



# User manual

Version 1.40

**Overview**

ACE of Aircraft is a software made to help its users estimate performances of different aircraft designs.

In ACE of Aircraft, users can model the air flow, compute the aerodynamic coefficients, estimate the angle of stalling, etc., using different CFD methods.

**Target audience**

This user manual is directed to an audience with knowledge in aerodynamics and aeronautics. We assume that the user is accustomed with the concepts and terms presented or used in the software.

# ACE of Aircraft

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# Part I.

## BEFORE USE

### 1. Installation

#### 1.1. Requirements

**For basic features (Access and bronze licenses):**

Supporting system : Windows 10 / Windows 11

Interpreter : Python 3.10 - 64 bits

CPU : no requirement

GPU : no requirement

RAM : 4 GB

HDD : 4 GB free

**For advanced features (Gold and platinum licenses):**

Supporting system : Ubuntu 22.04 LTS / 24.04 LTS

Interpreter : Python 3.10 - 64 bits

CPU : 8 to 24 processing cores @ 2.2GHz or more, per computer. If possible a CPU designed for HPC, CFD-computing (AMD epyc, Intel Xeon Gold/Platinum, etc.). A better CPU will allow you to process Navier-Stokes computations faster.

GPU : GTX 1650 or higher

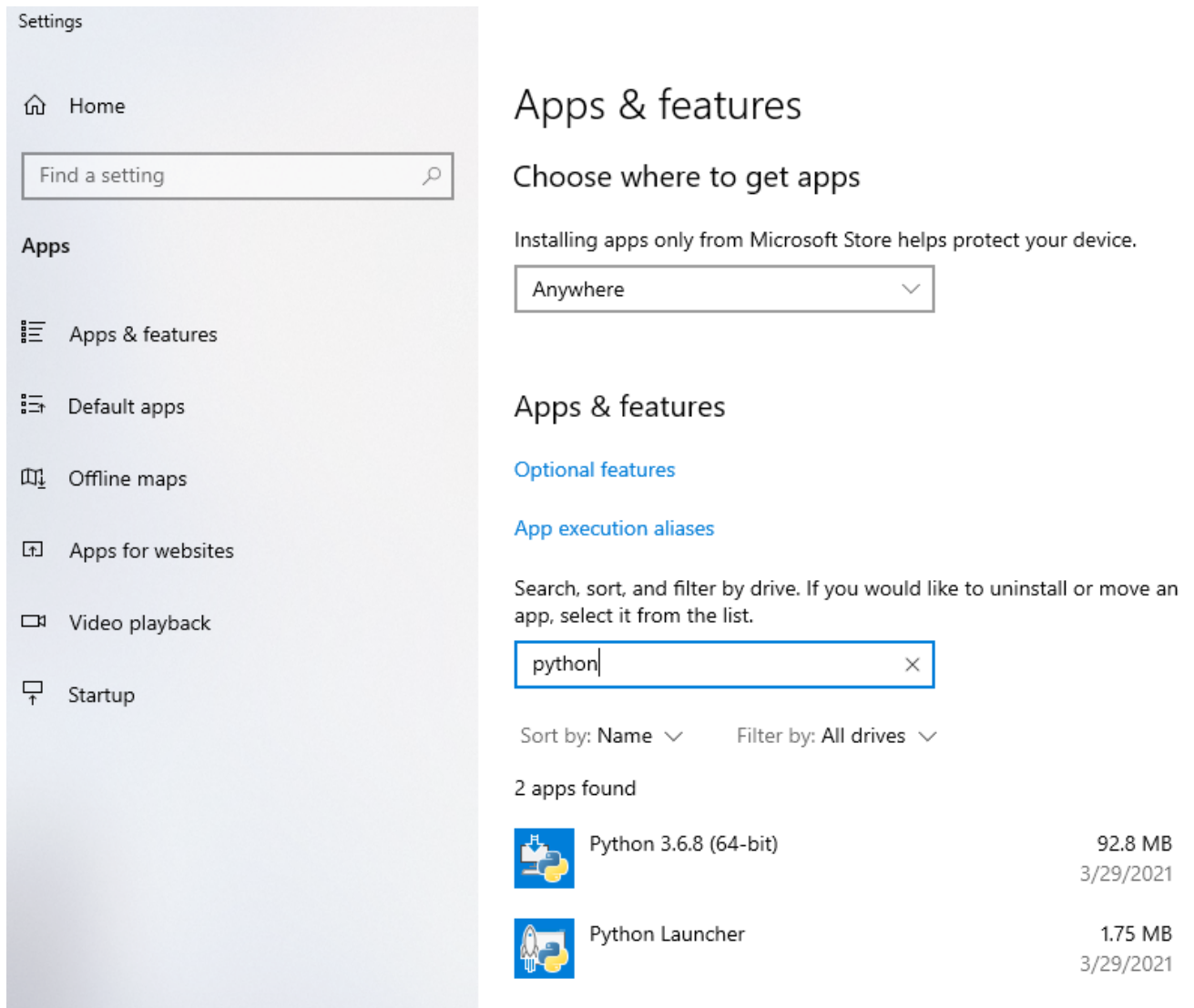
RAM : 21 to 256 Go of RAM per computer. More RAM will allow you to model geometrical details of smaller scale.

HDD : 8GB free space for installation. Then we recommend to have 1 TB space or more to store the data that will be generated by your Navier-Stokes computations.

#### 1.2. Windows install

##### Installation of Python 3.10

- Python 3.10 64 bits is required to use ACE of Aircraft. You may check if you already have this software by entering the following keywords in the windows search bar : “Add or remove programs”. This will lead you to a system settings window listing all software installed on the computer. In that window you can use the search bar to search for “python”, as shown in the following image.

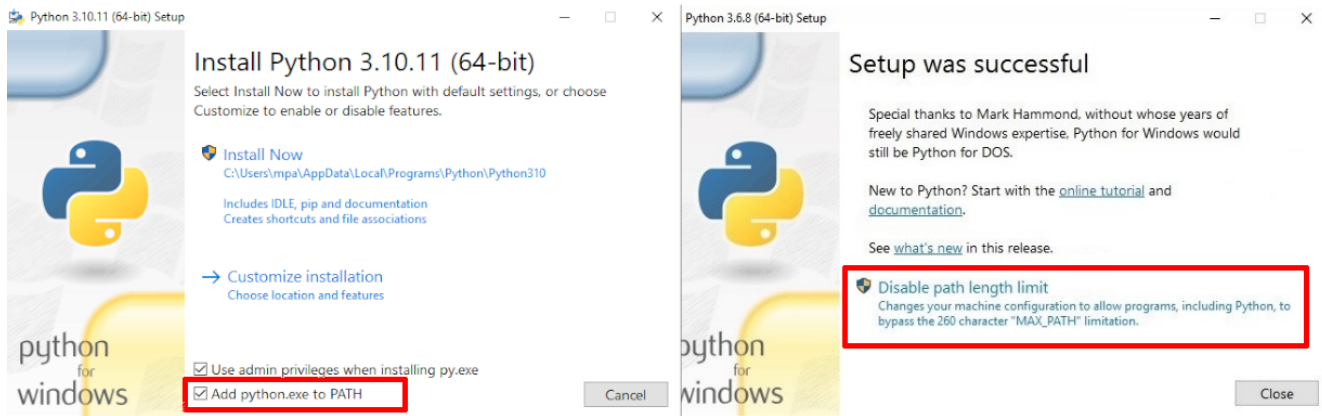


- If you already have an appropriate version of python, skip the following steps and proceed to install ACE of Aircraft. Otherwise, please download an appropriate version from [python.org](https://python.org).

**Note:** python versions 3.10.11 have been tested and is compatible. It is important to note that **only 64 bits versions are compatible**.

- Execute the installer for python 3.10.11
- Make sure to validate "Add python 3.10 to PATH" during the installation, as shown in the following image.
- You can disable "path length limit", as shown in the following image.





## Installation of Microsoft build tools

- Search the net for Microsoft Visual Studio website, and download the installer for the Microsoft C++ build tools.
- During the installation, make sure you enable the installation of the module named "Desktop Development with C++". All other modules are not necessary.

## Installation of ACE of Aircraft

- Find the installer named Ace\_of\_Aircraft\_vX.XX\_installer.exe.
- Execute this installer and follow the instructions of the installer.

## 1.3. Ubuntu install

The point of using the ubuntu version of Ace of Aircraft is to have access to the Navier-Stokes modeling which is powered by OpenFoam. This is available only at the gold and platinum license level. You will need an internet connection to install the software.

Go to the settings of Ubuntu, in the power settings, and disable any kind of power saving setting such as the inactivity blank screen. This can cause computations to halt when the mouse and keyboard are not used.

Our software have a few dependencies (Python 3.10, OpenFoam and freeCAD). All these dependencies , as well as Ace of Aircraft itself, are installed by running the installation script named "setup-ace-of-aircraft-vX.XX.sh".

To install on ubuntu:

- Download the files "setup-ace-of-aircraft-vX.XX.sh" and "ace-of-aircraft-vX.XX.deb". Both these files should be together in the same folder.
- Open this folder and make a right click on its background, choose the option "open in terminal".

- In the command prompt that opens, run the following command (replacing the *X.XX* by the current version number):

```
bash setup-ace-of-aircraft-vX.XX.sh 2>&1 | tee setup.log
```

This will launch the software downloads and installation.

NB: If there is a problem, the file "setup.log" that is created during the installation can be sent to our support team to help finding what went wrong.

## **1.4. Setting-up a cluster running Ubuntu LTS**

To reduce solving times of Navier-Stokes computations, you may want to build a cluster with several computer. One computer will run ACE of Aircraft graphical interface, we will call him "master" as he will be sending job orders to the other computers. The other computers will be called slave1, slave2, etc., as they merely execute Navier-Stokes simulations and send the data back to the master.

For the cluster to work properly it is important to set each of them exactly the same way. It is required that :

- The same user exists on all computers, with the same password
- This user account must have the same user ID on all computers. If possible, install users in the same order to facilitate the installation process
- All computers must have a fixed IP address
- All computers must have the same version of ACE of Aircraft installed as described in the preceding chapter. But only the master computer need to have a platinum license installed. The slave computers do not need any license.

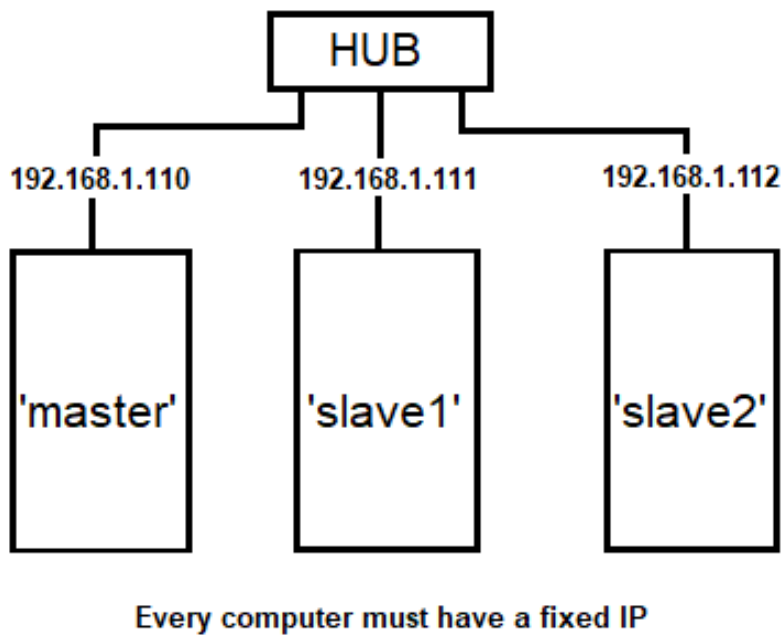


Figure 1: Representation of a computing cluster.

### Master computer set-up

On the master computer, open a terminal and launch the following command, to install a couple of software packages necessary for the computers to connect to each other and read data from network shares:

```
sudo apt install openssh-server nfs-kernel-server
```

Answer Yes when prompted for a choice. You will need an internet connection for this step.

On the master, open a terminal and launch the following command to create an authentication key:

```
ssh-keygen
```

When the prompt requests parameter choices, directly hit the enter key to use the default value of each option.

Then execute the following command with the Ip address of each slave computer to associate the key onto the slave machine:

```
ssh-copy-id (IP-address-of-slave)
```

Where (IP-address-of-slave) must be replaced by a valid IP address. You will need to enter your user password to validate the connection.

Then, edit the exports file with the command:

```
sudo nano /etc/exports
```

At the end of this file, add the following line (This is supposing the datadir is at the default adress, also note that in all addresses given in this manual, 'vX' must be replaced by the actual Ace of Aircraft software version.):

```
/usr/lib/ace-of-aircraft/ace-of-aircraft-vX/datadir/  
192.168.1.*(rw,sync,no_root_squash,no_subtree_check)
```

This must be a single line, even if the line may be splitted by the format of this document. This will authorise the folder pointed by the given path to be shared accessed through the network by authenticated users. And finally use this command to restart the nfs service:

```
sudo systemctl restart nfs-kernel-server
```

### **Slave computer set-up**

On each slave computer, open a terminal and install the necessary packages, as it was done before for the master, with the command:

```
sudo apt install openssh-server nfs-kernel-server
```

Remember each slave computer will need an internet connection for this step. Then run:

```
sudo mkdir /Ace_of_Aircraft_datadir
```

This will create a folder where the data share will be mounted, so that the slave will be able to read and write data on the master computer. To mount this share on your slave computer, you must edit the fstab file with the following command:

```
sudo nano /etc/fstab
```

At the end of this file, add the line:

```
(masterIPaddress):/usr/lib/ace-of-aircraft/ace-of-aircraft-vX/datadir  
/Ace_of_Aircraft_datadir nfs _netdev,bg,user,hard,intr,actimeo=900 0 0
```

As in preceeding steps, (masterIPaddress) must be replaced by the actual IP address of the master computer, and vX must be replaced by the actual software version. Please note this is in the case your datadir is at the default address. This is also a single line.

Then restart all computers, starting with the master. To check if it worked, from a slave computer, look what is in the /Ace\_of\_Aircraft\_datadir folder. If it is empty, something went wrong. You should see the same content of what is on the datadir folder on the master computer.

## 2. Updates

### 2.1. upgrading ACE of Aircraft on Windows

This is the recommended way to upgrade from one Ace\_ofAircraft version to another:

- Install the new version.
- Go to the installation directory, by default : %AppData%
- Copy your projects from the older version to the newest version. By default you projects are at the directory %AppData%/Ace\_of\_Aircraft\_vX/datadir
- At the same location, copy the userdata folder, containing your settings and license
- Check the file %AppData%/Ace\_of\_Aircraft\_vX/configuration.py, any special configuration made in this file should be copied to the file of the new version.
- Launch the new version and check that all your data and settings have been correctly transferred to the new version.
- Facultatively, you may uninstall the old version using windows system settings apps, "Add or remove programs" section. Note that this will not delete your projects data, if you want to clear space you will have to delete files at %AppData%/Ace\_of\_Aircraft\_vX/datadir manually.

### 2.2. upgrading ACE of Aircraft on Ubuntu

This is the recommended way to upgrade from Ace\_of\_Aircraft, supposing you upgrade from version X to version Y:

- Install the new version Y with the .deb package. This will create the directory /usr/lib/ace-of-aircraft/ace-of-aircraft-vY
- Locate the application directory for the old version at /usr/lib/ace-of-aircraft/ace-of-aircraft-vX.
- Copy your project files and the userdata folder, from the old version data-directory to the new one (by default at /usr/lib/ace-of-aircraft/ace-of-aircraft-vX/datadir).
- Check the file /usr/lib/ace-of-aircraft/ace-of-aircraft-vX/configuration.py, any special configuration made manually in this file should be copied to the file of the new version Y.
- Launch the new version Y and check that all your data and settings have been correctly transferred to the new version.
- Facultatively, you may remove the old version by running in a terminal the following command-line: `sudo apt remove ace-of-aircraft-vX`  
Note that this will not delete your projects data, if you want to clear space you will have to delete files left at /usr/lib/ace-of-aircraft/ace-of-aircraft-vX

## 2.3. upgrading ACE of Aircraft on a Ubuntu cluster

Proceed as described on the preceding chapter on the master computer. Then check if the datadir path in the exports file must be updated, with the command:

```
sudo nano /etc/exports
```

For the slave computers, install the new version Y with the .deb package. If needed, edit the fstab line to mount the correct datadir share:

```
sudo nano /etc/fstab
```

## 3. License information

### 3.1. License levels and corresponding features

The following table lists the features unlocked by each license type.





License level	Access 	Bronze 	Gold 	Platinum 
Analytic tools	✓	✓	✓	✓
Models	✓	✓	✓	✓
Draft projects	✓	✓	✓	✓
VLM projects		✓	✓	✓
NS projects			✓	✓
Additional options for NS projects *				✓
OS compatibility	Windows or Ubuntu	Windows or Ubuntu	Ubuntu	Ubuntu

Figure 2: License levels.

To understand the differences between Draft, VLM and NS projects, see part 2.2.

### \* **Platinum additional options for NS projects:**

At gold level there is only one turbulence model available in NS projects, the SA model. The platinum license gives you an extended choice of turbulence models : SA, KW, SA\_unsteady, KW\_unsteady. You can find more details about these turbulence models at the end of part 2.2.

The platinum license also allow you to use a cluster of computers to solve your Navier-Stokes run queue, instead of a single computer.

Additionally the platinum license unlocks multiple boundary conditions. With the gold license, any surface imported from CAD files will become an airtight wall surface in the model. With the platinum license more options are given, which enables the modeling of propeller flow, heat-exchangers, air-intake, air-exhaust and flow-report surfaces. See part 3.4 for more details.

## **3.2. How to install a license**

You can execute ACE of Aircraft without installing a license, but most features will be disabled. To request a license, launch ACE of Aircraft and follow these steps:

- Click on the “Settings” tab on the top right corner of the application.
- In the bottom right corner of the window, you will find your machine ID. Copy it and use it in the form available at : [www.aero-ce.com/en/ace-of-aircraft-downloads](http://www.aero-ce.com/en/ace-of-aircraft-downloads)
- On the 'Settings' screen is also displayed the address of the **userdata folder**. Note down this address, you will need it later.
- ACE will return you a license file named “lic.dat” by email.
- Paste the license file into the **userdata folder**, or use the 'import a license file' button in the "Settings" tab.
- Restart ACE of Aircraft and check the license validity in the “Settings” tab of the application.

# Part II.

## USING THE SOFTWARE

### 1. Navigation bar

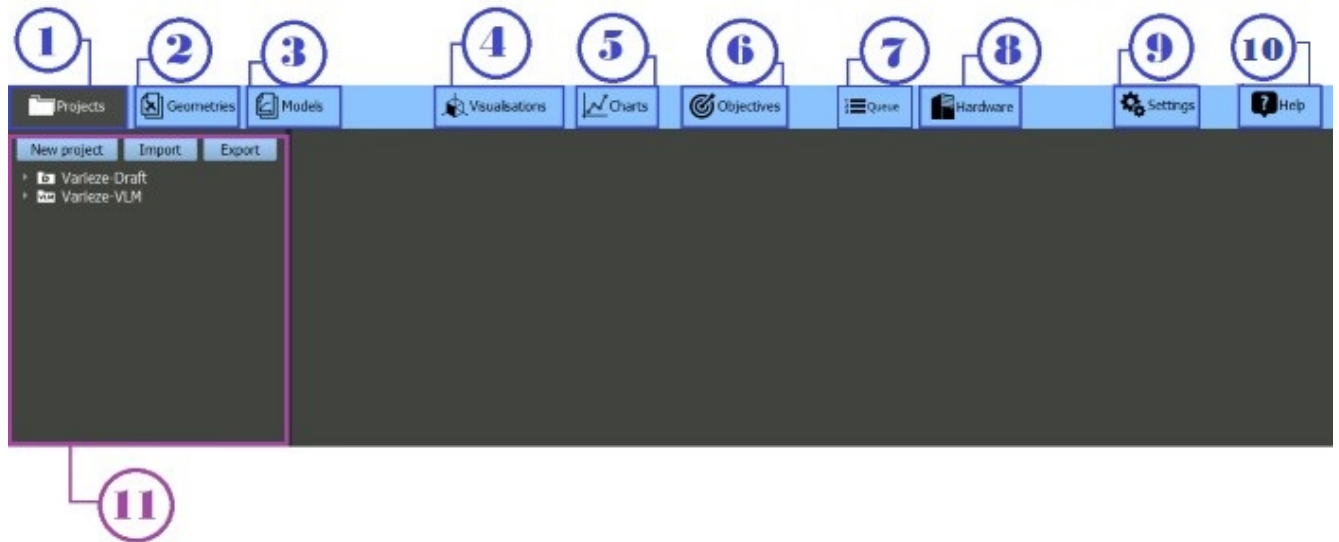


Figure 3: Screenshot of the software navigation bar.

#### 1. **Projects tab**

A project is a directory containing various data generated during a study.  
For more information, see 2. Projects

#### 2. **Geometries tab**

Geometry is the spatial modeling of the airplane shape cut into different parts.  
For more information, see 3. Geometries

#### 3. **Models tab**

Models are simple numerical laws binding a physical condition to another.  
For more information, see 4. Models

#### 4. **Visualisations tab**

3D visualisation and pictures to inspect and compare the Navier-Stokes results.  
For more information, see 5. Visualisations

#### 5. **Charts tab**

Charts is a tool to compare different configurations.  
For more information, see 6. Charts

#### 6. **Objectives tab**



Define objectives to evaluate your designs and compare them.  
For more information, see 7. Objectives

#### 7. **Queue tab (or job manager)**

Launch or stop runs of Navier-Stokes projects.  
For more information, see 8. Queue

#### 8. **Hardware tab**

See the CPU, RAM and disk usage. Add or remove computer(s) to the computing cluster.  
For more information, see 10. Hardware

#### 9. **Settings tab**

Add or remove a license. Get access to elements not allowed by your license. Define the default units.  
For more information, see 9. Settings

#### 10. **Help tab**

Manual, tutorials, support and contact.  
For more information, see 11. Help

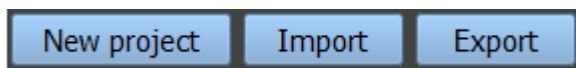
#### 11. **Tree view**

Each project produced creates a folder containing all the data you enter via the Projects, Geometry and Models tab.  
You can expand each folder to see its content and open any data study you have created.

## 2. Projects

A project is a directory containing various data generated during a study.  
Projects have an associated "type" indicating what kind of numerical modeling is used (Oswald efficiency factor, VLM, Navier-Stokes 2D or Navier-Stokes 3D).

### 2.1. Buttons



**New project:** create a new project.

**Import:** import a data folder from your computer.

**Export:** export a data folder. It is useful if you do not have a license and want to transfer your data folder to someone else.



The bin allows you to delete an analysis, a geometry, a data folder...

The pencil allows you to modify an analysis, a geometry or a model. If it is "locked" you cannot modify it anymore. You will probably need to delete children items in order to have this element come back to "unlocked" state.

## 2.2. Project types

### Draft

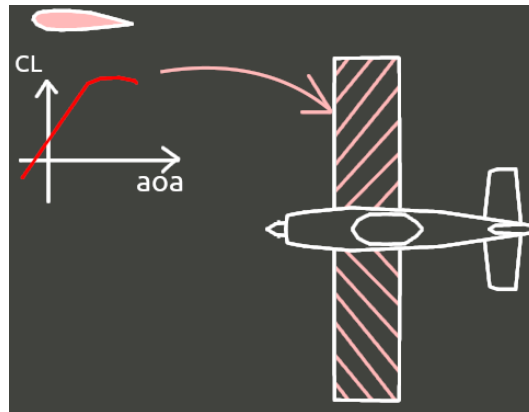


Figure 4: A draft analysis roughly models a lift law over a wing area.

A draft project requires the user to import a lift law from an airfoil polar, and will then apply this law according to the wing area given by the user. The Oswald efficiency factor (induced drag equation) is used to adjust the results from the 2D airfoil data to a more realistic 3D estimated lift and drag.

→ Estimate the performances of the lifting wing only.

- Pros :  
Quick. Only one equation to solve.
- Cons :  
Inaccurate, large approximation, no momentum analysis.

### VLM

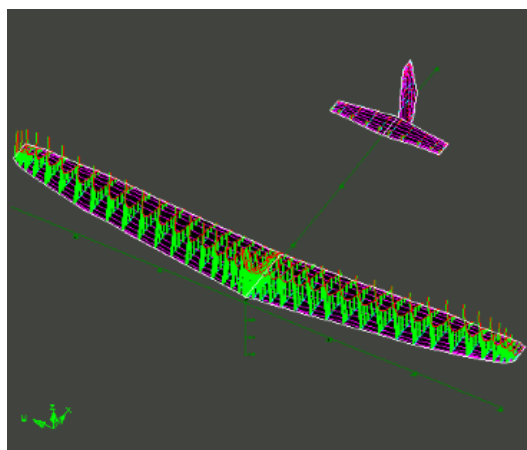


Figure 5: VLM computations are based on a rudimentary 3D geometry model.

Calculation using a third-party: AVL (Athena Vortex Lattice) by Mark Drela and Harold Youngren. This calculation is more precise than the Draft: a 3D geometry is used, modeling the airfoils in 3D, including the empennage.

→ Estimate the performances of an aircraft architecture.

- Pros :

Momentum analysis (but outside of stall effects). The quickest model type for dynamic calculations. 3D interactions between aircraft parts.

- Cons :

Basic geometry. Cannot model multi-element airfoils (slotted flaps) and under-cowl modeling. Inexact modeling of the drag and no modeling of the stall.

## NS2D

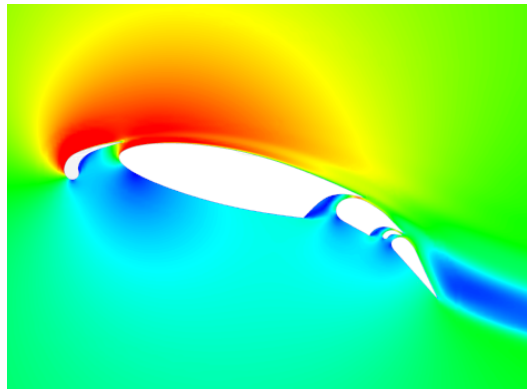


Figure 6: Example of a NS2D solution.

Calculation using a third-party: OpenFoam. Modeling of 2D airfoils. Accurate and detailed modeling of the air flow (speed, pressure and turbulence).

→ Estimate the performances of airfoils or 2D shapes. Can calculate slotted flaps and other multi-element airfoils. Generally used for the optimization of flaps and movement of control surfaces.

- Pros :

Detailed air flow model, can evaluate multi-element airfoils.

- Cons :

A precise CAD of the airfoil is required. The calculation is longer than the VLM.

## NS3D

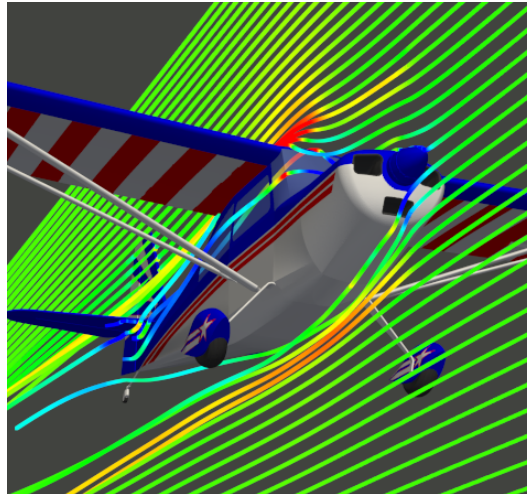


Figure 7: Example of a NS3D solution.

Calculation using a third-party: OpenFoam. Results in 3D for wings or detailed airplanes. Complete flow modeling with stalls effect, momentum, pressure gradients, ground effect. Can be used to study the impact of landing gear, optimize the shape of winglets, pods, fuselage, inflow ducts. Even good for modeling under-cowl environment and internal airflow. Possibility to add rotor models and porous zones (for the modeling of heat exchangers).

→ Estimate the performance of an airplane. Can calculate air flows precisely and optimise the airplane parts in detail.

- Pros :  
Closest to reality because of its accurate 3D geometry definition. Can find the ideal position for Pitot tubes, static pressure tap or optimizes the external and undercowl part shapes.
- Cons :  
A precise and clean CAD is required. The calculation is the longest.

### Turbulence models option

- SA

Turbulence model using the Spalart-Allmaras equation. Quick and simple model. Suitable for airfoils and tapered bodies.

- KW

Turbulence model using two equations :  $k$  and  $w$  (k-omega) with SST (Shear Stress Transport). This is a slightly more complex model. It can be better for bluff bodies, modeling

the wake, modeling under-cowl elements. This model can give slight inaccuracy in stalling angle determination. However stalled results are generally more accurate.

- SA\_unsteady

DDES (Detailed Detached Eddy Simulation) based on the SA model. Modeling several time steps, therefore modeling Vortex shedding and unsteady characteristics of the flow, which generally gives a better accuracy. Simulated duration is set automatically and the solution is averaged on the last few time-steps of the iteration. The computation duration will be long compared to the preceding models.

- KW\_unsteady

IDDES (Improved Detailed Detached Eddy Simulation) based on the k-omega-SST model. This unsteady model with improved wall-modeling capability should be used when accuracy is paramount. The computation duration will be the longest.

For more information, see part V. Correlations.

## 2.3. Analysis types

### Analysis types for VLM projects

- Aerodynamics and sideslip :  
Analysis of an airplane basic performances.  
Computation of several angles of attack and angles of sideslip, to check the stability of the airplane design.
- Forward longitudinal stability limit (VLM) :  
Investigation of the CoG forward limit for longitudinal stability.
- Stability and control derivatives (static,VLM) :  
Measurement of the rate of change in each aerodynamic coefficient as the angle of attack and angle of sideslip changes. (Calculation done for near-zero angles).
- Dynamic stability (VLM) :  
Estimation of dampening and frequency value when the aircraft faces various stability modes, including dutch-roll, phugoid and short period.
- Custom (VLM) :  
Define the parameters of your run(s) : add run(s), select the configuration you want to apply, add option(s).
- Manual :  
It opens an AVL terminal with the selected geometry pre-loaded.

## Analysis types for NS projects (NS2D and NS3D)

- Aerodynamics :  
Computations at different angles of attack which will determine the main performances criteria (stalling angle, maximum lift, maximum lift to drag ratio...).
- Aerodynamics with Reynolds correction :  
Two sets of computation at different angles of attack, for two velocities. Interpolation of a polar at a constant mass. The main performances criteria are more precise.
- Sideslip :  
A set of computation at various sideslip angles. Usually used to check the directional stability of the aircraft.
- Custom :  
Define the parameters of your run(s) : add run(s), select the configuration you want to apply, add options.

## Analysis types for NS3D projects

- Stability derivatives (static) :  
Creation of 3 runs, one for a straight flight, one for a flight with a small angle of attack, and one with a small angle of sideslip.  
The goal being to measure the magnitude of the variation of the aerodynamic coefficients when the angle of attack changes, and when the sideslip angle changes.  
This data can be useful to analyze stability or make flight simulators, or develop auto-pilots.
- Control derivatives:  
Creation of multiple runs, one for a straight flight with null command angles, then one additional run for each command angle that the user want to test (pitch, yaw, roll, flaps or air brake).  
The goal being to measure the magnitude of the variation of the aerodynamic coefficients when a command angle is changed.  
This data can be useful to analyze stability or make flight simulators, or develop auto-pilots.
- Forward longitudinal stability limit (VLM) :  
Investigation of the CoG forward limit for longitudinal stability.
- VTOL:  
This analysis will set up the boundary conditions to model an hover flight. Instead of having a horizontal air flow to model the aircraft forward motion, the flow is initialized with no velocity, and the velocity of the aircraft relative to the ground is null. The air flow will be built from the rotors only. As for the Custom analysis type, many parameters can be set, including ground distance.

## 2.4. Analysis contents

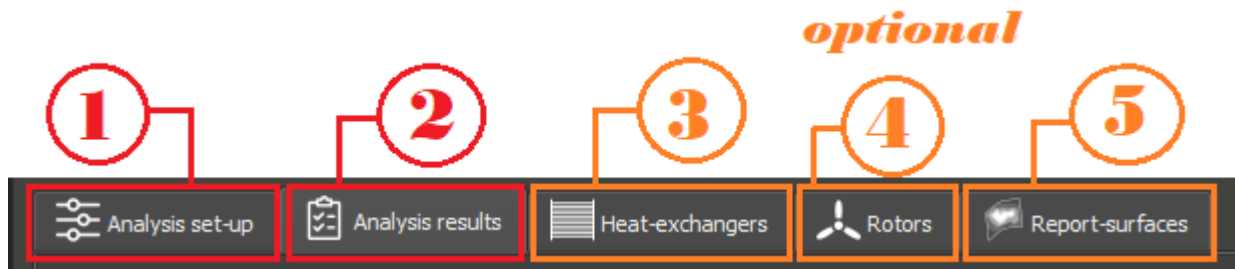


Figure 8: Software screenshot of the tabs presented in the analysis screen within the Projects tab.

### 1. Analysis set-up

Summary of the information you entered when you created your analysis.  
See the advancement of your analysis.

### 2. Analysis results

Results of your analysis.  
More information depending on the type of analysis.

### 3. Heat-exchangers

Results of the heat-exchanger(s) calculation  
Including a results visualisation.

### 4. Rotors

Results of the rotor(s) calculation  
Including a results visualisation.

### 5. Report-surfaces

Results of the report-surface(s) calculation  
Including a results visualisation.

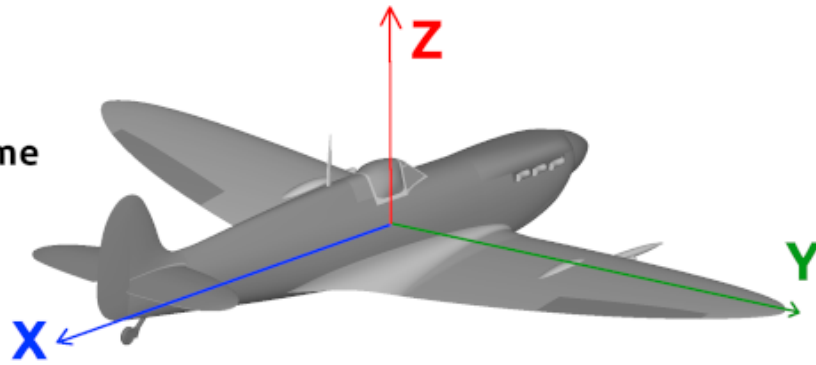
## 3. Geometries

Spatial modeling of an airplane shape cut into different parts.  
You need to define the placement and the delimitation of the parts of your aircraft.  
Note: draft projects do not use geometries .

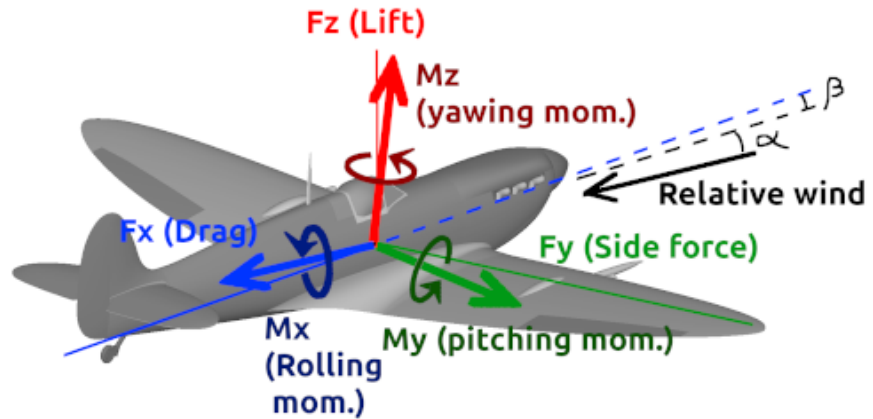
### 3.1. Referential frame, forces and moments directions

All parts created in the software or imported in this software should use the following referential frame:

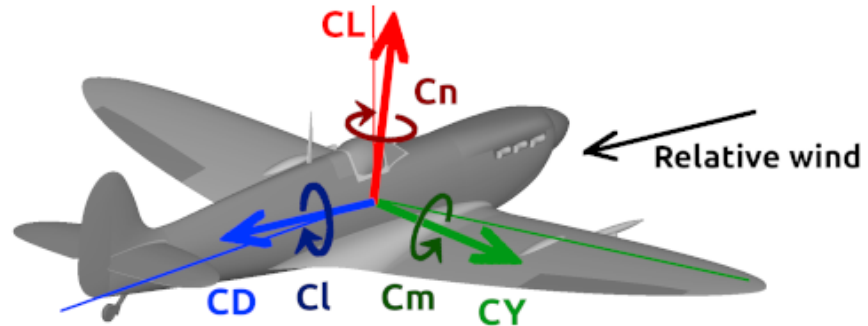
**Geometry CAD  
referential frame**



**Aerodynamic  
torses**



**Aerodynamic  
coefficients**



In the results of the aerodynamic simulation you may find torsor values indicating the aerodynamic forces and moments, as well as the aerodynamic coefficients.

Please note the  $C_n$  is in the opposite direction of  $M_z$ , and  $C_l$  is in the opposite direction of  $M_x$ . This is because the standard aerodynamic referential frame as the Z axis down, and X axis forward, which is not the referential frame expected for the geometry in our case.

### 3.2. Parental bonds for geometries

When creating or editing a geometries, you can set if you wish another geometry as its 'main parent'. Then is is also possible to define one or more geometries as 'other parents'. This functionality allows the user to set parental bonds between geometries. Their relative hierarchical positions can then be seen a tree (available from a button display on a geometry



page).

This parental bonds, with the use of comments in the geometry definition, can help the user to arrange and classify his data, to easily keep track of design branches.

### 3.3. Parts VLM

Define the different parts of your aircraft.

Each part is a geometrical element, it can be a wing, a fuselage, a winglet...

The aerodynamic forces applied will be calculated on each delimited part.

There are two types of parts : body and surface. The first type uses a slender body model, while the other should be preferred for wings and stability surfaces.

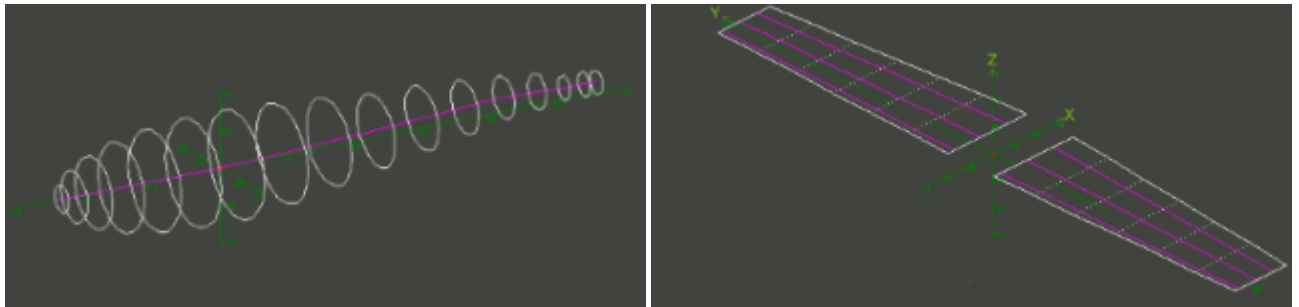


Figure 9: Software picture of the body and surface parts.

Add the center of gravity.

Make sure the unit used for the parts (mm, m, inch, ft) is correct.

For more information, see the AVL manual in the References compressed folder.

### 3.4. Parts NS2D / NS3D

Define the different parts of your aircraft.

Each part is a geometrical element, it can be a wing, a fuselage, a winglet, (...) and must be an .igs file or .stl file.

The aerodynamic forces and moments will be calculated on each delimited part.

Make sure the unit used for the parts (mm, m, inch, ft) is correct. For example, if your CAD software work in millimeters, it will likely export files in millimeters, and you must set the unit choice to "mm" to indicate the imported files are written with that unit.

If you have a bronze or gold license, all parts will be airtight surfaces. However if you have a platinum license and you are setting a 3D geometry in for a NS project, you will have the following options to define the part type :

- Airtight surface :  
A hermetic surface where the air cannot get through.
- Refinement volume :

A closed volume or multiple closed volumes, used only for meshing construction. The cells contained within the given volume are going to be refined to the requested size.

There are 5 size levels :

- ds: detail size (this is a parameter defined for the whole project at project creation)
- ds/2: half of the detail size
- ds/4: quarter of the detail size
- ds/8: eighth of the detail size
- ds/16: sixteenth of the detail size

- Air intake or exhaust :

Model the air intake or exhaust. This is a surface boundary to which a flow rate is applied.

- Flow report surface :

A surface to visualize velocity and pressure (it will not impact the air flow).

- Exchanger volume :

Volume of the radiator core. It does not include the water box but only the volume where the heat exchange takes place. See 4. Exchanger models in 4. Models below.

- Exchanger inlet surface :

Help to calculate the distance from the inlet to the outlet. The surface must be plane and parallel to the outlet.

- Exchanger outlet surface :

The surface must be plane and parallel to the inlet.

- Rotor volume :

It must be cylindrical and positioned where the propeller blades are. Cf Chapter 20.

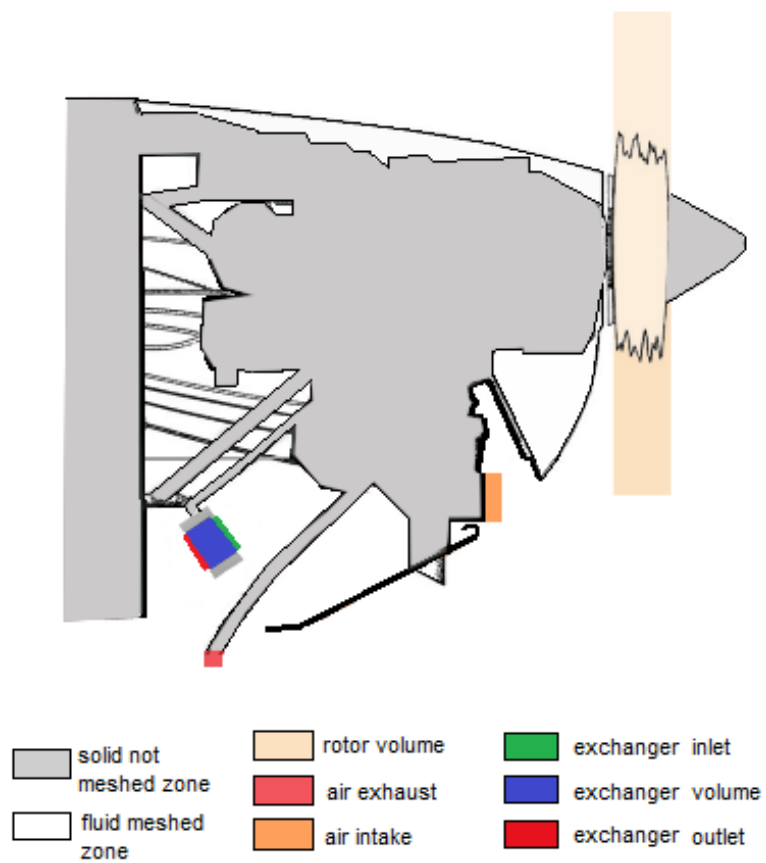
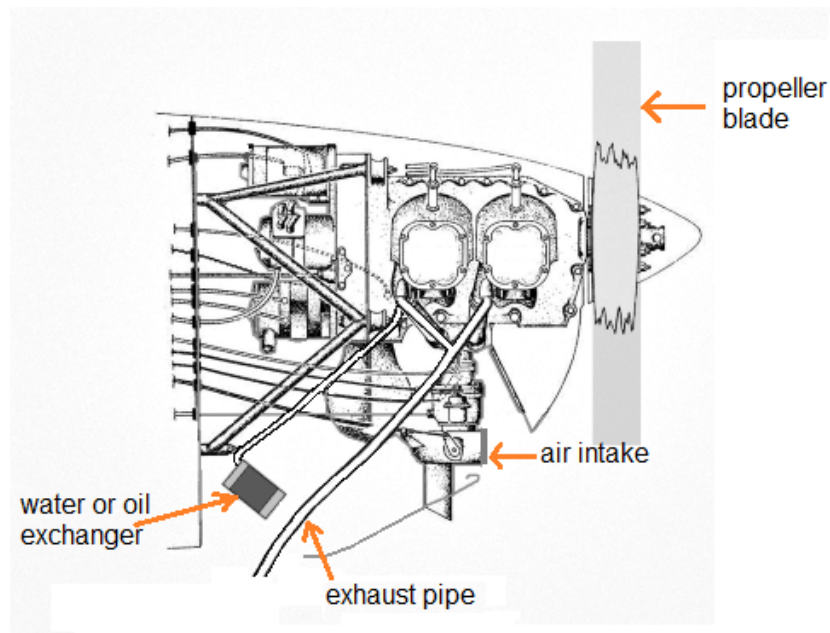


Figure 10: Aircraft under-cowl schemes.

## 4. Models

Models use user-provided values to create numerical laws binding a physical condition to another. These models are relatively simple and fast to solve.

Power models use experimental data (technical note N.640 from the NASA) to build a model of propeller thrust and torque.

For more information on the construction of the power models in ACE of Aircraft, see the ACE of Aircraft - power models file.

You can find the technical note and the ACE of Aircraft - power models PDF file in the References compressed folder provided.

Multiple types of models can be added to studies :

- **Power model (fixed pitch propeller) :**

The addition of the engine and the fixed pitched propeller.

Modeling of the power given to the airplane. This modeling will be determined by some parameters (speed of the propeller, density of air,...).

- **Power model (constant speed propeller) :**

A variable speed propeller turning depending of the speed of the aircraft.

Same modeling as the fixed pitch propeller with a constant speed propeller instead.

- **Power model (custom coefficients) :**

If your propeller manufacturer can provide the thrust and power coefficients of the propeller at various advance-ratio values, you can use this type of model.

When using the fixed-pitch or constant-speed power models, these coefficients are extrapolated from a database, reproducing the behavior of a 'standard' propeller. But with the custom-coefficients model, you can directly input these values for your specific propeller.

- **Exchanger models :**

The software define two laws depending on the air velocity crossing the exchanger :

- The pressure drop
- The heat exchange

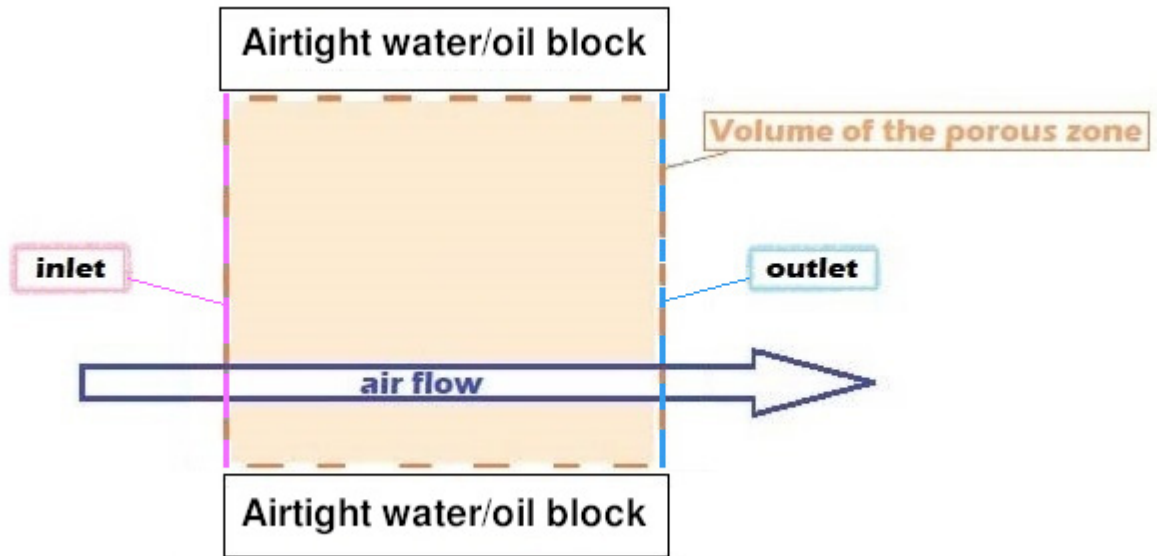


Figure 11: Air flow through an exchanger.

The heat exchanger is modeled by a porous zone.

The pressure drop and heat exchange will be calculated from the velocities passing through the zone.

**Be cautious in your CAD modeling :**

The inlet and outlet must be two parallel planar surfaces.

- **Airfoil model :**

2D geometric definition of an airfoil, from a list of points with X and Y coordinates. A Selig format file should be used to define this list of points.

The Selig format file must be in a .dat file extension to be exported in the software.

→ You can find .dat files for various airfoil at [airfoiltools.com](http://airfoiltools.com), or export .dat files from Xfoil or XFLR5 softwares.

The Selig format file is a succession of precise points that must be defined in the order **(A) → (B) → (C)**.

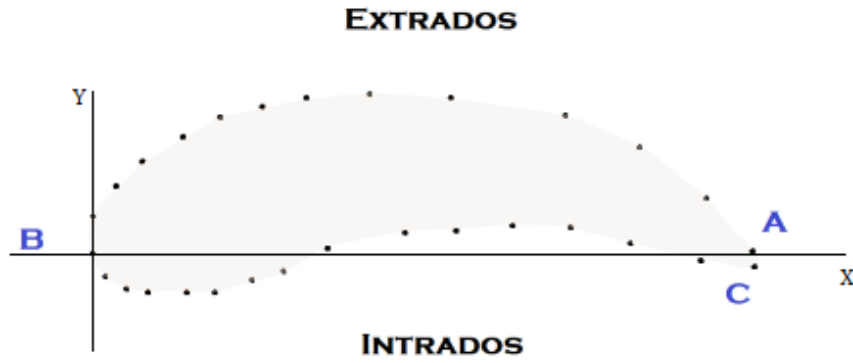


Figure 12: Content of a Selig file.

- **Aerodynamic Coefficient model :**

Import external aerodynamic coefficient results to compare them in the Charts tab.  
Useful to import and compare experimental data.

#### 4.1. Importing a file into an Aerodynamic Coefficient model

When creating an 'Aerodynamic Coefficient model' the user must complete a table of values ; or import a file containing the values by clicking the "Load table from file" button.  
In this case, the file must be a .csv or .dat containing values of the angles of attack (AoA), sideslip (AoS) and the aerodynamic coefficients :

- It must contain 8 columns : AoA, AoS, CD, CY, CL, Cl, Cm, Cn.
- The first line has to start with "# " or "//" : the software will not read it because it is a commentary.  
Between each values, insert a comma (,) or a blank space.
- You need to provide data at least for the AoA and AoS columns.  
If you do not have values for a column, do not leave it empty: type "NA" or any letters.

Here is an example to illustrate :

```
commentary #AOA,AOY,CD,CY,CL,Cl,Cm,Cn
-4,0,0.05,NA,0.02,NA,-0.081,NA
0,0,0.035,NA,0.45,NA,-0.093,NA
9,0,0.062,NA,1.30,NA,-0.112,NA
14,0,0.97,NA,1.7,NA,-0.107,NA
20,0,0.178,NA,1.6,NA,-0.097,NA
```

no values

Figure 13: Example of a .csv file to import aero. coefficients.

## 4.2. Importing a file into a Power model (Custom coefficients)

Import a .csv or .dat file containing values of the advance ratio (J), power coefficient (Cp) and thrust coefficient (Ct):

- It must contain 3 columns : J, Cp, Ct.
- The first line can start with "# " or "//" : the software will not read it because it is a commentary.  
Between each values, insert a comma (,) or a blank space.
- You need to provide data at least for the AoA and AoS columns.  
If you do not have values for a column, do not leave it empty: type "NA" or any letters.

Here is an example to illustrate :

```
#J, Cp, Ct  
0, 0.24, 0  
0.0104275, 0.237519, 0.1206661  
0.348092, 0.221876, 0.12555943  
0.621055, 0.210575, 0.120298886  
0.828301, 0.19887, 0.11169234  
1.01242, 0.1884, 0.105599855  
1.20891, 0.18068, 0.103872  
1.43852, 0.162737, 0.08902282  
1.69505, 0.124028, 0.06102  
1.99375, 0.0722589, 0.026265  
2.2, 0.06, 0
```

Figure 14: Example of a .csv file to import propeller data.

## 4.3. Defining a command model

In this chapter we will give an example on how to build a command model for a differential aileron. Let's consider an aileron mechanism slightly cloaked forward, producing a non-linear deflection, as in the following image.

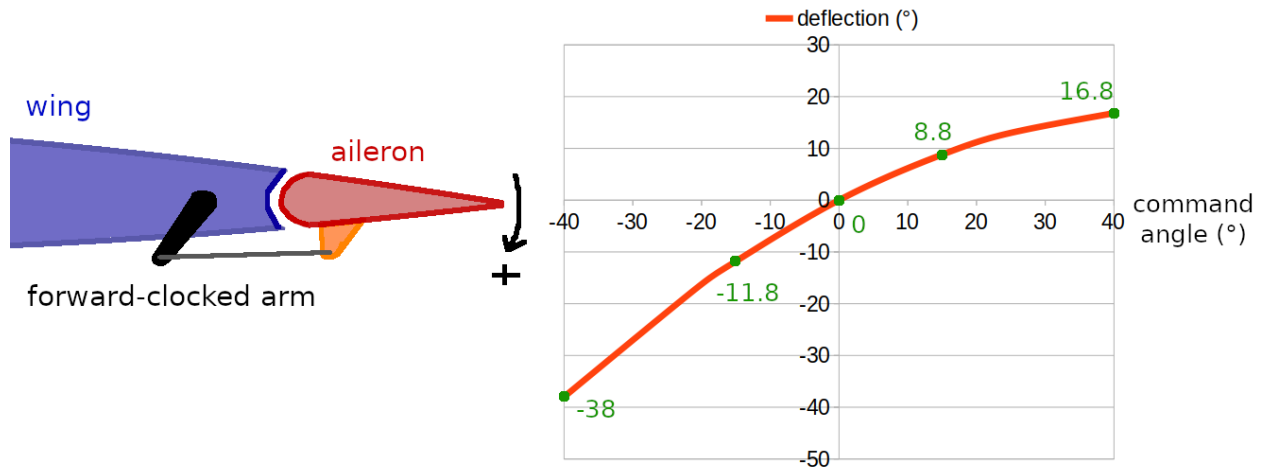


Figure 15: Deflection produced by an aileron mechanism.

With this mechanism a positive deflection is smaller than a negative deflection. This kind of differential behavior is often used to reduce adverse yawing that may occur when rolling. We note down the values for the 5 points marked in green in the preceding image. Our model can only work with linear behaviors, so we will break-down our deflection law into 4 linear segments:

- one segment for the command angles below  $-15^\circ$ .
- one segment for command angles between  $-15^\circ$  and  $0^\circ$ .
- one segment for command angles between  $0^\circ$  and  $+15^\circ$ .
- one segment for the command angles above  $+15^\circ$ .

The 5 points are put in a spreadsheet to quickly find out the slope coefficients and offsets of our segments.

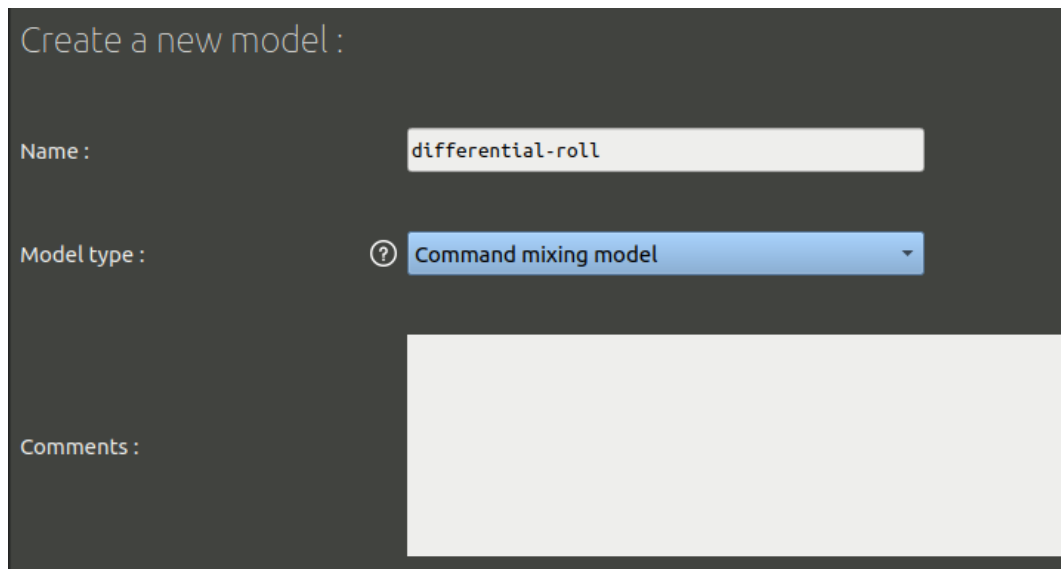
Command angle (°)	deflection angle (°)		
X	Y	dy/dx	offset
-40	-38		
		1,048	3,920
-15	-11,8		
		0,787	0,000
0	0		
		0,587	0,000
15	8,8		
		0,320	4,000
40	16,8		

$\frac{(-11.8) - (-38)}{(-15) - (-40)}$   
 $(-11.8) - 1.048 * (-15)$

Figure 16: Reducing our deflection law to a set of  $Ax + B$  equations in a spreadsheet.



Then we can create our model in Ace of Aircrat. To do that we click on the 'Models button in the navigation bar, select a project in the left-side tree, and click the button 'Add a new model'. We give a name to this model and set its type to 'Command mixing model'



The screenshot shows a dark-themed dialog box titled "Create a new model :". It contains three main input fields:

- Name :** A text input field containing the text "differential-roll".
- Model type :** A dropdown menu with a blue highlight and a question mark icon to its left. The selected option is "Command mixing model".
- Comments :** A large, empty text area for additional notes.

Figure 17: Creating a New command mixing model.

Since we are doing a differential aileron in this example, we add the coefficients found in our spreadsheet into the 'Roll' column. This kind of model can mix-up several command axis to create elevons or flaperons if needed.






Range		Pitch	Yaw	Roll	Flaps	Airbrake		
from	-180°							
		coef.	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="1.048"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
		offset	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="3.92"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
to	-15							
		coef.	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0.787"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
		offset	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
to	0							
		coef.	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0.587"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
		offset	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
to	15							
		coef.	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="0.32"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
		offset	<input type="text" value="0"/>	<input type="text" value="0"/>	<input type="text" value="4"/>	<input type="text" value="0"/>	<input type="text" value="0"/>	
to	180°							
 Add a range								

Figure 18: Filling up the form with 4 angle ranges.

Click the 'Test' button, and in the plot below select 'Roll command contribution to visualize the result.

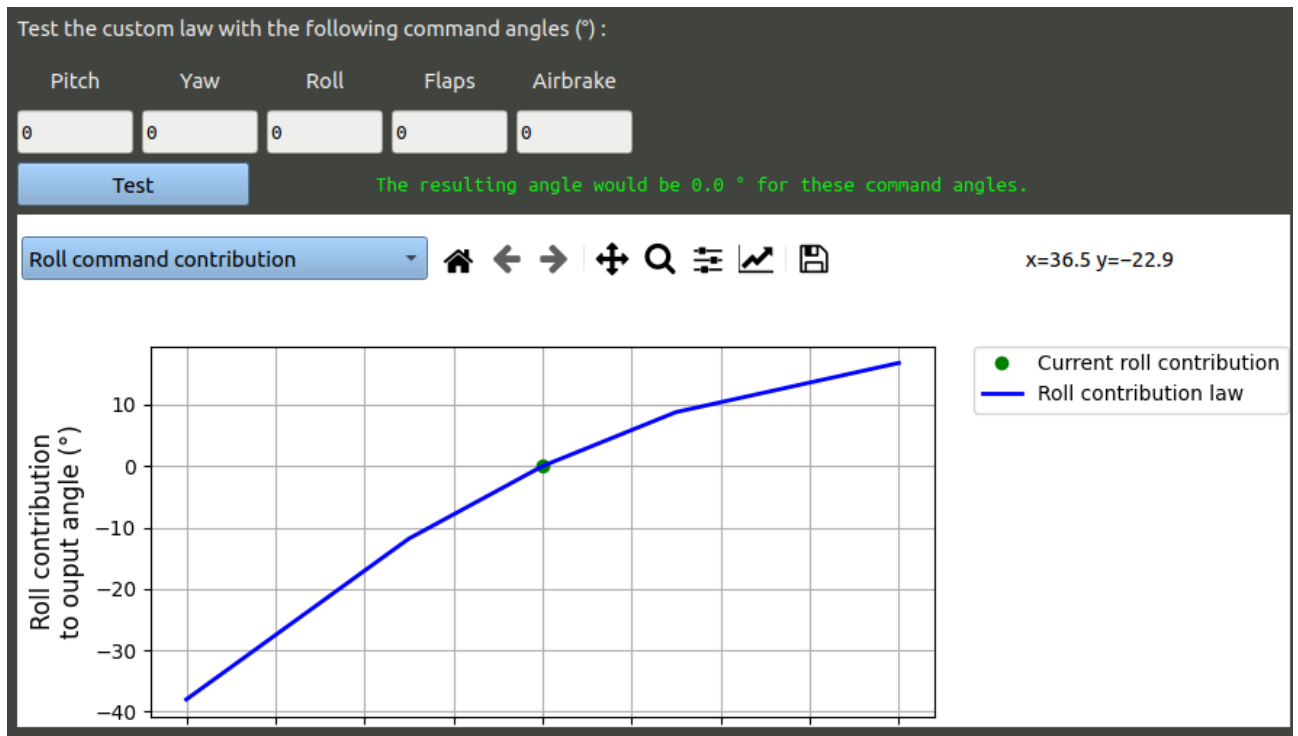


Figure 19: Visualizing the model created.

Do not forget to click the 'Create' button at the bottom of the screen to validate the form and actually save the new model in your project.

## 5. Visualisations

A tool to quickly get visualisations of Navier-Stokes runs (NS\_2D or NS\_3D projects) inside an interactive window. The tool can be set to visualise from 1 to 4 runs at a time in split frames. Selecting more than one run permits visual comparisons between the runs.

## 6. Charts

Fast chart building tool to compare the results of different analysis: select a type, select the different project and analysis, add option(s), filter the data you want to use.

→ **The different types of comparisons :**

- Global coef. :  
Comparison of aerodynamic coefficients. You can select multiple runs except for draft projects.
- Part forces :  
Comparison of force or moment coefficients. You can select multiple runs and parts.
- Rotor data :

Comparison of thrust or torque. You can select multiple runs and rotors except for draft projects.

- **Exchanger data :**

Comparison of flow rates, inlet pressures, outlet pressures and heat exchanges. You can select multiple runs and exchangers except for draft projects.

- **Report surface flow rates :**

Comparison of flow rates and pressures. You can select multiple runs and surfaces except for draft projects.

→ **Comparison with external analysis :**

You can import external aerodynamic coefficients data to do a comparison with any analysis calculated in the software.

To add external data :

1. Go to the Model tab.
2. Select a folder project where you will save your data.
3. Select the "Aerodynamic Coefficient Model" model type.
4. Complete the Name input.
5. Import the external results.

For more information about the importation, see 4. Aerodynamic Coefficient Model.

→ **Save the results :**

Comparisons will not be saved into the Charts tab.

To save your comparison, click on the save button at the top of comparison curve :

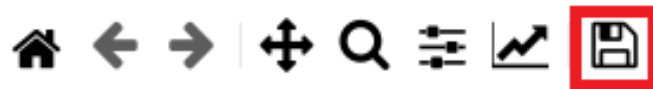


Figure 20: Software screenshot of the tool bar in the Charts tab.

## 7. Objectives

The objectives page contains two tools:

- **A mission tool :** A mission is defined by setting various masses, fuel and battery capacity for the aircraft, as well as a list of steps describing the mission profile. In the next chapter the different types of mission steps available are described in more details. Once the mission is created the user can select an aerodynamic analysis and power model to run the mission profile. This will give an estimation of fuel quantity used and duration.
- **A pugh matrix tool :** This lets the user define scoring rules on several performance criteria or mission results. These rules can then be applied to an aerodynamic analysis to obtain scores and compare objectively concurrent designs.

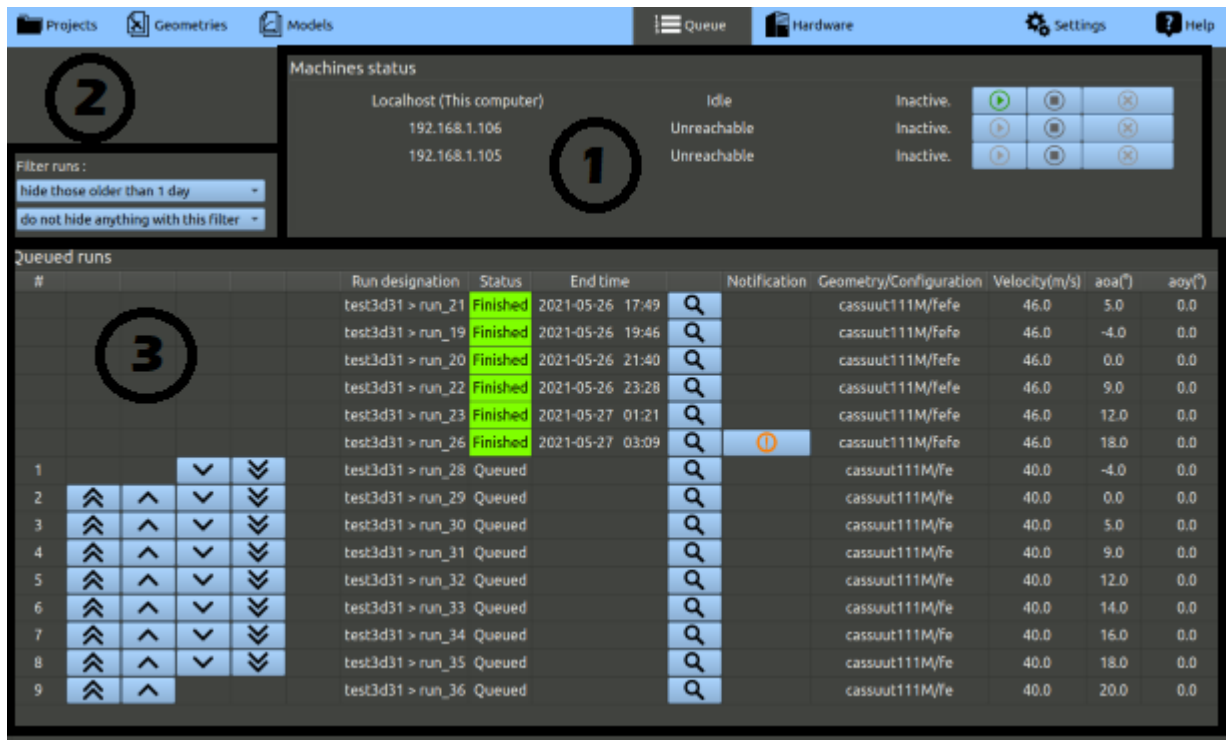
### 7.1. Mission step types

- **Altitude change** : to model a climb, or a descent if a negative value is given. The movement is calculated at the best climb rate speed found. The computation is actually made of 50 sub-steps (the weight and the best climb rate being re-evaluated at each sub-step).
- **Cruise over distance** : A distance and a speed value must be set. The speed can be automatically computed to be the speed giving the best range (longest distance flown per watt) or the best endurance (longest flight duration per watt). The step computation is actually made of 200 sub-steps.
- **Cruise over given time** : A duration and a speed value must be set. The speed can be automatically computed to be the speed giving the best range (longest distance flown per watt) or the best endurance (longest flight duration per watt). The step computation is actually made of 200 sub-steps.
- **Cruise until fuel threshold** : A threshold of fuel mass and a speed value must be set. The speed can be automatically computed to be the speed giving the best range (longest distance flown per watt) or the best endurance (longest flight duration per watt). The step computation is actually made of 200 sub-steps.
- **Cruise until battery threshold** : A threshold of battery capacity and a speed value must be set. The speed can be automatically computed to be the speed giving the best range (longest distance flown per watt) or the best endurance (longest flight duration per watt). The step computation is actually made of 200 sub-steps.
- **Fuel mass change** : A change of fuel mass, positive or negative, without movement calculation and instantaneous. It can be used to model fuel lost into taxiing or refueling for example. It can also be put at the last part of the mission and represent a given amount of reserve fuel that must not be used during the mission but kept for security.
- **Payload mass change** : A change of payload mass, positive or negative, without movement calculation and instantaneous. It can be used to model cargo-loading, cargo jettison, passengers loading, or skydivers jumping for example.

## 8. Queue

Queue or Job manager.

Launch or stop queue processing for different calculations.



### 1. Machine status :

You can launch, pause or stop runs on the computer of your choice (including the computer(s) from your computing cluster).

### 2. Filters runs :

You can hide or show runs depending on the day or hour.

### 3. Queued runs :

See the status of your run (queued, finished or failed).

Rank the runs according to the arrows.

For more information, see Buttons below.

### Buttons



If the status is 'inactive', click on this button to start or resume the runs.



The **black** button stops all runs after the end of the calculation.

The **red** button stops all runs and puts the calculation on failure.



Change the order of your runs with the arrows:  
 The double arrow will set the run at the top or at the bottom.  
 Simple arrow will set the run one position before or after.



This is a notification.  
 It is recommended to look at it.



There is a problem, you must look at it.  
 You can see more details in the logs of the run. Follow the instructions to spot the problem.



This button will open the results.

## 9. Settings

### 9.1. General

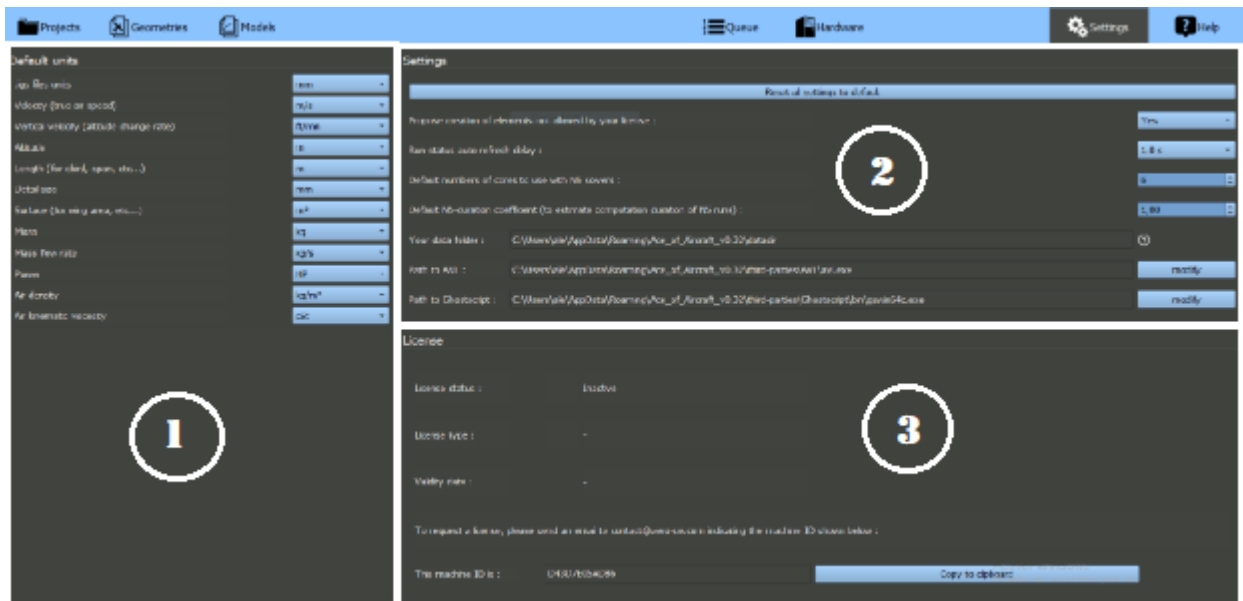


Figure 21: Software screenshot of the Settings tab.

#### 1. Default units :

Set the default units you will use in the software.

#### 2. Settings :

- Propose creation of elements not allowed by your license :

Visualize elements not allowed in the free version. It allows you to prepare analyses without a license.

To be able to run the calculation, you need to export the study data and send it to someone in possession of a license.

- Run status auto-refresh delay :

Set the number of second you want between updates on the pages having an auto-refresh feature.

- Default numbers of cores to use with NS solvers :

Set the default numbers of cores you want to use to solve Navier-Stokes calculations. This is the number set by default for every computer you add.

You can change this number for each computer in the Hardware tab.

- Default NS-duration coefficient :

The time estimation has been calculated for 2.2GHz and 12 cores CPU.

If your computer is faster, set the number below 1. Otherwise, set the number above 1.

#### 3. License :



To install a license , please refer to chapter 3.2.

## 9.2. User data folder

The data folder indicated in the settings tab is composed of different sub-folders containing various data:

- **userdata** : the sub-folder where you copy / paste your license. This sub-folder also contains other user parameters.
- **Project folders** : each folder has the name of the project you created.  
In each of the project folders, you may find the **Exports** sub-folder containing the data you exported.

**Manually modifying or deleting these sub-folders or their files could cause permanent loss of data or prevent the software from starting-up correctly.**

The location of the data folder by default is the folder `datadir` within the application folder. However, you can change the path of the folder used as data folder in the file `configuration.py` within the application folder. This can also be used to have different users sharing the application. In order to do that:

1. Edit the file `configuration.py`
2. Find at the start of the file the dictionary called `custom_user_data_paths`.
3. Add a line within the dictionary brackets indicating your username in the operative system and the path of the folder you want to use as a data folder. Here is an example correctly formatted for two users named Bob and Jennifer:

```
custom_user_data_paths = {  
    "Bob": r"/home/Bob/Documents/AoA-data",  
    "Jennifer": r"/NAS/Jennifer/ace-of-aircraft",  
}
```

## 9.3. Third parties

Third parties are software independent from ACE of Aircraft that are needed to use some features. The path of each software must be properly set. There are four dependencies:

- **AVL**, needed to make vortex lattice computations.
- **OpenFOAM**, needed to make Navier Stokes computations.
- **Ghostscript**, needed to make image conversion.
- **FreeCAD**, needed to convert igs files to stl files

The paths of each software should be good by default. If needed you can force another path with the following way:

1. Edit the file `configuration.py`
2. Find near the start of the file the dictionary called `default_settings`.

3. Edit the line within the dictionary brackets starting by the software name. Here is an example correctly formatted to change the path of openFOAM:

```
default_settings = {  
    "gs_path": r"",  
    "avl_path": r"",  
    "of_path": r"/opt/OpenFOAM/of1912",  
    "FreeCAD_library_directory_path": r"",  
}
```

## 10. Hardware

Monitor the CPU, RAM and disk usages.

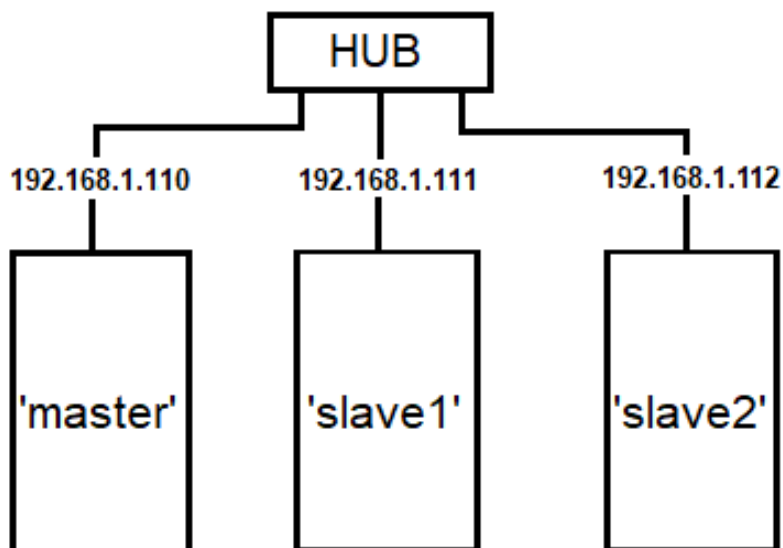
Add or remove computer(s) to the computing cluster.

### 10.1. Create a computing cluster

We do not recommend the use of computers with different processors, it could impact the results.

To add a computer to the computing cluster :

1. In ACE of Aircraft, go to the Hardware tab.
2. Click on the "Add a computer to the computing cluster" button.
3. Type manually the IP adress of the computer you want to add.

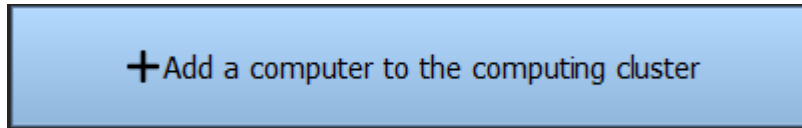


**Every computer must have a fixed IP**

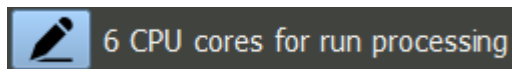
Figure 22: Representation of a computing cluster.

Your computer need to be connected to the same HUB and have a fixed IP adress. For more information about setting up the cluster, please refer to chapter 1.4.

## 10.2. Buttons



See above how to add a computer to the computing cluster.  
You can add as many computers as you want.



You can change the number of cores you want your computer(s) to use to perform Navier-Stokes calculations.

To be efficient :

- do not use all your cores (keep at least 1 core for your GUI and other background processes).
- do not set a number higher than the cores you have.
- do not hyper-thread : it is preferable to use only 1 thread per core.

(The Draft and VLM project use 1 or 2 cores and do not need to be set to a certain number.)

## 11. Help

The help tab contains a user manual, tutorials, support and contact.

You can research word(s) in the research bar from the Help bar. It can be one word or an expression.

The result is composed of a colored square and the location(s) where your research was found:

A green square means the result is spotted in a title (in the manual).

A grey square means the result is spotted in a text (in the manual).

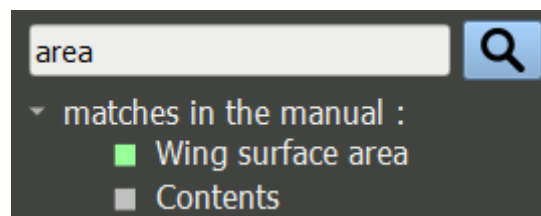


Figure 23: 'area' searched in the research bar.

# Part III.

## LEXICON

### 1. Airfoil lift coeff

The draft project needs values to establish the lift coefficient (CL) based on the angle of attack (AoA).

A .csv file is necessary to do this calculation as it defines lift values for a large range of angles of attack.

It contains the airfoil lift values for numerous angles of attack (when the airfoil is not stalled). You can find compatible .csv file at [airfoiltools.com](http://airfoiltools.com), or from Xfoil and XFLR5 softwares.

Here is an extract of a file from [airfoiltools.com](http://airfoiltools.com) :

```
Xfoil polar. Reynolds number fixed. Mach number fixed
Polar key,xf-naca23012-il-1000000
Airfoil,naca23012-il
Reynolds number,1000000
Ncrit,9
Mach,0
Max Cl/Cd,96.786
Max Cl/Cd alpha,8.75
Url,http://airfoiltools.com/polar/csv?polar=xf-naca23012-il-1000000

Alpha,Cl,Cd,Cdp,Cm,Top_Xtr,Bot_Xtr
-15.250,-1.0627,0.06220,0.05971,-0.0331,1.0000,0.0142
-15.000,-1.0952,0.05313,0.05040,-0.0395,1.0000,0.0142
-14.750,-1.1159,0.04706,0.04411,-0.0428,1.0000,0.0143
-14.500,-1.1291,0.04270,0.03955,-0.0442,1.0000,0.0144
-14.250,-1.1381,0.03932,0.03598,-0.0443,1.0000,0.0145
-14.000,-1.1426,0.03672,0.03321,-0.0434,1.0000,0.0146
-13.750,-1.1428,0.03474,0.03108,-0.0420,1.0000,0.0147
-13.500,-1.1396,0.03320,0.02940,-0.0402,1.0000,0.0148
-13.250,-1.1329,0.03211,0.02819,-0.0382,1.0000,0.0149
-13.000,-1.1469,0.02890,0.02470,-0.0341,1.0000,0.0153
```

Figure 24: Extract from a .csv file.

The software will use only the data highlighted in green and red.

The red numbers are interpreted as angles of attack and lift coefficients (in this order).

### 2. C<sub>dmin</sub> / C<sub>d0</sub>

The C<sub>dmin</sub> is the minimum drag coefficient that you can obtain from an airfoil (or an aircraft).

The  $C_{D0}$  is the drag coefficient that you obtain from an airfoil (or an aircraft) when it is set at an angle of attack producing zero lift.

The  $C_{Dmin}$  and  $C_{D0}$  can be equal if the airfoil is symmetrical or if a simple numerical model is used to compute the drag model from lift values.

In the draft project, the Oswald efficiency factor is used to model the induced drag coefficient. This model can only produce parabolic polars, which can be slightly inaccurate near the zero-lift point and stall point. In this case,  $C_{Dmin}$  is equal to  $C_{D0}$ .

For actual wind tunnel measurements or accurate Navier-Stokes models of asymmetric airfoils, the polar obtained would be equivalent to the "actual drag polar" on the following figure. In this case  $C_{D0}$  and  $C_{Dmin}$  are close but not equal.

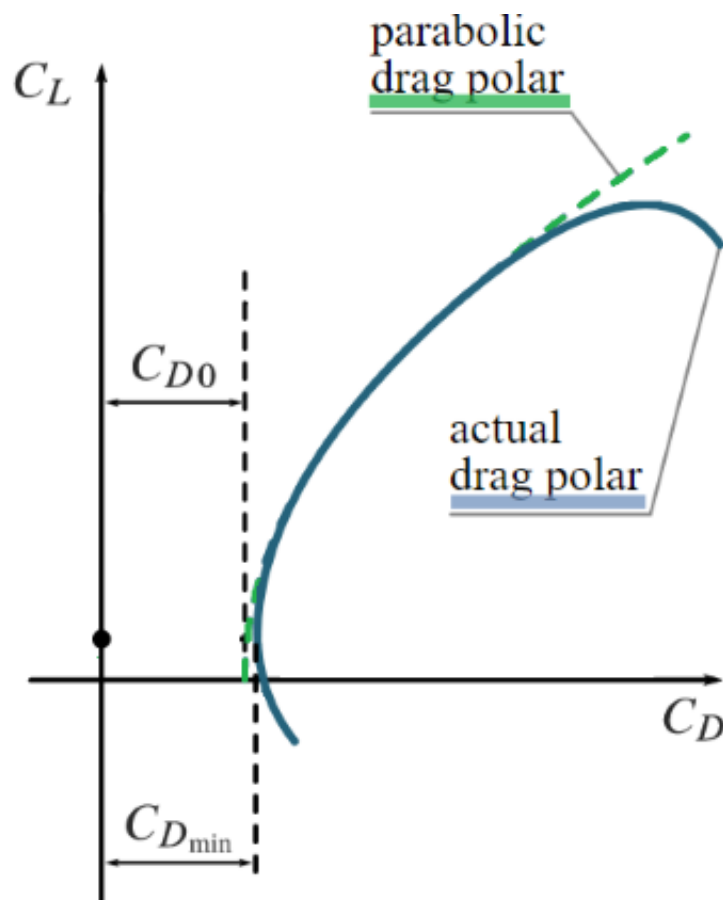


Figure 25: Parabolic drag and actual drag polar.

### 3. Custom analysis modelisation

When defining a custom analysis a "modelisation" option must be set to one of the values listed below. This choice will determine the boundary conditions used in the CFD calculation as well as the type of solver used.

- Standard horizontal-flight, to model a level flight. The air flow is rectilinear, the trajectory of the aircraft is a straight line.
- Pitching rotation, to model a flight with a constant pitching rate. The air flow is rotational, the trajectory of the aircraft is a circle.
- Yawing rotation, to model a flight with a constant yawing rate. The air flow is rotational, the trajectory of the aircraft is a circle.
- Rolling rotation, to model a flight with a constant rolling rate. The air flow is relative to the aircraft spiraling around the longitudinal axis. The trajectory is a straight line, but the aircraft is rolling while following this straight trajectory.

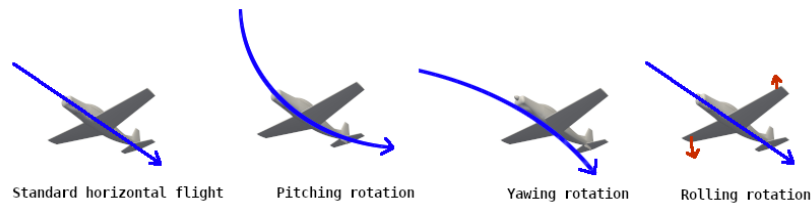


Figure 26: Different modelisations offered in a custom analysis, with blue arrows representing the air flow, and red arrows indicating aircraft motion relative to the measurement axis.

Regardless of the mode chosen, the user can define attitude angles (angle of attack, angle of sideslip, angle of roll). It should be noted that Ace of Aircraft uses wind axes to measure the coefficients.  $C_D$ ,  $C_L$ ,  $C_m$ ,  $C_n$ , etc are given around the wind axis, in this type of analysis as in the others. The pitching/yawing/rolling rotation (if selected), are also defined around the wind axis and not around the aircraft body axis.

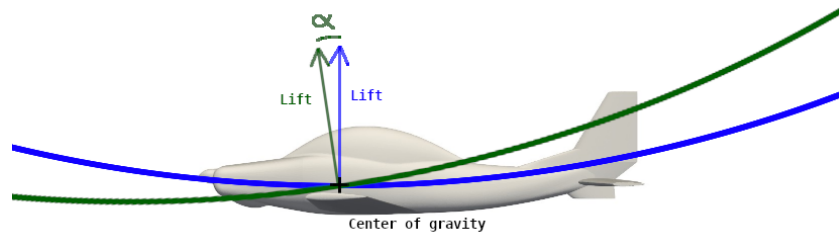


Figure 27: Trajectories for modelisations with a constant pitch rate, with a null angle of attack in blue, and positive angle of attack in green.

## 4. Custom measurements

*Optional.*

Custom measurements are defined in configurations. At the end of a run, additional values will be computed according to these custom measurements. To read these values, click the export

button on a run page or analysis page. This will generate a .csv file containing the custom measurements. There are 4 types of custom measurements : probes, moment readers, force slicers, torsor groups.

**Probes** are defined by a name and the XYZ coordinate of a point. This point must be placed outside of the plane to obtain results. The results will be the pressure and velocity of the airflow in that point. It can be used for example to check the pressure entering a inlet duct, or test potential position for pitot tubes or static pressure sensors.

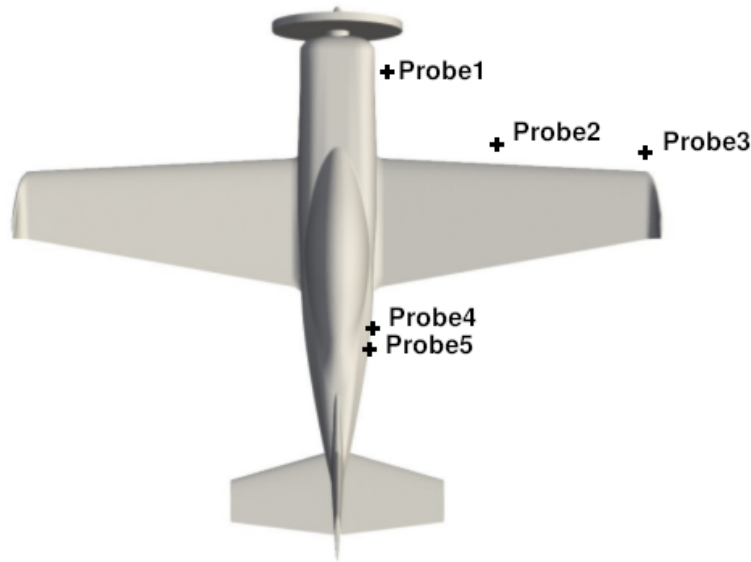


Figure 28: Example of probe points placed around the aircraft.

**Moment readers** are meant to compute the aerodynamic moment around a custom axis and for a custom part list. They can be used for example to evaluate the moment on an elevator or aileron axis. They are defined by :

- a name.
- a point and a direction (XYZ components), to define a rotation axis around which the moment is measured.
- the list of parts for which the aerodynamic moment computation is done.

**Force slicers** are meant to visualize the force distribution along an axis. It will virtually cut the parts selected into slices along the requested axis, and give torsor figures for each slices separately. It can be used to see the span-wise aerodynamic load of a wing for example. They are defined by :

- a name.
- a center point (XYZ coordinates).

- a direction (XYZ components).
- a number of slices to produce along the part length in the given direction.
- a list of parts. Only the aerodynamic forces on these parts are evaluated.

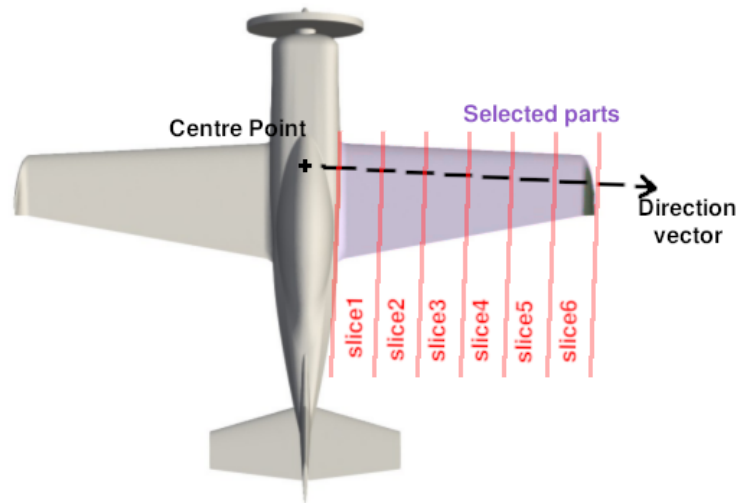


Figure 29: Example of slicer function used on the wing of an aircraft.

If you use this custom measurement options, several exports will be added to the results .csv file:

- $F_x$ ,  $F_y$  and  $F_z$  value of each slice. NB: in this file,  $x$  is the drag axis,  $z$  is the lift axis. These are not CAD axes.
- $M_x$ ,  $M_y$ , and  $M_z$  value of each slice. Measured around the center of gravity defined in the geometry page.
- $M_c$  : moment measured around the axis defined with the point and direction given to define the slicer function.

**Torsor groups** are meant to group the torsor results of multiple parts. For example if a wing is split in several parts : primary, flap, aileron, etc. , this function will sum up the torsors of all these parts and produce a global torsor for the wing. They are defined by a name and a list of parts.

**Skin friction reports** are an indirect way to estimate the magnitude of air cooling on surface, or verifying flow separation in the model. It integrates on the selected surfaces the magnitude of shear stresses from the air. High air velocities on the surface will give an high value. If the velocity is low, or if the flow is detached from the surface however, the resulting value will be relatively small. Tutorial 6 gives an example of how it can be used.



## 5. Custom refinements

*Optional.*

If you do not use these optional settings when defining your geometry, the mesh size will be automatically adapted on the surface curvature of the parts. By default, the variation of size will go from 'detail size' for low-curvature surfaces, to 'detail size x 4' for sharp edges. Also by default, 5 layers of prism cells are extruded from surfaces.

If you do define custom refinements on parts, the mesh will be refined at the size you selected, and the quantity of prism layers you selected will be extruded. To define a custom refinement:

1. Click the button 'define a custom refinement on a part'.
2. Select in the list the surface you want to refine.
3. Select the refinement size parameter you want to apply.
4. Select the quantity of prism layers you want to apply.

Be careful, these refinements can increase the quantity of cells in the mesh, which means the computation will become slower and require more RAM.

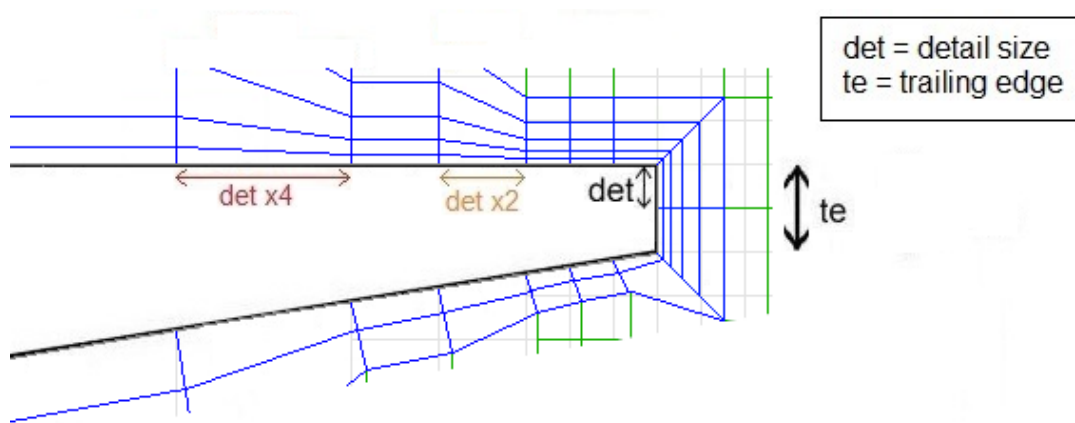


Figure 30: Representation of the mesh around a trailing edge. The bottom surface has been set to extrude only 2 layers of prism instead of the default 5 layers.

By changing the quantity of prism layers, you can adjust the  $Y^+$  values observed in the runs, as it is proportional to the first cell height.  $Y^+$  values are important for accuracy of the aerodynamic forces and can be checked in the images automatically generated at the end of a run, as explained in part IV, chapter 5.

During meshing, prism extrusion is tested, if the resulting cell quality is not good enough, the extrusion is cancelled. As a result, a surface where 5 layers are requested, may locally have 4, or 3, or 2, or 1 or even no layers at all. The global prism coverage can be checked in the images automatically generated at the end of a run, also explained in part IV, chapter 5.

NB: the 'prism generation iterations' parameter at the top of the custom refinements panel does not indicate how many prism layers will be extruded. It indicates how many steps are done to obtain the total quantity of prism layers.

By default the parameter is set at 1, which means all layers will be extruded in a single meshing step.

If you set the parameter to 2 and that 5 layers must be extruded, 3 layers will be extruded in a first step, then 2 layers will be extruded in the second step.

Increasing the value of the 'prism generation iterations' parameter results in longer meshing durations, as the cell extrusion computations are repeated several times. However, the prism layers produced generally have a slightly better coverage when the extrusion was done in several steps.

## 6. Detail size

The user must set a 'detail size' for a project, this is a reference size, roughly indicating what is the smallest detail length that should be kept during the meshing process.

The smaller it is, the smaller the cells of the mesh will be. Cells on the mesh have different sizes depending on their proximity to the aircraft surfaces and proximity to sharp edges. However all sizes are computed relatively to the 'detail size' value. Be careful to choose a value neither too big nor too small.

- A value too big will give bad quality meshes, and unreliable solving (see examples below).
- A value too small will take a lot of RAM usage and a lot of computation time to get results.

Generally, it is recommended to take half of the trailing edge thickness, or less, as detail size value, to ensure reliable results. If the trailing edge of the empennage and wings are different, the smallest trailing edge thickness should be considered.

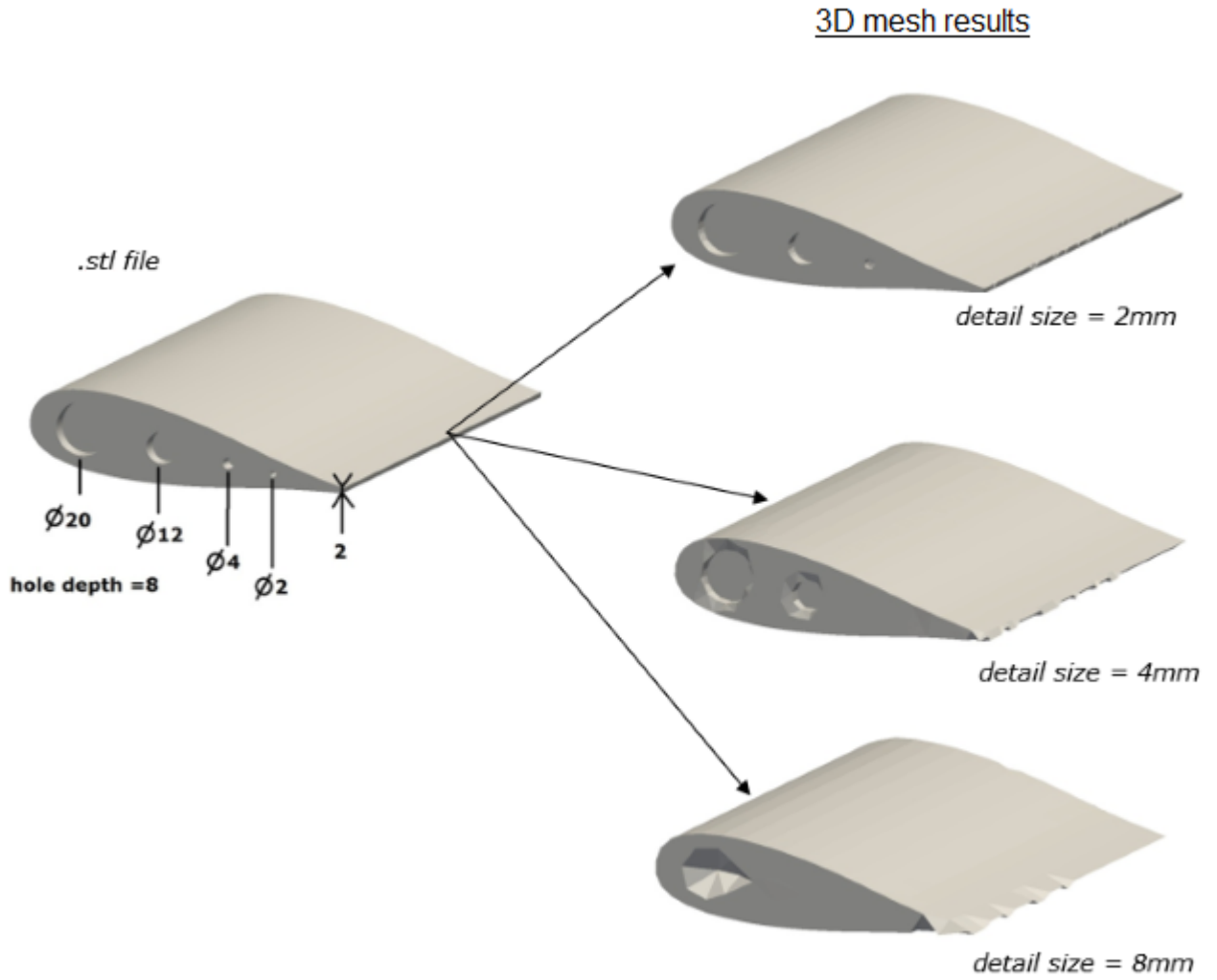


Figure 31: Representation of different detail sizes influencing the precision of the refinement.

Sizes of the cells meshed also impact the  $Y^+$  values. Numerical models used in the software are only valid for a given range of  $Y^+$ . You can roughly estimate what would be the maximum acceptable value of the detail size according to the equations:

- $d[\text{mm}] = 130 / V[\text{m/s}]$
- $d[\text{mm}] = 253 / V[\text{kn}]$
- $d[\text{mm}] = 468 / V[\text{kph}]$
- $d[\text{in}] = 9.9 / V[\text{kn}]$
- $d[\text{in}] = 11.4 / V[\text{mph}]$

where  $V$  is the maximum velocity that will be used in the simulations.

For example: Considering an aircraft having a smallest trailing edge thickness of 3 mm, to have a proper mesh the detail size chosen should be smaller than 1.5 mm ( $3/2$ ). Then, if the estimated maximum velocity would be around 100 m/s, we should avoid using a detail size parameter that is more than 1.3 mm ( $130/100$ ). For this aircraft, a good detail size would be in the range of 1 mm to 1.3 mm for example, as it is just under the two limits given before.

There is also a minimum limit to the detail size, because of the acceptable  $Y^+$  range. However, this limit is generally is extremely small. In the example given before, the smallest acceptable detail size would be lower than 0.0065mm.

The user should avoid using detail size values that are a lot smaller than necessary, because the smaller the detail size, the higher the computational cost will be, as shown in the following plots.

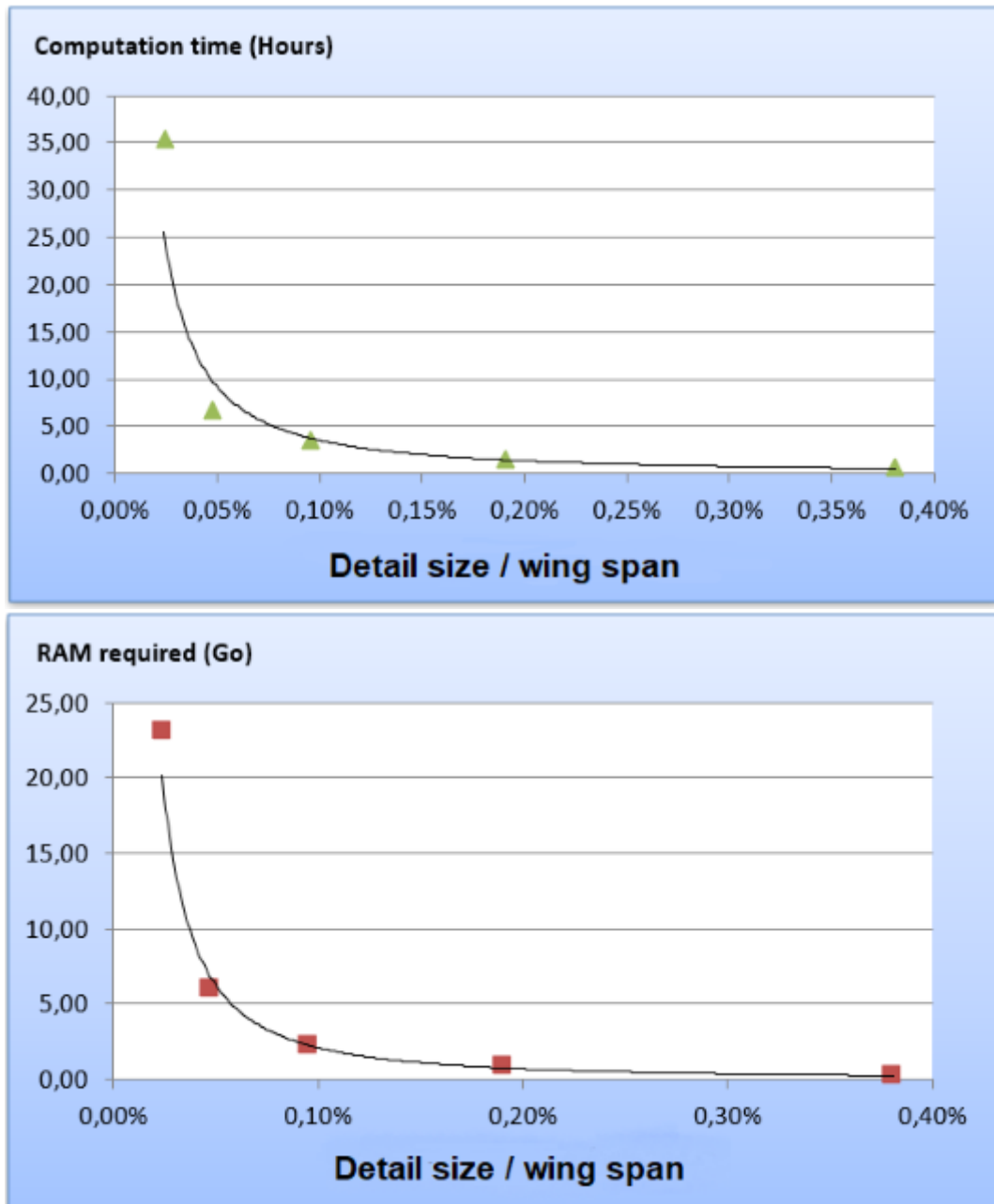


Figure 32: Computation time and RAM usage depending on the detail size over wing span ratio.

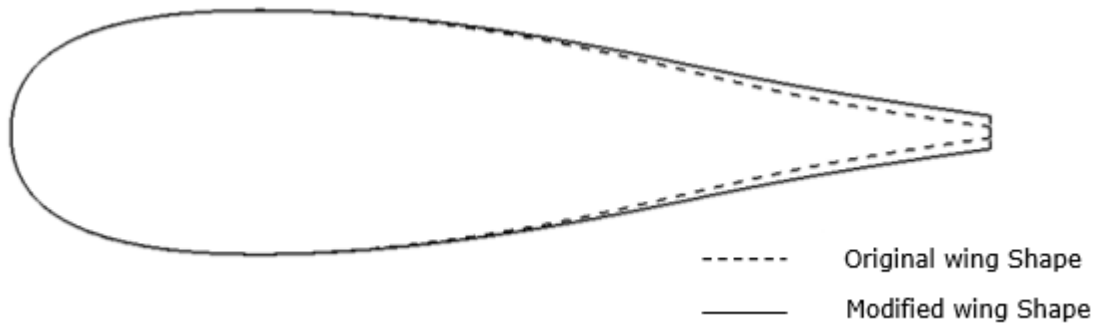


Figure 33: 1mm thick trailing edge modified to accept a 2mm detail size.

If the computation time is a concern, or if the trailing edge in the CAD is unrealistically thin, the trailing edge should be remodeled a bit thicker than it is, as shown in the previous image. This allows you to define a higher detail size value, and to reduce the solving time, while the effect on the drag coefficient is generally insignificant.

To obtain additional details, see the part V. Correlations.

## 7. Engine-propeller unit efficiency

When setting a power model, the user must set a global efficiency for the engine-propeller unit, this includes power losses due to:

- engine accessories power draw
- gear reduction and transmission efficiency
- propeller efficiency

Generally the global efficiency factor is around 75-80% This means that with an engine of 100 HP rated power output, 75 to 80 HP will actually go to final effective thrust.

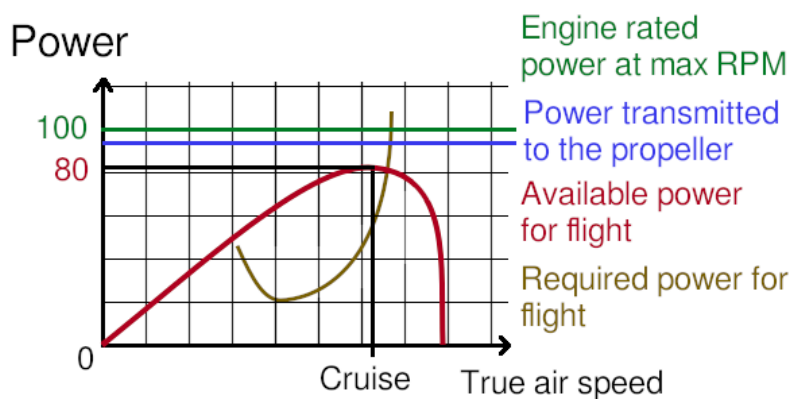


Figure 34: Engine-Propeller unit efficiency with respect to air velocity.

## 8. Engine power loss relative to altitude

The power models have a feature representing the engine power output being scaled down when the aircraft gains altitude.

This power loss is considered to be linear in the model. During the model creation, the user must specify how many HP is lost for a 1000 feet altitude gain. The power loss is then considered linear to this rule, for any altitude.

For a thermal engine, the power loss is generally 3% per thousand feet. (For a 100 HP engine, you would set the parameter to 3 HP)

For an electrical engine, you may set the parameter to 0 HP, as they don't breath air.

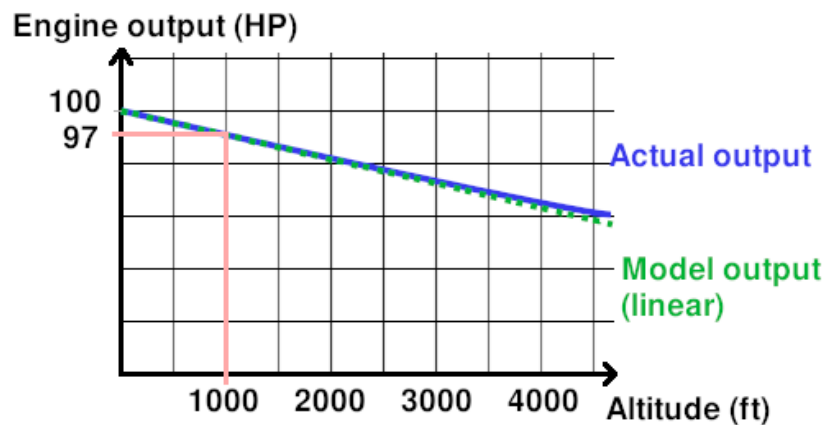


Figure 35: Modeling of the engine power output relative to the altitude for a 100 HP rated engine, with a power loss parameter of 3 HP per thousand feet.

## 9. Flying altitude

The software uses the altitude given by the user to find an equivalent of air density and/or air viscosity which will be used in calculations.

This is done by extrapolating values from the International Standard Atmosphere (ISA). The ISA is a standard reference for Earth air pressure, temperature, viscosity and density values at various altitudes.

## 10. Heat exchangers

When defining a configuration for a geometry of an NS project, with the correct license level you may have defined parts for heat exchange.

The heat exchanger models are porous volume

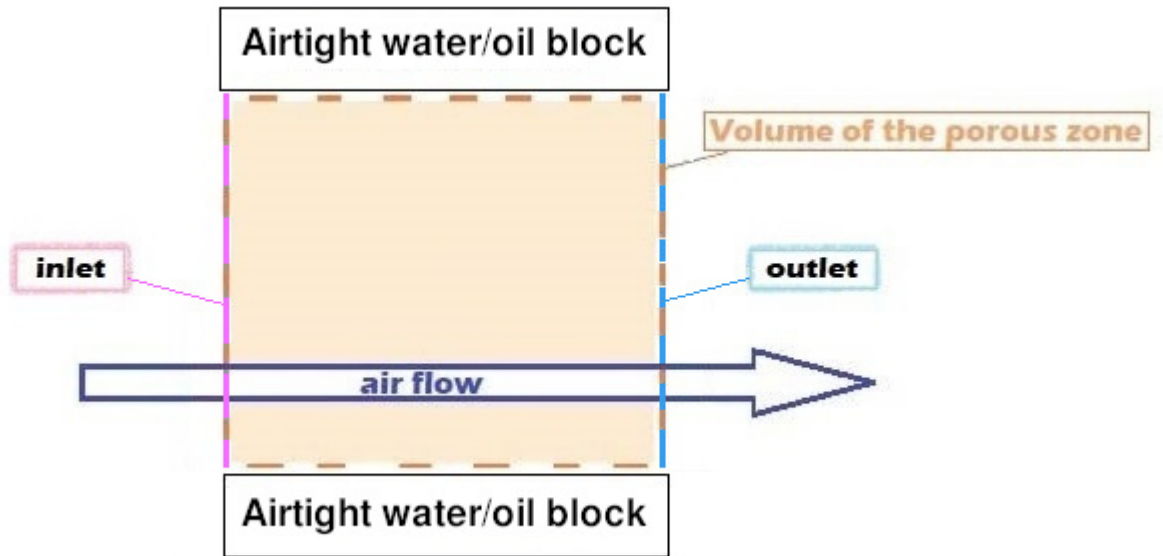


Figure 36: Air flow through an exchanger.

## 11. Hole detection points

The sum of your parts should create a closed volume, the software will verify if there is any hole left.

Write the coordinates of a point located inside the volume created by the parts you imported. You can add multiple coordinates if you have multiple volumes. It is better to test the impermeability of every volume by adding a coordinate for each part in your geometry.

The software will search for a path between the point(s) you gave and a point in the farfield. If the part is impermeable, the software will not find a path.

Here is an example with a problematic situation, the flap is not closed :



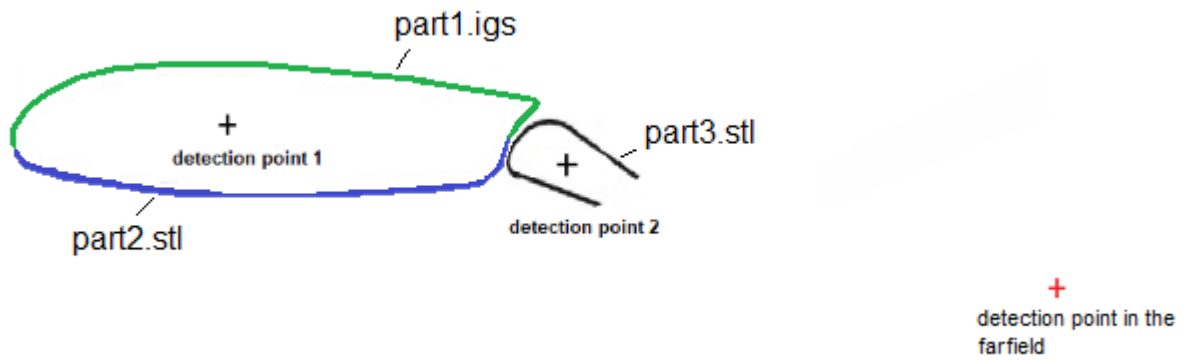


Figure 37: Example of an open volume.

The software will search for a path from detection point 1 and 2 to the detection point in the far field :

- The primary wing is impermeable, the software will not find a path.
- The elevator is open, the software will find a path and an error message will appear.

If you start the calculation with hole(s) in your parts, the software will try to compute an air flow inside the hollow part(s) which is unnecessary : it will take a lot of time and the results will be unreliable.

## 12. Low curvature surfaces refinement

The mesher can adapt the refinement depending on the local curvature of the surface. The following image shows a refinement done with the default value for the "Low curvature surfaces refinement" parameter, the "coarse" value:

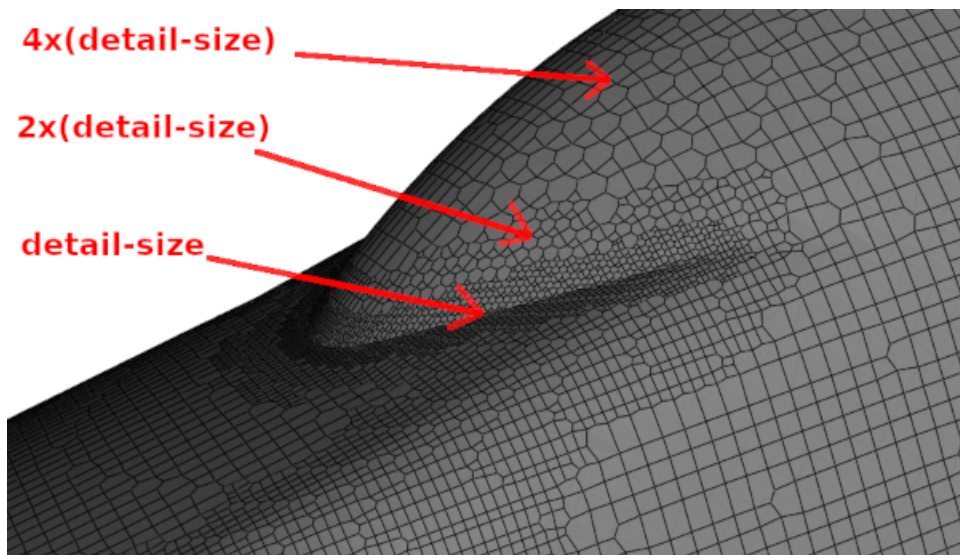


Figure 38: Meshed Surface for a NS3D run.

If the parameter had been set to "intermediate", the faces meshed with a  $4 \times (\text{detail-size})$  would have been meshed at the  $2 \times (\text{detail-size})$ .

If the parameter had been set to "fine", the entire surface would have been meshed at detail-size.

## 13. Mass and inertia

When defining a configuration for a geometry of a VLM project, you may define a list of mass and inertia values.

This definition will not be used in most analysis, but is required to perform dynamic stability analysis.

Provide a list of the elements inside your airplane. Define their mass and inertia characteristics. The list provided can be precise or global:

- You can separate each element and write one element per line to be more precise.
- You can write the global mass value of several elements or the whole aircraft in one line.

## 14. Mean aero chord length

- For 2D airfoil : the reference length used for the calculation of aerodynamic coefficients is generally **the chord of the airfoil**.
- For 3D wing (or entire aircraft) : the chord length can be different depending on where it is measured along the span. A representative chord value must be found from the geometric definition of the planform, this reference value is **the mean aerodynamic chord**.

The calculation you need to do to obtain the mean aerodynamic chord will depend on the shape of the wing.

You can see on the next figure that the mean aerodynamic chord is different for each shape of planform.

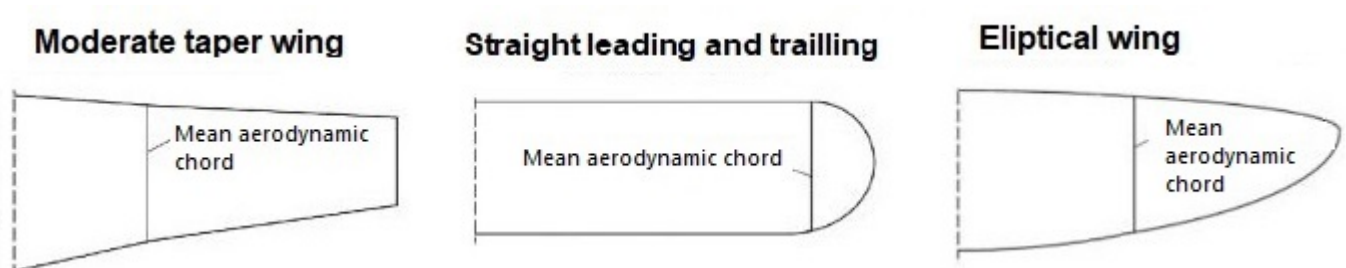


Figure 39: Different planforms and their mean aerodynamic chords.

## 15. Oswald efficiency factor

The Oswald efficiency factor depends on the lift distribution along the span.

It also depends on the twist of the wing, the fuselage and all appendixes added on the wing (winglet, landing gear or engine motor).

$$CD = C_{dmin} + \frac{CL^2}{\pi * e * S / c^2}$$

Figure 40: Oswald equation.  
 $e$  is the Oswald efficiency factor.

This equation uses the Oswald efficiency factor to establish drag values from the lift values. The lift values are obtained from the .csv file provided.

The number obtained will change based on the size and the shape of the wing.

→ Rectangular wings will have an  $e$  coefficient around 0.7.

→ A perfect elliptical wing will have an  $e$  coefficient of 1.

Here are a few examples for a few aircraft :

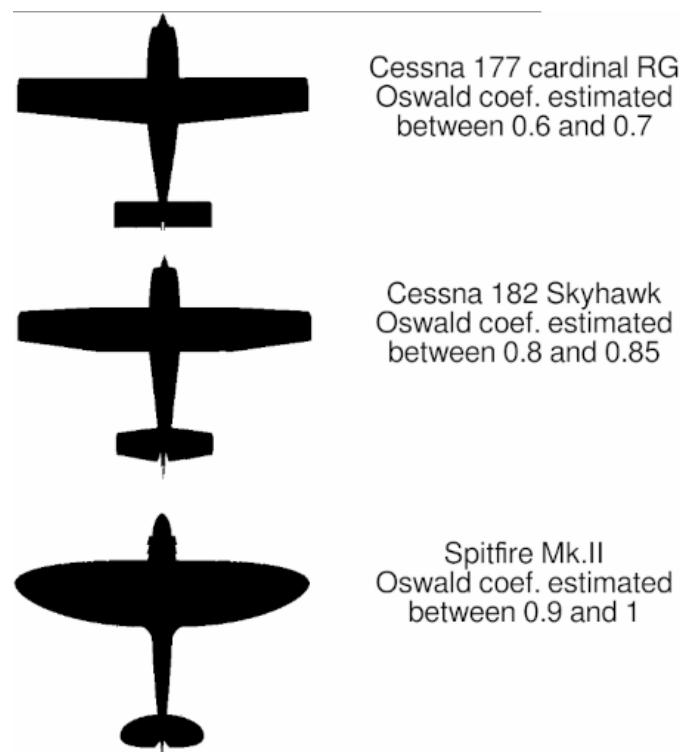


Figure 41: Oswald efficiency factor for different shapes.

The following paper is a good read on how to estimate the Oswald efficiency factor of an aircraft :

*"Estimating the Oswald factor from basic aircraft geometrical parameters"* by M.Nita and D.Scholz, Hamburg University of Applied Sciences, DocumentID 281424.

You can find the complete report in the References compressed folder provided.

## 16. Parts movements and command angles

This chapter describes how the motion of one or multiple parts can be modeled for a NS project/geometry/configuration. A geometry always has a list of reference parts, these parts are in a neutral position, have zero deflection or deformation.

During geometry creation or edition, part movements can be defined in three ways : defining rotations, using shifting parts, and setting up translations.

### Rotating parts:

Let's consider the case of an horizontal stabilizer with an elevator and a trim tab. In cases where the airflow through the slot gap between the fixed part and the moving part is neglectable, it is better to modify the shapes in order to have overlapping volumes, and make sure no gaps ever appear, as shown in the following image.

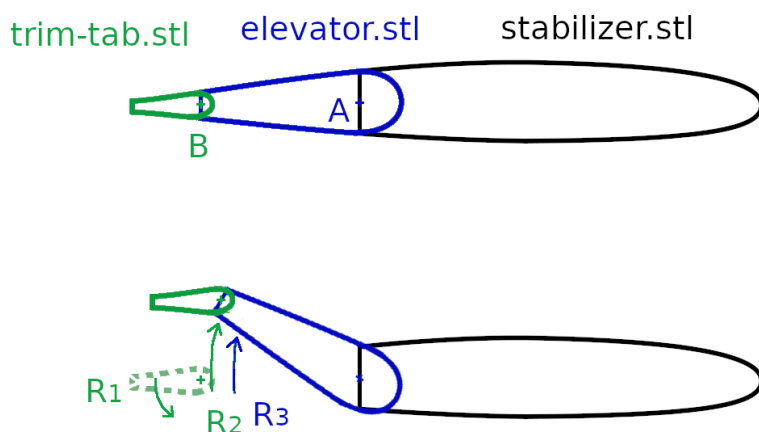


Figure 42: Parts and rotations for an horizontal tail.

In this case 3 rotations must be done. The order is important! If R2 is defined before of R1 the results will be wrong. In the geometry set-up page this should look like this:

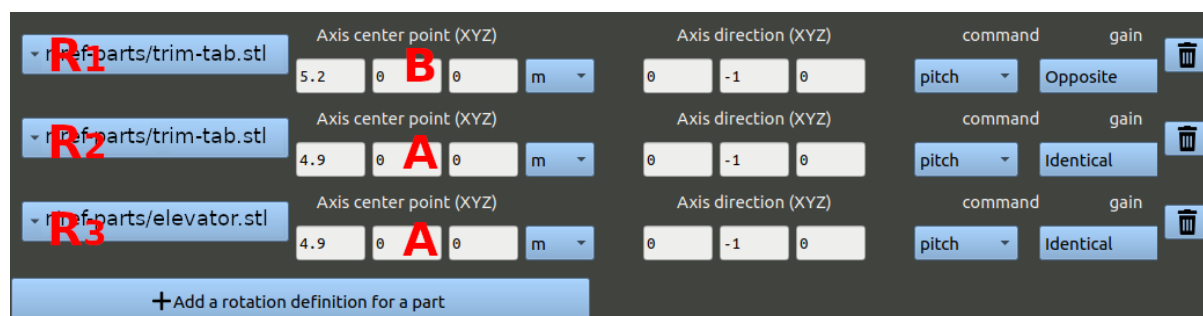


Figure 43: Defining rotations in the geometry set-up page.

NB: in the 'command' column, yaw, pitch, roll, flaps and air brake axis are selectable by default and correspond to a direct 1/1 rotation angle between the part and the command axis.

But custom command mixing models can be created in the model tab. If there are such models in the project, they will be selectable in this column too, which can allow modeling of differential ailerons for example.

### Shifting parts:

The second way is called "shifting", it will replace a reference part with an alternative part, depending on a command angle condition. You need to select a reference part to replace in the drop down menu.

Import an .igs or .stl file with the part in the new position you want, or deformed. Then, specify the command angle parameters to indicate what this new position corresponds to. This can also be very usefull to fill-up gaps when a part is retracted.

Example :

Considering a wing with a flap as in the following image:

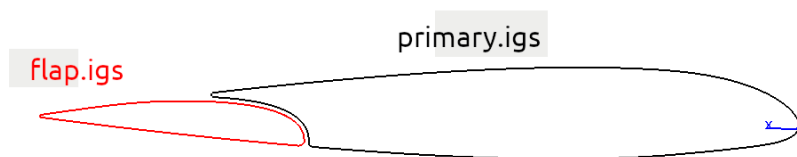


Figure 44: Reference parts.

The flap part can have a rotation definition around an axis, and be bound to the flaps command axis. The problem is that when the flap is not rotated, the gap between it and the primary is very small, which can cause problem to the mesher. We can define an alternative version of the flap part that will fill-up this gap when the command angle is requesting a retracted flap.// To do that a 'shifting' definition is made and bound to the following command angles :

- : pitch command: no angle specified
- : yaw command: no angle specified
- : roll command: no angle specified
- : flaps command:  $0^\circ$
- : airbrake command: no angle specified

With this definition, everytime a flap command angle is requested, flap.igs will be rotated and used. When the command angle is zero, flap-bump.igs will replace flap.igs.

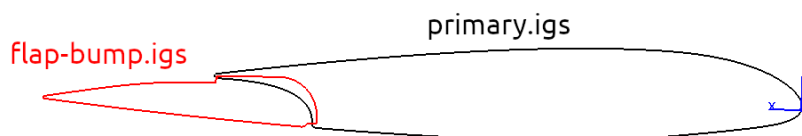


Figure 45: Shifting flap.igs to flap-bump.igs.

### Translating parts:

Translations can be defined for individual parts in the geometry parameters, they are a simple X/Y/Z vector applied to a part. Unlike rotations and shifting definitions, translations are not linked to command angles, they are always executed.

## 17. Position of the center of gravity (X Y Z)

You must define the center of gravity (CoG) precisely to obtain correct moment values without re-calculations.

The center of gravity (also called center of mass) is used as a position reference point. It is used to calculate the aerodynamic moments (pitching, yawing and rolling moments).

This figure shows the CoG of an airplane :

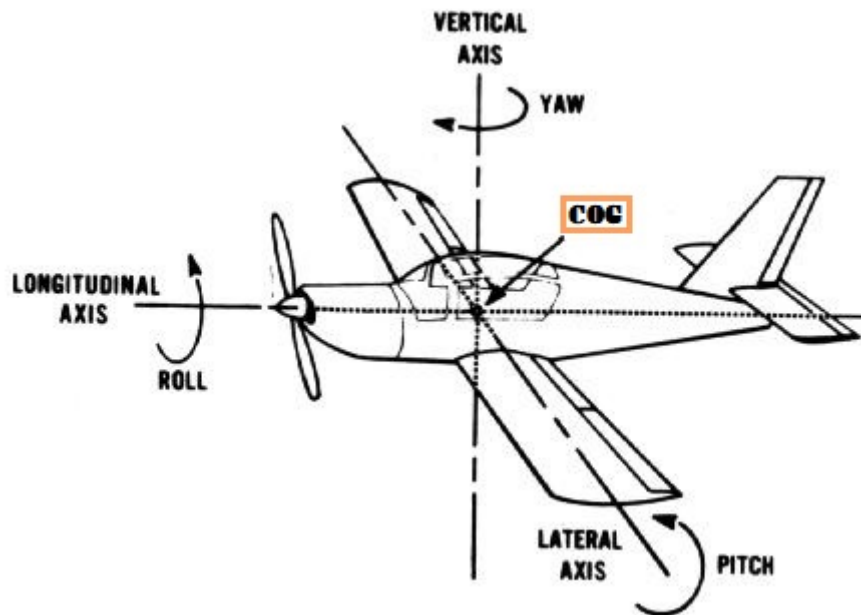


Figure 46: Center of gravity and axis of an airplane

## 18. Prism expansion ratio

The prism expansion ratio parameter can be set between 1.5 and 1.0, 1.25 being the default value. This changes the size of a prism layer relatively to the preceding prism layer. Using a high value reduces the height of the layers being close to the surface.

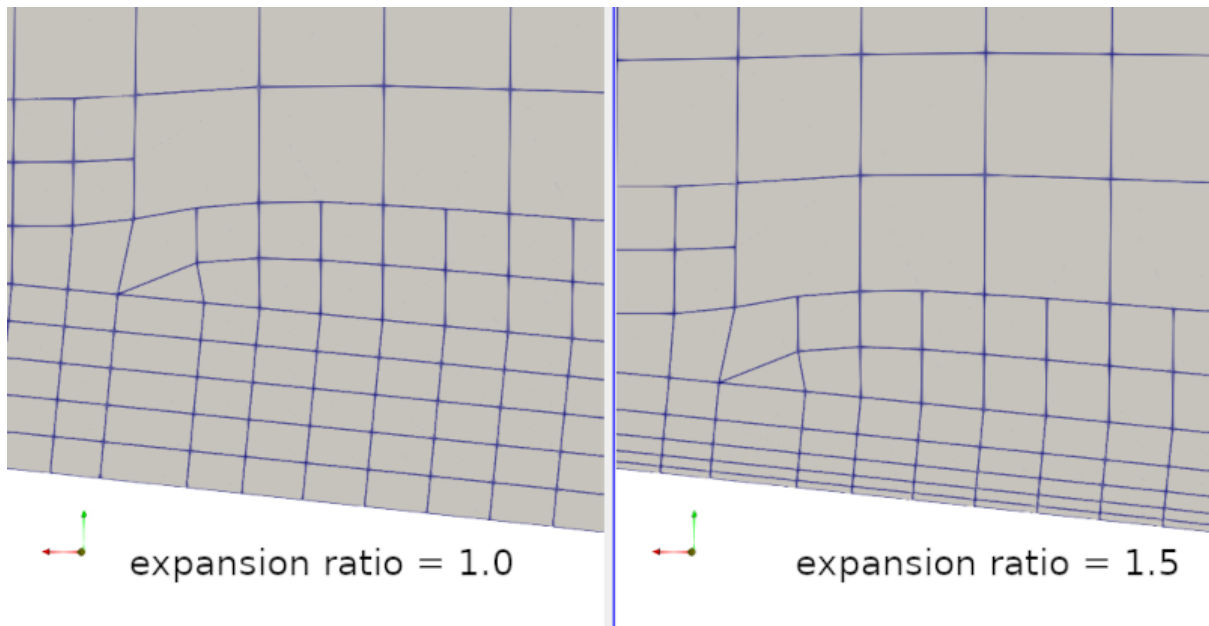


Figure 47: section of mesh showing the prism layer with two different values of expansion ratio.

## 19. Rolling / Pitching / Yawing moment with modified Center of Gravity positions

Visualisation of moment curves for various user-defined CoG.

- CoG 1 is part of the geometry definition and cannot be modified.
- You may input coordinates for other CoGs (2, 3 and 4) and visualize the impact of a CoG displacement on the moment curves.

In the aerodynamic type analysis, a suggestion of X coordinate for the aerodynamic center is displayed. This is generally the aft limit of the acceptable CoG range. The software computes this value by searching an X coordinate nullifying the pitching moment for an AoA varying between  $-1^\circ$  and  $+1^\circ$ .

For the forward longitudinal stability limit analysis, a suggestion of X coordinate for the forward limit of the CoG range is given. It is the coordinates resulting in a null pitching moment at the reference AoA of the analysis (it should be the stall angle).

## 20. Rotors

When defining a configuration for a geometry of an NS project, with the correct license level you may have defined parts for modeling rotors.

A rotor volume represent the volume swept by the propeller blades, it should have the shape of a cylinder, or disc. For a good meshing, we recommend to make the thickness of this disc approximately 15 or 20 times the project's detail-size parameter.

The orientation of the geometry given is detected automatically. The software will always set the flow direction to the X positive direction when the orientation is X dominant. When the orientation is mainly Z dominant, it will direct the airflow to the Z negative direction.

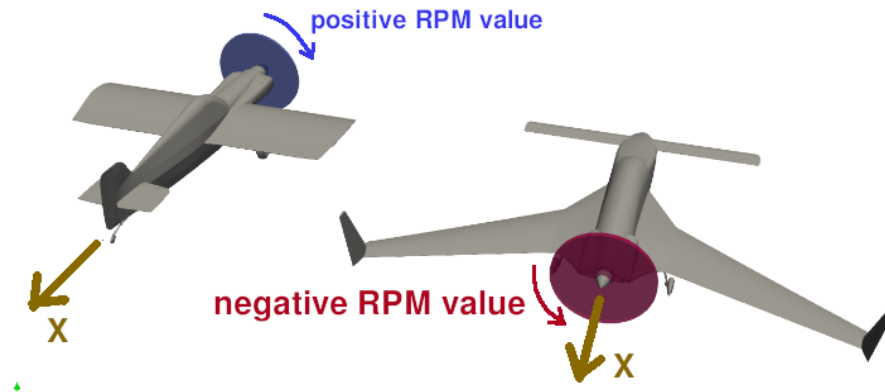


Figure 48: Rotor direction when main orientation is X.

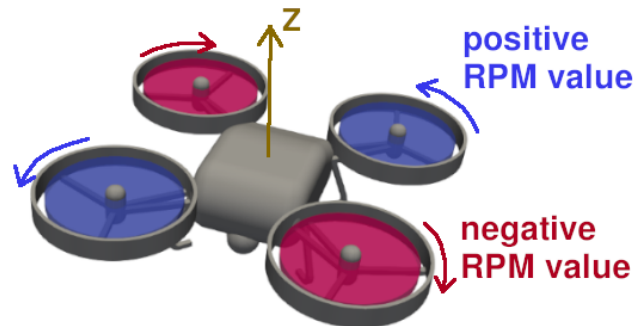


Figure 49: Rotor direction when main orientation is Z.

When setting up a configuration, you will have to set the RPM speed of the propeller. Note that if you set a positive value, the rotor will turn clockwise. If the value given is negative, it will rotate counter-clockwise (This is when observing the rotor from the downstream position).

## 21. Solving parameters

When creating a new configuration in a NS project, you can set a few parameters that will modify the time required to execute the runs, in the "Solving parameters" frame of the UI.

Firstly, the user can enter **3 angles of attack values, that will define the range for iteration quantity pre-sets**. If these fields are left blank, all runs will run with a standard quantity of iterations. If they are filled-up, the runs created from this configuration will have a quantity of iteration depending of their angle of attack. For example, if the angles given are 12, 8 and 3:



Solving parameters ⓘ (leave blank to solve everything with a standard duration):

longest (3500it for steady solving) (6500it for transient solving)	AoA(°)	long (3000it for steady solving) (5500it for transient solving)	AoA(°)	standard (2500it for steady solving) (4500it for transient solving)	AoA(°)	fast (2000it for steady solving) (3500it for transient solving)
	12		8		3	
<input checked="" type="checkbox"/> skip the image generation stage of the mesh		<input checked="" type="checkbox"/> skip the image generation stage of the solution of the aircraft		<input checked="" type="checkbox"/> skip the image generation stage of the solution of slices		
<input checked="" type="checkbox"/> clean intermediate data at the end of the process		maximum allowed speed factor :	8		blockMesh Y rotation (°) :	0,00

- All runs having an angle of attack below 3 will be executed with a 'fast' iteration quantity setting.
- Runs having an angle of attack between 3 and 8 will be executed with a 'standard' iteration quantity setting.
- Runs having an angle of attack between 8 and 12 will be executed with a 'long' iteration quantity setting.
- All runs having an angle of attack above 12 will be executed with a 'longest' iteration quantity setting.

This way the user can increase the iteration quantity as stalls appear and the flow become less streamlined, a situation leading generally to an higher iteration quantity requirement.

It is also possible to have all runs of a polar curve computed with a 'longest' iteration setting for example, simply by defining very low angles of attack in these fields, for example -350, -349, -348.

Then there are **3 check-boxes allowing the user to skip some steps of image generation during the run**. Image generation can be long depending on your configuration and of the mesh produced, especially the slices. Skipping all 3 proposed steps generally reduces processing duration of 3D-NS runs by 30%.

Fianlly there are an additional checkbox and a couple of parameters :

- the checkbox to **clean intermediate data**, when checked, at the end of runs an operation will be made to remove the data saved in OpenFoam format, keeping only the exported data redable in Ace-of-Aircraft, Paraview and Excel. If the box is not ticked almost all the data will be kept, but the space used on the disk will be much greater.
- the **maximum allowed speed factor**, set the global velocity check setting in the run, the run would be considered divergent and failed if a point in the mesh has a velocity goes above the given value. For example if it is set at 8, if the inlet velocity of the run is set at 10m/s, any point reaching a velocity of 80 m/s would make the run fail. Regardless of this parameter setting, velocities above 400 m/s will always set the run to the failed status as well.
- the **blockMesh Y rotation**, allows the user to rotate the global orientation of the mesh around the Y axis, to align it manually. This does not change the angle of attack or the computational domain limits, it is just the background mesh orientation that changes. This was mainly added considering computations including an active rotor, the forces repartition on the rotor disk are better when the mesh is aligned with the disk.

## 22. Template NS

The Navier-Stokes template contains a list of instructions sent to OpenFoam (a third-party software). It is an automation script containing a list of commands.

**Always use the latest available version of the template.**  
**It could impact the results of the calculation.**

## 23. Velocity for fixed pitch propeller

When setting up a power model with a fixed pitch propeller, the user must indicate a 'Reference propeller speed' and a 'flight velocity' for which the propeller is the most effective. In reality this is determined by the blade pitch angle, which will correspond to an ideal advance ratio of the propeller.

For most aircraft, the ideal advance ratio of the propeller is chosen to be the cruise speed of the aircraft. Most likely you should set the propeller RPM and true air speed corresponding to this long duration cruise situation.

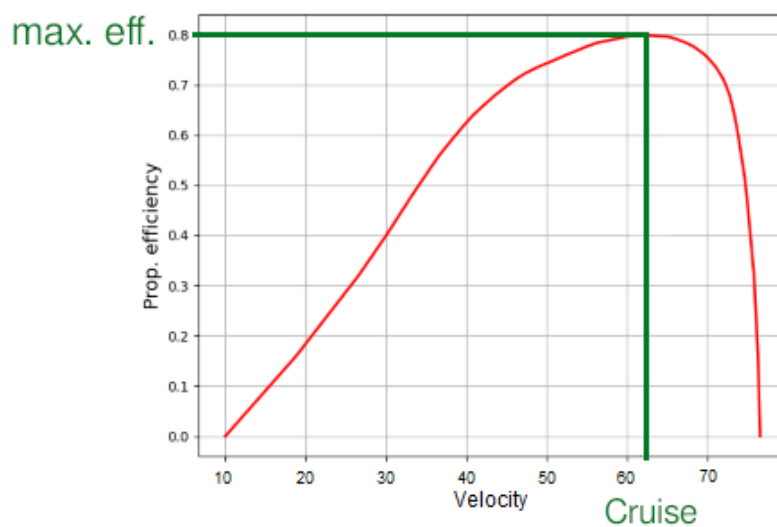


Figure 50: Propeller efficiency with respect to velocity.

## 24. Velocity for constant speed propeller

When setting up a power model with a constant-speed propeller, the user must indicate a 'Reference propeller speed' and a 'velocity range with adjusted blade pitch'. Generally the Reference propeller speed will correspond to the highest RPM speed the engine can run at for an extended time.

The range correspond to:

- **Min. velocity** : The true air speed resulting from the smallest blade pitch angle when running at the reference propeller speed, which gives the maximum propeller efficiency.
- **Max. velocity** : The true air speed resulting from the largest blade pitch angle when running at the reference propeller speed, which gives the maximum propeller efficiency.

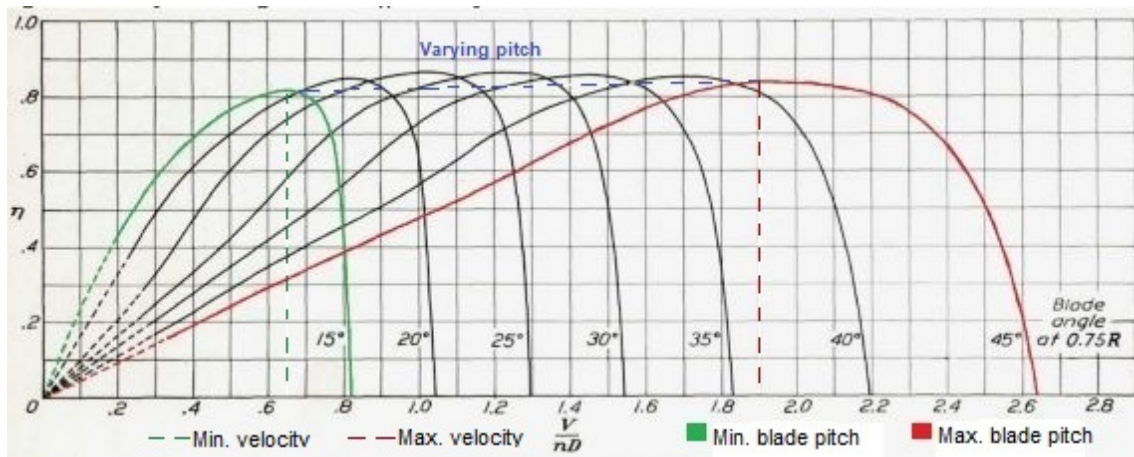


Figure 51: Propeller efficiency with respect to advance ratio for various blade pitch angles.

Generally, the max. velocity parameter can be set at the aircraft cruise speed. And the min. velocity can be set a bit above the stall speed.

## 25. VLM coefficients exception in sideslip

The coefficients computed by the vlm solver are given in a specific frame. When there is a non-zero sideslip angle the  $C_D$ ,  $C_Y$ ,  $C_l$  and  $C_m$  coefficients given by the solver are not the "true" coefficients because they don't take into account the sideslip angle and are not aligned with the relative wind direction.

For an "Aerodynamics and sideslip analysis", the plots and values given in the GUI are re-computed in the 'correct' relative wind frame, taking into account the sideslip angle. Exporting a .csv file from that kind of analysis, the "AeroVLM" and "power\_analysis" tab will contain the same data as displayed by the GUI, i.e. the correct coefficients in the relative wind frame. But other tabs detailing values of individual runs, broken down by parts, are coefficients given directly by the solver and are in the frame where sideslip is ignored.

Regarding the "Custom (VLM)" analysis, all coefficients come directly from the solver and are in the frame where sideslip is ignored.

Other types of analysis don't have sideslip runs or are not computed by VLM and are not impacted.

## 26. Wing surface area

The wing surface area is the surface area of the wing including the fuselage surface between the wings.

Be careful to extend the wing shape in the fuselage as the figure shows:

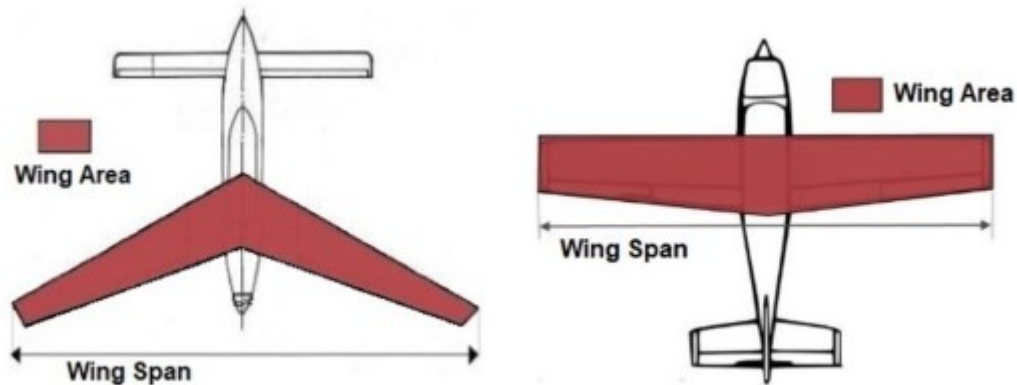


Figure 52: Different wing areas on various wing shapes.

The wing surface area is used as a reference in the aerodynamic coefficients calculations.

## Part IV.

# MODELING BEST PRACTICES

### 1. Avoiding bad comparisons

Avoid the comparison of different calculation results if the calculation process is not the same.

For example, we will try to compare the results of two wing profiles :

- The first wing profile was studied with a detail size parameter of 0.5mm for a 1m chord.
- The second wing profile was studied with a detail size parameter of 4mm for a 1m chord.

It is impossible to know if the differences between the results are due to the wing profiles or the *detail size / chord* ratio.

However, we will see below that this ratio has a huge impact on the results.

A difference in *detail size / chord* ratio creates large discrepancies between the results, making them incomparable. It is better to have the same ratio when making a comparison.

To illustrate, we are going to compare the detail sizes 0.5 and 4 for a 15° AoA on a single wing profile :

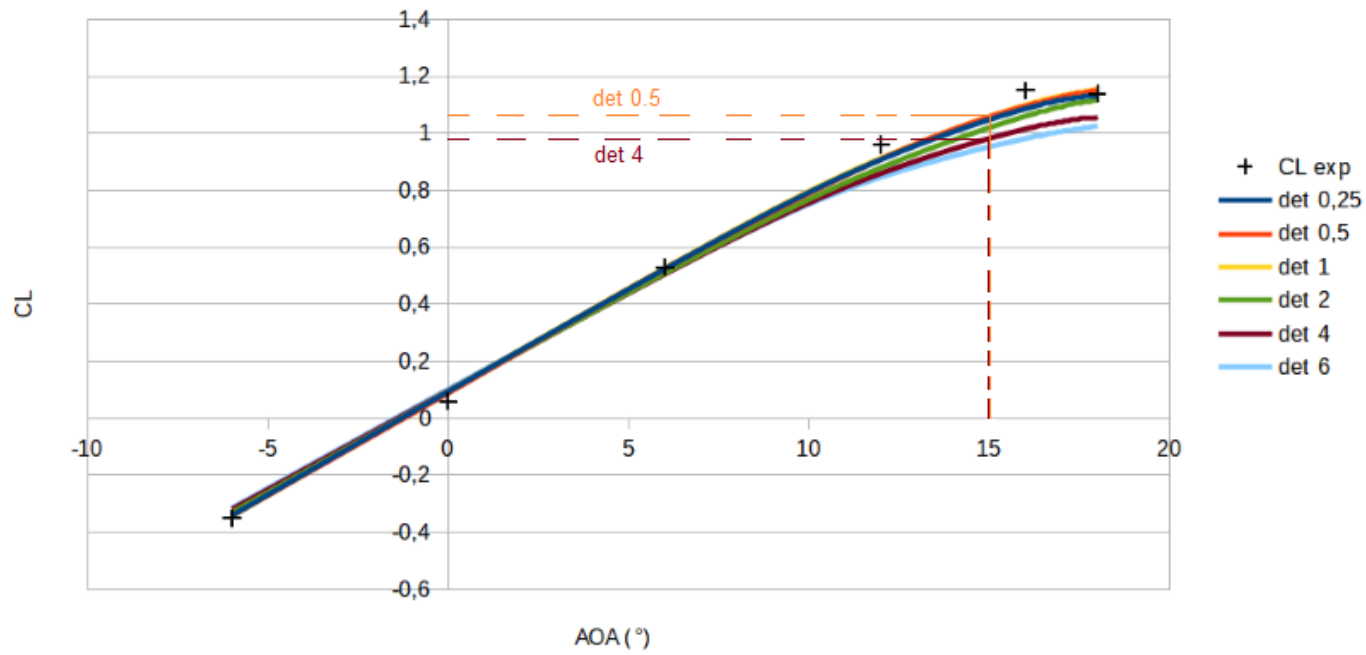


Figure 53:  $CL$  w.r.t  $AOA$  (different detail sizes).

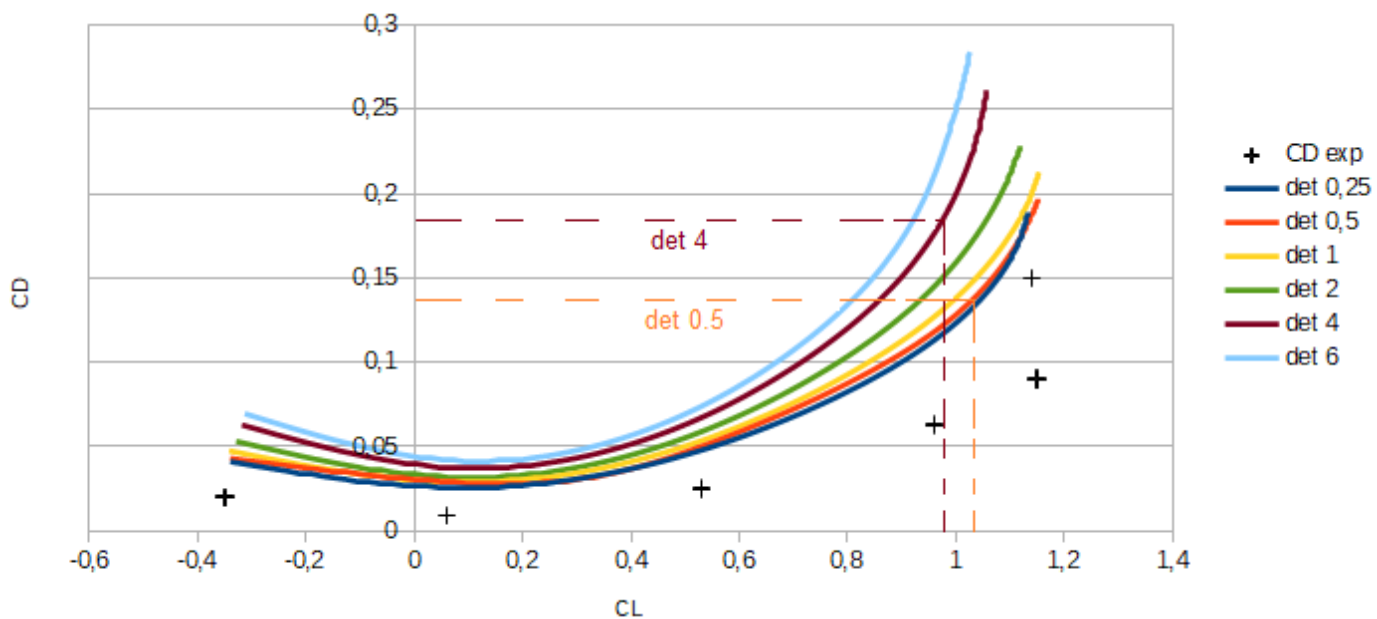


Figure 54:  $CD$  w.r.t  $CL$  (different detail sizes).

The lift coefficient is higher for the detail size 0.5.  
The drag coefficient is higher for the detail size 4.

As you can see, changing one parameter is enough to create a great disparity in results. Therefore, during your analysis, it is recommended not to change more than one thing at a time in order to always identify clearly the cause of each consequence. Also keep in mind that

each part of the geometry (may it be in the front or at the rear of the aircraft) can have a strong influence on the flow both upstream and downstream. To give you an example : a modification on the empennage can slightly change the airflow at the front of the plane.

## 2. Preparation of CAD for NS geometries

### 2.1. Cutting the geometric modeling in several parts

Cutting the surfaces of the plane in several parts allows you to evaluate the forces applied on each part.

Be careful: the sum of the parts must be a closed volume. Create a closed volume containing only .igs or .stl files :

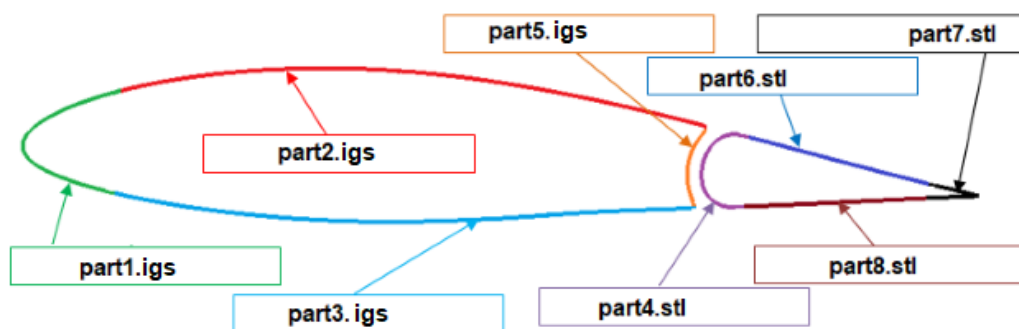


Figure 55: Closed volume composed of multiple parts.

The hole detection points will verify if there are any holes left in the volume. Cf. chapter 11. To see the results, create a configuration : it will generate pictures in the Projects tab. The pictures named "STLholeDetection" indicate if there are holes. If there is a hole, a red highlight indicates its position.

#### NS2D exception :

It is expected for the NS2D to provide an extruded profile (the extrusion must be at least 2 chords long). The holes naturally present on both sides of the extrusion are acceptable.

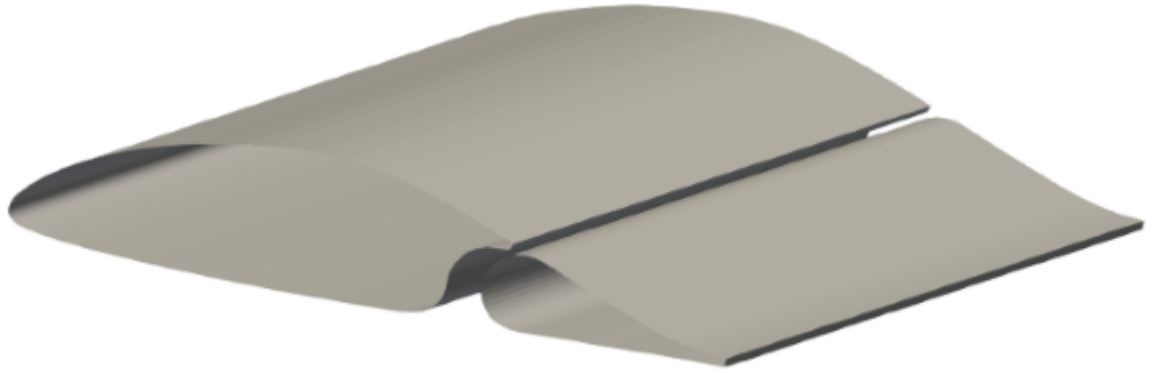


Figure 56: Extruded profile used for NS2D.

To obtain more details, see 11. Hole detection points

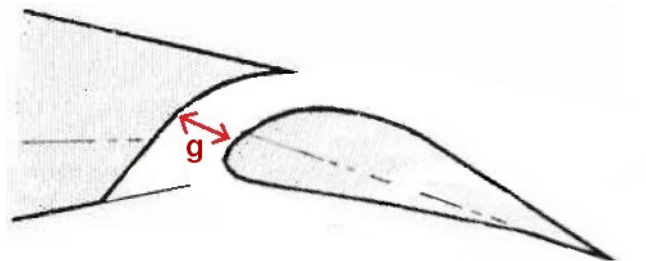
## 2.2. Refinement of the adjacent and the detailed zones

### Refinement of the adjacent zones :

Refining adjacent zones increases computation time.

If no air flow is expected between your foils, you can fill the gap and avoid the calculation.

#### → Refining the gap



In this example,  $g=1$  and the detail size is 1.

We must refine the surfaces within the interstice with a custom refinement choosing *detail size* / 4, to insure that the gap is meshed properly.

Select the suitable ratio *detail size* /  $n$  for your geometry.

#### → Filling the gap

If no airflow is expected between the foils, you can fill the gap between the parts. It will avoid long computation and inaccurate results due to a bad meshing.

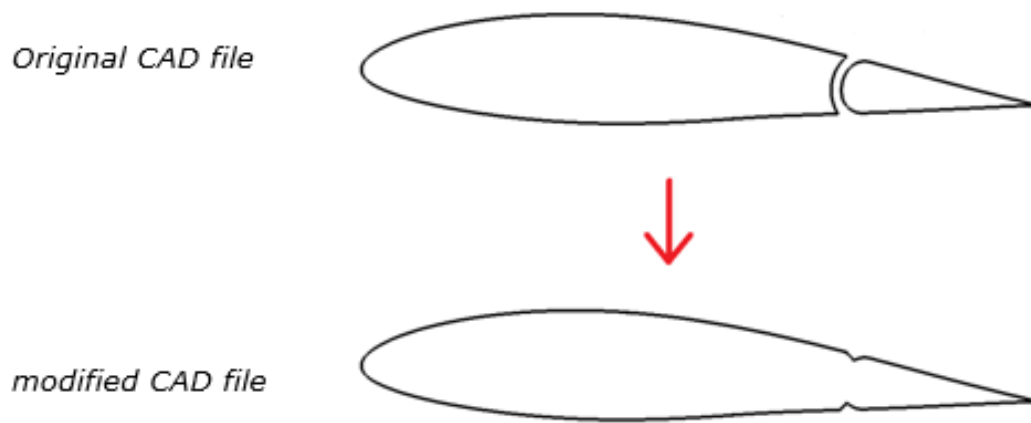


Figure 57: Modification of a CAD file to fill the distance between the parts.

**Refinement of the detailed shapes :**

**Do not overdo it:** the more refined, the longer the computation time.

Select the suitable ratio *detail size* /  $n$  for your geometry.

Smaller refinement sizes give more accurate results than bigger ones :



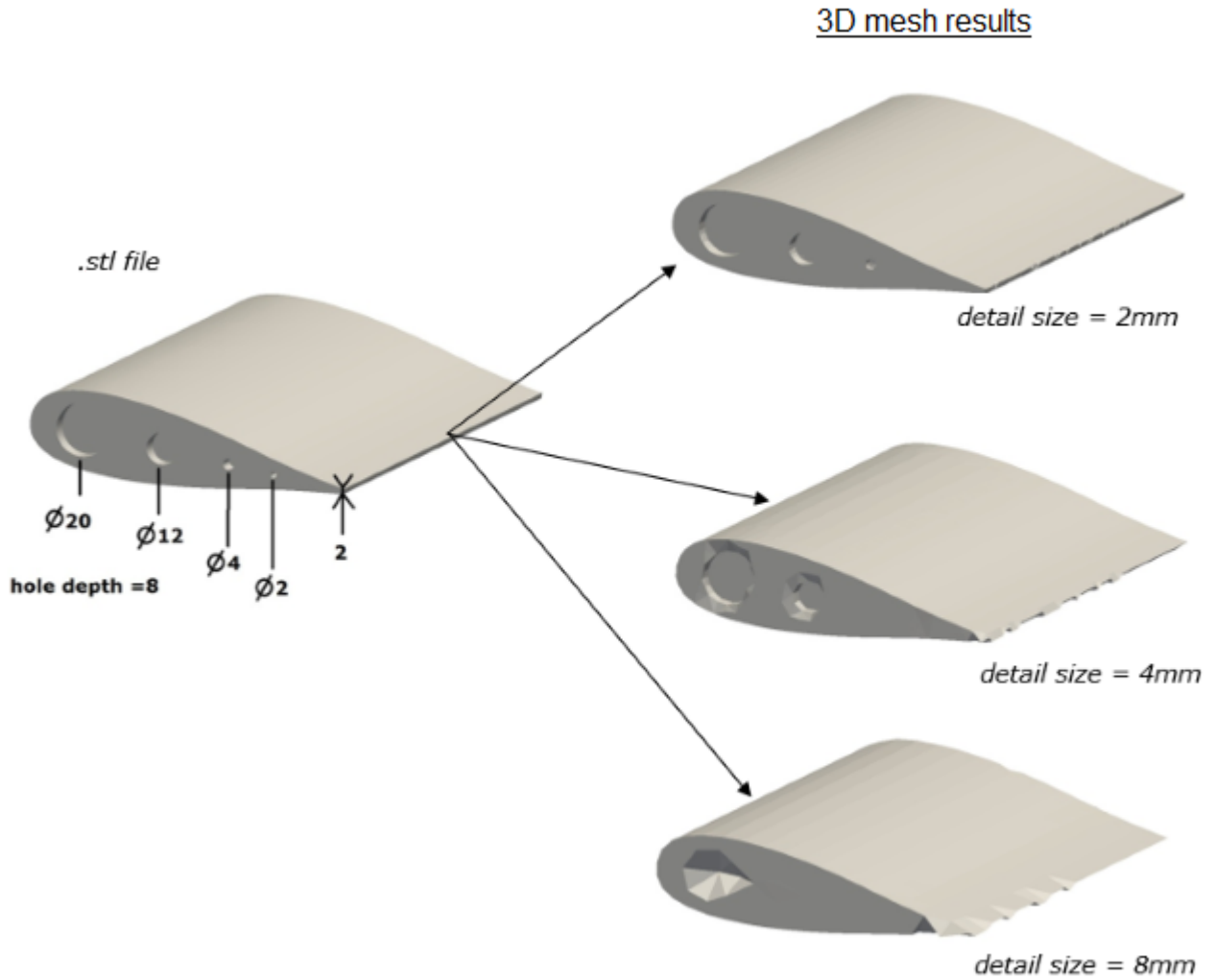


Figure 58: Representation of different detail sizes on a STL file.

When the detail size is too large, the meshed shapes can become inaccurate. The quality of the cells in the mesh can also become bad means runs become unreliable (randomly failing, diverging, giving inaccurate results).

Generally, it is best to use a detail size that is half the thickness of the smallest trailing edge in the CAD, and to modify the CAD to remove all details that would not be meshed well given this size. In the preceding image, the trailing edge thickness is 2mm, so the ideal detail size would be 1 mm. All the features that are less a couple of millimeters should be removed or edited in the CAD. If this is not possible, custom refinements can be used, see 5. Custom refinement

In case of cylindrical shapes, make sure the refinement provides enough sides (minimum 8 sides per circle) to constitute a almost cylindrical volume.

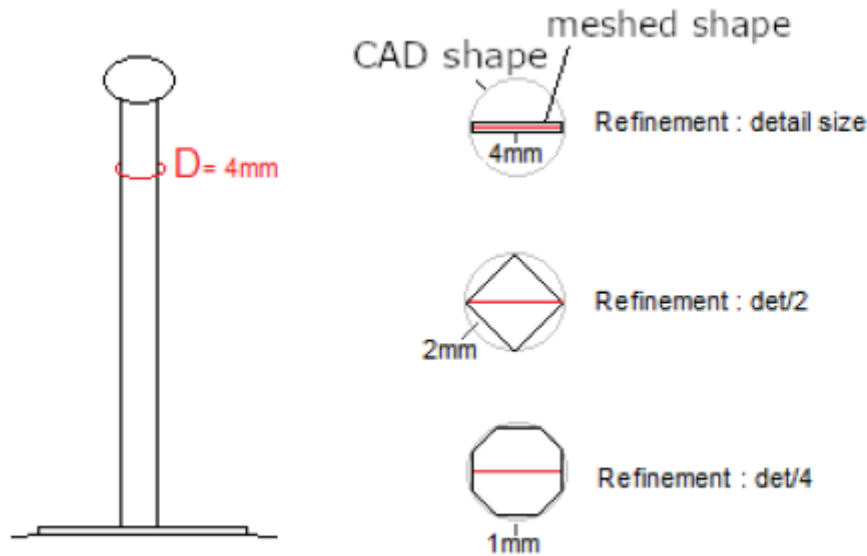


Figure 59: Aircraft antenna.

For more information, see 6. Detail size

### 2.3. Surface angles

#### Acute angles :

If you have any acute angles in your parts, the software could mesh the angle incorrectly. Edit the part to avoid it.

The following example shows a way to avoid an acute angle and get a mesh of better quality. The mesh must have at least 2 cells on the modified (red) surface.

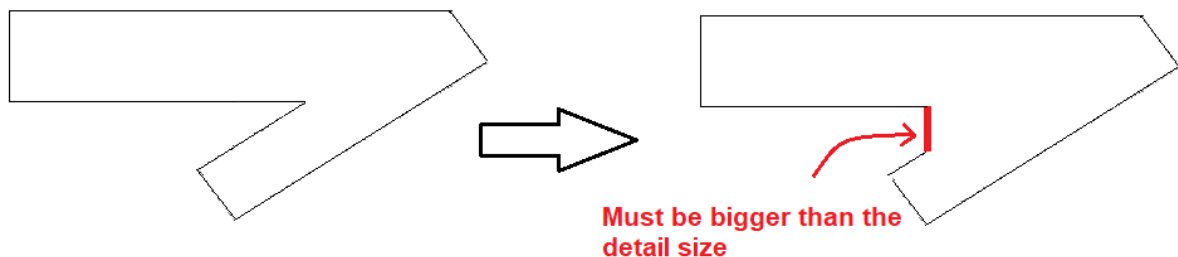


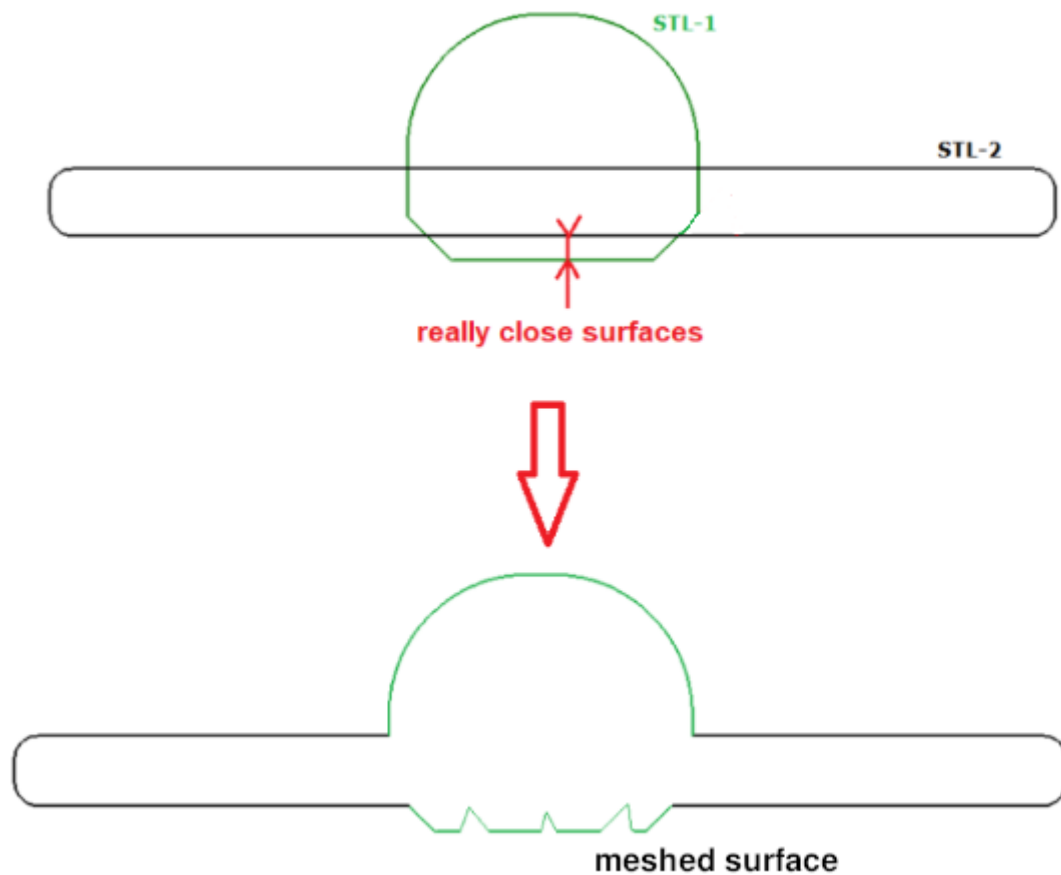
Figure 60: Modeling the part differently to avoid problems with meshing.

To avoid bad meshing, avoid angles below 90°.

#### Bad meshing near adjacent surfaces :

When two surfaces are close to each other, it is better to define only one surface for both in order to avoid bad meshing.

This example shows the mesh you can obtain with two closely spaced surfaces :



To prevent problems, avoid overlapping parts as much as possible.

### 3. STL Generation

Any .igs file imported into the software will be automatically converted into a .stl file by a script.

This automation is fallible and can create problems after the conversion of the part(s).

If your .igs file contains a few simple parts, you can proceed with it : it will be converted into a .stl file automatically.

If your .igs file contains numerous and complex parts, create and import a .stl file directly.

A high-quality .stl file :

- has its points coordinates close to the surface definition of the CAD.
- possesses enough coordinates to define precisely the surface.
- considers the placement of the sharp edges.

#### Exchanger surfaces and flow report surface :

Provide a well **refined** .stl file. *It is not recommended to use an .igs file.*

If your file is not refined enough, the mesh might be of bad quality and the computation will give inaccurate results.

The post-processing of the flow depends on the refinement of your .stl file because the interpolation is done on the meshing of the file.

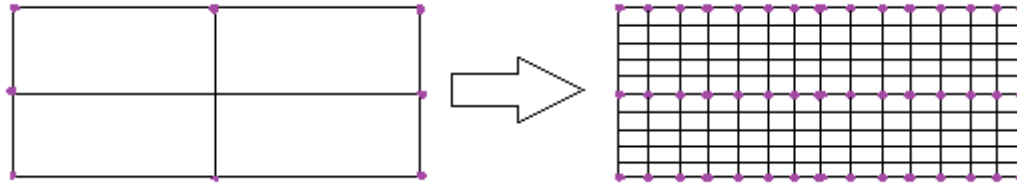


Figure 61: Refining part(s) avoids problems with the interpolation of results on the .stl mesh.

**Be cautious when you create an exchanger :**

The inlet and outlet must be parallel and flat.

The exchanger must be a closed volume.

## 4. Exchanger heat exchange and pressure loss curves

When you create an exchanger model, the software asks for a list of the exchanger operating points, that is, the difference of pressure between the inlet and the outlet at different velocities going through the exchanger.

This list of values determines a law of pressure loss and heat exchange depending of the airflow speed.

It is better to provide precise values for the largest velocity range possible. Add as many values as you want by clicking on the "+" button.

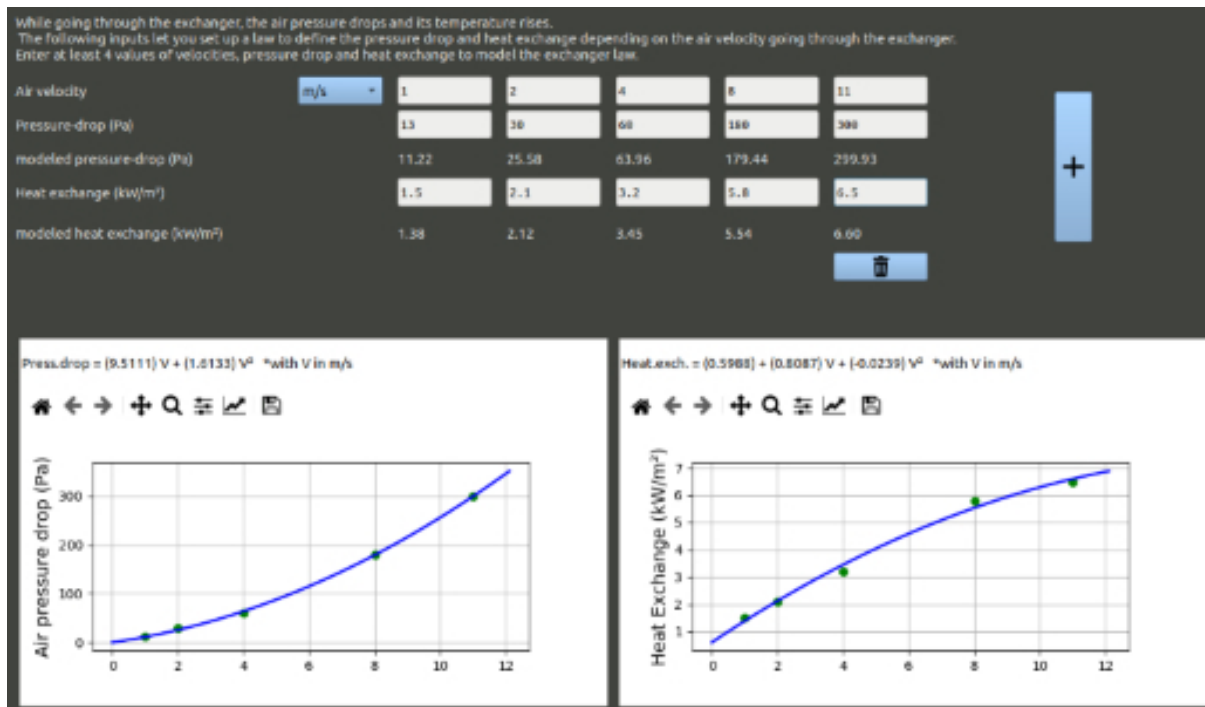


Figure 62: Software screenshot of the air pressure drop and heat exchanger curves.

→ To obtain the pressure loss data, contact the manufacturer or search the Internet for available data on your exchanger (make sure it is the same reference as yours). You may also measure the inlet and outlet pressures with a pressure gauge yourself :

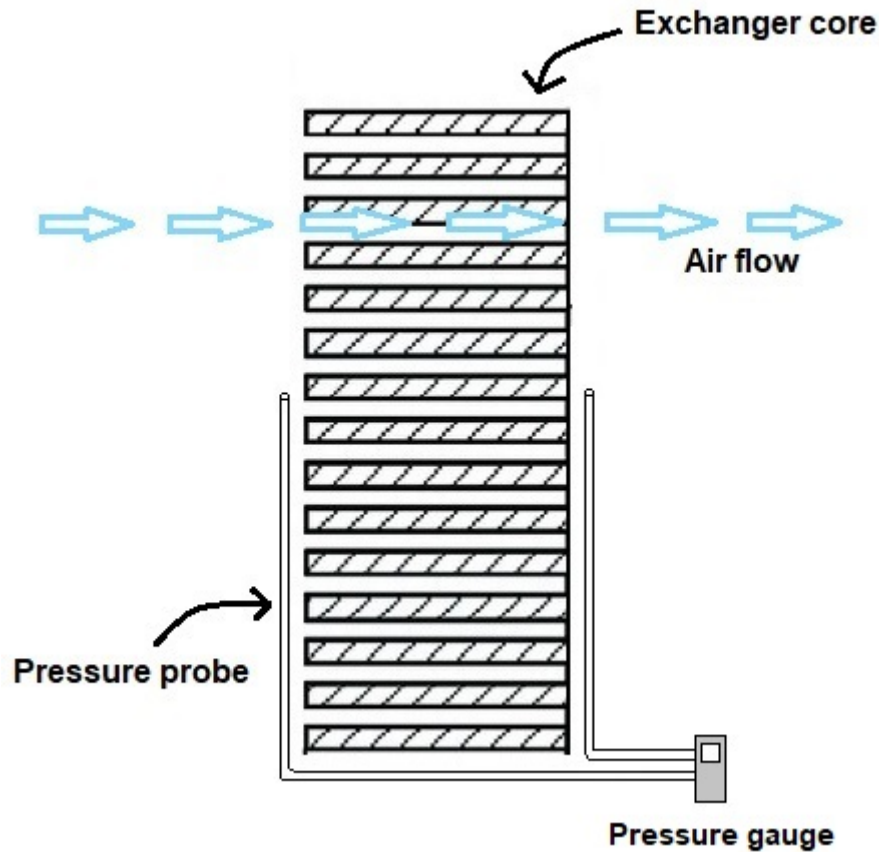


Figure 63: Representation of the pressure measurement for a heat exchanger.

→ If you have no heat exchange data, you may define a dummy curve where the heat exchange coefficient is equal to the air speed. However, keep in mind that this curve will be false and that you should not take the results into account.

**Be careful:** in your Navier-Stokes runs, the air speed going through the exchanger has to be in the range of values you provided or it will give you inaccurate results.

## 5. Self-evaluation of the calculation results

Use your own judgement to evaluate if the results seem logical or if there is a problem.

It is advised to verify the following checklist for the first calculation in a series :

**In the configuration of your geometry tab, check :**

- The hole detection points pictures :  
Red highlight in the pictures represent holes, it is advised to fill the hole or a problem might occur later.
- The view orientation pictures : The blue vector ( $x$  axis) is longitudinal and points to the rear.

The green vector ( $y$  axis) is spanwise and points to the right.

The red vector ( $z$  axis) is vertical and points upwards.

Verify if the parts are misplaced or if you did not forget any parts.

**In the runs of your projects tab, check :**

- **MeshInternal pictures :**

The pictures must show holes representing the shapes inside your aircraft : it proves that these zones are not meshed.

- **Prisms pictures :**

By default 5 surface prism layers should be extruded. This images let you see where some cell extrusion were cancelled to insure cell quality. The more surface layers the better, generally. Spots with less layers or no layers can be sources of inaccurate drag force estimation, but are generally acceptable as long as the imperfections in layer coverage are small.

- **YPlus pictures :**

$Y+$  is a non-dimensional scalar used in Navier Stokes model to represent wall distance for a wall-bounded flow. For the results to be accurate in Ace of Aircrat, the values of  $Y+$  should be between 1 and 300.

You can check this on the images generated automatically at the end of a run, images called `Solution_yPlus_*.jpg`. If values of  $Y+$  seem too large, you should use a smaller detail size, or locally refine the mesh of the part, or decrease the air velocity.

- **Convergence pictures :**

Within the "averaged for results" section the curve must be stable. Large jumps in values indicate a problem. If the curve is not stable, verify if the amplitudes are logical. The residuals are the estimations of the remaining error during computation. Their values should ideally decrease and remain as small as possible.

- **RAM used :**

If your RAM used is at 90 or 100%, change your detail size parameters or add a computer to the computing cluster.

**Error or warning message :** (An orange message is a warning ; a red message indicates an error) :

- **Errorview pictures :**

Errorview pictures appears only if your calculation has failed. Those pictures shows the bad quality meshes.

- **Logs :**

Each log represents an OpenFoam operation, you can consult them in case of problem. If a warning icon appears, it is advised to look at it.

# Part V.

## CORRELATIONS

### 1. Detail size parameter

#### Investigation of the detail size parameter impact.

This investigation is based on a NASA experiment made on the geometry seen below (Wartime report L-373) and studied in the Langley Memorial Aeronautical Laboratory (Langley Field, Va.). *You can find the complete report in the References compressed folder provided.*

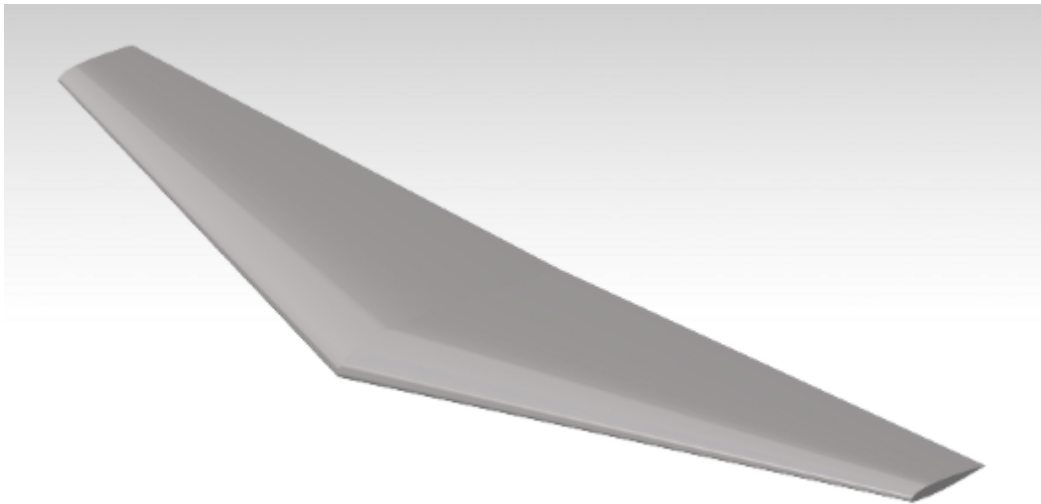


Figure 64: 3D Tappered NACA 23012.

#### Captions for figures 65 and 66 :

exp (black crosses) : NASA wind tunnel experiment.

det : detail size parameter.

te : trailing edge thickness.



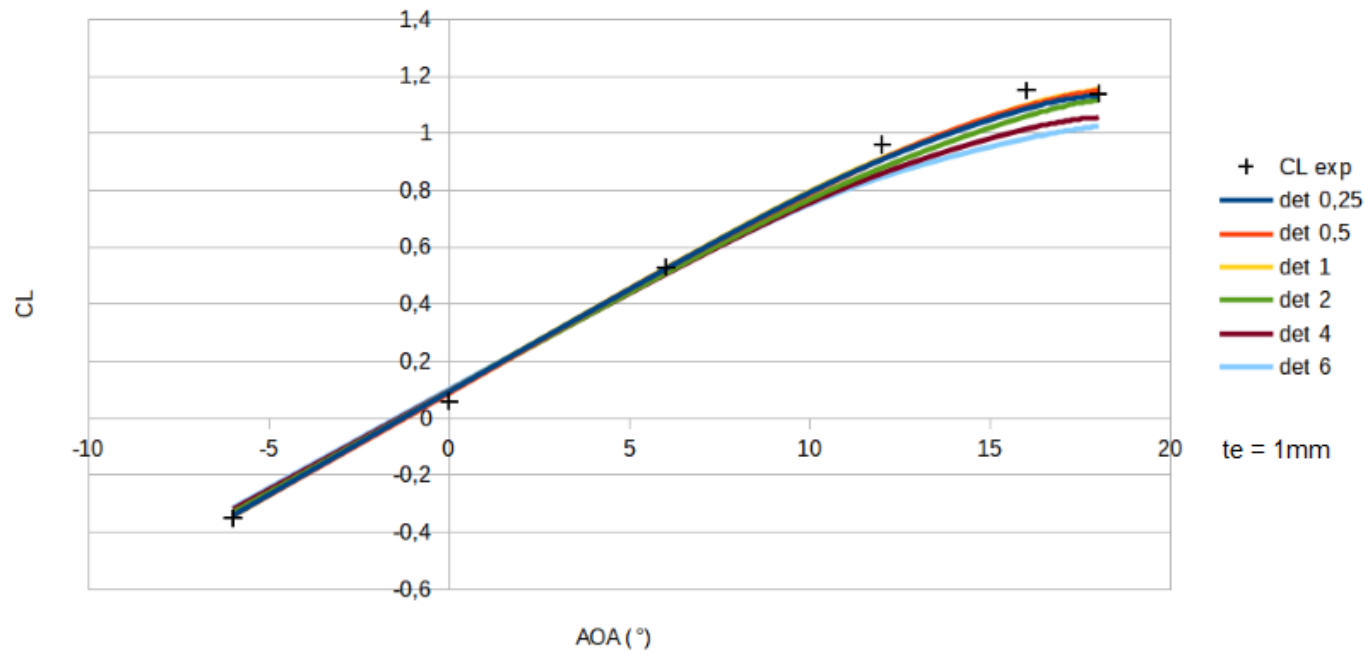


Figure 65: CL w.r.t AOA (different detail sizes).

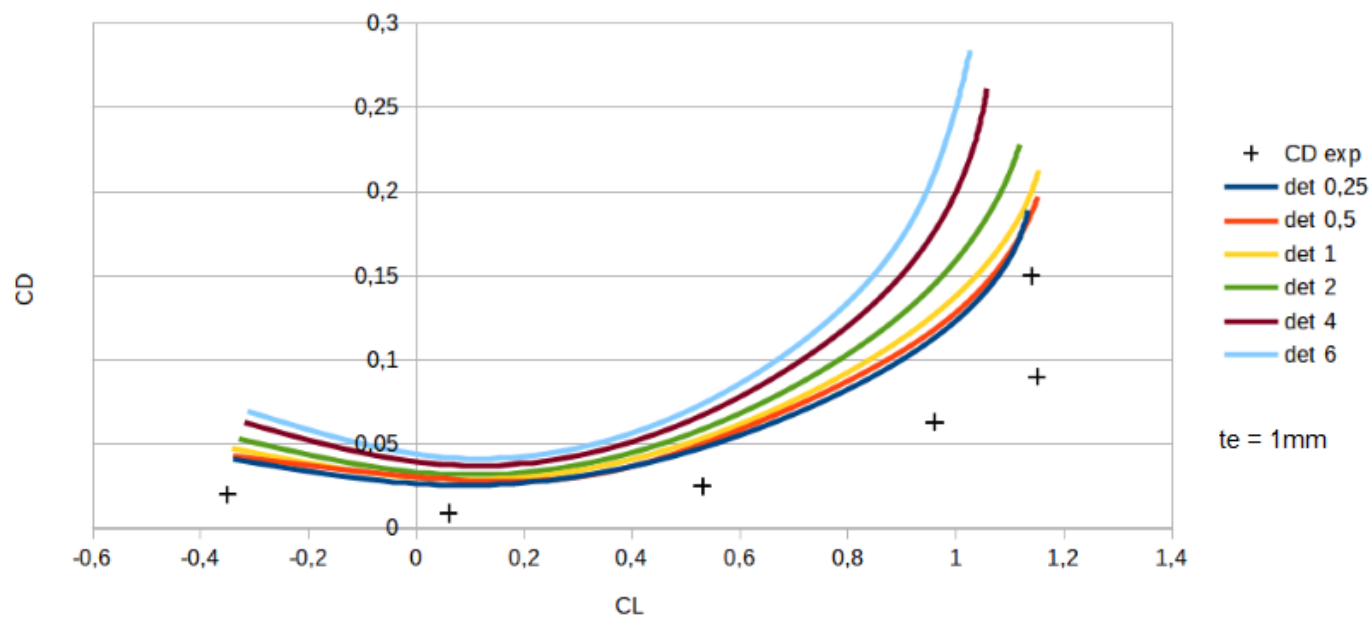
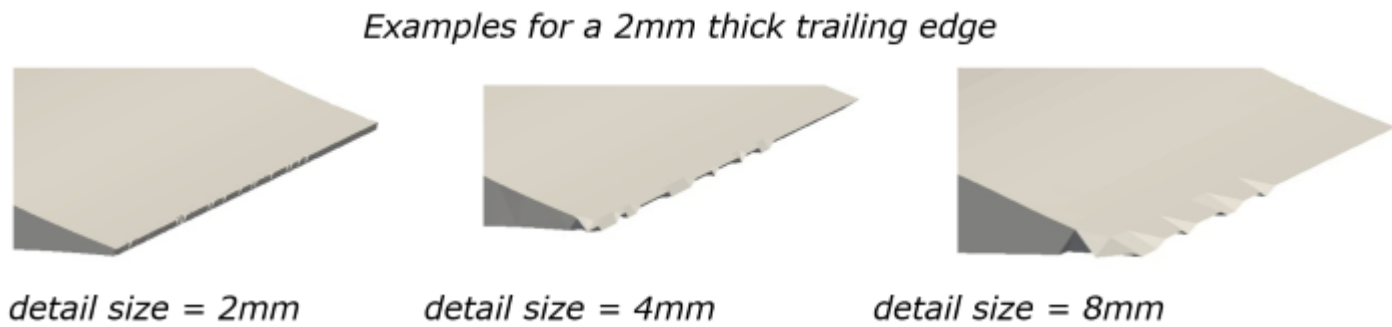


Figure 66: CD w.r.t CL (different detail sizes).



If the detail size specified is larger than the trailing edge thickness, the mesh will not respect the trailing edge shape.

### **Conclusion :**

The detail size defines the size of the meshing in the Navier-Stokes calculations.

The detail size number has a bigger impact on the drag coefficient (CD) than the lift coefficient (CL).

Set your detail size to a value neither too small nor too big :

If it is too small, the computation will take a lot of time and RAM.

If it is too big, it will be less accurate.

It is recommended to set the detail size value to half the trailing edge.

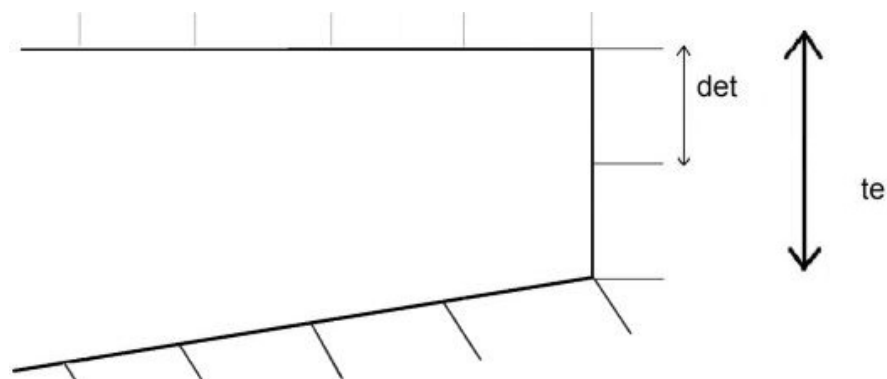


Figure 67: Detail size and resulting mesh.

For more information, see the 6. Detail size

## **2. Trailing edge thickness**

### **Investigation of the trailing edge thickness impact.**

This investigation is based on a NASA experiment made on the geometry seen below (Wartime report L-373) and studied in the Langley Memorial Aeronautical Laboratory (Langley Field, Va.). *You can find the complete report in the References compressed folder provided.*

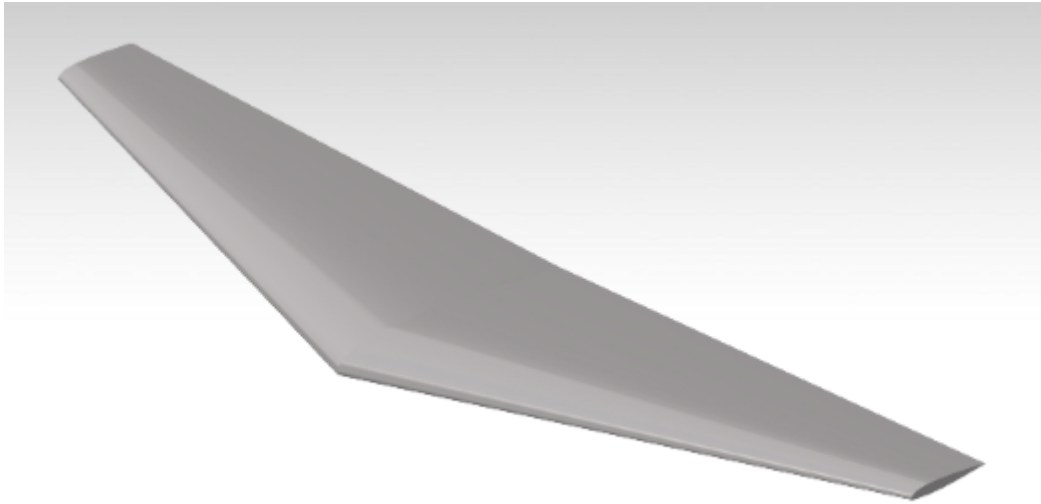


Figure 68: 3D Tappered NACA 23012.

**Captions for figures 69 and 70 :**

exp (black crosses) : NASA wind tunnel experiment.

te : trailing edge thickness.

The detail size is always half the trailing edge.

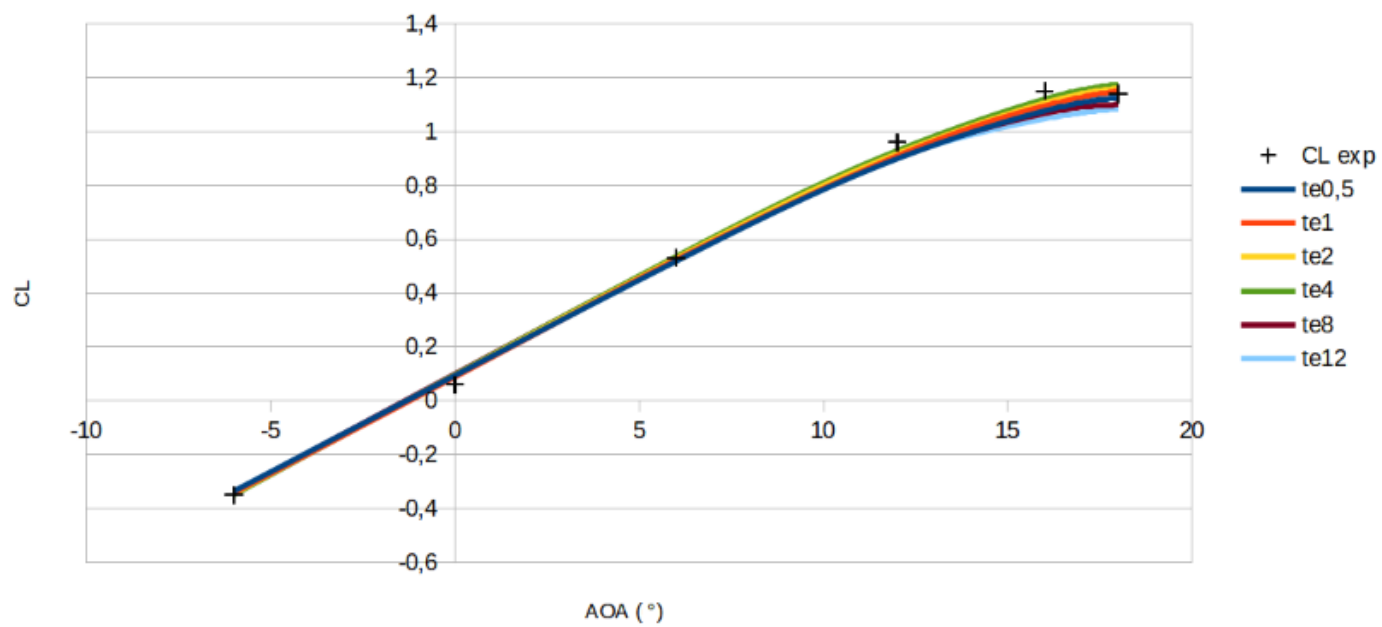


Figure 69: CL w.r.t AoA.

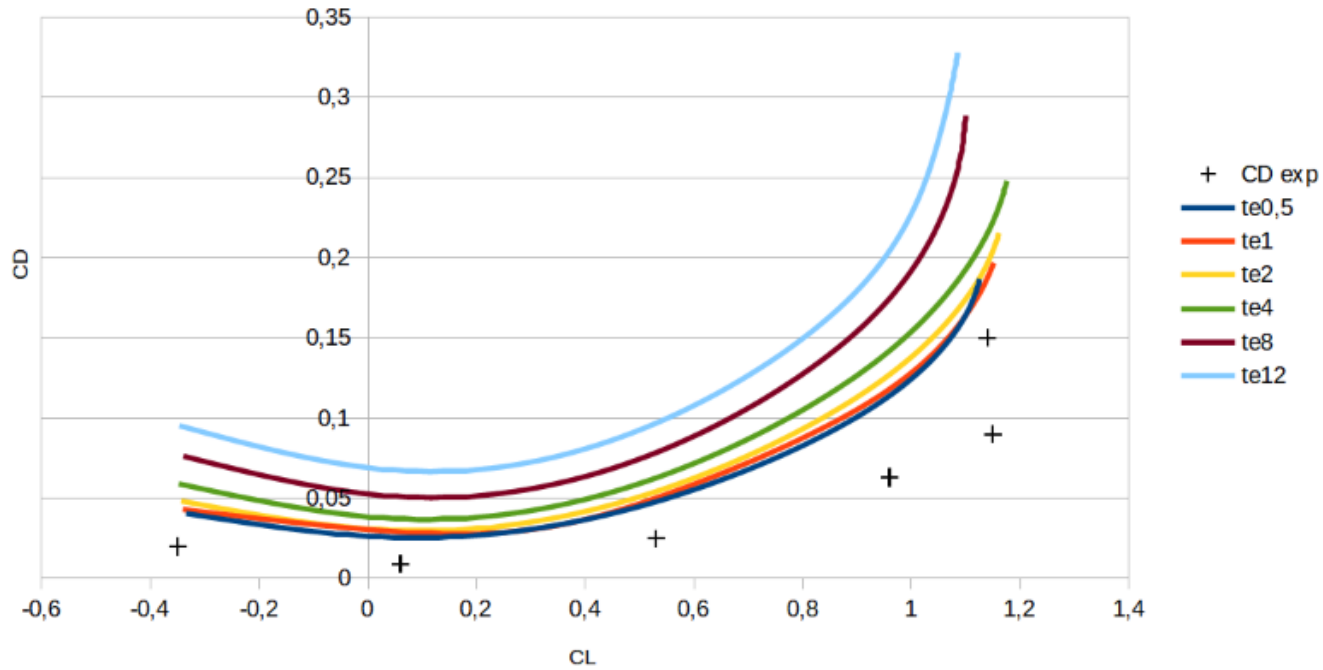


Figure 70: CD w.r.t CL.

#### Conclusion:

The trailing edge thickness has a bigger impact on the drag coefficient (CD) than the lift coefficient (CL).

A trailing edge thickness closer to reality is better.

However, in case you need to limit the RAM used or the computation time, you may increase the thickness in the CAD. This will allow you to define a bigger detail size and create a lighter mesh. Be aware that it may slightly overestimate the drag.

For more information, see the 6. Detail size

### 3. Turbulence models comparison for a 2D geometry

#### Correlation between a NASA wind tunnel experiment, Ace of Aircraft, and StarCCM+ software.

This correlation is based on a NASA experiment made on the geometry seen below (Wartime report L-697) and studied in the Langley Memorial Aeronautical Laboratory (Langley Field, Va.) in 1943. *You can find the complete report in the References compressed folder provided.* For this correlation we will use the case with a flap deflection of 35°.

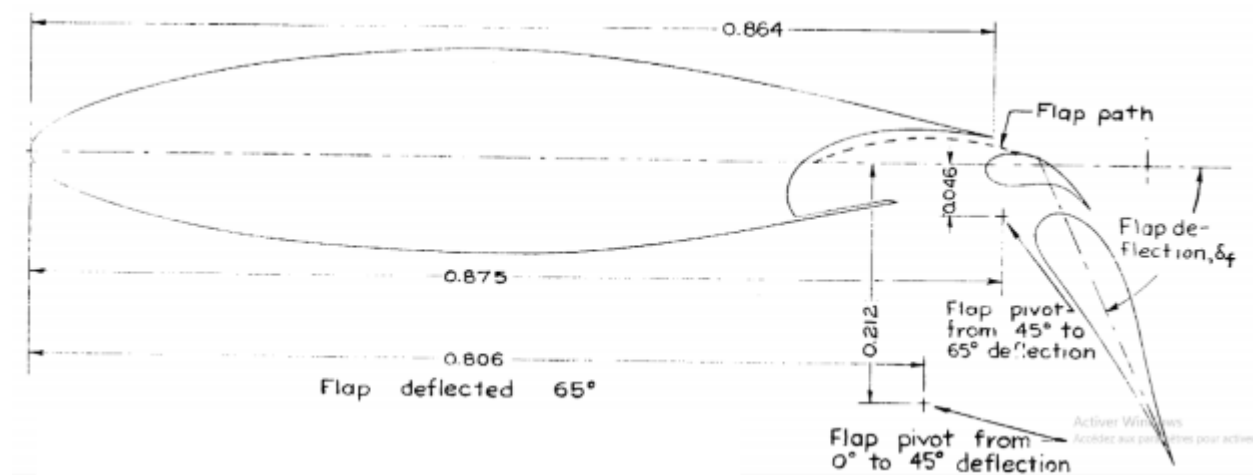


Figure 71: Flapped wings NACA 65,3-118, deflection 35°.

### Captions for figures 72 to 74

- NASA experiment (black crosses) : NASA wind tunnel experiment as reported in report L-697.
- AoA sa and AoA kwsst : Models solved in Ace of Aircraft using the steady turbulence models.
- AoA sa-ddes and AoA kwsst-iddes : Models solved in Ace of Aircraft using the unsteady turbulence models.
- StarCCM+ sa and StarCCM+ kwsst : Models solved in StarCCM+ using the steady turbulence models.

For more information about each type of turbulence model, see Steady turbulence model and Unsteady turbulence model in 2.2. Projects

The mesh sizes of the CFD computations are about 120 000 cells for all models.

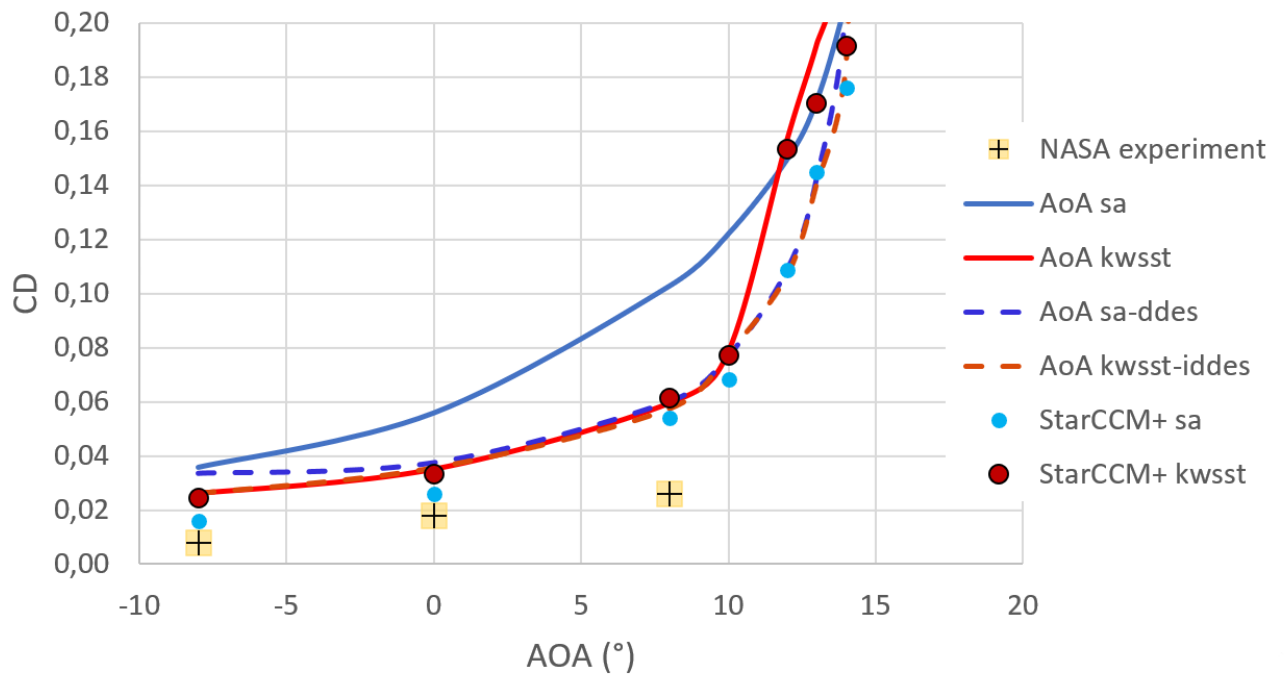


Figure 72: Drag coefficient w.r.t angle of attack.

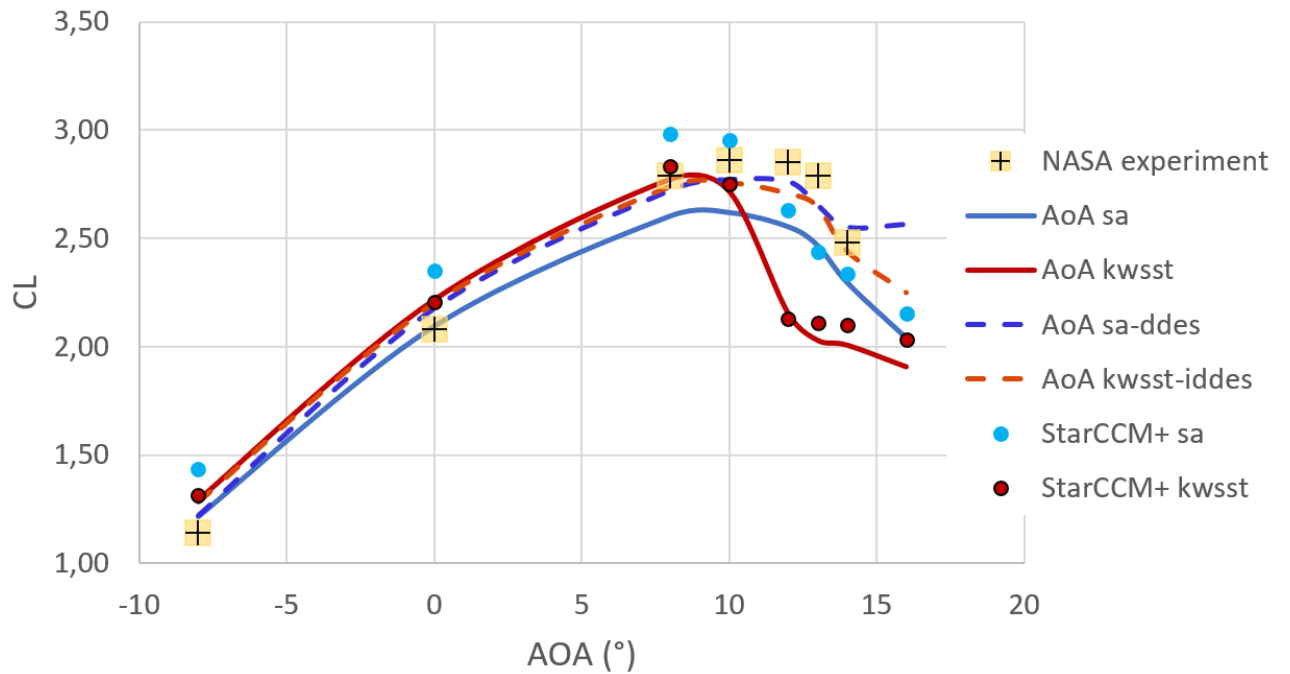


Figure 73: Lift coefficient w.r.t angle of attack.

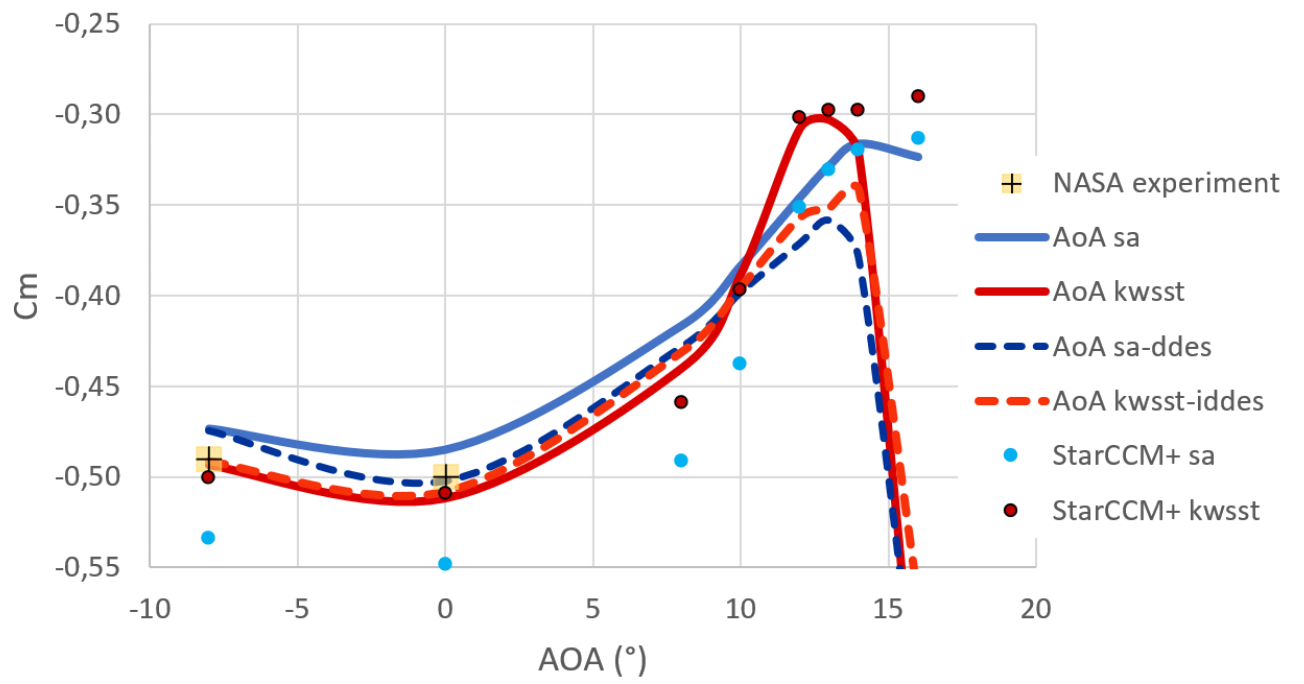


Figure 74: Pitching coefficient w.r.t angle of attack.

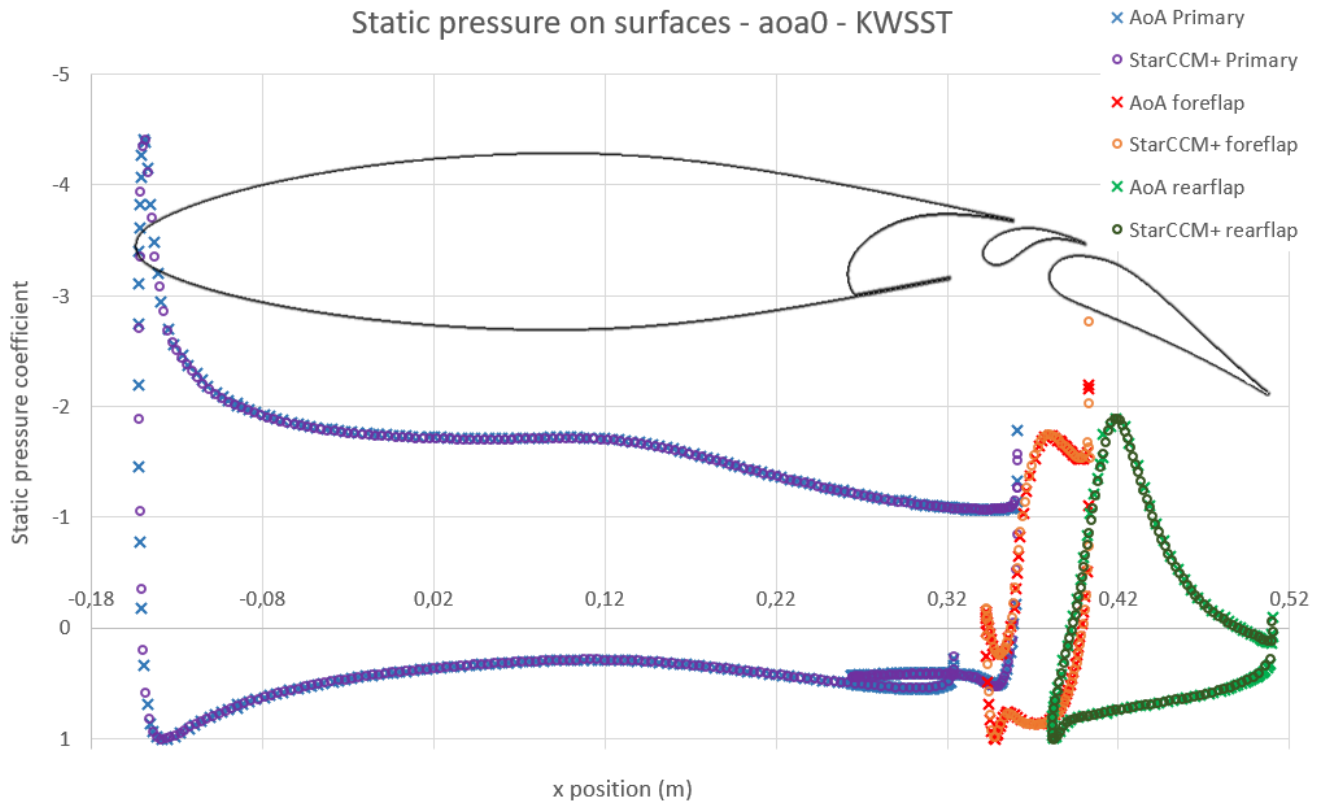


Figure 75: Comparison of static pressure values at 0° of angle of attack using the k-omega SST turbulence model, for Ace of Aircraft and StarCCM+.



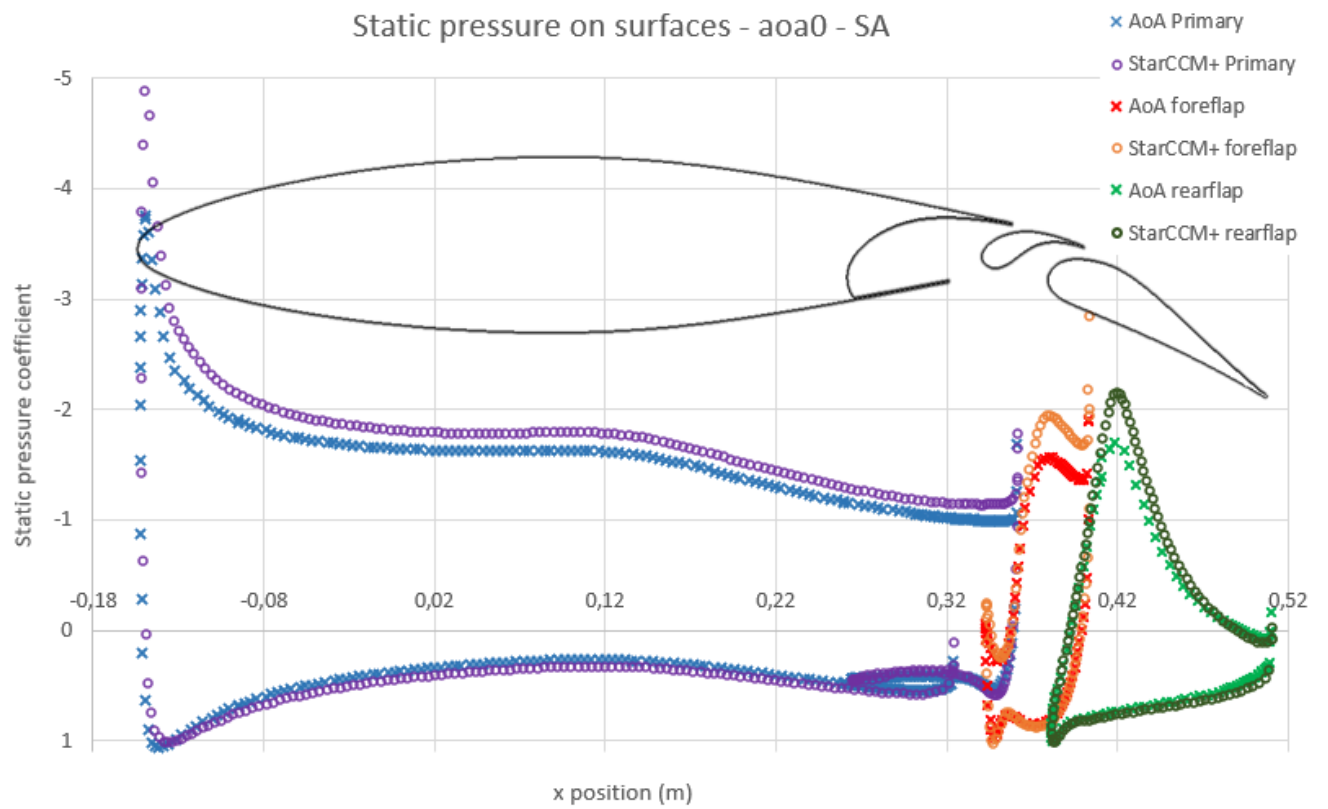


Figure 76: Comparison of static pressure values at 0° of angle of attack using the Spalart-Allmaras turbulence model, for Ace of Aircraft and StarCCM+.

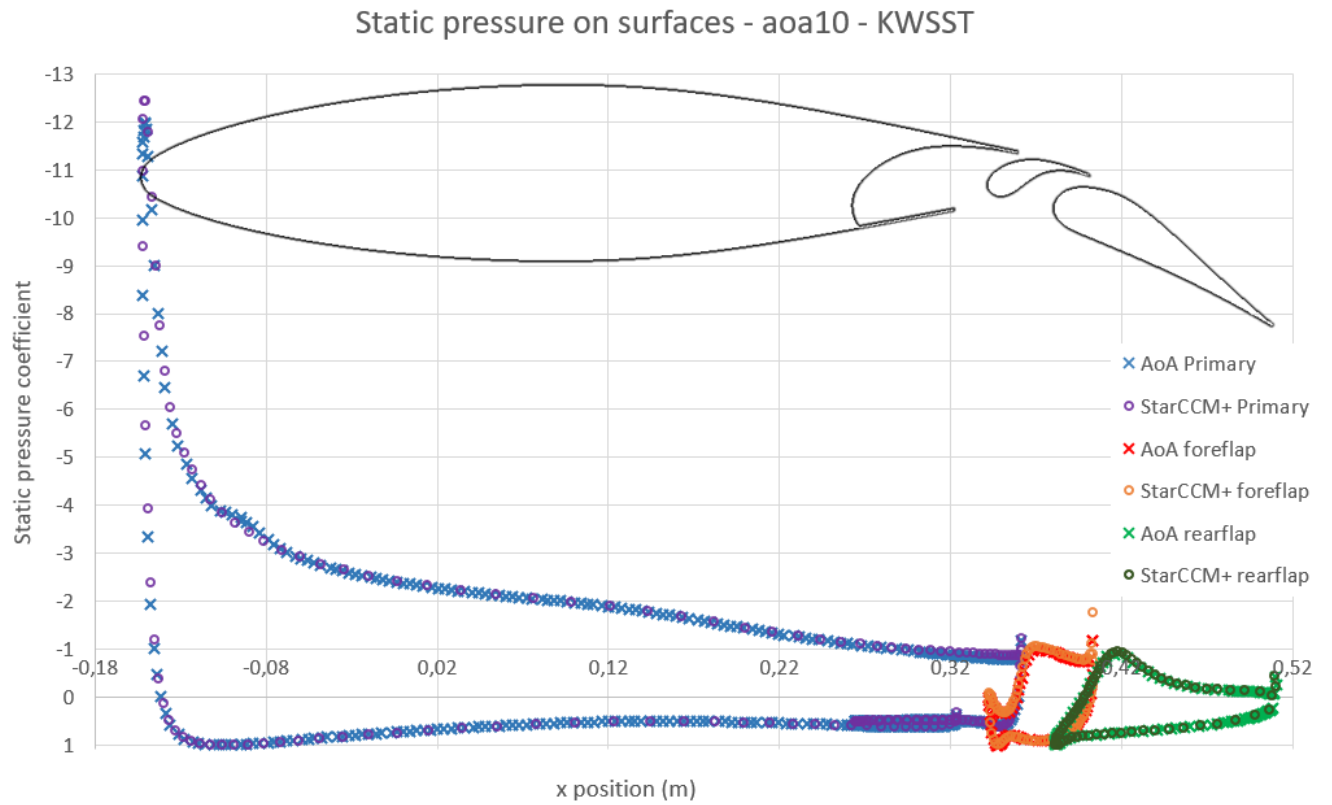


Figure 77: Comparison of static pressure values at  $10^\circ$  of angle of attack using the k-omega SST turbulence model, for Ace of Aircraft and StarCCM+.

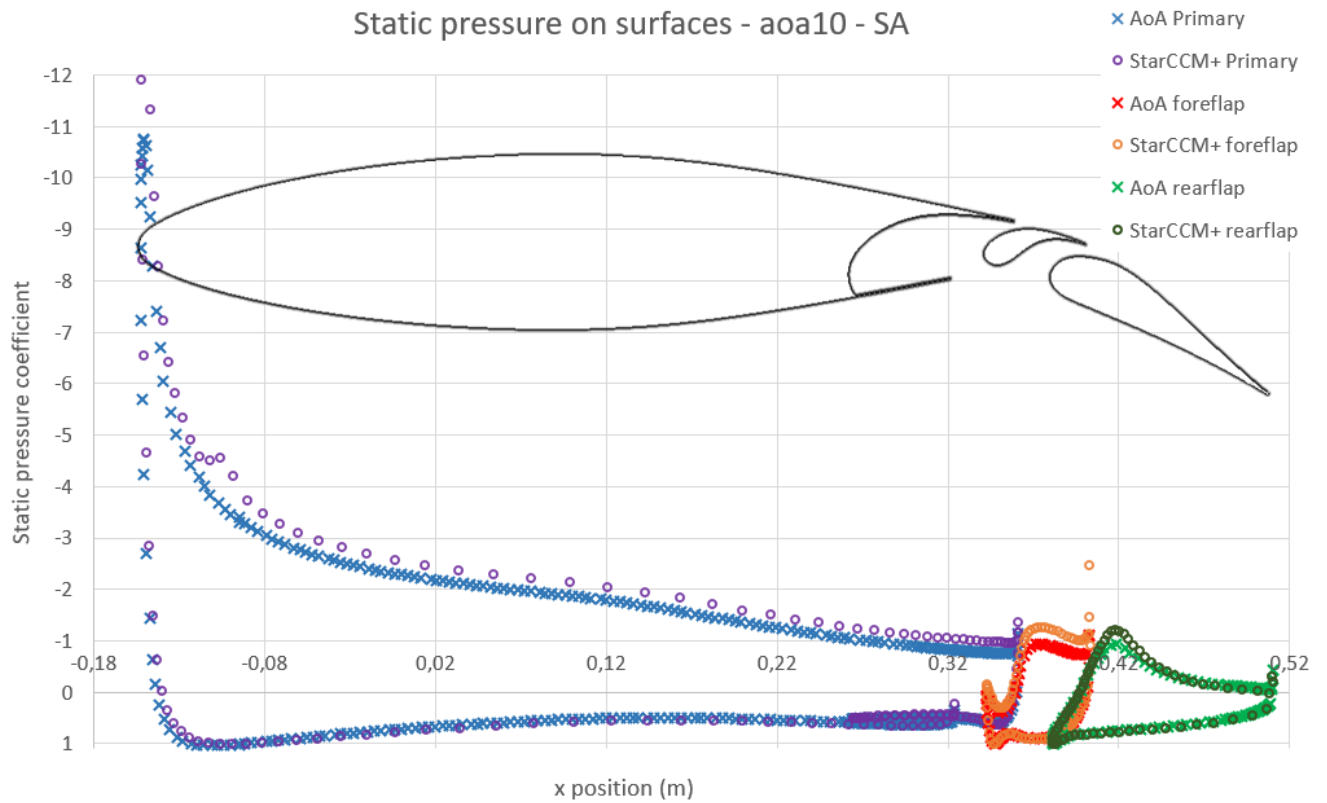


Figure 78: Comparison of static pressure values at 10° of angle of attack using the Spalart-Allmaras turbulence model, for Ace of Aircraft and StarCCM+.

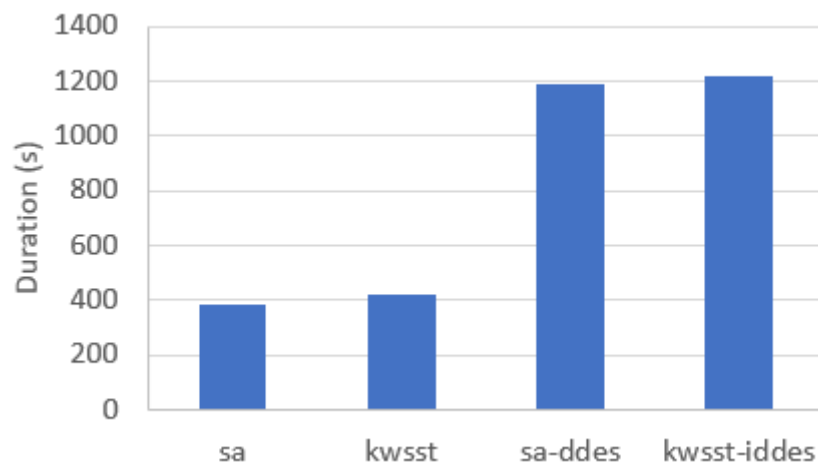


Figure 79: Solving time for one computation in Ace of Aircraft, depending on the turbulence model used.

## 4. Turbulence models comparison for a 3D wing with a flap

**Correlation between a NASA wind tunnel experiment, Ace of Aircraft, and StarCCM+ software.**

This correlation is based on a NASA experiment made on a wing with flap as seen below. The experiment is detailed in NASA Technical Note D-8236, it was conducted at the Langley Research Center (Hampton, Virginia) in 1976.

*You can find the complete report in the References compressed folder.*

This paper gives the drag, lift moment, for various wing configuration. In this chapter we will focus on the case with a flap deflection of  $20^\circ$  and closed spoiler.

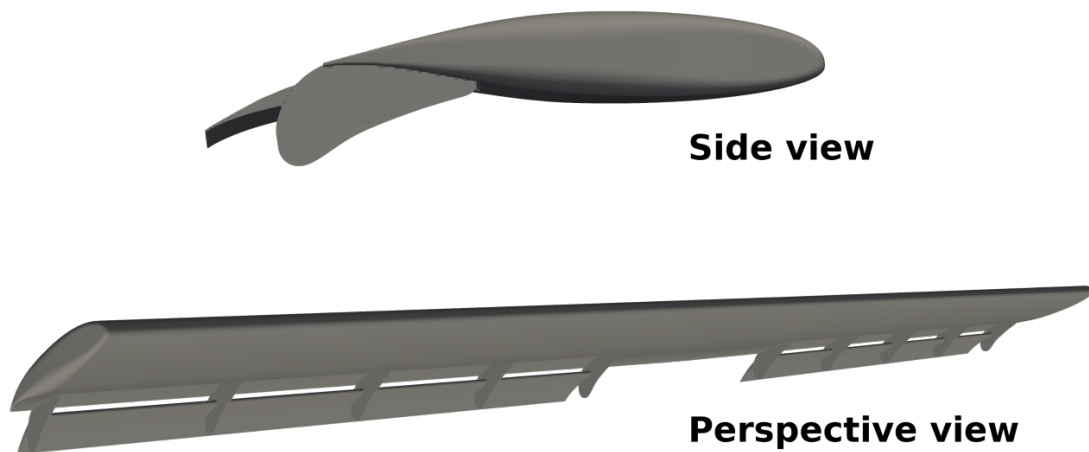


Figure 80: Geometry of the 3D wing with a flap at  $20^\circ$  of deflection.

### Captions for figures 81 to 83

- NASA experiment (black crosses) : NASA wind tunnel experiment as reported in Technical Note D-8236.
- AoA sa and AoA kwsst : Models solved in Ace of Aircraft using the steady turbulence models.
- AoA sa-ddes and AoA kwsst-iddes : Models solved in Ace of Aircraft using the unsteady turbulence models.
- StarCCM+ sa and StarCCM+ kwsst : Models solved in StarCCM+ using the steady turbulence models.

For more information about each type of turbulence model, see Steady turbulence model and Unsteady turbulence model in 2.2. Projects

The mesh size of the CFD computations are between 10 and 15 million cells for a half-wing.

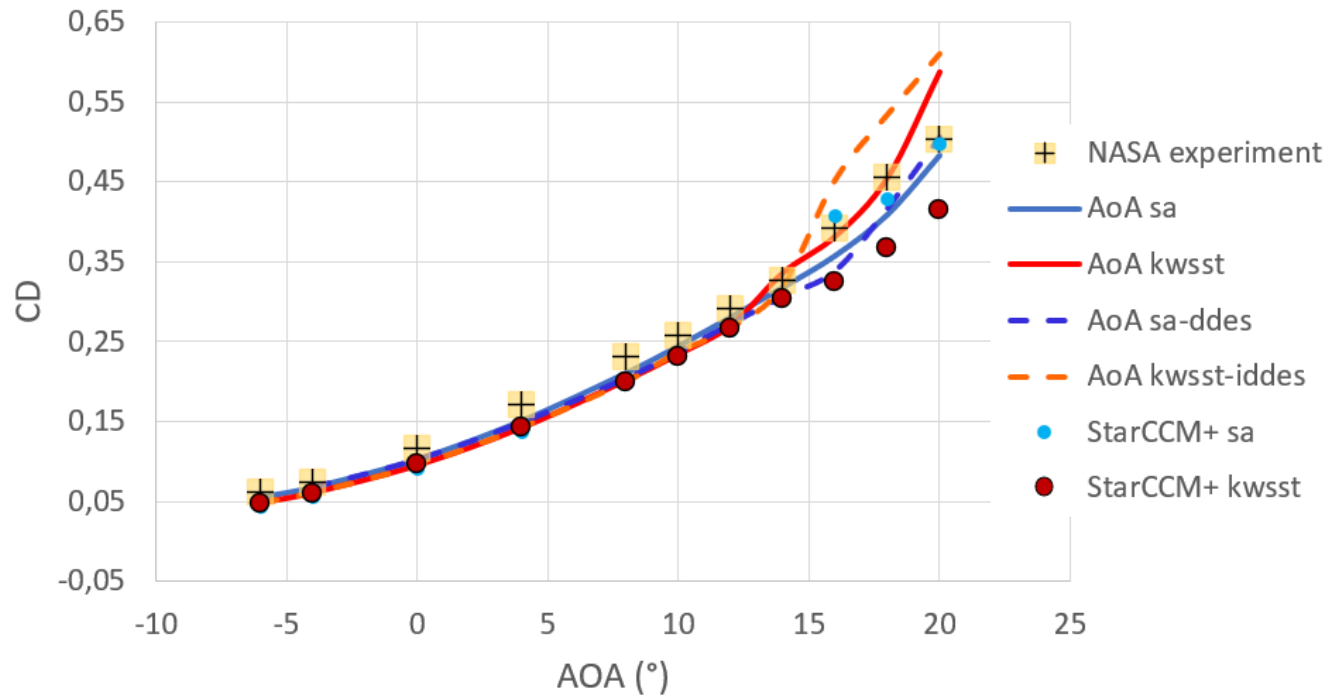


Figure 81: Drag coefficient w.r.t angle of attack.

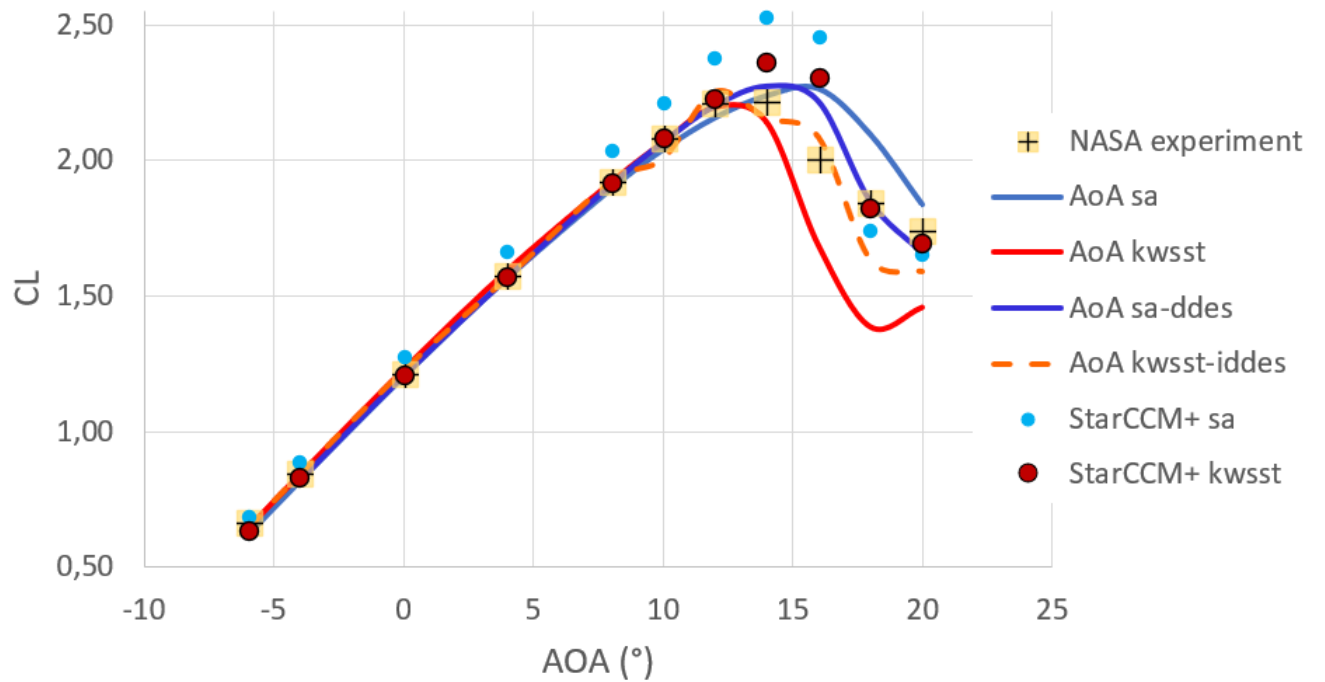


Figure 82: Lift coefficient w.r.t angle of attack.

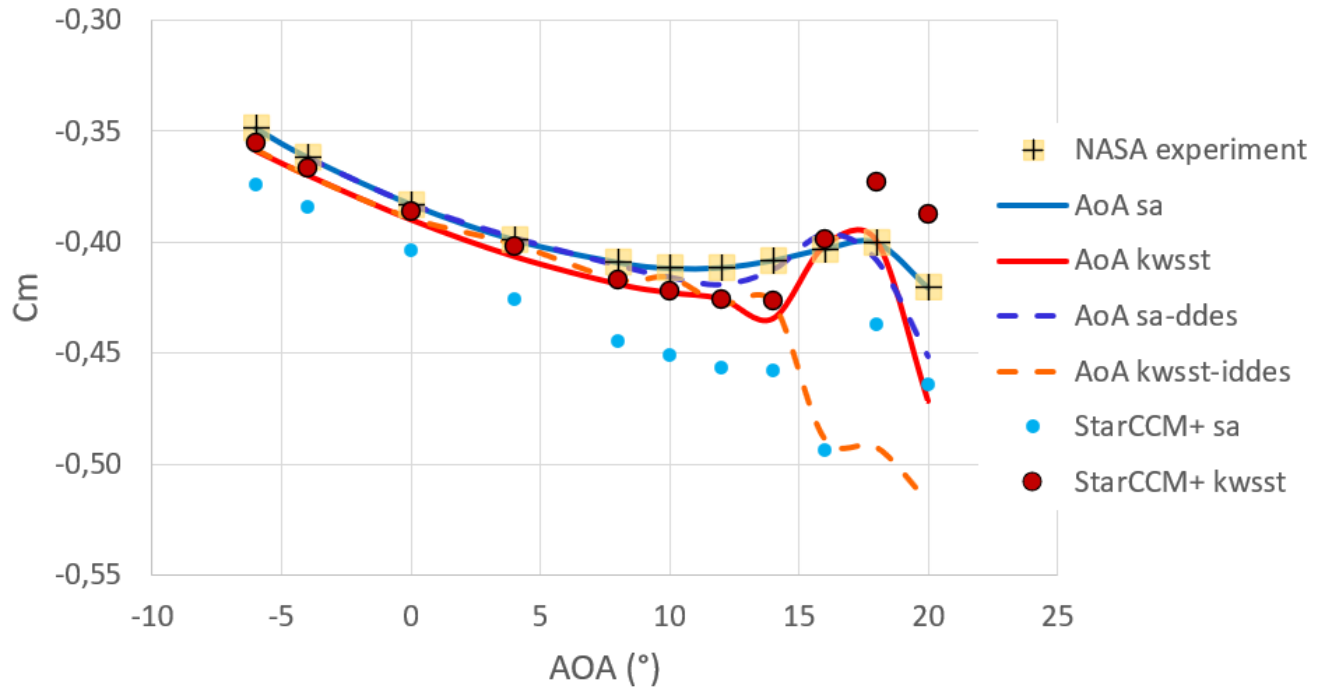


Figure 83: Pitching moment coefficient w.r.t angle of attack.

## 5. Turbulence models comparison for an aircraft

### Correlation between a NASA wind tunnel experiment and Ace of Aircraft software

This correlation is based on a NASA experiment made on full scale Varieze aircraft (Technical Paper 2382). It was studied in the Langley Research Center (Hampton, Virginia) in 1985.

*You can find the complete report in the References compressed folder.*

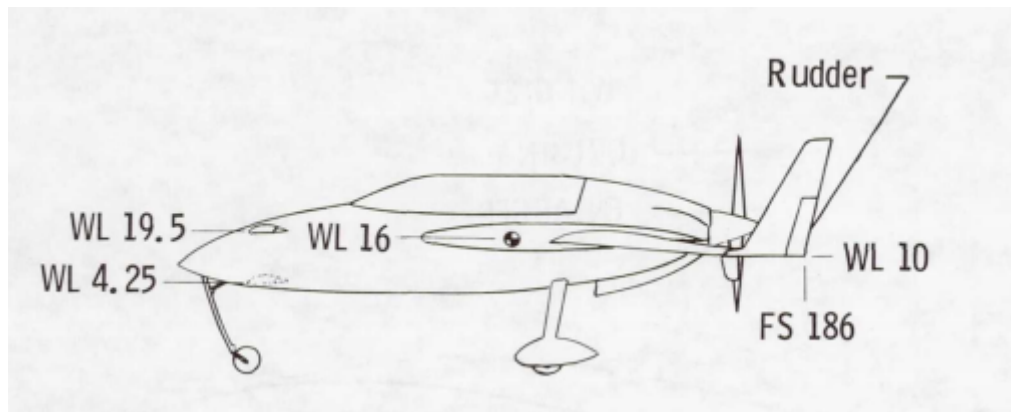


Figure 84: Varieze.

### Caption for the figures 85 to 88 :

exp (black crosses) : experimental data from NASA (on the same aircraft).

sa and kw : steady turbulence models.

sa-ddes and kw-iddes : unsteady turbulence models.

For more information about each type of turbulence model, see Steady turbulence model and Unsteady turbulence model in 2.2. Projects.

In average, the meshes for each calculation are made of 19 million cells.

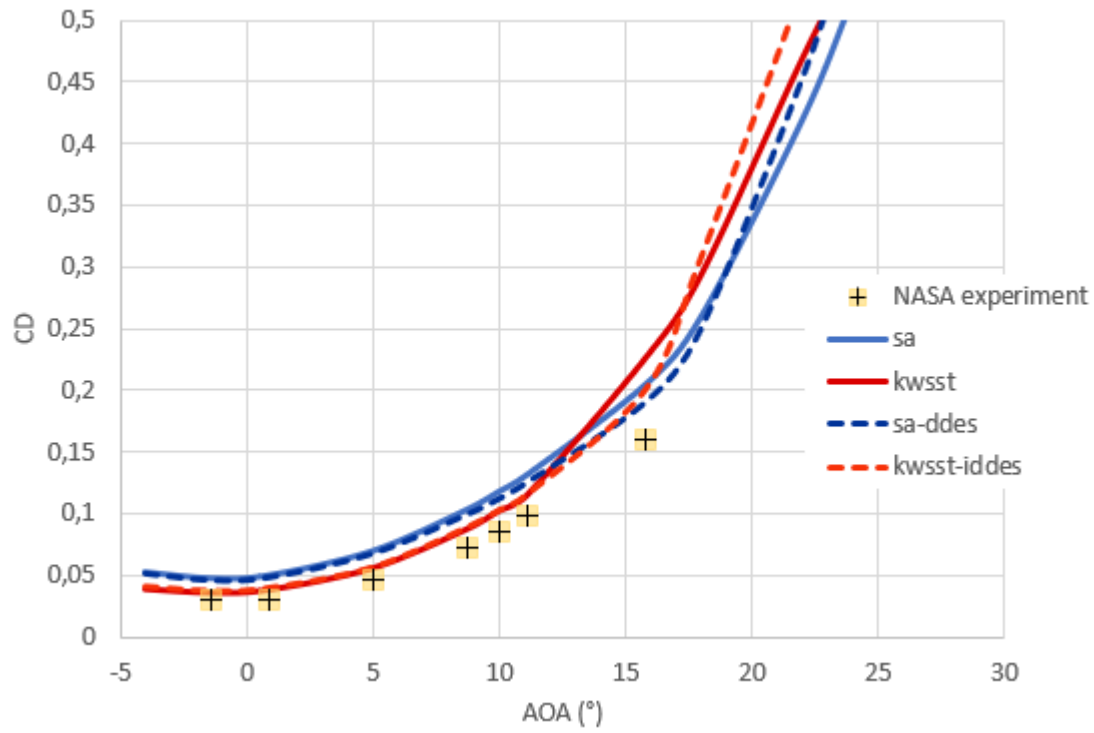


Figure 85: Drag coefficient w.r.t angle of attack.

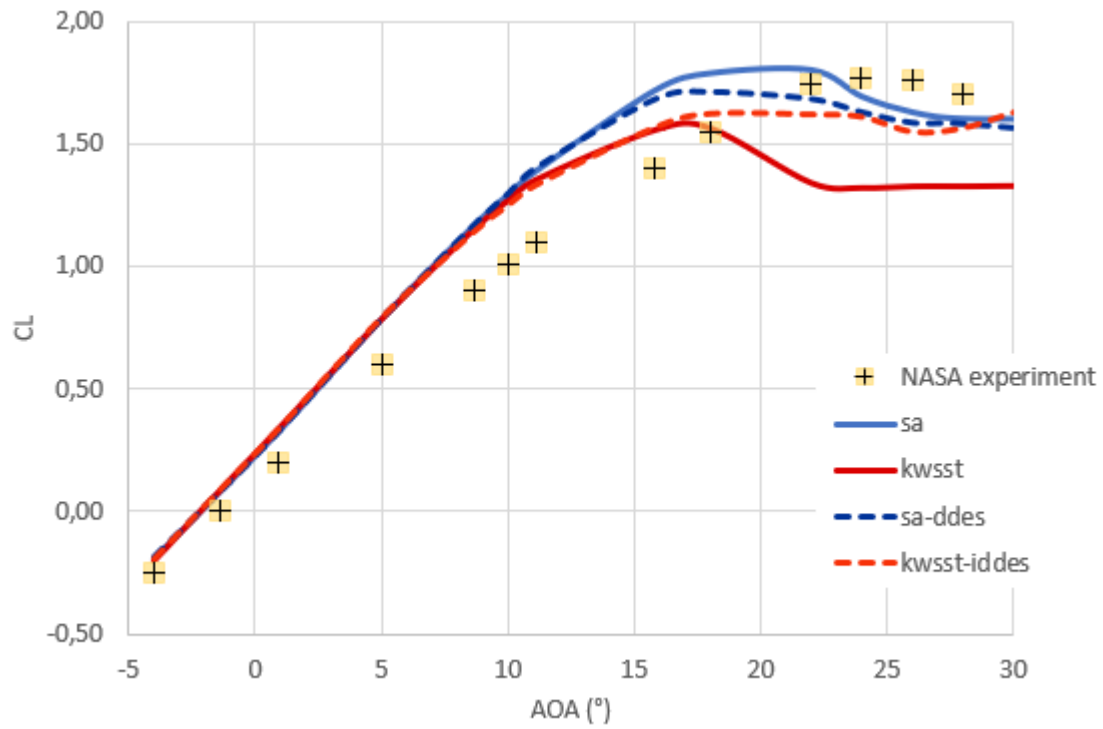


Figure 86: Lift coefficient w.r.t angle of attack.

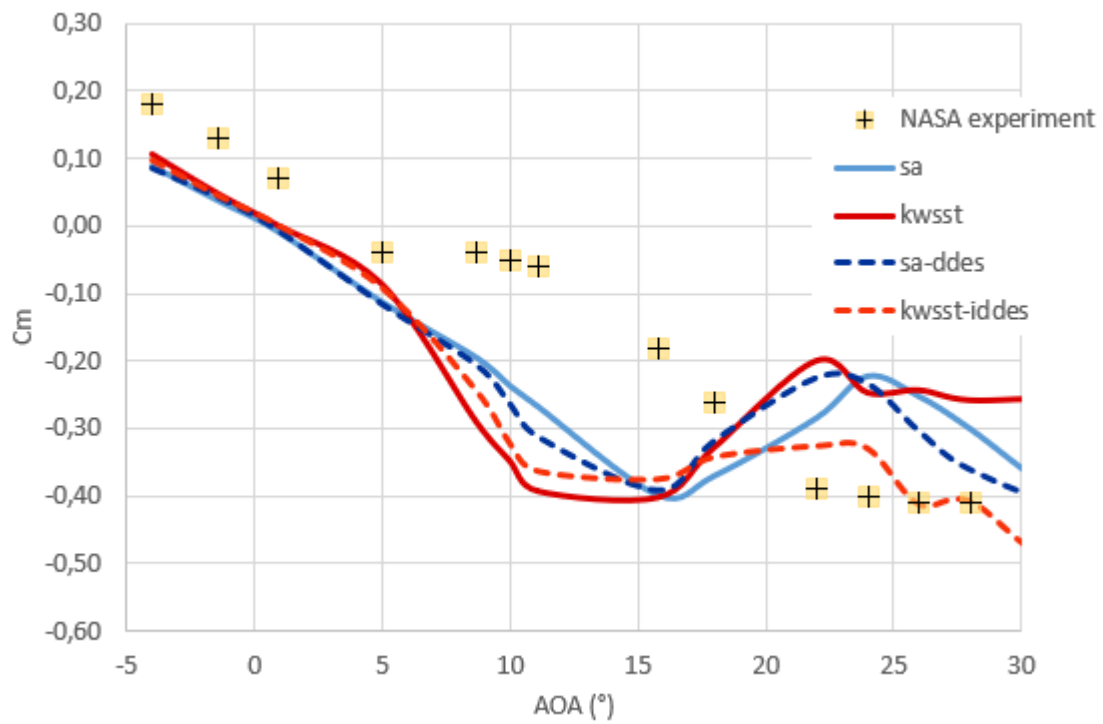


Figure 87: Pitching moment coefficient w.r.t angle of attack.



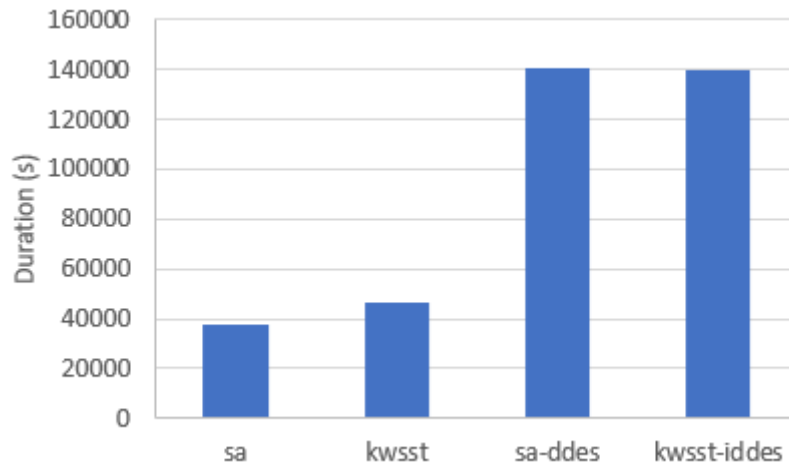


Figure 88: Solving time for one computation in Ace of Aircraft, depending on the turbulence model used.

## Part VI.

# HELP AND SUPPORT

### 1. Troubleshooting

- **Application not opening / Application crashing at launch without errors:** This generally indicates a python error, but the application window closes immediately and there is no time to see the error. In order to visualize the error, launch the application with a terminal:

**On Windows**, press simultaneously the windows key and the R key on the keyboard, and run :

*cmd*

This will open a terminal, in this terminal go to the application directory using the command `cd`. For example for the default installation directory type :

*cd %AppData%/Ace\_of\_Aircraft\_vX*

Then execute the app by typing :

*Ace\_of\_Aircraft.exe*

**On Ubuntu**, proceed similarly, launch a terminal and use the commands:

*cd /usr/lib/ace-of-aircraft/ace-of-aircraft-vX*

*./AceOfAircraft*

- **Windows: Error during Ace of Aircraft installation : pip not found:** Generally this happens when the user forgot to select the option 'Add python 3.10 to PATH' during the installation of python. Uninstalling and re-installing python, without forgetting to activate this option during the install, should fix the problem.

- **Windows: Error : python310.dll not found:** This indicates that the software cannot find a path to the python libraries. Generally this happens when the user forgot to select the option 'Add python 3.10 to PATH' during the installation of python. Uninstalling an re-installing python, without forgetting to activate this option during the install, should fix the problem.
- **Windows: Error 0xc000007b:** Indicates a 32bits vs 64 bits incompatibility. Ace\_of\_Aircraft only work in 64 bits. Make sure your python version is 64 bits as well.
- **Truncated text in the software:** This often happens with windows, depending on your screen resolution. Open the windows settings, select the 'system' category, then find the 'display' section. In there, find a percentage setting for size of texts and apps, set it to 100%.
- **Text and images appear very small in the software:** This can happen if you have a very high resolution on a relatively small display. In ACE of Aircraft, go to the settings tab, and make a small increase on the 'UI scale coefficient' parameter. Close and restart the application for the parameter to take effect. All texts and graphical elements should appear bigger on screen.
- **A run in the queue seems to be stuck at the same percentage of completion for several hours, blocking the queue processing:** It can sometime happen that a the graphical interfaces fails to update the status of the runs. You may find the run folder in the userdata folder, in the corresponding project folder, and check the content of the file named 'runStatus' to be sure. The first line of this file is the percentage of completion for the run. If the status is incoherent compared to what the graphical interface indicates, restarting the software should update the graphical interface with the correct values and unlock the queue processing.  
If the status seems to not make any progress on both sides, the run probably got interrupted without finishing. One reason for that may be the power saving settings of the computer. On Ubuntu, go to "Settings", "Power", and set the option "Automatic suspend" to "Off".
- **Ubuntu login screen is stuck:** You may need to change the login screen of ubuntu from GDM3 to lightdm, because GDM3 can cause problems. In order to do that, boot in recovery mode, in the recovery choices choose to enable networking and use root mode. Then, run the following commands:
 

```
sudo apt update
sudo apt upgrade
sudo apt install lightdm
```

 When prompted, select lightdm then OK.  
You can reboot with the command:
 

```
sudo reboot
```

## 2. Contact us

Please read the User manual before contacting us. If you do not find what you need, or if you want to report a bug please send us an e-mail explaining your problem.

Website: [aero-ce.com](http://aero-ce.com)  
e-mail : [support-aoa@aero-ce.com](mailto:support-aoa@aero-ce.com)