Altair

HyperWorks

Altair MotionView 2019 Tutorials

MV-1015: Using Spline3D to Model Combustion Forces in an Engine

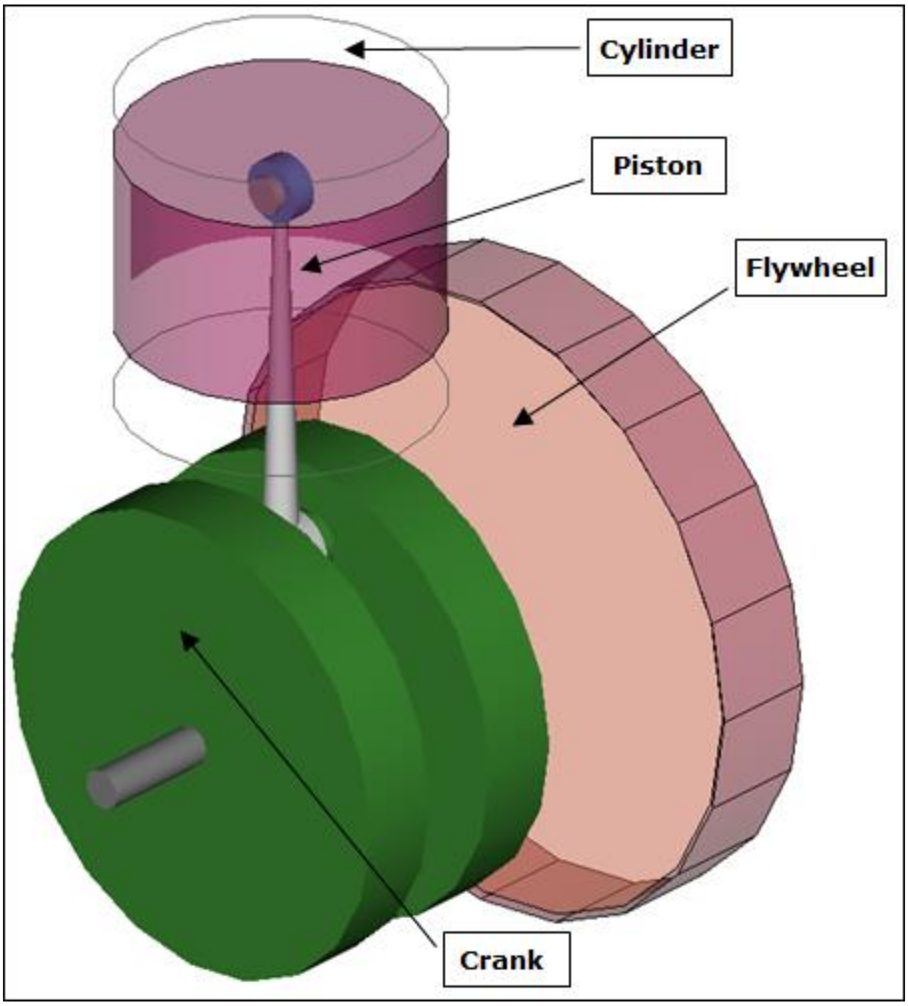
altairhyperworks.com

MV-1015: Using Spline3D to Model Combustion Forces in an Engine

In this tutorial you will learn how to:

- Use **Spline3D** to model an input which depends on two independent variables.

This will be accomplished by building a Single Cylinder Engine model similar to the one shown below:



What are Spline3Ds?

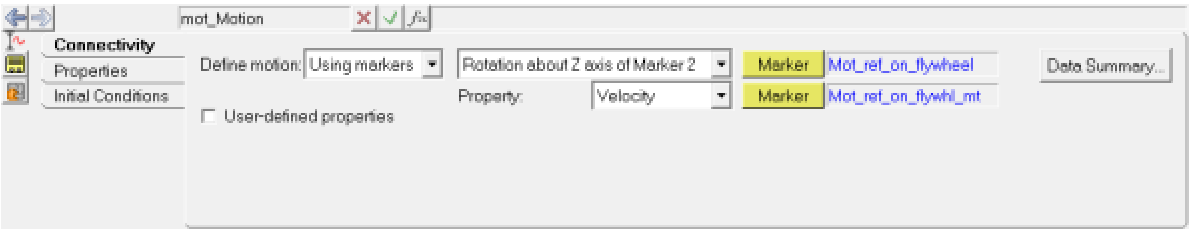
Spline3Ds are reference data plotted in three-dimensional coordinates which have two independent vectors or axis. These can be visualized as a number of 2D Splines (Curves) placed at regular intervals along a third axis. For instance, a bushing is generally characterized by a Force versus the Displacement curve. Let's say, the Force versus displacement also varies with temperature. Effectively, there are two independent variables for the bushing force - Displacement and Temperature. Another example is the Engine Pressure (or Force) versus the Crank angle map (popularly known as P-Theta diagram). The P-theta map will vary at different engine speeds (or RPM). Such a scenario can be modeled using Spline3D.

Exercise

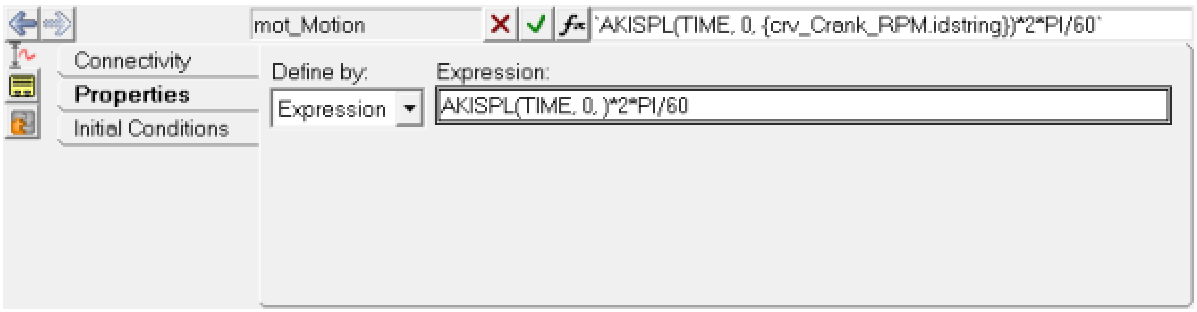
In this exercise, an engine mechanism is simulated where the combustion force that varies with regard to the crank angle and engine speed is modeled using Spline3D.

Step 1: Reviewing the model.

1. Copy the files `SingleCylEngine.mdl` and `FTheta.csv` , located in the `mbd_modeling\interactive\spline3d` folder, to your `<working directory>`.
2. Start a new MotionView session.
3. Open the `SingleCylEngine.mdl` model file.
4. Review the model.
   - The model is a piston cylinder mechanism with a flywheel.
   - The model has two systems: **System Cyl1** and **System Flywheel**.
   - In the **System Flywheel**, the Flywheel (fixed to Crank) is driven by a velocity based Motion between markers which refers to a curve (**Crank_RPM**) for inputs.

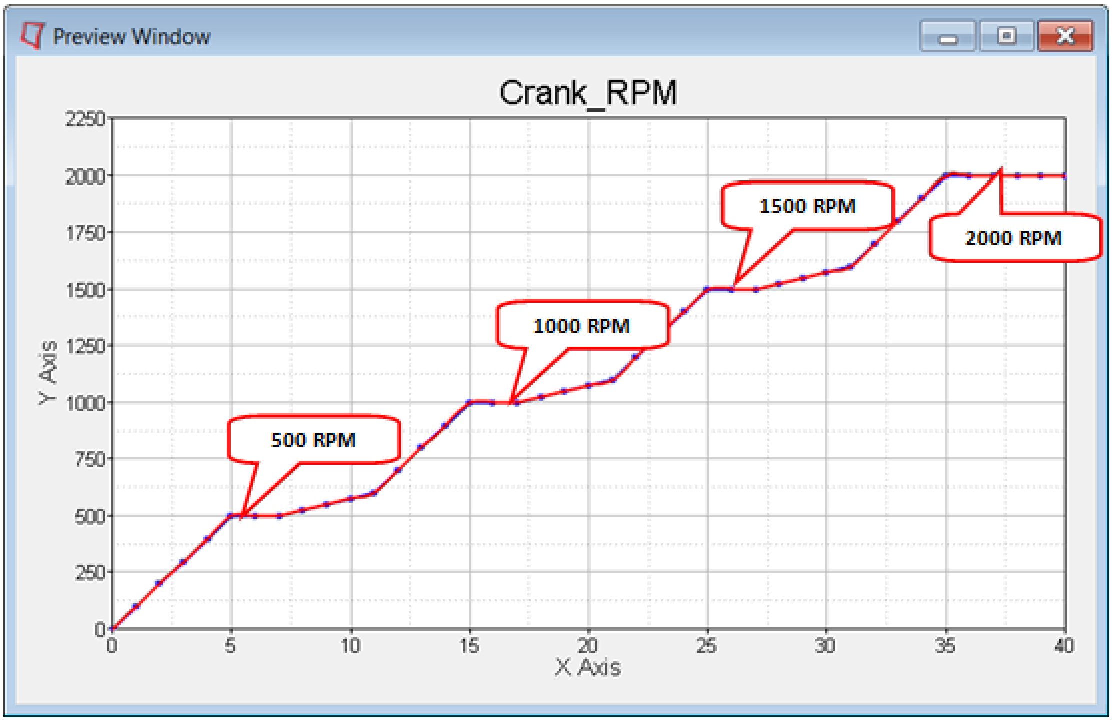


Motion Panel - Connectivity Tab



Motion Panel - Properties Tab (with Expression referring to the Curve using AKISPL function)

– The curve **Crank_RPM** indicates the time history of crank speed during the simulation. The speed ramps up to 500 RPM and then to 1000, 1500, and 2000 RPM.



Curve Crank_RPM

– Two Solver Variables: **Crank_angle (deg)** and **Crank_RPM** keep track of the angular rotation (in degrees) and velocity (in RPM) of the crank respectively.

– Outputs are defined to measure the crank angle and RPM.

– In **System Cyl1**:

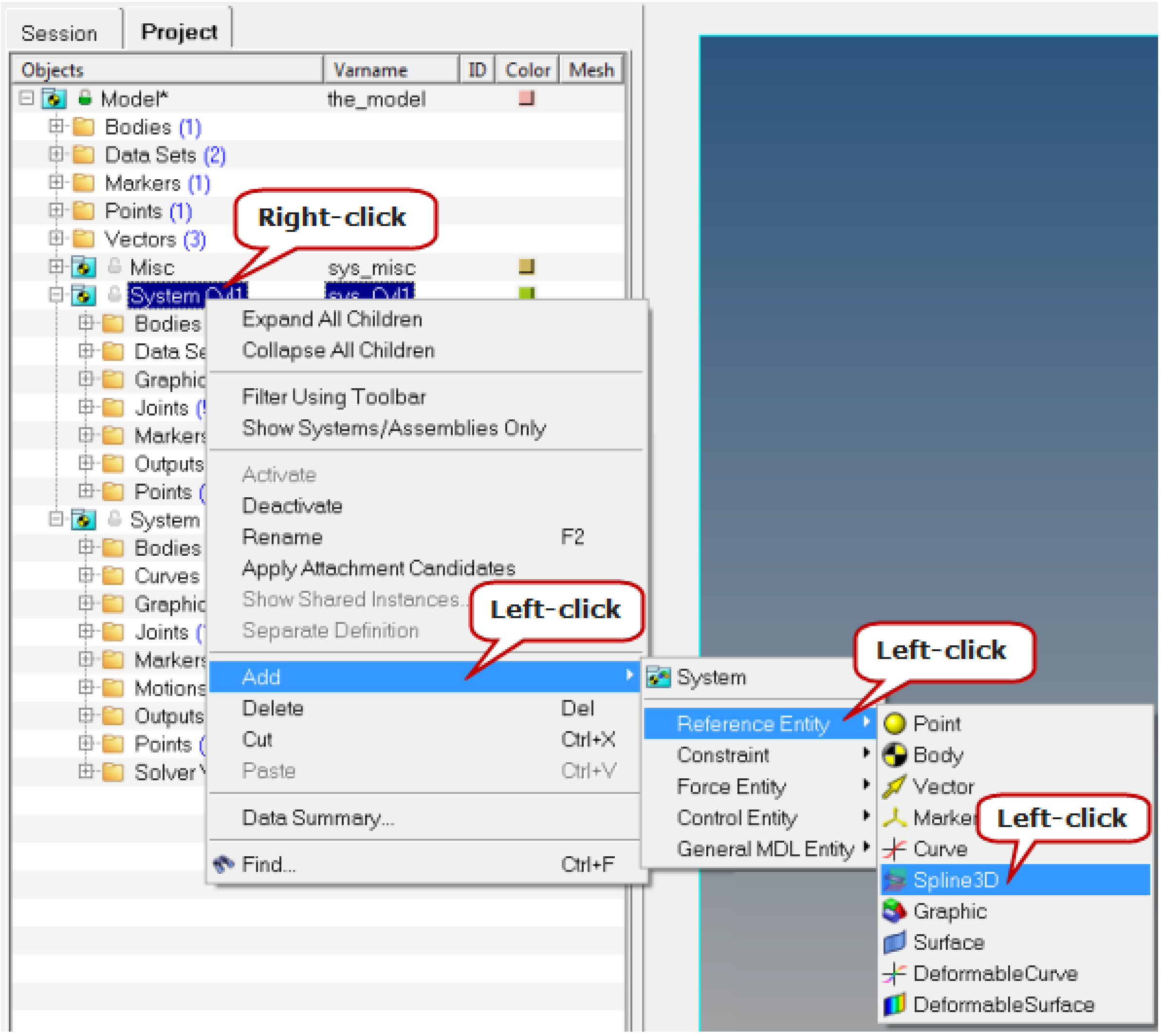
- The solver variables in **System Flywheel** are passed as attachments to this system and carry the variable names `arg_Crank_angle_SolVar` and `arg_Crank_RPM_SolVar`. These will be used in defining the independent variables while defining the combustion force using Spline3D
- A **Combustion_ref** marker exists as a reference for a combustion force whose Z axis is aligned along the direction of travel of the piston.

Next, a combustion force will be added on the piston using a Spline3D.

Step 2: Adding a Spline3D entity.

1. Add a Spline3D using one of the following methods:

   – From the **Project Browser**, right-click on ***System Cyl1*** and select ***Add > Reference Entity > Spline3D*** from the context menu.

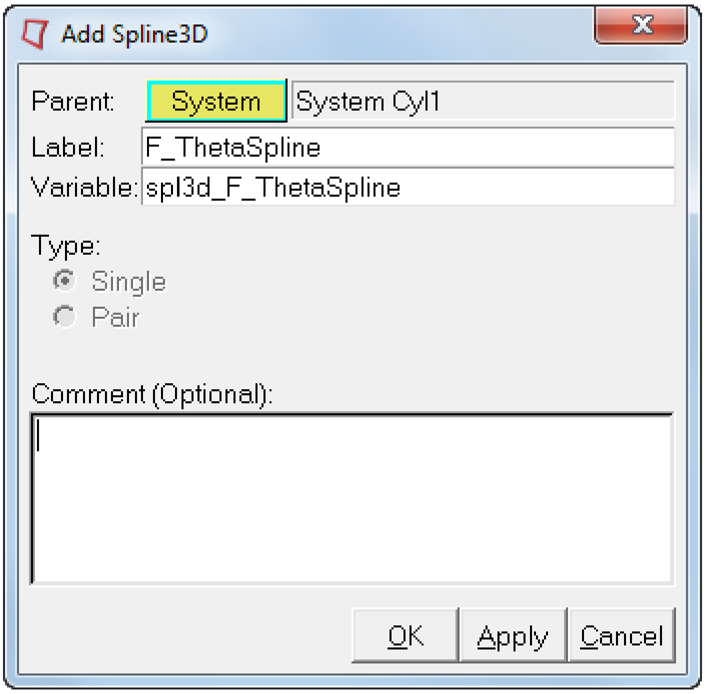


   OR

   – Select ***System Cyl1*** in the **Project Browser** and then right-click on the ***Spline3D*** icon on the **Reference Entity** toolbar.

   The **Add Spline3D** dialog is displayed.

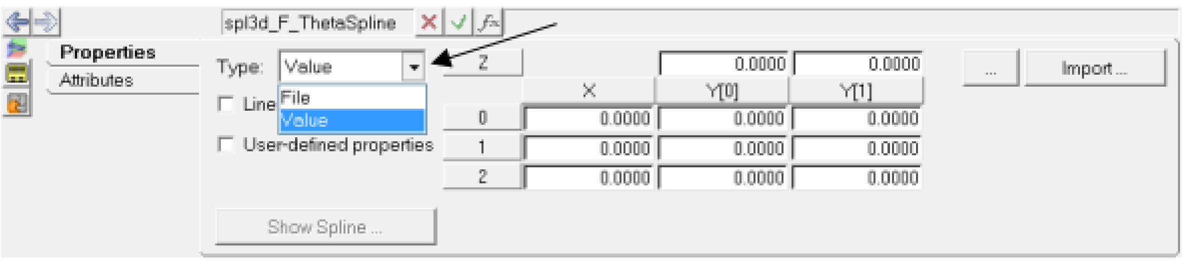
2. Enter `F_ThetaSpline` for the **Label** and `spl3d_F_ThetaSpline` for the **Variable**.



3. Click ***OK*** to close the dialog.

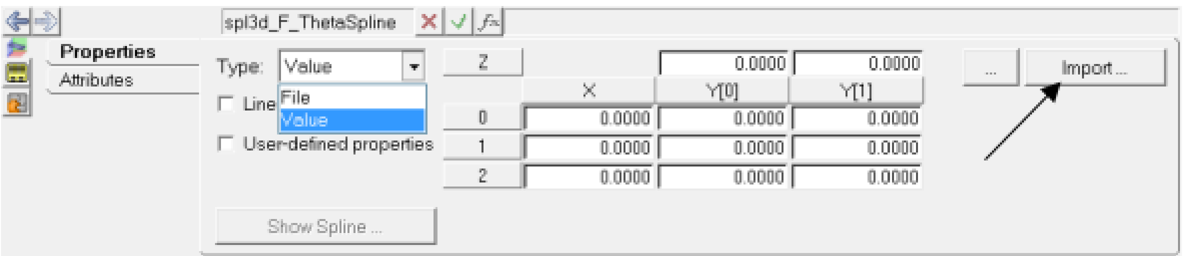
   The Spline3D panel is displayed in the panel area with the **Properties** tab active.

4. Click on the **Type** drop-down menu and select **Value**.

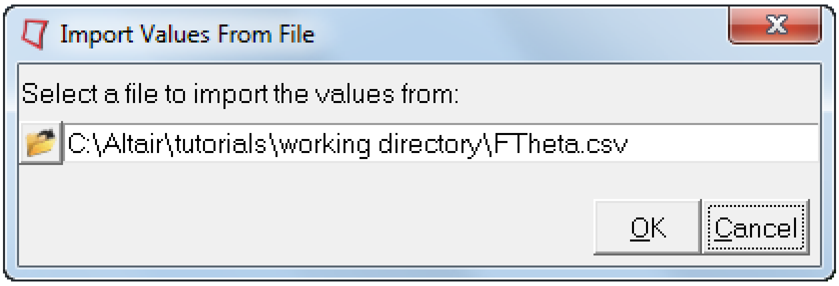


The data for the spline can be defined using either the **File** or **Value** methods. For the **File** type, a reference to an external file in `.csv` format must be provided. In case of the **Value** type, the values can be imported from a .CSV file (using **Import**) or they can be entered in manually. In this tutorial, we will import the values from an external file.

5. Click the **Import** button to display the **Import Values From File** dialog.



6. Browse to the `FTheta.csv` file in your `<working directory>` and click ***OK***.



7. In the **Warning** dialog that appears, click ***Yes*** to continue.

The `.csv` file that is to be used as the source for Spline3D needs to be in the following format:

- The first column must hold the X-axis values (shown in blue below) which is the first independent variable.
- The top row holds the Z-axis values (shown in red below) which is the second independent variable.
- The other columns must have the Y-axis values (shown in green below) with each column belonging to the particular Z-axis values heading that column.

	A	B	C	D	E
1		500	1000	1500	2000
2	0	2223.353	2001.018	1778.682	1667.515
3	1	2202.574	1982.317	1762.059	1651.931
4	2	2181.795	1963.616	1745.436	1636.346
5	3	2161.016	1944.914	1728.813	1620.762
6	4	2161.016	1944.914	1728.813	1620.762
7	5	2140.237	1926.213	1712.19	1605.178
8	6	2098.679	1888.811	1678.943	1574.009
9	7	2069.588	1862.63	1655.671	1552.191
10	8	2036.342	1832.708	1629.074	1527.257
11	9	1994.784	1795.306	1595.827	1496.088
12	10	1961.538	1765.384	1569.23	1471.153
13	11	1928.291	1735.462	1542.633	1446.218
14	12	1919.98	1727.982	1535.984	1439.985
15	13	1911.668	1720.501	1529.334	1433.751
16	14	1903.356	1713.021	1522.685	1427.517
17	15	1895.045	1705.54	1516.036	1421.284
18	16	1878.422	1690.579	1502.737	1408.816
19	17	1878.422	1690.579	1502.737	1408.816
20	18	1870.11	1683.099	1496.088	1402.583
21	19	1861.798	1675.619	1489.439	1396.349
22	20	1853.487	1668.138	1482.789	1390.115
23	21	1853.487	1668.138	1482.789	1390.115
24	22	1845.175	1660.658	1476.14	1383.881
25	23	1845.175	1660.658	1476.14	1383.881
26	24	1836.864	1653.177	1469.491	1377.648
27	25	1836.864	1653.177	1469.491	1377.648

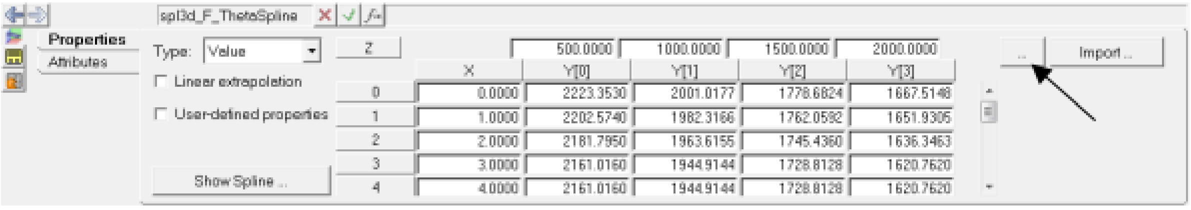
Z-axis: Independent variable 2

X-axis: Independent variable 1

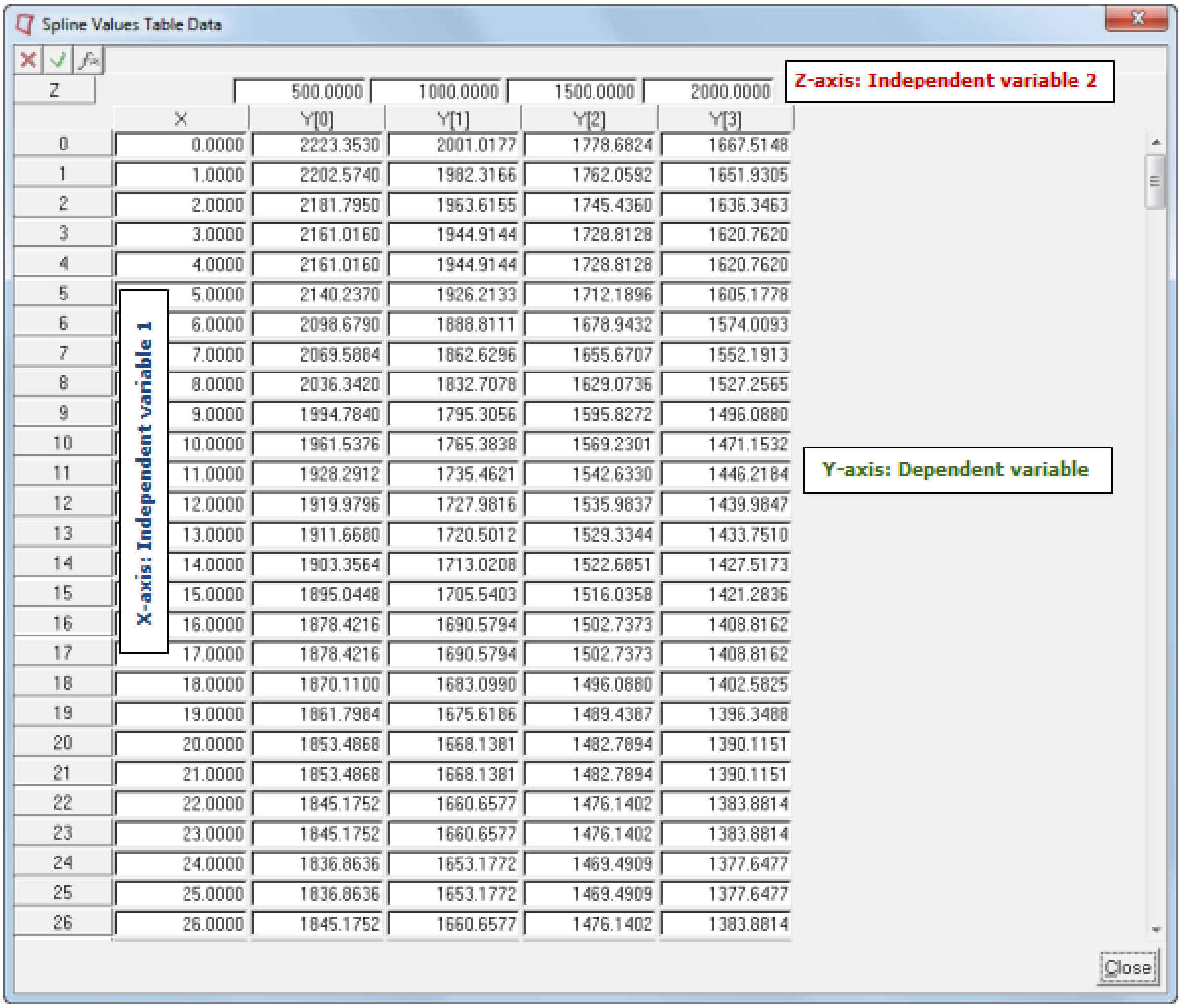
Y-axis: Dependent variable

Note The same format is applicable when using the **File** input type.

8. Once imported, the values are populated in the panel. You may review these by clicking on the ***Expansion button*** [...] in the panel to open the **Spline Values Table Data** window.

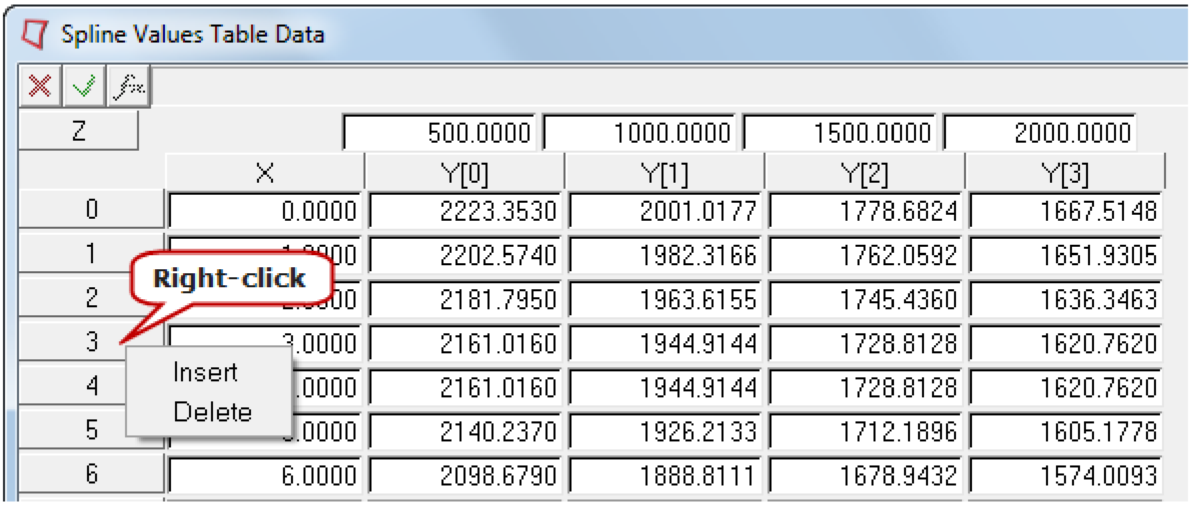


Z		500.0000	1000.0000	1500.0000	2000.0000
	X	Y[0]	Y[1]	Y[2]	Y[3]
0	0.0000	2223.3530	2001.0177	1778.6824	1667.5148
1	1.0000	2202.5740	1982.3166	1762.0592	1651.9305
2	2.0000	2181.7950	1963.6155	1745.4360	1636.3463
3	3.0000	2161.0160	1944.9144	1728.8128	1620.7620
4	4.0000	2161.0160	1944.9144	1728.8128	1620.7620

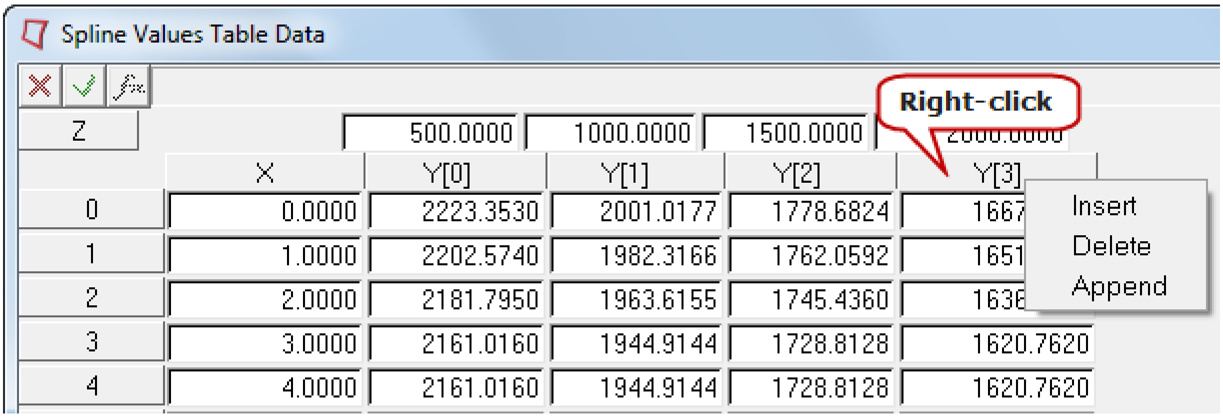


Z		500.0000	1000.0000	1500.0000	2000.0000
	X	Y[0]	Y[1]	Y[2]	Y[3]
0	0.0000	2223.3530	2001.0177	1778.6824	1667.5148
1	1.0000	2202.5740	1982.3166	1762.0592	1651.9305
2	2.0000	2181.7950	1963.6155	1745.4360	1636.3463
3	3.0000	2161.0160	1944.9144	1728.8128	1620.7620
4	4.0000	2161.0160	1944.9144	1728.8128	1620.7620
5	5.0000	2140.2370	1926.2133	1712.1896	1605.1778
6	6.0000	2098.6790	1888.8111	1678.9432	1574.0093
7	7.0000	2069.5884	1862.6296	1655.6707	1552.1913
8	8.0000	2036.3420	1832.7078	1629.0736	1527.2565
9	9.0000	1994.7840	1795.3056	1595.8272	1496.0880
10	10.0000	1961.5376	1765.3838	1569.2301	1471.1532
11	11.0000	1928.2912	1735.4621	1542.6330	1446.2184
12	12.0000	1919.9796	1727.9816	1535.9837	1439.9847
13	13.0000	1911.6680	1720.5012	1529.3344	1433.7510
14	14.0000	1903.3564	1713.0208	1522.6851	1427.5173
15	15.0000	1895.0448	1705.5403	1516.0358	1421.2836
16	16.0000	1878.4216	1690.5794	1502.7373	1408.8162
17	17.0000	1878.4216	1690.5794	1502.7373	1408.8162
18	18.0000	1870.1100	1683.0990	1496.0880	1402.5825
19	19.0000	1861.7984	1675.6186	1489.4387	1396.3488
20	20.0000	1853.4868	1668.1381	1482.7894	1390.1151
21	21.0000	1853.4868	1668.1381	1482.7894	1390.1151
22	22.0000	1845.1752	1660.6577	1476.1402	1383.8814
23	23.0000	1845.1752	1660.6577	1476.1402	1383.8814
24	24.0000	1836.8636	1653.1772	1469.4909	1377.6477
25	25.0000	1836.8636	1653.1772	1469.4909	1377.6477
26	26.0000	1845.1752	1660.6577	1476.1402	1383.8814

9. When manually keying in the values, context menus are available which allow you to **Insert**/**Delete**/**Append** row and column data. You can access these menus by right-clicking on any of the row or column headers. If the right-click is made on the last row/column, an **Append** option will also be available.



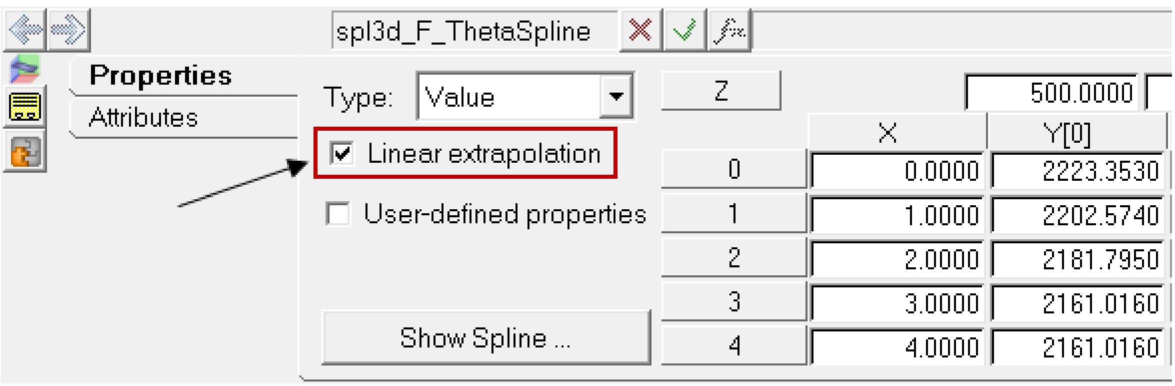
Context Menu (Row)



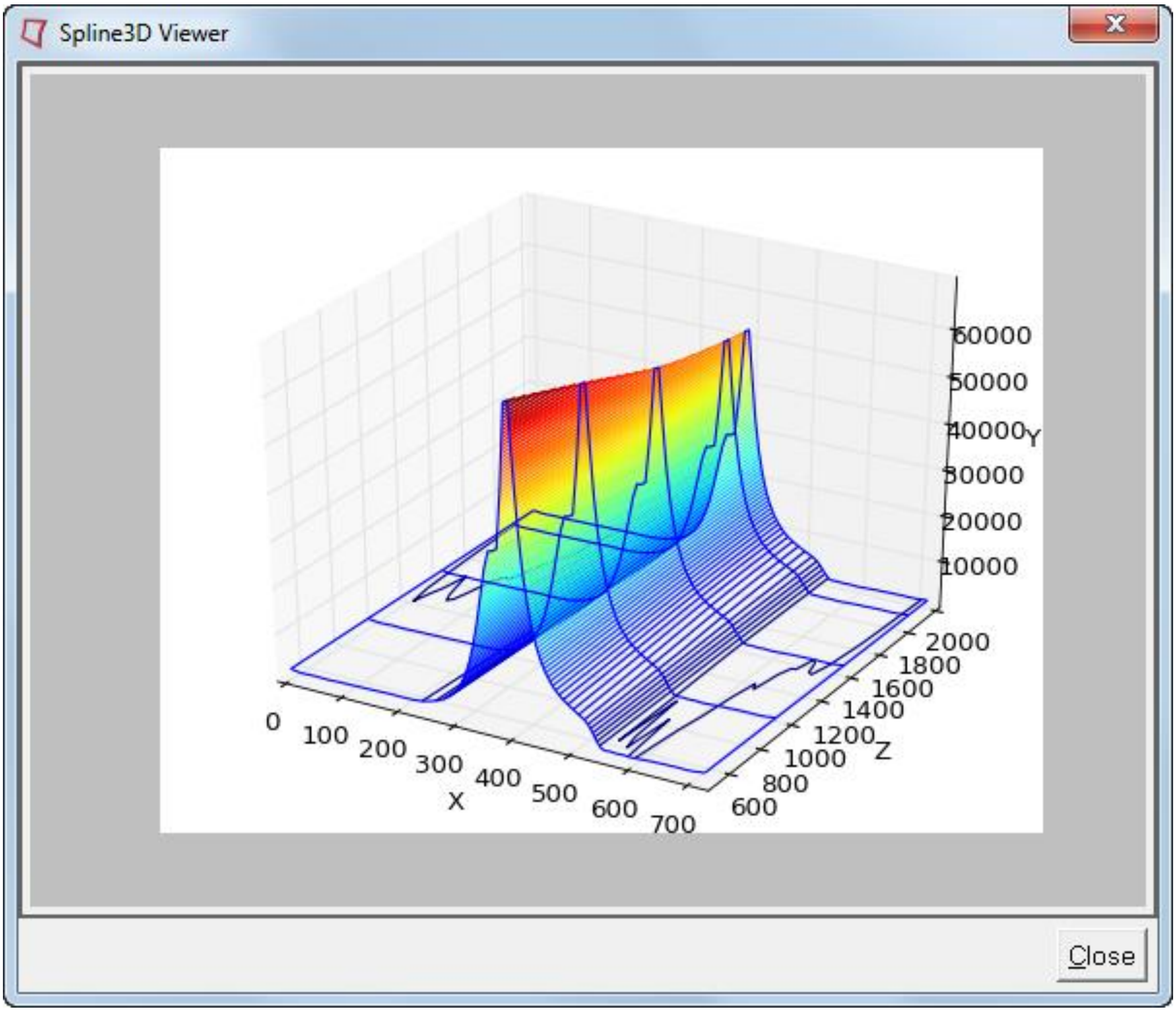
Context Menu (Column)

10. Click ***Close*** to close the **Spline Values Table Data** table.

11. Activate the ***Linear Extrapolation*** check box. This will ensure that the values are extrapolated if the Solver starts looking for values beyond the range of the user provided data.



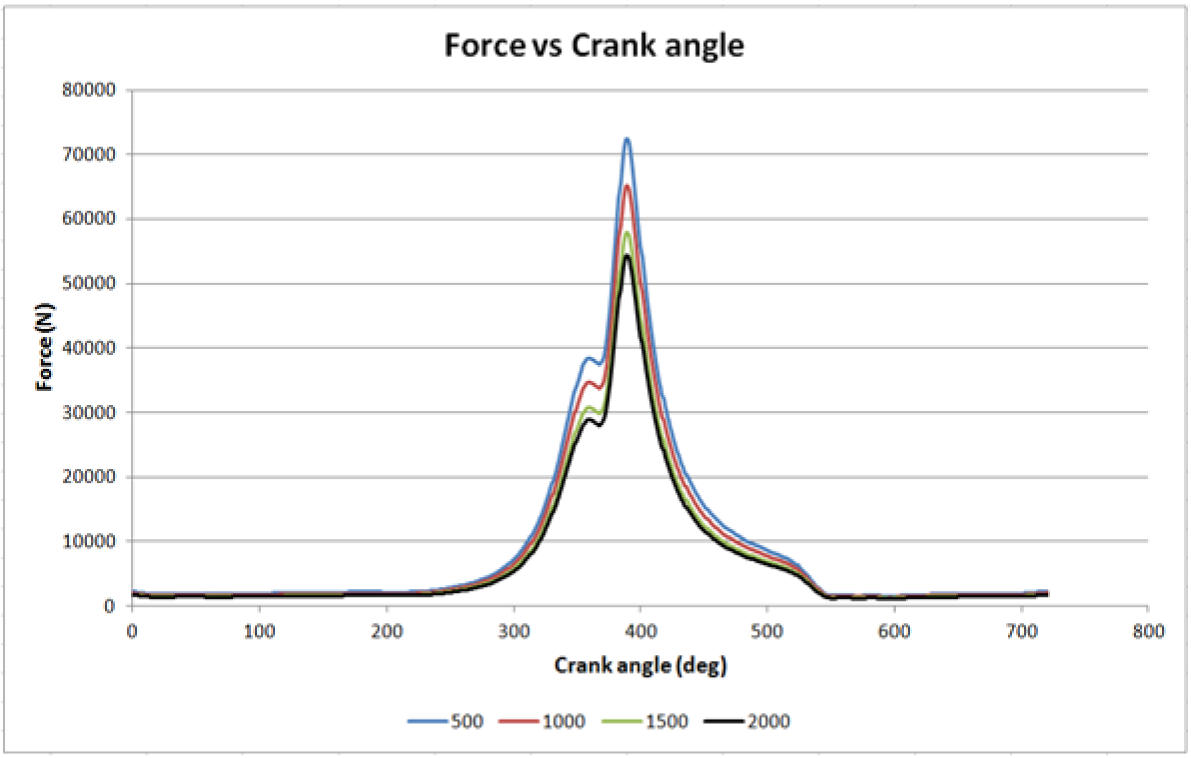
12. To visualize the spline graphically, click on the **Show Spline** button to display the **Spline3D viewer** dialog.



All three axes can be viewed in an isometric view in this window.

13. Click ***Close*** to close the viewer.

    The imported values are **Combustion Force on Piston vs Theta** (crank angle) diagrams at different speeds (as shown below). The F-Theta profiles vary slightly at different engine or crank speeds. The same plot was visualized in the previous section in the **Spline3D viewer** by placing the four different plots along the Z-axis.



Input Data for Spline3D

Step 3: Adding a force using the Spline3D.

A force will now be added to represent the combustion in the cylinder. This force will be mapped to the Spline3D added in the previous section.

1. Add a Force using one of the following methods:

   – From the **Project Browser**, right-click on ***System Cyl1*** and select ***Add > Force Entity > Force*** from the context menu.

   OR

   – Select ***System Cyl1*** in the **Project Browser** and then right-click on the ***Force*** icon on the **Force Entity** toolbar.

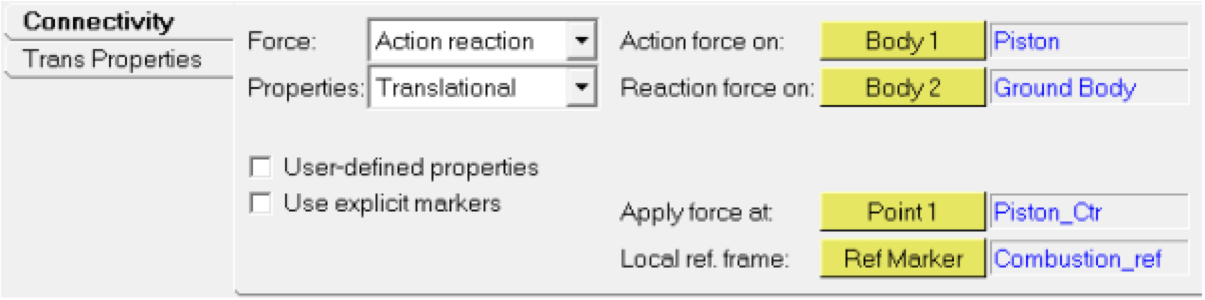
   The **Add Force or ForcePair** dialog is displayed.

2. Enter an appropriate **Label** and **Variable** name and click ***OK***.

   The **Force** panel is displayed in the panel area with the **Connectivity** tab active.

3. From the **Connectivity** tab, use the **Force** drop-down menu to change the type to ***Action reaction***.

4. Resolve the connections as shown in the image below, either through picking in the graphics area or using the model tree (by double clicking on the input collector).

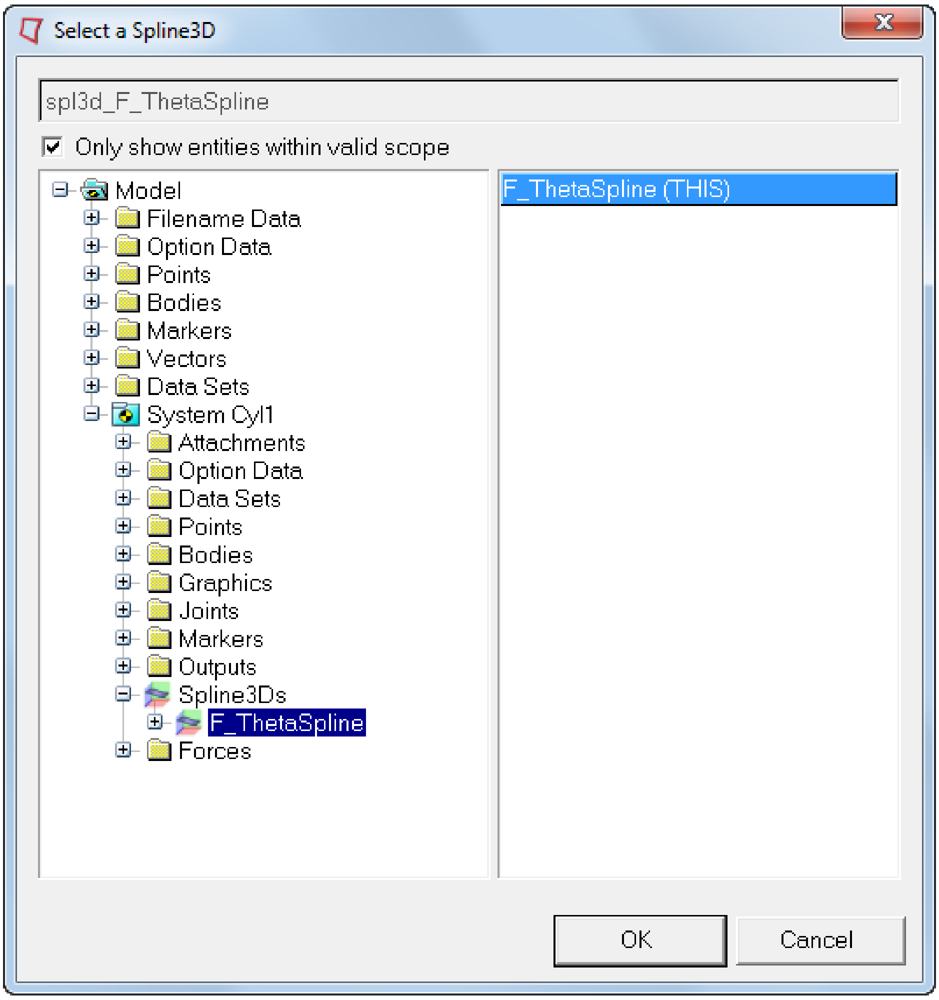


Note The **Body 2** reference to **Ground Body** is through an attachment to the **System Cyl1** system.

5. Go to **Trans Properties** tab and change the **Fz** type to **Spline3D**.

6. Double click on the ***Spline3D*** collector, Spline3D, to display the **Select a Spline3D** dialog.

7. Select **System Cyl1** in the model tree and then navigate to and select the **F_ThetaSpline** Spline3D (which will then be displayed in the right pane).



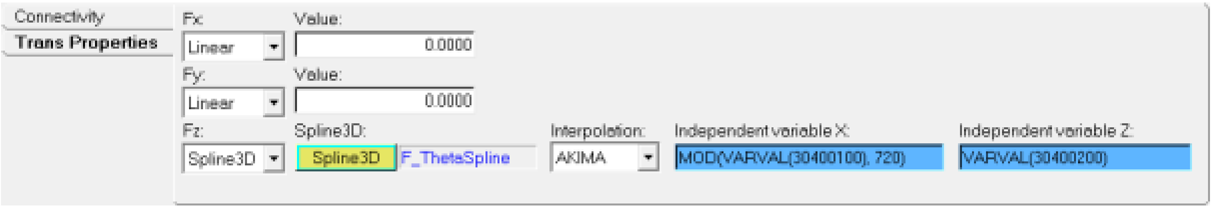
8. Click ***OK*** to close the window.

9. In the **Independent variable X** field, enter in the following expression: `` `MOD({arg_Crank_angle_SolVar.VARVAL}, 720)` ``.

10. In the **Independent variable Z** field, enter in the following expression: `` `{arg_Crank_RPM_SolVar.VARVAL}` ``.

11. Click the ***Check Model*** button on the **Model Check** toolbar to check the model for errors.

    The completed panel is shown below:



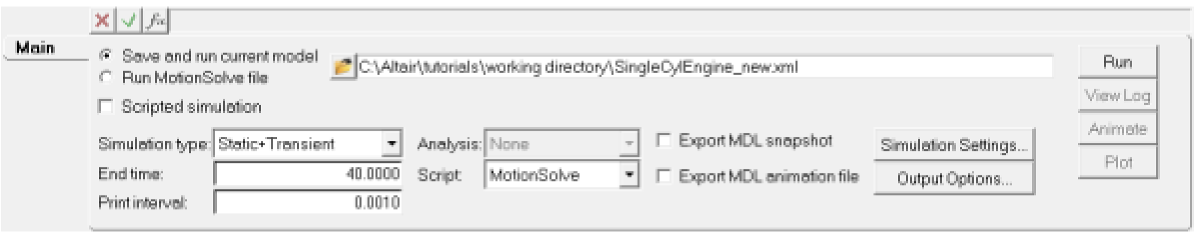
Note The solver function MOD() used in **Independent variable X** refers to the solver variable **Crank_angle (deg)** in **System Flywheel** (via attachment **arg_Crank_angle_SolVar** to **System Cyl1**). This function calculates the remainder of the division of first argument value (**value of the solver variable**) by the second argument value (**720**); thereby resetting the value of **Independent variable X** every 720 degrees.

12. Save the model with a different name (***File > Save As > Model***).

Step 4: Solving the model and post-processing.

The model is now complete and can be solved in MotionSolve.

1. To solve the model, invoke the **Run** panel using the **Run Solver** button on the **General Actions** toolbar.
2. Since the crank RPM input data is for 40 seconds, enter `40` in the **End time** field and change the **Print interval** to `0.001`.
3. Assign a name and location for the MotionSolve XML file using the browser icon.
4. The **Run** panel with the inputs from the previous steps is shown below:

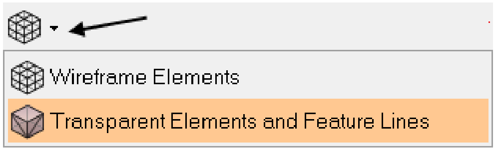


5. Click the ***Run*** button in the panel to invoke MotionSolve and solve the model.
6. ***Close*** the solver window after the job is completed.
7. Click the **Animate** button in the panel (now active) to load the animation results in a HyperView window.

8. From the **Animation** toolbar, use the **Start/Pause Animation** button to animate the model.

9. Visualize forces on the Piston using the **Vector** panel (select the Piston graphics for the **Assemblies** collector).

   You may also set all graphics to be transparent for easy visualization using the **WireFrame/Transparent Elements and Feature Lines** option located on the **Visualization** toolbar.



10. From the **Page Controls** toolbar, click the ***Add Page*** icon to add a new page.

11. Use the **Select application** drop-down menu to change the client on the new page to **HyperGraph 2D**.

12. From the **Page Controls** toolbar, click the arrow next to the **Page Window Layout** button and select the three window layout.

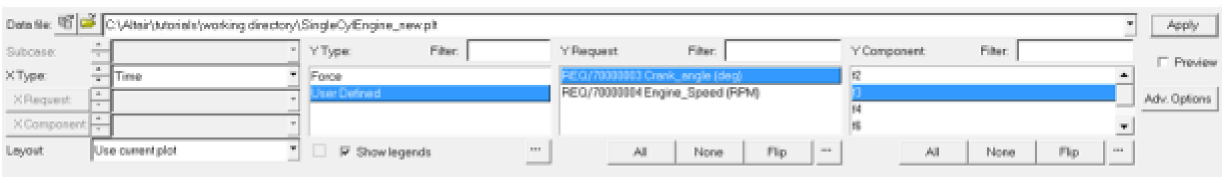
13. From the **Build Plots** panel, use the **Data file** browser to load the `.plt` file from the MotionSolve run.

14. In the first window (top left), plot the **Crank_angle (deg)** by selecting the following:

   – **Y Type** = ***User Defined***

   – **Y Request** = ***REQ/70000003 Crank_angle (deg)***

   – **Y Component** = ***f3***



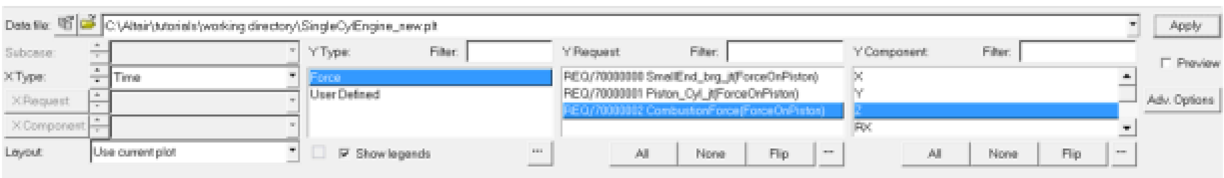
Selections for plotting Crank_angle (deg)

15. Next, click in the graphics area of the second window (top right) to make it the active window and plot the **CombustionForce** in the Z direction:

   – **Y Type** = ***Force***

   – **Y Request** = ***REQ/70000002 CombustionForce (ForceOnPiston)***

   – **Y Component** = ***Z***



Selections for plotting CombustionForce

16. Finally, we will plot the **Force vs Theta** plots at different speeds as applied on the piston (this will demonstrate the usage of Spline3D input used in **Step 2** of this tutorial). Click in the graphics area of the third window (bottom) to make it the active window.

17. Click on the ***Define Curves*** icon on the **Curves** toolbar.

18. Click the ***Add*** button to add a curve.

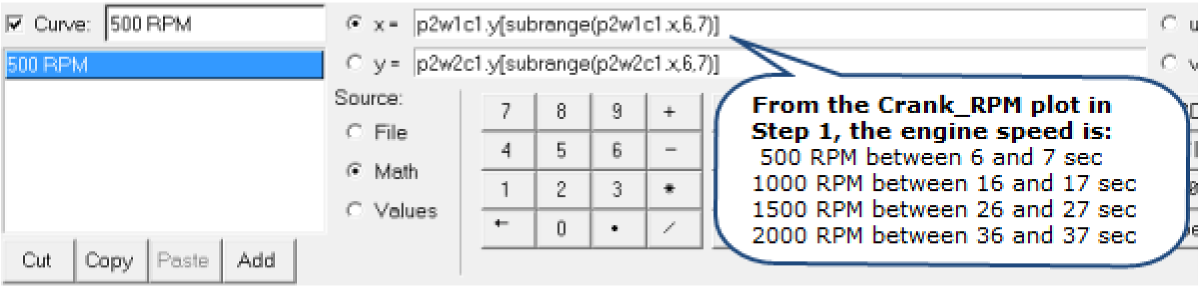
19. Click in the **Curve** field and rename the curve as `500 RPM`.

20. Change the **Source** to ***Math***.

21. Enter the expressions shown below to extract the data from the curve in the first and the second window respectively between 6 and 7 seconds.

    – **x =** `p2w1c1.y[subrange(p2w1c1.x,6,7)]`

    – **y =** `p2w2c1.y[subrange(p2w2c1.x,6,7)]`



Panel entries for plotting Force vs Theta

22. Click **Apply** to plot.

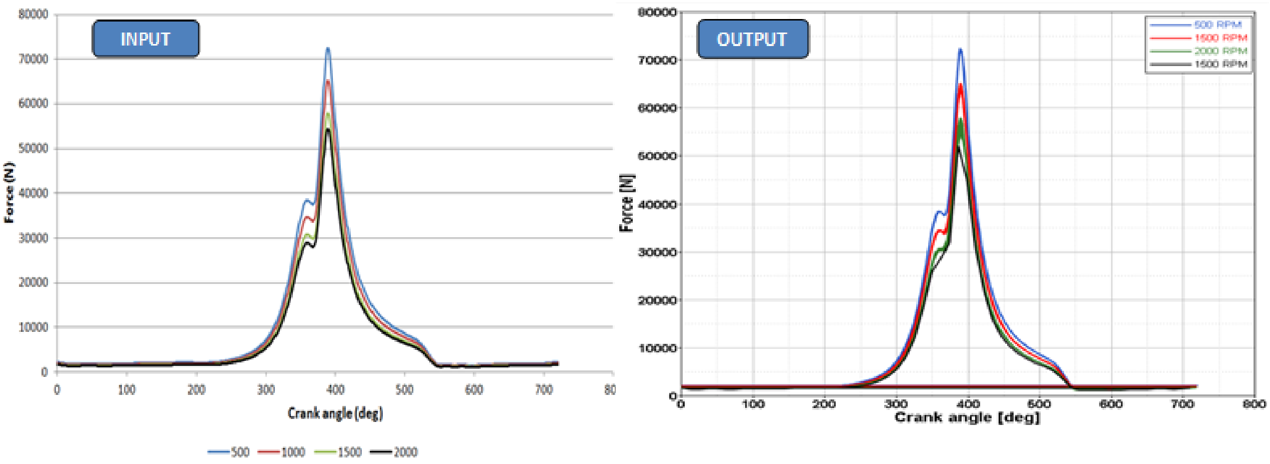
    Note `p2w1c1` refers to the Curve 1 plotted on Page 2, Window 1. If for any reason the page, window, or curve numbering is different, suitable modifications should be made to the expression.

    The `subrange` function returns the indices of the vector within a specified range. For more information on the `subrange` function, please refer to the *Templex and Math Reference Guide*.

23. Similarly, add three more plots for **1000**, **1500**, and **2000** RPM. Use time values of: `16`, `17`; `26`, `27`; and `36`, `37` respectively (in place of `6`, `7` shown in the expression above).

24. Assign different colors to these curves using the **Curve Attributes** panel, or by selecting the curves in the **Plot Browser** and changing the color in the **Properties** table.

25. After completing the plots, compare them with the input data for the Spline3D plot in Step 2. A comparison is shown below:



Validating the Spline3D used by the Solver