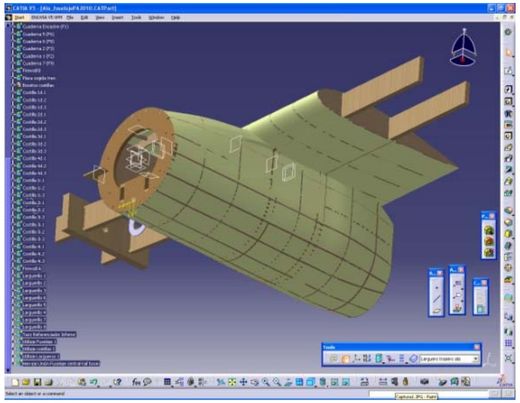

Céfiro
Prototype II
3DM-GX1
MicroStrain

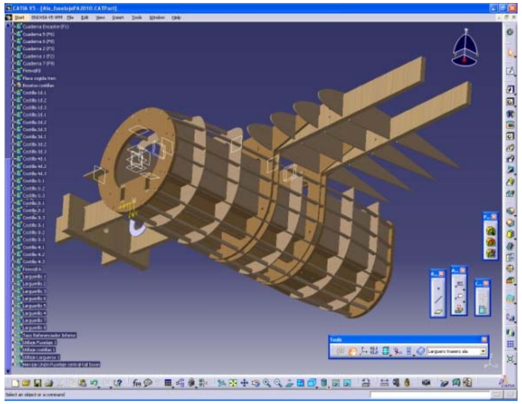
Céfiro II - Requirements

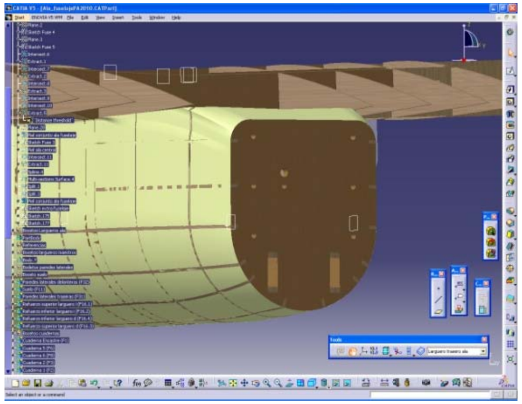
- Once validated the design $\Rightarrow$ Modifications such that permits to accomplish goals of the GIA Group:
  - Automatic flight control
  - Trajectory optimization.
  - Air Trafic Management.
  - Aircraft dynamics and engine performance modeling.
- Improvements on the 2nd prototype:
  - Design Improvements
  - Electric propulsion system.
  - Advanced Aircraft Modelling.
  - Aerodynamic Sensors.
  - Flight Computer Systems.
  - Flight Control Strategies & Navigation control strategies.

Design Improvements

- Weight Reduction.
- Imrpoved construction techniques.
- Introduction of newer materials (fiberglass).
- Better aerodynamics signature (fairings,wingtips)










Electric Propulsion System

- Electric propulsion allows:
  - Easier propulsion modelling.
  - Easier performance anaysis ⇒ wind tunnel
  - Vibrations reduction.
  - Greener design ⇒ batteries.
- Engine Selection:
  - Brushless Engine
  - Power requirements ~3000 W
    - AXI 5345/ 16
    - Variador Spin99
  - Lithium iron phosphate ($LiFePO_4$) battery (Li-Fe)

- Study of Engine Performance:
  - Generation of theoretic models
  - Design and construction of test-bench
  - Creation of experimental Models ⇒ wind tunnel
    - Torque (δ, RPM)
    - Thrust (δ, RPM)
    - RPM

Theoretic Models

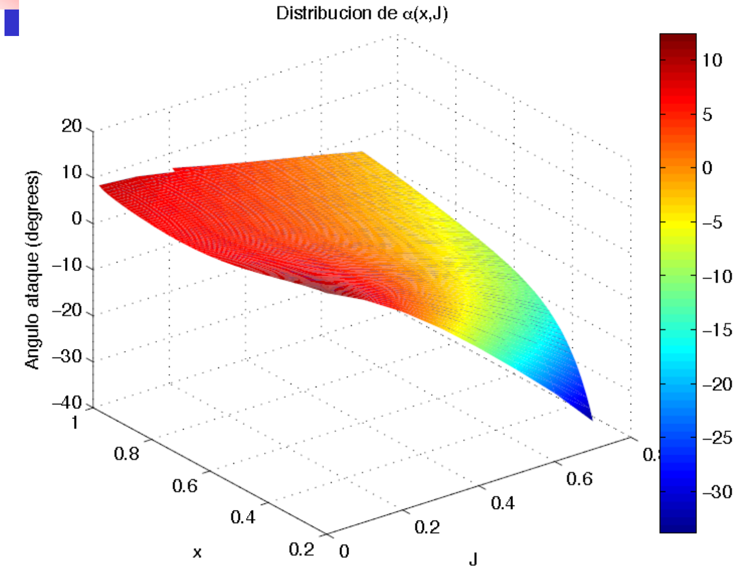


Figura 49 Distribución del ángulo de ataque (x,J)

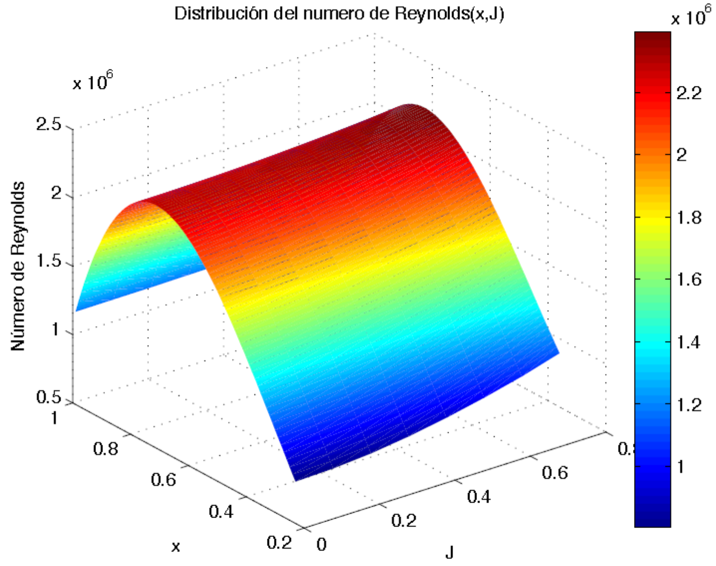


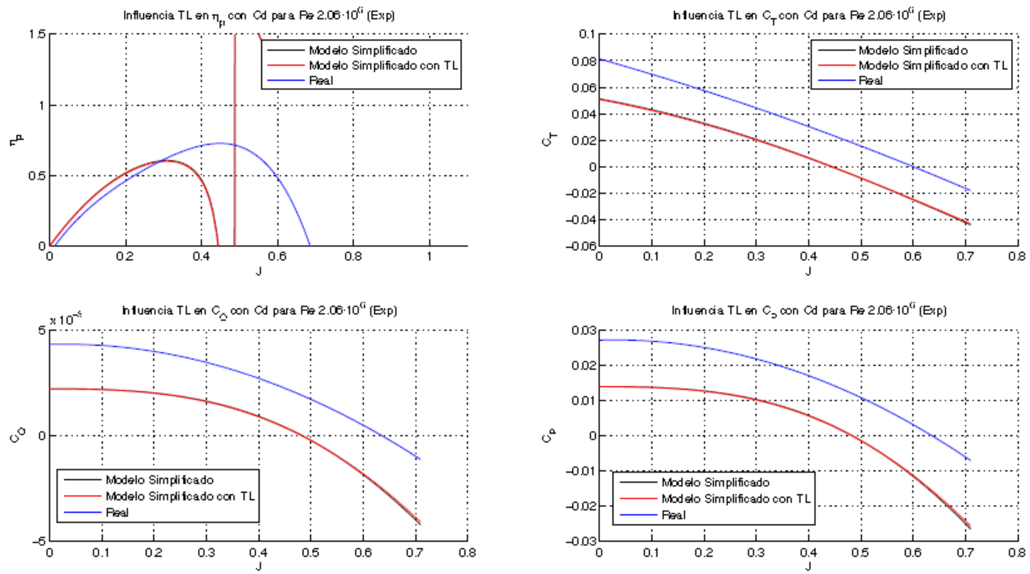
Figura 52 Distribución número de Reynolds (x,J)

$$C_T = \int_0^1 \frac{1}{2}\sigma(x)\sqrt{x^2 + \left(\lambda_c + \lambda_i(x)\right)^2}\left(C_{l_\alpha}\alpha(x)x^2 - \left(\lambda_c + \lambda_i(x)\right)C_d(x)\right)dx$$

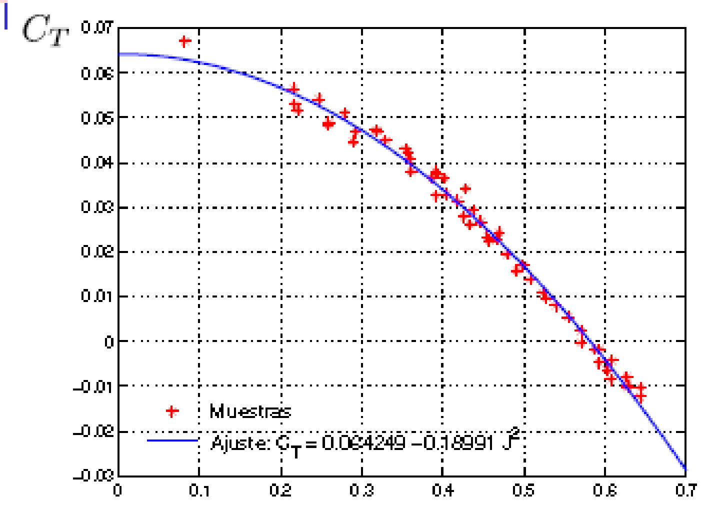
$$C_P = \int_0^1 \frac{1}{2}\sigma(x)\sqrt{x^2 + \left(\lambda_c + \lambda_i(x)\right)^2}\left(C_l\left(\lambda_c + \lambda_i(x)\right)x + C_d(x)x^2\right)dx$$

$$C_l(x) = C_{l_\alpha}(\alpha - \alpha_0) = C_{l_\alpha}\left(\theta - arctan\left(\frac{\lambda}{x}\right) - \alpha_0\right)$$

$$C_d(x) = \delta_0 + \delta_1\alpha + \delta_2\alpha^2 + \delta_4\alpha^3 + \delta_4\alpha^4$$



Wind Tunnel Engine Experiments - I



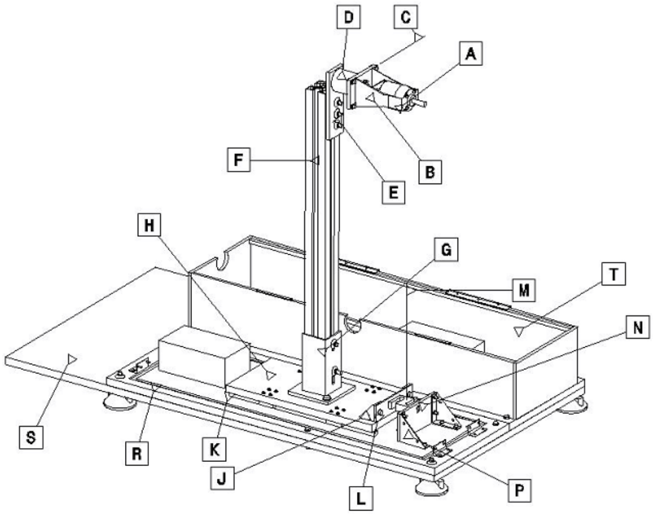
$$J = \frac{V_a}{4\pi R\Omega}$$

$$F_T = \frac{4}{\pi^2}\rho R^4 \Omega^2 C_T(J)$$

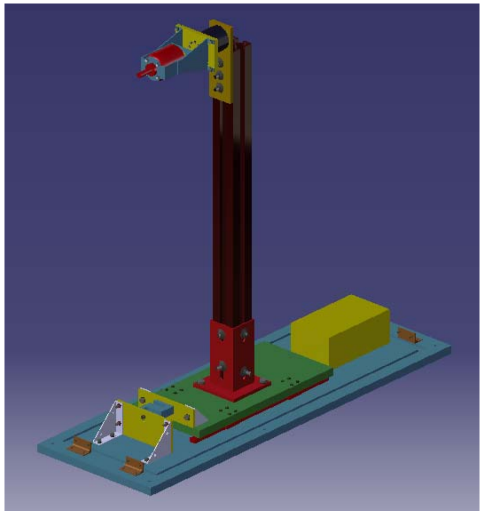
$$\Downarrow$$

$$C_T = C_{T_0} + C_{T_2} J^2 \Leftarrow \begin{array}{l} C_{T_0} = 0.064249 \\ C_{T_2} = -0.18991 \end{array}$$

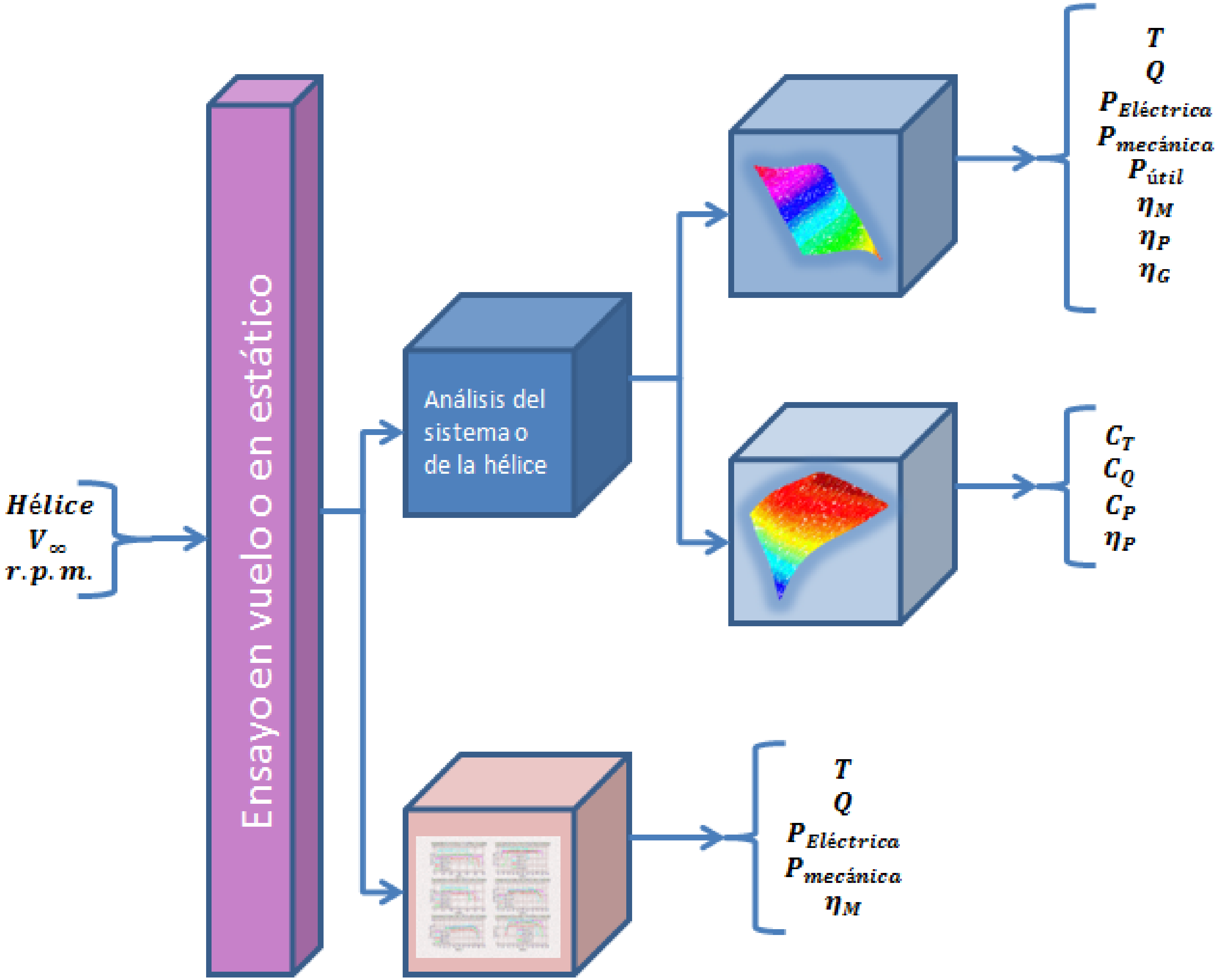
$$F_T = \pi\rho R^4 C_{T_0}\Omega^2 - \frac{\rho R^2 C_{T_2}}{16\pi} V_a^2$$



A	MOTOR
B	BANCADA DEL MOTOR
C	GALLETA
D	SENSOR DE PAR
E	PLACA A
F	VIGA-SOPORTE
G	ANCLAJE
H	BASE MÓVIL
J	ESCUADRAS ALU-STOCK
K	GUIAS
L	PLACA 1
M	CELULA DE CARGA
N	PLACA 2
P	ESCUADRAS LEROY MERLIN
R	BASE DE BANCADA TÚNEL
S	BASE FIJA
T	CAJA ELECTRONICA

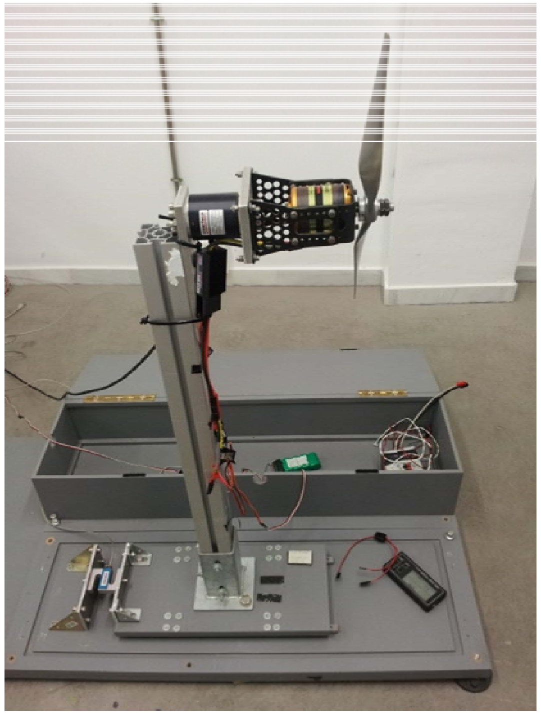


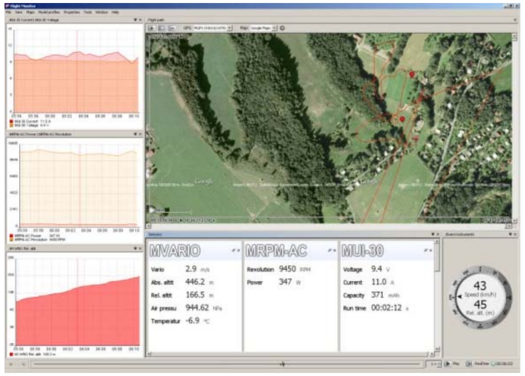
Wind Tunnel Engine Experiments - II



Wind Tunnel Engine Experiments - III

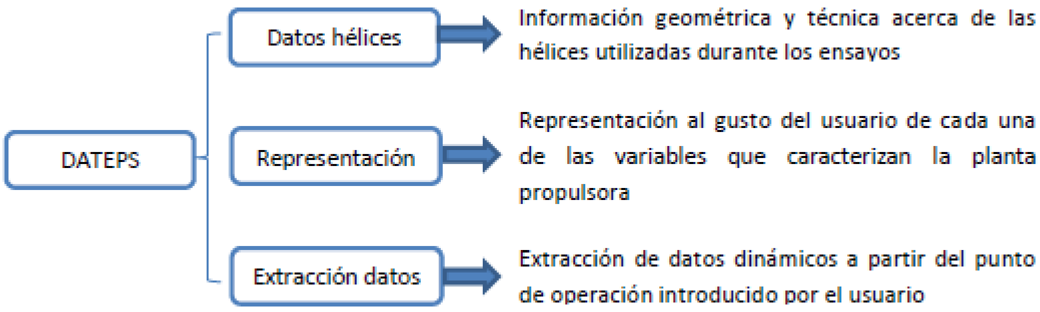
- Extensive Propeller Analysis
  - Performance Study for 3 engines
    - AXI 5345HD
    - AXI 4130/16
    - AXI 2826/10
  - Performance Analysis of Propellers:
    - 11's in, 12's in, 13's in, 14's in, 15's in, 21's in, 22's, in
  - Wireless system: 2.4 GHz Duplex JETI Model
    - Battery: voltage, intensity, capacity, PWM
    - Trust, Torque, RPM
    - Airspeed
    - Flight Monitor: Real Time Data

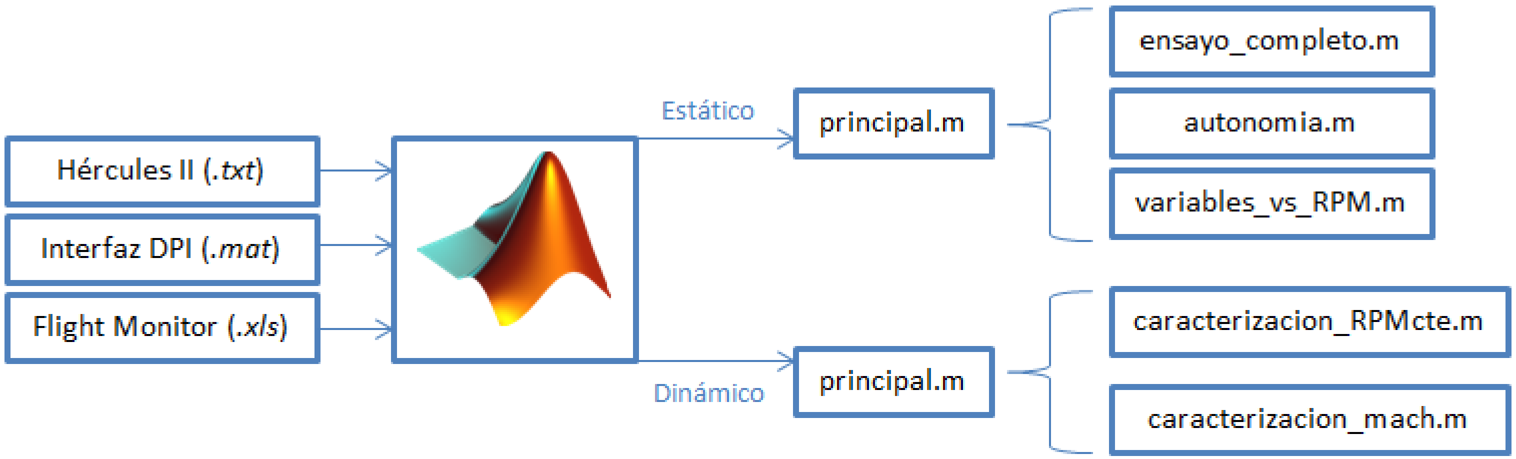




Wind Tunnel Engine Experiments - IV

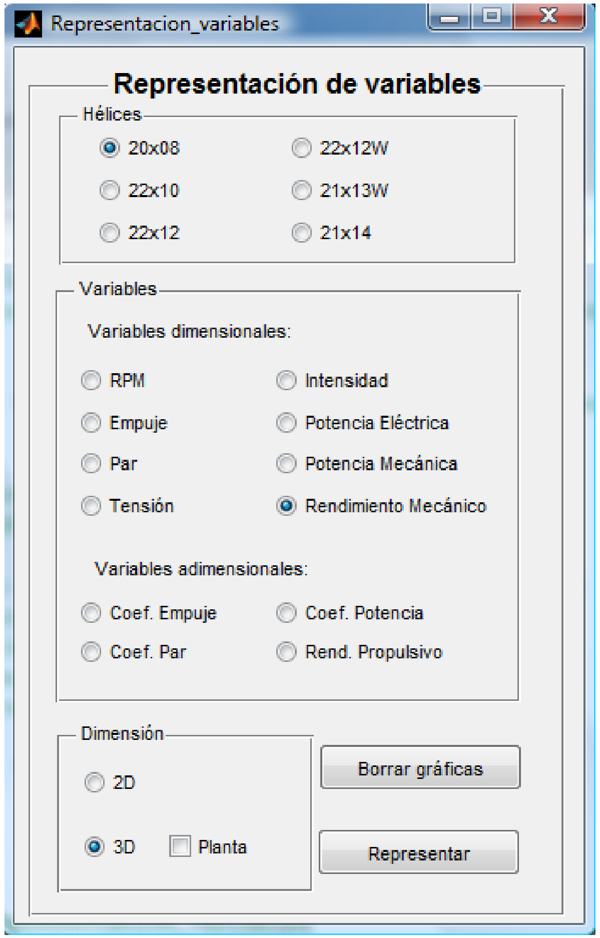
- Integration of Sources: Data Analysis Tool for Engine-Propeller Systems (DATEPS)

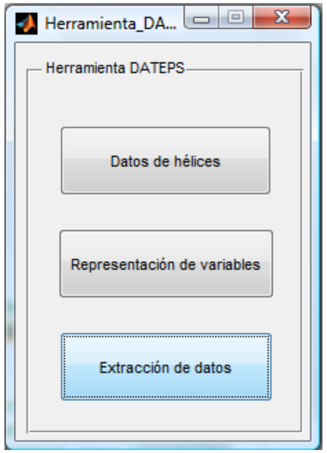


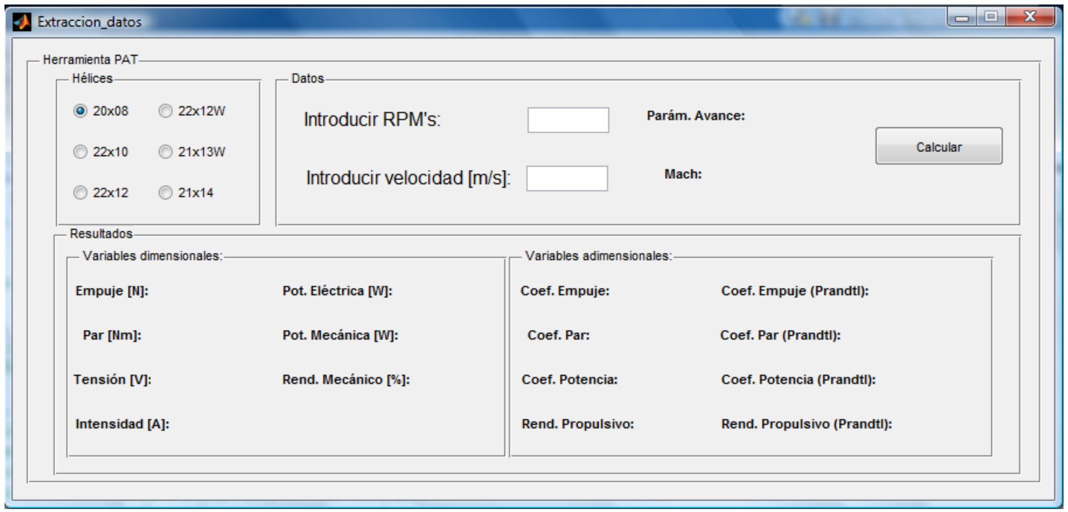


Wind Tunnel Engine Experiments - V

- Integration of Sources: Data Analysis Tool for Engine-Propeller Systems (DATEPS)







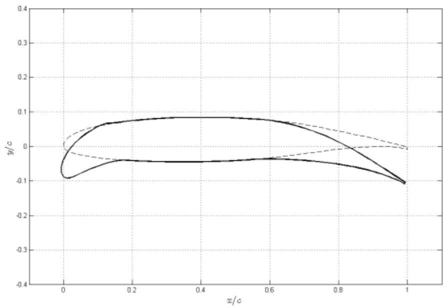
Students' Production

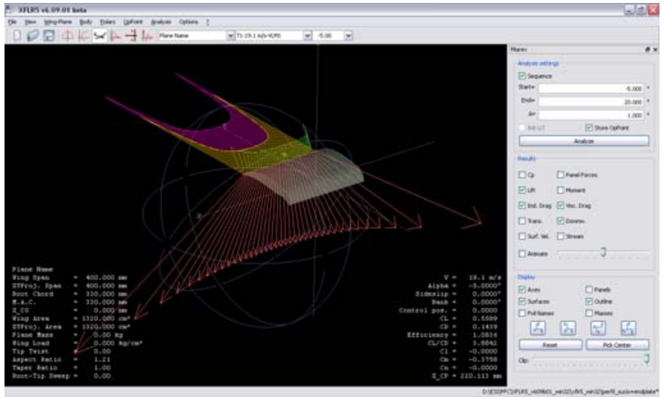
- Creation of 4 Thesis Projects (Proyectos Fin de Carrera)

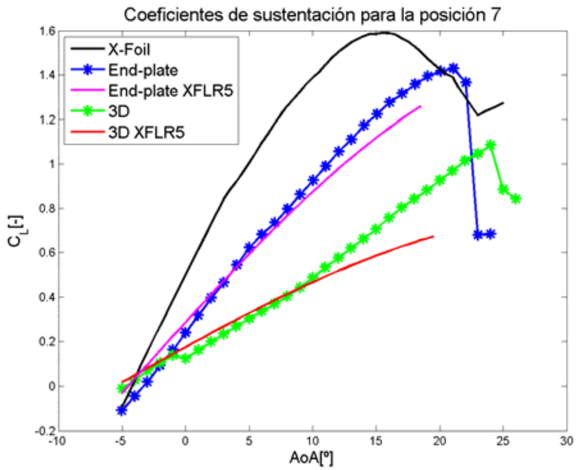
- Theoretic Electrical Engine Performance Models:
  - Alberto García Martínez, "Caracterización de un sistema de propulsión por hélice con motor eléctrico." Advisor: Sergio Esteban
- Design and construction of a test-bench for prop-testing:
  - Hugo López Pérez, "Diseño y construcción de una bancada para caracterización de plantas propulsoras por hélice con motor eléctrico." Advisor: Sergio Esteban
- Experimental Electrical Engine Performance Models:
  - Elio Carrasco Guerrero, "Caracterización y estudio de las actuaciones experimentales de un sistema de propulsión por hélice con motor eléctrico." Advisor: Sergio Esteban
- Design of Tools for Automatic Wind-Tunnel Testing of Propulsion Systems:
  - Juan Manuel moral Gámez, "Diseño y creacion de herramientas y aplicaciones para la gestion automatizada de experimentos de plantas propulsoras de motor electrico y helice en tunel de viento." Advisor: Sergio Esteban

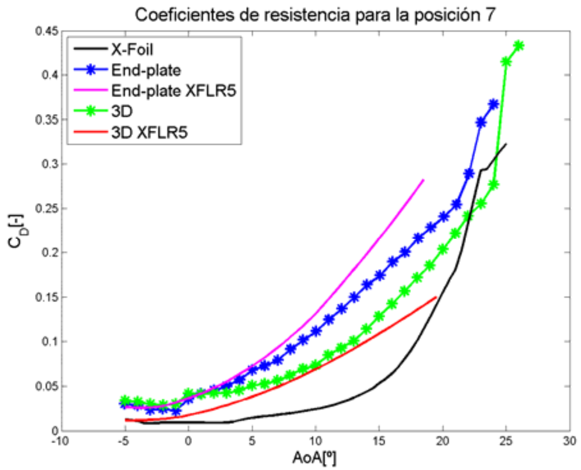
Wind Tunnel Aerodynamic Experiments

- 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









Ingeniería Aeroespacial

Students’ Production

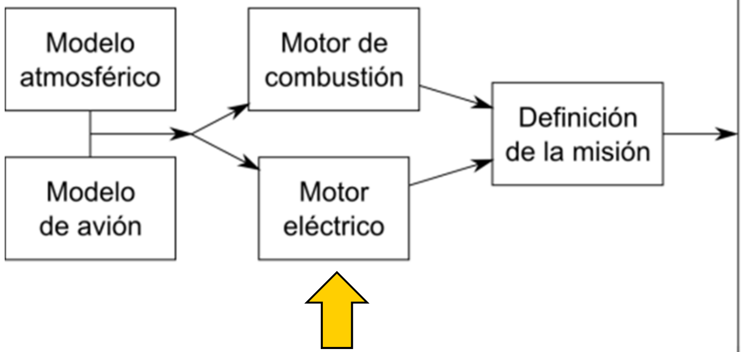
- Creation of 1 Thesis Projects (Proyectos Fin de Carrera)

- Experimental Aerodynamic Study ofr Wing Morphing Wings
  - Isabel Gomez Fuster, “Plataforma para la medición de fuerzas y momentos aerodinámicos de modelos a escala en túnel de viento.” Advisor: Antonio Franco and Sergio Esteban

Aircraft Trajectory Optimization - I

- Generation of tools to analyze aircraft trajectory optimization:
  - TRAJECTORY
    - Estimation of aircraft trajectories
  - PAT
    - TRAJECTORY Modified to be used in the analysis of UAVs' Performance:
    - Different propulsion systems:
      - Electric and internal combustion (actual data from wind tunnel and experimments)
    - Advanced Performance Analysis
      - Analysis of complete mission defined by the user
        - Take off
        - Climb
        - Cruise: advanced Range & Endurance analysis for different propulsion systems (engine models)
        - Landing and gliding

Aircraft Trajectory Optimization - II



$$m \cdot \frac{dV}{dt} = T - D - m \cdot g \cdot \sin\gamma$$

$$m \cdot V \cdot \cos\gamma \cdot \frac{d\chi}{dt} = L \cdot \sin\mu$$

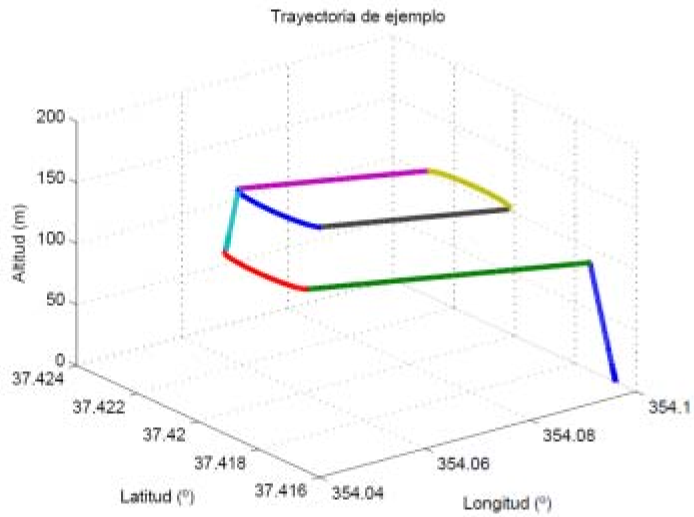
$$m \cdot V \cdot \frac{d\gamma}{dt} = L \cdot \cos\mu - m \cdot g \cdot \cos\gamma$$

$$\frac{dm}{dt} = -\frac{c_P}{g \cdot \eta_P} \cdot T \cdot V$$

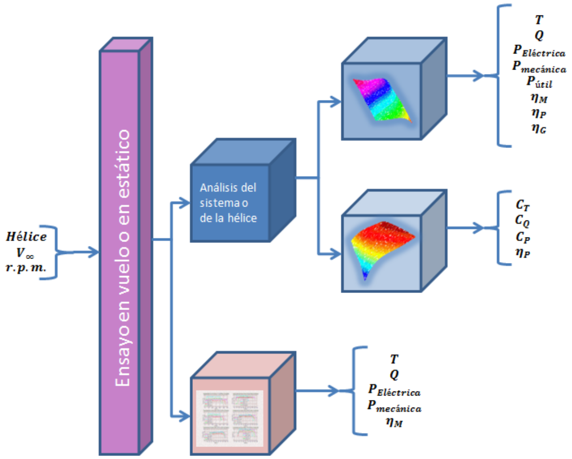
$$\frac{dx}{dt} = V \cdot \cos\gamma \cdot \cos\chi$$

$$\frac{dy}{dt} = V \cdot \cos\gamma \cdot \sin\chi$$

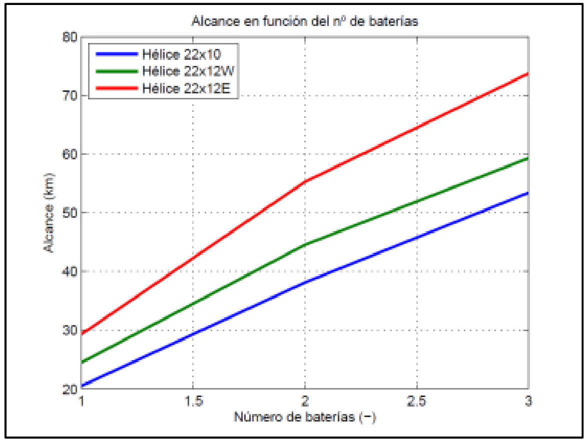
$$\frac{dh}{dt} = V \cdot \sin\gamma$$



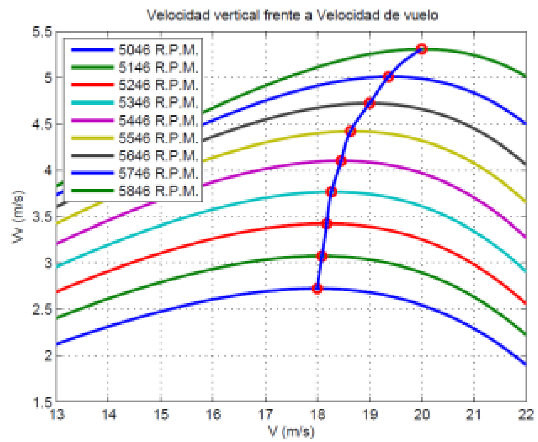
Complete flight profile



Electric Propulsive Model



Range vs prop and # batteries



Climb speed vs hor. vel. and RPM

Students' Production

- Creation of 3 Thesis Projects (Proyectos Fin de Carrera)

- Precise Aircraft Global Trajectory Prediction: trajectory
  - Alfonso Valenzuela, "Desarrollo de una Herramienta Software para el Cómputo de Trayectorias Globales de Aviones: Aplicación al Caso de Resolución de Conflictos." Advisor: Damián Rivas
  - José Luis de Augusto, "Generación de Trayectorias Globales de Aviones Comerciales." Advisor: Alfonso Valenzuela, Damián Rivas.
- Advanced Aircraft Performance Analysis for Electric Prop UAVs
  - Juan Andrés Doblado Agüera, "Análisis de las actuaciones de vuelo para UAV propulsado con motor eléctrico." Advisor: Sergio Esteban

- Creation of a Ph.D. Thesis:

- Aircraft trajectory Optimization:
  - Alfonso Valenzuela, "Aircraft Trajectory Optimization Using Parametric Optimization Theory.. PhD Thesis, Universidad de Sevilla 2012." Advisor: Damián Rivas

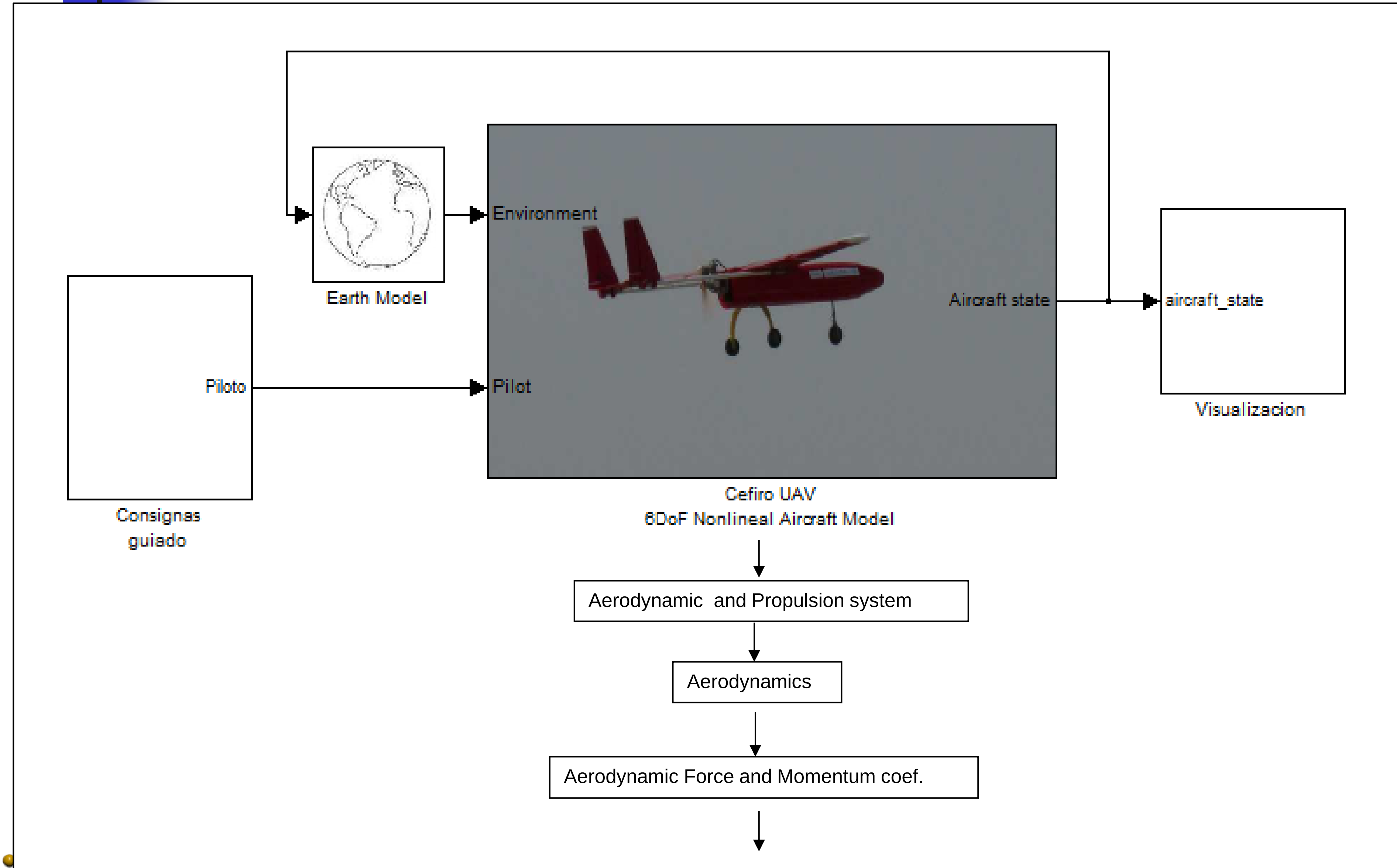
Advanced Aircraft Modelling

- Motivation: Creation of 6-DOF model where to test:
  - Stability and Control design criteria.
  - Test control strategies.
  - Test Navigation strategies

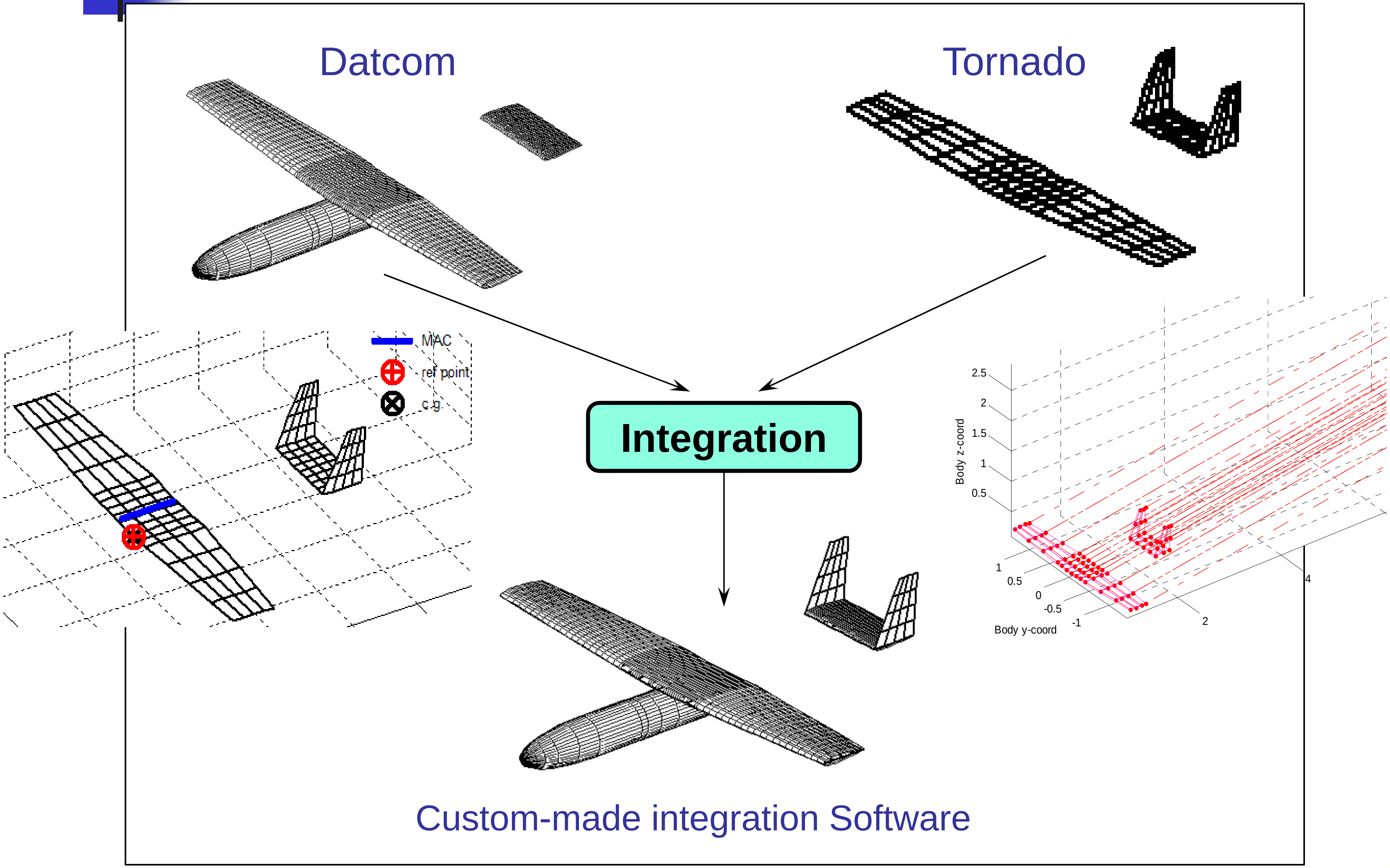
- Design of Custom-made Software: Able to estimate:
  - Force and moment coefficients
  - Stability Derivatives
  - Control derivatives

- Integration of
  - DATCOM
    - The USAF stability and control Digital Datcom
  - Tornado
    - Numerical Vortex Lattice

Advanced Aircraft Modelling



Advanced Aircraft Modelling



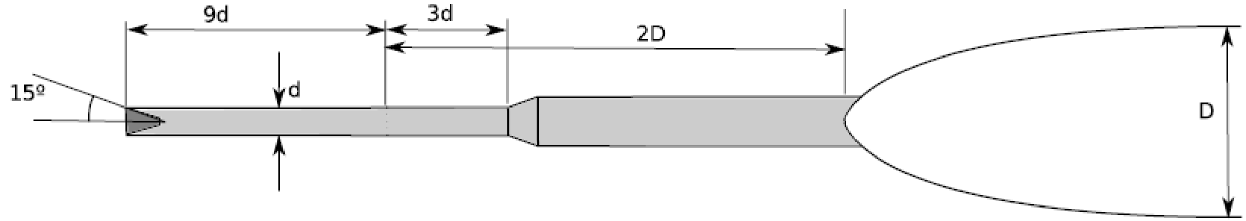
Students' Production

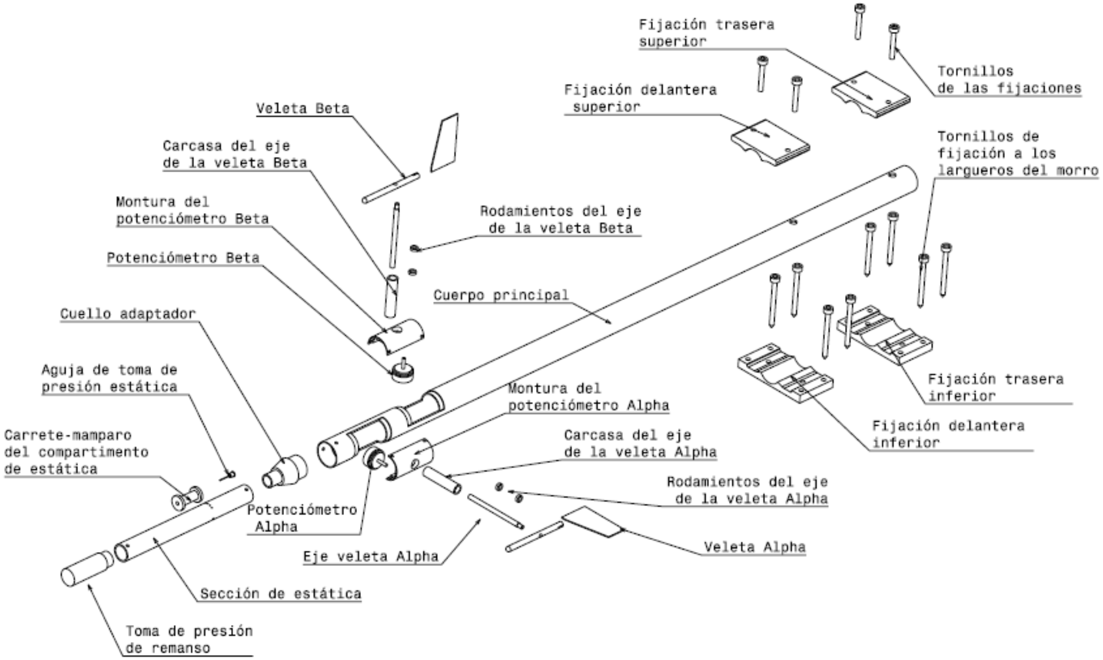
- Creation of Thesis Projects (Proyectos Fin de Carrera)
- Advanced Aircraft Modelling:
  - Manuel Jiménez Guerrero, "Diseño de herramientas para el análisis de modelos aerodinámicos de aviones." Advisor: Francisco Gavilán
- Creation of a Ph.D. Thesis:
- Advanced Aircraft Modelling:
  - Francisco Gavilán, "Sistemas de control y guiado para vehículos aéreos no tripulados: diseño de algoritmos y sistemas embarcados. PhD Thesis, Universidad de Sevilla 2012." Advisor: Rafael Vázquez

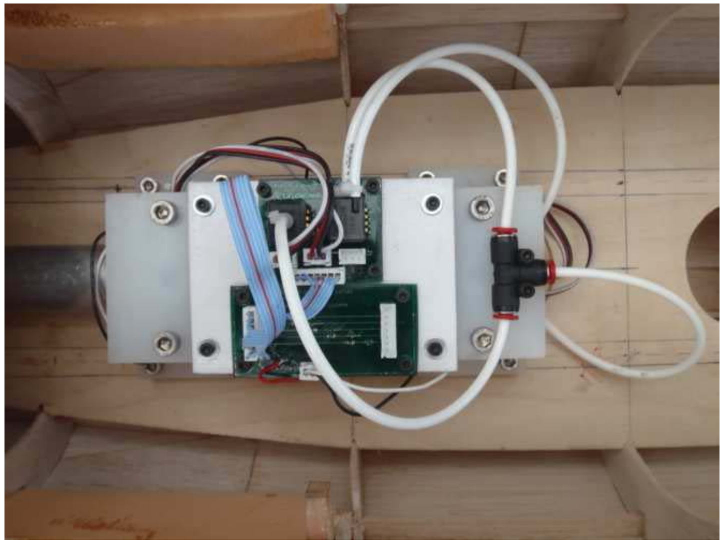
Aerodynamic Sensors - I

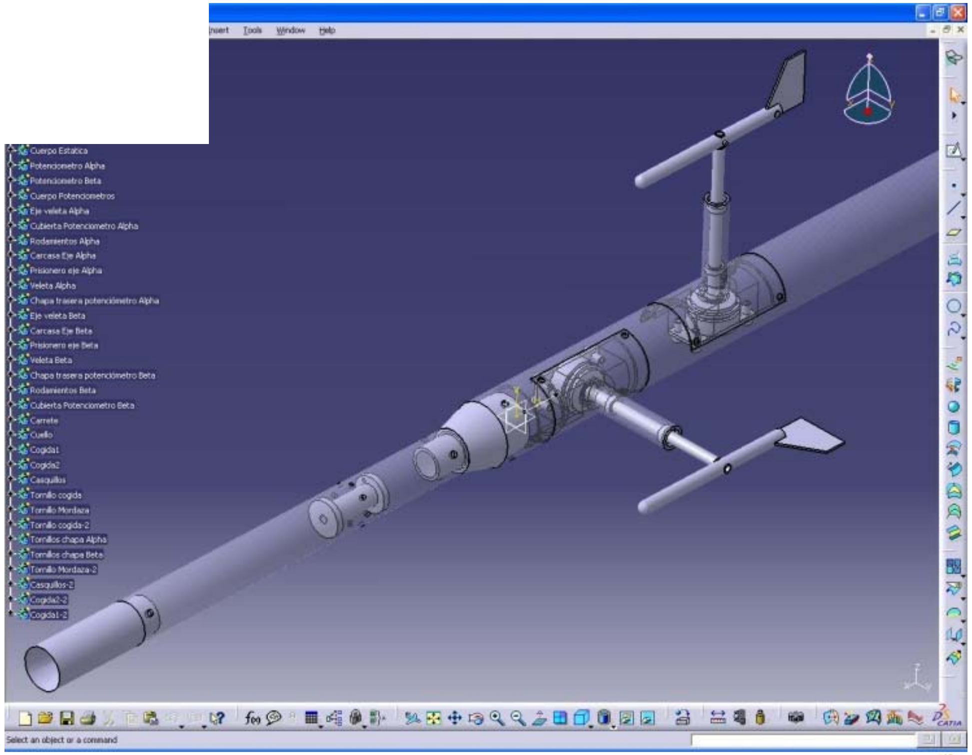
- Motivation:
  - To predict aircraft perfromance models $\Rightarrow$ meassure airspeed
  - Ensure Céfiro maintains flight envelope.
  - Use it as input $\Rightarrow$ control laws and navigation.
  - Elevated cost of commercial units (>10000€ high precision).
- Custom-made pitot-tube
  - Meassure:
    - 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



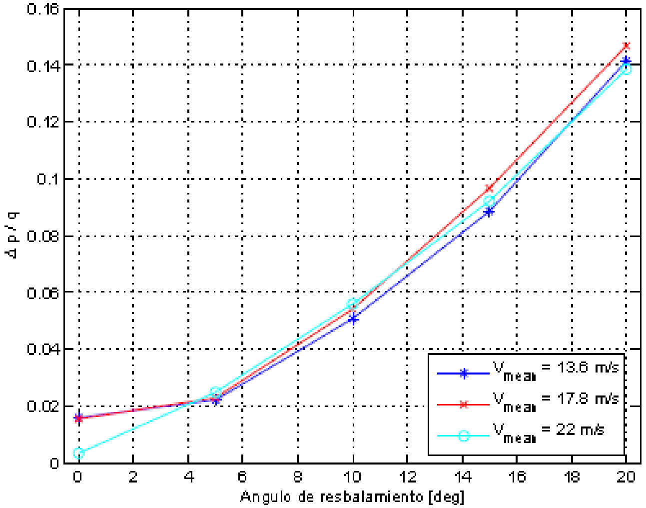

Fijación trasera superior
Tornillos de las fijaciones
Fijación delantera superior
Veleta Beta
Carcasa del eje de la veleta Beta
Tornillos de fijación a los largueros del morro
Montura del potenciómetro Beta
Rodamientos del eje de la veleta Beta
Potenciómetro Beta
Cuerpo principal
Cuello adaptador
Aguja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



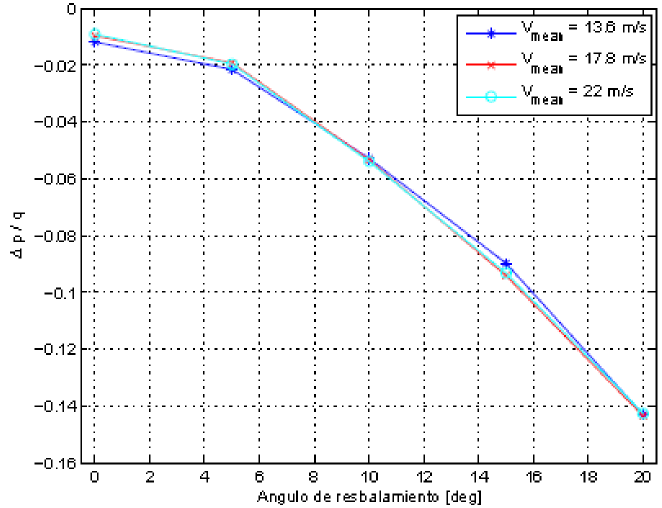


Wind Tunnel Measured error α and β

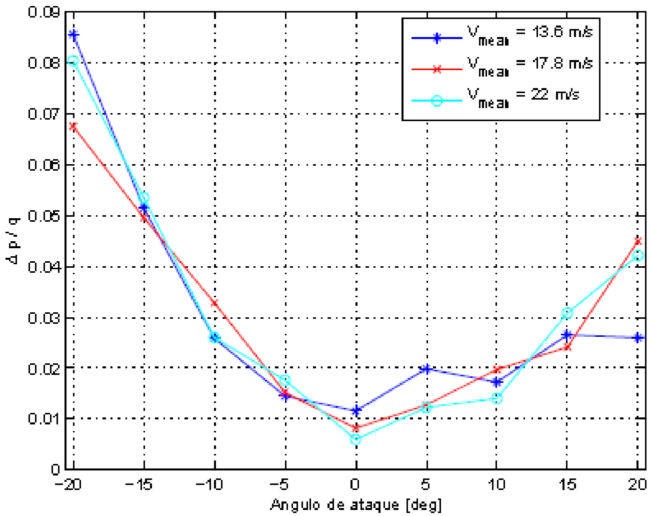
Angle of attack sensitivity (α)

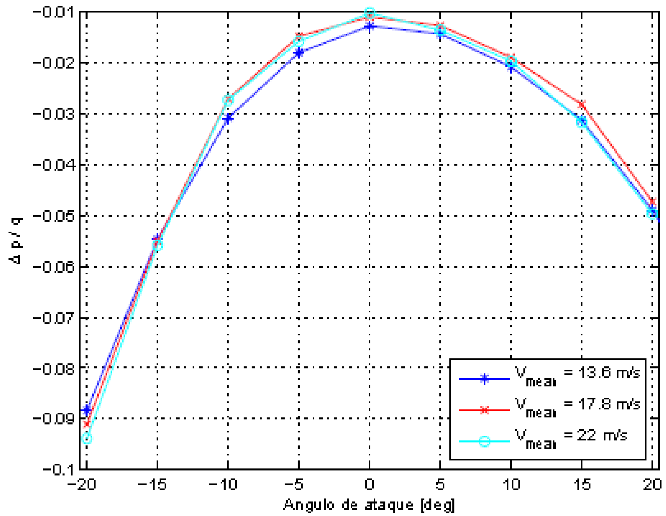


Dynamic Pressure



Static Pressure





Side-slip sensitivity (β)

Students' Production

- Creation of Thesis Projects (Proyectos Fin de Carrera)

- Aerodynamic Sensors:
  - Andrés Fernández Lucena, "Diseño, fabricación, integración y pruebas de un sistema de anemometría para UAVs." Advisor: Francisco Gavilán

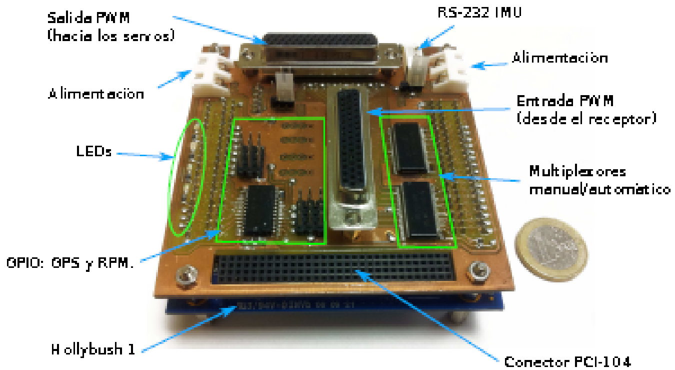
- Creation of a Ph.D. Thesis:

- Aerodynamics Sensors:
  - Francisco Gavilán, "Sistemas de control y guiado para vehículos aéreos no tripulados: diseño de algoritmos y sistemas embarcados. PhD Thesis, Universidad de Sevilla 2012." Advisor: Rafael Vázquez

Flight Computer System - I

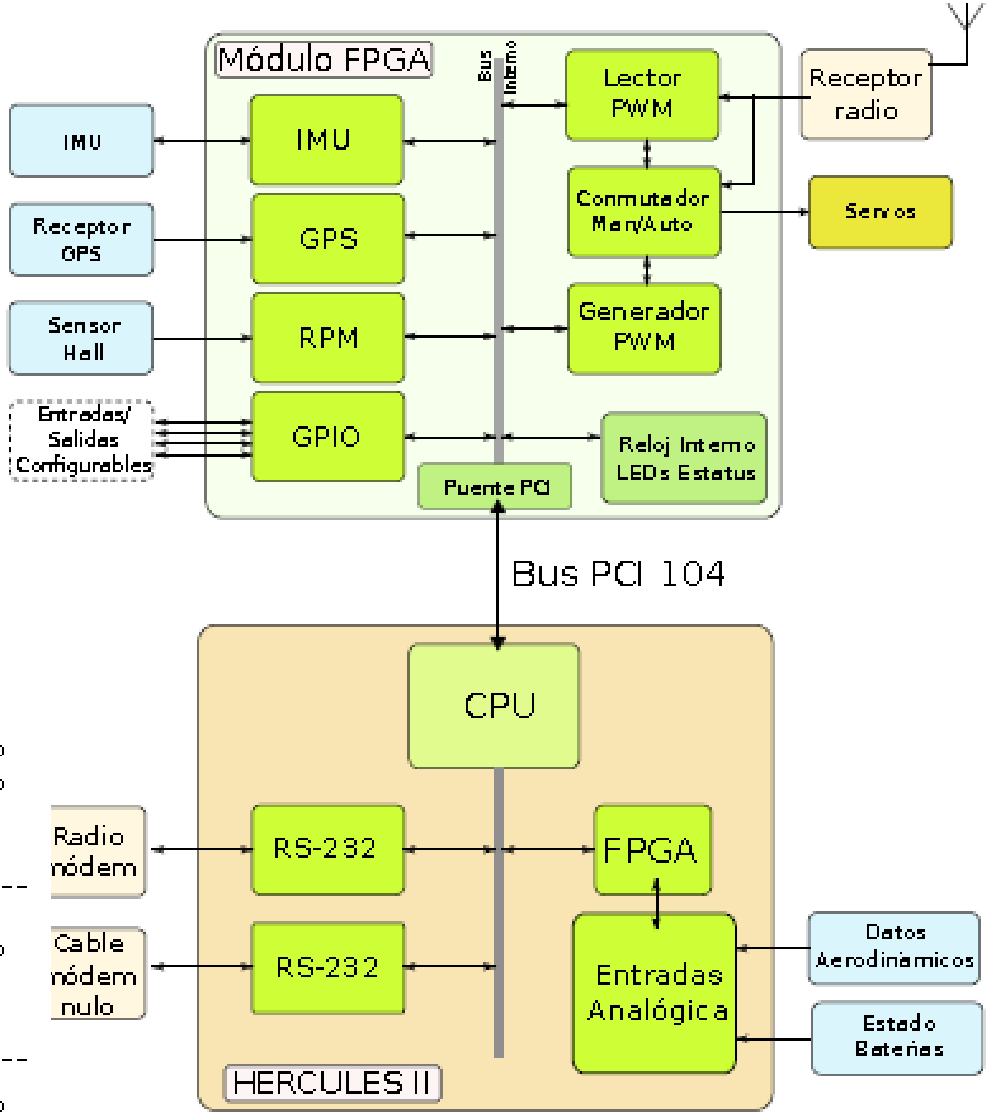
- Need of a hardware platform to implement control strategies:
  - High computing power
  - Versatility
  - Robustness
  - Size and weight compatible with Céfiro
  - Low cost

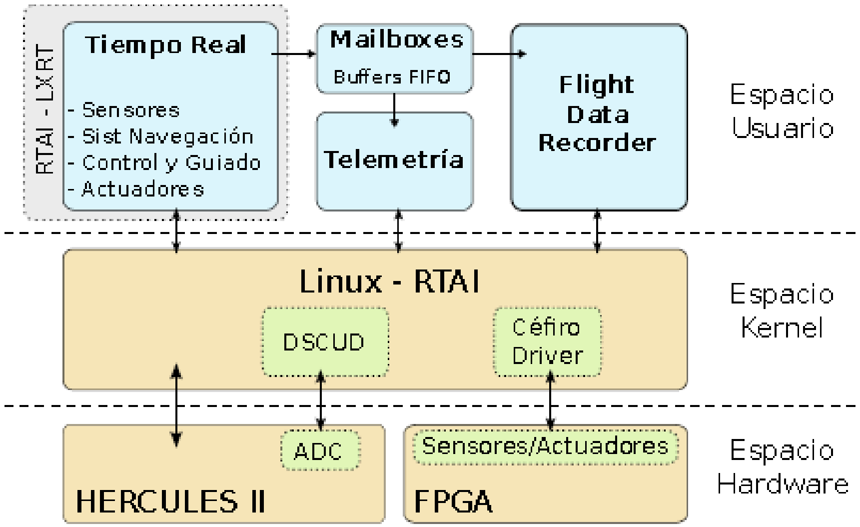
- Needed Functionability:
  - Implementation of control strategies and Navigation systems
  - Manage communications and onboard sensors
    - IMU, GPS, pressure sensors, Pitot-tube…
  - Able to generate PWM signals to control servo-actuators
  - Able to read PWM signals generated by the radio
  - Multiplexor Manual/Automatic
  - Sending telemetry via wireless
  - Development of a custom –made FPGA

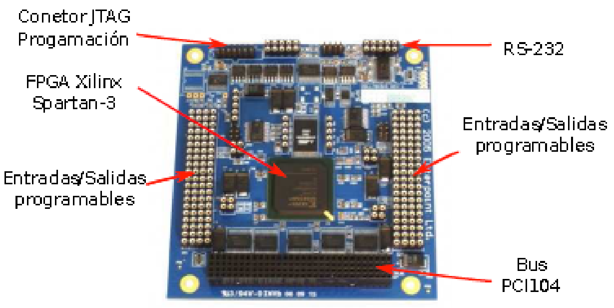


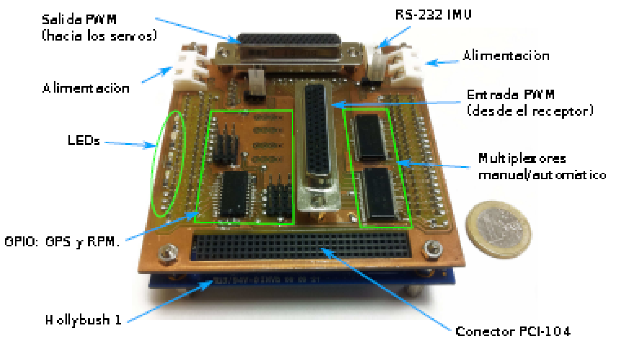
Flight Computer System - II

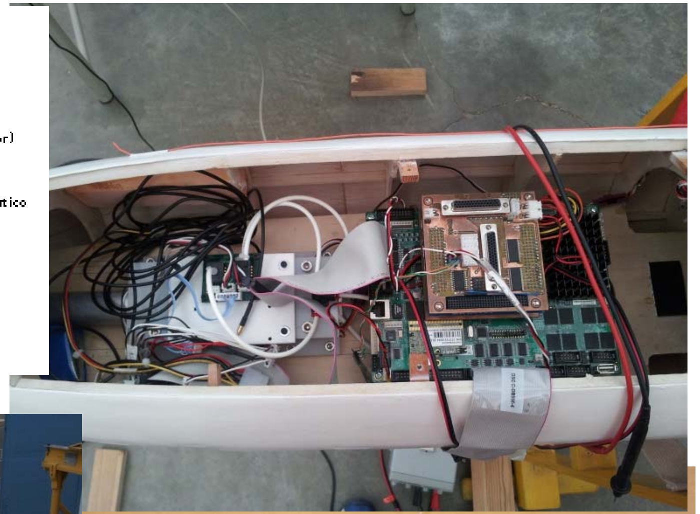
- FPGA (embedded Hollybush)
  - Power control
  - Tension adaptation
  - Multiplexors MAN/AUTO
- Real Time Software
  - Periodic execution of control laws
  - Linux 2.6.23, patched with RTAI 8
  - Development of own integrated drive SO kernel for communications with Fl
  - Recording of state variables






Conetor JTAG
Progamación
FPGA Xilinx
Spartan-3
Entradas/Salidas
programables
RS-232
Entradas/Salidas
programables
Bus
PCI104


Salida PWM
(hacia los servos)
Alimentación
LEDs
GPIO: GPS y RPM.
Hollybush 1
RS-232 IMU
Alimentación
Entrada PWM
(desde el receptor)
Multiplexores
manual/automático
Conector PCI-104



Students' Production

- Creation of Thesis Projects (Proyectos Fin de Carrera)

- Flight Computer System:
  - Vicente Payo Ollero, "Diseño e implementación de un Flight Data Rercorder." Advisor: Francisco Gavilán

- Creation of a Ph.D. Thesis:

- Flight Computer System:
  - Francisco Gavilán, "Sistemas de control y guiado para vehículos aéreos no tripulados: diseño de algoritmos y sistemas embarcados. PhD Thesis, Universidad de Sevilla 2012." Advisor: Rafael Vázquez

Project Céfiro