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Altair HyperStudy 2019 Tutorials

HS-4000: Optimization Method Comparison: Arm Model Shape Optimization

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HS-4000: Optimization Method Comparison: Arm Model Shape Optimization

Continuing from Tutorial HS-3000: Fit Method Comparison: Approximation on the Arm Model, you will perform an Optimization and compare different methods for efficiency and effectiveness.

Before running this tutorial, complete tutorial HS-3000: Fit Method Comparison: Approximation on the Arm Model. You can also import the archive file `HS-3000.hstx`, available in `<hst.zip>/HS-4000/`.

The corresponding output response values for your baseline design (all shape variables set to 0.0) were:

- Volume = 1.77E+06 mm3
- Max_Disp = 1.41 mm
- Max_Stress = 195.29 MPa

In this tutorial, the Optimization objective is to reduce Volume, while respecting a constraint on Max_Disp that should be less than 1.5 mm.

In HS-3000, you learned that it was difficult to accurately capture the Max_Stress function using a Fit approximation. In the DOE analysis, you learned that most of the tested design configurations for Max_Stress were below 300 MPa. For these reasons, you will not consider a constraint on the Max_Stress function. Max_Stress values can be collected throughout the Optimization when running the exact solver.

Single Objective, Deterministic Optimization Study

In this tutorial, you will be comparing six single-objective, deterministic Optimization studies. You will be changing the number of shape variables used, as well as the Optimization method.

The following Optimization methods will be used during this tutorial:

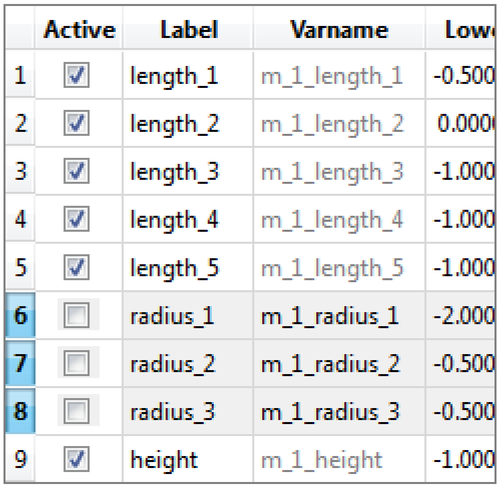
- Adaptive Response Surface Method (ARSM)
- Global Response Search Method (GRSM)
- Sequential Quadratic Programming (SQP)
- Genetic Algorithm (GA)

Step 1: ARSM, Six Input Variables, Exact Solver

Using the conclusions of the different design of experiments, you will consider only six shape variables for the Optimization and omit the three radii (which will be fixed at their nominal values).

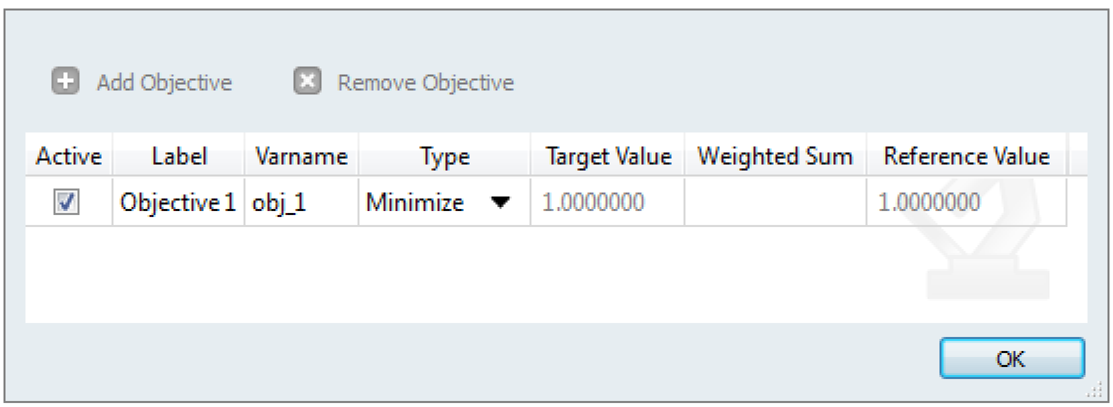
1. In the **Explorer**, right-click and select ***Add*** from the context menu.
2. In the **Add - HyperStudy** dialog, select ***Optimization*** and click ***OK***.

3. Go to the **Select Input Variables** step.
4. In the work area, **Active** column, clear the ***radius_1***, ***radius_2*** and ***radius_3*** check boxes.

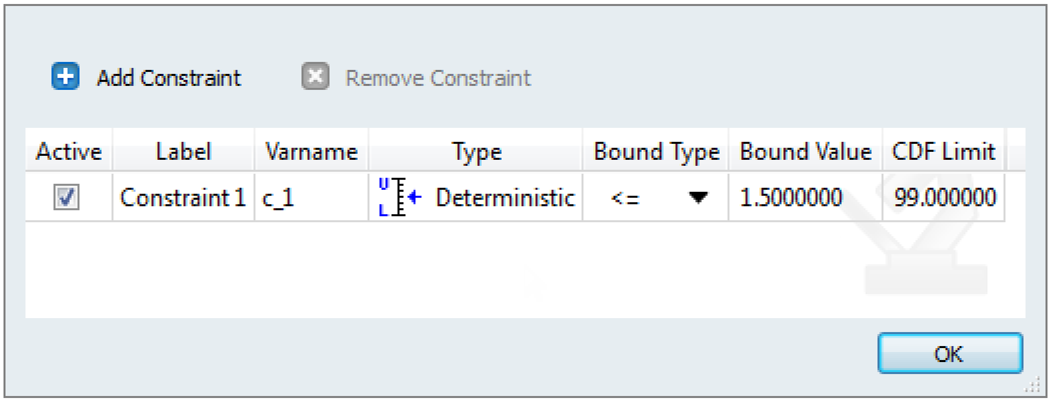


	Active	Label	Varname	Lowe
1	☑	length_1	m_1_length_1	-0.500
2	☑	length_2	m_1_length_2	0.000
3	☑	length_3	m_1_length_3	-1.000
4	☑	length_4	m_1_length_4	-1.000
5	☑	length_5	m_1_length_5	-1.000
6	☐	radius_1	m_1_radius_1	-2.000
7	☐	radius_2	m_1_radius_2	-0.500
8	☐	radius_3	m_1_radius_3	-0.500
9	☑	height	m_1_height	-1.000

5. Go to the **Select Output Responses** step.
6. Apply an objective on the Volume output response.
   a. In the **Objectives** column for **Volume**, click .
   b. In the pop-up window, set **Type** to ***Minimize*** and click ***OK***.



7. Apply a constraint on the Max_Disp output response.
   a. In the **Constraints** column for **Max_Disp**, click .
   b. In the pop-up window, define the following settings and click ***OK***.
      - Set **Type** to ***Deterministic***.
      - Set **Bound Type** to **<=**.
      - For **Bound Value**, enter `1.5`.



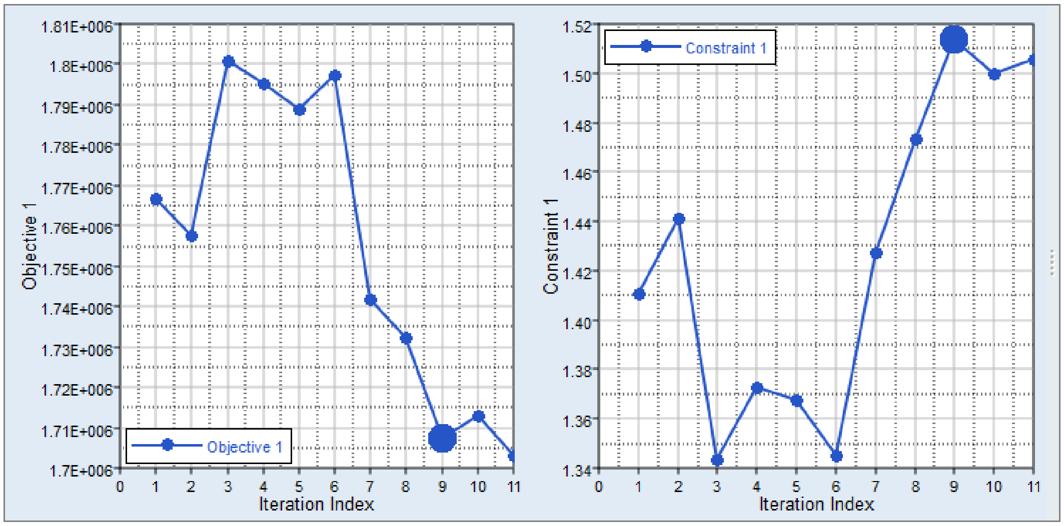
8. Click ***Apply***.
9. Go to the **Specifications** step.
10. In the work area, set the **Mode** to ***Adaptive Response Surface Method (ARSM)***.

    Note: Only the methods that are valid for the problem formulation are enabled.
11. Click ***Apply***.
12. Go to the **Evaluate** step.
13. Click ***Evaluate Tasks***.
14. Click the ***Iteration History*** tab to view the optimum solution, which is highlighted green in the table.

    Note that the optimal design for Max_Stress is equal to 215, which is lower than 300.

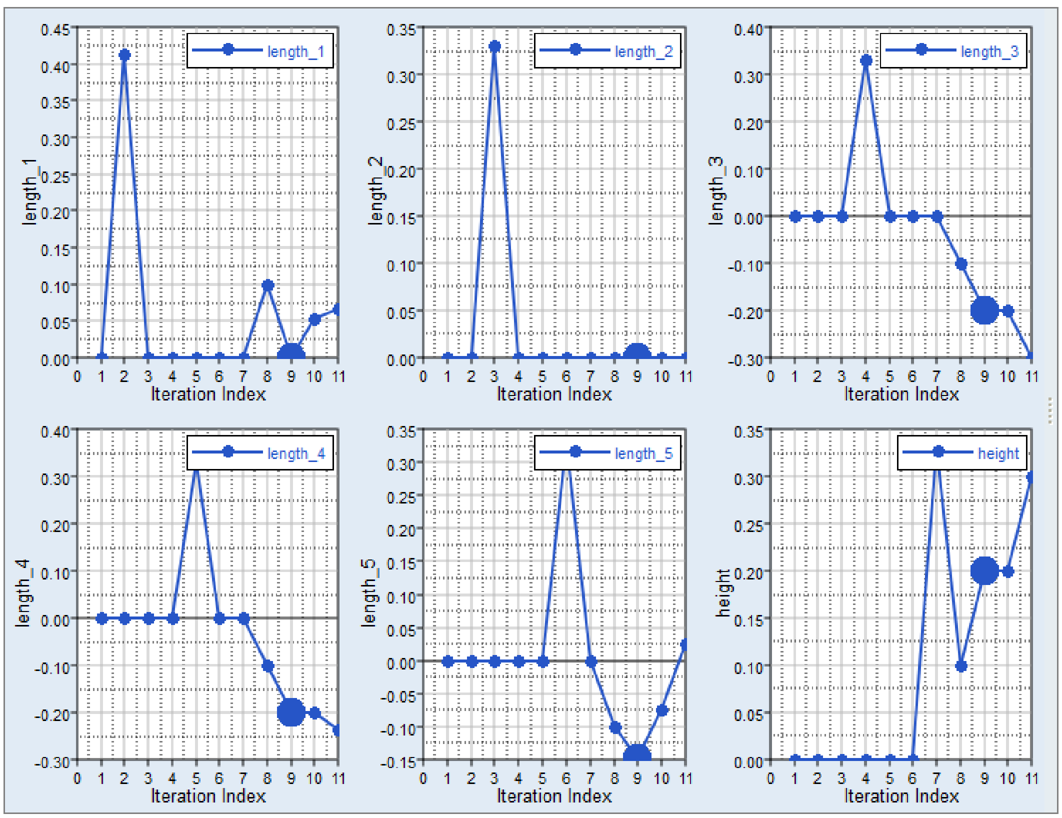
	length_1	length_2	length_3	length_4	length_5	height	Max_Disp	Max_Stress	Volume	Objective 1	Const
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	1.4108398	195.29431	1766760.0	1766760.0	1.4108398
2	0.4125000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	1.4409881	210.95905	1757670.0	1757670.0	1.4409881
3	0.0000000	0.3300000	0.0000000	0.0000000	0.0000000	0.0000000	1.3433180	190.23517	1800990.0	1800990.0	1.3433180
4	0.0000000	0.0000000	0.3300000	0.0000000	0.0000000	0.0000000	1.3726212	195.16753	1795180.0	1795180.0	1.3726212
5	0.0000000	0.0000000	0.0000000	0.3300000	0.0000000	0.0000000	1.3673790	195.45073	1789070.0	1789070.0	1.3673790
6	0.0000000	0.0000000	0.0000000	0.0000000	0.3300000	0.0000000	1.3449796	190.43332	1797460.0	1797460.0	1.3449796
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.3300000	1.4275311	199.92467	1741680.0	1741680.0	1.4275311
8	0.1000000	0.0000000	-0.1000000	-0.1000000	-0.1000000	0.1000000	1.4735028	201.00284	1732440.0	1732440.0	1.4735028
9	0.0000000	0.0000000	-0.2000000	-0.2000000	-0.1480214	0.2000000	1.5136583	207.92407	1707450.0	1707450.0	**1.513658**
10	0.0528775	0.0000000	-0.2000000	-0.2000000	-0.0749443	0.2000000	1.5001578	208.66656	1713010.0	1713010.0	1.5001578
11	0.0668381	0.0000000	-0.3000000	-0.2373589	0.0250557	0.3000000	1.5054342	215.68036	1703330.0	1703330.0	1.505434

15. Click the ***Iteration Plot*** tab to review the results of the optimization in an iteration plot.
    - Select the **Objective** (Volume) and **Constraint** (Max_Disp) functions to see their variations during the Optimization process.



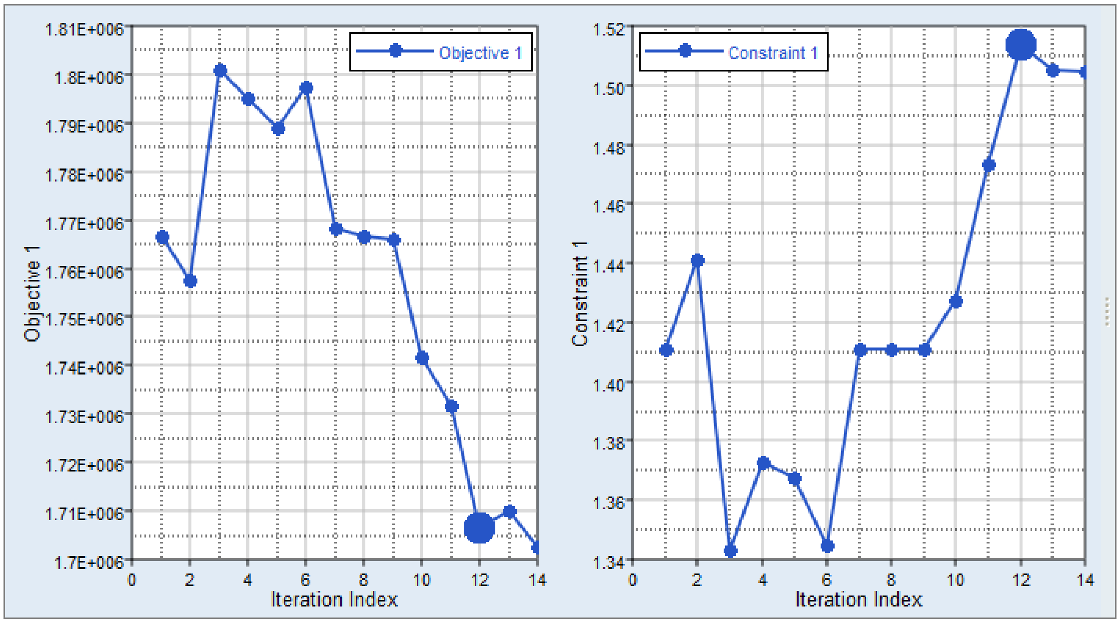
- Select all of the design variables to see their variations during the Optimization process.

  Note if any of the input variables meet their bounds in the optimal design. If any input variable's values meet their bounds, this indicates that relaxing these bounds may enable you to find better solutions. In the plots below, only length_2 and length_5 meet their lower bounds.



Step 2: ARSM, Nine Input Variables, Exact Solver

1. Run a single objective, deterministic Optimization study by repeating Step 1: ARSM, Six Input Variables, Exact Solver.
   a. In the **Define Input Variables** step, activate all input variables.
2. Click the ***Iteration History*** and ***Iteration Plot*** tabs to review the results of the Optimization.
   a. Select the **Objective** (Volume) and **Constraint** (Max_Disp) functions to see their variations during the Optimization process.



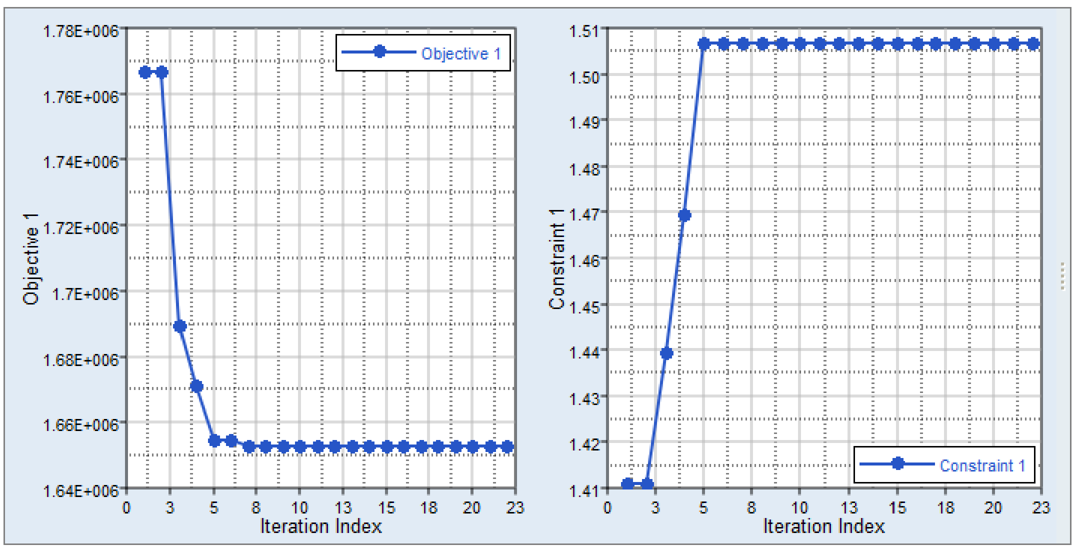
Step 3: GRSM, Six Input Variables, Exact Solver

1. Run a single objective, deterministic Optimization study by repeating Step 1: ARSM, Six Input Variables, Exact Solver.
   a. In the **Specifications** step, set the **Mode** to ***Global Response Search Method (GRSM)***.
2. Click the ***Iteration history*** tab to review the results of the Optimization in a table.

   Note that the optimal solution is found at the 19th evaluation (from 50).

	length_1	length_2	length_3	length_4	length_5	height	Max_Disp	Max_Stress	Volume	Objective 1	Constraint 1	Iteration Index	Evaluation Reference	Iterat
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	1.4108398	195.29431	1766760.0	1766760.0	1.4108398	1	1	1
2	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	1.4108398	195.29431	1766760.0	1766760.0	1.4108398	2	1	1
3	-0.4992779	0.0016672	-0.9912966	0.0498490	0.7815539	0.9990854	1.4392618	223.01530	1689540.0	1689540.0	1.4392618	3	12	3
4	-0.4291008	5.86e-04	-0.9886176	0.2059647	0.4663968	0.9995159	1.4693619	217.24883	1671190.0	1671190.0	1.4693619	4	14	4
5	-0.2325116	1.34e-04	-0.9993315	0.3377470	0.2309717	0.9999555	1.5068227	214.70786	1654510.0	1654510.0	1.5068227	5	16	5
6	-0.2325116	1.34e-04	-0.9993315	0.3377470	0.2309717	0.9999555	1.5068227	214.70786	1654510.0	1654510.0	1.5068227	6	16	5
7	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	7	19	7
8	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	8	19	7
9	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	9	19	7
10	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	10	19	7
11	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	11	19	7
12	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	12	19	7
13	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	13	19	7
14	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	14	19	7
15	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	15	19	7
16	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	16	19	7
17	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	17	19	7
18	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	18	19	7
19	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	19	19	7
20	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	20	19	7
21	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	21	19	7
22	-0.4764394	0.0000000	-1.0000000	0.4958683	0.0347269	1.0000000	1.5067935	209.69763	1652830.0	1652830.0	1.5067935	22	19	7

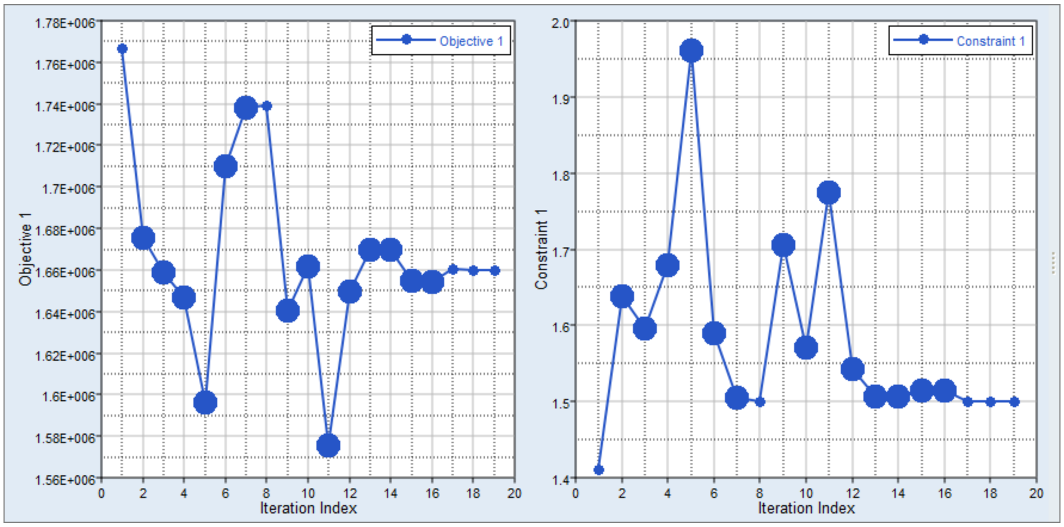
3. Click the ***Iteration Plot*** tab to review the results of the Optimization in an iteration plot.
    a. Select the **Objective** (Volume) and **Constraint** (Max_Disp) functions to see their variations during the Optimization process.



Step 4: SQP, Six Input Variables, Exact Solver

1. Run a single objective, deterministic Optimization study by repeating Step 1: ARSM, Six Input Variables, Exact Solver.
    a. In the **Specifications** step, set the **Mode** to ***Sequential Quadratic Programming (SQP)***.
2. Click the ***Iteration Plot*** tab to review the results of the Optimization in an iteration plot.

a. Select the **Objective** (Volume) and **Constraint** (Max_Disp) functions to see their variations during the Optimization process.



Step 5: SQP, Six Input Variables, RBF_MELS

1. Run a single objective, deterministic Optimization study by repeating Step 1: ARSM, Six Input Variables, Exact Solver.

   a. In the **Select Output Responses** step, **Responses** tab, set **Evaluate From** to ***Fit, RBF (fit_4)*** for Max_Disp and Volume.

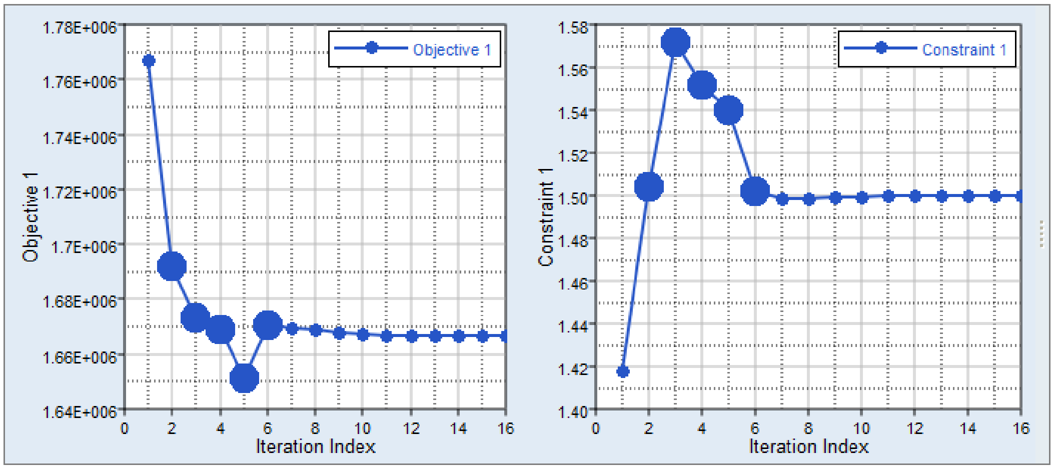
	Active	Label	Varname	Objectives	Constraints	Evaluate From	Expression	Comment
1	☑	Max_Disp	m_1_r_1		<= 1.5000000 ...	Fit, RBF (fit_4)	max(m_1_ds_1)	Data Source 1 ...
2	☑	Max_Stress	m_1_r_2			Solver	max(m_1_ds_2)	Data Source 2 ...
3	☑	Volume	m_1_r_3	Minimize ...		Fit, RBF (fit_4)	m_1_ds_3[0]	Data Source 3 ...

   b. Clear the checkbox in the **Active** column for Max_Stress.

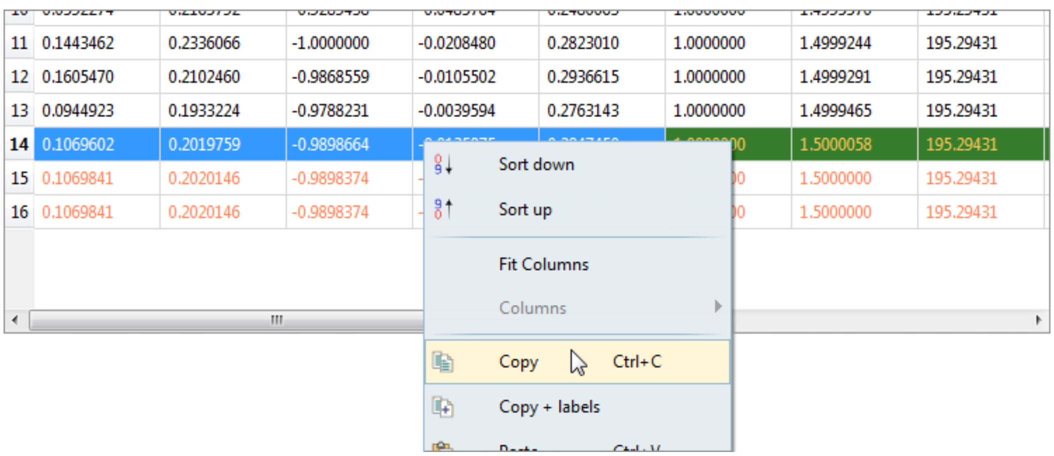
   c. In the **Specifications** step, set the **Mode** to ***Sequential Quadratic Programming (SQP)***.

2. Click the ***Iteration Plot*** tab to review the results of the Optimization in an iteration plot.

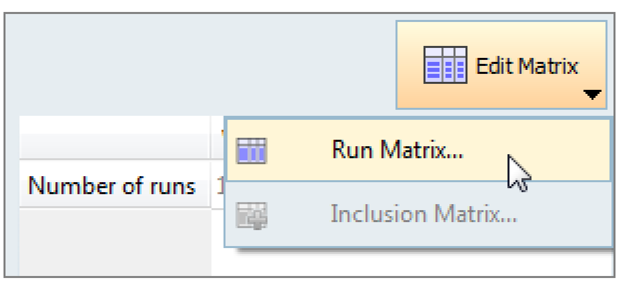
   a. Select the **Objective** (Volume) and **Constraint** (Max_Disp) functions to see their variations during the Optimization process.



3. For Optimizations using a Fit, it is recommended that you perform a validation run of the optimal solution.
   a. Click on ***Iteration History*** tab.
   b. Select the parameter values for the optimal solution, then right-click and select ***Copy*** from the context menu.



   c. Go to the study **Setup**, **Specifications** step and click ***Edit Matrix*** > ***Run Matrix*** from the top-right corner of the work area.



   d. In the **Edit Data Summary** dialog, click ***Add Run*** and paste the copied values.
   e. For the three radii, enter `0`.

f. For height, enter `1`.

	length_1	length_2	length_3	length_4	length_5	radius_1	radius_2	radius_3	height
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	0.1069602	0.2019759	-0.9898664	-0.0135975	0.2847450	0.0000000	0.0000000	0.0000000	1.0000000

g. Click ***Apply***, then click ***OK*** to close the dialog.

h. Go to the **Evaluate** step and clear the checkbox in the **Active** column for the previous nominal run, then click ***Evaluate Tasks***.

	Active	Write	Execute	Extract	Comment
1	☐	Success	Success	Success	
2	☑				

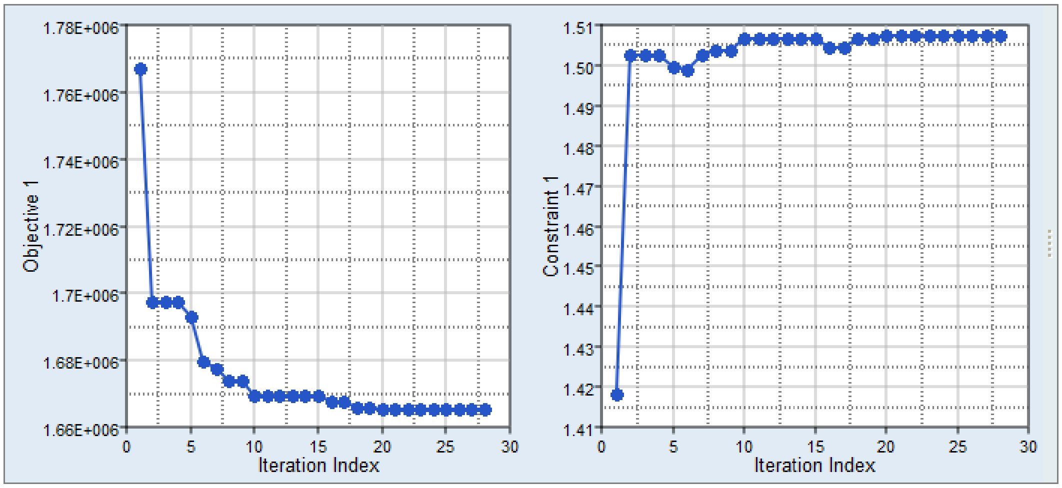
4. Click the ***Evaluate Data*** tab, and compare the Volume, Max_Disp, and Max_Stress values to those founds by the Optimization.

   Note that the values are very similar.

	length_3	length_4	length_5	radius_1	radius_2	radius_3	height	Max_Disp	Max_Stress	Volume
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	1.4108398	195.29431	1766760.0
2	-0.9898664	-0.0135975	0.2847450	0.0000000	0.0000000	0.0000000	1.0000000	1.5324579	226.13705	1649340.0

Step 6: GA, Six Input Variables, RBF_MELS

1. Run a single objective, deterministic Optimization study by repeating Step 1: ARSM, Six Input Variables, Exact Solver.
   a. In the **Select Output Responses** step, **Responses** tab, set **Evaluate From** to ***RBF (fit_4)*** for Max_Disp and Volume.
   b. Clear the **Active** checkbox for Max_Stress.
   c. In the **Specifications** step, set the **Mode** to ***Genetic Algorithm (GA)***.
2. Click the ***Iteration Plot*** tab to review the results of the Optimization in an iteration plot.
   a. Select the Objective (Volume) and Constraint (Max_Disp) functions to see their variations during the Optimization process.



3. As you did in the previous Optimization (SQP, 6 IV, RBF_MELS), it is suggested that you perform a validation run to compare the values provided by the Fit and by the solver.

Optimization Methods Comparison

The number of evaluations and the optimum found using the different Optimization methods are compared in the table below. ARSM and GRSM are both response surface based methods. Even though ARSM is the default method for single objective problems, it can fail when a global optima is required. In such cases, it is suggested that you use GRSM. The best volume decrease was obtained using GRSM by means of 50 solver evaluations. When SQP was used with a solver, a good solution was found at the expense of additional evaluations. Also, when SQP is used with a solver, it is sensitive to the starting point. When GA was applied on a Fit, a solution similar to GRSM was found. GA was not run with the exact solver because it requires many evaluations. In conclusion, GRSM or GA on a fit are the most efficient methods to solve the Optimization problem.

Optimization Method	# of Evaluations	Volume Objective
ARSM, 9 IVs, Exact Solver	14	1702450.0
ARSM, 6 IVs, Exact Solver	11	1703330.0
GRSM, 6 IVs, Exact Solver	50 (22th is the optimum)	1652830.0
SQP, 6 IVs, Exact Solver	179	1659730.0
SQP, 6 IVs, Fit	-	1666990.6
GA, 6 IVs, Fit	-	1665387.3

Reliability-Based Design Optimization Study

In this section of the tutorial, you will be searching for 95% reliability on the Optimization constraint (Max_disp < 1.5 mm). You will use fitting functions as opposed to the exact solver to evaluate the output responses. Among the approximations, you will use the RBF that was created with the MELS DOE. As a result, you will be using the SORA method. You will continue using the six important input variables, which will all follow a normal distribution with a variance of 0.1.

This topic will be discussed in HS-5000: Stochastic Method Comparison and Reliability-Based Design Optimization of the Arm Model.

Multi-Objective Optimization Study

In this section of the tutorial, you will be searching for the Pareto front that minimizes both volume and maximum displacement. You will be using MOGA with a Fit to save time.

Note: If a Fit was not available, GRSM would be the suggested method to use in order to solve a MOO problem. MOO problems require many evaluations, therefore GRSM is more efficient than MOGA.

This topic will be discussed in HS-4425: Multi-Objective Shape Optimization Study.

Last modified: v2017.2 (12.1156684)