



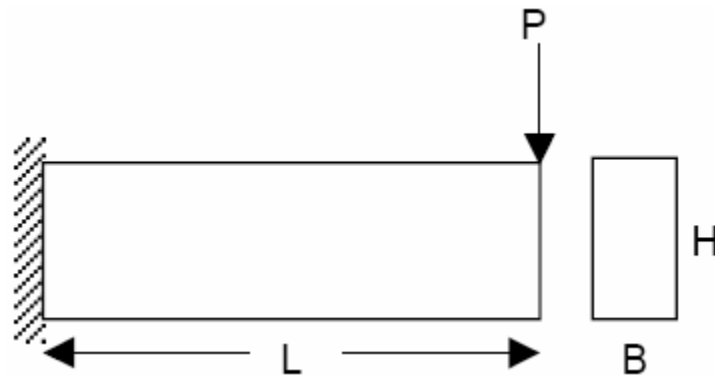
Altair

HyperWorks

HS-2005: DOE Study of a Cantilever Beam Using Templex

This exercise runs a simple DOE study on a cantilever beam to examine the influence of the length, width, and height of the beam on its volume, maximum bending stress, and deflection. We would like to know all of the main effects and all of the interactions between the beam's dimensions, so full factorial is used for this DOE study. The base input Templex template, `beam.tpl`, defines three input variables (L, B, and H) for the beam dimensions labeled as length, width, and height, respectively (see figure below).

The sample base input template `beam.tpl` used in this tutorial can be in `<hst.zip>/HS-2005/` and copied to your working directory.



Cantilever Beam

```
{parameter(L, "Length", 50, 50, 100) }
{parameter(B, "Width", 2.5, 2.5, 5) }
{parameter(H, "Height", 5, 5, 10) }
{P = 100}
{E = 2e11}
{M = P*L}
{c = H/2}
{I = (B*H^3)/12}
{MAX_STRESS = (M*c)/I}
{MAX_DISP = (P*L^3)/(3*E*I) }
{VOLUME = B*H*L}
{MAX_STRESS}
{MAX_DISP}
{VOLUME}
```


In this exercise, you will learn how to:

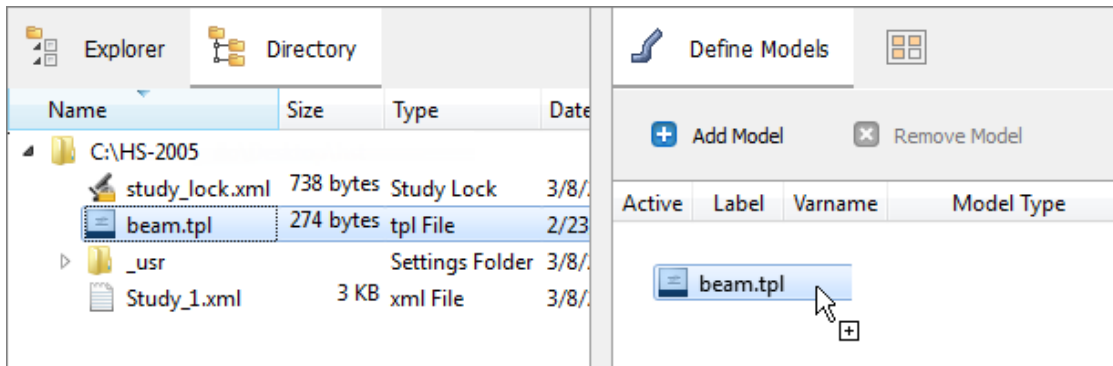
- Setup a study
- Add a model
- Add output responses
- Set up a DOE approach
- Perform DOE Runs

- Extract output responses for a DOE study
- Perform post processing and evaluate the results
- Observe the interactions between variables
- Add approximations for a regression equation

Step 1: Perform the Study Setup

This setup requires you to add a study and load the input file into HyperStudy. The input variables for the DOE study (length, width, and height) are selected as factors. A nominal run is performed (with Templex as the solver), and the output responses for the DOE study are selected (in this case: volume, max. stress, and max. displacement).

1. Start HyperStudy.
2. To start a new study, click **File > New** from the menu bar, or click  on the toolbar.
3. In the **HyperStudy – Add** dialog, enter a study name, select a location for the study, and click **OK**.
4. Go to the **Define models** step.
5. Add a Parameterized File model.
 - a. From the **Directory**, drag-and-drop the `beam.tpl` file into the work area.



- b. In the **Solver input file** column, enter `beam.tpl`. This is the name of the solver input file HyperStudy writes during any evaluation.
- c. In the **Solver execution script** column, select **Templex (templex)**.

Active	Label	Varname	Model Type	Resource	Solver input file	Solver execution script	Solver input arguments
1	<input checked="" type="checkbox"/>	Model1	m_1	{ } Parameterized File C:/.../HS-2005/beam.tpl	beam.tpl	Templex (templex)	\$file

6. Click **Import Variables**. Three input variables are imported from the `beam.tpl` resource file.
7. Go to the **Define Input Variables** step.
8. Review the input variable's lower and upper bound ranges.
9. Go to the **Specifications** step.

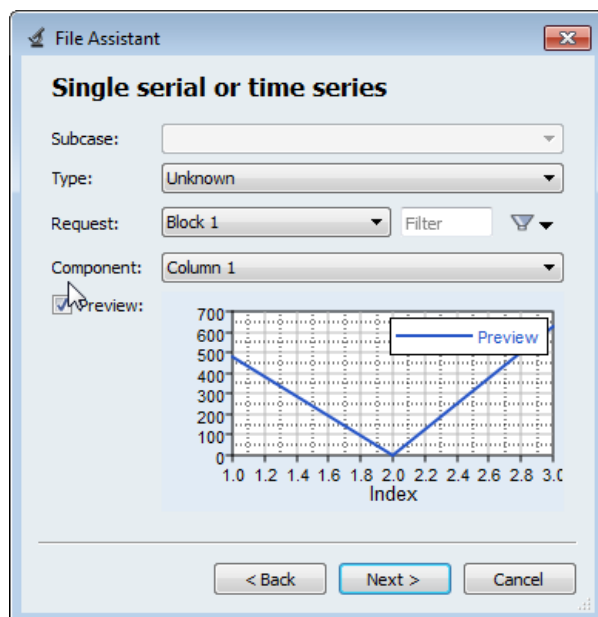
Step 2: Perform the Nominal Run

1. In the work area, set the **Mode** to **Nominal Run**.
2. Click **Apply**.
3. Go to the **Evaluate** step.
4. Click **Evaluate Tasks**. An `approach/nom_1/` directory is created inside the study directory.
5. Go to the **Define Output Responses** step.

Step 3: Create and Define Output Responses

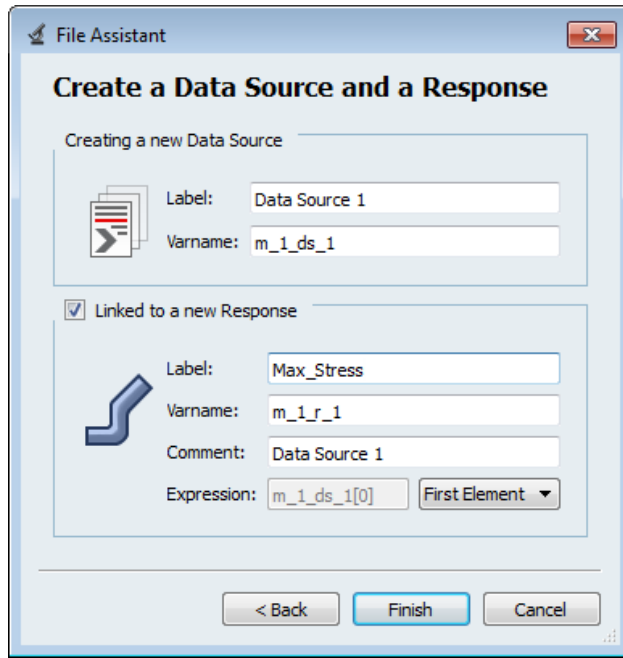
In this step you will create three output responses: Max_Stress, Max_Displacement, and Volume.

1. Create the Max_Stress output response.
 - a. From the **Directory**, drag-and-drop the `beam.tpl` file, located in `approaches/nom_1/run_00001/m_1`, into the work area.
 - b. In the **File Assistant** dialog, set the **Reading technology** to **Altair® HyperWorks®** and click **Next**.
 - c. Select **Single item in a time series**, then click **Next**.
 - d. Define the following options, then click **Next**.
 - Set **Type** to **Unknown**.
 - Set **Request** to **Block 1**.
 - Set **Component** to **Column 1**.



- e. Label the output response Max_Stress.
- f. Set **Expression** to **First Element**.

Note: Because there is only a single value in this data source, HyperStudy inserts [0] after m_1_ds_1, thereby choosing the first (and only) entry in the data source.



- g. Click **Finish**. The Max_Stress output response is added to the work area.
- 2. Repeat step 1 to create the Max_Displacement and Volume output responses.
- 3. In the **Expression** field:
 - a. For **Max_Displacement**, after m_1_r_2, change [0] to [1].
 - b. For **Volume**, after m_1_r_3, change [0] to [2].
- 4. Click **Evaluate Expressions** to extract the output response values of each expression.

	Active	Label	Varname	Expression	Value	Comment
1	<input checked="" type="checkbox"/>	Max_Stress	m_1_r_1	m_1_ds_1[0] ...	Not Extracted	Data Source 1 ...
2	<input checked="" type="checkbox"/>	Max_Displacement	m_1_r_2	m_1_ds_2[1] ...	Not Extracted	Data Source 2 ...
3	<input checked="" type="checkbox"/>	Volume	m_1_r_3	m_1_ds_3[2] ...	Not Extracted	Data Source 3 ...

Step 4: Run a DOE Study

The following steps illustrate how to set up a DOE approach through the selection of a DOE matrix and input variables. Input variables can either be controlled or uncontrolled. In this exercise, a full factorial DOE matrix is considered. This provides the main effect of the input variables and their interactions with one another for selected output responses. The length,

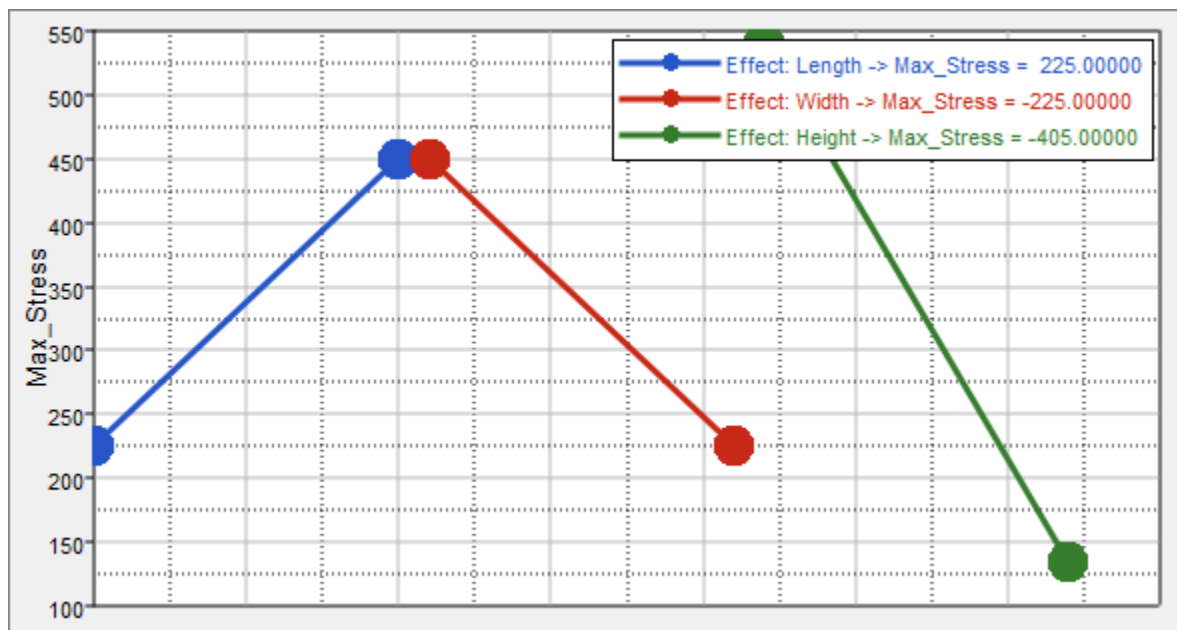
width, and depth of the input variables are introduced as controlled and their effects are studied for the following output responses: maximum stress, maximum displacement, and volume.

1. In the **Explorer**, right-click and select **Add** from the context menu.
2. In the **Add - HyperStudy** dialog, select **DOE** and click **OK**.
3. Go to the **Specifications** step.
4. In the work area, set the **Mode** to **Full Factorial**.
5. Click **Apply**.
6. Go to the **Evaluate** step.
7. Click **Evaluate Tasks**.
8. Monitor the progress of the evaluation by clicking the **Evaluation Data** and **Evaluation Plot** tabs.
9. Go to the **Post-Processing** step.

Step 5: Perform Post Processing and Evaluate the Results

1. Click the **Linear Effects** tab to review the main effect of each controlled parameter on a selected output response.

Review the effects of a single input variable on an output response, or multiple input variables on an output response.

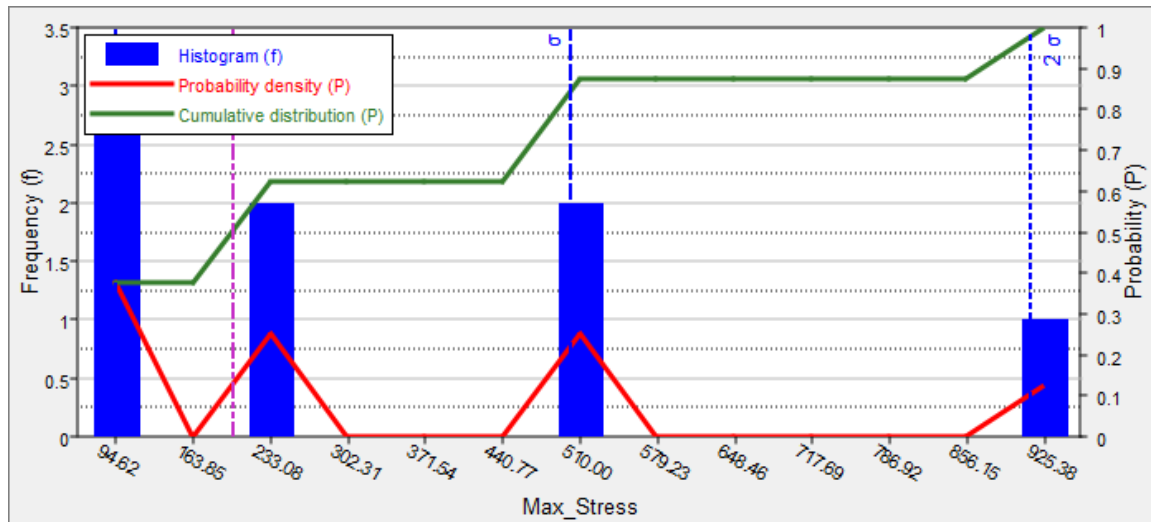


As illustrated in the plot above, as the length increases from 50 to 100 units, the max stress increases from 225 to 450. Increasing the width from 2.5 to 5 units decreases the max stress by the same amount. The contributions for max stress from both length and width are identical. Increasing the height from 5 to 10 units decreases the max

stress by a larger extent (from 530 to 130). It is clear that for the max stress output response, height has a larger main effect than length or width.

Input Variable	Max_Stress - Lower Bound	Max_Stress - Upper Bound
Length	225	450
Width	450	225
Height	540	135

2. Click the **Distribution** tab to review a histogram of **Max Stress**.



Step 6: Add Approximations for a Regression Equation

In the following steps, you will create approximations for the DOE study. A first order regression equation for each output response (**Max Stress**, **Max disp**, and **Volume**) is created based on the DOE study. Since the input variables are of two levels, only the first order equation can be generated.

1. In the **Explorer**, right-click and select **Add** from the context menu.
2. In the **Add - HyperStudy** dialog, select **Fit** and click **OK**.
3. Go to the **Select Matrices** step.
4. Click **Add Matrix**.
5. In the **Add - HyperStudy** dialog, add one matrix.
6. In the **Matrix Source** column, select **DOE 1 (doe_1)**.
7. Click **Import Matrix**. The matrix from the DOE is imported into the Fit approach.
8. Go to the **Specifications** step.

9. In the work area, set the **Mode** to **Least Squares Regression (LSR)**.
10. Click **Apply**.
11. Go to the **Evaluate** step.
12. Click **Evaluate Tasks**.
13. Go to the **Post-Processing** step.
14. Click the **Residuals** tab.

The Residuals table displays the difference between the output response value from the solver and the output response value calculated from the regression equation. This table can also be used to determine which runs are generating more errors in the regression model. The % error column shows that the predicted output response is not close to the observed value. The % error can be reduced if more levels are chosen for example, using a three-level design in this exercise.

	Length	Width	Height	Max_Stress	Max_Stress_LSR	Error	Percent Error
1	50.000000	2.5000000	5.0000000	480.00000	540.00000	-60.000000	-12.500000
2	50.000000	2.5000000	10.000000	120.00000	135.00000	-15.000000	-12.500000
3	50.000000	5.0000000	5.0000000	240.00000	315.00000	-75.000000	-31.250000
4	50.000000	5.0000000	10.000000	60.000000	-90.000000	150.00000	250.00000
5	100.00000	2.5000000	5.0000000	960.00000	765.00000	195.00000	20.312500
6	100.00000	2.5000000	10.000000	240.00000	360.00000	-120.00000	-50.000000
7	100.00000	5.0000000	5.0000000	480.00000	540.00000	-60.000000	-12.500000
8	100.00000	5.0000000	10.000000	120.00000	135.00000	-15.000000	-12.500000

15. Click the **Trade-Off** tab to plot output responses vs. input variables.
 - a. In the **Inputs** pane, select the **X Axis** and **Y Axis** checkboxes for Length.
 - b. Using the **Channel** selector, selector **Max_Stress_LSR**.
 - c. Review the plot in the **Outputs** pane.

