Altair

HyperWorks

HS-2000: DOE Method Comparison: Arm Model Study

In this tutorial you will:

- Set up a Full Factorial DOE

- Set up a Fractional Factorial DOE with Resolution III

- Set up a Fractional Factorial DOE with Resolution IV

- Set up a Fractional Factorial DOE with Resolution V

- Compare these methods in accuracy and efficiency

The files used in this tutorial can be found in `<hst.zip>/HS-2000/`. Copy the files from this directory to your working directory. The tutorial directory includes the following files:

`arm_model.tpl`	Template file
`arm_model.optistruct.node.tpl`	Grid coordinates template
`arm_model.shp`	Grid perturbation vector data for arm_model.optistruct.node.tpl

Problem Definition

An arm model is used for this tutorial; the arm is clamped at one end and under an axial loading on the other end. It has been meshed and modeled in HyperMesh and analyzed using OptiStruct.
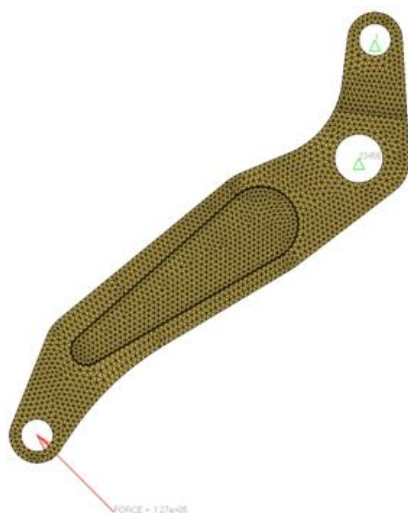
Concentrated load and boundary conditions
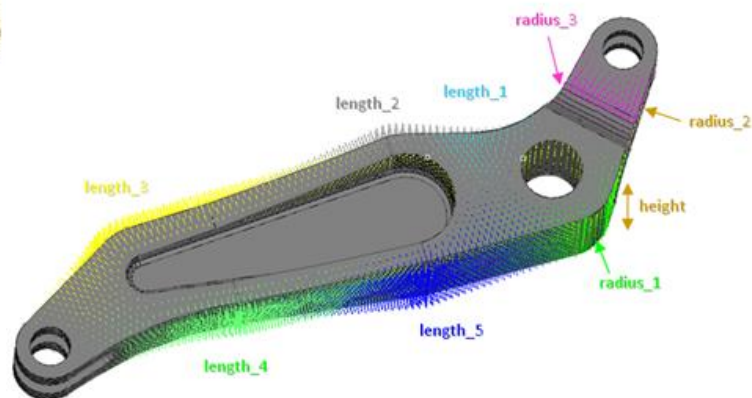
Shapes defined on the arm model

The design can change shape in nine different regions, as shown in the image above, and three output responses are of interest as detailed below.

Shape input variables	Length1: Lower Bound = -0.5, Initial Bound = 0.0, Upper Bound = 2.0
	Length2: Lower Bound = 0.0, Initial Bound = 0.0, Upper Bound = 2.0
	Length3: Lower Bound = -1.0, Initial Bound = 0.0, Upper Bound = 1.0
	Length4: Lower Bound = -1.0, Initial Bound = 0.0, Upper Bound = 1.0
	Length5: Lower Bound = -1.0, Initial Bound = 0.0, Upper Bound = 1.0
	Radius1: Lower Bound = -2.0, Initial Bound = 0.0, Upper Bound = 2.0
	Radius2: Lower Bound = -0.5, Initial Bound = 0.0, Upper Bound = 1.0
	Radius3: Lower Bound = -0.5, Initial Bound = 0.0, Upper Bound = 1.0
	Height: Lower Bound = -1.0, Initial Bound = 0.0, Upper Bound = 1.0
Output Responses	Volume (Nominal design volume 1.7667e6 mm3)
	Max Von Mises Stress (Current design value = 195.29 MPa)
	Nodal displacement of the node where the force is applied (mm) (1.411 mm)

Step 1: Perform the Study Setup

Shape variables are created using HyperMesh's morphing technology HyperMorph. In this tutorial you will start from an already morphed model. Moreover these shape variables are already exported for HyperStudy and a template is created.

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 `arm_model.tpl` file into the work area.
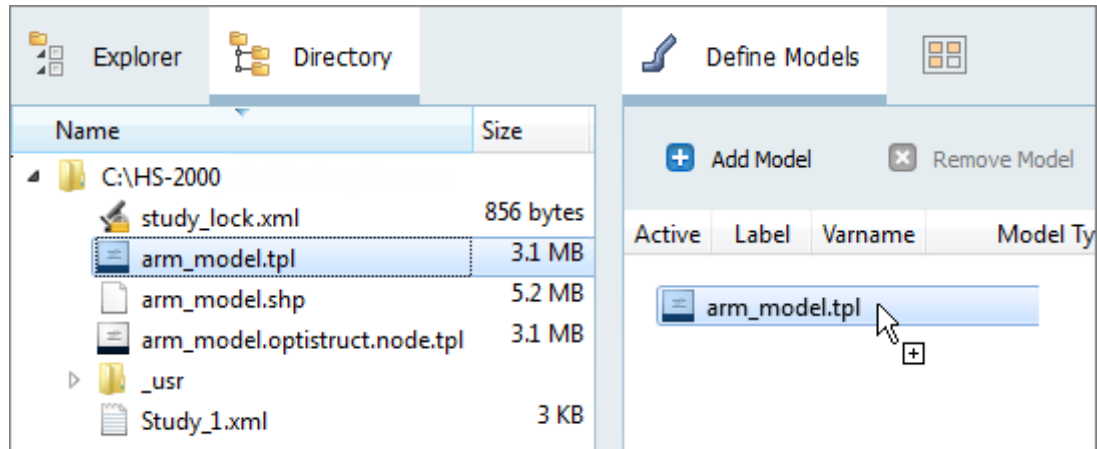
b. In the **Solver input file** column, enter `crank.fem`. This is the name of the solver input file HyperStudy creates during any evaluation.

c. In the **Solver execution script** column, select ***OptiStruct (os)***.

	Active	Label	Varname	Model Type	Resource	Solver input file	Solver execution script	Solver input arguments
1	☑	Model 1	m_1	{ } Parameterized File	C:/.../HS-2000/arm_model.tpl	crank.fem	OptiStruct (os)	${file}

6. Click ***Import Variables***. HyperStudy imports nine input variables from the `arm_model.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. The `approaches/nom_1/run__00001/m_1` directory contains the `.res` file, which is the result of the nominal run.

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_Disp, Max_Stress, and Volume.

1. Create the Max_Disp output response.

a. From the **Directory**, drag-and-drop the `crank.h3d` 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® (Hyper3D Reader)* and click *Next*.

c. Select *Multiple items at multiple time steps (readsim)*, then click *Next*.

d. Define the following options, then click *Next*.

- Set **Subcase** to *Subcase 1 (SUBCASE1)*.

- Set **Type** to *Displacement (Grids)*.

- For **Request** (Start - End), enter *N27099 - N40946*.

- For **Components**, select *MAG*.
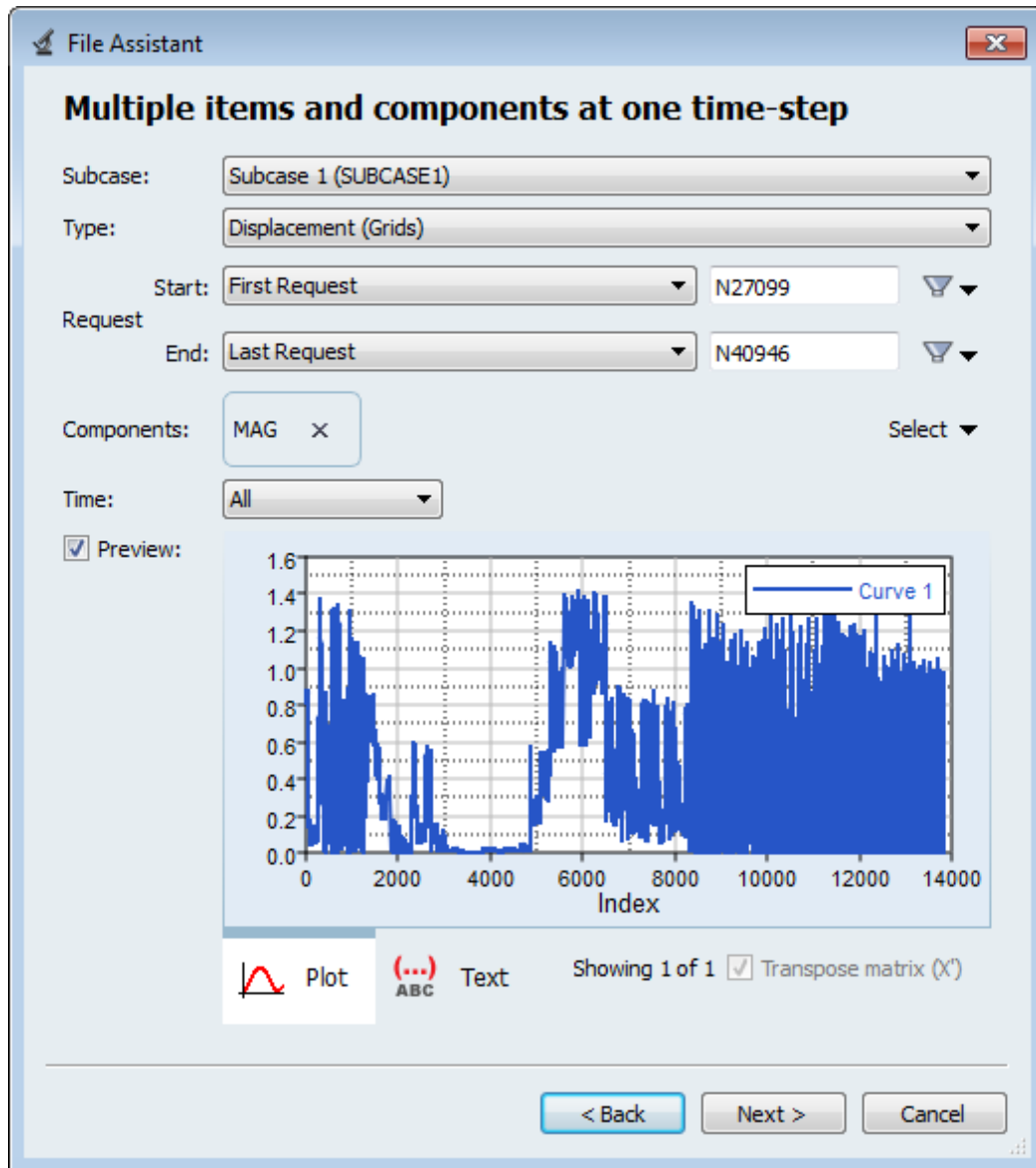
e. Label the output response Max_Disp.

      f.   Set **Expression** to *Maximum*.
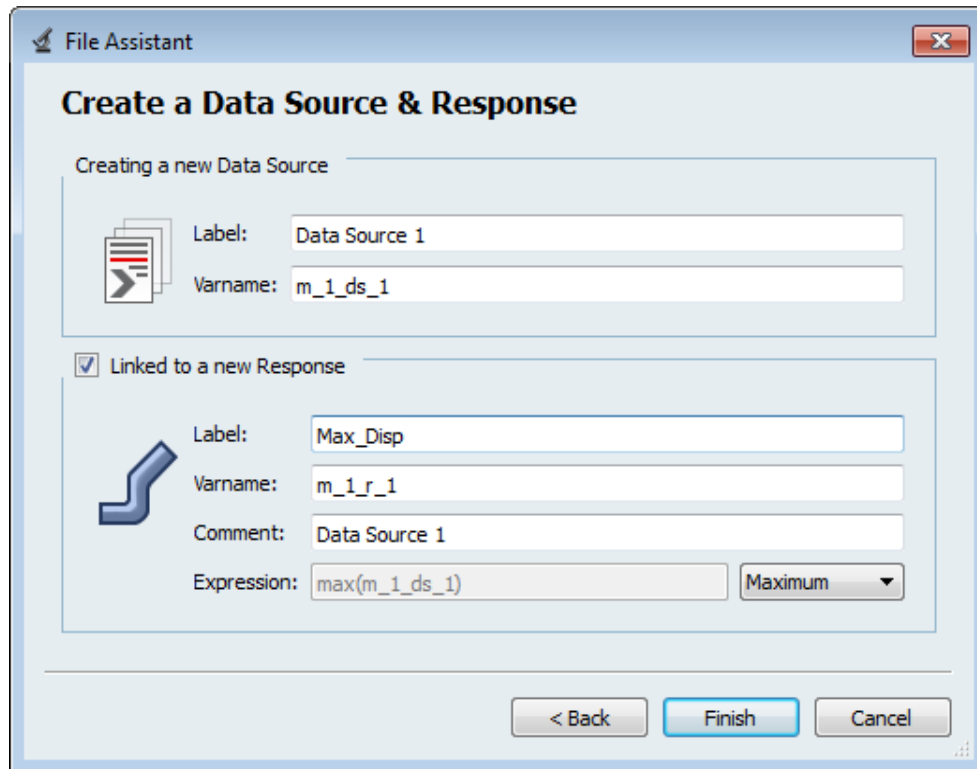
      g.   Click **Finish**. The Max_Disp output response is added to the work area.

2. Create the Max_Stress output response.

      a.   From the **Directory**, drag-and-drop the `crank.h3d` 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® (Hyper3D Reader)* and click **Next**.

      c.   Select *Multiple items at one time step (readsim)*, then click **Next**.

      d.   Define the following options, then click **Next**.

- Set **Subcase** to *Subcase 1 (SUBCASE1)*.
- Set **Type** to *Element Stresses (3D)*.
- For **Request** (Start-End), enter *E38257 - E94809*.
- For **Components**, select *vonMises (2D & 3D)*.

      e.   Label the output response Max_Stress.

      f.   Set **Expression** to *Maximum*.

      g.   Click **Finish**. The Max_Stress output response is added to the work area.

3. Create the Volume output response.

      a.   From the **Directory**, drag-and-drop the `crank.out` 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® (osmass.tpl)* 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 *OptiStruct Analysis*.

- Set **Request** to *Out File*.

- Set **Component** to *Volume*.

e.   Label the output response Volume.

f.   Set **Expression** to *First Element*.

g.   Click *Finish*. The Volume output response is added to the work area.

4.   To minimize the size of the result files in the study directory, go to the **Define Output
     Responses** step, **Data Sources** tab, and clear the **Retain** checkbox for Max_Disp
     (Data Source 1) and Max_Stress (Data Source 2) data sources.

5.   Click *Evaluate* to extract the output response values of each expression.

	Active	Label	Varname	Expression		Value	Comment	
1	☑	Max_Disp	m_1_r_1	max(m_1_ds_1)	...	1.4108398	Data Source 1	...
2	☑	Max_Stress	m_1_r_2	max(m_1_ds_2)	...	195.29431	Data Source 2	...
3	☑	Volume	m_1_r_3	m_1_ds_3[0]	...	1766760.0	Data Source 3	...

Parameter Screening DOE Setup

In this section, you will study the results from different parameter screening DOEs. For each
screening, only the results obtained on the Max_stress output response will be reviewed
using Pareto plot, Interactions, and Ordination displays.

As you proceed, keep the following points in mind:

- A Full Factorial provides excellent resolution but typically requires an exceedingly
  large number or runs.

- A Fractional Factorial with a Resolution III confounds main effects with interactions;
  results could be inaccurate if interactions are significant.

- A Fractional Factorial with a Resolution IV main effects are not confounded, but
  interactions are confounded with each other.

- A Fractional Factorial with a Resolution V main effects and interactions are not
  confounded.

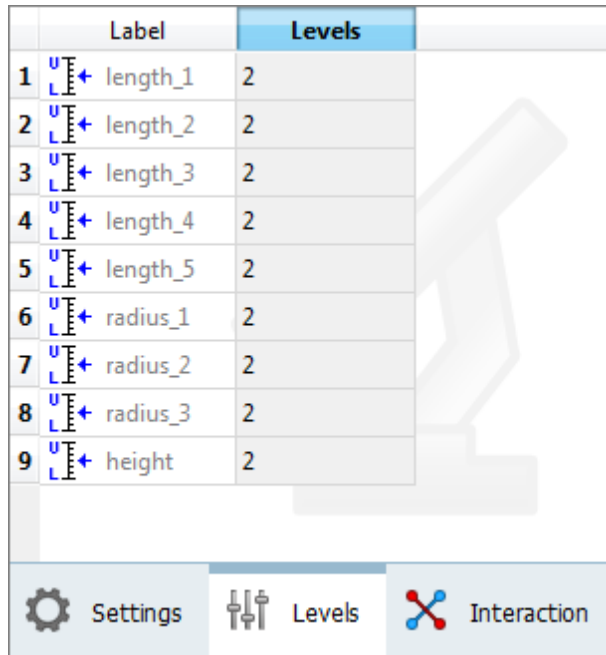### Step 4: Run a Full Factorial DOE Study

In this Full Factorial DOE, you will set the shape variables to two levels. Since Full Factorial
runs all combinations of input variable values, you will have no loss of information; however
you will have an expensive DOE. You will use this study as a reference to compare the loss

of accuracy in the conclusions to other DOEs that are less expensive.

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 the **Levels** tab, and verify that the number of levels for each input variable is 2.

Using nine shape variables with two levels gives a full factorial plan made of 512 runs (2^9).

	Label	Levels
1	length_1	2
2	length_2	2
3	length_3	2
4	length_4	2
5	length_5	2
6	radius_1	2
7	radius_2	2
8	radius_3	2
9	height	2

Settings	Levels	Interaction

6.   Click **Apply**.

7.   Go to the **Evaluate** step.

8.   Above the **Run Tasks** tab, click **Multi-Execution** and select the **Multi-Execution** checkbox. In the field below, verify that 4 Jobs is selected.

Multi-Execution - 4

☑ Multi-Execution

4 Jobs

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☐ Log output
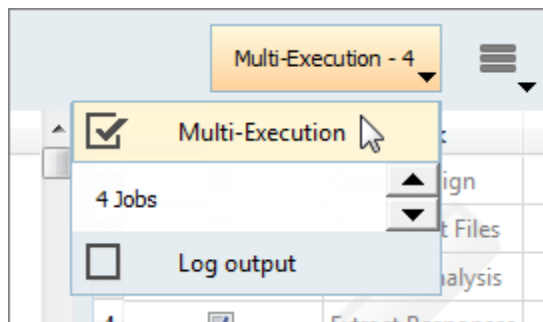
9.   Click **Evaluate Tasks**.

10. Go to the **Post-Processing** step.

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11. Click the **Pareto Plot** tab to view Pareto plots obtained from the Full Factorial DOE (512 runs).

    A Pareto Plot shows the ranked influence (highest to lowest) of the design variables on the response.

    You can see that the 5 lengths have the largest influence, and the 3 radii have the least influence on Max_stress. The slope of the hashed lines (positive or negative) indicates a positive or a negative effect of a variable on the response. length_4, length_2, length_5, and length_3 have negative slopes, which indicates that if these variables increase, Max_stress will decrease. On the other hand, length_1 has a positive slope, which indicates that increasing length_1 increases Max_stress.
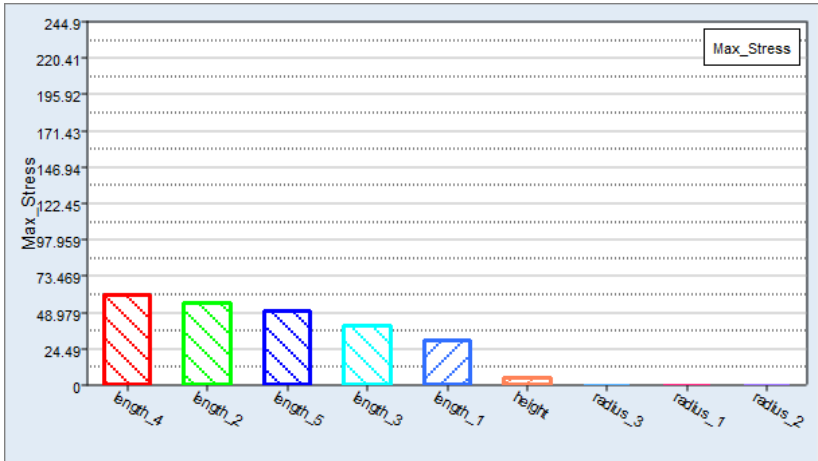
12. Click the **Interactions** tab to plot the interactions between input variables.

    An interaction is the failure of one variable to produce the same effect on a response at different levels of another variable. An interaction can be either positive or negative. The Interaction plot displays parallel lines if there is no interaction. The bigger the interaction is, the less parallel the lines will be.

    Looking at the Max_stress output response, you can see that several of the interactions are very small. You can still find instances with a true interaction, such as the interaction of length_5 and length_4. The effect of the variable length_4 on the output response Max_Stress is in the same direction regardless of the value of length_5, but the effect (magnitude) is much more important when length_5 is larger.
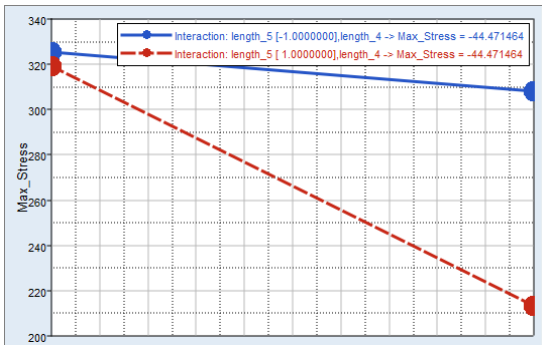

Interaction between length_5 and length_4 on Max_Stress
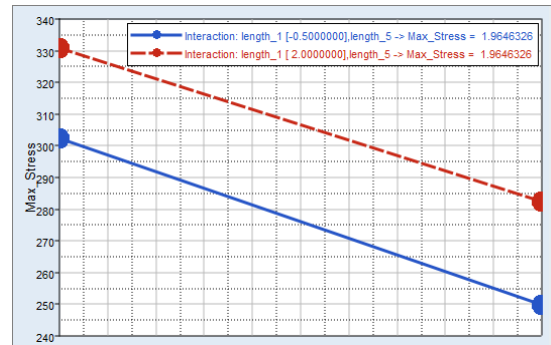
No interaction between length_1 and length_5 on Max_Stress

13. Click the **Ordination** tab to see the Principal Component Analysis results.

Each input variable and output response in the biplot is represented by a line. Lines that point in the same direction have strong correlations (positive or negative depending on whether the lines point in the same or opposite directions). You can see that lengths 2, 3, 4, and 5 contribute the most to the volume value, and improve the structural performance the most along with height and length_1.
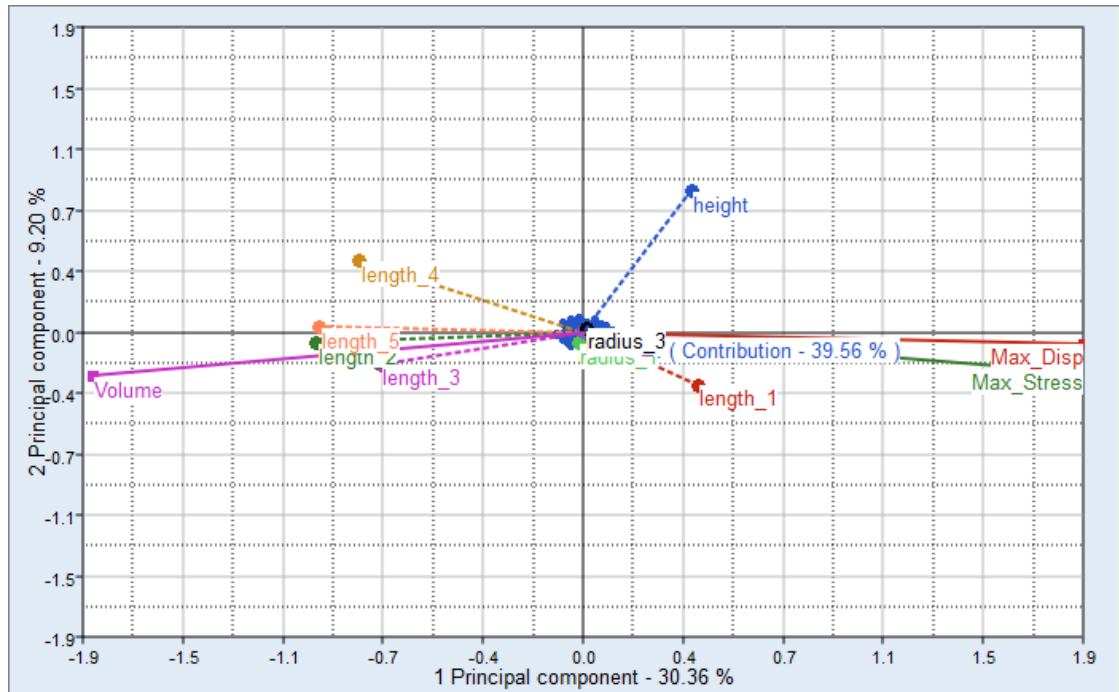
Step 5: Run a Fractional Factorial DOE Study with Resolution III

In this step you will set up a Fractional Factorial DOE, with resolution III and the same levels as the previous Full Factorial DOE. Use the nine input variables with two levels, without turning on any interaction, leads to a 12 run Fractional Factorial plan.

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. In the **Specifications** step, set the **Mode** to **Fractional Factorial**.

4. In the **Settings** tab, set **Resolution** to **III**.
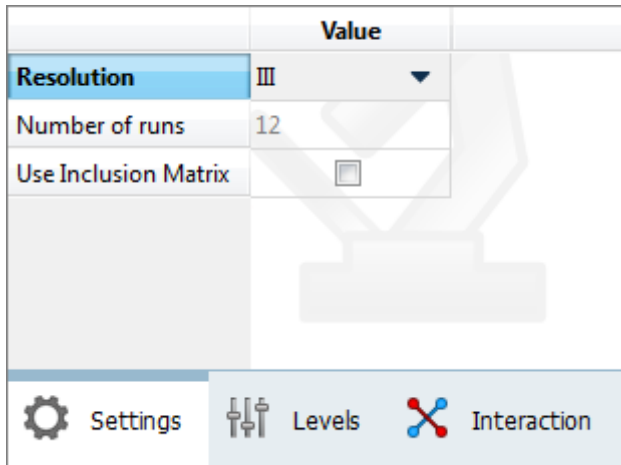
5. Click **Apply**.

6. Go to the **Evaluate** step.

7. Click **Evaluate Tasks**.

8. Go to the **Post-Processing** step.

9. Click the **Pareto Plot** tab to view Pareto plots on Max_stress obtained from the Fractional Factorial III DOE (12 runs).

    Compared to the Pareto plot from the Full Factorial, several differences can be observed.

    - The rank of variables is not the same; for instance, length_4 is the most influential input variable in the Full Factorial, whereas length_2 is the most influential input variable in the Fractional Factorial III.

    - The effect of length_5 has decreased, while the effects of the three radii has significantly increased, especially the effects of radius_3 and radius_1.
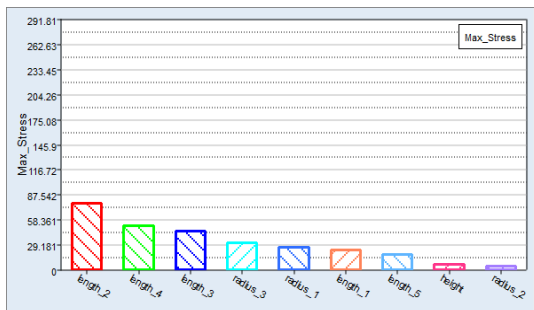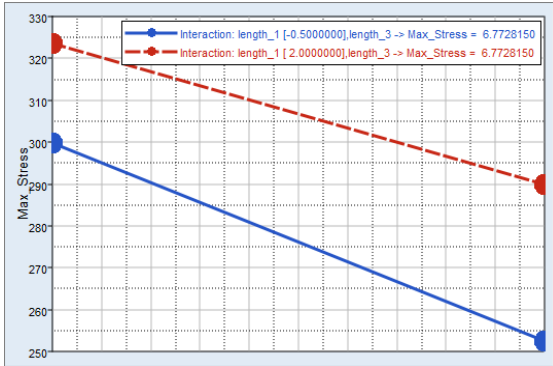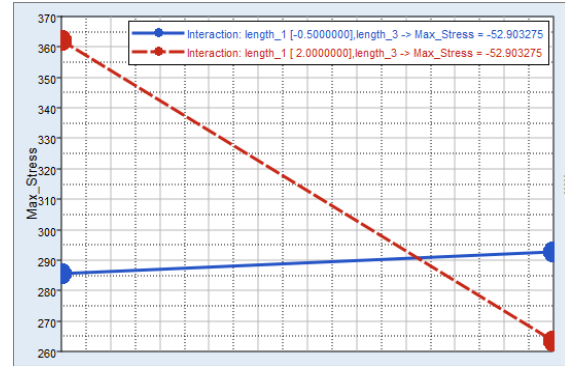

Fractional Factorial III
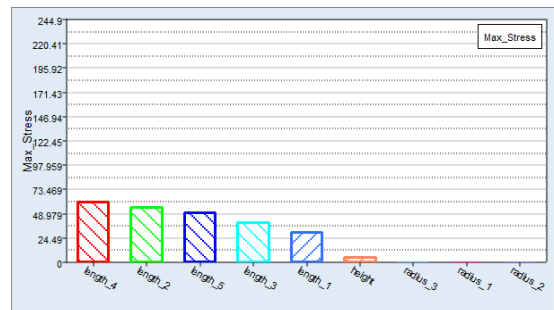
Full Factorial

10. Click the **Interactions** tab to plot the interactions between input variables.

    Compare the interaction between length_1 and length_3 on Max_stress. Note that the results provided from the Full Factorial and Fractional Factorial III are quite different. The Full Factorial establishes the real interactions, while the Fractional factorial III detects confounded interactions inaccurately.
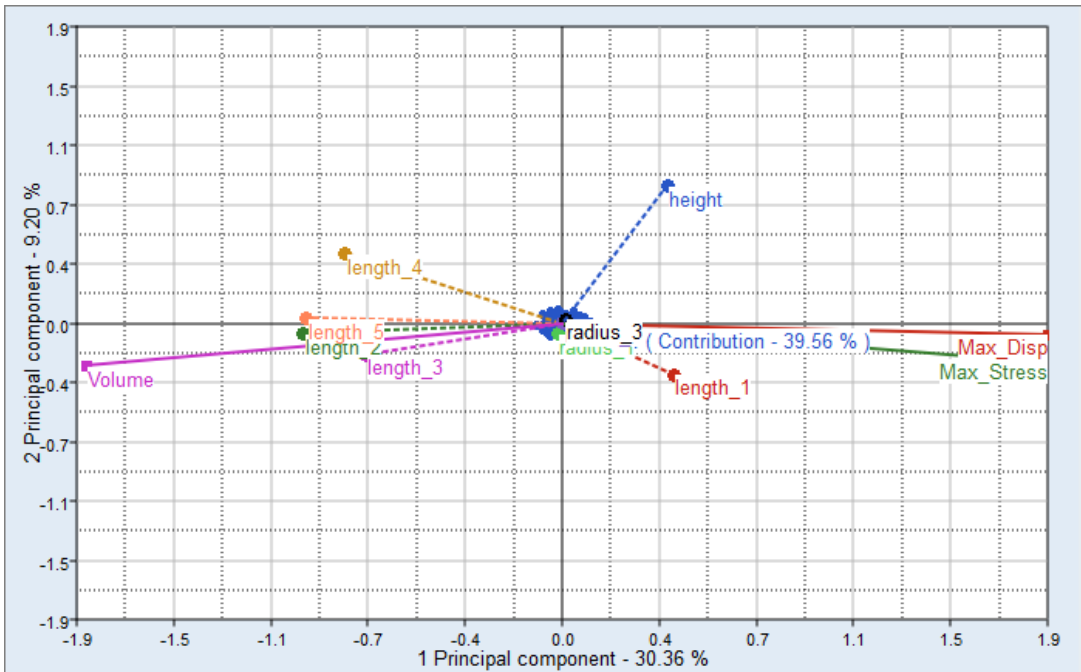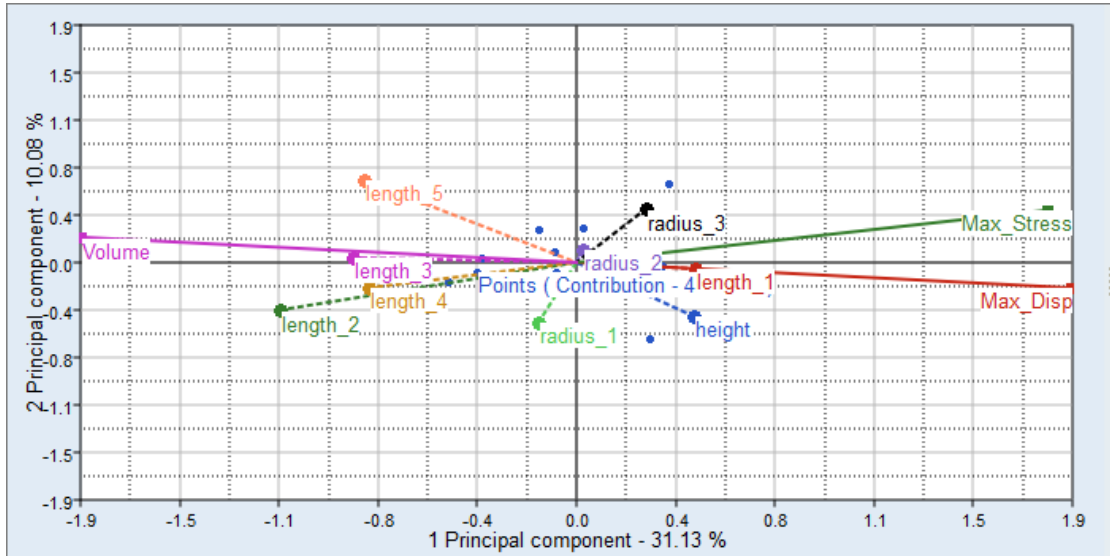
Full Factorial

Fractional Factorial III

11. Click the ***Ordination*** tab to see the Principal Component Analysis results obtained with the Fractional factorial III.

In the Full Factorial, you can see that length_2, length_3, and length_5 are correlated to the Volume output response. In the Fractional Factorial III, the relationship is not as clear. In the Fractional Factorial III, the lines representing length_2, length_3, length_5, and Volume are not as collinear as they are in the Full Factorial.
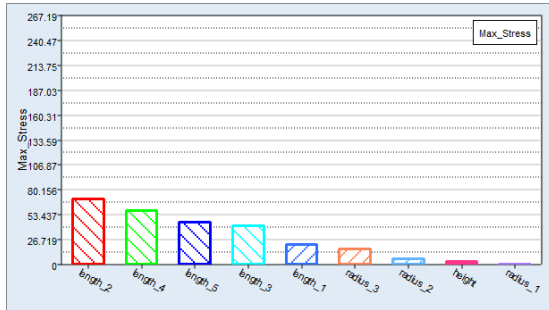

Full Factorial

Fractional Factorial III

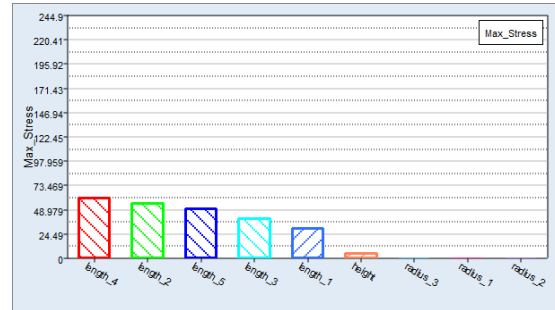## Step 6: Run a Fractional Factorial DOE Study with Resolution IV

In this step you will set up a Fractional Factorial DOE with Resolution IV. Using the nine input variables with two levels, without turning on any interaction, leads to a 24 run Fractional Factorial plan.

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 **Fractional Factorial**.

5. In the **Settings** tab, set **Resolution** to **IV**.

6. Click **Apply**.

7. Go to the **Evaluate** step.

8. Click **Evaluate Tasks**.

9. Go to the **Post processing** step.

10. Click the **Pareto Plot** tab to view Pareto plots on Max_stress obtained from the Fractional Factorial IV DOE (24 runs).

    Compared to the results obtained from the Full Factorial, you can see that the places of length_2 and length_4 have been inversed in the ranking, but the rest of the information is quite similar.

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Fractional Factorial IV

Full Factorial

## Step 7: Run a Fractional Factorial DOE Study with Resolution V

In this step you will set up a Fractional Factorial DOE with Resolution V. Using the nine input variables with two levels, without turning on any interaction, leads to a 128 run Fractional Factorial plan.

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 **Fractional Factorial**.

5. In the **Settings** tab, set **Resolution** to **V**.

6. Click **Apply**.

7. Go to the **Evaluate** step.

8. Click **Evaluate Tasks**.

9. Go to the **Post-Processing** step.

10. Click the **Pareto Plot** tab to view Pareto plots on Max_stress obtained from the Fractional Factorial V DOE (128 runs).

    Notice that the results obtained from both DOE methods are the same, but the number of runs for the Fractional Factorial V is only 1/4th of the runs for the Full Factorial.
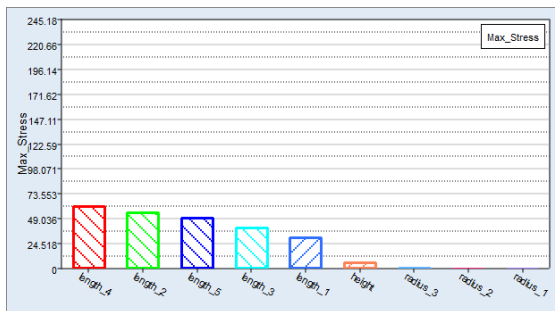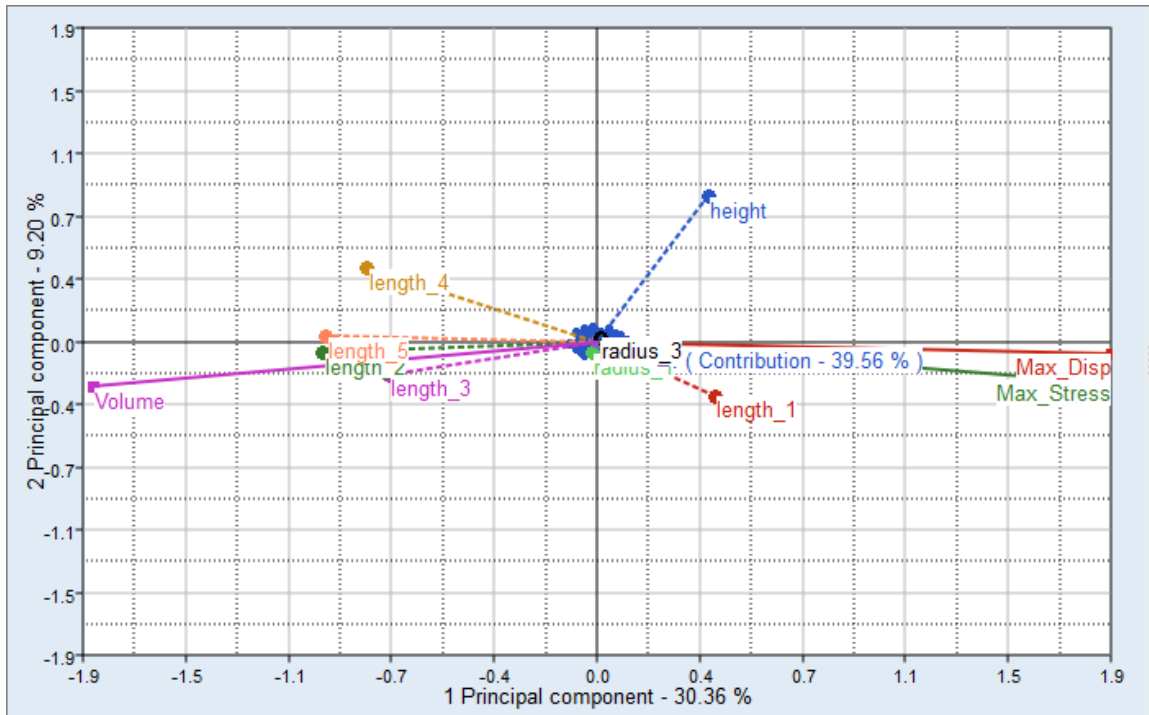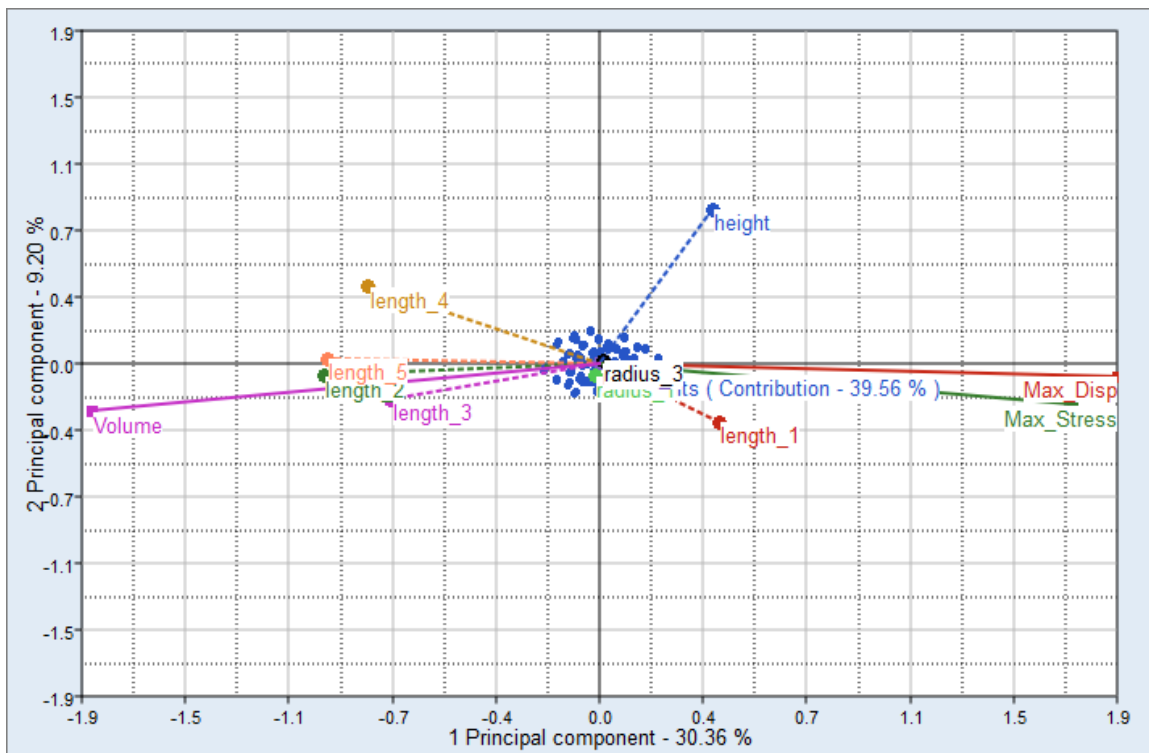

Fractional Factorial V
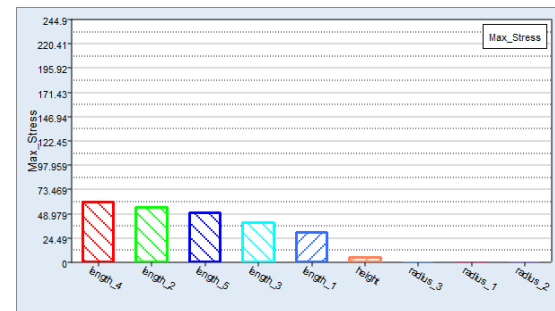
Full Factorial

11. Click the **Ordination** tab to see the Principal Component Analysis results obtained from the Fractional factorial V.

Notice that there are no differences between the results obtained from the Full Factorial and the Fractional Factorial V.

Full Factorial

Fractional Factorial V

Comparison

In this tutorial, you focused on the Max_Stress output response, but the same steps should be applied for all output responses. Conclusions on the screened output responses are summarized for the four DOE methods in the table below. Results for the Full Factorial and Fractional Factorial V are the same; however, the Fractional Factorial V required only 1/4th the number of runs as the Full Factorial. You can also observe that as the resolution decreased, the accuracy of the information gathered also decreased. For example, the conclusions from the Fractional Factorial III are the least accurate.

	Full Factorial	Fractional Factorial V	Fractional Factorial IV	Fractional Factorial III
Number of runs	512	128	24	12
Max_Stress	Remove all radii and height	Remove all radii and height	Remove radii 1, 2 and height	Remove radius 2 and height
Max_Disp	Remove all radii	Remove all radii	Remove all radii	Remove all radii
Volume	Remove all radii	Remove all radii	Remove all radii	Remove all radii
Conclusion	Remove all radii	Remove all radii	Remove radii 1 and 2	Remove radius 2

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