

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

Ashwin P Gurnani, Juan Pablo Leiva, Garret N. Vanderplaats

**Vanderplaats Research & Development, Inc.
Colorado Springs, CO, USA**

Outline of Presentation

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



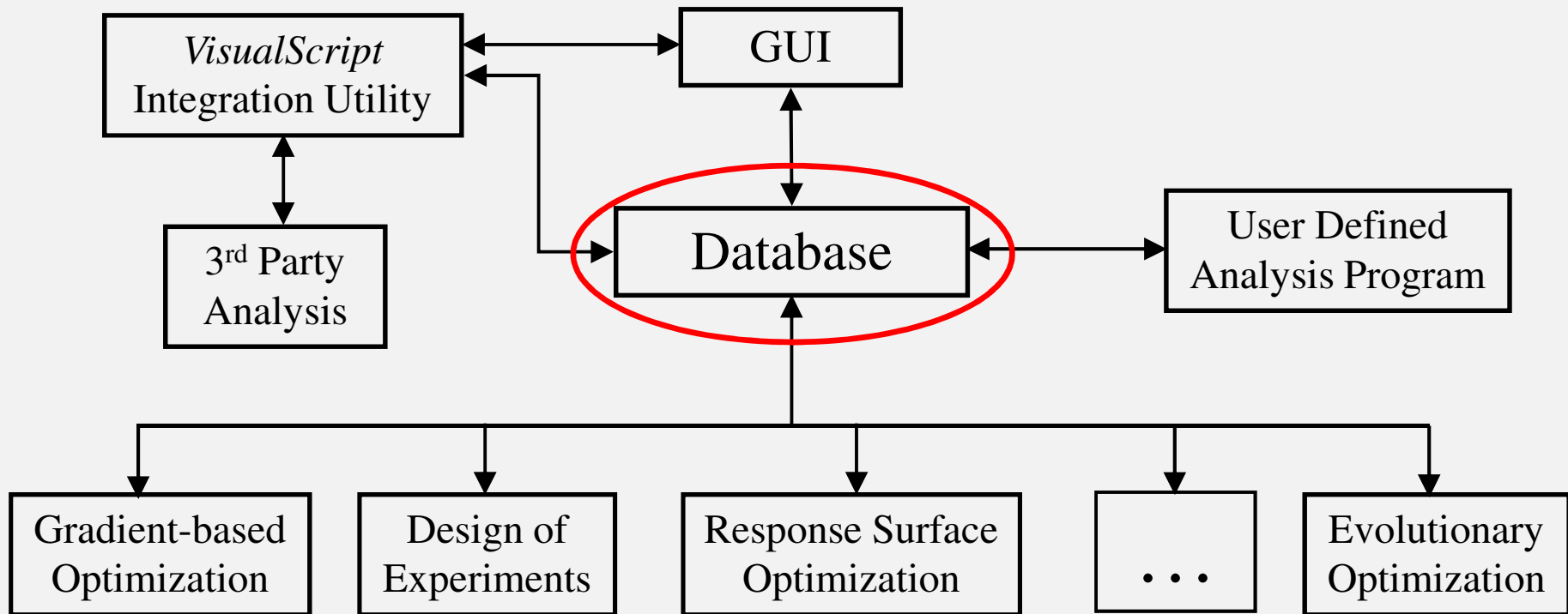
Introduction

- *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

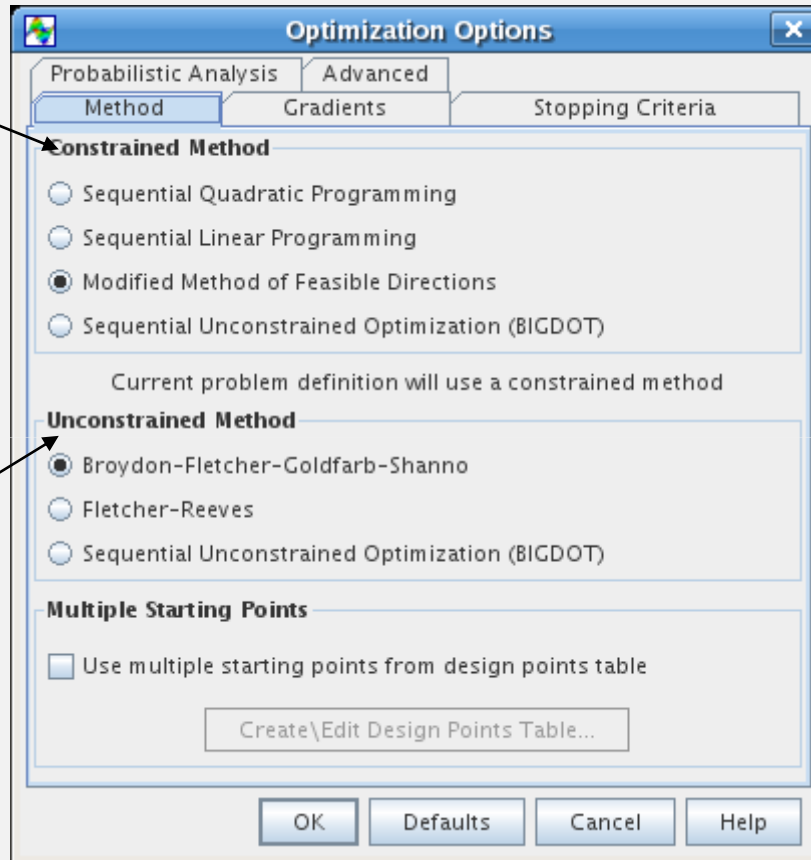
- *Database is the central component of the software.*
- *Saved as platform independent .vdb file*



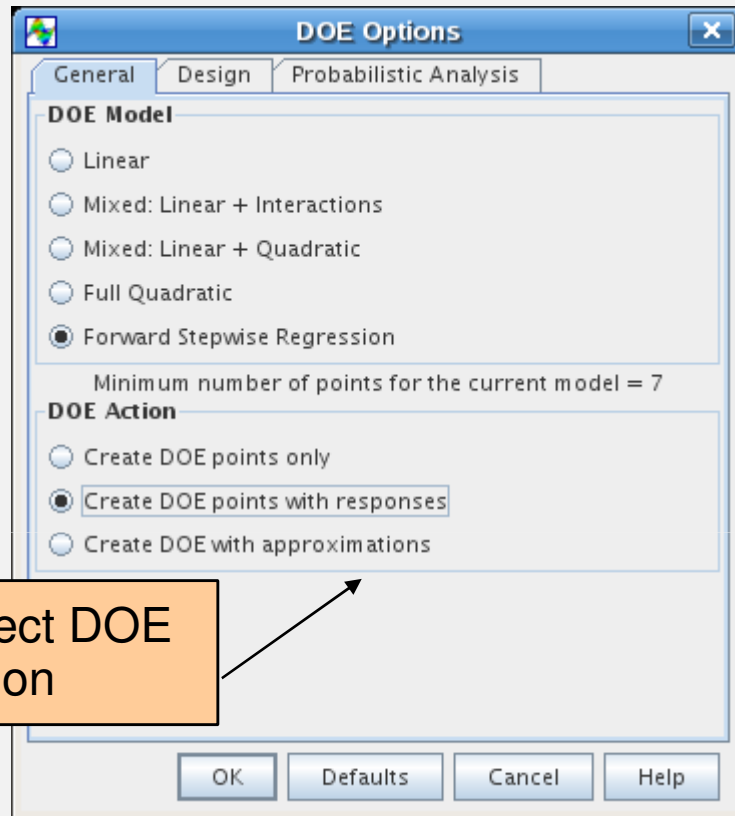
Gradient Based Optimization

Constrained

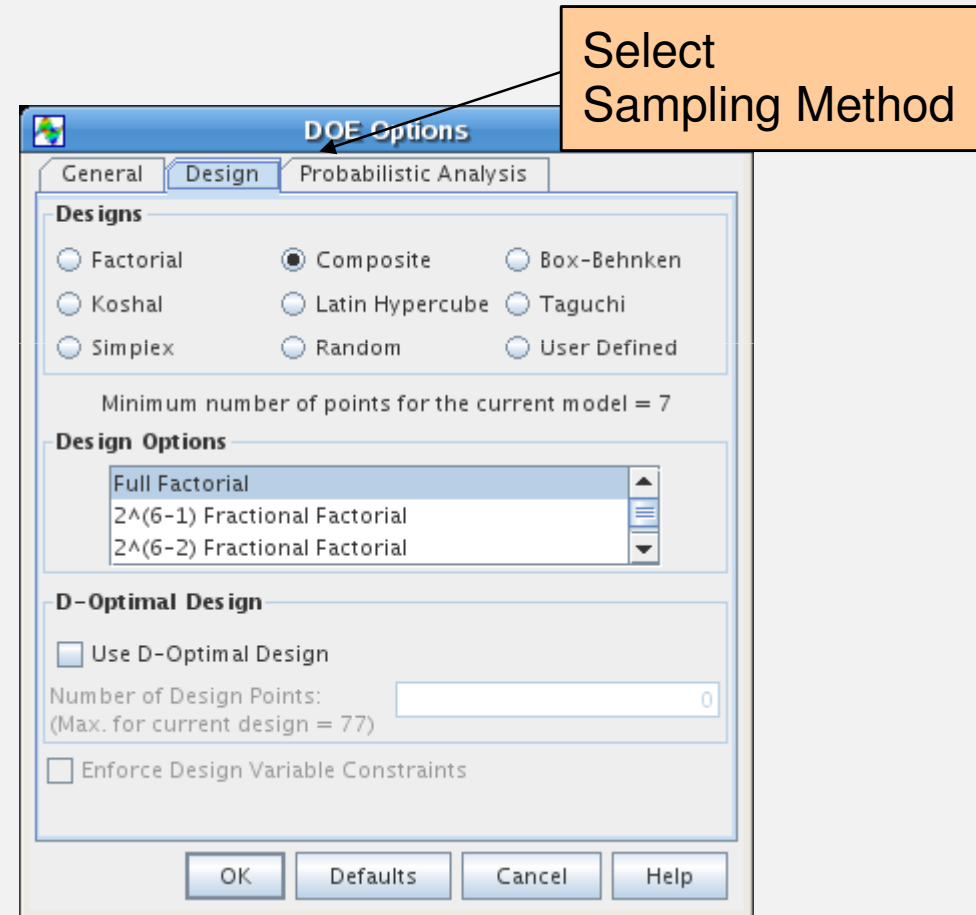
Unconstrained



Design of Experiments



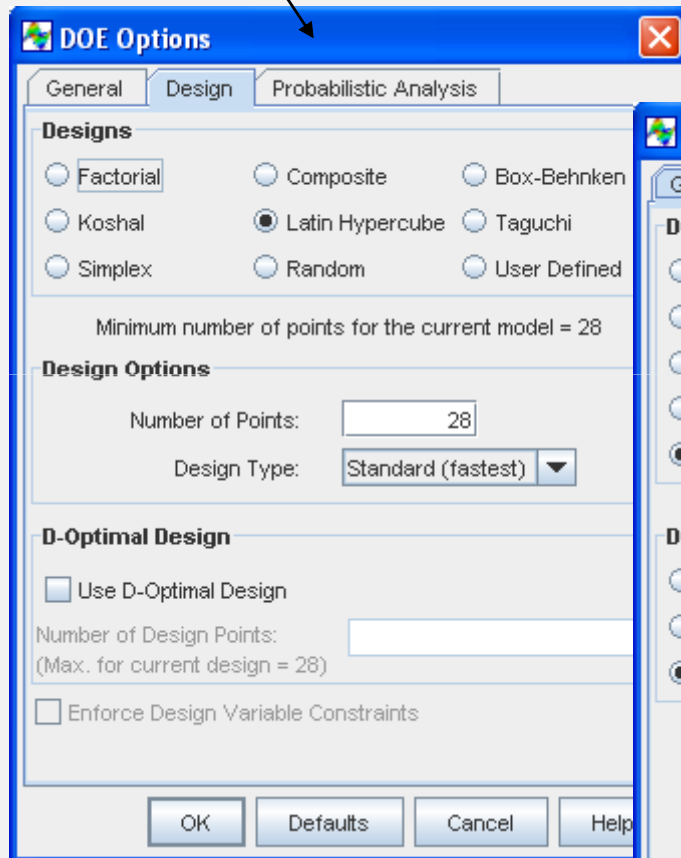
- Create an experimental design



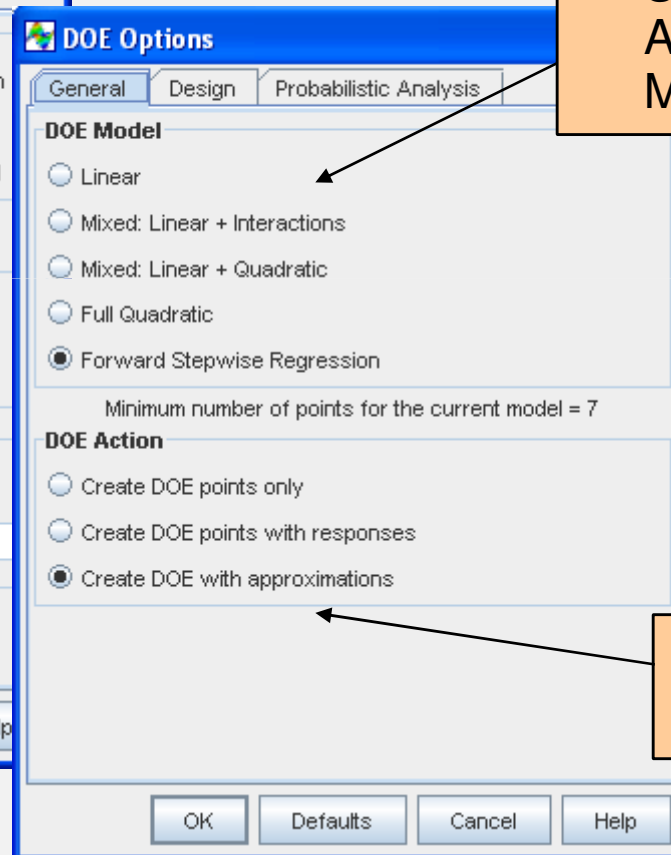
Design of Experiments

Select Sampling Method

- Approximate responses



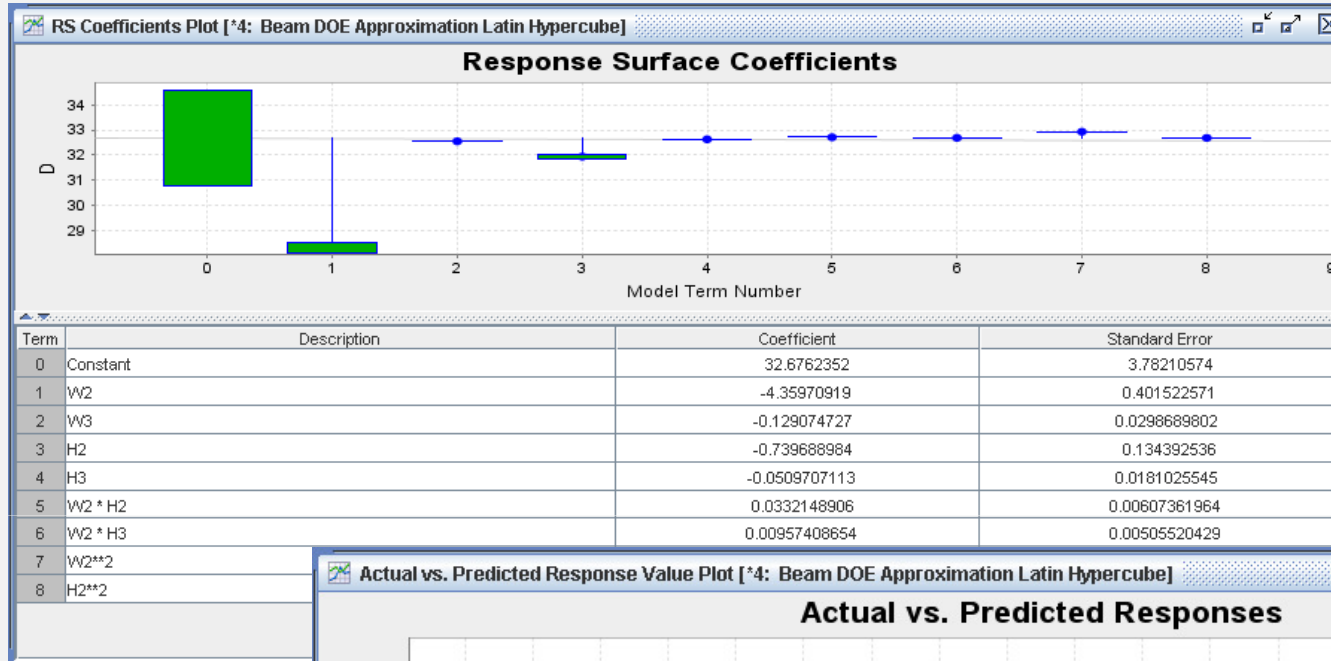
Select Approximation Model



Select DOE Action

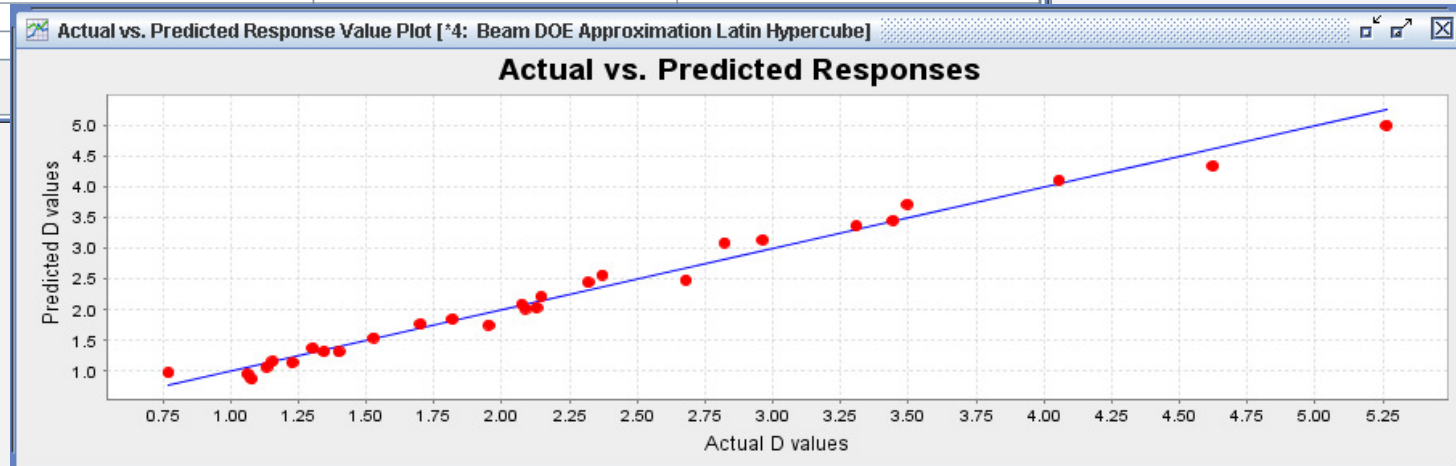


Design of Experiments

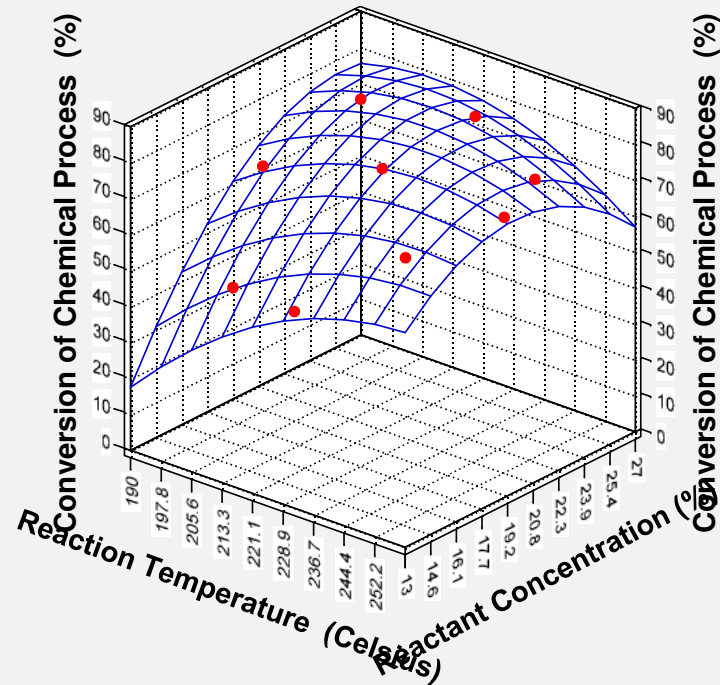


- RS coefficients

- Actual vs. Predicted



Response Surface Optimization



Select the Starting Strategy

The screenshot shows the 'Response Surface Optimization' dialog box with the 'General' tab selected. The 'Model Order' section has radio buttons for Linear, Mixed: Linear + Interactions, Mixed: Linear + Quadratic, and Full Quadratic (which is selected). The 'Starting Strategy' section has radio buttons for Koshal, Simplex (which is selected), Taylor Series, and User Defined. There are buttons for 'Set Optimization Options', 'OK', 'Defaults', 'Cancel', and 'Help'. A callout box points to the 'Full Quadratic' option.

Select the Approximation Model Order



Non-Gradient Based Optimization

Select Optimization Algorithm

Select Starting Strategy

Define Algorithm related parameters

Optimization Options

Probabilistic Analysis | Advanced

General | PSO | GA | Stopping Criteria

NGO Method

Particle Swarm Optimization (PSO)

Genetic Algorithm (GA)

Starting Strategy

Random Population Size:

User Defined Create/Edit Design Point Table...

Defaults | Cancel | Help

Optimization Options

Probabilistic Analysis | Advanced

General | PSO | GA | Stopping Criteria

Cross-Over Type:

Probability of Cross-Over:

Probability of Mutation:

OK | Defaults | Cancel | Help



Probabilistic Analysis and Optimization

The screenshot displays the VisualDOC software interface. The main window shows two tables: 'Inputs' and 'Responses'. The 'Inputs' table lists parameters like h_Param1, h_Param2, w, d_Mean, and d_StdDev. The 'Responses' table lists system outputs like System POF, Area_Mean, Area_StdDev, Area_POF, Volume_Mean, Volume_StdDev, and Volume_POF. A 'Response Surface Options' dialog box is open, showing the 'Probabilistic Analysis' tab. This dialog allows selecting a method (Direct Monte Carlo Sampling is selected) and setting simulation points (1,000). It also includes options for saving simulation points and using a fixed random seed value.

Set up random Inputs and Responses

Select Probabilistic Analysis Method

Index	Name	Type	Objective	Low Bound	Initial Value	Upp Bound
1	h_Param1	Continuous	<input type="checkbox"/>	2.00	2.00	None
	h_Param2(h_Param1)	Link	<input type="checkbox"/>	0.01	0.50	None
2	w	Continuous	<input type="checkbox"/>	2.00	2.00	None
3	d_Mean	Continuous	<input type="checkbox"/>	2.00	2.00	None
	d_StdDev	Constant	<input type="checkbox"/>	None	0.40	None

Index	Name	Type	Objective	Constraint
	System POF		<input type="checkbox"/>	<input checked="" type="checkbox"/>
1	Area_Mean	Independent	<input type="checkbox"/>	<input checked="" type="checkbox"/>
	Area_StdDev		<input checked="" type="checkbox"/>	<input type="checkbox"/>
	Area_POF		<input type="checkbox"/>	<input type="checkbox"/>
2	Volume_Mean	Independent	<input type="checkbox"/>	<input checked="" type="checkbox"/>
	Volume_StdDev		<input type="checkbox"/>	<input type="checkbox"/>
	Volume_POF		<input type="checkbox"/>	<input checked="" type="checkbox"/>

Response Surface Options

Move Limits | **Probabilistic Analysis**

General | Stopping Criteria

Probabilistic Analysis Method

- Direct Monte Carlo Sampling
- Latin Hypercube Sampling
- Mean Value Approximation Method
- Approximate Direct Monte Carlo Sampling
- Approximate Latin Hypercube Sampling

Simulation Points

Number of Simulation Points: 1,000

- Save Simulation Points in Database
- Use Fixed Random Seed Value

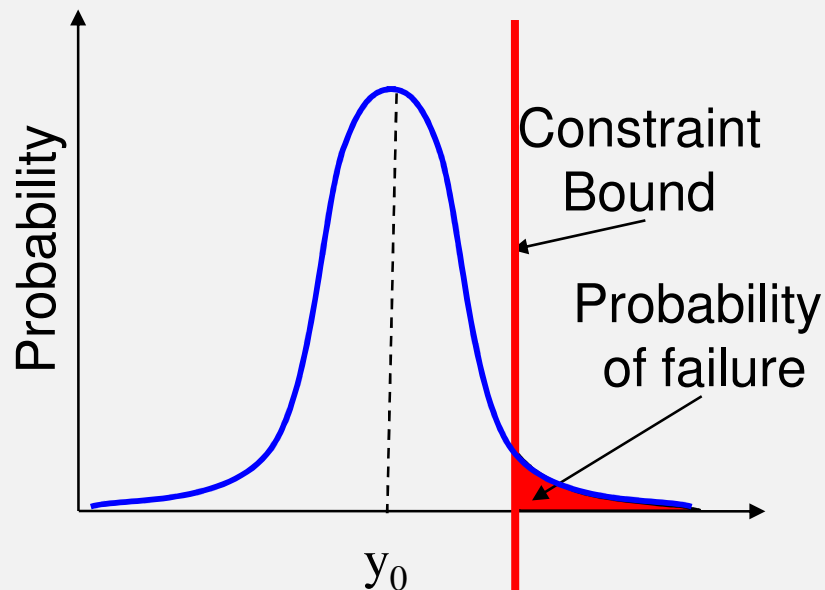
OK Defaults Cancel Help



Probabilistic Analysis and Optimization

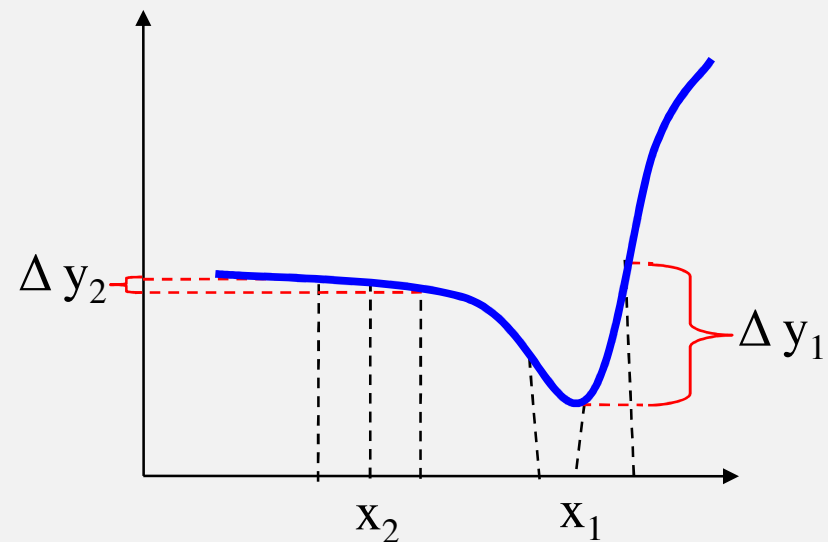
Reliability Optimization

Control the probability of failure

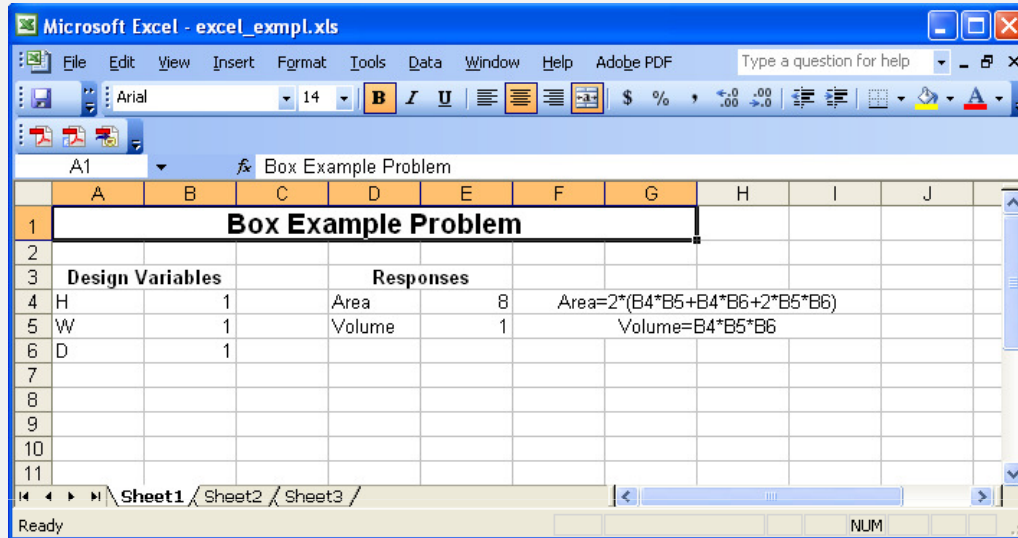


Robust Optimization

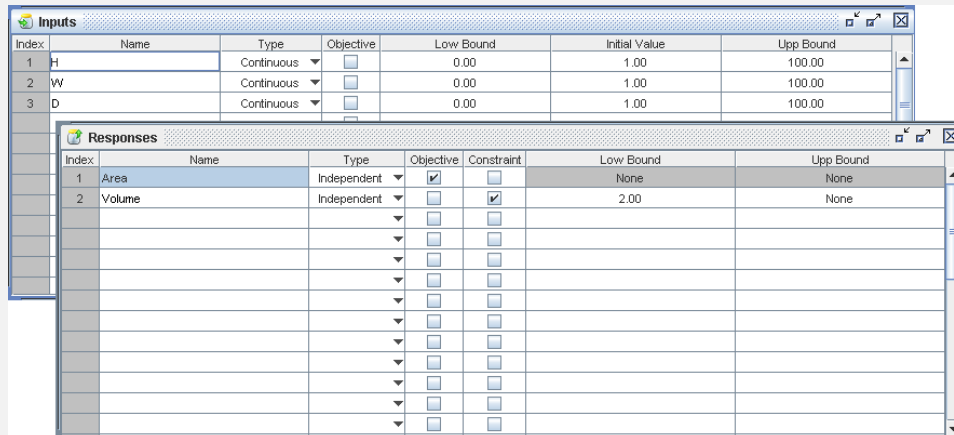
Control the variability of a response



Direct Interface --Excel



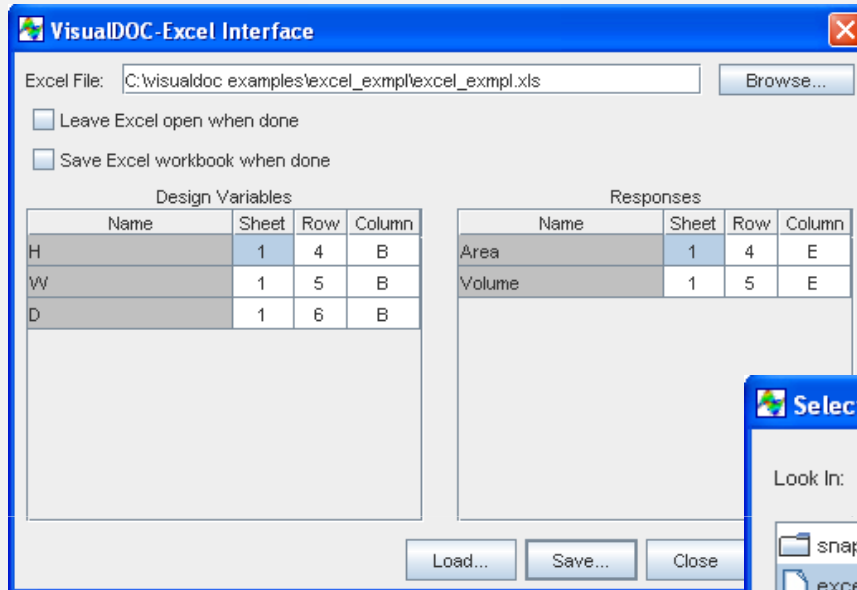
- Prepare Excel spreadsheet



- Define inputs and responses in VisualDOC

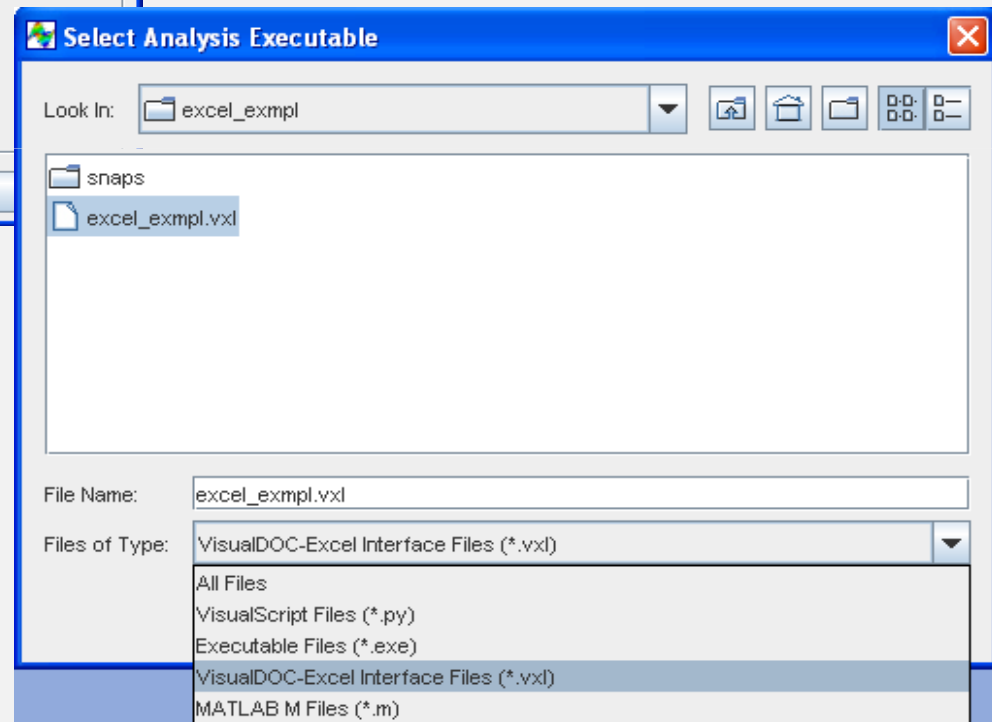


Direct Interface -- Excel



- 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 box
% 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

Index	Name	Type	Objective	Low Bound	Initial Value	Upp Bound
1	H	Continuous	<input type="checkbox"/>	0.00	1.00	100.00
2	W	Continuous	<input type="checkbox"/>	0.00	1.00	100.00
3	D	Continuous	<input type="checkbox"/>	0.00	1.00	100.00

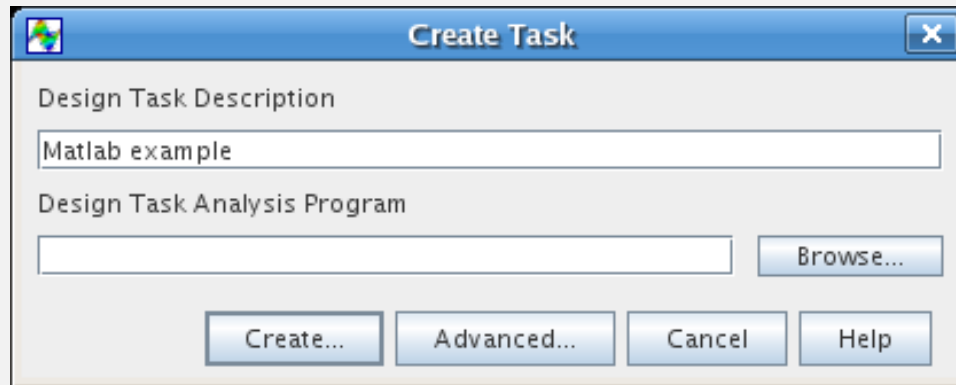
Index	Name	Type	Objective	Constraint	Low Bound	Upp Bound
1	Area	Independent	<input checked="" type="checkbox"/>	<input type="checkbox"/>	None	None
2	Volume	Independent	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2.00	None

- Define the Inputs and Responses in

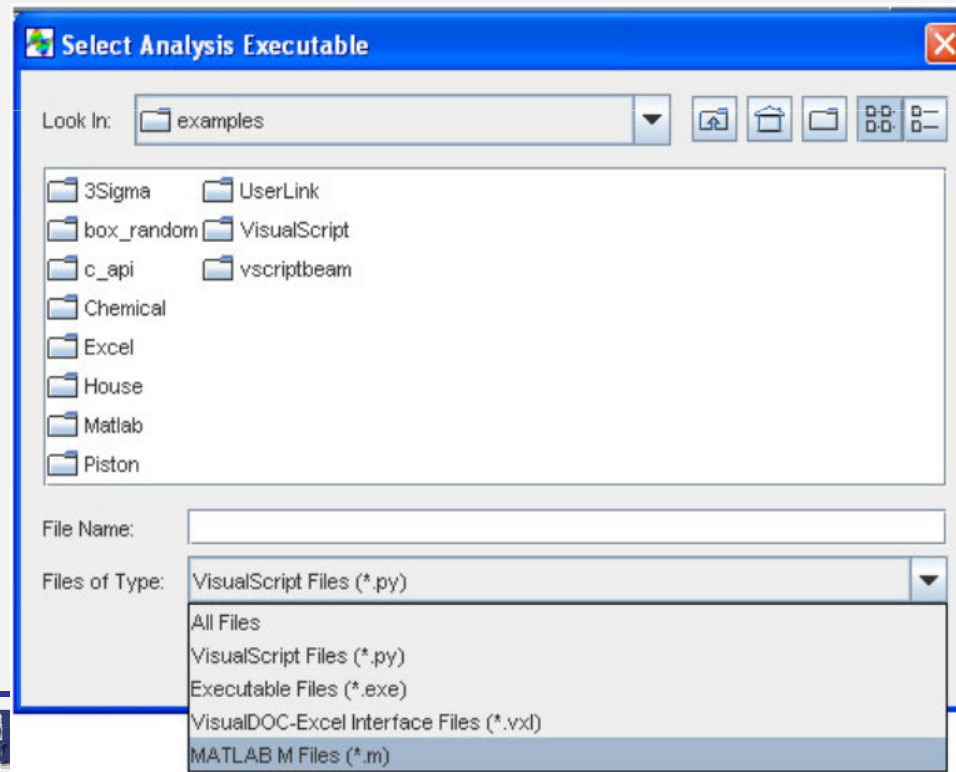
VisualDOC



Direct Interface -- Matlab



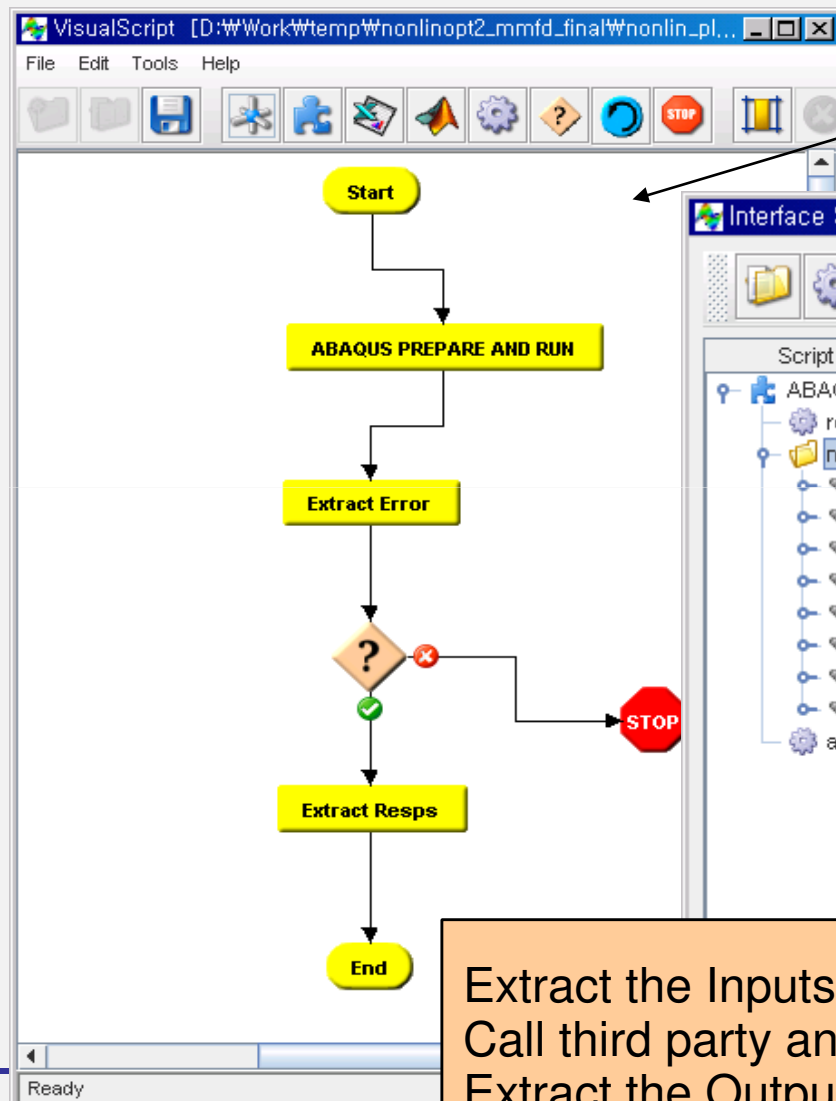
- **Create a task**



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



Coupling Third Party Software Through VisualScript



Create analysis workflow in VisualScript

Script Definition

- ABAQUS PREPARE AND RUN
 - remprev.bat
 - nonlin_plate2.inp
 - TOLE (skin)
 - E6 (long stiff)
 - E7 (cross stiff)
 - E8 (cross stiff)
 - E9 (main stiff)
 - E10 (main stiff)
 - E1 (Beam Left)
 - E2
- abaqus.bat

D:\Work\temp\nonlinopt2_mmfd_final\nonlin_plate2.inp

```

    123456789+123456789+123456789+123456789+123456789+123456789
    49 *BEAM SECTION, MATERIAL=ACIER, SECTION=RECT,
    50 ELSET=E0000002
    51 0.0286804881181, 0.0286804881181
    52 0.000000E+00, 8.695324E-03, -9.999622E-01
    53 *SHELL SECTION, ELSET=E0000003, MATERIAL=ACIER
    54 7.000E-03, 3
    55 *SHELL SECTION, ELSET=E0000004, MATERIAL=ACIER
    56 1.000E-02, 3
    57 *SHELL SECTION, ELSET=TOLE, MATERIAL=ACIER
    58 0.0025392198963, 3
    59 *SHELL SECTION, ELSET=E0000006, MATERIAL=ACIER
    60 0.0246090903694, 3
    61 *SHELL SECTION, ELSET=E0000007, MATERIAL=ACIER
  
```

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

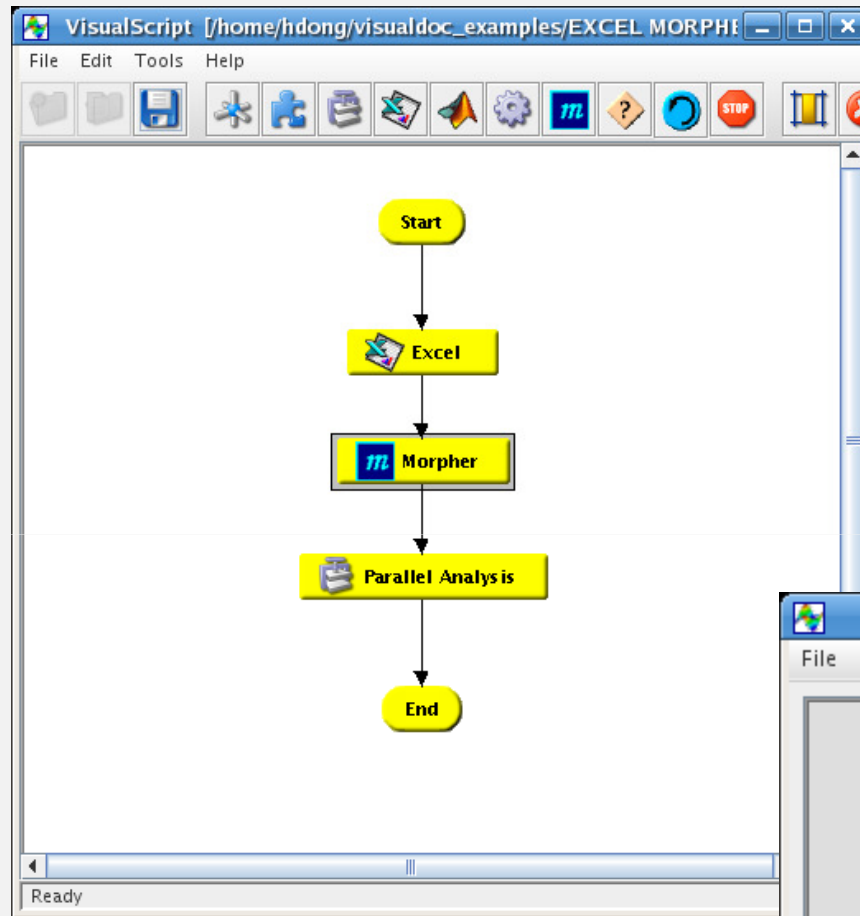


VisualDOC API

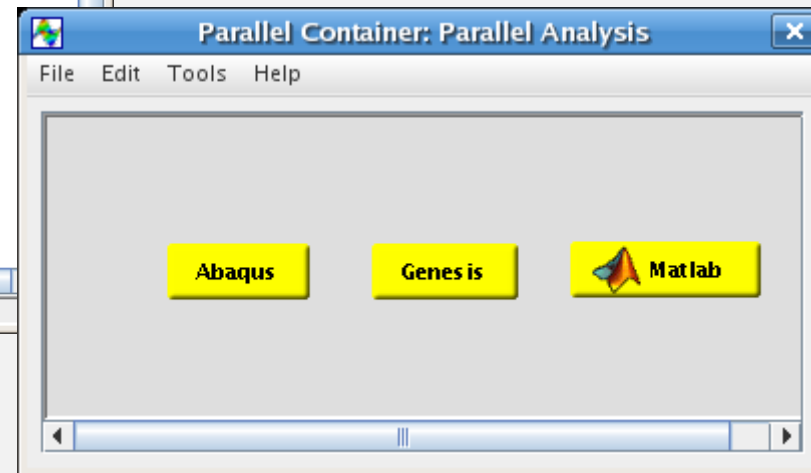
- **VisualDOC C/C++ Application Programming Interface (API) functions allow users to embed all the capabilities of VisualDOC into users' own program.**
- **These capabilities include**
 - **Direct Gradient-based Optimization (DGO)**
 - **Response Surface Approximate Optimization (RSA)**
 - **Design Of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



Parallel Analysis



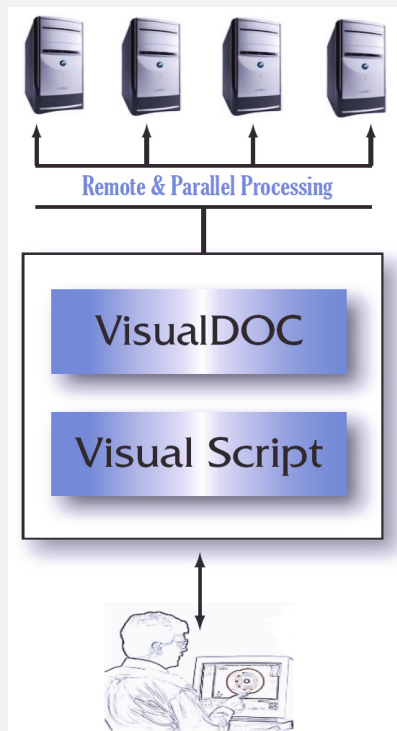
- Put multiple analysis elements in the Parallel Container



- Add Parallel Container to the workflow



Remote Run



- Analysis – Remote computers

Analysis Program Specification

Run on Remote Machine

Analysis Program: Browse...

Program Arguments:

Analysis Return Code

Extract Return Code as Response

Terminate Overall Task Execution for all Invalid Return Codes

Valid Return Code:

Remote Execution

Connection Protocol: SSH RSH

Remote User Name: Advanced Setup

Remote Host Name: Test Connection

Remote Work Directory:

Input and Output File List:

Input File List: Output File List:

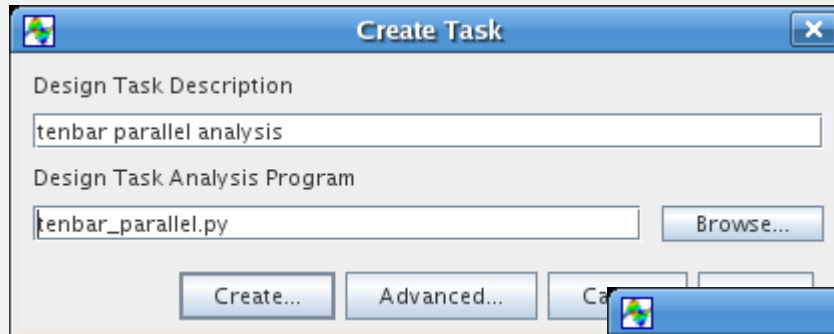
OK Cancel Help

- VisualDOC – local computer

Define remote connection properties

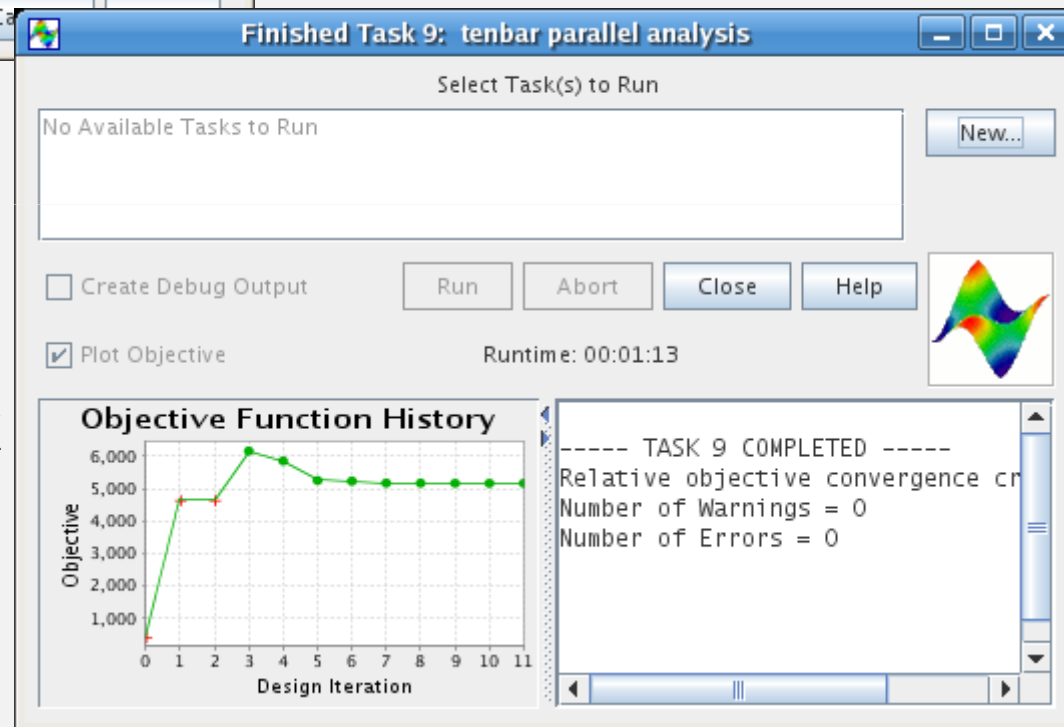


Create and Run Task

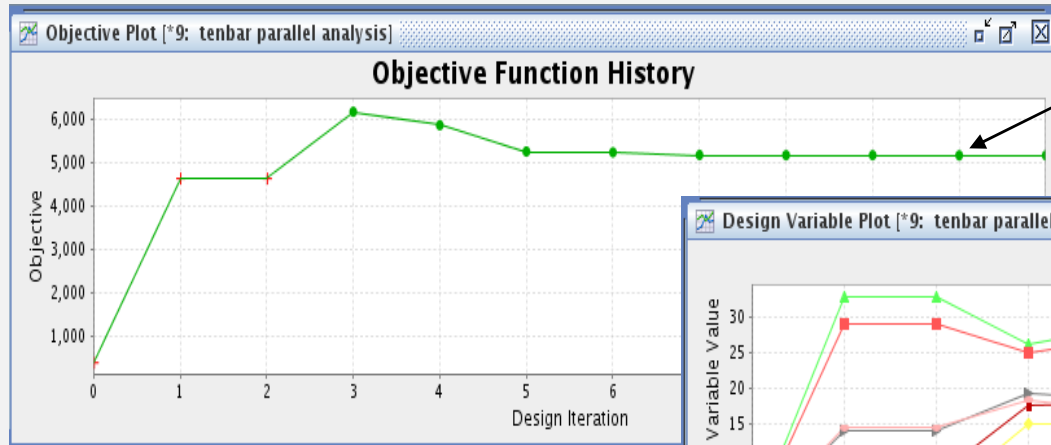


- **Create an optimization task**

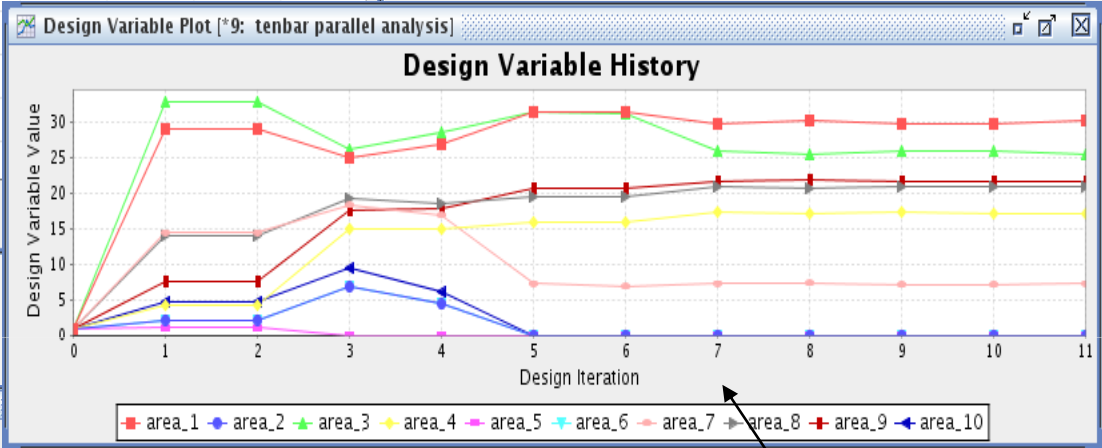
- **Run the optimization task and graphically visualizing**



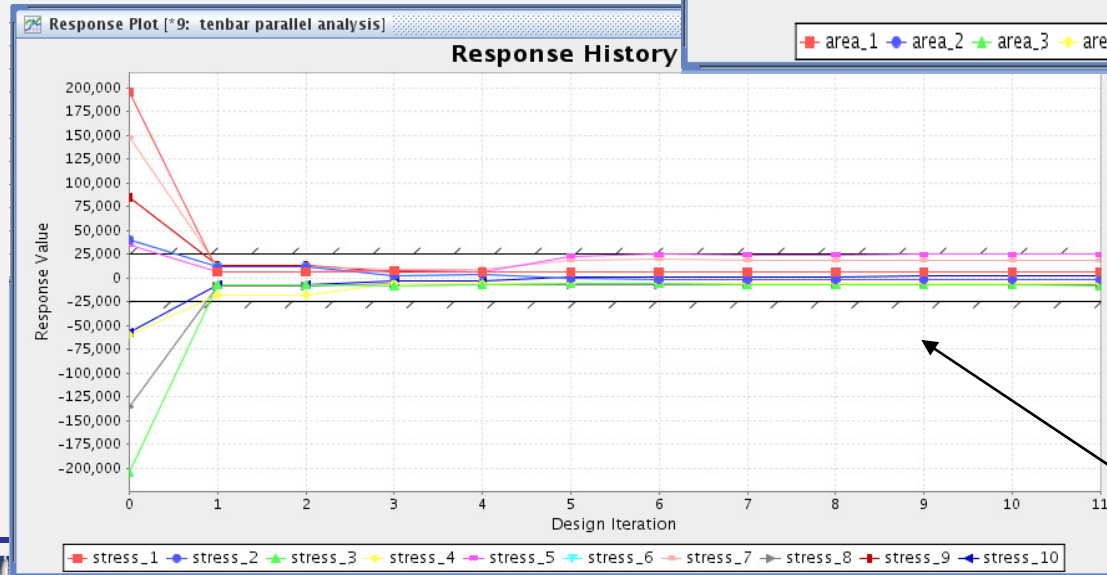
Post Process the Optimization Results



Plot Objective



Plot Design Variables



Plot Responses and show the constraints



“What-If?” Study Tool

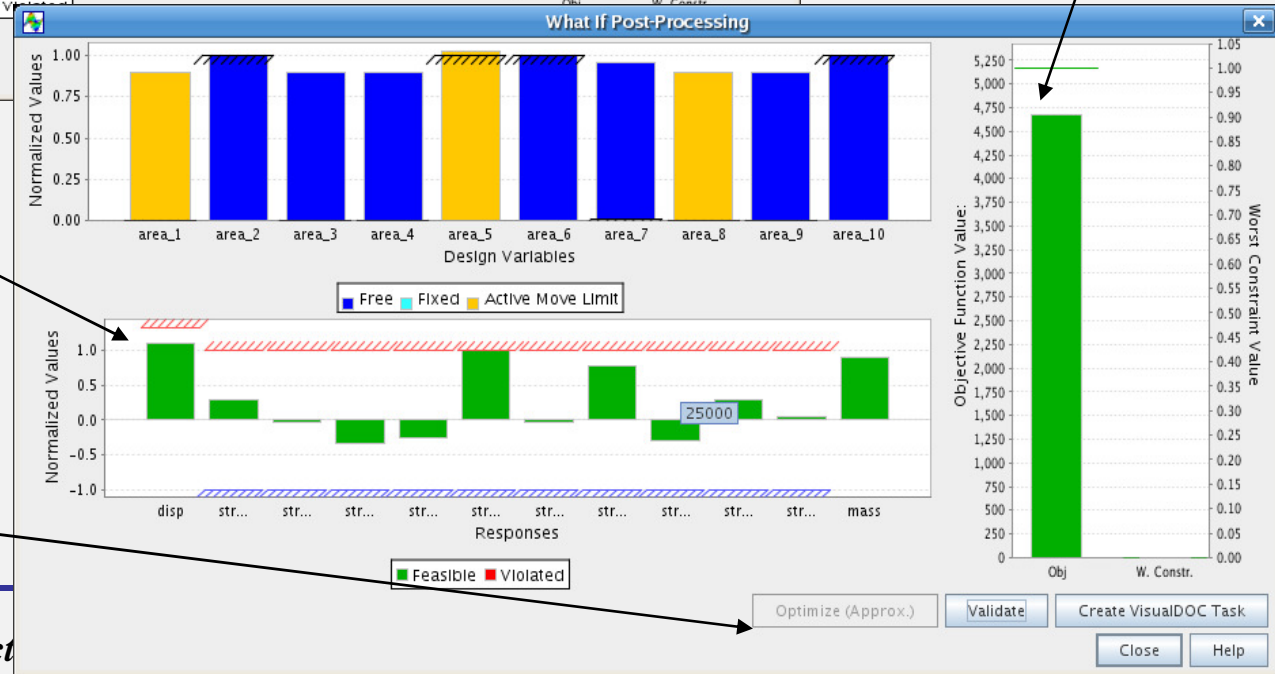


Original optimization result

New optimization result

Relax the displacement constraint

Run Approximate Optimization with new constraint



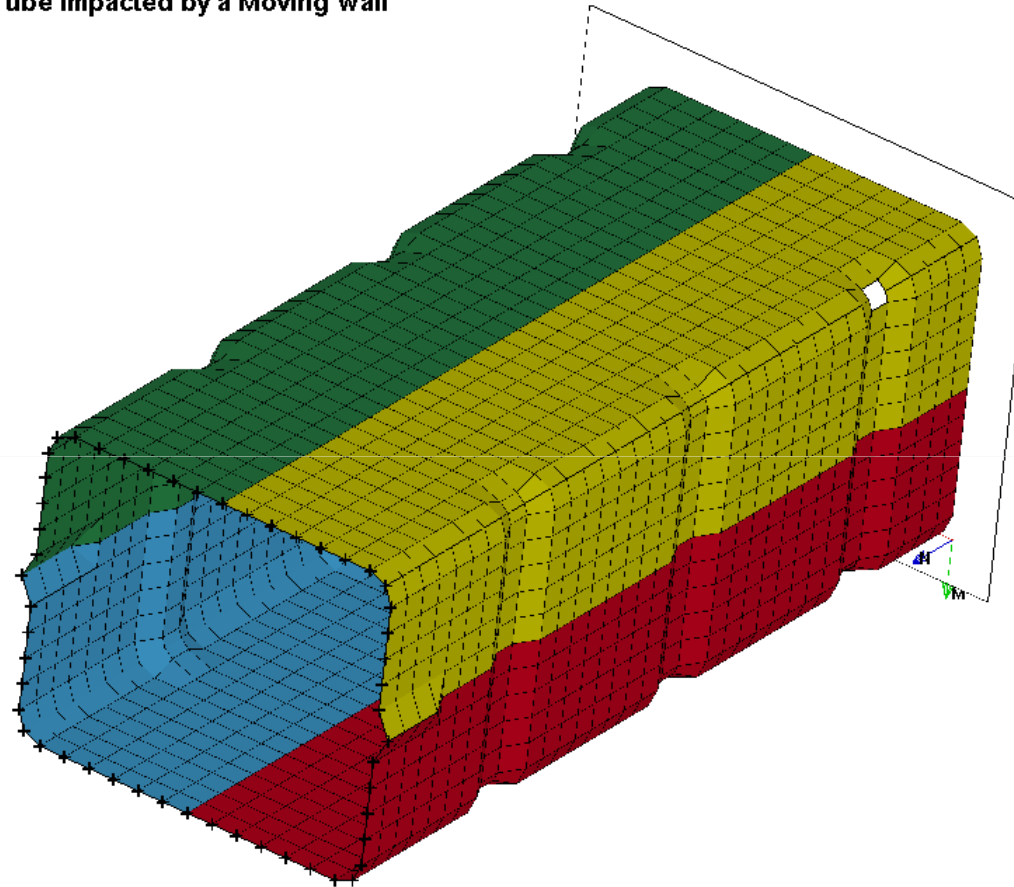
Examples



Problem Description

- **LS-Dyna Optimization**

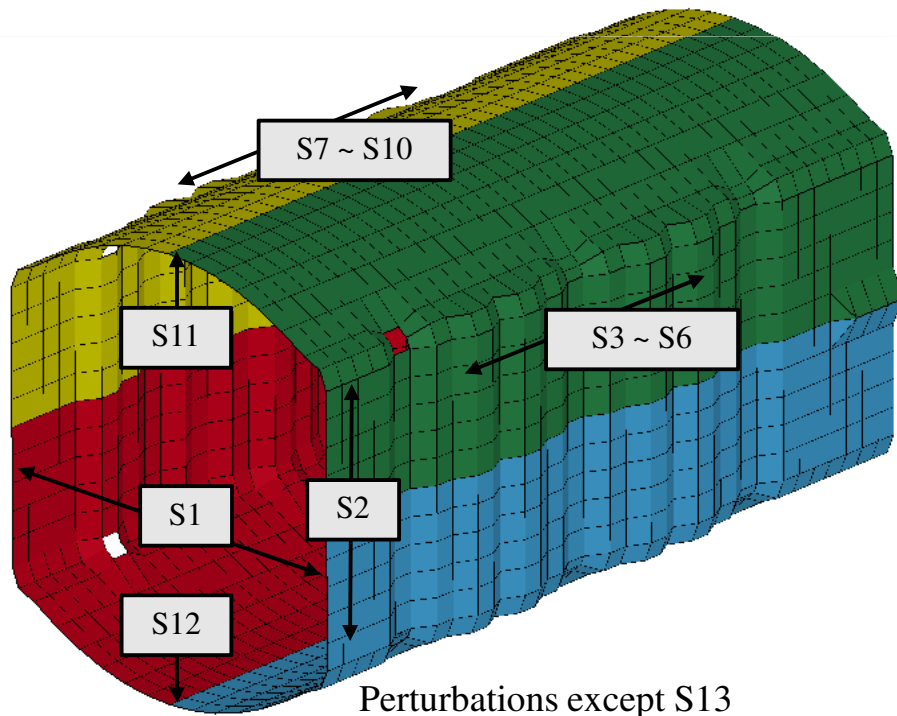
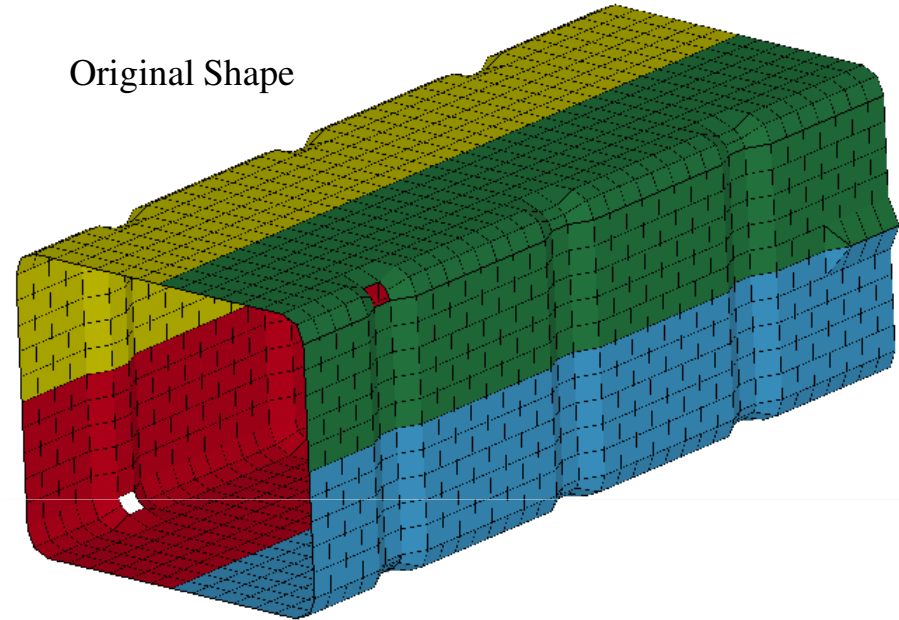
Short Crush Tube Impacted by a Moving Wall



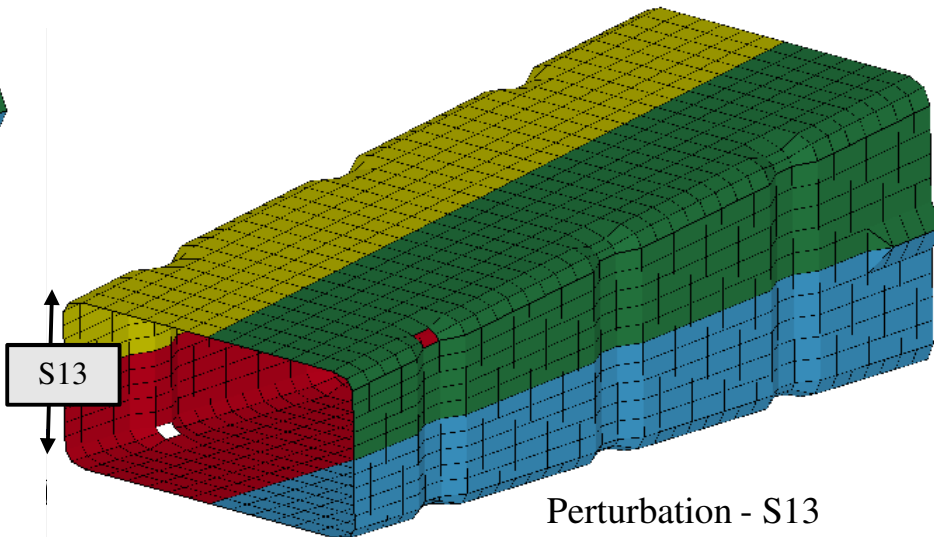
Optimization Problem

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

Original Shape



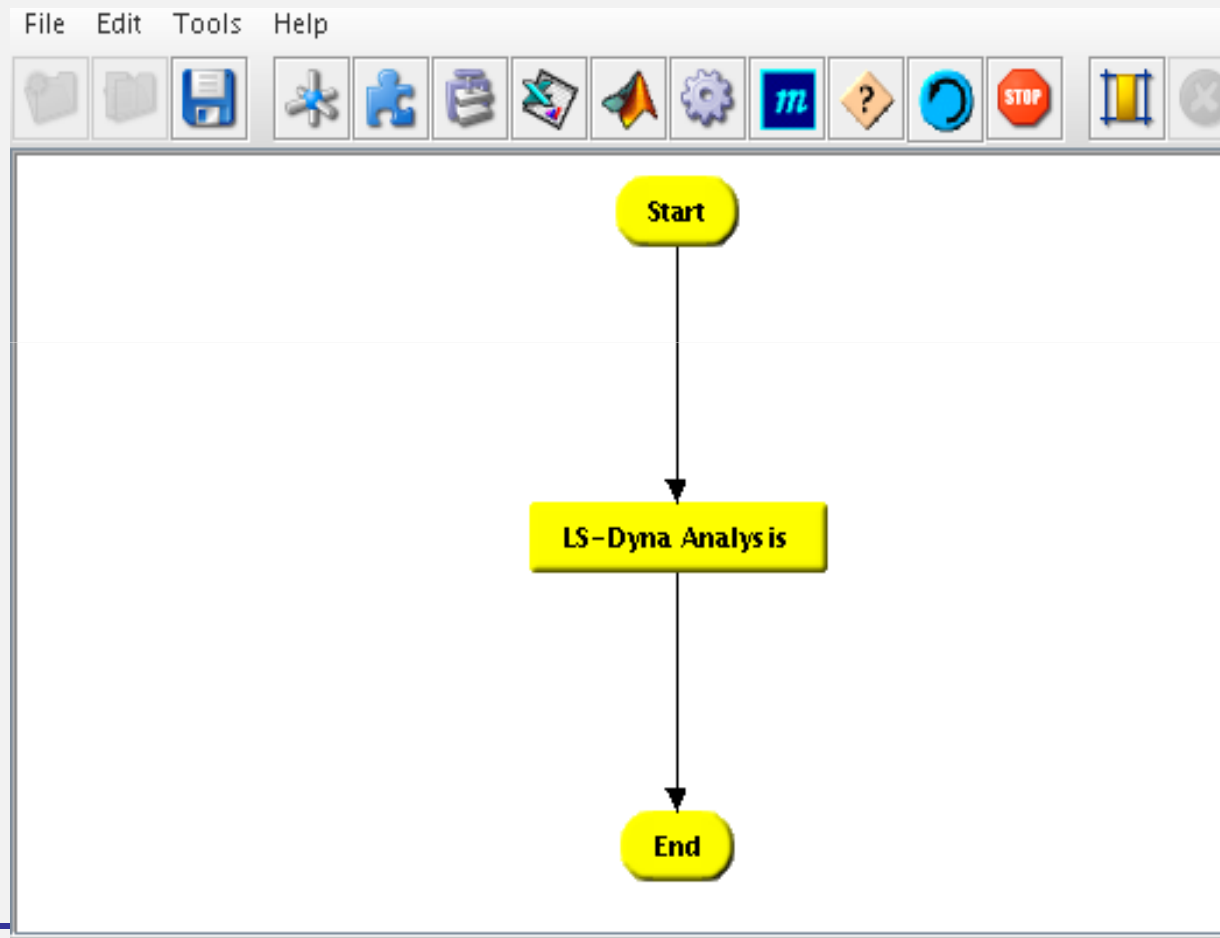
Perturbations except S13



Perturbation - S13

VisualScript

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



VisualScript

The image displays two side-by-side screenshots of the VisualScript software interface, both titled "Analysis Element Properties".

Left Screenshot (tube.k):

- Script Definition:**
 - LS-Dyna Analysis
 - shape.var
 - Width
 - Depth
 - Bead1
 - Bead2
 - Bead3
 - Bead4
 - Bead5
 - Bead6
 - Bead7
 - Bead8
 - Curvature1
 - Curvature2
 - Trapeziodal
 - tube.k
 - Thickness Search
 - Thick1
 - Thick2
 - Thick3
 - Thick4
 - ShapeChange+DynaRun
 - glstat
 - FinalCycle Search
 - KE
 - IE
 - TE

Table Data (tube.k):

	1	2	3	4
123456789*123456789*123456789*123456789*				
100	*PART			
101	\$HEADING			
102	CORNER 4			
103	\$	PID	SECID	MID
104		4	1	1
105	\$	----	1	----
106	\$	----	2	----
107	\$	----	3	----
108	\$	----	4	----
109	\$	----	1	----
110	*SECTION_SHELL			
111	\$	SECID	ELFORM	SHRF
112		1	2	
113	\$	T1	T2	T3
114		2.844	2.844	2.844
115	\$	----	1	----
116	\$	----	2	----
117	\$	----	3	----
118	\$	----	4	----
119	\$	----	1	----
120	*MAT_PIECEWISE_LINEAR_PLASTICITY			
121	\$MAT0001			
124	\$			
125		40.0	5.0	
126	\$	EPS1	EPS2	EPS3
127		0.0	0.025	0.049
128	\$	ES1	ES2	ES3
129		0.366	0.424	0.476
130	\$	----	1	----
131	\$	----	2	----
132	\$	----	3	----
				BOUNDARY

Design Variables (highlighted box):

2.844

Right Screenshot (glstat):

- Script Definition:**
 - LS-Dyna Analysis
 - shape.var
 - Depth
 - Bead1
 - Bead2
 - Bead3
 - Bead4
 - Bead5
 - Bead6
 - Bead7
 - Bead8
 - Curvature1
 - Curvature2
 - Trapeziodal
 - tube.k
 - Thickness Search
 - Thick1
 - Thick2
 - Thick3
 - Thick4
 - ShapeChange+DynaRun
 - glstat
 - FinalCycle Search
 - InternalEnergy

Table Data (glstat):

	1	2	3	4
123456789*123456789*123456789*123456789*				
4594				eroded kinetic energy..... 0.00000E+00
4595				eroded internal energy..... 0.00000E+00
4596				total energy..... 3.19631E+04
4597				total energy / initial energy.. 9.99801E-01
4598				energy ratio w/o eroded energy. 9.99801E-01
4599				global x velocity..... -3.90513E-05
4600				global y velocity..... 1.19060E-05
4601				global z velocity..... -1.00073E+00
4602				time per zone cycle.(nanosec).. 0
4603				
4604				
4605				dt of cycle 30975 is controlled by shell
4606				
4607				time..... 1.99996E+01
4608				time step..... 6.37437E-04
4609				kinetic energy..... 3.69640E+02
4610				internal energy..... 3.12069E+04
4611				stonewall energy..... 1.45811E+01
4612				spring and damper energy..... 1.00000E-20
4613				hourglass energy 2.48273E+02
4614				system damping energy..... 0.00000E+00
4615				sliding interface energy..... 1.26663E+02
4616				external work..... 0.00000E+00
4618				eroded kinetic
4619				eroded internal
4620				total energy..
4621				total energy / initial energy.. 9.99801E-01
4622				energy ratio w/o eroded energy. 9.99801E-01
4623				global x velocity..... -1.61178E-05
4624				global y velocity..... 4.73480E-06
4625				global z velocity..... -9.56564E-01
4626				time per zone cycle.(nanosec).. 0

Responses (highlighted box):

3.12069E+04

VisualDOC

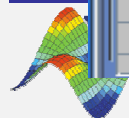
File Edit Catalog Task Post Attributes Database Window Help

Responses

Index	Name	Type	Objective	Constraint	Low Bound	Upp Bound
1	IE	Independent	<input checked="" type="checkbox"/>	<input type="checkbox"/>	None	None
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		
			<input type="checkbox"/>	<input type="checkbox"/>		

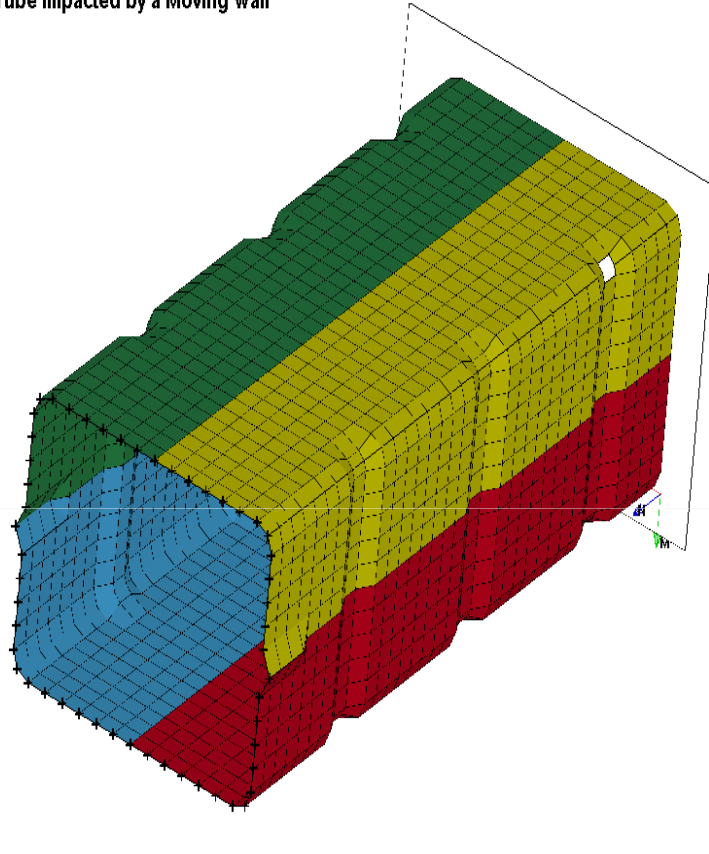
Inputs

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



Results

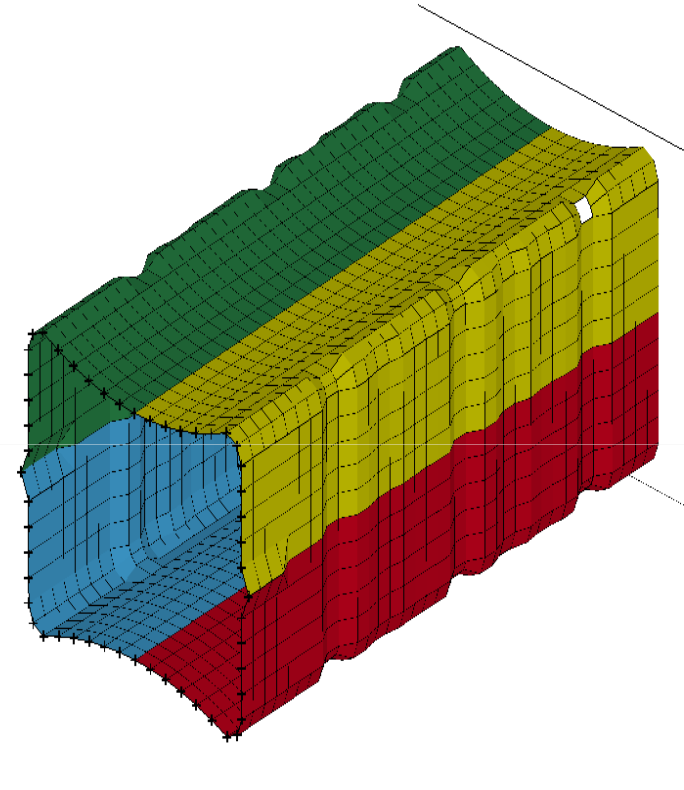
Short Crush Tube Impacted by a Moving Wall



Initial Design

Internal Energy = 10407.20

Short Crush Tube Impacted by a Moving Wall



Optimal Design

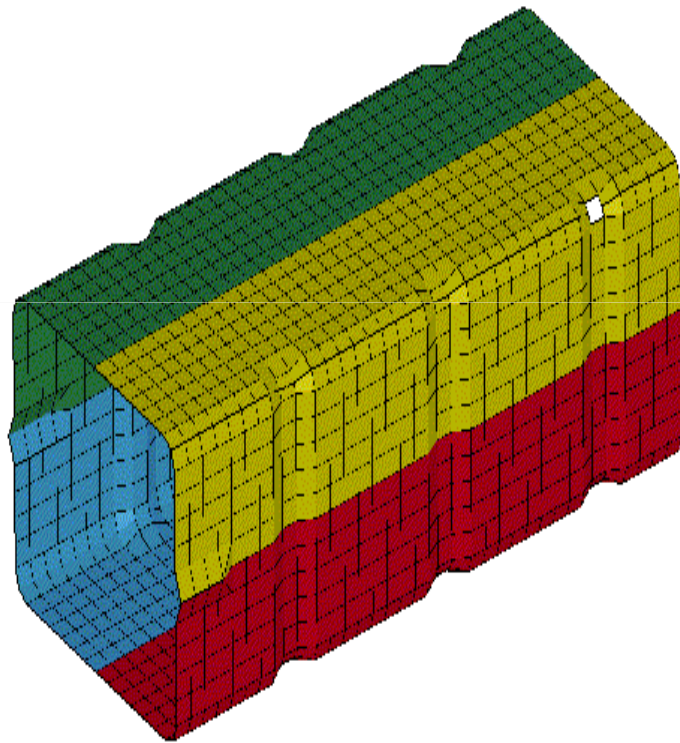
Internal Energy = 31795.60



Results

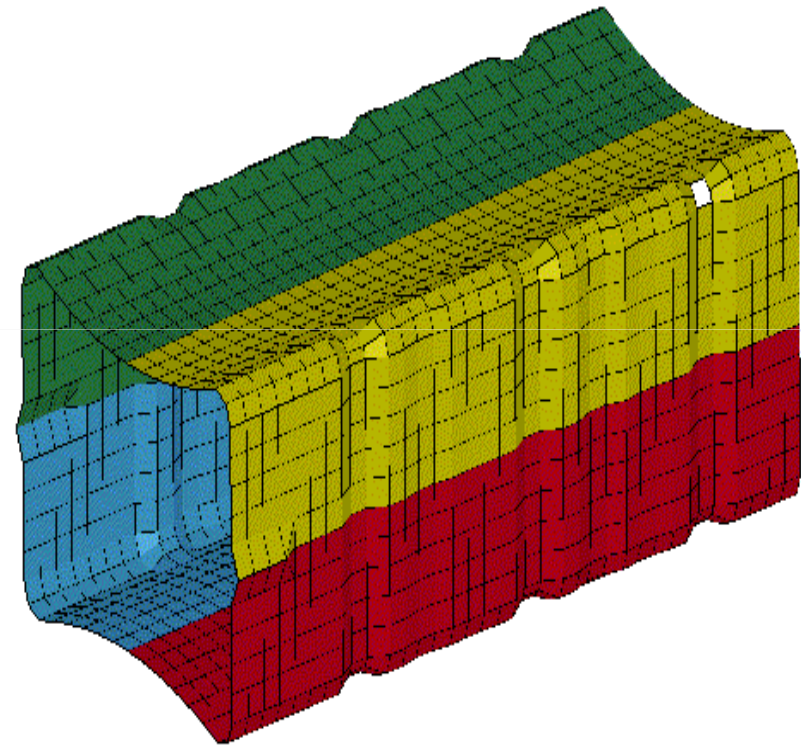
SHORT CRUSH TUBE IMPACTED BY A MOVING W

Time = 0

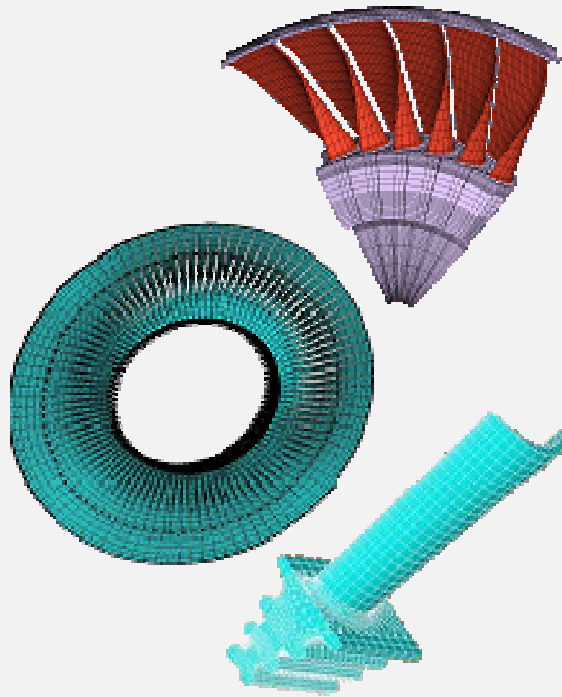


SHORT CRUSH TUBE IMPACTED BY A MOVING W

Time = 0



Case Study – Turbomachinery System Design



Preliminary Design

AxSTREAM

Meshing

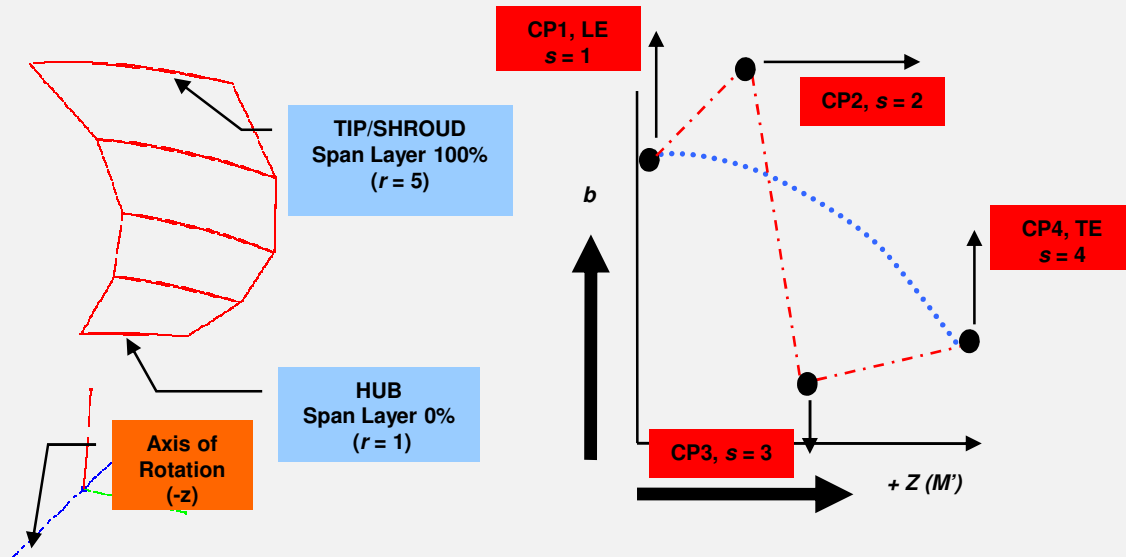
Structural and CFD
Analysis and Optimization

GENESIS / VisualDOC

Blades, Disks, Complete Systems



Case Study – Turbomachinery System Design



- 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

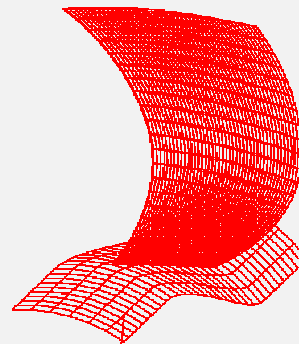
$$\partial M = \sqrt{\partial R \cdot \partial R + \partial Z \cdot \partial Z} = \partial Z$$

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

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

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

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



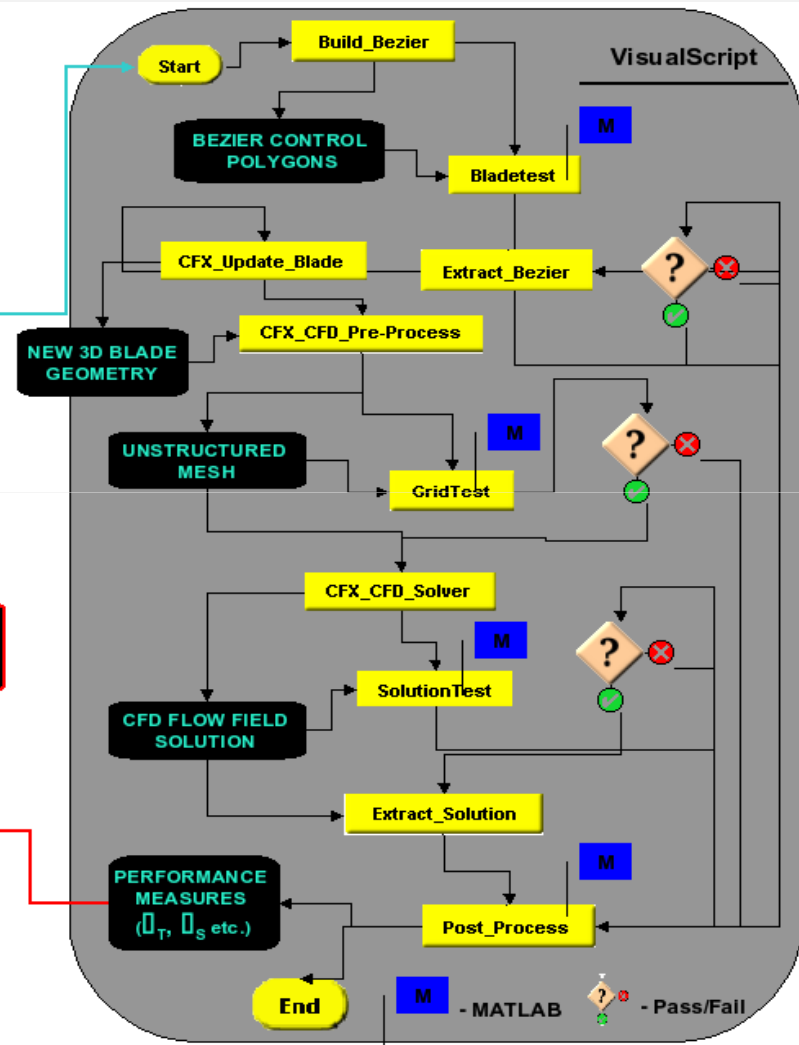
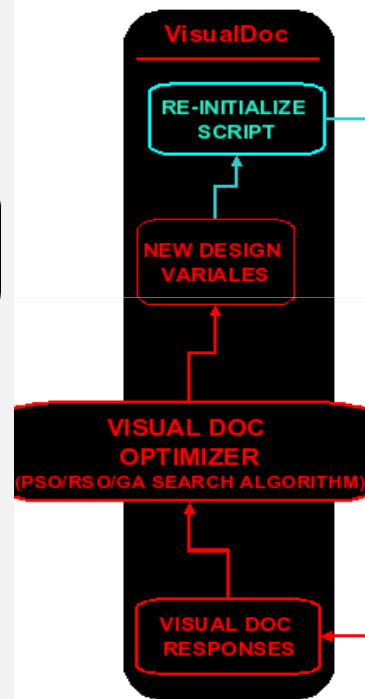
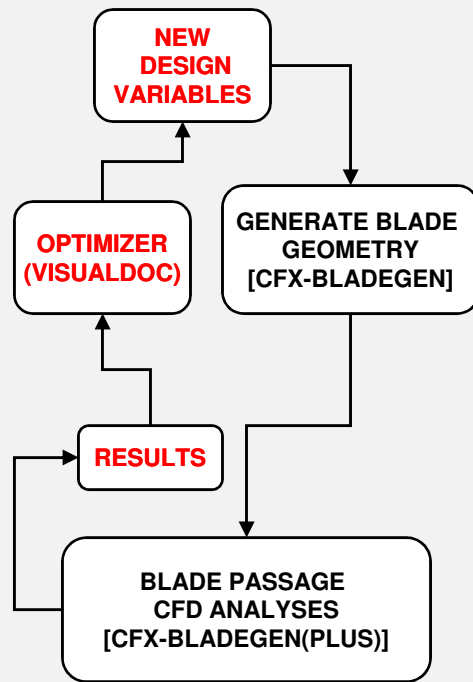
S - Fractional distance along the curve $0 \leq S \leq 1$



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

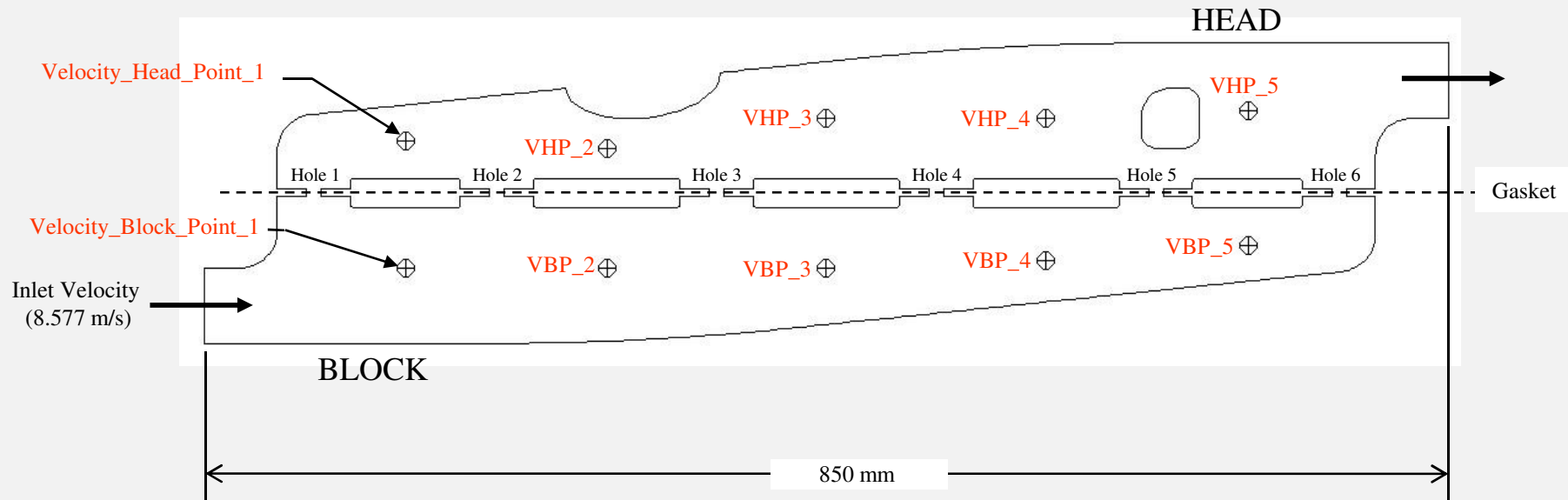
2-D Z-Flow engine cooling system (Block, Head, and Gasket)

Objective: Maximize the fluid velocity averaged at 10 locations

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

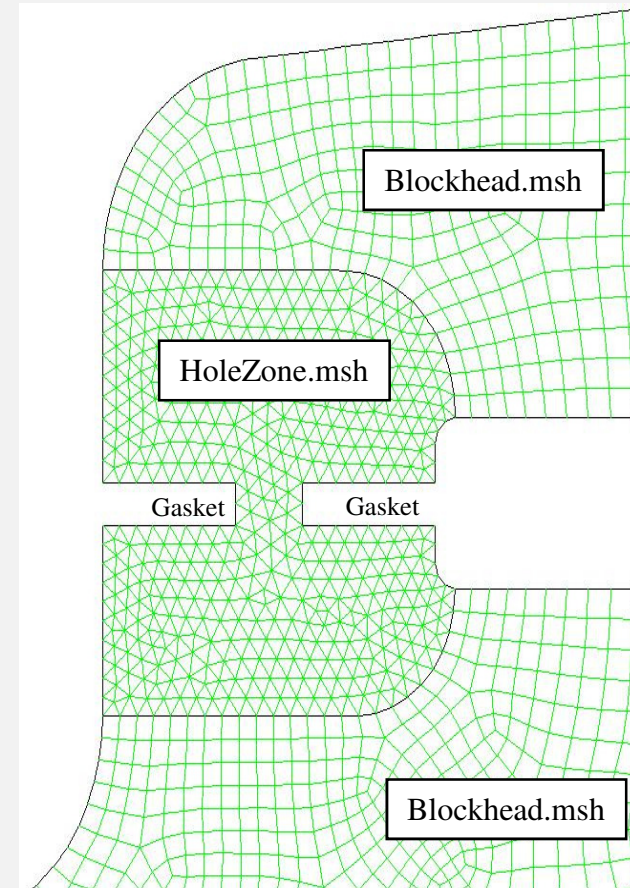
Constraints: Minimum velocity at 10 locations

Analysis: FLUENT CFD program



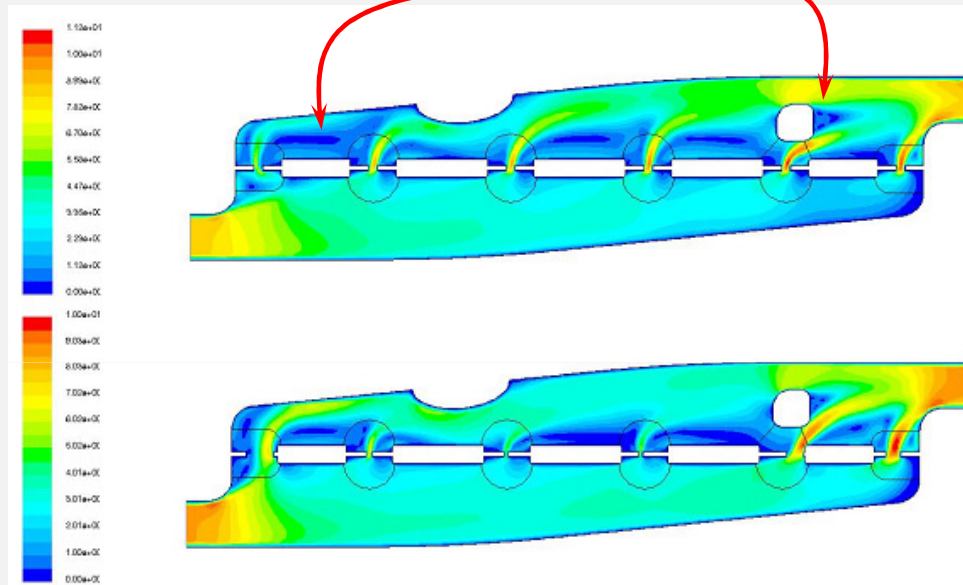
Case Study – Engine Head Gasket

- *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

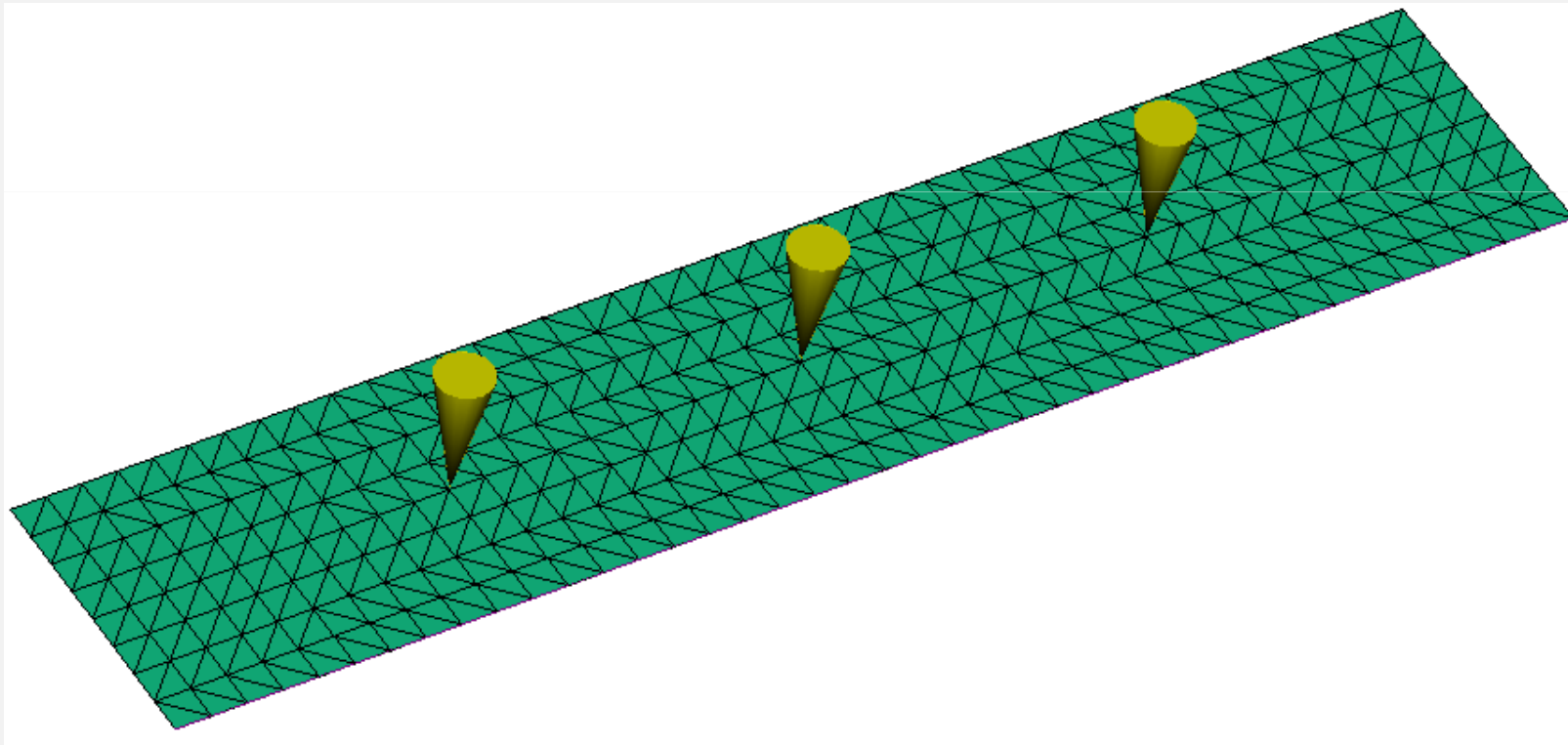
Optimal design

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



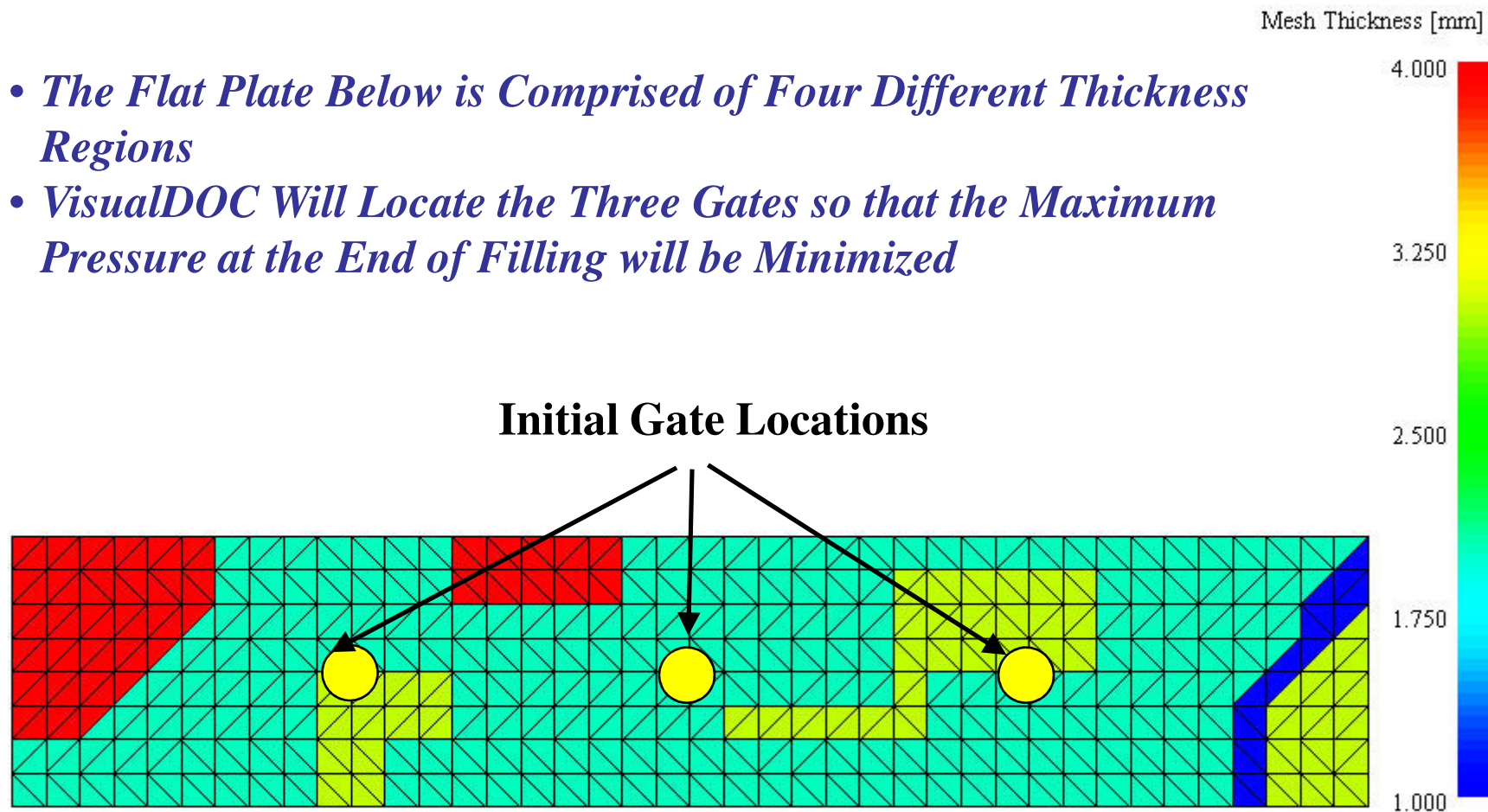
Case Study – Integration with MoldFlow

- *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*

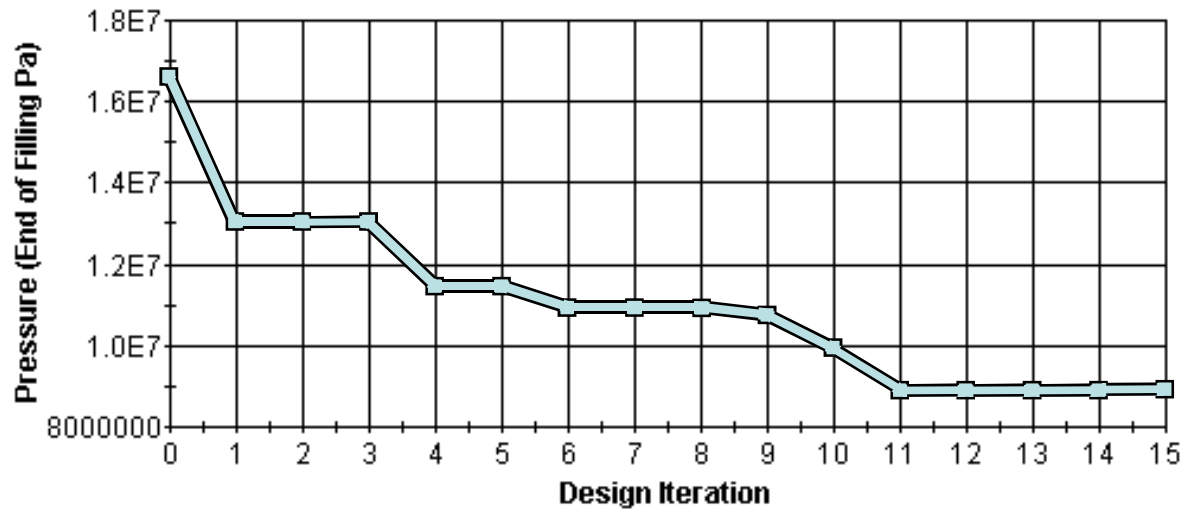


Case Study – Integration with MoldFlow

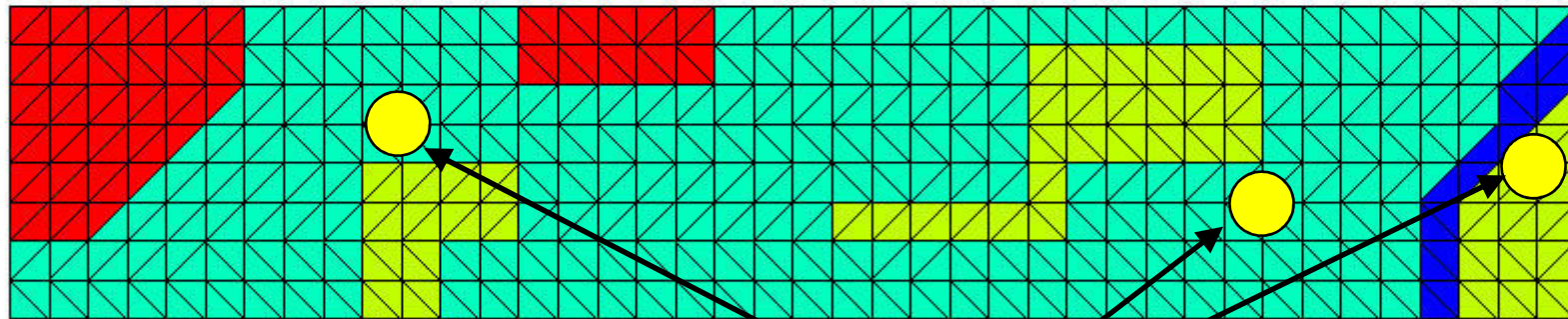
Optimization Process Sequence



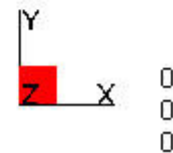
Objective Function History



Mesh Thickness [mm]



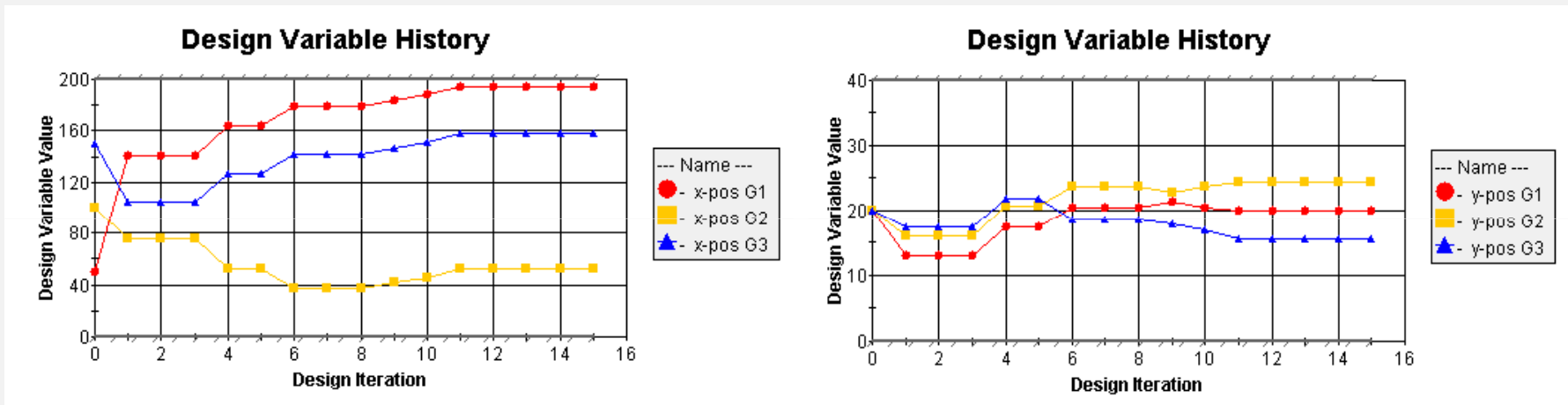
Optimal Gate Locations



Scale (120 mm)

Case Study – Integration with MoldFlow

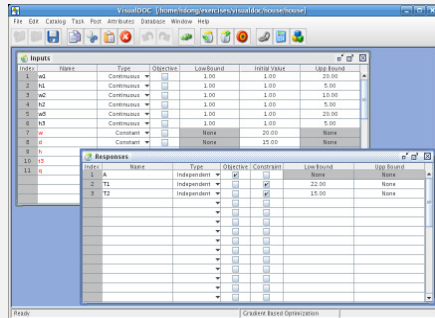
- *During 15 iterations, injector X and Y coordinates for each gate migrated to plate locations that minimized the maximum pressure at the end of fill time.*
- *Total 22 analyses were performed for this optimization.*



- *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.*

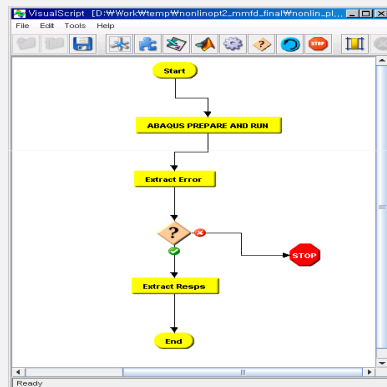
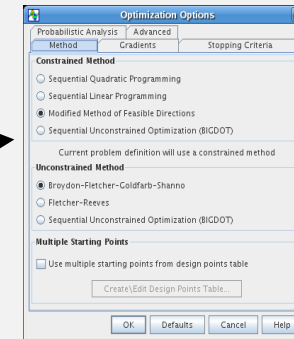


Summary



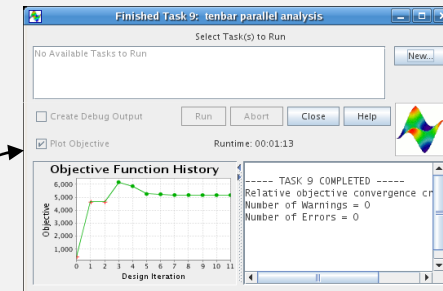
Set up Input and Output

Set Optimization Module and Respective Options

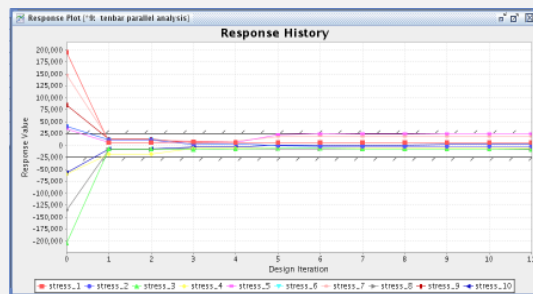


Integrate with Analysis

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.*

