Created in COMSOL Multiphysics 6.2

Transonic Flow over the ONERA M6 Wing

Introduction

The present example demonstrates how to set up the classical external-flow problem of solving for the high-speed, compressible, turbulent flow over the ONERA M6 wing. The example originates from experiments performed in the 1970s (Ref. 1), which were designed to be used in the validation of simulation codes. The problem involves finding a steady-state solution of the flow field around the 3D, swept wing geometry for different flow speeds and angles of attack. However, the present example looks at transonic flow speeds and a moderately high angle of attack, leading to the formation of weak shocks on the upper surface of the wing. The High Mach Number Flow, Spalart–Allmaras interface is set-up to solve for the flow of air, while assuming ideal gas conditions. The validation of the numerical solution is performed by the comparison of the computed surface values of the nondimensional coefficient of pressure, C_p, with the experimental values at various cross-sections along the span of the wing.

Model Definition

GEOMETRY

The geometry involves an enclosure around the wing large enough such that far-field conditions for the inlet and outlet boundaries may be imposed suitably. The enclosing boundary is placed at a distance of $10C_0$ from the wing, where C_0 is the chord length at the base of the wing; see Figure 1. The geometry of the wing, imported as a CAD file, is obtained from Ref. 2. In this case, a sharp trailing edge is created (as opposed to a blunt trailing edge used in the experiments), which is suitable for numerical simulations (see Ref. 3).

PHYSICS INTERFACE SETTINGS

The High Mach Number Flow interface and Spalart–Allmaras turbulence model with automatic wall treatment model the flow of air under ideal gas conditions. Additionally the Sutherland's law accounts for the dependency of thermal conductivity k and dynamic viscosity μ on temperature.

INITIAL AND BOUNDARY CONDITIONS

The initial condition corresponds to a pressure of 1 atm. The inlet Mach number is incremented in stages using the auxiliary sweep functionality available in the Stationary study step. The Mach number is computed as $M_{\text{step}}M_{\infty}$, where, the value of the parameter M_{step} for the first auxiliary sweep is taken to be 0.25 and incremented up to a value of 1. Here, the desired far-field Mach number, M_{∞}, is taken to be 0.84. The no slip wall condition and thermal insulation conditions are applied to the wing surface. The characteristics-based inflow condition is specified at the inlet boundary. The hybrid flow condition with a static pressure of 1 atm is applied at the outflow boundary. Also, a symmetry condition is applied to minimize the number of degrees of freedom of the problem.

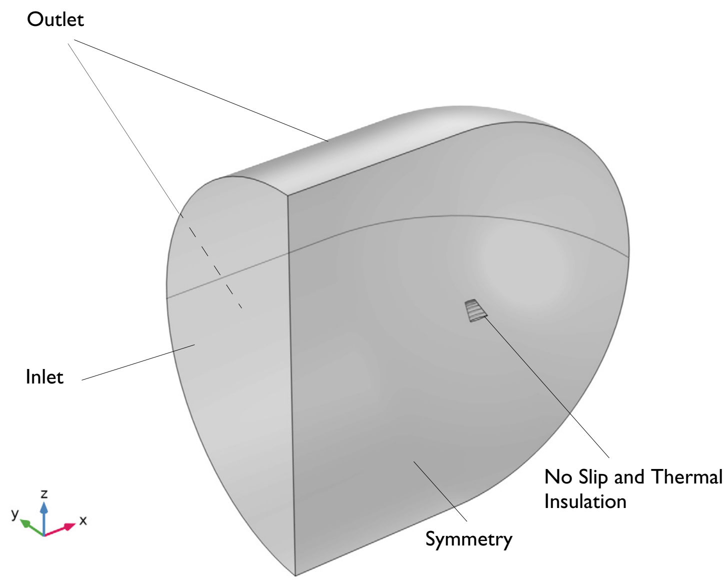

Figure 1: A schematic of the geometry and boundary conditions of the problem.

MESHING

The meshing process begins with a swept surface mesh on the wing from a suitable predefined distribution of mesh nodes on the wing's profile. A free triangular mesh is applied for the wing tip surface. As a final step, a volume mesh is populated in the domain with a suitable spatial resolution and element growth rate.

STUDY

The study contains a Wall Distance Initialization step followed by the Stationary step. The Stationary step involves an aforementioned auxiliary sweep of the parameter M_{step} in order to increment the far-field Mach number to the desired value.

Results and Discussion

The steady-state solution on the wing is visualized through the surface plot of the Mach number with contours of pressure as shown in Figure 2. A merging of two weak shocks along the span of the wing is noticeable.

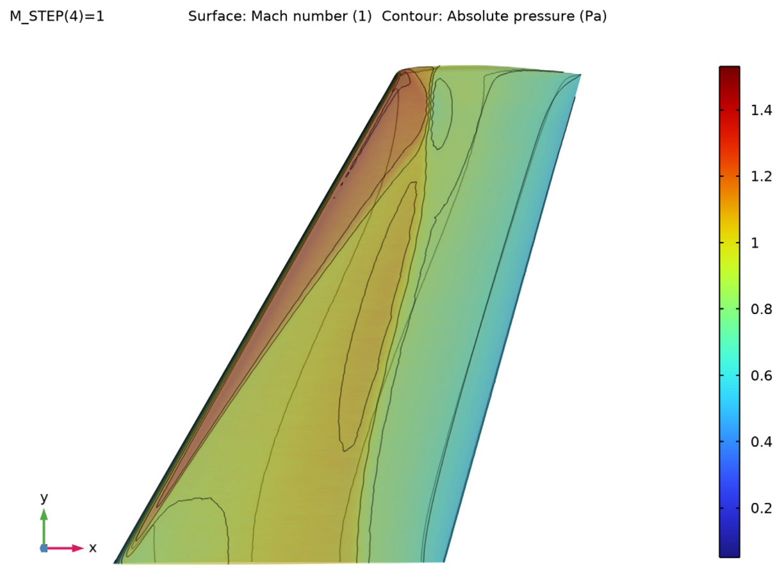

Figure 2: Surface plot of Mach number with contours of pressure.

The validation of the simulations is provided by the comparison with the experiments of the coefficient of pressure, given by the expression

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\gamma p_\infty M_\infty^2} \tag{1}$$

where p is the pressure, γ is the ratio of specific heats of the fluid, and the subscript ∞ signifies far-field values. Figure 3, which shows the comparison at both the top and bottom edges of the wing and at several locations along its span, indicates a good correlation between the experiment and the simulation results. The location of the shocks and the magnitude of the jumps in the pressure coefficient are captured accurately.

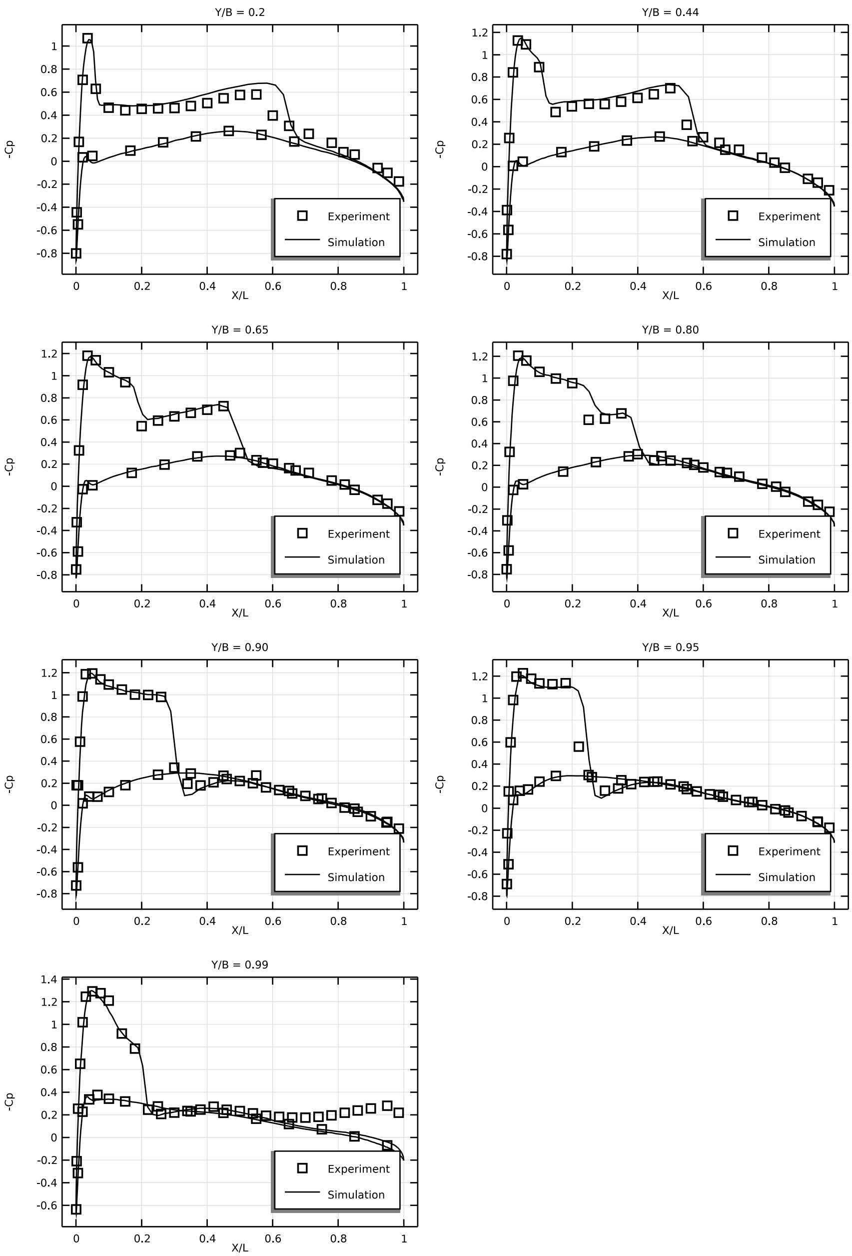

Figure 3: A comparison of C_p values at different locations along the wing span.

References

1. V. Schmitt and F. Charpin, "Pressure Distributions on the ONERA-M6-Wing at Transonic Mach Numbers," *Experimental Data Base for Computer Program Assessment,* report of the Fluid Dynamics Panel Working Group 04, AGARD AR 138, May 1979.

2. NASA Langley Research Center Turbulence Modeling Resource, 3D ONERA M6 Wing Validation Case, https://turbmodels.larc.nasa.gov/onerawingnumerics_val.html.

3. J. Mayeur, A. Dumont, D. Destarac, and V. Gleize, "RANS simulations on TMR test cases and M6 wing with the Onera elsA flow solver," *54th AIAA Aerospace Sciences Meeting*, pp. 2015–1745, 2015.

Application Library path: `CFD_Module/High_Mach_Number_Flow/onera_m6_wing`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Blank Model**.

ADD COMPONENT

In the **Home** toolbar, click **Add Component** and choose **3D**.

GEOMETRY 1

Set the geometry representation to use the CAD Kernel. Import the geometry from the prepared geometry sequence. Refer to the end of the documentation on instructions to create the geometry sequence.

1 In the **Settings** window for **Geometry**, locate the **Advanced** section.

2 From the **Geometry representation** list, choose **CAD kernel**.

3 In the **Geometry** toolbar, click **Insert Sequence** and choose **Insert Sequence**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_geom_sequence.mph`.

5 In the **Geometry** toolbar, click **Build All**.

GLOBAL DEFINITIONS

Parameters 2

1 In the **Home** toolbar, click **Parameters** and choose **Add>Parameters**.
2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
3 In the table, enter the following settings:

Name	Expression	Value	Description
M_INF	0.84	0.84	Far-field Mach Number
M_STEP	0.25	0.25	Multiplication factor for Mach Number

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.
2 Go to the **Add Material** window.
3 In the tree, select **Built-in>Air**.
4 Right-click and choose **Add to Component 1 (comp1)**.
5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

DEFINITIONS

Prepare explicit surface and edge selections to help in applying boundary conditions, generating the mesh and plotting the results.

Top and bottom surfaces of the wing

1 In the **Definitions** toolbar, click **Explicit**.
2 In the **Settings** window for **Explicit**, type `Top and bottom surfaces of the wing` in the **Label** text field.
3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.
4 Click **Paste Selection**.
5 In the **Paste Selection** dialog box, type `5-20` in the **Selection** text field.
6 Click **OK**.

Trailing edge surfaces of the wing

1 In the **Definitions** toolbar, click **Explicit**.
2 In the **Settings** window for **Explicit**, type `Trailing edge surfaces of the wing` in the **Label** text field.
3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `25-40` in the **Selection** text field.

6 Click **OK**.

Tip surfaces of the wing

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Tip surfaces of the wing` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `21-24, 41, 42` in the **Selection** text field.

6 Click **OK**.

All surfaces of the wing

1 In the **Definitions** toolbar, click **Union**.

2 In the **Settings** window for **Union**, type `All surfaces of the wing` in the **Label** text field.

3 Locate the **Geometric Entity Level** section. From the **Level** list, choose **Boundary**.

4 Locate the **Input Entities** section. Under **Selections to add**, click **Add**.

5 In the **Add** dialog box, in the **Selections to add** list, choose **Top and bottom surfaces of the wing**, **Trailing edge surfaces of the wing**, and **Tip surfaces of the wing**.

6 Click **OK**.

Edges of the wing at Y/B = 0.20

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.20` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `11, 12, 44, 46` in the **Selection** text field.

6 Click **OK**.

Edges of the wing at Y/B = 0.44

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.44` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `14, 15, 49, 51` in the **Selection** text field.

6 Click **OK**.

Edges of the wing at Y/B = 0.65

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.65` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `17, 18, 54, 56` in the **Selection** text field.

6 Click **OK**.

Edges of the wing at Y/B = 0.80

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.80` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `20, 21, 59, 61` in the **Selection** text field.

6 Click **OK**.

Edges of the wing at Y/B = 0.90

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.90` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `23, 24, 64, 66` in the **Selection** text field.

6 Click **OK**.

Edges of the wing at Y/B = 0.95

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.95` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `26, 27, 69, 71` in the **Selection** text field.

6 Click **OK**.

Edges of the wing at Y/B = 0.99

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, type `Edges of the wing at Y/B = 0.99` in the **Label** text field.

3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Edge**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `29, 30, 74, 76` in the **Selection** text field.

6 Click **OK**.

MESH 1

Generate a suitable surface mesh for the wing, followed by an appropriate volume mesh for the computational domain.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Sequence Type** section.

3 From the list, choose **User-controlled mesh**.

Edge 1

Create an edge mesh with appropriate node distribution.

1 In the **Mesh** toolbar, click **Boundary** and choose **Edge**.

2 In the **Settings** window for **Edge**, locate the **Edge Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `8, 9, 11, 12, 14, 15, 17, 18, 20, 21, 23, 24, 26, 27, 29, 30` in the **Selection** text field.

5 Click **OK**.

Distribution 1

1 Right-click **Edge 1** and choose **Distribution**.

2 In the **Settings** window for **Distribution**, locate the **Distribution** section.

3 From the **Distribution type** list, choose **Predefined**.

4 In the **Number of elements** text field, type `100`.

5 In the **Element ratio** text field, type `20`.

6 From the **Growth rate** list, choose **Exponential**.

7 Select the **Symmetric distribution** check box.

Edge 2

1 In the **Mesh** toolbar, click **Boundary** and choose **Edge**.

2 In the **Settings** window for **Edge**, locate the **Edge Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `39, 41, 44, 46, 49, 51, 54, 56, 59, 61, 64, 66, 69, 71, 74, 76, 80, 82, 83` in the **Selection** text field.

5 Click **OK**.

Distribution 1

1 Right-click **Edge 2** and choose **Distribution**.

2 In the **Settings** window for **Distribution**, locate the **Distribution** section.

3 In the **Number of elements** text field, type `4`.

Mapped 1

Create a surface mesh, which preserves the curvature of the wing profile, using the mapped mesh functionality.

1 In the **Mesh** toolbar, click **Boundary** and choose **Mapped**.

2 In the **Settings** window for **Mapped**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `5-18, 25-40` in the **Selection** text field.

5 Click **OK**.

Size 1

1 Right-click **Mapped 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 From the **Calibrate for** list, choose **Fluid dynamics**.

4 From the **Predefined** list, choose **Extremely fine**.

5 Click the **Custom** button.

6 Locate the **Element Size Parameters** section.

7 Select the **Maximum element size** check box. In the associated text field, type `4e-3`.

8 Select the **Minimum element size** check box. In the associated text field, type `4e-3`.

Convert 1

Create a surface mesh with triangular elements at the wing tip. This ensures good element quality in the volume mesh generated in the next step.

1 In the **Mesh** toolbar, click **Modify** and choose **Convert**.

2 In the **Settings** window for **Convert**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Boundary**.

4 Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `39, 40` in the **Selection** text field.

6 Click **OK**.

7 In the **Settings** window for **Convert**, locate the **Element Split Method** section.

8 From the **Element split method** list, choose **Insert centerpoints**.

Free Triangular 1

1 In the **Mesh** toolbar, click **Boundary** and choose **Free Triangular**.

2 In the **Settings** window for **Free Triangular**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `19-24, 41, 42` in the **Selection** text field.

5 Click **OK**.

Size 1

1 Right-click **Free Triangular 1** and choose **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 From the **Calibrate for** list, choose **Fluid dynamics**.

4 From the **Predefined** list, choose **Extremely fine**.

5 Click the **Custom** button.

6 Locate the **Element Size Parameters** section.

7 Select the **Maximum element size** check box. In the associated text field, type `4e-3`.

8 Select the **Minimum element size** check box. In the associated text field, type `1e-3`.

Size

As a final step in meshing, generate the volume mesh.

1 In the **Model Builder** window, under **Component 1 (comp1)>Mesh 1** click **Size**.

2 In the **Settings** window for **Size**, locate the **Element Size** section.
3 From the **Calibrate for** list, choose **Fluid dynamics**.
4 From the **Predefined** list, choose **Coarse**.
5 Click the **Custom** button.
6 Locate the **Element Size Parameters** section. In the **Maximum element size** text field, type `4`.
7 In the **Minimum element size** text field, type `1e-3`.
8 In the **Maximum element growth rate** text field, type `1.1`.

Free Tetrahedral 1

1 In the **Model Builder** window, right-click **Free Tetrahedral 1** and choose **Move Down**.
2 Right-click **Free Tetrahedral 1** and choose **Move Down**.
3 Right-click **Free Tetrahedral 1** and choose **Move Down**.
4 Right-click **Free Tetrahedral 1** and choose **Move Down**.
5 Right-click **Free Tetrahedral 1** and choose **Move Down**.
6 Right-click **Mesh 1** and choose **Build All**.

ADD PHYSICS

1 In the **Home** toolbar, click **Add Physics** to open the **Add Physics** window.
2 Go to the **Add Physics** window.
3 In the tree, select **Fluid Flow>High Mach Number Flow>Turbulent Flow> High Mach Number Flow, Spalart-Allmaras (hmnf)**.
4 Click **Add to Component 1** in the window toolbar.
5 In the **Home** toolbar, click **Add Physics** to close the **Add Physics** window.

HIGH MACH NUMBER FLOW, SPALART-ALLMARAS (HMNF)

Initial Values 1

1 In the **Model Builder** window, under **Component 1 (comp1)>High Mach Number Flow, Spalart-Allmaras (hmnf)** click **Initial Values 1**.
2 In the **Settings** window for **Initial Values**, locate the **Initial Values** section.
3 Specify the **u** vector as

M_INF*sqrt(hmnf.gamma*hmnf.Rs*293.15[K])*M_STEP	x

0	y
0	z

Symmetry 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Symmetry**.

2 In the **Settings** window for **Symmetry**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type 2 in the **Selection** text field.

5 Click **OK**.

Inlet 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Inlet**.

2 In the **Settings** window for **Inlet**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type 1 in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Inlet**, locate the **Flow Properties** section.

7 In the $T_{0,\mathrm{stat}}$ text field, type 293.15[K].

8 In the Ma_0 text field, type M_INF*M_STEP.

Outlet 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Outlet**.

2 In the **Settings** window for **Outlet**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type 3-4 in the **Selection** text field.

5 Click **OK**.

ADD STUDY

1 In the **Home** toolbar, click **Add Study** to open the **Add Study** window.

2 Go to the **Add Study** window.

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Stationary with Initialization**.

4 Click **Add Study** in the window toolbar.

5 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY 1

Step 2: Stationary

1 In the **Model Builder** window, click **Step 2: Stationary**.

2 In the **Settings** window for **Stationary**, click to expand the **Study Extensions** section.

3 Select the **Auxiliary sweep** check box.

4 Click **Add**.

5 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
M_STEP (Multiplication factor for Mach Number)	`0.25 0.5 0.75 1`	

The parameter M_STEP is used to sequentially increase the far-field Mach number values to the requisite transonic flow regime.

6 In the table, click to select the cell at row number 1 and column number 1.

7 In the **Model Builder** window, click **Study 1**.

8 In the **Settings** window for **Study**, locate the **Study Settings** section.

9 Clear the **Generate default plots** check box.

10 In the **Study** toolbar, click **Get Initial Value**.

RESULTS

Table 2

Import tabulated experimental results.

1 In the **Model Builder** window, expand the **Results** node.

2 Right-click **Results>Tables** and choose **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.20

1 In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.20` in the **Label** text field.

2 Locate the **Data** section. Click **Import**.

3 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_1_up.txt`.

Table 3

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.20

1. In the **Model Builder** window, under **Results>Tables** click **Table 2**.
2. In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.20` in the **Label** text field.
3. Locate the **Data** section. Click **Import**.
4. Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_1_down.txt`.

Table 4

In the **Results** toolbar, click **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.44

1. In the **Model Builder** window, under **Results>Tables** click **Table 3**.
2. In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.44` in the **Label** text field.
3. Locate the **Data** section. Click **Import**.
4. Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_2_up.txt`.

Table 5

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.44

1. In the **Model Builder** window, under **Results>Tables** click **Table 4**.
2. In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.44` in the **Label** text field.
3. Locate the **Data** section. Click **Import**.
4. Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_2_down.txt`.

Table 6

In the **Results** toolbar, click **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.65

1. In the **Model Builder** window, under **Results>Tables** click **Table 5**.
2. In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.65` in the **Label** text field.
3. Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_3_up.txt`.

Table 7

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.65

1 In the **Model Builder** window, under **Results>Tables** click **Table 6**.

2 In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.65` in the **Label** text field.

3 Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_3_down.txt`.

Table 8

In the **Results** toolbar, click **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.80

1 In the **Model Builder** window, under **Results>Tables** click **Table 7**.

2 In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.80` in the **Label** text field.

3 Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_4_up.txt`.

Table 9

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.80

1 In the **Model Builder** window, under **Results>Tables** click **Table 8**.

2 In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.80` in the **Label** text field.

3 Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_4_down.txt`.

Table 10

In the **Results** toolbar, click **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.90

1 In the **Model Builder** window, under **Results>Tables** click **Table 9**.
2 In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.90` in the **Label** text field.
3 Locate the **Data** section. Click **Import**.
4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_5_up.txt`.

Table 11

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.90

1 In the **Model Builder** window, under **Results>Tables** click **Table 10**.
2 In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.90` in the **Label** text field.
3 Locate the **Data** section. Click **Import**.
4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_5_down.txt`.

Table 12

In the **Results** toolbar, click **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.95

1 In the **Model Builder** window, under **Results>Tables** click **Table 11**.
2 In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.95` in the **Label** text field.
3 Locate the **Data** section. Click **Import**.
4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_6_up.txt`.

Table 13

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.95

1 In the **Model Builder** window, under **Results>Tables** click **Table 12**.
2 In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.95` in the **Label** text field.
3 Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_6_down.txt`.

Table 14

In the **Results** toolbar, click **Table**.

Experimental Cp values along the top edge of the wing at Y/B = 0.99

1 In the **Model Builder** window, under **Results>Tables** click **Table 13**.

2 In the **Settings** window for **Table**, type `Experimental Cp values along the top edge of the wing at Y/B = 0.99` in the **Label** text field.

3 Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_7_up.txt`.

Table 15

In the **Results** toolbar, click **Table**.

Experimental Cp values along the bottom edge of the wing at Y/B = 0.99

1 In the **Model Builder** window, under **Results>Tables** click **Table 14**.

2 In the **Settings** window for **Table**, type `Experimental Cp values along the bottom edge of the wing at Y/B = 0.99` in the **Label** text field.

3 Locate the **Data** section. Click **Import**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing_Cp_YbyB_7_down.txt`.

Cp values at Y/B = 0.20

Plot Cp values from experiment and simulation.

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.20` in the **Label** text field.

3 Locate the **Data** section. From the **Time selection** list, choose **Last**.

4 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.

5 In the **Title** text area, type `Y/B = 0.2`.

6 Locate the **Plot Settings** section.

7 Select the **x-axis label** check box. In the associated text field, type `X/L`.

8 Select the **y-axis label** check box. In the associated text field, type `-Cp`.

9 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

Table Graph 1

1 Right-click **Cp values at Y/B = 0.20** and choose **Table Graph**.

2 In the **Settings** window for **Table Graph**, locate the **Coloring and Style** section.

3 Find the **Line style** subsection. From the **Line** list, choose **None**.

4 From the **Color** list, choose **Black**.

5 Find the **Line markers** subsection. From the **Marker** list, choose **Square**.

6 Click to expand the **Legends** section. Select the **Show legends** check box.

7 From the **Legends** list, choose **Manual**.

8 In the table, enter the following settings:

Legends
`Experiment`

Table Graph 2

1 Right-click **Table Graph 1** and choose **Duplicate**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.20**.

4 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Square**.

5 Locate the **Legends** section. Clear the **Show legends** check box.

Line Graph 1

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.20** and choose **Line Graph**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.20**.

4 Locate the **y-Axis Data** section. In the **Expression** text field, type `(1[atm] - hmnf.pA)/(0.5*hmnf.gamma*M_INF^2*1[atm])`.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

Normalize the position in the x-direction with respect to the local chord length of the wing.

6 In the **Expression** text field, type `(x-0.13793[m])/(0.87646[m]-0.13793[m])`.

7 Click to expand the **Coloring and Style** section. From the **Color** list, choose **Black**.

8 Click to expand the **Legends** section. Select the **Show legends** check box.

9 From the **Legends** list, choose **Manual**.

10 In the table, enter the following settings:

Legends
`Simulation`

Cp values at Y/B = 0.20

Similarly, reproduce the Cp plots at other sections along the wing span.

Cp values at Y/B = 0.44

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.20** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.44` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Y/B = 0.44`.

Table Graph 1

1 In the **Model Builder** window, expand the **Cp values at Y/B = 0.44** node, then click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the top edge of the wing at Y/B = 0.44**.

Table Graph 2

1 In the **Model Builder** window, click **Table Graph 2**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.44**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.44**.

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `(x-0.30346[m])/(0.95700[m]-0.30346[m])`.

Cp values at Y/B = 0.65

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.44** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.65` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Y/B = 0.65`.

Table Graph 1

1 In the **Model Builder** window, expand the **Cp values at Y/B = 0.65** node, then click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the top edge of the wing at Y/B = 0.65**.

Table Graph 2

1 In the **Model Builder** window, click **Table Graph 2**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.65**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.65**.

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `(x-0.44829[m])/(1.0275[m]-0.44829[m])`.

Cp values at Y/B = 0.80

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.65** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.80` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Y/B = 0.80`.

Table Graph 1

1 In the **Model Builder** window, expand the **Cp values at Y/B = 0.80** node, then click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the top edge of the wing at Y/B = 0.80**.

Table Graph 2

1 In the **Model Builder** window, click **Table Graph 2**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.80**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.80**.

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `(x-0.55174[m])/(1.0778[m]-0.55174[m])`.

Cp values at Y/B = 0.90

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.80** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.90` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Y/B = 0.90`.

Table Graph 1

1 In the **Model Builder** window, expand the **Cp values at Y/B = 0.90** node, then click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the top edge of the wing at Y/B = 0.90**.

Table Graph 2

1 In the **Model Builder** window, click **Table Graph 2**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.90**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.90**.

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `(x-0.62070[m])/(1.1114[m]-0.62070[m])`.

Cp values at Y/B = 0.95

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.90** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.95` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Y/B = 0.95`.

Table Graph 1

1 In the **Model Builder** window, expand the **Cp values at Y/B = 0.95** node, then click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the top edge of the wing at Y/B = 0.95**.

Table Graph 2

1 In the **Model Builder** window, click **Table Graph 2**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.95**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.95**.

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `(x-0.65519[m])/(1.1282[m]-0.65519[m])`.

Cp values at Y/B = 0.99

1 In the **Model Builder** window, right-click **Cp values at Y/B = 0.95** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Cp values at Y/B = 0.99` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Y/B = 0.99`.

Table Graph 1

1 In the **Model Builder** window, expand the **Cp values at Y/B = 0.99** node, then click **Table Graph 1**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the top edge of the wing at Y/B = 0.99**.

Table Graph 2

1 In the **Model Builder** window, click **Table Graph 2**.

2 In the **Settings** window for **Table Graph**, locate the **Data** section.

3 From the **Table** list, choose **Experimental Cp values along the bottom edge of the wing at Y/B = 0.99**.

Line Graph 1

1 In the **Model Builder** window, click **Line Graph 1**.

2 In the **Settings** window for **Line Graph**, locate the **Selection** section.

3 From the **Selection** list, choose **Edges of the wing at Y/B = 0.99**.

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `(x-0.68277[m])/(1.1416[m]-0.68277[m])`.

Mach number with pressure contours

1 In the **Results** toolbar, click **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Mach number with pressure contours` in the **Label** text field.

3 Click to expand the **Selection** section. From the **Geometric entity level** list, choose **Boundary**.

4 From the **Selection** list, choose **All surfaces of the wing**.

5 Locate the **Plot Settings** section. Clear the **Plot dataset edges** check box.

Surface 1

1 Right-click **Mach number with pressure contours** and choose **Surface**.

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 In the **Expression** text field, type `hmnf.Ma`.

Contour 1

1 In the **Model Builder** window, right-click **Mach number with pressure contours** and choose **Contour**.

2 In the **Settings** window for **Contour**, locate the **Expression** section.

3 In the **Expression** text field, type `hmnf.pA`.

4 Locate the **Levels** section. In the **Total levels** text field, type `10`.

5 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

6 From the **Color** list, choose **Black**.

7 Clear the **Color legend** check box.

Mach number with pressure contours

Click the **Go to XY View** button in the **Graphics** toolbar.

Geometry Modeling Instructions

Follow these steps below to generate the geometry.

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
C0	0.8059[m]	0.8059 m	Chord length at the wing base
B	1.1963[m]	1.1963 m	Span of the wing
D	10*C0	8.059 m	Distance to far-field boundaries
YbyB_1	0.20[1]	0.2	Wing section 1
YbyB_2	0.44[1]	0.44	Wing section 2
YbyB_3	0.65[1]	0.65	Wing section 3
YbyB_4	0.80[1]	0.8	Wing section 4
YbyB_5	0.90[1]	0.9	Wing section 5
YbyB_6	0.95[1]	0.95	Wing section 6
YbyB_7	0.99[1]	0.99	Wing section 7
ALPHA	3.06[deg]	0.053407 rad	Angle of attack

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Advanced** section.

3 From the **Geometry representation** list, choose **CAD kernel**.

Work Plane 1 (wp1)

1 In the **Geometry** toolbar, click **Work Plane**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. From the **Plane** list, choose **xz-plane**.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 1 (wp1)>Circle 1 (c1)

1 In the **Work Plane** toolbar, click **Circle**.

2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `D`.

4 In the **Sector angle** text field, type `180`.

5 Locate the **Position** section. In the **xw** text field, type `-C0/2`.

6 Locate the **Rotation Angle** section. In the **Rotation** text field, type `-90`.

Revolve 1 (rev1)

1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** right-click **Work Plane 1 (wp1)** and choose **Revolve**.

2 In the **Settings** window for **Revolve**, locate the **Revolution Angles** section.

3 Click the **Angles** button.

4 In the **End angle** text field, type `90`.

5 Locate the **Revolution Axis** section. Find the **Point on the revolution axis** subsection. In the **xw** text field, type `-C0/2`.

Work Plane 2 (wp2)

1 In the **Geometry** toolbar, click **Work Plane**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. From the **Plane** list, choose **yz-plane**.

4 In the **x-coordinate** text field, type `-D`.

Work Plane 2 (wp2)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 2 (wp2)>Circle 1 (c1)

1 In the **Work Plane** toolbar, click **Circle**.

2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `D`.

4 In the **Sector angle** text field, type `180`.

5 Locate the **Rotation Angle** section. In the **Rotation** text field, type `-90`.

Extrude 1 (ext1)

1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** right-click **Work Plane 2 (wp2)** and choose **Extrude**.

2 In the **Settings** window for **Extrude**, locate the **Distances** section.

3 In the table, enter the following settings:

Distances (m)
`D-C0/2`

Import 1 (imp1)

1 In the **Geometry** toolbar, click **Import**.

2 In the **Settings** window for **Import**, locate the **Import** section.

3 Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `onera_m6_wing.igs`.

5 Click **Import**.

Work Plane 3 (wp3)

1 In the **Geometry** toolbar, click **Work Plane**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. From the **Plane** list, choose **xz-plane**.

Work Plane 3 (wp3)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 3 (wp3)>Circle 1 (c1)

1 In the **Work Plane** toolbar, click **Circle**.

2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.

3 In the **Radius** text field, type `D`.

4 In the **Sector angle** text field, type `180`.

5 Locate the **Position** section. In the **xw** text field, type `-C0/2`.

6 Locate the **Rotation Angle** section. In the **Rotation** text field, type `-90`.

Convert to Solid 1 (csol1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Conversions>Convert to Solid**.
2 In the **Settings** window for **Convert to Solid**, locate the **Input** section.
3 Click the **Paste Selection** button for **Input objects**.
4 In the **Paste Selection** dialog box, type `imp1, wp3` in the **Selection** text field.
5 Click **OK**.

Rotate 1 (rot1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Rotate**.
2 In the **Settings** window for **Rotate**, locate the **Input** section.
3 Click the **Paste Selection** button for **Input objects**.
4 In the **Paste Selection** dialog box, type `csol1` in the **Selection** text field.
5 Click **OK**.
6 In the **Settings** window for **Rotate**, locate the **Rotation** section.
7 From the **Axis type** list, choose **y-axis**.
8 In the **Angle** text field, type `ALPHA`.

Difference 1 (dif1)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Difference**.
2 In the **Settings** window for **Difference**, locate the **Difference** section.
3 Click the **Paste Selection** button for **Objects to add**.
4 In the **Paste Selection** dialog box, type `rev1` in the **Selection** text field.
5 Click **OK**.
6 In the **Settings** window for **Difference**, locate the **Difference** section.
7 Click the **Paste Selection** button for **Objects to subtract**.
8 In the **Paste Selection** dialog box, type `rot1` in the **Selection** text field.
9 Click **OK**.

Work Plane 4 (wp4)

1 In the **Geometry** toolbar, click **Work Plane**.
2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.
3 Locate the **Plane Definition** section. From the **Plane** list, choose **xz-plane**.
4 In the **y-coordinate** text field, type `YbyB_1*B`.

Work Plane 4 (wp4)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

Work Plane 4 (wp4)>Rectangle 1 (r1)

1 In the **Work Plane** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `1.5`.

4 In the **Height** text field, type `0.5`.

5 Locate the **Position** section. In the **yw** text field, type `-0.25`.

Intersection 1 (int1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Booleans and Partitions>Intersection**.

2 In the **Settings** window for **Intersection**, locate the **Intersection** section.

3 Click the **Paste Selection** button for **Input objects**.

4 In the **Paste Selection** dialog box, type `dif1, wp4` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Intersection**, locate the **Intersection** section.

7 Select the **Keep input objects** check box.

Work Plane 4 (wp4)

In the **Model Builder** window, right-click **Work Plane 4 (wp4)** and choose **Duplicate**.

Work Plane 5 (wp5)

1 In the **Model Builder** window, click **Work Plane 5 (wp5)**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. In the **y-coordinate** text field, type `YbyB_2*B`.

Intersection 2 (int2)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.

2 In the **Settings** window for **Intersection**, locate the **Intersection** section.

3 Click the **Paste Selection** button for **Input objects**.

4 In the **Paste Selection** dialog box, type `dif1, wp5` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Intersection**, locate the **Intersection** section.

7 Select the **Keep input objects** check box.

Work Plane 5 (wp5)

Right-click **Work Plane 5 (wp5)** and choose **Duplicate**.

Work Plane 6 (wp6)

1 In the **Model Builder** window, click **Work Plane 6 (wp6)**.
2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.
3 Locate the **Plane Definition** section. In the **y-coordinate** text field, type `YbyB_3*B`.

Intersection 3 (int3)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.
2 In the **Settings** window for **Intersection**, locate the **Intersection** section.
3 Click the **Paste Selection** button for **Input objects**.
4 In the **Paste Selection** dialog box, type `dif1, wp6` in the **Selection** text field.
5 Click **OK**.
6 In the **Settings** window for **Intersection**, locate the **Intersection** section.
7 Select the **Keep input objects** check box.

Work Plane 6 (wp6)

Right-click **Work Plane 6 (wp6)** and choose **Duplicate**.

Work Plane 7 (wp7)

1 In the **Model Builder** window, click **Work Plane 7 (wp7)**.
2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.
3 Locate the **Plane Definition** section. In the **y-coordinate** text field, type `YbyB_4*B`.

Intersection 4 (int4)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.
2 In the **Settings** window for **Intersection**, locate the **Intersection** section.
3 Click the **Paste Selection** button for **Input objects**.
4 In the **Paste Selection** dialog box, type `dif1, wp7` in the **Selection** text field.
5 Click **OK**.
6 In the **Settings** window for **Intersection**, locate the **Intersection** section.
7 Select the **Keep input objects** check box.

Work Plane 7 (wp7)

Right-click **Work Plane 7 (wp7)** and choose **Duplicate**.

Work Plane 8 (wp8)

1 In the **Model Builder** window, click **Work Plane 8 (wp8)**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. In the **y-coordinate** text field, type `YbyB_5*B`.

Intersection 5 (int5)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.

2 In the **Settings** window for **Intersection**, locate the **Intersection** section.

3 Click the **Paste Selection** button for **Input objects**.

4 In the **Paste Selection** dialog box, type `dif1, wp8` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Intersection**, locate the **Intersection** section.

7 Select the **Keep input objects** check box.

Work Plane 8 (wp8)

Right-click **Work Plane 8 (wp8)** and choose **Duplicate**.

Work Plane 9 (wp9)

1 In the **Model Builder** window, click **Work Plane 9 (wp9)**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. In the **y-coordinate** text field, type `YbyB_6*B`.

Intersection 6 (int6)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.

2 In the **Settings** window for **Intersection**, locate the **Intersection** section.

3 Click the **Paste Selection** button for **Input objects**.

4 In the **Paste Selection** dialog box, type `dif1, wp9` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Intersection**, locate the **Intersection** section.

7 Select the **Keep input objects** check box.

Work Plane 9 (wp9)

Right-click **Work Plane 9 (wp9)** and choose **Duplicate**.

Work Plane 10 (wp10)

1 In the **Model Builder** window, click **Work Plane 10 (wp10)**.

2 In the **Settings** window for **Work Plane**, click **Go to Plane Geometry**.

3 Locate the **Plane Definition** section. In the **y-coordinate** text field, type `YbyB_7*B`.

Intersection 7 (int7)

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Intersection**.

2 In the **Settings** window for **Intersection**, locate the **Intersection** section.

3 Click the **Paste Selection** button for **Input objects**.

4 In the **Paste Selection** dialog box, type `dif1, wp10` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Intersection**, locate the **Intersection** section.

7 Select the **Keep input objects** check box.

Form Union (fin)

1 In the **Model Builder** window, click **Form Union (fin)**.

2 In the **Settings** window for **Form Union/Assembly**, click **Build Selected**.

Ignore Faces 1 (igf1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Ignore Faces**.

2 In the **Settings** window for **Ignore Faces**, locate the **Input** section.

3 Click the **Paste Selection** button for **Faces to ignore**.

4 In the **Paste Selection** dialog box, type `6` in the **Selection** text field.

5 Click **OK**.

Ignore Faces 2 (igf2)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Ignore Faces**.

2 In the **Settings** window for **Ignore Faces**, locate the **Input** section.

3 Click the **Paste Selection** button for **Faces to ignore**.

4 In the **Paste Selection** dialog box, type `7-13` in the **Selection** text field.

5 Click **OK**.

Ignore Edges 1 (ige1)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Ignore Edges**.

2 In the **Settings** window for **Ignore Edges**, locate the **Input** section.

3 Click the **Paste Selection** button for **Edges to ignore**.

4 In the **Paste Selection** dialog box, type `5` in the **Selection** text field.

5 Click **OK**.

Ignore Faces 3 (igf3)

1 In the **Geometry** toolbar, click **Virtual Operations** and choose **Ignore Faces**.
2 In the **Settings** window for **Ignore Faces**, locate the **Input** section.
3 Click the **Paste Selection** button for **Faces to ignore**.
4 In the **Paste Selection** dialog box, type `9, 12, 15, 18, 21, 24, 27` in the **Selection** text field.
5 Click **OK**.
6 In the **Settings** window for **Ignore Faces**, locate the **Input** section.
7 Clear the **Ignore adjacent edges and vertices** check box.
8 In the **Geometry** toolbar, click **Build All**.