Aeolus

Aero Sketch Pad

Tutorial

# UAV Design Example

Aeolus ASP 3.11

January 2019

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

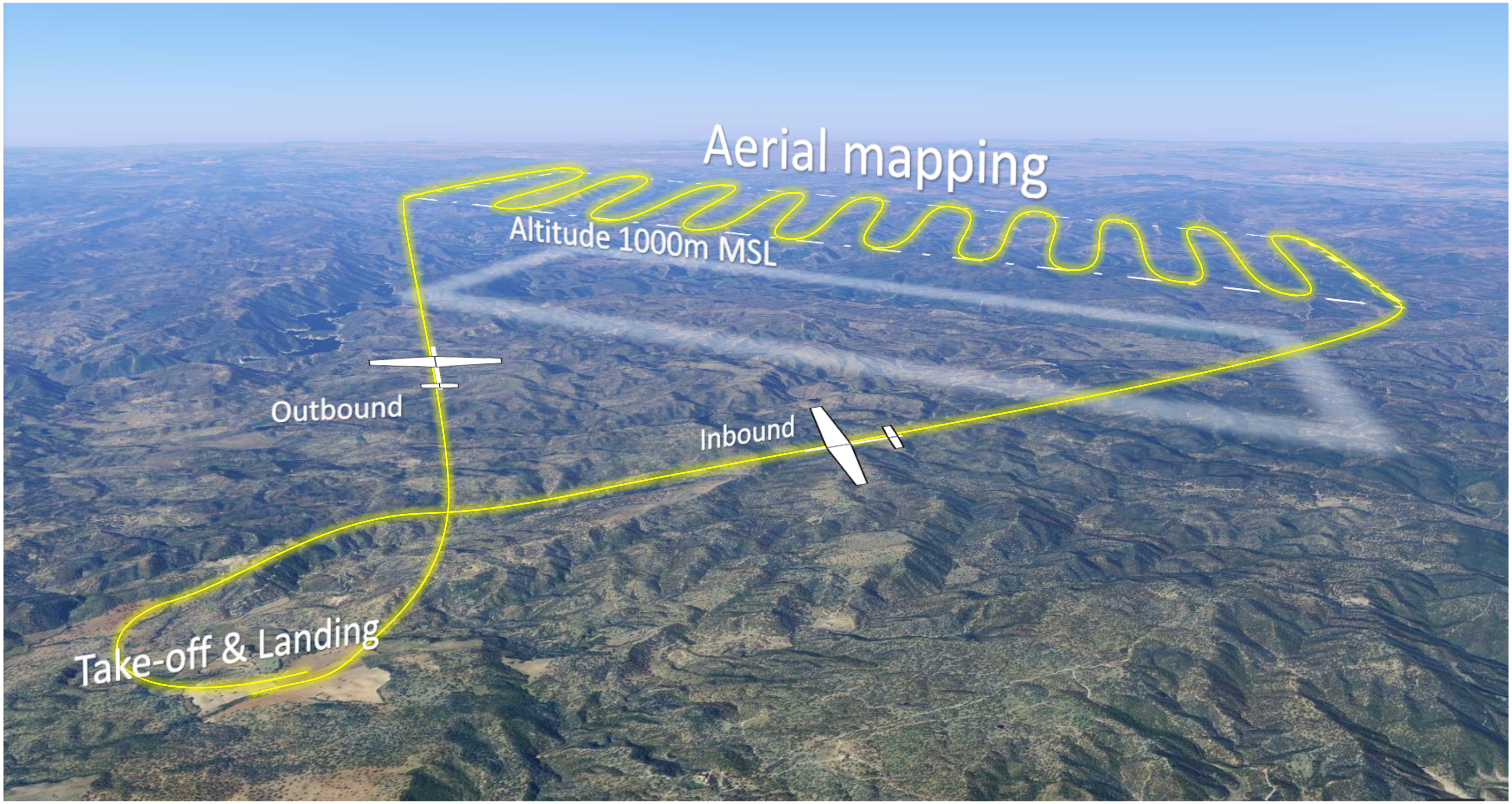
Mission

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

Flight mechanics

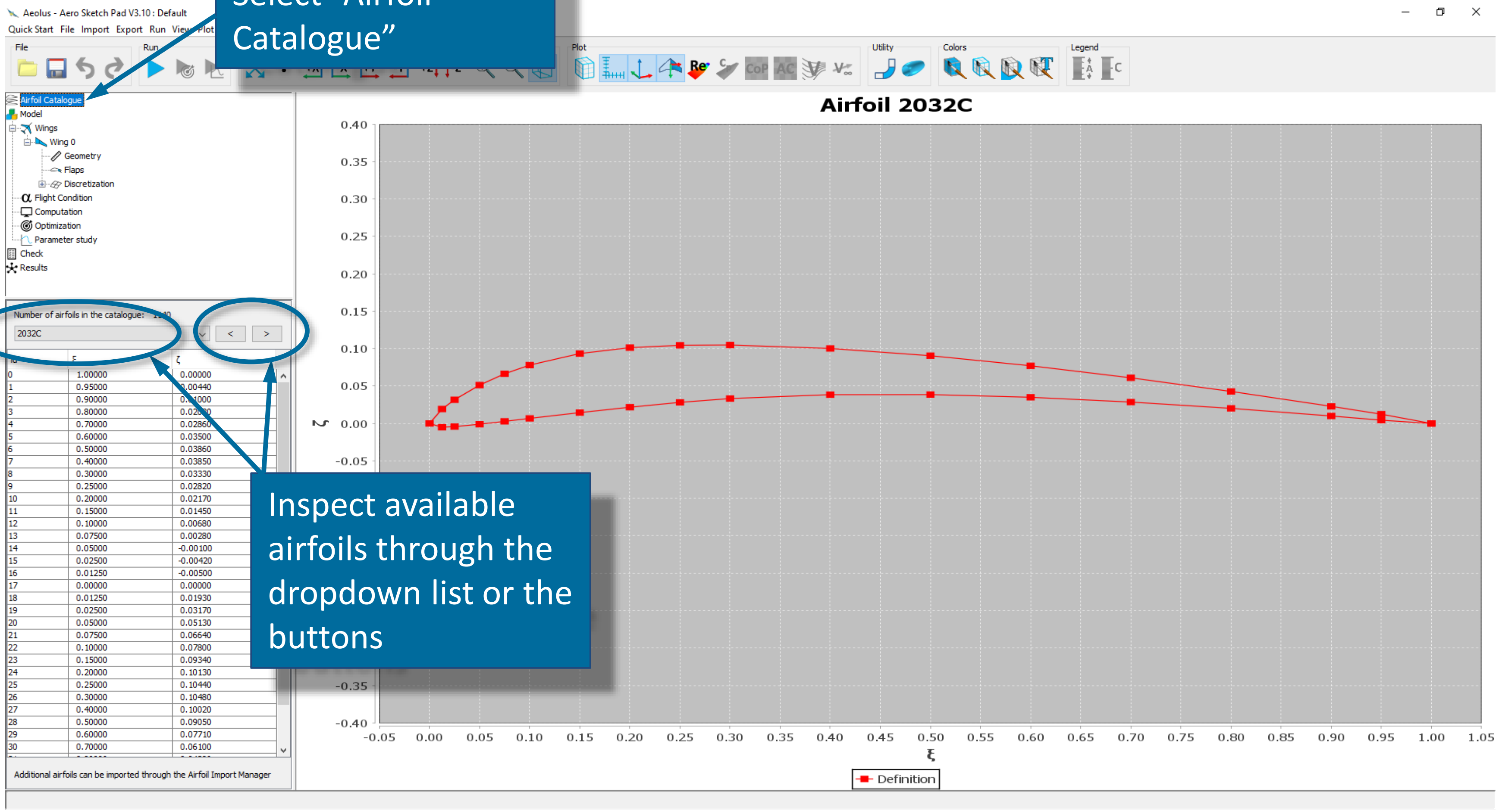
- Static longitudinal stability margin 2% - 4%

# Product Requirements



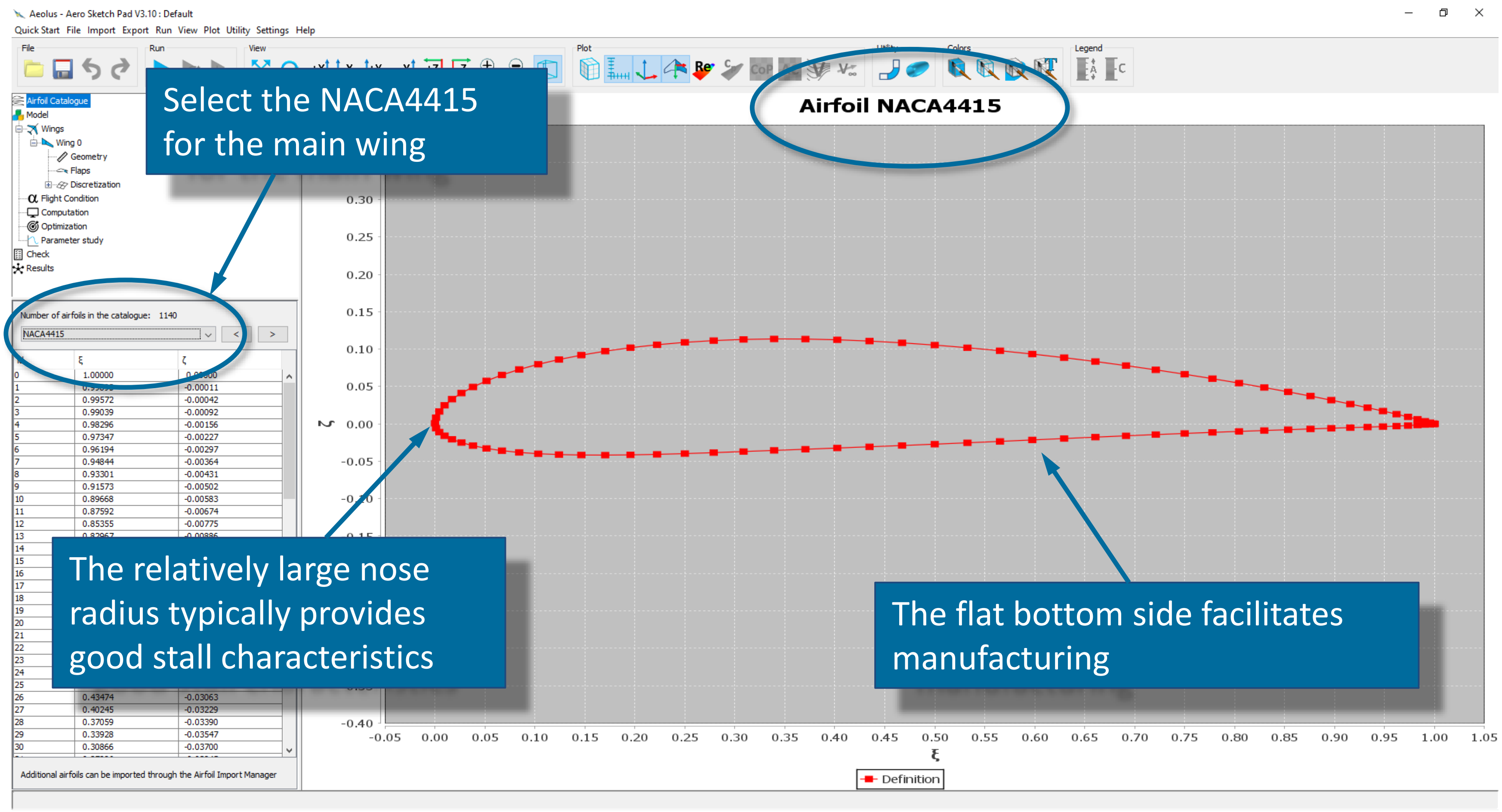
# Initial Design

Select “Airfoil Catalogue”




Inspect available airfoils through the dropdown list or the buttons

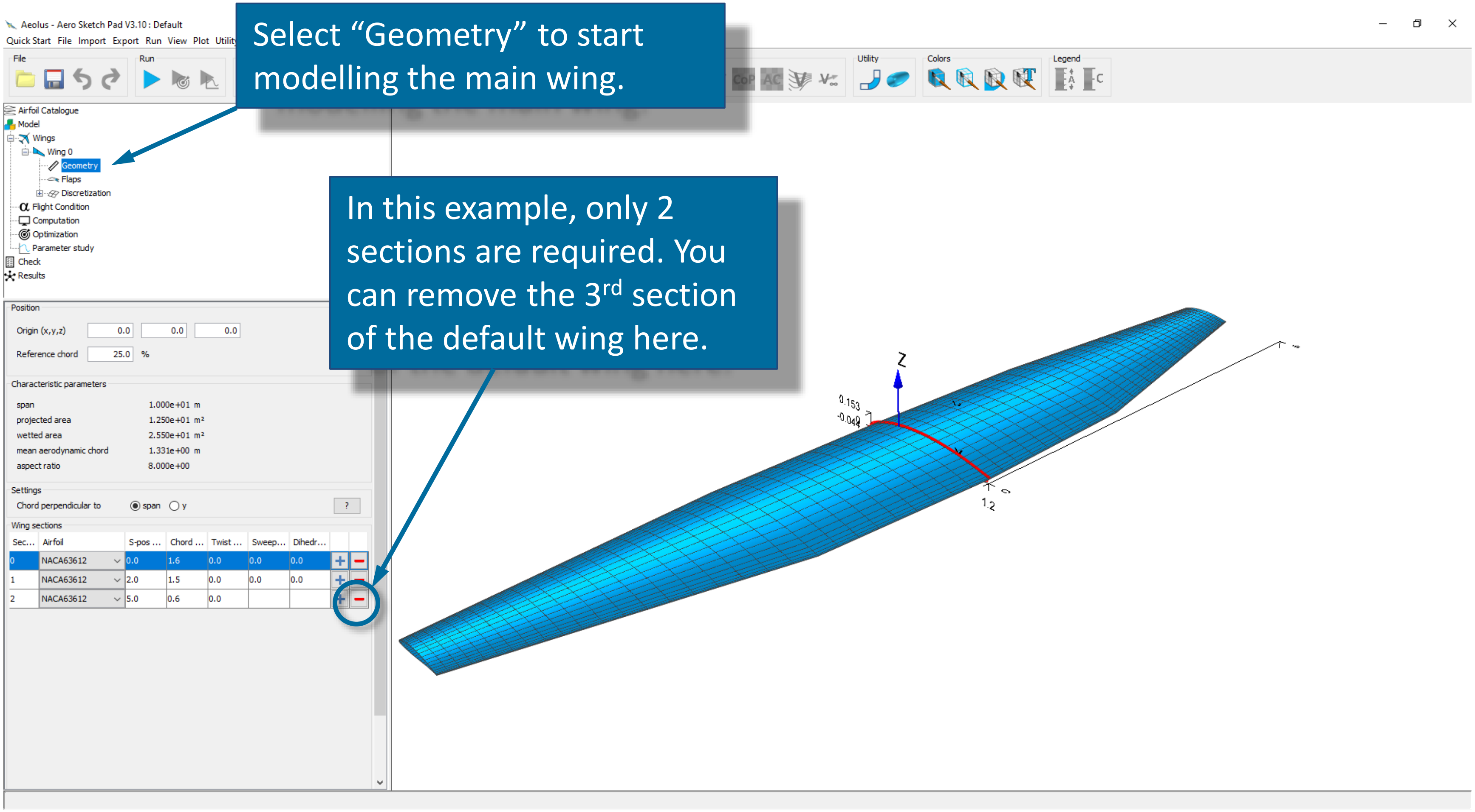
# Initial Design



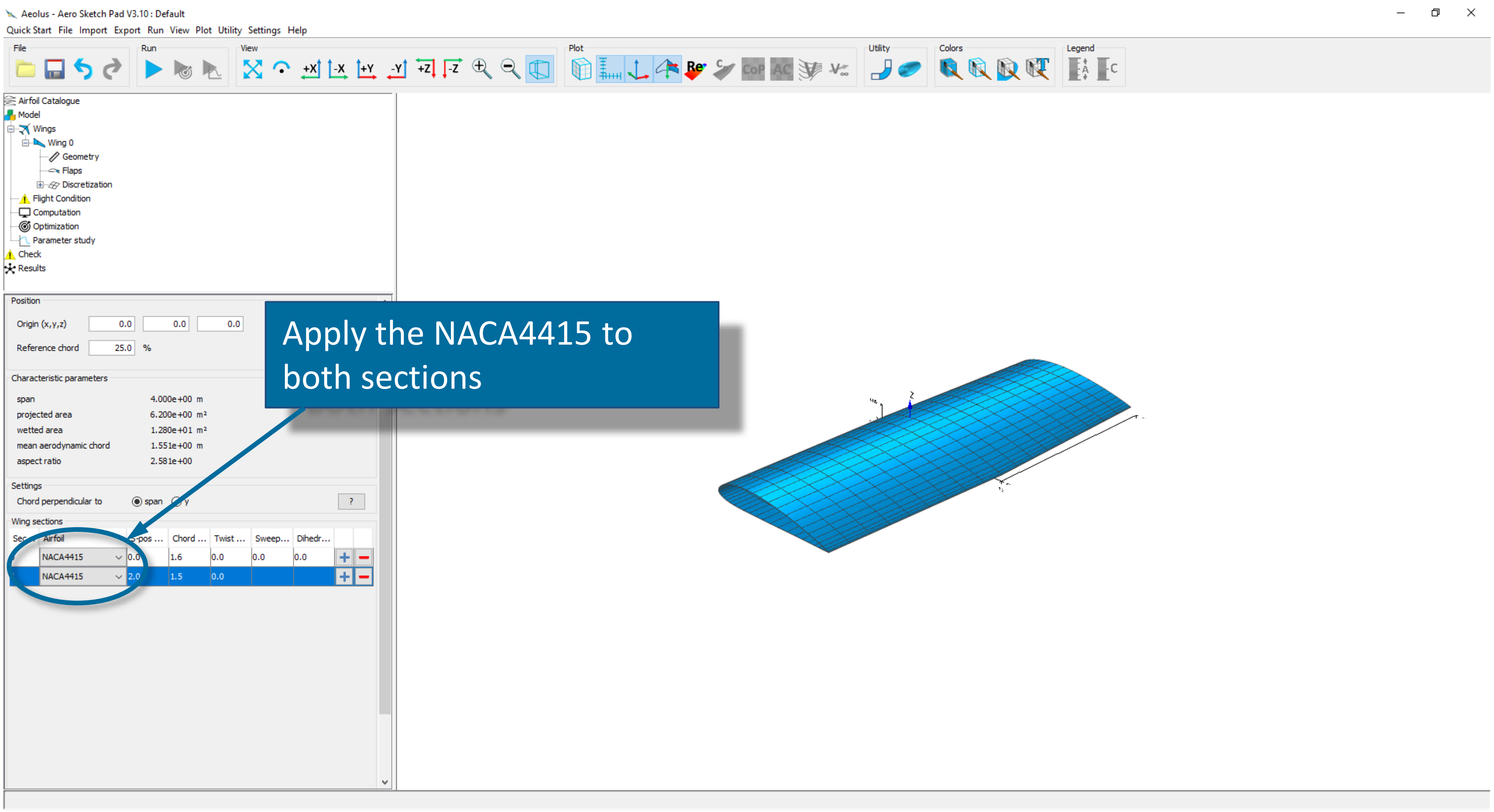
# Initial Design

Select “Geometry” to start modelling the main wing.

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

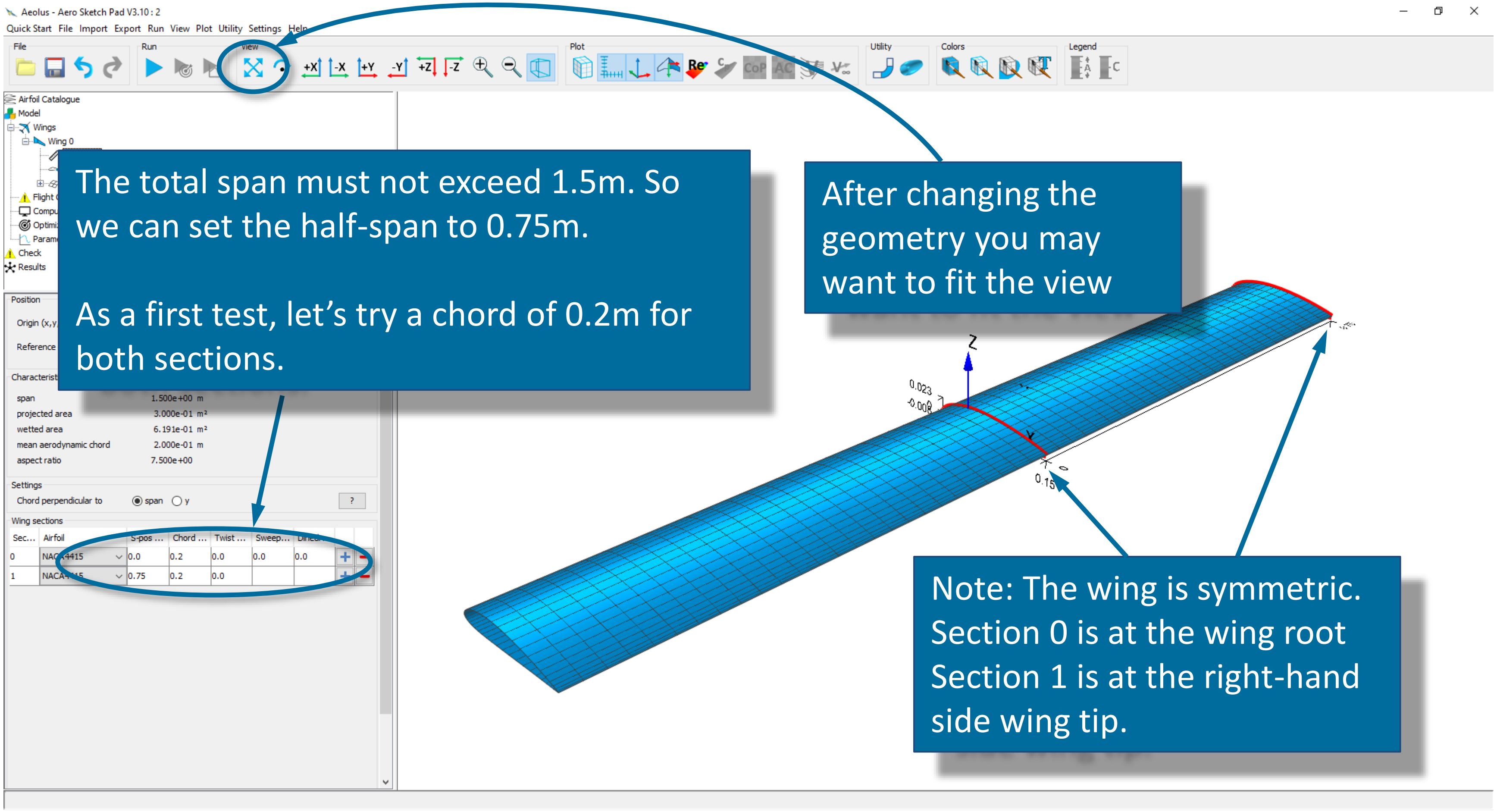


# Initial Design




Apply the NACA4415 to both sections

# Initial Design




The total span must not exceed 1.5m. So we can set the half-span to 0.75m.

As a first test, let's try a chord of 0.2m for both sections.

After changing the geometry you may want to fit the view

Note: The wing is symmetric. Section 0 is at the wing root Section 1 is at the right-hand side wing tip.

# 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.

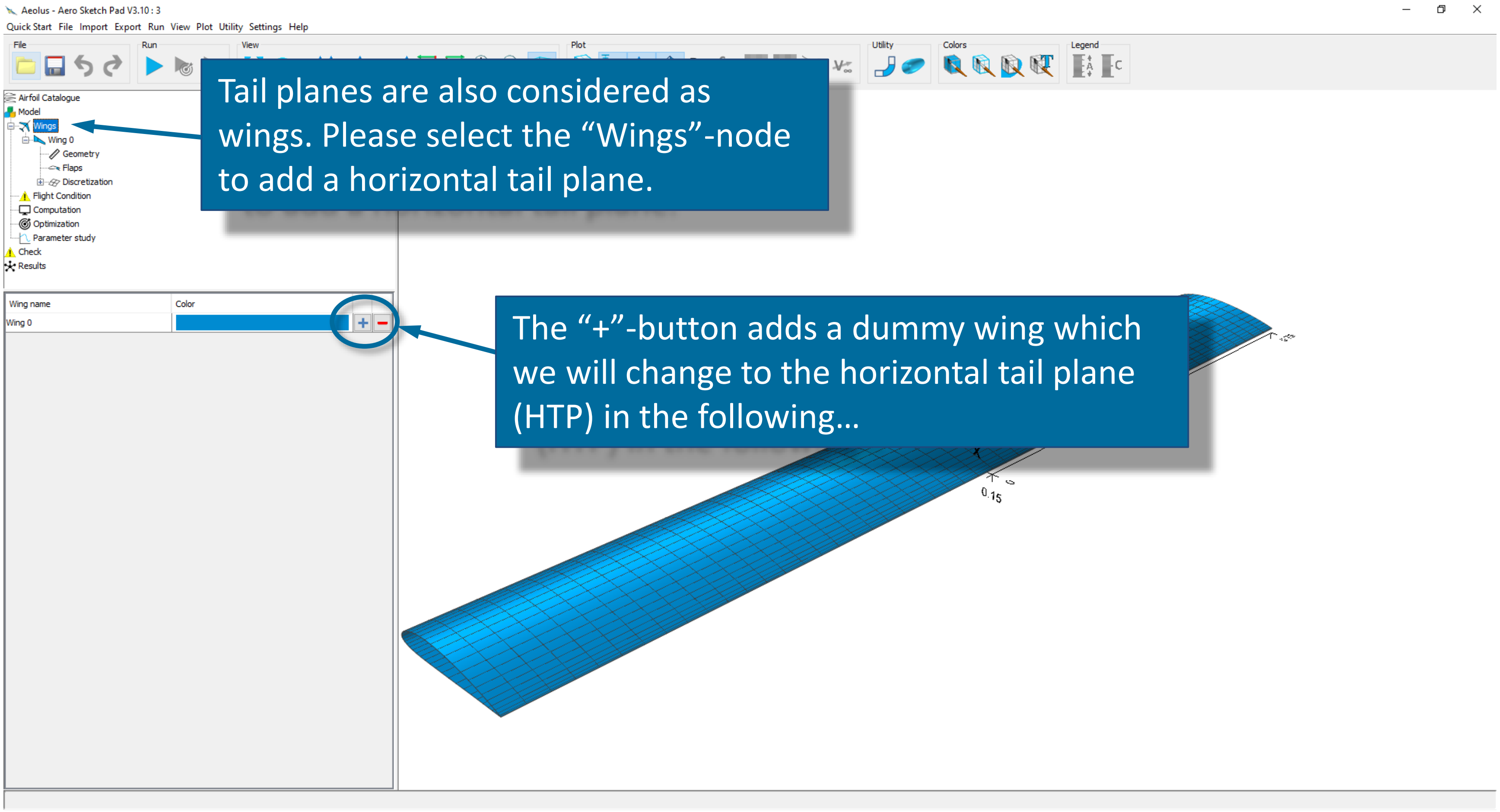
Y: Use y= 0 for a symmetric aircraft

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.

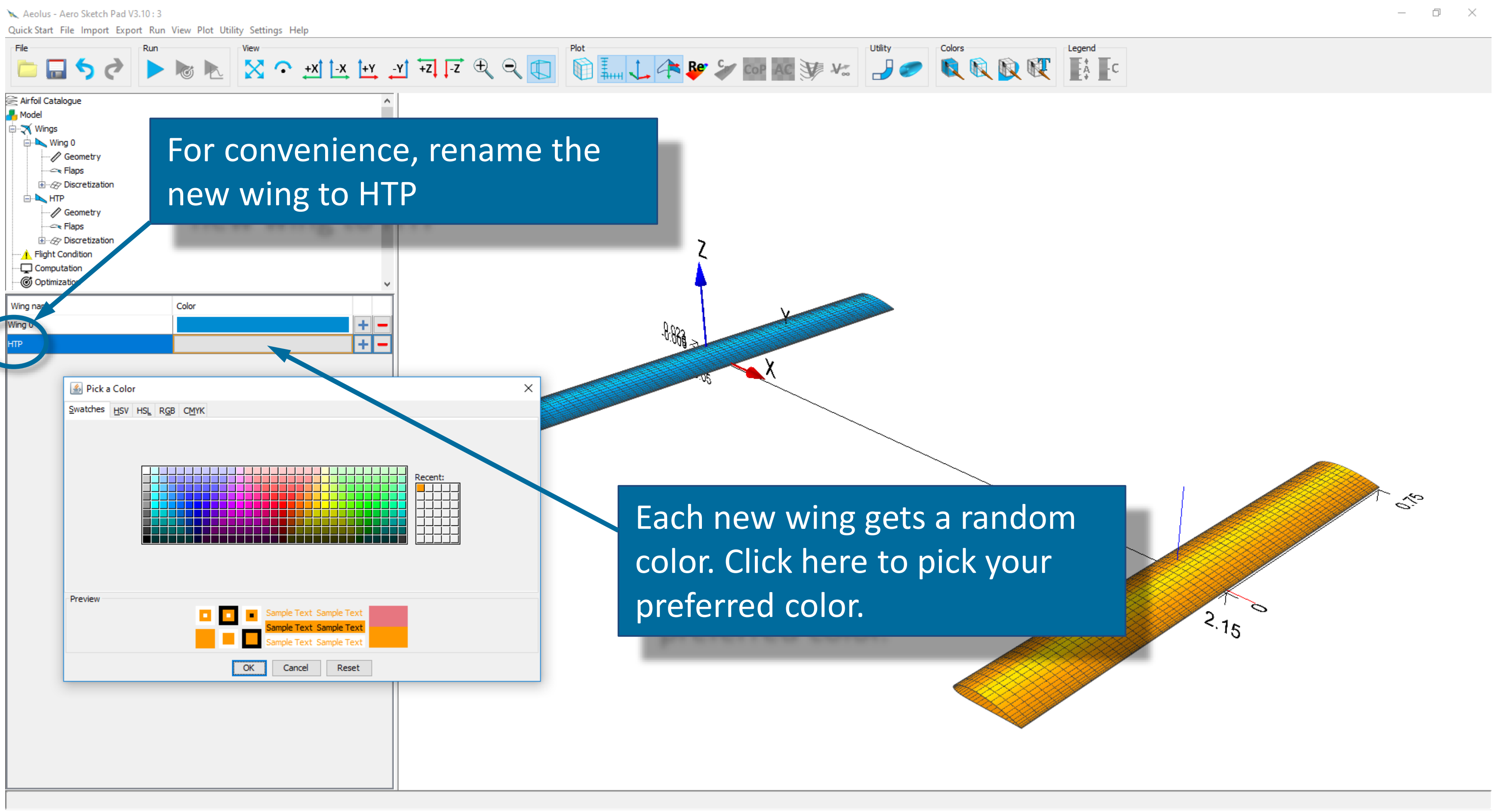
**Surface and aspect ratio:** As a rule of thumb, assume 10% of the main wing. That is ≈ 0.03 $m^2$. In view of the aircraft stall characteristics, the HTP must stall later than the main wing. Therefore, the aspect ratio should be smaller than the aspect ratio of the main wing.

**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



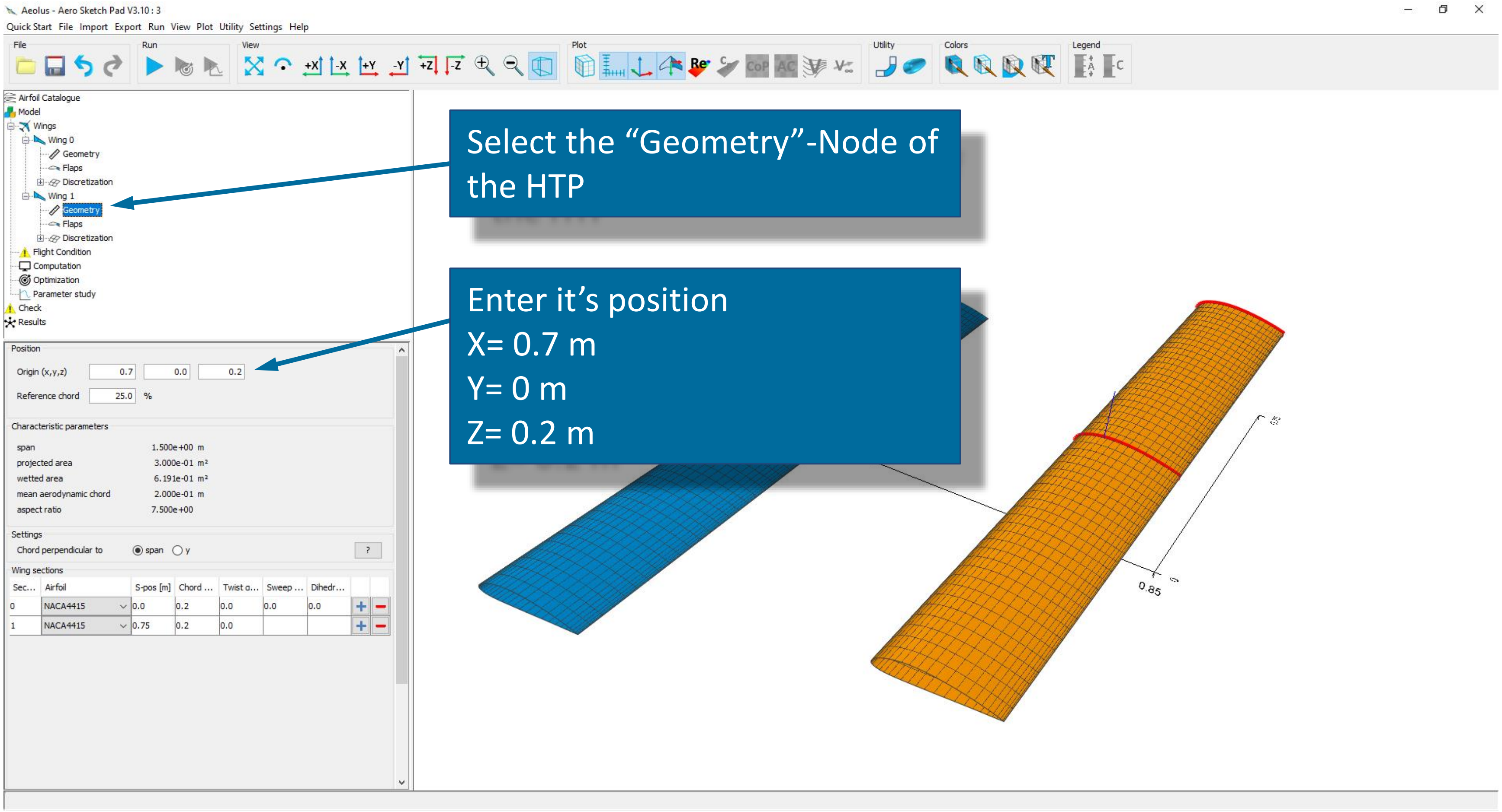
# Initial Design




For convenience, rename the new wing to HTP

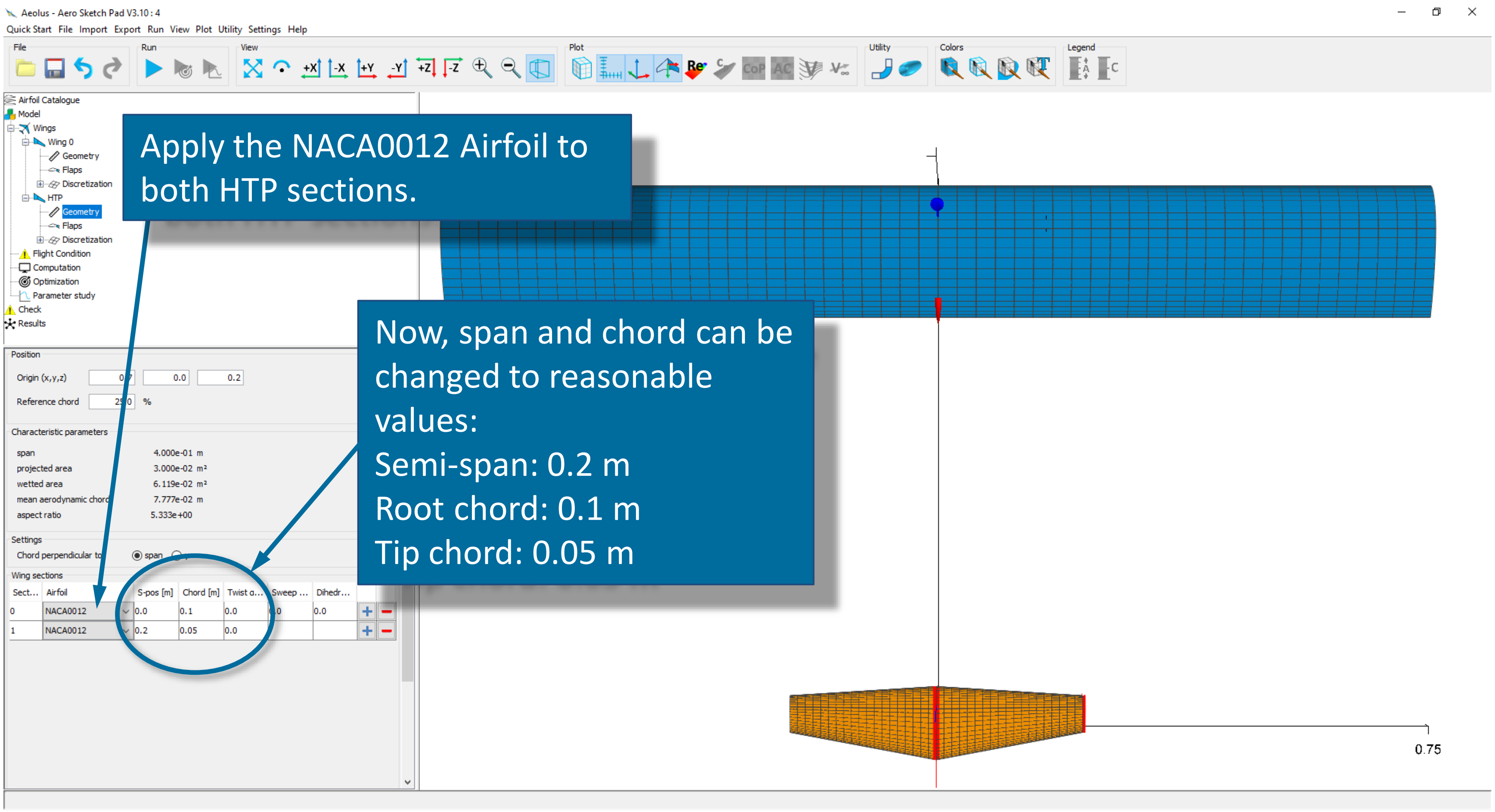
Each new wing gets a random color. Click here to pick your preferred color.

# Initial Design




| 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 | | |

# Initial Design




Apply the NACA0012 Airfoil to both HTP sections.

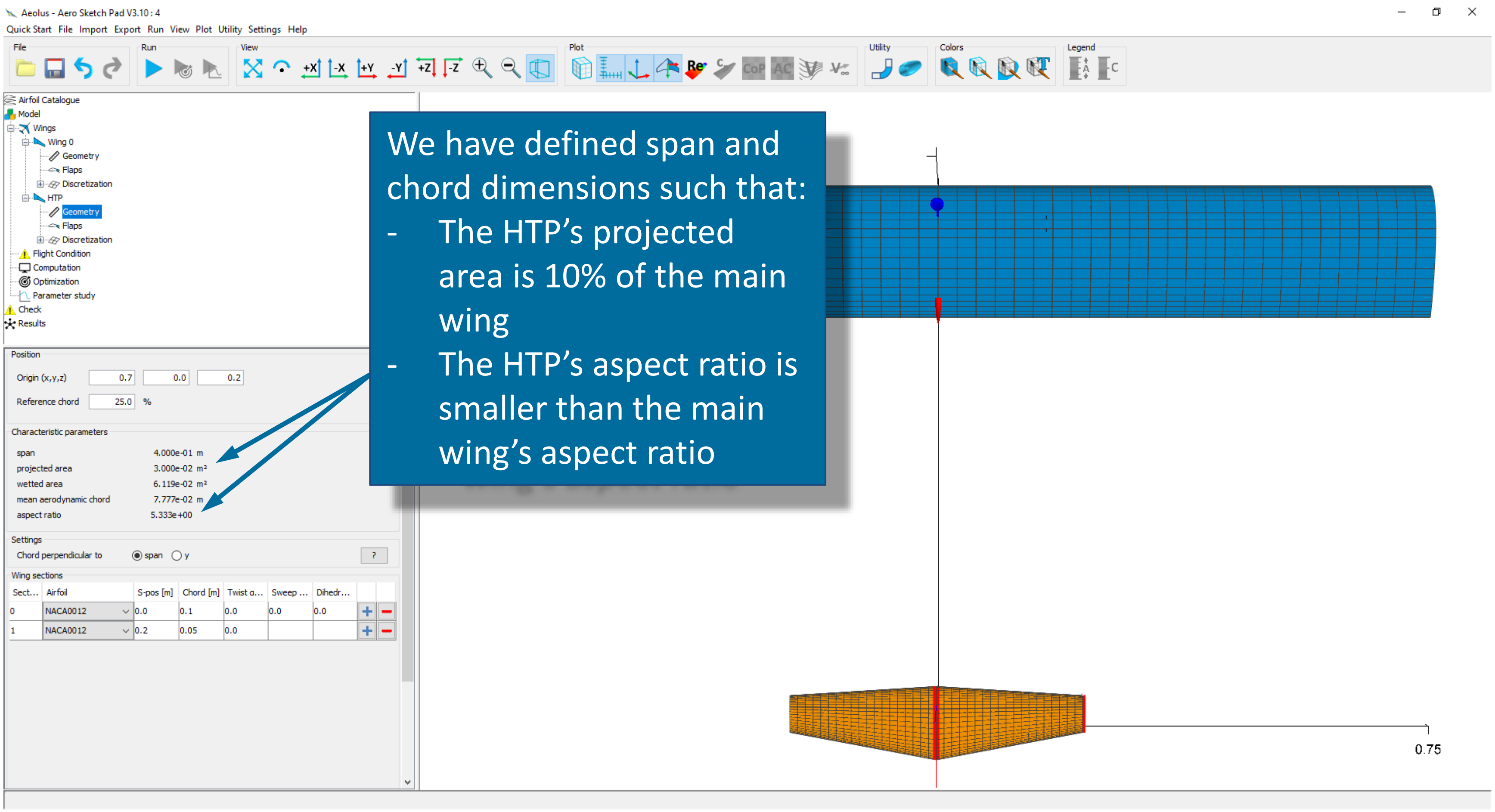
Now, span and chord can be changed to reasonable values:

Semi-span: 0.2 m

Root chord: 0.1 m

Tip chord: 0.05 m

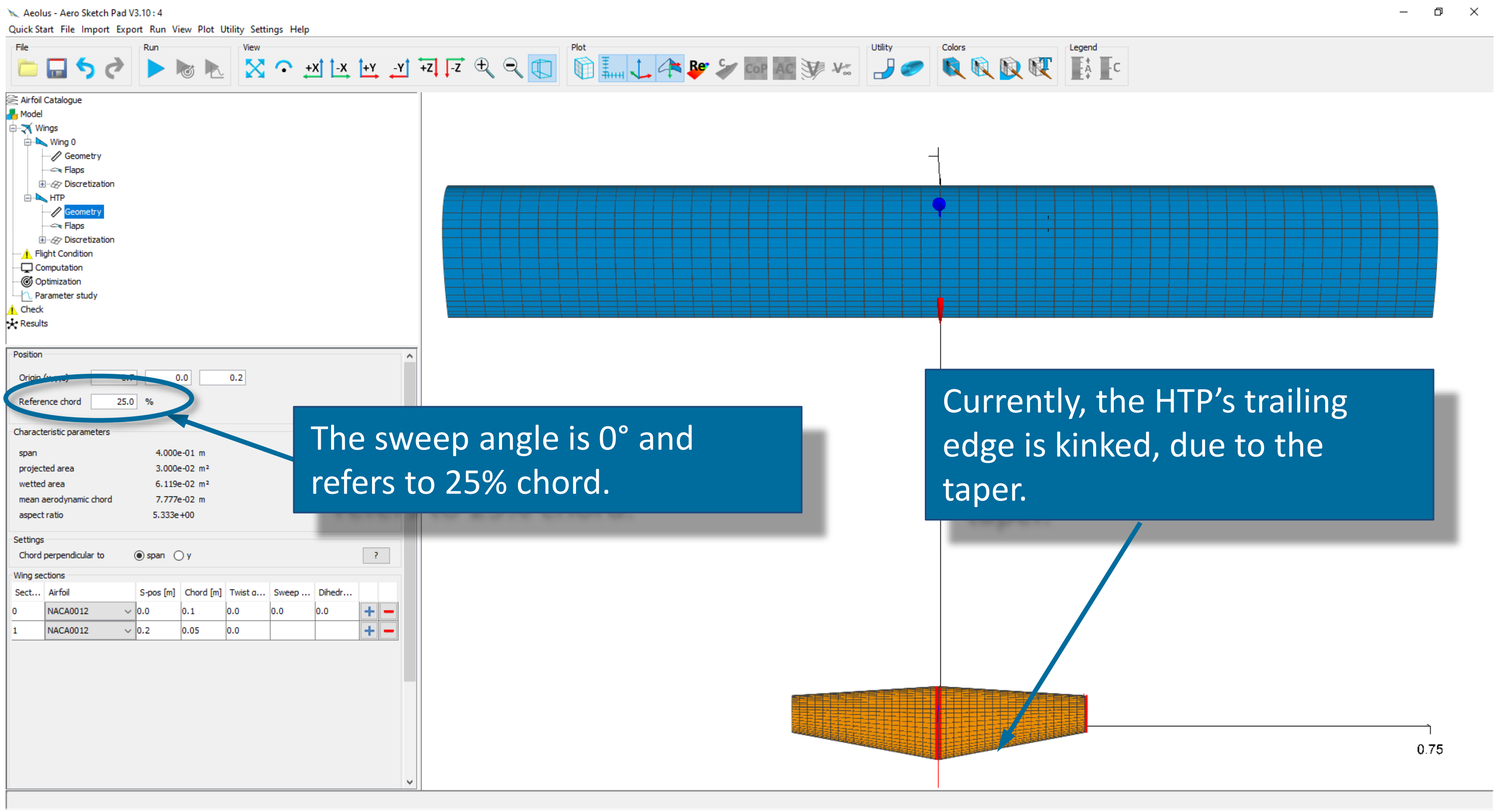
# Initial Design




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

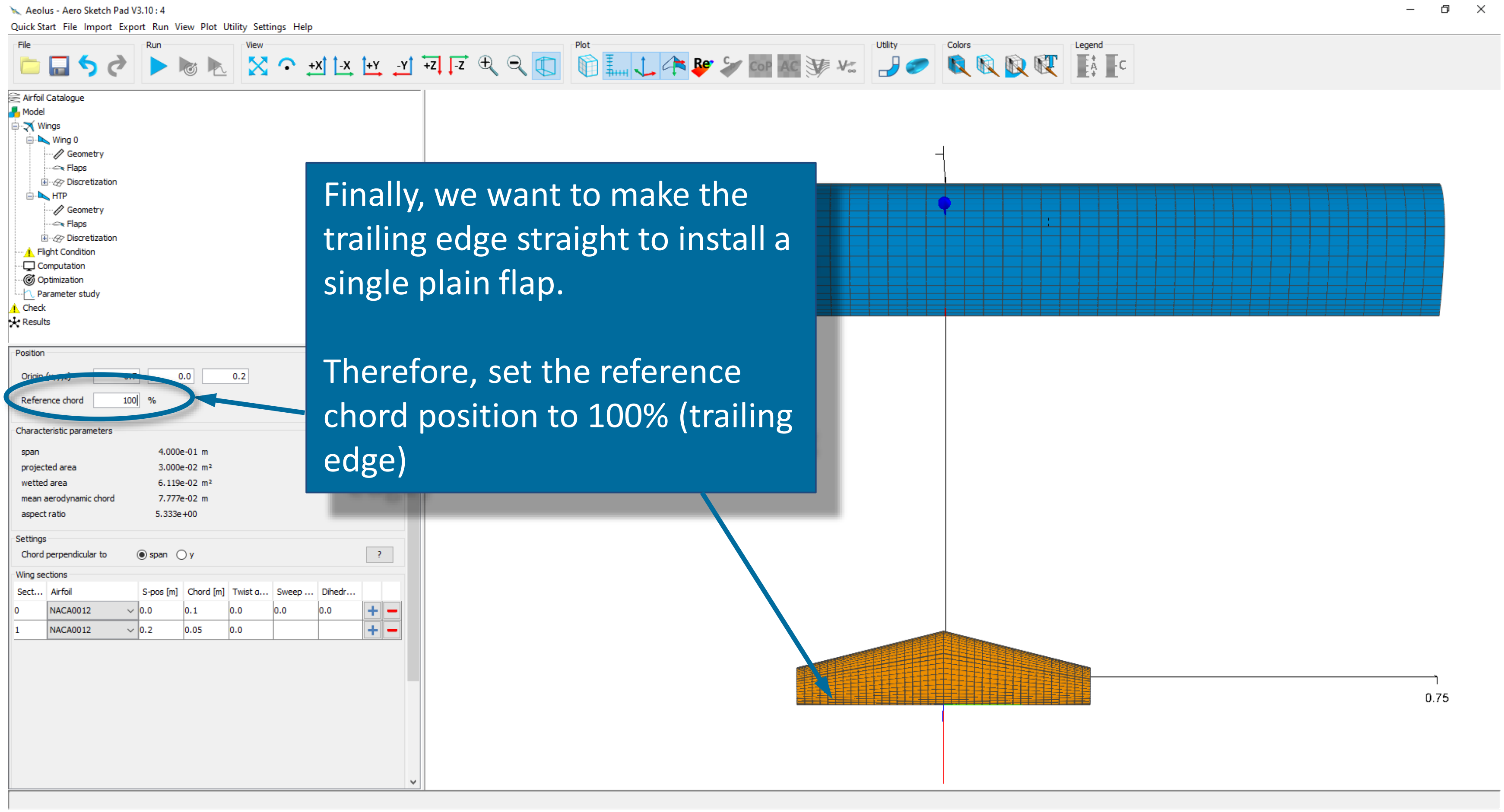
# Initial Design




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

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

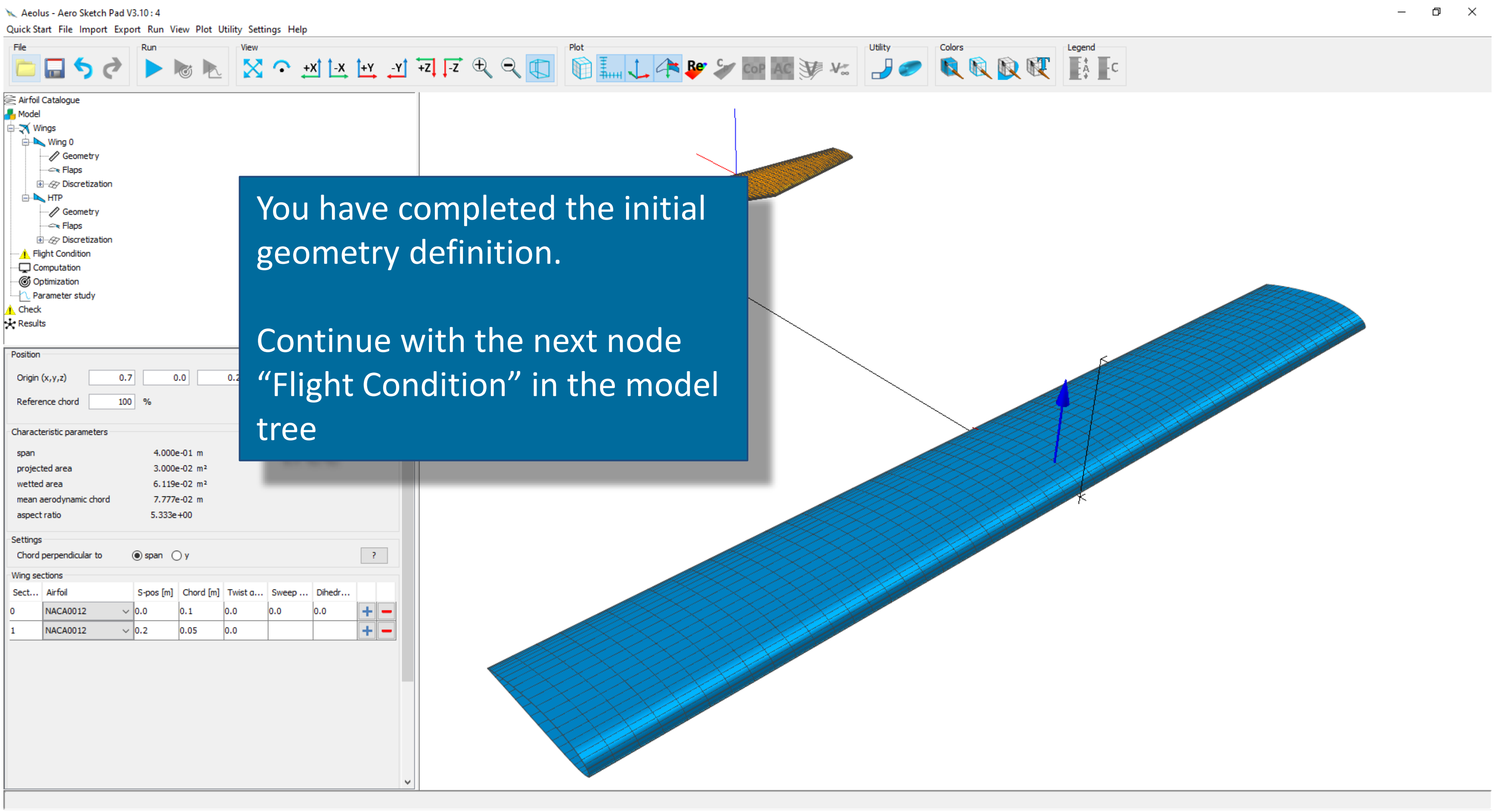
# Initial Design




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)

# Initial Design




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?**

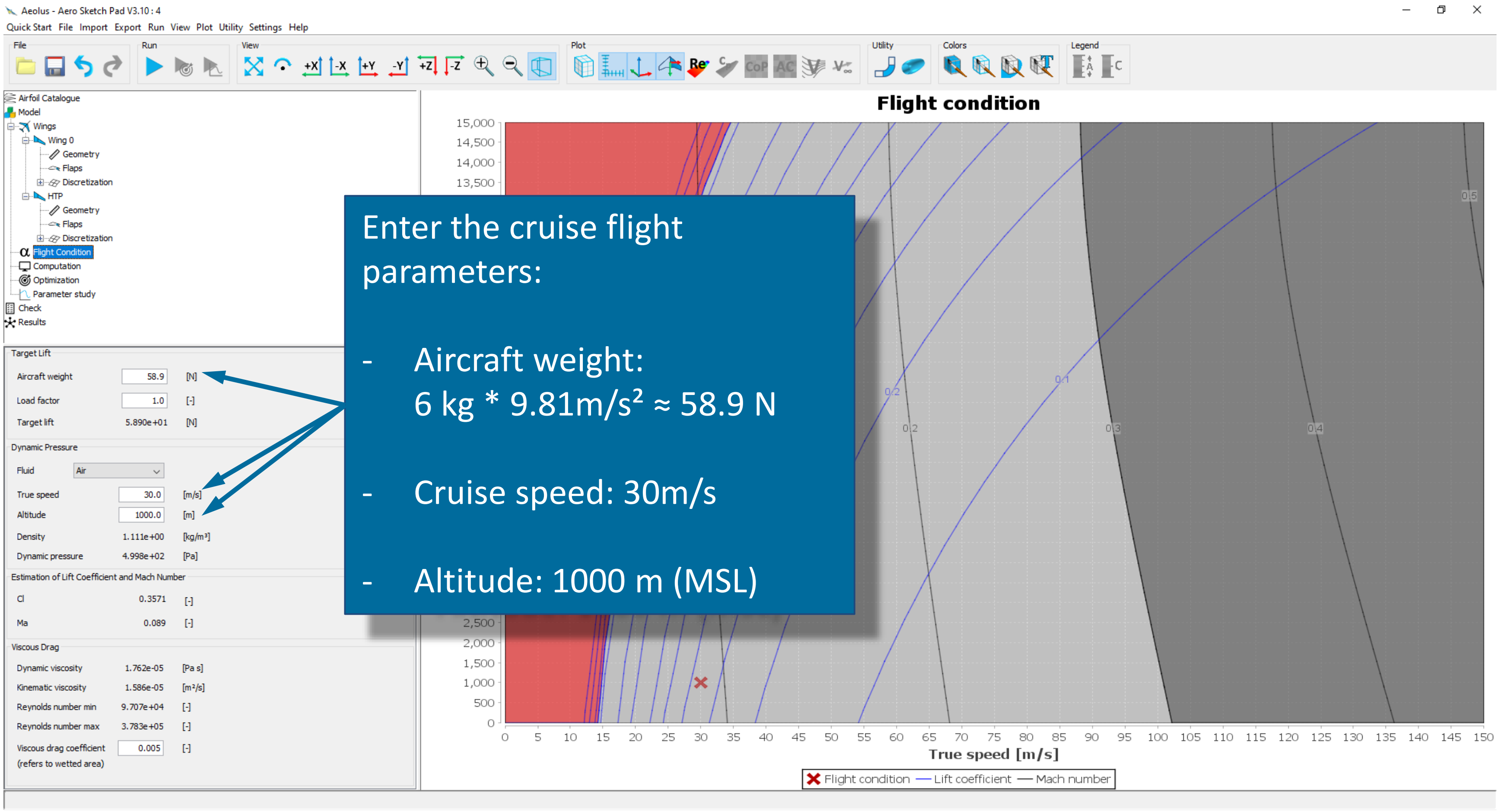
There is a number of different flight conditions at which the aircraft should be analysed in view of performance and stability. For example

- 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.

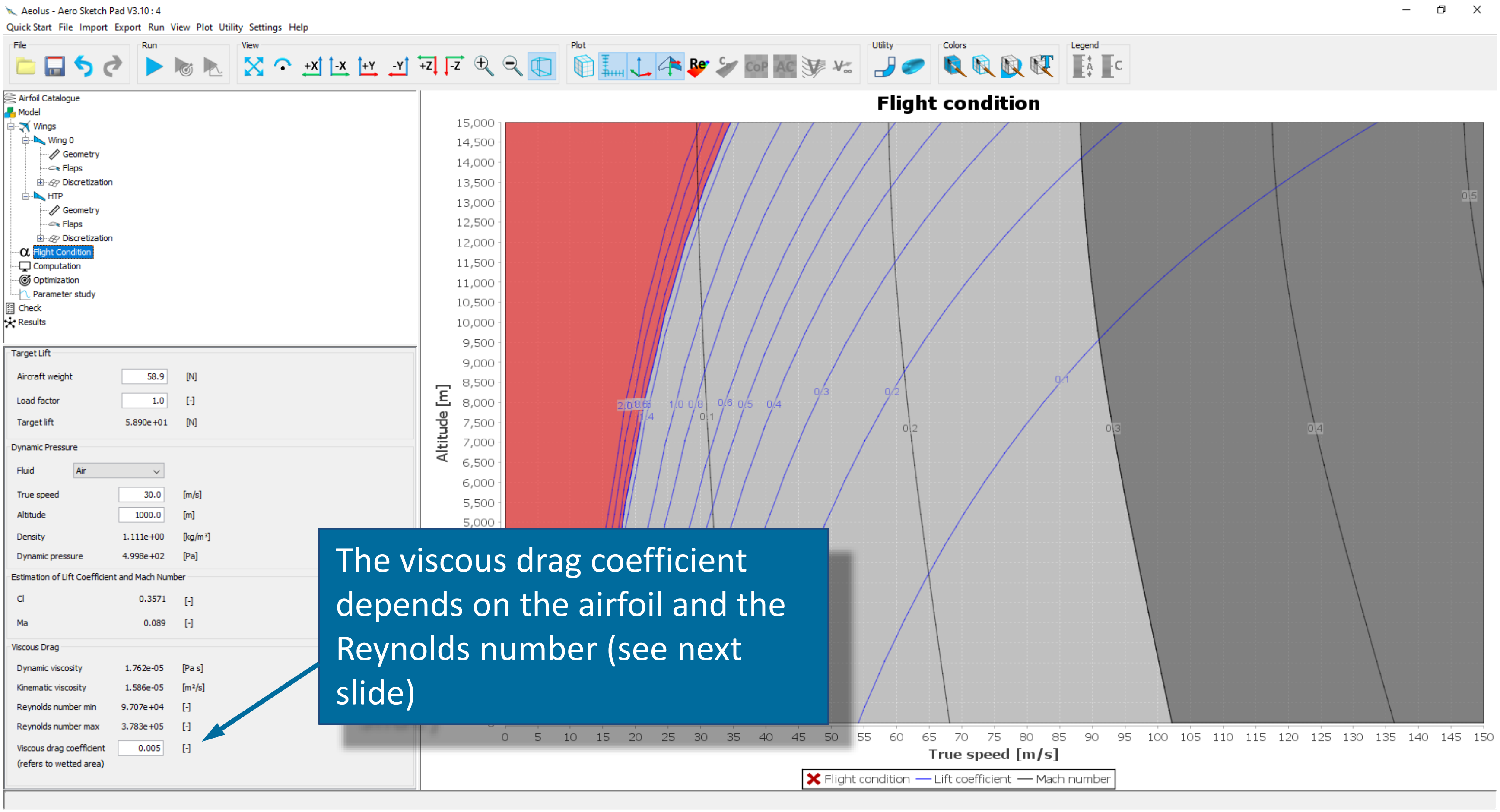
# Initial Design




Enter the cruise flight parameters:

- Aircraft weight: 6 kg * 9.81m/s² ≈ 58.9 N
- Cruise speed: 30m/s
- Altitude: 1000 m (MSL)

# Initial Design




The viscous drag coefficient depends on the airfoil and the Reynolds number (see next slide)

# 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

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

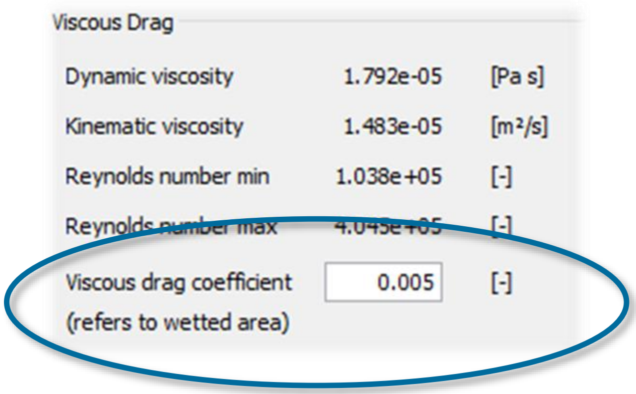
with

| | |
|---|---|
| $q$ | 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.

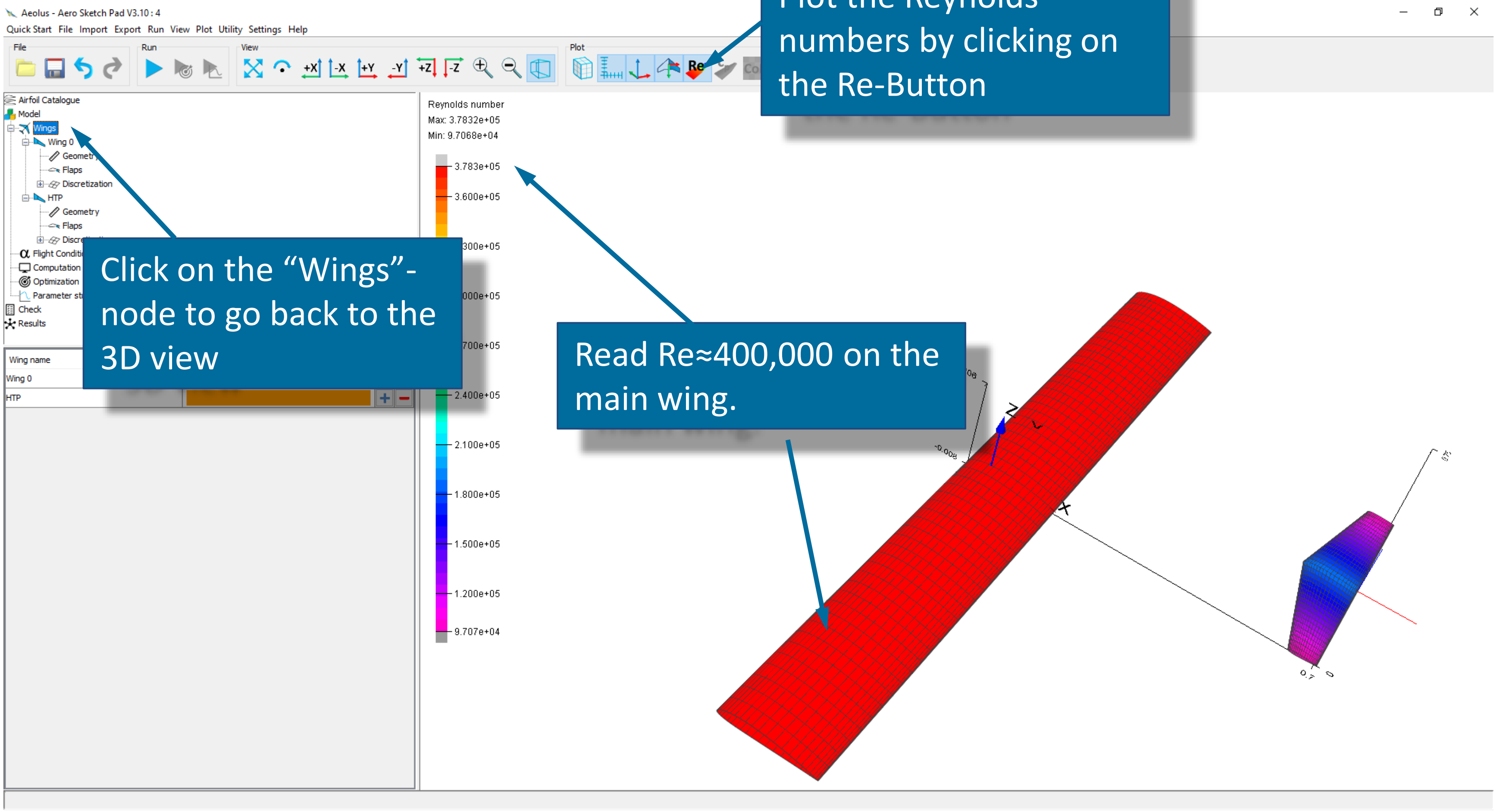
The default value is 0.005, which is a fairly good estimation for the most fixed-wing UAV cases.




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




Plot the Reynolds numbers by clicking on the Re-Button

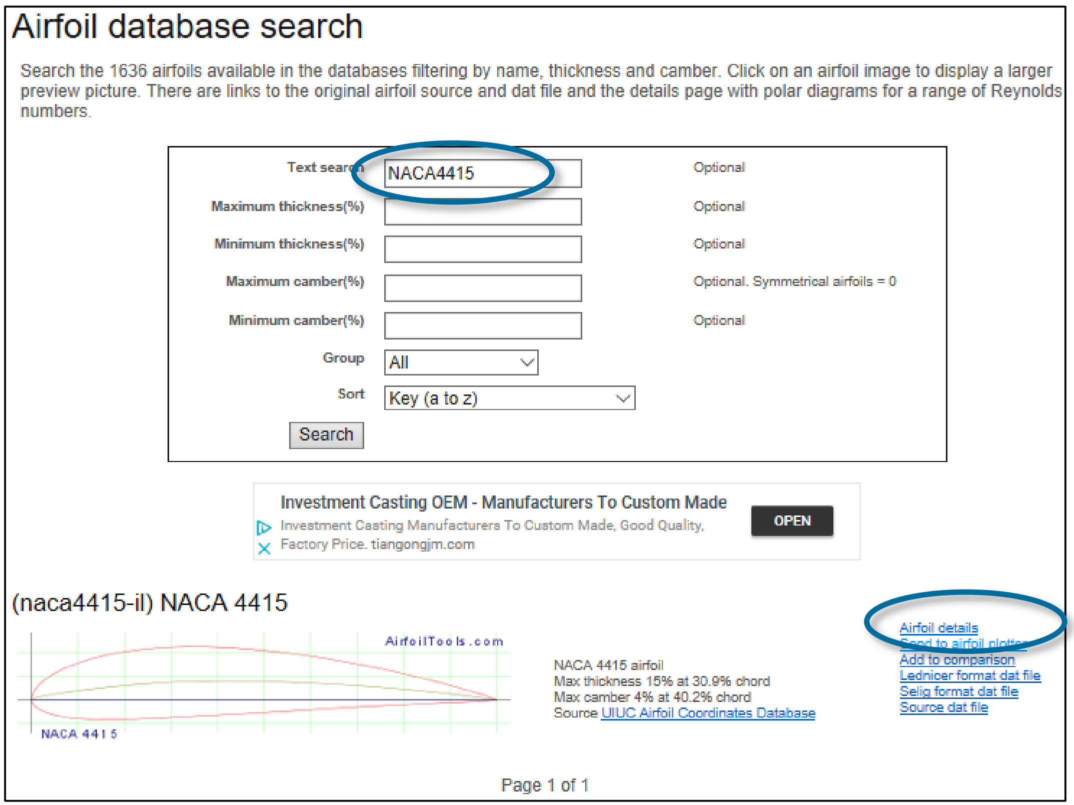
Click on the “Wings”-node to go back to the 3D view

Read Re≈400,000 on the main wing.

# Initial Design

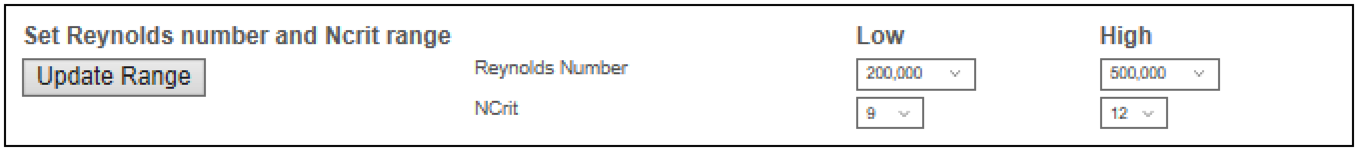
Airfoil data sheets are available from various online sources, such as http://airfoiltools.com.

Search for NACA4415 and click on "Airfoil details" (http://airfoiltools.com/airfoil/details?airfoil=naca4415-il).

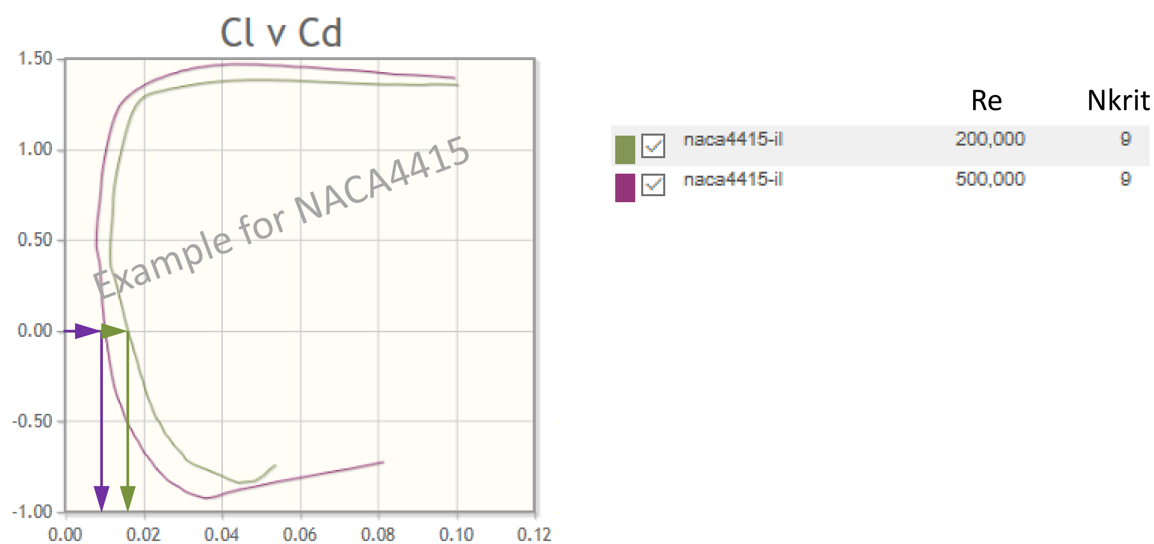


# Initial Design

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




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




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

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

# 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:

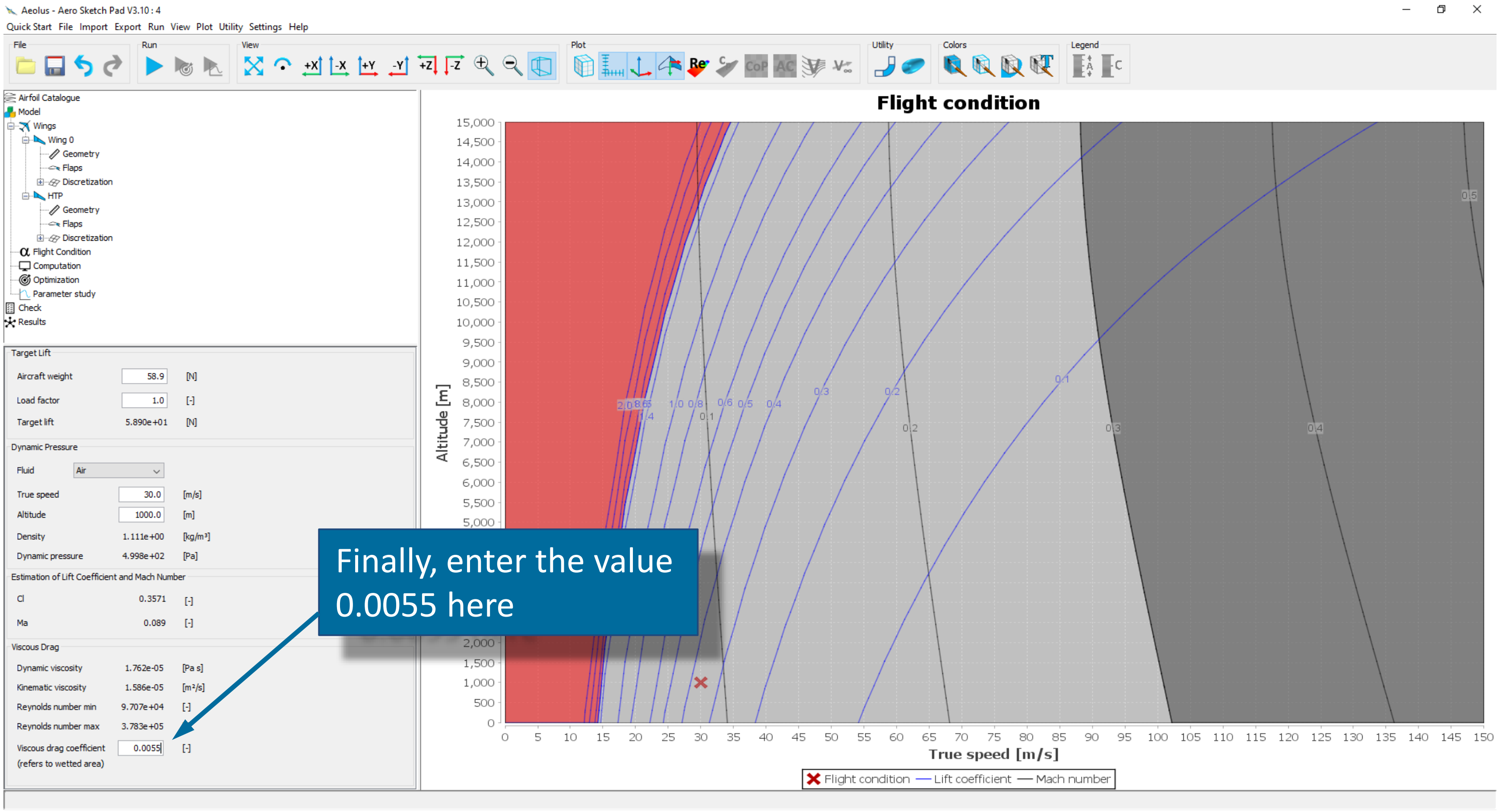
$$C_{d,visc,proj}^{Re=400,000} \approx 0.011$$

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:

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

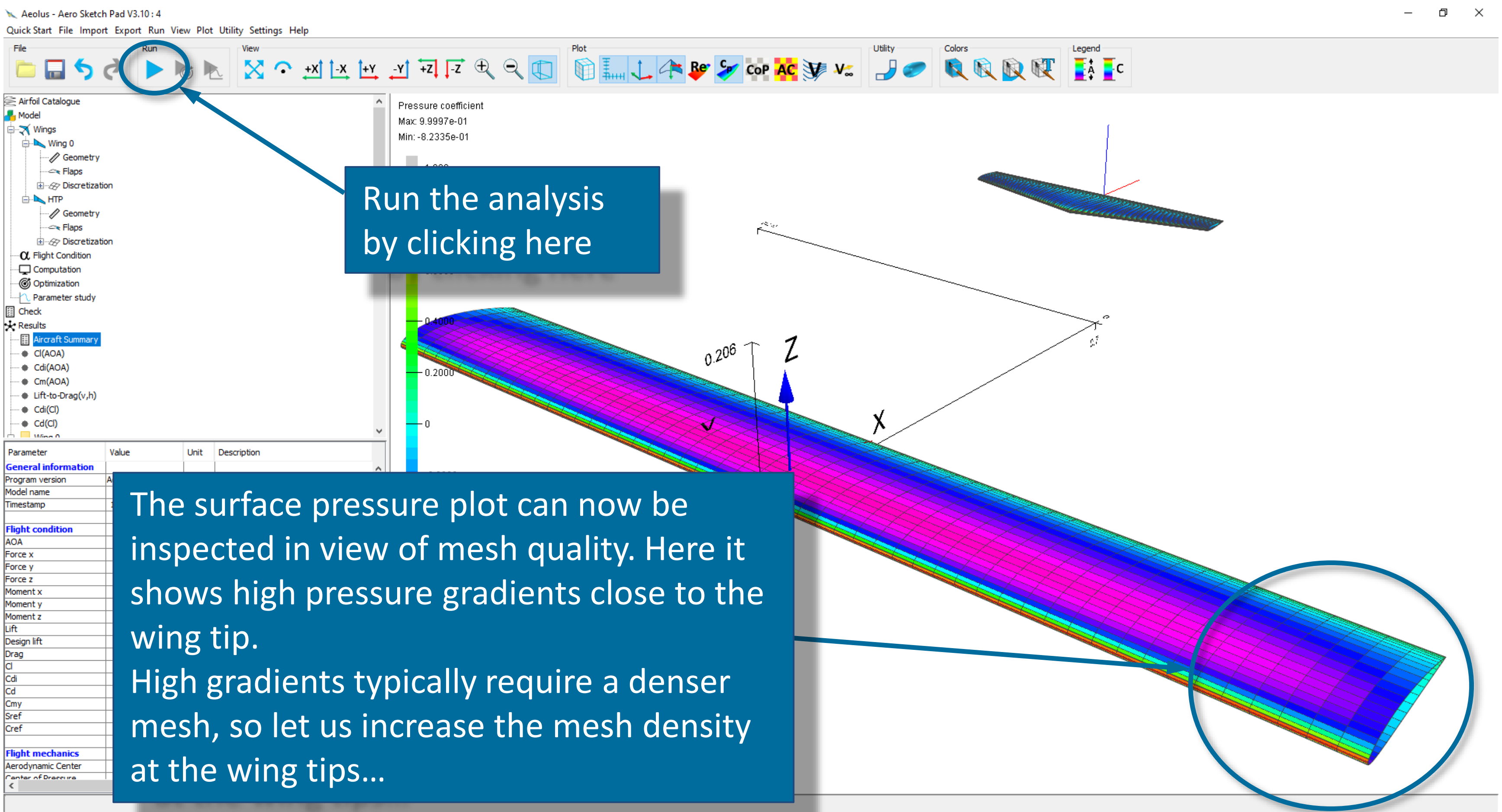
$$\boxed{C_{d,visc,wet} = 0.0055}$$

# Initial Design




Finally, enter the value 0.0055 here

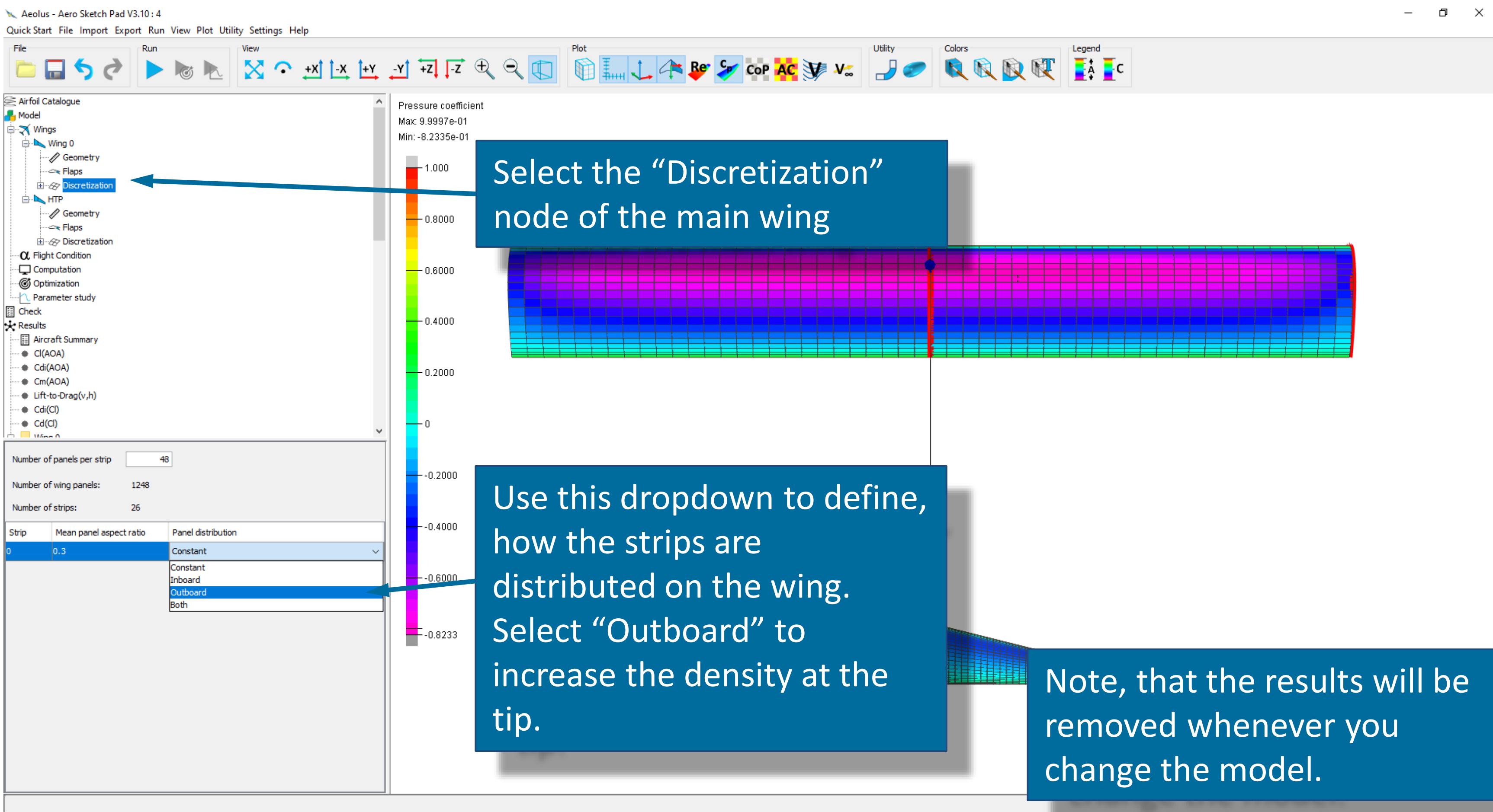
# Initial Design




Run the analysis by clicking here

The surface pressure plot can now be inspected in view of mesh quality. Here it shows high pressure gradients close to the wing tip.
High gradients typically require a denser mesh, so let us increase the mesh density at the wing tips…

# Initial Design



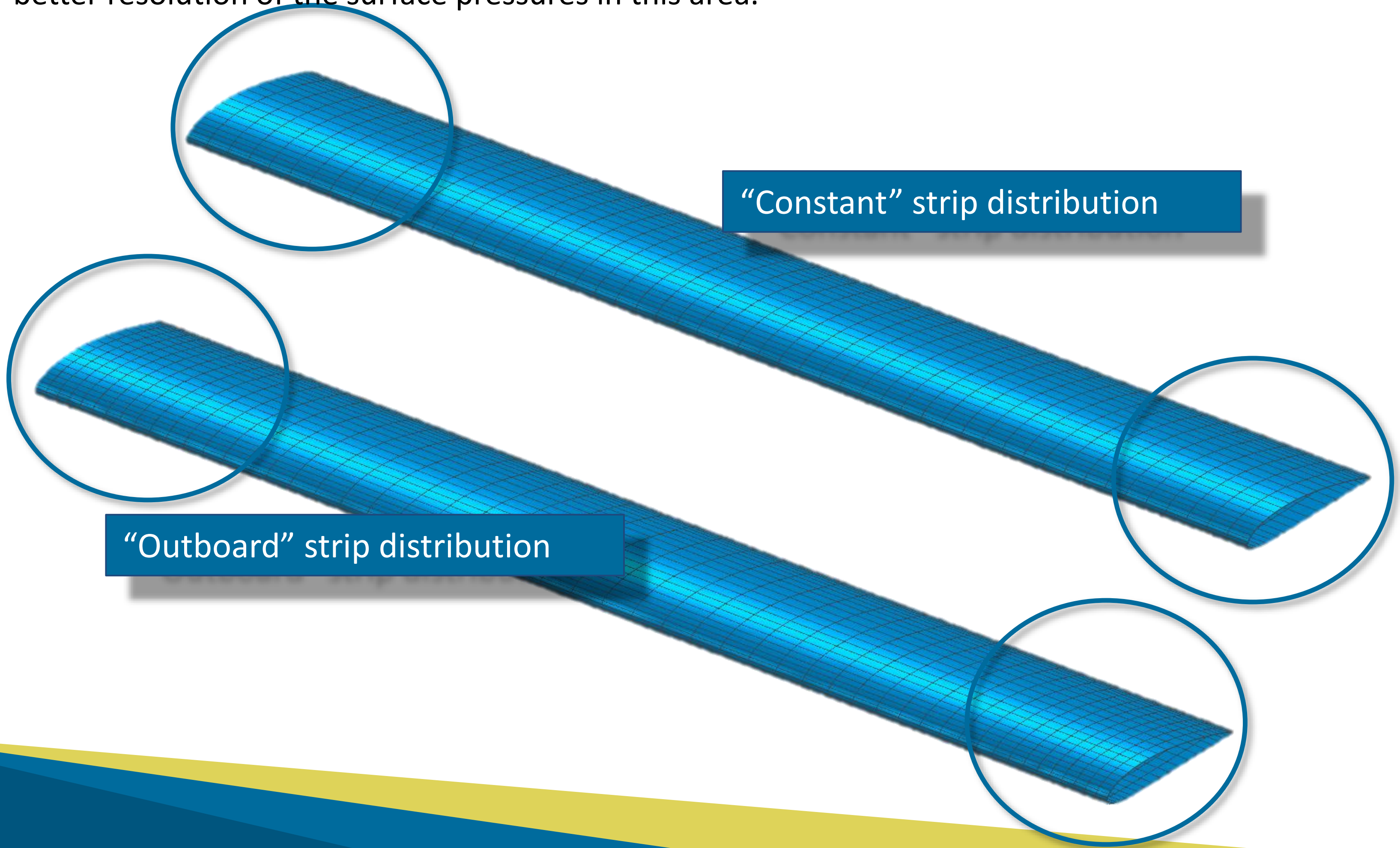

Select the “Discretization” node of the main wing

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.

# Initial Design

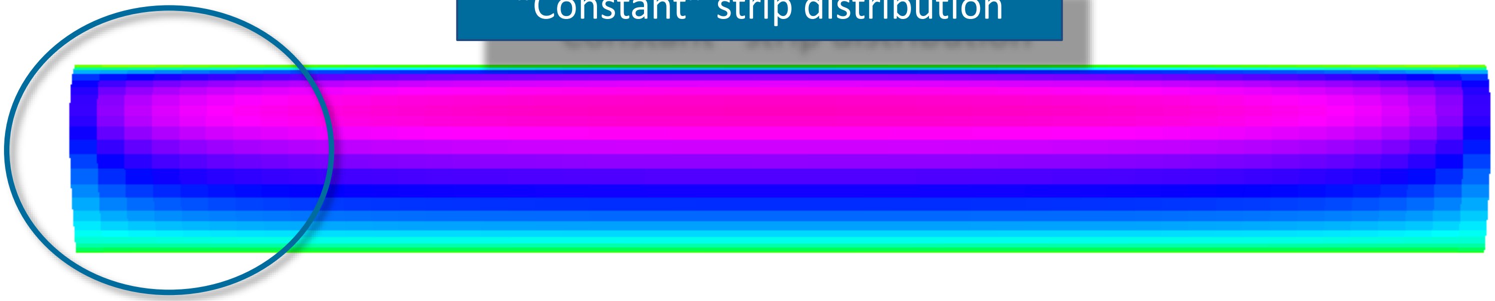
- The strip distribution option “Outboard” increases the panel density at the wing tip and enables a better resolution of the surface pressures in this area.



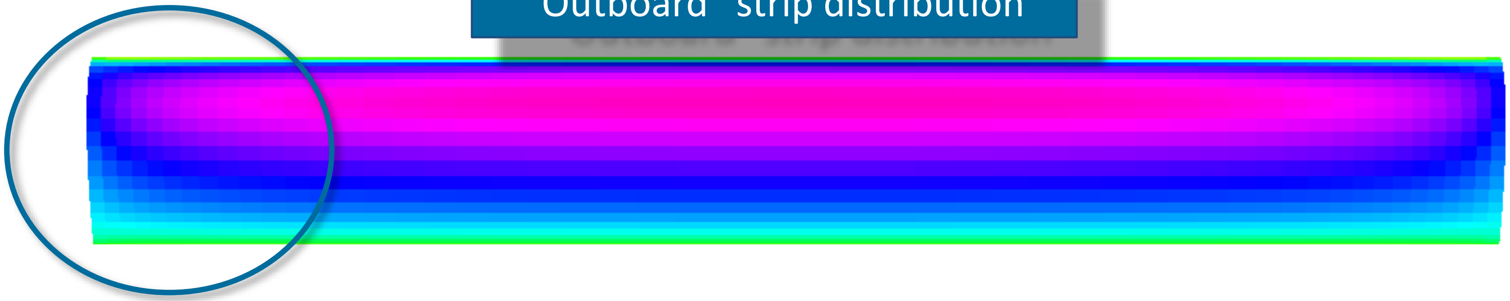
# Initial Design

- 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

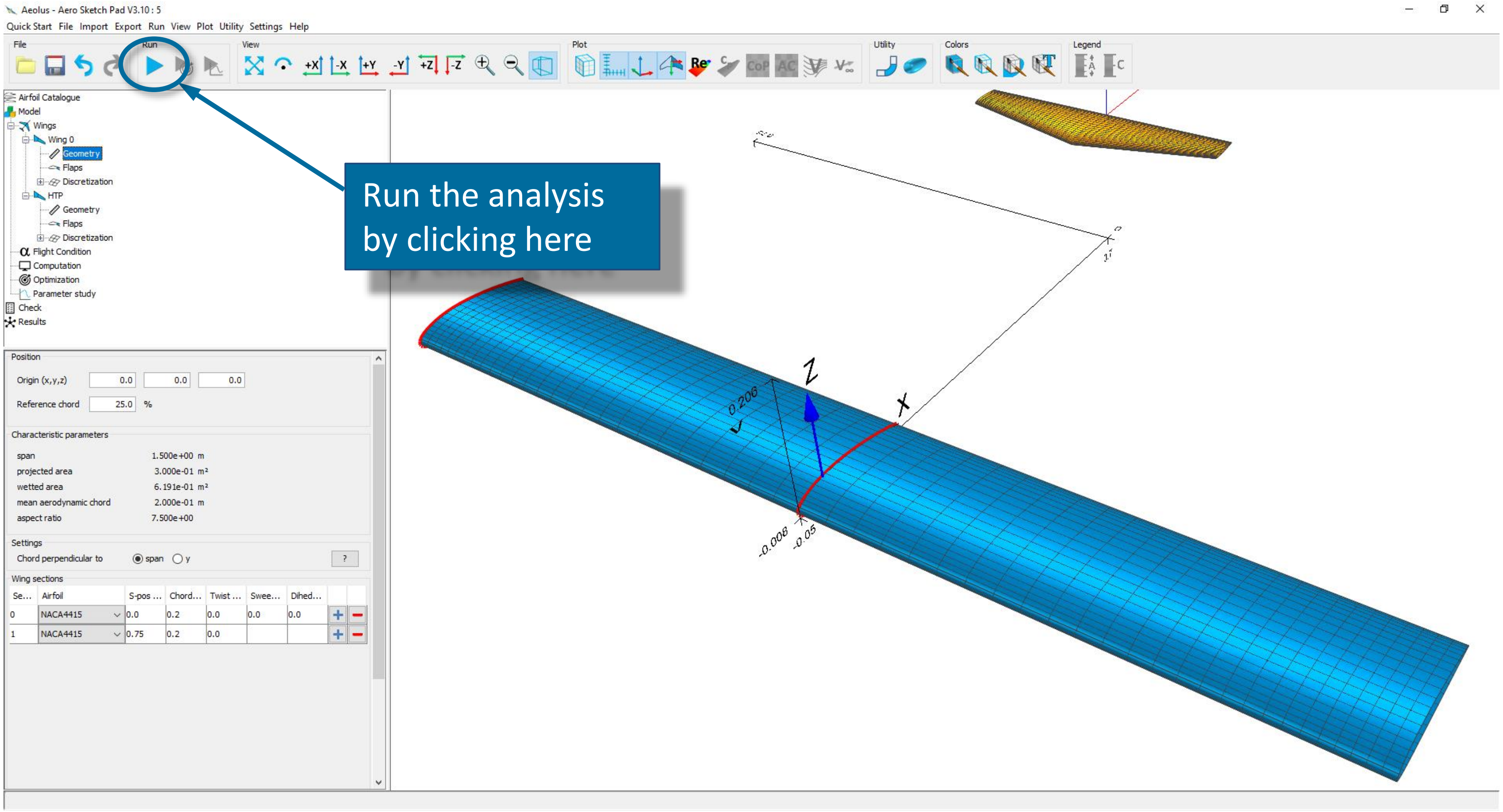
“Constant” strip distribution



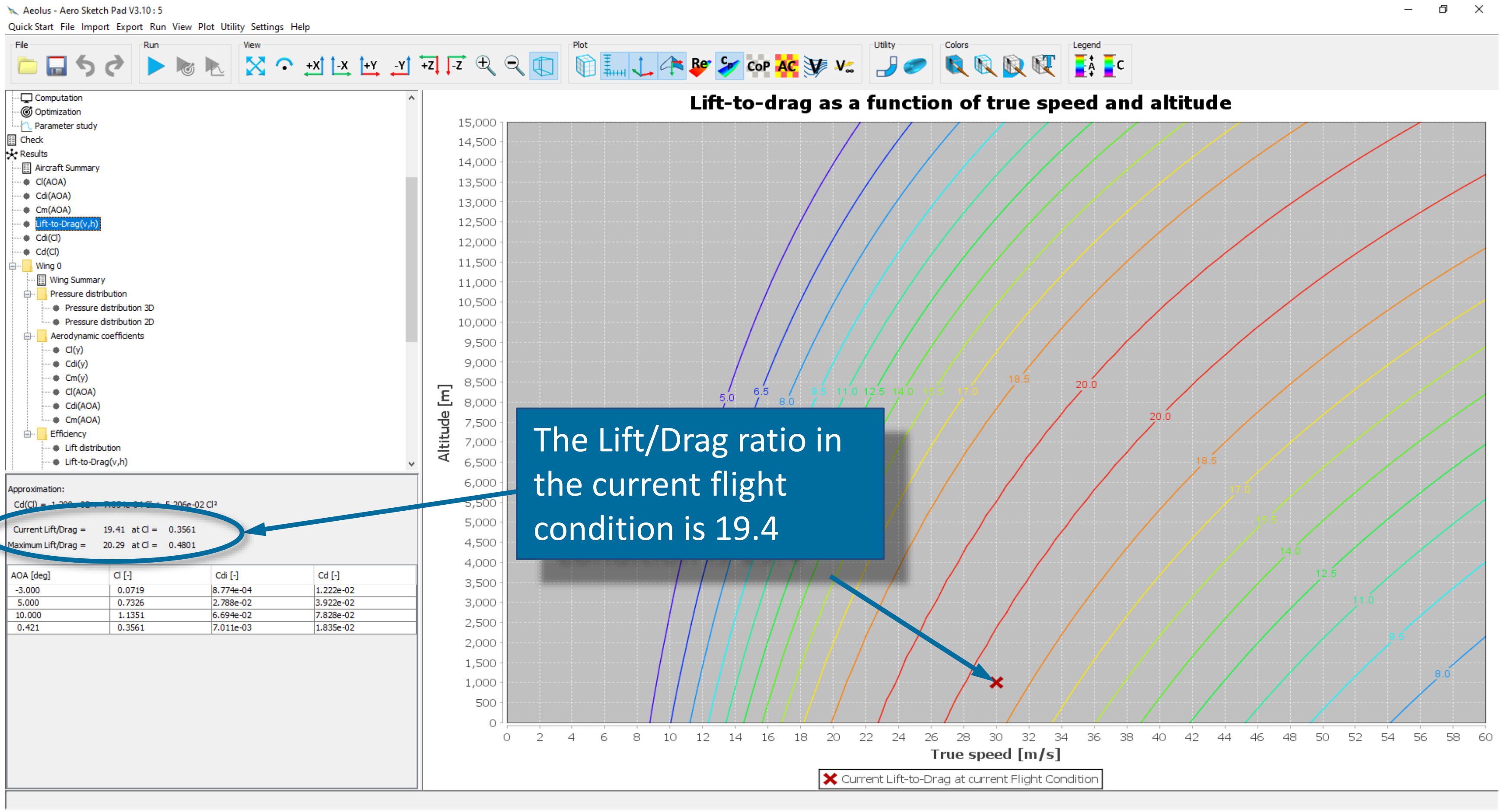
“Outboard” strip distribution



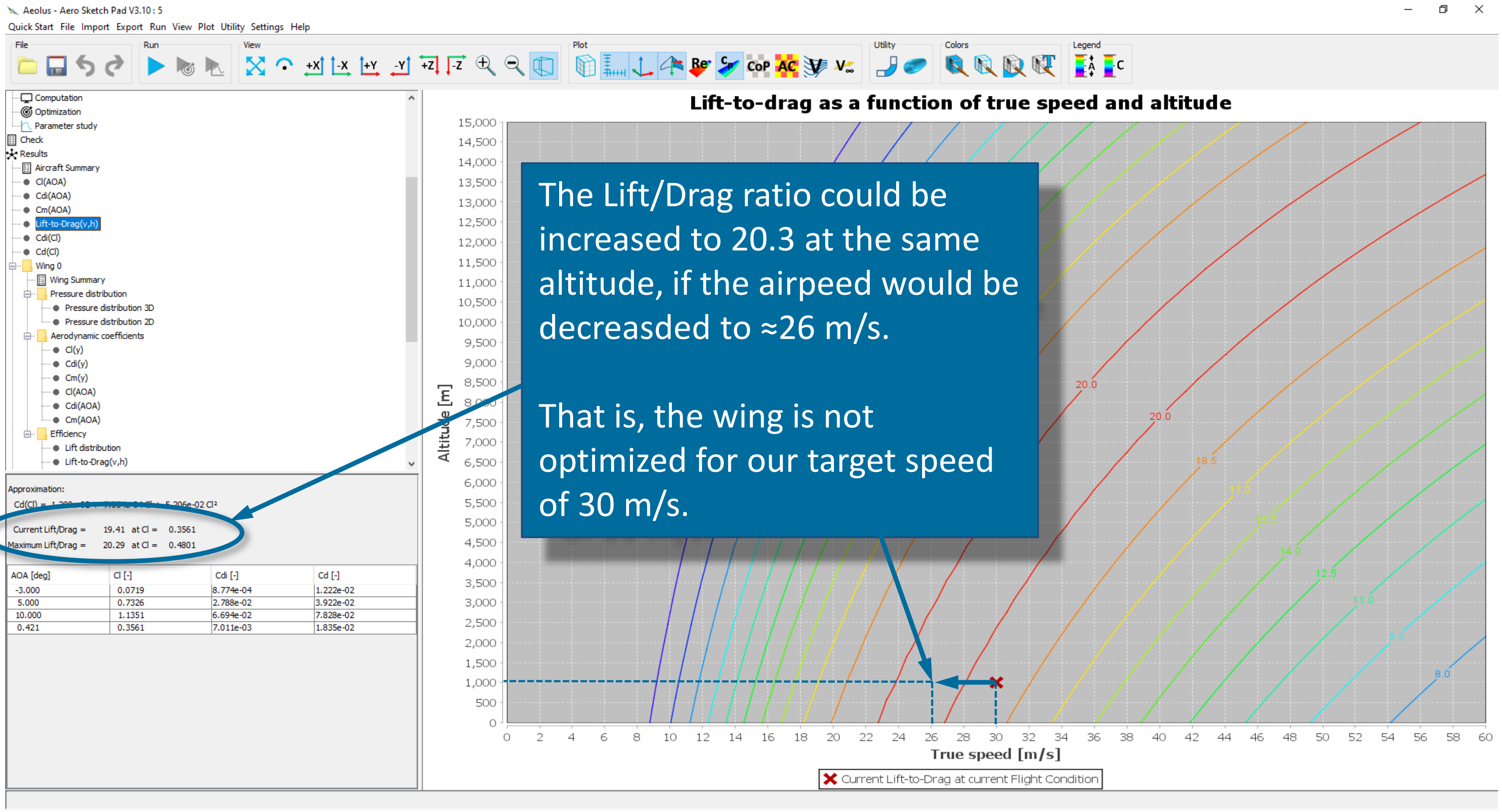
# Analysis of the Initial Design



# Analysis of the Initial Design



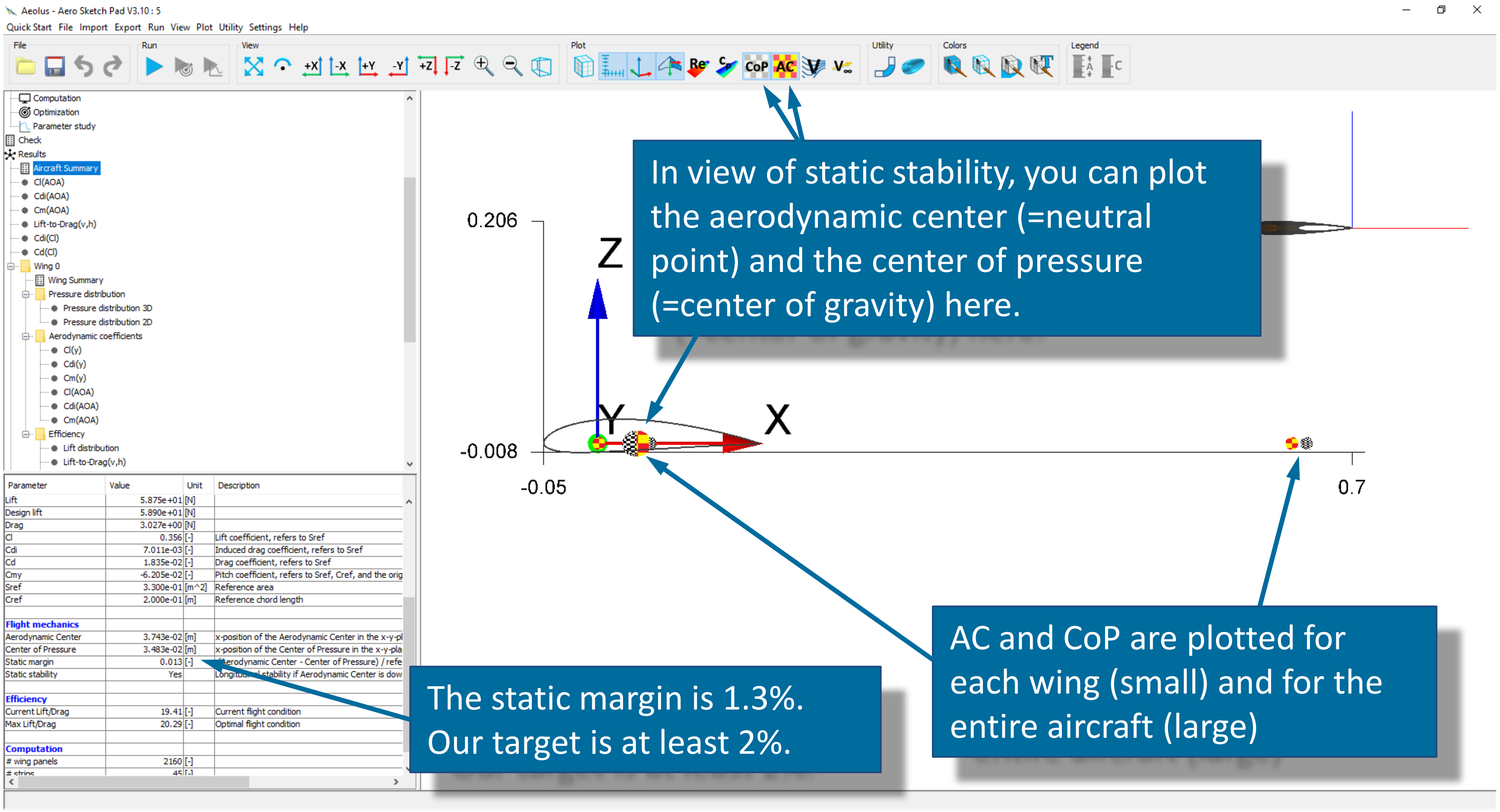
# Analysis of the Initial Design




The Lift/Drag ratio could be increased to 20.3 at the same altitude, if the airpeed would be decreasded to ≈26 m/s.

That is, the wing is not optimized for our target speed of 30 m/s.

# Analysis of the Initial Design

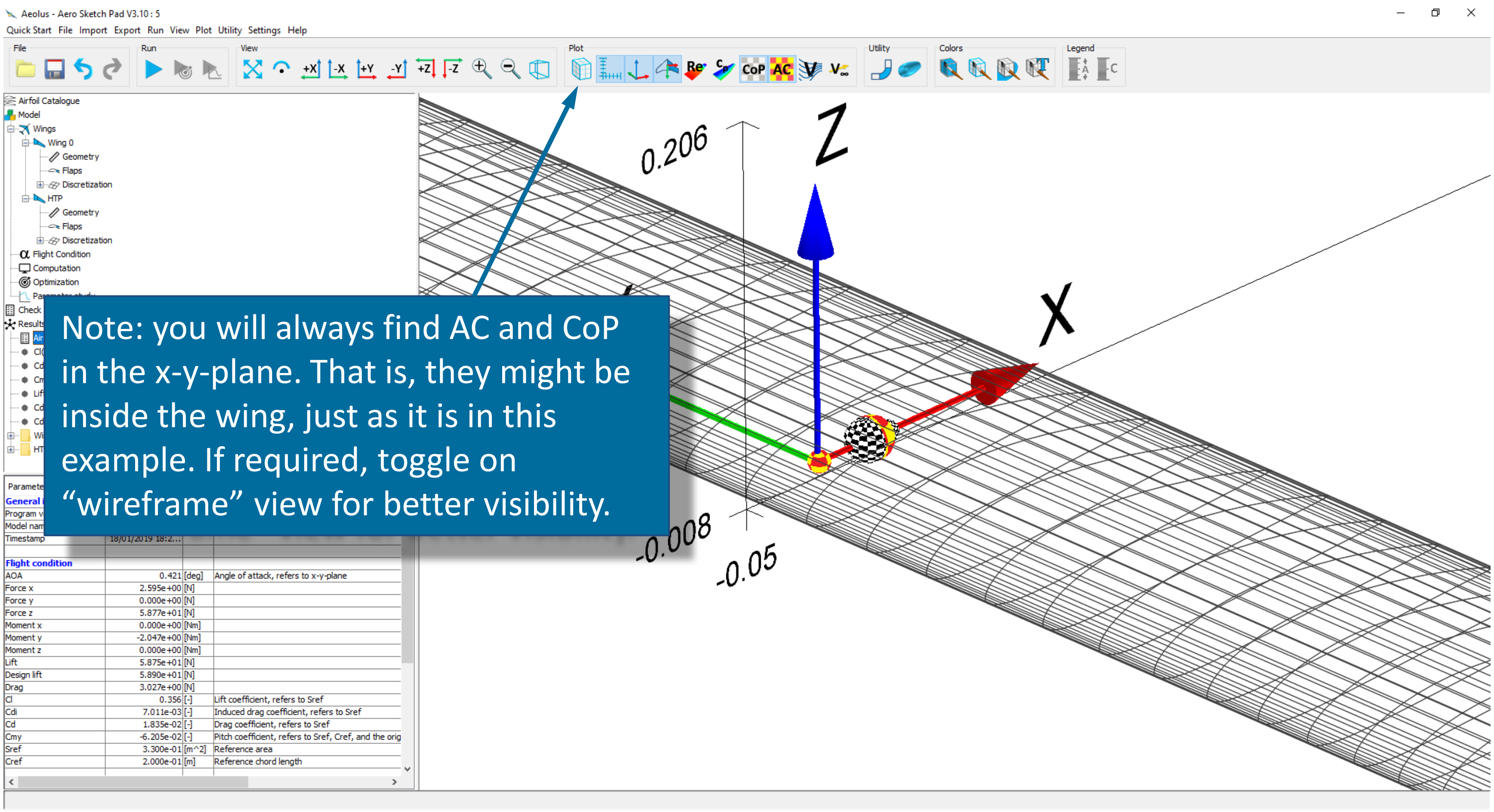



In view of static stability, you can plot the aerodynamic center (=neutral point) and the center of pressure (=center of gravity) here.

The static margin is 1.3%. Our target is at least 2%.

AC and CoP are plotted for each wing (small) and for the entire aircraft (large)

# Analysis of the Initial Design




Note: you will always find AC and CoP in the x-y-plane. That is, they might be inside the wing, just as it is in this example. If required, toggle on “wireframe” view for better visibility.

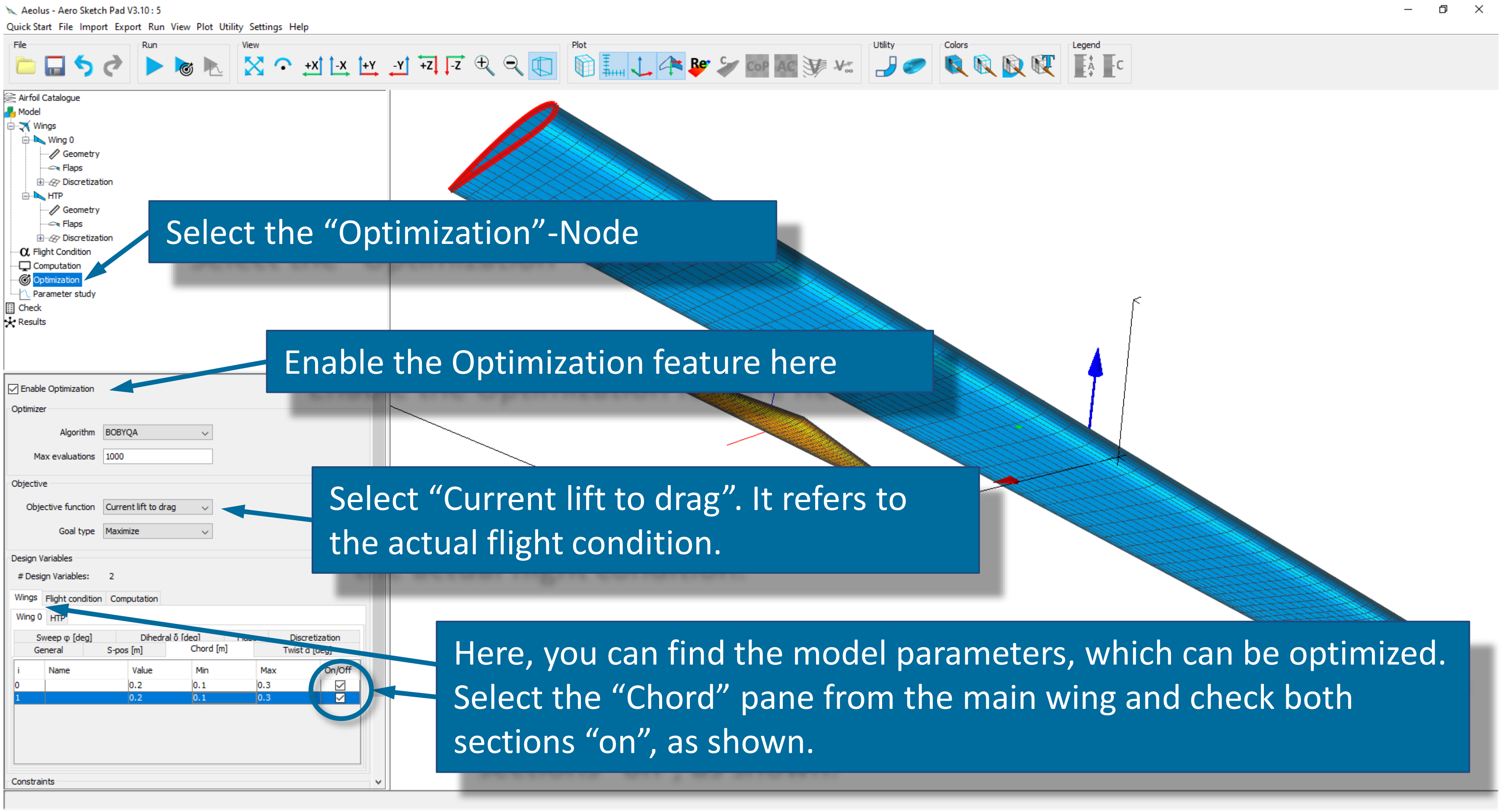
# Wing Shape Optimization

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:

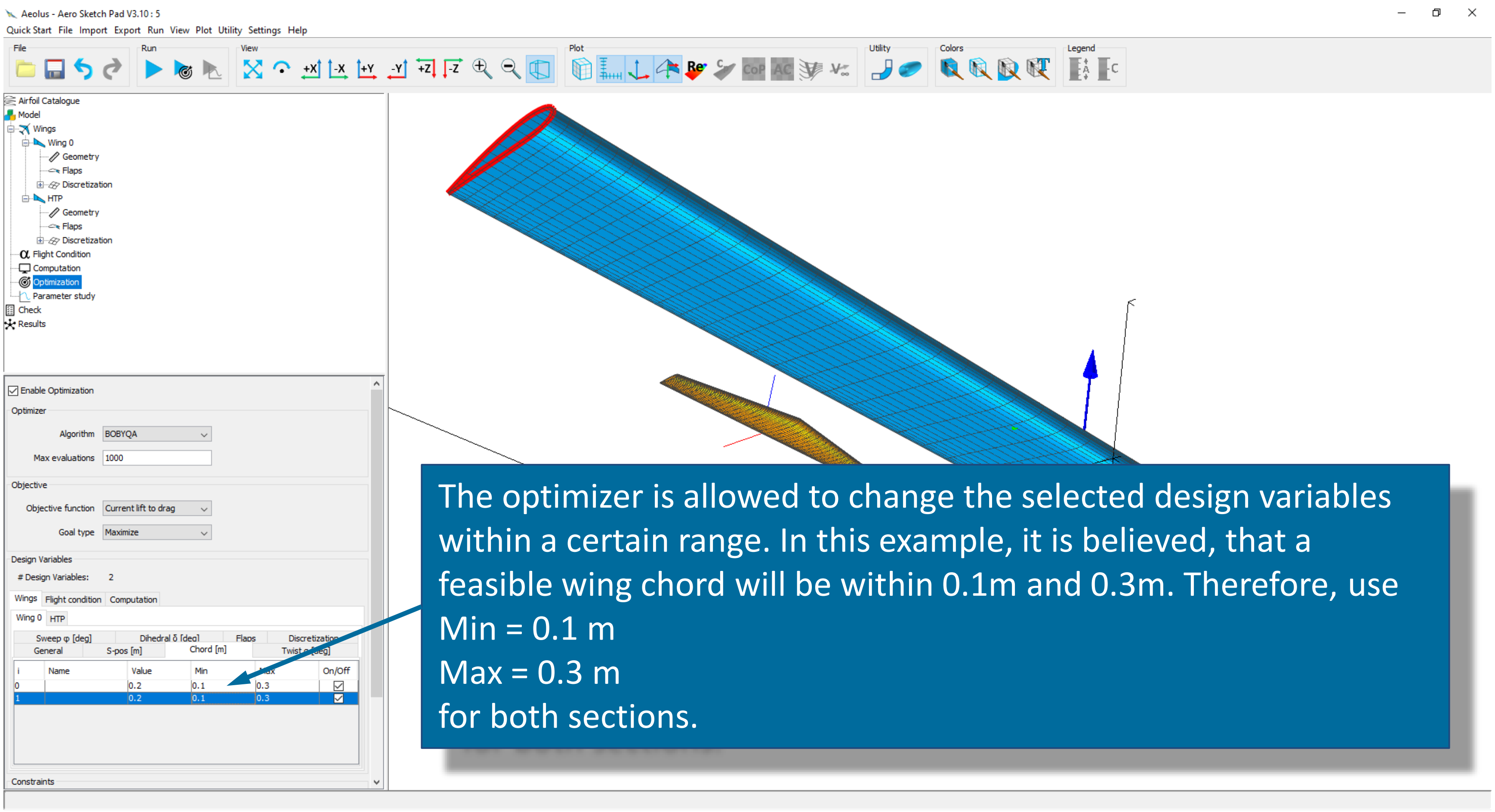
- Root chord length
- Tip chord length
- Tip twist

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

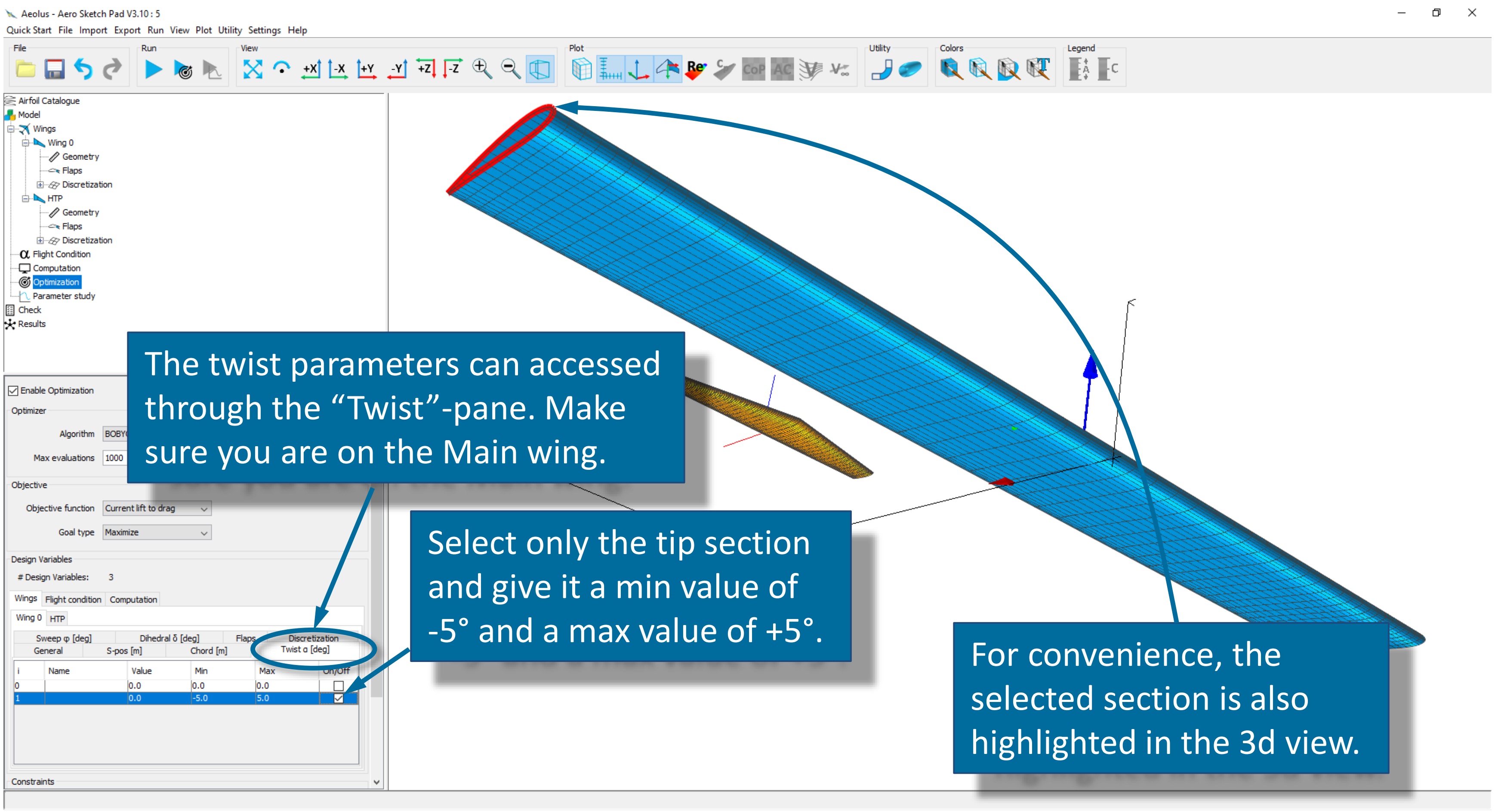


# Wing Shape Optimization




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




The twist parameters can 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° and a max value of +5°.

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

# Wing Shape Optimization

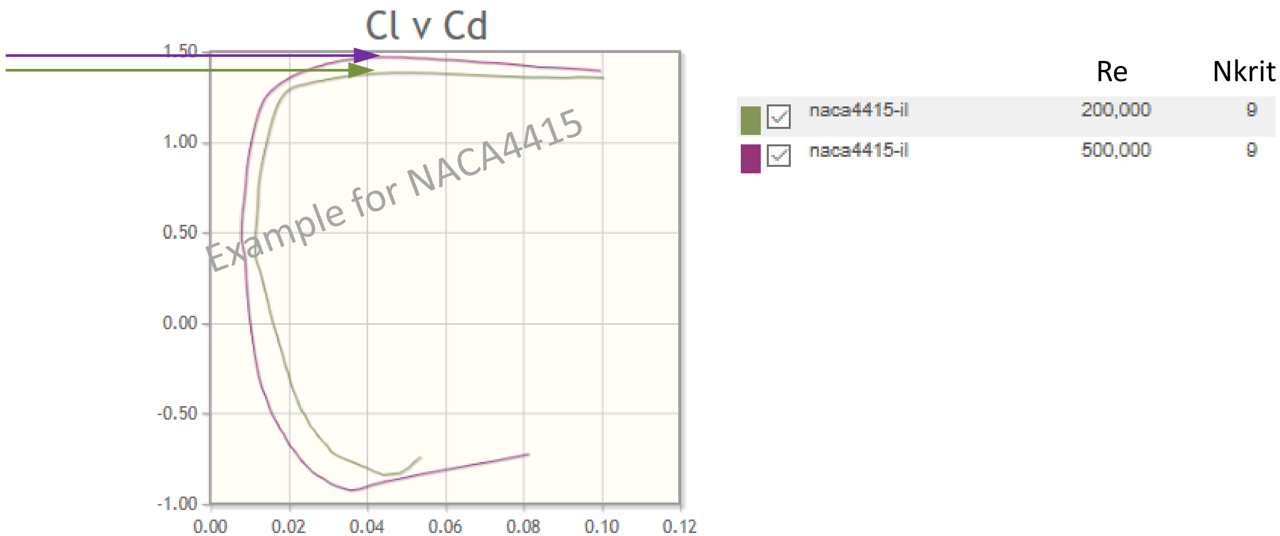
The last step is the definition of constraints. Depending on the optimization problem, constraints can be required to avoid any unfeasible results.

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:

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

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



# Wing Shape Optimization

To be conservative, we assume

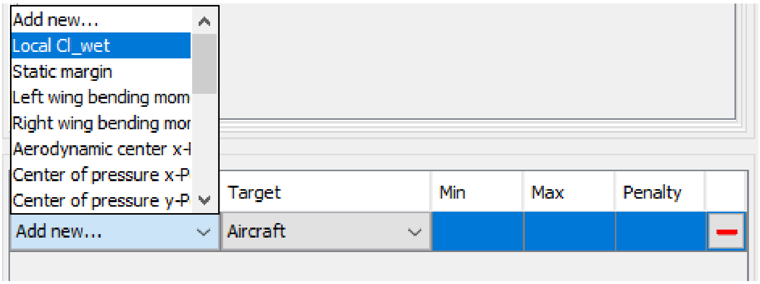
$$c_{l,max} = 1.2$$

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° 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 | | | | − |

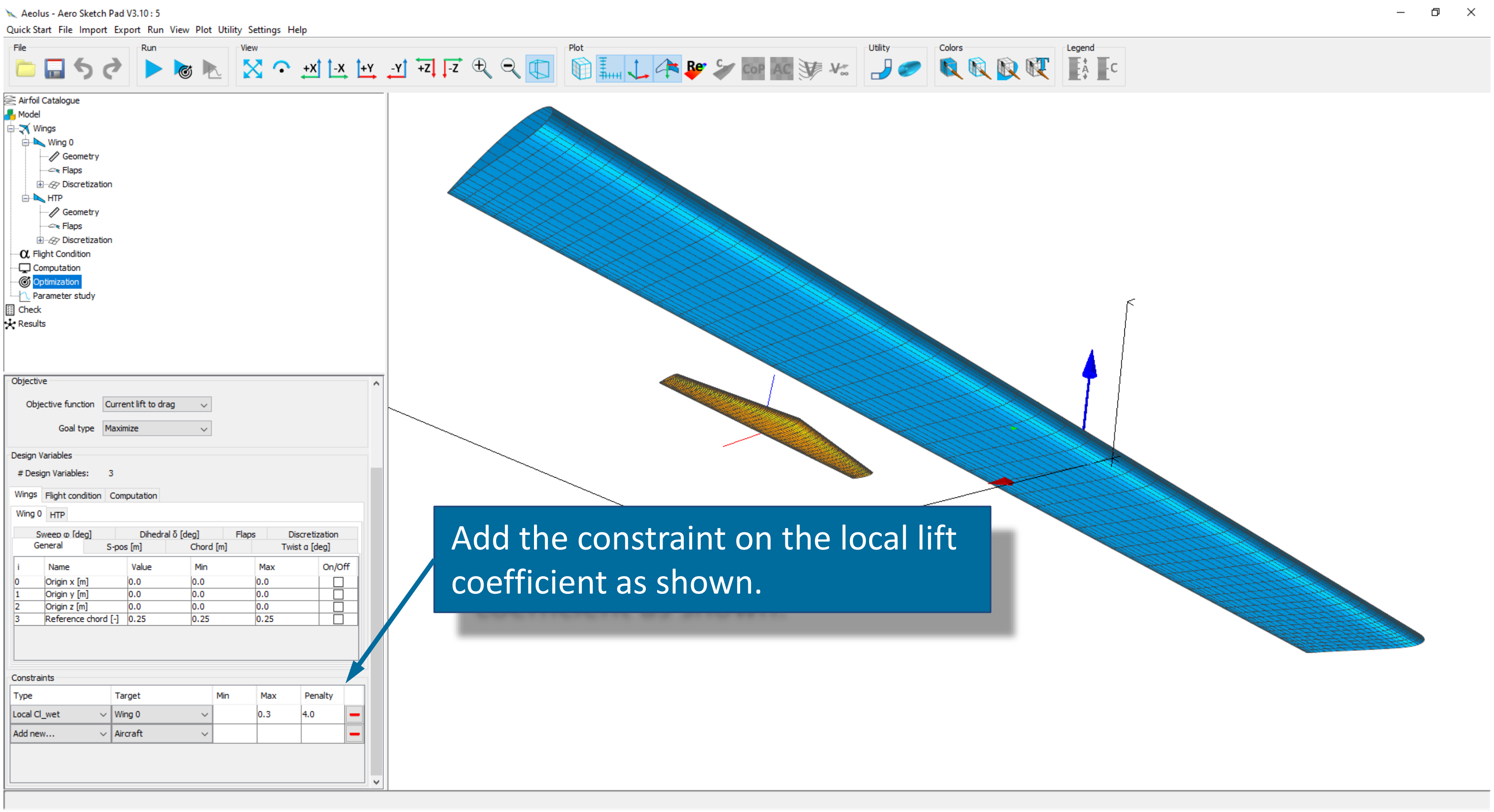
The coefficient's index „wet" indicates a reference to the wetted wing area. Again, the conversion can simply be done knowing that $\frac{S_{proj}}{S_{wet}} \approx 0.5.$

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

$$= 0.3$$

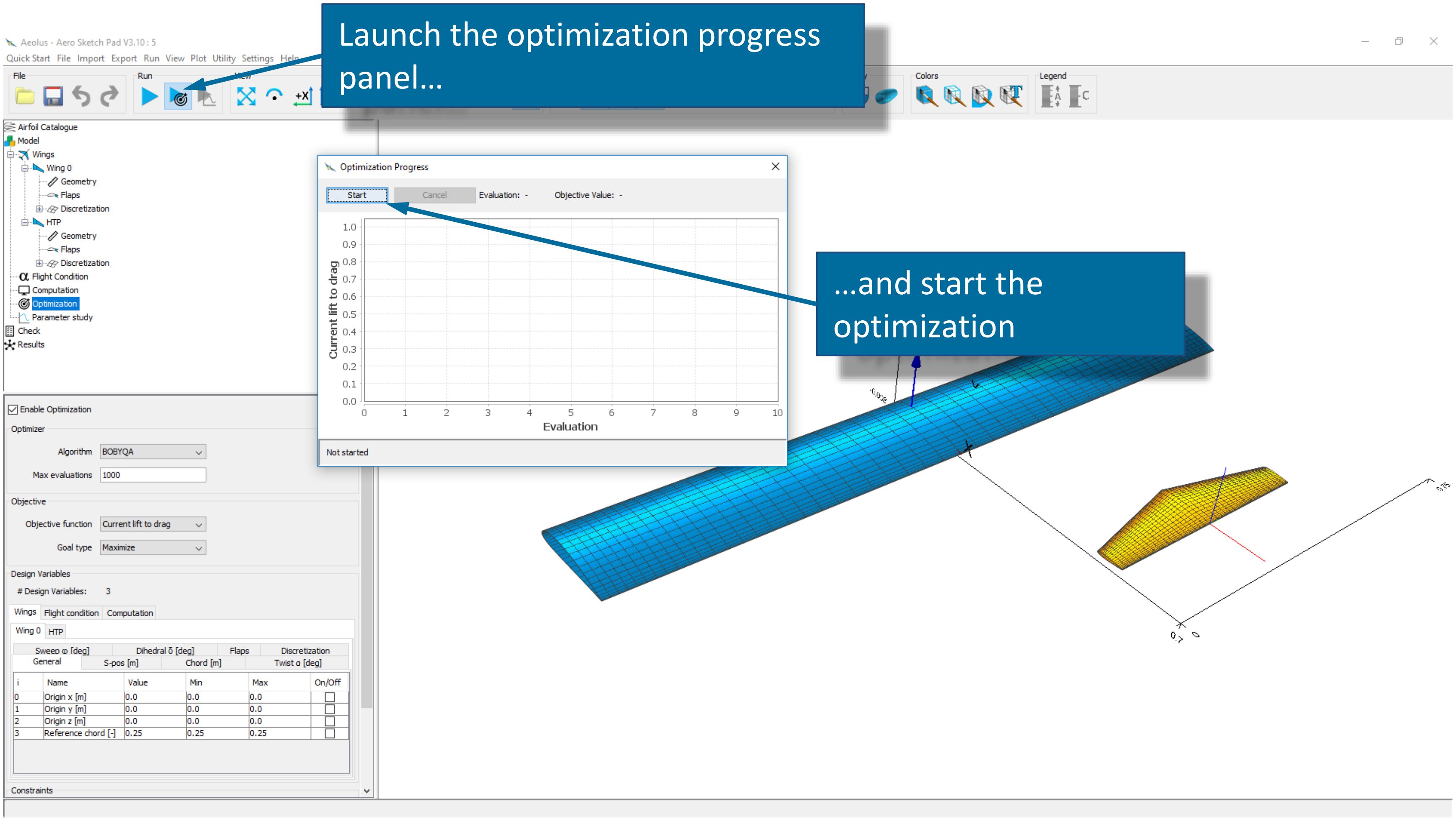
The penalty value is set automatically and typically does not need to be changed.

# Wing Shape Optimization

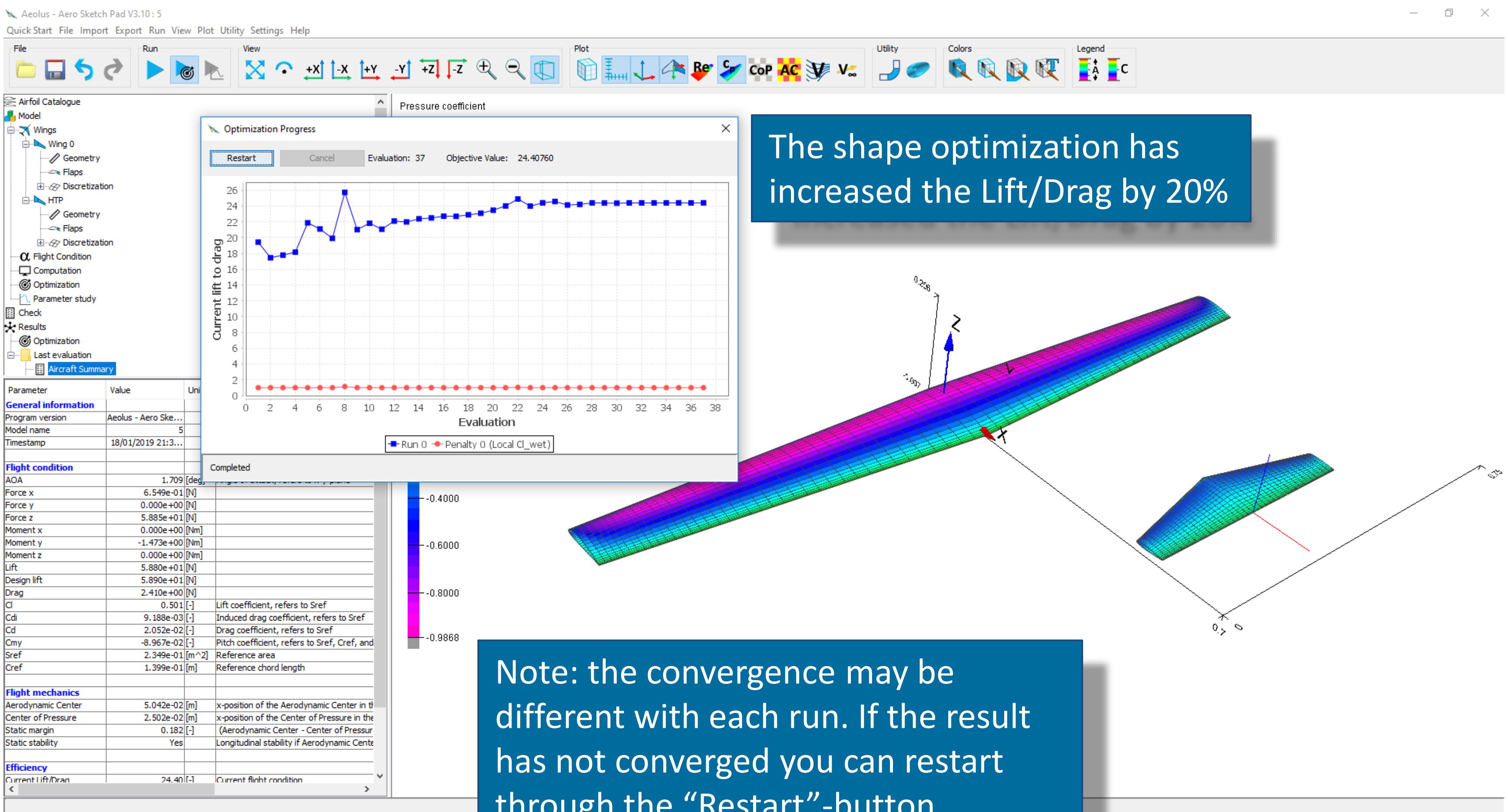



Add the constraint on the local lift coefficient as shown.

# Wing Shape Optimization



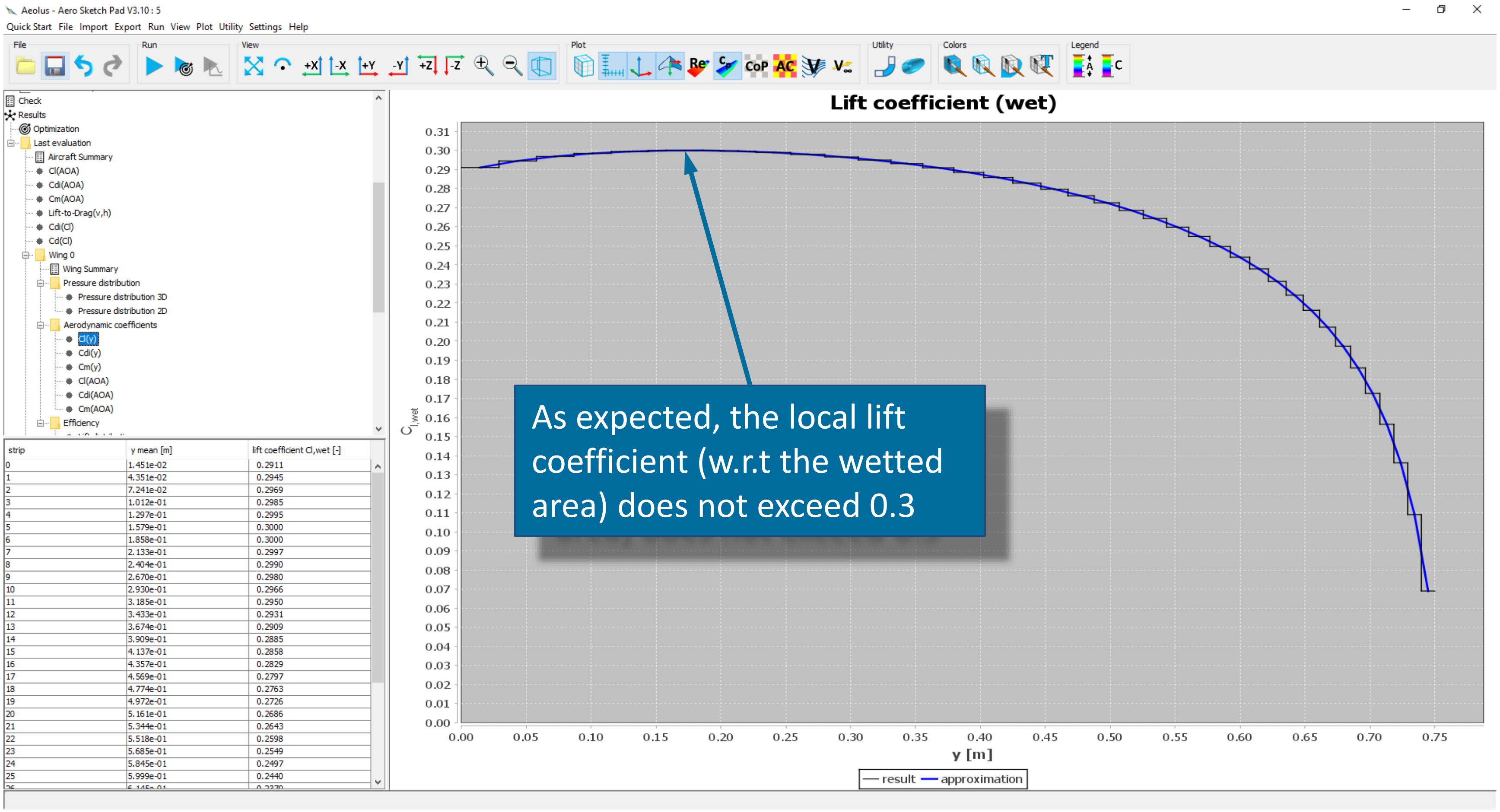
# Wing Shape Optimization




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



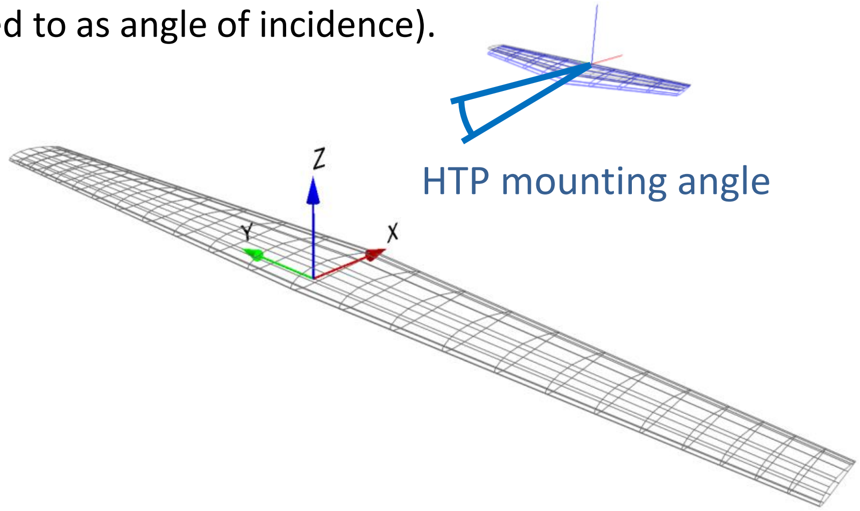

| strip | y mean [m] | lift coefficient Cl,wet [-] |
|---|---|---|
| 0 | 1.451e-02 | 0.2911 |
| 1 | 4.351e-02 | 0.2945 |
| 2 | 7.241e-02 | 0.2969 |
| 3 | 1.012e-01 | 0.2985 |
| 4 | 1.297e-01 | 0.2995 |
| 5 | 1.579e-01 | 0.3000 |
| 6 | 1.858e-01 | 0.3000 |
| 7 | 2.133e-01 | 0.2997 |
| 8 | 2.404e-01 | 0.2990 |
| 9 | 2.670e-01 | 0.2980 |
| 10 | 2.930e-01 | 0.2966 |
| 11 | 3.185e-01 | 0.2950 |
| 12 | 3.433e-01 | 0.2931 |
| 13 | 3.674e-01 | 0.2909 |
| 14 | 3.909e-01 | 0.2885 |
| 15 | 4.137e-01 | 0.2858 |
| 16 | 4.357e-01 | 0.2829 |
| 17 | 4.569e-01 | 0.2797 |
| 18 | 4.774e-01 | 0.2763 |
| 19 | 4.972e-01 | 0.2726 |
| 20 | 5.161e-01 | 0.2686 |
| 21 | 5.344e-01 | 0.2643 |
| 22 | 5.518e-01 | 0.2598 |
| 23 | 5.685e-01 | 0.2549 |
| 24 | 5.845e-01 | 0.2497 |
| 25 | 5.999e-01 | 0.2440 |

As expected, the local lift coefficient (w.r.t the wetted area) does not exceed 0.3

# Static Stability

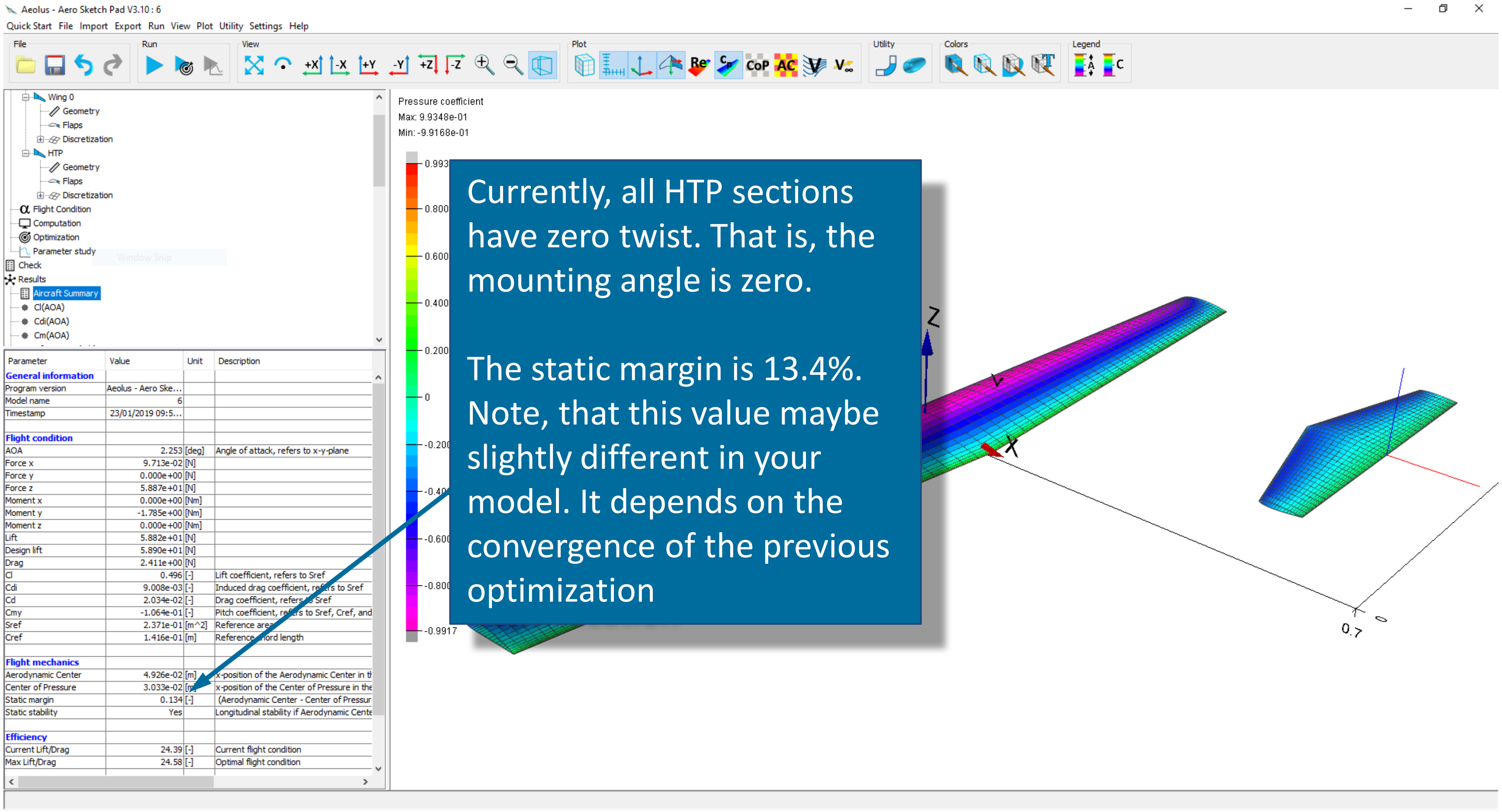
In this section the static longitudinal stability of the aircraft will be tuned. A common measure for longitudinal stability is the static margin, which is defined as the distance between the center of gravity and the aerodynamic center (neutral point) of the aircraft, expressed as a percentage of the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



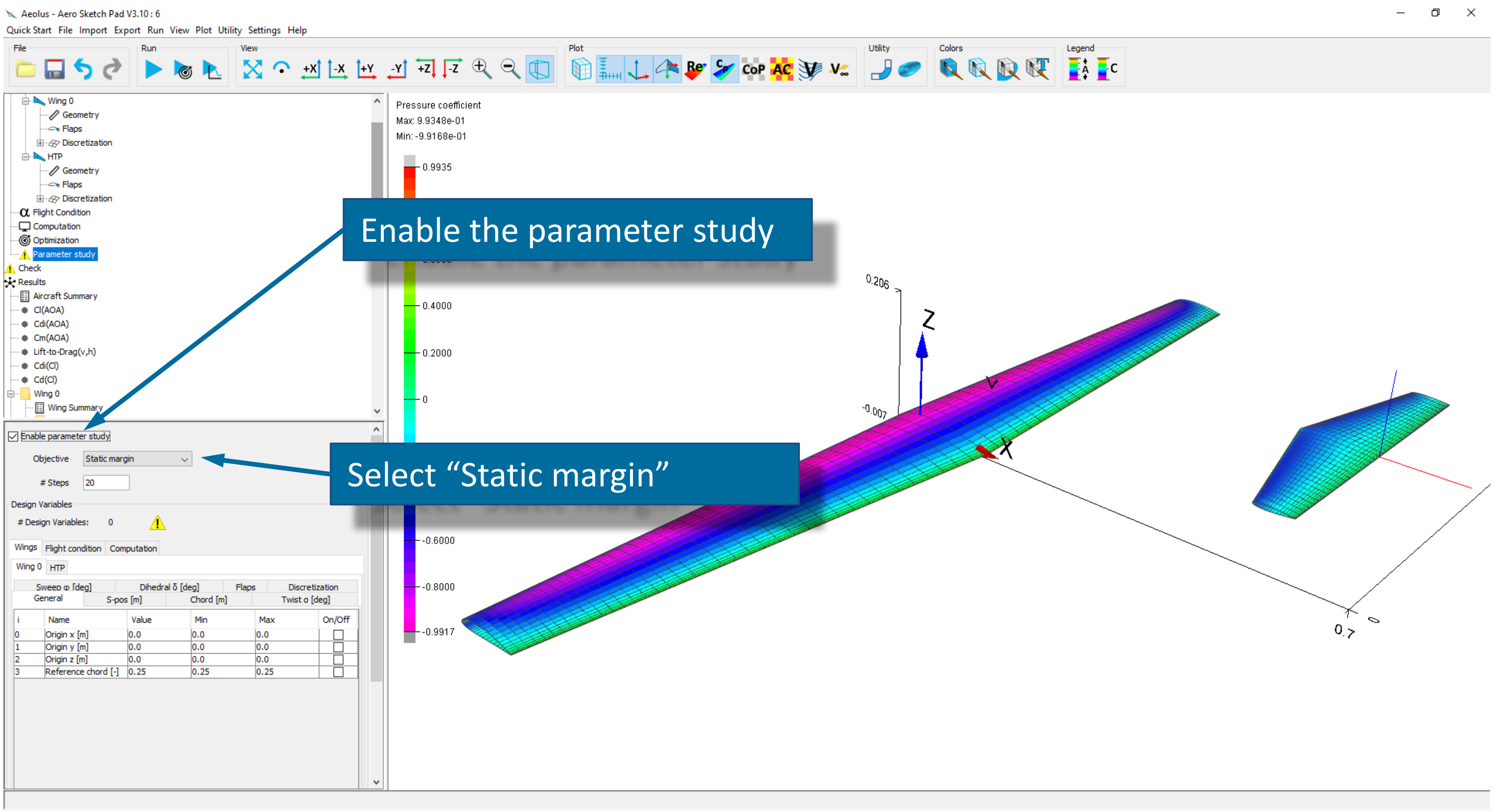

In this example, the use of the „Parameter Study“-feature will be demonstrated for this purpose. The objective is to plot the static margin for a certain range of HTP mounting angles.

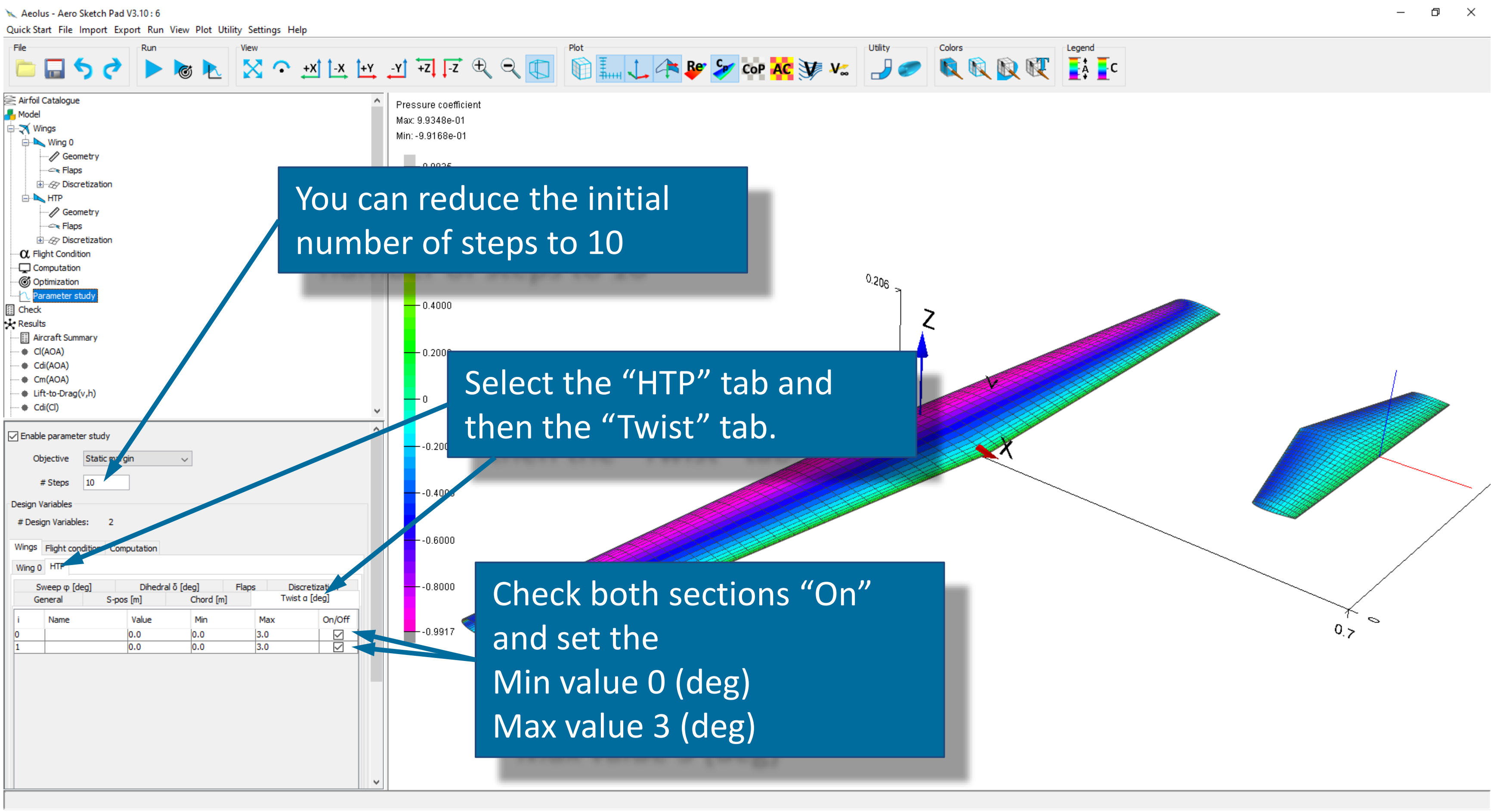
# Static Stability



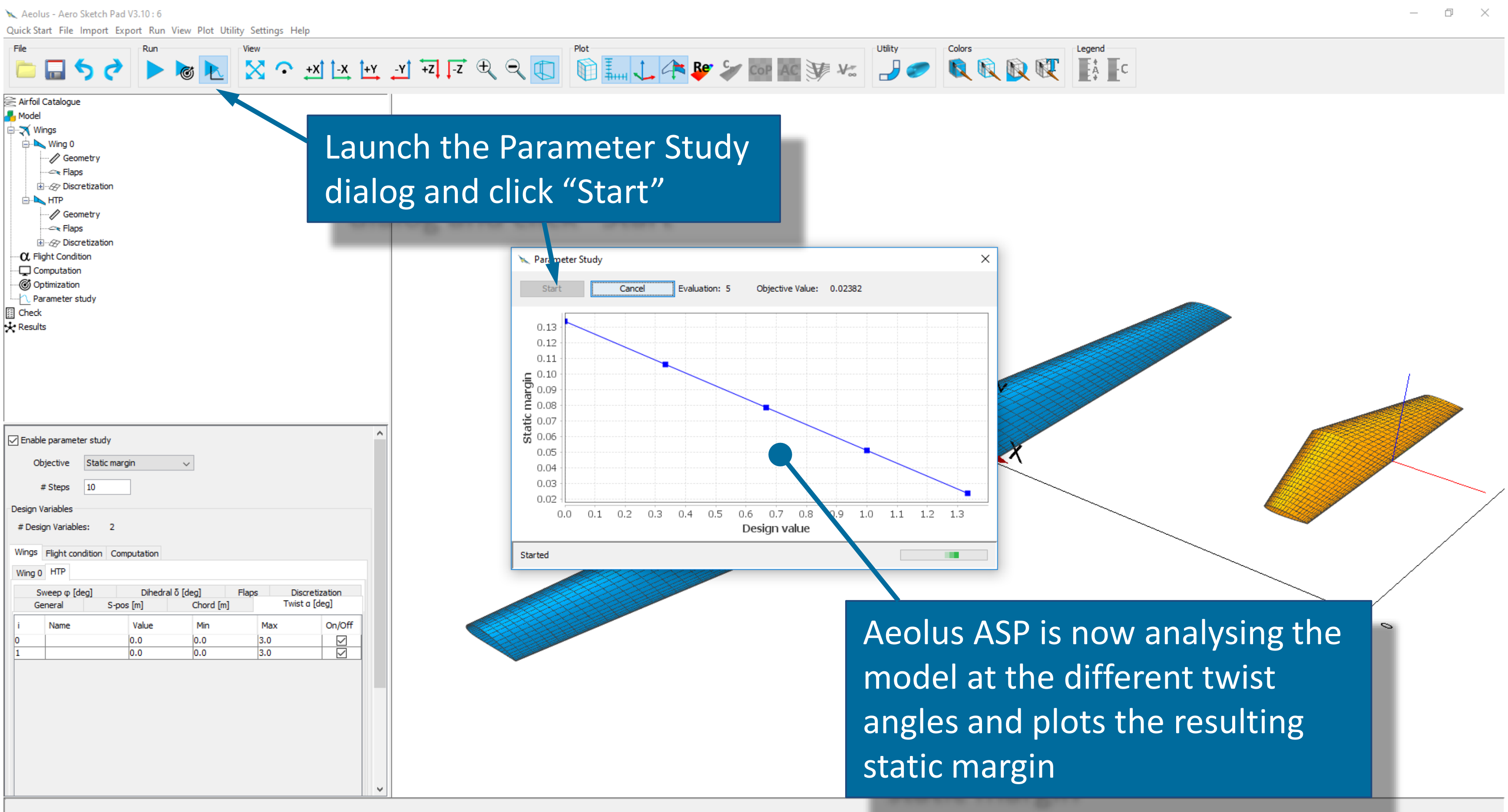

Currently, all HTP sections have zero twist. That is, the mounting angle is zero.

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


Aeolus - Aero Sketch Pad V3.10 : 6
Quick Start File Import Export Run View Plot Utility Settings Help
Pressure coefficient
Max: 9.9348e-01
Min: -9.9168e-01
Enable the parameter study
Select “Static margin”
Enable parameter study
Objective
Static margin
# Steps
20
Design Variables
# Design Variables: 0
Wing 0
Geometry
Flaps
Discretization
HTP
Flight Condition
Computation
Optimization
Parameter study
Check
Results
Aircraft Summary
Wing Summary

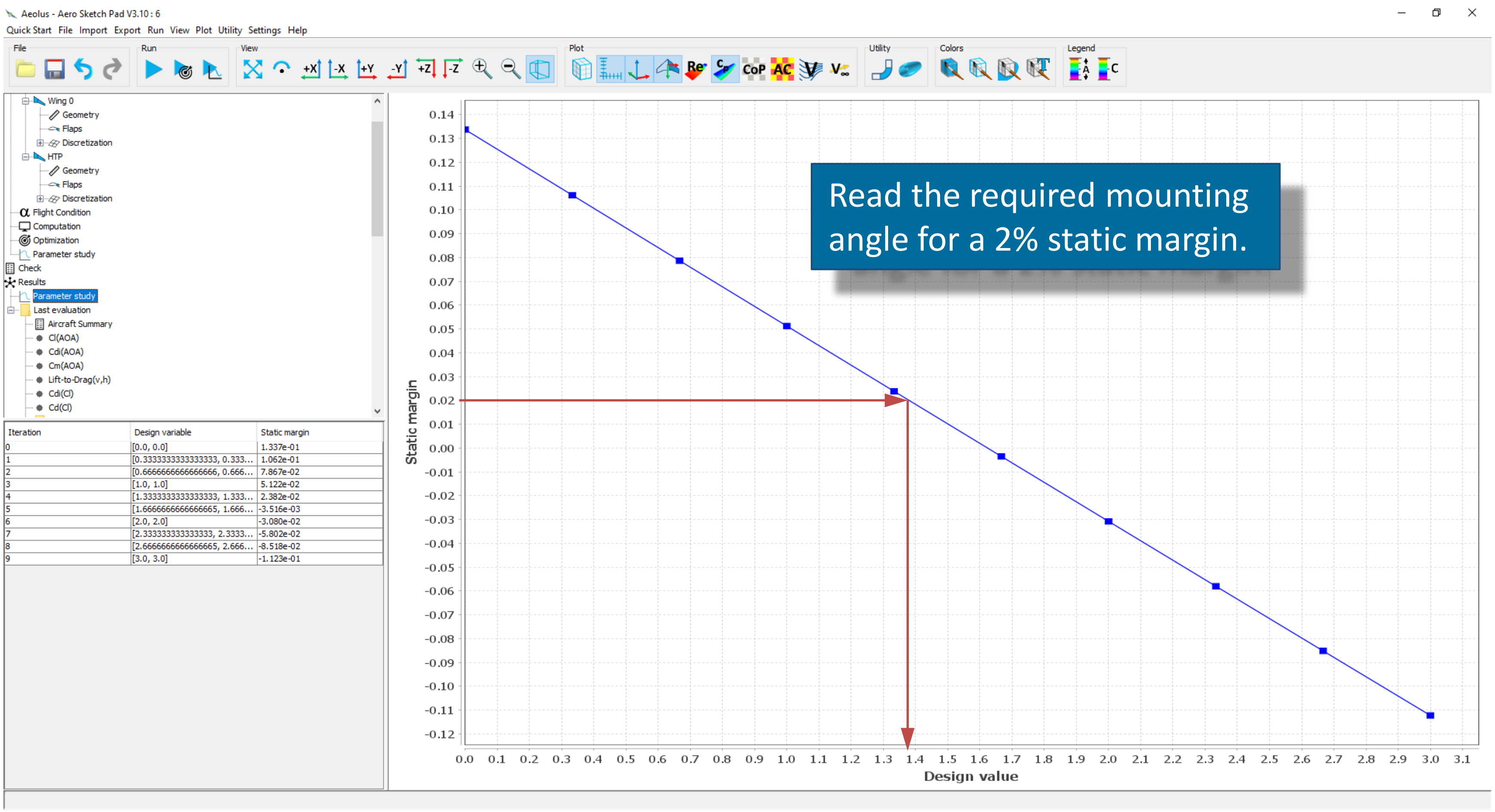


Aeolus - Aero Sketch Pad V3.10 : 6
You can reduce the initial number of steps to 10
Select the “HTP” tab and then the “Twist” tab.
Check both sections “On” and set the
Min value 0 (deg)
Max value 3 (deg)



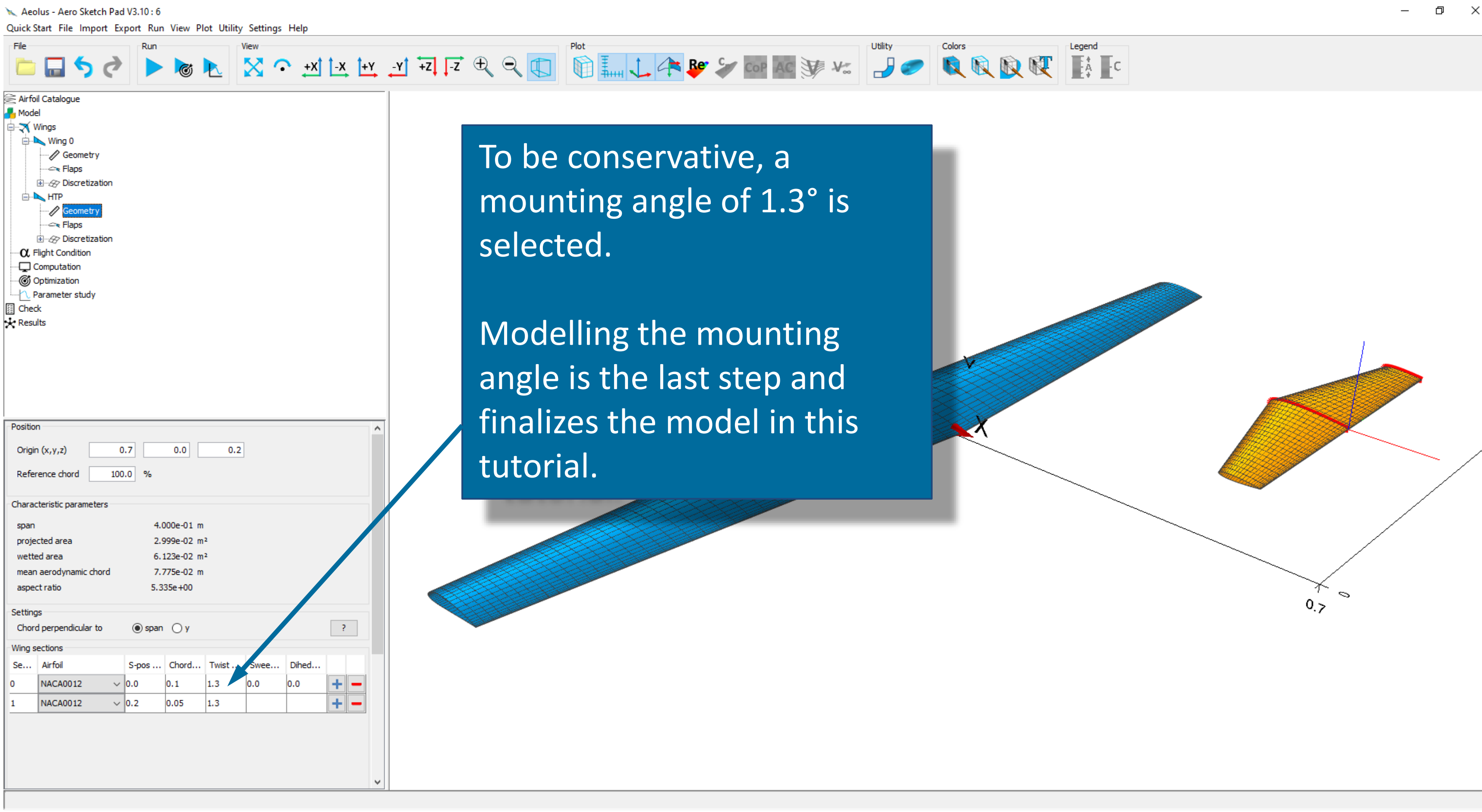

Launch the Parameter Study dialog and click "Start"

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




| Iteration | Design variable | Static margin |
|---|---|---|
| 0 | [0.0, 0.0] | 1.337e-01 |
| 1 | [0.3333333333333333, 0.333... | 1.062e-01 |
| 2 | [0.6666666666666666, 0.666... | 7.867e-02 |
| 3 | [1.0, 1.0] | 5.122e-02 |
| 4 | [1.3333333333333333, 1.333... | 2.382e-02 |
| 5 | [1.6666666666666665, 1.666... | -3.516e-03 |
| 6 | [2.0, 2.0] | -3.080e-02 |
| 7 | [2.3333333333333333, 2.3333... | -5.802e-02 |
| 8 | [2.6666666666666665, 2.666... | -8.518e-02 |
| 9 | [3.0, 3.0] | -1.123e-01 |

Read the required mounting angle for a 2% static margin.




To be conservative, a mounting angle of 1.3° is selected.

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

Aeolus

Aero Sketch Pad

# Thank you

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January 2019

www.aeolus-aero.com