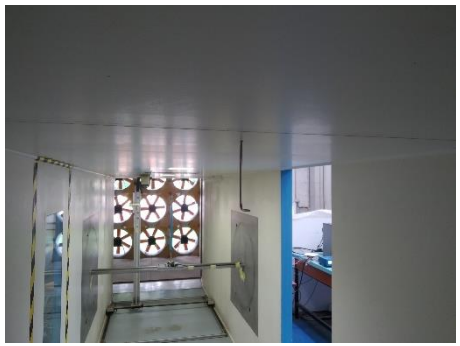
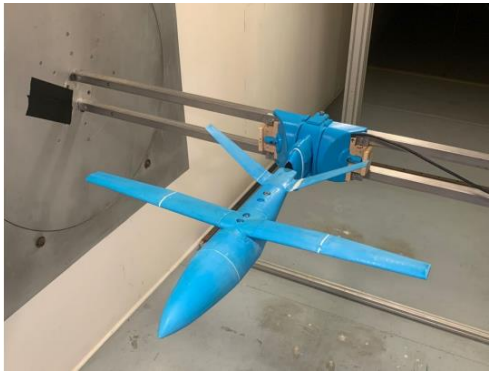
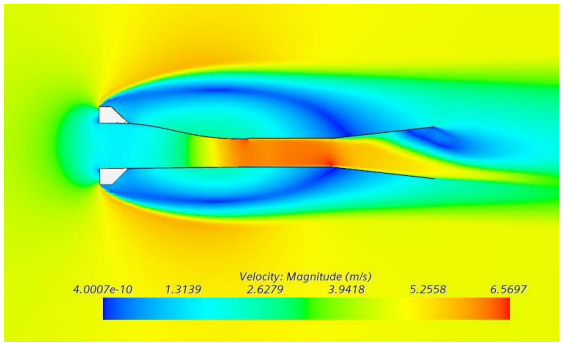
Wind Tunnel Capabilities
Escuela Técnica Superior de Ingeniería (ETSi)
University of Seville







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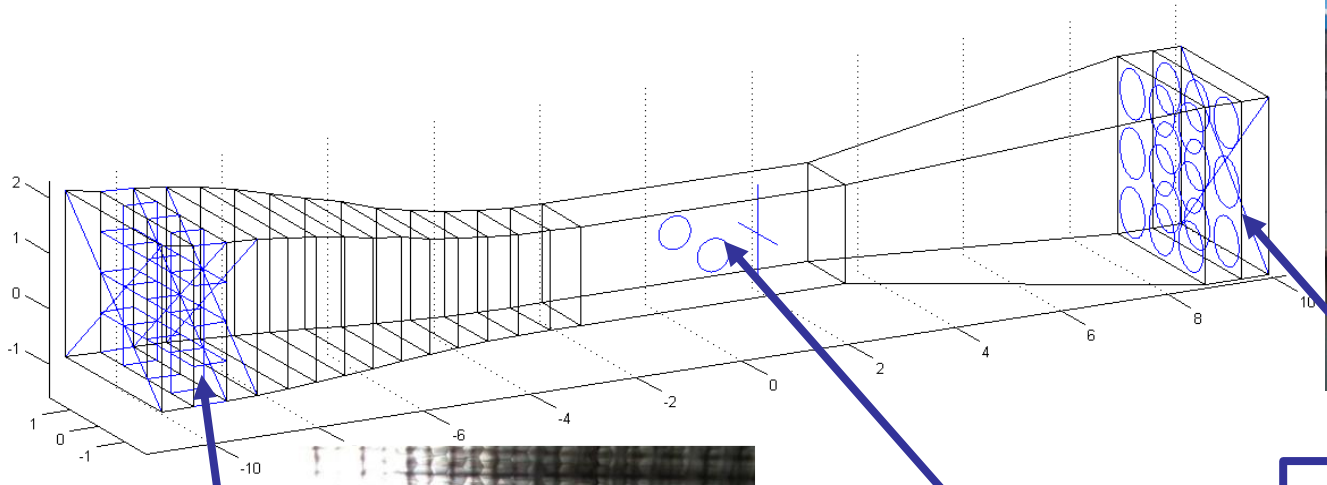
Escuela Técnica Superior de INGENIERÍA DE SEVILLA

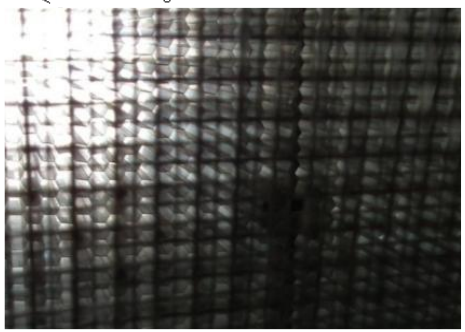
Introduction

- **Wind tunnel**
- Measuring equipment
- Positioning equipment
- Manufacturing equipment
- Processing Data
- Project examples: ProVANt - EMERGENTIA
  - Wind Tunel Experiments
  - Propulsive Experiments
  - CFD Validation

Wind Tunnel - I

- Length~23 m
- Test Section: 1.4m x 1.8m





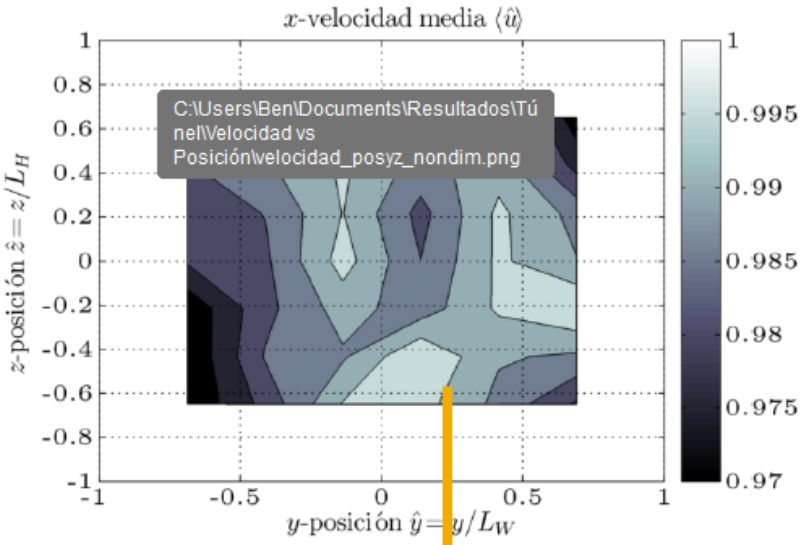
Straightener,
Honeycomb
Turbulence Networks

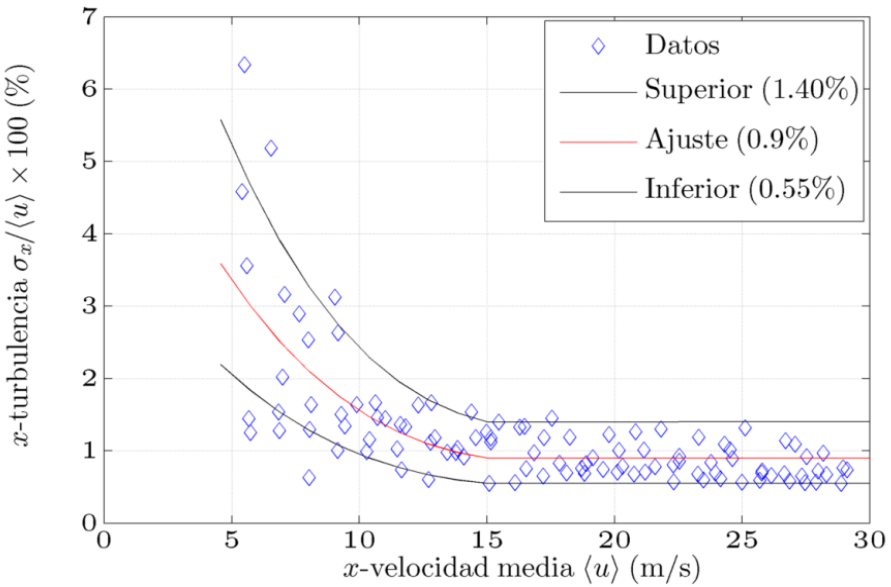
Test room
-2x turntables
xyz-positioner

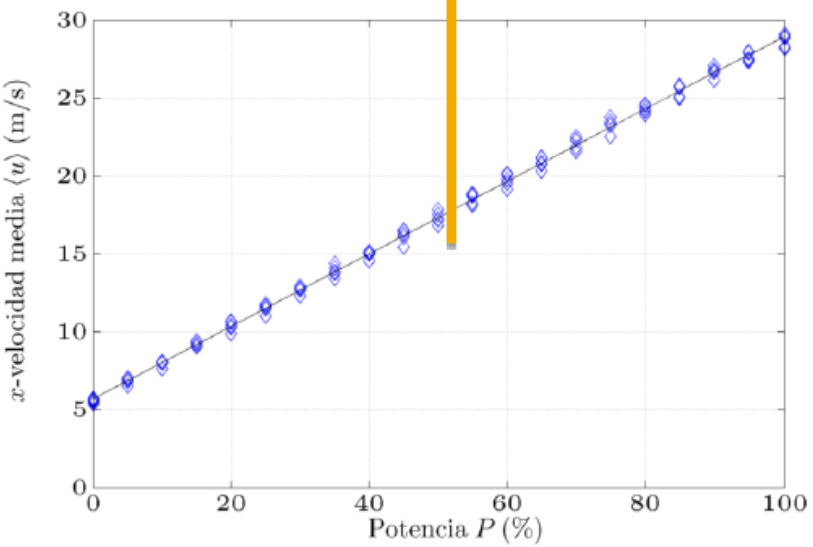
9x Fans
(HCT-90-4T-7.5/AL IE3)

Wind Tunnel - II

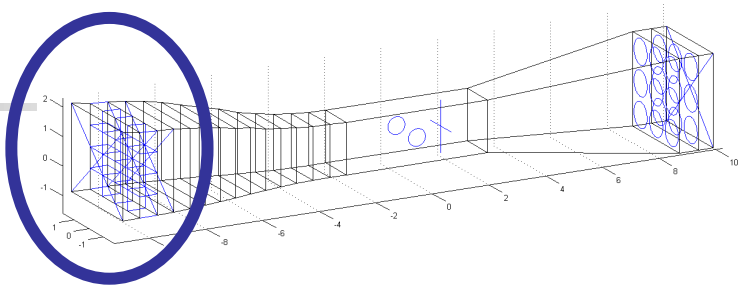
- Maximum speed: ~28m/s
- Turbulence level: <1%.
- Virtually uniform flow.
- In a cross section,
  - the spatial variation of the flow is <3%.





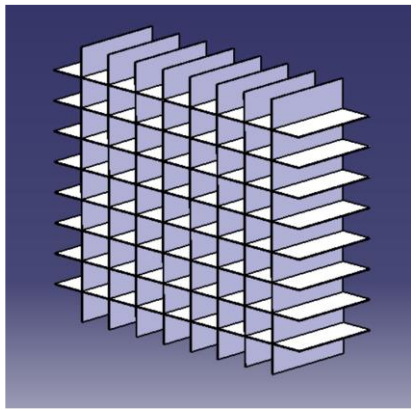


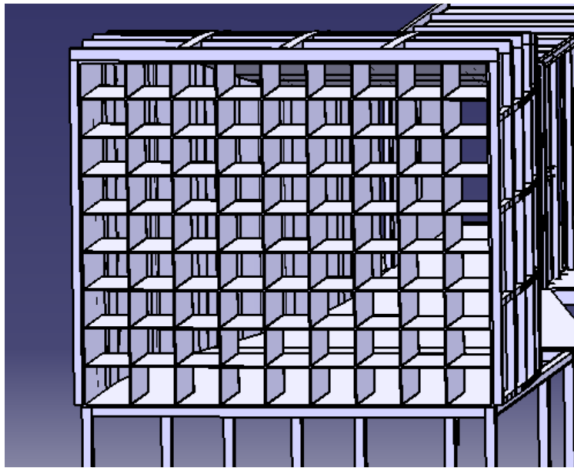
Wind Tunnel - III



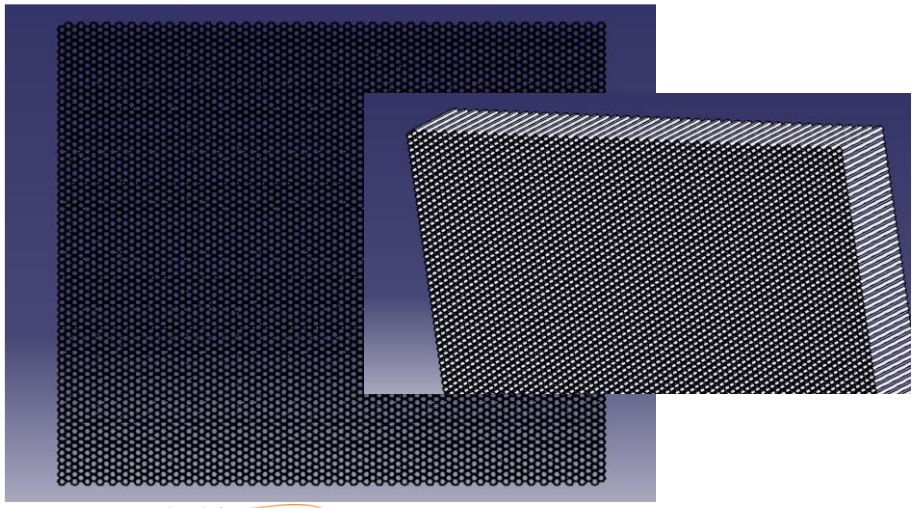
Straightener, Honeycomb Turbulence Networks

Externa Square Straightener

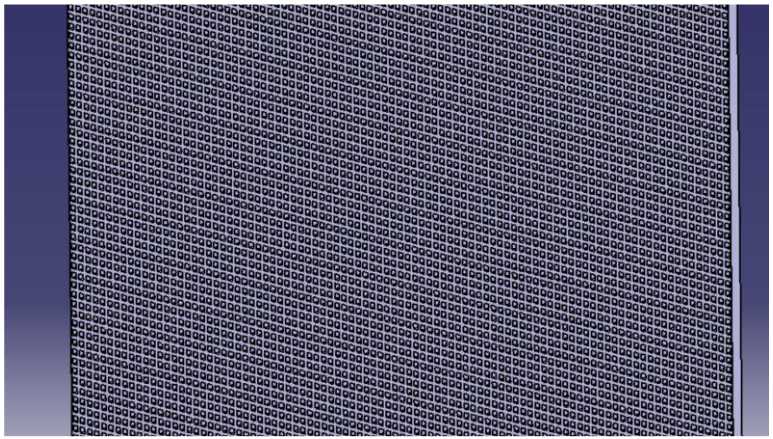




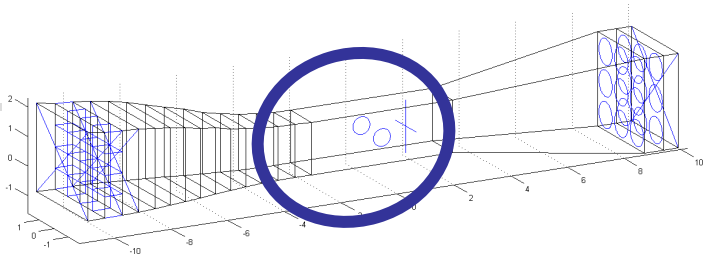
Inrternal double layer Hexagonal honeycomb

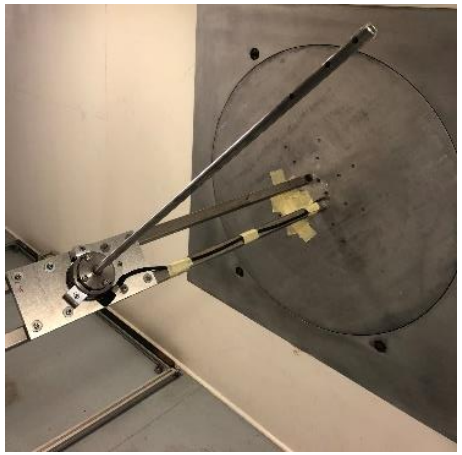


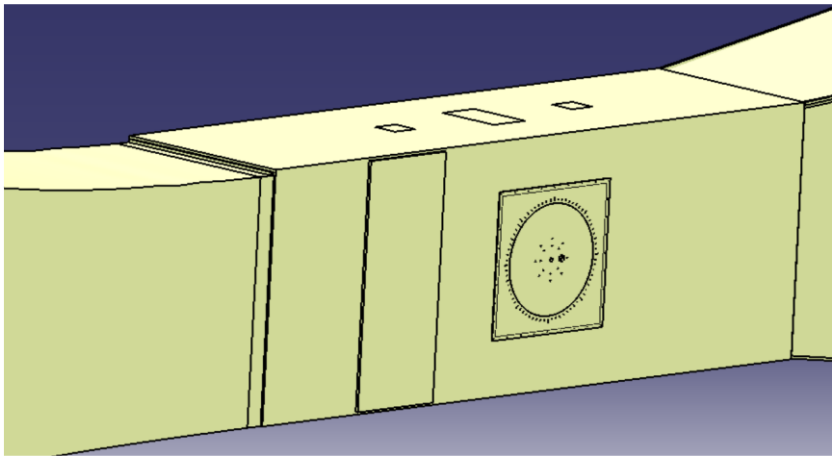
Internal double layer Square mesh

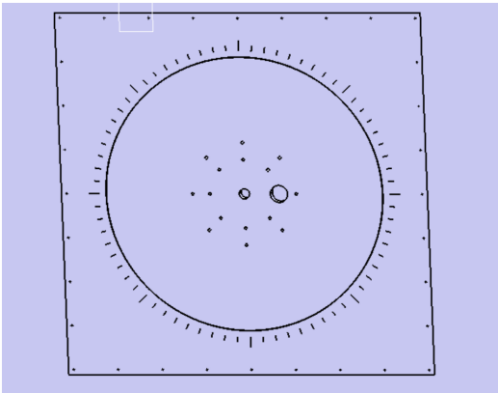


Wind Tunnel - IV

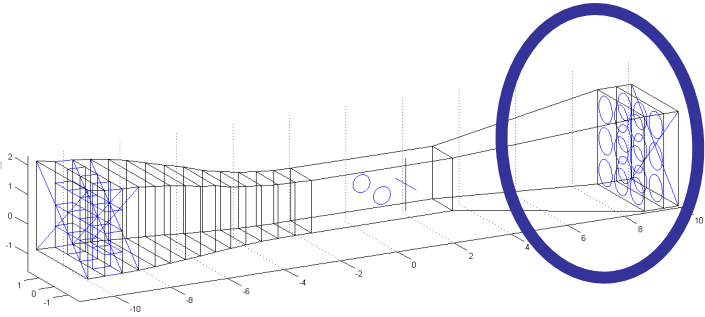




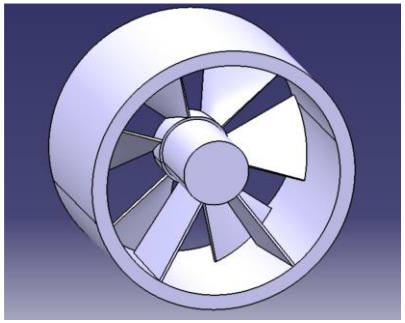




Wind Tunnel - V

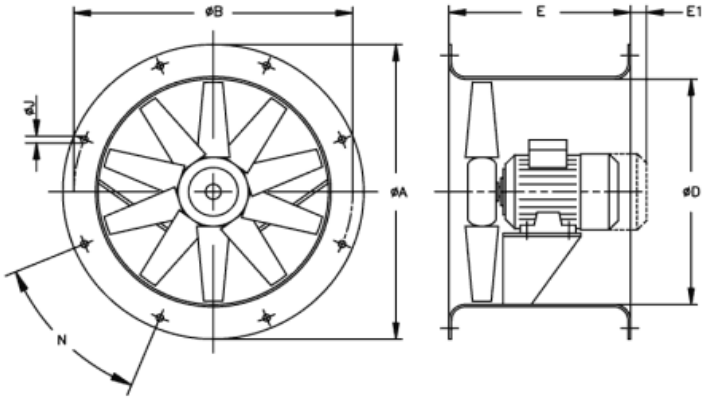


9x Fans (HCT-90-4T-7.5/AL IE3)



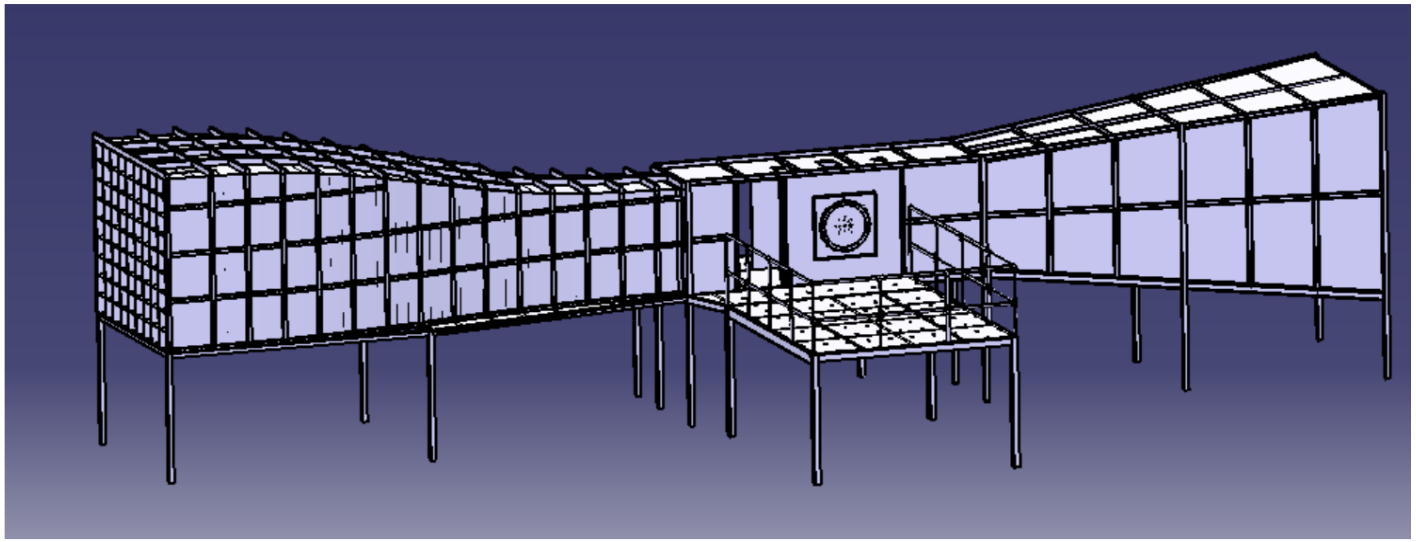
ØA	ØB	ØD	E	ØJ	N
1015	970	900	500	15	16x22º30'

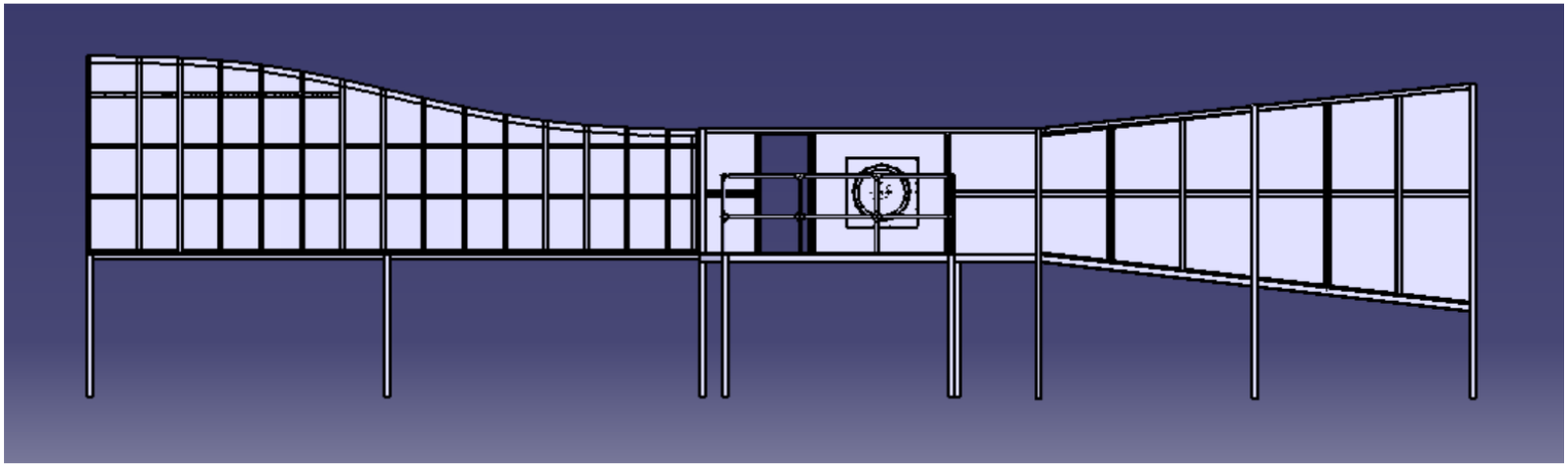
Las dimensiones sin unidades definidas explícitamente se muestran en milímetros (mm). Dimensiones dependientes del motor son aproximadas



Wind Tunnel - VI

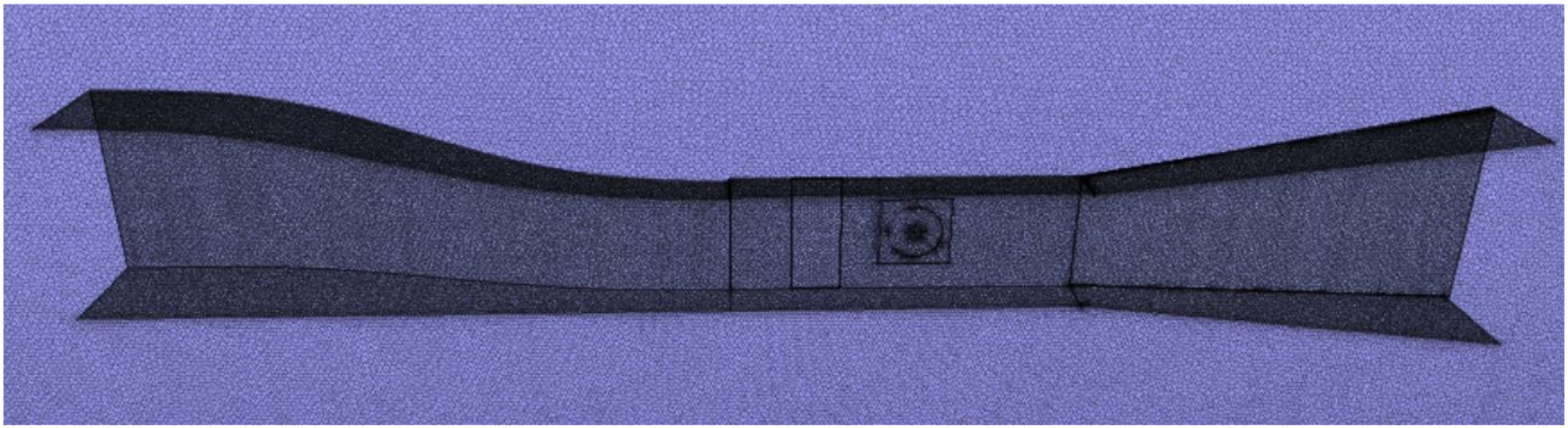
- CAD Characterization

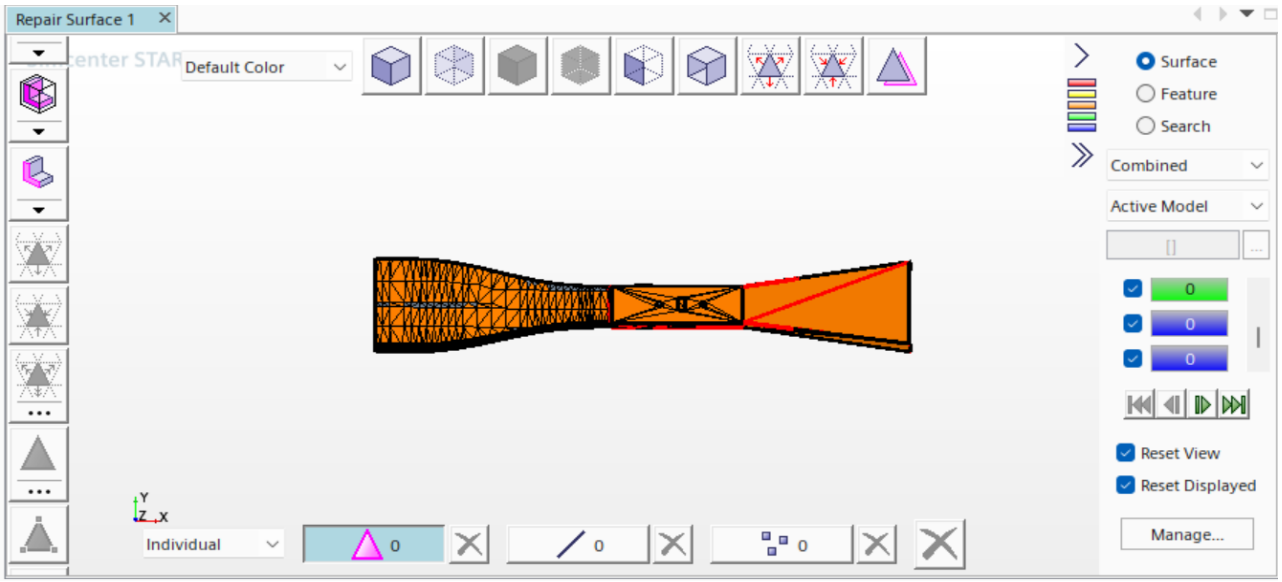




Wind Tunnel - VII

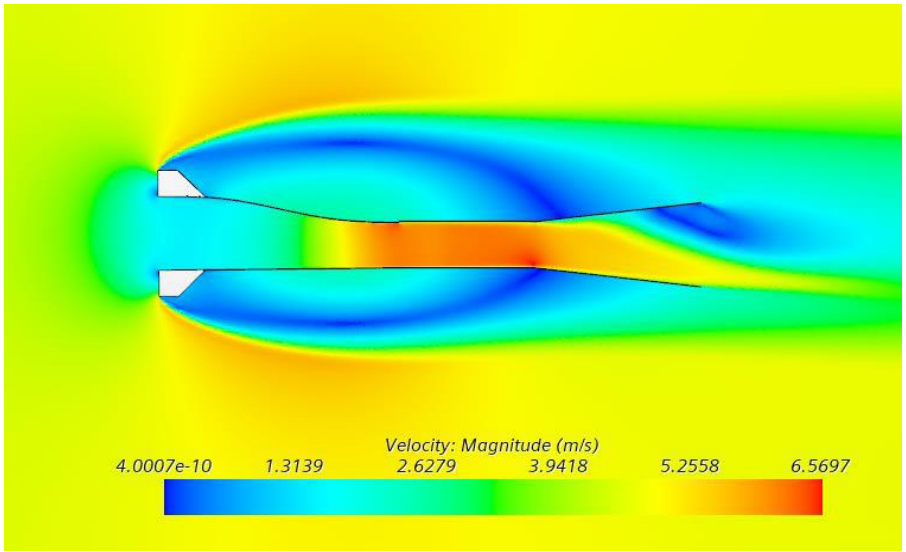
- CFD Characterization



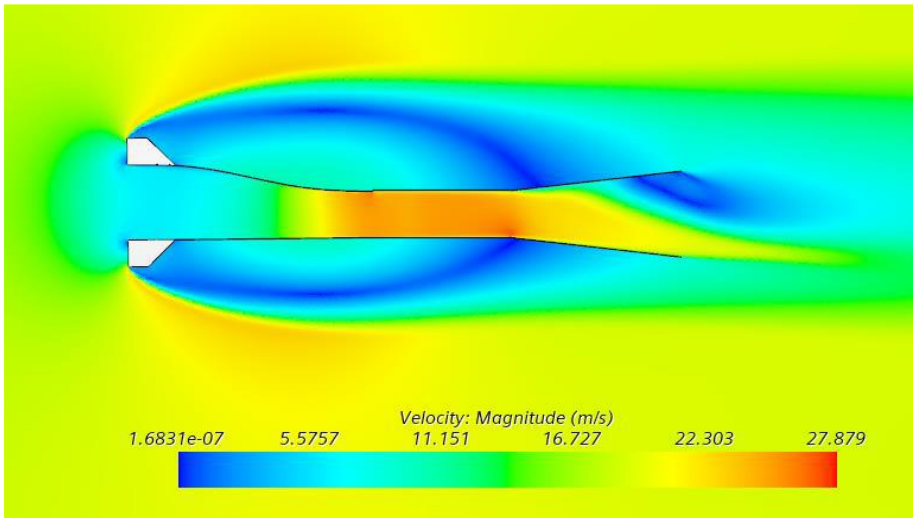


Wind Tunnel - VIII

- CFD Characterization



Velocity profiles at minimum speed



Velocity profiles at maximum speed

Introduction

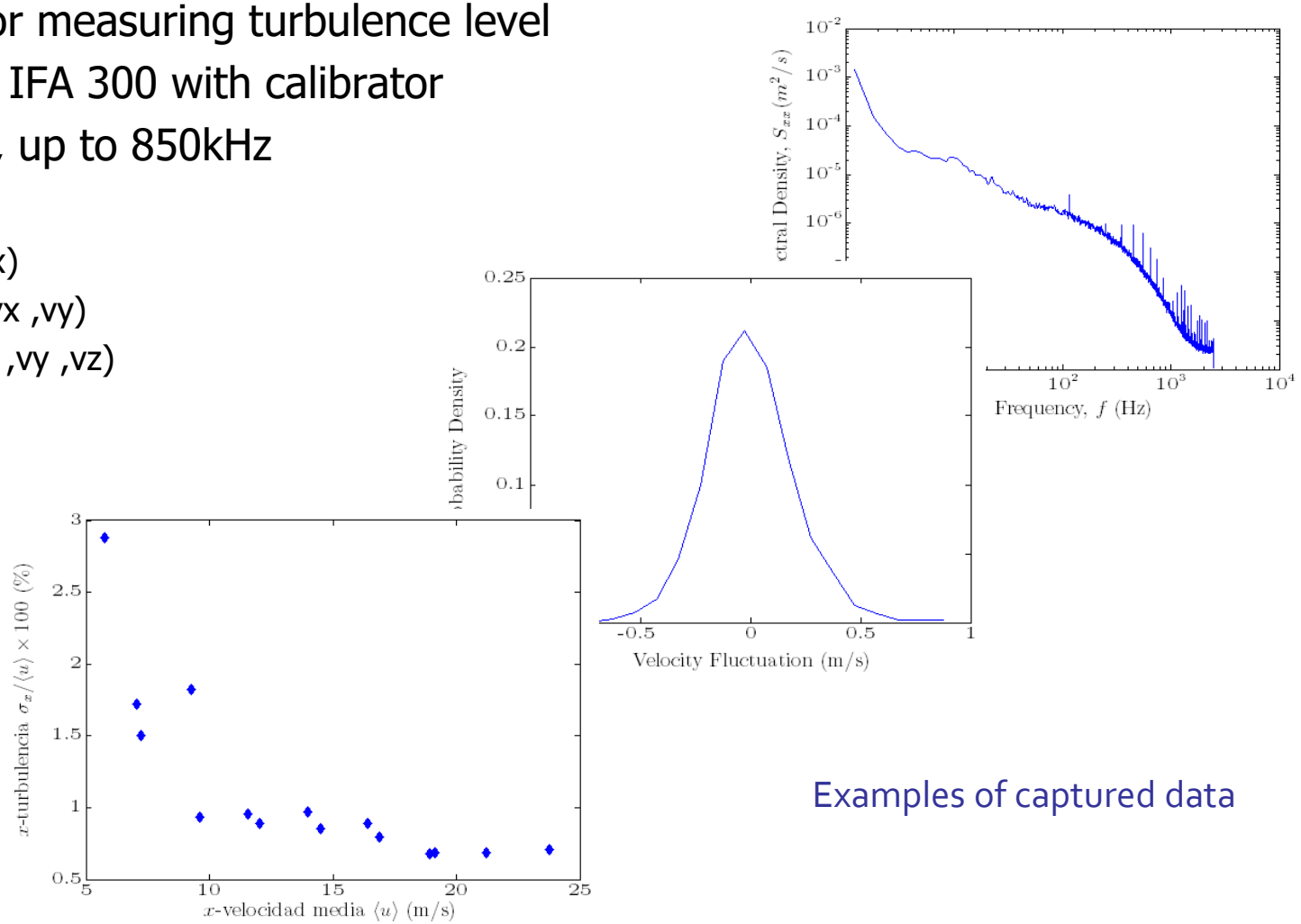
- Wind tunnel
- **Measuring equipment**
- Positioning equipment
- Manufacturing equipment
- Processing Data
- Project examples: ProVANt - EMERGENTIA
  - Wind Tunel Experiments
  - Propulsive Experiments
  - CFD Validation

Measuring equipment - I

- Air velocity
  - Hot wire (TSI)
  - Digital Multimanometer (Pressure Systems)
  - 5-hole anemometers (Aeroprobe)
- Other quantities
  - 6-axis balances (ATI)
  - MEMS Accelerometers (Measurement Specialities)
  - Laser distance sensors (MEL)

Hot wire

- Measures air velocity at high sampling frequency
- Excellent for measuring turbulence level
- Model: TSI IFA 300 with calibrator
- 4 channels, up to 850kHz
- Probes:
  - single (vx)
  - double (vx ,vy)
  - triple (vx ,vy ,vz)

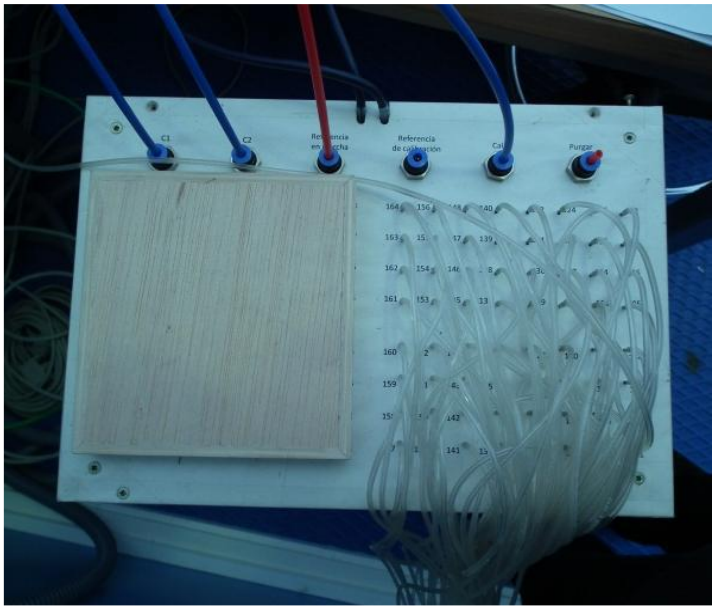


Examples of captured data

Digital Multimanometer

- Measures the distribution of pressures on the surface of models.
- Model: Pressure Systems PSI 8400
- 128 channels
- Range: ±10 "H20=2.5kPa differential, accuracy: ±<<1Pa

The multimanometer and the control and programming system

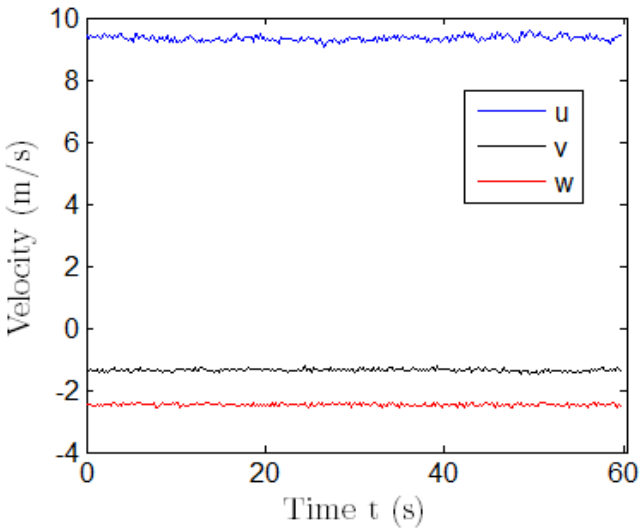


Junction box, half in use

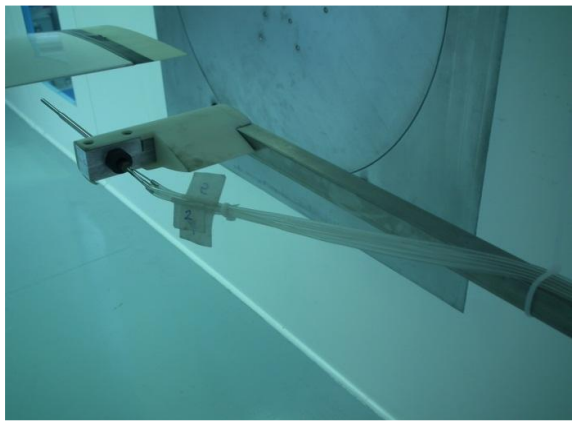
5-hole anemometer

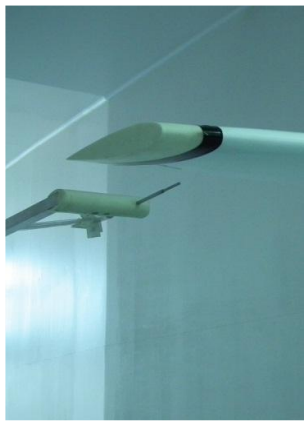
- They measure the velocity vector at a point over large ranges of angles of incidence.
- Manufacturer: Aeroprobe
- Probes of two types: straight and 'L' shaped
- Velocity: 1<v<40 m/s
- Incidence angle: ±60°.

Straight probe mounted on the positioner



Example of data

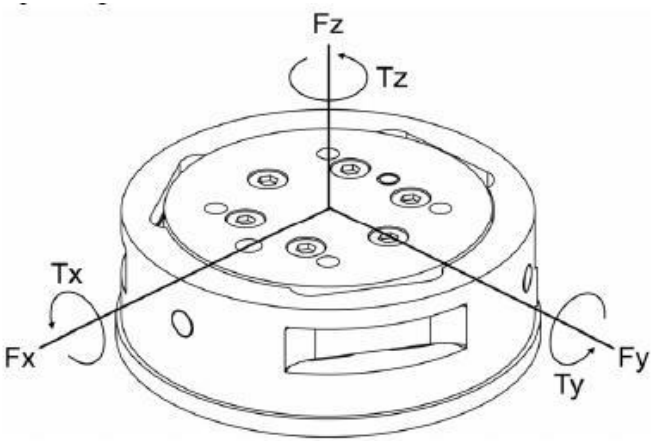




Measurements in the wake of a test wing

6-axis scale

- Measure forces and torques Fx, Fy, Fz, Txy, Tyz, Tzx
- Models: ATI Gamma and Mini
- Mounted inside the model
- Gamma: maximum load ±400N
- Mini: maximum load ± 120N



Measurements of the 6 force components

Gamma balance in wind tunnel

Gamma balance

Introduction

- Wind tunnel
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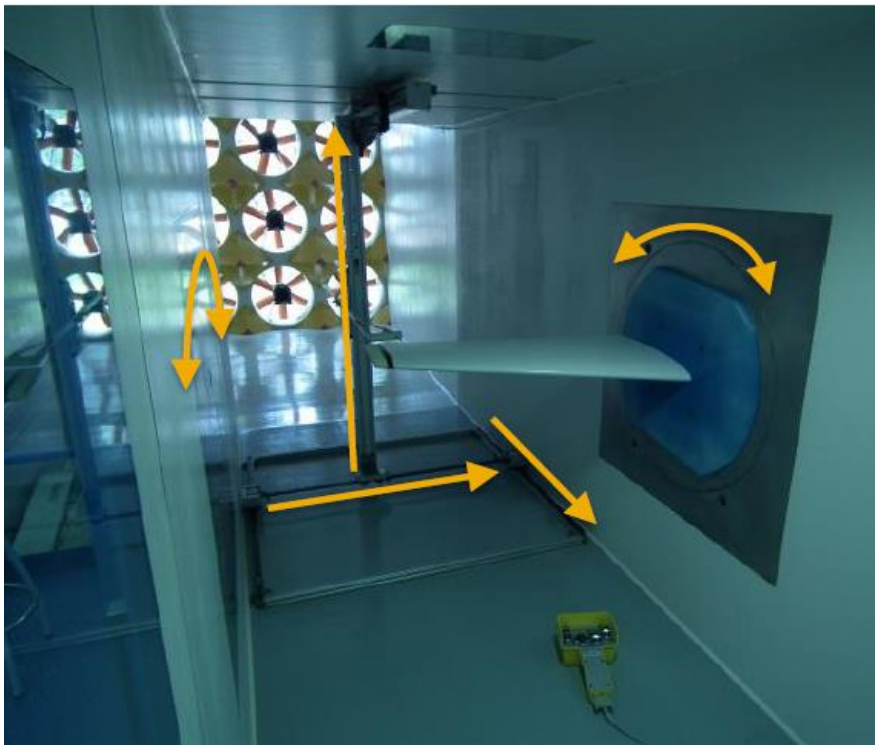
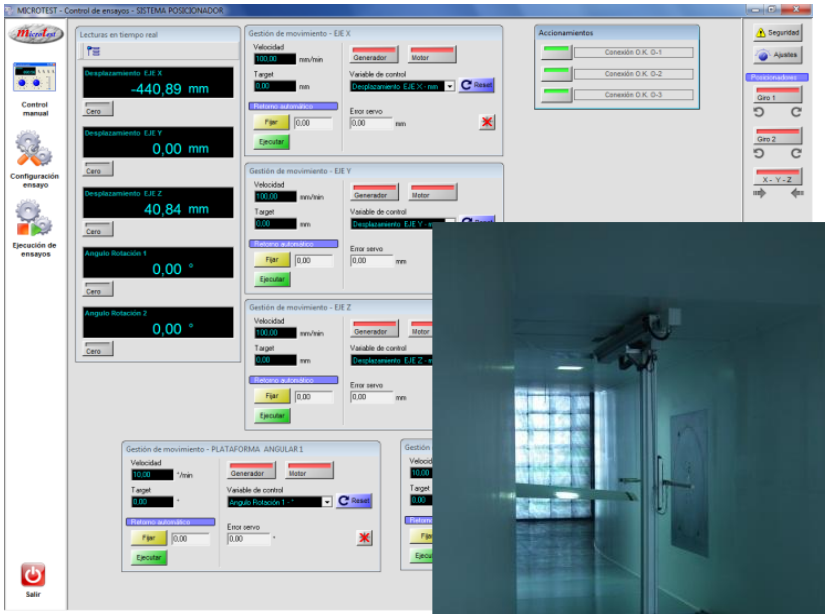
Positioning equipment

- 3-axis system - x, y, z to place either probes or models
- 2 turntables - θ1, θ2 to position models



The positioner with the 5 marked axes



Control program

Reverse view

Introduction

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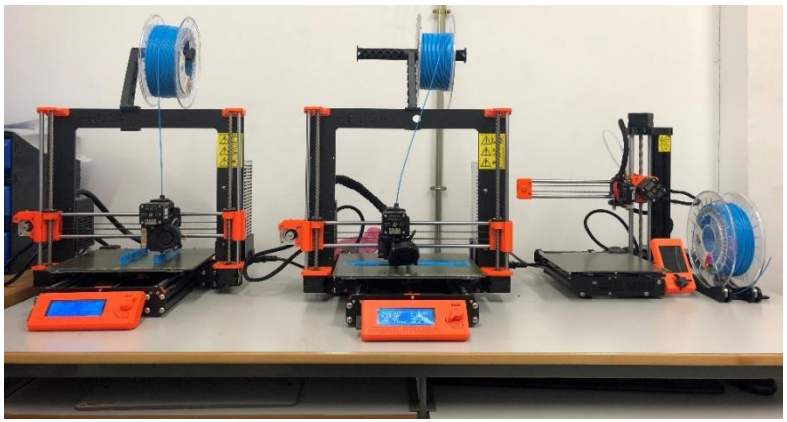
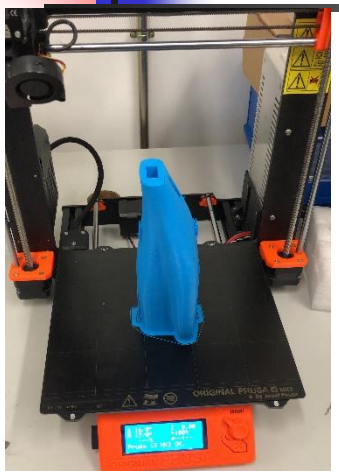
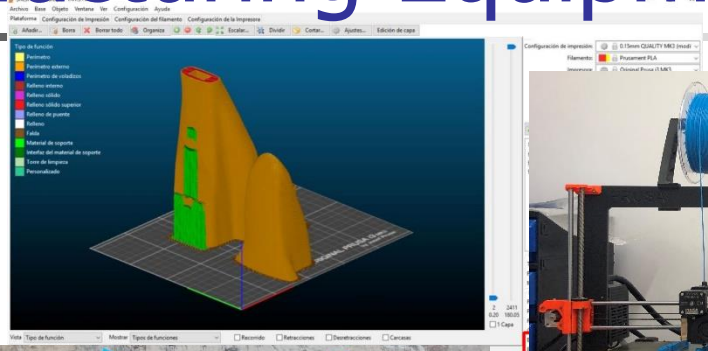
Manufacturing Equipment

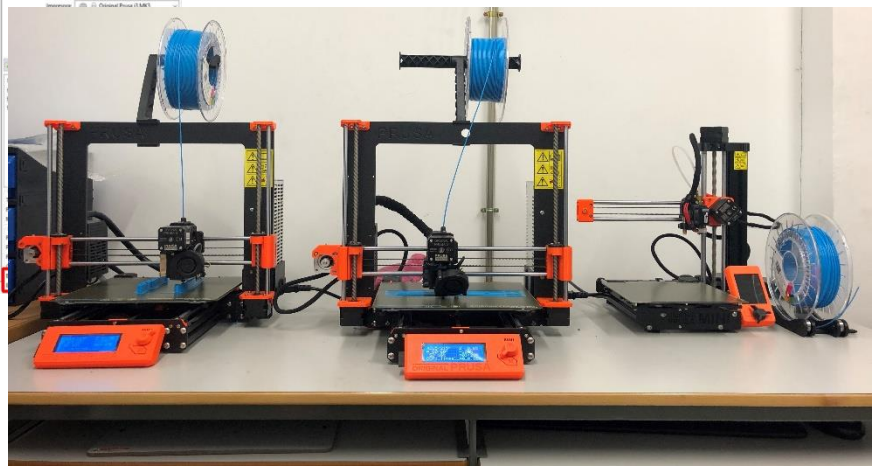
- Computerized manufacturing equipment
- 3D Printer (3D Systems)
  - Rapid prototyping directly from CAD files
  - RESIN
  - Design volume: 220 x 170 x 200 mm
  - Plastic based: PET, ABS, PTG, etc…
  - Resin based: Epoxy material resin
    - Resolution: ~200 x 200 x 200 x 100 µm
    - Deposits layer by layer; wipes off excess material; and cures with ultraviolet ligh
- Laser Cutter
- Pantograph (Mecanicam)
  - Prototypes manufactured directly from CAD files

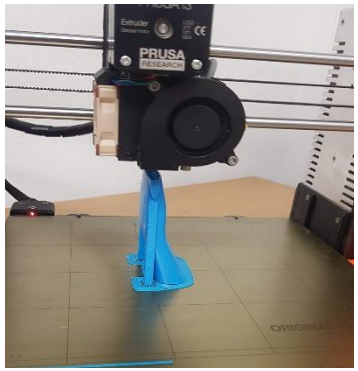


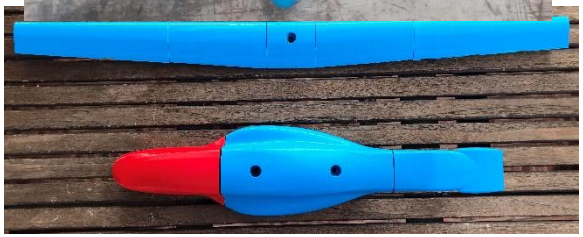
Manufacturing Equipment

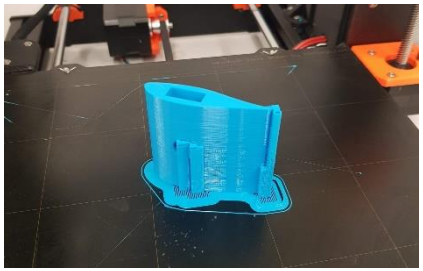












3D printing Capabilities

Introduction

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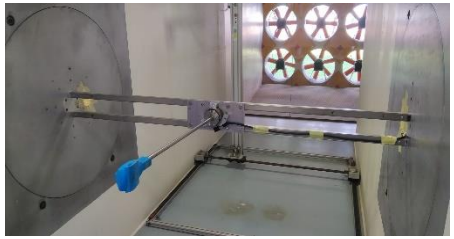
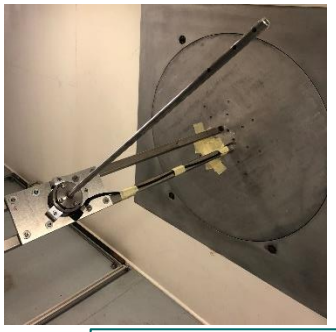
Processing Data - I

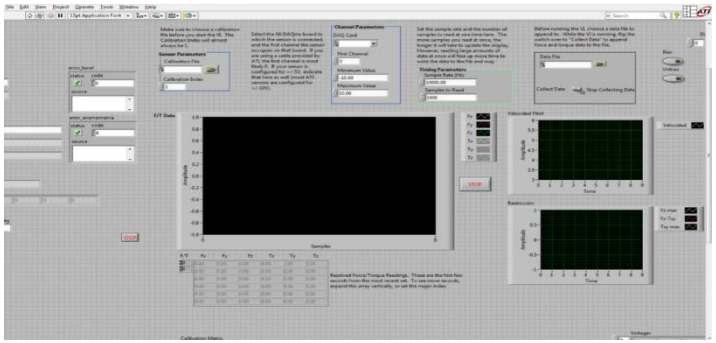
Wind Tunnel Facilities



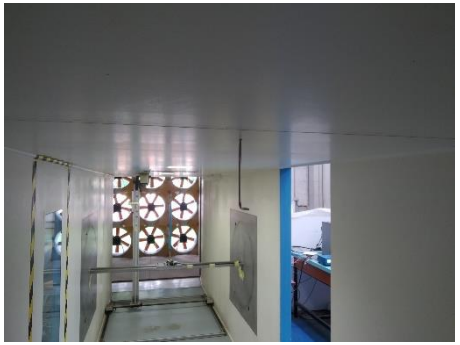
Assembly System



Positioning System



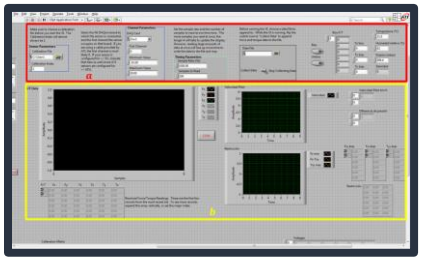
Labview Force and moments SetUp



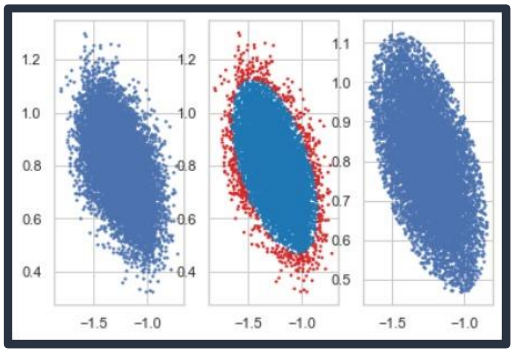
Velocity Adquisition system

Processing Data - II

Data Adquisition



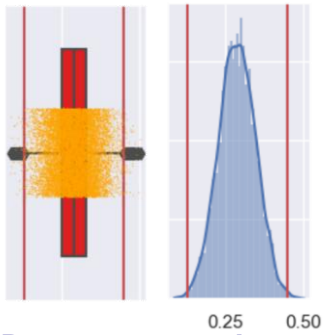
Data Filtering



Campaign 2

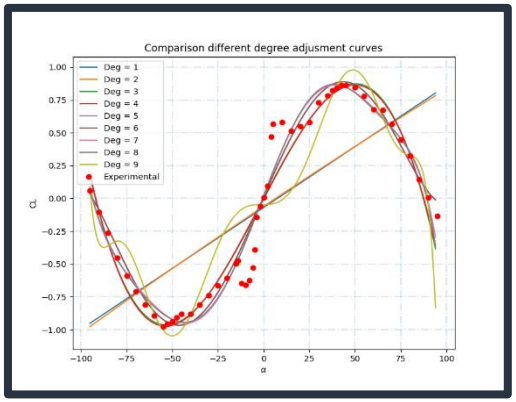
PYTHON

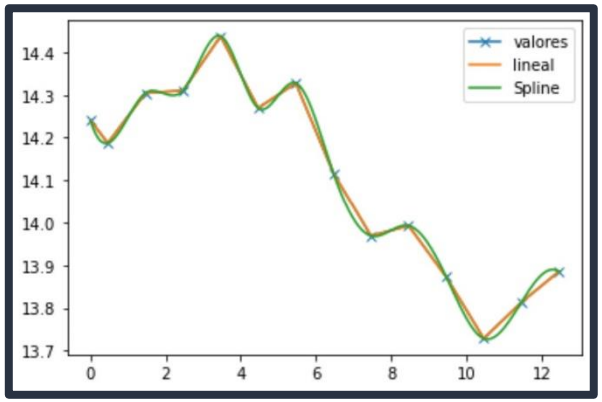
Fx



Data Post-processing

Data Fitting





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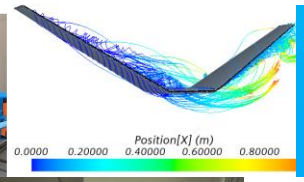
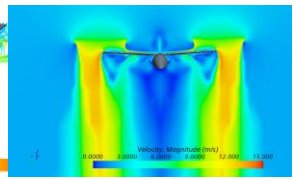
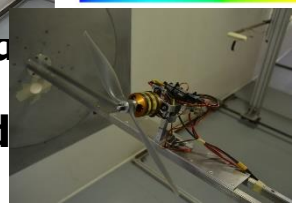
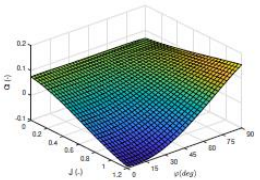
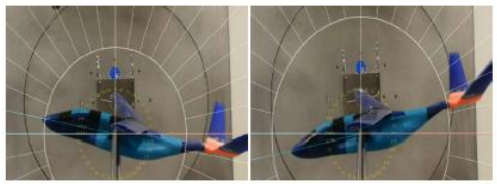
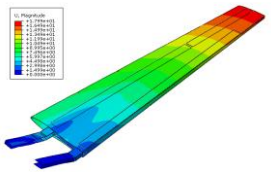
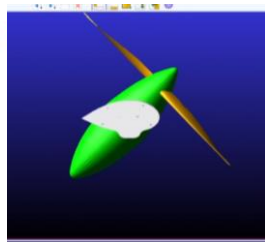
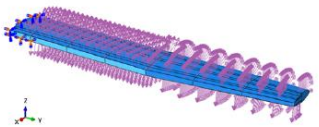
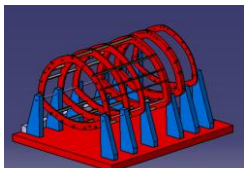
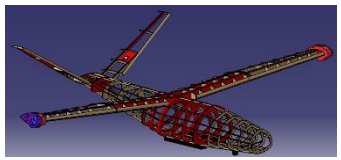
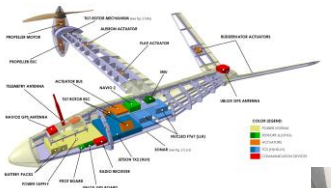
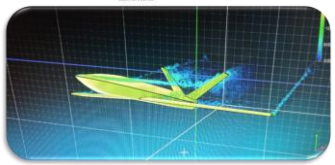
  - **ProVANt - EMERGENTIA**
    - **Wind Tunel Experiments**
    - **Propulsive Experiments**
    - **CFD Validation**
  - Straight and Sweept Wing

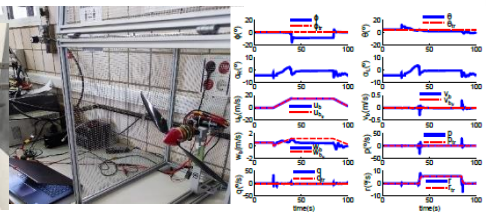
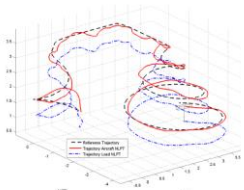
EMERGENTIA PROVANT

- **Aerodynamic Studies: wind tunnel and CFD**
- **Propulsive studies: wind tunnel and theoretical mod**
- **Flying Qualities Studies: wind tunnel and 6DOF Mod**
- Structural Studies: FEM
- Mechanical Analysis
- CAD-CAM process: multilevel BOM, CTI, ATI, manufacturing
- Embedded Cyberphysical systems Design
- Generation and Management of Energies: hibridization of battery and fuel cell
- Autonomous Guidance, Navigation and control
- Remote Carrier Small
- Swarming
- MUT

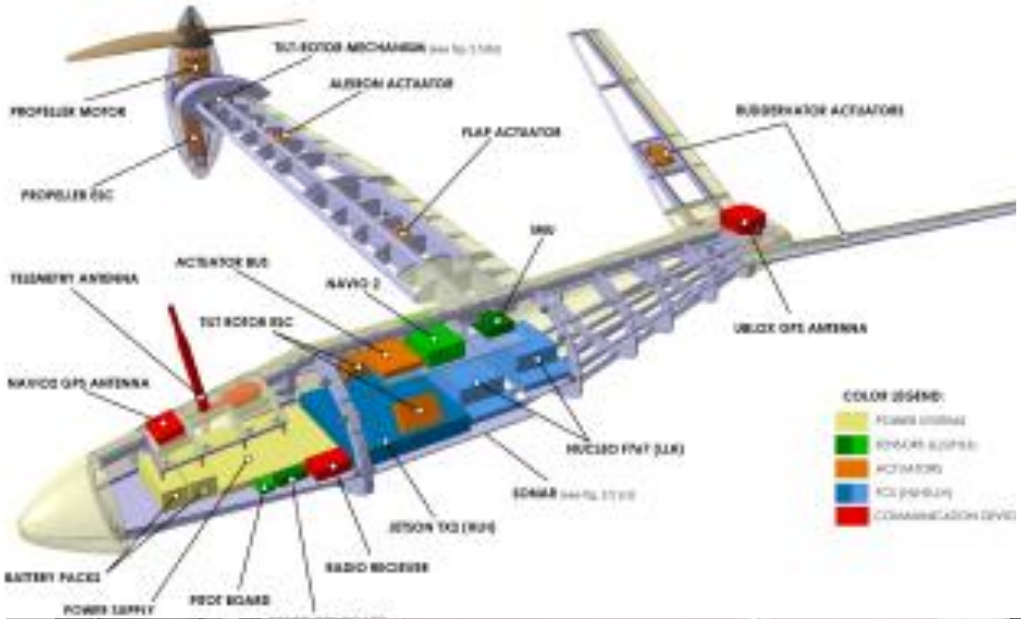
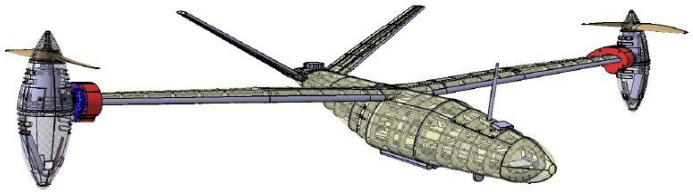
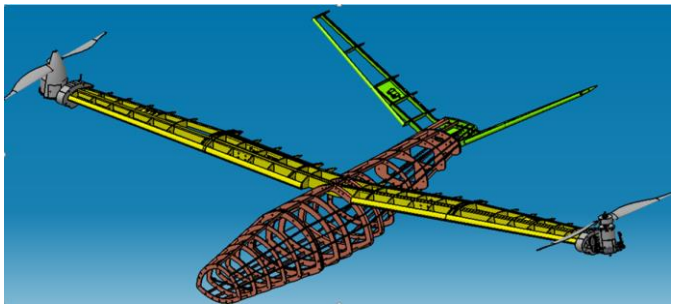


Tabla 2.1 Características geométricas del modelo.

Parámetro	Notación	Valor
Longitud del fuselaje	L_{fus}	1.690 $[m]$
Altura máxima del fuselaje	h_{max}	26.735 $[cm]$
Anchura máxima del fuselaje	b_{max}	36.802 $[cm]$
Envergadura alar	b	2.546 $[m]$
Superficie alar	S_w	0.4799 $[m^2]$
Cuerda media	c	0.19 $[m]$
Cuerda en la raiz	c_{root}	0.22815 $[m]$
Cuerda en la punta	c_{tip}	0.15826 $[m]$
Envergadura $v-tail$	b_{v-tail}	1.3247 $[m]$
Superficie $v-tail$	S_{v-tail}	0.212 $[m^2]$
Cuerda media $v-tail$	c_{v-tail}	0.1487 $[m]$
Cuerda en la raíz $v-tail$	$c_{r_{v-tail}}$	0.1956 $[m]$
Cuerda en la punta $v-tail$	$c_{t_{v-tail}}$	0.1018 $[m]$
Diedro de la cola	Γ_{v-tail}	29.3 $[°]$
Flecha en el borde de ataque $v-tail$	$\Psi_{LE_{v-tail}}$	10.294 $[°]$
Flecha en el borde de salida $v-tail$	$\Psi_{TE_{v-tail}}$	0 $[°]$





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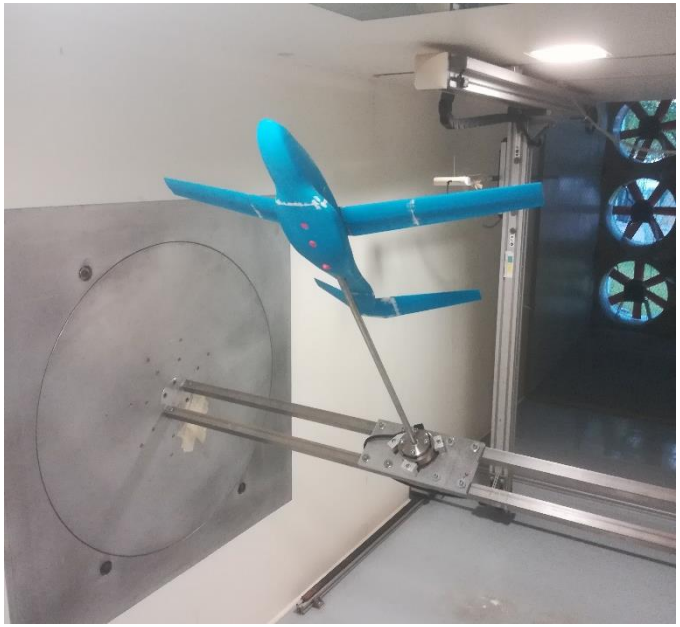
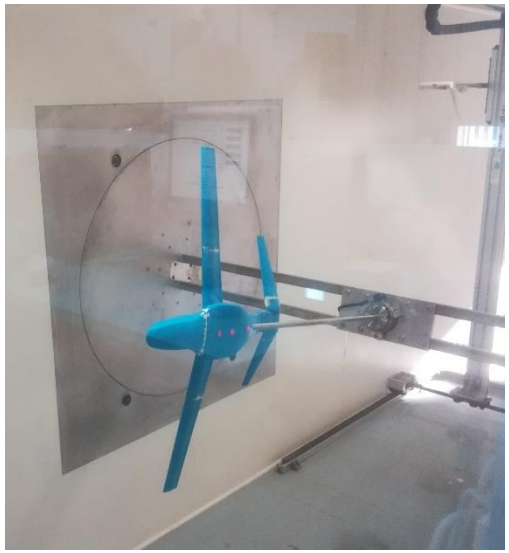
Campaign 1



Wind Tunnel Experiments



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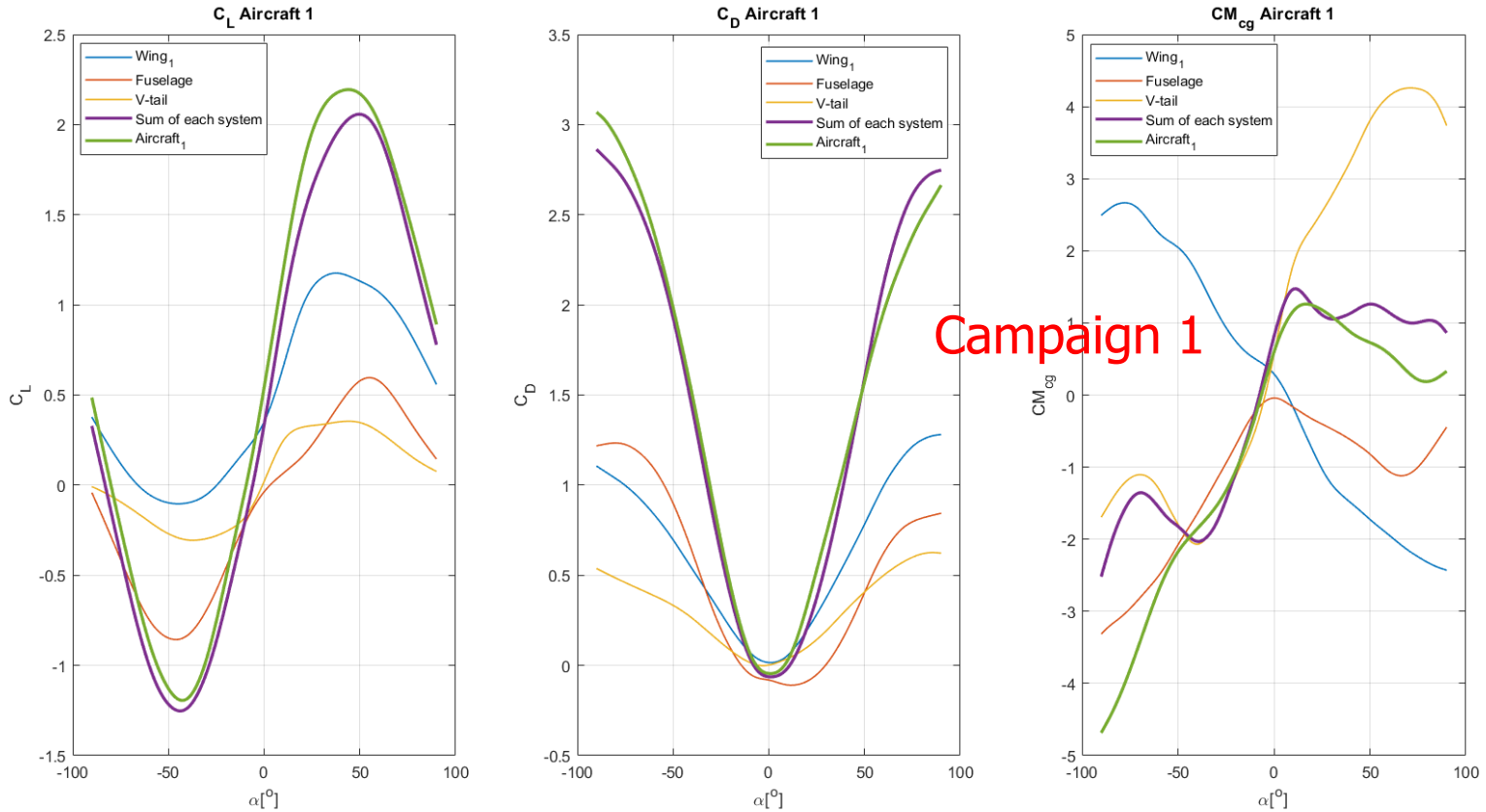
Superposition Contribution



Campaign 1

$$C_{L_{a/c}} = C_{L_{fus}} + C_{L_{vee}} + C_{L_{wing}} + C_{L_{interference}}$$

$$C_{D_{a/c}} = C_{D_{fus}} + C_{D_{vee}} + C_{D_{wing}} + C_{D_{interference}}$$

$$C_{M_{a/c}} = C_{M_{fus}} + C_{M_{vee}} + C_{M_{wing}} + C_{M_{interference}}$$

$$C_L = \frac{L}{\frac{1}{2}\rho_\infty V^2 S} = f(\alpha) = \sum_{i=0}^{n} a_i \alpha^i$$

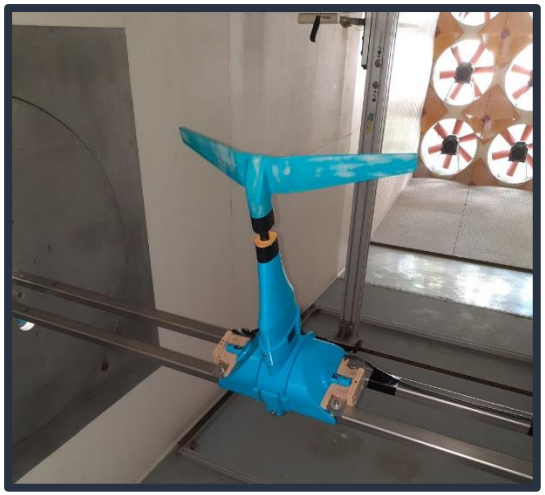
$$C_D = \frac{D}{\frac{1}{2}\rho_\infty V^2 S} = g(\alpha) = \sum_{i=0}^{n} b_i \alpha^i$$

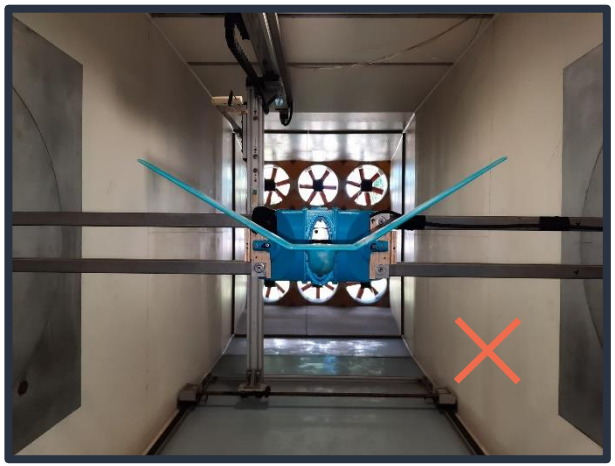
$$C_M = \frac{M}{\frac{1}{2}\rho_\infty V^2 Sc} = h(\alpha) = \sum_{i=0}^{n} c_i \alpha^i$$

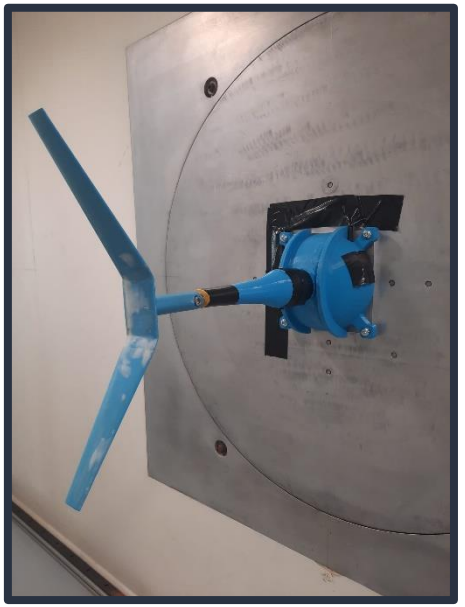
AERODYNAMIC Studies

Wind Tunnel Experiments

Campaign 2 - V-tail





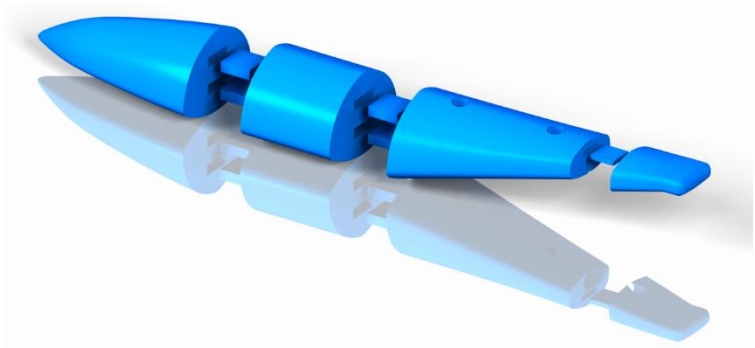


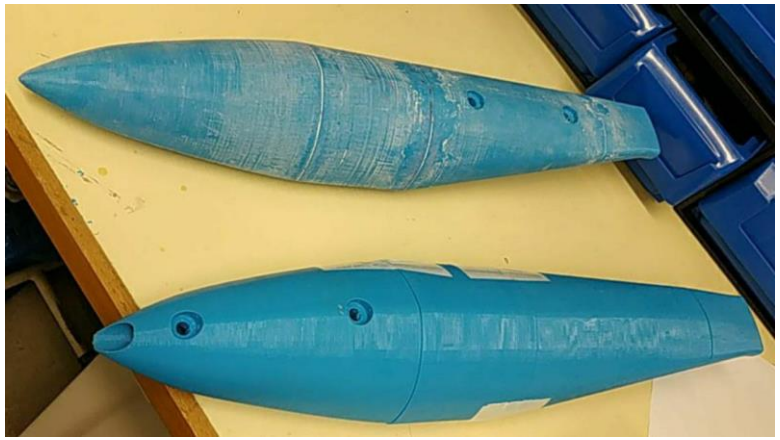
Fairing designs for drag reduction

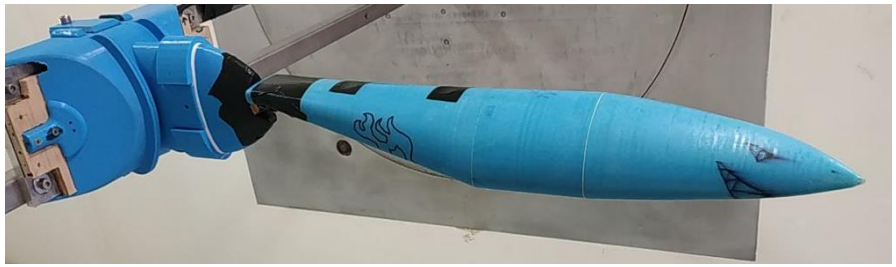
AERODYNAMIC Studies

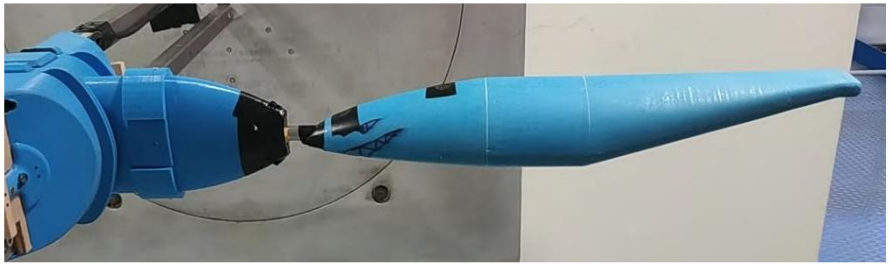
Wind Tunnel Experiments

Campaign 2 - fuselage









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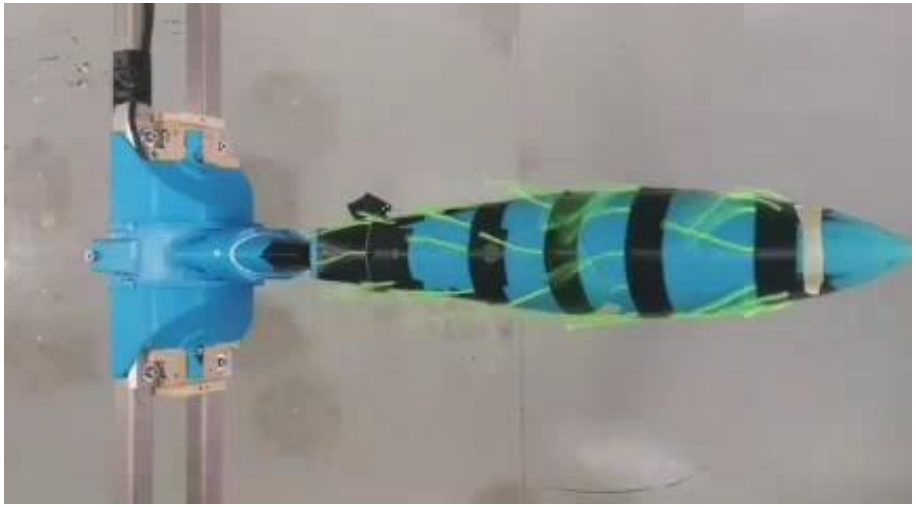
Wind Tunnel Experiments



Campaign 2 - fuselaje

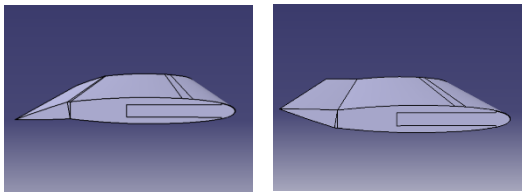
Test from α=-45º through α=-60º

Test α=45º through α=60º

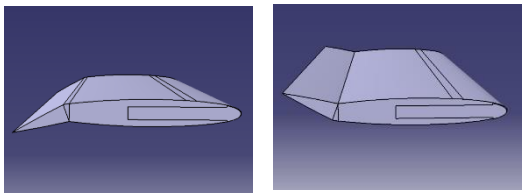
Tuft used only for flow visualization

AERODYNAMIC Studies

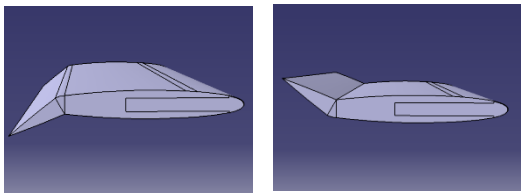
Campaign 3 – Vtail w deflections



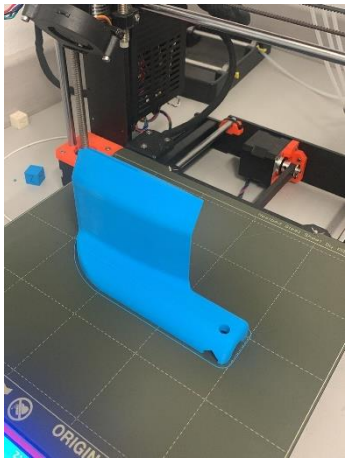
$\delta = 10°$ $\delta = -10°$

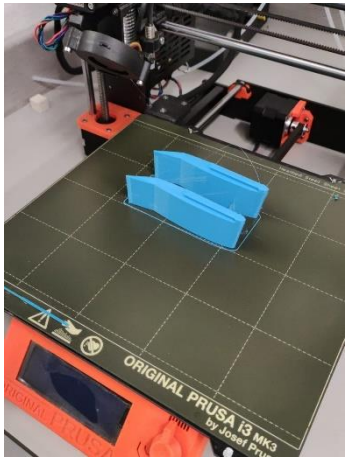


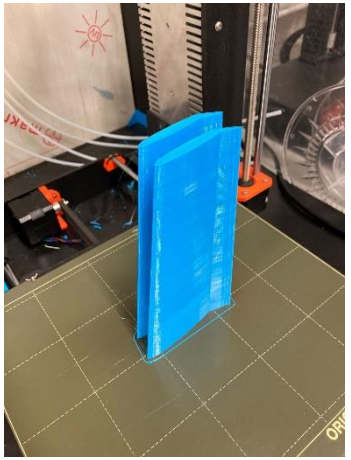
$\delta = 20°$ $\delta = -20°$

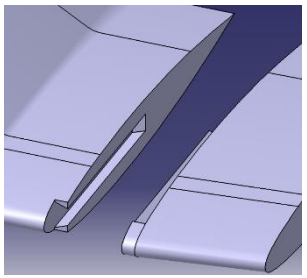


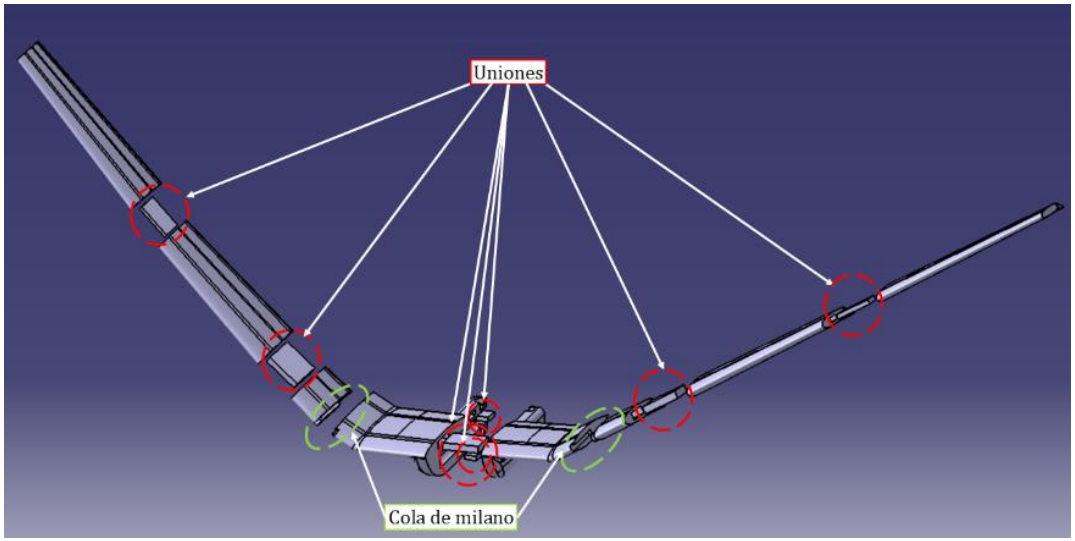
$\delta = 30°$ $\delta = -30°$











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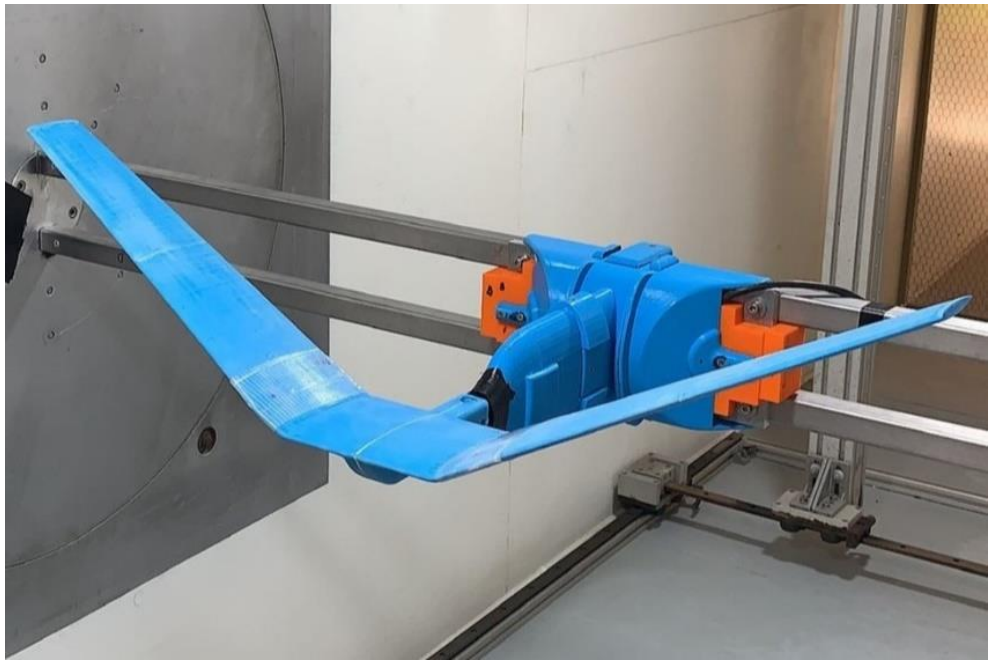
Campaign 3 – Vtail w deflections



AERODYNAMIC Studies

Wind Tunnel Experiments

Campaign 3 – Vtail w deflections

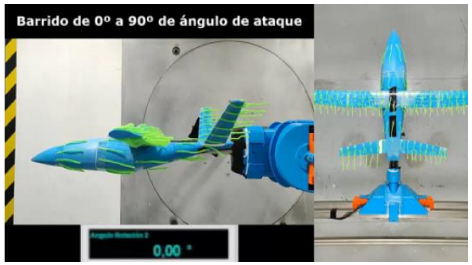
Deflection δ=20, 20; sweep from α=–30° a α=30°

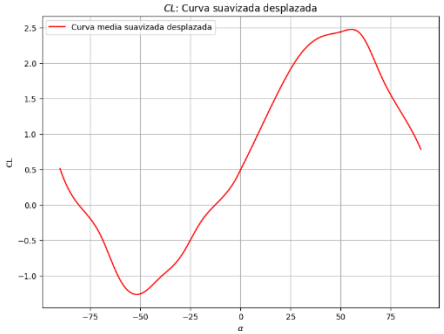
Deflection δ=-20, -20; sweept from α=–30° a α=30°

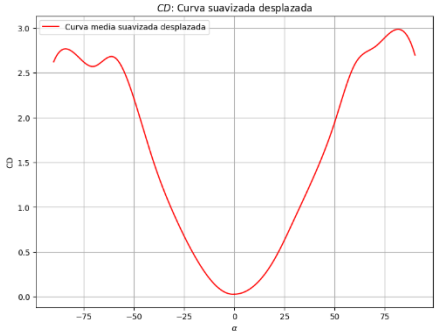
Tuft used only for flow visualization

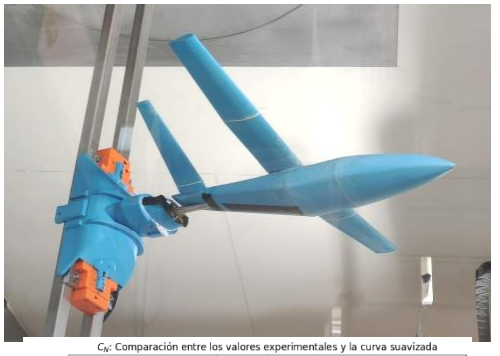
AERODYNAMIC Studies

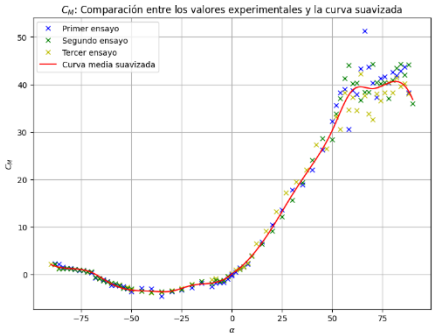
Wind Tunnel Experiments Campaign 3 – Complete Aircraft

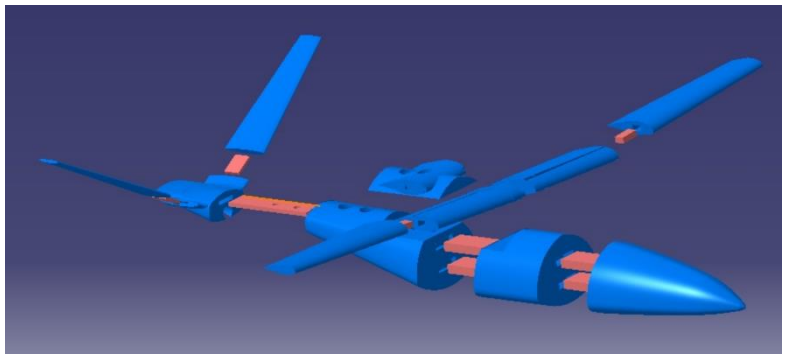


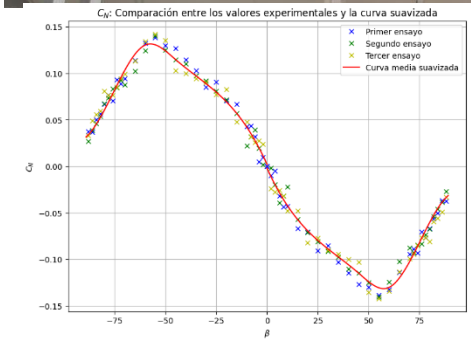


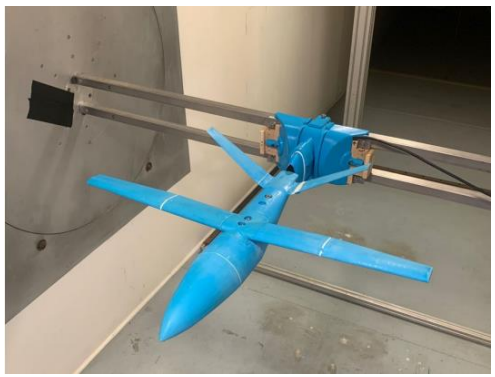


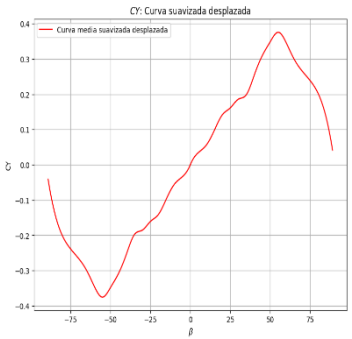


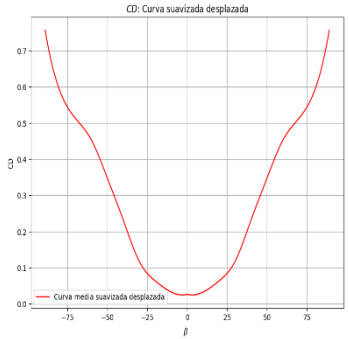


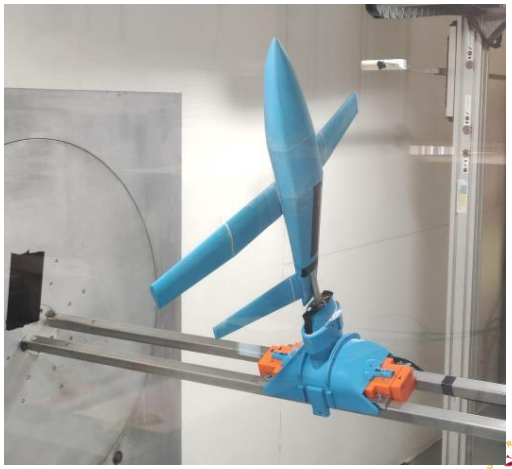








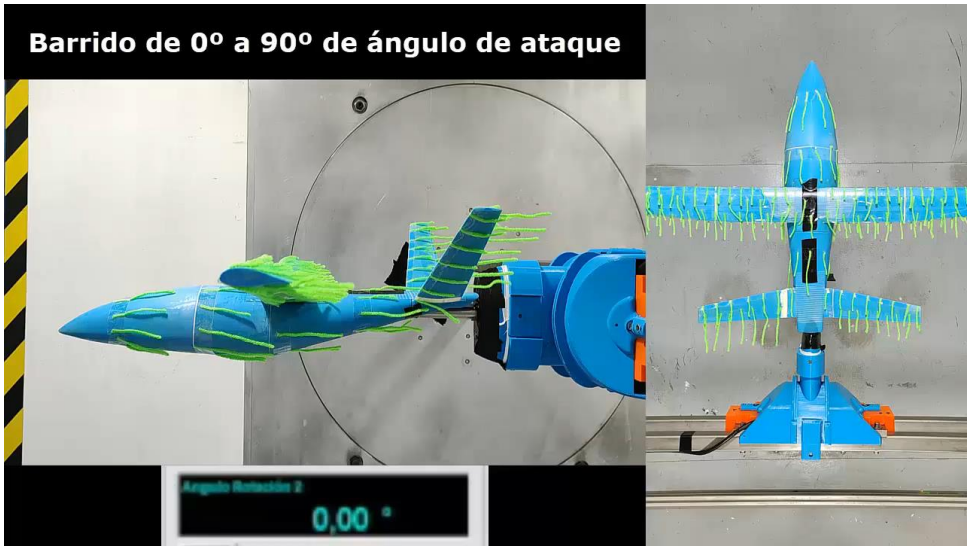




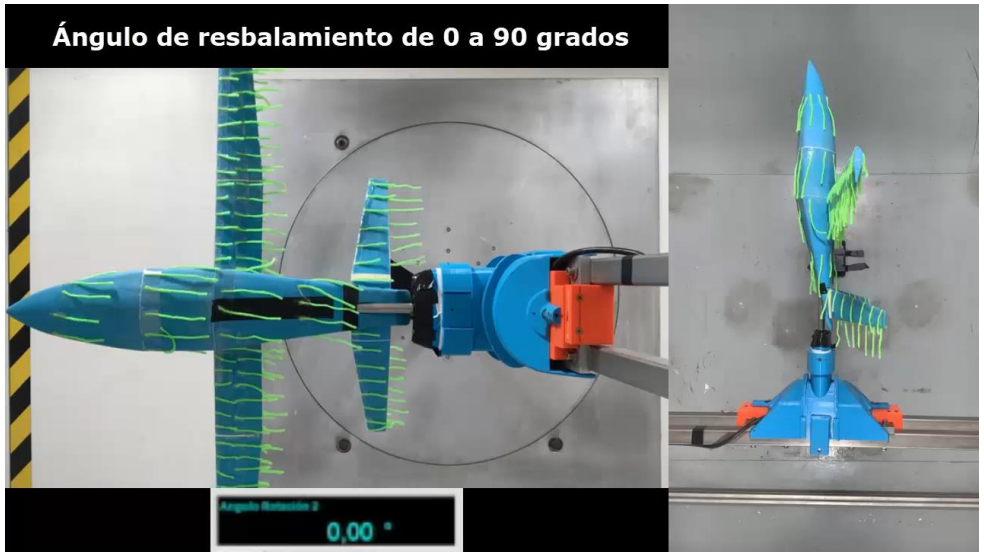
AERODYNAMIC Studies

Wind Tunnel Experiments

Campaign 3 – Complete Aircraft



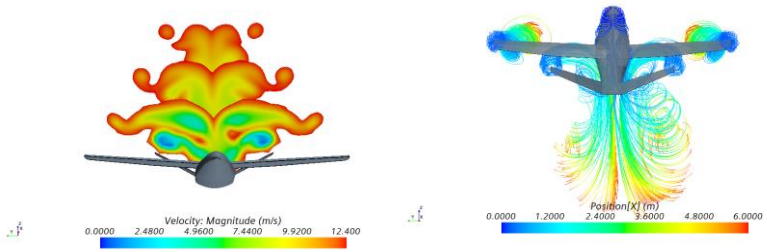
Tuft used only for flow visualization

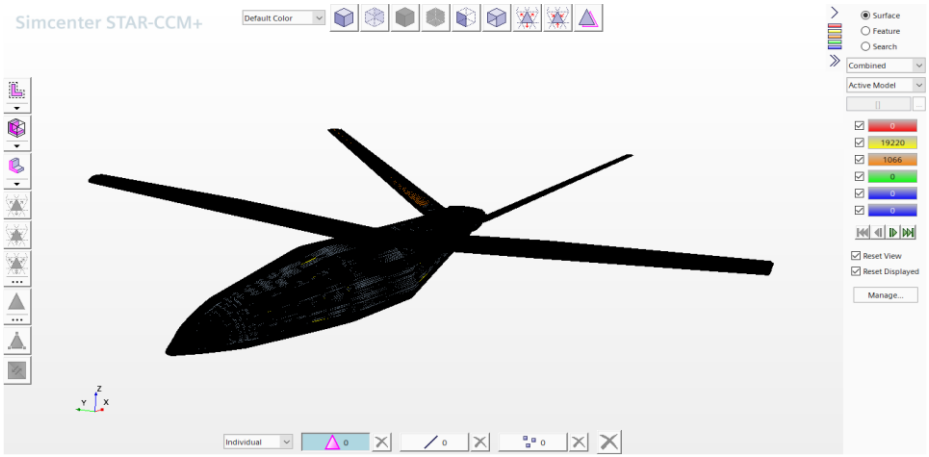


AERODYNAMIC Studies

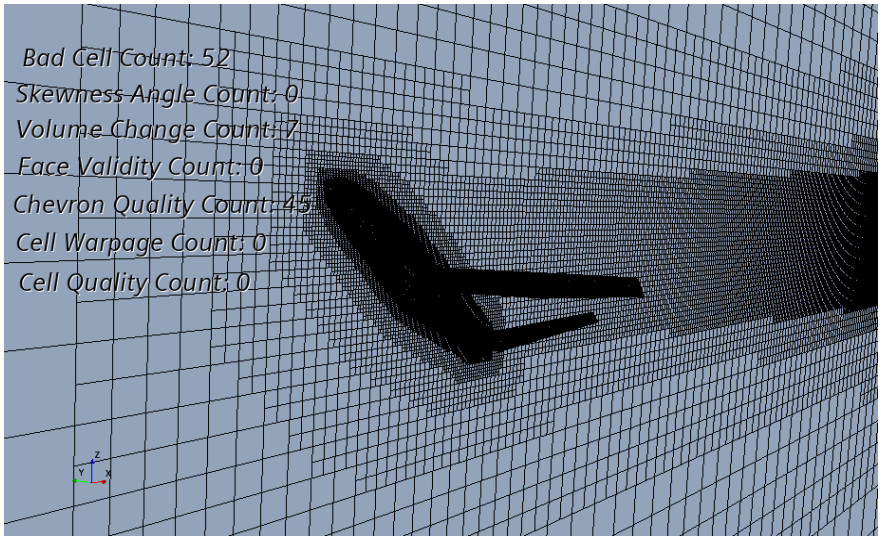
CFD Studies

Complete Aircraft CFD

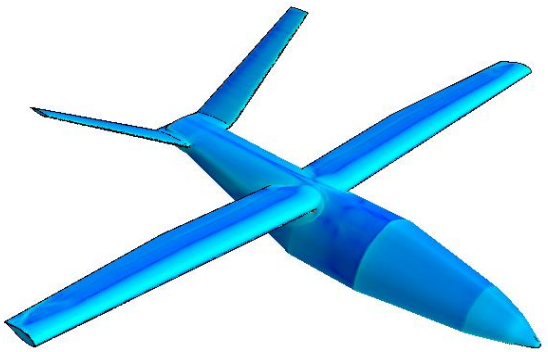




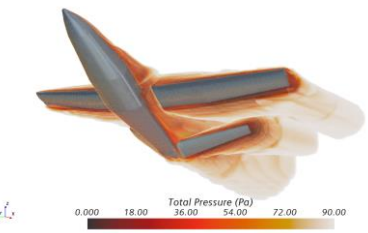
Star CCM+

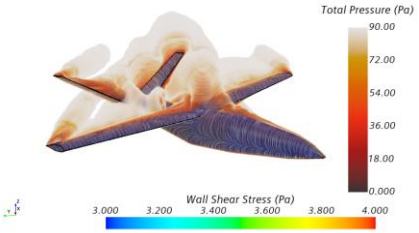


Mesh



Y+

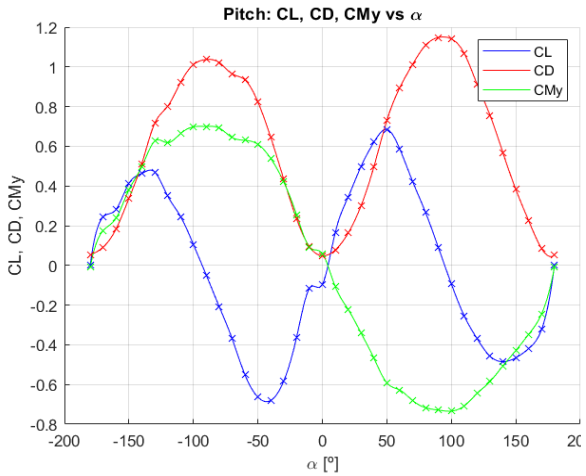


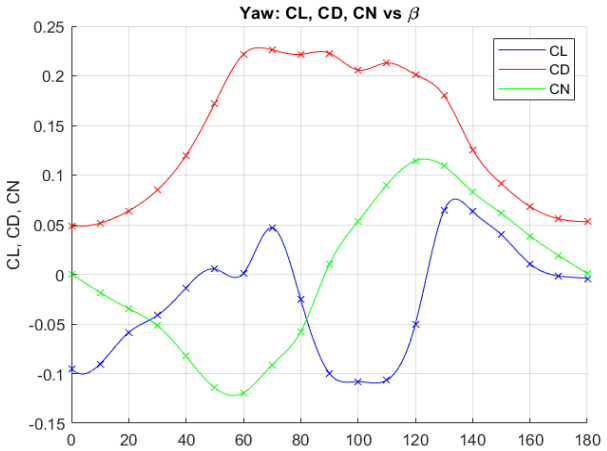


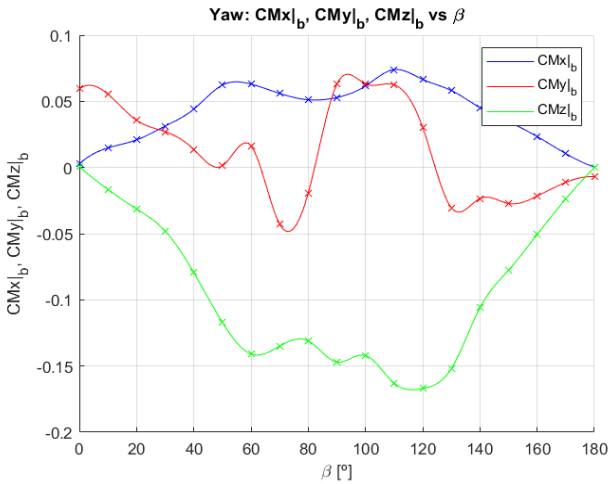
AERODYNAMIC Studies

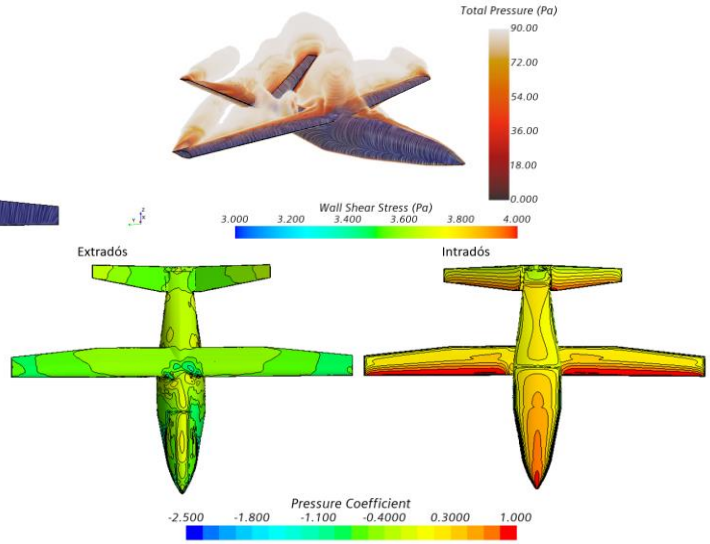
CFD Studies

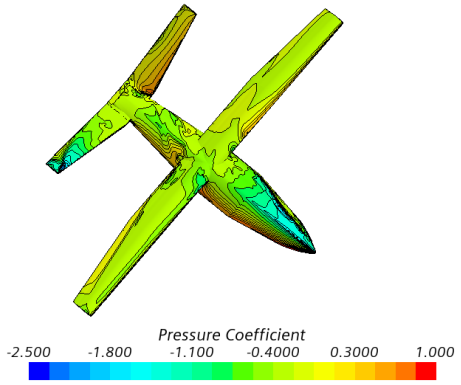
Complete Aircraft CFD Longitudinal & Directional









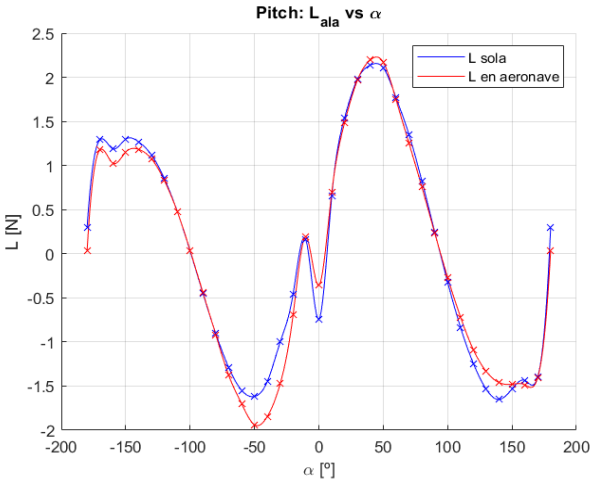


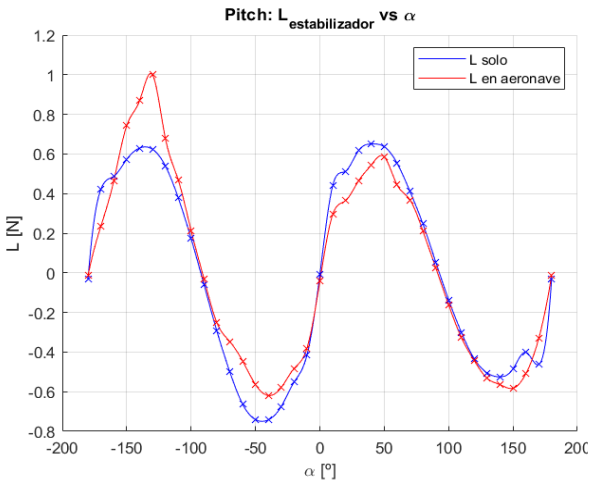
Complete Aircraft CFD results samples @ 40 deg of angle of attack

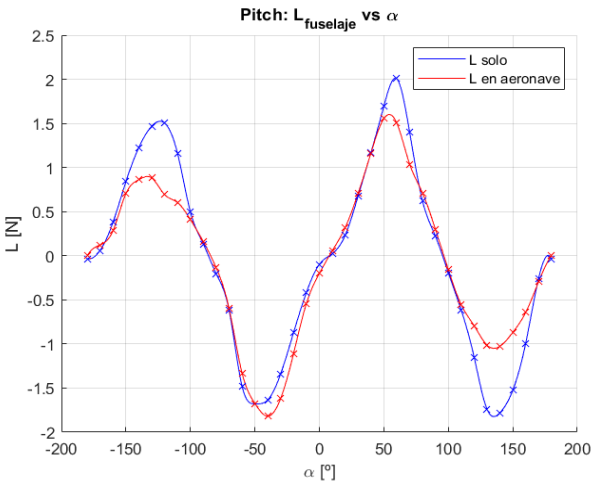
AERODYNAMIC Studies

CFD Studies

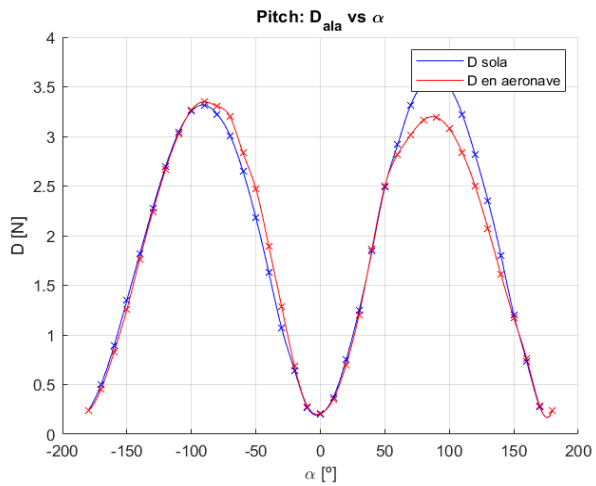
Complete Aircraft CFD Longitudinal

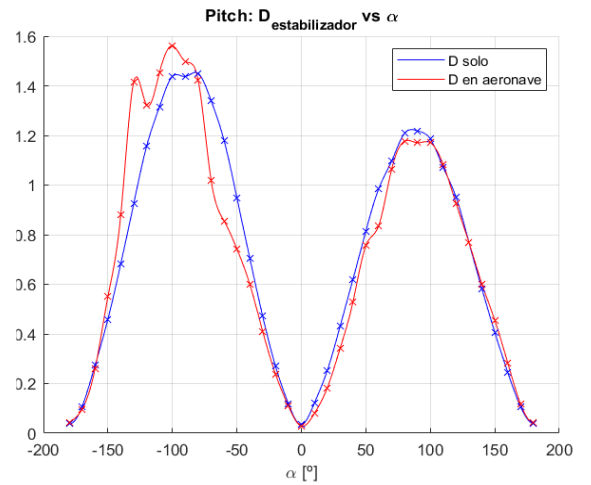


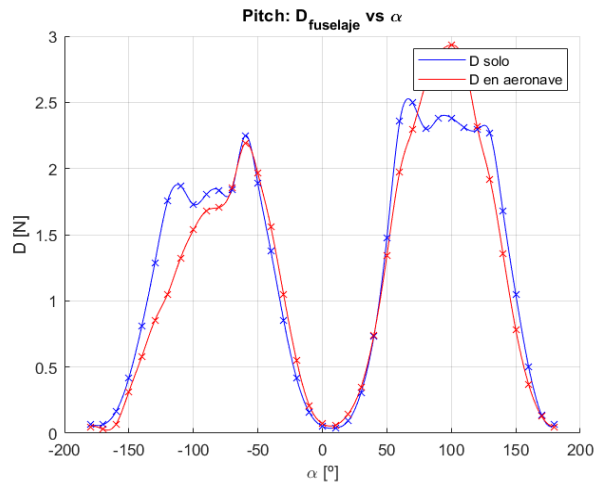




Contributions alone and with aircraft interference



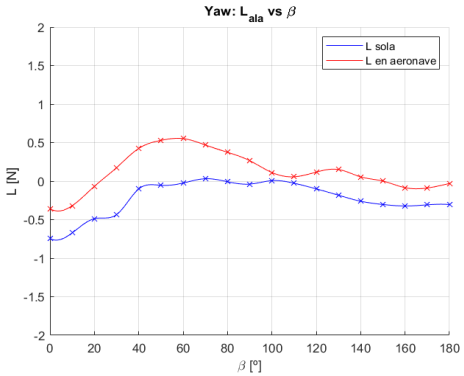


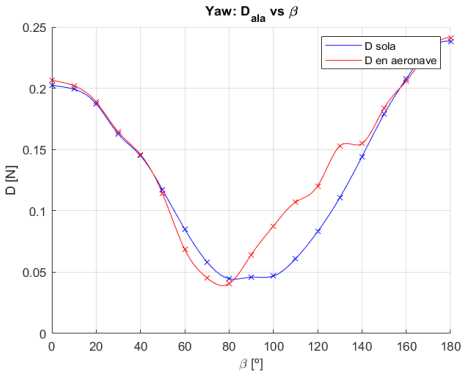


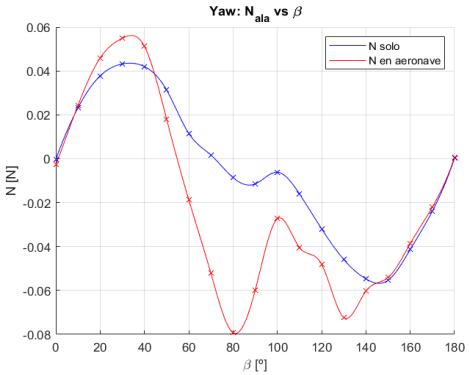
AERODYNAMIC Studies

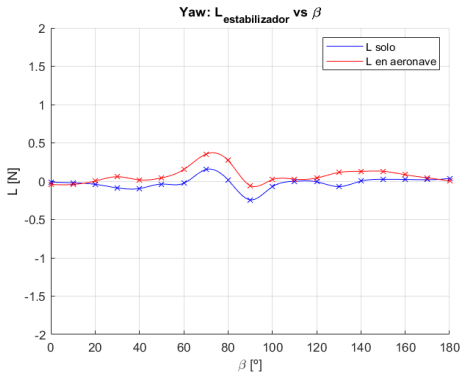
CFD Studies

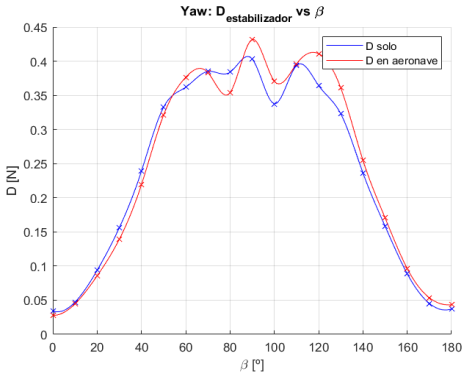
Complete Aircraft CFD Lateral

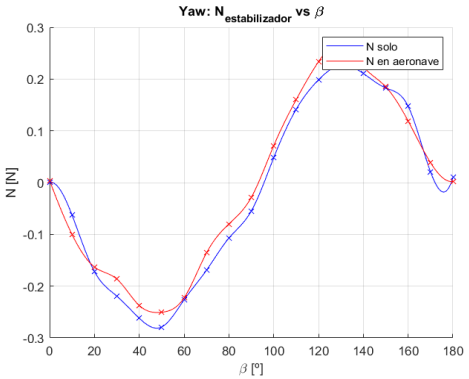


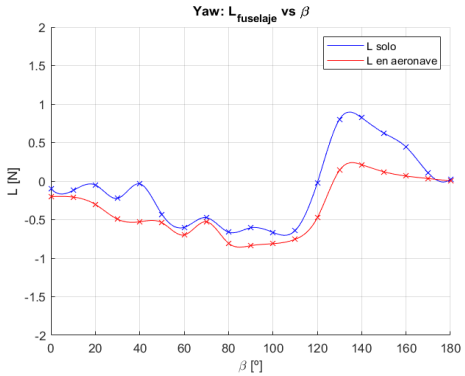


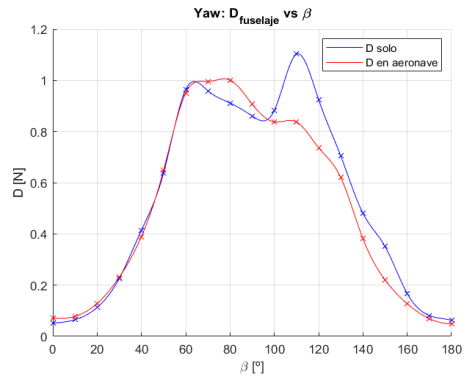


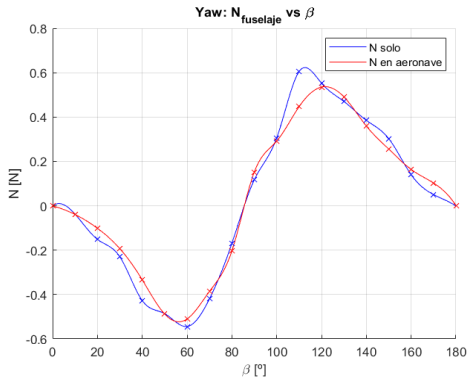






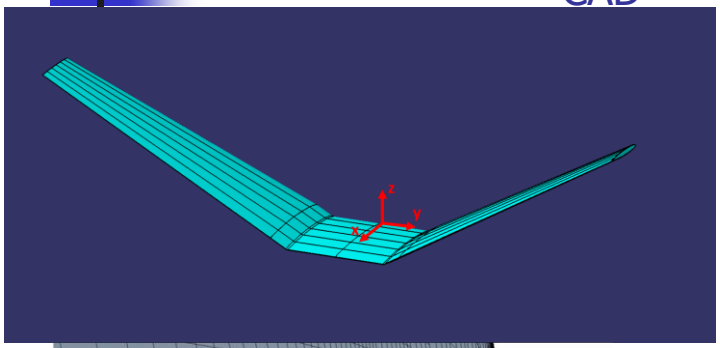


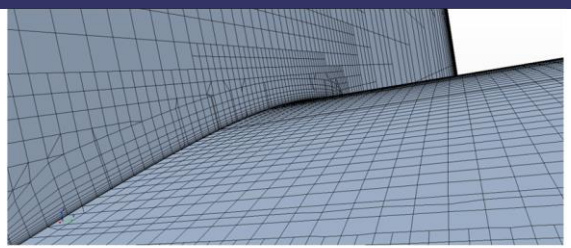


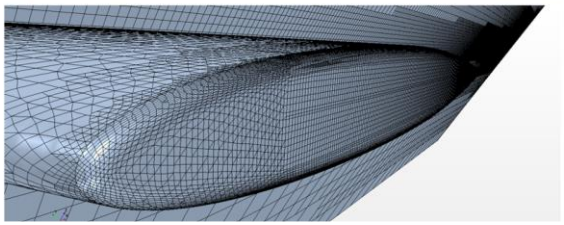


AERODYNAMIC Studies

CAD



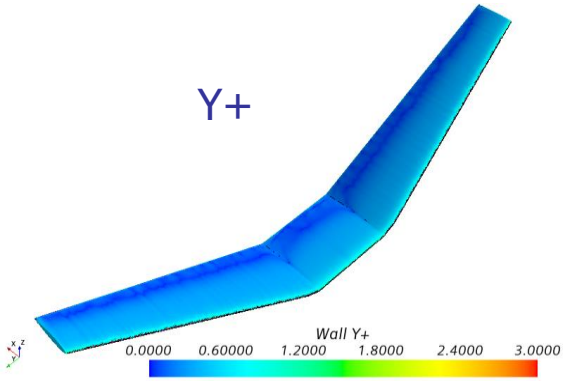


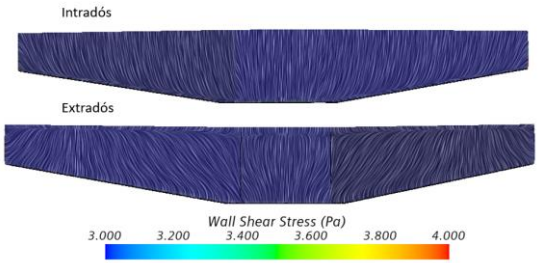


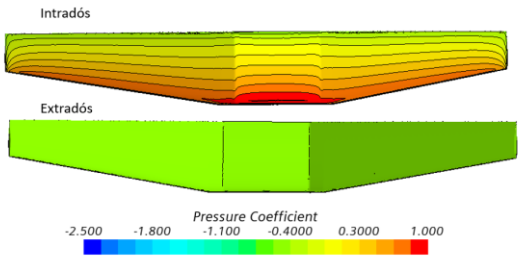
Mesh

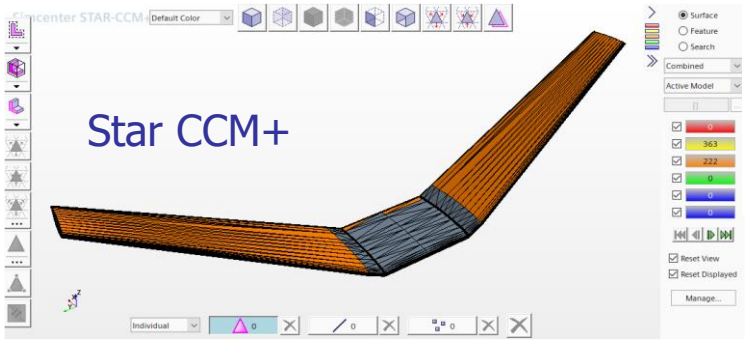
CFD Studies

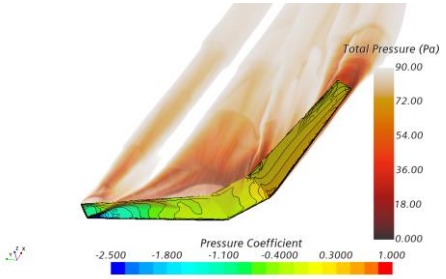
Y+

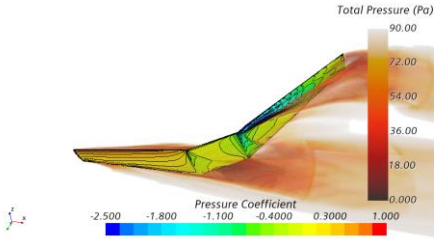








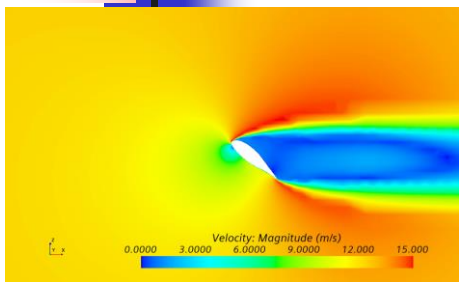


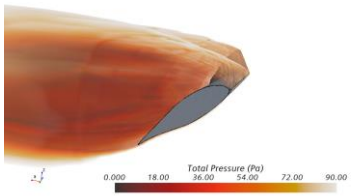


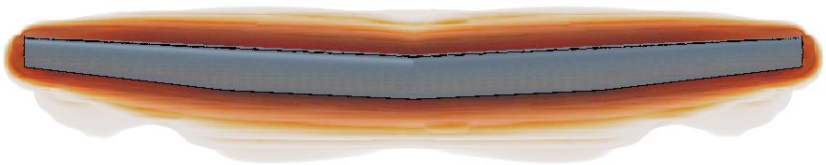
AERODYNAMIC Studies

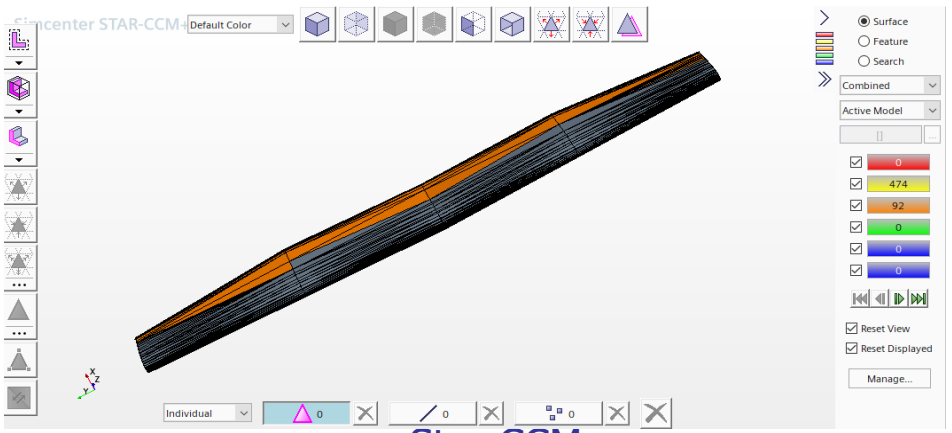
CFD Studies

Wing CFD Longitudinal & directional

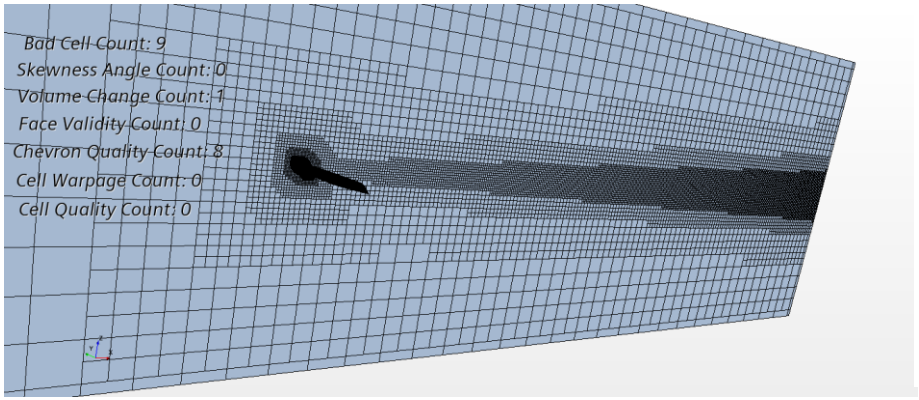




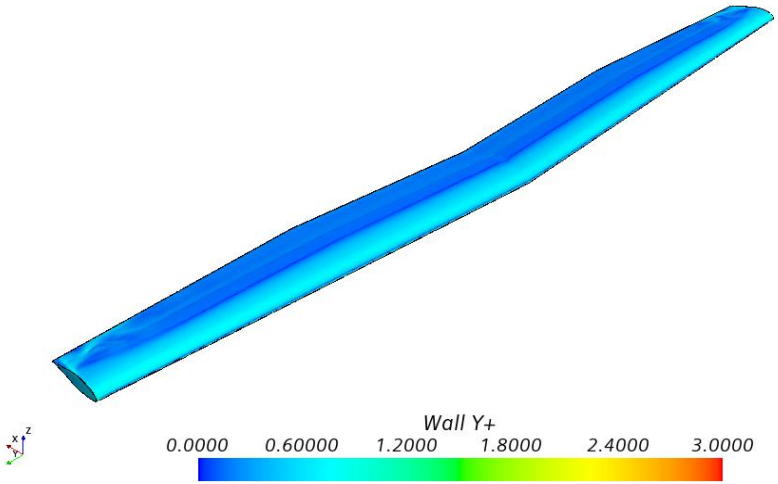




Star CCM+



Mesh

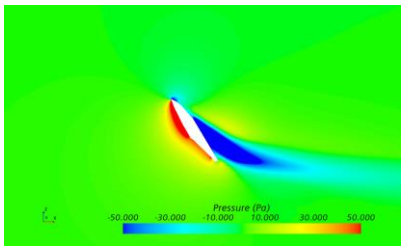


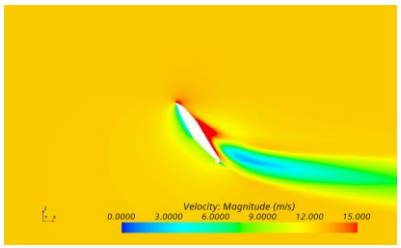
Y+

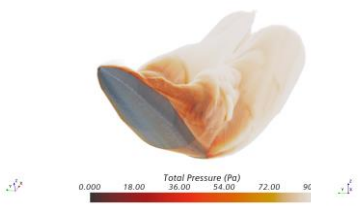
AERODYNAMIC Studies

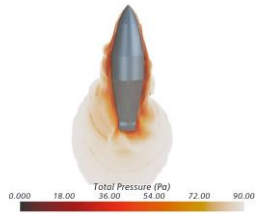
CFD Studies

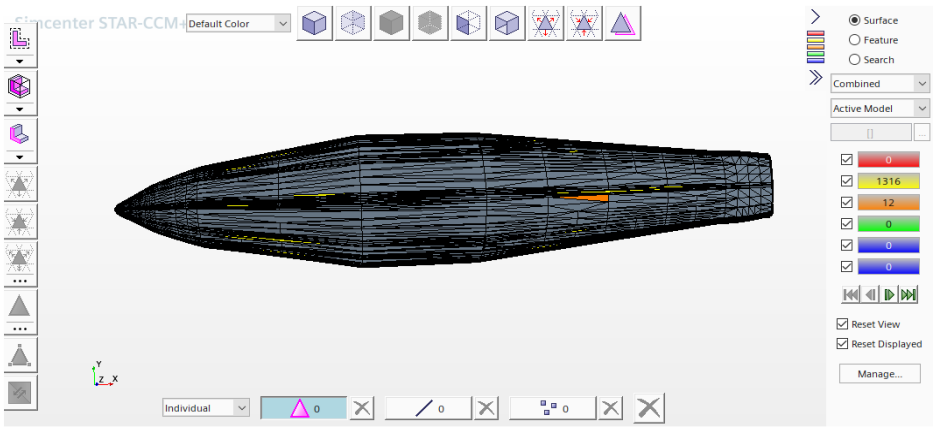
Fuselage CFD



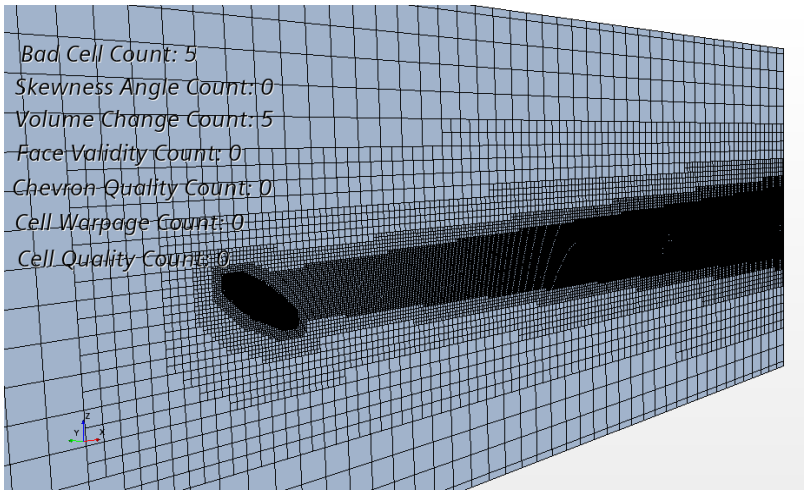




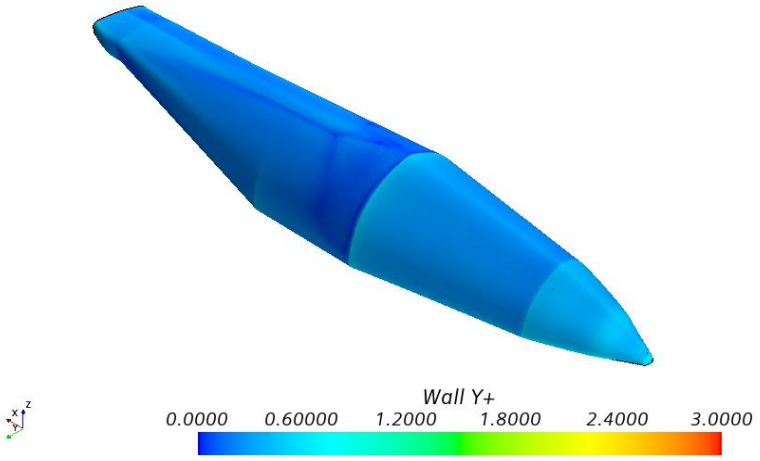




Star CCM+



Mesh

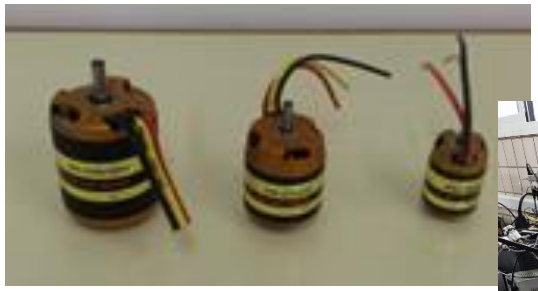


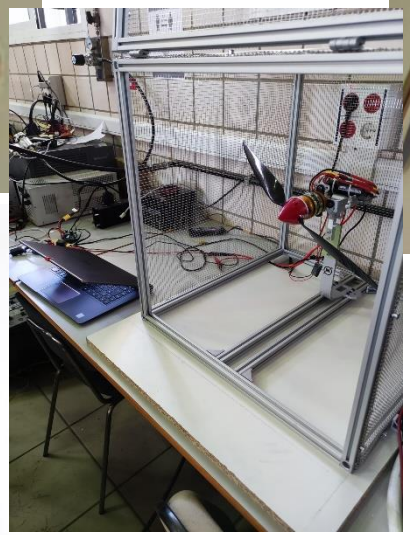
Y+

PROPULSIVE Studies

Wind Tunnel Experiments

- Objectives:
  - Propulsive Characterization over the entire flight envelope
  - Tilt-Rotor Propulsion sensitivity studies: fixed and variable pitch
    - Design and construction of a test-bench for prop-testing in wind tunnel
    - Several speeds (0-22 m/s)
    - Several blade pitch angles: 0,4,8,12, degrees:
    - Several tilt angles: 0,5,10,15,20, 30, 45, 60, 75, 90 degrees:

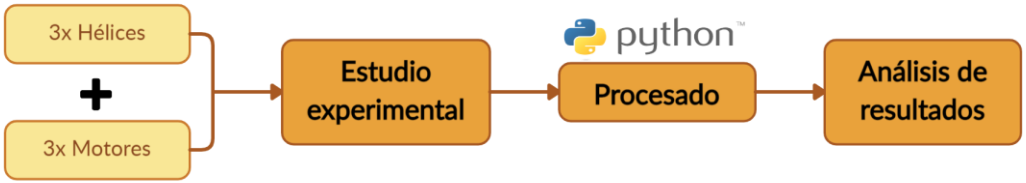


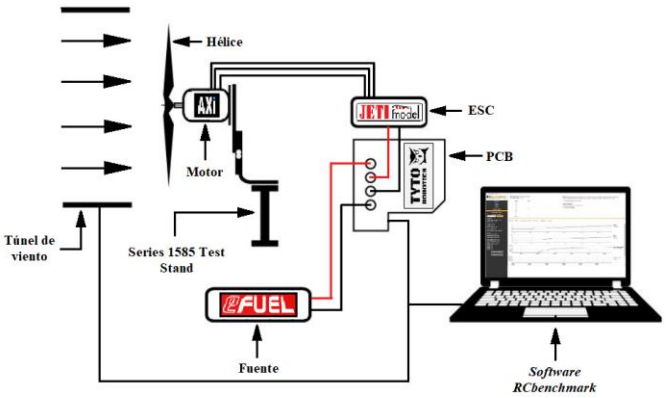


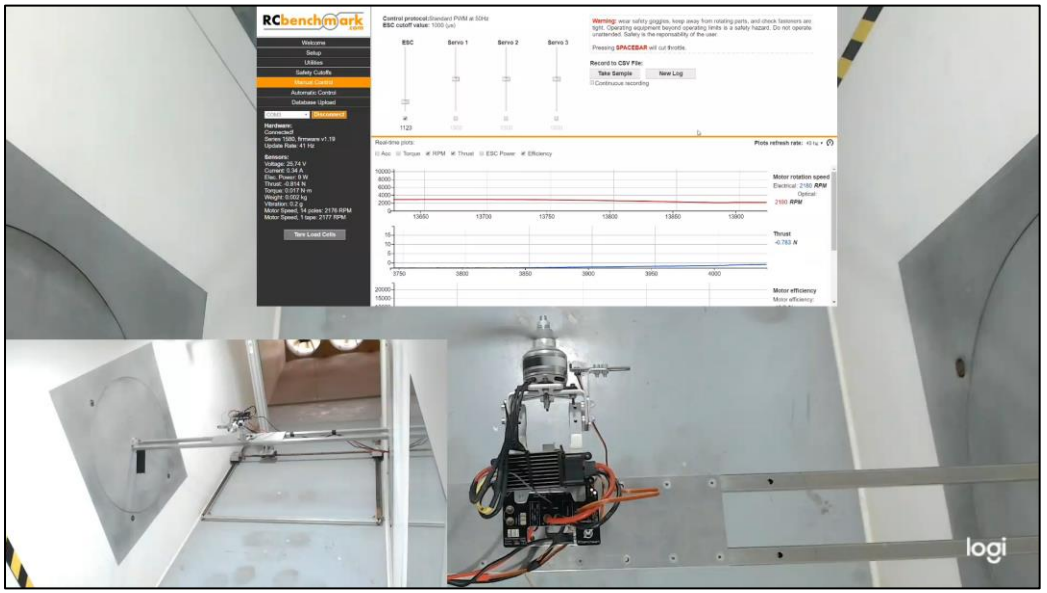
Commercial available test bench (RC Bench Mark Dynamometer Series 1580 & 1585)

PROPULSIVE Studies

Wind Tunnel Experiments

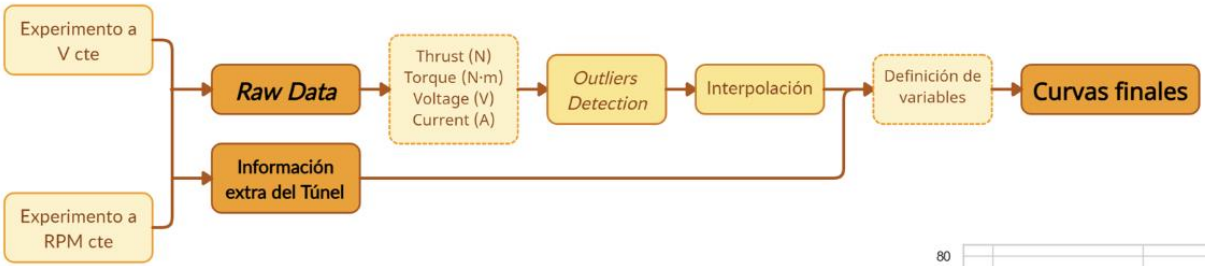






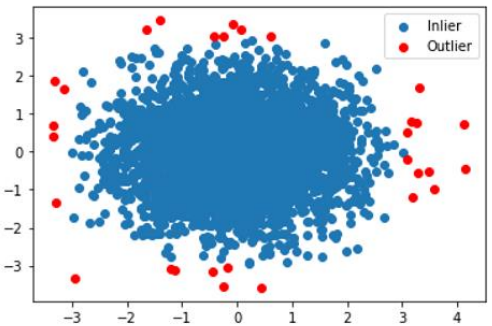
PROPULSIVE Studies

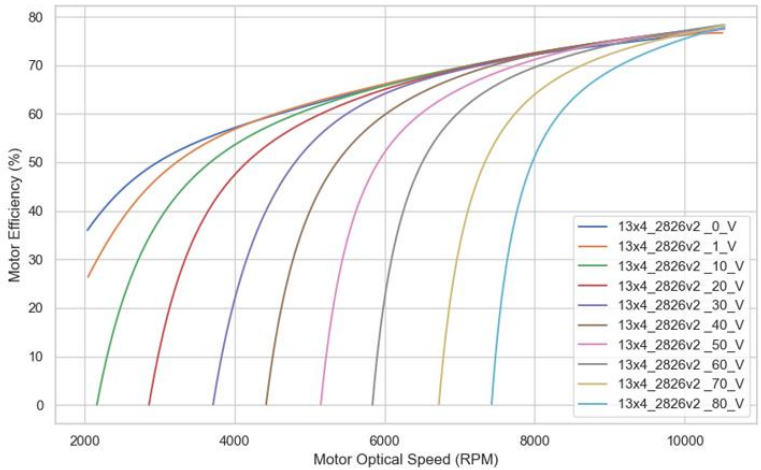
Wind Tunnel Experiments



python™

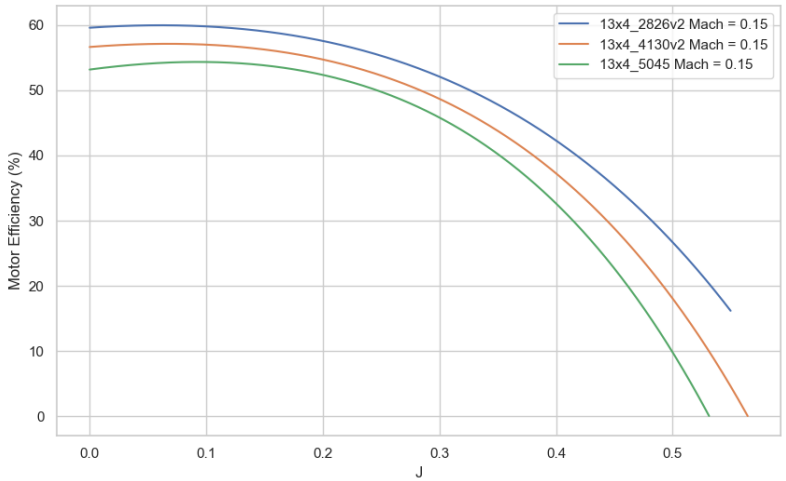
Elliptic Envelope

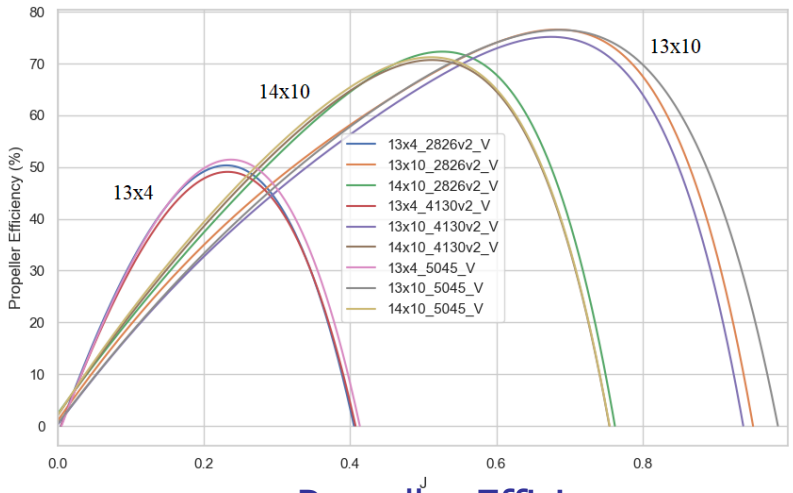




PROPULSIVE Studies

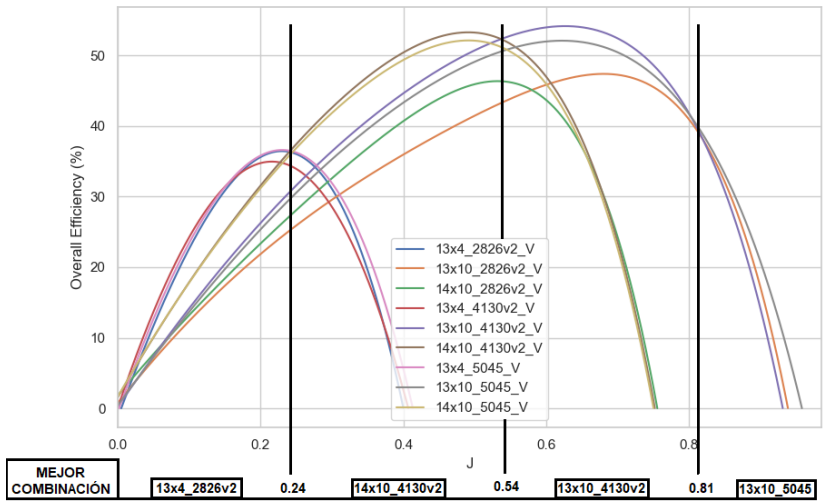
Motor Efficiency





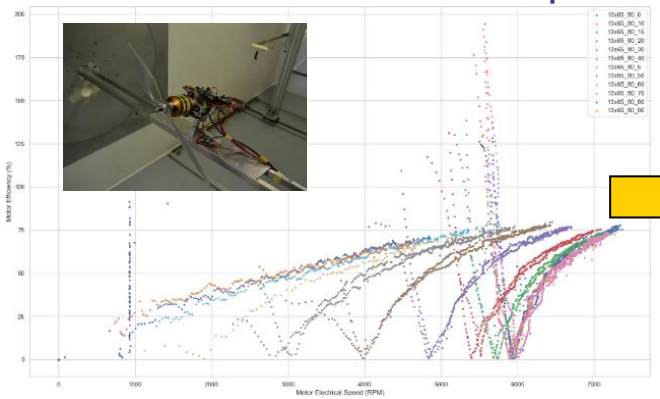
Propeller Efficiency

Overall Efficiency



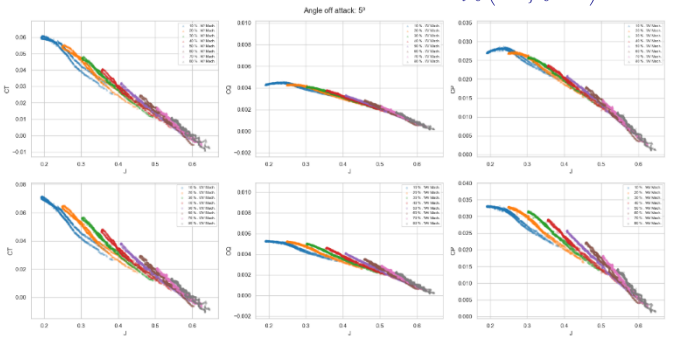
PROPULSIVE Studies

Wind Tunnel Experiments

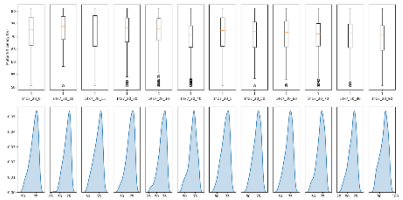


Regression Algorithms

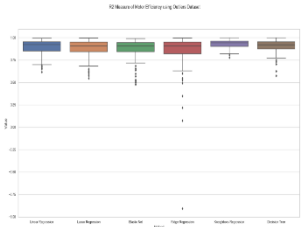
$$\sum_{i=0}^{N}\left(y_i - \sum_{j=0}^{M} x_{ij}W_j\right)^2$$



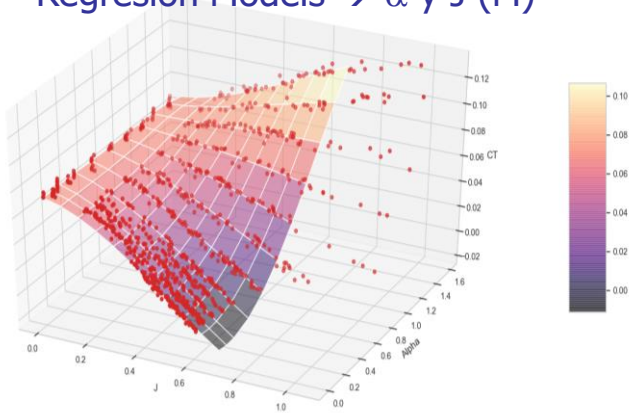
Detection of Outliers

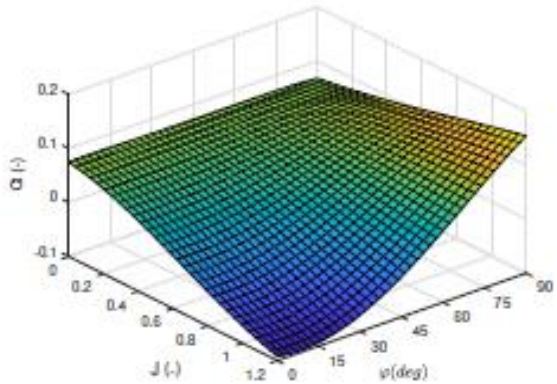


Metrics



Regresión Models → α y J (M)



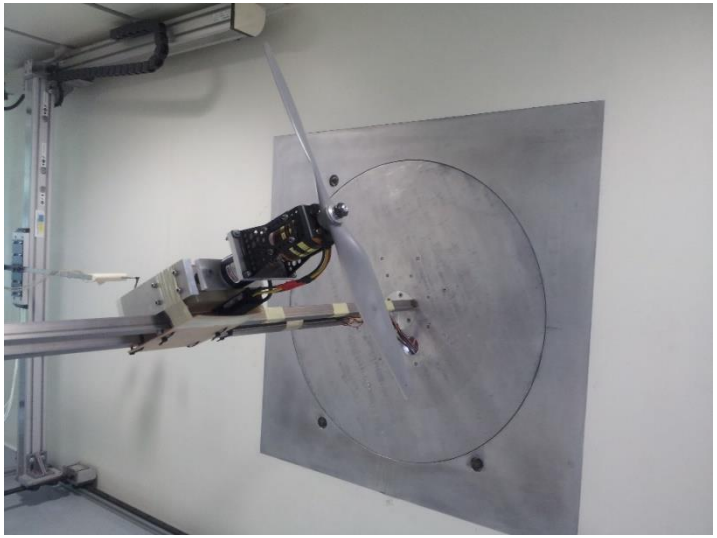


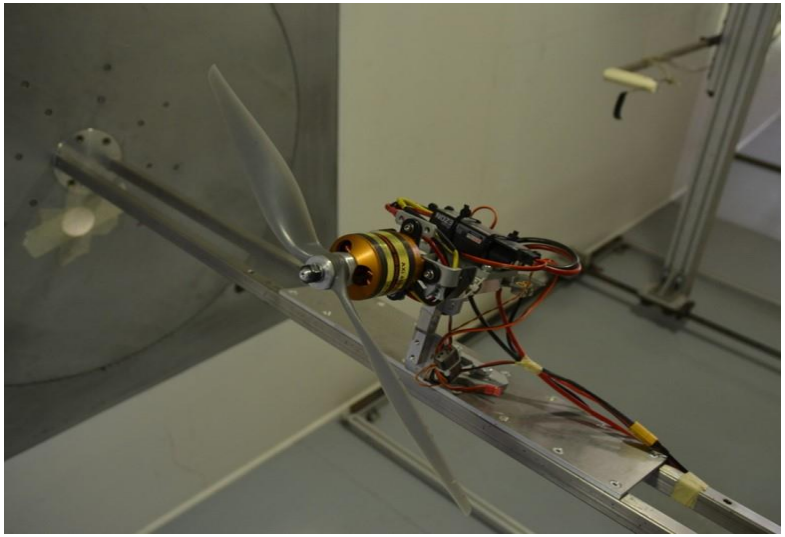
$$C_t(J,\varphi) = f(J,\varphi) = \sum_{i=0}^{4}\sum_{j=0}^{4} a_{ij}J^i\varphi^j$$

$$C_q(J,\varphi) = g(J,\varphi) = \sum_{i=0}^{4}\sum_{j=0}^{4} b_{ij}J^i\varphi^j$$

$$T = \rho_\infty n^2 D^4 C_t(J,\varphi); \qquad Q = \rho_\infty n^2 D^5 C_q(J,\varphi)$$

PROPULSIVE Studies



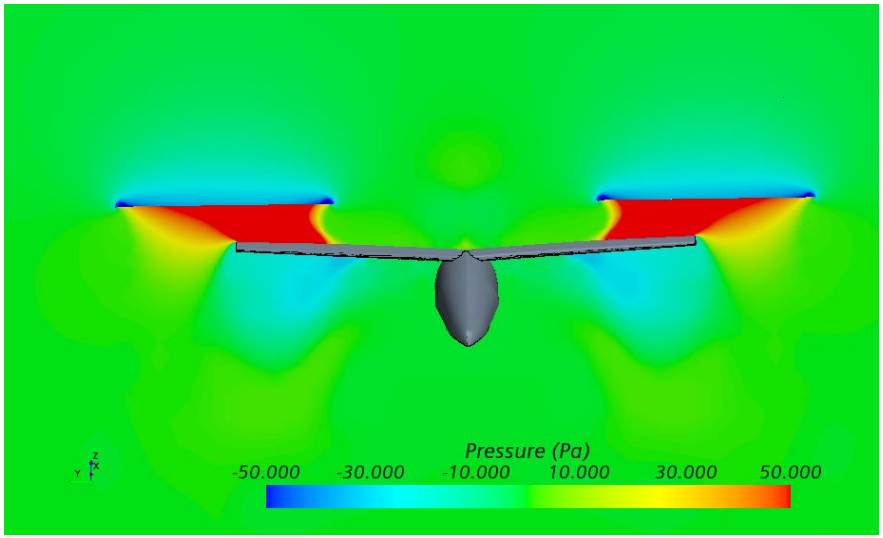


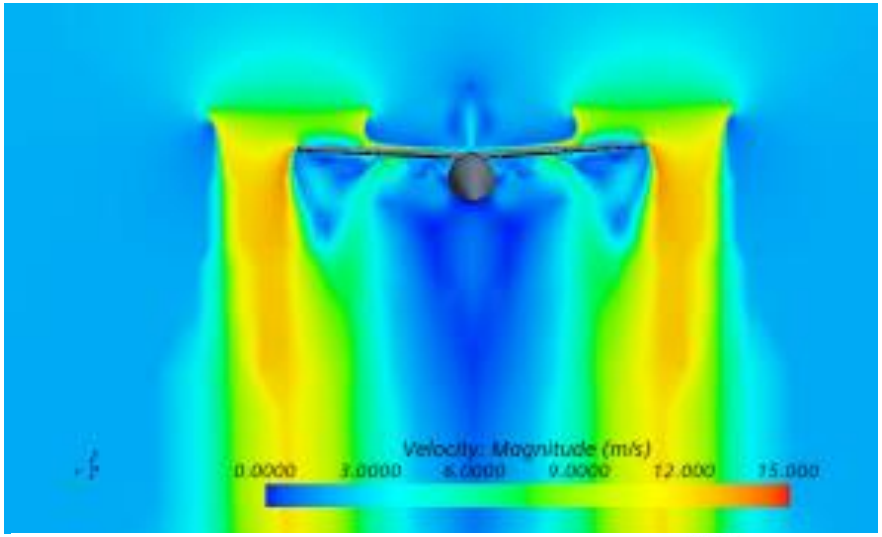
Wind Tunnel Experiments

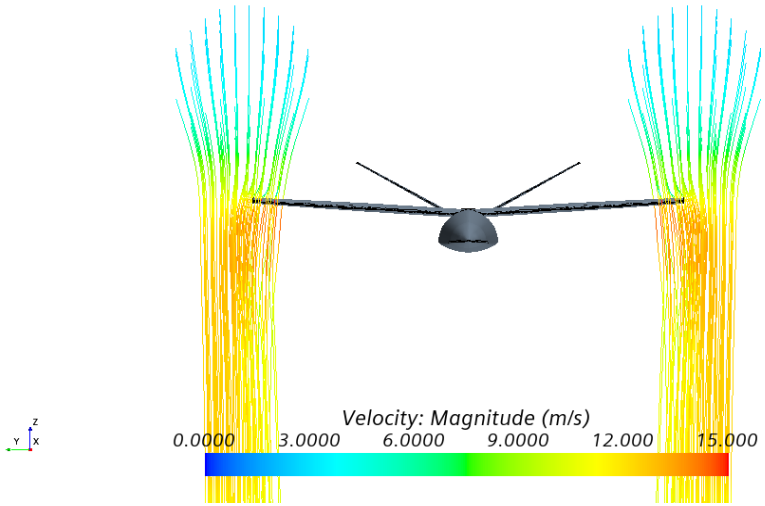
AERODYNAMIC Studies

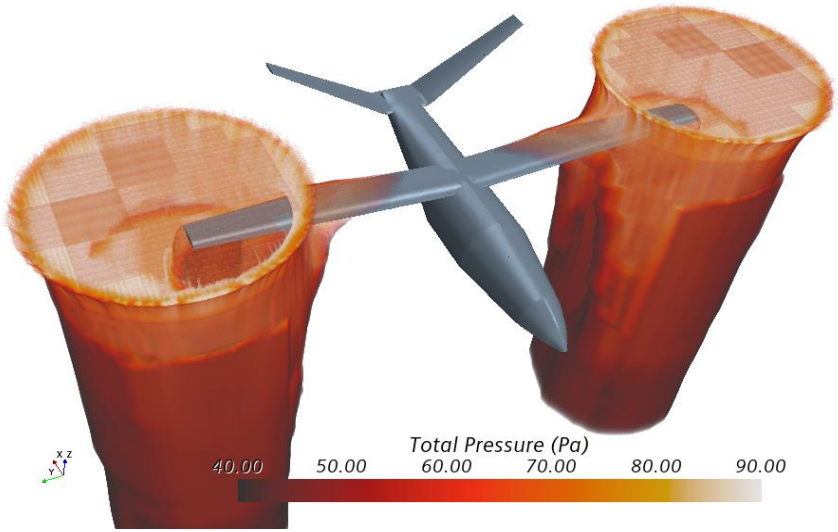
CFD Studies

Complete Aircraft CFD – Prop interaction – VTOL – Presure Flow rate curves

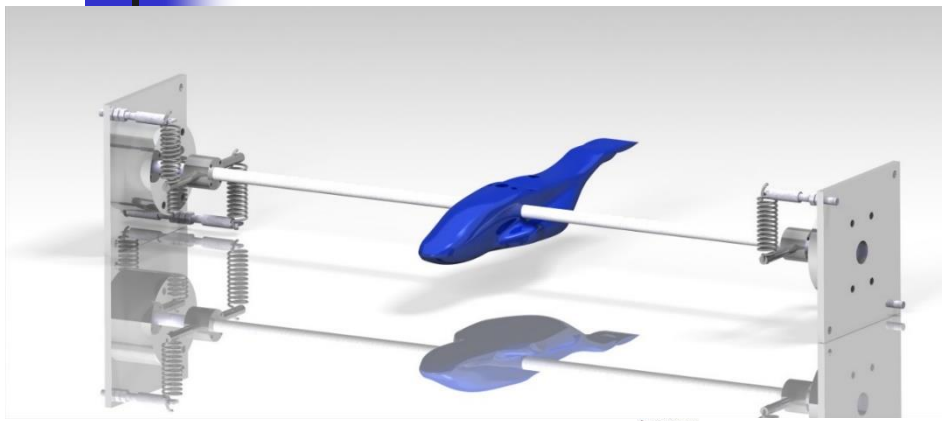


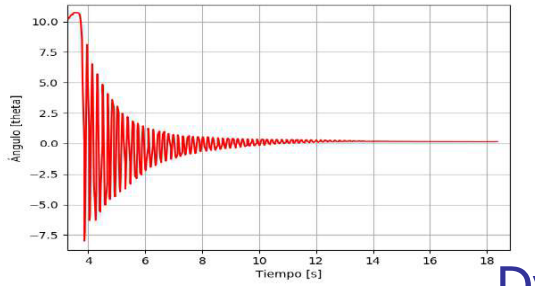


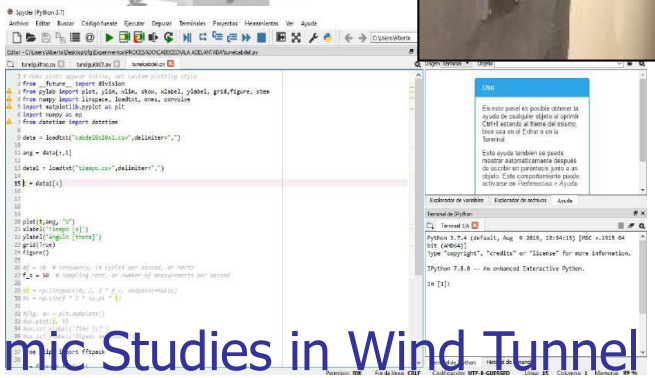


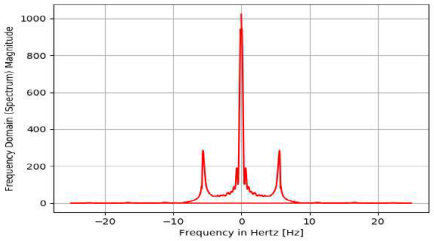


Flying Qualities Studies

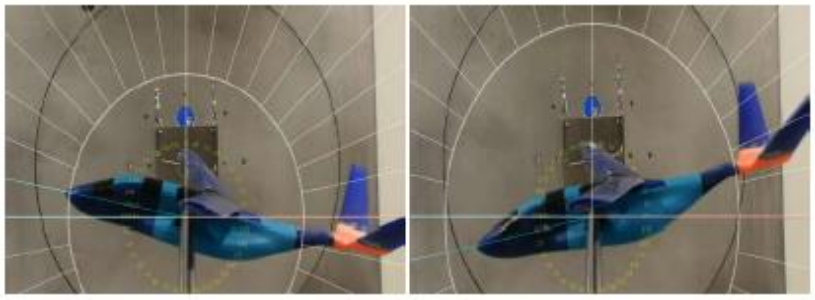




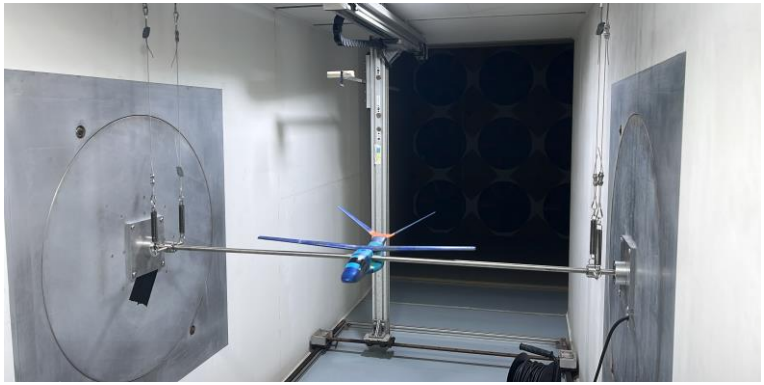


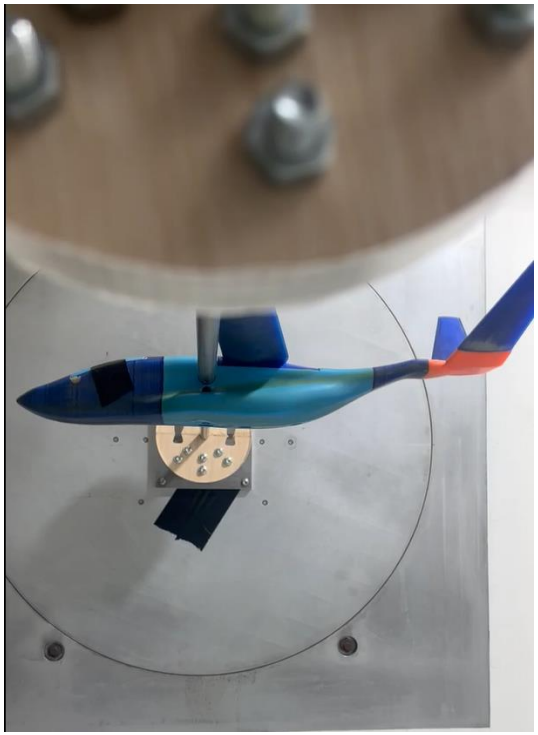


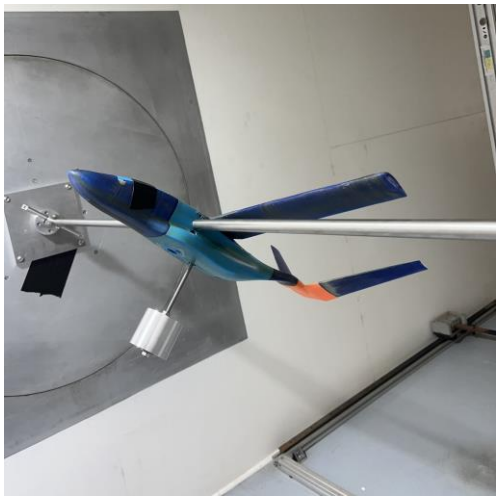
Dynamic Studies in Wind Tunnel

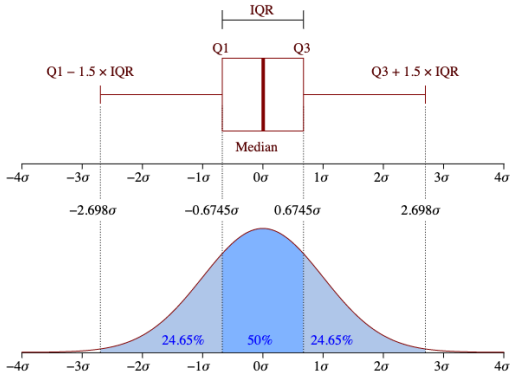


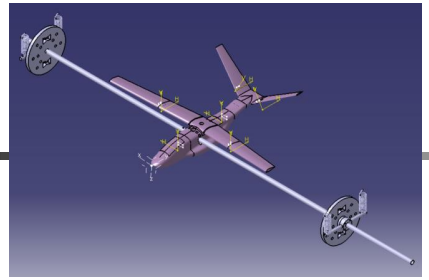
Flying Qualities Studies

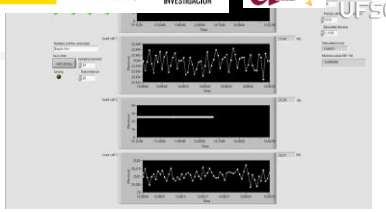












Selection of experiments to be analyzed.

Definition of test number, angles and tunnel powers

Angle, velocity and angular acceleration extraction from test files

Determination of the starting time of the test

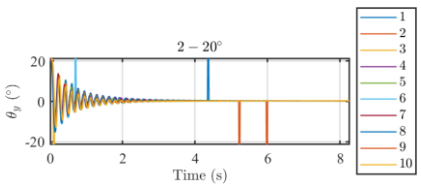
Elimination of possible peaks

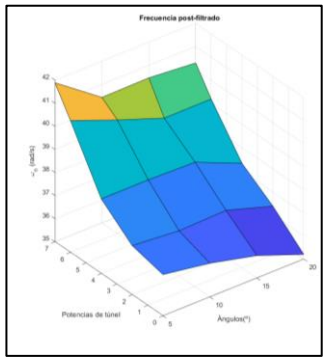
Fourier Transform

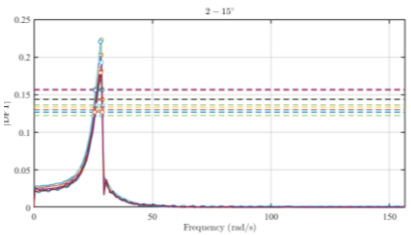
Calculation of natural frequency and damping

Recording of results in a table.

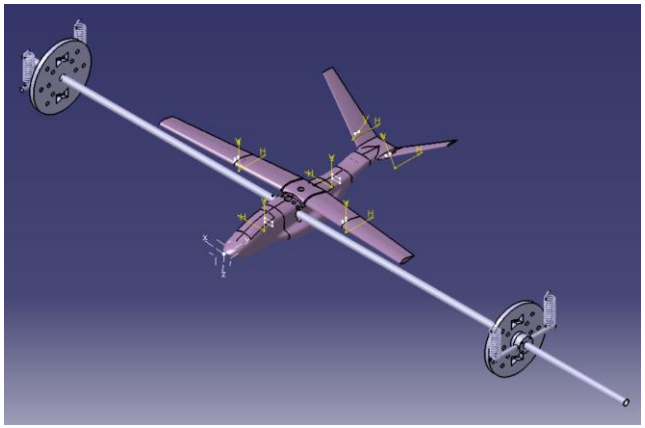
Filtering of results

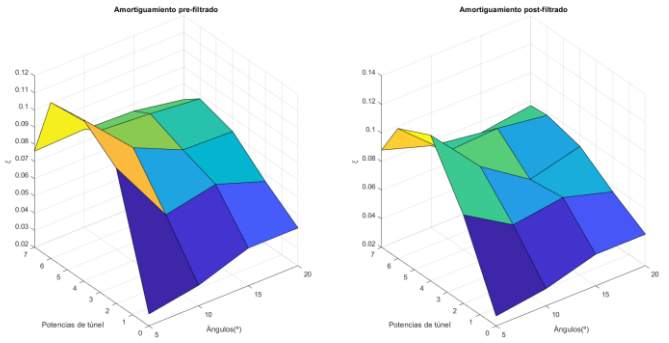




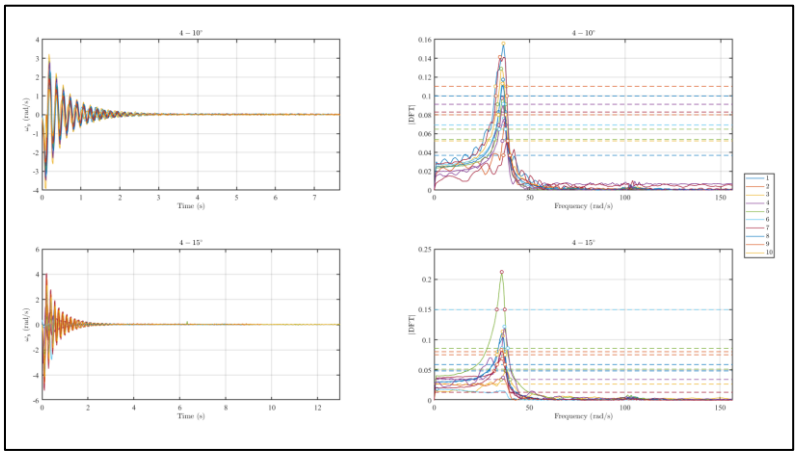


Flying Qualities Studies





		ξ pre-filtrado			ξ post-filtrado		
Potencia túnel	Ángulo (°)	μ	σ	CV	μ	σ	CV
0_{nt}	5	0.0386	0.0182	47.296 %	0.0247	0.0021	8.321 %
0_{nt}	10	0.0206	0.0032	15.437 %	0.0203	0.0033	16.136 %
0_{nt}	15	0.0224	0.0038	16.923 %	0.0224	0.0038	16.923 %
0_{nt}	20	0.0271	0.0076	28.048 %	0.0242	0.0038	15.938 %
0	5	0.0270	0.0023	8.588 %	0.0270	0.0023	8.588 %
0	10	0.0317	0.0036	11.295 %	0.0301	0.0031	10.204 %
0	15	0.0423	0.0083	19.560 %	0.0437	0.0073	16.787 %
0	20	0.0415	0.0036	8.591 %	0.0408	0.0027	6.686 %
2	5	0.0995	0.0429	43.158 %	0.0816	0.0235	28.833 %
2	10	0.0602	0.0083	13.762 %	0.0608	0.0085	14.018 %
2	15	0.0658	0.0146	22.173 %	0.0658	0.0146	22.173 %
2	20	0.0561	0.0065	11.564 %	0.0561	0.0065	11.564 %
4	5	0.1143	0.0418	36.578 %	0.1219	0.0299	24.500 %
4	10	0.0859	0.0200	23.309 %	0.0859	0.0200	23.309 %
4	15	0.0727	0.0209	28.685 %	0.0631	0.0046	7.321 %
4	20	0.0718	0.0098	13.657 %	0.0713	0.0056	7.838 %
6	5	0.1113	0.0256	22.981 %	0.1113	0.0256	22.981 %
6	10	0.0832	0.0099	11.870 %	0.0805	0.0056	6.981 %
6	15	0.0812	0.0069	8.524 %	0.0817	0.0038	4.705 %
6	20	0.0784	0.0121	15.435 %	0.0811	0.0092	11.339 %
7	5	0.0756	0.0391	51.700 %	0.0884	0.0084	9.459 %
7	10	0.0770	0.0096	12.465 %	0.0770	0.0096	12.465 %
7	15	0.0762	0.0146	19.211 %	0.0721	0.0076	10.509 %
7	20	0.0705	0.0208	29.445 %	0.0767	0.0077	10.076 %

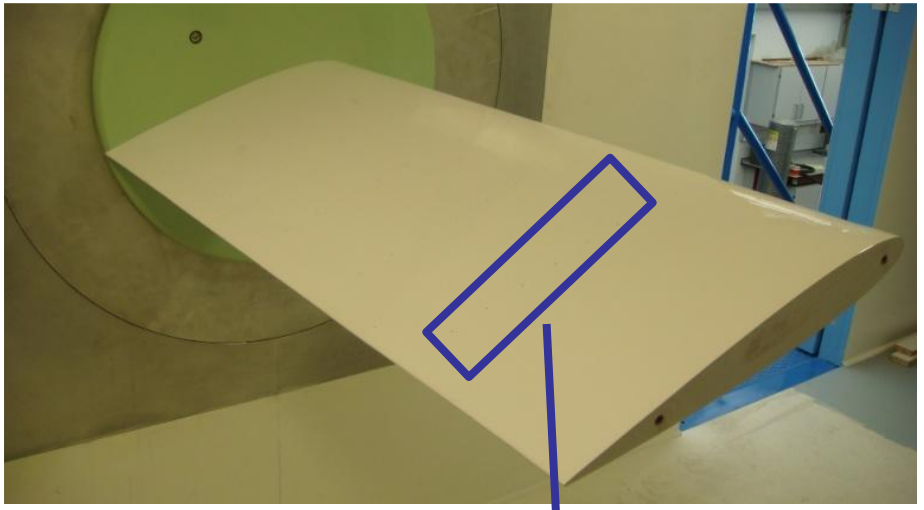


Introduction

- Wind tunnel
- Measuring equipment
- Processing Data
- Positioning equipment
- Manufacturing equipment
- **Project examples:**
  - ProVANt - EMERGENTIA
    - **Wind Tunel Experiments**
    - **Propulsive Experiments**
    - **CFD Validation**
  - **Straight and Sweept Wing**

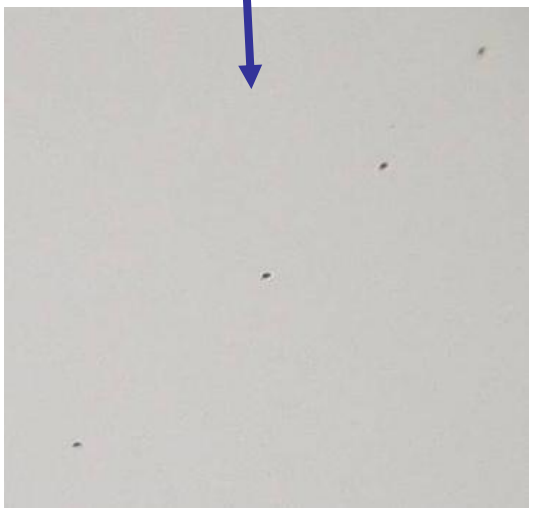
Straight Wing - I

- Finite wing
- Symmetrical profile NACA0012
- 5 rows of 12 pressure ports
- Measurements at various angles of attack
- Equipment: multimanometer, turntables



Mounted wing on windtunnel

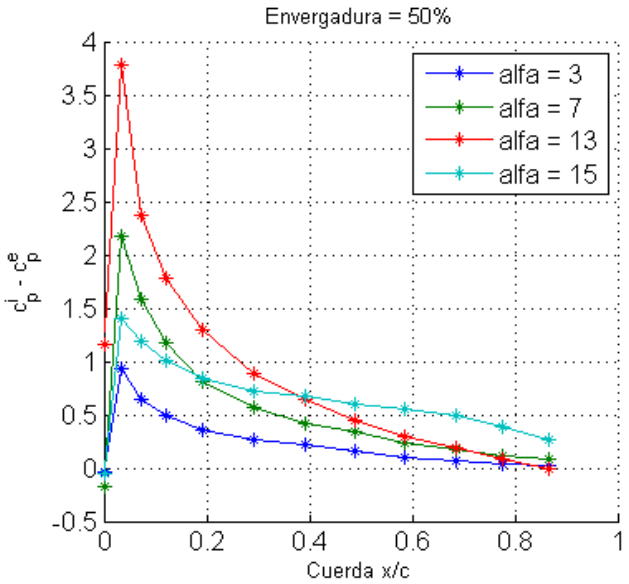
Manufacturing process

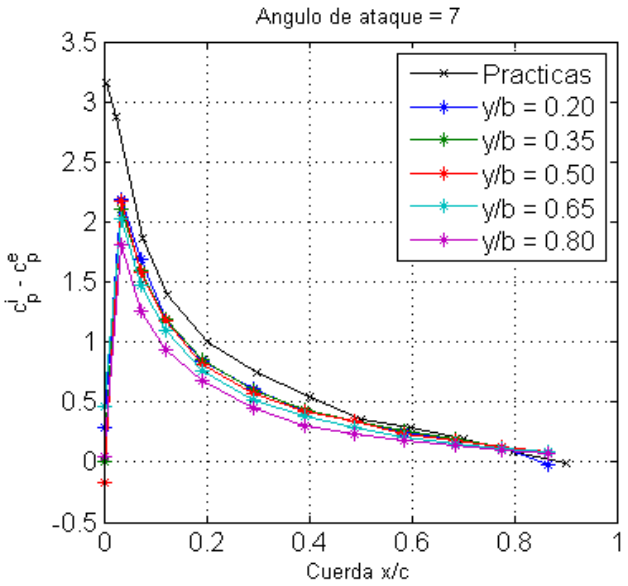


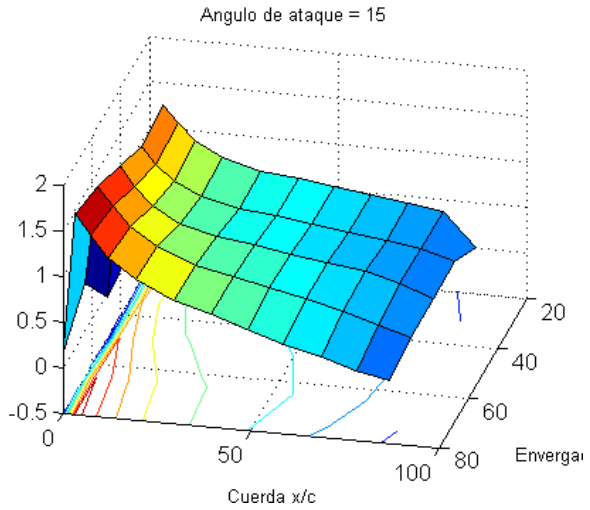
Pressure ports

Straight Wing - I

- Studies of how the pressure varies along the wingspan.
- cp and lift coefficient calculations
- Comparison with a boundary element code

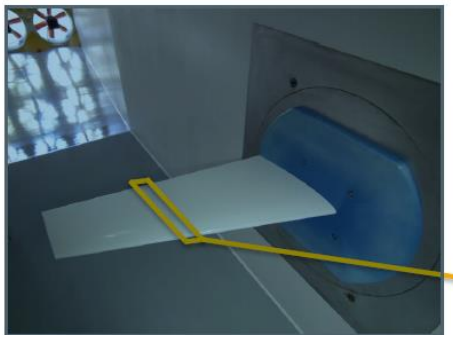




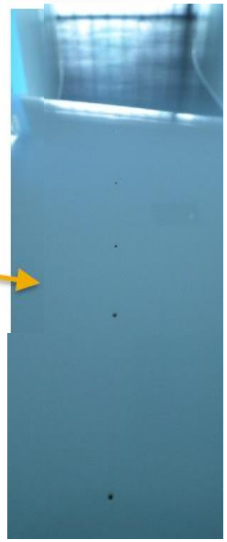


Sweept Wing - I

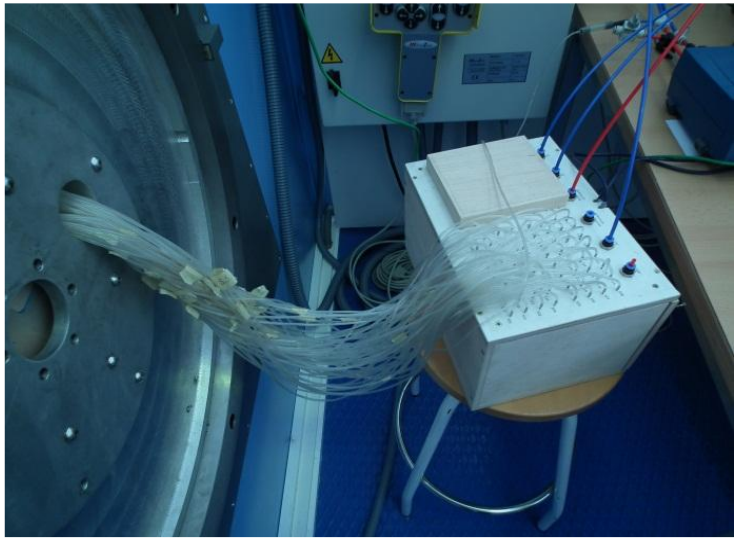
- Profile NACA0013
- 63 pressure taps
- Measurements at various angles of attack
- Equipment: multimanometer, turntables



Wing mounted on turnaround



Pressure ports

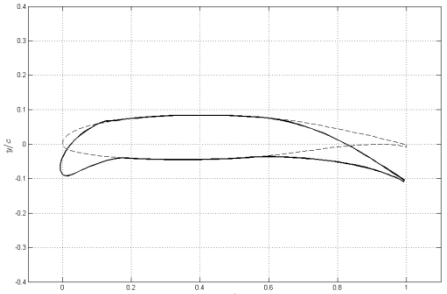


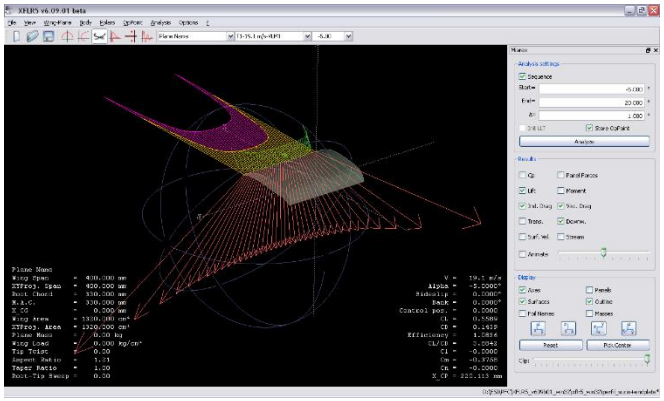
Junction box for pressure tapping

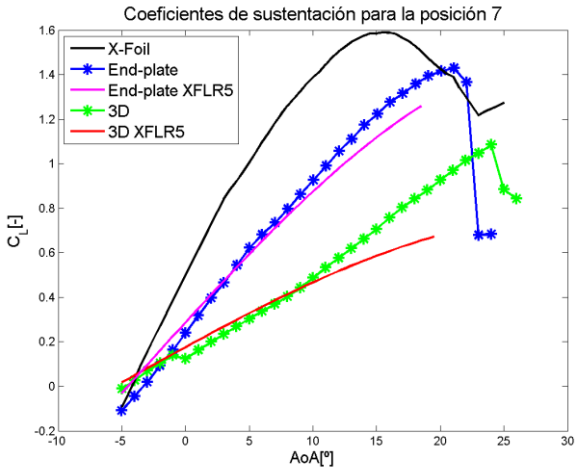
Control and measurement equipment

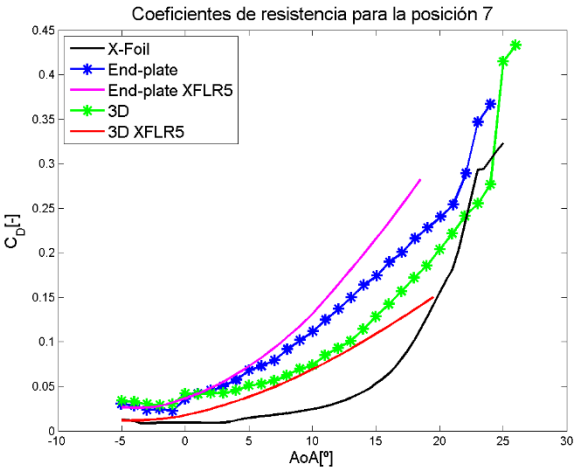
Wind Tunnel Aerodynamic Experiments

- Experimental Aerodynamic Study ofr Wing Morphing Wings
  - Experimental and theory comparison of wing morphing
  - Preliminary project previous to design and construction of wind tunnel setup for scaled UAVs





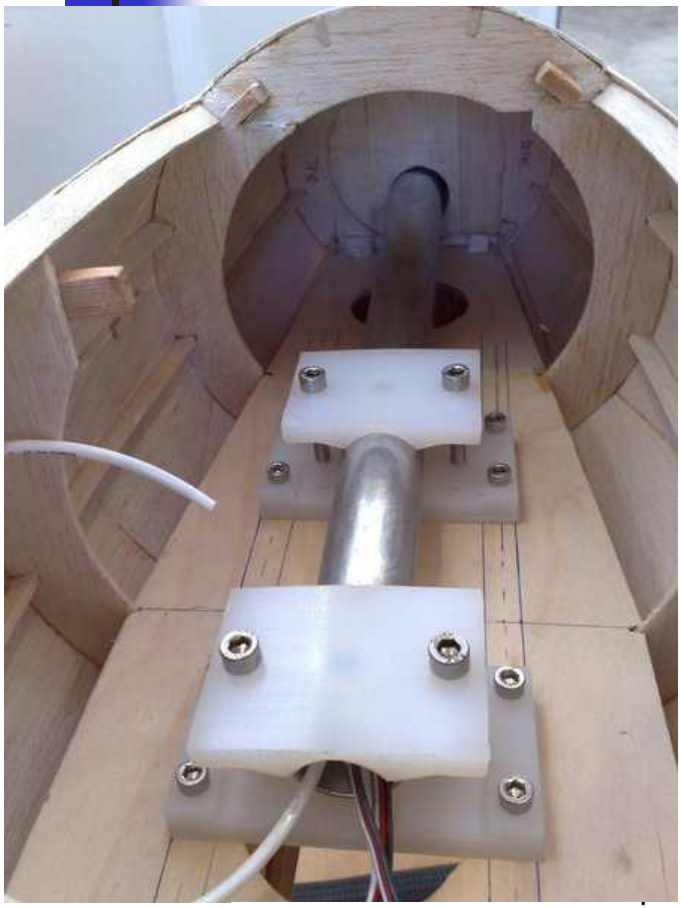


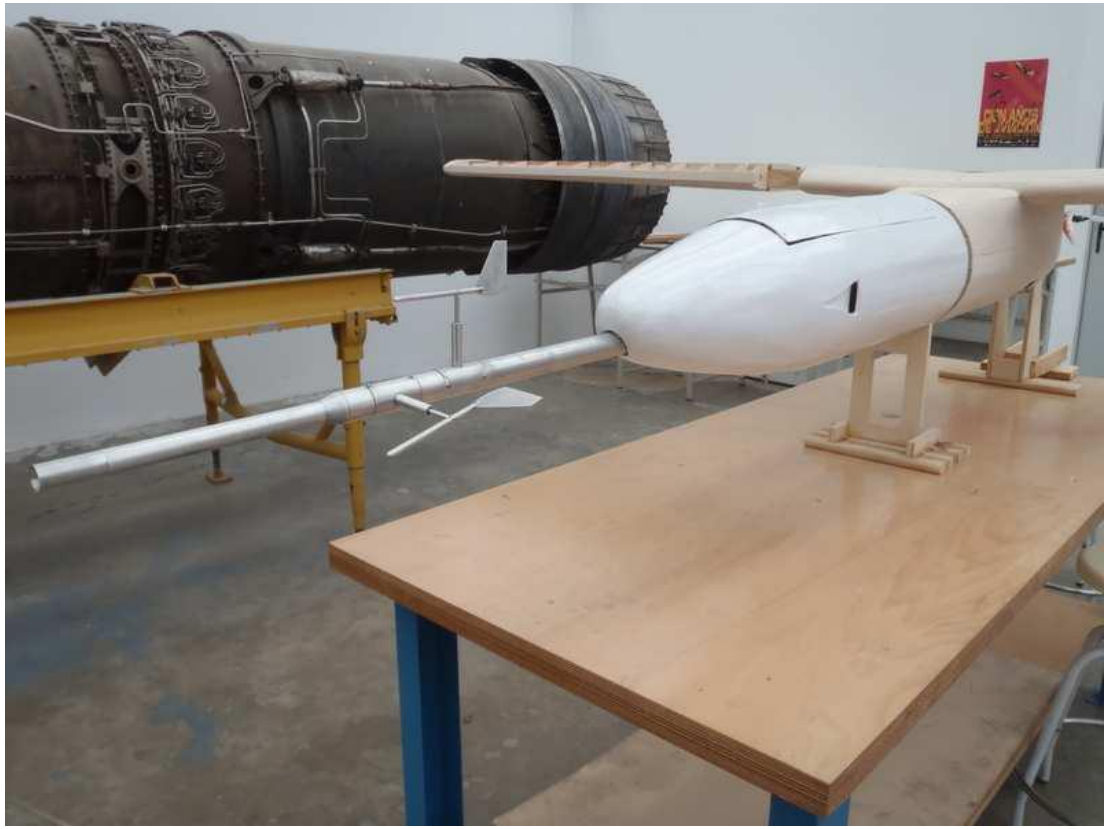


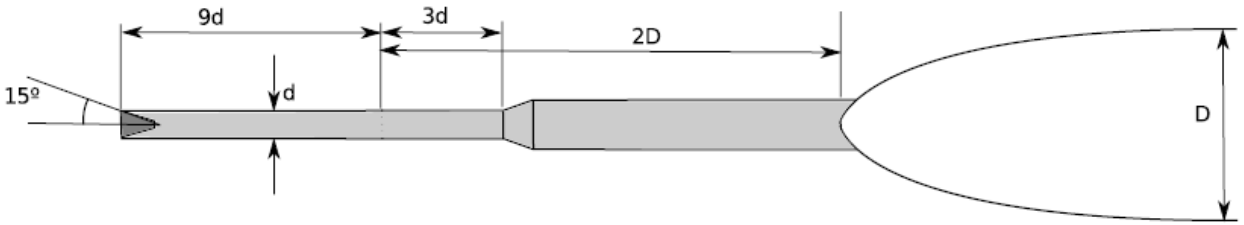
Aerodynamic Sensors - I

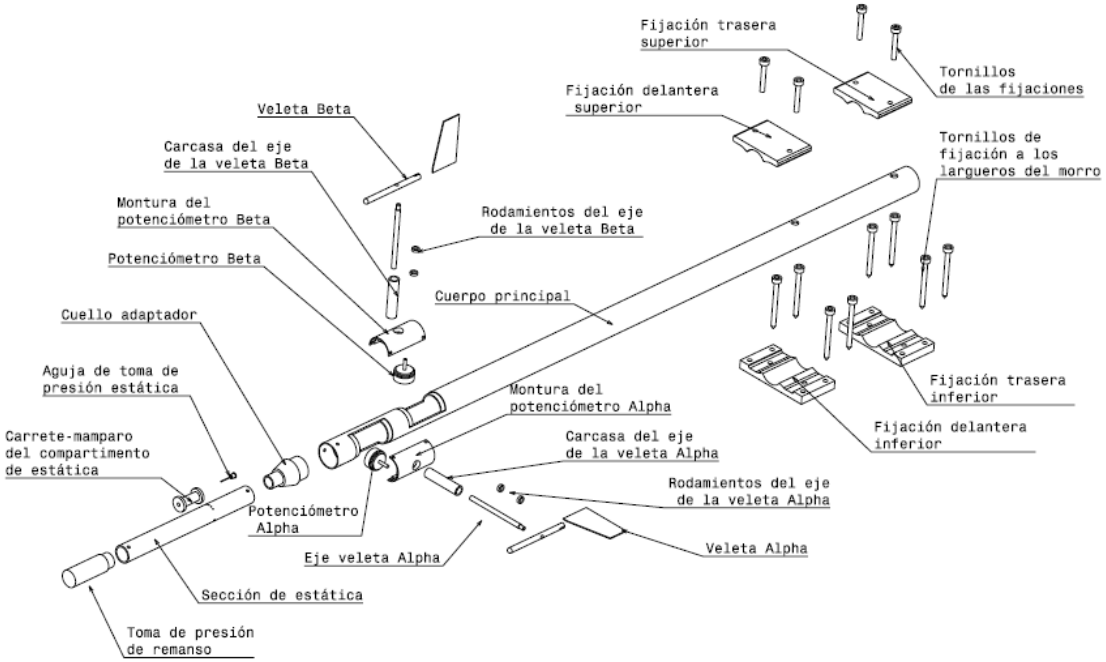
- Motivation:
  - To predict aircraft perfromance models $\Rightarrow$ meassure airspeed
  - Ensure Céfiro maintains flight envelope.
  - Use it as input $\Rightarrow$ control laws and navigation.
  - Elevated cost of commercial units (>10000€ high precision).
- Custom-made pitot-tube
  - Meassure:
    - Angle of attack (α), Side-slip (β), Temperature (T), Airspeed (V)
  - Follow literature guidelines to ensure propper design for Céfiro's nose fuselage geometry:
    - NACA TN-1367, 1957; NACA TN-4151, 1958, NACA RP-1046,1980
  - Pressure sensor
    - Increase the insensibility to 1% error in meassured pressure.
    - Design of static source
    - Design of total source
  - Aerodynamics Vanes for α and β meassuremts
    - Propper design to avoid floating angles
    - Reduce aerodynamic interference (custom-made for Céfiro's geometry)
  - Total Cost: under 400 €! $\Rightarrow$ entire anemoetry system designed and built by GIA.
  - Need to demonstrate high precision $\Rightarrow$ wind tunnel testing

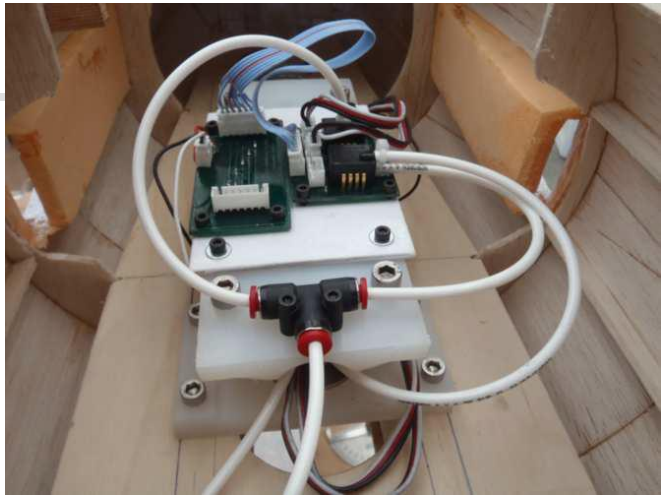
Aerodynamic Sensors - II

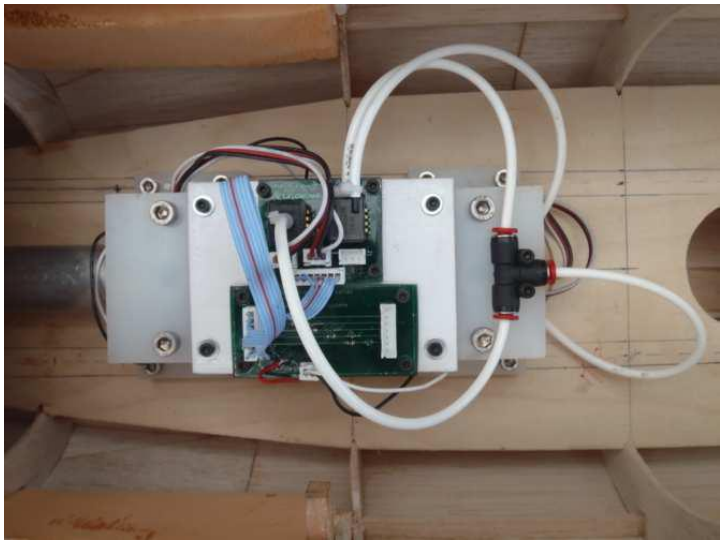


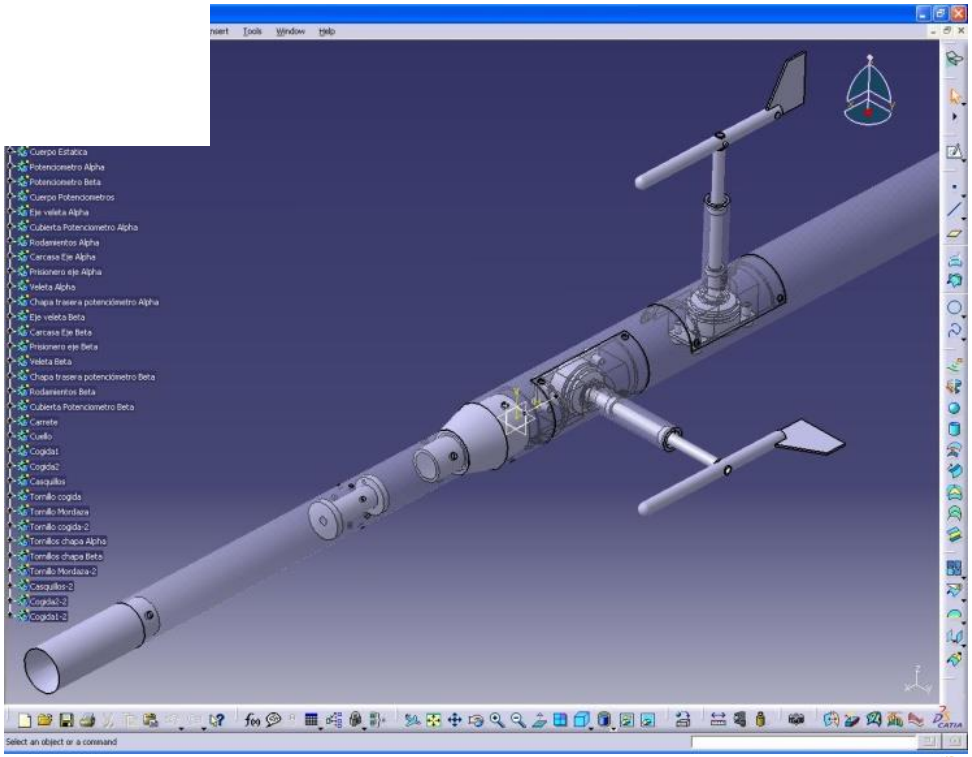





Fijación trasera superior
Tornillos de las fijaciones
Fijación delantera superior
Veleta Beta
Carcasa del eje de la veleta Beta
Tornillos de fijación a los largueros del morro
Montura del potenciómetro Beta
Rodamientos del eje de la veleta Beta
Potenciómetro Beta
Cuerpo principal
Cuello adaptador
Aguja de toma de presión estática
Fijación trasera inferior
Montura del potenciómetro Alpha
Fijación delantera inferior
Carrete-mamparo del compartimento de estática
Carcasa del eje de la veleta Alpha
Rodamientos del eje de la veleta Alpha
Potenciómetro Alpha
Veleta Alpha
Eje veleta Alpha
Sección de estática
Toma de presión de remanso

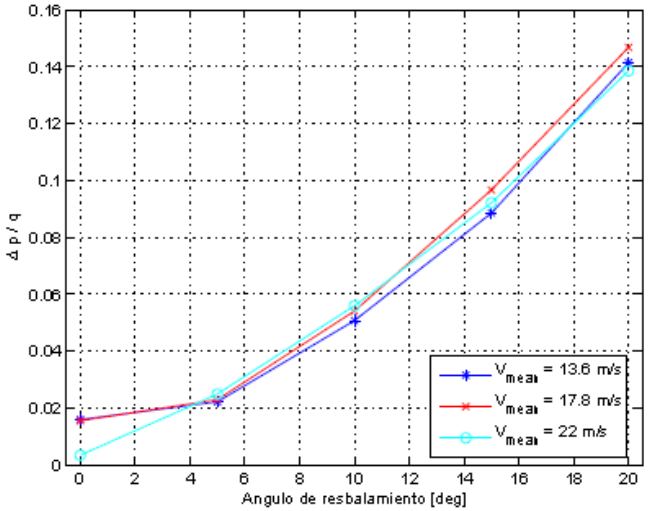


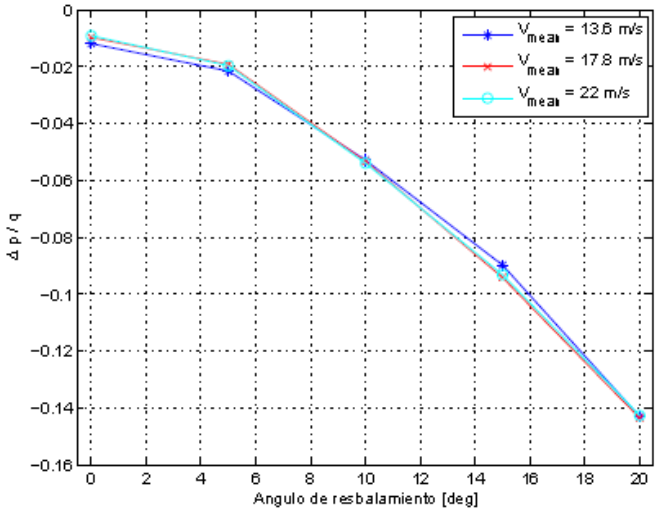



Cuerpo Estática
Potenciometro Alpha
Potenciometro Beta
Cuerpo Potenciometros
Eje veleta Alpha
Cubierta Potenciometro Alpha
Rodamientos Alpha
Carcasa Eje Alpha
Prisionero eje Alpha
Veleta Alpha
Chapa trasera potenciómetro Alpha
Eje veleta Beta
Carcasa Eje Beta
Prisionero eje Beta
Veleta Beta
Chapa trasera potenciómetro Beta
Rodamientos Beta
Cubierta Potenciometro Beta
Carrete
Cuello
Cogida1
Cogida2
Casquillos
Tornillo cogida
Tornillo Mordaza
Tornillo cogida-2
Tornillos chapa Alpha
Tornillos chapa Beta
Tornillo Mordaza-2
Casquillos-2
Cogida2-2
Cogida1-2

Wind Tunnel Measured error α and β

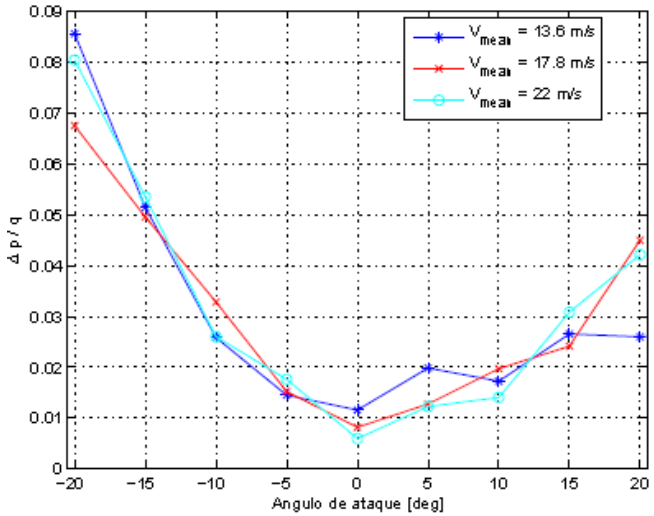
Angle of attack sensitivity (α)

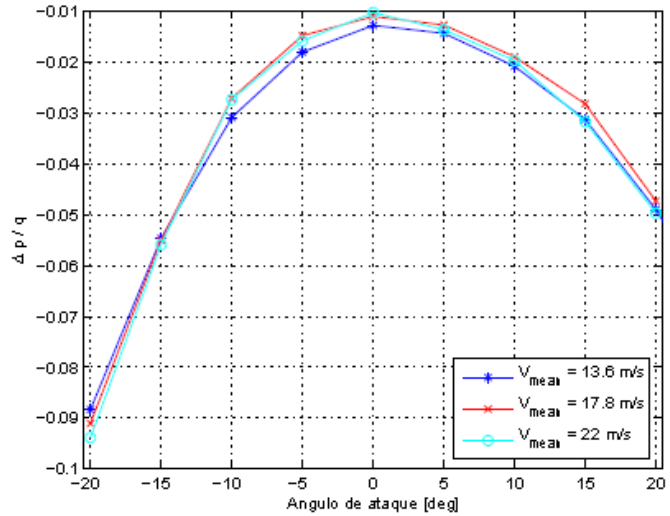




Dynamic Pressure

Static Pressure





Side-slip sensitivity (β)