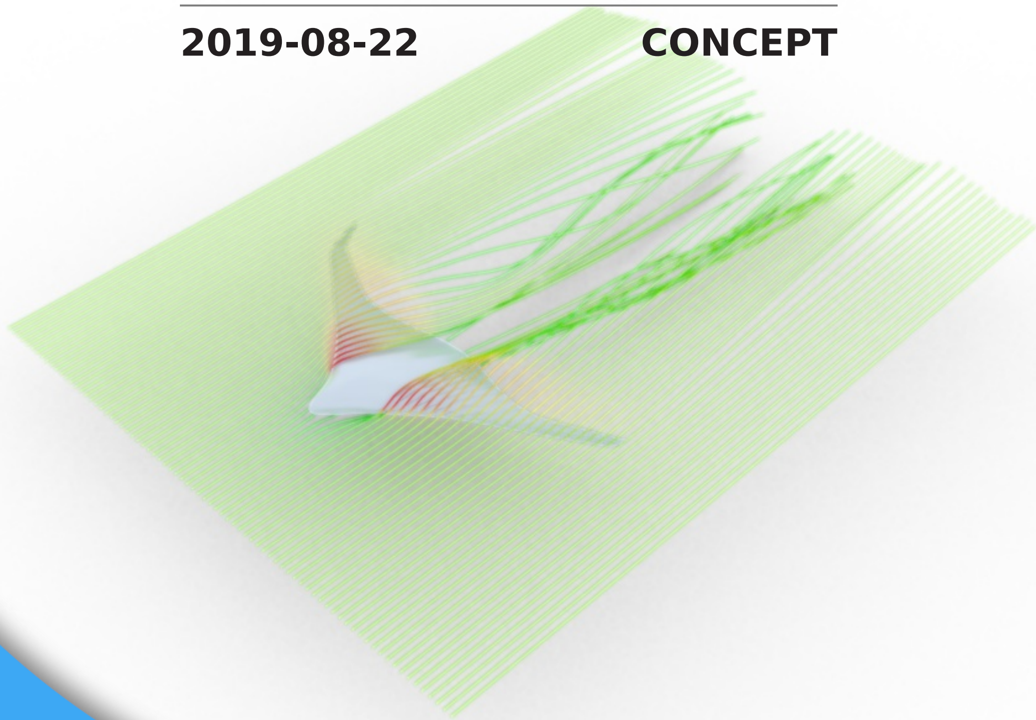
GENERIC DRONE

AERODYNAMIC SIMULATION REPORT

DATE:	ACCURACY:
2019-08-22	**CONCEPT**



AirShaper

TABLE OF CONTENT

INTRODUCTION

Thank you for choosing airshaper to analyze & optimize the aerodynamics of your design. We hope that this report will provide you with the necessary insight. Should you require further assistance, feel free to get in touch with our experts via info@airshaper.com

PROJECT DETAILS

Project name	Generic drone
Date	2019-08-22
Location	Above the ground
Motion	Moving
Fluid	Air
3D file	BWB_cleaned_up_hires_decimated.stl
Rotation - X Y Z [°]	0.0, 15.0, 0.0
Units	meter
Scale	1.0
wind speed [m/s]	15.0
Temperature [°C]	15
Density [kg/m³]	1.225
Atmospheric pressure [Pa]	101300
Calculation algorithm	v0.1
Number of cells	2925367

DISCLAIMER

Calculation results provided by airshaper are based on a “virtual wind tunnel”. The size of this virtual wind tunnel is much larger than the flow phenomena you see on the following images. So don’t worry, your model was not “clamped” between virtual walls.

No matter how accurate, simulations are always a simplification of reality, containing modeling, discretization and iteration errors. Therefore, especially in safety critical applications, we always recommend to perform a physical wind tunnel test. To find a wind tunnel institute suited for your project, please contact us at info@airshaper.com

3D MODEL

These are the dimensions of the bounding box around the object after rotation and scaling - according to the dimensions of the virtual wind tunnel (X = flow direction, Y = sideways, Z = vertical)

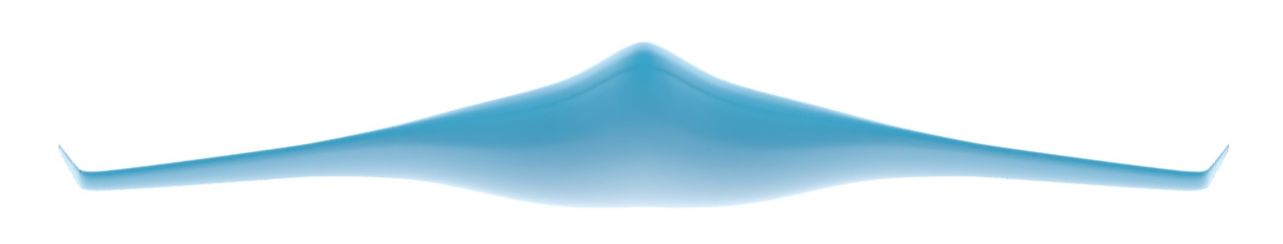
BOUNDING BOX DIMENSIONS

X [m]	7.24e-01
Y [m]	1.28
Z [m]	1.82e-01
Frontal surface area [m²]	8.78e-02

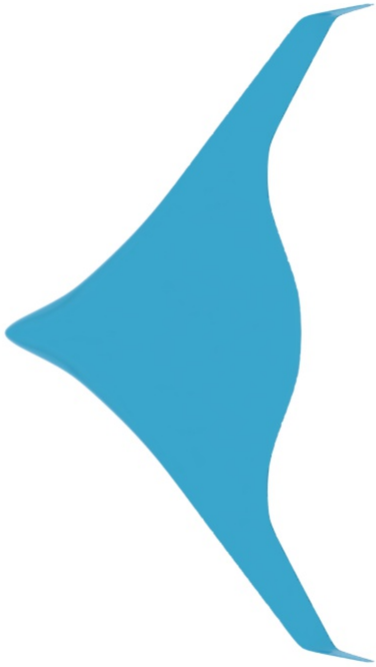
VIEWS

3D view

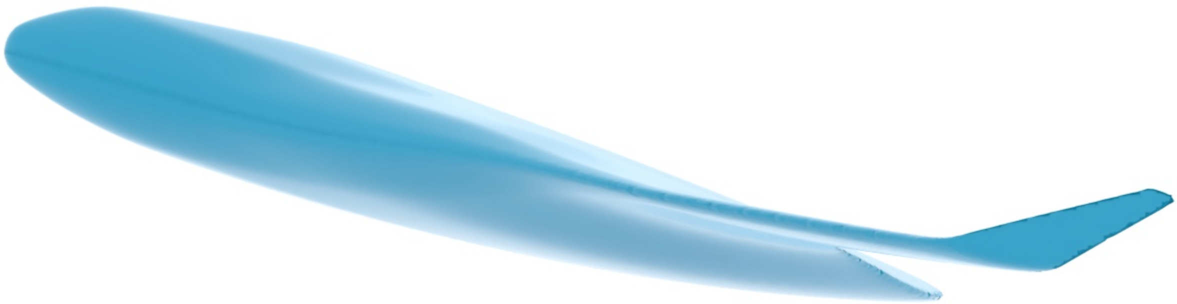
Front view



Top view



Side view



PERFORMANCE ANALYSIS

FORCES

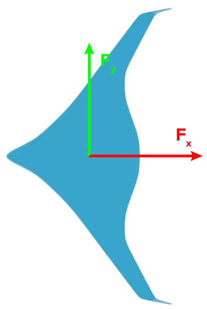
The force generated on the object by the wind has three components:

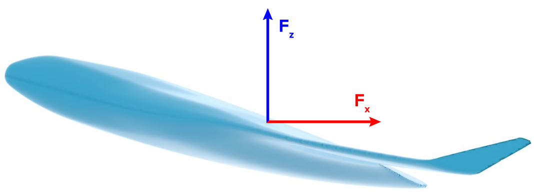
- F_x - Drag force: Along the direction of the wind
- F_y - Lateral force: Perpendicular to the direction of the wind - horizontal
- F_z - Lift force: Perpendicular to the direction of the wind - vertical

There are two ways in which the wind generates force:

- Pressure force: arises from the pressure difference between two opposite sides of an object. It is the sum of all the local forces pushing or pulling perpendicular to the surface.
- Friction force: arises from the wind sliding across the surface of the object. It is the sum of all the local friction forces parallel to the surface.

Note:
Negative values indicate a force acting in the direction opposite to the arrows shown below.
Original coordinate system: origin location & axis orientation as provided with the original 3D file
Wind tunnel coordinate system (shown on images): origin set to the center of the object and the axes aligned with the air vector





WIND TUNNEL COORDINATE SYSTEM

	F_x	F_y	F_z
Pressure	4.86 N (0.49 kg)	-0.00 N (-0.00 kg)	21.69 N (2.21 kg)
Friction	0.24 N (0.02 kg)	-0.00 N (-0.00 kg)	-0.03 N (-0.00 kg)
Total	5.10 N (0.52 kg)	-0.00 N (-0.00 kg)	21.66 N (2.21 kg)

ORIGINAL COORDINATE SYSTEM

	F_x	F_y	F_z
Pressure	-0.92 N (-0.09 kg)	-0.00 N (-0.00 kg)	22.21 N (2.26 kg)
Friction	0.24 N (0.02 kg)	-0.00 N (-0.00 kg)	0.03 N (0.00 kg)
Total	-0.68 N (-0.07 kg)	-0.00 N (-0.00 kg)	22.24 N (2.27 kg)

MOMENTS

The moments have been calculated around the global coordinate system as defined in the uploaded 3D model.
Moments also have a friction & pressure component and have been calculated around the X, Y and Z axis.

WIND TUNNEL COORDINATE SYSTEM

	M_x	M_y	M_z
Pressure	-0.00 Nm (-0.00 kg·m)	0.94 Nm (0.10 kg·m)	-0.00 Nm (-0.00 kg·m)
Friction	-0.00 Nm (-0.00 kg·m)	-0.00 Nm (-0.00 kg·m)	0.00 Nm (0.00 kg·m)
Total	-0.00 Nm (-0.00 kg·m)	0.93 Nm (0.10 kg·m)	-0.00 Nm (-0.00 kg·m)

ORIGINAL COORDINATE SYSTEM

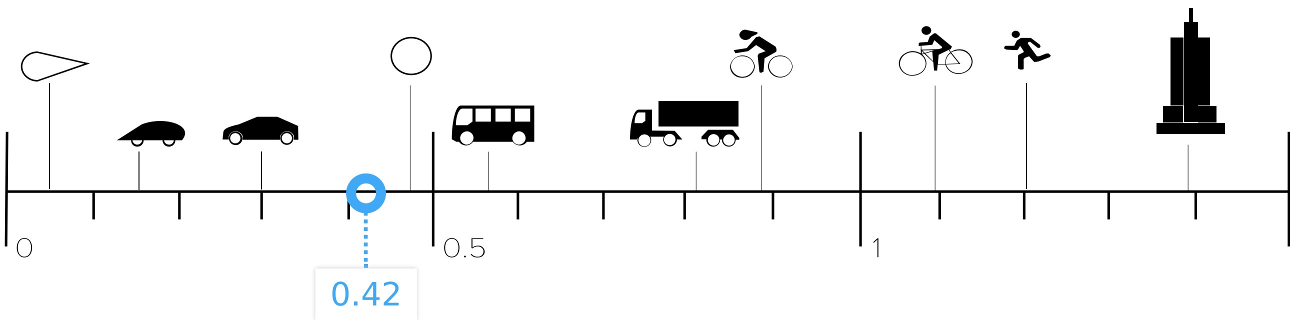
	M_x	M_y	M_z
Pressure	3466.72 Nm (353.39 kg·m)	-4690.49 Nm (-478.13 kg·m)	143.54 Nm (14.63 kg·m)
Friction	4.79 Nm (0.49 kg·m)	2.43 Nm (0.25 kg·m)	-37.25 Nm (-3.80 kg·m)
Total	3471.51 Nm (353.87 kg·m)	-4688.06 Nm (-477.89 kg·m)	106.28 Nm (10.83 kg·m)

DRAG COEFFICIENT

Drag, or air resistance, is the force of the wind on an object in the direction of the wind. It is composed of pressure drag (pushing/pulling normal the surface) and friction drag (sliding over the surface). In most cases the pressure drag is dominant.
The drag coefficient is a dimensionless quantity that indicates the aerodynamic resistance of an object moving through its medium. It is defined as follows:

$$C_d = \frac{2F_d}{\rho v^2 A}$$

The scale below illustrates typical Cd values (NASA and Wikipedia). More streamlined objects will have a low Cd, less streamlines objects will have a high Cd. The Cd of your project has been indicated as well. Please note that this is an indicative figure, mainly suited for comparing different concepts. For a highly accurate value, contact us at info@airshaper.com.



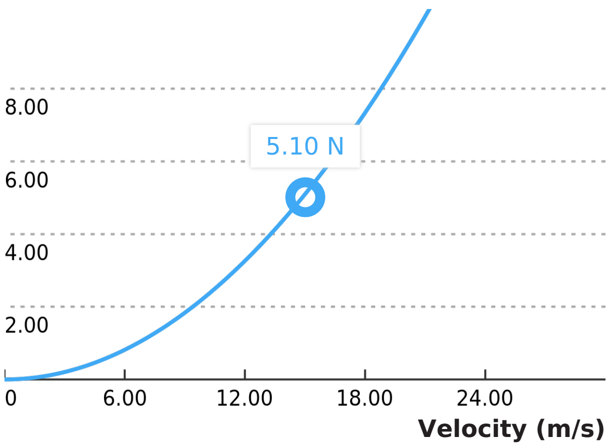
FORCE AND POWER CURVES

The Cd provides a measure for the aerodynamic efficiency of an object. By approximation, the actual drag force Fd on the object as well as the power required to propel it will vary in function of the wind speed according the following formula:

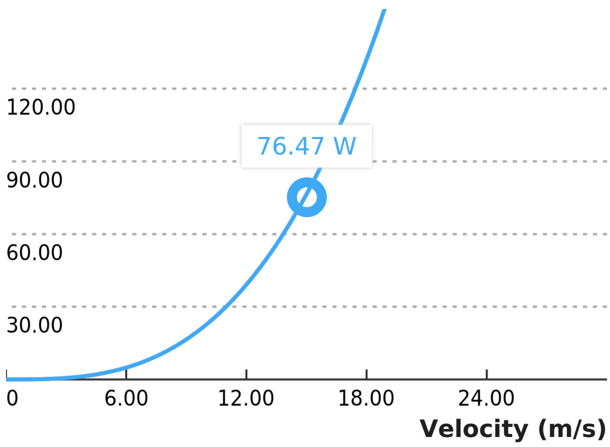
$$F_d = \frac{\rho v^2 C_d A}{2} \qquad P = F_d v$$

For your project, that leads to the force & power curves shown below. Please keep in mind that this curve is an estimation, based on extrapolation from the simulation wind speed. For more accurate forces at a given velocity, please perform a simulation for that velocity.

Drag Force Fd(N)



Required Power P(W)



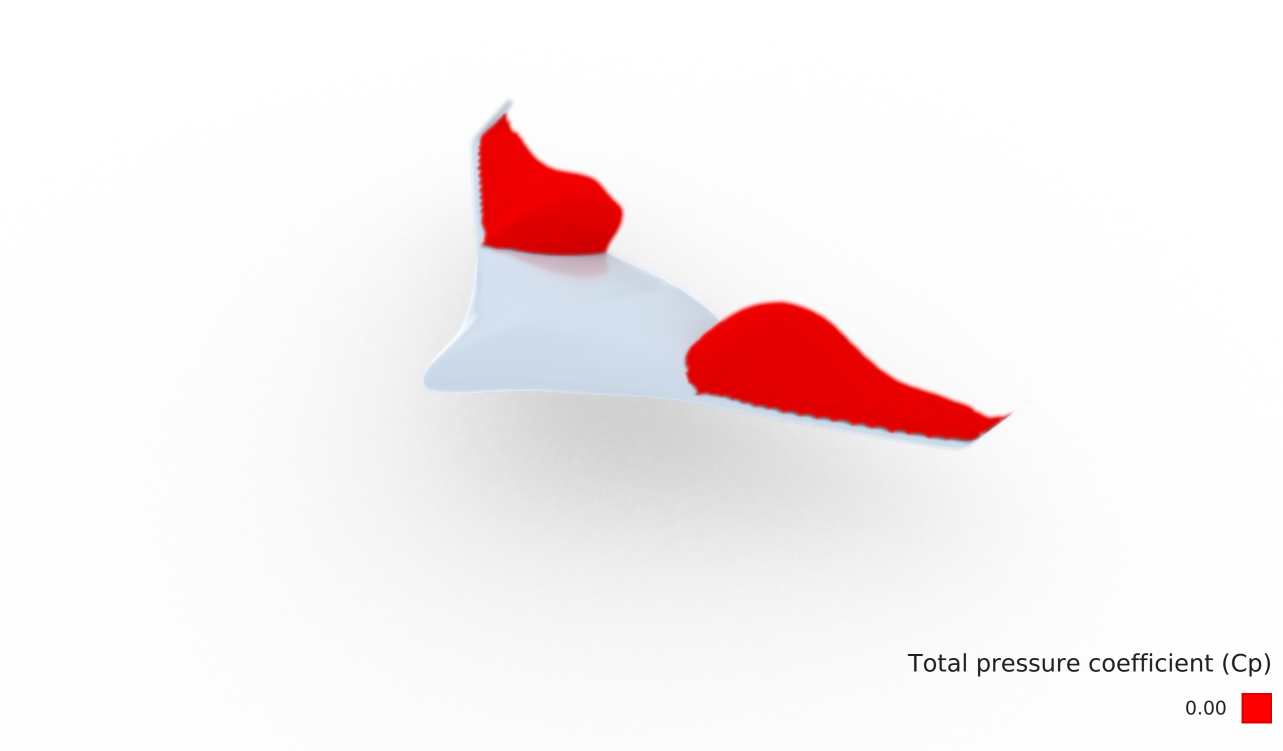
DRAG ANALYSIS

3D PRESSURE CLOUDS

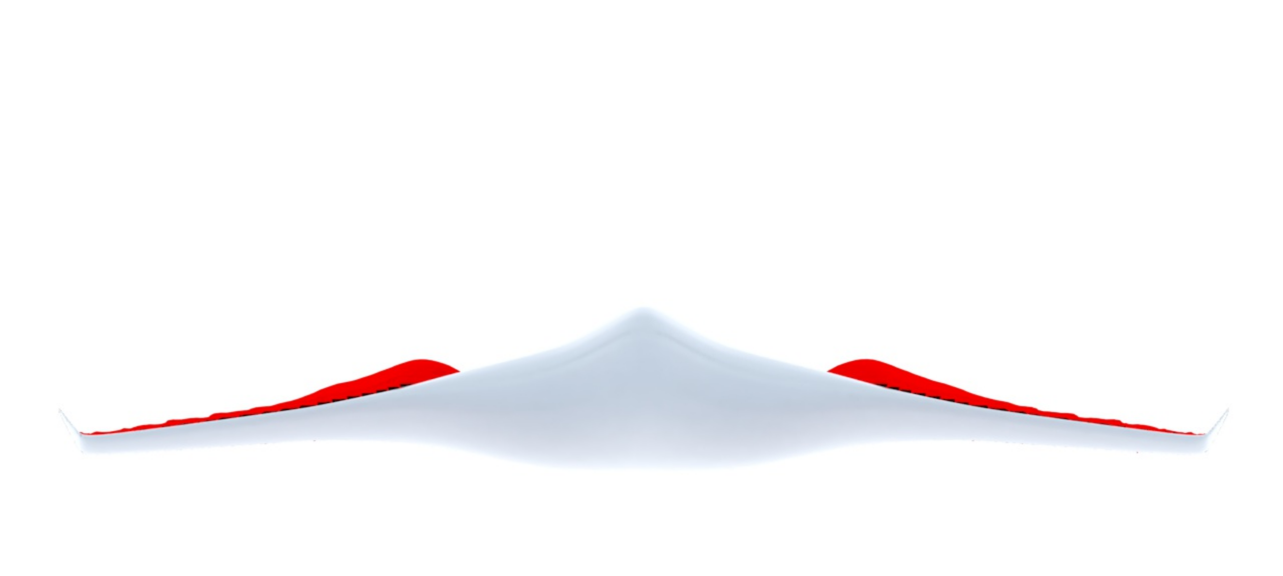
Underpressure zones are areas with a pressure lower than that of the local surrounding air. Often these zones are caused by abrupt changes in shape, most pronounced by abrupt changes in cross section or surface geometry. Smooth these out to lower drag.

The following images provide insight into which features of your object are causing drag by showing “clouds” of low pressure.

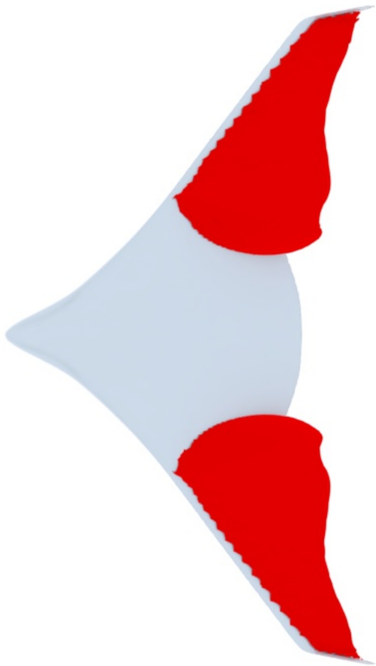
3D view



Front view



Top view



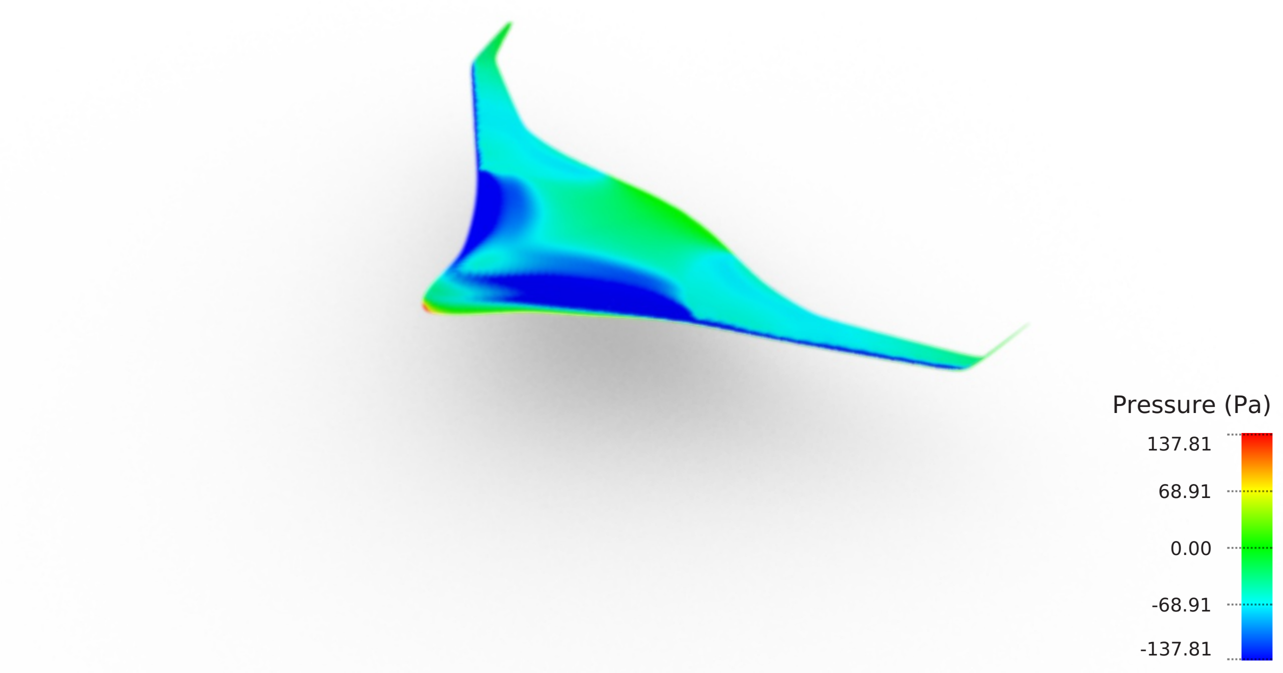
Side view

SURFACE PRESSURE

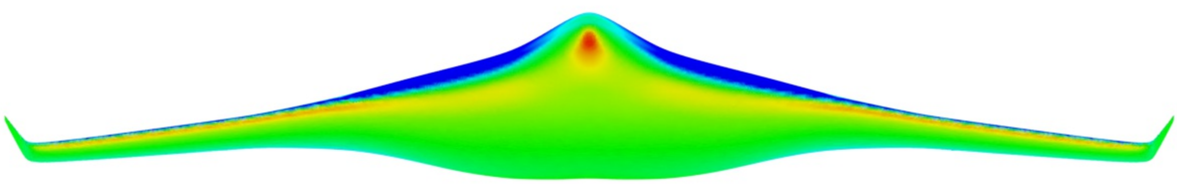
Air impacts the object and this creates overpressure. The highest pressure is reached when the air comes to a complete standstill (with respect to the object), for example at the tip of a rocket. It’s called the stagnation point and the pressure at that location is the stagnation pressure.

The more perpendicular a forward-facing surface is to the flow, the more likely it will create overpressure and thus drag. Likewise, a backward-facing surface experiencing underpressure will pull the object backwards, again creating drag. Try to reduce peaks in overpressure and underpressure by smoothing the surface at peak locations, critical transitions etc. to recude drag.

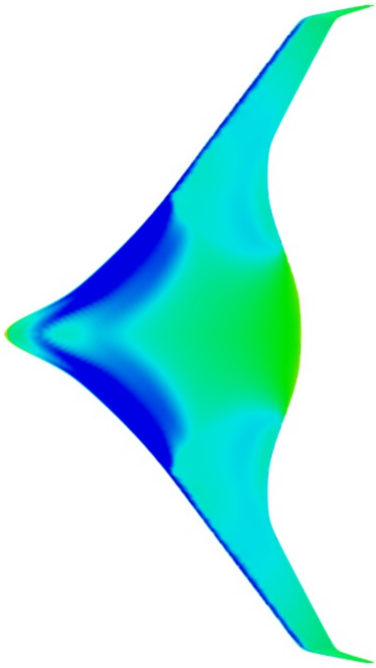
3D view



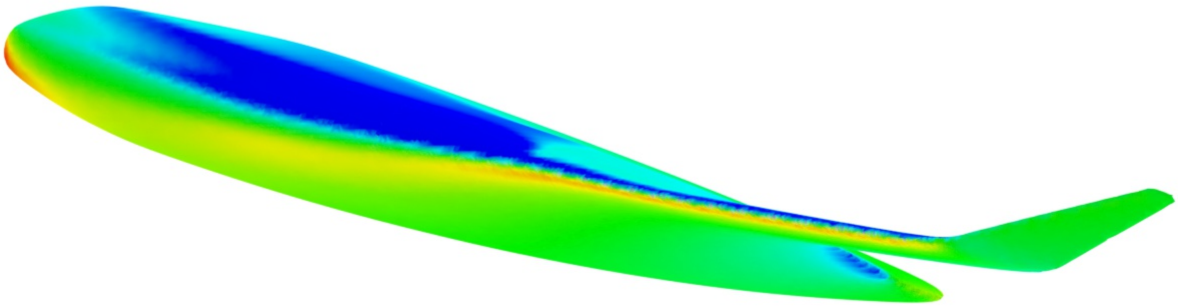
Front view



Top view



Side view



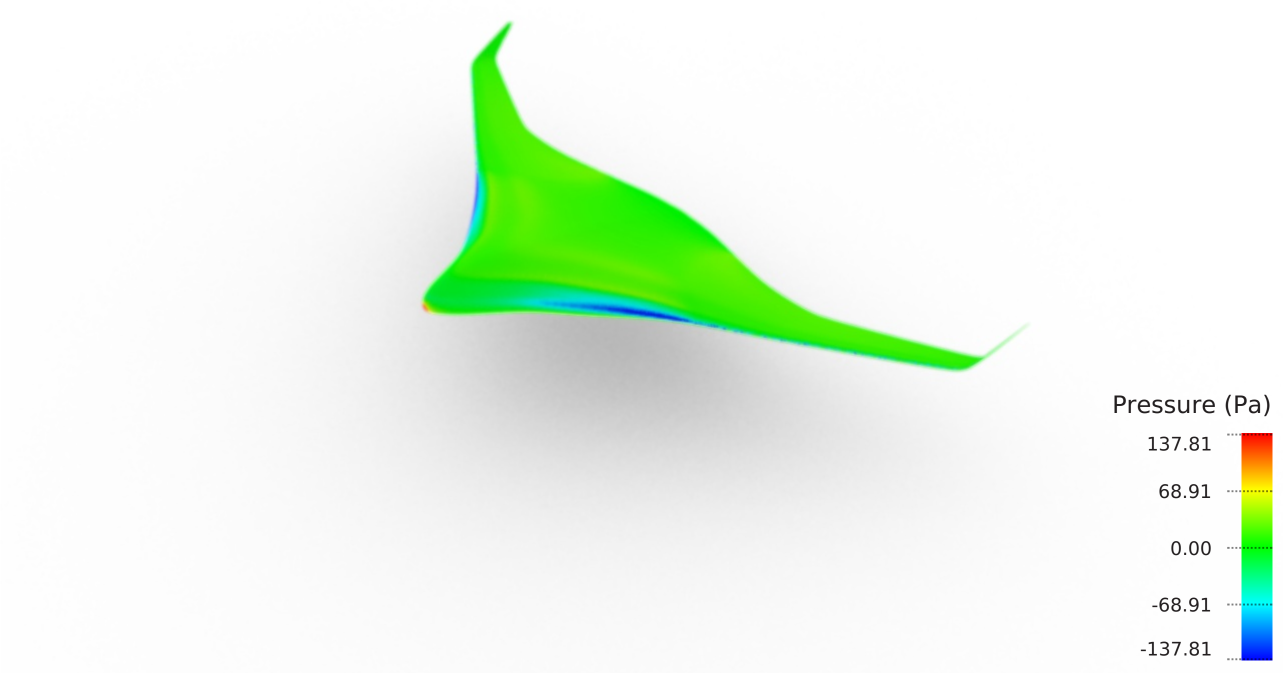
SURFACE PRESSURE DRAG

Pressure maps alone don’t tell the full story: a high pressure acting on the front of the object will push it back, creating drag. A high pressure on the rear of the object however will push the object forward, reducing drag!

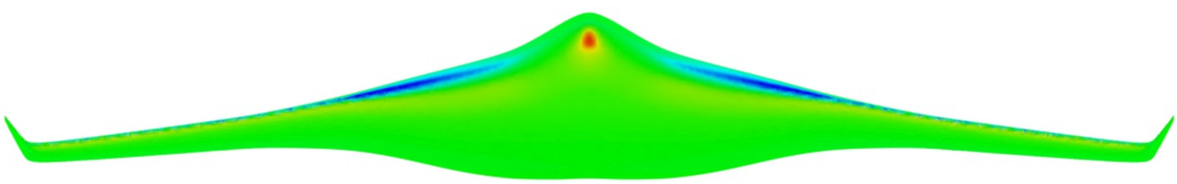
So to gain insight into the real contribution to the drag, the local orientation of the surface needs to be taken into account: forward facing surfaces (facing upstream of the wind) with positive pressure, or backward facing surfaces (facing downstream of the wind) with negative pressure create drag. Forward facing surfaces with negative pressure, or backward facing surfaces with positive pressure reduce drag.

This product of surface orientation (also called the “surface normal” – the component along the wind direction in our case) and pressure is shown in the images below. This way you can clearly identify which parts cause drag and which reduce it.

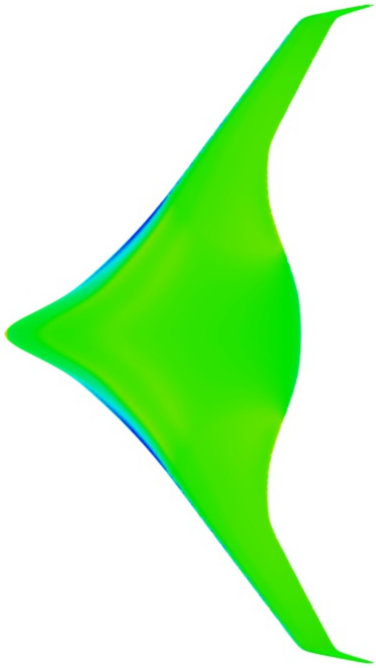
3D view



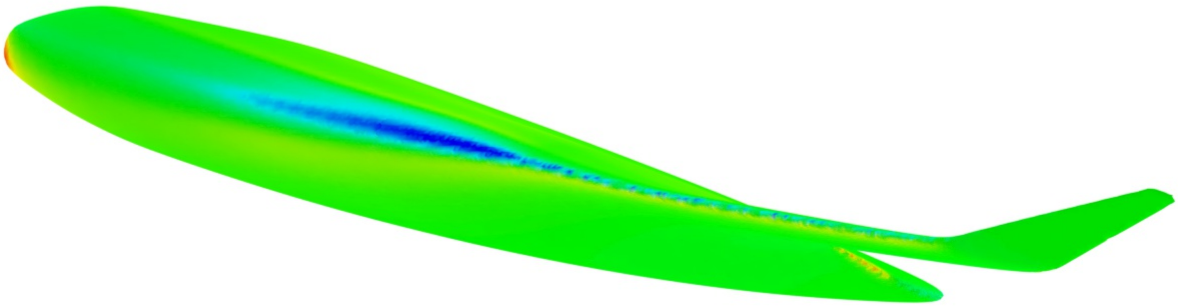
Front view



Top view



Side view



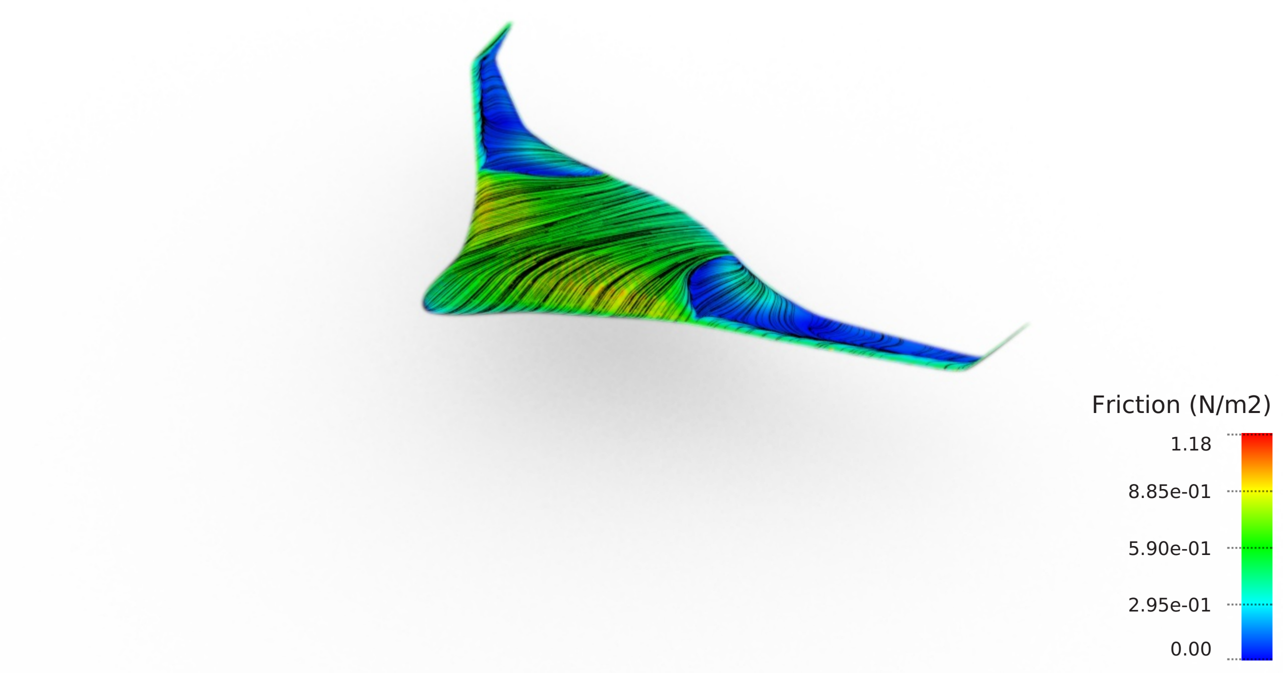
SURFACE FRICTION

Friction drag is caused by air sliding across the surface, generating friction in the process. The faster the air moves along a surface, the higher the friction force. A smooth surface (a coating with low roughness for example) can reduce friction drag.

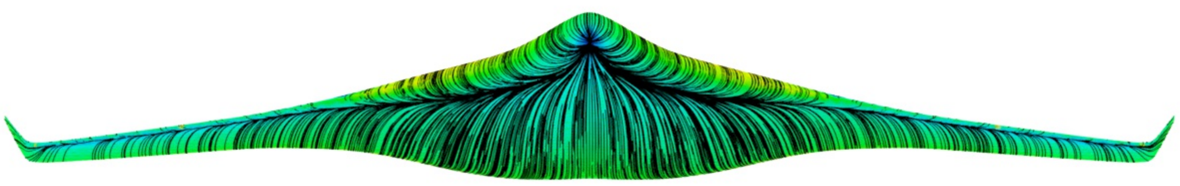
The following images show the friction drag, mapped in color on the surface of your object. Although friction drag typically contributes only a small amount to the total drag, it might be worth to try and re-route some of the air to reduce it.

Also shown are streamlines, showing the pattern followed when air moves across the surface. This allows you to find locations where detachment occurs: as long as the flow is able to follow the surface (attached flow), you will see rather straight streamlines and at least some shear (color green to red) force associated with it. Once the flow detaches, it will start to swirl (curly streamlines) and move slower with respect to the surface (lower shear forces – color towards blue). To optimize airflow, look at these detachment spots and try to make transitions & angles smoother.

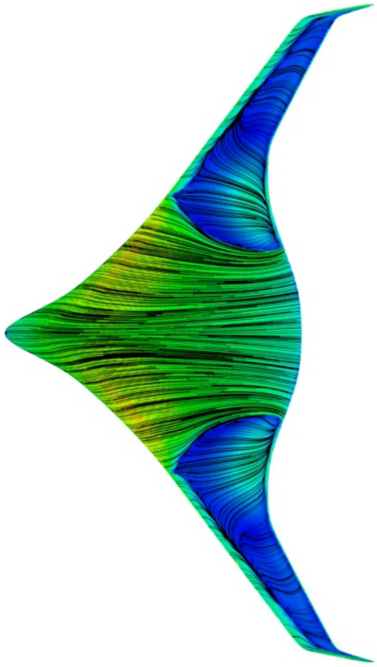
3D view



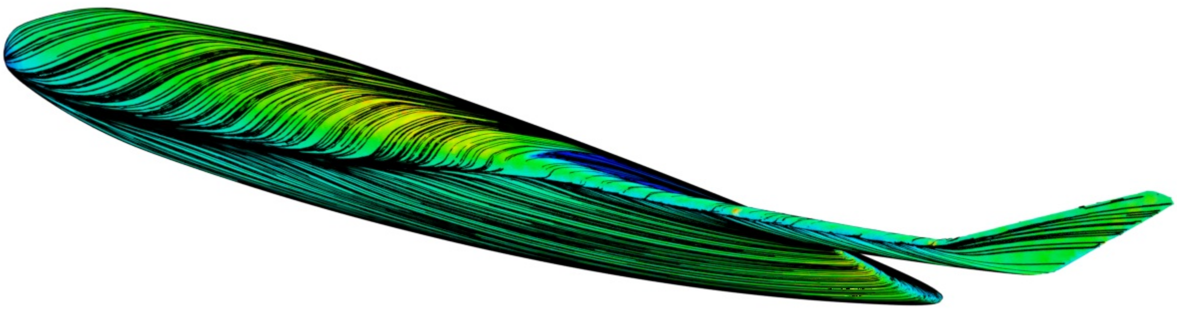
Front view



Top view

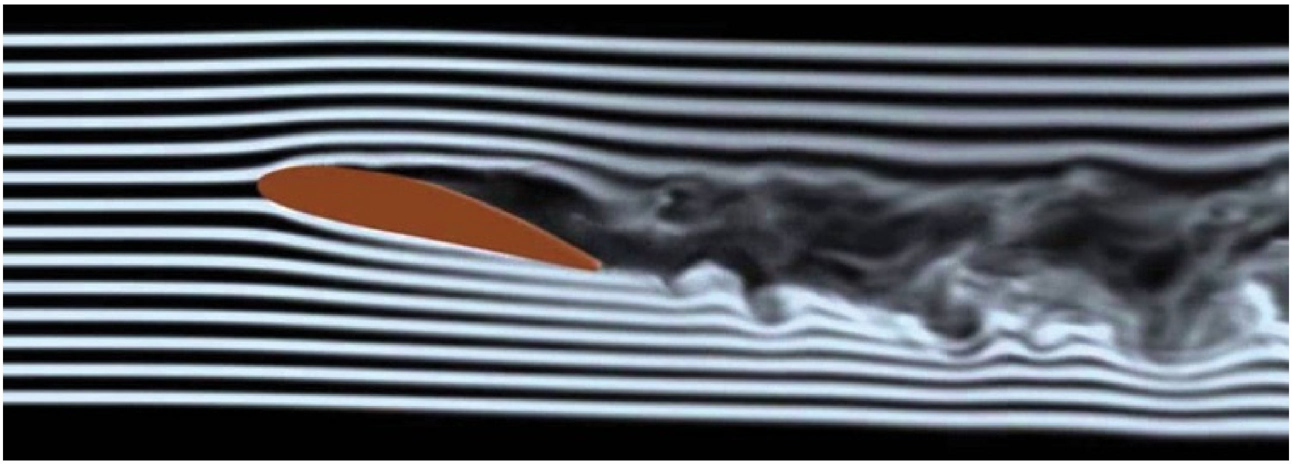


Side view



FLOW ANALYSIS

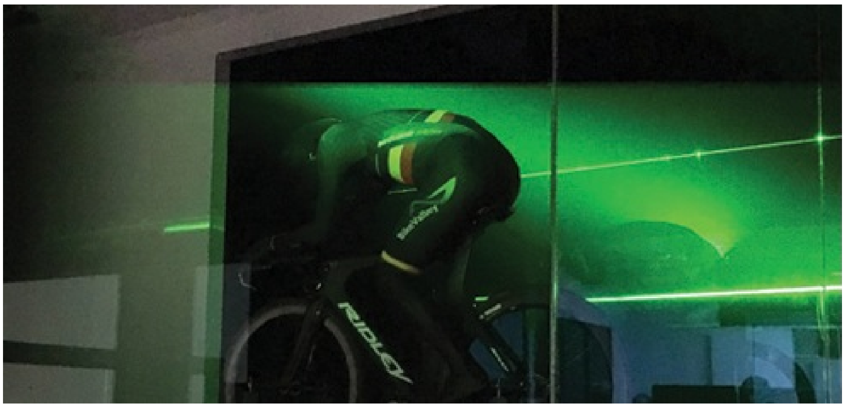
Understanding the way the wind flows past your object is the basis for optimizing your design. In physical wind tunnels, this is often done by releasing smoke (small oil droplets) in the air, upstream of the object, as illustrated below (image courtesy of Paul Selhi).

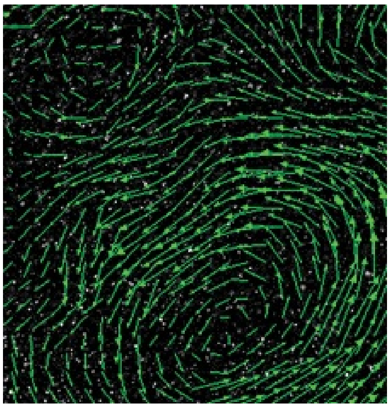


These streamlines can provide multiple insights. First of all, it allows to spot laminar flow zones (steady streamlines) and turbulent zones (swirling streamlines). The transition from laminar to turbulent often occurs when the airflow is unable to follow the surface of the object, because the “negative angle” of the surface is too large or because of a geometrical disturbance in the surface. This is called separation which, in most cases, increases drag.

Another observation is the compression and expansion of these streamlines (the density of the streamlines). As the air can be considered as incompressible, the air needs to speed up when the available cross section narrows. Speeding up and slowing down air, by changes in geometry / cross section, can again be a source of drag. Reducing these changes in velocity, by smoothing these geometry / cross section changes, can reduce drag.

In the virtual world, the streamlines can be colored by the velocity, allowing to detect increases/decreases in velocity directly and not just via streamline density. The images below show the streamlines (the trajectory a weightless particle would follow when released in the air) both for a vertical and horizontal array of “smoke” sources.



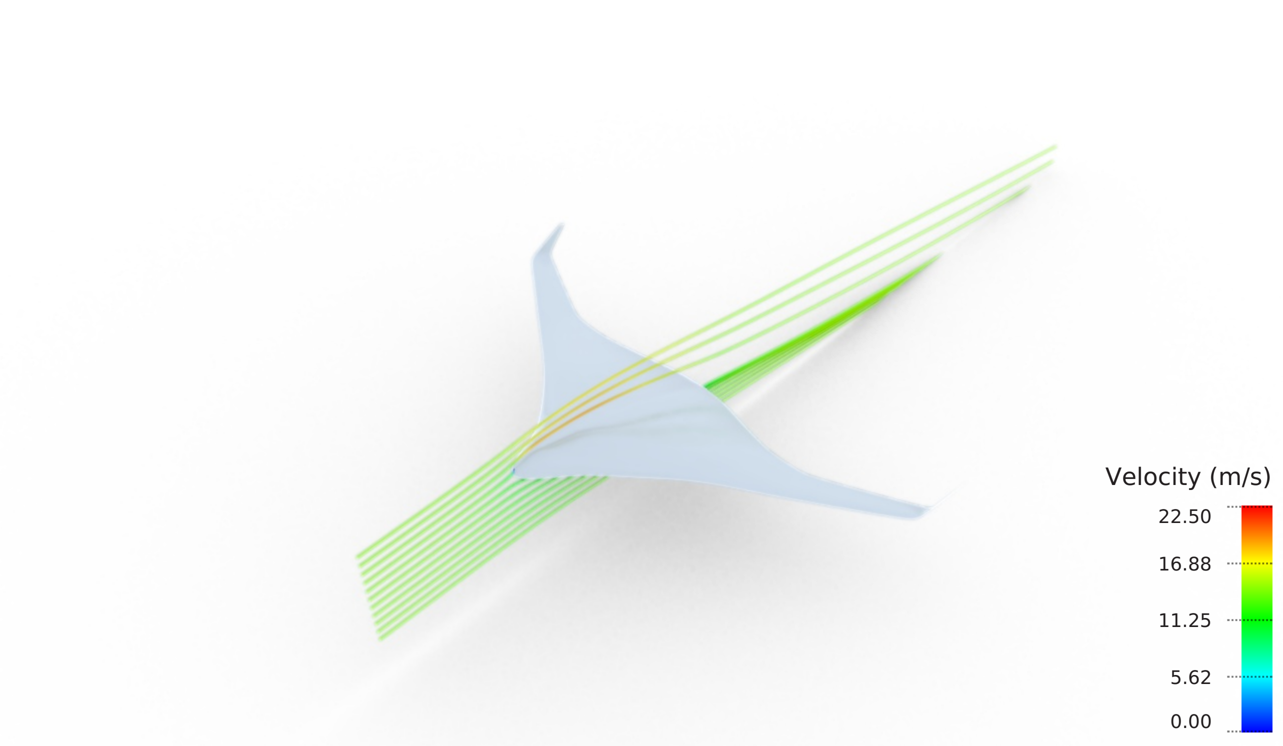


A second, more advanced visualization technique in physical wind tunnels is to light up a 2D plane with a laser and film it from a direction perpendicular to this plane (see images above – courtesy of Flanders Bike Valley and formula1-dictionary.net). This makes it possible to detect in-plane movement patterns of “particles”. This is shown in the second series of images, 2D flow patterns, colored by velocity and by pressure.

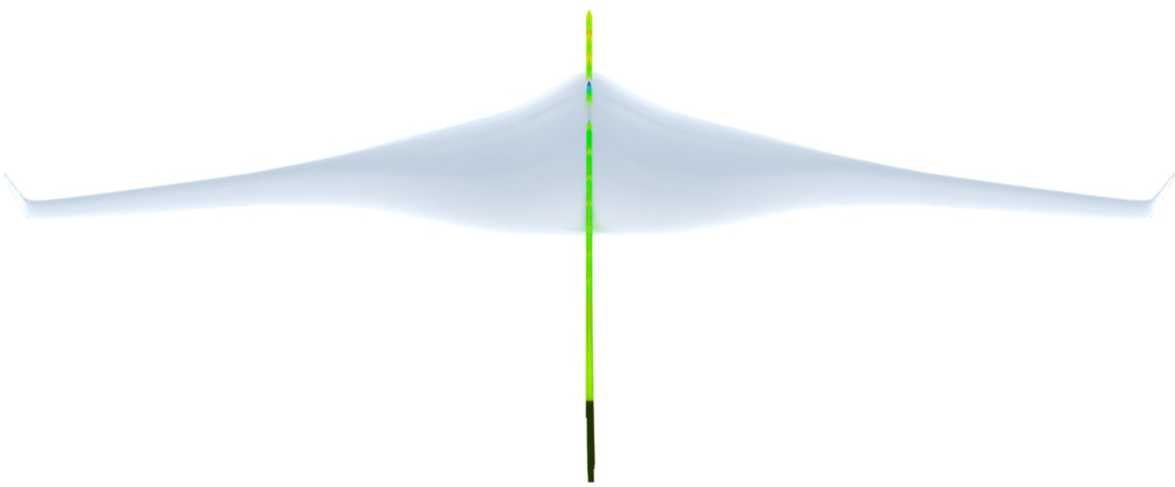
STREAMLINES

VERTICAL

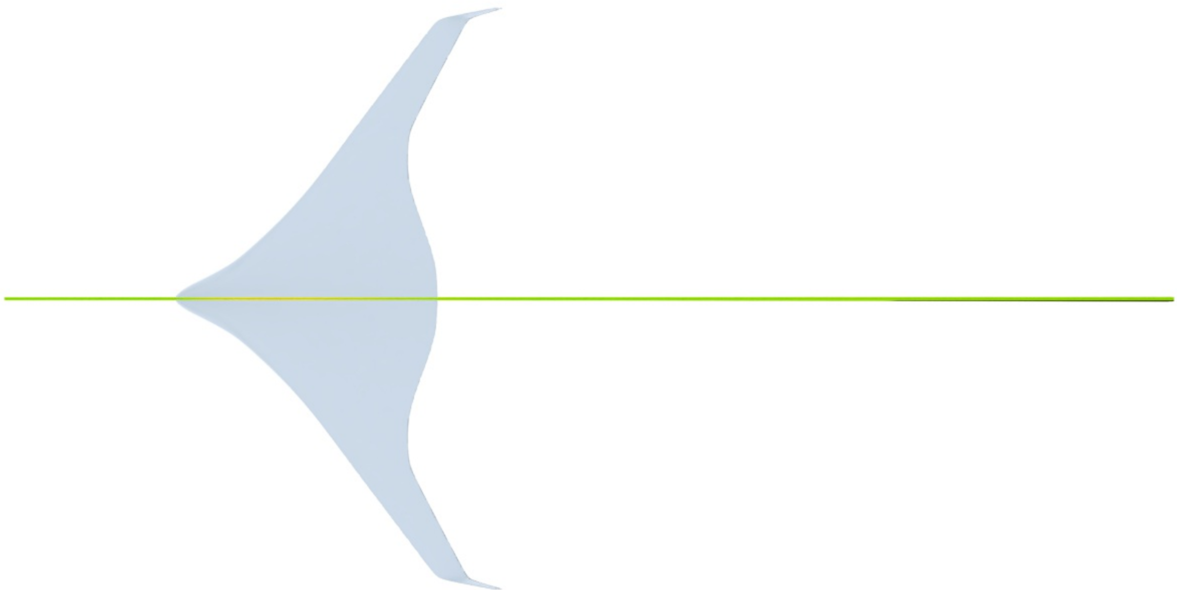
3D view



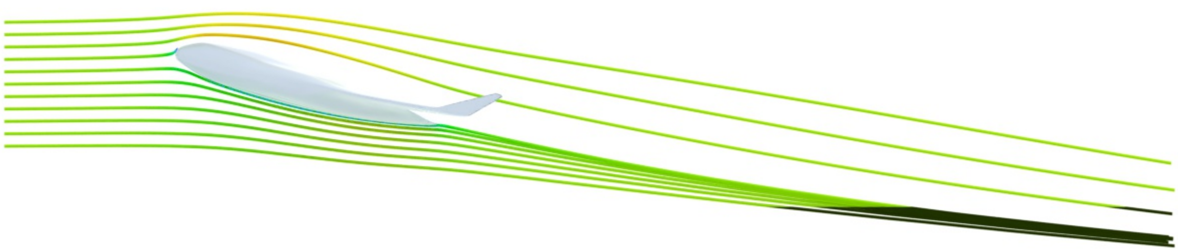
Front view



Top view

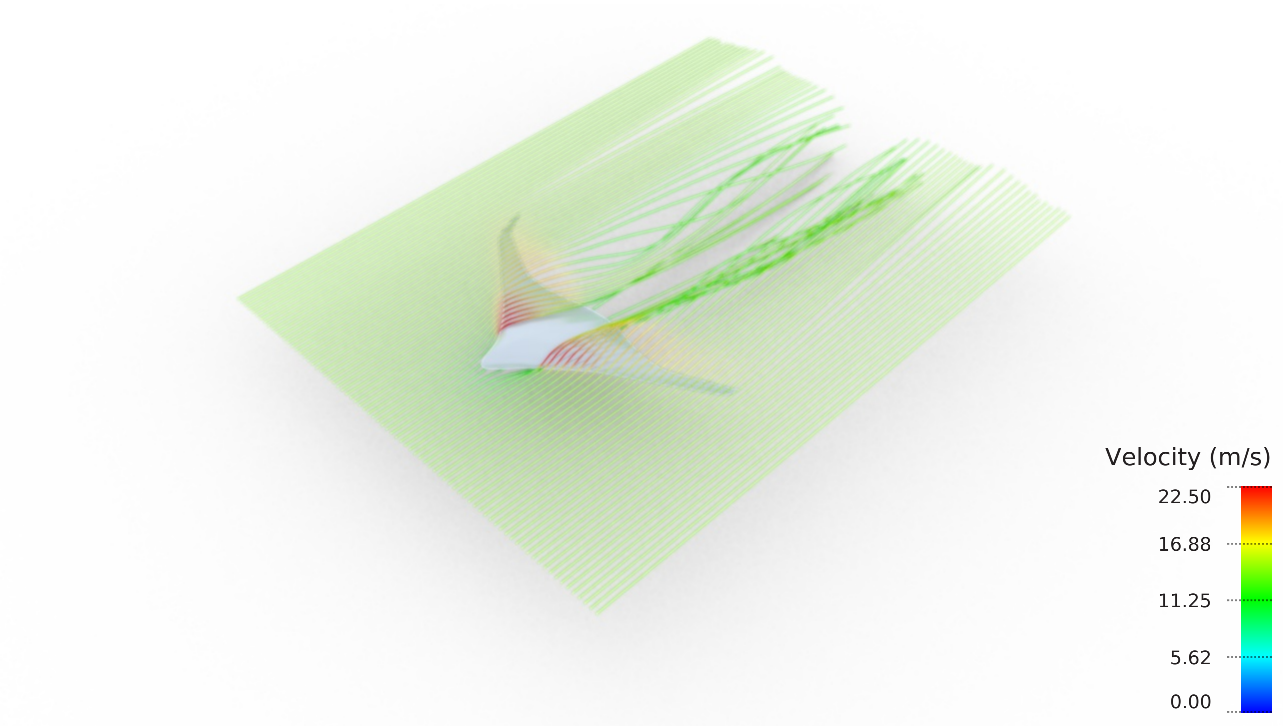


Side view

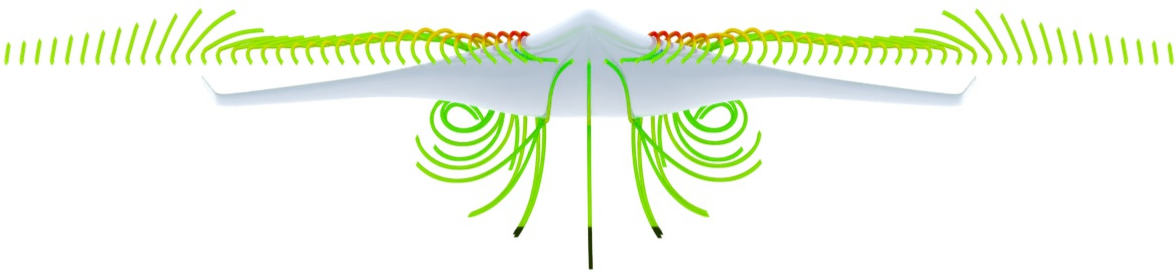


HORIZONTAL

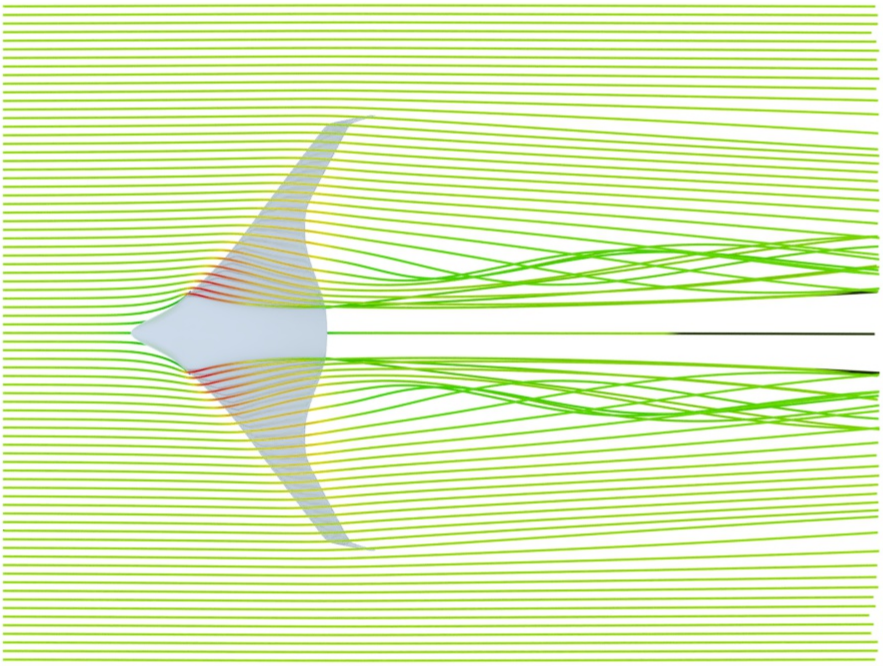
3D view



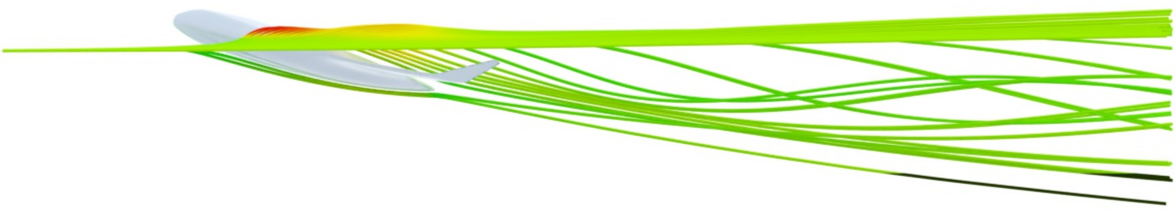
Front view



Top view



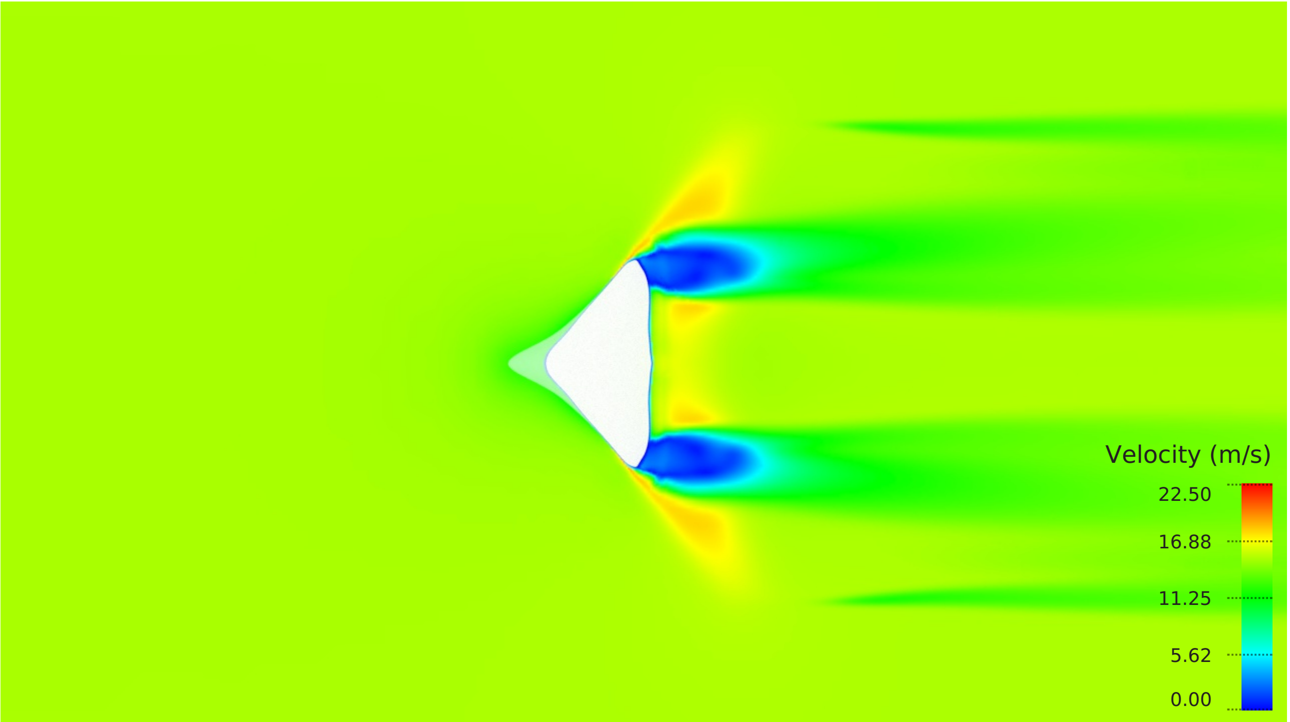
Side view



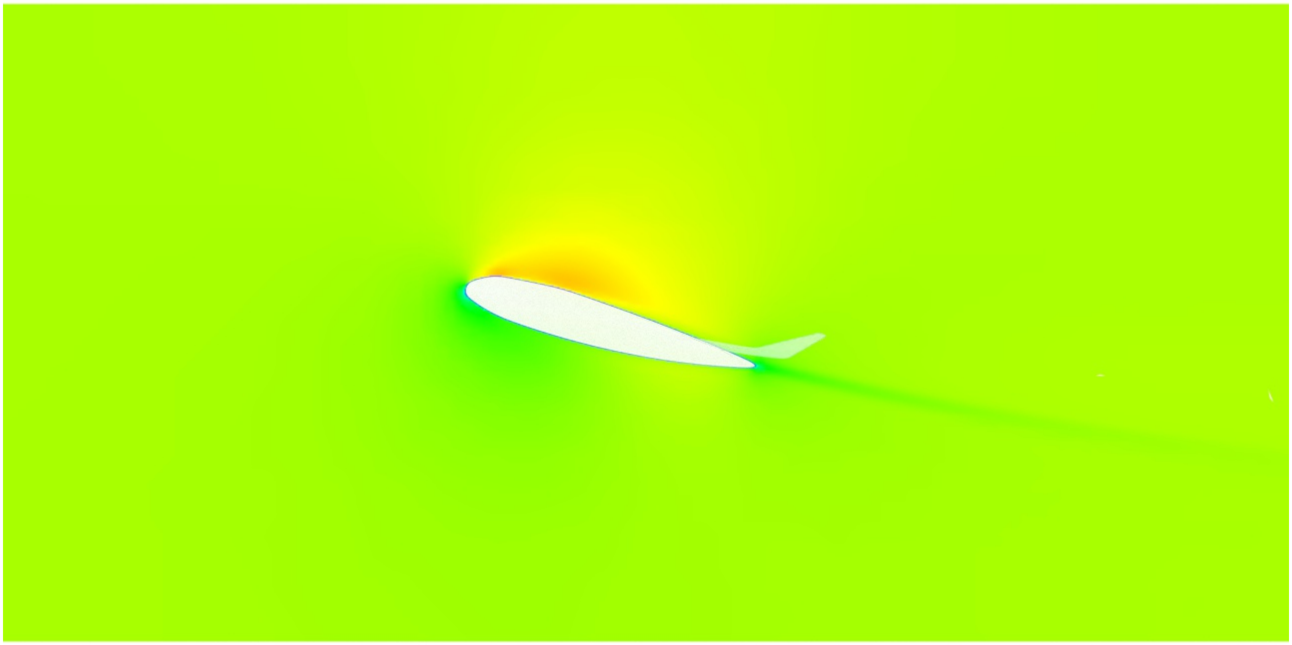
2D SECTIONS

VELOCITY

Top view

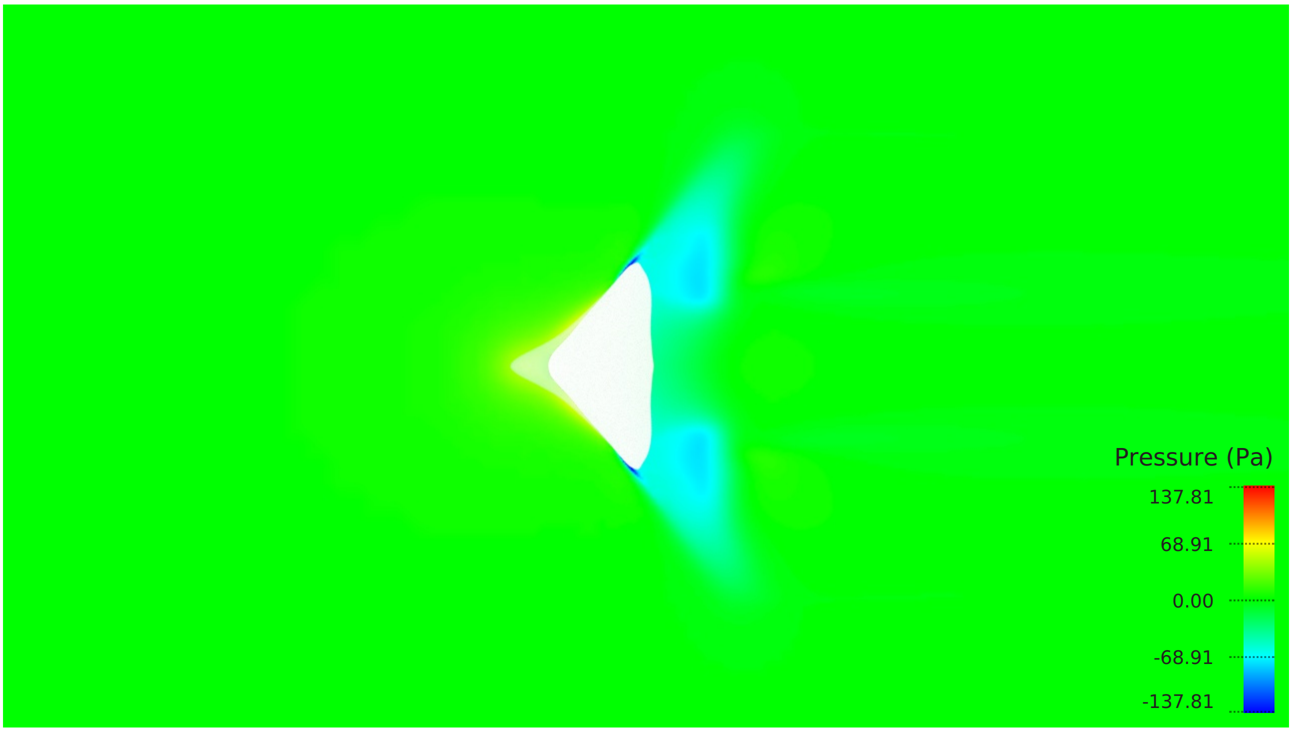


Side view

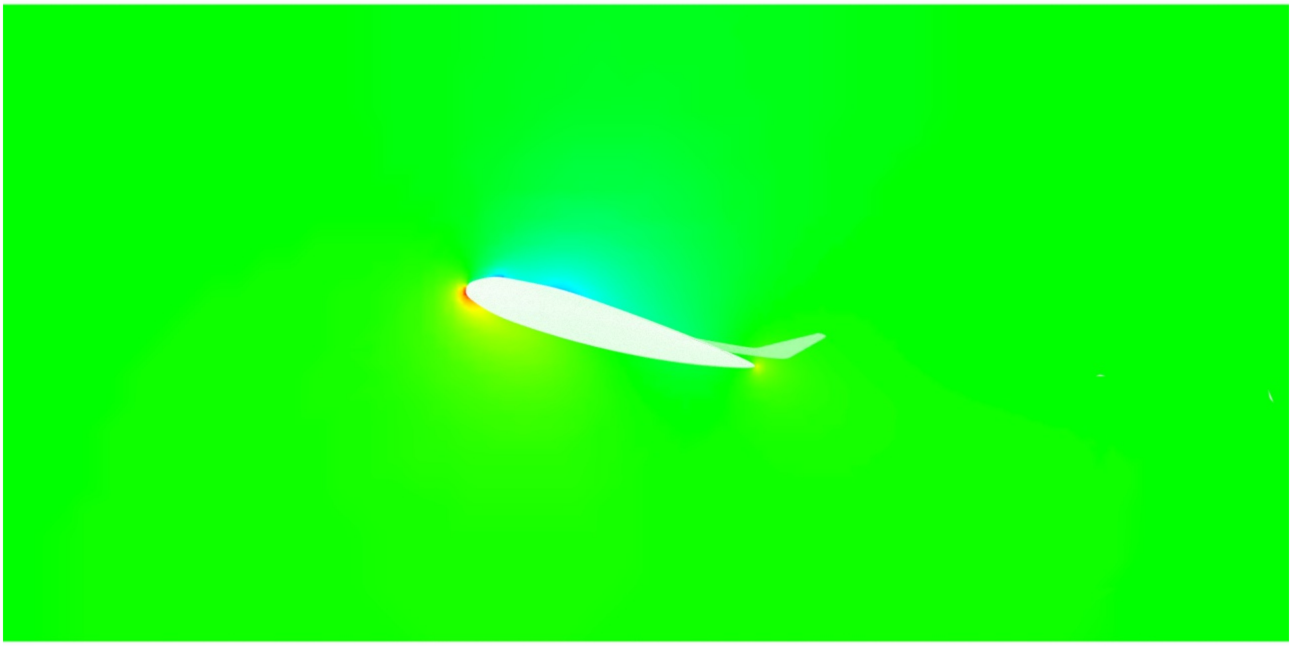


PRESSURE

Top view



Side view



NOISE ANALYSIS

Noise estimation by means of simulations is an advanced field of engineering. Therefore, more simplified models ('acoustic analogies') have been introduced to obtain a rough estimation of the local noise generation without going through prohibitively expensive simulations.

To reduce the noise generation in your design, look for the origin of these “noise clouds” in the following images. Typically, noise is generated slightly downstream of the location where the flow is disturbed. Smoothen the source and you can reduce noise generation. Avoid cavities and external parts.

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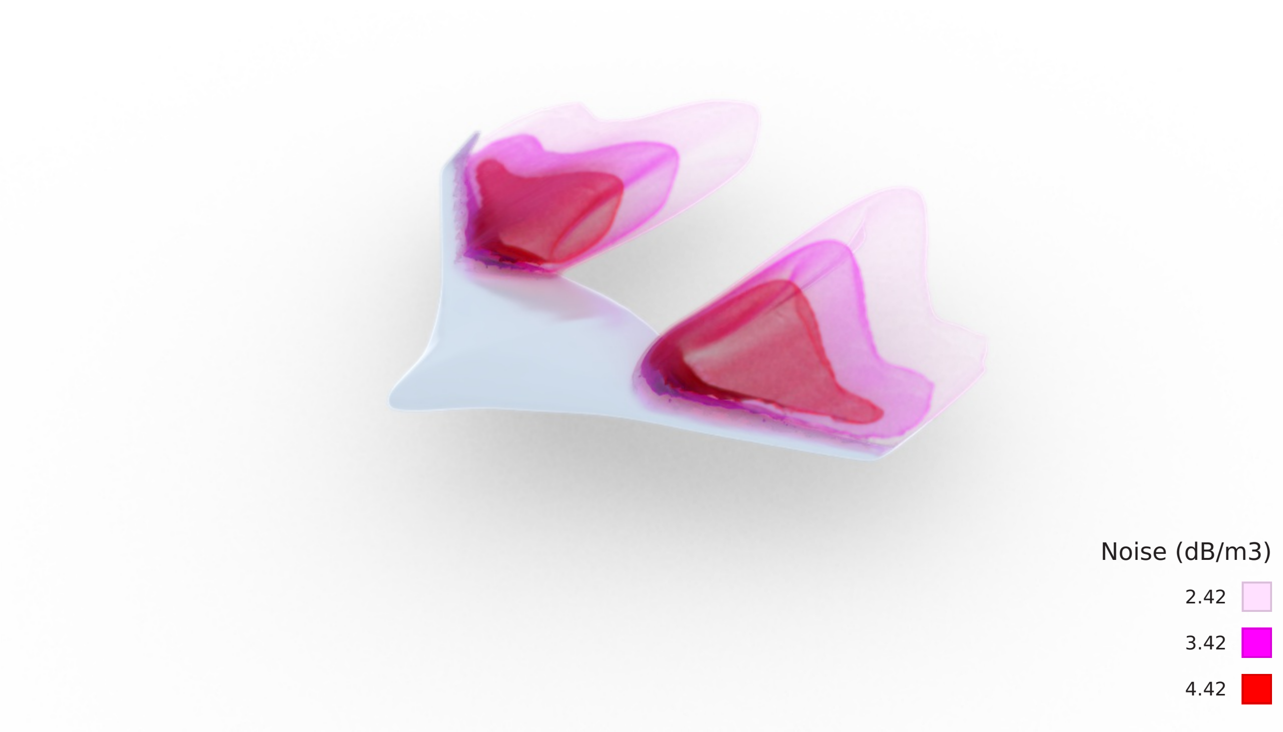
3D view



Side view

Front view

Top view