VisualDOC: A Practical Software Integration and General Purpose Design Optimization Solution Suite

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Outline of Presentation

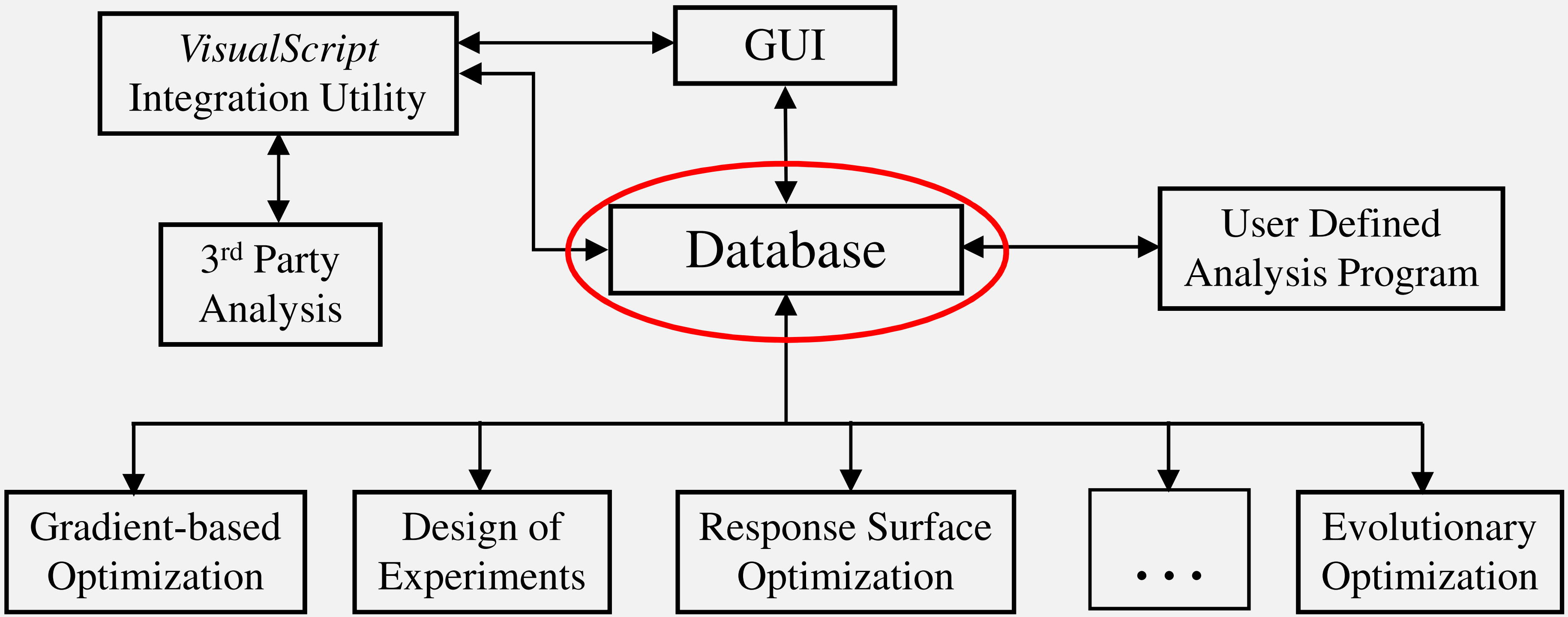
- *Introduction*
- *VisualDoc Framework*
- *VisualDoc Grapical Interfaces and Key Windows*
- *Examples*
- *Summary*
- *Conclusions*

Introduction

- ***Design of large scale products and processes require interaction from several different disciplines.***
- ***These disciplines utilize computationally expensive analyses codes, for example, FEA, CFD etc.***
- ***With rapidly increasing costs, never before has there been a need for producing optimally designed products.***
- ***This paper presents a product design solution suite that provides engineers the capability to integrate multiple analyses software AND optimize designs over these multiple analyses codes.***

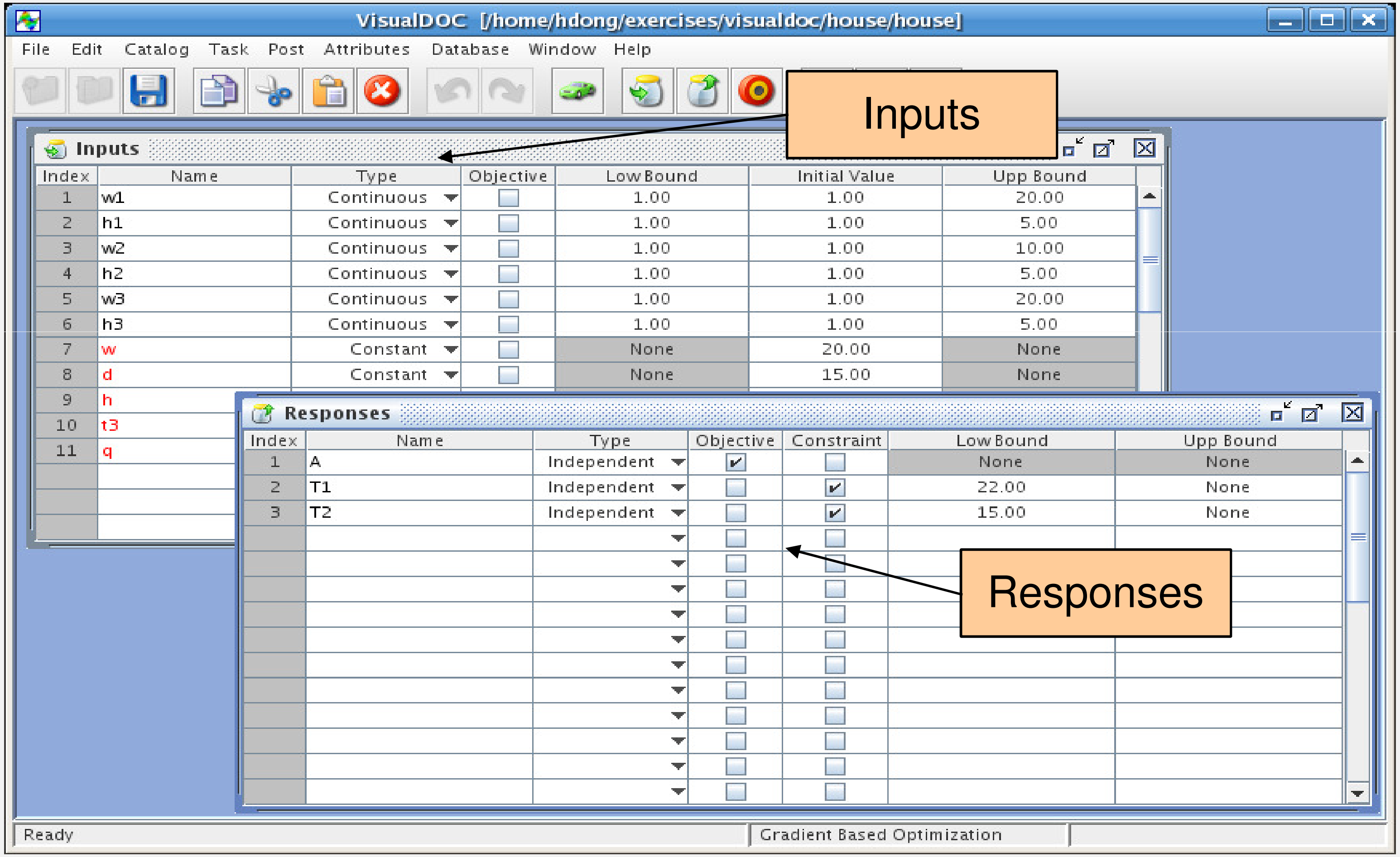
VisualDOC – Framework

- ***Database is the central component of the software.***
- ***Saved as platform independent .vdb file***

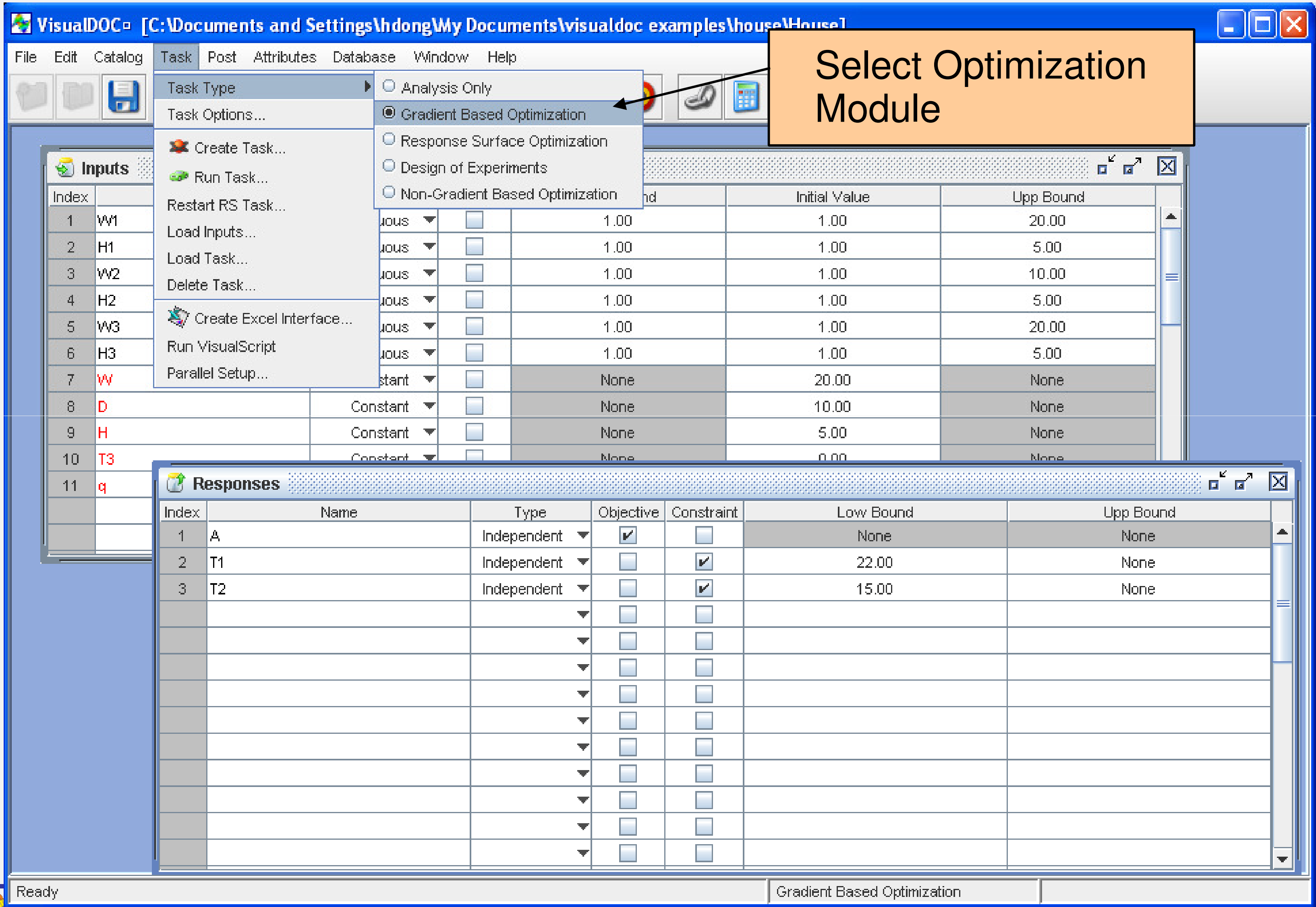


VisualDOC Introduction

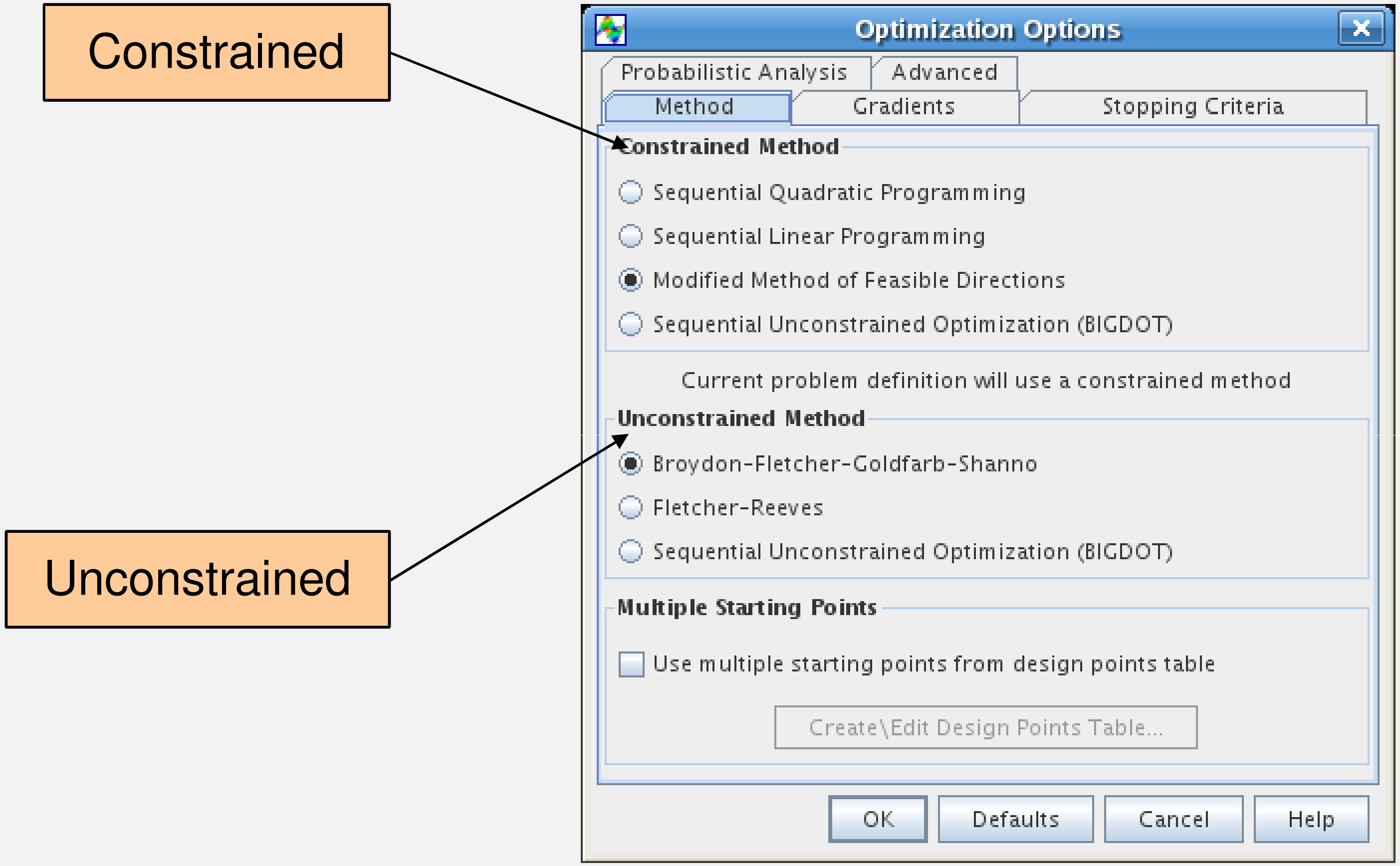
- VisualDOC GUI



Optimization Modules

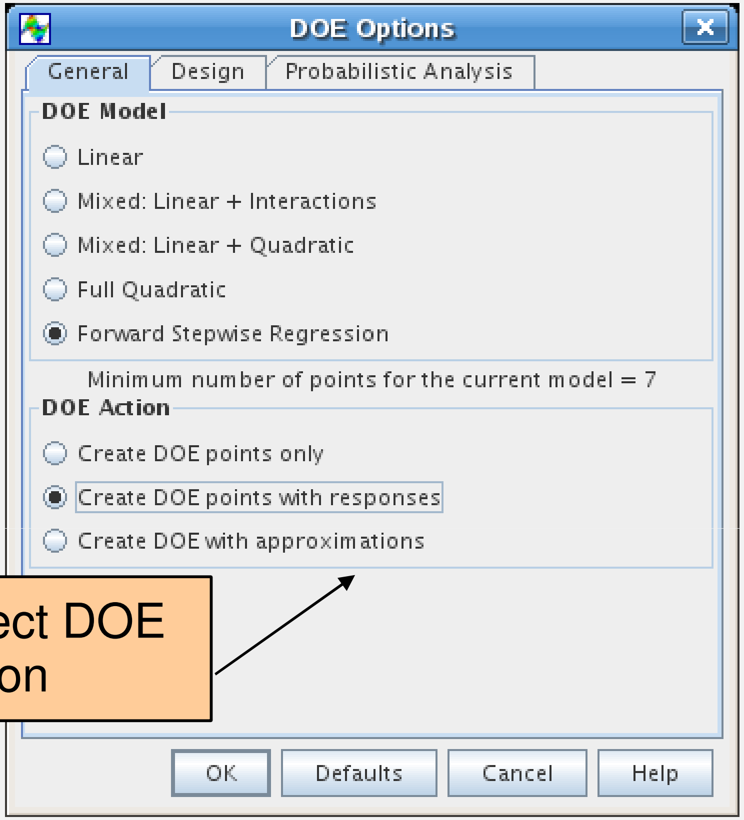


Gradient Based Optimization



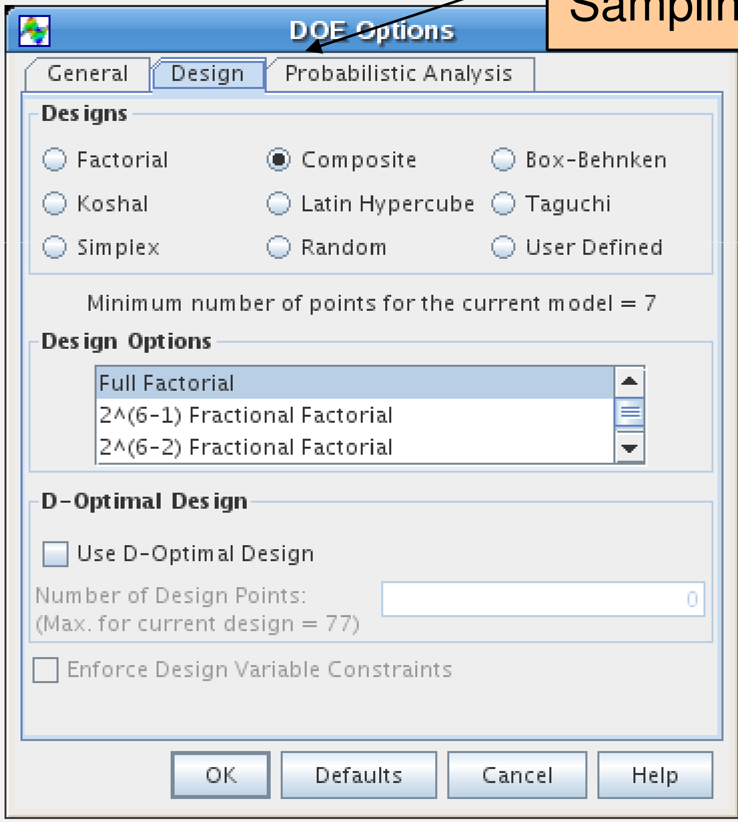
Design of Experiments

- Create an experimental design



Select DOE Action

Select Sampling Method

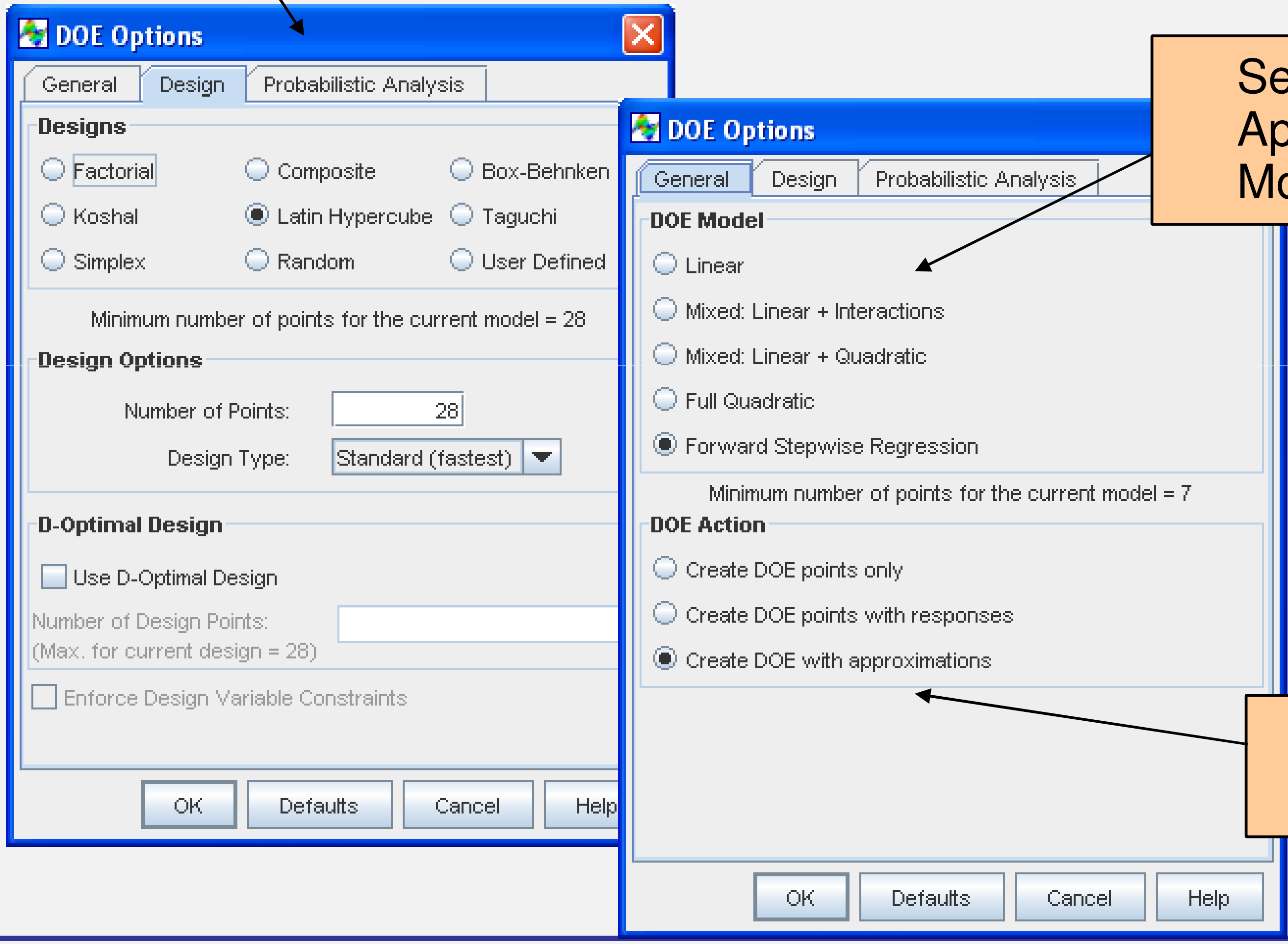


Design of Experiments

Select
Sampling Method

- Approximate responses

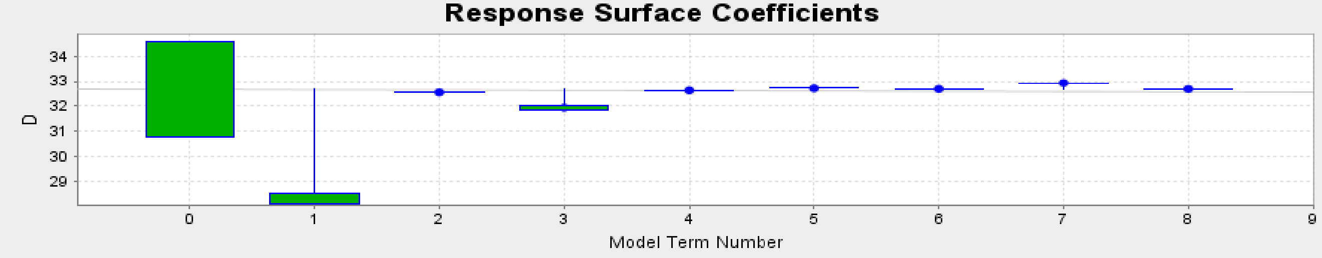
Select
Approximation
Model



Select
DOE Action

Design of Experiments

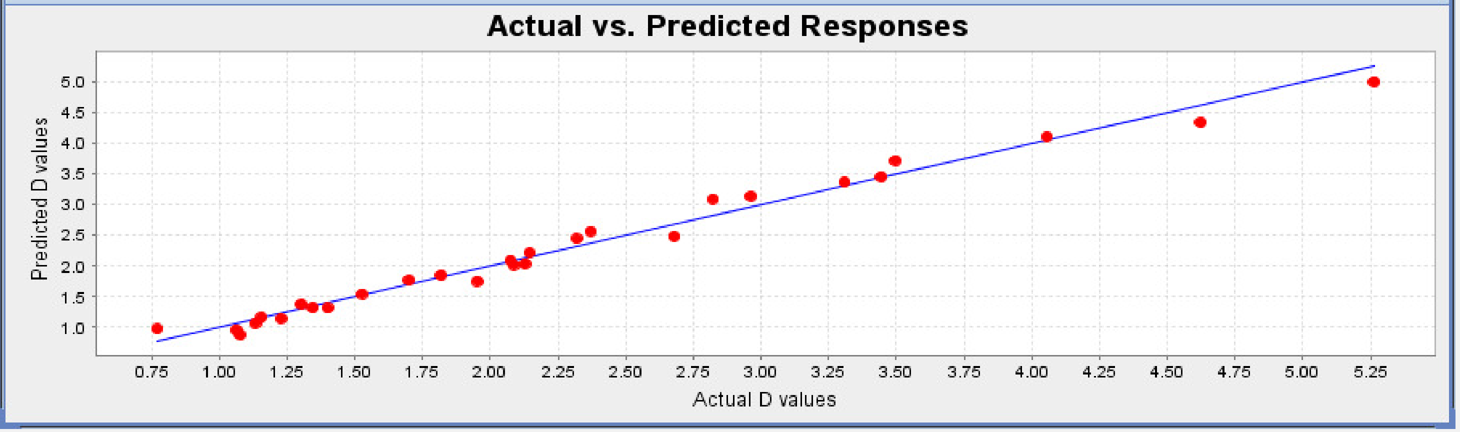
RS Coefficients Plot [*4: Beam DOE Approximation Latin Hypercube]



Term	Description	Coefficient	Standard Error
0	Constant	32.6762352	3.78210574
1	W2	-4.35970919	0.401522571
2	W3	-0.129074727	0.0298689802
3	H2	-0.739688984	0.134392536
4	H3	-0.0509707113	0.0181025545
5	W2 * H2	0.0332148906	0.00607361964
6	W2 * H3	0.00957408654	0.00505520429
7	W2**2	[illegible]	[illegible]
8	H2**2	[illegible]	[illegible]

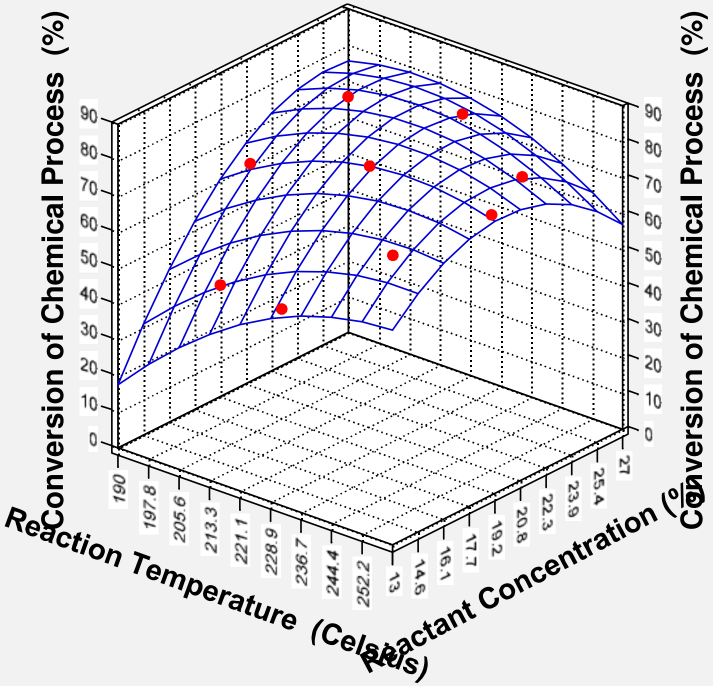
- RS coefficients

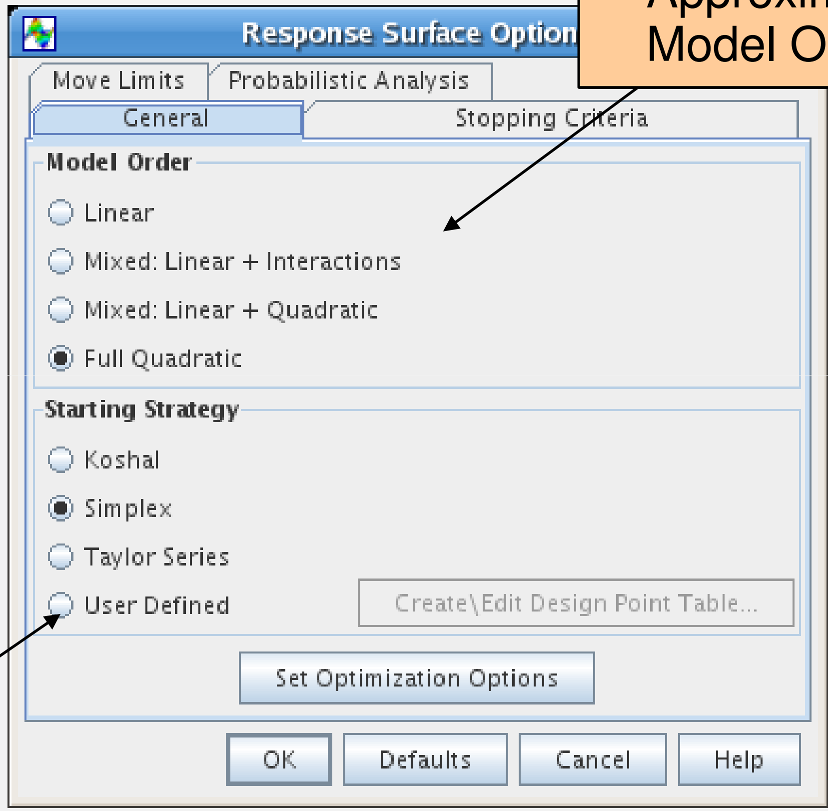
Actual vs. Predicted Response Value Plot [*4: Beam DOE Approximation Latin Hypercube]



- Actual vs. Predicted

Response Surface Optimization

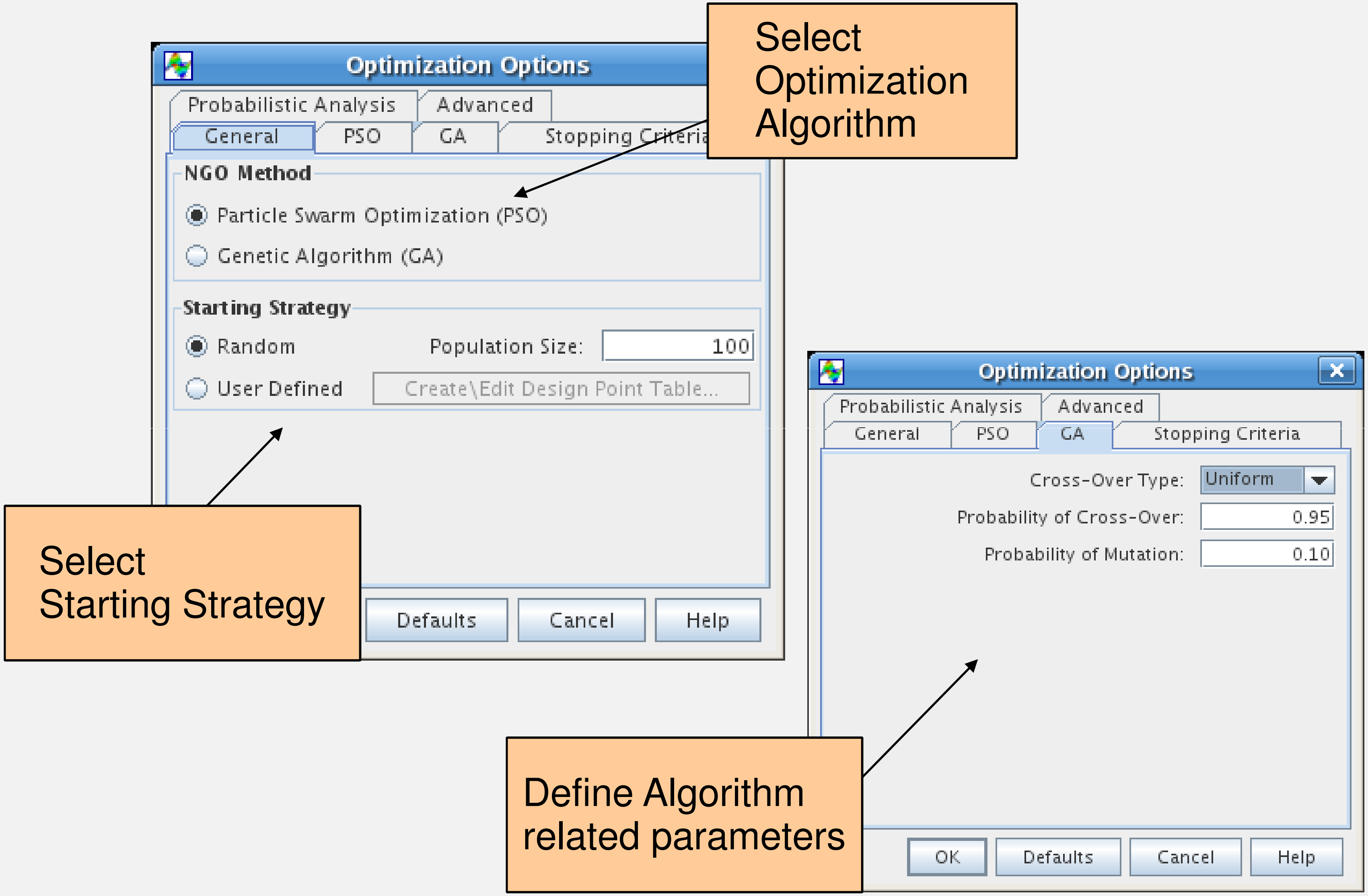




Select the Approximation Model Order

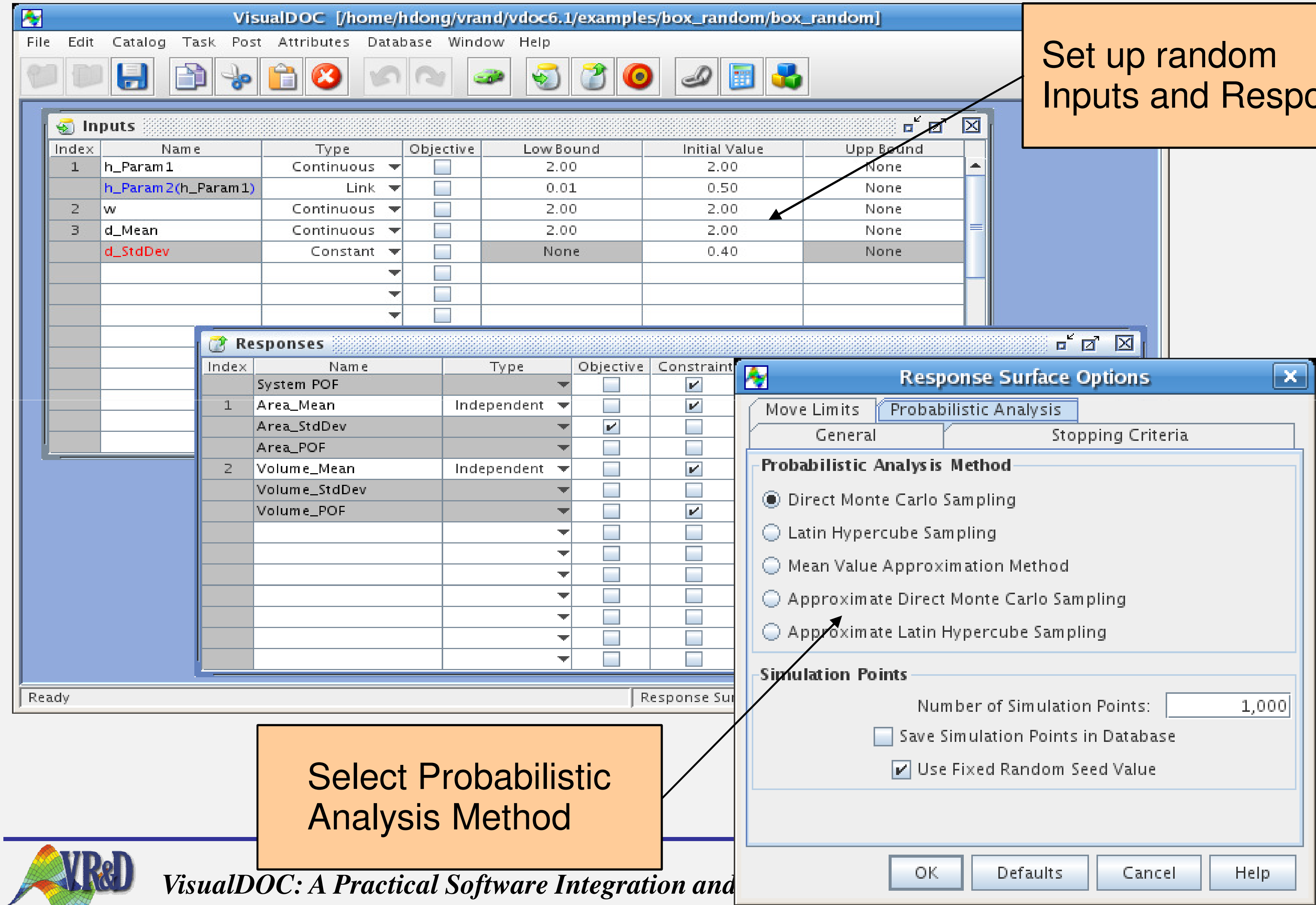
Select the Starting Strategy

Non-Gradient Based Optimization



Probabilistic Analysis and Optimization

Set up random Inputs and Responses

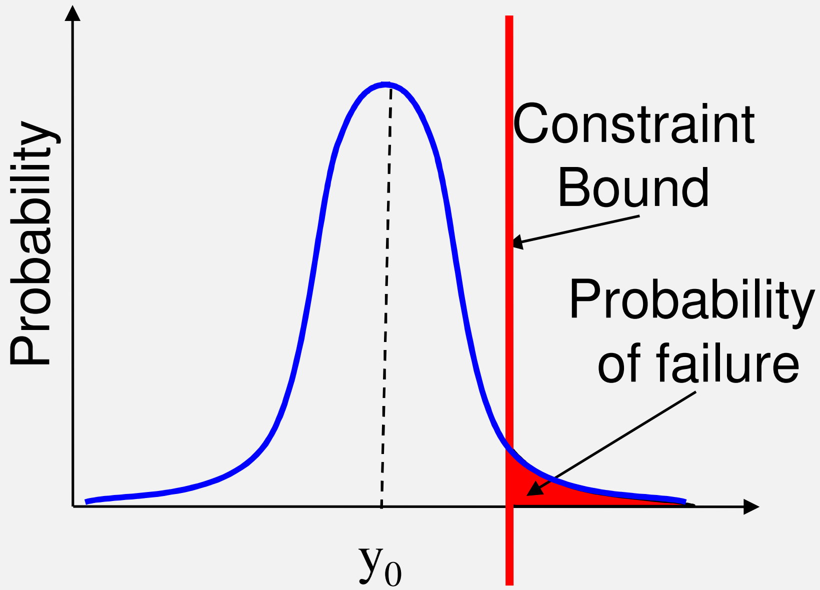


Select Probabilistic Analysis Method

Probabilistic Analysis and Optimization

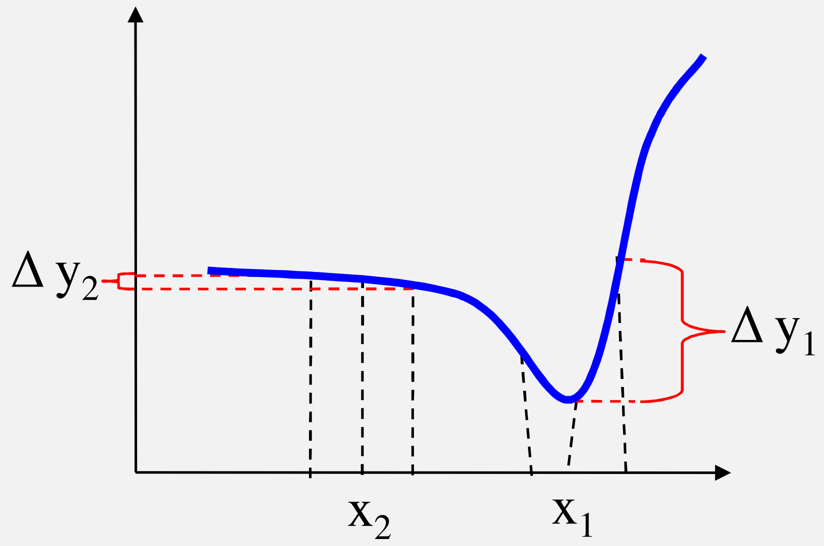
Reliability Optimization

Control the probability of failure

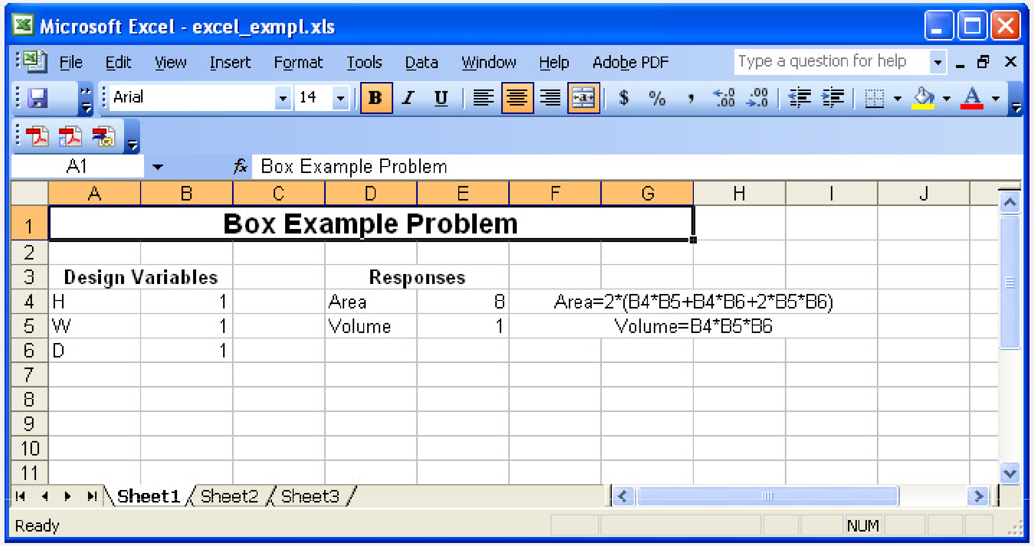


Robust Optimization

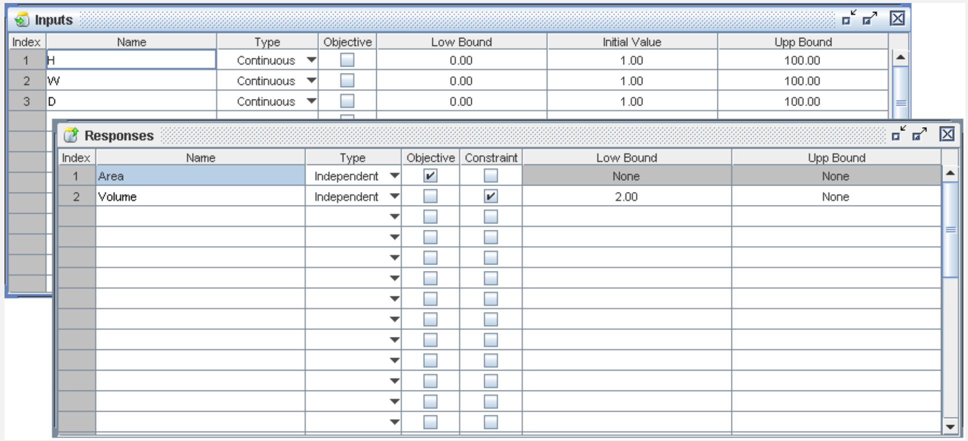
Control the variability of a response



Direct Interface --Excel

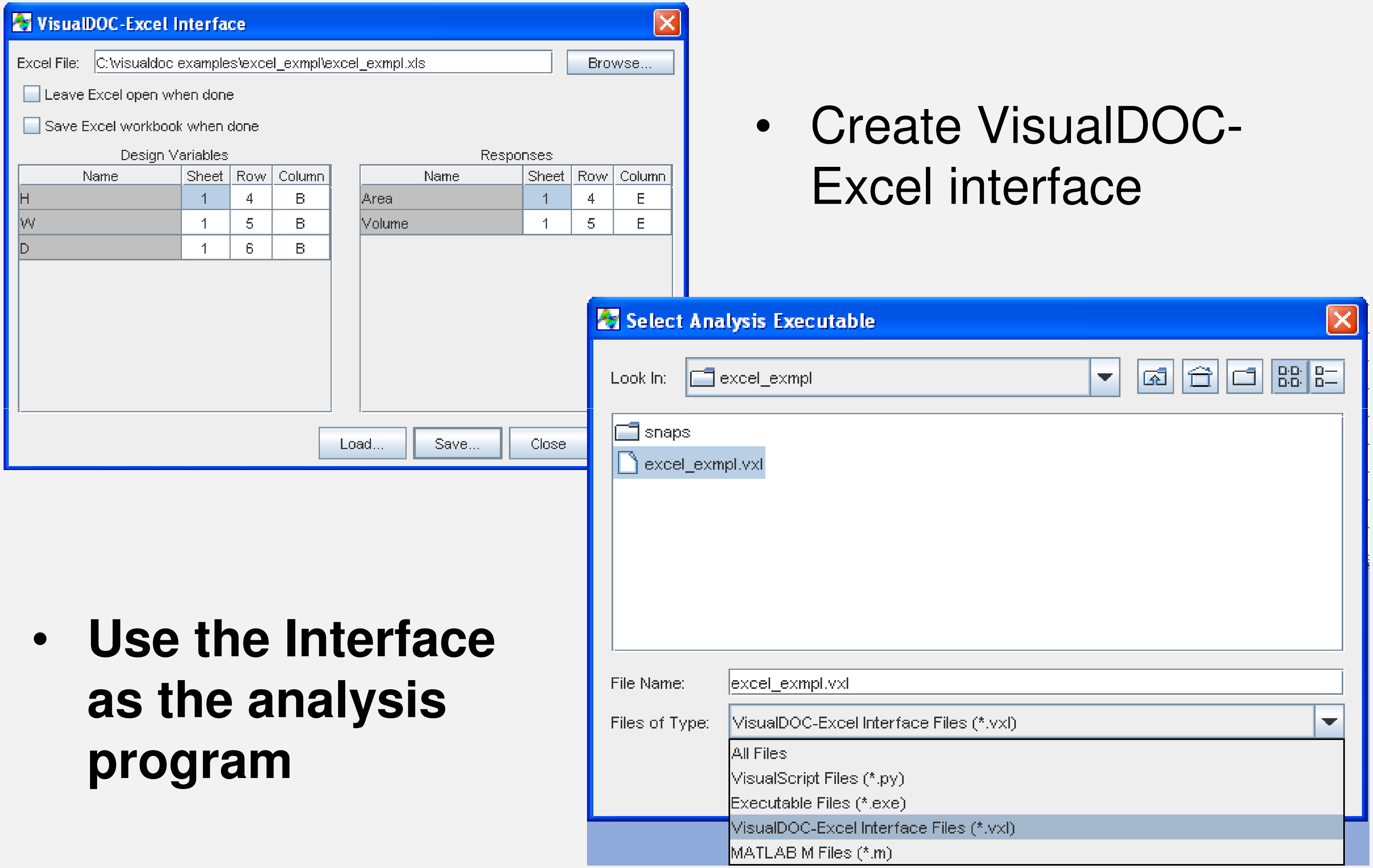


- Prepare Excel spreadsheet



- Define inputs and responses in VisualDOC

Direct Interface -- Excel



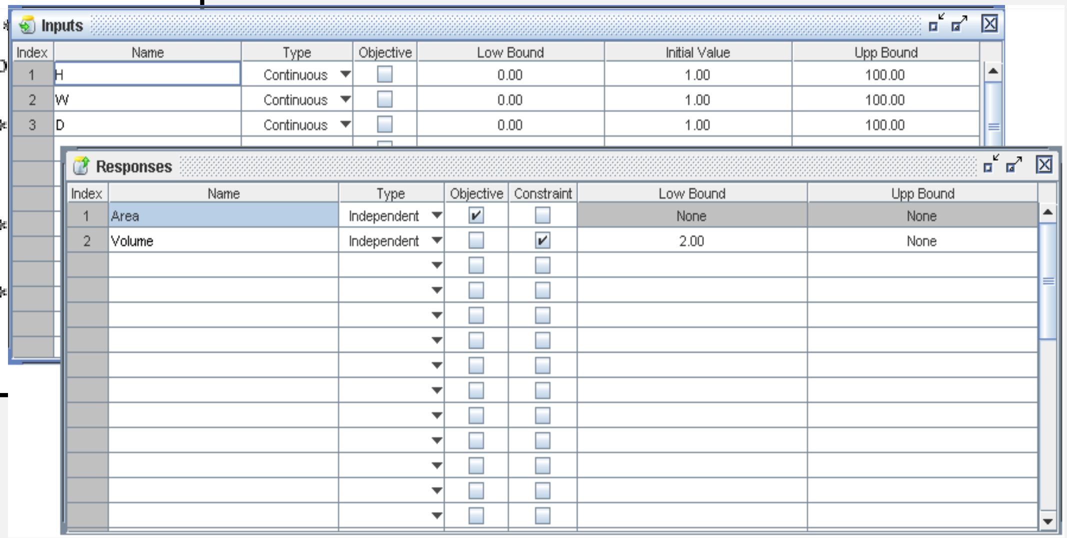
- Create VisualDOC-Excel interface

- **Use the Interface as the analysis program**

Direct Interface -- Matlab

```
% ****************************************************
% Example MATLAB function for calculating surface area (A)
% of a material to make a box, and a volume (V) of a box.
% The inputs should be height (H), width (W), and depth (D)
% of a box.
% ****************************************************
function [RESP] = box(DVAR)
% ****************************************************
% Copy design vector to local design variables
% (DVAR-vector to H, W and D)
% NOTE: The DVAR vector indices correspond to the location
% of the design variables in VisualDOC Inputs window
% ****************************************************
H = DVAR(1);
W = DVAR(2);
D = DVAR(3);
% ****************************************
% Calculate the surface area of a material to make a bo
% and the volume of a box (V)
% ****************************************
A = 2.0*( H*W + H*D + 2*W*D );
V = H*W*D;
% ****************************************
% Map the responses back to the RESP vector
% ****************************************
RESP(1) = A;
RESP(2) = V;
```

- **Prepare Matlab M-file**



Inputs

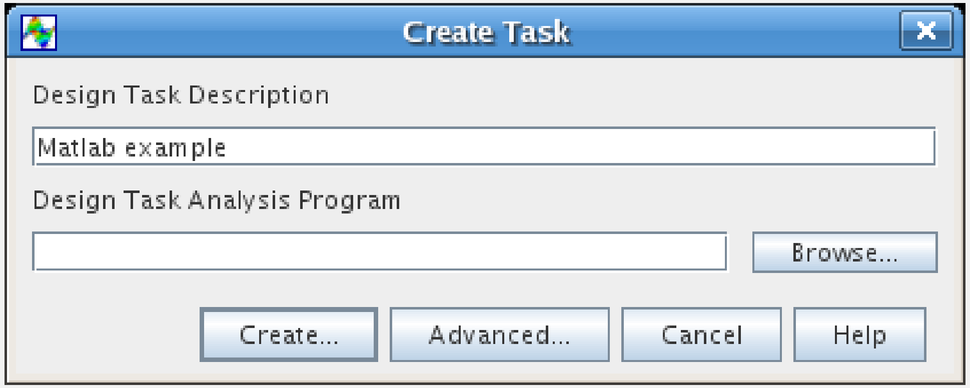
Index	Name	Type	Objective	Low Bound	Initial Value	Upp Bound
1	H	Continuous	☐	0.00	1.00	100.00
2	W	Continuous	☐	0.00	1.00	100.00
3	D	Continuous	☐	0.00	1.00	100.00

Responses

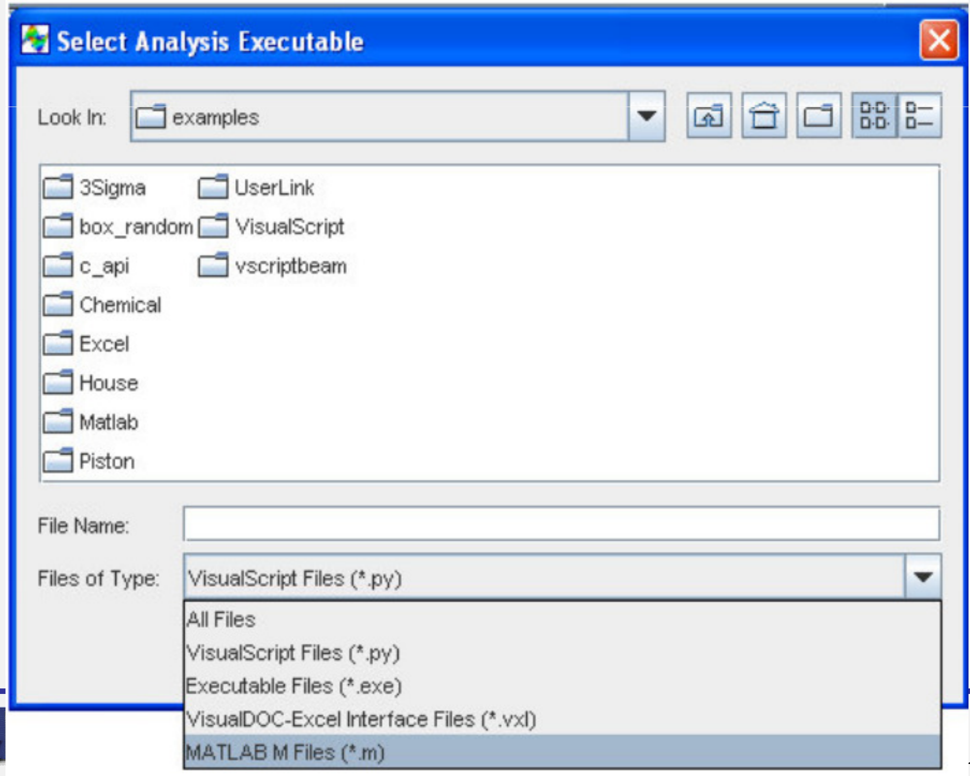
Index	Name	Type	Objective	Constraint	Low Bound	Upp Bound
1	Area	Independent	☑	☐	None	None
2	Volume	Independent	☐	☑	2.00	None

- **Define the Inputs and Responses in VisualDOC**

Direct Interface -- Matlab



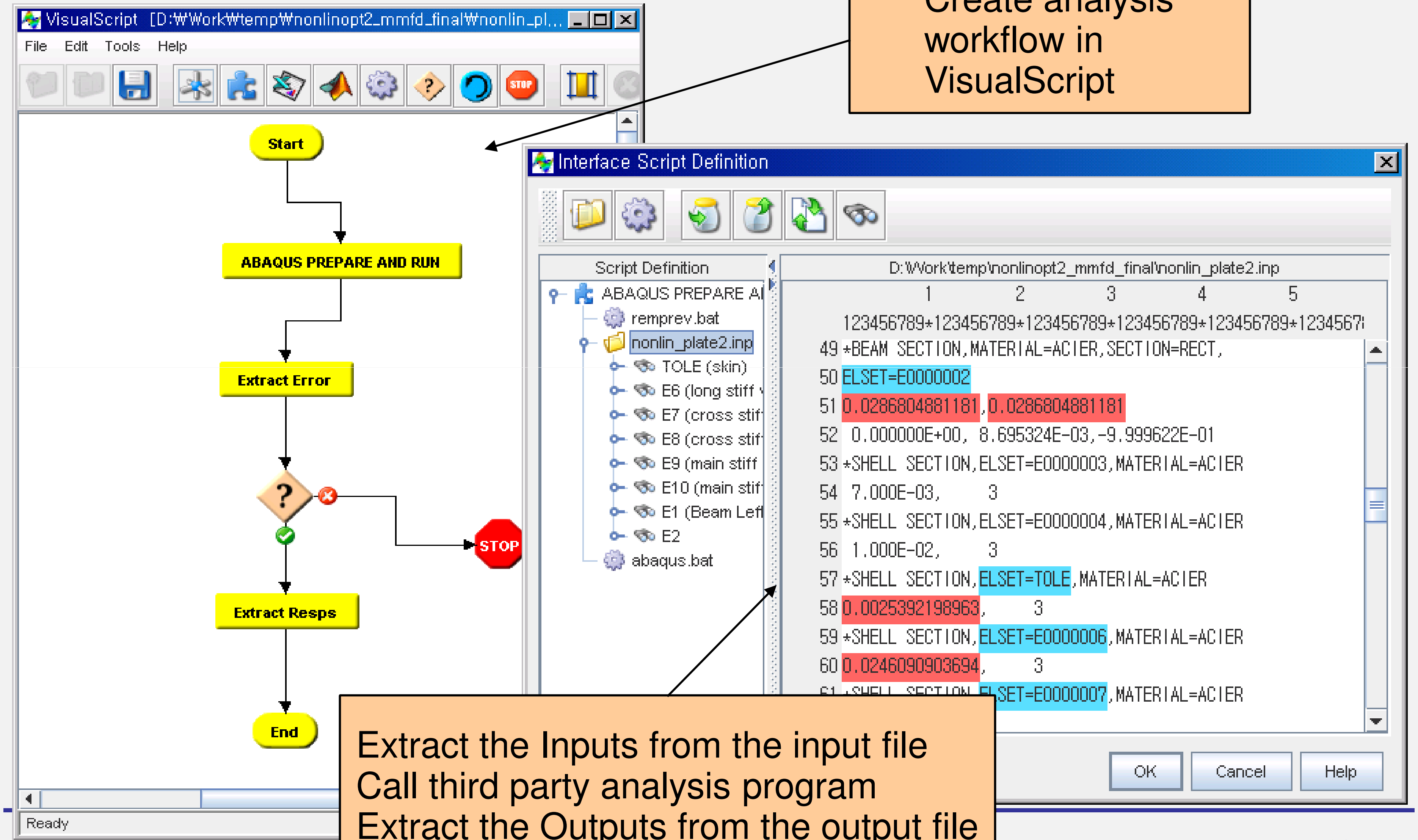
- **Create a task**



- **Specify the Matlab M-file as the analysis program**

Coupling Third Party Software Through VisualScript

Create analysis workflow in VisualScript

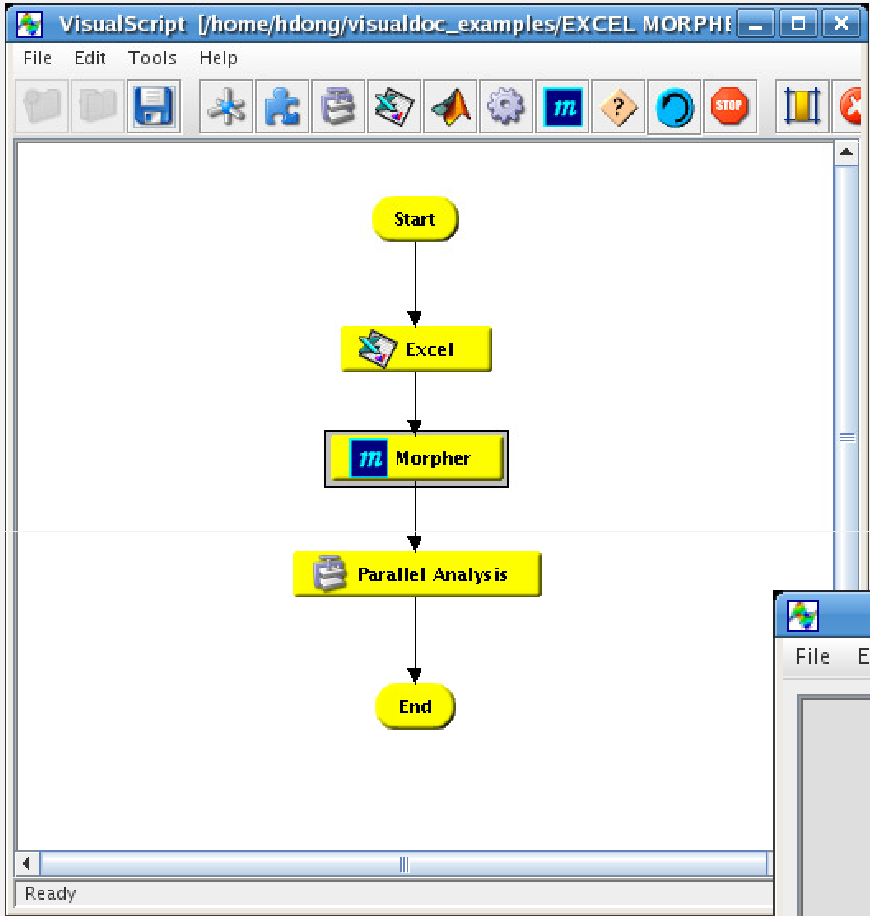


Extract the Inputs from the input file
Call third party analysis program
Extract the Outputs from the output file

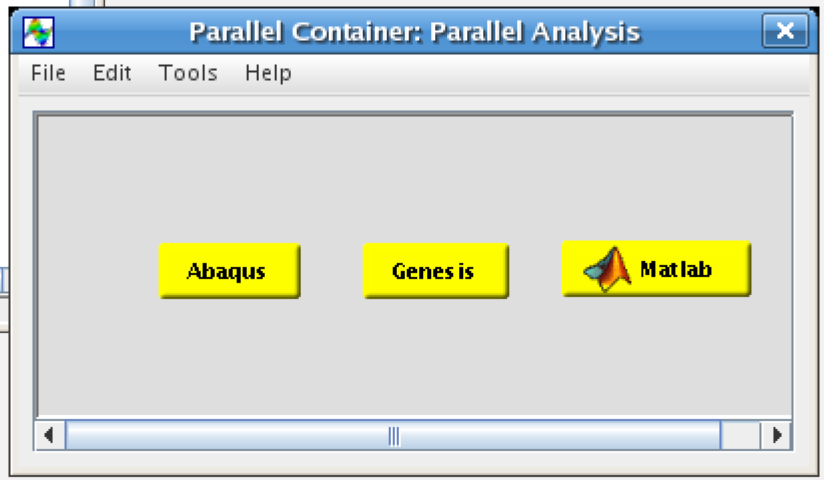
VisualDOC API

- **VisualDOC C/C++ Application Programming Interface (API) functions allow users to embed all the capabilities of VisualDOC into users' own program.**
- **These capabilities include**
  - **Direct Gradient-based Optimization (DGO)**
  - **Response Surface Approximate Optimization (RSA)**
  - **Design Of Experiments (DOE)**
  - **Non-gradient-based Optimization (NGO)**
  - **Single Analysis**
  - **Probabilistic Optimization.**

Parallel Analysis

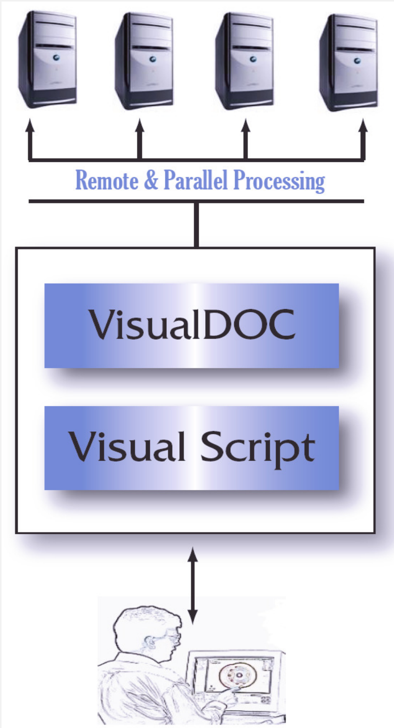


- **Put multiple analysis elements in the Parallel Container**

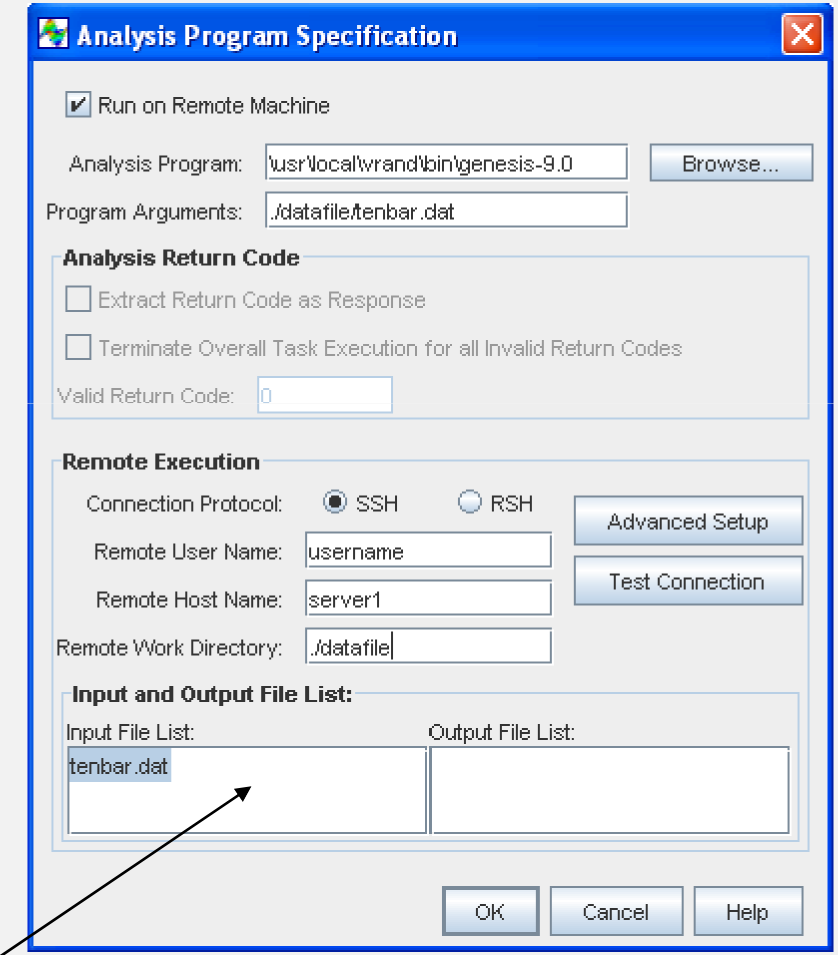


- Add Parallel Container to the workflow

Remote Run



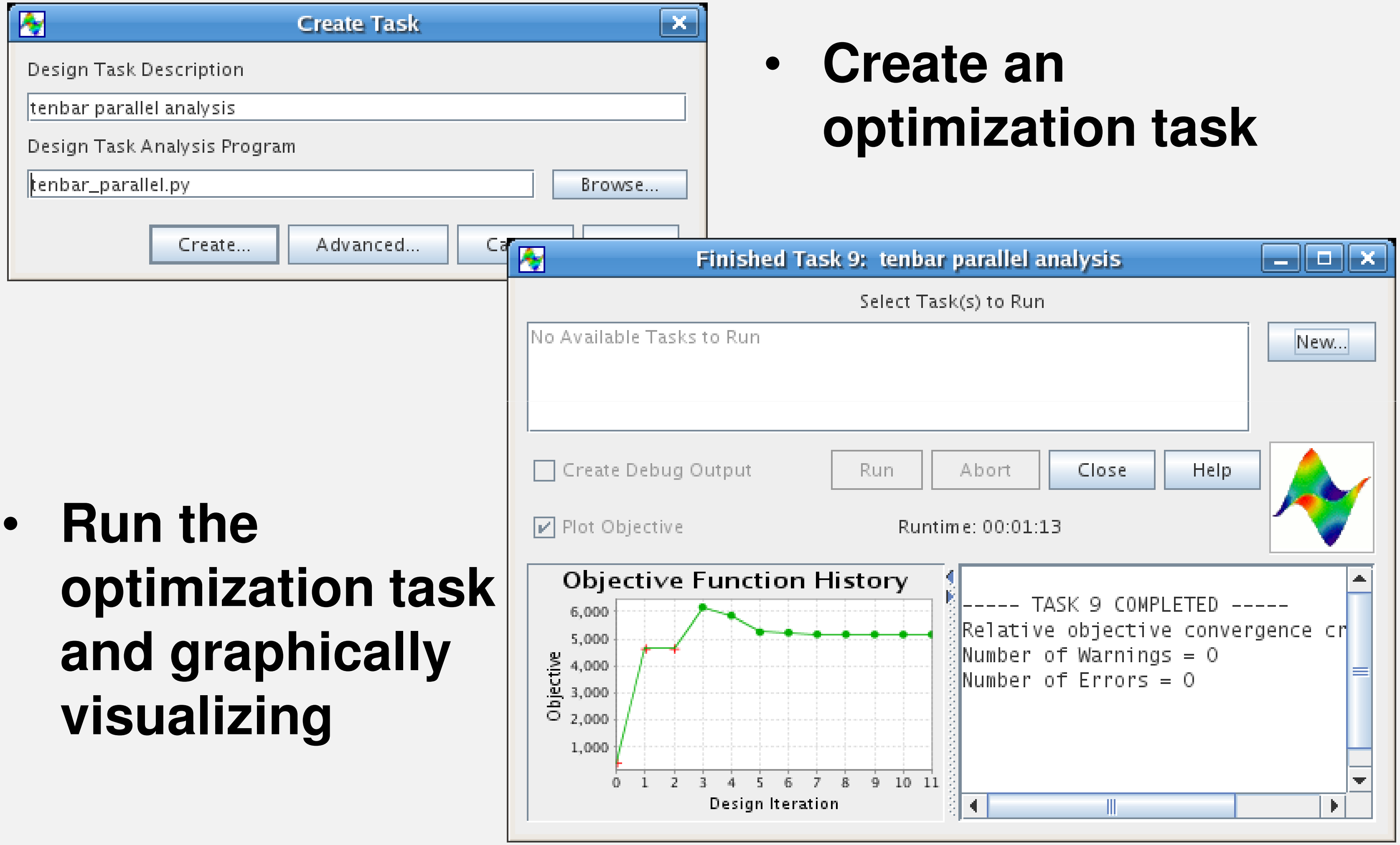
- **Analysis – Remote computers**



- VisualDOC – local computer

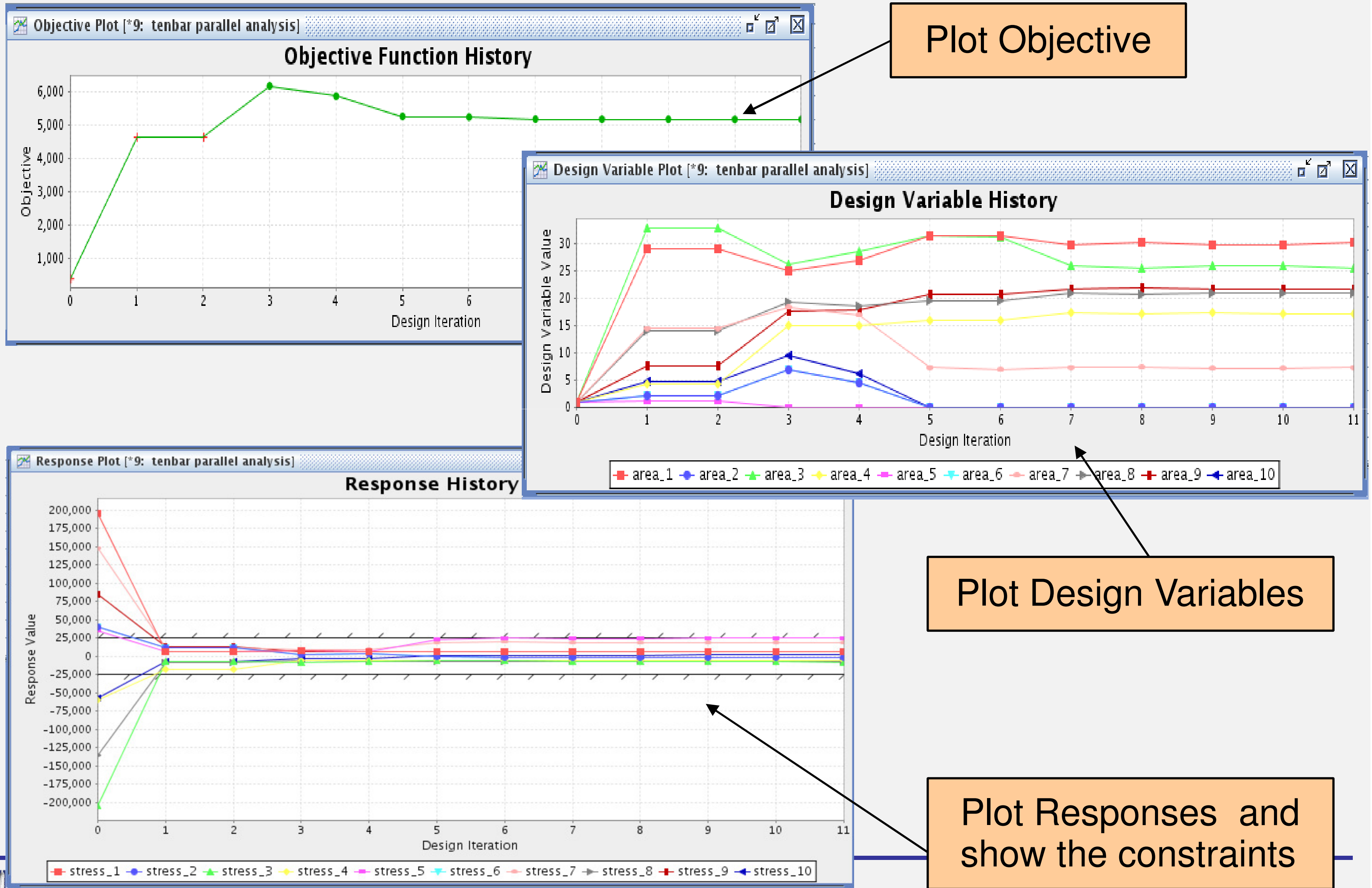
Define remote connection properties

Create and Run Task

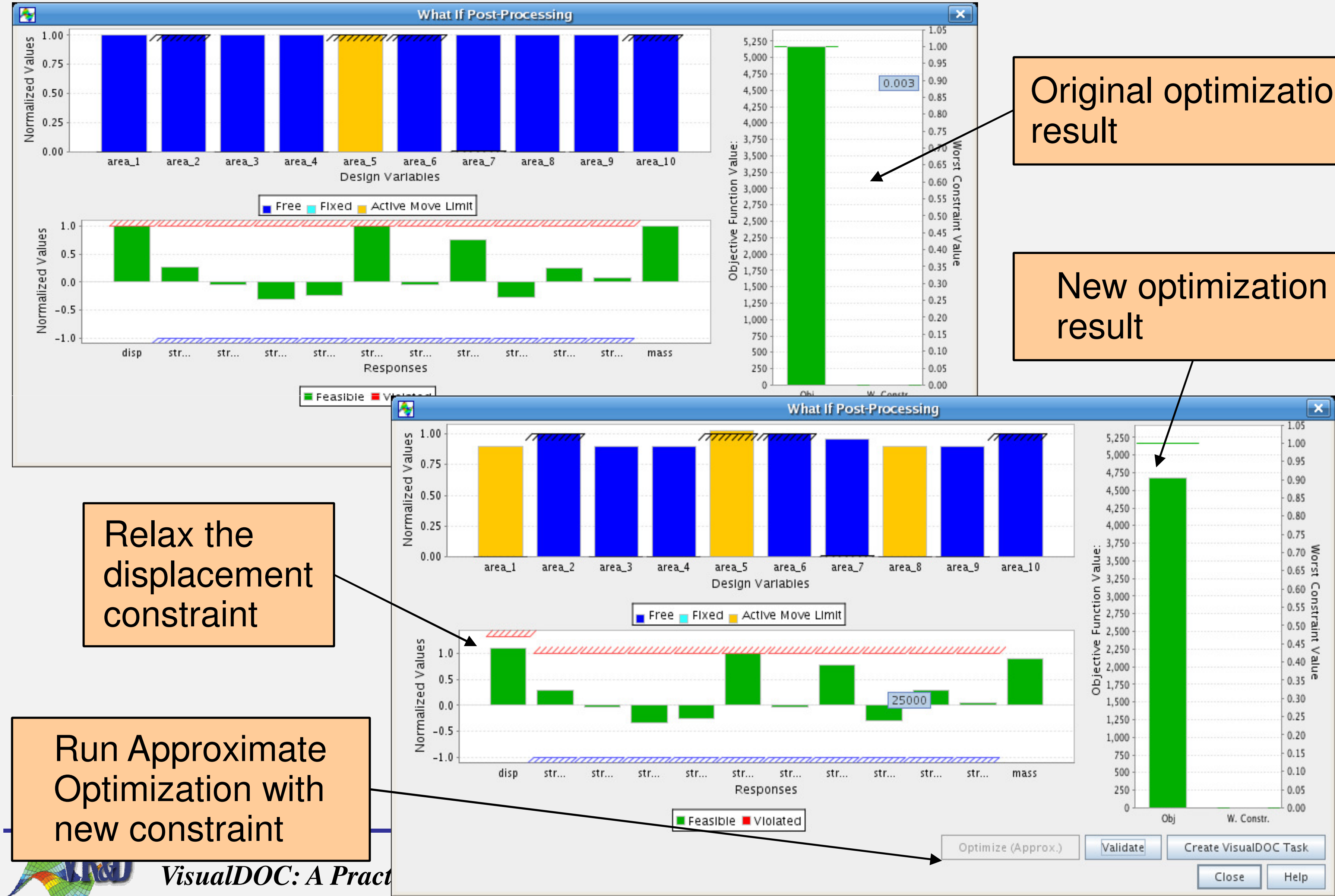


- **Create an optimization task**
- **Run the optimization task and graphically visualizing**

Post Process the Optimization Results



“What-If?” Study Tool



Original optimization result

New optimization result

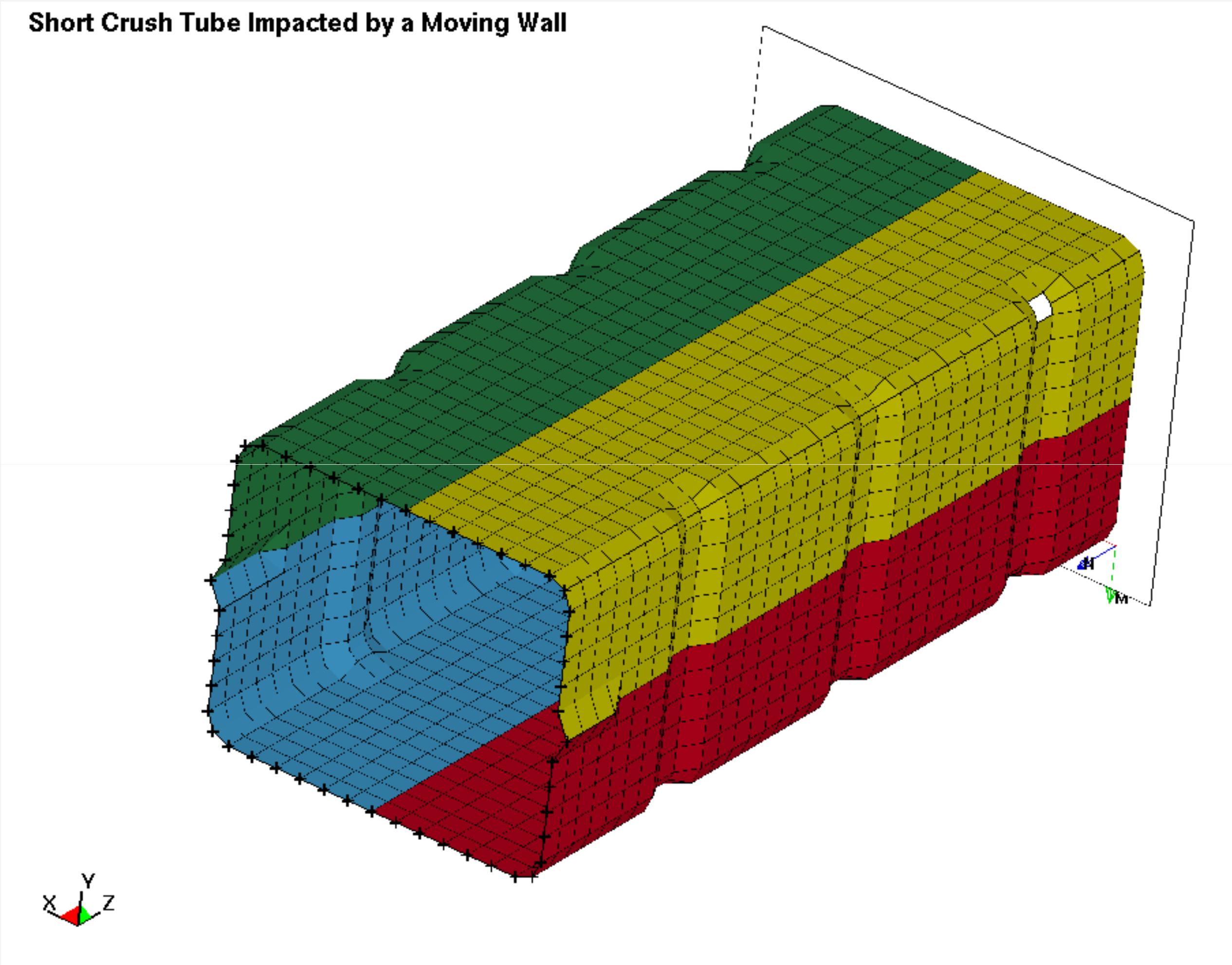
Relax the displacement constraint

Run Approximate Optimization with new constraint

Examples

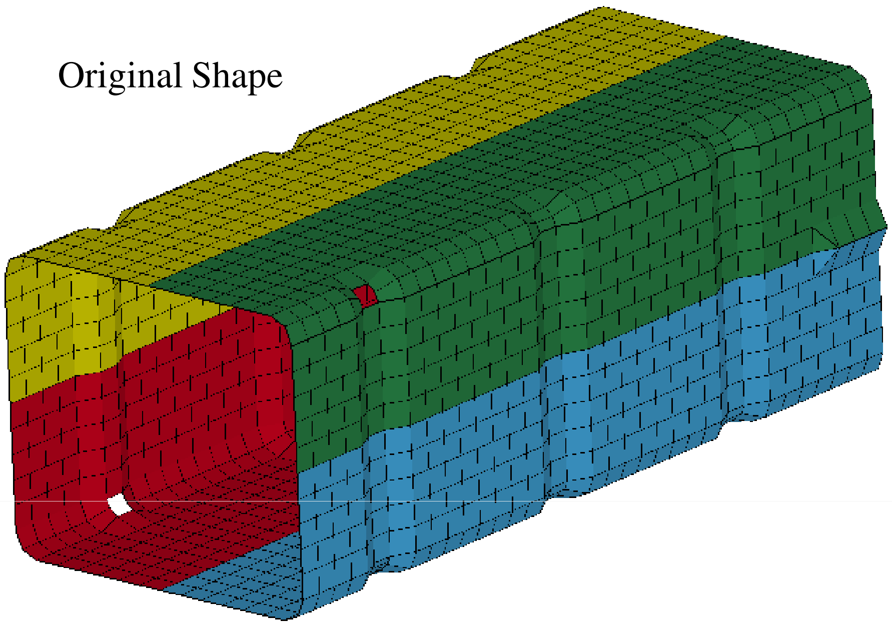
Problem Description

- **LS-Dyna Optimization**

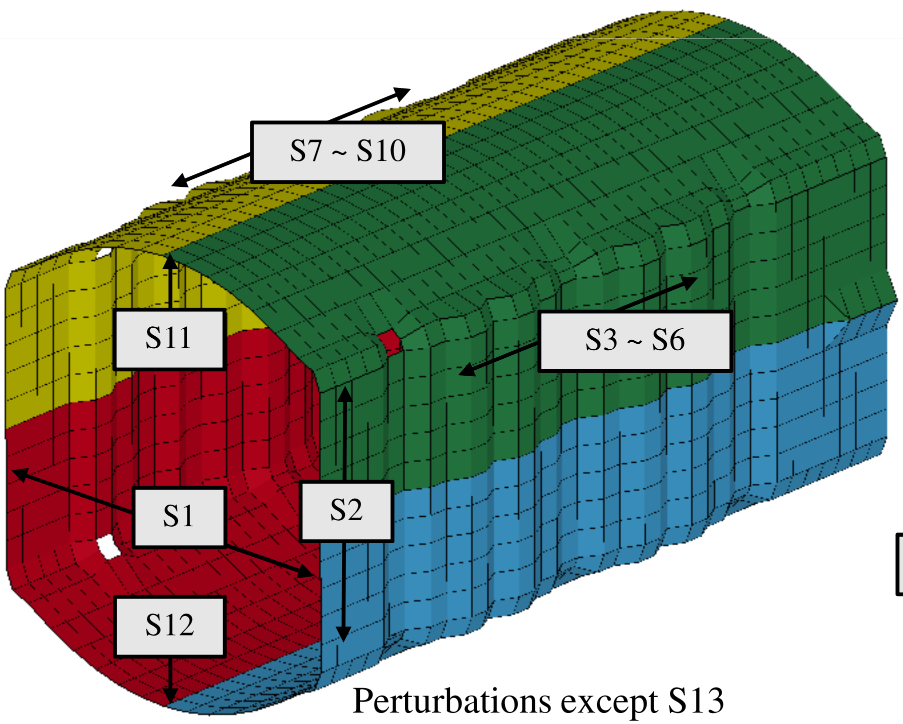


Optimization Problem

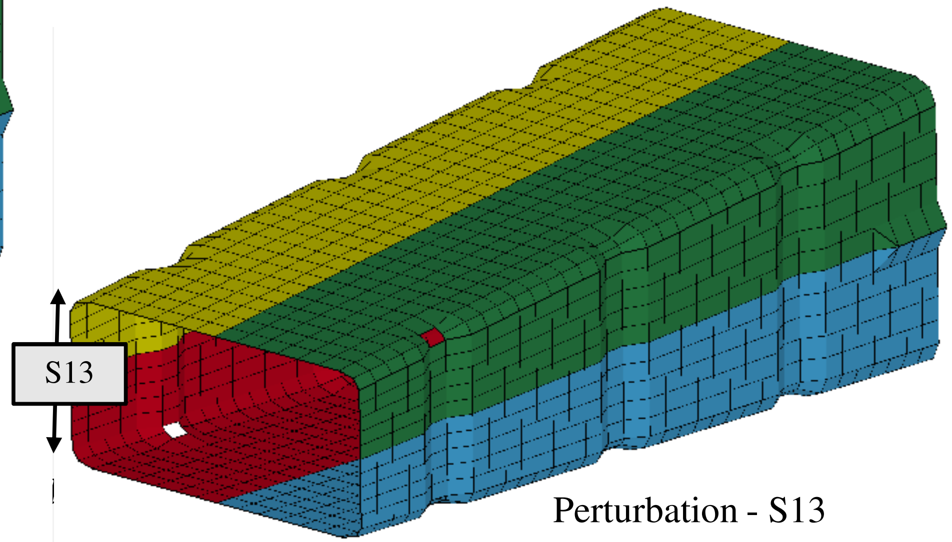
- Objective
  - Maximize Internal Energy
- Design Variables
  - Thickness of the shell elements
  - Shape changes of the tube
  - Linking to ensure symmetry



Original Shape



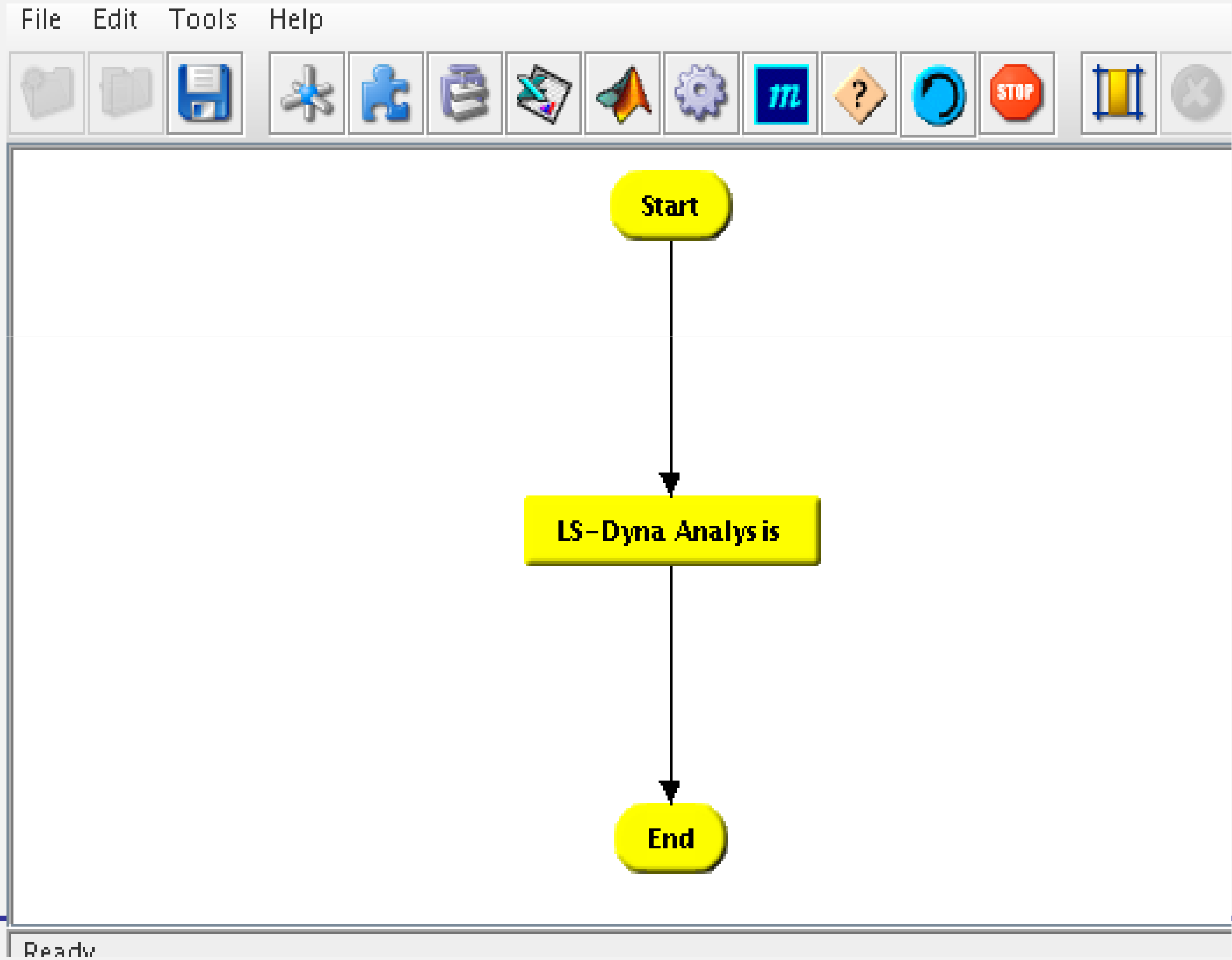
Perturbations except S13



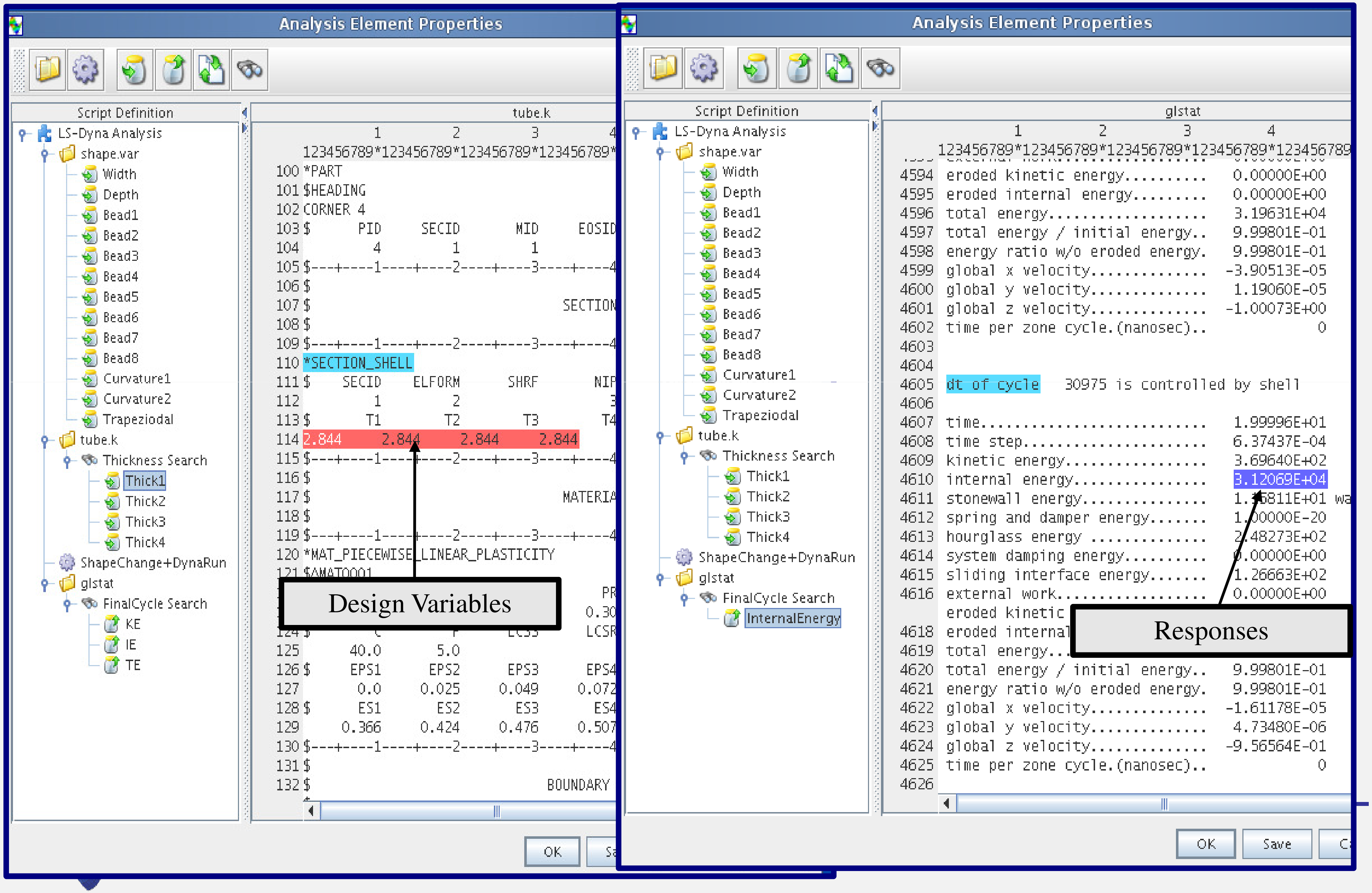
Perturbation - S13

VisualScript

- Used to define the interaction between VisualDOC and LS-Dyna



VisualScript



VisualDOC

File Edit Catalog Task Post Attributes Database Window Help

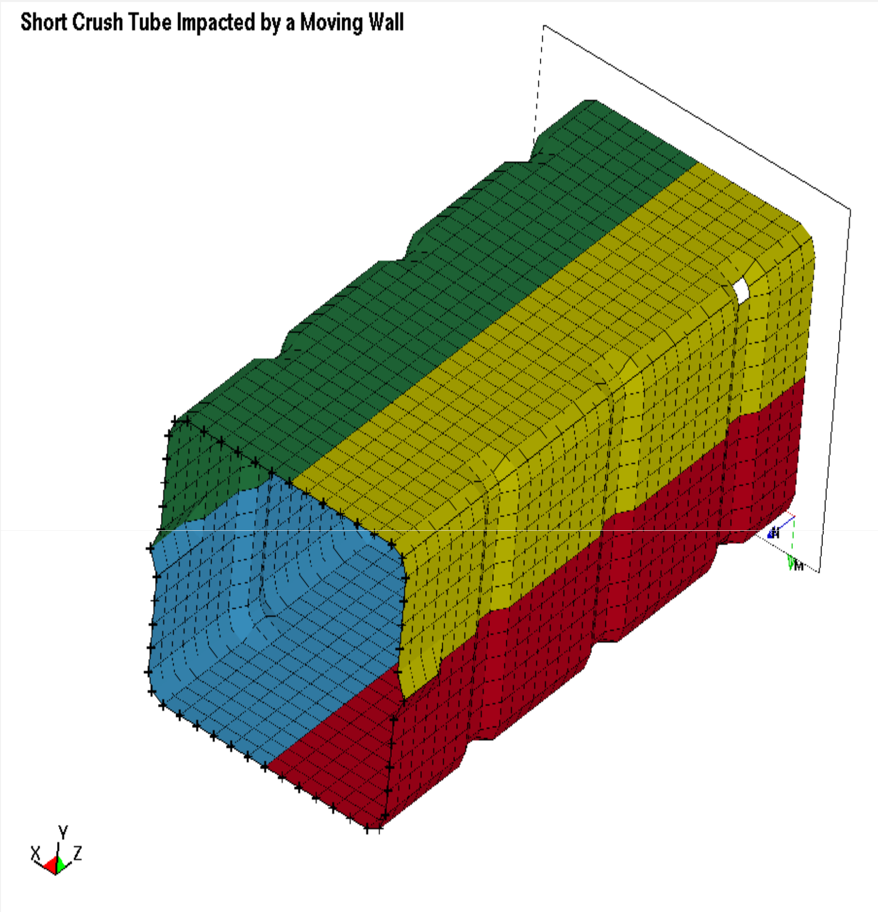
Responses

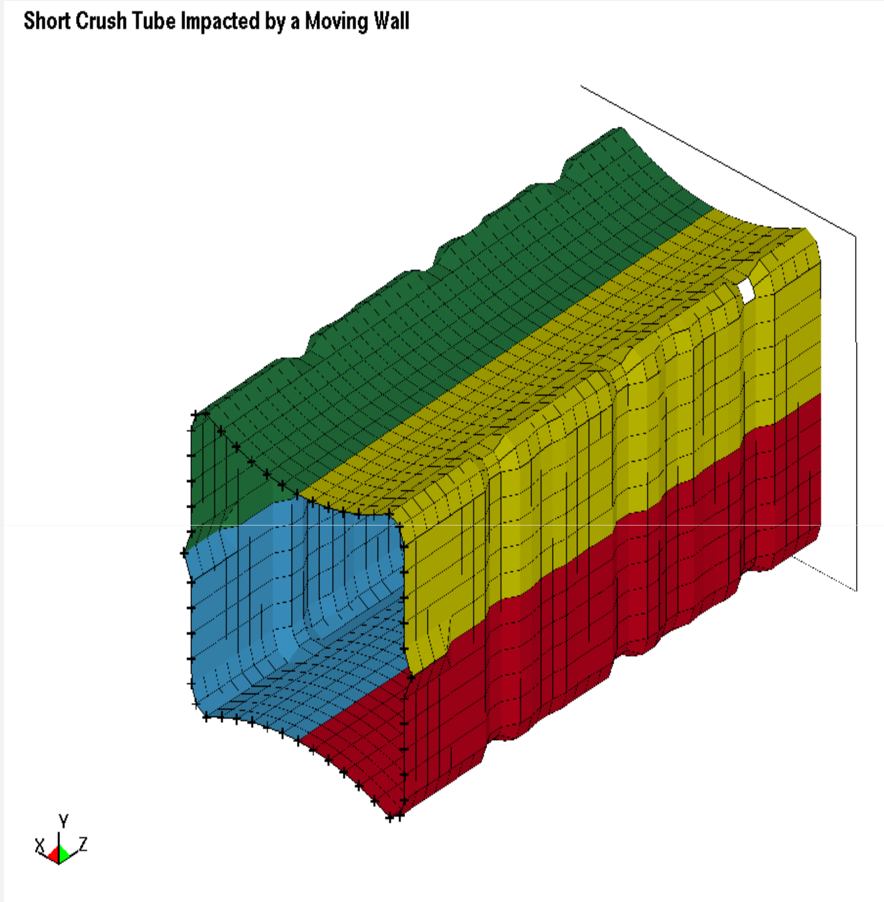
Index	Name	Type	Objective	Constraint	Low Bound	Upp Bound
1	IE	Independent	✔	☐	None	None

Inputs

Index	Name	Type	Objective	Low Bound	Initial Value	Upp Bound
1	Width	Continuous	☐	-1.00	0.00	1.00
2	Depth	Continuous	☐	-1.00	0.00	1.00
3	Bead1	Continuous	☐	-1.00	0.00	1.00
4	Bead2	Continuous	☐	-1.00	0.00	1.00
5	Bead3	Continuous	☐	-1.00	0.00	1.00
6	Bead4	Continuous	☐	-1.00	0.00	1.00
7	Bead5(Bead1)	Link	☐	-1.00	0.00	1.00
8	Bead6(Bead2)	Link	☐	-1.00	0.00	1.00
9	Bead7(Bead3)	Link	☐	-1.00	0.00	1.00
10	Bead8(Bead4)	Link	☐	-1.00	0.00	1.00
11	Curvature1	Continuous	☐	-1.00	0.00	1.00
12	Curvature2	Continuous	☐	-1.00	0.00	1.00
13	Trapeziodal	Continuous	☐	-1.00	0.00	1.00
14	Thick1	Continuous	☐	0.10	2.00	5.00
15	Thick2(Thick1)	Link	☐	0.10	2.00	5.00
16	Thick3(Thick1)	Link	☐	0.10	2.00	5.00
17	Thick4(Thick1)	Link	☐	0.10	2.00	5.00

Results





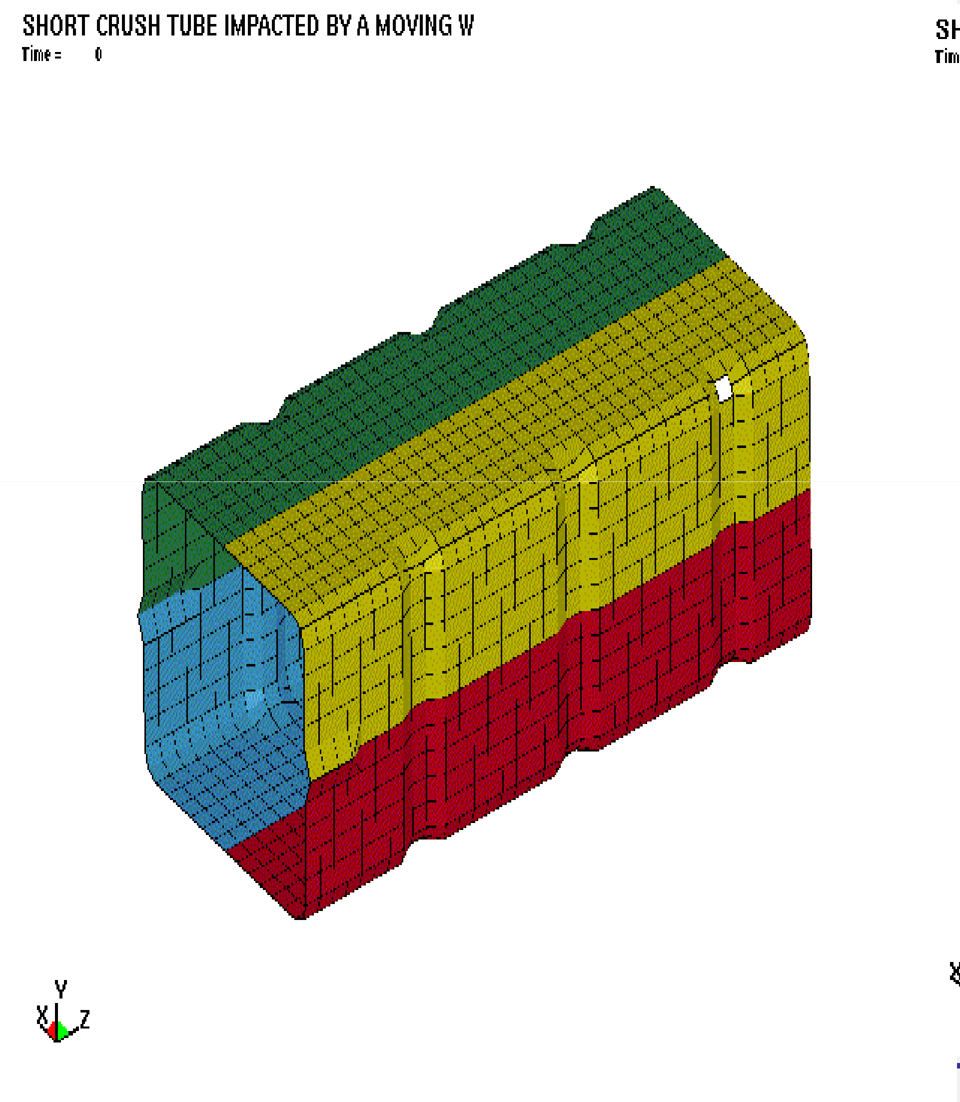
Initial Design

Internal Energy = 10407.20

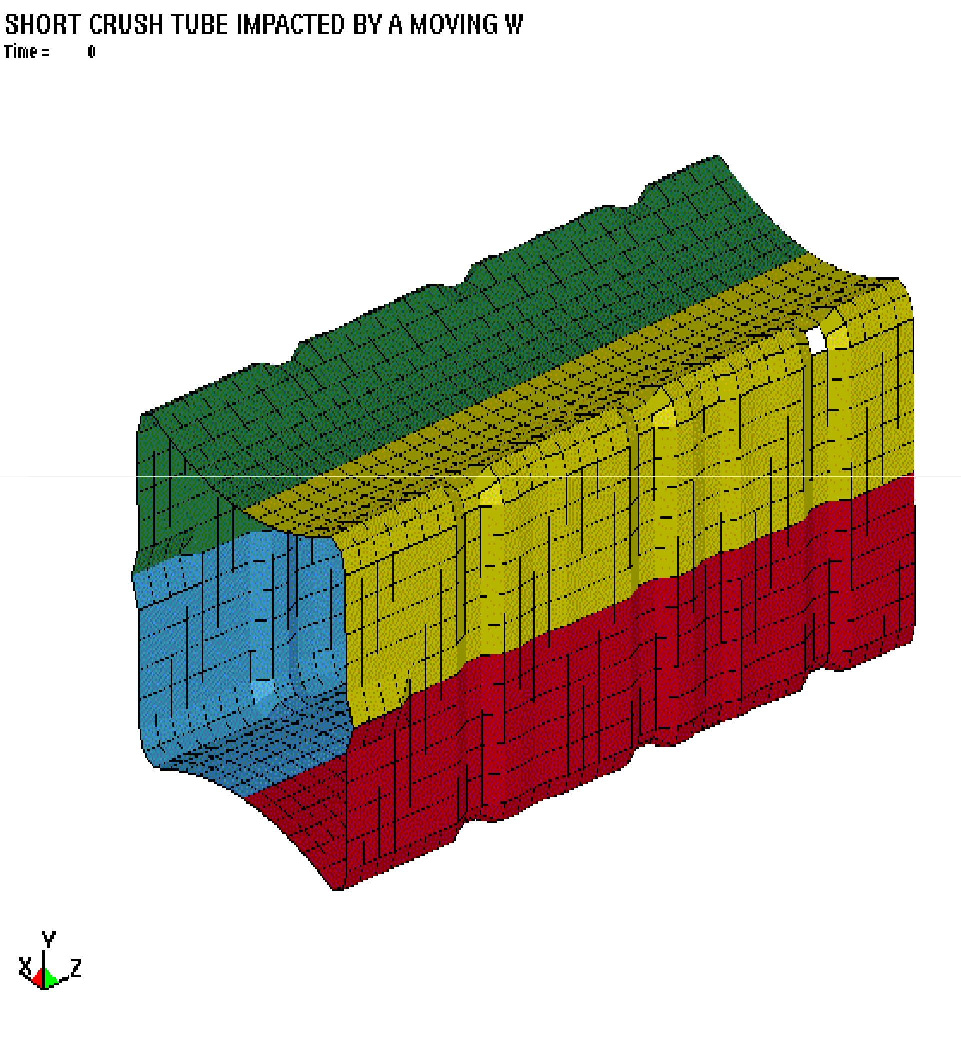
Optimal Design

Internal Energy = 31795.60

Results

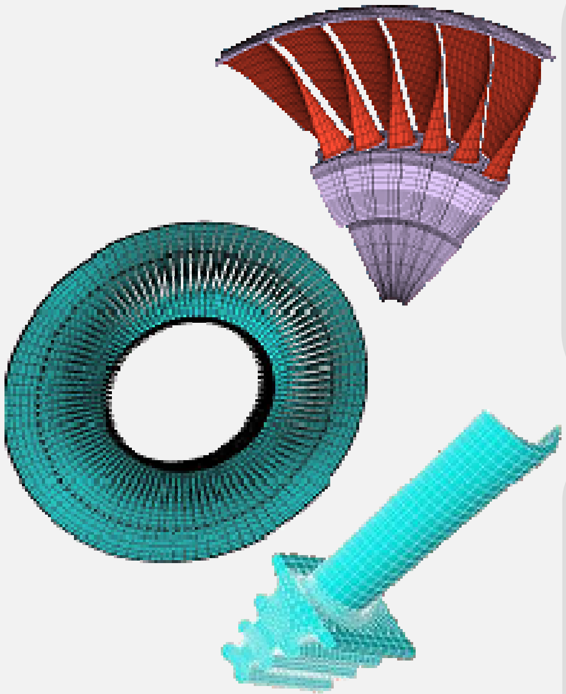


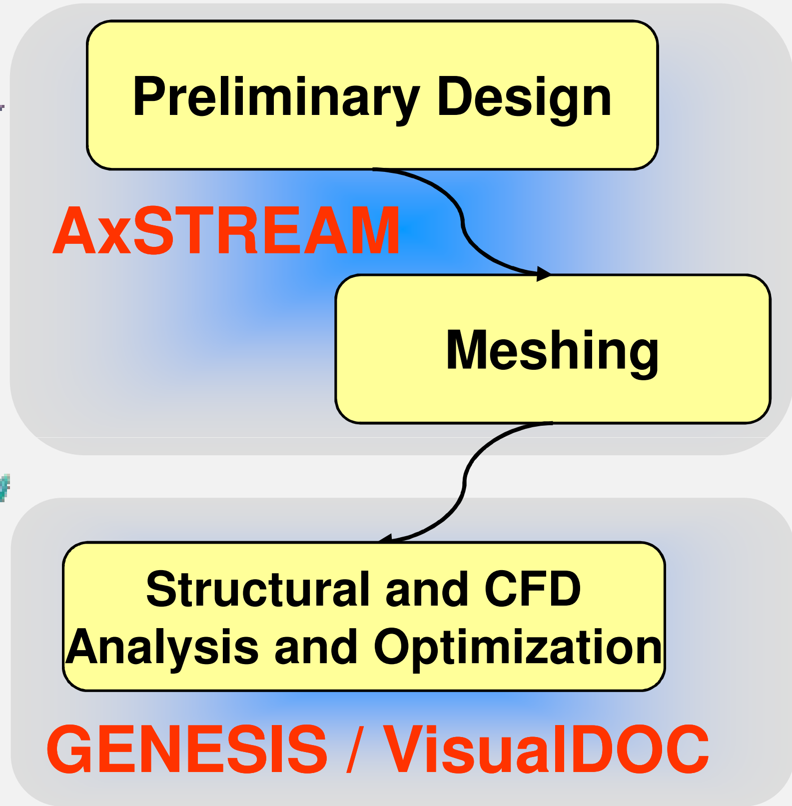
Initial Design



Optimal Design

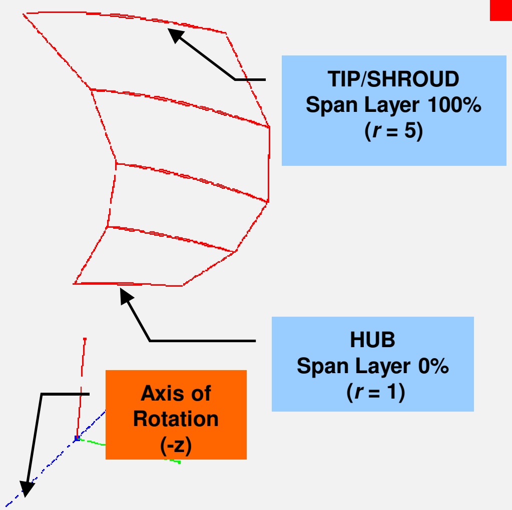
Case Study – Turbomachinery System Design

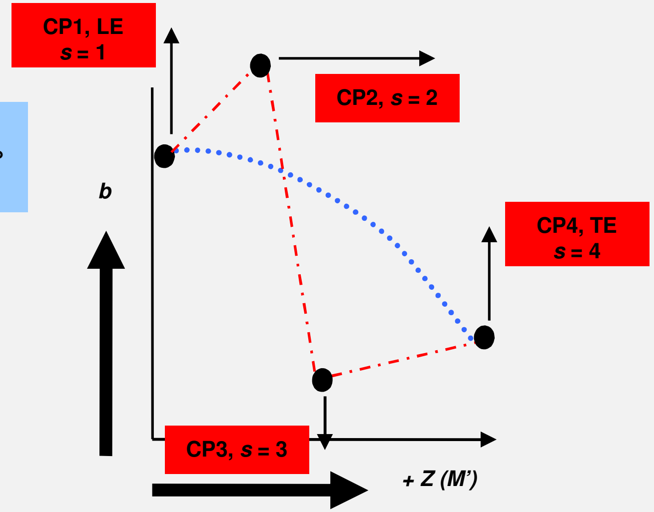




Blades, Disks, Complete Systems

Case Study – Turbomachinery System Design



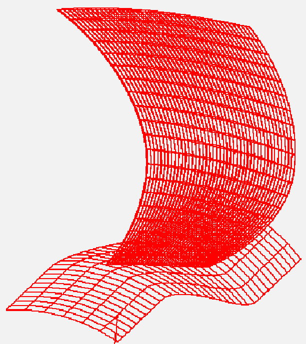


$$\partial M = \sqrt{\partial R \cdot \partial R + \partial Z \cdot \partial Z} = \partial Z$$

$$\partial M' = \frac{\partial M}{R} \qquad M' = \int_0^s \partial M' \cdot ds$$

$$\beta = a\tan\left(\frac{\partial \theta}{\partial M'}\right)$$

$$\underline{M'}_{r|s} = \left(\frac{M'_{r|s}}{M'_{r|TE}}\right) * 100$$



- *A radial interpolation between the airfoils at the each layer to generate the 3D blade Shape*

- *The blade geometry is divided into 5 constant radius layers evenly distributed along the span*

  (0.00% - Hub and 100 % - Shroud)

- *At each span layer, the mean (camber) line is generated using a 4-point Bezier control polygon*

- *Each Bezier Control Point (CP) is specified as a ($\underline{M'}_{r|s}$, b) coordinate pair:*

  ($1 \leq r \leq 5$) – Hub to Shroud Index

  ($1 \leq s \leq 4$) – LE to TE Index

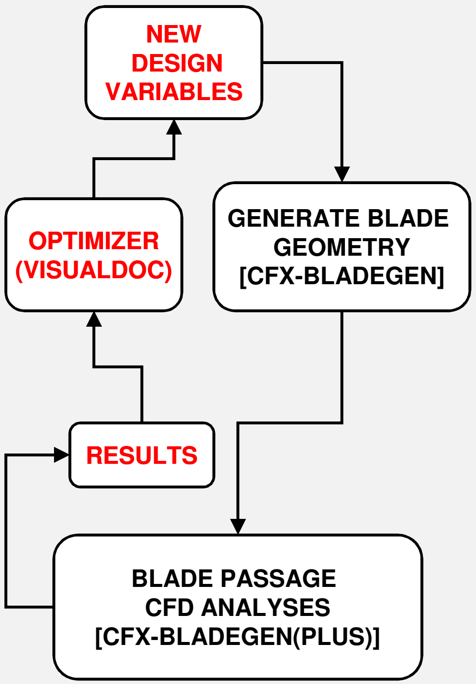
- *LE Edge Sweep (q_r) indicated at each Span Layer*

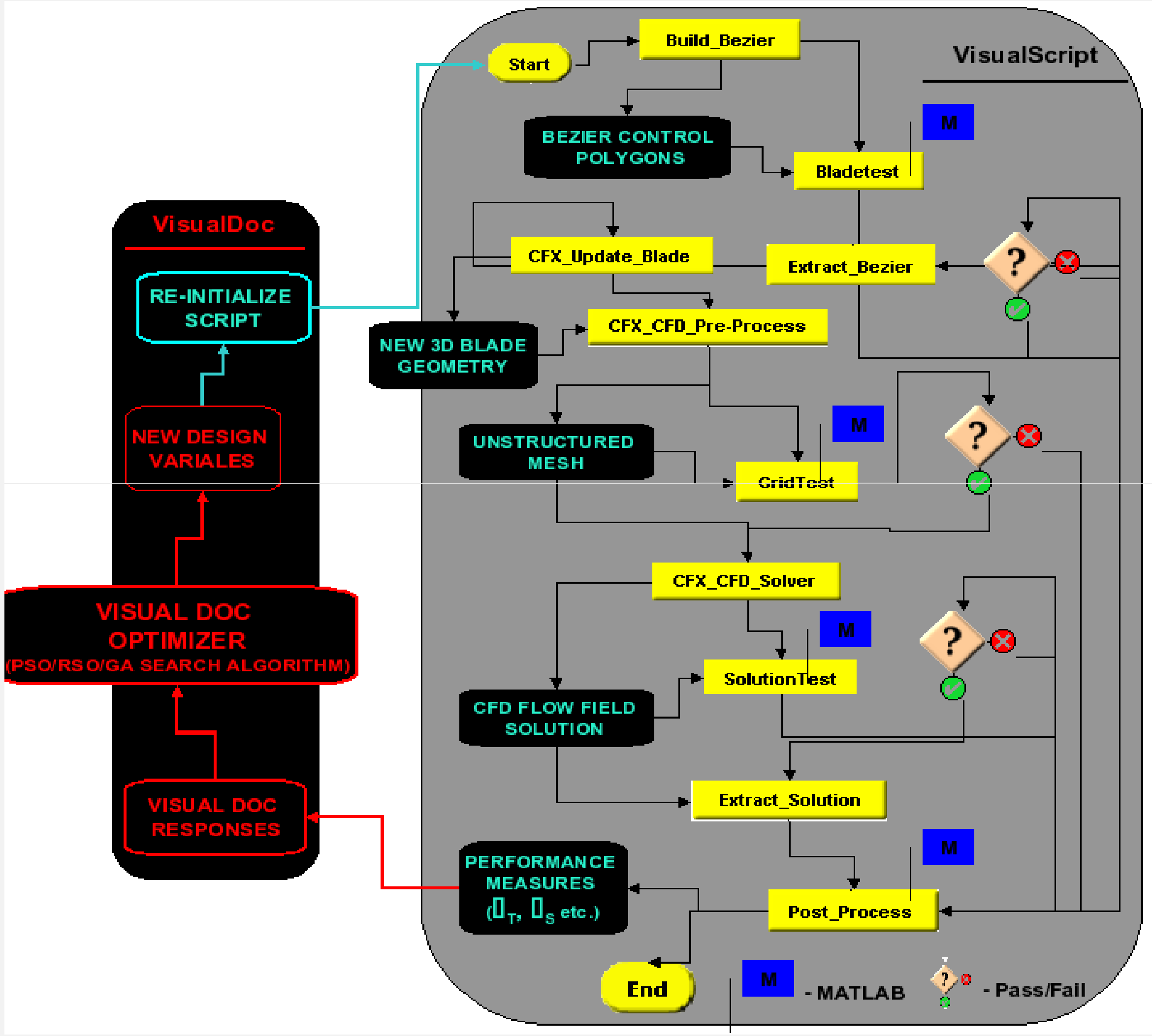
S - Fractional distance along the curve $0 \leq S \leq 1$

Case Study – Turbomachinery System Design

Objective:

Maximize efficiency





Case Study – Turbomachinery System Design

Blade Results:

- **An average of 9% increase in total efficiency was obtained**
- **Robustness of the approach evidenced in its ability to yield significant efficiency gains in spite of the noisy objective function.**

Case Study – Engine Head Gasket

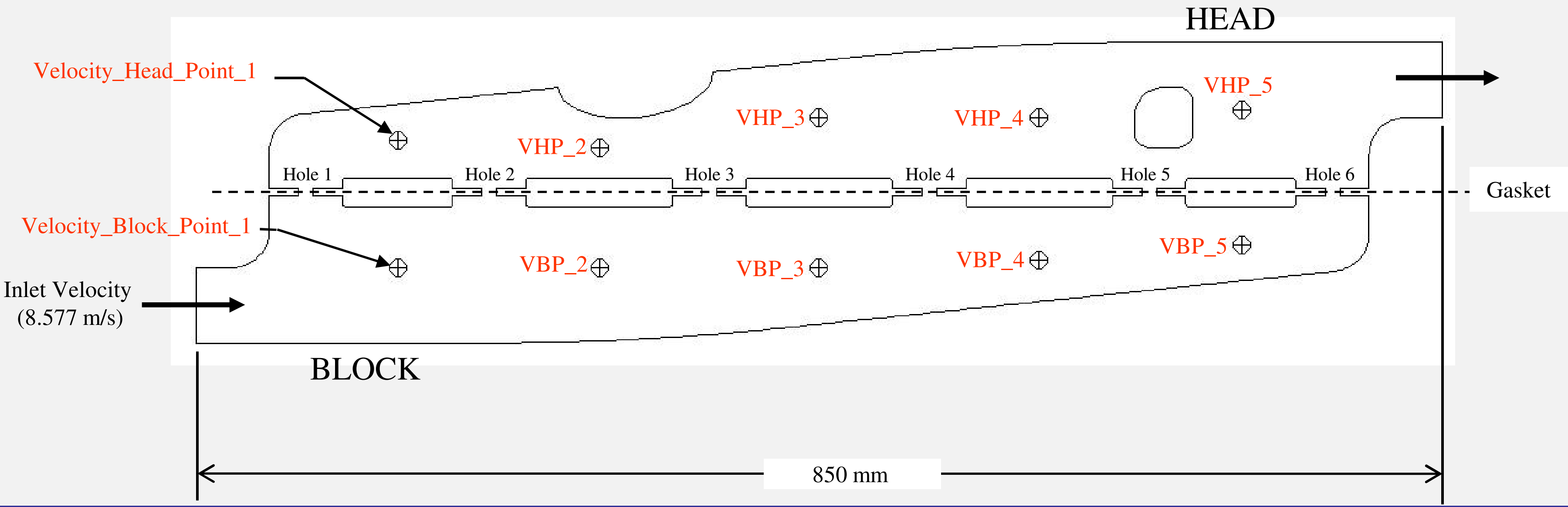
2-D Z-Flow engine cooling system (Block, Head, and Gasket)

Objective: **Maximize the fluid velocity averaged at 10 locations**

Design variables: **Holes' diameter and location (offset from center) (12 design variables total)**

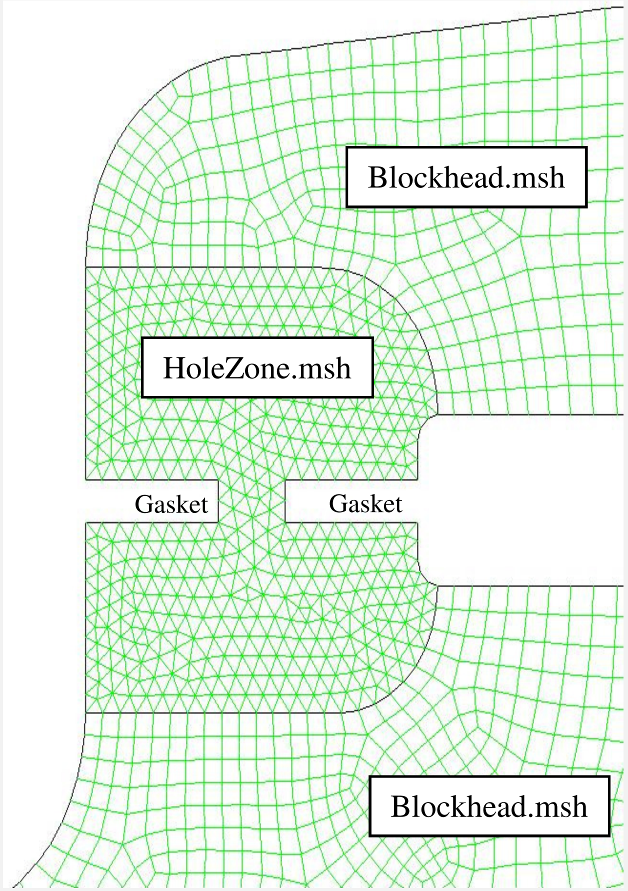
Constraints: **Minimum velocity at 10 locations**

Analysis: **FLUENT CFD program**



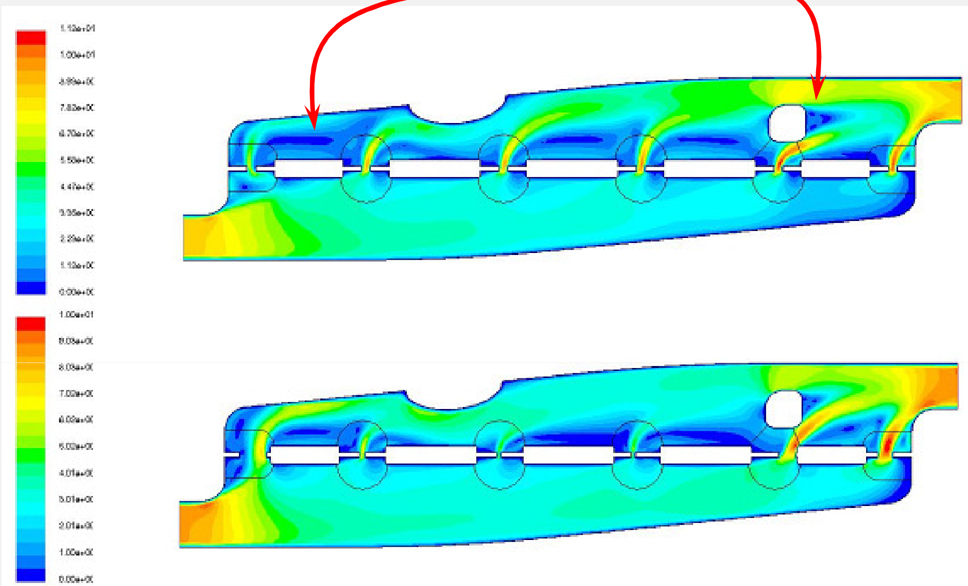
Case Study – Engine Head Gasket

- ***GAMBIT (mesher) journal file parameterization***
- ***Block / Head mesh is unchanged during optimization***
- ***Hole regions mesh is changed by VisualDOC using GAMBIT journal file***



Case Study – Engine Head Gasket

Velocity constraint not satisfied at 2 locations initially



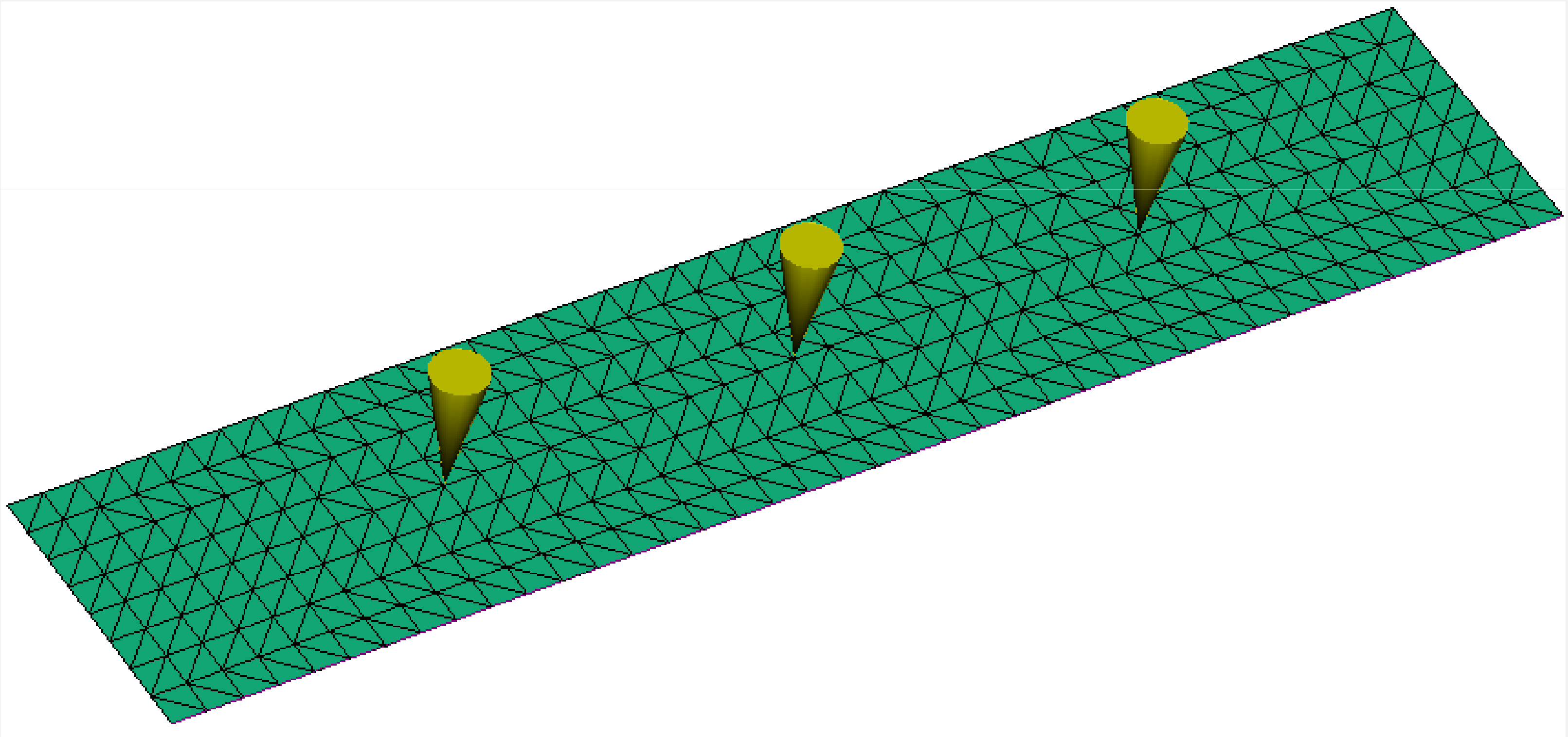
Initial design

Optimal design

- *24 FLUENT calls*
- *Constraints satisfied after 15 FLUENT calls*
- *Average velocity increase: 20%*

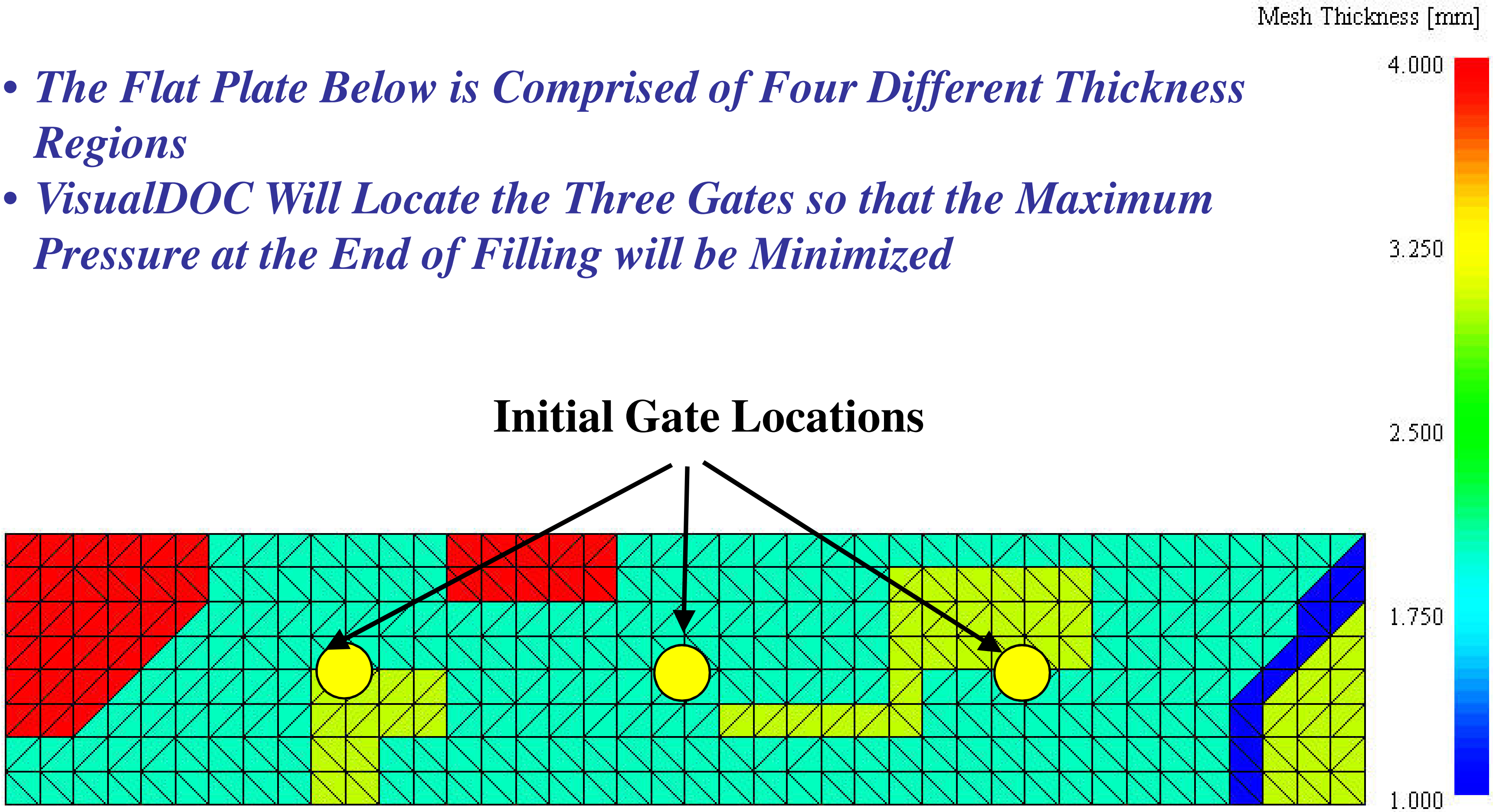
Case Study – Integration with MoldFlow

- *VisualDOC has been integrated with MoldFlow's MoldFlow Plastics Insight (MPI) software to determine Optimal gate location.*
- *Optimal gate location will be the geometry that minimizes the maximum pressure at the end of the filling.*



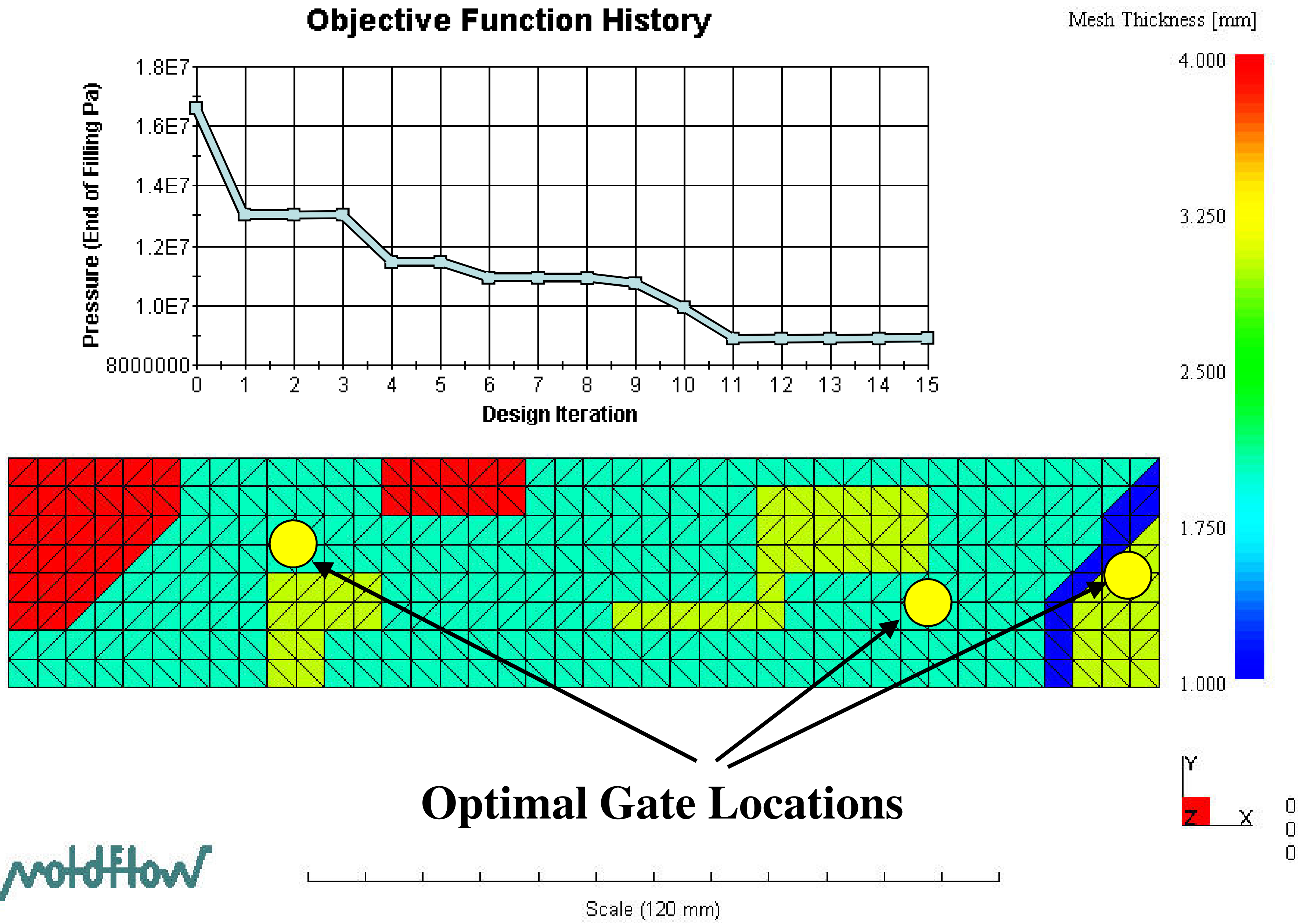
Case Study – Integration with MoldFlow

- *The Flat Plate Below is Comprised of Four Different Thickness Regions*
- *VisualDOC Will Locate the Three Gates so that the Maximum Pressure at the End of Filling will be Minimized*



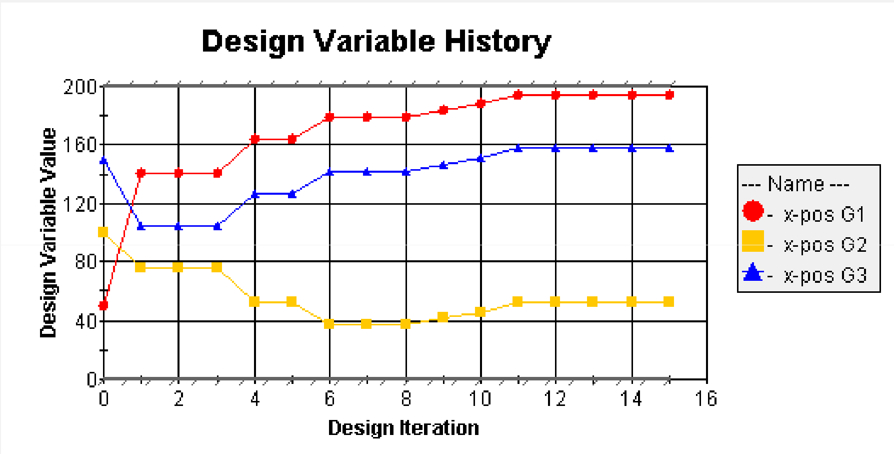
Case Study – Integration with MoldFlow

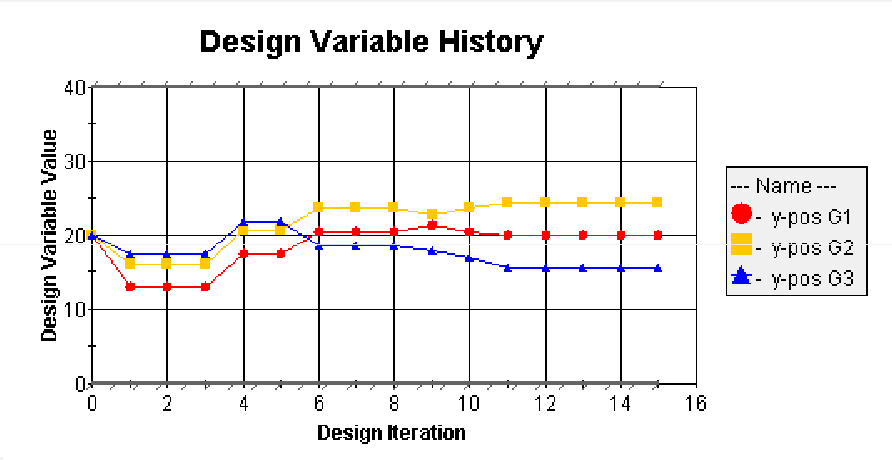
Optimization Process Sequence


Objective Function History
Pressure (End of Filling Pa)
1.8E7
1.6E7
1.4E7
1.2E7
1.0E7
8000000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Design Iteration
Mesh Thickness [mm]
4.000
3.250
2.500
1.750
1.000
Optimal Gate Locations
Y
Z
X
Scale (120 mm)

Case Study – Integration with MoldFlow

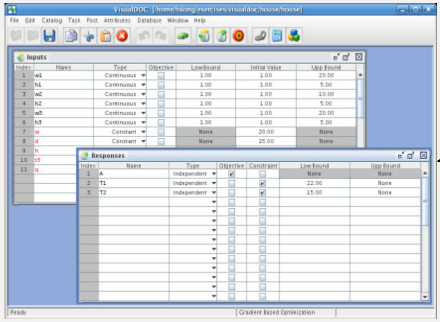
- *During 15 iterations, injector X and Y coordinates for each gate migrated to plate locations that minimized the maximum pressure at the end of fill time.*
- *Total 22 analyses were performed for this optimization.*





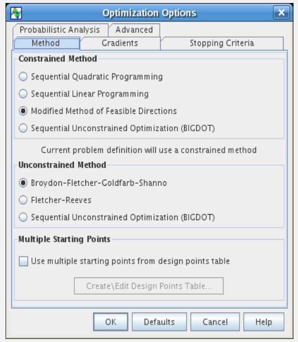
- *VisualDOC optimization parameters may be set to reduce total number of analyses to achieve "better" rather than "best" design.*
- *A better guess for the initial gate locations will also reduce total number of analyses.*

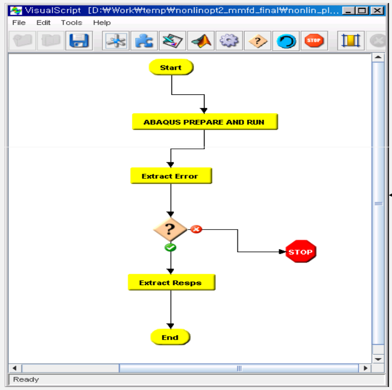
Summary



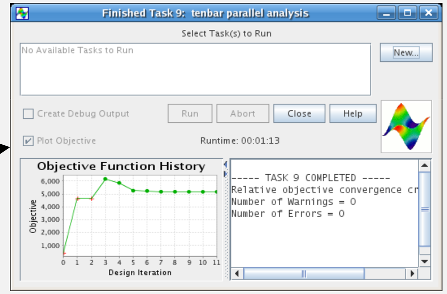
Set up Input and Output

Set Optimization Module and Respective Options

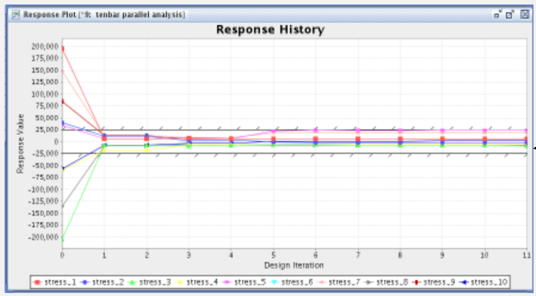




Integrate with Analysis



Create and Run Task



Post-processing

“What-If?” Study

Conclusions

- ***This paper presents a solution suite for complete product design optimization, namely VisualDOC.***
- ***VisualDOC has the capability to wrap design and optimization algorithms around any ASCII based 3rd party analysis software.***
- ***VisualDOC can be used within parallel computing clusters where different analysis are run concurrently on remote machines. This allows for solution of large scale optimization problems that involve several computationally intensive analysis codes.***
- ***VisualDOC's optimization routines have proven to improve product designs and product design processes.***