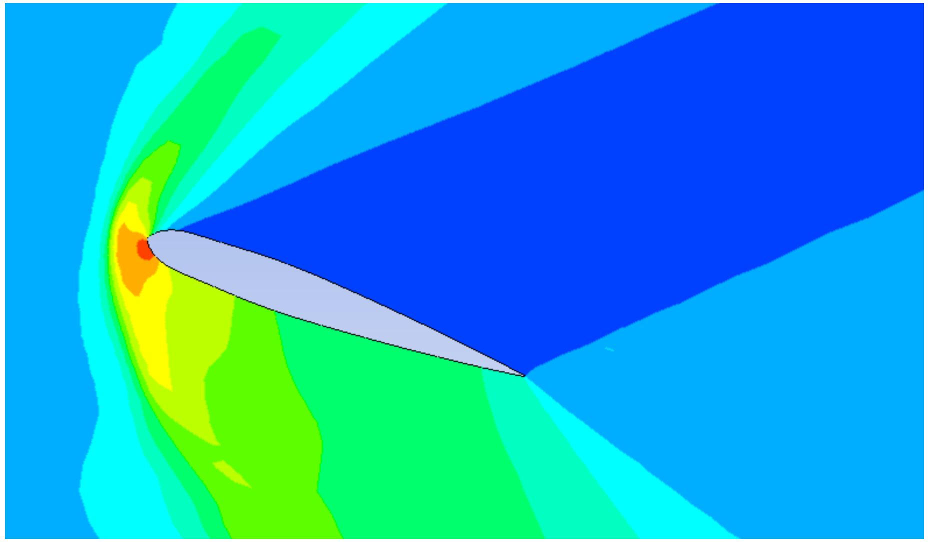
Optimum Design Course
Fall 2016

Ansys Tutorial 7

Airfoil

Introduction



Objective:

Optimize the angle of attack of a NACA 0012 airfoil to maximize lift while minimizing drag. Supersonic air flow at 600 m/s will be used with the SST turbulence model

Approach:

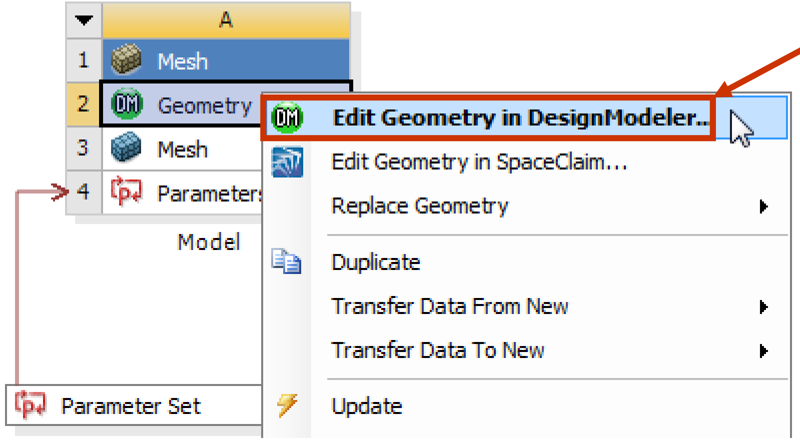
We will model a 2D slice of the airfoil only 1 element thick in order to capture the flow as it passes over the airfoil. We will then run a Response Surface Optimization on lift and drag by varying the angle of attack

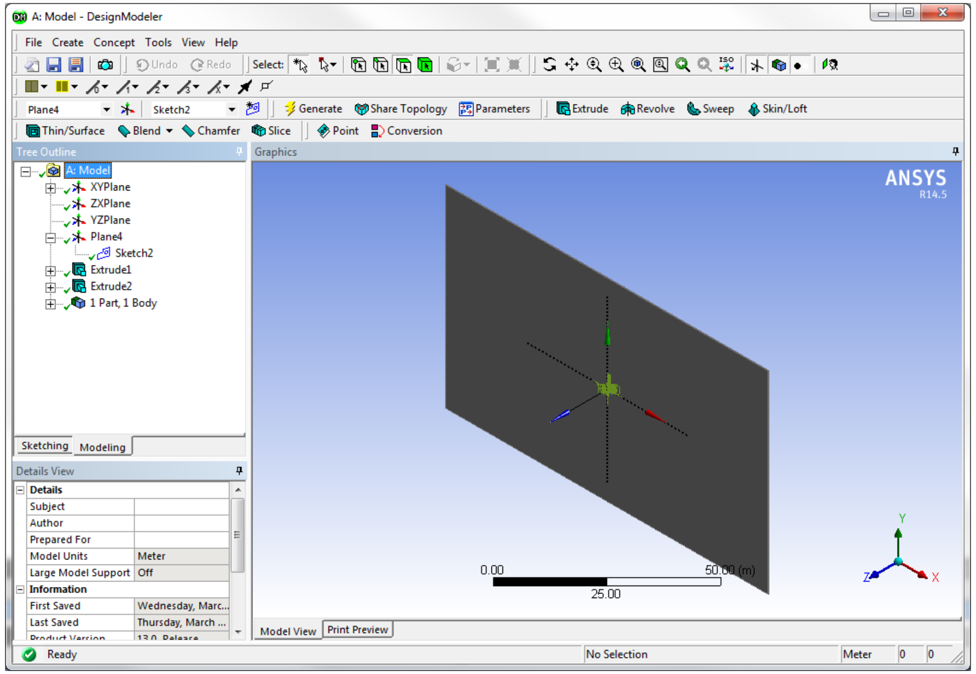
Project Startup

1. Launch Workbench then File > open > Airfoil Optimization.wbpj

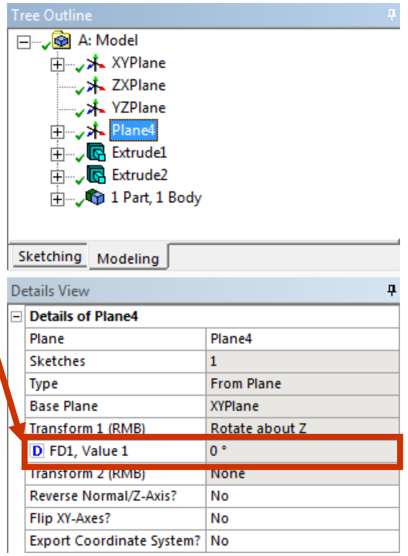
Geometry

2. RMB on Geometry and click Edit Geometry in DesignModeler

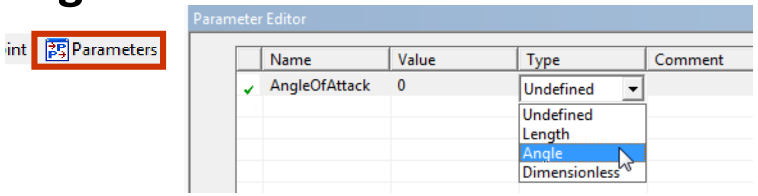




3. Select Plane4
and check that
Transform 1>FD1
is parameterized

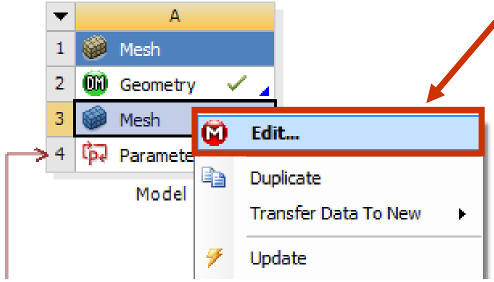


4. Open the parameter manager. Define the
Angle unit and click Check

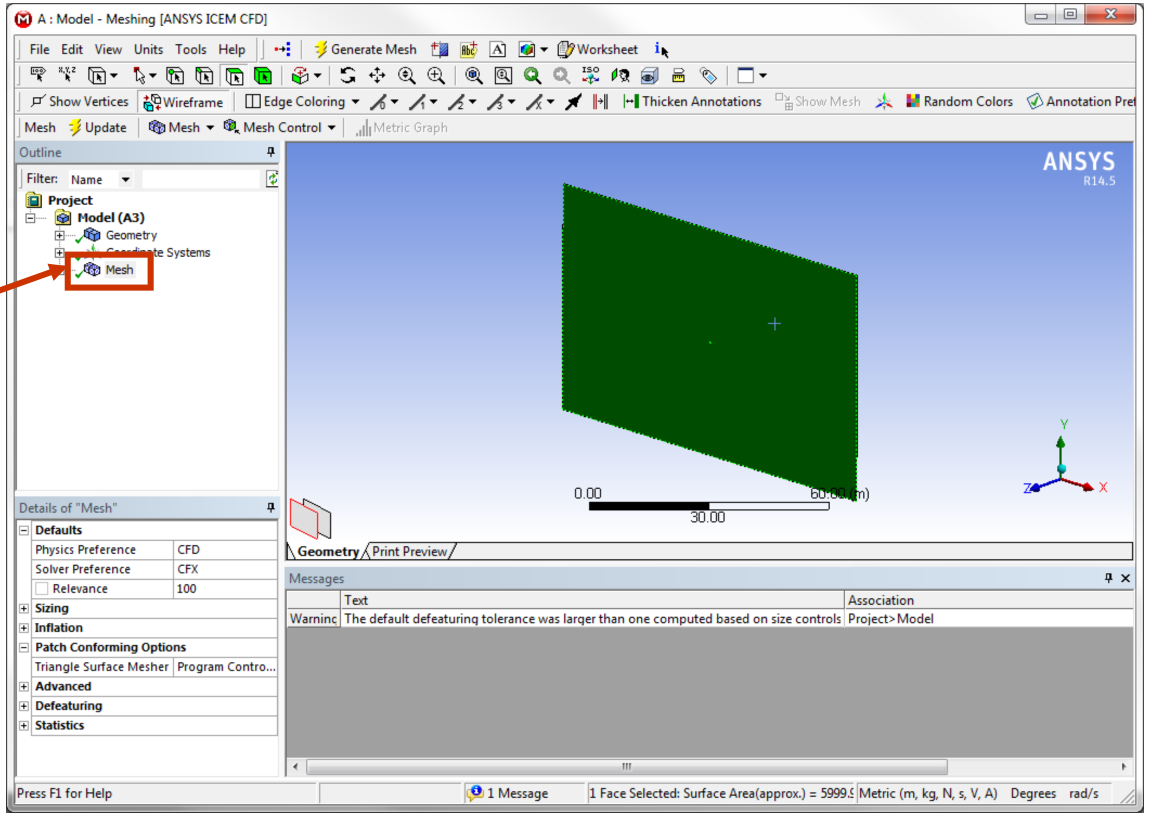


Meshing Application

5. Close DesignModeler, RMB on Mesh and click Edit to launch the Meshing Application

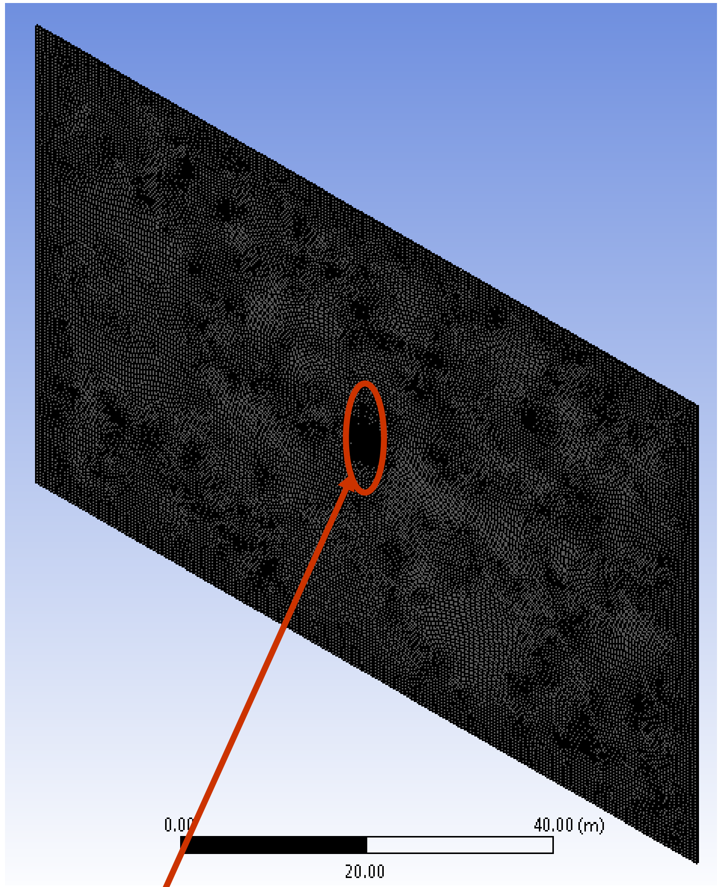


6. Select Mesh



Mesh Review

Take a moment to inspect the mesh

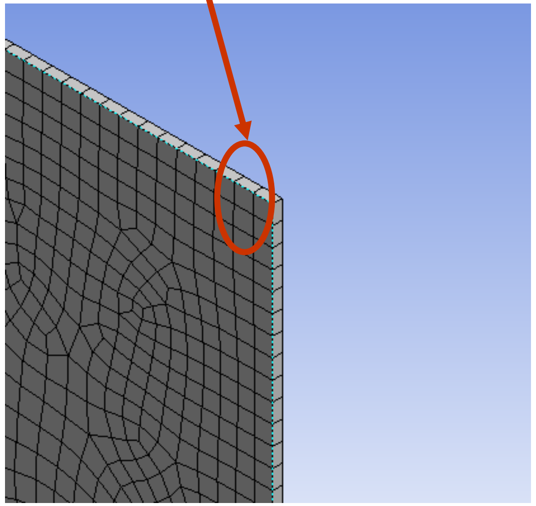


The airfoil is small relative to the domain

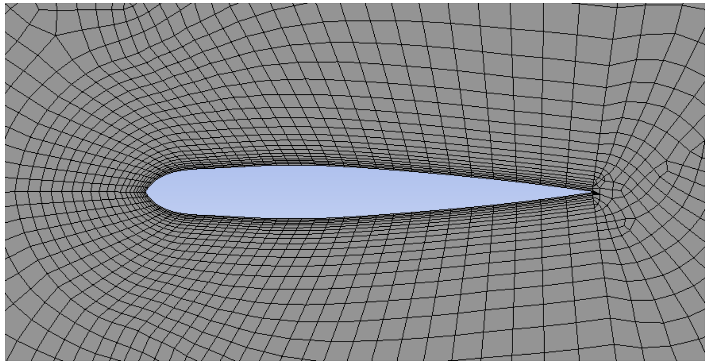
Details of "Mesh"

Defaults	
Physics Preference	CFD
Solver Preference	CFX
Relevance	100
Sizing	
Inflation	
Advanced	
Defeaturing	
Statistics	
Nodes	70618
Elements	34884
Mesh Metric	None

It is one element thick



Sizing controls and inflation layer around the airfoil



Named Selections [1]

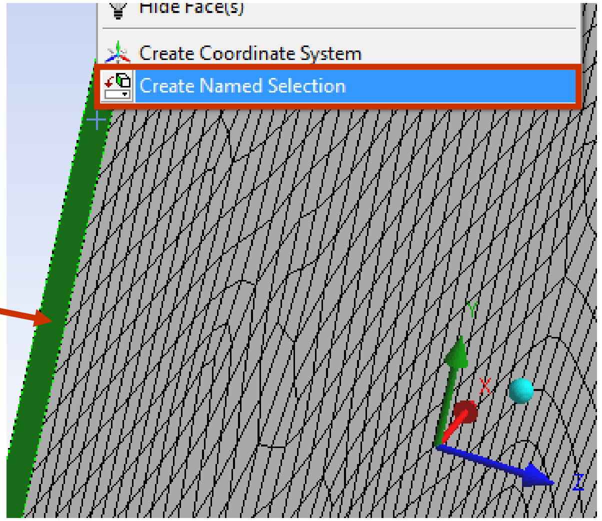
We need to make named selections in the Meshing Application for use in CFX.
We will be making 7 named selections:

airfoil: the 3 center faces making up the airfoil shape

inlet:	thin	-x side
outlet:	thin	+x side
sym high:		+z side
sym low:		-z side
top:	thin	+y side
bottom:	thin	-y side

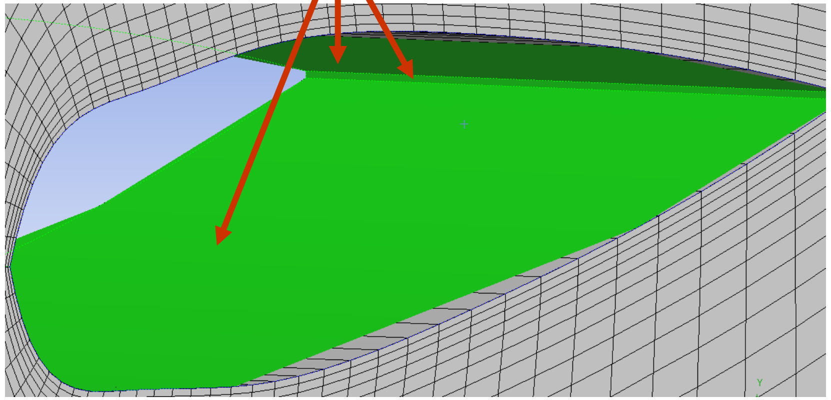
7. Make a named selection on the inlet by selecting the inlet face, then RMB and select Create Named Selection. Name it inlet in the pop up window and press OK

low-x

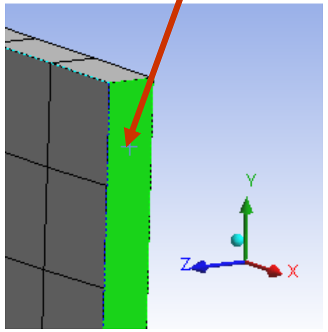


Named Selections [2]

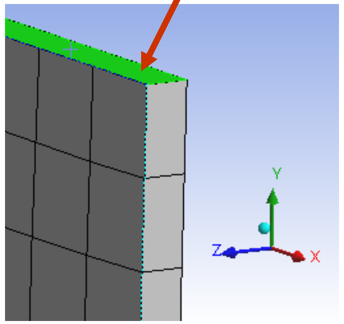
8. Make named selection airfoil (3 faces)



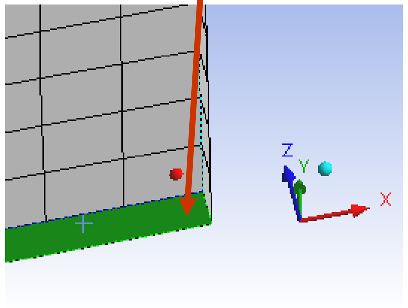
9. outlet



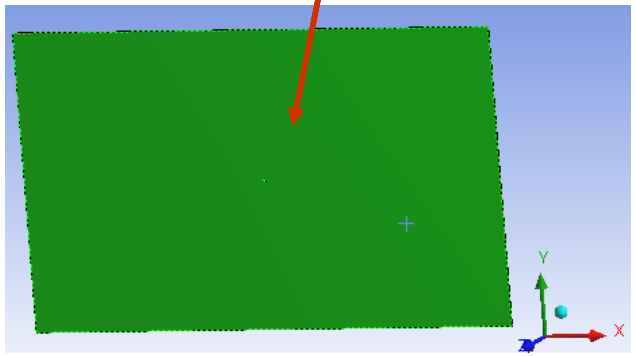
10. top



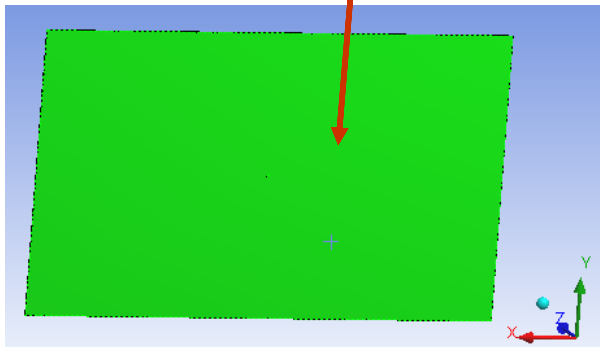
12. bottom



13. sym high

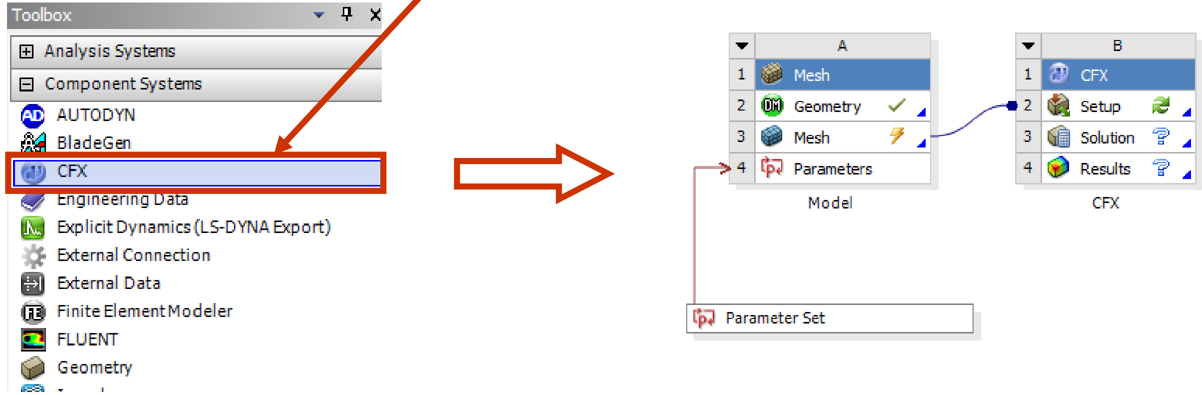


14. sym low



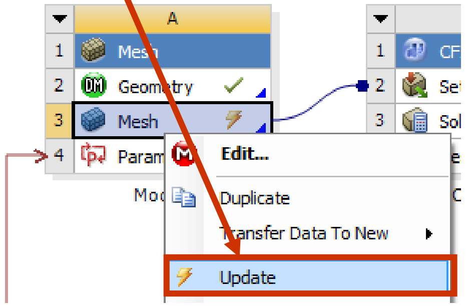
Adding CFX System

16. Drag and drop a CFX ‘Component System’ onto your mesh

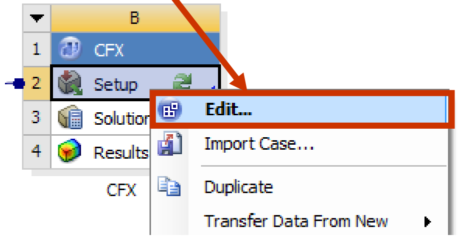


17. RMB on the Mesh and click Update

This does not create a new mesh, it just exports the mesh we just looked at in the file format that CFX requires

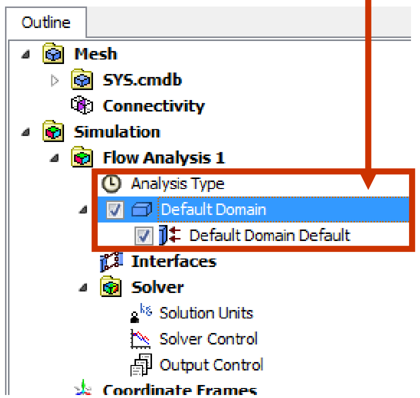


18. RMB on the Setup cell of CFX and click Edit to launch CFX-Pre

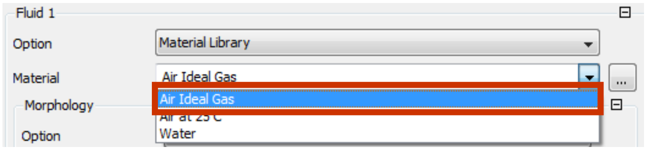


CFX General Settings

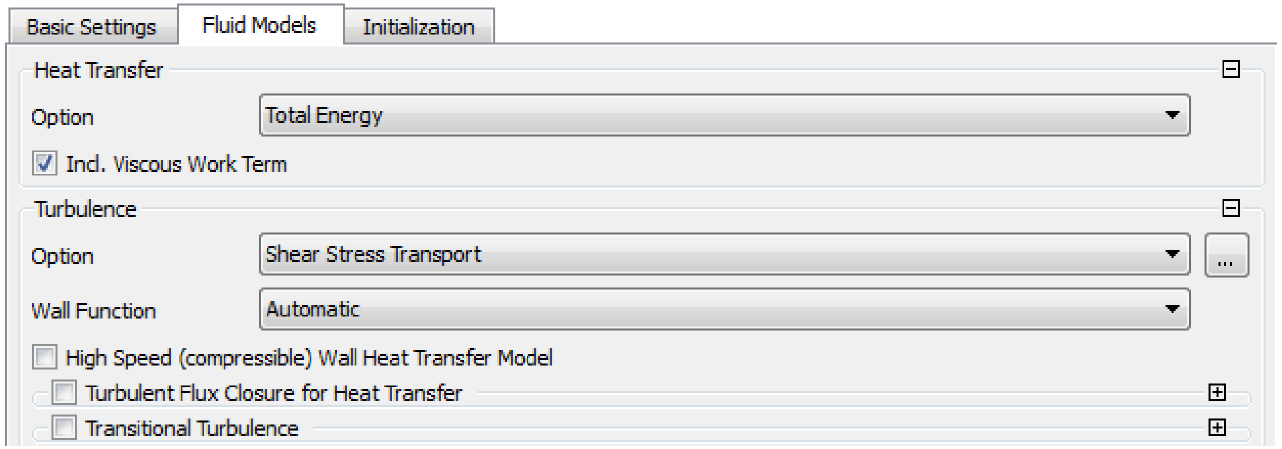
19. Double click on Default Domain to edit it



20. Set the material to Air Ideal Gas (This is necessary for supersonic flow, since the density will vary significantly as a function of pressure and temperature)



21. Click on the Fluid Models tab, set Heat Transfer to Total Energy, Turbulence to Shear Stress Transport, and then click OK

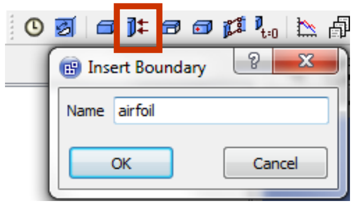


Boundary Conditions [1]

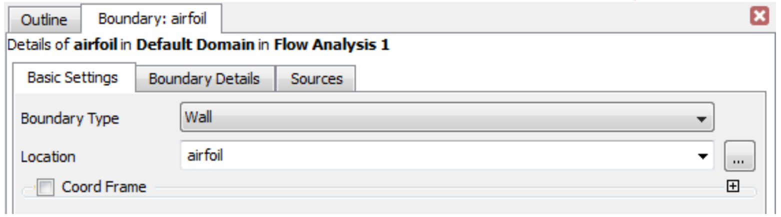
Now we need to make boundaries for each of the named selections we made earlier:

airfoil:	no slip wall
inlet:	supersonic, 600 m/s, 300 K
outlet:	supersonic
sym high:	symmetry
sym low:	symmetry
top:	free slip wall
bottom:	free slip wall

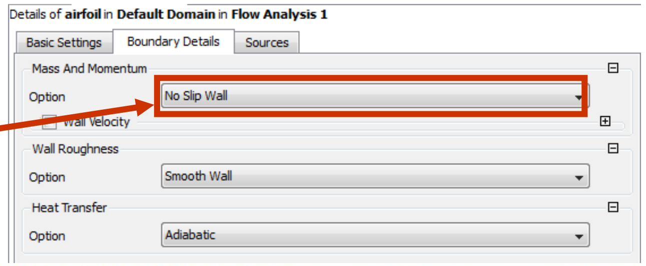
22. To create a boundary condition, click the Boundary button. Name the new boundary airfoil, and click OK



Set the Boundary Type to Wall and ensure that the correct location is specified



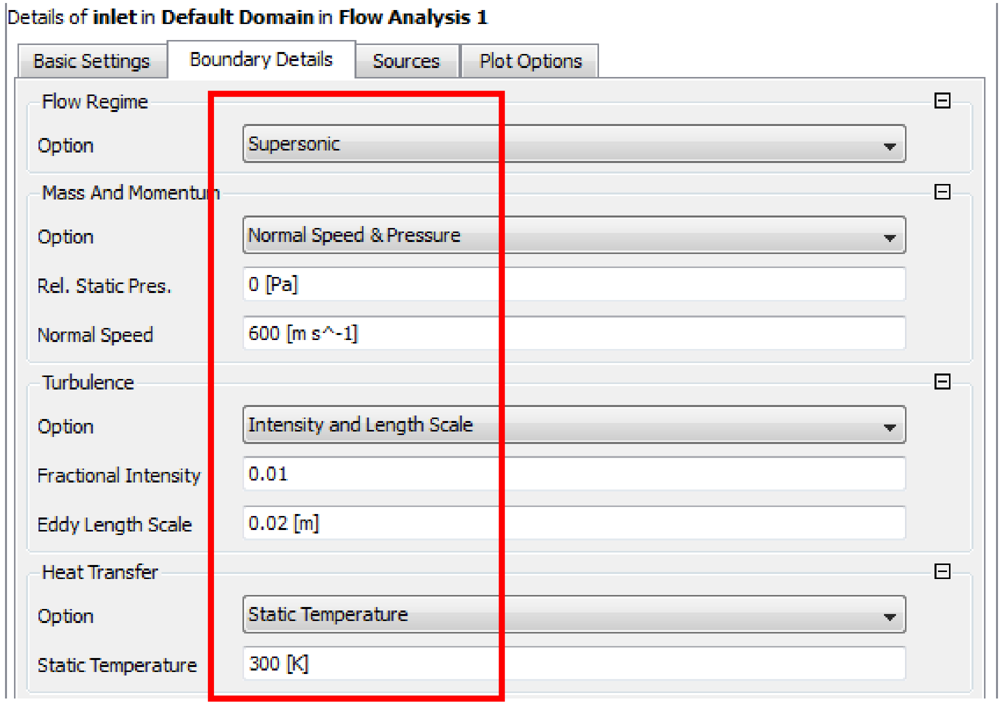
Select the Boundary Details tab and make sure that the Mass and Momentum Option is set to No Slip Wall



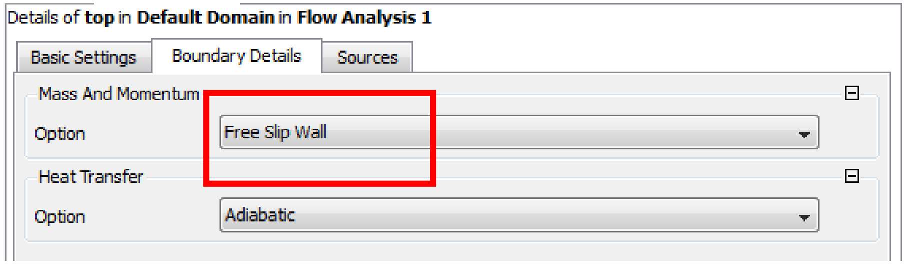
Click OK to create the boundary

Boundary Conditions [2]

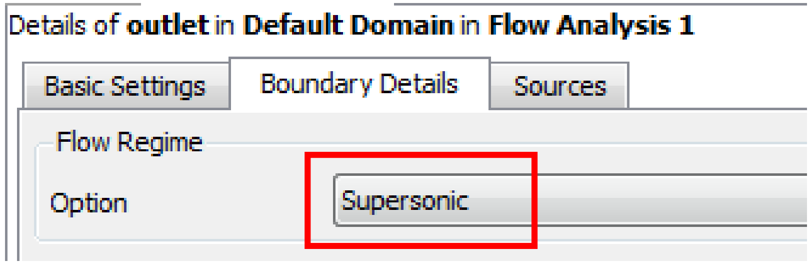
23. Create the inlet boundary



24. top – type: wall – free slip

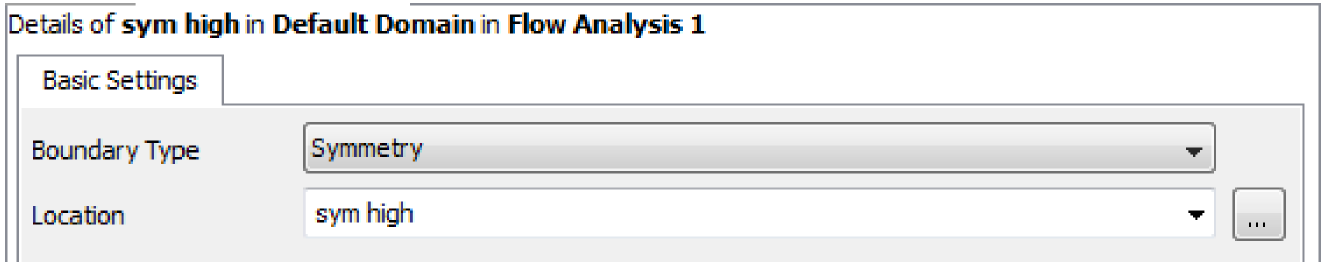


25. outlet – type: outlet - supersonic

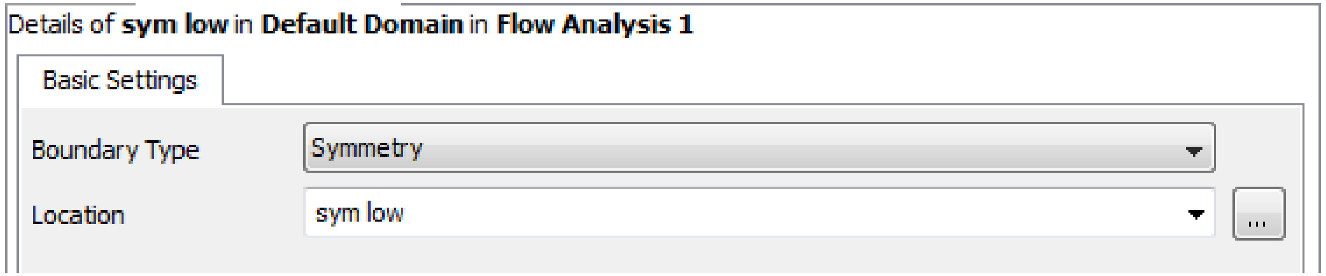


Boundary Conditions [3]

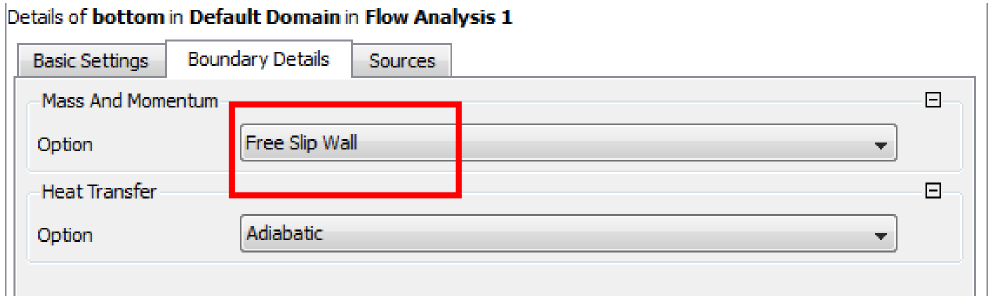
26. sym high - type: symmetry



27. sym low – type: symmetry

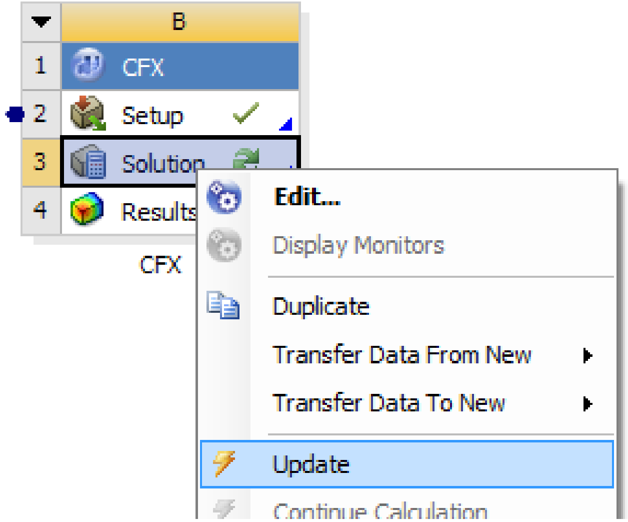


28. bottom – type: wall – free slip

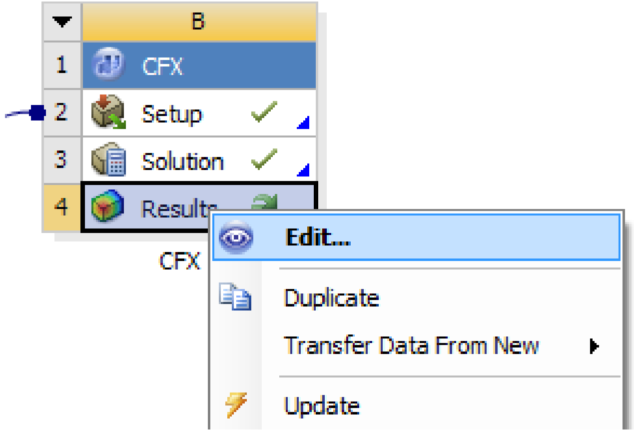


Solving CFX Model

29. On the Workbench Project Page, Save your work, then RMB the Solution cell in CFX and click Update to solve the case
(the solver will take a few minutes to generate the solution)

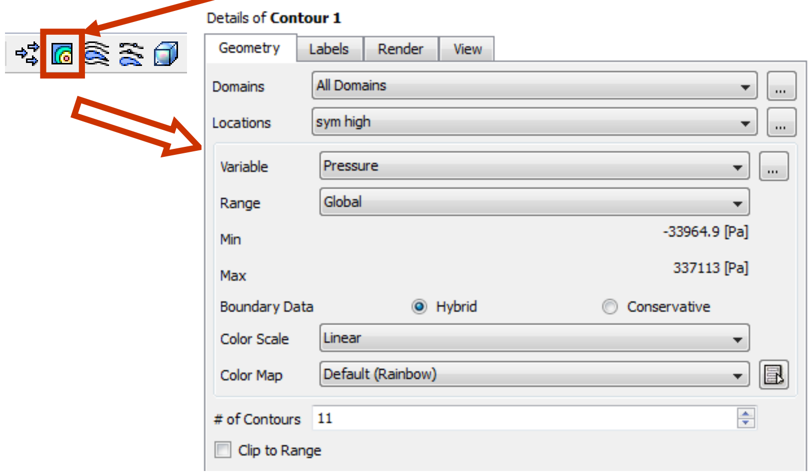


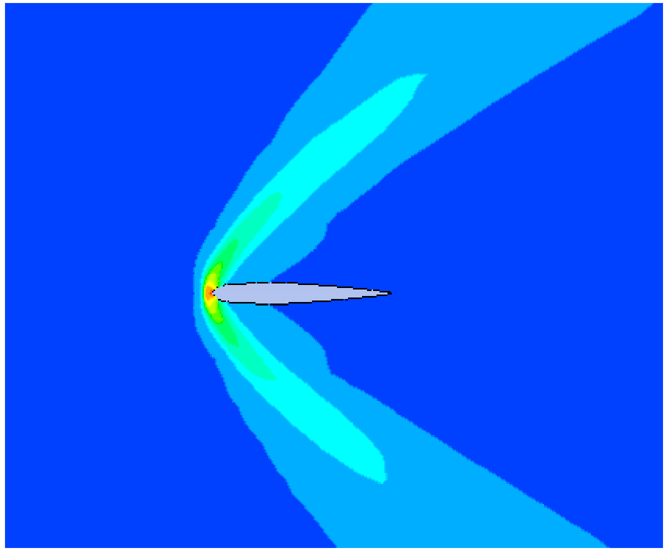
30. When the solution is finished updating, RMB the Results cell and click Edit to open CFX Post



Postprocessing

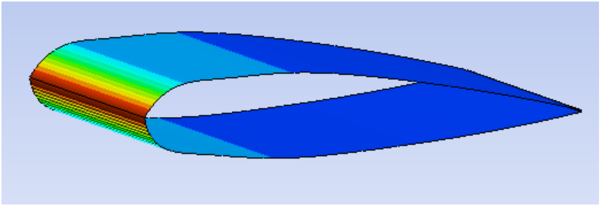
30. Generate a contour plot of pressure on sym high





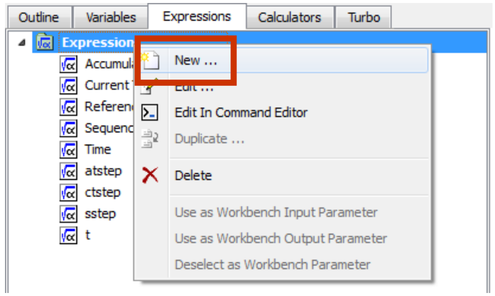
Try plotting other variables such as temperature, velocity, and mach number

Also try plotting on other locations like the airfoil



Creating Expressions for Output

31. Create a new Expression by clicking on the Expressions tab, RMB in the window and clicking new



Name the expression *Lift* and enter:

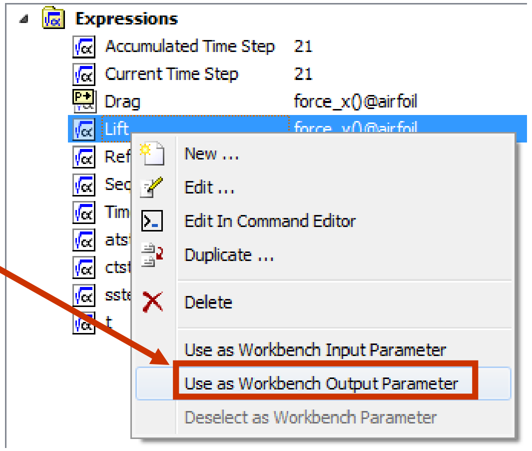
force_y()@airfoil

Tip: Although you could type this expression, it is better to use RMB to pick the function 'force_y' and the location 'airfoil' from the menu to avoid typo errors

Click Apply to create the Expression

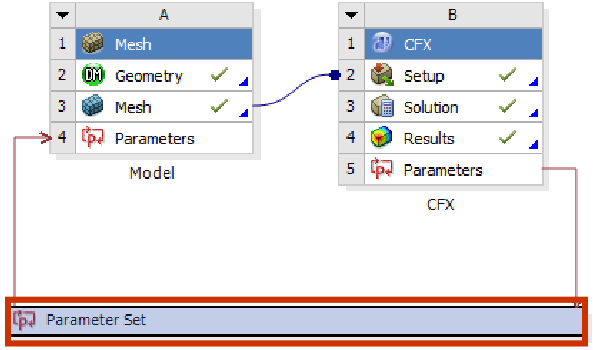
32. Create another expression called Drag with the value: force_x()@airfoil

33. Turn both Lift and Drag into output parameters by RMB on them and clicking Use as Workbench Output Parameter



Observe Parameters in Workbench

33. Return to Workbench and Double Click on Parameter Set



Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	Model (A1)			
4	P1	AngleOfAttack	0	
*	New input parameter	New name	New expression	
6	Output Parameters			
7	CFX (B1)			
8	P2	Drag	4744.9	N
9	P3	Lift	-15.564	N
*	New output parameter		New expression	
11	Charts			

Table of Design Points

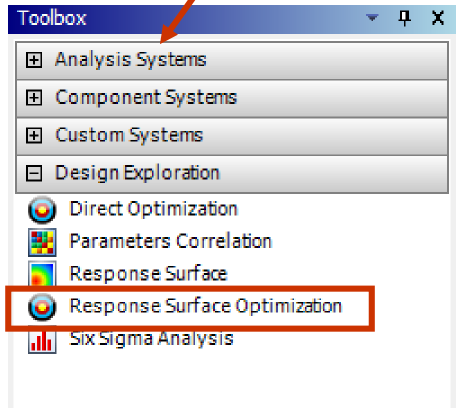
	A	B	C	D	E	F	G
1	Name	P1 - AngleOfAttack	P2 - Drag	P3 - Lift	Retain	Retained Data	Note
2	Units		N	N			
3	DP 0 (Current)	0	4744.9	-15.564	☑	✓	
*					☐		

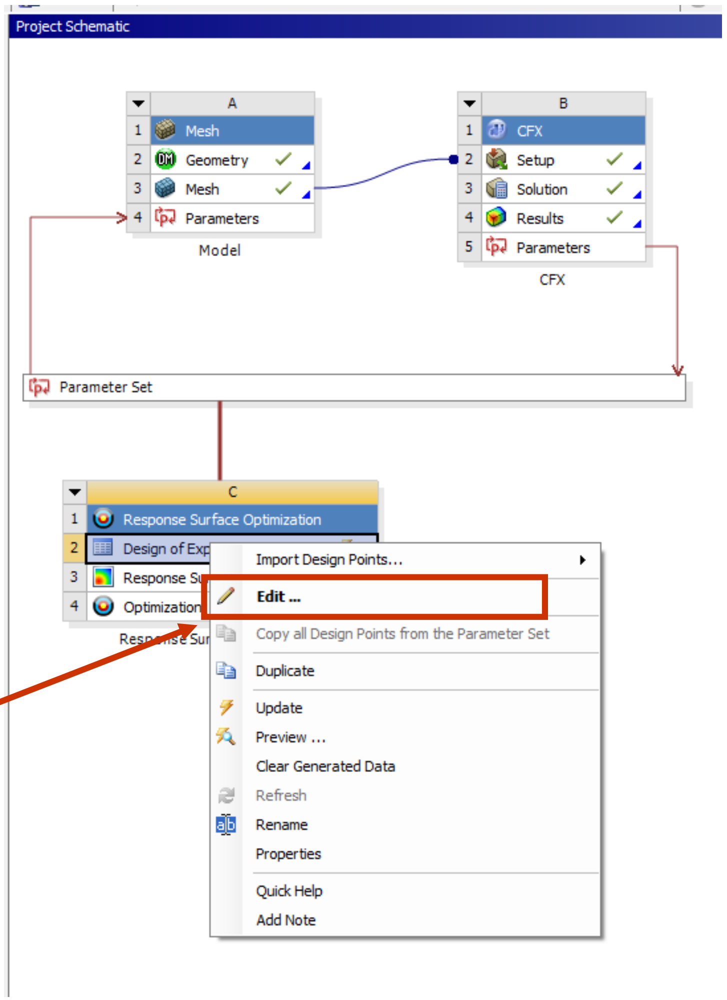
Here we can see all of our parameters and design points which we will be using as part of our optimization

Return to the main project page

Adding Design Exploration Tools

31. Drag a Response Surface Optimization component onto the Project Schematic

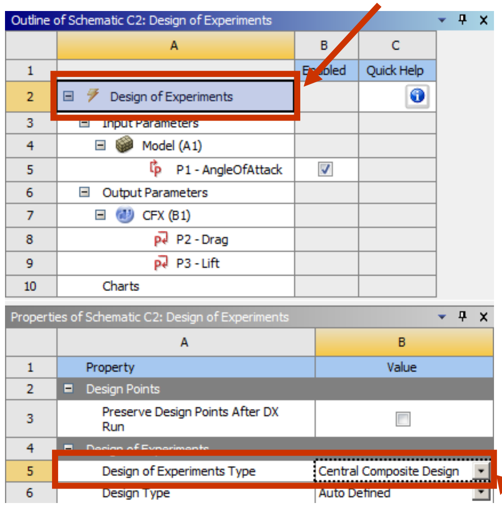




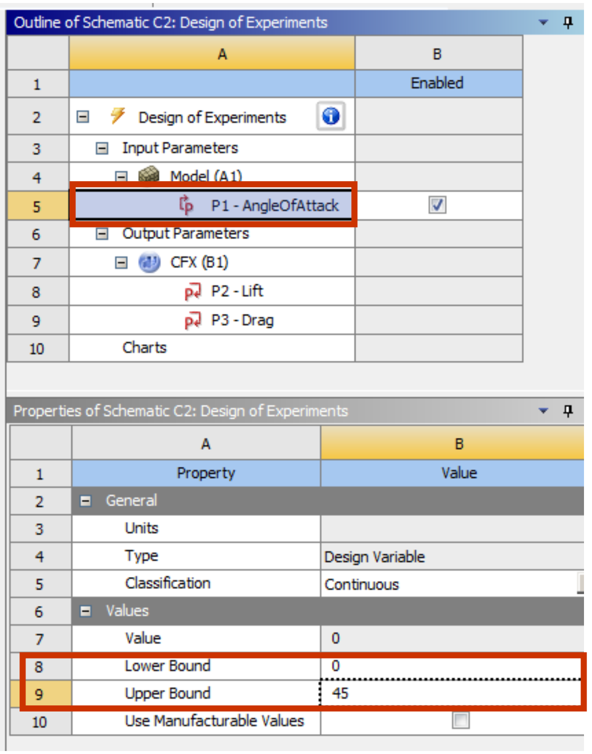
32. RMB Design of Experiments and click edit

Computing the DOE

33. Select Design of Experiments



By default Design of Experiments Type is Central Composite Design



34. Select AngleOfAttack and set the lower and upper bounds to vary from 0 to 45. Save the Project

35. Preview and then Update Design of Experiments (this will take approximately 40 minutes). Say 'Yes' if a pop-up window appears

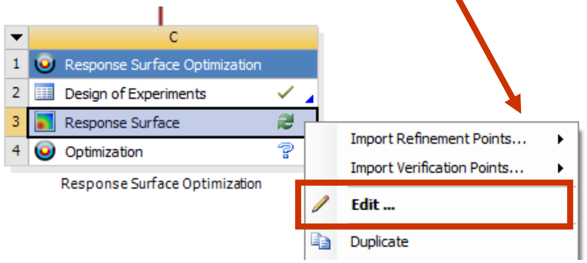
Creating Response Surface

Results:

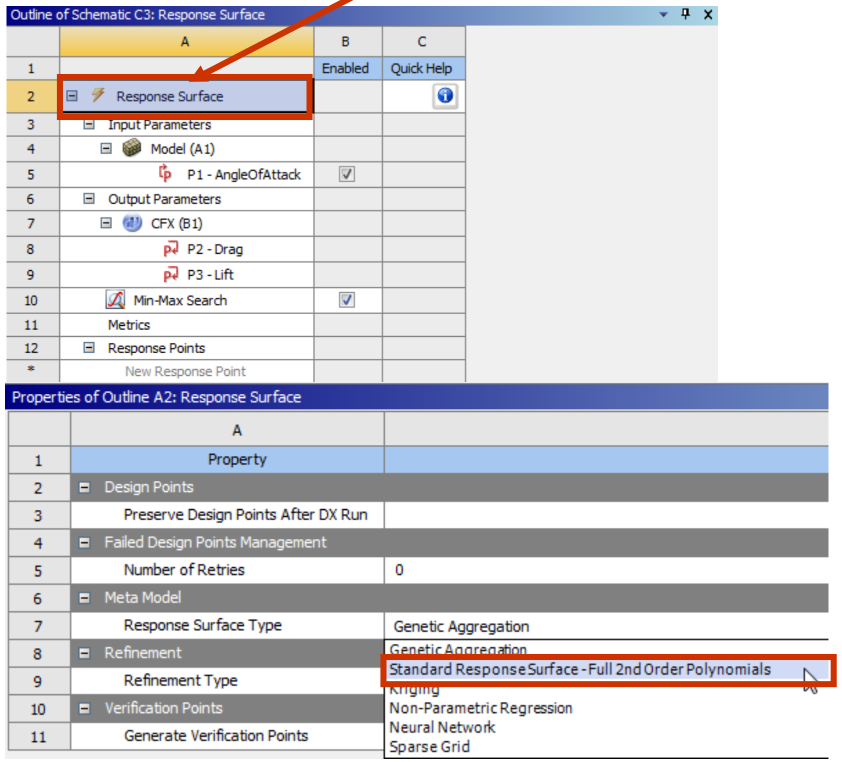
Table of Schematic C2: Design of Experiments (Central Composite Design : Auto Defined)

	A	B	C	D
1	Name	P1 - AngleOfAttack	P2 - Drag (N)	P3 - Lift (N)
2	1	22.5	20381	40505
3	2 DP 0	0	4744.9	-15.564
4	3	45	49696	48427
5	4	11.25	8392.6	19880
6	5	33.75	36307	50819

36. Return to the Project Schematic, RMB Response Surface, and click Edit



37. Select Response Surface and set its type to Full 2nd Order Polynomials



38. Click 'Update' to calculate the response surface from the DOE

Response Profiles

39. Select Response

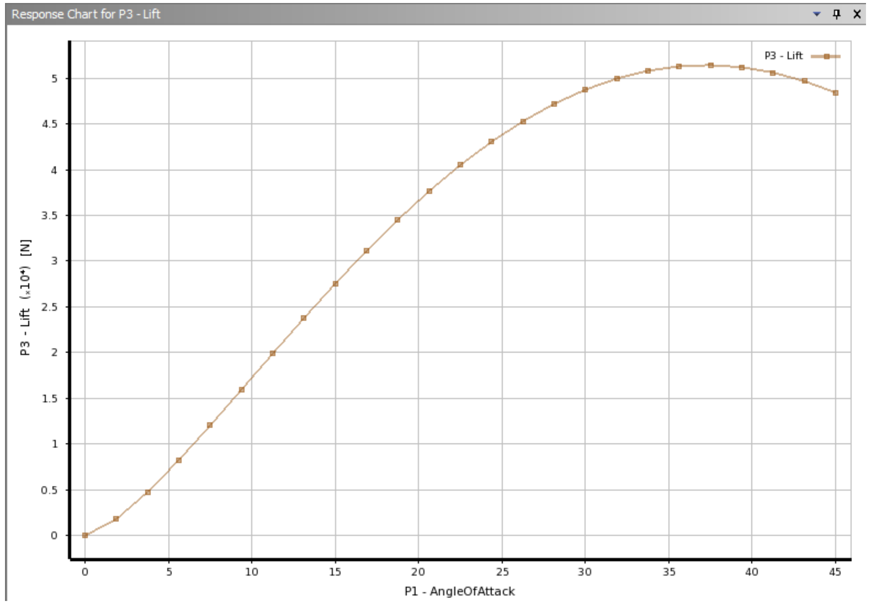
Outline of Schematic C3: Response Surface

	A	B
1		Enabled
2	⊟ ✓ Response Surface	
3	⊟ Input Parameters	
4	⊟ Model (A1)	
5	P1 - AngleOfAttack	☑
6	⊟ Output Parameters	
7	⊟ CFX (B1)	
8	P2 - Lift	
9	P3 - Drag	
10	✓ Min-Max Search	☑
11	⊟ Metrics	
12	✓ Goodness Of Fit	
13	⊟ Response Points	
14	⊟ ✓ Response Point	
15	✓ Response	
16	✓ Local Sensitivity	
17	✓ Local Sensitivity Curves	
18	✓ Spider	
*	New Response Point	

Plot AngleOfAttack vs. Lift (10 points in X)

Properties of Outline A15: Response

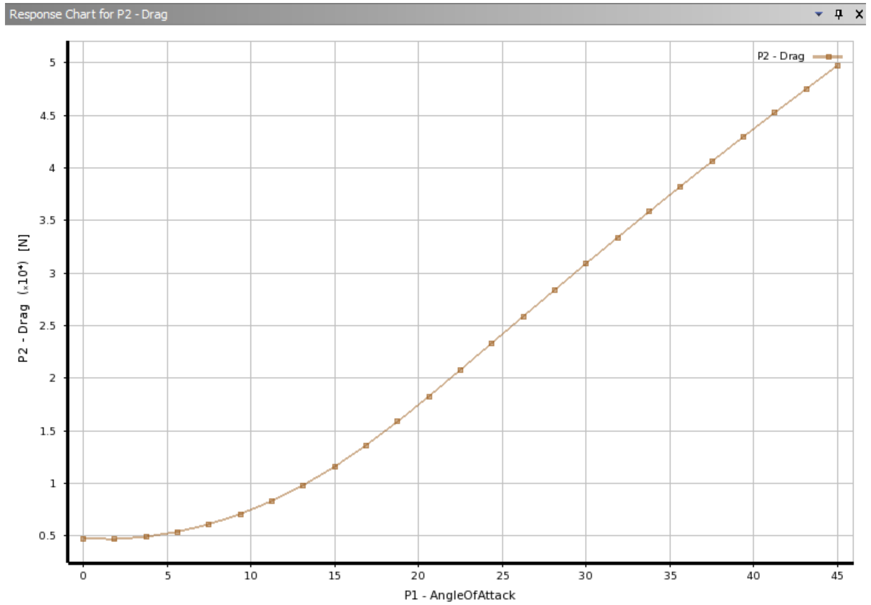
	A	B
1	Property	Value
2	⊟ Chart	
3	Display Parameter Full Name	☑
4	Number of Points on X	10
5	Show Design Points	☐
6	⊟ Axes	
7	X axis	P1 - AngleOfAttack
8	Y axis	P3 - Lift
9	⊟ Input Parameters	
		22.5



Plot AngleOfAttack vs. Drag

Properties of Outline A15: Response

	A	B
1	Property	Value
2	⊟ Chart	
3	Display Parameter Full Name	☑
4	Number of Points on X	10
5	Show Design Points	☐
6	⊟ Axes	
7	X axis	P1 - AngleOfAttack
8	Y axis	P2 - Drag
9	⊟ Input Parameters	
		22.5



Min-Max Search

40. Select Min-Max Search

Outline of Schematic C3: Response Surface

	A	B
1		Enabled
2	Response Surface	
3	Input Parameters	
4	Model (A1)	
5	P1 - AngleOfAttack	☑
6	Output Parameters	
7	CFX (B1)	
8	P2 - Lift	
9	P3 - Drag	
10	Min-Max Search	☑
11	Metrics	
12	Goodness Of Fit	
13	Response Points	
14	Response Point	
15	Response	
16	Local Sensitivity	
17	Local Sensitivity Curves	
18	Spider	
*	New Response Point	

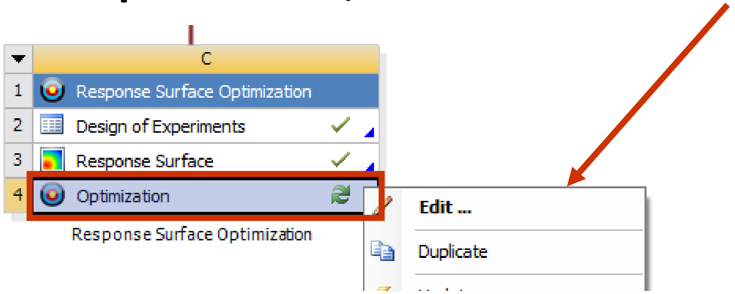
Here we can see the minimum and maximum values of each parameter

Table of Outline A10: Min-Max Search

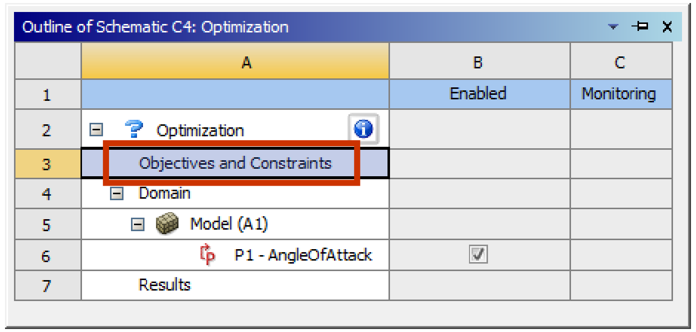
	A	B	C	D
1	Name	P1 - AngleOfAttack	P2 - Drag (N)	P3 - Lift (N)
2	Output Parameter Minimums			
3	P2 - Drag	1.3287	**4672.8**	1087.4
4	P3 - Lift	0	4753.2	**-15.564**
5	Output Parameter Maximums			
6	P2 - Drag	45	**49747**	48427
7	P3 - Lift	37.249	40307	**51446**

Optimization

41. Return to the Project Schematic, RMB Optimization, and click Edit



42. Select 'Objectives and Constraints'



43. In the Table of Schematic, create two rows with the objectives of:

- **minimize drag**
- **maximize lift**

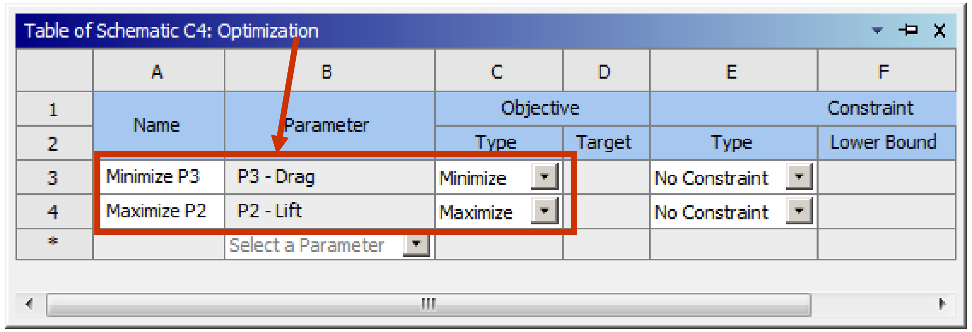


Table of Schematic C4: Optimization

	A	B	C	D	E	F
1	Name	Parameter	Objective		Constraint	
2			Type	Target	Type	Lower Bound
3	Minimize P3	P3 - Drag	Minimize		No Constraint	
4	Maximize P2	P2 - Lift	Maximize		No Constraint	
*		Select a Parameter				

44. Click 'Update'

This will explore the response surface to identify points that appear to best meet these objectives

Review Candidate Points

8	Candidate Points			
9		Candidate Point 1	Candidate Point 2	Candidate Point 3
10	P1 - AngleOfAttack	21.443	23.828	26.213
11	P2 - Drag (N)	★ 19373	★ 22600	25830
12	P3 - Lift (N)	★★ 38930	★★ 42346	★★ 45253

These are the best points suggested from examining the Response Surface. Note that we have not (yet) actually run a simulation under these precise conditions, this is just the predicted response

Here we can see what combination of lift and drag can be obtained

45. Select Tradeoff

Outline of Schematic C4: Optimization

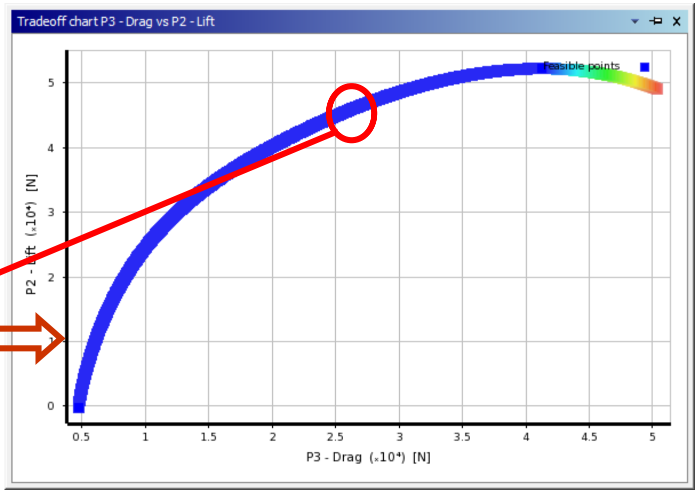
	A	B	C
1		Enabled	Monitoring
2	Optimization		
3	Objectives and Constraints		
4	Minimize P3		
5	Maximize P2		
6	Domain		
7	Model (A1)		
8	P1 - AngleOfAttack	☑	
9	Results		
10	Candidate Points		
11	Tradeoff		
12	Samples		
13	Sensitivities		

Plot Drag vs. Lift

Properties of Outline A12: Tradeoff

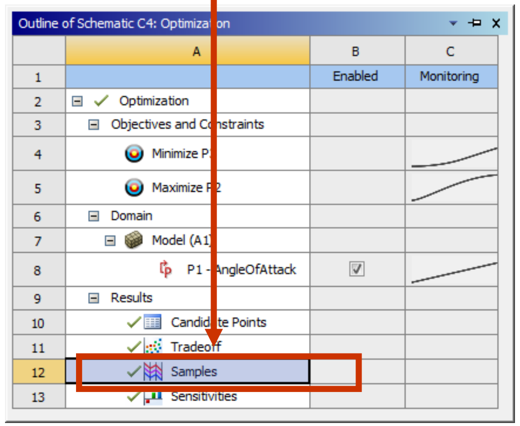
	A	B
1	Property	Value
2	Chart	
3	Display Parameter Full Name	☑
4	Mode	2D
5	Number of Pareto Fronts to Show	173
6	Axes	
7	X Axis	P2 - Drag
8	Y Axis	P3 - Lift
9	Input Parameters	
10	P1 - AngleOfAttack	25.133
11	Output Parameters	
12	P2 - Drag	24369
13	P3 - Lift	44002

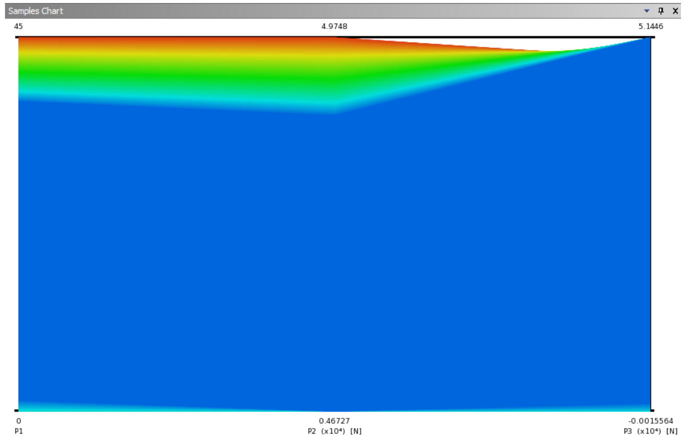
Click on any sample point to see the corresponding angle of attack



Trimming the number of Samples

45. Select Samples



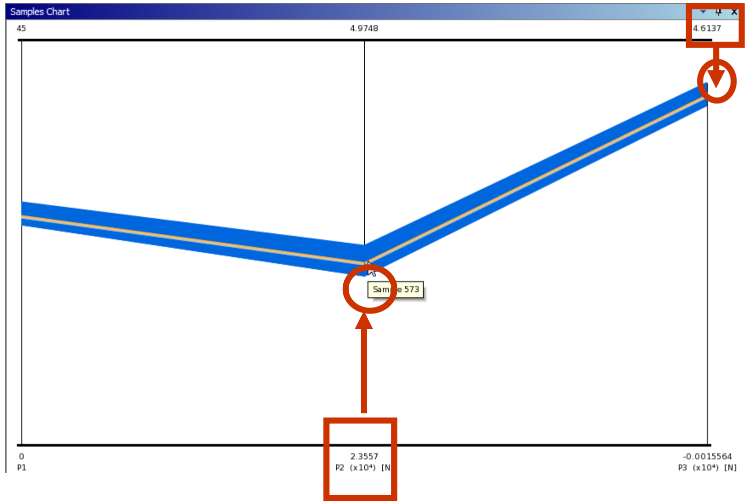


This chart shows a graphical representation of all samples used in the optimization. But right now there is too much data

Say we want to filter to find samples with:

- Maximum Drag of 3E4 N
- Minimum Lift of 4E4 N

46. Mouse over the extremities of each parameter and an orange handle will appear. Drag the handle up or down to find the appropriate range



Max of ~4.6E4

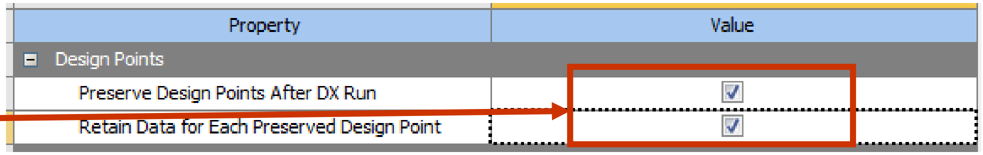
Click on any sample to report its details in the outline table

Min of ~2.3E4

Verifying the Optimal Design

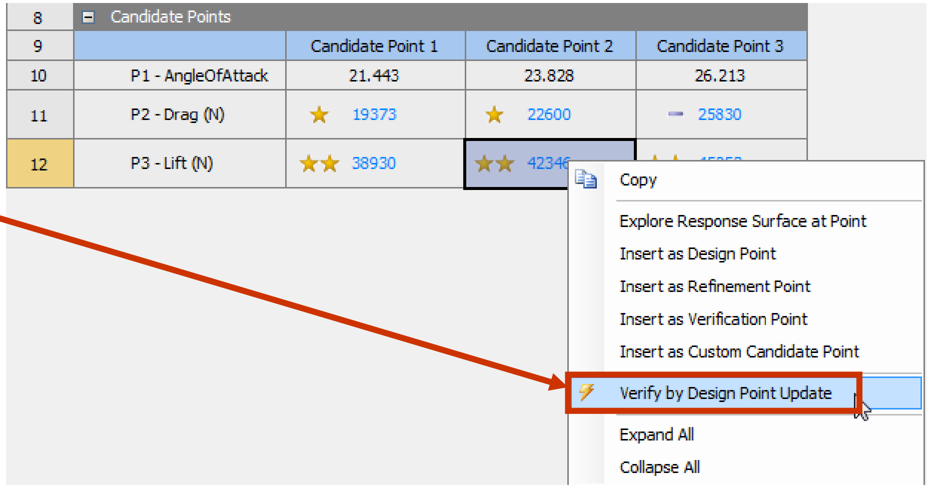
Recall the original DOE contained 5 points. The surface interpolated through these points suggested the optimal value. It is important to then run a simulation at this condition (attack angle) to verify the performance is indeed as predicted from the interpolated response surface

47. Under Optimiziation, enable Retain Data for Each Preserved Design Point



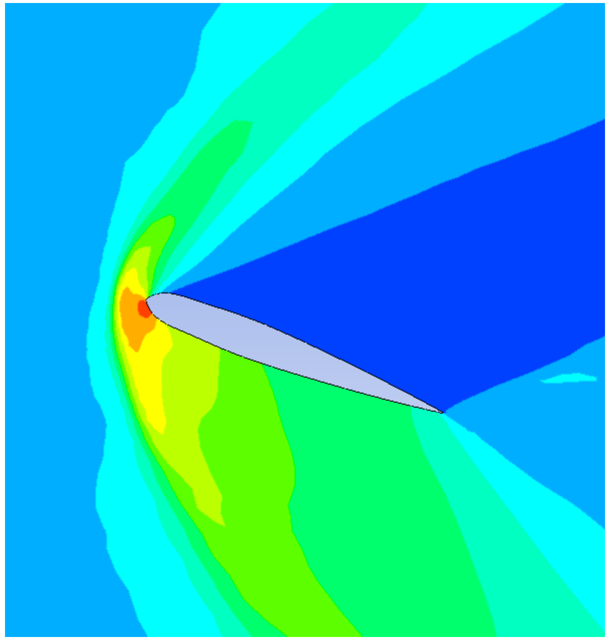
48. In this case Candidate 2 looks like the best option. RMB on Candidate 2 > Verify by Design Point Update

This may take a few minutes



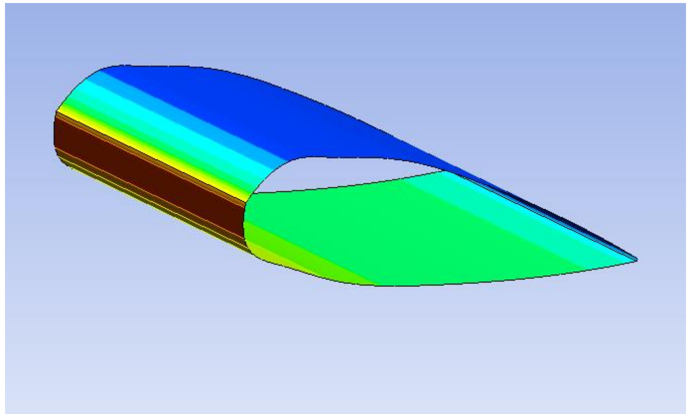
Examining the Verification Point

8	Candidate Points				
9		Candidate Point 1	Candidate Point 2	Candidate Point 2 (verified) DP 1	Candidate Point 3
10	P1 - AngleOfAttack	21.443	23.828		26.213
11	P2 - Drag (N)	★ 19373	★ 22600	★ 22380	– 25830
12	P3 - Lift (N)	★★ 38930	★★ 42346	★★ 42829	★★ 45253



The computed results compare well with the predicted values:
Drag: 22,380N (computed) / 22,600N (predicted)
Lift: 42,829N (computed) / 42,346 (predicted)

Notice that Candidate Point 2 (verified) is now labeled DP1 (Design Point 1)



Wrap-up

This workshop has shown how a design can be optimised. A geometric quantity (in this case the attack angle of the wing) was parameterized, as were the output metrics of Drag and Lift on the airfoil.

By computing a Design-of-Experiments (DOE) over 5 simulation points we could interpolate to produce a surface showing the response of the system.

This gives information showing the trade-off between the different quantities (which lift/drag combinations were possible), as well as letting us predict the optimum conditions (maximum lift / minimum drag).

However since these predictions are based on the interpolated response surface, it is important to then actually compute the chosen optimum conditions to verify the solution – in this case showing good agreement with what was expected.

Other quantities could have been parameterized instead – you may want to try these yourself. We could use the same techniques to test the sensitivity of the result to the mesh (esp boundary-layer mesh) density, or the sensitivity to the speed of the passing air.