

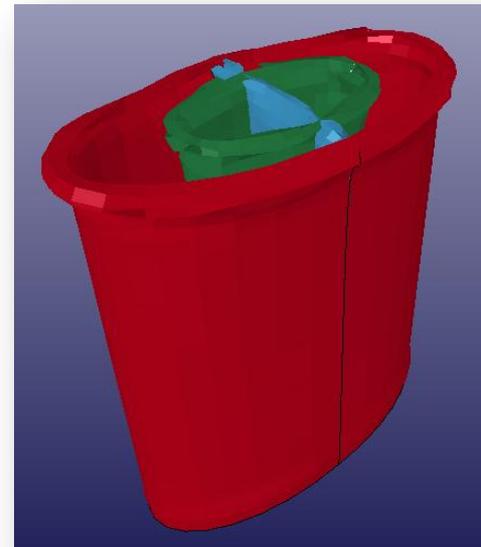
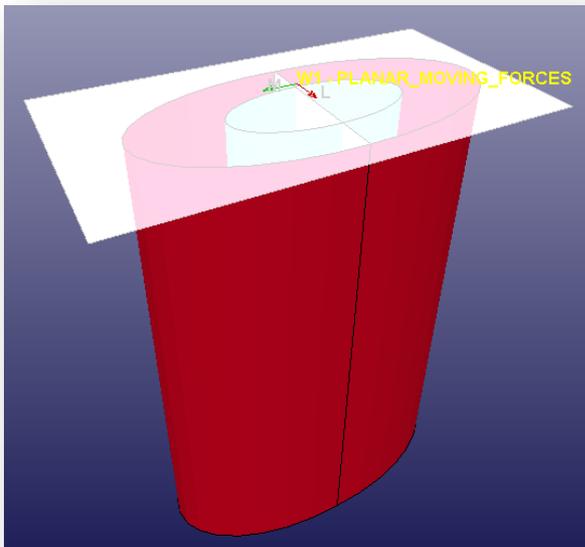
Introductory Course: Using LS-OPT[®] on the TRACC Cluster

1.6a - Design Optimization; Simple Problem

By: Cezary Bojanowski, PhD

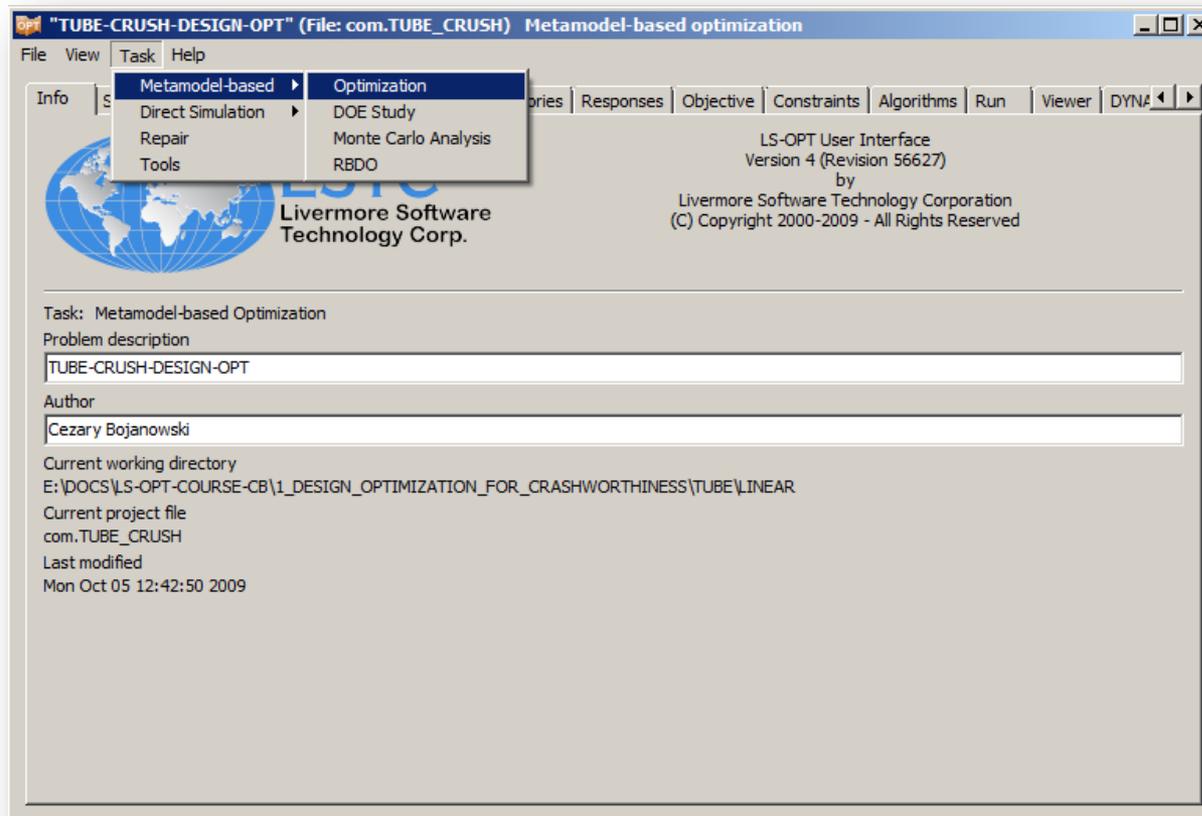
Problem Description

- Steel tubes crushed with falling rigid wall
- Objective: Minimize mass of the structure
- Constraints: maximum crush
- Three design variables:
 - thickness of inner tube – t_1
 - thickness of inner plate – t_2
 - thickness of outer tube – t_3



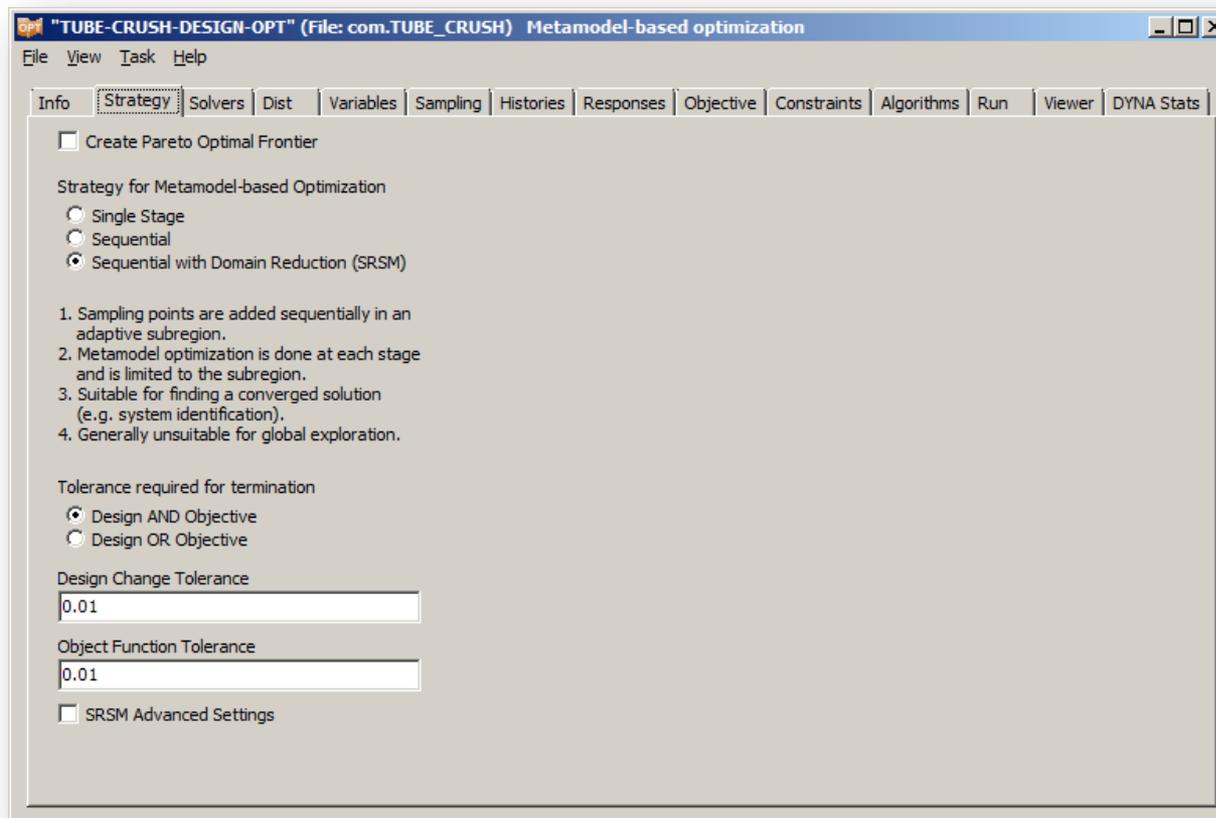
Task Selection

- Go to Task Tab and
- Select Metamodel – based Optimization



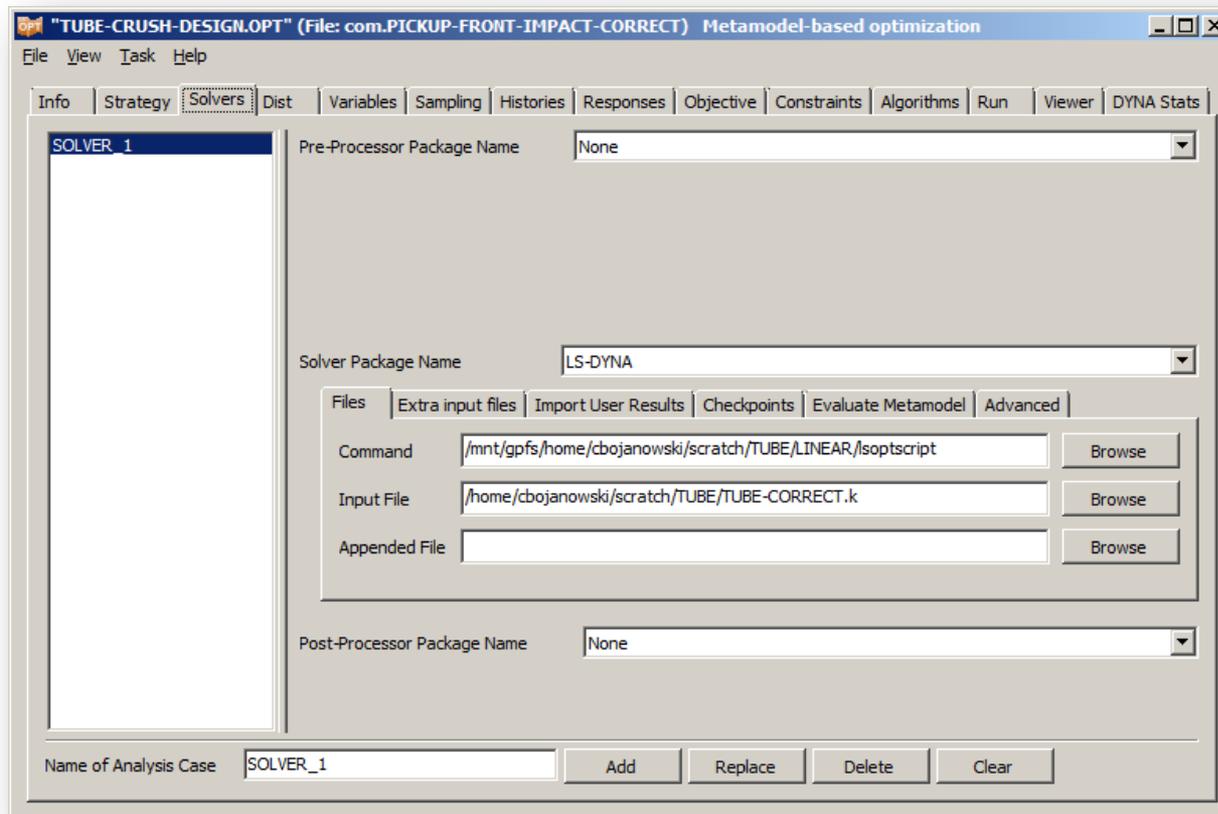
Linear Response Surface - First Iteration

- Go to the Strategy panel
- Choose Sequential with Domain Reduction (SRSM)
- Leave the defaults for the convergence tolerance



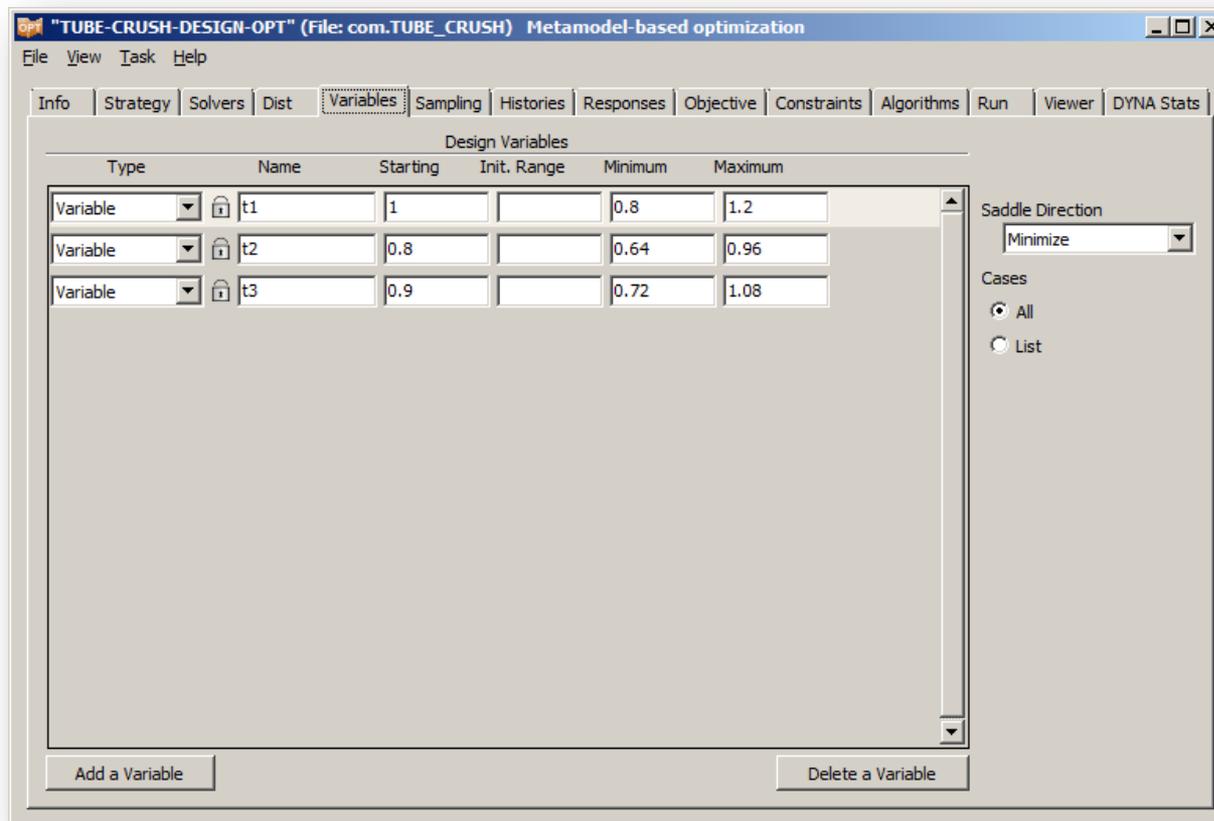
Solvers Panel

- In the Solvers panel browse to your LS-DYNA® executables (Windows) or to **Isopscript** (Linux system at TRACC) at Command line
- For the input file find the **TUBE-CORRECT.k** file
- Type **SOLVER_1** in the Name of Analysis Case field and hit Add



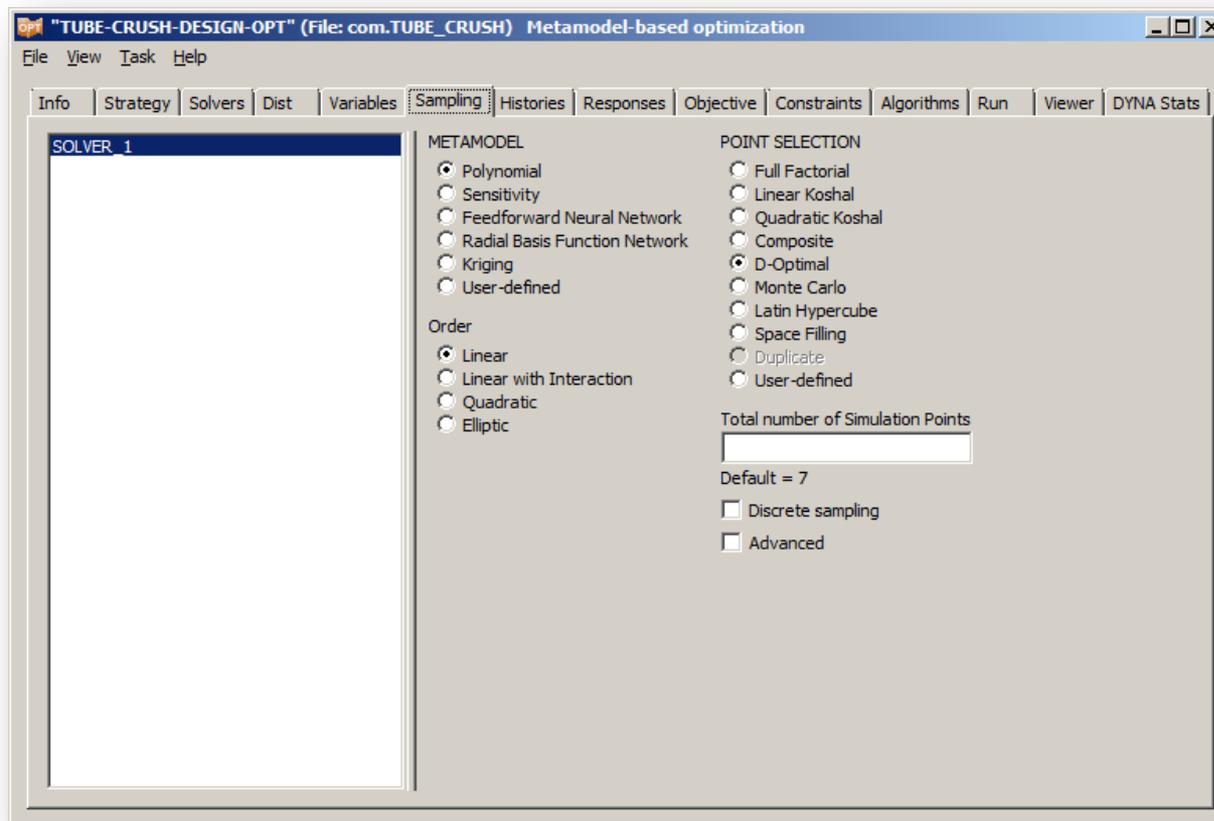
Variables Panel

- In the Variables panel Add three variables:
 - **t1** with starting value of **1** with lower bound **0.8** and upper bound **1.2**
 - **t2** with starting value of **0.8** with lower bound **0.64** and upper bound **0.96**
 - **t3** with starting value of **0.9** with lower bound **0.72** and upper bound **1.08**



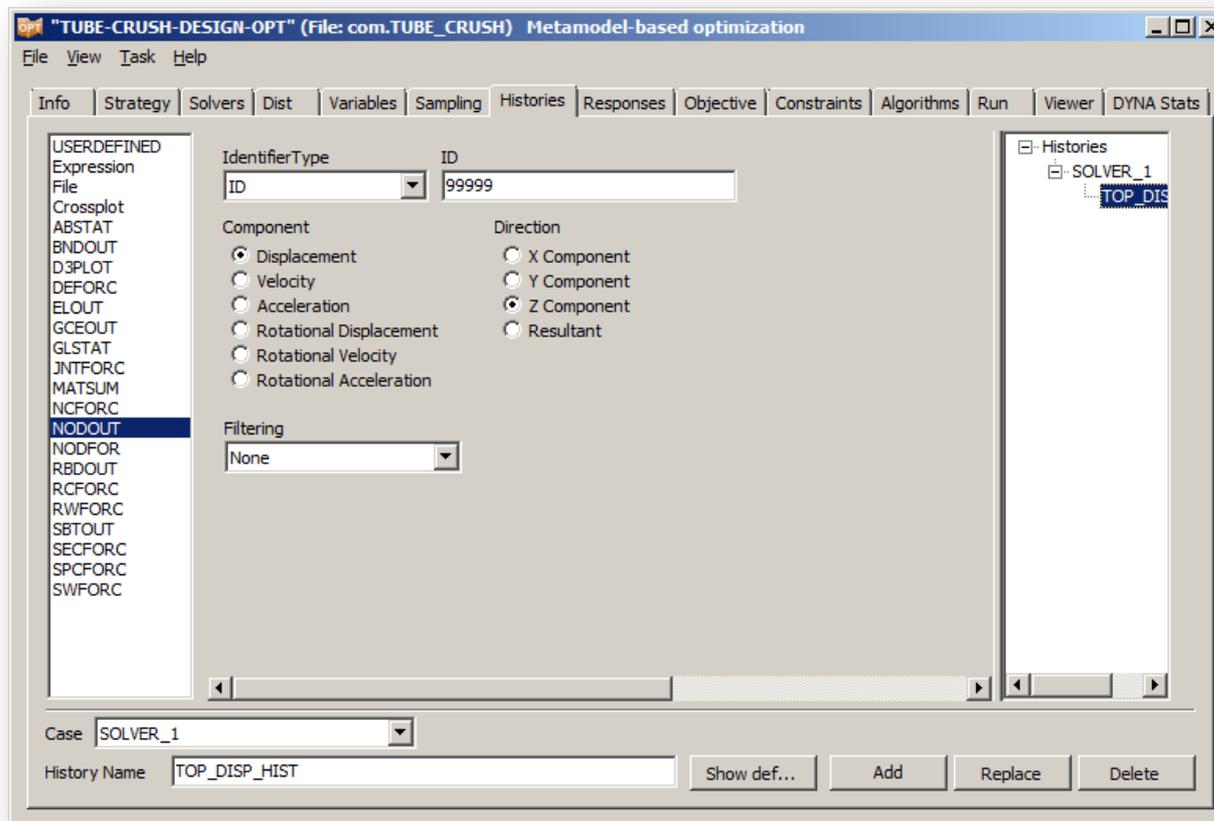
Sampling Panel

- In the Sampling panel select Polynomial Metamodel with Linear order
- For Point Selection choose D-Optimal criterion



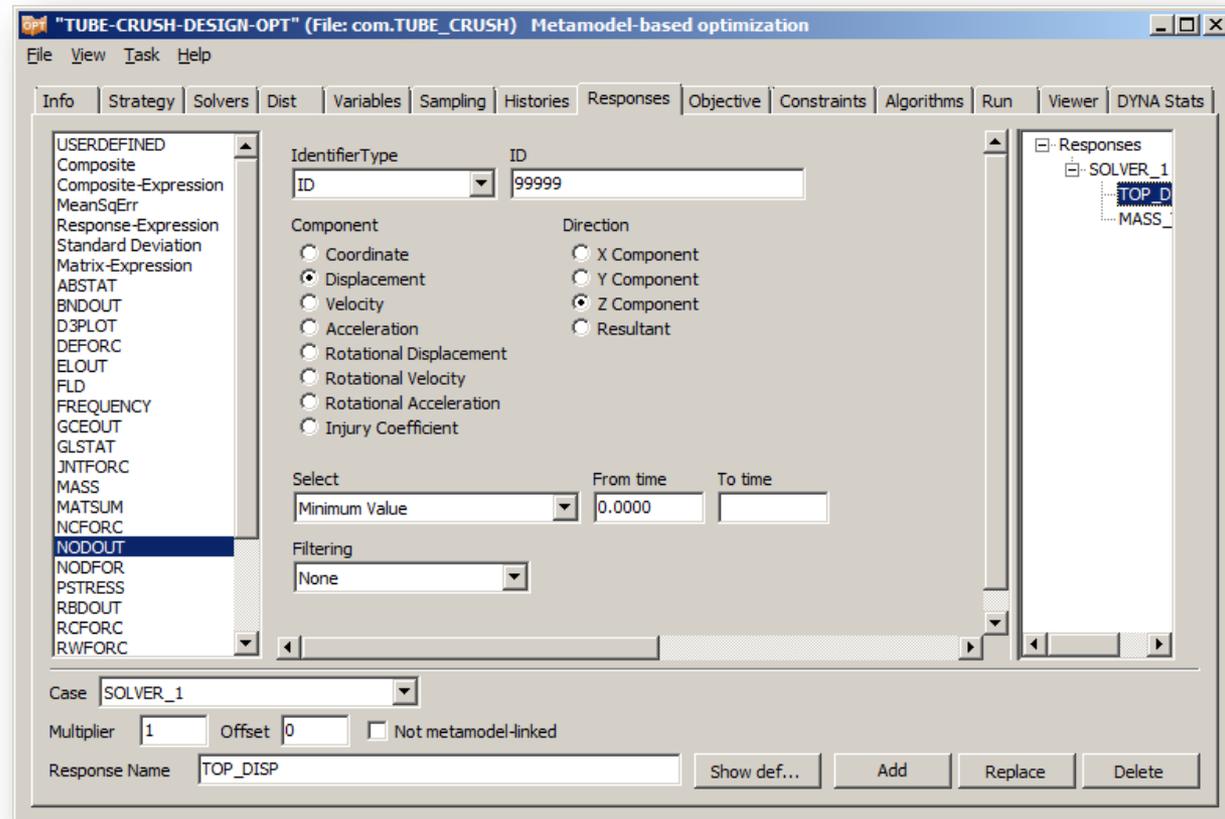
Histories Panel

- In the Histories panel from the right window select **NODOUT** file
- For ID identifier type **99999** – the node on rigid wall
- For the component choose Z Component of the displacement
- Give it a name **TOP_DISP_HIST** and confirm by Add button



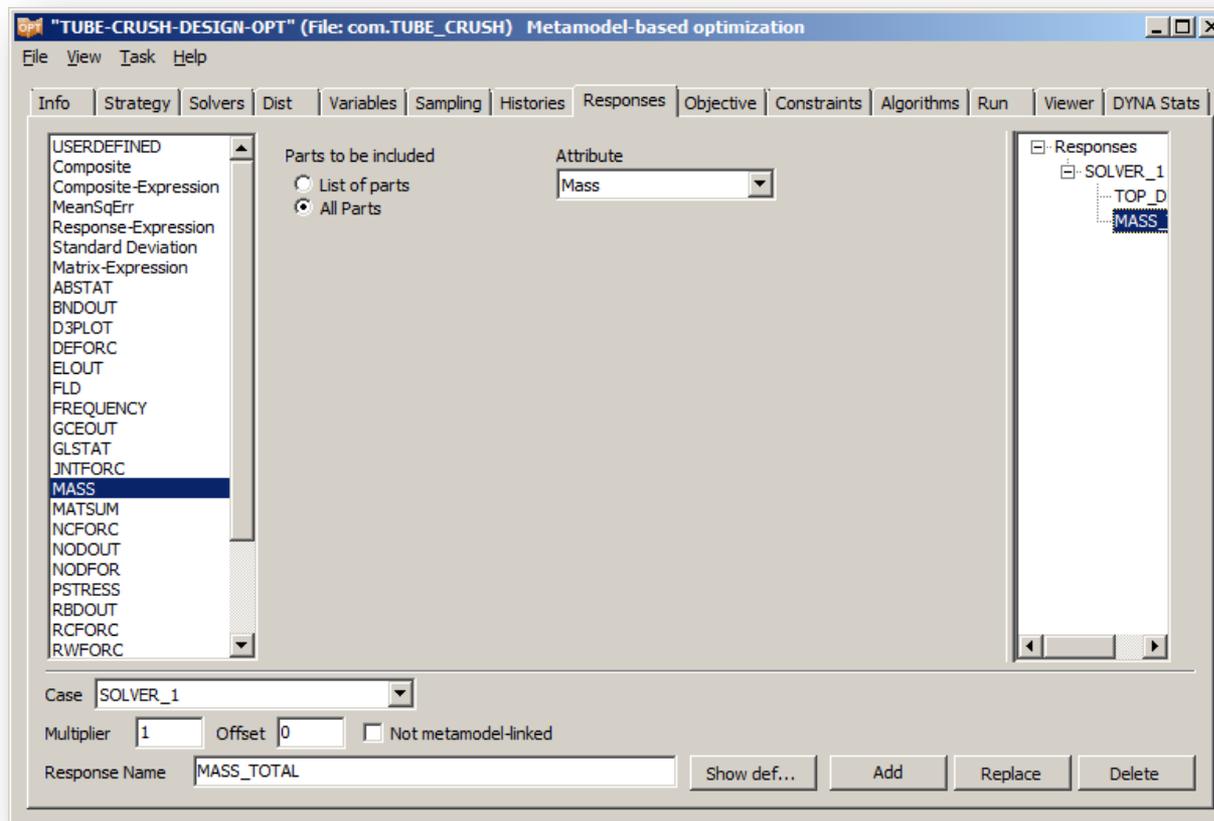
Responses Panel

- In the Responses panel also choose **NODOUT** from the left window
- For Z Displacement Component choose Identifier Type ID and type **99999** in ID window
- Select minimum value
- In Response Name type **TOP_DISP** and hit Add
- Note the difference response and history



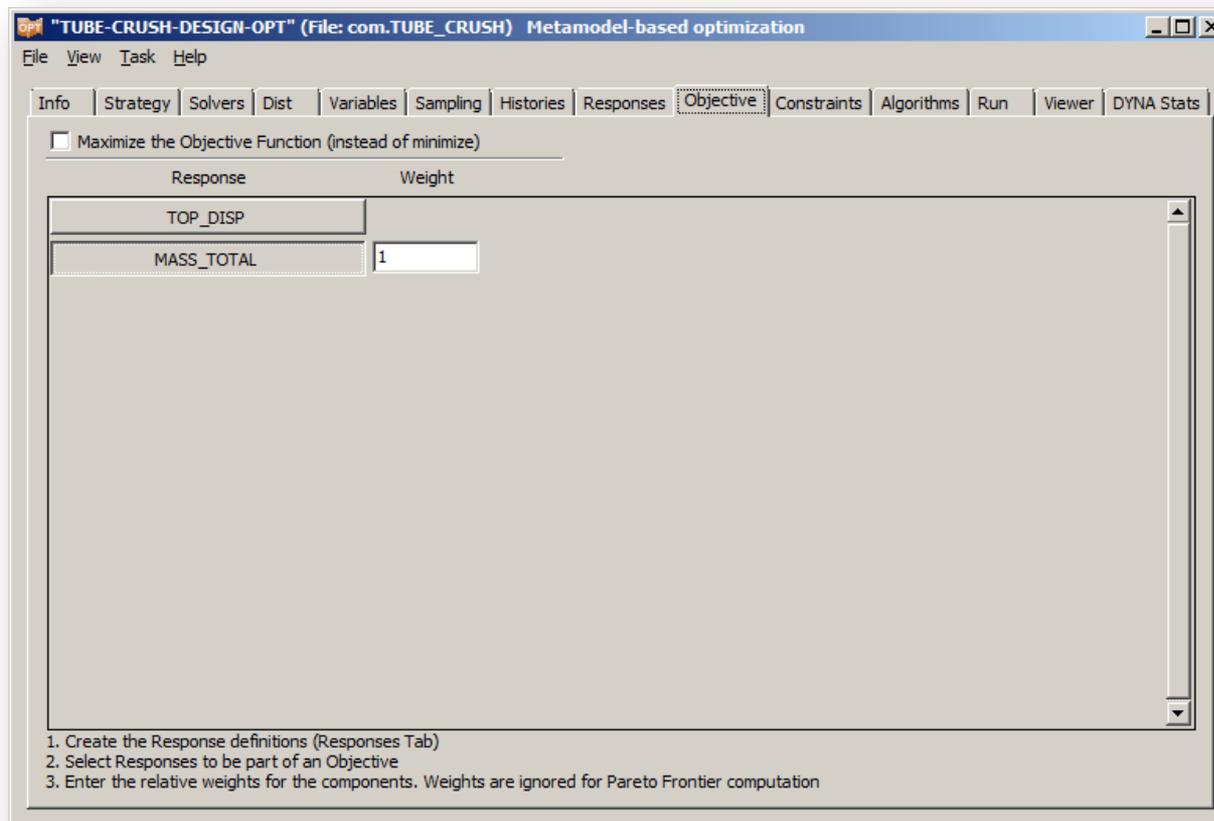
Responses Panel

- From responses window select **MASS**
- Select All Parts to be included and leave the Attribute Mass
- For Response Name enter **MASS_TOTAL**
- Hit Add to create the response



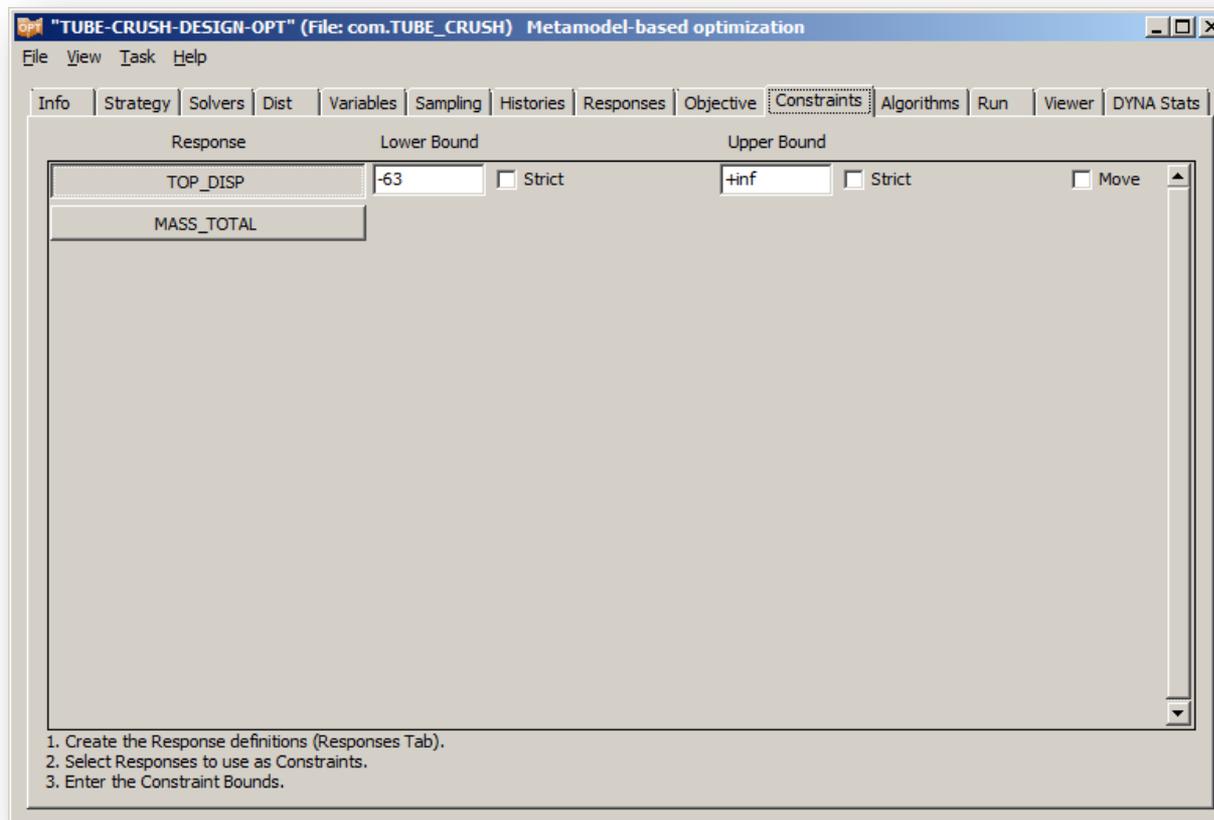
Objectives Panel

- In Objectives panel select **MASS_TOTAL** with default weight 1.0



Constraints Panel

- From Responses select **TOP_DISP**
- For lower bound type **-63** and leave the Upper bound default (**+inf**)



Run Panel

- Select PBS for QUEUING software (TRACC cluster users)
- For Concurrent Jobs enter **8**
- For Number of Iteration enter **1** and
- Check Omit last verification run and Clean Start from iteration **1**
- Hit Run to start simulations

The screenshot displays the 'Run' panel of the Opti software. The main window title is 'TUBE-CRUSH-DESIGN-OPT (File: com.TUBE_CRUSH) Metamodel-based optimization'. The interface includes a menu bar (File, View, Task, Help) and a tabbed interface with tabs for Info, Strategy, Solvers, Dist, Variables, Sampling, Histories, Responses, Objective, Constraints, Algorithms, Run, Viewer, and DYNA Stats. The 'Run' tab is active, showing a table of job progress and configuration options.

Job ID	PID	Progress
1	(20168)	Normal Termination
2	(20072)	Normal Termination
3	(19852)	Normal Termination
4	(18656)	Normal Termination
5	(17388)	Normal Termination
6	(18584)	Normal Termination

Configuration options in the Run panel:

- QUEUING:** None (dropdown), Concurrent Jobs: 8 (text input), Case: SOLVER_1 (dropdown)
- SEQUENTIAL OPTIMIZATION:** Number of iterations: 1 (text input), Omit last verification run, Clean Start from Iteration: 1 (text input)

Buttons: Run, Stop

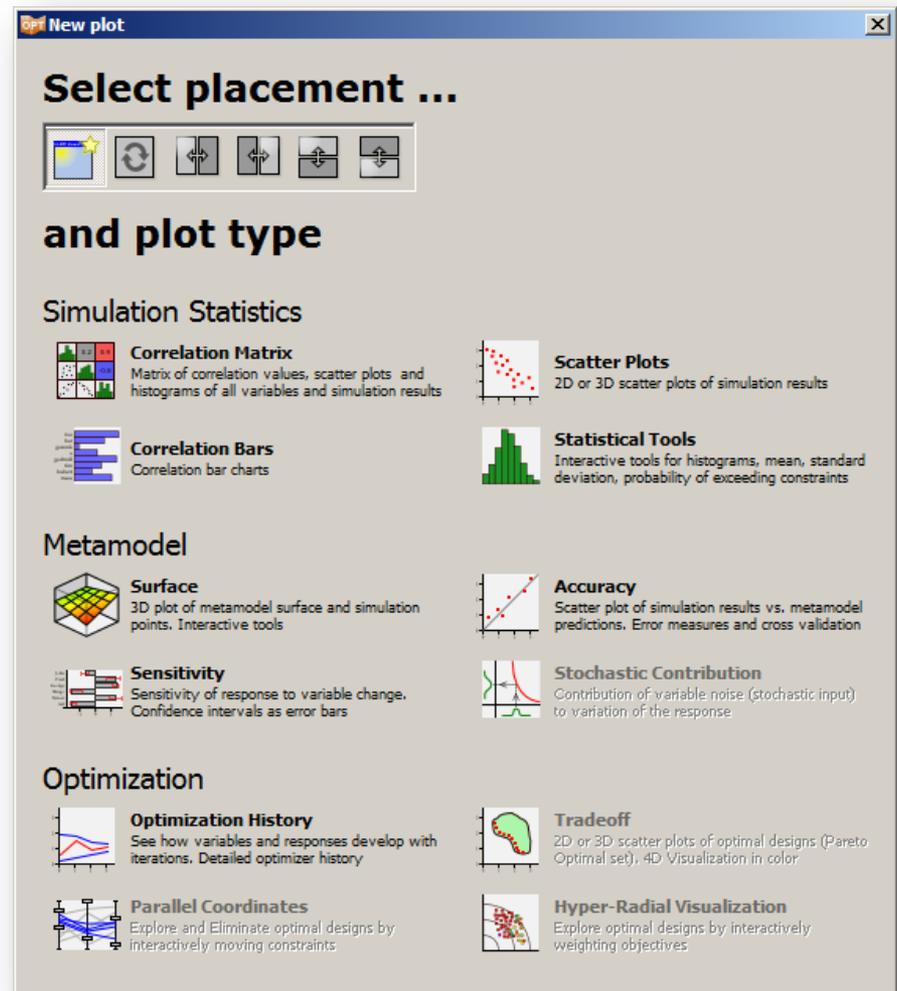
Time Step selection list:

- Time Step
- Kinetic Energy
- Internal Energy
- Total Energy
- Energy Ratio
- Global X Velocity
- Global Y Velocity
- Global Z Velocity
- Total CPU Time
- Time to Completion

Graph area: No Processes Selected. Y-axis: 1, 0. X-axis: 0, 1.

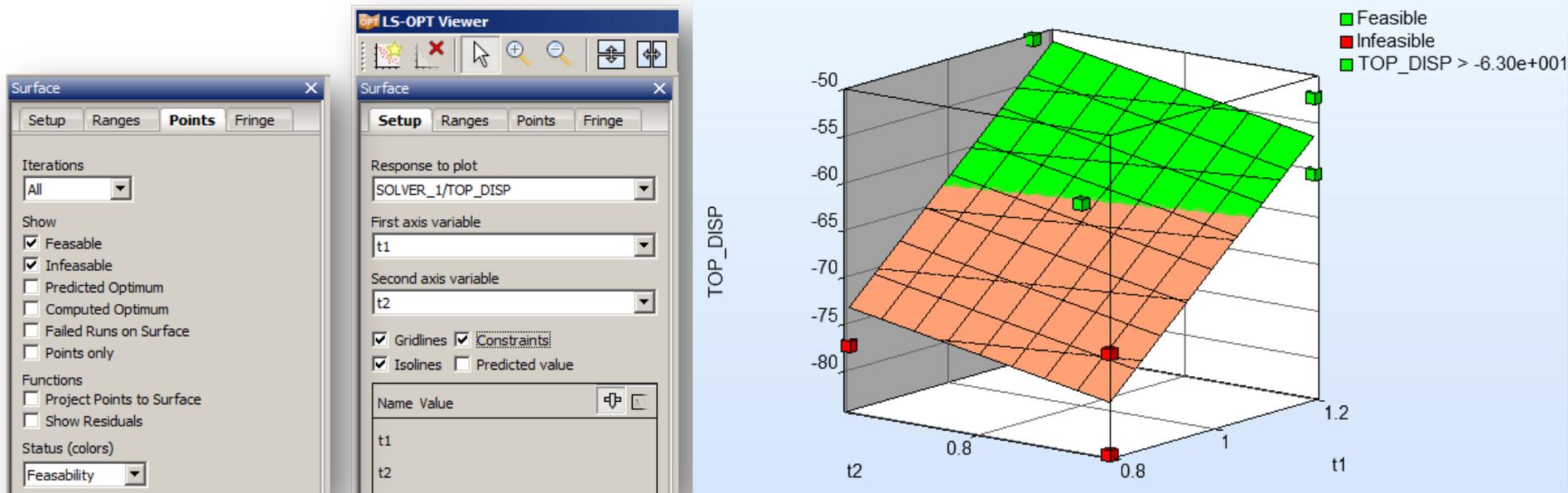
Viewer

- Go to Viewer panel and the viewer options should pop up automatically
- From Metamodel menu select Surface
- New window should appear



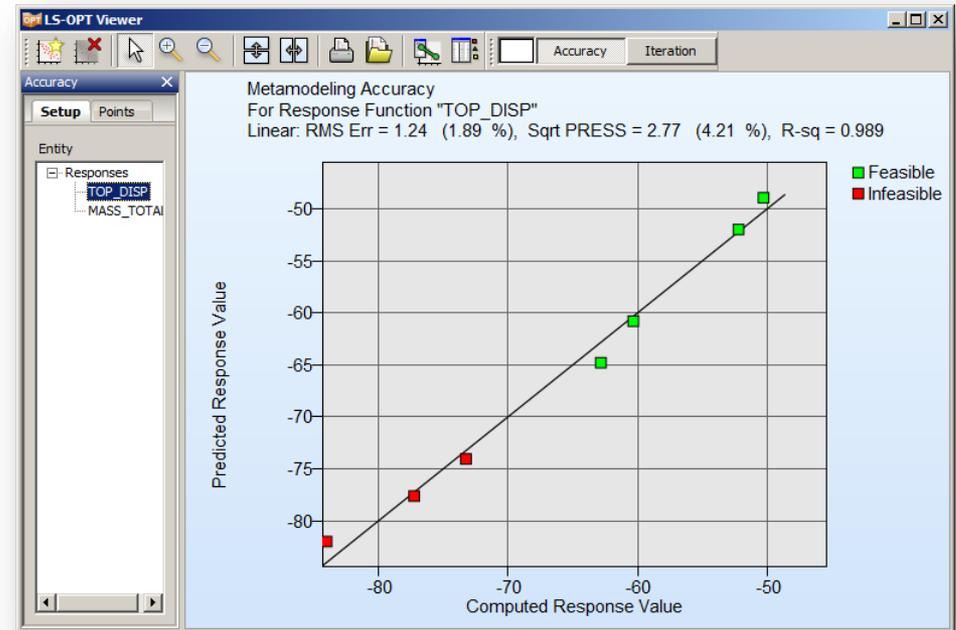
Linear Response Surface

- From the Points Menu select All Iterations
- Check Feasible and Infeasible, For Status select Feasibility
- In Setup menu Select **TOP_DISP** as a Response to plot
- First axis select **t1** and the second **t2**
- Check Constraints and Isolines



Accuracy

- In the Viewer tab press Restart viewer
- Select Accuracy in the Metamodel menu
- Select **TOP_DISP** from Responses to see the metamodeling errors
- Locate the same data in **Isopt_output** data file

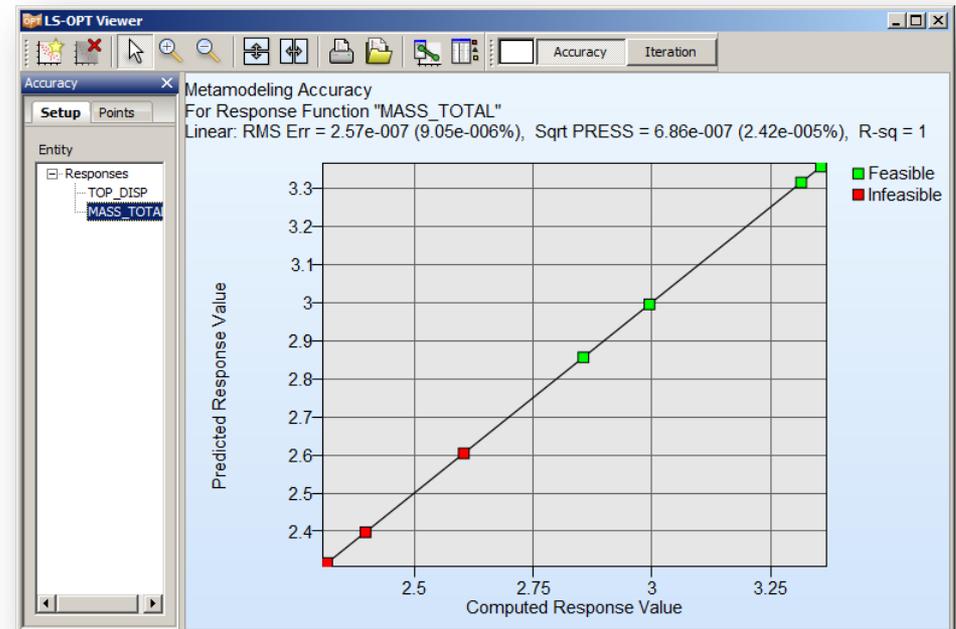


```
Isopt_output - Notepad
File Edit Format View Help

Global error parameters of response surface
-----
Linear Function Approximation:
-----
Mean response value           = -65.7494
RMS error                     = 1.2423 (1.89%)
Maximum Residual              = 2.0201 (3.07%)
Average Error                 = 1.0297 (1.57%)
Square Root PRESS Residual    = 2.7651 (4.21%)
Std. Dev. of the residuals    = 1.8976
R^2                           = 0.9890
R^2 (adjusted)                = 0.9780
R^2 (prediction)              = 0.9455
Determinant of [X]'[X]        = 17.277
```

Accuracy

- Select **MASS_TOTAL** from Responses to see the metamodeling errors for the mass
- Verify the perfect fit in the **Isopt_output** file



```
Isopt_output - Notepad
File Edit Format View Help

Global error parameters of response surface
-----
Linear Function Approximation:
-----
Mean response value           =      2.8341
RMS error                     =      0.0000 (0.00%)
Maximum Residual              =      0.0000 (0.00%)
Average Error                 =      0.0000 (0.00%)
Square Root PRESS Residual    =      0.0000 (0.00%)
Std. Dev. of the residuals     =      0.0000
R^2                           =      1.0000
R^2 (adjusted)                =      1.0000
R^2 (prediction)              =      1.0000
Determinant of [x]'[x]        =      17.277
```

Sensitivities

- Go back to the Viewer tab and restart the viewer
- Select Sensitivity in the Metamodel menu
- See the importance of variables for the response
- Locate the same data in the `Isopt_output` file

Isopt_output - Notepad

File Edit Format View Help

Individual regression coefficients: confidence intervals

Coeff.	Coeff. Value	Confidence Int. (90%)		Confidence Int. (95%)		% Confidence not zero
		Lower	Upper	Lower	Upper	
t1	22.07	18.14	26	16.75	27.38	100
t2	5.248	1.411	9.086	0.05851	10.44	95
t3	8.819	4.893	12.74	3.51	14.13	99

Ranking of terms based on bound of confidence interval

Coeff.	Absolute value (90%)	10-Scale
t1	18.14	10.0
t3	4.893	2.7
t2	1.411	0.8

Confidence intervals on mean value at center of region of interest

Coeff.	Coeff. Value	Confidence Int. (90%)		Confidence Int. (95%)	
		Lower	Upper	Lower	Upper
Mean	-64.81	-66.59	-63.03	-67.21	-62.41

LS-OPT Viewer

Sensitivities Iteration

Sensitivities

- SOLVER_1
 - TOP_DISP
 - MASS_TOTAL

Sensitivities Plot for TOP_DISP with 90% Confidence Interval

Terms in expansion of TOP_DISP

LS-OPT Viewer

Sensitivities Iteration

Sensitivities

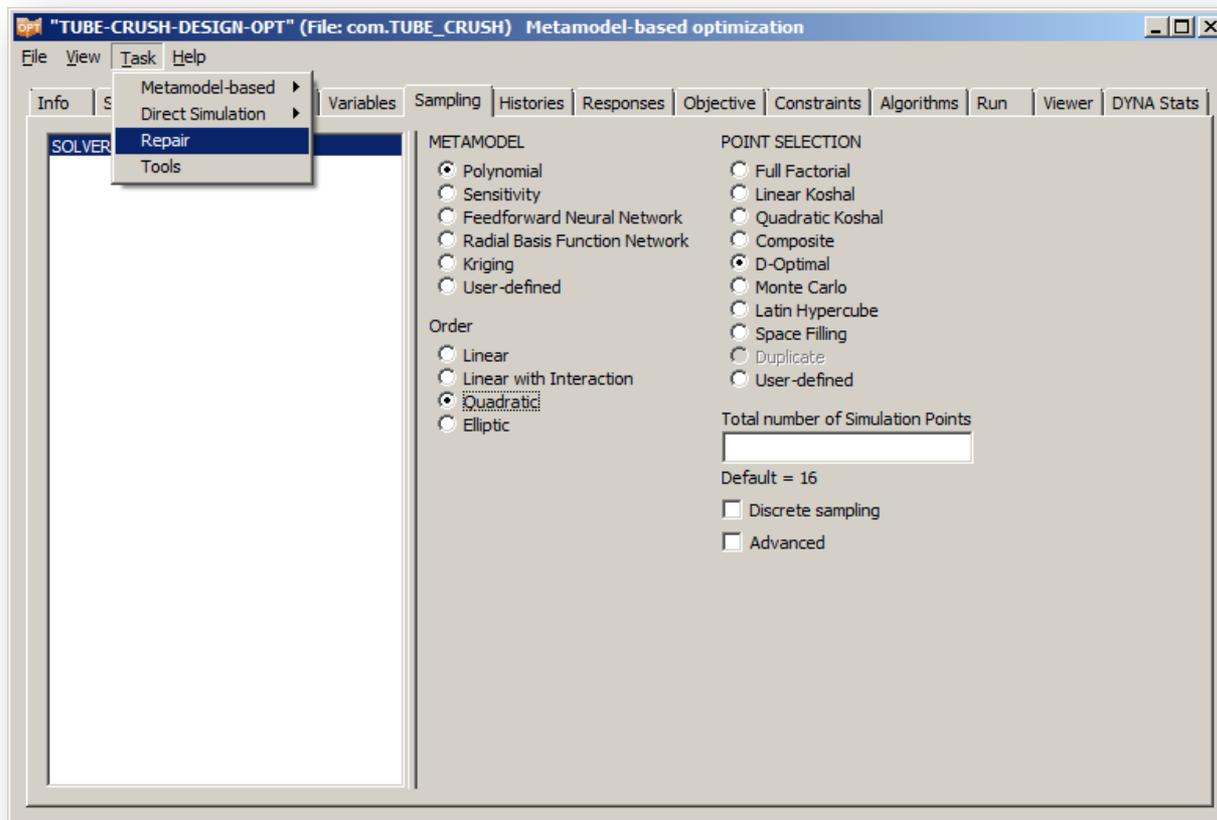
- SOLVER_1
 - TOP_DISP
 - MASS_TOTAL

Sensitivities Plot for MASS_TOTAL with 90% Confidence Interval

Terms in expansion of MASS_TOTAL

Repair Tool - Quadratic Response Surface

- Select Repair from the Task menu
- Go to Sampling panel to change the Order of polynomial to Quadratic
- We will build Quadratic response surface without losing already obtained data. Points can be augmented to existing vector.



$$X_a(x_p) = \begin{bmatrix} X \\ A(x_p) \end{bmatrix}$$

$$\max |X_a^T X_a| = \max |X^T X + A^T A|$$

Run Panel

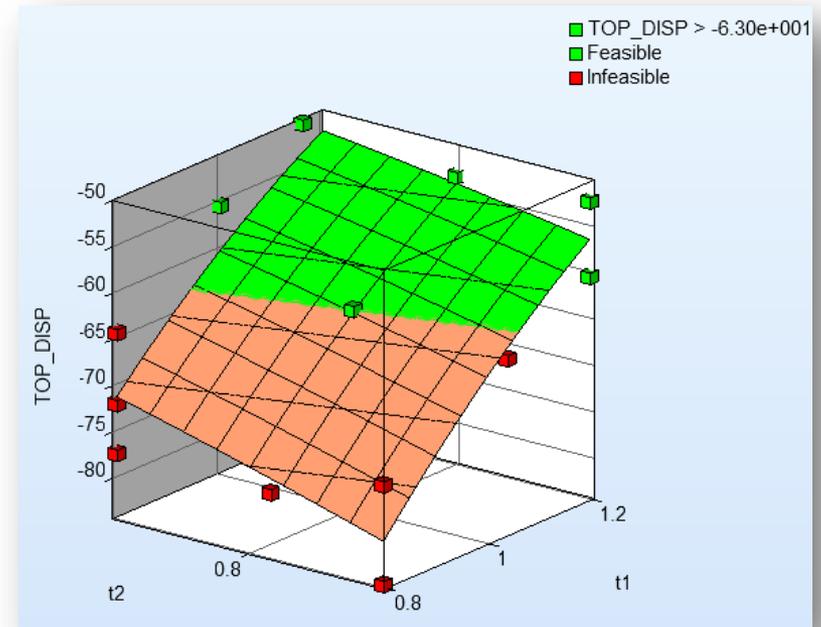
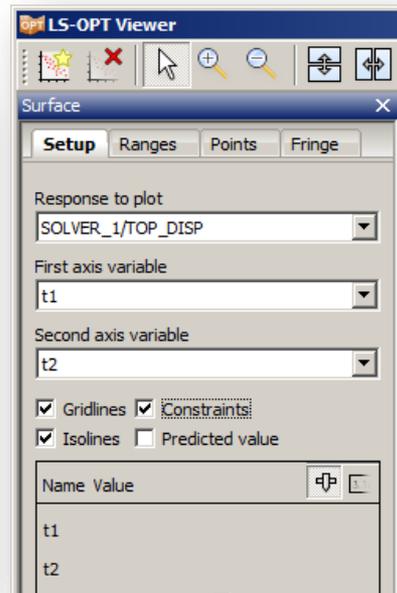
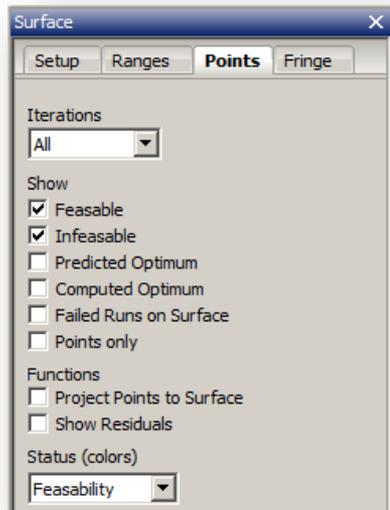
- Go to Run Panel
- From Repair menu select Add Metamodel points, press Run
- Select Run jobs, press Run
- Select Extract results, press Run
- Select Build Metamodels and press Run
- Select Optimize and press ...??? **RUN**

The screenshot shows the 'TUBE-CRUSH-DESIGN-OPT' software interface. The title bar indicates the file is 'com.TUBE_CRUSH' and the current menu is 'Repair'. The interface includes a menu bar (File, View, Task, Help) and a toolbar (Info, Strategy, Solvers, Dist, Variables, Sampling, Histories, Responses, Objective, Constraints, Algorithms, Run, Viewer, DYNA Stats). The main workspace is divided into several sections:

- Job Progress Table:** A table with columns 'Job ID', 'PID', and 'Progress'. All six jobs (IDs 1-6) show 'Normal Termination' in green.
- QUEUING Section:** Includes a 'None' dropdown, 'Concurrent Jobs' set to 8, and a 'Case' dropdown set to 'SOLVER_1'.
- REPAIR Section:** Includes an 'Iteration' field set to 1 and several radio button options: 'Read points', 'Add Metamodel points' (selected), 'Run jobs', 'Rerun failed jobs', 'Extract results', 'Import results (.csv)', 'Build Metamodels', 'Analyze checkpoints', and 'Optimize'.
- Variables List:** A list of variables including 'Time Step', 'Kinetic Energy', 'Internal Energy' (selected), 'Total Energy', 'Energy Ratio', 'Global X Velocity', 'Global Y Velocity', 'Global Z Velocity', 'Total CPU Time', and 'Time to Completion'.
- Plot Area:** A large blue area with the text 'No Processes Selected' and a coordinate system with axes from 0 to 1.

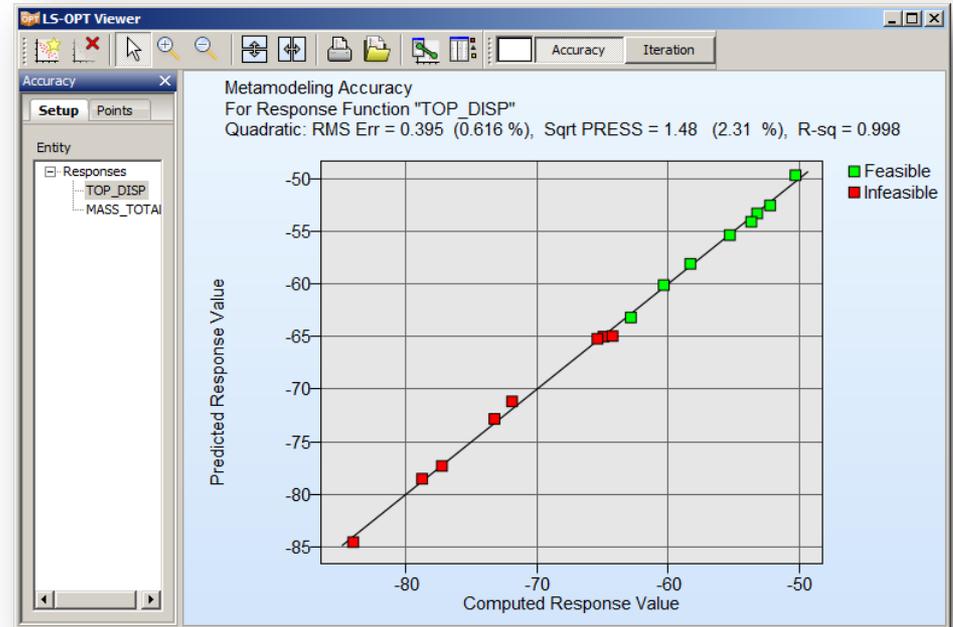
Viewer

- Go to Viewer panel and Restart Viewer
- Select Surface from Metamodel menu
- Show all points in the plot selecting this option in Points tab
- Show constraints on the surface checking this option in the Setup tab
- Clicking on a point we are obtaining numerical values in Point Selection window



Accuracy

- Go to Viewer panel and Restart Viewer
- From Metamodel menu select Accuracy
- Display accuracy of the metamodeling of **TOP_DISP** response
- Locate the error parameters in the **lsopt_output.5** file
- Compare them with results from linear metamodel



```

lsopt_output - Notepad
File Edit Format View Help

Global error parameters of response surface
-----
Linear Function Approximation:
Mean response value           = -65.7494
RMS error                     = 1.2423 (1.89%)
Maximum Residual              = 2.0201 (3.07%)
Average Error                 = 1.0297 (1.57%)
Square Root PRESS Residual    = 2.7651 (4.21%)
Std. Dev. of the residuals    = 1.8976
R^2                           = 0.9890
R^2 (adjusted)                = 0.9780
R^2 (prediction)              = 0.9455
Determinant of [X]'[X]        = 17.277
    
```

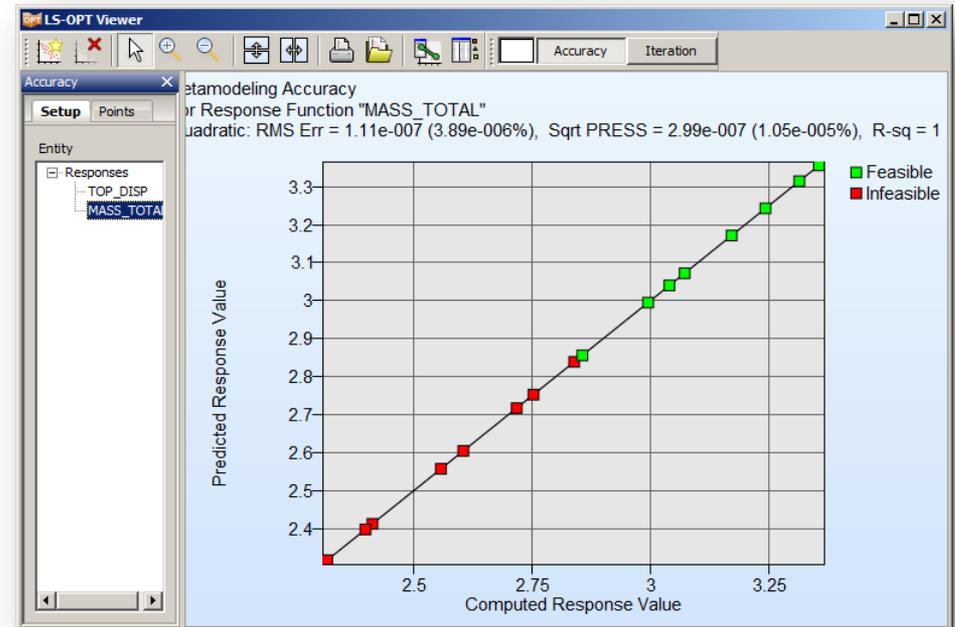
```

lsopt_output.5 - Notepad
File Edit Format View Help

Global error parameters of response surface
-----
Quadratic Function Approximation:
Mean response value           = -64.1259
RMS error                     = 0.3948 (0.62%)
Maximum Residual              = 0.7381 (1.15%)
Average Error                 = 0.3276 (0.51%)
Square Root PRESS Residual    = 1.4804 (2.31%)
Std. Dev. of the residuals    = 0.6447
R^2                           = 0.9985
R^2 (adjusted)                = 0.9969
R^2 (prediction)              = 0.9783
Determinant of [X]'[X]        = 0.22778
    
```

Accuracy

- Display accuracy of the metamodeling of **MASS_TOTAL** response
- Locate the same error parameters in the **Isopt_output** file

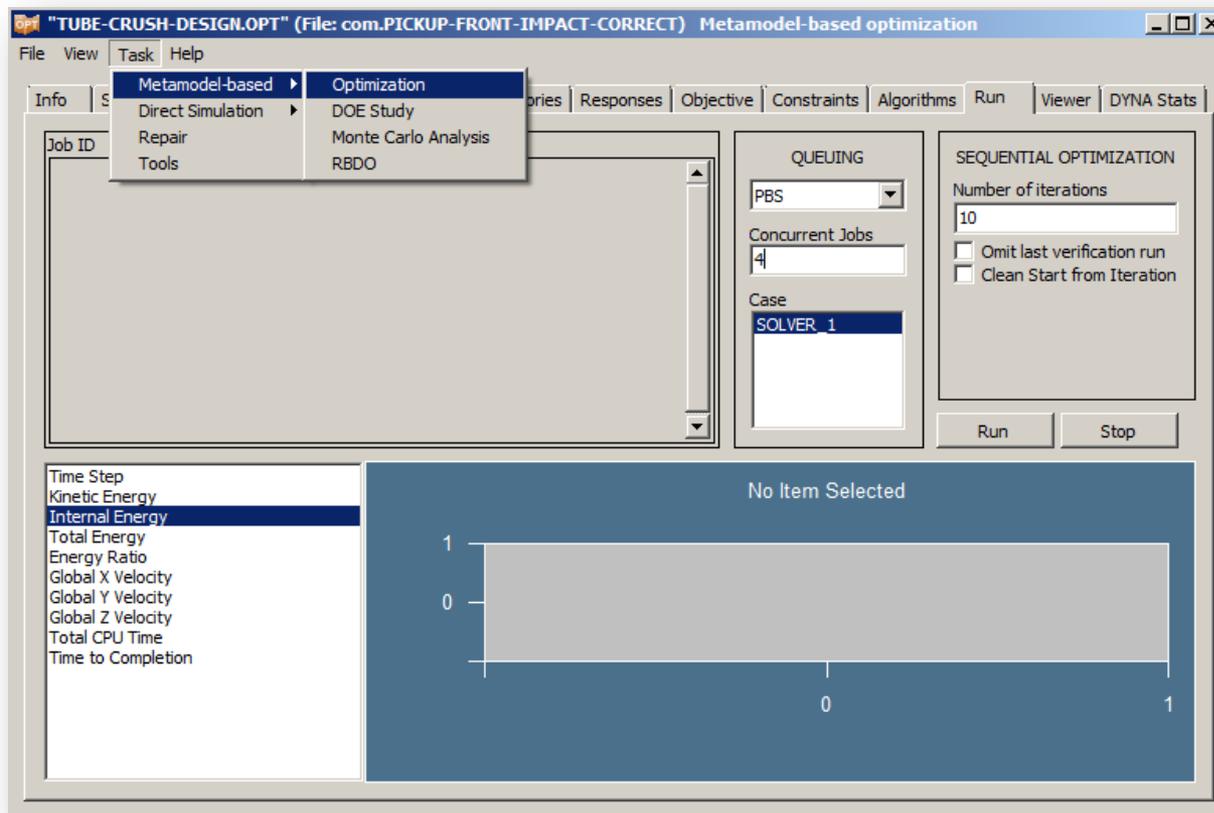


```
Isopt_output.5 - Notepad
File Edit Format View Help

Global error parameters of response surface
-----
Quadratic Function Approximation:
-----
Mean response value           =      2.8526
RMS error                     =      0.0000 (0.00%)
Maximum Residual              =      0.0000 (0.00%)
Average Error                 =      0.0000 (0.00%)
Square Root PRESS Residual    =      0.0000 (0.00%)
Std. Dev. of the residuals    =      0.0000
R^2                           =      1.0000
R^2 (adjusted)               =      1.0000
R^2 (prediction)              =      1.0000
Determinant of [X]'[X]       =      0.22778
```

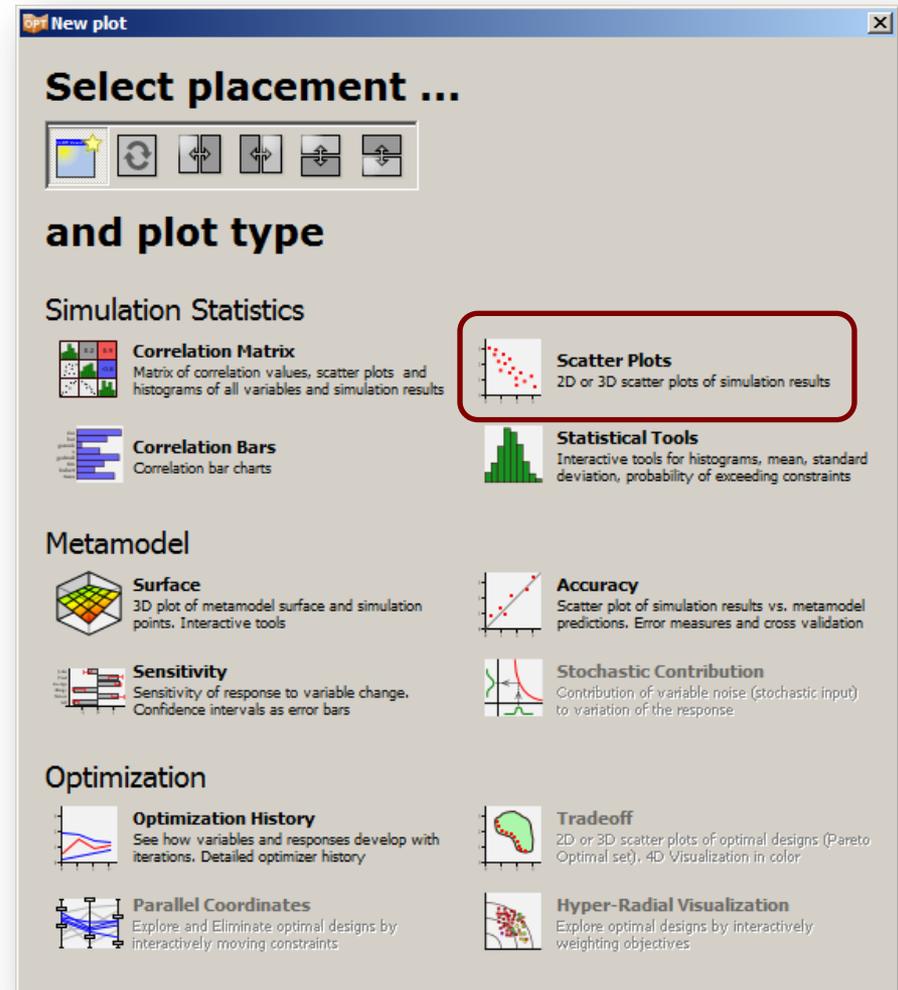
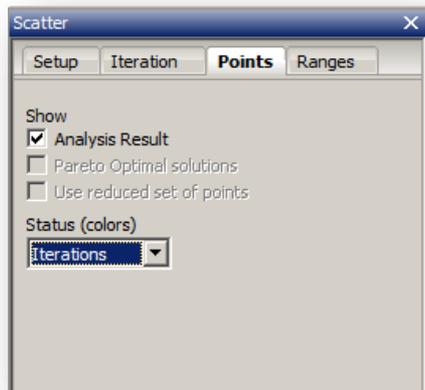
Linear Response Surface - Iterations

- Go to back to the command file created for linear metamodel
- Make sure that the Task is Metamodel-based Optimization
- Then go to Run panel
- Select PBS as QUEUING software and request **10** iterations, press Run



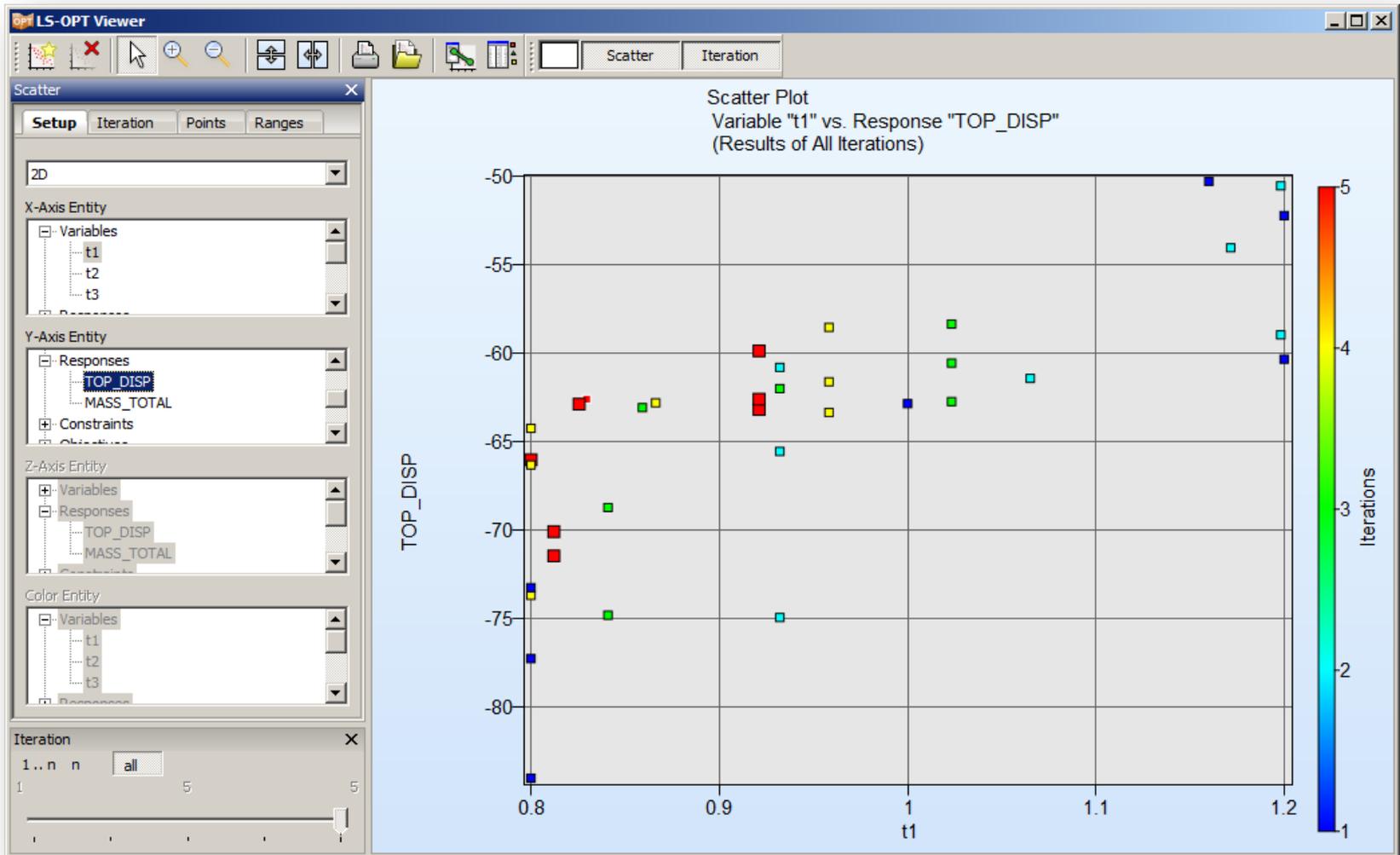
Viewer

- Go to Viewer panel and Restart Viewer
- Select Scatter Plots from the Simulations Statistics menu
- In the new window go Points and change Status (colors) to iterations



Scatter Plot

- In the Setup tab select for X-axis variable **t1** and **TOP_DISP** for y-axis

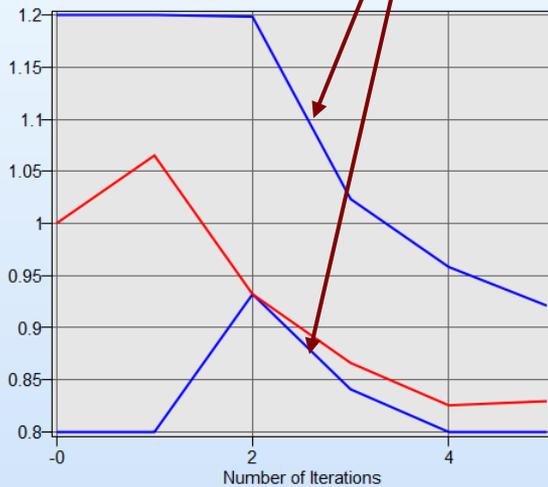


Optimization History

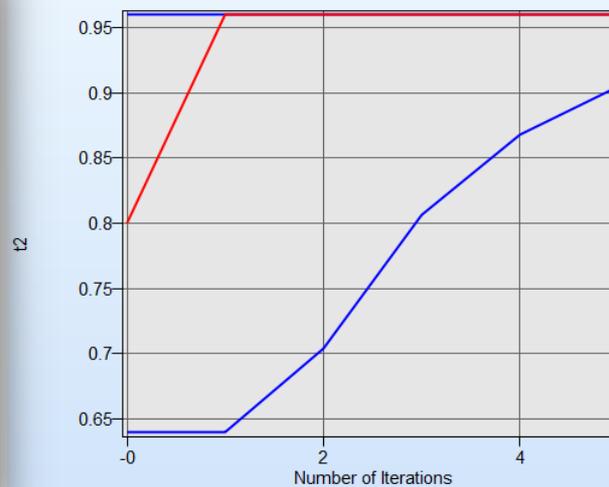
- Go to Viewer panel and Restart the Viewer
- Select Optimization History in the Optimization menu
- Follow the optimization process of various thicknesses **t1**, **t2**, **t3**

Shrinking bounds

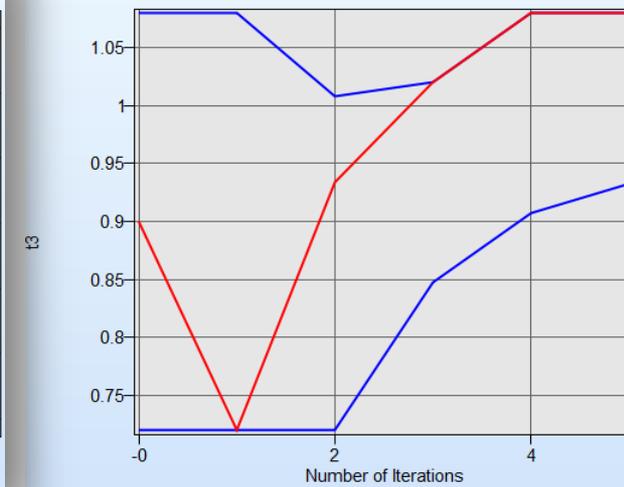
Optimization History For "t1"



Optimization History For "t2"

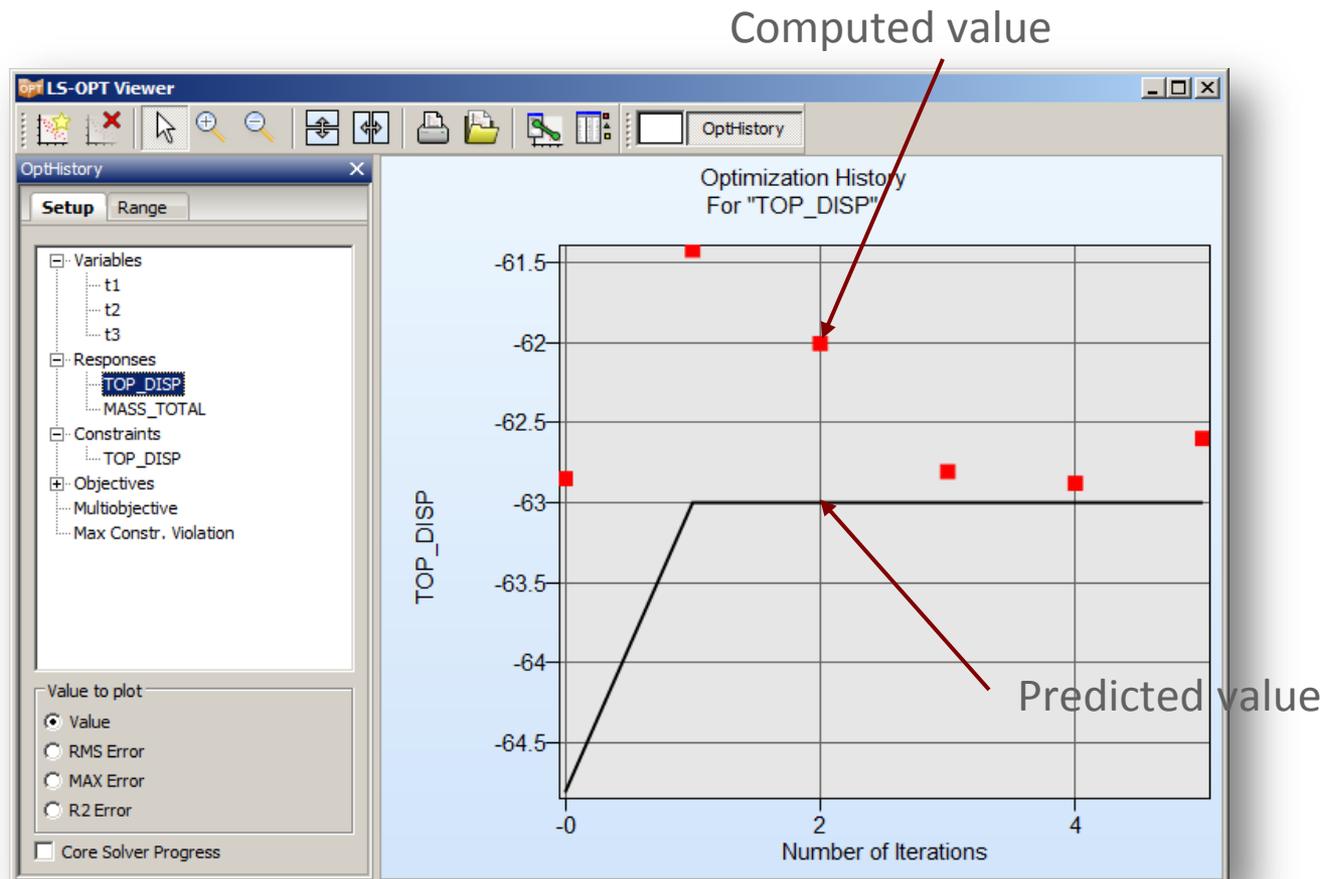


Optimization History For "t3"



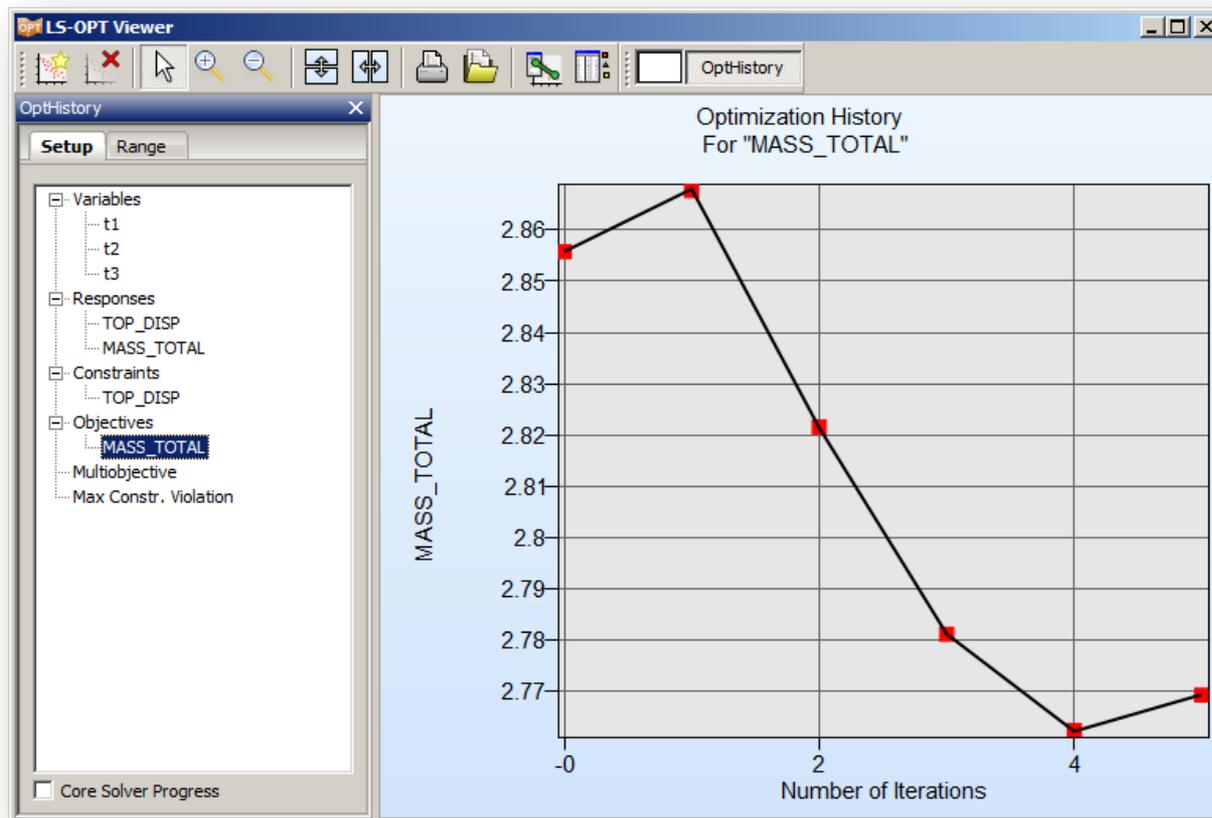
Optimization History

- Select from Responses **TOP_DISP**
- See the difference between computed (LS-DYNA®) value and the approximated one by Response Surface



Optimization History

- Select from Objectives **MASS_TOTAL**
- There is on difference between calculated and approximated values – the metamodel was exact for the mass – it is linearly dependent on three design variables



Optimization History

- Click on one of the points in the graph to open Point Selection Window
- In Point Selection window Check the initial and optimal values of Variables
- The overall mass was reduced from 2.856 to 2.769

Entity	Comp...	Predicted
Point		
Variables		
t1	1	1
t2	0.8	0.8
t3	0.9	0.9
Responses		
TOP_DISP	-62.8505	-64.8104
MASS_TOTAL	2.85577	2.85577
Constraints		
TOP_DISP	-62.8505	-64.8104
Objectives		
MASS_TOTAL	2.85577	2.85577
Multiobjective	2.85577	2.85577
Max Constraint Violation	0	1.81055

Entity	Comp...	Predicted
Point		
Variables		
t1	0.825555	0.825555
t2	0.96	0.96
t3	1.08	1.08
Responses		
TOP_DISP	-62.8793	-63
MASS_TOTAL	2.76224	2.76208
Constraints		
TOP_DISP	-62.8793	-63
Objectives		
MASS_TOTAL	2.76224	2.76208
Multiobjective	2.76224	2.76208
Max Constraint Violation	0	0

Constraint Violation

- Select Max Constr. Violation
- At the first iteration violation of constraints is dealt
- Then actual optimization progresses

