



**Aeolus**

Aero Sketch Pad

# Tutorial

# **UAV Design Example**

Aeolus ASP 3.11

January 2019

[www.aeolus-aero.com](http://www.aeolus-aero.com)



# Welcome

## Summary

In this tutorial, a simple Unmanned Aerial Vehicle (UAV) will be designed for a given mission to familiarize with the basic steps of modelling, analysis and optimization in Aeolus ASP.

## Prerequisites

- Aeolus ASP 3.11
- Quick Start tutorial recommended

## Contents

- Product Requirements
- Initial Design
- Analysis of the Initial Design
- Wing Shape Optimization
- Static Stability



# Product Requirements

In this example, the objective is to design an UAV for **aerial mapping** and **wildlife protection** with high aerodynamic efficiency for low energy consumption and long range.

The design shall be based on the following top level requirements:

## Mass and Dimensions

- Take-off mass      6 kg
- Max span            1.5 m

## Mission

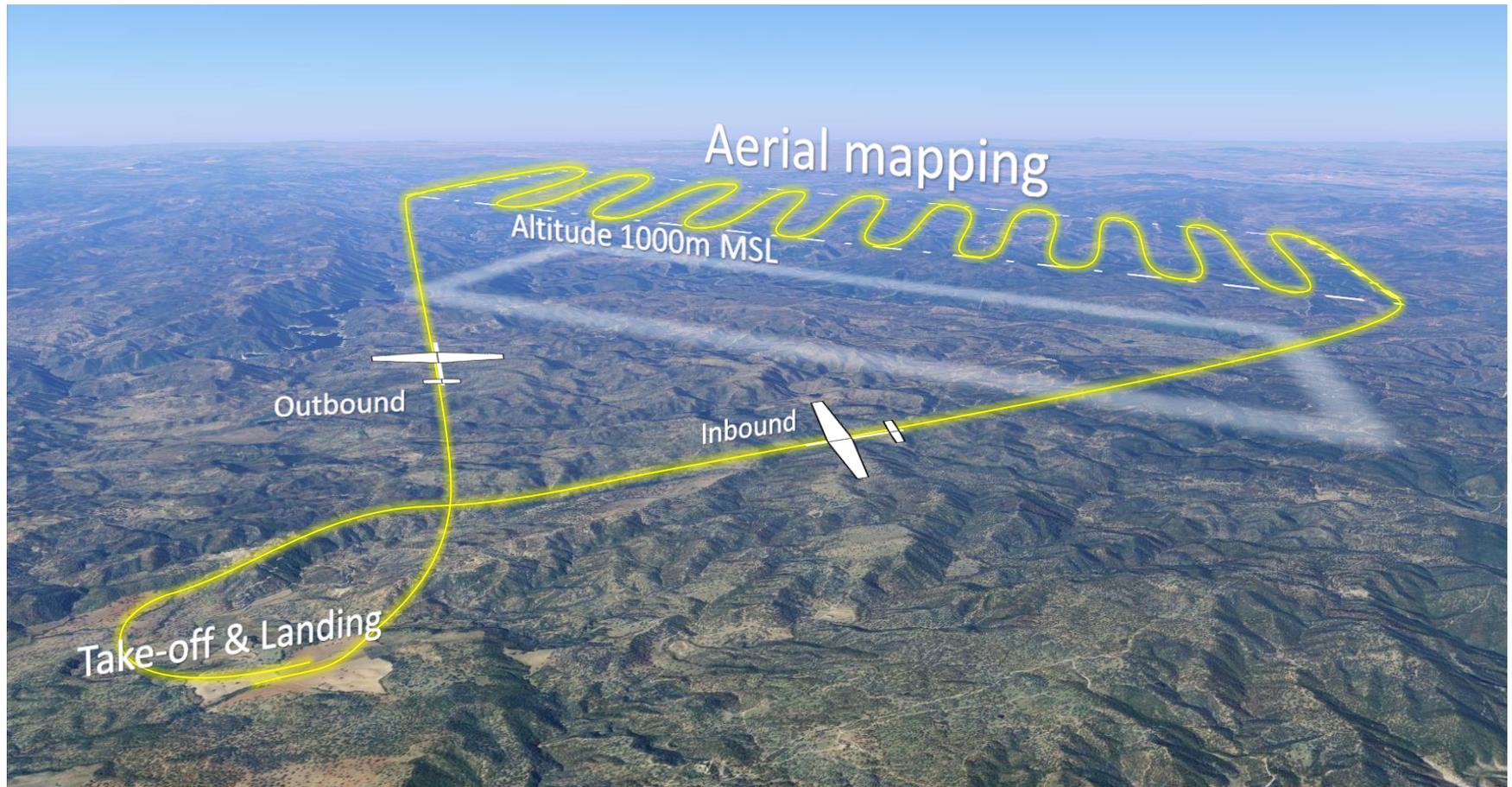
- Cruise speed        30 m/s
- Cruise altitude    1000 m MSL
- Longest range possible

## Flight mechanics

- Static longitudinal stability      margin 2% - 4%



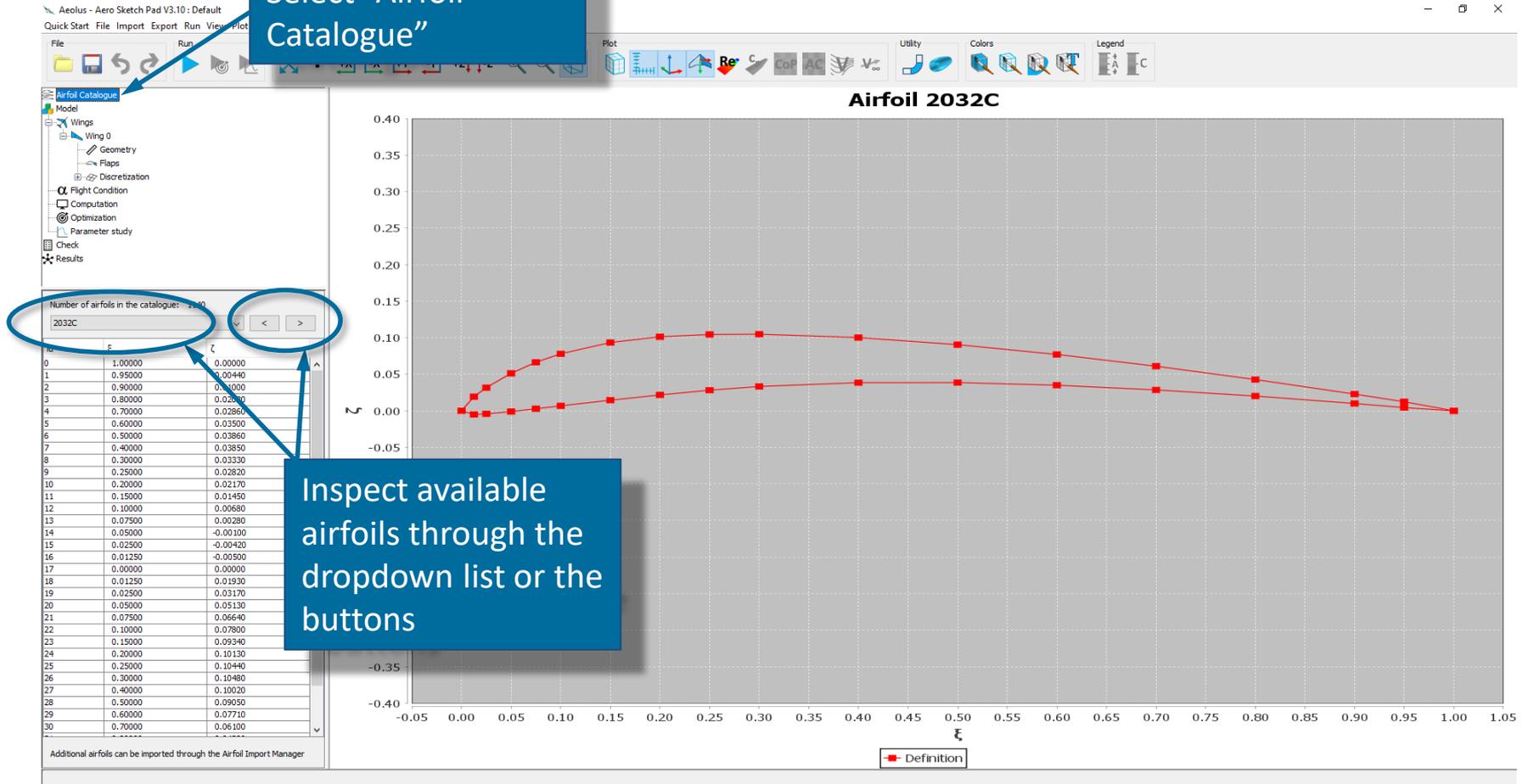
# Product Requirements





# Initial Design

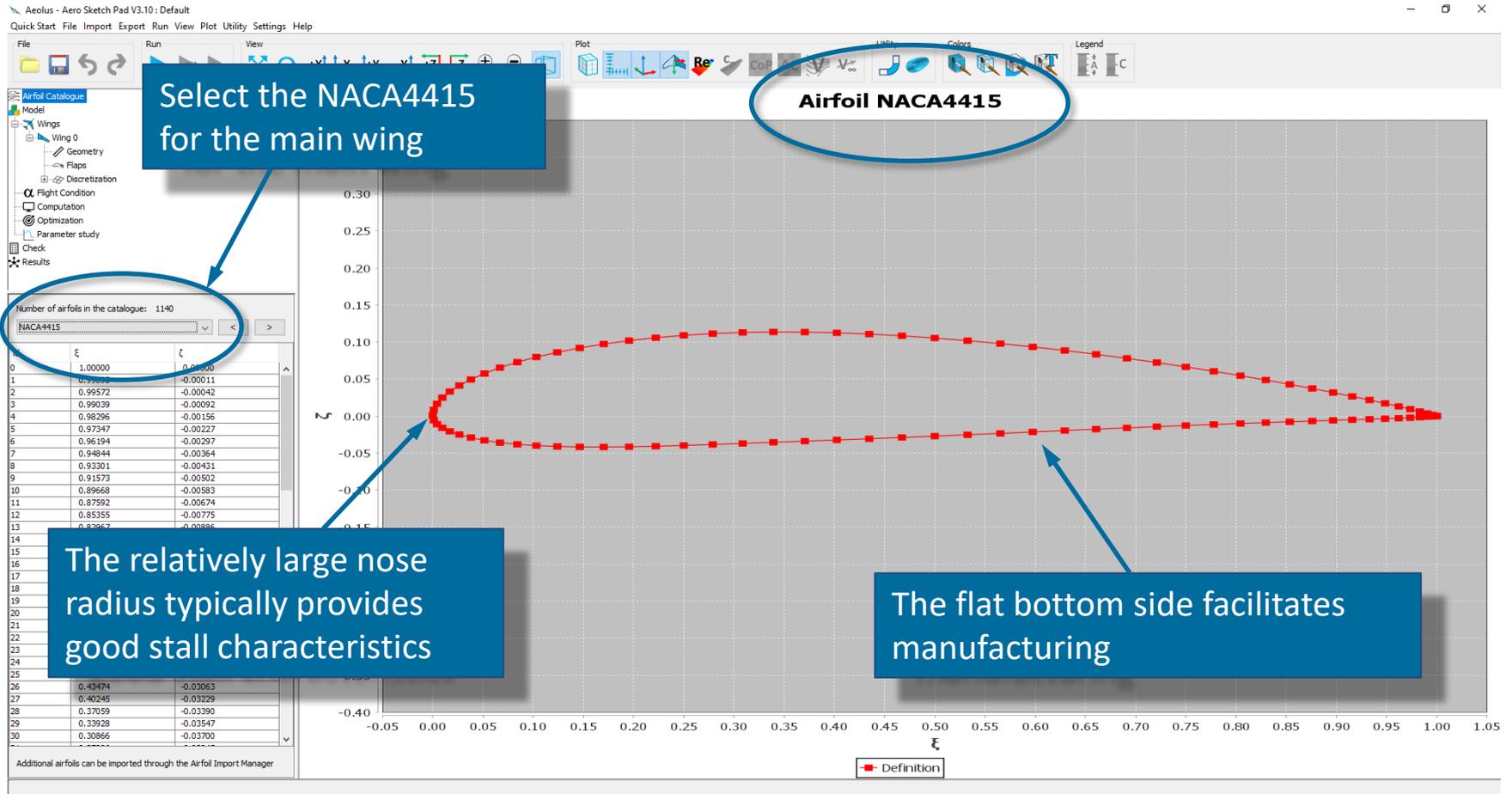
Select "Airfoil Catalogue"



Inspect available airfoils through the dropdown list or the buttons



# Initial Design

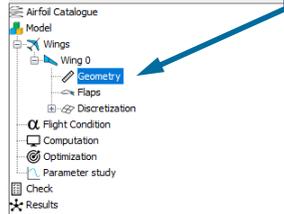
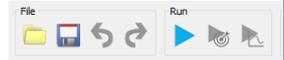




# Initial Design

Aeolus - Aero Sketch Pad V3.10 : Default  
Quick Start File Import Export Run View Plot Utilit

Select "Geometry" to start modelling the main wing.



In this example, only 2 sections are required. You can remove the 3<sup>rd</sup> section of the default wing here.

Position

Origin (x,y,z)

Reference chord  %

Characteristic parameters

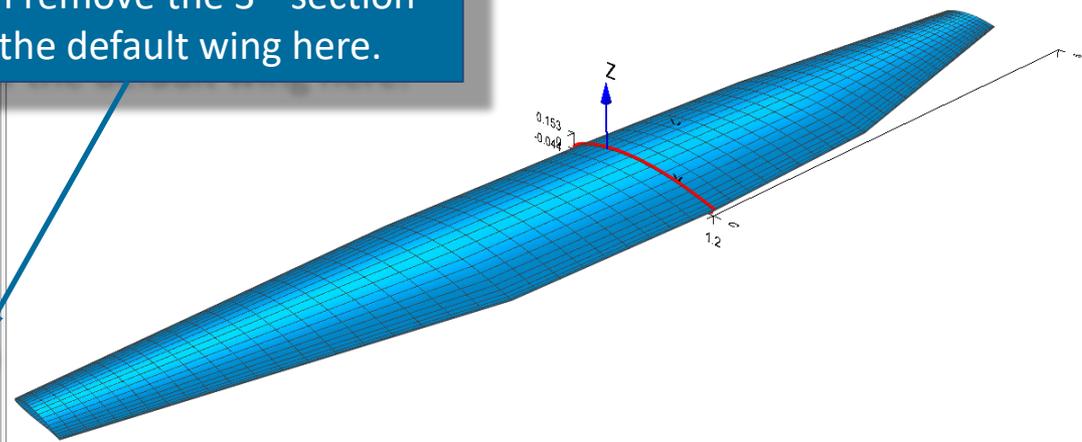
span 1.000e+01 m  
projected area 1.250e+01 m<sup>2</sup>  
wetted area 2.550e+01 m<sup>2</sup>  
mean aerodynamic chord 1.331e+00 m  
aspect ratio 8.000e+00

Settings

Chord perpendicular to  span  y

Wing sections

Sec...	Airfoil	S-pos ...	Chord ...	Twist ...	Sweep...	Dihedr...		
0	NACA63612	0.0	1.6	0.0	0.0	0.0	+	-
1	NACA63612	2.0	1.5	0.0	0.0	0.0	+	-
2	NACA63612	5.0	0.6	0.0			+	-





# Initial Design

Aeolus - Aero Sketch Pad V3.10 : Default  
Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results

Position  
Origin (x,y,z) 0.0 0.0 0.0  
Reference chord 25.0 %

Characteristic parameters  
span 4.000e+00 m  
projected area 6.200e+00 m<sup>2</sup>  
wetted area 1.280e+01 m<sup>2</sup>  
mean aerodynamic chord 1.551e+00 m  
aspect ratio 2.581e+00

Settings  
Chord perpendicular to  span  y ?

Wing sections

Sec	Airfoil	pos ...	Chord ...	Twist ...	Sweep ...	Dihedr ...		
	NACA4415	0.0	1.6	0.0	0.0	0.0	+	-
	NACA4415	2.0	1.5	0.0			+	-

Apply the NACA4415 to both sections



# Initial Design

The screenshot shows the Aeolus Aero Sketch Pad V3.10.1.2 interface. The 3D model of the wing is shown in a perspective view, with a blue grid overlay. The wing is symmetric about the Z-axis. The root is at the origin, and the tip is at the right-hand side. The wing is shown in a perspective view, with a blue grid overlay. The wing is shown in a perspective view, with a blue grid overlay. The wing is shown in a perspective view, with a blue grid overlay.

**Wing Configuration Table:**

Sec...	Airfoil	s-pos ...	Chord ...	Twist ...	Sweep ...	Dir...
0	NACA4415	0.0	0.2	0.0	0.0	+
1	NACA4415	0.75	0.2	0.0		-

**Annotations:**

- View Control:** The 'view' button in the top toolbar is circled in blue.
- Span Constraint:** A blue box states: "The total span must not exceed 1.5m. So we can set the half-span to 0.75m."
- Chord Setting:** A blue box states: "As a first test, let's try a chord of 0.2m for both sections." An arrow points to the 'Chord' column in the table.
- Geometry Adjustment:** A blue box states: "After changing the geometry you may want to fit the view". An arrow points to the 'view' button.
- Symmetry Note:** A blue box states: "Note: The wing is symmetric. Section 0 is at the wing root. Section 1 is at the right-hand side wing tip." Arrows point to the root and tip of the wing model.



# Initial Design

## Main requirements of a horizontal tail plane (HTP)

- Provide aerodynamic forces to ensure static and dynamic longitudinal stability
- Pitch control for manoeuvres
- Trim for steady flight at different speeds

## Positioning of the HTP:

X: Typically, the HTP is located downstream of the main wing at a distance of 40-50% of the wing span. With a wing span of 1.5 m we can assume  $x = 0.7$  m.

Y: Use  $y = 0$  for a symmetric aircraft

Z: The HTP should be at a sufficiently high z-position to avoid turbulences from the propeller hitting the HTP and causing vibrations. Assume  $z = 0.2$  m.

**Surface and aspect ratio:** As a rule of thumb, assume 10% of the main wing. That is  $\approx 0.03$  m<sup>2</sup>. In view of the aircraft stall characteristics, the HTP must stall later than the main wing. Therefore, the aspect ratio should be smaller than the aspect ratio of the main wing.

**Airfoil:** The HTP must be able to provide positive and negative lift forces. Symmetric airfoils, such as the NACA0012 are preferred as they provide good stall characteristics for positive and negative angles of attack.



# Initial Design

Tail planes are also considered as wings. Please select the "Wings"-node to add a horizontal tail plane.

The "+"-button adds a dummy wing which we will change to the horizontal tail plane (HTP) in the following...

Wing name	Color
Wing 0	



# Initial Design

For convenience, rename the new wing to HTP

Each new wing gets a random color. Click here to pick your preferred color.



# Initial Design

Software interface: Aeolus - Aero Sketch Pad V3.10: 3

QuickStart File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue

- Model
  - Wings
    - Wing 0
      - Geometry
      - Flaps
      - Discretization
    - Wing 1
      - Geometry
      - Flaps
      - Discretization
  - Flight Condition
  - Computation
  - Optimization
  - Parameter study
  - Check
  - Results

Position

Origin (x,y,z)

Reference chord  %

Characteristic parameters

span	1.500e+00 m
projected area	3.000e-01 m <sup>2</sup>
wetted area	6.191e-01 m <sup>2</sup>
mean aerodynamic chord	2.000e-01 m
aspect ratio	7.500e+00

Settings

Chord perpendicular to  span  y

Wing sections

Sec...	Airfoil	S-pos [m]	Chord ...	Twist a...	Sweep ...	Dihedr...		
0	NACA4415	0.0	0.2	0.0	0.0	0.0	+	-
1	NACA4415	0.75	0.2	0.0			+	-

Select the "Geometry"-Node of the HTP

Enter it's position  
X= 0.7 m  
Y= 0 m  
Z= 0.2 m



# Initial Design

Application: Aeolus - Aero Sketch Pad V3.10 : 4

Apply the NACA0012 Airfoil to both HTP sections.

Now, span and chord can be changed to reasonable values:  
Semi-span: 0.2 m  
Root chord: 0.1 m  
Tip chord: 0.05 m

Position  
Origin (x,y,z) 0.0 0.0 0.2  
Reference chord 25.0 %

Characteristic parameters  
span 4.000e-01 m  
projected area 3.000e-02 m<sup>2</sup>  
wetted area 6.119e-02 m<sup>2</sup>  
mean aerodynamic chord 7.777e-02 m  
aspect ratio 5.333e+00

Settings  
Chord perpendicular to  span

Wing sections	Sect...	Airfoil	S-pos [m]	Chord [m]	Twist a...	Sweep ...	Dihedr...
0		NACA0012	0.0	0.1	0.0	0	0.0
1		NACA0012	0.2	0.05	0.0		



# Initial Design

Software interface: Aeolus - Aero Sketch Pad V3.10 : 4

Quick Start File Import Export Run View Plot Utility Settings Help

File Edit Run View Plot Utility Settings Help

Airfoil Catalogue

- Model
  - Wings
    - Wing 0
      - Geometry
      - Flaps
      - Discretization
    - HTP
      - Geometry
      - Flaps
      - Discretization
    - Flight Condition
    - Computation
    - Optimization
    - Parameter study
    - Check
    - Results

Position

Origin (x,y,z)

Reference chord  %

Characteristic parameters

span	4.000e-01 m
projected area	3.000e-02 m <sup>2</sup>
wetted area	6.119e-02 m <sup>2</sup>
mean aerodynamic chord	7.777e-02 m
aspect ratio	5.333e+00

Settings

Chord perpendicular to  span  y

Wing sections

Sect...	Airfoil	S-pos [m]	Chord [m]	Twist a...	Sweep ...	Dihedr...	
0	NACA0012	0.0	0.1	0.0	0.0	0.0	+ -
1	NACA0012	0.2	0.05	0.0			+ -

We have defined span and chord dimensions such that:

- The HTP's projected area is 10% of the main wing
- The HTP's aspect ratio is smaller than the main wing's aspect ratio

0.75



# Initial Design

Software interface: Aeolus - Aero Sketch Pad V3.10 : 4

File Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue

- Model
  - Wings
    - Wing 0
      - Geometry
      - Flaps
      - Discretization
    - HTP
      - Geometry
      - Flaps
      - Discretization
    - Flight Condition
    - Computation
    - Optimization
    - Parameter study
    - Check
    - Results

Position

Origin (x,y,z) 0,0 0,2

Reference chord 25.0 %

Characteristic parameters

- span 4.000e-01 m
- projected area 3.000e-02 m<sup>2</sup>
- wetted area 6.119e-02 m<sup>2</sup>
- mean aerodynamic chord 7.777e-02 m
- aspect ratio 5.333e+00

Settings

Chord perpendicular to  span  y

Wing sections

Sect...	Airfoil	S-pos [m]	Chord [m]	Twist a...	Sweep ...	Dihedr...	
0	NACA0012	0.0	0.1	0.0	0.0	0.0	+ -
1	NACA0012	0.2	0.05	0.0			+ -

The sweep angle is 0° and refers to 25% chord.

Currently, the HTP's trailing edge is kinked, due to the taper.

0.75



# Initial Design

Finally, we want to make the trailing edge straight to install a single plain flap.

Therefore, set the reference chord position to 100% (trailing edge)

Position

Origin (x,y,z) 0.0 0.2

Reference chord 100 %

Characteristic parameters

span	4.000e-01 m
projected area	3.000e-02 m <sup>2</sup>
wetted area	6.119e-02 m <sup>2</sup>
mean aerodynamic chord	7.777e-02 m
aspect ratio	5.333e+00

Settings

Chord perpendicular to  span  y

Wing sections

Sect...	Airfoil	S-pos [m]	Chord [m]	Twist a...	Sweep ...	Dihedr...	
0	NACA0012	0.0	0.1	0.0	0.0	0.0	+ -
1	NACA0012	0.2	0.05	0.0			+ -

0.75



# Initial Design

AEOLUS - Aero Sketch Pad V3.10 : 4  
Quick Start File Import Export Run View Plot Utility Settings Help

File Edit Run View Plot Utility Settings Help

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results

Position  
Origin (x,y,z) 0.7 0.0 0.2  
Reference chord 100 %

Characteristic parameters  
span 4.000e-01 m  
projected area 3.000e-02 m<sup>2</sup>  
wetted area 6.119e-02 m<sup>2</sup>  
mean aerodynamic chord 7.777e-02 m  
aspect ratio 5.333e+00

Settings  
Chord perpendicular to  span  y

Wing sections

Sect...	Airfoil	S-pos [m]	Chord [m]	Twist a...	Sweep ...	Dihedr...	
0	NACA0012	0.0	0.1	0.0	0.0	0.0	+ -
1	NACA0012	0.2	0.05	0.0			+ -

You have completed the initial geometry definition.  
Continue with the next node "Flight Condition" in the model tree



# Initial Design

## **Which flight condition should be modeled?**

There is a number of different flight conditions at which the aircraft should be analysed in view of performance and stability. For example

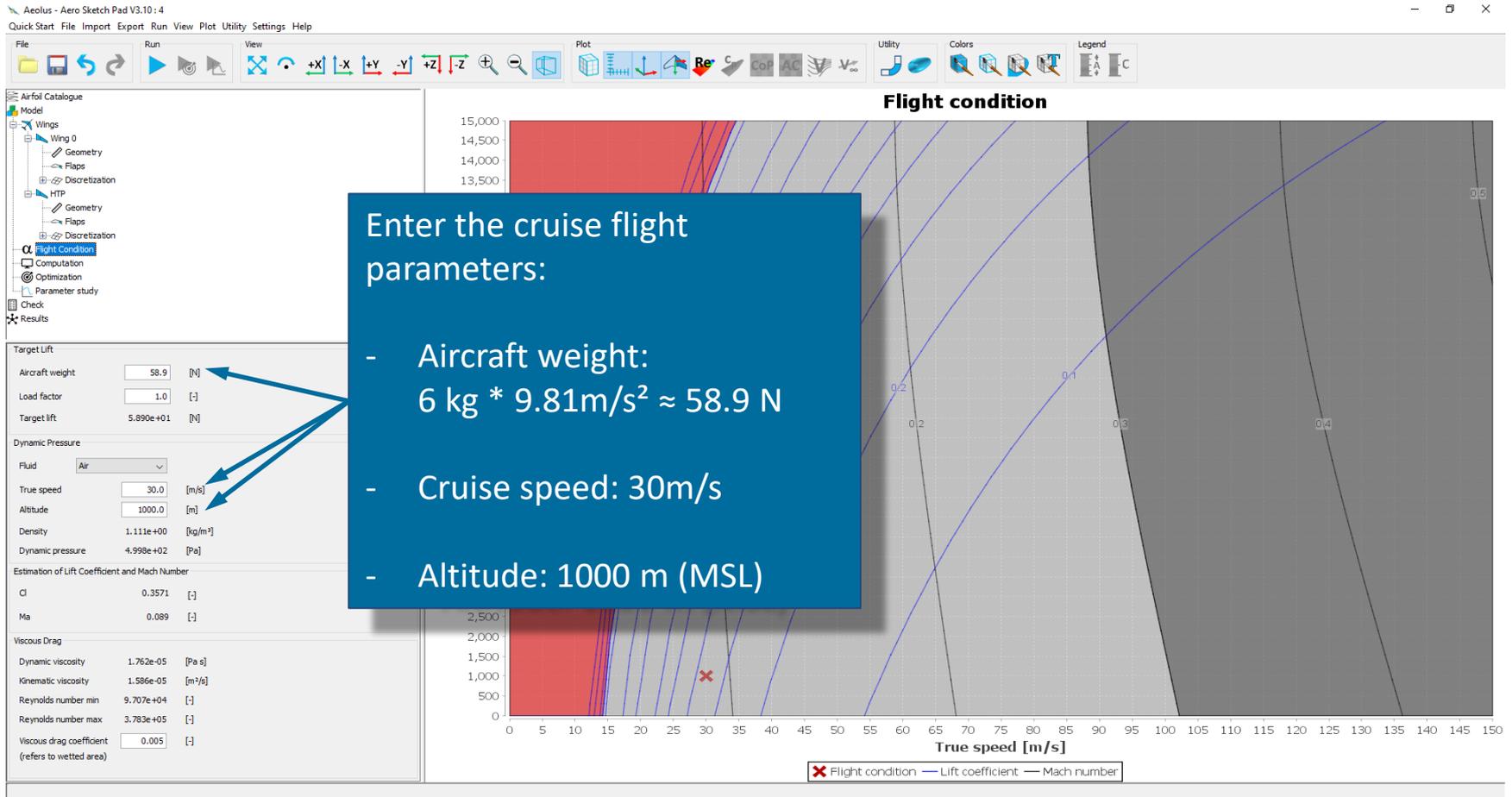
- Cruise
- Take-off and landing
- Maneuvers
- Loiter

In this tutorial, the defined mission is aerial mapping. We can expect that the aircraft will be operated in cruise flight most of the time, and that the aircraft performance largely depend on it's cruise flight characteristics.

So it is a good starting point to tailor the global wing dimensions to this primary condition in a first step.

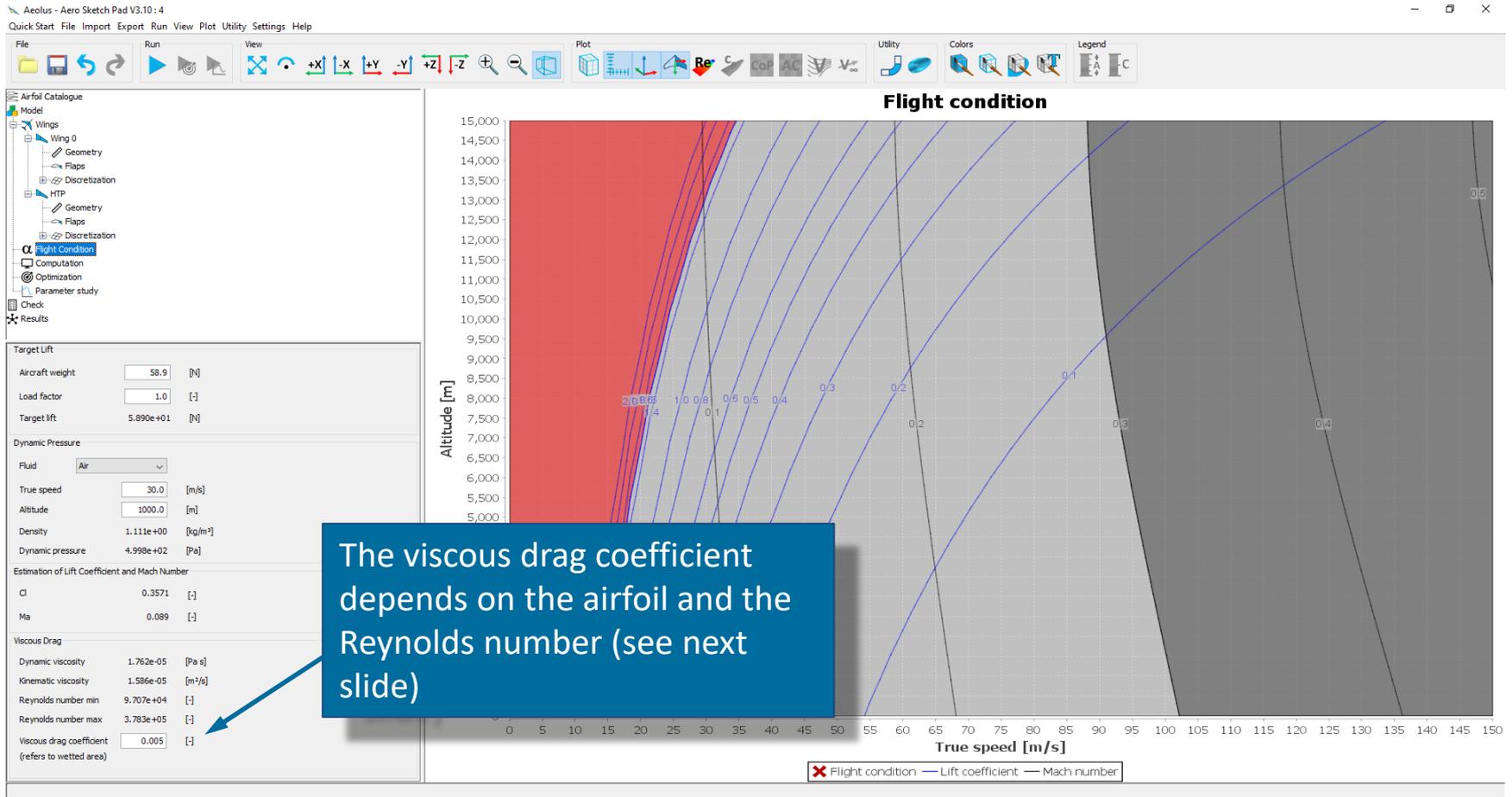


# Initial Design





# Initial Design





# Initial Design

The total aircraft drag  $D_{tot}$  is comprised of induced drag  $D_{ind}$  and viscous drag  $D_{visc}$ :

$$D_{tot} = D_{ind} + D_{visc}$$

Induced drag is calculated automatically in Aeolus ASP, whereas viscous drag is very difficult to predict with numerical methods and is therefore mostly based on experimental data. These data typically have the form of coefficients for viscous drag  $C_{d,visc}$  and allow the computation of the viscous drag force from

$$D_{visc} = q S_{wet} C_{d,visc,wet}$$

or

$$D_{visc} = q S_{proj} C_{d,visc,proj}$$

with

$q$	dynamic pressure
$S_{wet}$	wetted wing area
$S_{proj}$	projected wing area
$C_{d,visc,wet}$	viscous drag coefficient, refers to the wetted wing area
$C_{d,visc,proj}$	viscous drag coefficient, refers to the projected wing area



# Initial Design

In Aeolus ASP, the coefficient  $C_{d,visc,wet}$  must be provided as an input in the “Flight Condition” panel.

The default value is 0.005, which is a fairly good estimation for the most fixed-wing UAV cases.

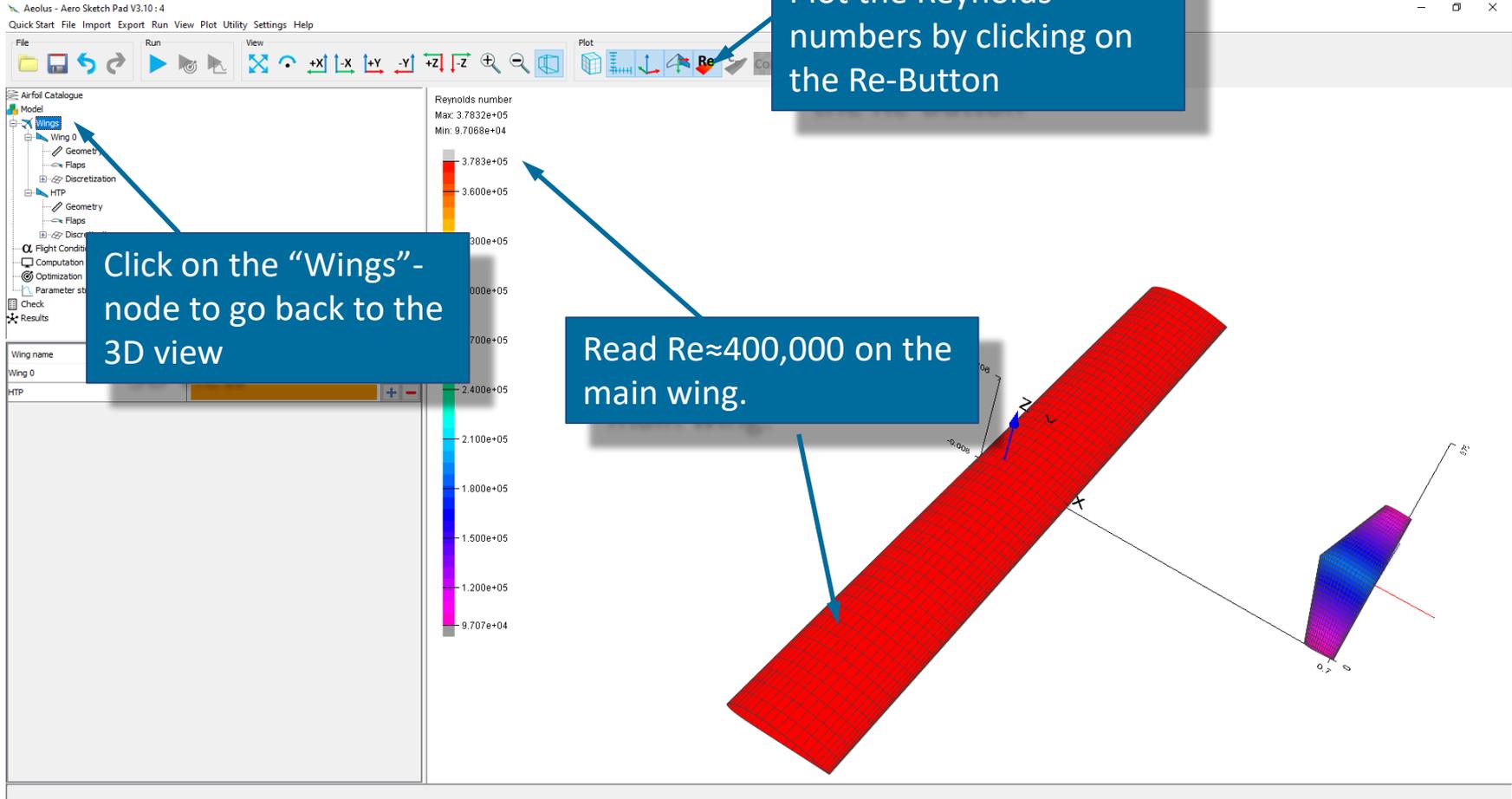
Viscous Drag		
Dynamic viscosity	1.792e-05	[Pa s]
Kinematic viscosity	1.483e-05	[m <sup>2</sup> /s]
Reynolds number min	1.038e+05	[-]
Reynolds number max	4.045e+05	[-]
Viscous drag coefficient (refers to wetted area)	<input type="text" value="0.005"/>	[-]

However, let us see how more reliable data can be found. Note, that  $C_{d,visc,wet}$  mainly depends on

- the Reynolds number ( $Re$ ) and
- the airfoil



# Initial Design





# Initial Design

Airfoil data sheets are available from various online sources, such as <http://airfoiltools.com>. Search for NACA4415 and click on “Airfoil details” (<http://airfoiltools.com/airfoil/details?airfoil=naca4415-il>).

**Airfoil database search**

Search the 1636 airfoils available in the databases filtering by name, thickness and camber. Click on an airfoil image to display a larger preview picture. There are links to the original airfoil source and dat file and the details page with polar diagrams for a range of Reynolds numbers.

Text search:  Optional

Maximum thickness(%)  Optional

Minimum thickness(%)  Optional

Maximum camber(%)  Optional. Symmetrical airfoils = 0

Minimum camber(%)  Optional

Group:  ▾

Sort:  ▾

**Investment Casting OEM - Manufacturers To Custom Made**

[▶ Investment Casting Manufacturers To Custom Made, Good Quality.](#)

[✕ Factory Price. tiangongjm.com](#)

(naca4415-il) NACA 4415

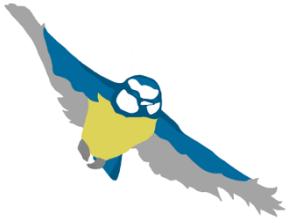
AirfoilTools.com

NACA 4415

NACA 4415 airfoil  
Max thickness 15% at 30.9% chord  
Max camber 4% at 40.2% chord  
Source [UIUC Airfoil Coordinates Database](#)

[Airfoil details](#)  
[Send to airfoil plotter](#)  
[Add to comparison](#)  
[Lednicer format dat file](#)  
[Selig format dat file](#)  
[Source dat file](#)

Page 1 of 1



# Initial Design

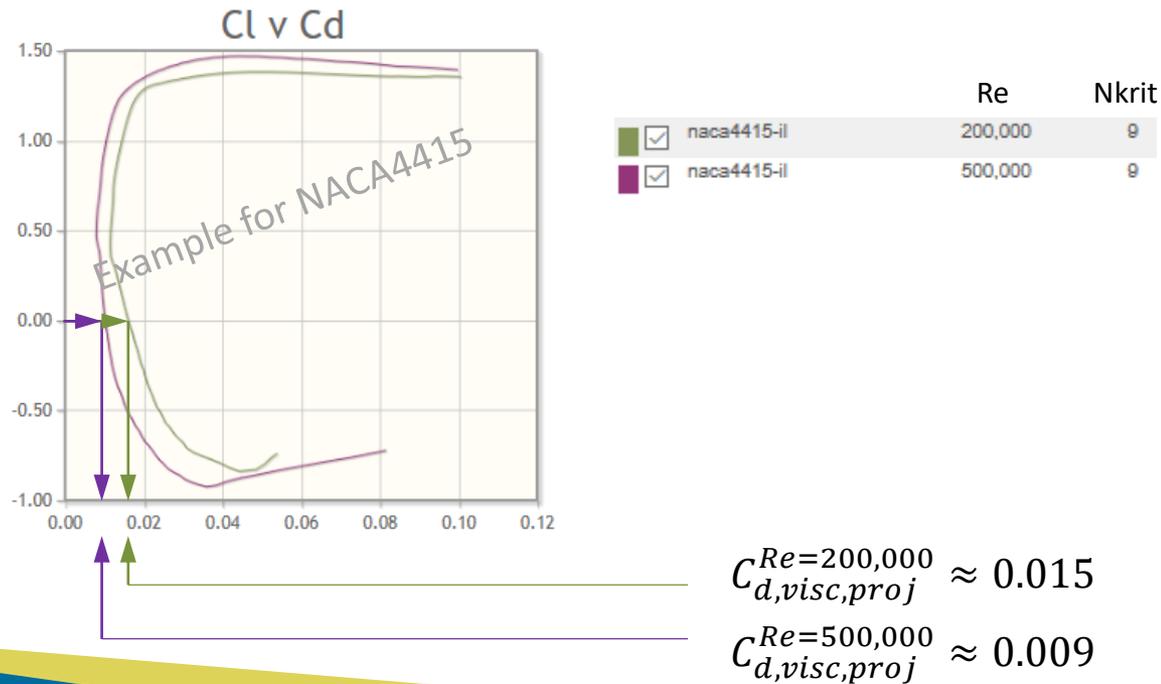
We are now looking for curves with  $Re = 400,000$  and  $N_{krit} \geq 9$  assuming a clean wing surface.

**Set Reynolds number and Ncrit range**

Reynolds Number: Low  High

Ncrit:

The required coefficient  $C_{d,visc,proj}$  can be approximated from the value of  $C_d$  at  $Cl=0$  as shown below:





# Initial Design

From the results

$$C_{d,visc,proj}^{Re=200,000} \approx 0.015$$

$$C_{d,visc,proj}^{Re=500,000} \approx 0.009$$

we can approximate a value for  $Re = 400,000$ , which is:

$$C_{d,visc,proj}^{Re=400,000} \approx 0.011$$

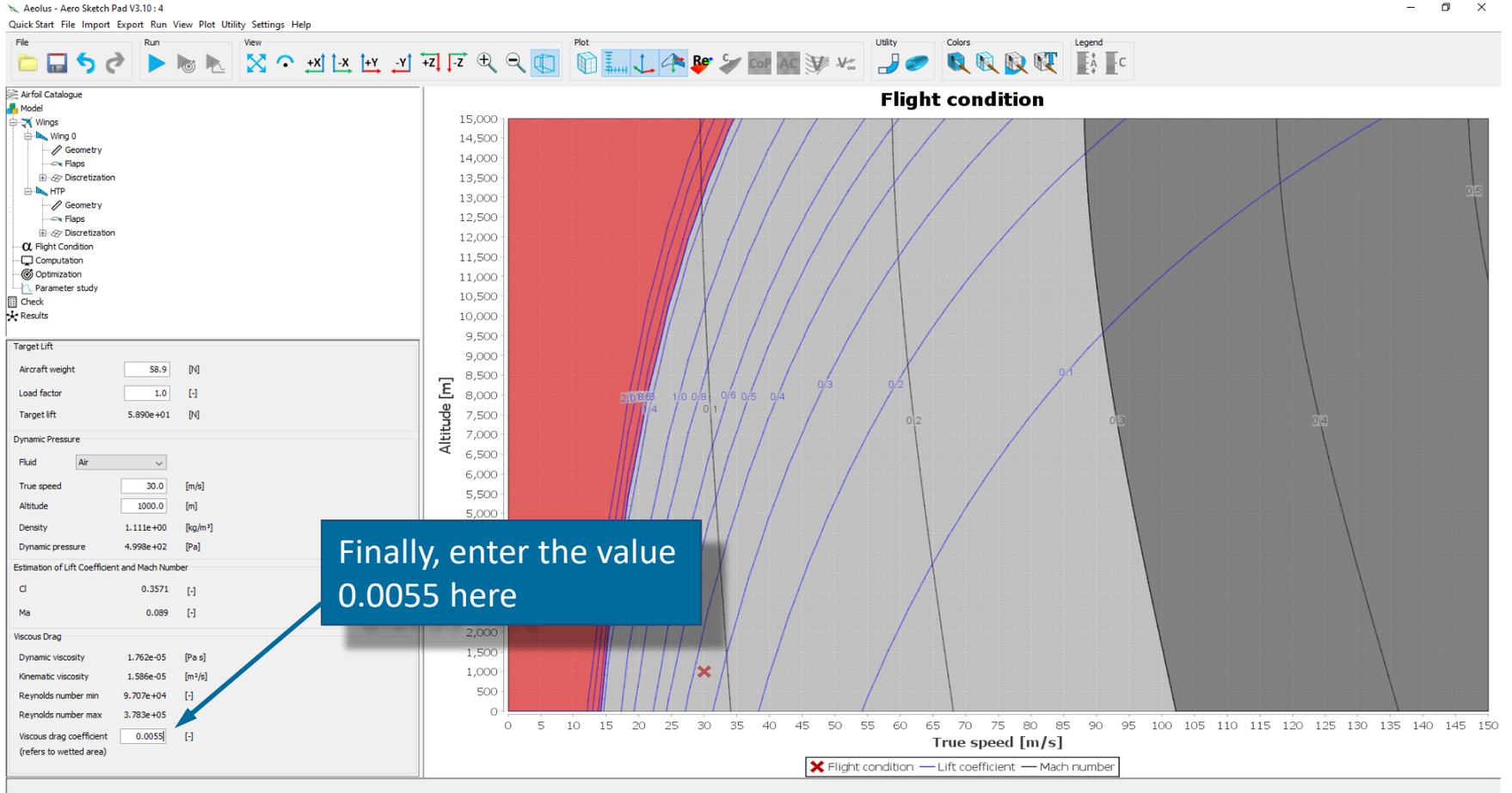
Note, that the index “proj” is added to differentiate the database values, which typically refer to the projected area, from the Aeolus ASP coefficient  $C_{d,visc,wet}$ , which must refer to the wetted area. The conversion from “projected” to “wetted” can easily be done:

$$C_{d,visc,wet} = C_{d,visc,proj}^{Re=400,000} \cdot \underbrace{\frac{S_{proj}}{S_{wet}}}_{\approx 0.5}$$

$$C_{d,visc,wet} = 0.0055$$

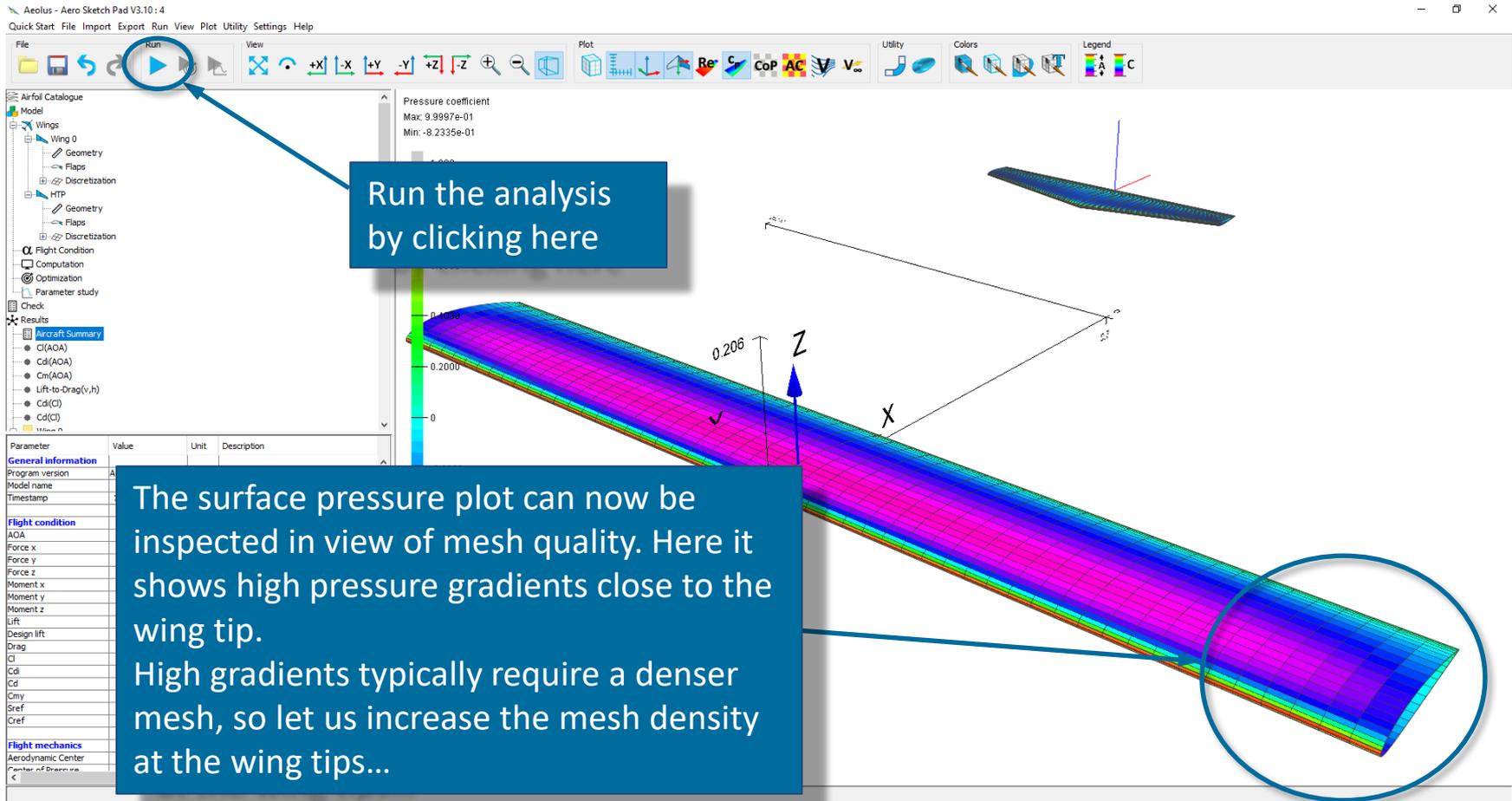


# Initial Design





# Initial Design





# Initial Design

aeolus - Aero Sketch Pad V3.10 : 4  
Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results  
Aircraft Summary  
Cl(AOA)  
Cd(AOA)  
Cm(AOA)  
Lift-to-Drag(v,h)  
Cd(Cl)  
Cd(Cl)

Pressure coefficient  
Max: 9.9997e-01  
Min: -8.2335e-01

1.0000  
0.8000  
0.6000  
0.4000  
0.2000  
0  
-0.2000  
-0.4000  
-0.6000  
-0.8233

Select the "Discretization" node of the main wing

Use this dropdown to define, how the strips are distributed on the wing. Select "Outboard" to increase the density at the tip.

Note, that the results will be removed whenever you change the model.

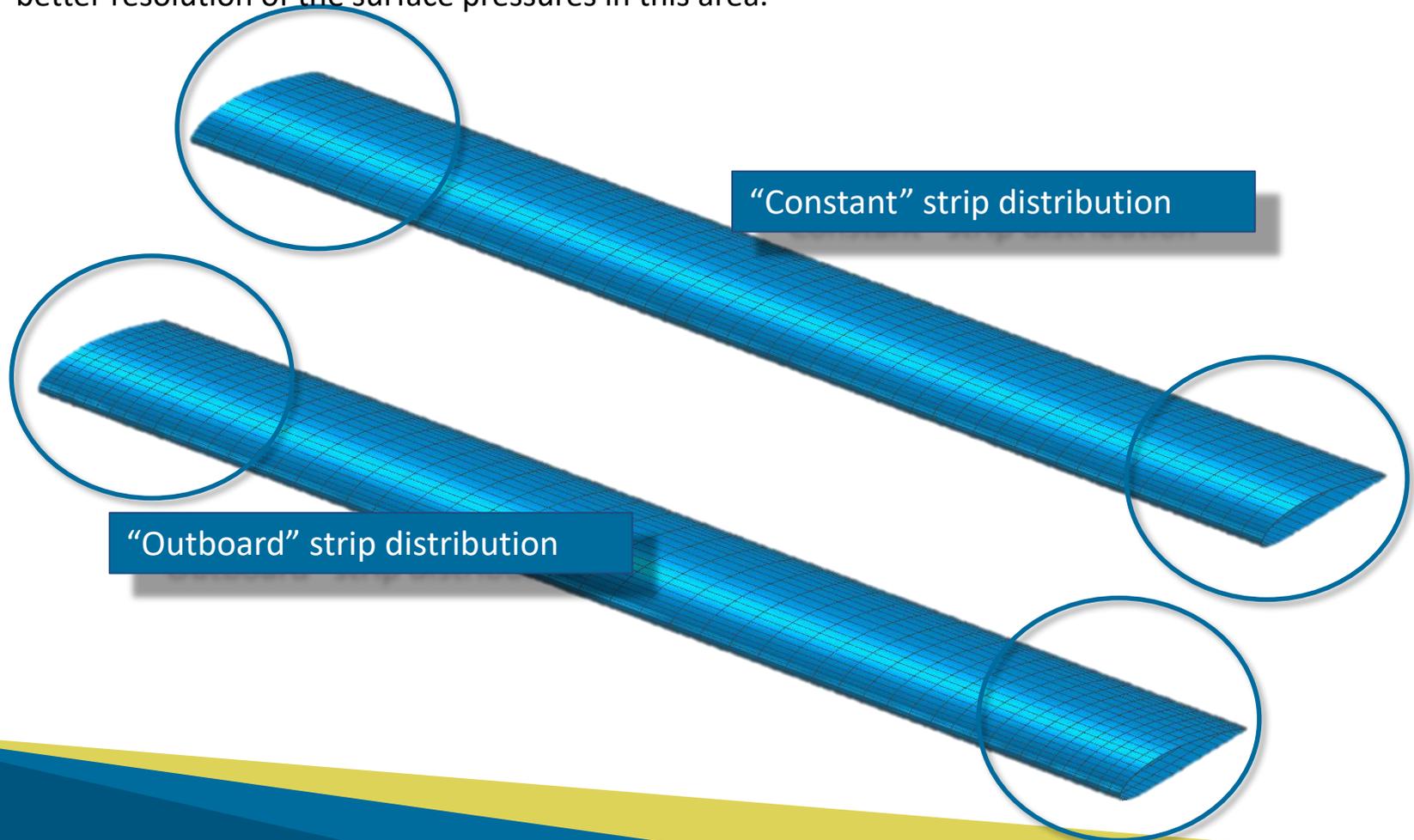
Number of panels per strip: 48  
Number of wing panels: 1248  
Number of strips: 26

Strip	Mean panel aspect ratio	Panel distribution
0	0.3	Constant
		Constant
		Inboard
		Outboard
		Both



# Initial Design

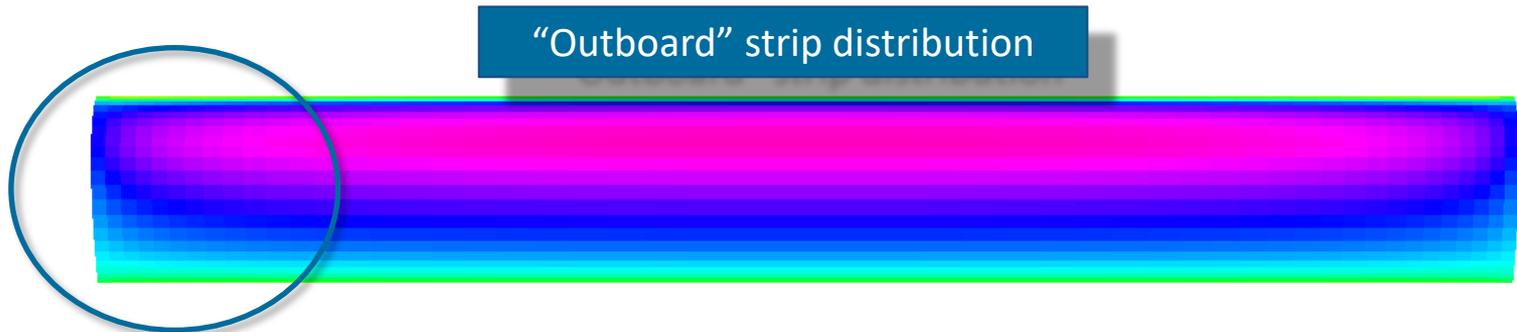
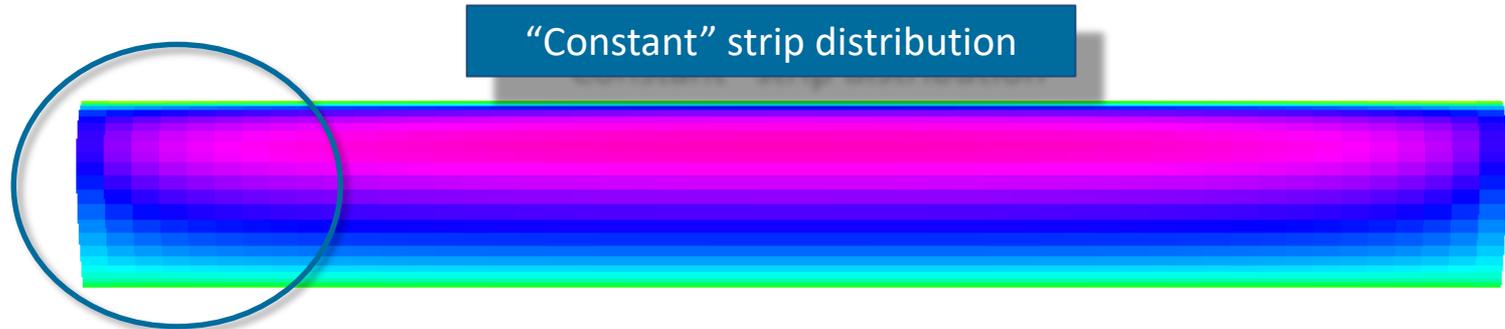
- The strip distribution option “Outboard” increases the panel density at the wing tip and enables a better resolution of the surface pressures in this area.

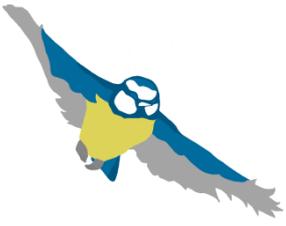




# Initial Design

- The strip distribution option “Outboard” increases the panel density at the wing tip and enables a better resolution of the surface pressures in this area.
- Note the improved resolution of the surface pressure





# Analysis of the Initial Design

aeolus - Aero Sketch Pad V3.10 : 5  
Quick Start File Import Export Run View Plot Utility Settings Help

File View Plot Utility Colors Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results

Position  
Origin (x,y,z) 0.0 0.0 0.0  
Reference chord 25.0 %

Characteristic parameters  
span 1.500e+00 m  
projected area 3.000e-01 m<sup>2</sup>  
wetted area 6.191e-01 m<sup>2</sup>  
mean aerodynamic chord 2.000e-01 m  
aspect ratio 7.500e+00

Settings  
Chord perpendicular to  span  y

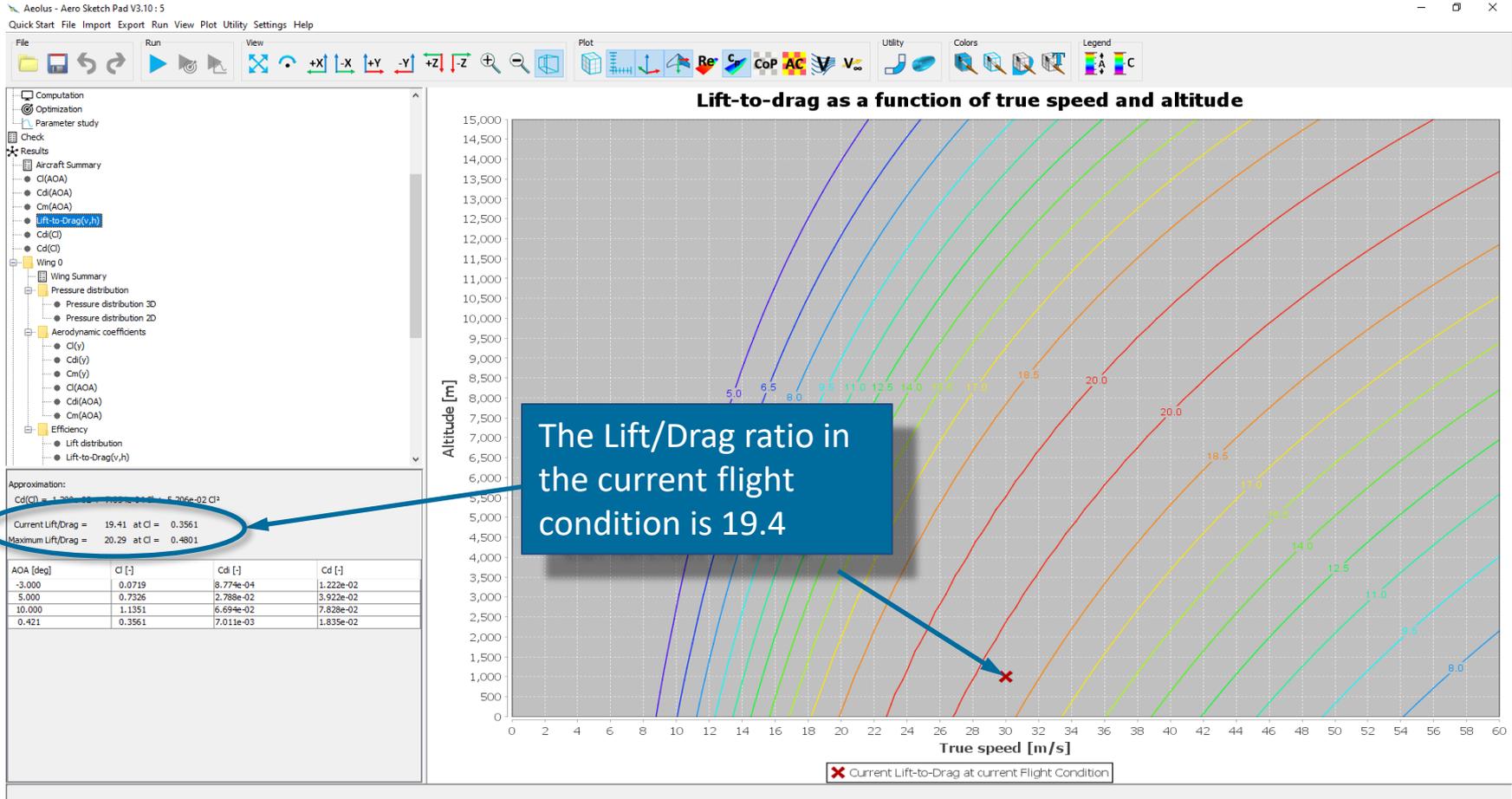
Wing sections

Se...	Airfoil	S-pos ...	Chord...	Twist ...	Swee...	Dihed...		
0	NACA4415	0.0	0.2	0.0	0.0	0.0	+	-
1	NACA4415	0.75	0.2	0.0			+	-

Run the analysis by clicking here

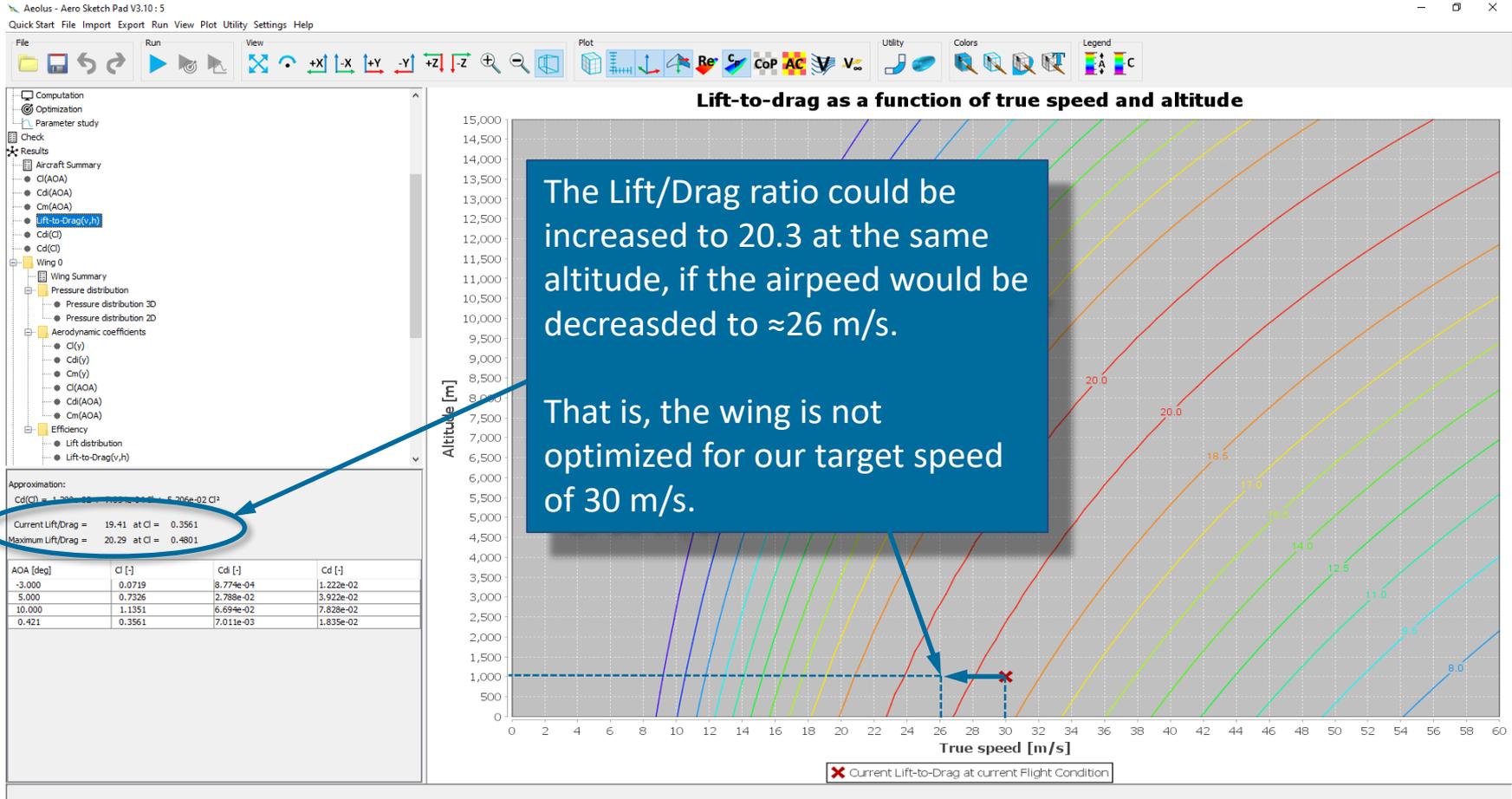


# Analysis of the Initial Design



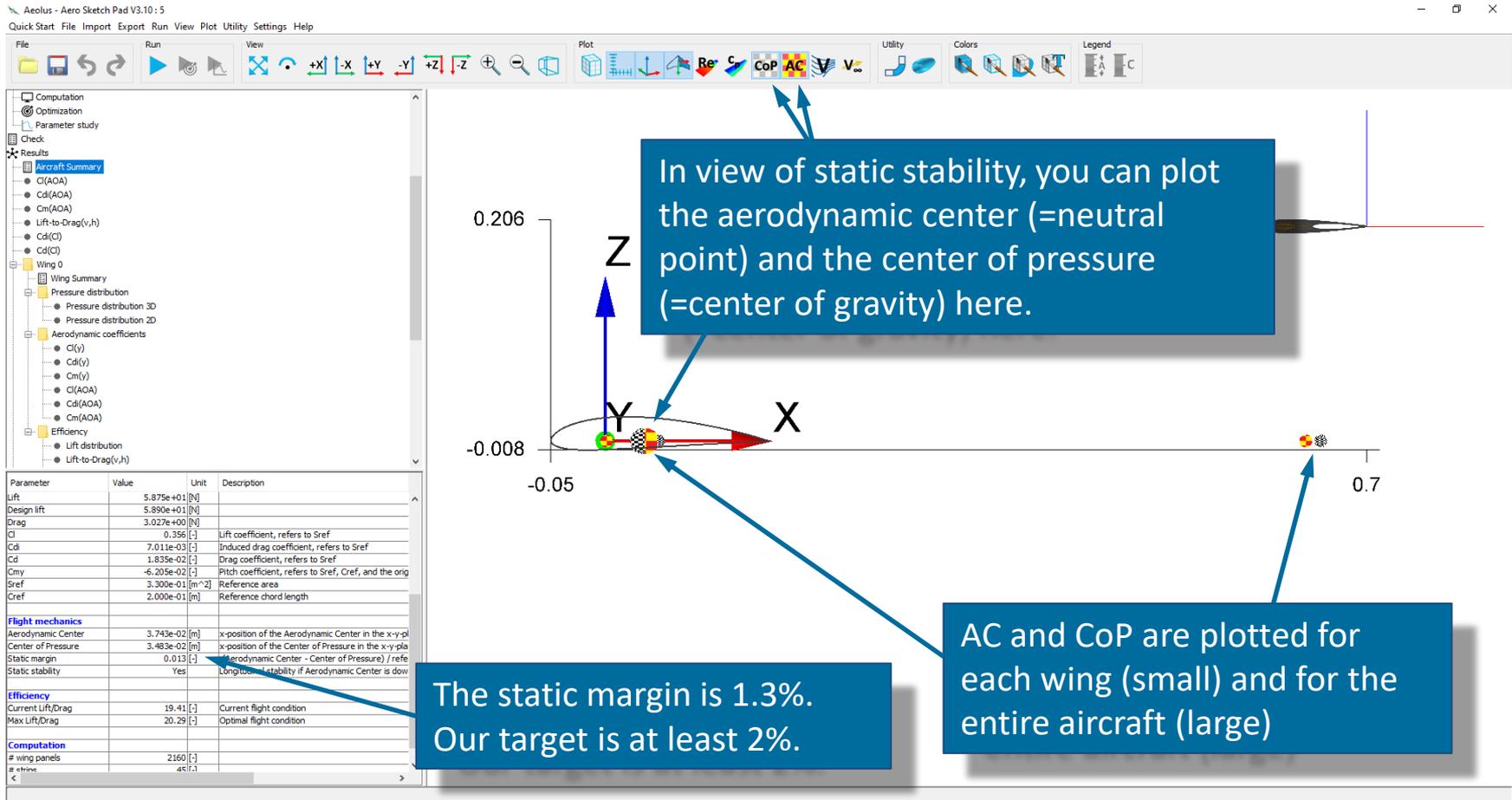


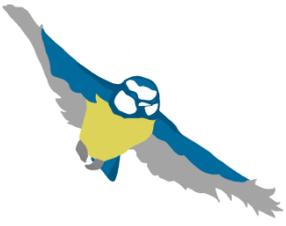
# Analysis of the Initial Design



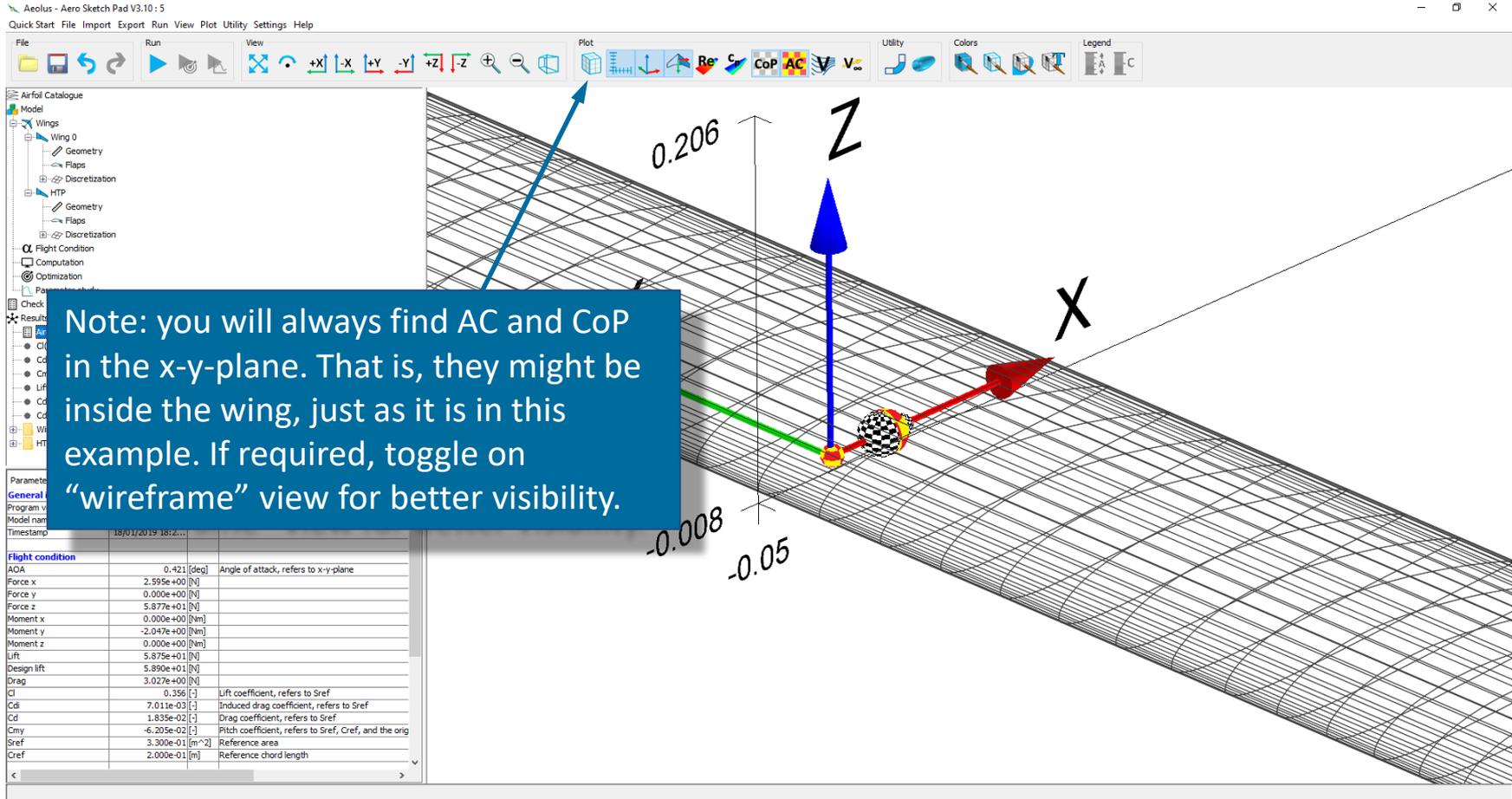


# Analysis of the Initial Design





# Analysis of the Initial Design





# Wing Shape Optimization

Finally, you can optimize the wing shape using the built-in optimization feature. All of the geometry parameters are accessible for optimization. To keep this example simple, only the following **design variables** shall be optimized:

- Root chord length
- Tip chord length
- Tip twist

According to the mission requirements, the UAV must be efficient and should fly as far as possible. Therefore, a good objective is to **maximize the Lift/Drag-ratio** which is a measure of efficiency.

# Wing Shape Optimization



Select the "Optimization"-Node

Enable the Optimization feature here

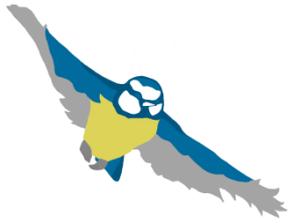
Select "Current lift to drag". It refers to the actual flight condition.

Here, you can find the model parameters, which can be optimized. Select the "Chord" pane from the main wing and check both sections "on", as shown.

Wings Flight condition Computation

i	Name	Value	Dihedral $\delta$ [deg]		Chord [m]		Discretization Twist $\theta$ [deg]	On/Off
			S-pos [m]	Chord [m]	Min	Max		
0		0.2	0.1	0.3			<input type="checkbox"/>	
1		0.2	0.1	0.3			<input checked="" type="checkbox"/>	

# Wing Shape Optimization



Aeolus - Aero Sketch Pad V3.10: 5  
Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results

Enable Optimization  
Optimizer  
Algorithm: BOBYQA  
Max evaluations: 1000  
Objective  
Objective function: Current lift to drag  
Goal type: Maximize  
Design Variables  
# Design Variables: 2  
Wings Flight condition Computation  
Wing 0 HTP

i	Name	Value	Chord [m]		On/Off
			Min	Max	
0		0.2	0.1	0.3	<input checked="" type="checkbox"/>
1		0.2	0.1	0.3	<input checked="" type="checkbox"/>

Constraints

The optimizer is allowed to change the selected design variables within a certain range. In this example, it is believed, that a feasible wing chord will be within 0.1m and 0.3m. Therefore, use  
Min = 0.1 m  
Max = 0.3 m  
for both sections.



# Wing Shape Optimization

Aeolus - Aero Sketch Pad V3.10 : 5  
Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results

Enable Optimization  
Optimizer  
Algorithm: BOBY  
Max evaluations: 1000  
Objective  
Objective function: Current lift to drag  
Goal type: Maximize  
Design Variables  
# Design Variables: 3  
Wings Flight condition Computation  
Wing 0 HTP  
Sweep  $\phi$  [deg] Dihedral  $\delta$  [deg] Flaps Discretization  
General S-pos [m] Chord [m] Twist  $\alpha$  [deg]  
i Name Value Min Max ON/OFF  
0 0.0 0.0 0.0  
1 0.0 -5.0 5.0

The twist parameters can be accessed through the "Twist"-pane. Make sure you are on the Main wing.

Select only the tip section and give it a min value of  $-5^\circ$  and a max value of  $+5^\circ$ .

For convenience, the selected section is also highlighted in the 3d view.



# Wing Shape Optimization

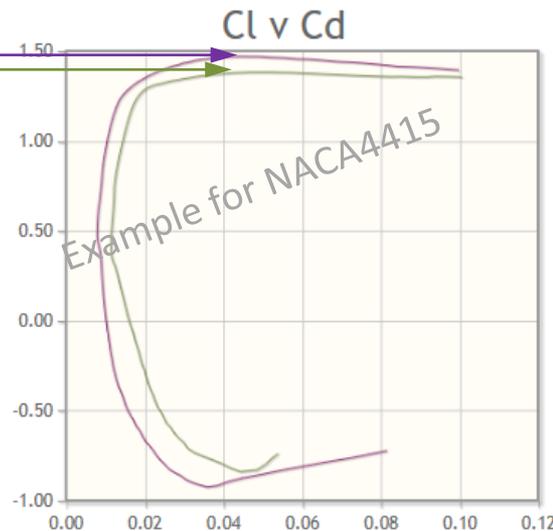
The last step is the definition of constraints. Depending on the optimization problem, constraints can be required to avoid any unfeasible results.

It is good practice to start a first optimization without any constraints. You can then inspect the result and decide which constraints are required. In our example, the optimization will result in a very small wing area and hence high local lift coefficients.

Note, that a typical airfoil stalls at approximately  $c_{l,max} \approx 1.3$ . Again, more specific data can be found from the drag polar, as shown in the example below:

$$c_{l,max}^{Re=500000} \approx 1.45$$

$$c_{l,max}^{Re=200000} \approx 1.35$$



	Re	Nkrit
<input checked="" type="checkbox"/> naca4415-il	200,000	9
<input checked="" type="checkbox"/> naca4415-il	500,000	9



# Wing Shape Optimization

To be conservative, we assume

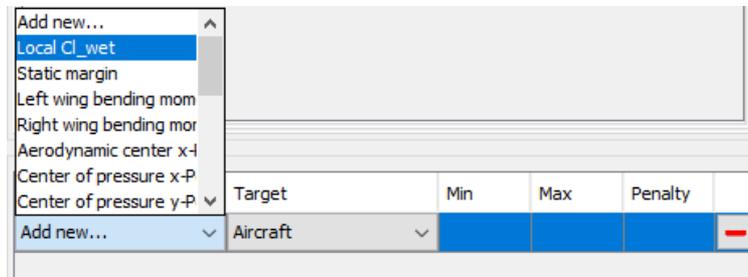
$$c_{l,max} = 1.2$$

as the maximum lift coefficient, which the airfoil can provide before stall onset.

In view of the mission, the UAV should be able to perform a maneuver with a max load factor  $n_{max} = 2$ , for example a turn at  $60^\circ$  bank angle. That is, that the allowed lift coefficient in cruise is

$$c_{l,max,allowed}^{cruise} = \frac{c_{l,max}}{n_{max}} = 0.6$$

You can add this constraint to the optimization through the drop-down list item „Local CL\_wet“.





# Wing Shape Optimization

Constraints					
Type	Target	Min	Max	Penalty	
Local Cl_wet	Wing 0		0.3	4.0	[-]
Add new...	Aircraft				[-]

The coefficient's index „wet“ indicates a reference to the wetted wing area. Again, the conversion can simply be done knowing that  $\frac{S_{proj}}{S_{wet}} \approx 0.5$ .

$$\begin{aligned} \text{Local Cl\_wet}^{\max} &= c_{l,max,allowed}^{cruise} \cdot \frac{S_{proj}}{S_{wet}} \\ &= 0.3 \end{aligned}$$

The penalty value is set automatically and typically does not need to be changed.



# Wing Shape Optimization

Software interface for wing shape optimization, showing the model, design variables, and constraints.

**Objective function:** Current lift to drag  
**Goal type:** Maximize

**Design Variables:** 3

**Wings:** Flight condition, Computation

**Wing 0 | HTP:**

General	Sweep $\alpha$ [deg]	Dihedral $\delta$ [deg]		Flaps		Discretization	
		S-pos [m]	Chord [m]	Min	Max	Twist $\alpha$ [deg]	On/Off
0	Origin x [m]	0.0	0.0	0.0	0.0		<input type="checkbox"/>
1	Origin y [m]	0.0	0.0	0.0	0.0		<input type="checkbox"/>
2	Origin z [m]	0.0	0.0	0.0	0.0		<input type="checkbox"/>
3	Reference chord [m]	0.25	0.25	0.25	0.25		<input type="checkbox"/>

**Constraints:**

Type	Target	Min	Max	Penalty
Local $C_{l_{wet}}$	Wing 0		0.3	4.0
Add new...	Aircraft			

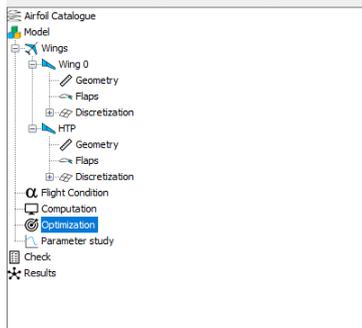
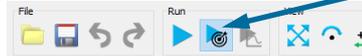
**Add the constraint on the local lift coefficient as shown.**



# Wing Shape Optimization

Aeolus - Aero Sketch Pad V3.10: 5

Quick Start File Import Export Run View Plot Utility Settings Help



Enable Optimization

Optimizer

Algorithm: BOBYQA

Max evaluations: 1000

Objective

Objective function: Current lift to drag

Goal type: Maximize

Design Variables

# Design Variables: 3

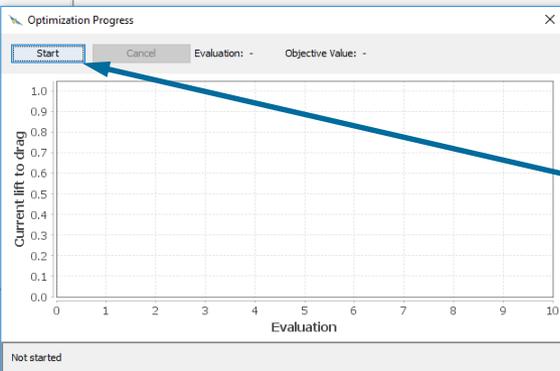
Wings | Flight condition | Computation

Wing 0 | HTP

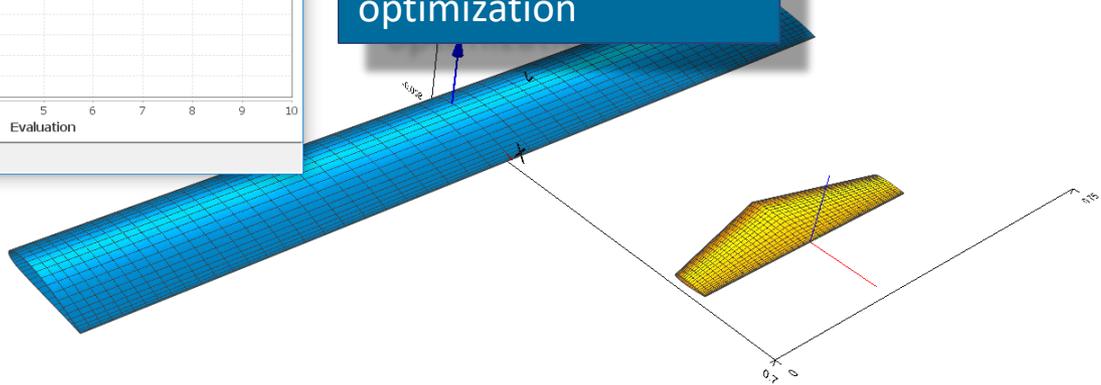
i	Name	Dihedral $\delta$ [deg]		Flaps		Discretization	
		S-pos [m]	Chord [m]	Min	Max	Twist $\alpha$ [deg]	On/Off
0	Origin x [m]	0.0	0.0	0.0	0.0		<input type="checkbox"/>
1	Origin y [m]	0.0	0.0	0.0	0.0		<input type="checkbox"/>
2	Origin z [m]	0.0	0.0	0.0	0.0		<input type="checkbox"/>
3	Reference chord [-]	0.25	0.25	0.25	0.25		<input type="checkbox"/>

Constraints

Launch the optimization progress panel...



...and start the optimization





# Wing Shape Optimization

Optimization Progress

Restart Cancel Evaluation: 37 Objective Value: 24.40760

Parameter	Value	Unit
<b>General information</b>		
Program version	Aeolus - Aero Ske...	
Model name	5	
Timestamp	18/01/2019 21:3...	
<b>Flight condition</b>		
AOA	1.709	[deg]
Force x	6.549e-01	[N]
Force y	0.000e+00	[N]
Force z	5.885e+01	[N]
Moment x	0.000e+00	[Nm]
Moment y	-1.473e+00	[Nm]
Moment z	0.000e+00	[Nm]
Lift	5.880e+01	[N]
Design lift	5.890e+01	[N]
Drag	2.410e+00	[N]
Cl	0.501	[-]
Cd	9.180e-03	[-]
Cd	2.052e-02	[-]
Cmy	-8.967e-02	[-]
Sref	2.349e-01	[m^2]
Cref	1.399e-01	[m]
<b>Flight mechanics</b>		
Aerodynamic Center	5.042e-02	[m]
Center of Pressure	2.502e-02	[m]
Static margin	0.182	[-]
Static stability	Yes	
<b>Efficiency</b>		
Current Lift/Dras	24.40	[-]

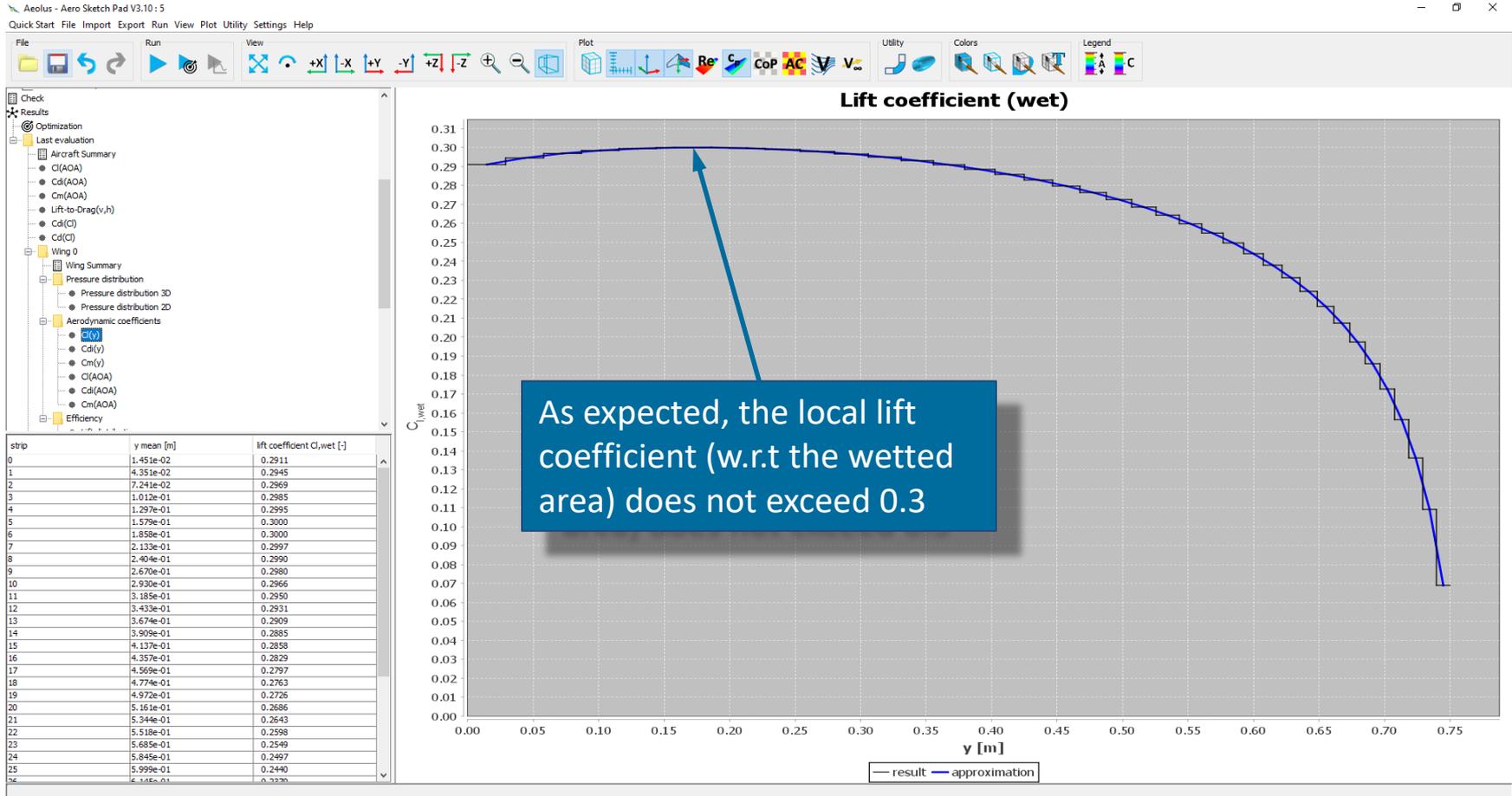
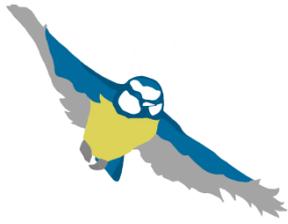
Completed

Pressure coefficient

The shape optimization has increased the Lift/Drag by 20%

Note: the convergence may be different with each run. If the result has not converged you can restart through the "Restart"-button.

# Wing Shape Optimization

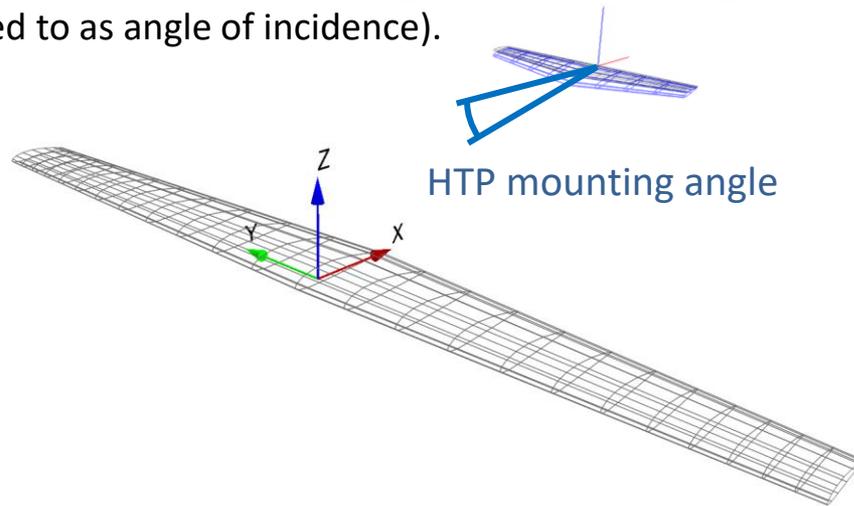




# Static Stability

In this section the static longitudinal stability of the aircraft will be tuned. A common measure for longitudinal stability is the static margin, which is defined as the distance between the center of gravity and the aerodynamic center (neutral point) of the aircraft, expressed as a percentage of the mean aerodynamic chord of the wing.

A typical value is 2%, which is also the target value for this UAV. It can be achieved by modifying the mounting angle of the HTP. The task for the designer is to find the right value for this mounting angle (sometimes also referred to as angle of incidence).



In this example, the use of the „Parameter Study“-feature will be demonstrated for this purpose. The objective is to plot the static margin for a certain range of HTP mounting angles.



# Static Stability

Aeolus - Aero Sketch Pad V3.10 : 6  
 Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Wing 0  
 Geometry  
 Flaps  
 Discretization  
 HTP  
 Geometry  
 Flaps  
 Discretization  
 Flight Condition  
 Computation  
 Optimization  
 Parameter study  
 Check  
 Results  
 Aircraft Summary  
 C<sub>L</sub>(AOA)  
 C<sub>d</sub>(AOA)  
 C<sub>m</sub>(AOA)

Pressure coefficient  
 Max: 9.9348e-01  
 Min: -9.9168e-01

0.993  
 0.800  
 0.600  
 0.400  
 0.200  
 0  
 -0.200  
 -0.400  
 -0.600  
 -0.800  
 -0.9917

Currently, all HTP sections have zero twist. That is, the mounting angle is zero.

The static margin is 13.4%. Note, that this value maybe slightly different in your model. It depends on the convergence of the previous optimization

Z  
 X  
 Y  
 0.7

Parameter	Value	Unit	Description
<b>General information</b>			
Program version	Aeolus - Aero Ske...		
Model name	6		
Timestamp	23/01/2019 09:5...		
<b>Flight condition</b>			
AOA	2.253	[deg]	Angle of attack, refers to x-y-plane
Force x	9.713e-02	[N]	
Force y	0.000e+00	[N]	
Force z	5.887e+01	[N]	
Moment x	0.000e+00	[Nm]	
Moment y	-1.795e+00	[Nm]	
Moment z	0.000e+00	[Nm]	
Lift	5.882e+01	[N]	
Design lift	5.890e+01	[N]	
Drag	2.411e+00	[N]	
C <sub>L</sub>	0.496	[-]	Lift coefficient, refers to Sref
C <sub>d</sub>	9.008e-03	[-]	Induced drag coefficient, refers to Sref
C <sub>d</sub>	2.034e-02	[-]	Drag coefficient, refers to Sref
C <sub>m<sub>y</sub></sub>	-1.064e-01	[-]	Pitch coefficient, refers to Sref, Cref, and Sref
Sref	2.371e-01	[m <sup>2</sup> ]	Reference area
Cref	1.416e-01	[m]	Reference chord length
<b>Flight mechanics</b>			
Aerodynamic Center	-4.926e-02	[m]	x-position of the Aerodynamic Center in the x-y-plane
Center of Pressure	3.033e-02	[m]	x-position of the Center of Pressure in the x-y-plane
Static margin	0.134	[-]	(Aerodynamic Center - Center of Pressure) / Reference chord length
Static stability	Yes		Longitudinal stability if Aerodynamic Center is behind Center of Pressure
<b>Efficiency</b>			
Current Lift/Drag	24.39	[-]	Current flight condition
Max Lift/Drag	24.58	[-]	Optimal flight condition



Aeolus - Aero Sketch Pad V3.10 : 6

QuickStart File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Pressure coefficient  
Max: 9.9348e-01  
Min: -9.9168e-01

0.9935  
0.4000  
0.2000  
0  
-0.6000  
-0.8000  
-0.9917

0.206  
Z  
-0.007  
0.7

**Enable the parameter study**

**Select "Static margin"**

Enable parameter study  
Objective: Static margin  
# Steps: 20

Design Variables  
# Design Variables: 0

Wings Flight condition Computation  
Wing 0 HTP

i	Sweep $\alpha$ [deg]		Dihedral $\delta$ [deg]		Flaps		Discretization	
	General	S-pos [m]	Chord [m]	Twist $\alpha$ [deg]	Min	Max	On/Off	
0	Origin x [m]	0.0	0.0	0.0	0.0	0.0	<input type="checkbox"/>	
1	Origin y [m]	0.0	0.0	0.0	0.0	0.0	<input type="checkbox"/>	
2	Origin z [m]	0.0	0.0	0.0	0.0	0.0	<input type="checkbox"/>	
3	Reference chord [-]	0.25	0.25	0.25			<input type="checkbox"/>	



AEOLUS - Aero Sketch Pad V3.10 : 6  
Quick Start File Import Export Run View Plot Utility Settings Help

File Run View Plot Utility Colors Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter Study  
Check  
Results  
Aircraft Summary  
C<sub>L</sub>(AOA)  
C<sub>d</sub>(AOA)  
C<sub>m</sub>(AOA)  
Lift-to-Drag(v,h)  
C<sub>d</sub>(C)

Pressure coefficient  
Max: 9.9348e-01  
Min: -9.9168e-01

0.206  
Z  
0.7

You can reduce the initial number of steps to 10

Select the "HTP" tab and then the "Twist" tab.

Check both sections "On" and set the  
Min value 0 (deg)  
Max value 3 (deg)

Enable parameter study  
Objective: Static margin  
# Steps: 10  
Design Variables: 2  
Wings: Flight condition, Computation  
Wing 0: HTP

i	Sweep $\phi$ [deg]		Dihedral $\delta$ [deg]		Flaps		Discretization	
	Name	Value	Min	Max	Chord [m]	Twist $\alpha$ [deg]	On/Off	On/Off
0		0.0	0.0	3.0			<input type="checkbox"/>	<input type="checkbox"/>
1		0.0	0.0	3.0			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>



Windows title bar: Aeolus - Aero Sketch Pad V3.10 : 6  
Menu bar: Quick Start File Import Export Run View Plot Utility Settings Help

Toolbar: File, Run, View, Plot, Utility, Colors, Legend

Airfoil Catalogue  
Model  
Wings  
Wing 0  
Geometry  
Flaps  
Discretization  
HTP  
Geometry  
Flaps  
Discretization  
Flight Condition  
Computation  
Optimization  
Parameter study  
Check  
Results

Enable parameter study  
 Enable parameter study  
Objective: Static margin  
# Steps: 10  
Design Variables  
# Design Variables: 2  
Wings Flight condition Computation  
Wing 0 HTP

i	Sweep $\phi$ [deg]		Dihedral $\delta$ [deg]		Flaps		Discretization	
	General	S-pos [m]	Value	Min	Chord [m]	Max	Twist $\alpha$ [deg]	On/Off
0	Name	0.0	0.0	3.0				<input checked="" type="checkbox"/>
1		0.0	0.0	3.0				<input checked="" type="checkbox"/>

Parameter Study dialog: Start, Cancel, Evaluation: 5, Objective Value: 0.02382

Static margin

Design value

Started

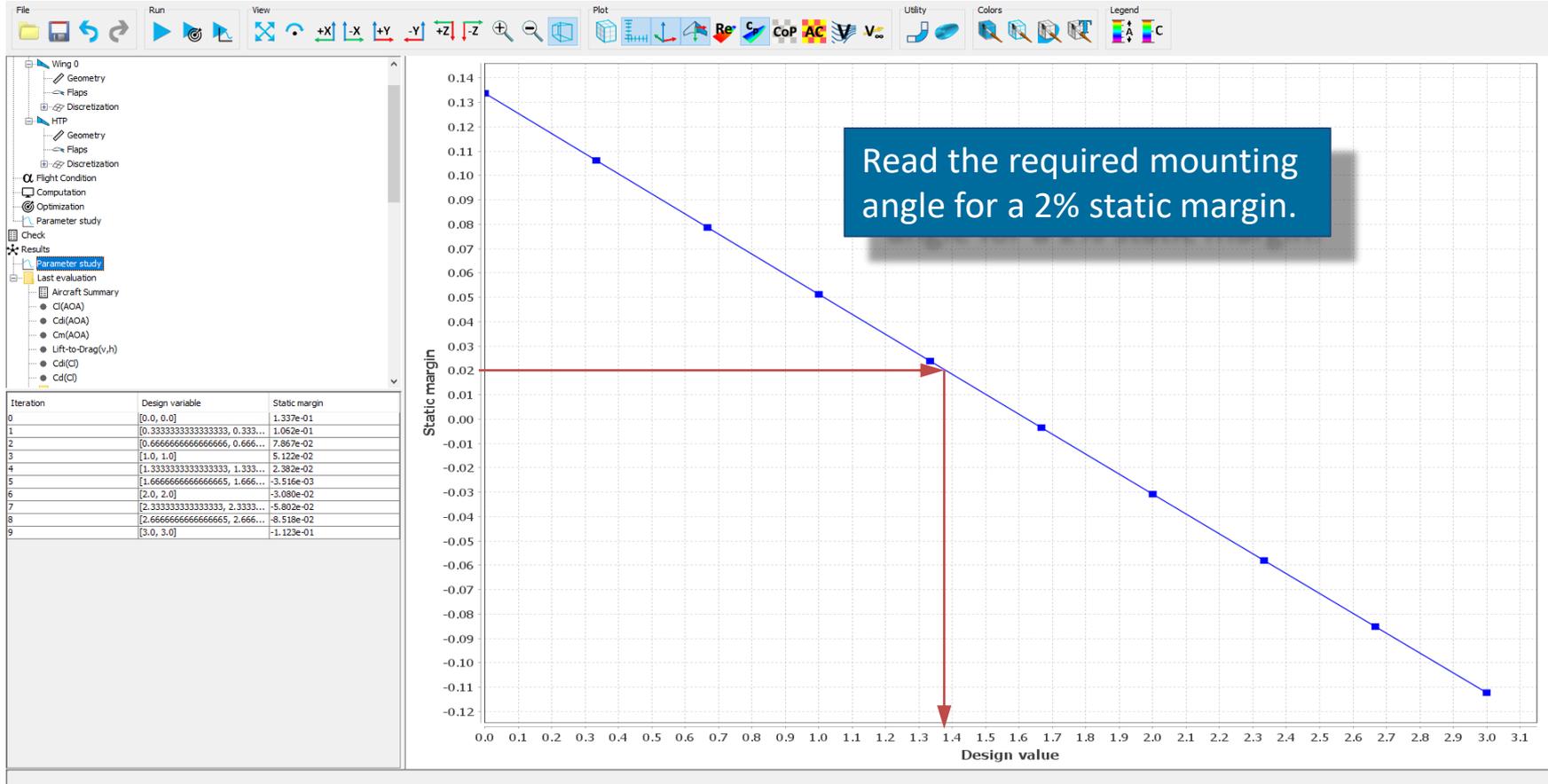
Launch the Parameter Study dialog and click "Start"

Aeolus ASP is now analysing the model at the different twist angles and plots the resulting static margin



Aeolus - Aero Sketch Pad V3.10 : 6

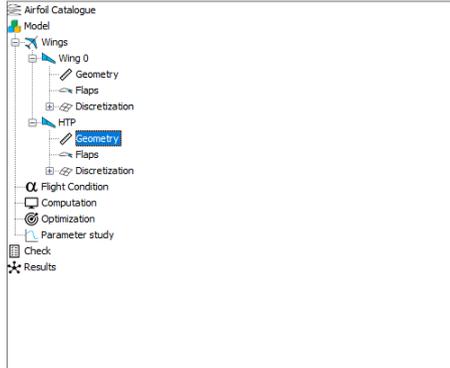
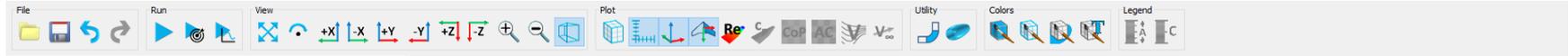
Quick Start File Import Export Run View Plot Utility Settings Help





Aeolus - Aero Sketch Pad V3.10 : 6

QuickStart File Import Export Run View Plot Utility Settings Help



Position

Origin (x,y,z)

Reference chord  %

Characteristic parameters

span 4.000e-01 m  
projected area 2.999e-02 m<sup>2</sup>  
wetted area 6.123e-02 m<sup>2</sup>  
mean aerodynamic chord 7.775e-02 m  
aspect ratio 5.335e+00

Settings

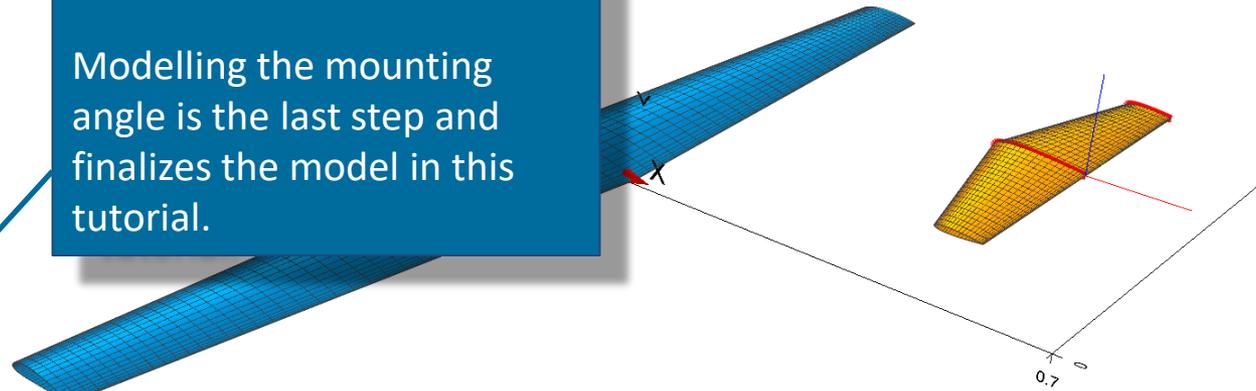
Chord perpendicular to  span  y

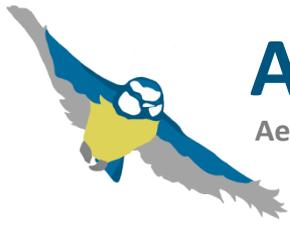
Wing sections

Se...	Airfoil	S-pos ...	Chord...	Twist...	Swive...	Dihed...		
0	NACA0012	0.0	0.1	1.3	0.0	0.0	+	-
1	NACA0012	0.2	0.05	1.3			+	-

To be conservative, a mounting angle of  $1.3^\circ$  is selected.

Modelling the mounting angle is the last step and finalizes the model in this tutorial.





# Aeolus

Aero Sketch Pad

## Thank you

Dipl.-Ing. Uwe Schuster

January 2019

[www.aeolus-aero.com](http://www.aeolus-aero.com)