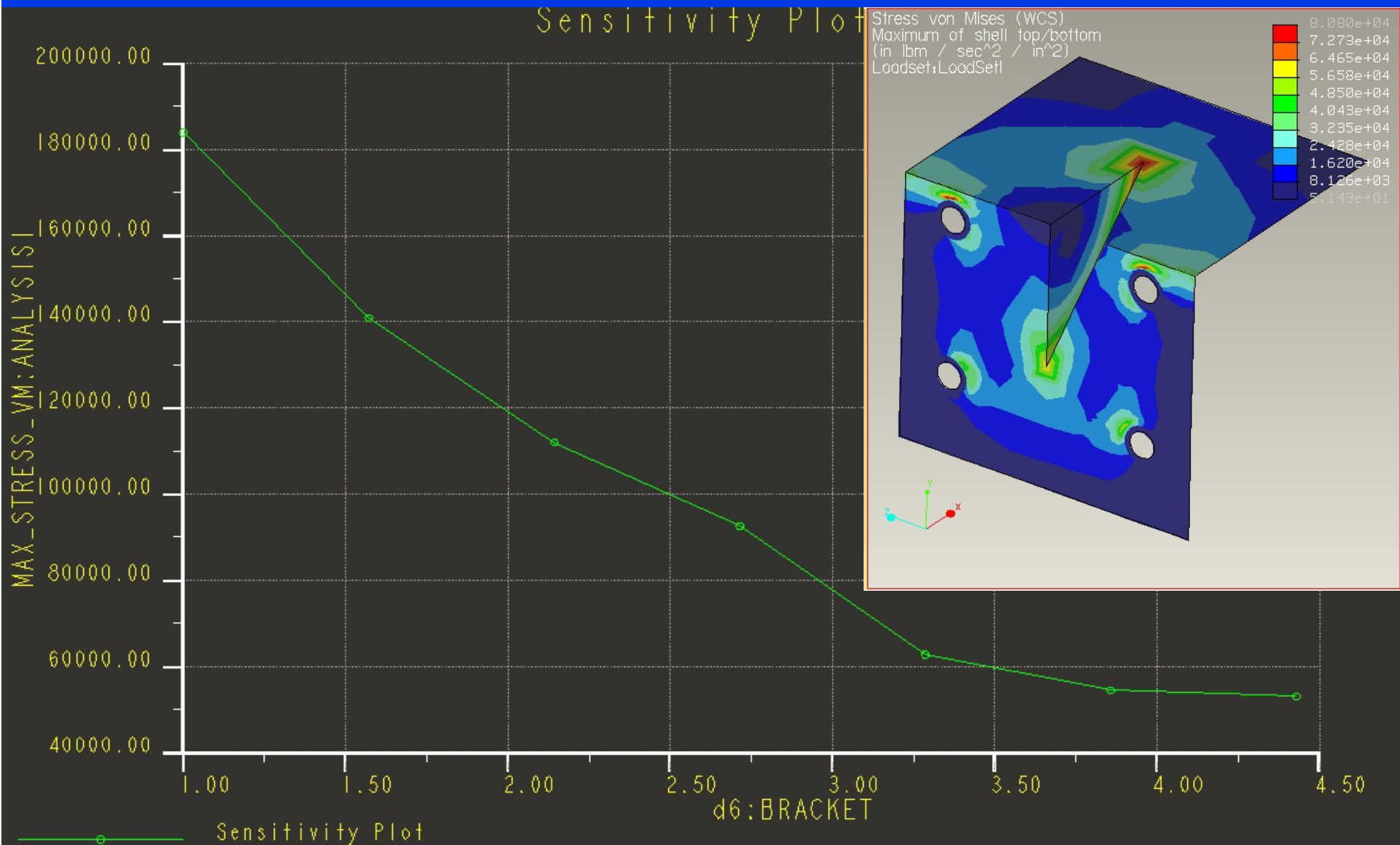
Create	Param name	Description
YES	total_cost	total mode
YES	max_beam_bending	max beam
YES	max_beam_tensile	max beam

The 'Param name' field is set to 'total\_cost'.

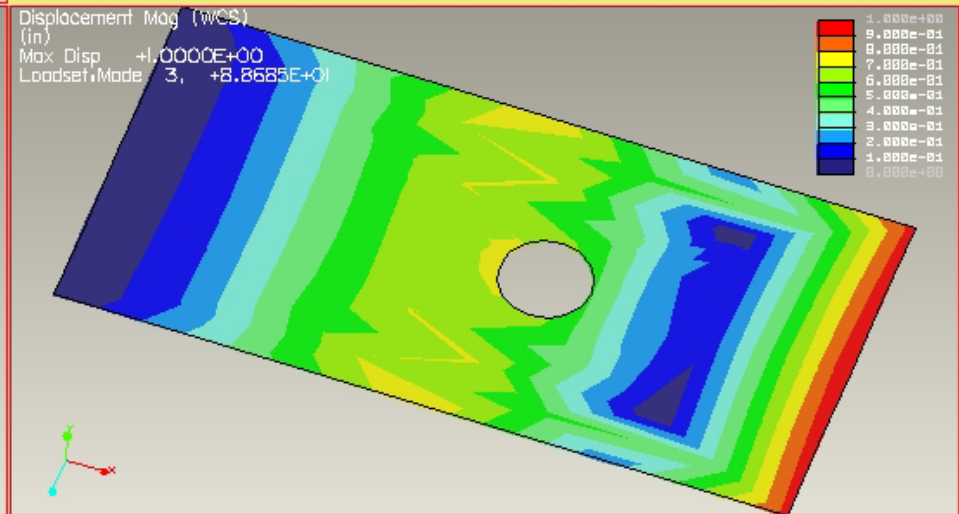
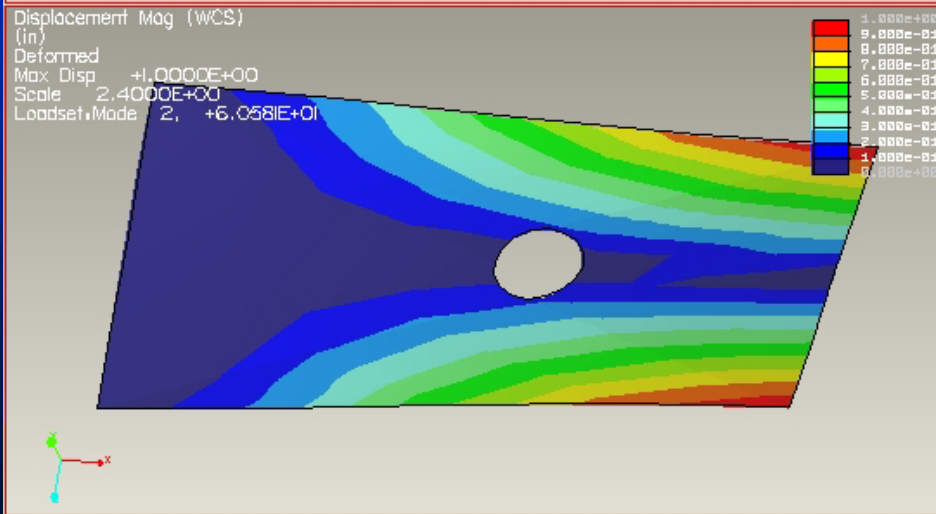
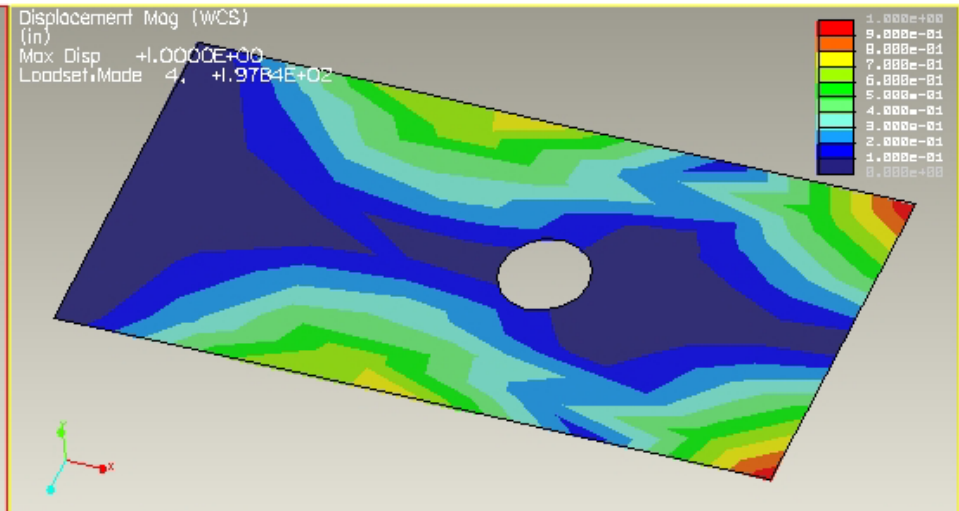
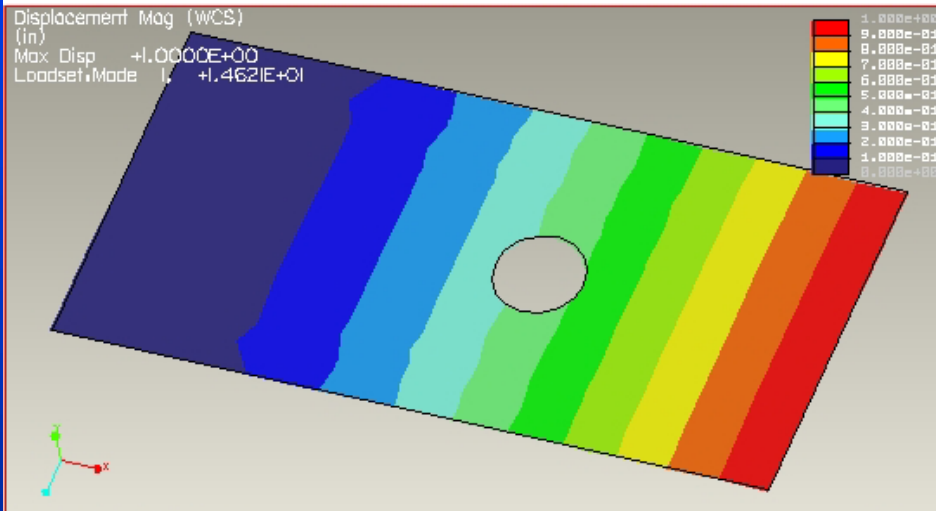
# Sensitivity of Rib's length on Max Displacement



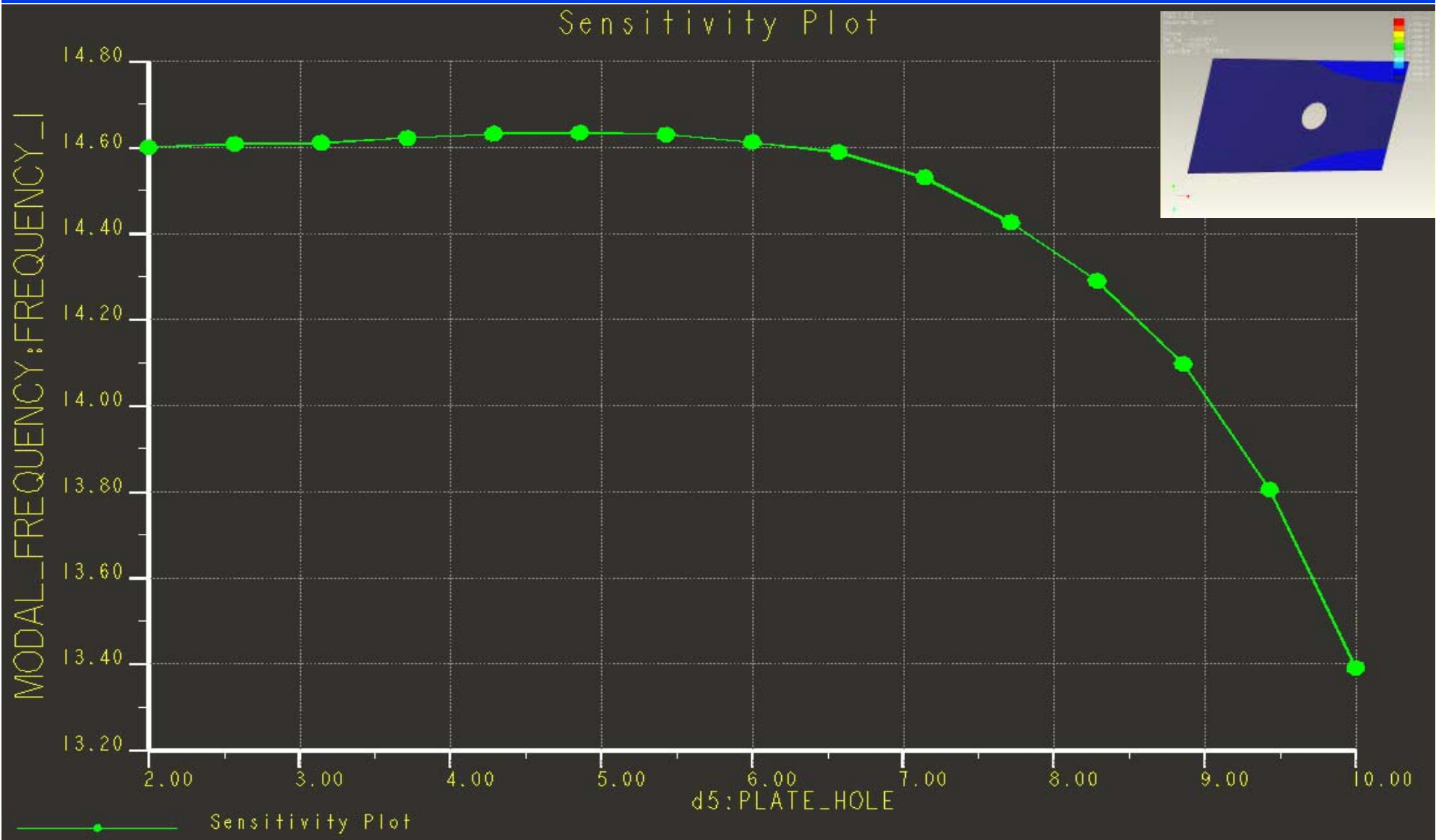
# Sensitivity of Rib's length on Max stress



# BMX-Modal analysis



# Sensitivity of Hole Diameter on Natural Frequency



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# Application activity # 5

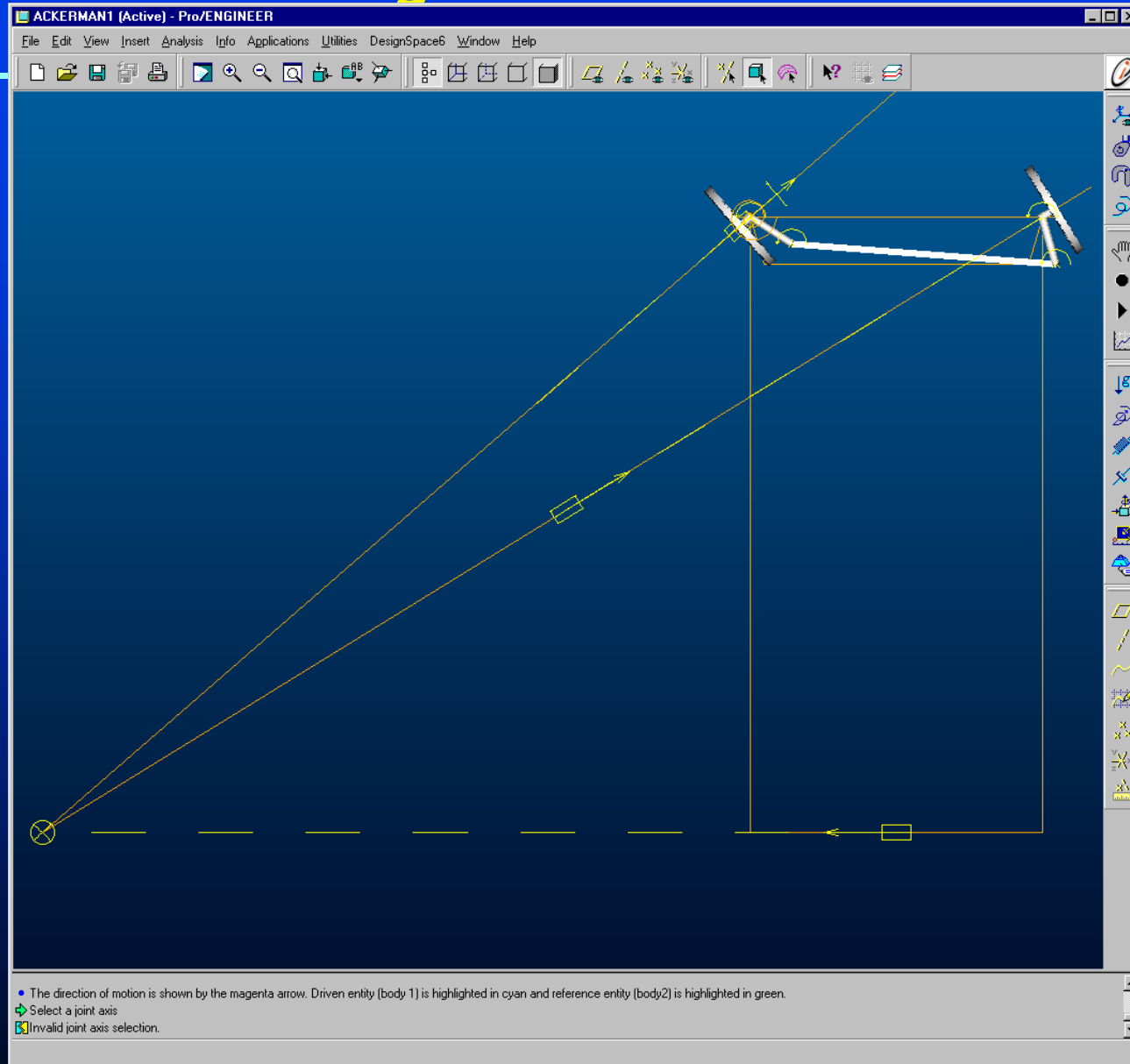
## Mechanism Optimization







# Ackerman Steering Mechanism

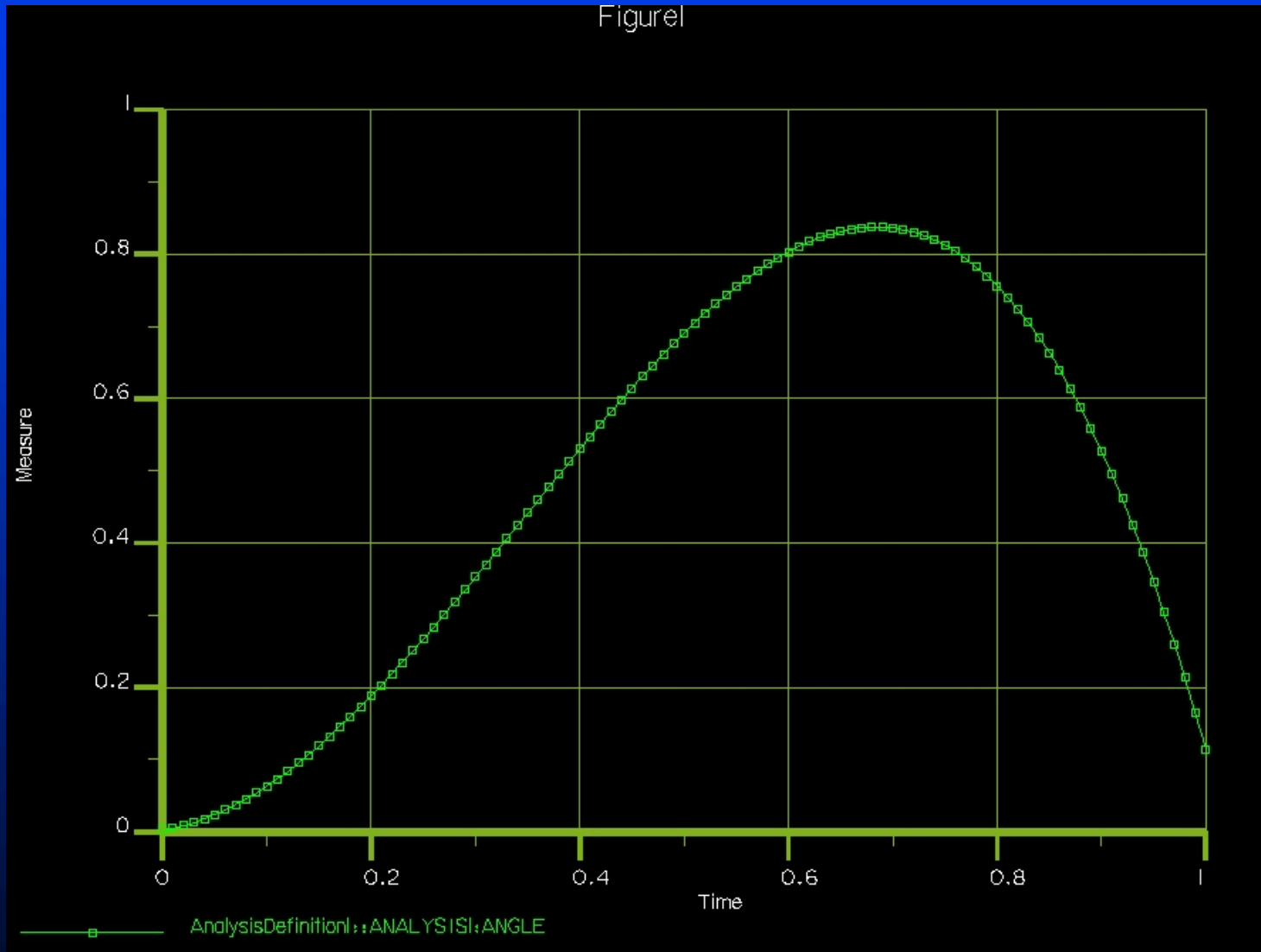


# Ackerman Steering Optimization

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- Assumptions:
  - Low speed steering is achieved by pure rolling of wheels
  - For low speed the slip angles are negligible small
- Goals:
  - Identify the instantaneous center of rotation
  - Establish measures for the steering error
  - Plot the steering error versus time for a given Ackerman angle
  - Using Behavioral Modeling plot the maximum steering error versus the Ackerman angle
  - Find the optimum Ackerman angle that minimizes the steering error

# Steering error versus time for Ackerman angle = 16 deg





**Create a Vision,  
Adopt it,  
Adapt to Achieve it**

