Céfiro: An aircraft design project, and a test bed for research at the University of Seville

Departamento de Ingeniería Aeroespacial y Mecánica de Fluidos
Grupo de Ingeniería Aeroespacial

Ingeniería Aeroespacial
ESI · Universidad de Sevilla

Index

Introduction

- Motivations:
  - Research
    - Some of the areas of research of the Department of the Aerospace Engineering at the University of Seville are:
      - Trajectory optimization.
      - ATM.
      - Aircraft design.
      - Aircraft dynamics and engine performance modeling.
      - Automatic flight control systems.
    - The need of advancing in many of these research fields calls for the use of scaled platforms (UAV).
    - Low availability of adequate commercial off-the-shelf scaled aerospace platforms creates the need of designing and building custom UAV testing platforms.
  - Education
    - The department's philosophy identified as necessary to dedicate an special effort towards aircraft design.
      - Unify the knowledge acquired by the student after 5 years of education.
      - Give the students a real vision of how the aerospace industry works.
- Department's research and educational needs yielded in the project Céfiro.

Grupo de Ingeniería Aeroespacial
Escuela Técnica Superior de Ingenieros
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Grupo de Ingeniería Aeroespacial

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  - Carlos Antúnez — Prof. Asociado (Airbus Mil.)
  - Rafael Vallejo — Prof. Asociado (Airbus Mil.)

Ingeniería Aeroespacial
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Classes Taught by GIA

- **Introduction to Aerospace Engineering:**
  - Introducción a la Ingeniería Aeroespacial
- **Propulsion:**
  - Fundamentos de Propulsión
  - Sistemas de Propulsión
  - Propulsión Aérea y Espacial
- **Flight Mechanics:**
  - Mecánica de Vuelo y Operaciones de Vuelo
  - Mecánica de Vuelo y Operaciones de Vuelo
  - Mecánica del Vuelo I
  - Mecánica del Vuelo II
- **Navigation**
  - Fundamentos de Navegación Aérea
  - Navegación Aérea
- **Space Vehicles**
  - Astronáutica y Aeronaves Diversas
  - Vehículos Espaciales y Misiles
- **Rotatory Wings**
  - Astronáutica y Aeronaves Diversas
- **Aircraft Design**
  - Cálculo de Aviones
- **Systems Integration**
  - Instalaciones de Aeronaves
  - Integración de Sistemas y Pruebas Funcionales

Aircraft Design at the university of Seville

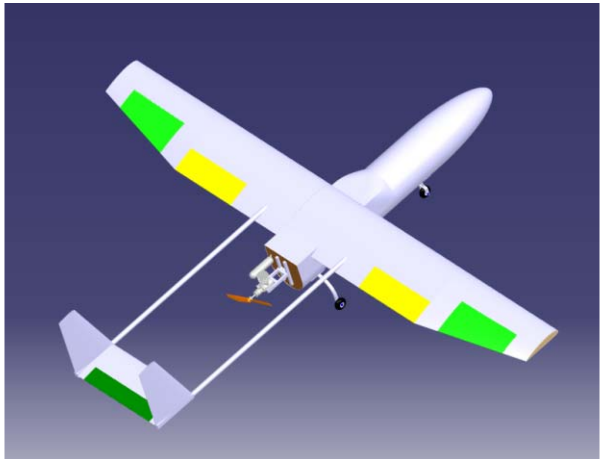
- Aircraft Design (Cálculo de Aviones) is a class taught during the last year of the Aerospace program at the University of Seville.
- The main objectives of the class are:
  - Teach the students all the aspects related with the design process of airplanes.
    - Learn how to use all the engineering tools, methods and procedures that are employed in the industry during the conceptual design process.
    - Unify all the knowledge learned throughout their degree and be able to apply those concepts to a real engineering problem.
  - Give them their first industry experience:
    - Learn to manage a big project with delivery and goal deadlines.
    - Experience the challenges of a competitive industry.
      - Students work in groups (5-6) and compete to design an airplane that meets the RFP.
  - Learn to work in groups: Concurrent Engineering
    - Teach them that there is no space for the concept of "cubical engineering."

Céfiro

Prototype I

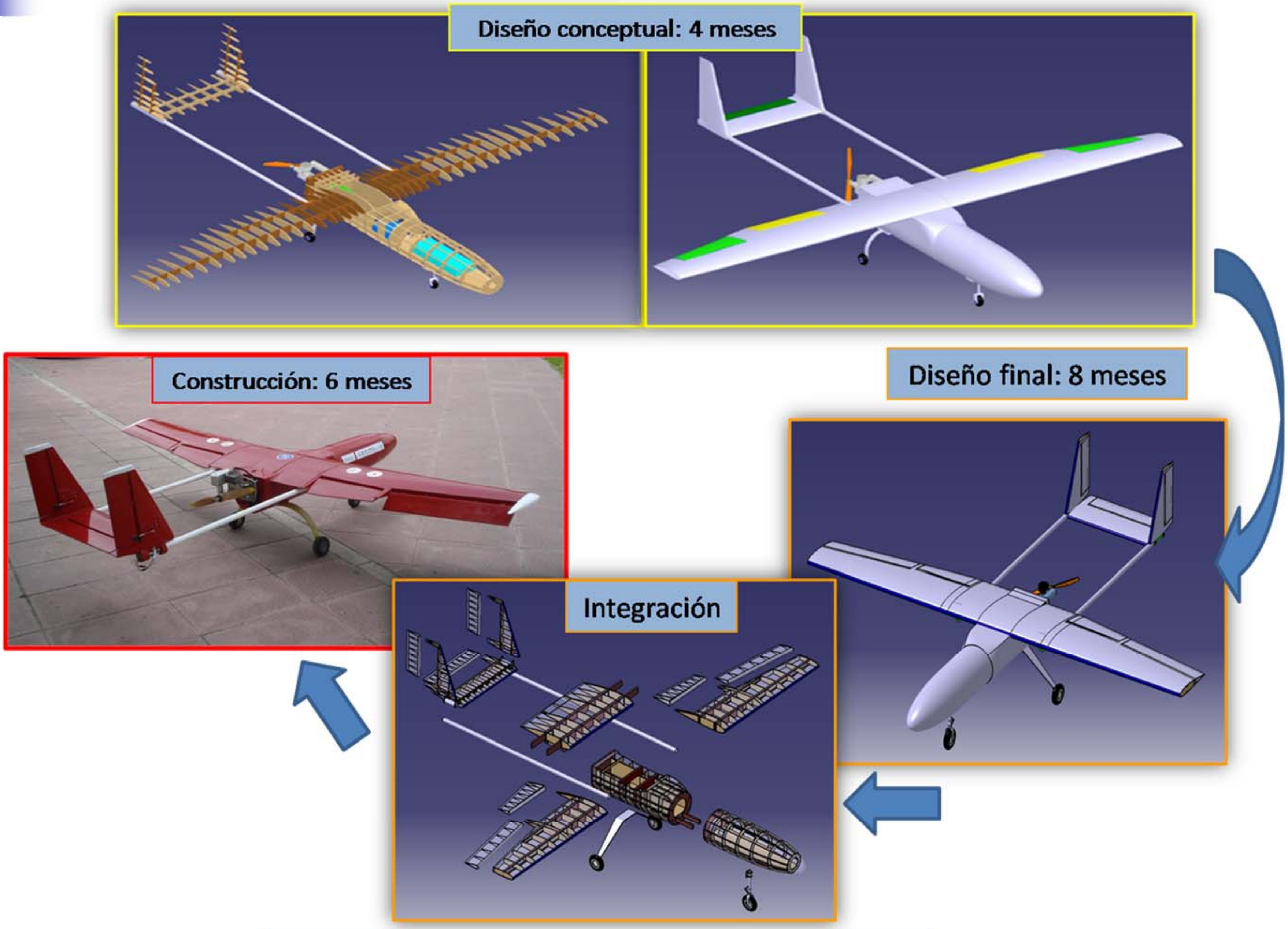
Cefiro: An Aircraft Design Project - I

- Department's research and educational needs yielded in project Cefiro.
- Cefiro's Request For Proposal (RFP):
  - Performance requirements
    - Endurance: 45 minutes.
    - Cruise speed 90-140 km/h.
    - Cruise altitude 500 m.
  - Modular design UAV
    - Easy Transportation.
    - Easy Reconfiguration.
  - Mission profile:
    - Defined mission profile.
    - Capability of adequate space for avionic systems (different missions):
      - Observation.
      - Experiments of identification.
    - Payload bay area able to transport 7,5 kg



- The level of details achieved during the preliminary design of Cefiro was limited to the scope of the Aircraft Design Class.

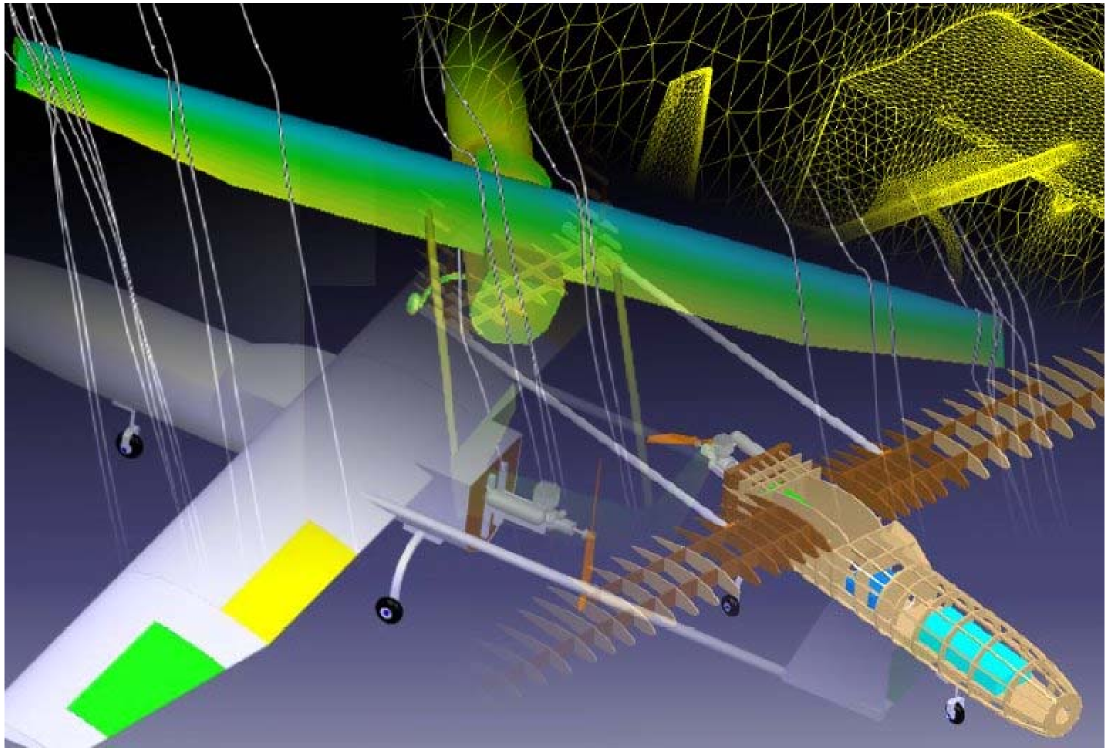
Cefiro’s Timeline



Duración total del proyecto Céfiro: 18 meses

Cefiro: An Aircraft Design Project - II

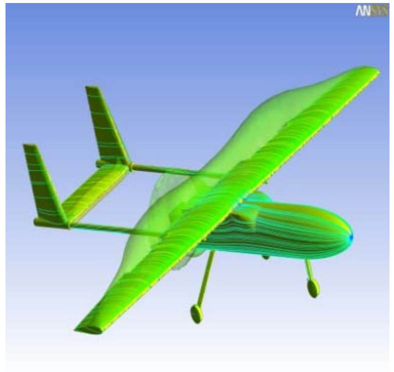
- Need to extend each one of the design areas to transition from a design concept to a prototype.
  - "Cálculo de Aviones" gave a good proof of concept design, but not good enough to be a flying airplane.
  - Each one of the main 5 design areas of the preliminary design were assigned to students in order to be optimized (thesis):



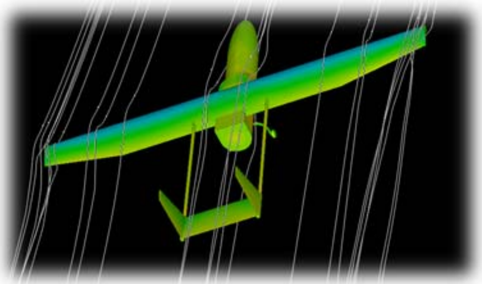
- Aerodynamics.
- Engine and aircraft performance.
- Stability and control.
- Structural design and manufacturing process.
- Production and systems integration.

Aerodynamics - I

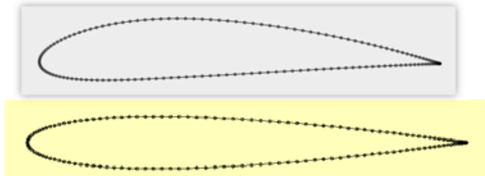
- Compromise between performance and the mission configuration.
- Optimize for the chosen design:
  - Pusher configuration.
  - Double vertical tail configuration.
  - Surfaces, span and wing geometry, control surfaces and tail.



- Study of complete drag polar using several methods:
  - Classical methods:
    - Composite build up methods.
    - Equivalent friction methods.
  - Extensive use of computer aided methods:
    - Vortex Lattice parametric wing model.
    - CFD:ANSYS CFX 10.0.

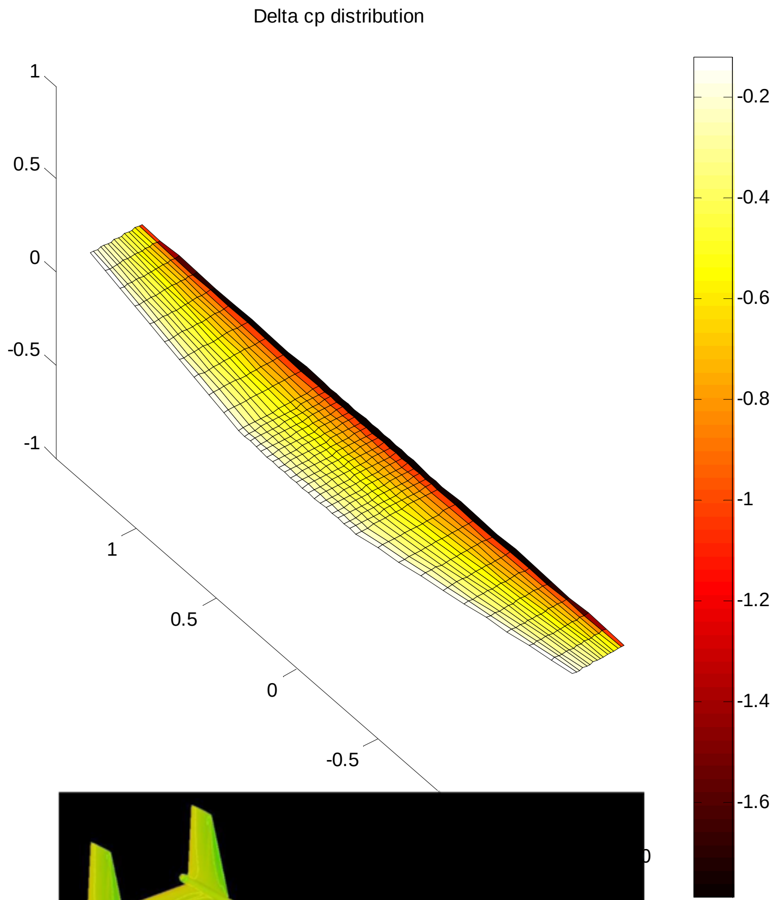


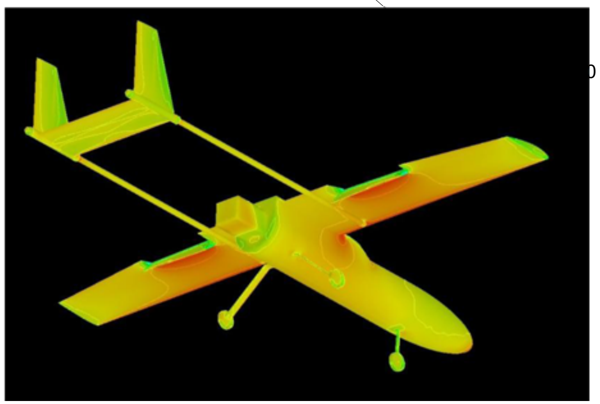
- Airfoil design
  - Wing profile NACA 2415.
  - Tail profile NACA 0012.

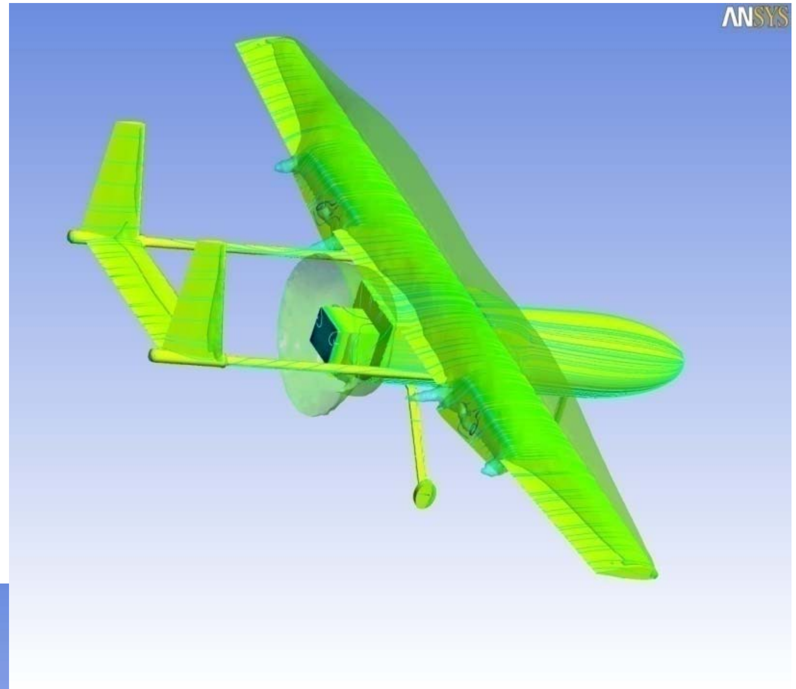


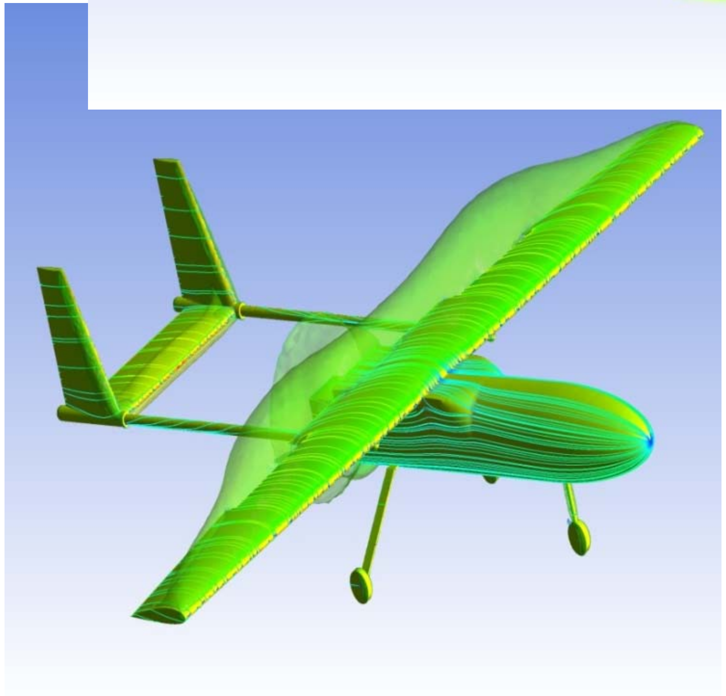
- Optimization of the wing profile, and tail configuration.
- Design and analysis of the control surfaces: ailerons, flaps, elevator and rudders.
- Polar studies for all the mission configuration.
- Concurrent engineering process.

Aerodynamics - II

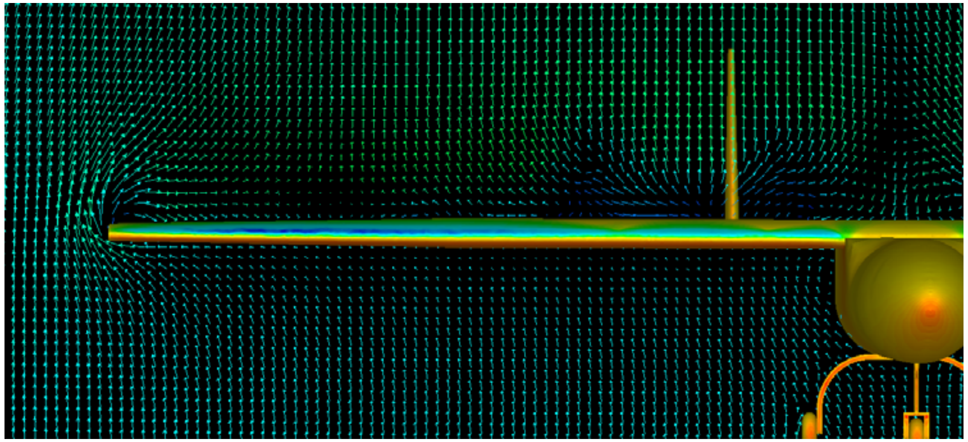


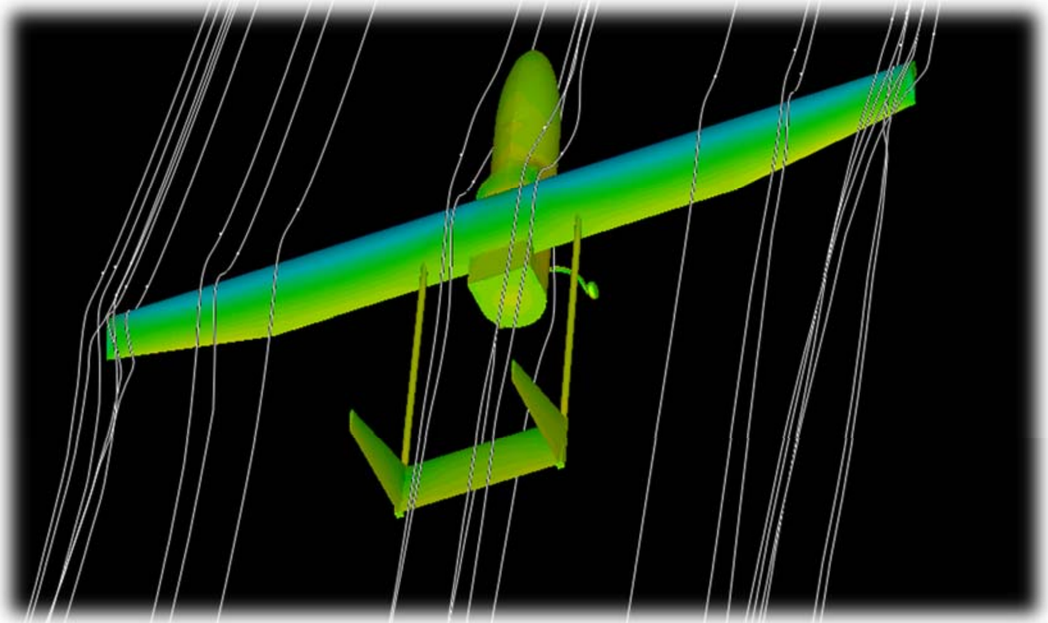


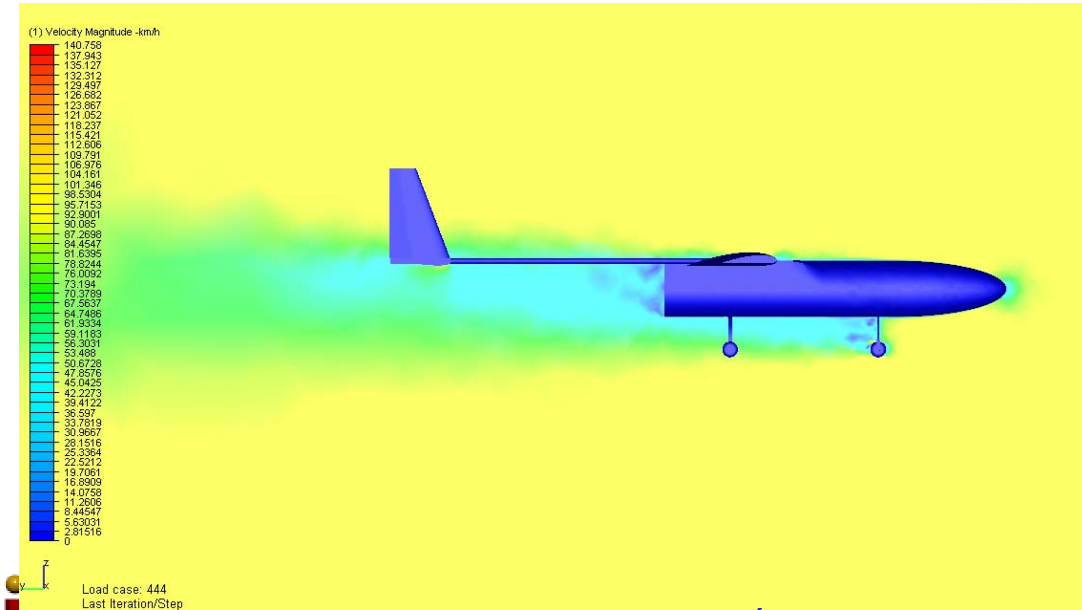


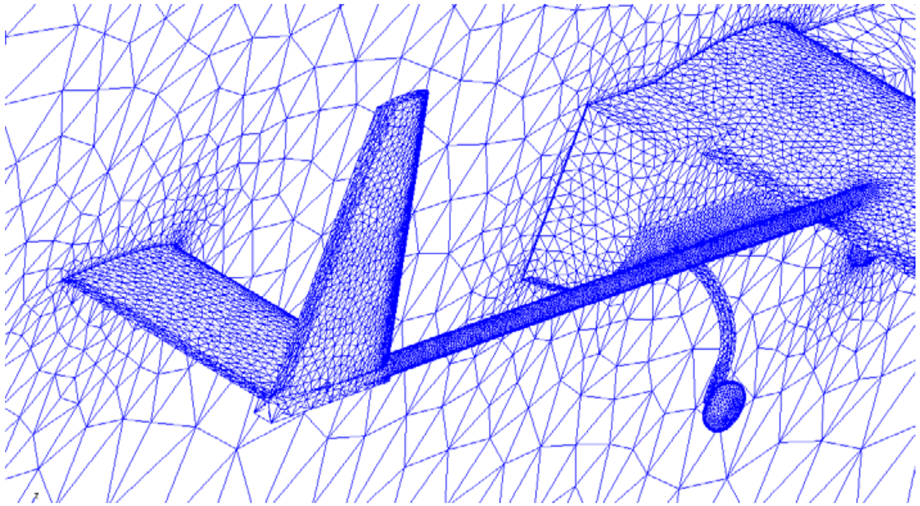


Aerodynamics - III

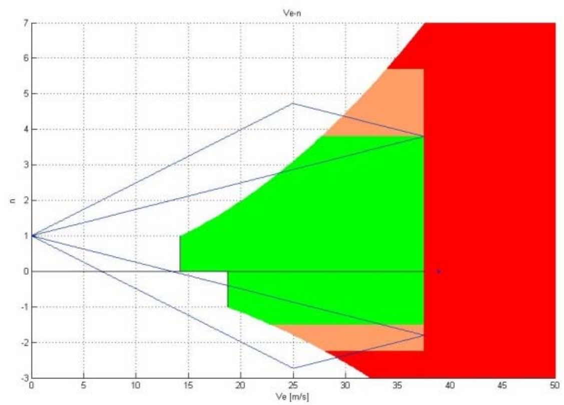








Engine and aircraft performance - I

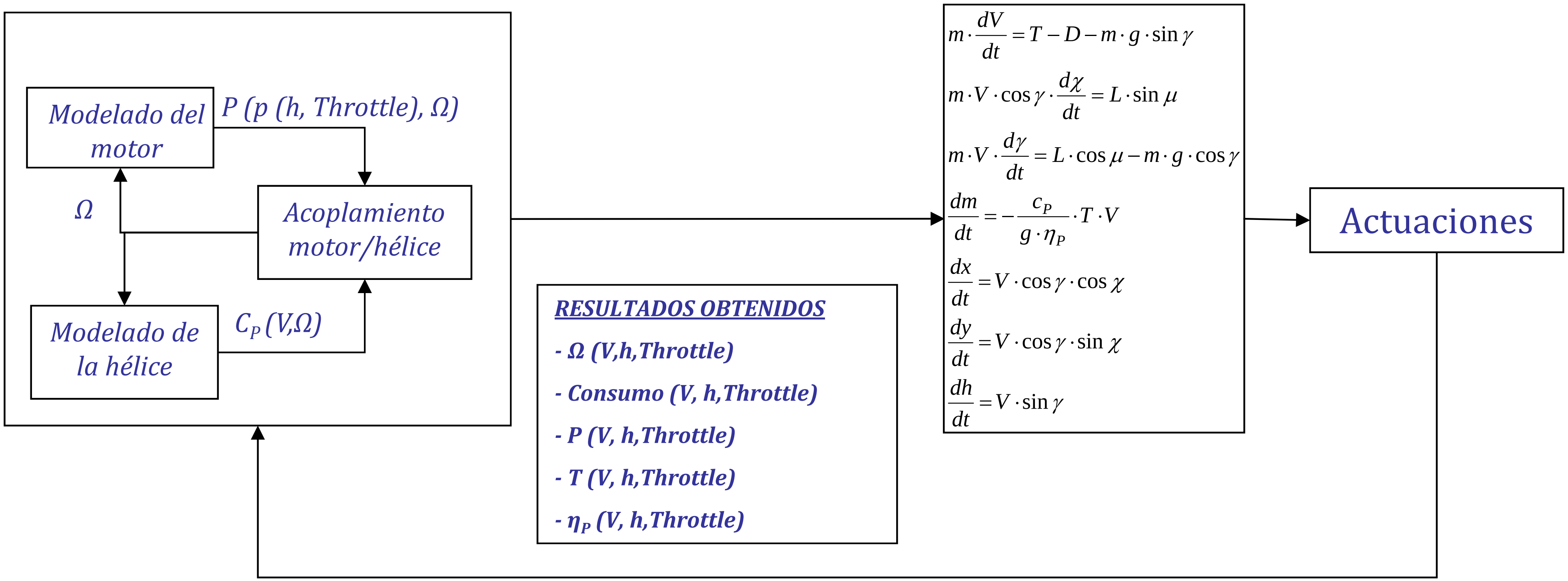


- Flight Performance Analysis:
  - Takeoff and landing
  - Climb and descent
  - Cruise (mission profile defined RFP).
- Advanced Study Range and Endurance:
  - Optimization of flight speeds vs. fuel consumption, height, and throttle (theory).
  - Expressions for optimal performance parameters for:
    - Polar $C_D = C_{D_0} + KC_L^2$
    - Polar $C_D = C_{D_0} + k_1 C_L^2 - k_2 C_L$
- Propeller modeling:
  - Combined blade element and momentum theory models (w & w/o tip loses).
  - Analytical tool to determine engine performance for varying propeller geometry.
  - Validation of model using available real data.
- Engine Modeling:
  - Theoretical modeling balancing power requirements.
  - Validating model with data from engine test-stand.

Engine Performance: Modelling I

Engine Modelling

Equations of Movement



$$R = \int_{W_i}^{W_f} -\frac{v}{g \cdot c_P \cdot P} \cdot dW = \frac{\eta_P}{g \cdot c_P(M)} \frac{2 \cdot E_{máx}}{\sqrt{1 - 2 \cdot k_1 \cdot E_{máx}}} \arctan\left(\frac{(W_i - W_f)\sqrt{1 - 2 \cdot k_1 \cdot E_{máx}} \cdot C_{Lopt} \cdot q_0 \cdot \delta \cdot M^2}{(1 - k_1 \cdot E_{máx}) \cdot ((C_{Lopt} \cdot q_0 \cdot \delta \cdot M^2)^2 + W_i \cdot W_f) + (W_i + W_f) \cdot C_{Lopt} \cdot q_0 \cdot \delta \cdot M^2 \cdot k_1 \cdot E_{máx}} \right)$$

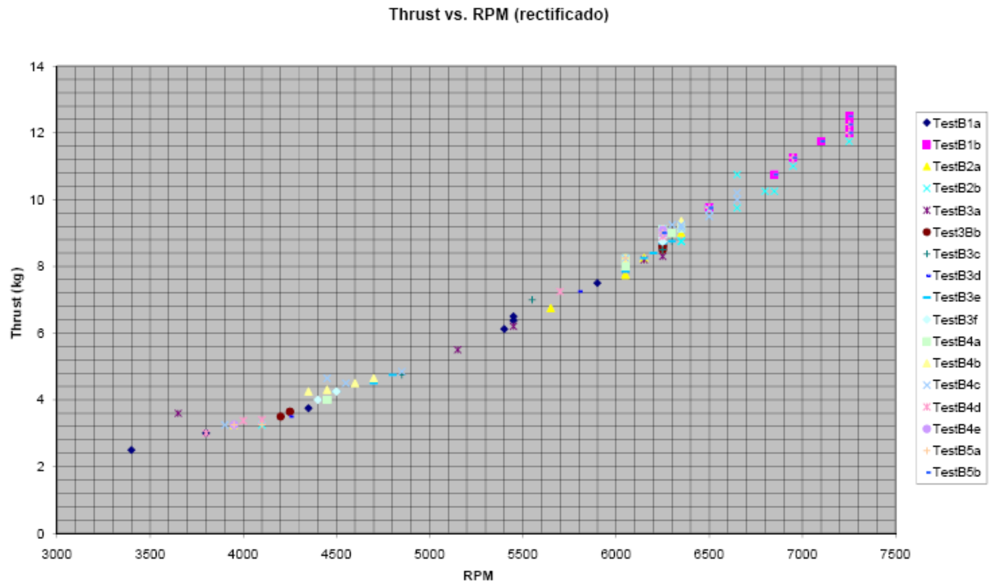
$$E = \int_{W_i}^{W_f} -\frac{dW}{g \cdot c_P \cdot P} = \frac{\eta_P}{g \cdot c_P(M)} \cdot \frac{1}{M \cdot a_0 \cdot \sqrt{\theta}} \frac{2 \cdot E_{máx}}{\sqrt{1 - 2 \cdot k_1 \cdot E_{máx}}} \arctan\left(\frac{(W_i - W_f)\sqrt{1 - 2 \cdot k_1 \cdot E_{máx}} \cdot C_{Lopt} \cdot q_0 \cdot \delta \cdot M^2}{(1 - k_1 \cdot E_{máx}) \cdot ((C_{Lopt} \cdot q_0 \cdot \delta \cdot M^2)^2 + W_i \cdot W_f) + (W_i + W_f) \cdot C_{Lopt} \cdot q_0 \cdot \delta \cdot M^2 \cdot k_1 \cdot E_{máx}} \right)$$

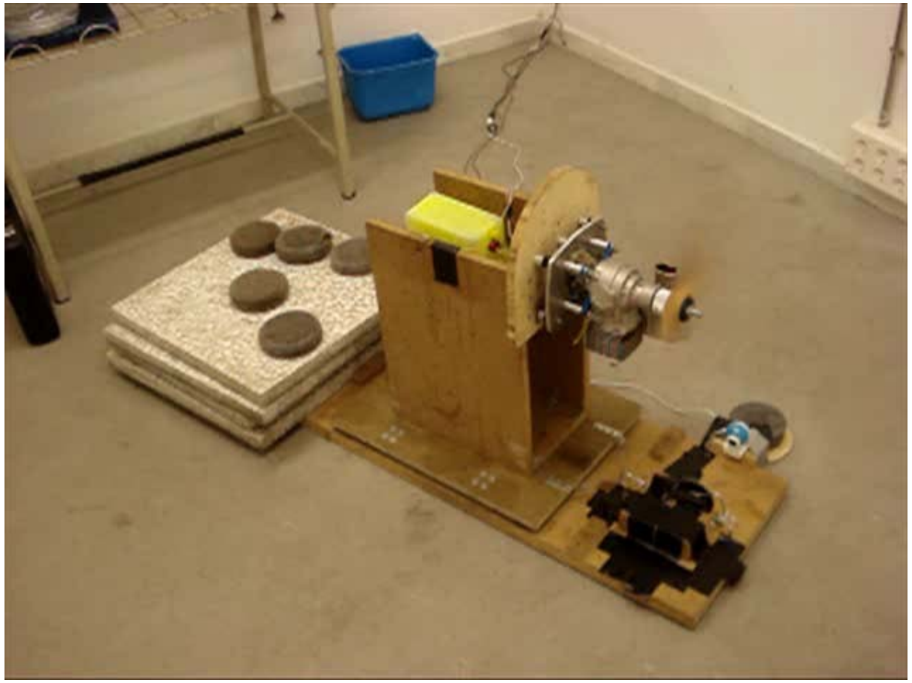
Engine Performance: Modelling II

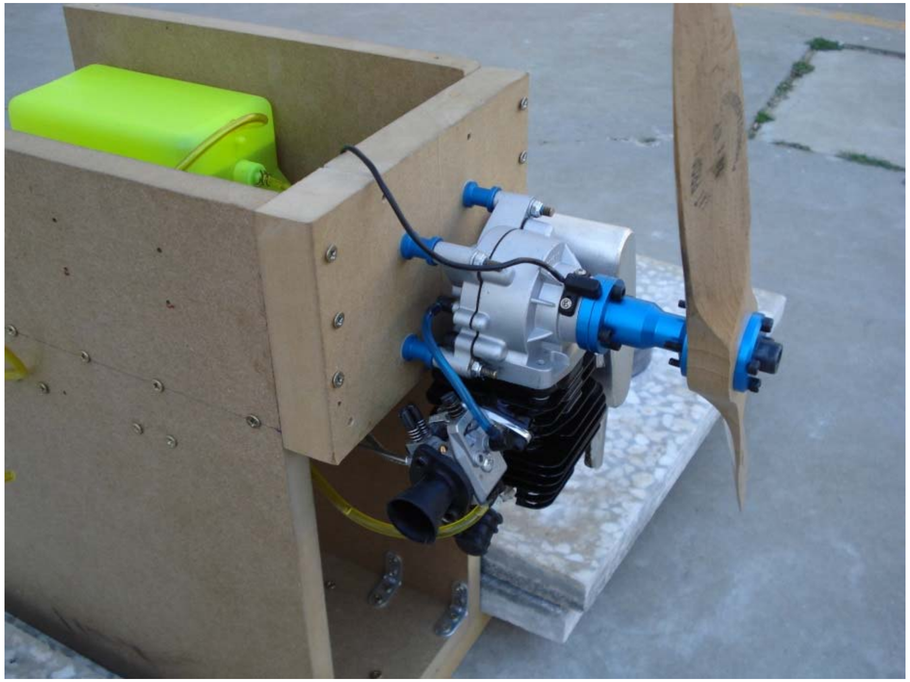
THOR 45

Graupner G58

Engine Performance: Engine Tests

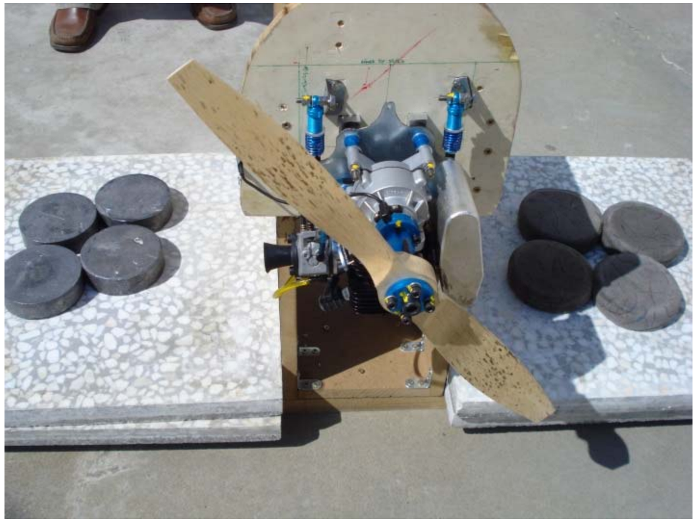


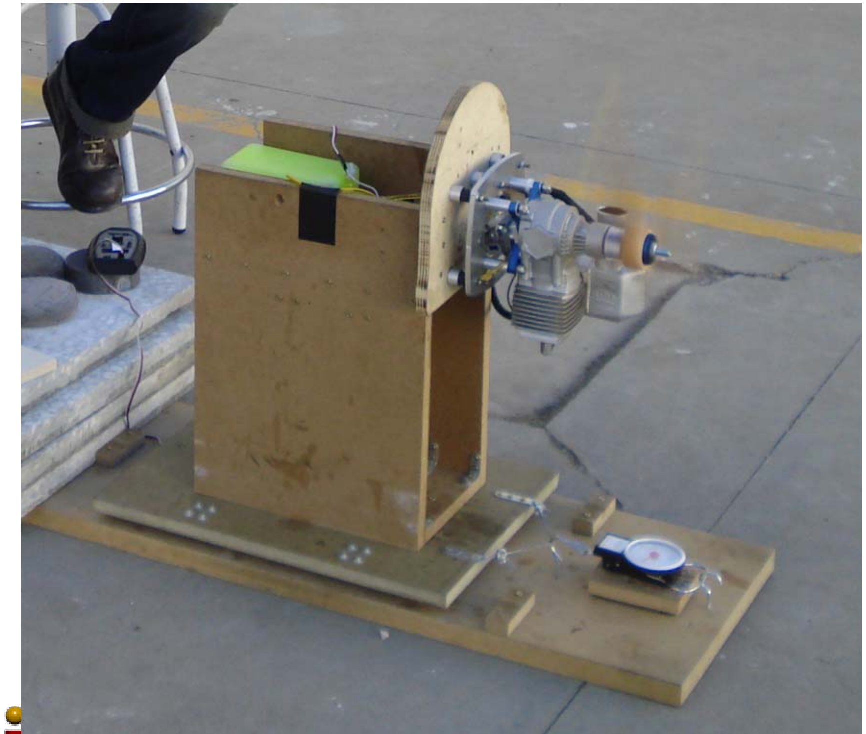




Engine Performance: Engine Tests - II

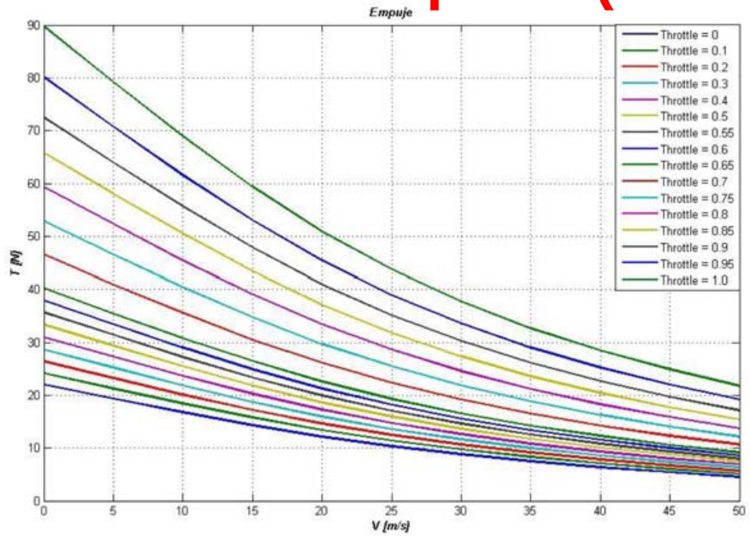
Testing different engines and different vibration-reduction systems



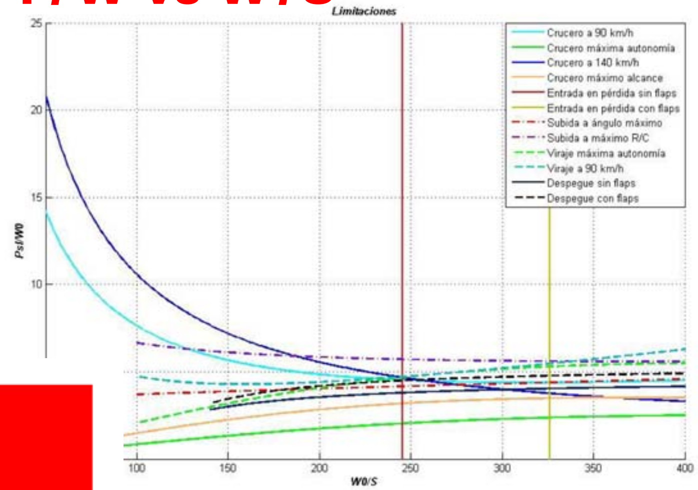


Aircraft Performance Analysis

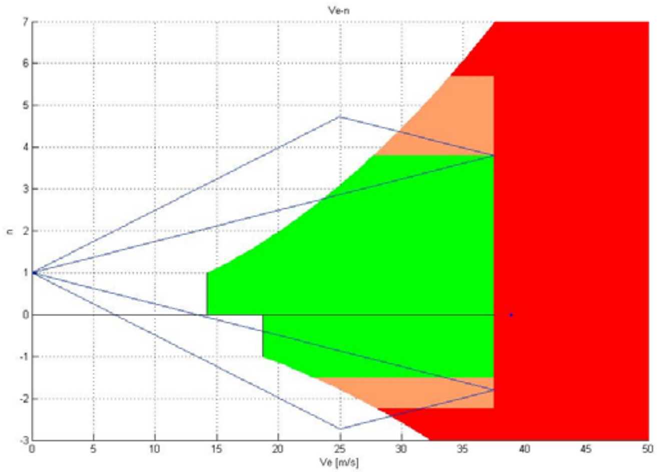
Thrust vs Speed f(throttle)



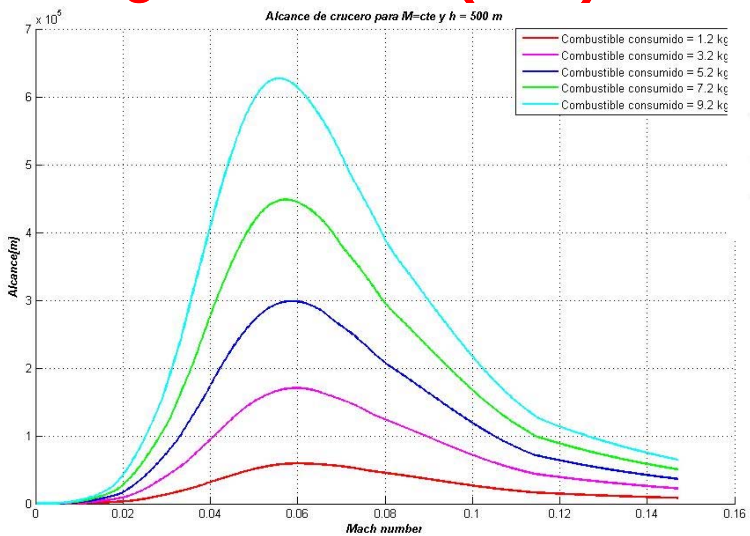
T/W vs W/S



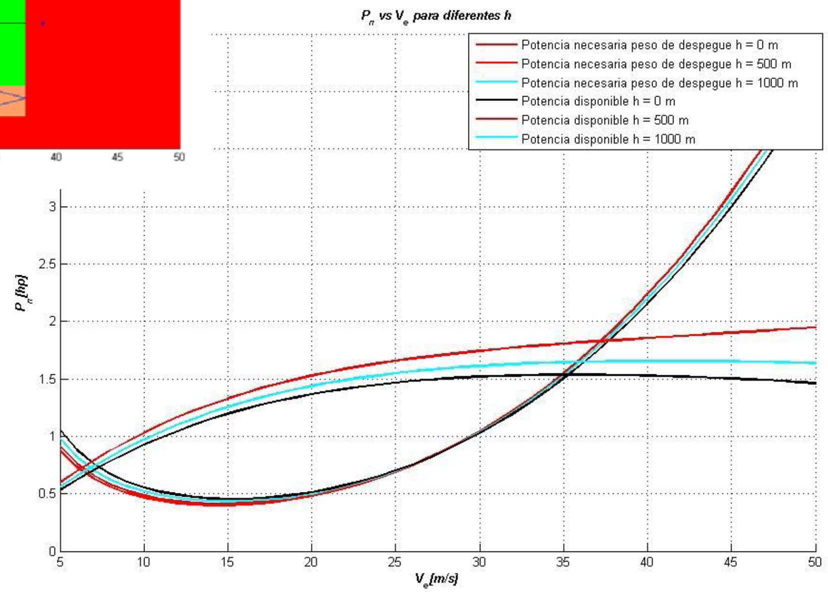
Flight Envelope



Range vs Mach f(fuel)



P vs. V



Céfiro Performance

- **Engine:**
  - Two-stroke engine: Graupner G58
  - Power (Hp) 8.5
  - Cylinder capacity (cm^3) 58
  - Blade (in) 22

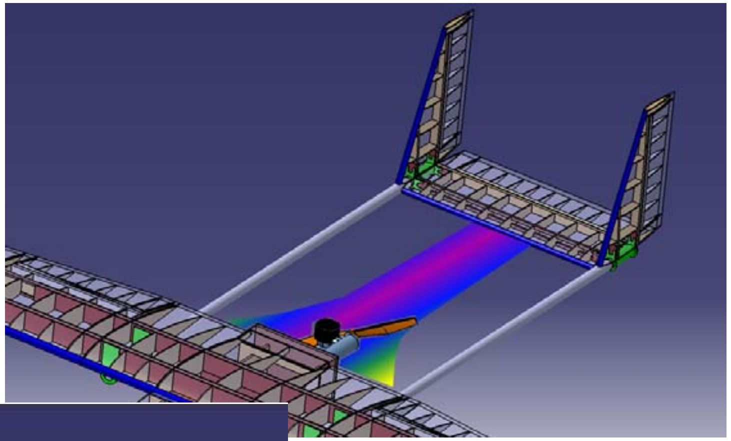
- **Performances**
  - Cruise speed (Km/hr): 90
  - Climb speed (m/s): 3.2
  - Long range cruice speed (km/hr) 74
  - Loiter cruise speed (km/hr) 65
  - Clean stall speed (km/hr) 54,3
  - Dirty stall speed (km/hr) 47
  - Ceiling @ MTOW (m) 1500
  - Endurance (hr) 1.4
  - Range (km) 100
  - Takeoff distance (m) 180
    - 59 m rolling
  - Landing distance (m) 613
    - 78 m rolling

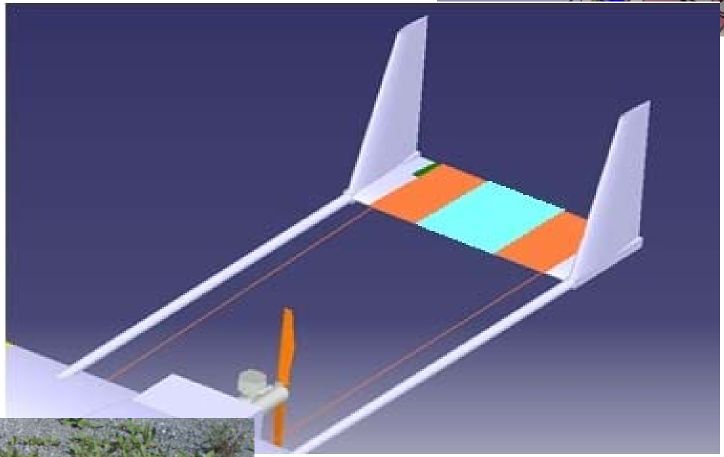
- **Weights:**
  - Maximum TakeOff Weight (MTOW) (kg) 25.6
  - Maximum Payload (kg) 7.5
  - Máximun Fuel (kg) 2.0
    - (posibility to increase by exchanging it by payload)

Stability and control - I

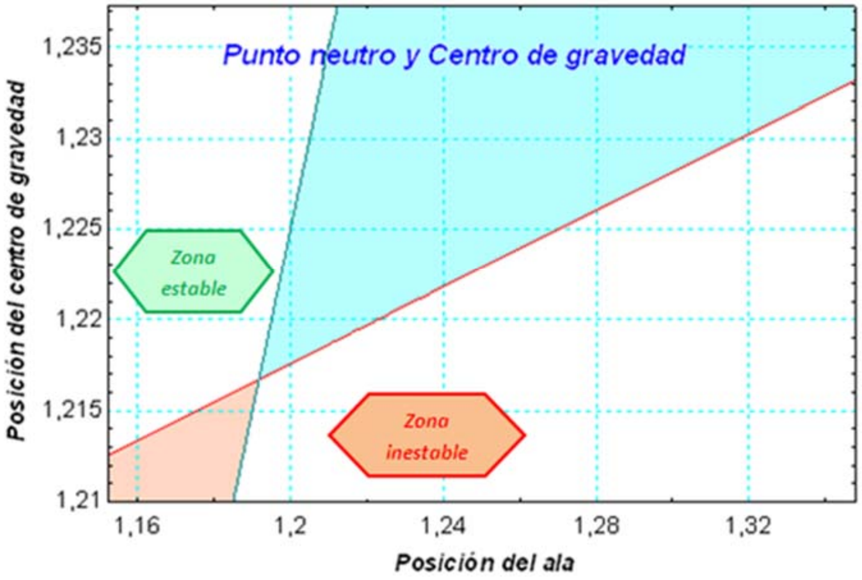
- The necessity of a precise estimation of Cefiro’s dynamic and static behavior yielded in a very complete stability and control study.
  - Use of classical tools to study the static and dynamic responses.
    - Longitudinal and lateral static stability.
  - Static margin analysis:
    - Payload studies.
  - Optimization of aerodynamic surfaces (concurrent engineering).
    - Wing position.
    - Shape, size and location of the tail.
    - Trim analysis.
    - Incidence of the tail.
    - Pusher configuration effects on horizontal stabilizer during critical maneuvers.
      - Takeoff and landing
- Great deal of work was directed towards obtaining a parametric model able to estimate the stability derivatives:
  - Merge of the available literature: F. Smetana, B. Pamadi, J. Roskam.
  - Comparison of analytical methods with a real airplane (B-747).
  - Yielded an extensive dynamic study:
    - Dynamic longitudinal stability: Phugoid and Short Period.
    - Dynamic lateral stability: Spiral mode, Dutch roll and Roll subsidence.

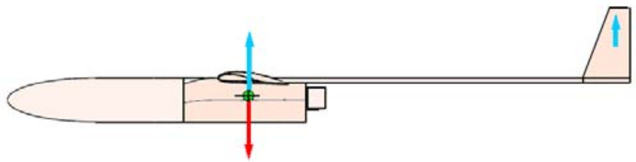
Stability and control - I





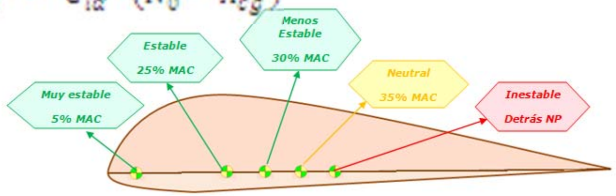
Stability and control - II



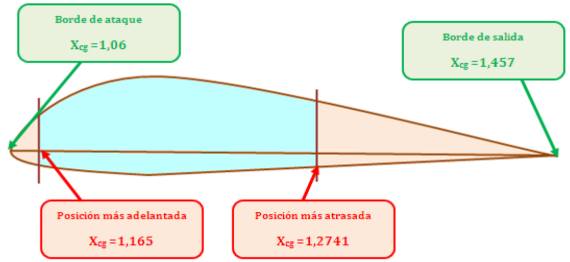


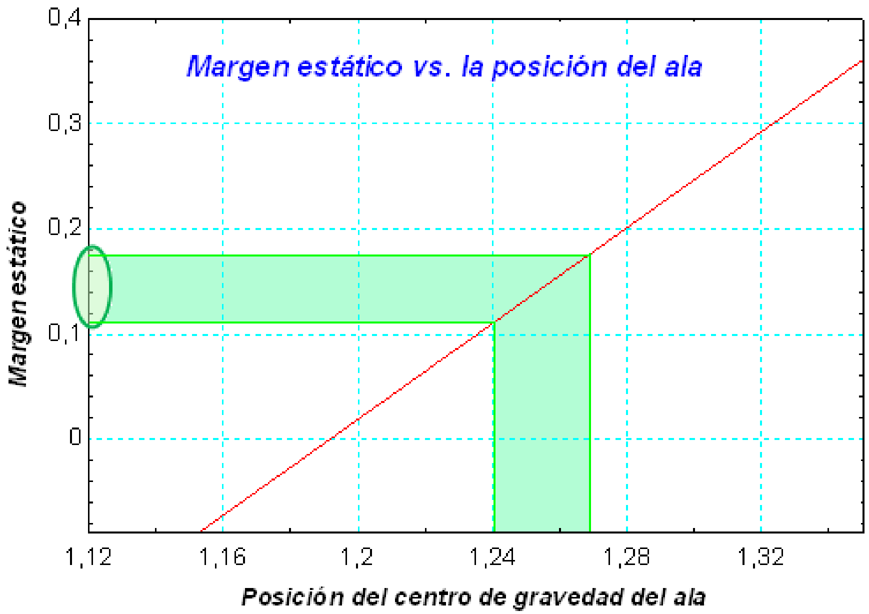
$$0 = C_{lawb} \cdot (\overline{X_{cg}} - \overline{X_{cawb}}) - C_{lat} \cdot \left(1 - \frac{\partial \varepsilon}{\partial \alpha}\right) \cdot \left(\eta_{hafe} \cdot {S_{afe}}/{S} + \eta_{hnoafe} \cdot {S_{noafe}}/{S}\right) \cdot (\overline{X_{cat}} - \overline{X_{cg}})$$

$$C_{m\alpha} = -C_{l\alpha} \cdot (N_0 - \overline{X_{cg}})$$



Center of gravity Studies





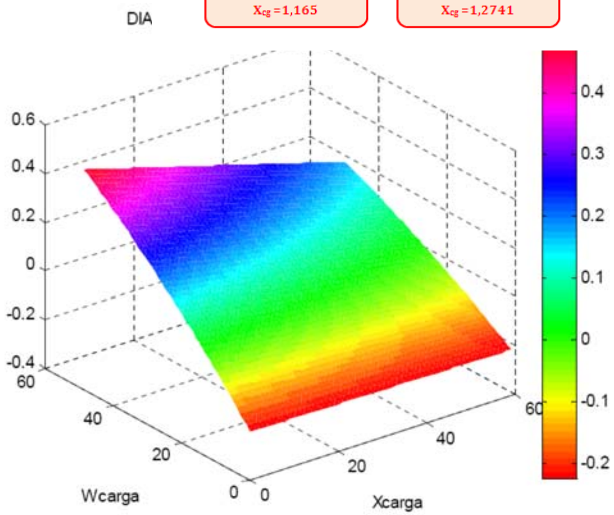
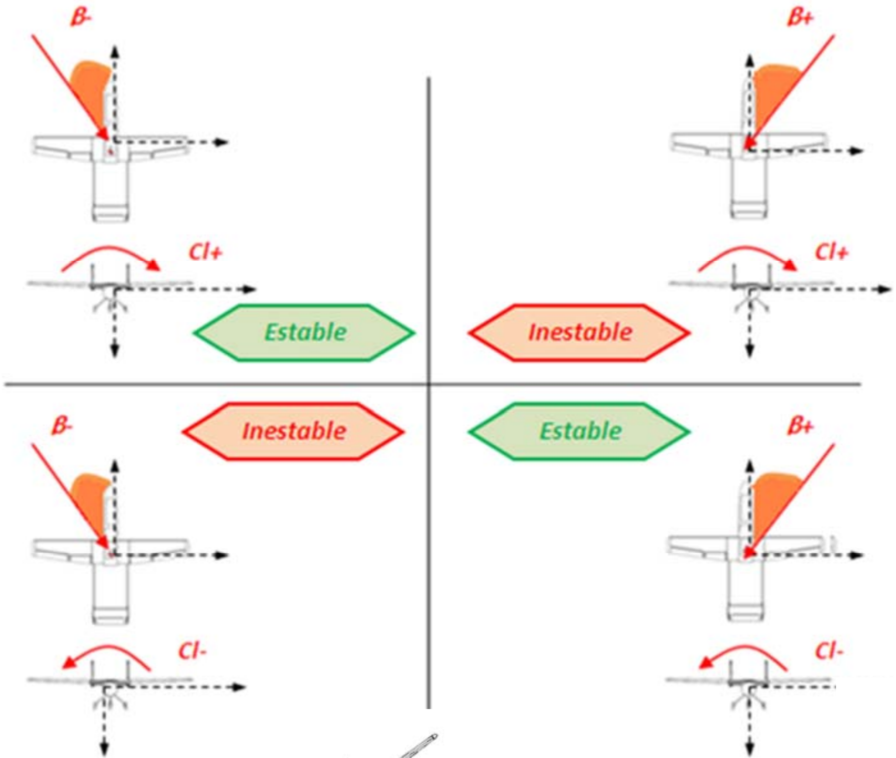
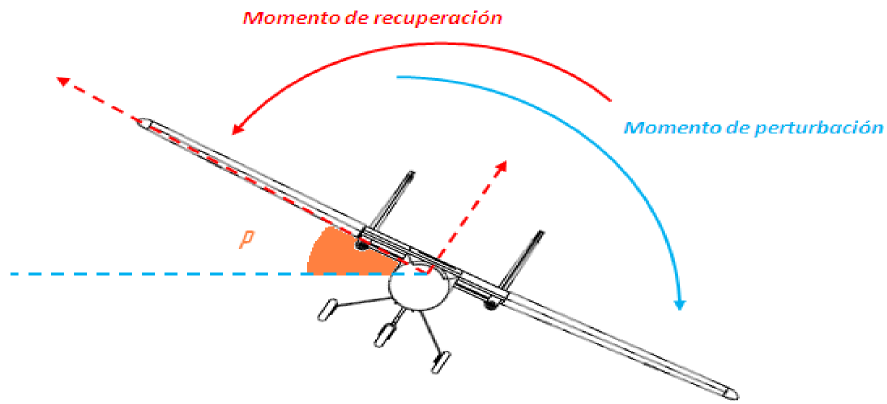
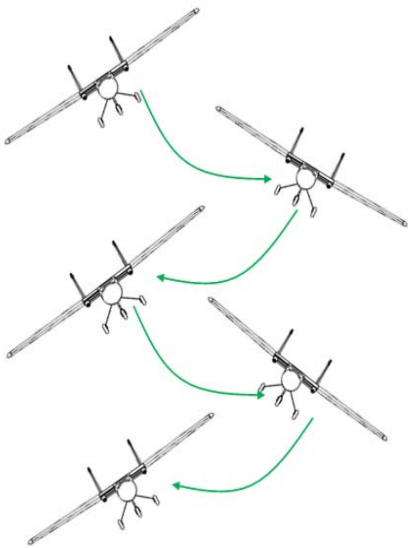


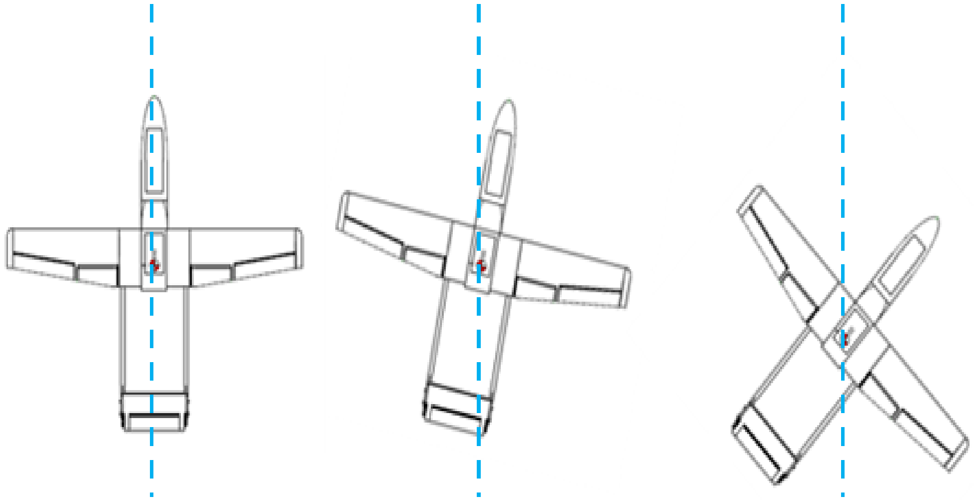
Figura 4.29. - Centrado carga de pago delantera estimada

Stability and control - II



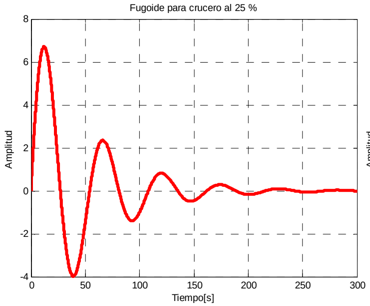


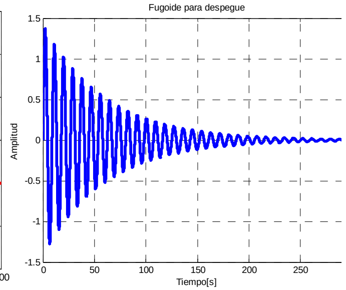


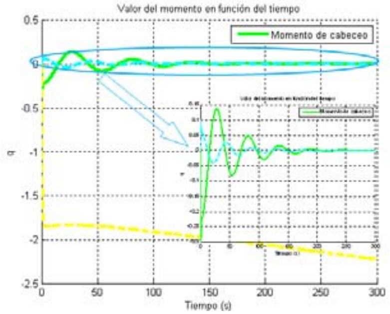


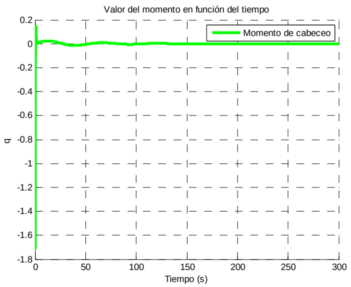
Stability and control - II

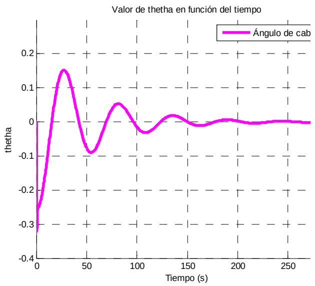
Dynamics Stability Analysis











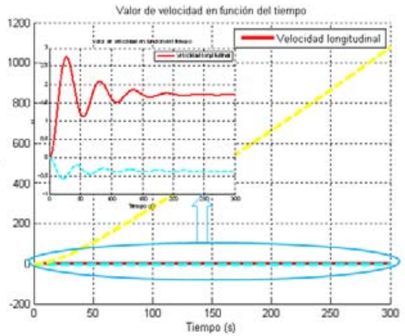


Tabla de autovalores

	Autovalores	Frecuencia	Amortiguamiento	Periodo
Crucero al 25 %	$-0,019 \pm 0,116i$	0,1179	0,1646	54,044
	$-2,824 \pm 3,021i$	4,1353	0,683	2,08
Crucero al 75 %	$-0,029 \pm 0,239i$	0,2415	0,1240	26,2205
	$-4,431 \pm 4,772i$	6,5124	0,6804	1,3166
Despegue	$-0,017 \pm 0,703i$	0,7028	0,0237	8,9421
	$-2,178 \pm 2,537i$	3,3438	0,6513	2,4763
Aterrizaje	$-0,004 \pm 0,626i$	0,626	0,0056	10,037
	$-1,646 \pm 1,758i$	2,4084	0,6834	3,5735

Equilibrio de fuerzas | **Equilib**

$$F = m\left(\frac{dV}{dt}\right)_i \qquad M = \left(\frac{dH}{dt}\right)_i = \left(\frac{d(I\omega)}{dt}\right)_i = \left(\frac{dI}{dt}\right)_i \omega + I\left(\frac{d\omega}{dt}\right)_i$$

$$F_x = m\left(\dot{U} + qW - rV\right) \qquad L = \dot{p}I_x - I_{xz}(pq + \dot{r}) + qr\left(I_z - I_y\right)$$
$$F_y = m\left(\dot{V} + rU - pW\right) \qquad M = \dot{q}I_y + rp\left(I_x - I_z\right) + I_{xz}\left(p^2 - r^2\right)$$
$$F_z = m\left(\dot{W} + pV - qU\right) \qquad N = \dot{r}I_z - I_{xz}(\dot{p} - qr) + pq\left(I_y - I_x\right)$$

Linealización del problema

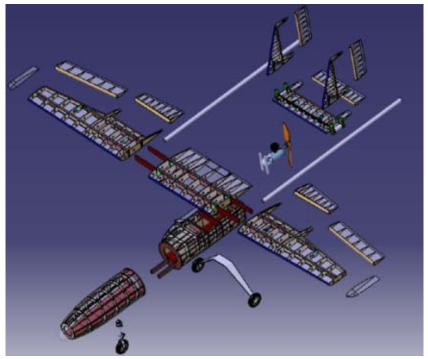
$$\Delta C_x = \frac{\partial C_x}{\partial u}u + \frac{\partial C_x}{\partial \alpha}\Delta\alpha + \frac{\partial C_x}{\partial \theta}\Delta\theta + \frac{\partial C_x}{\partial \dot{\alpha}}\Delta\dot{\alpha} + \frac{\partial C_x}{\partial q}q + \frac{\partial C_x}{\partial \delta_e}\Delta\delta_e \ldots$$

Autovalores estabilidad lateral-direccional

Crucero al 25 %	-14,8229	-0.945 ± 3.011 i	-0,0059	0
Crucero al 75 %	-22,9344	-1,2425 ± 4,6495 i	-0,0411	0
Despegue	-7,8425	-1,2176 ± 1,7648 i	0,0444	0
Aterrizaje	-7,3948	-1,1827 ± 1,7533 i	0,0455	0

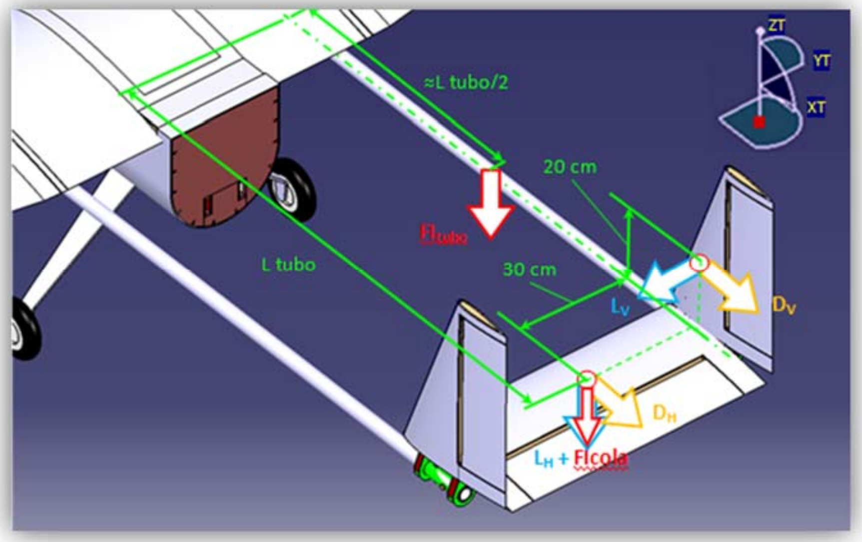
Structural design and manufacturing process

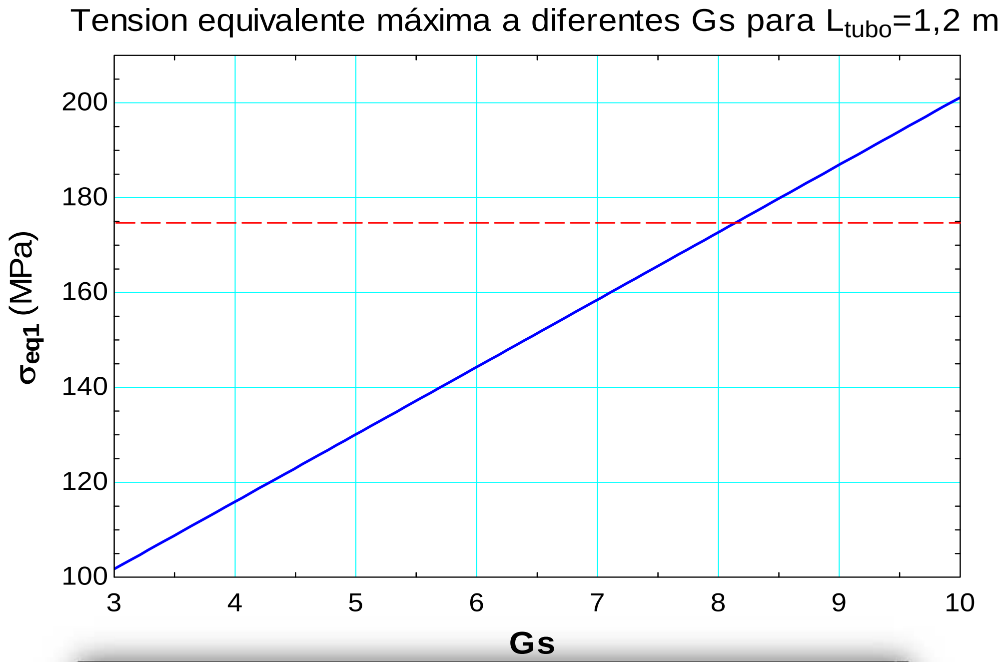
- During the preliminary design, emphasis was made that the UAV had to meet:
  - The performance requirements (RFP).
  - Construction requirements:
    - Use of conventional materials to ease the construction of first prototype.
    - Modular design: transportability and reparability.
    - Easiness and fast reparability Process: friendly to handle and repair materials.
    - Simple and sound construction process.
      - Extensive use of jigs: repetitivity and precision.
- During the design phase it was identified the importance of optimizing both the construction and fabrication processes:
  - Extensive use of Computer Aided Tools (CAD & CAM).
  - Improvement of the original design and construction techniques
- Analysis of stress and strain in the plane with Patran/Nastran was made in critical zones:
  - Union with wing and fuselage.
  - Tail-booms.
  - Nose and main fuselage union.

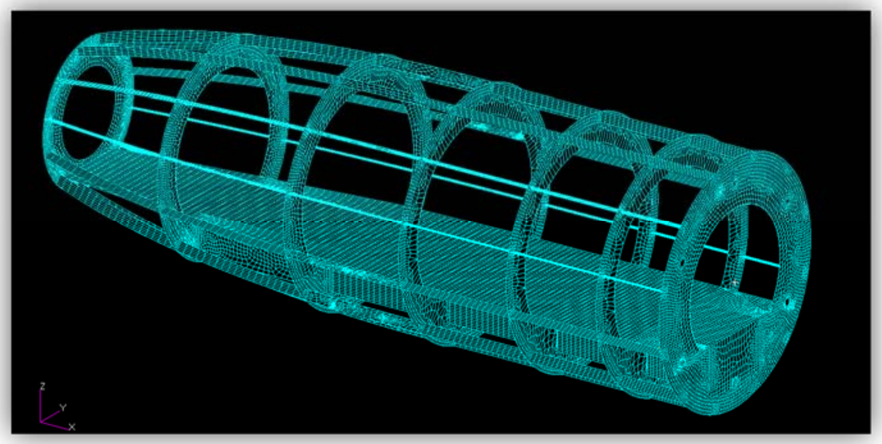


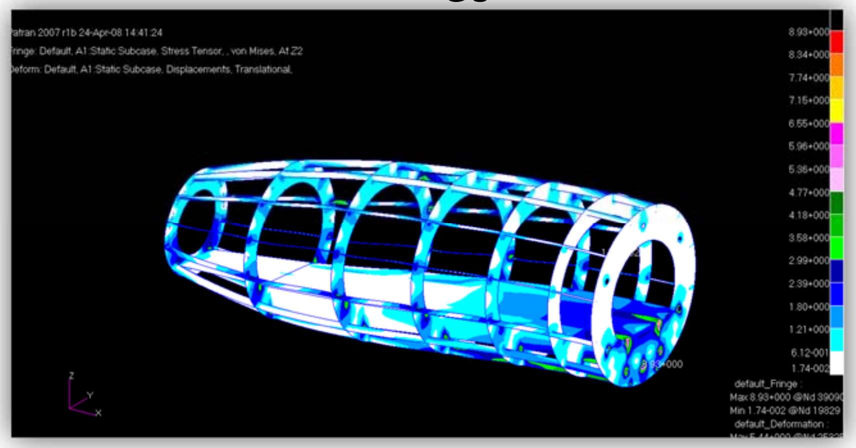
Structural Analysis

- Study of the loads for the principal structural elements:
  - Fuselage and wing spars, and tail-booms: use of PATRAN-NASTRAN.

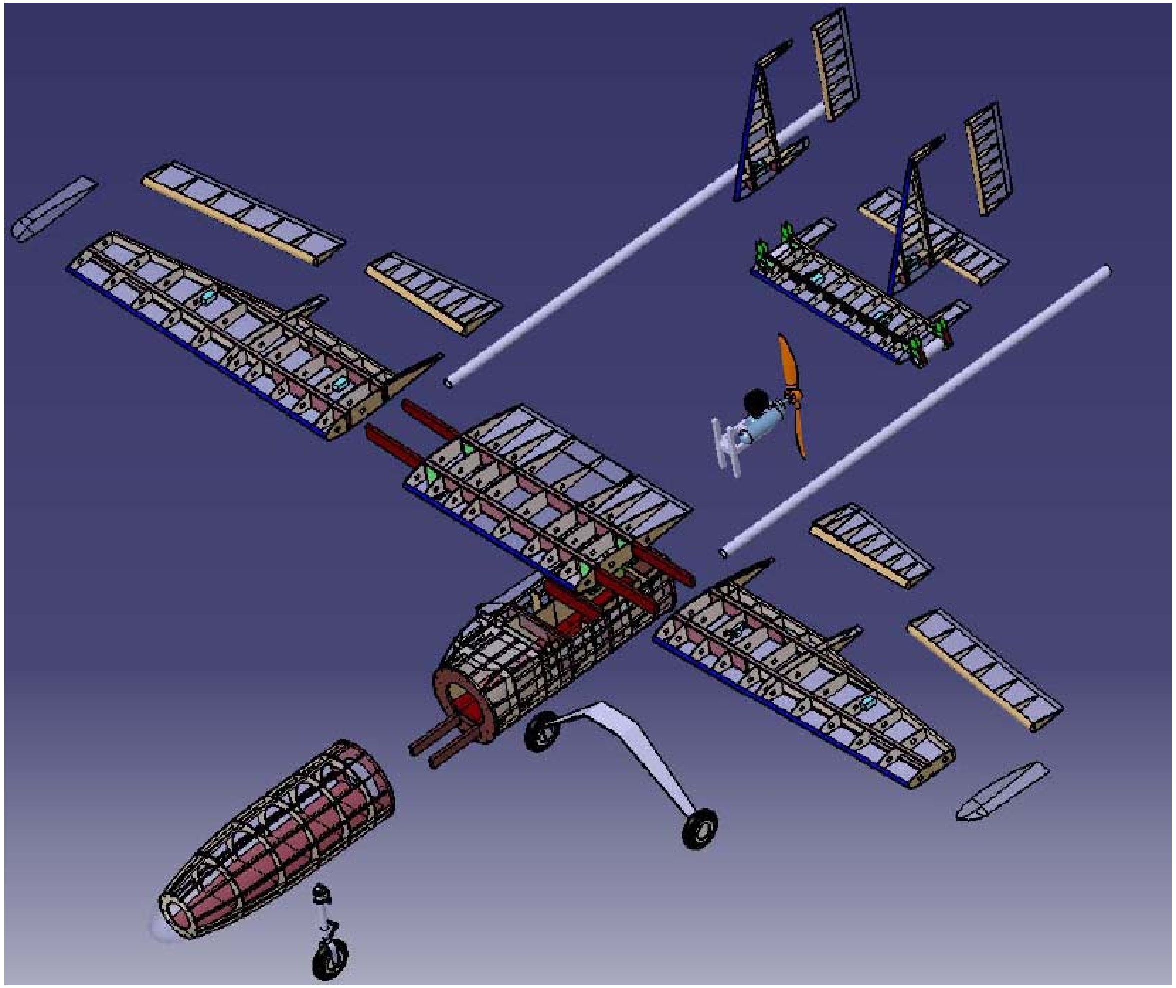


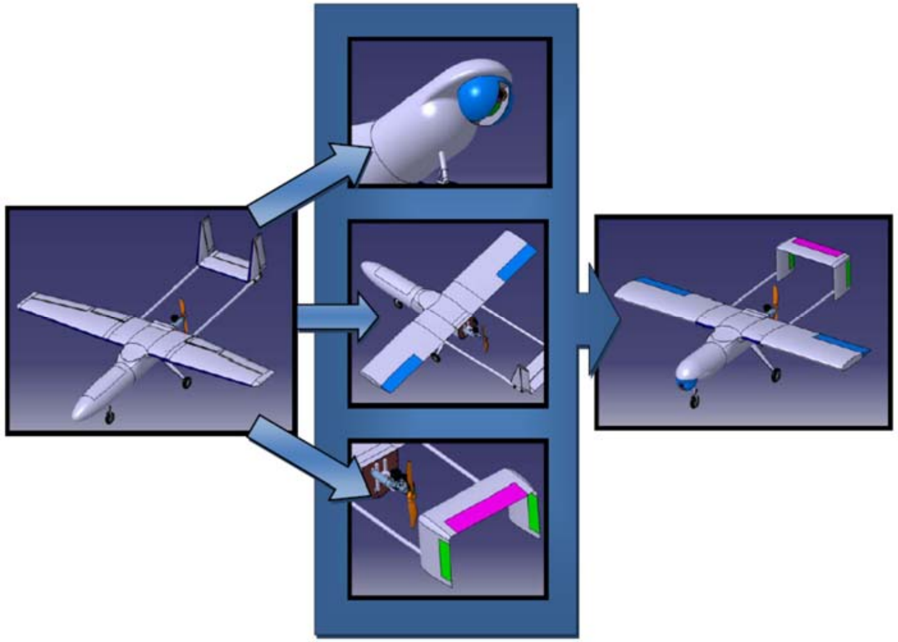






Modular design - I





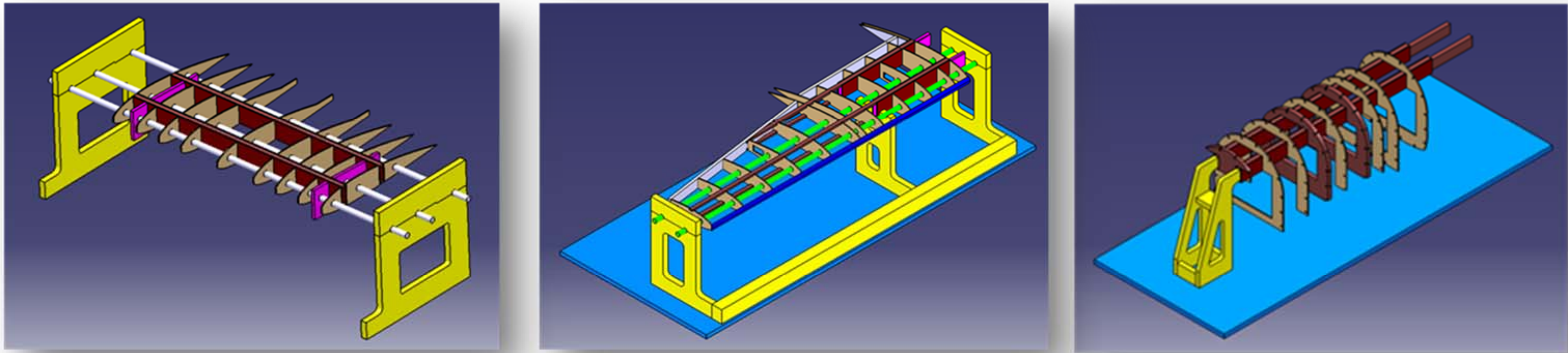
- Nose fuselage.
- Center fuselage.
- Wing divided in three sections.
- Tail.
- Tail-booms.

Modular design - II

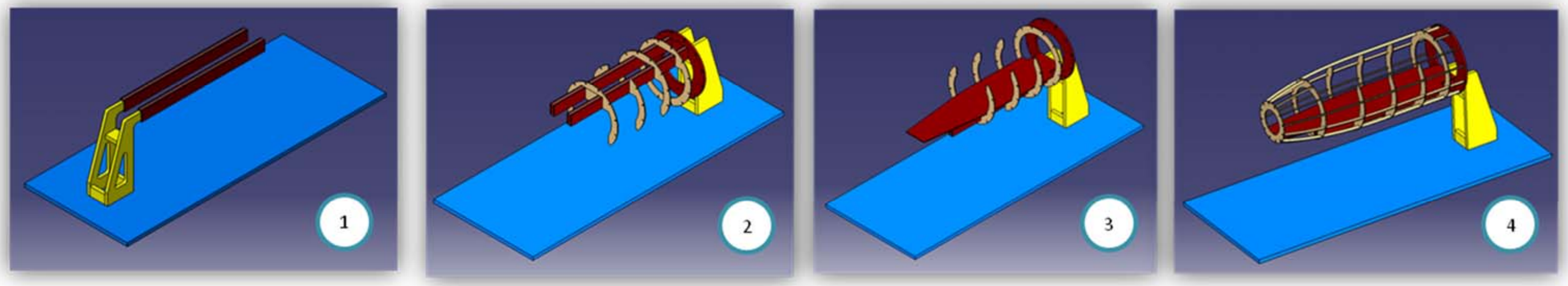
Manufacturing Process - I

- Extensive use of construction techniques

Construction Jigs

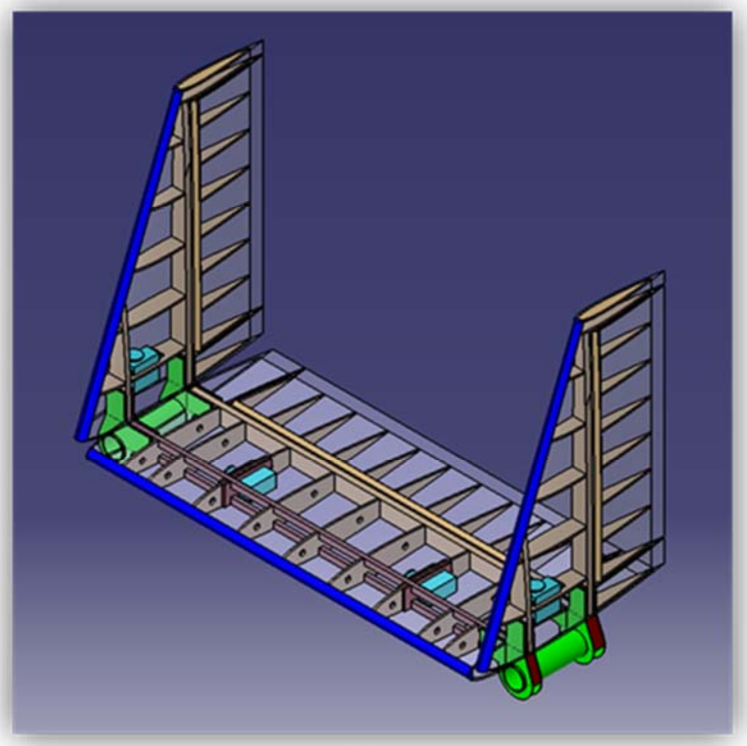


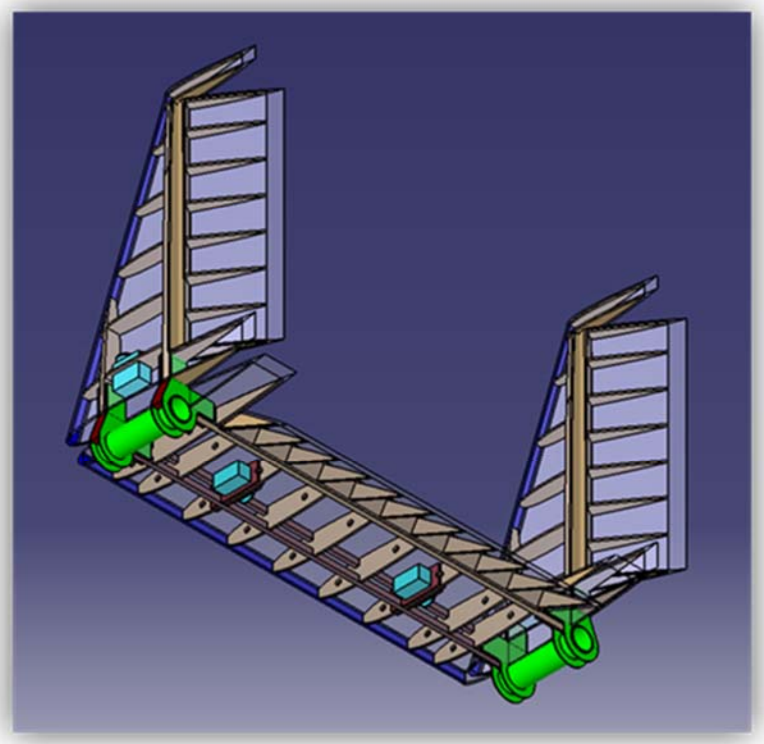
Construction Process

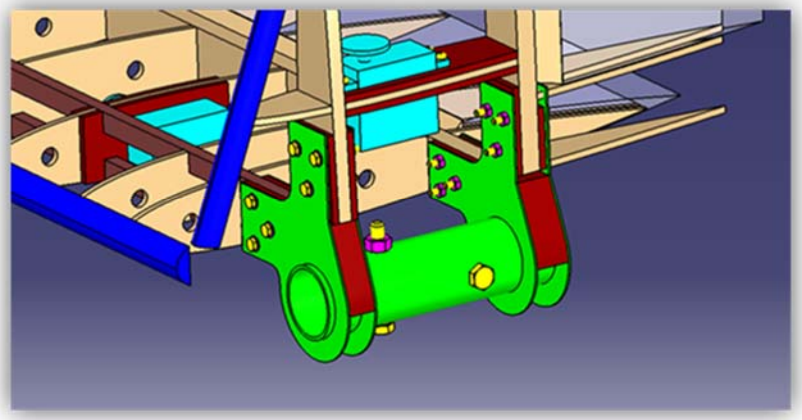


Manufacturing Process - II

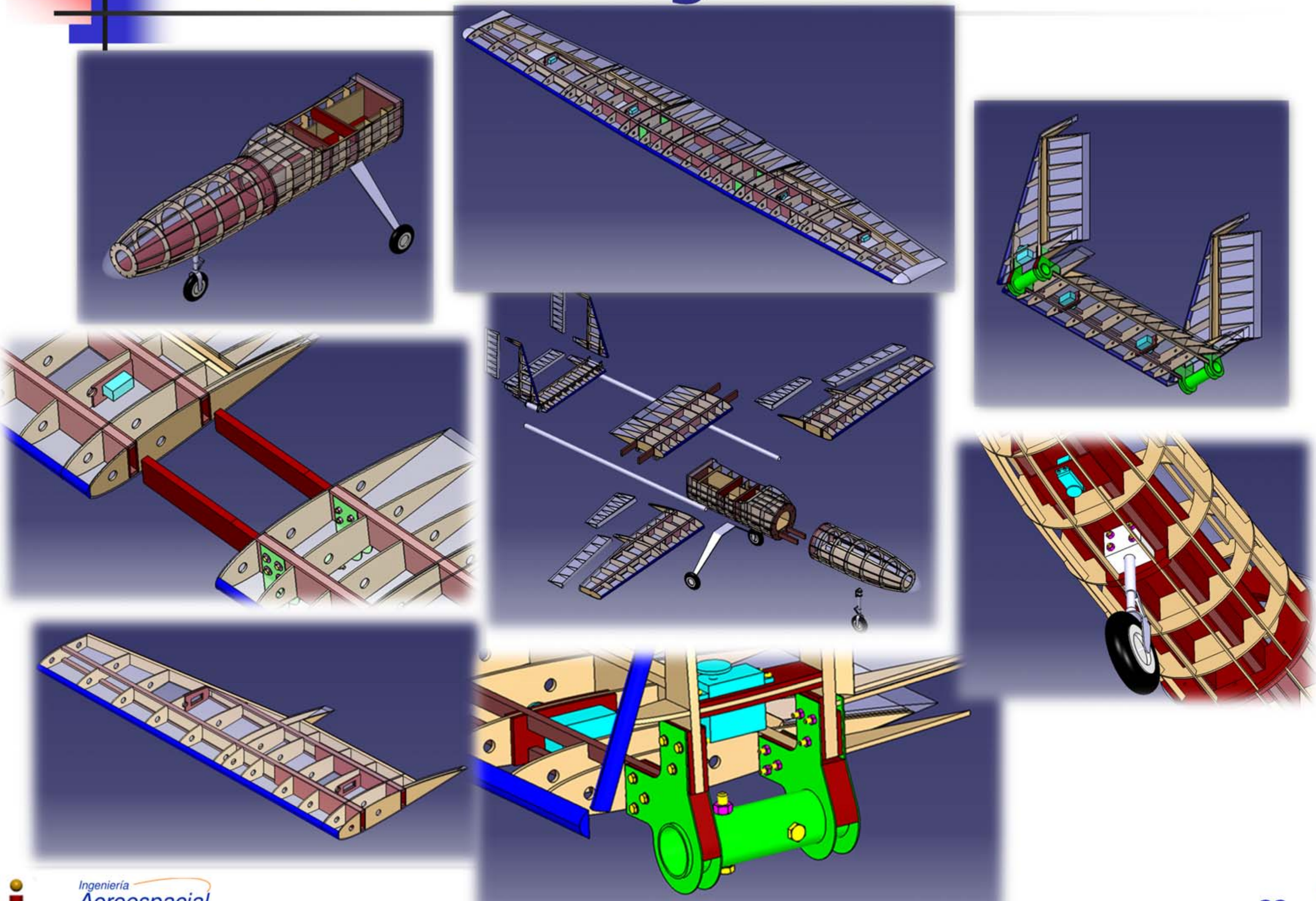
- Great detail CAD Model



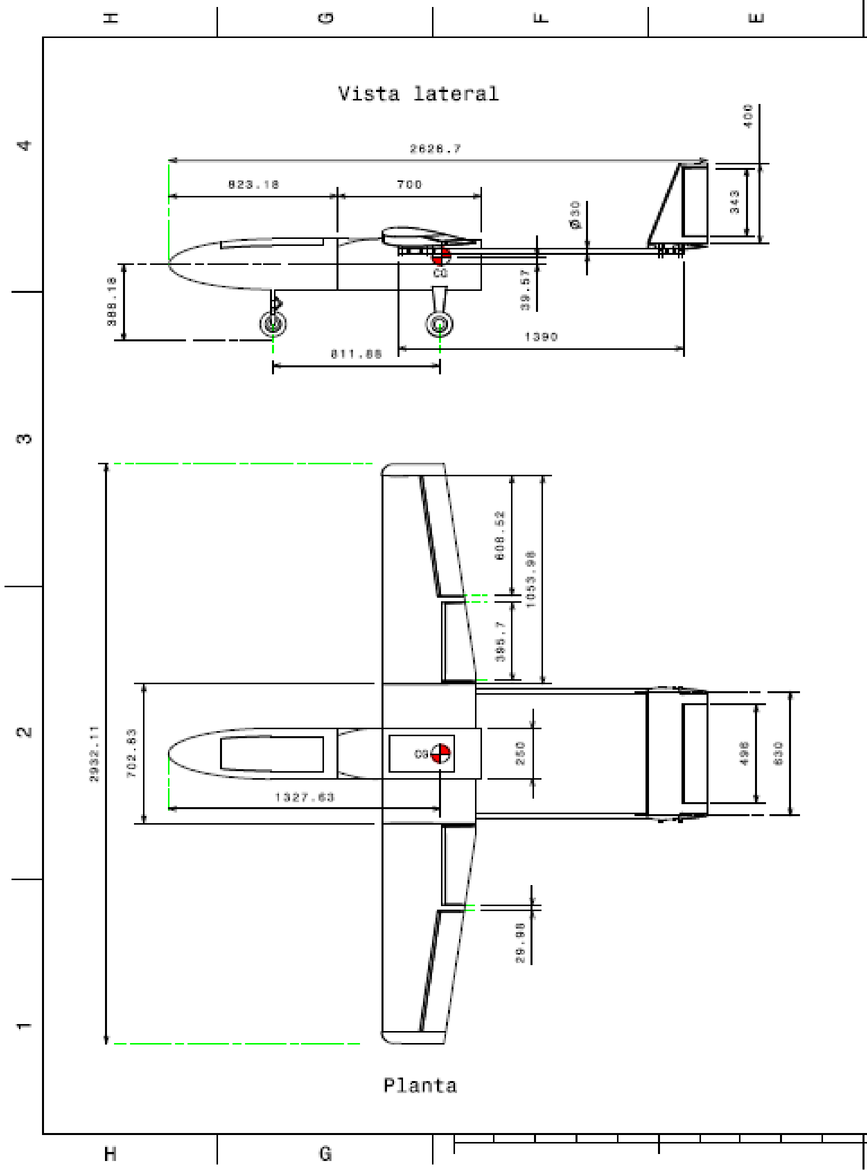


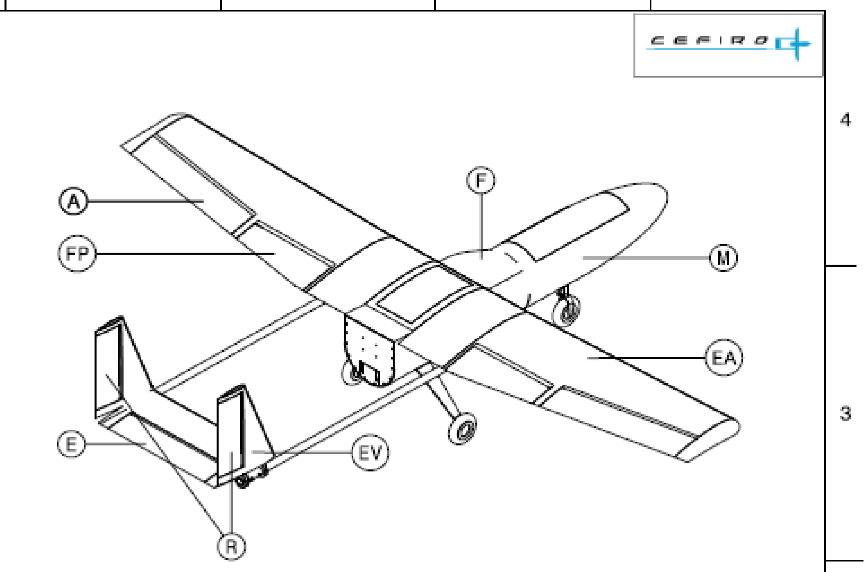


Manufacturing Process - III



Cefiro's Geometry - I



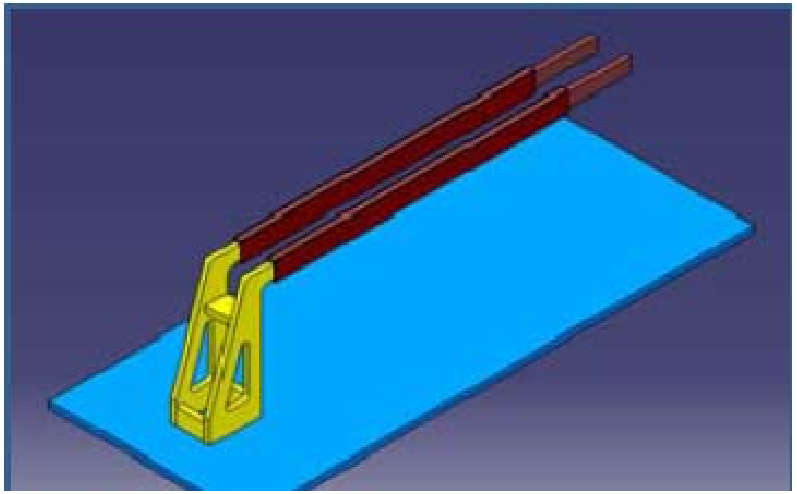


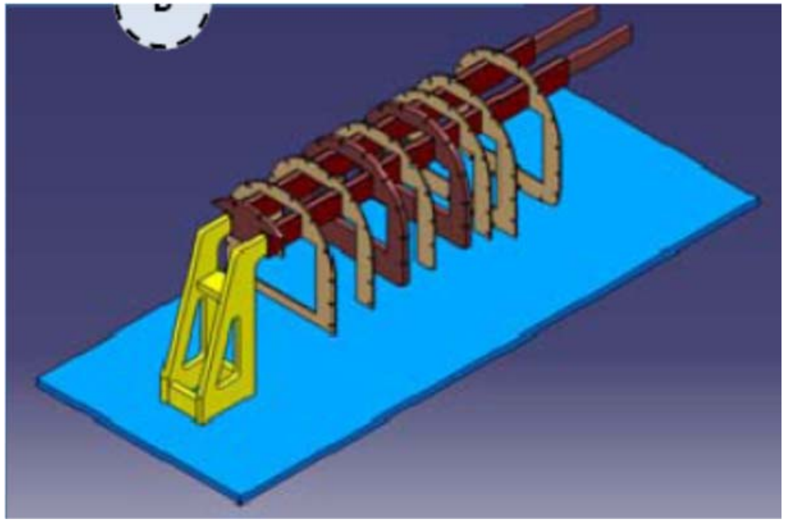
- **Cefiro's Geometry:**
  - **S = 1,088 m²**
  - **S_t = 0,176 m²**
  - **S_t = 0,176 m²**
  - **c = 0,39299 m**
  - **Root chord - c_r = 0,459 m**
  - **Tip chord – c_t = 0,308 m**
  - **Aspect ratio - AR = 8,05**
  - **Wingspan - b = 2,96 m**
  - **Fuselage length – 1,51 m**
- **Empty weight: 15 kg**

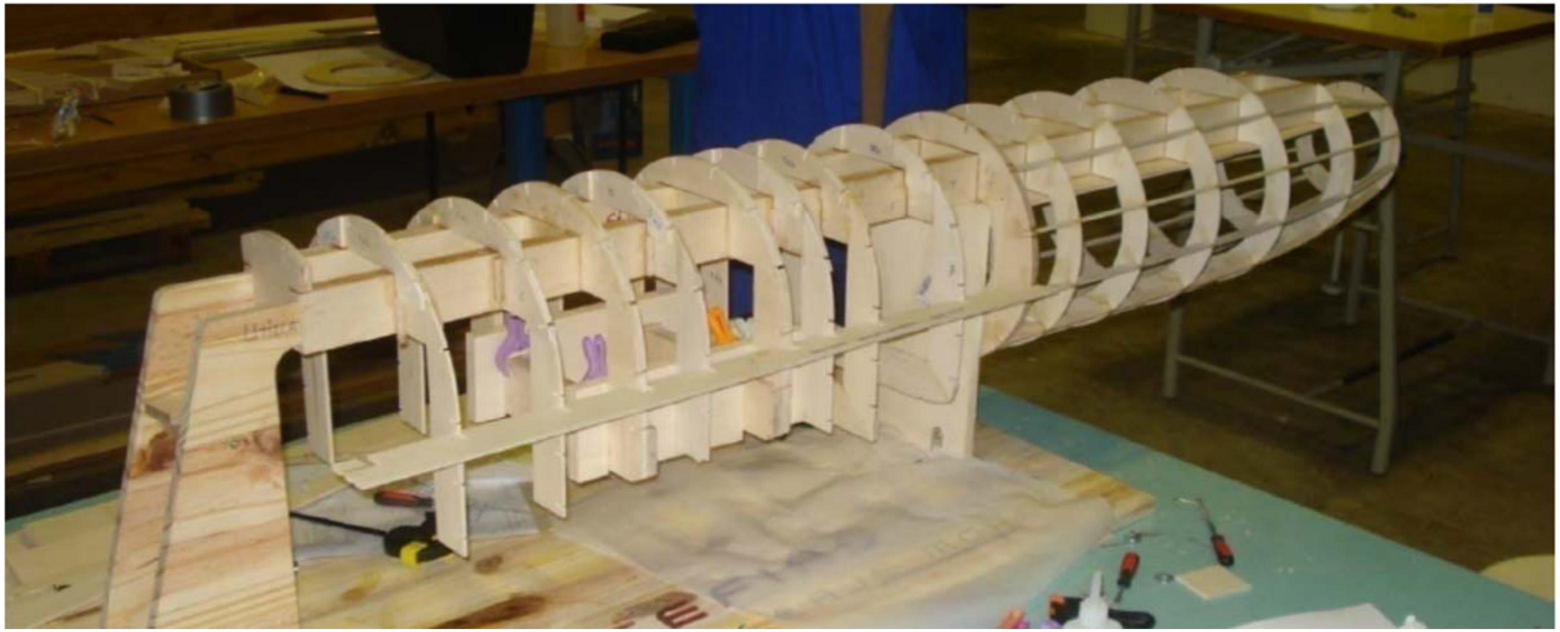
Materials


White Film
Red Film
Balsa
Plywood
Spruce
Aluminum
Steel
Fibre glass
Beech

Construction process - I



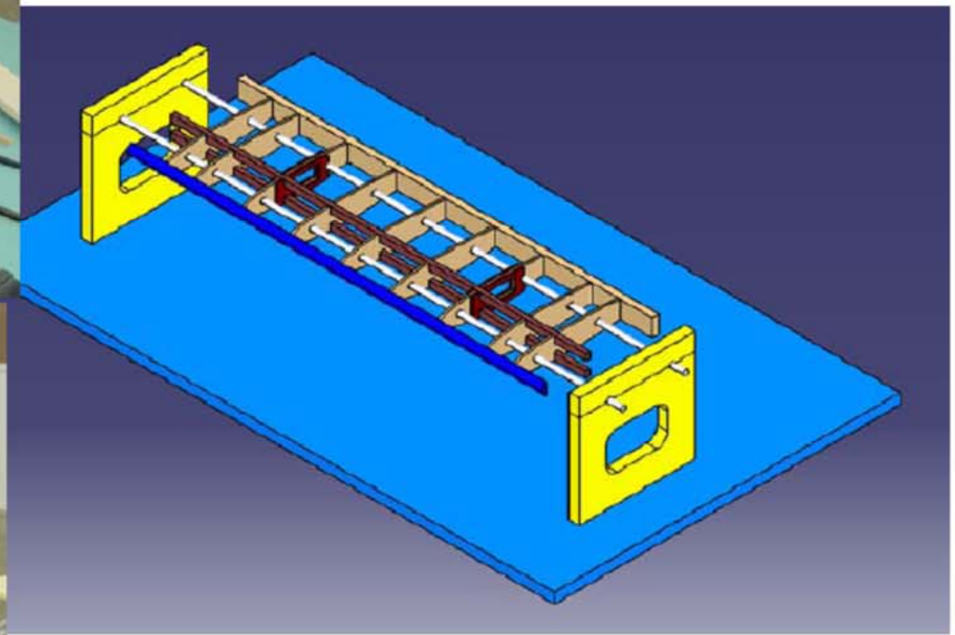




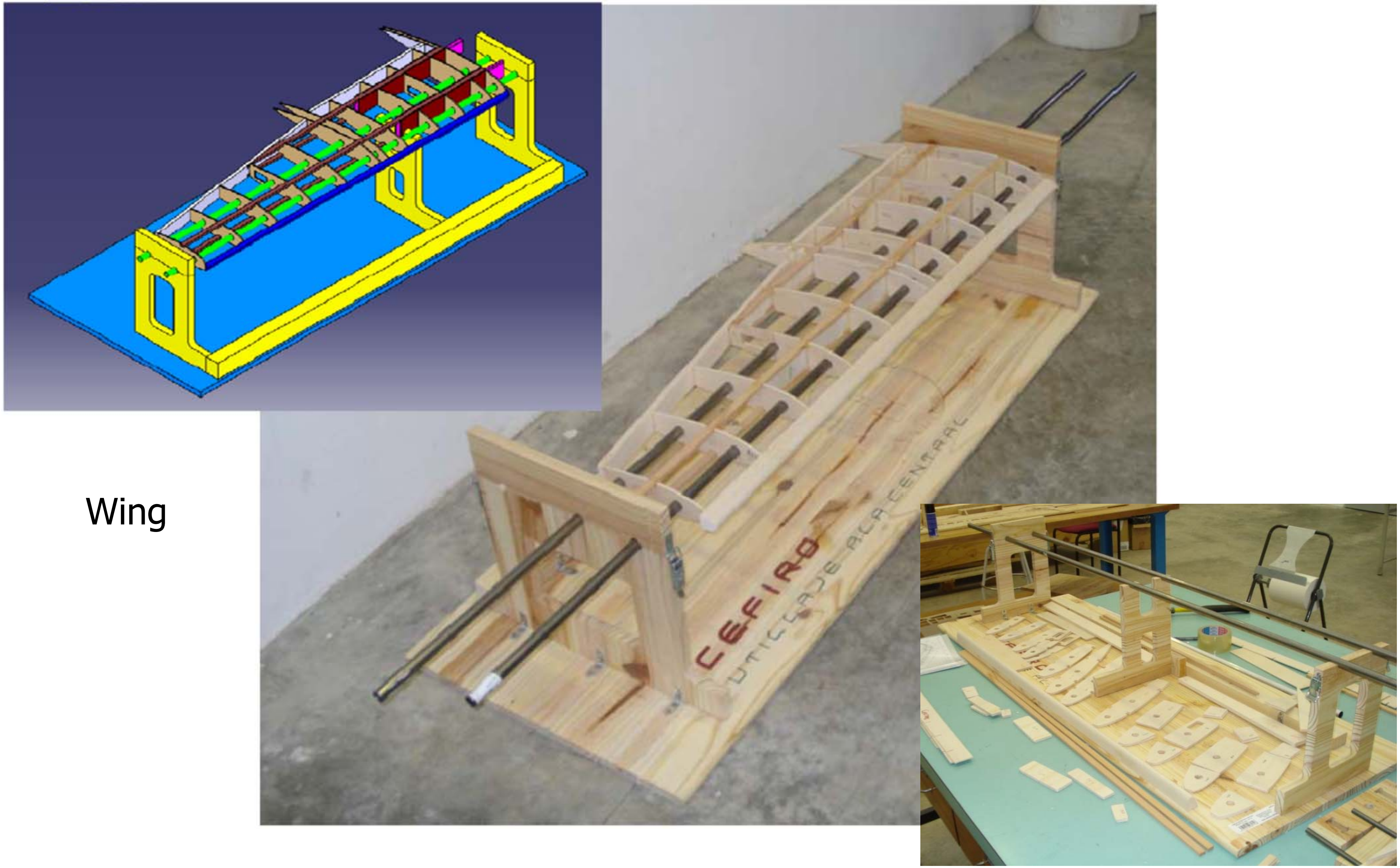
Fuselage

Construction process - I

Horizontal Tail



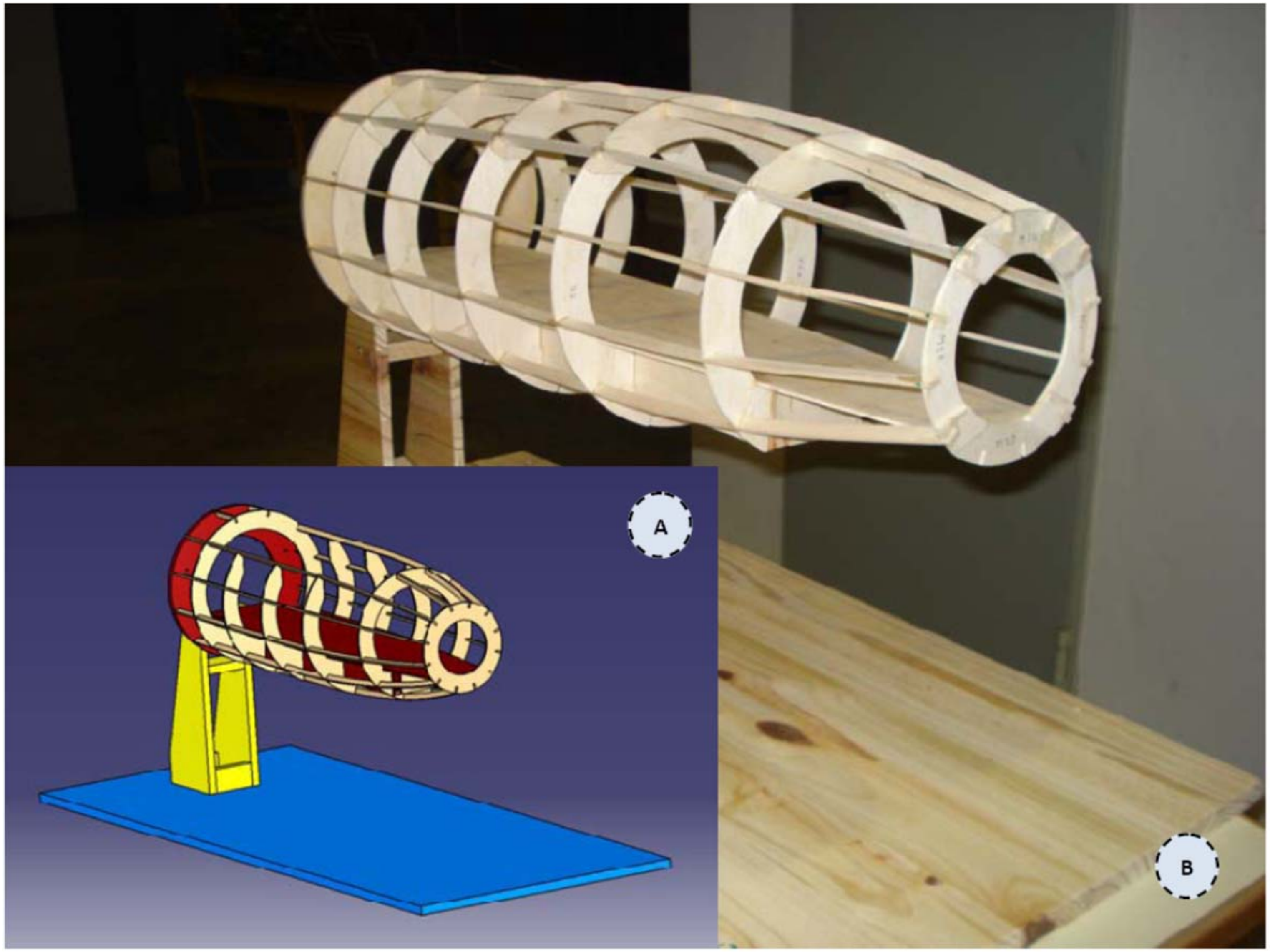
Construction process - III



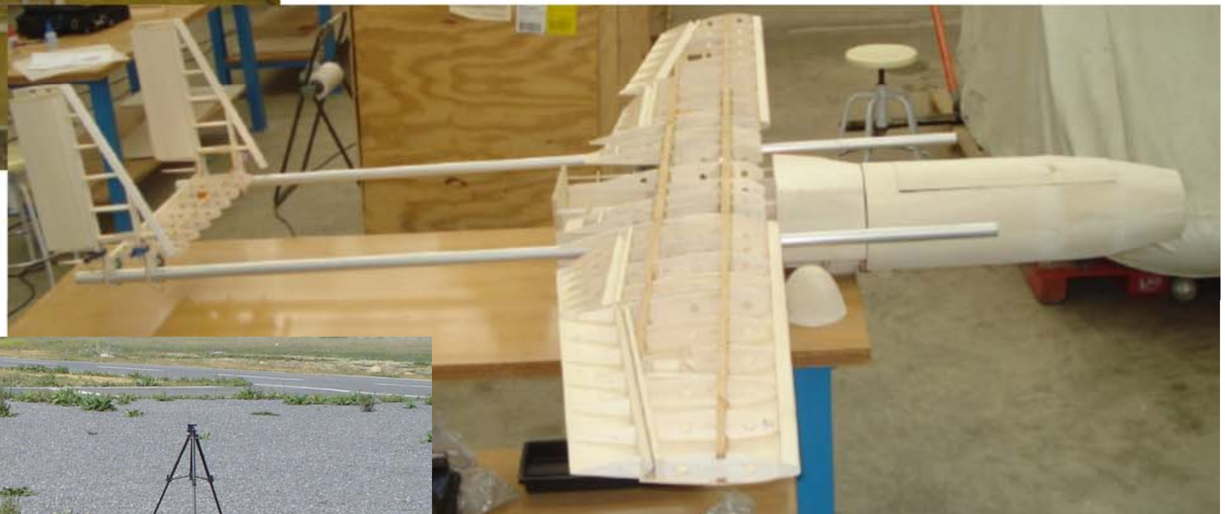
Wing

Construction process - IV

Nose Fuselage

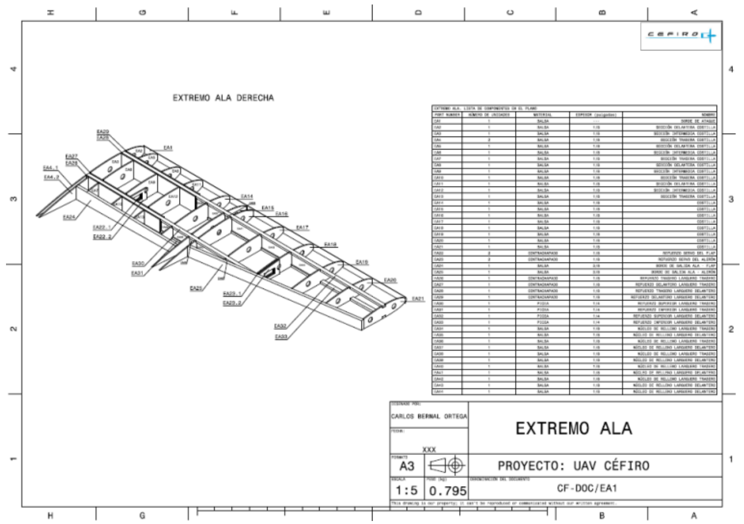


Construction process - V



Production and systems integration - I

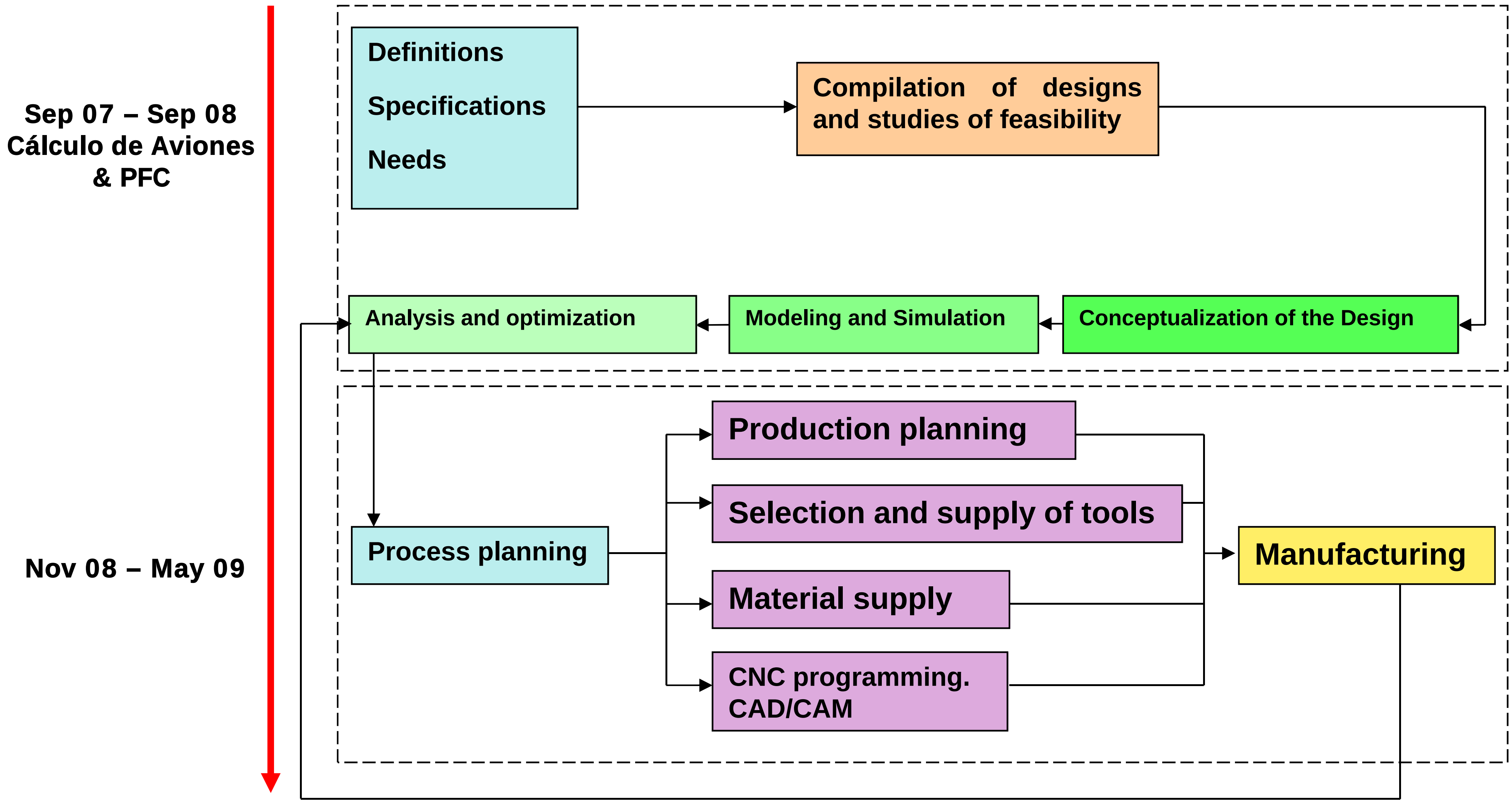
- During the design phase it was identified the importance of optimizing both the construction and fabrication processes.
- In order to do such integration it was identified the need of having a well defined construction and integration of systems sequence:
  - Organization of parts and procedures.
  - Integration of structures.
  - Fuselage Integration:
    - Nose and main fuselage.
    - Fuselage – Wing.
    - Wing–tail.
  - Landing gear integration.
  - Tail-booms integration.
  - Systems Integration
    - Engine and electronic systems
  - Testing Procedures
    - Engine systems integration: from test-stand to airframe.
    - Electronic testing: batteries, RF range, servos.



- Interior harnessing of system.
- Exterior Covering.
- Flight Testing:
  - Engine characterization: Fuel consumption and thrust estimation.
  - Flight test and validation of prototype.

Production and systems integration - II

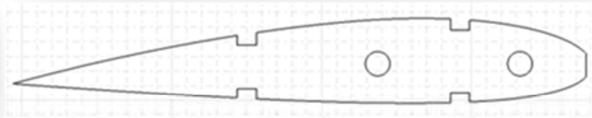
Cefiro's Procedures from Design to Manufacturing



CAD/CAM Design & Development- I

- Methodology:
  - **Environment CATIA V5**
    - Saving each component to be manufactured (CATIA PART)
    - Generate front view of each componen in a 1:1 scale (CATIA DRAWING → .dxf)
  - **Environment VCarve Pro**
    - Treatment of archives .dxf:
    - Generation of the cut trajectories:
    - Generates archives for post-procesing (.tap)
  - **Environment WinPC-NC Professional**
    - Reproduction of tap archives.
    - Executes the cutting trayectories.

2. Módulo Drafting



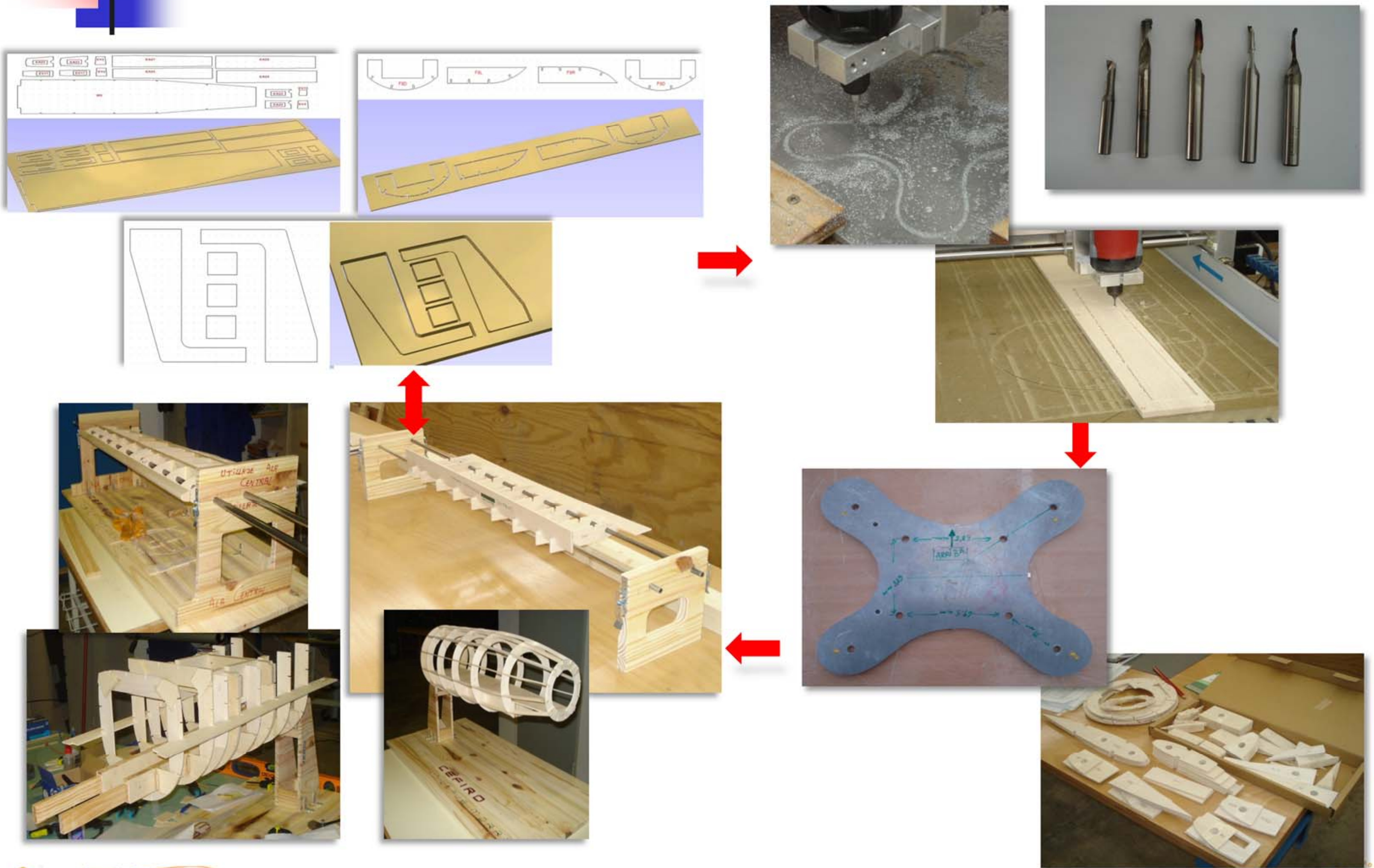
3. Plano a escala 1:1 del componente EA 15. [Archivo .dxf]

4. Preproceso y Postproceso

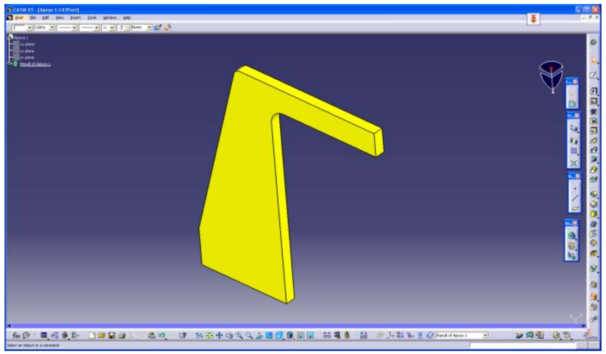
1. Componente EA 15 (costilla de Extremo de Ala) en CATIA V5. [Archivo CATIA PART]

¿mejora?

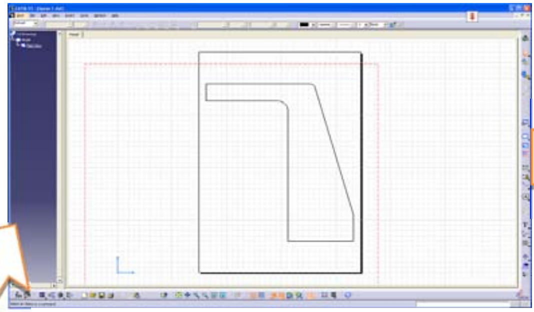
CAD/CAM Design & Development- II



CAD/CAM Design & Development- III

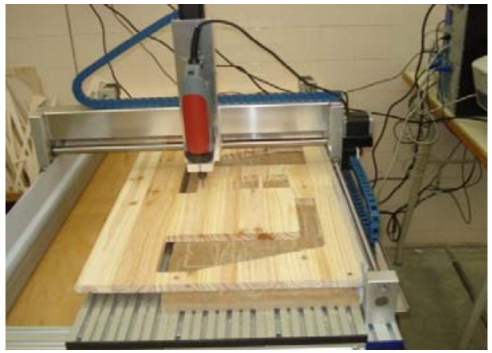


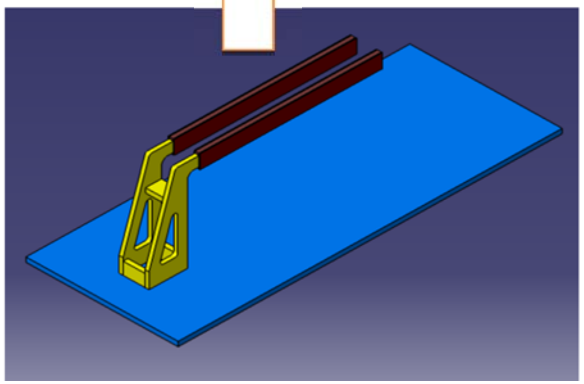
Parts created with CATIA

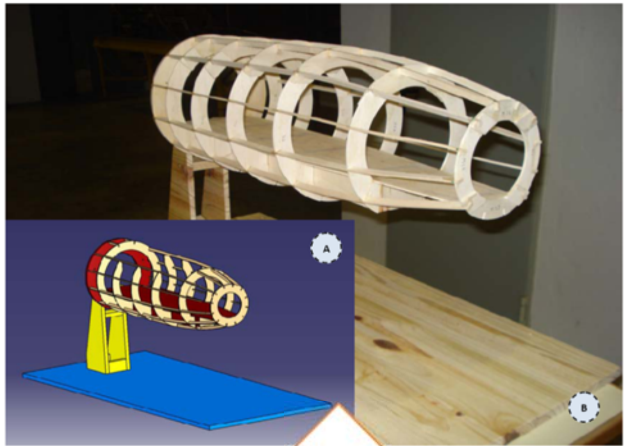


Cutting path programmed in Vcarve software

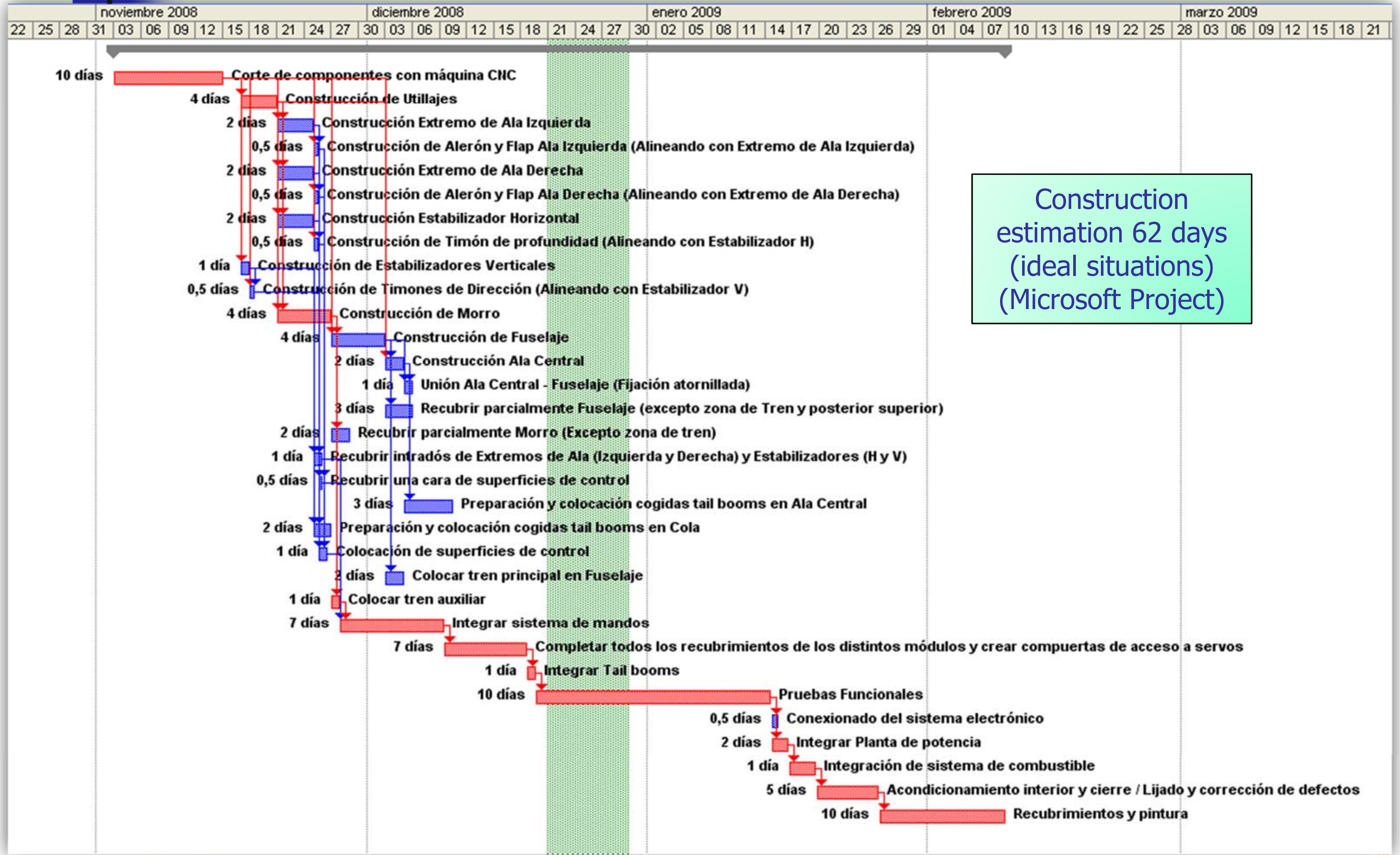
Generated cutting path send to the CNC machine





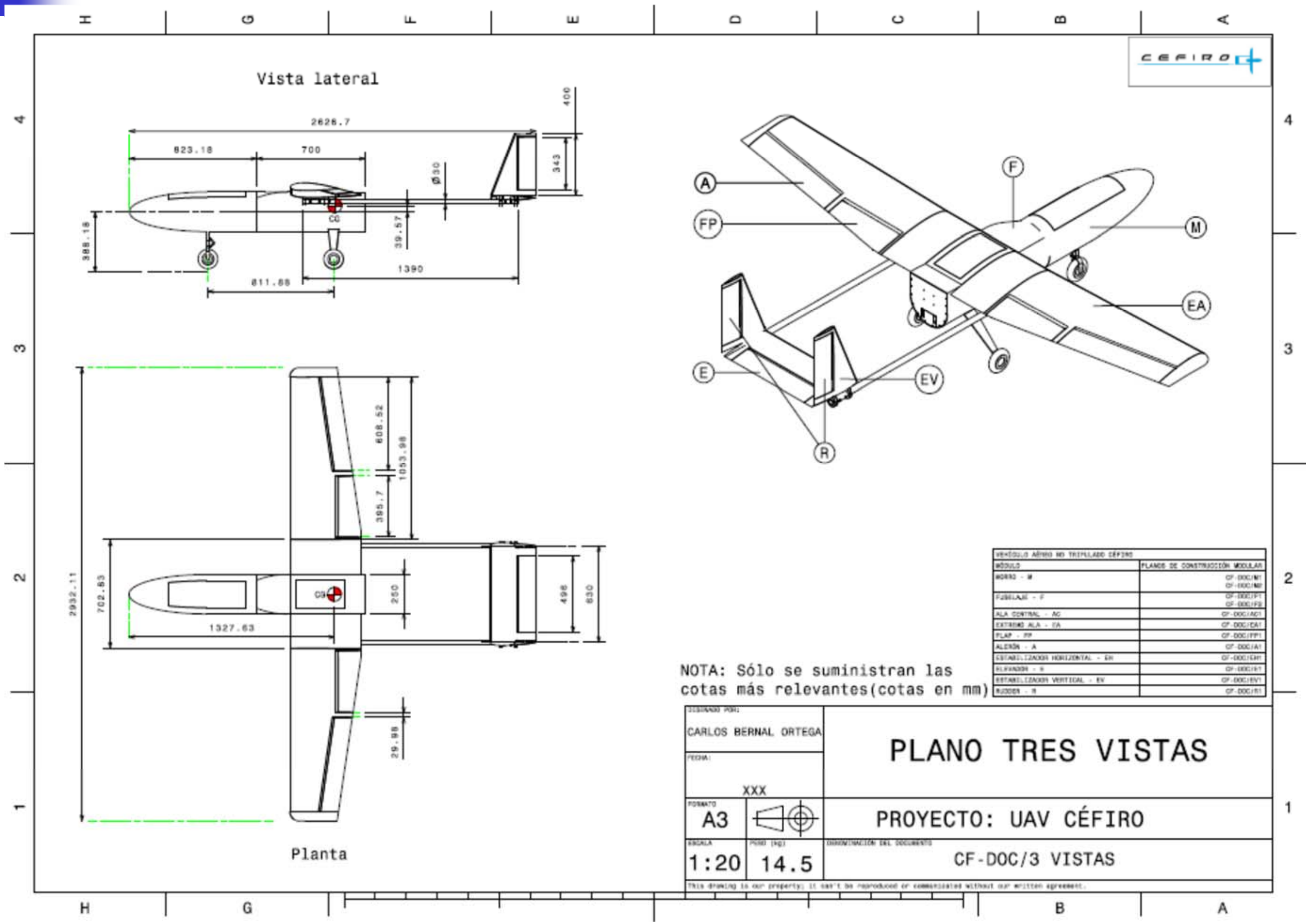


Construction Planning

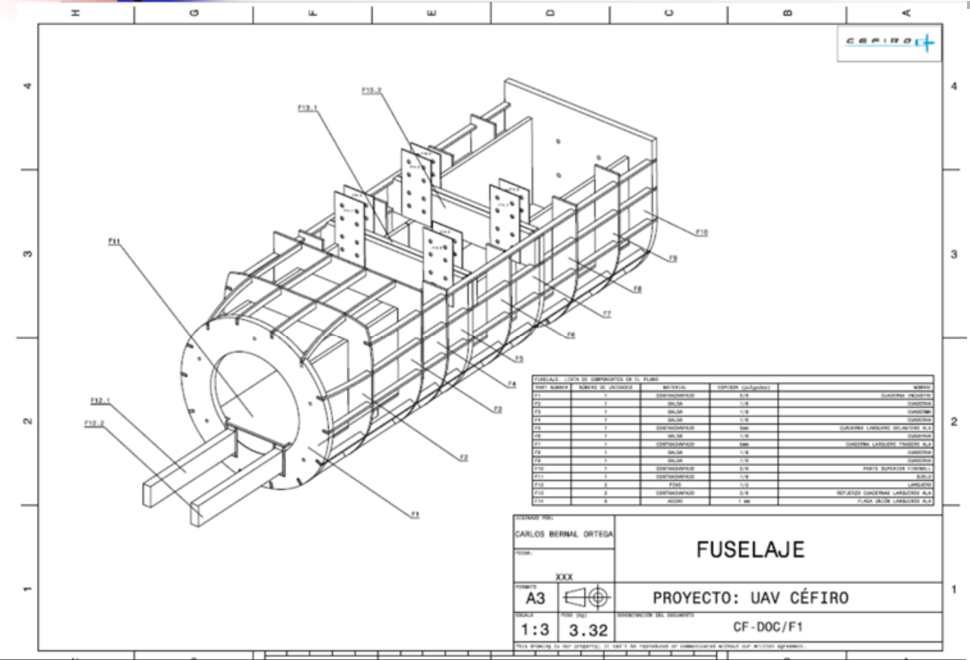


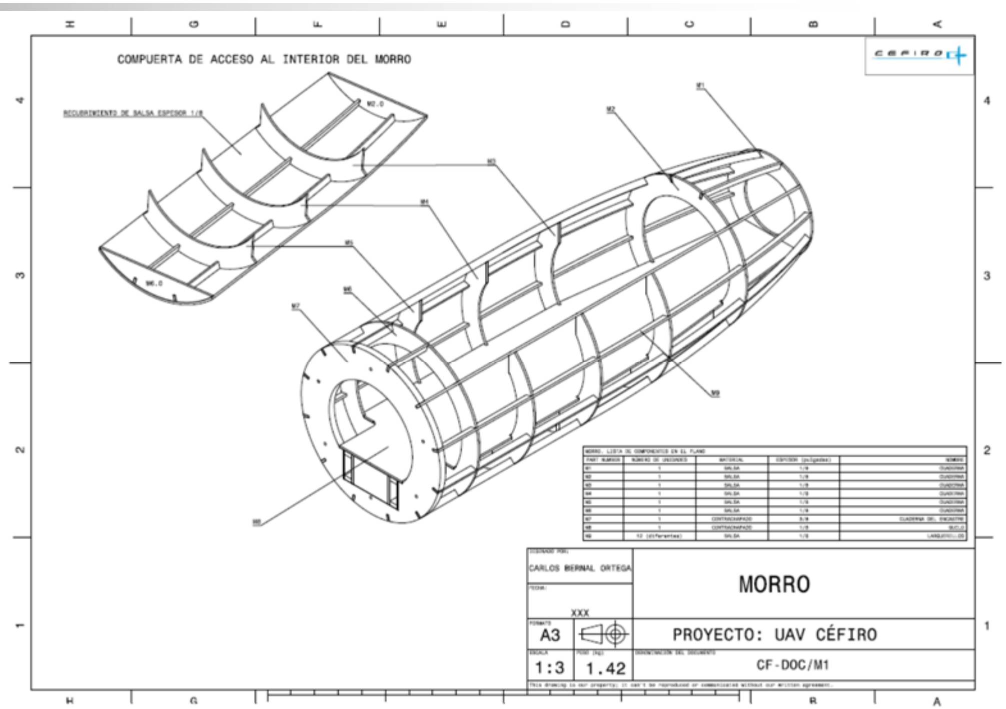
Construction estimation 62 days (ideal situations) (Microsoft Project)

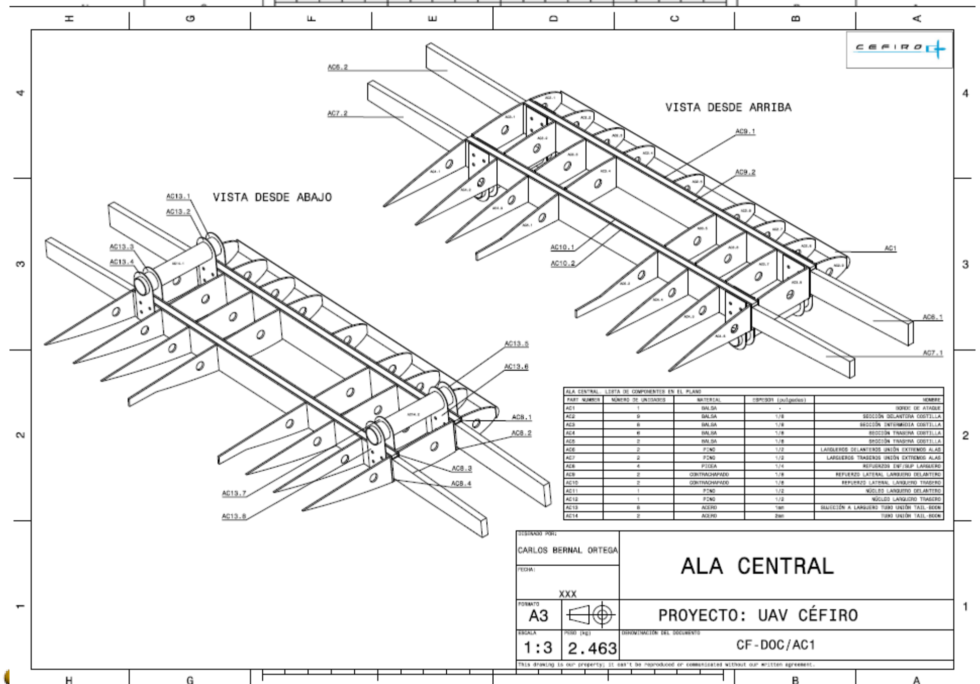
Céfiro's Blueprints - I

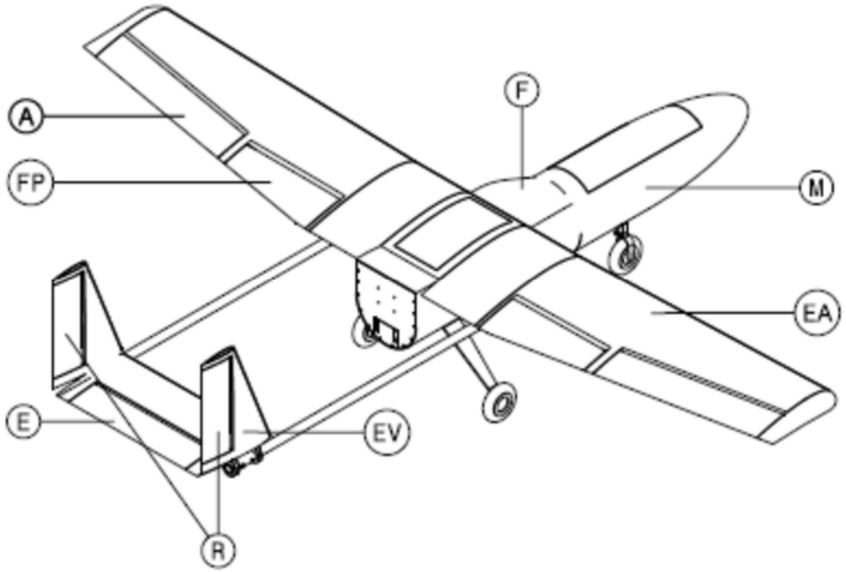


Céfiro’s Blueprints - II

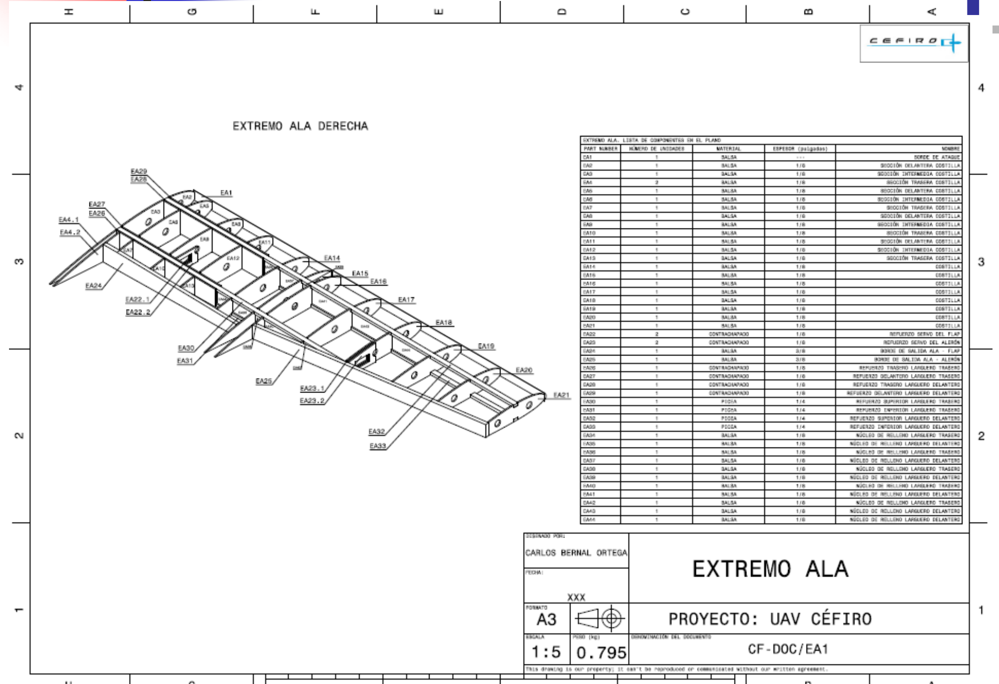


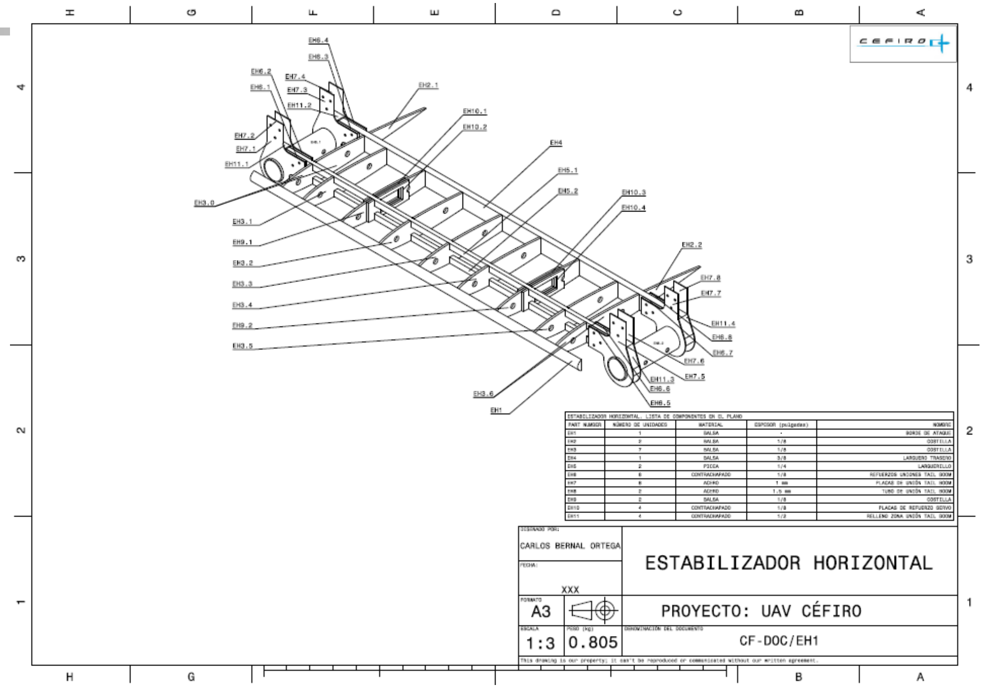


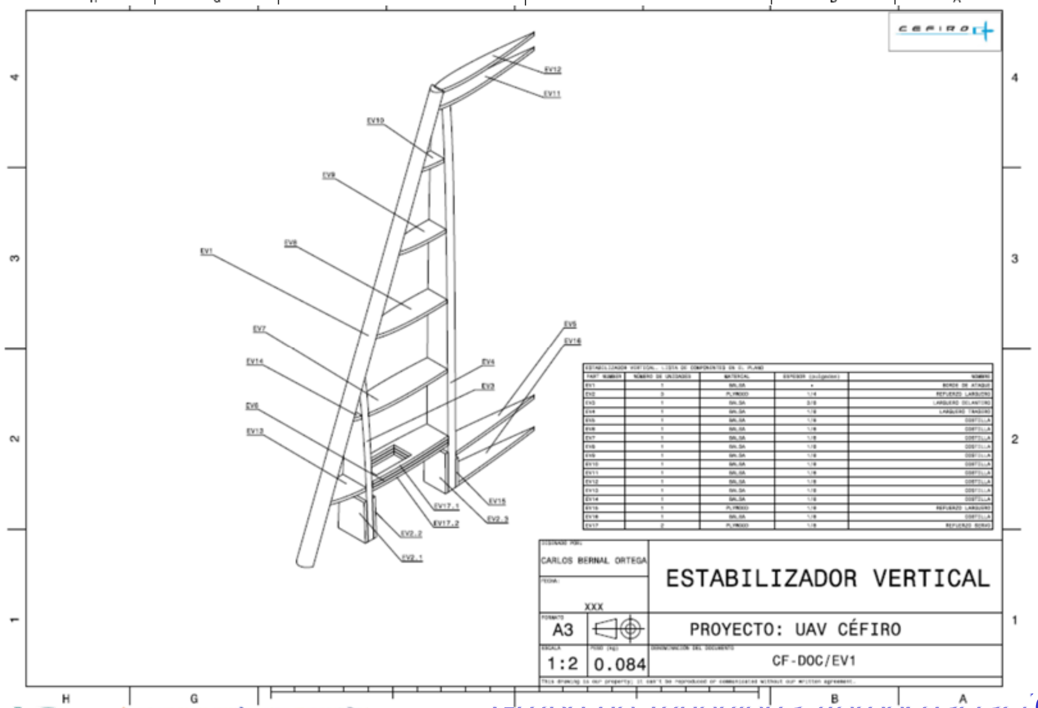


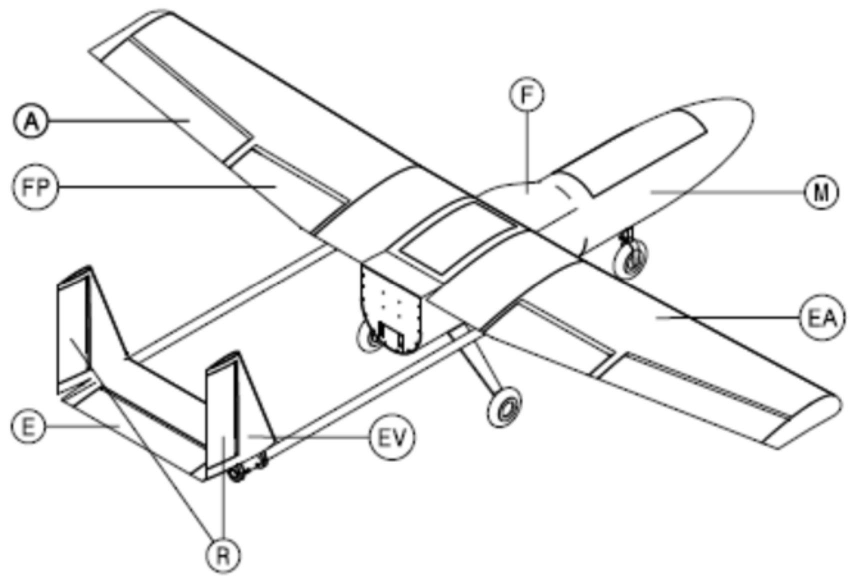


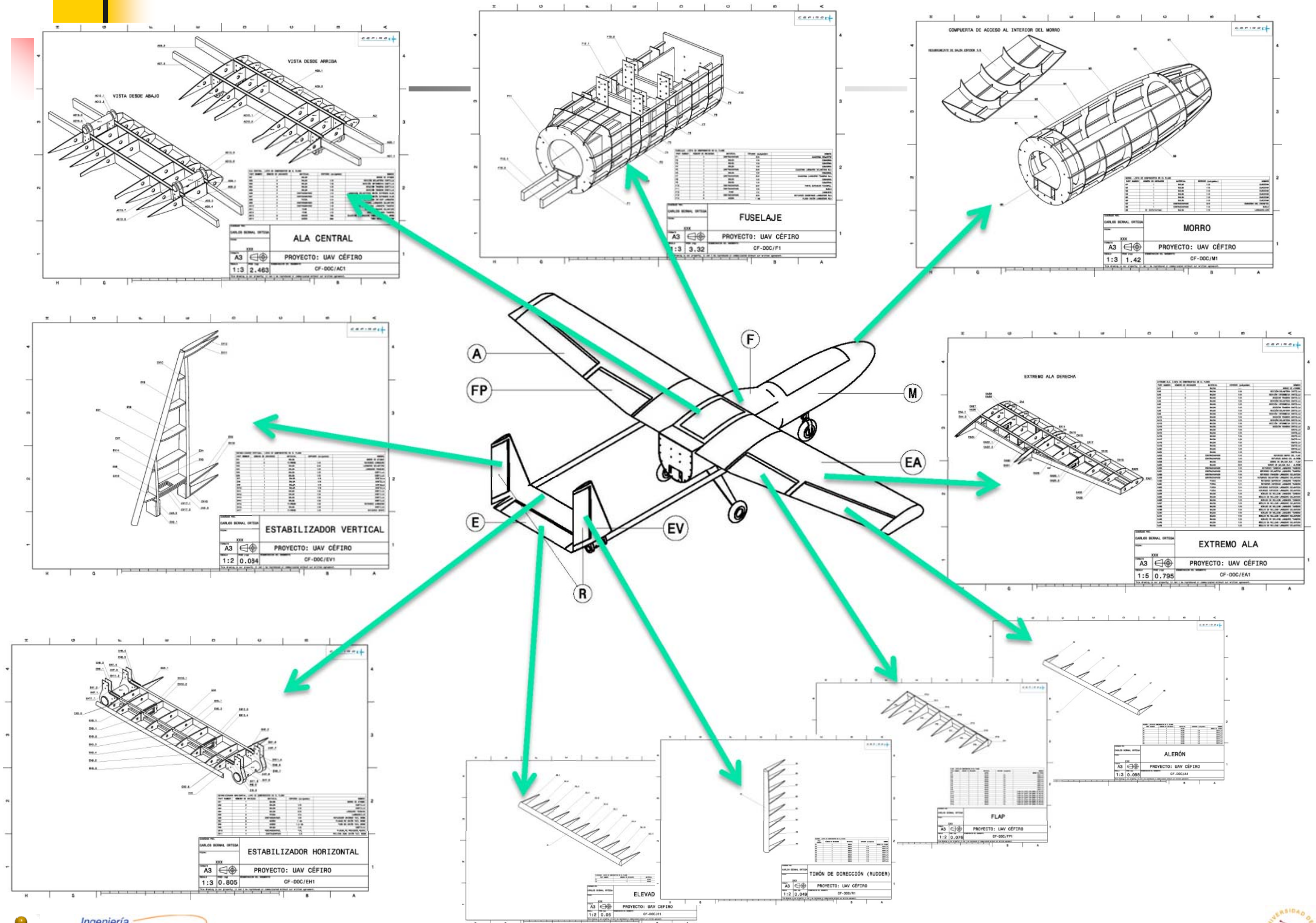
Céfiro's Blueprints - III







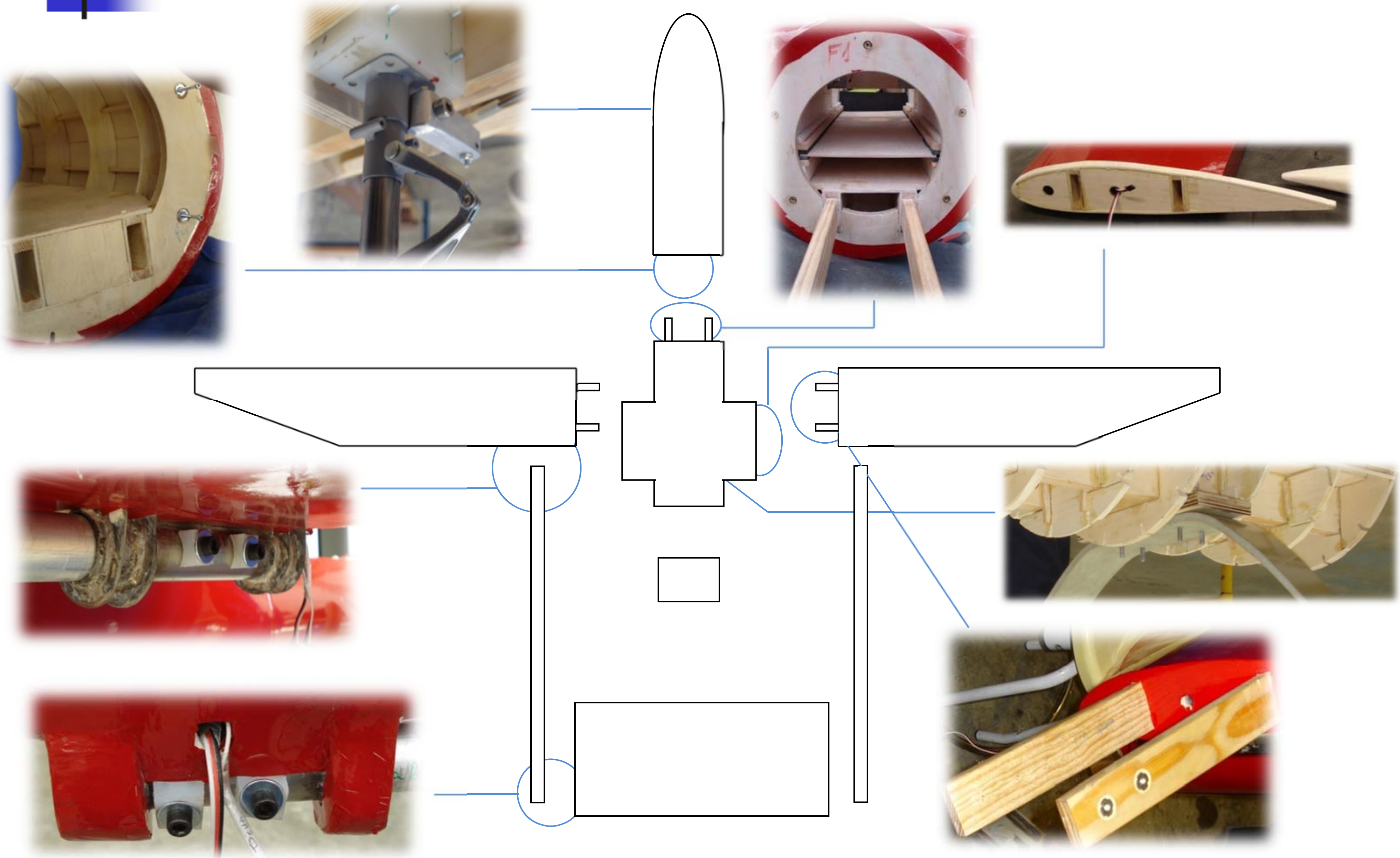



VISTA DESDE ARRIBA
VISTA DESDE ABAJO
ALA CENTRAL
PROYECTO: UAV CÉFIRO
CF-DOC/AC1
FUSELAJE
PROYECTO: UAV CÉFIRO
CF-DOC/F1
COMPUERTA DE ACCESO AL INTERIOR DEL MORRO
MORRO
PROYECTO: UAV CÉFIRO
CF-DOC/M1
A
FP
F
M
EA
E
EV
R
ESTABILIZADOR VERTICAL
PROYECTO: UAV CÉFIRO
CF-DOC/EV1
EXTREMO ALA DERECHA
EXTREMO ALA
PROYECTO: UAV CÉFIRO
CF-DOC/EA1
ESTABILIZADOR HORIZONTAL
PROYECTO: UAV CÉFIRO
CF-DOC/EH1
ELEVAD
TIMÓN DE DIRECCIÓN (RUDDER)
FLAP
ALERÓN

Systems Integration - I

- Definition of testing procedures to ensure the propper system integrations:
  - Sistem integrations for the Main Structural Groups
    - Sistem integration of nose fuselage equipment
    - Sistem integration of Wing and Tail equipment
    - Sistem integratio of center fuselage equipment
  - Structural Integration of the different UAV modules:
    - Integration ⇒ Landing Gear ⇔ fuselage
    - Integration ⇒ Nose Fuselage ⇔ Center Fuselage
    - Integration ⇒ Wing Groupdel Grupo Alar
    - Integration ⇒ Central Wing ⇔ Central Fuselage
    - Integration ⇒ Tail-booms ⇔ Winge Group ⇔ Tail Group
    - Integration ⇒ Control Surfaces ⇔ Wing Group and Tail Group
    - Integration ⇒ Payload ⇔ Nose Fusealge
    - Integration ⇒ Engine ⇔ Firewall
  - System Integration:
    - Engine/Fuel system integtration
    - Electric system integration
    - Communications system integration

Systems Integration - II



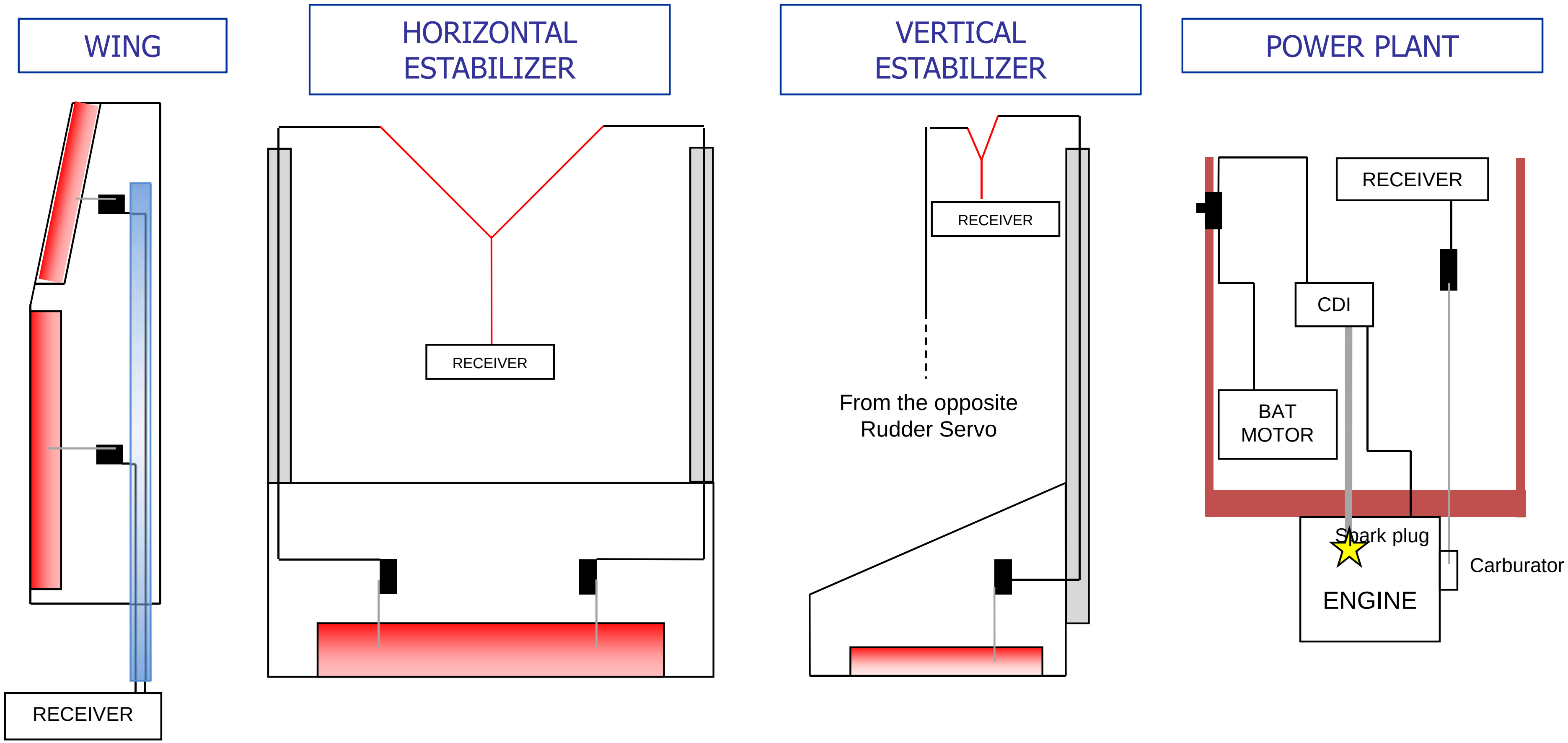
Systems Integration and Functional Tests - III

- Ensure the continuity of the electric system (servo actuators, wiring) and power management)
- Weight management
- Alignment of actuators:
  - Control surfaces:
    - Elevator,
    - Rudder,
    - Ailerons,
    - Flaps,
  - Landing Gear
  - Engine throttle

Systems Integration - III

Systems Integration and Functional Tests - IV

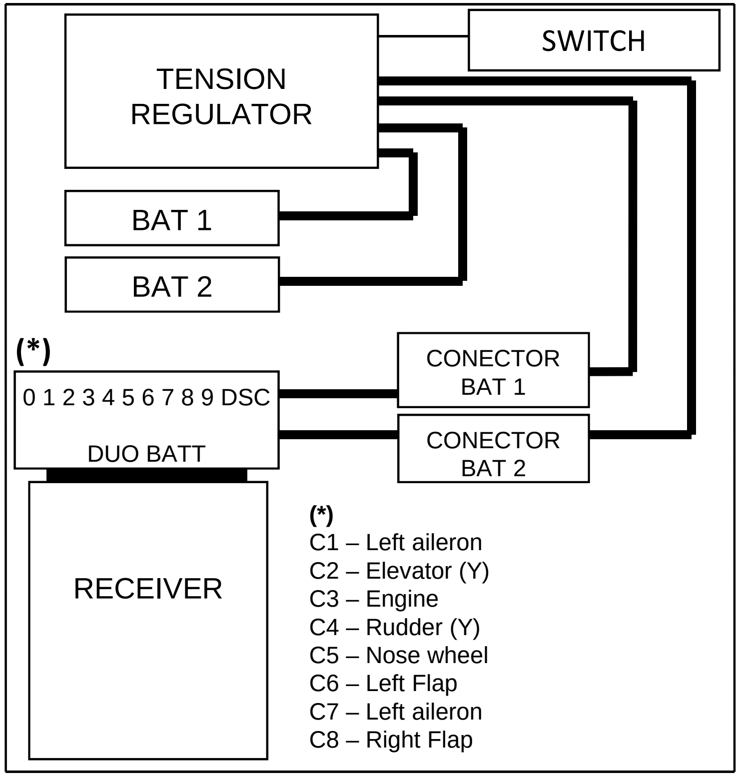
- Squematics of the flight control wiring:
  - Servo-actuator for the control surfaces
  - Servo-actuator for the engine
  - Servo-actuator for the landing gear

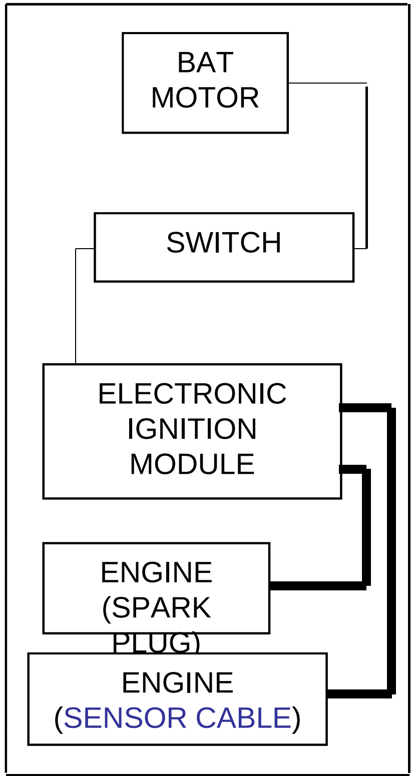


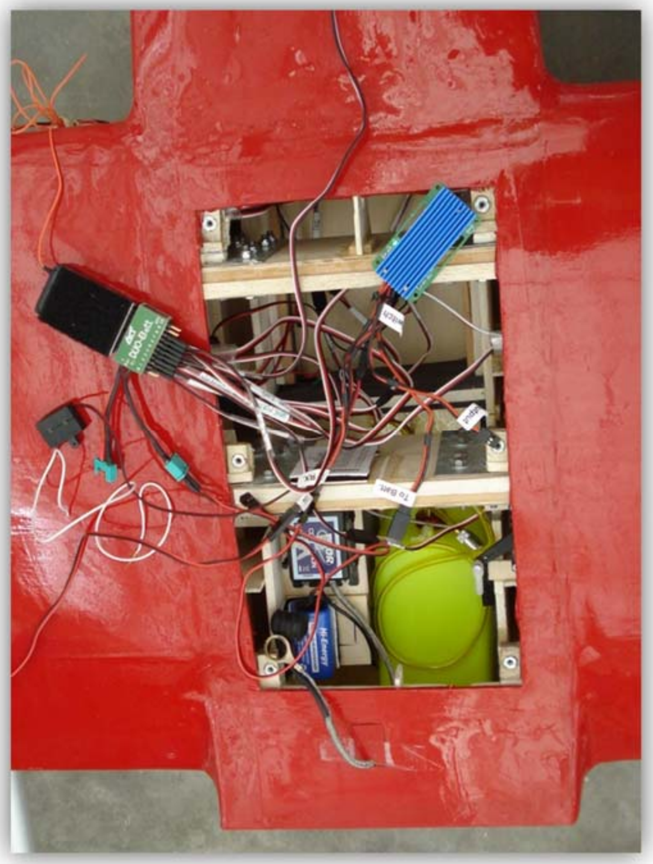
Systems Integration and Functional Tests - V

Electric Architecture

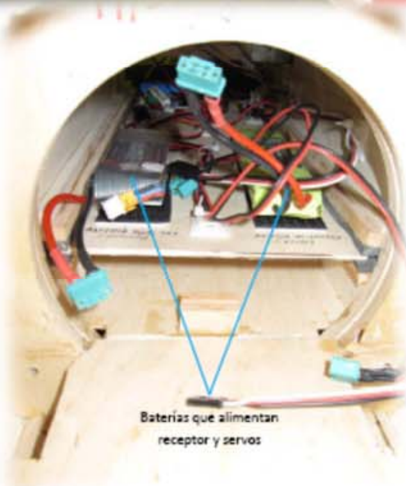
- Communication system
- Flight control systems
- Engine control system
- Steerable nose landing gear system

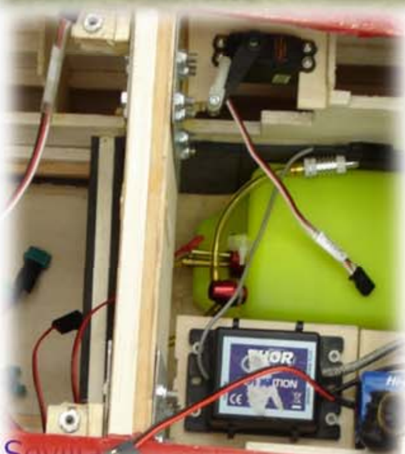






Systems Integration - III






CEFIRO
EC-EPT

Students’ Production

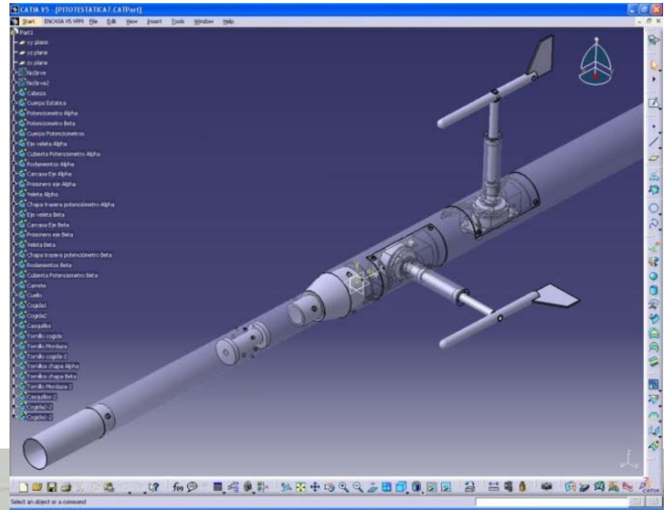
- Creation of 5 Thesis Projects (Proyectos Fin de Carrera)
- Aerodynamics:
  - Martín Cañal, Adrián, “Diseño aerodinámico de un UAV de baja velocidad: El proyecto Céfiro.” Advisor: Francisco Gavilán
- Structural design and manufacturing process:
  - Pérez Alcaraz, Daniel, “Diseño estructural y construcción de un avión no tripulado: El proyecto Céfiro.” Advisor: Sergio Esteban
- Engine and aircraft performance:
  - Samblás Carrasco, Francisco Ventura, “Análisis de las actuaciones y modelado de la planta propulsora de un avión no tripulado: El proyecto Céfiro.” Advisor: Sergio Esteban
- Stability and control:
  - “López Teruel, Pedro, “Análisis de la estabilidad y el control de un avión no tripulado: El proyecto Céfiro.” Advisor: Sergio Esteban
- Production and systems integration:
  - Bernal Ortega, Carlos “Integración de sistemas y pruebas funcionales de un avión no tripulado: El proyecto Céfiro.” Advisor: Sergio Esteban

Conclusions

- Cefiro has turned out to be a great educational experience for the students.
  - The students have been exposed to the challenges associated to all the phases involved in the construction and operation of a UAV.
- During the design phase it was identified the importance of optimizing both the construction and fabrication processes:
  - Extensive use of Computer Aided Tools (CAD & CAM).
  - Improvement of the original design and construction techniques.
    - Have been updated into the CAD in real time, allowing their immediate use.
    - The construction process of the Céfiro v2.0 has already incorporated these improvements.
- Demonstrated:
  - The importance of the concurrent engineering approach to optimize the design process.
  - Capability of designing and constructing a custom design UAV.
  - The use of aircraft design as a tool to complete the education process of the aerospace engineers:
    - Gives the students an insight view of what's required to design, construct, and test and airplane.

Video

Céfiro



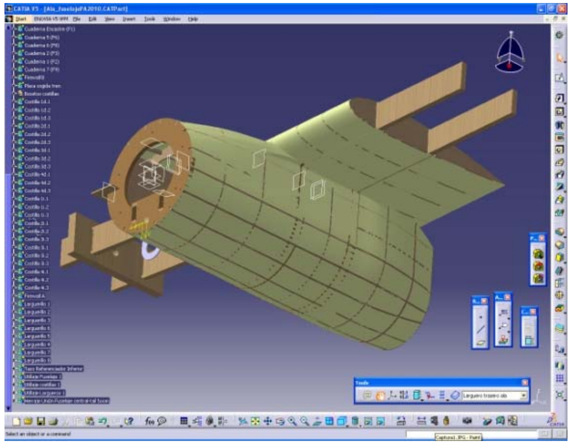
Prototype II

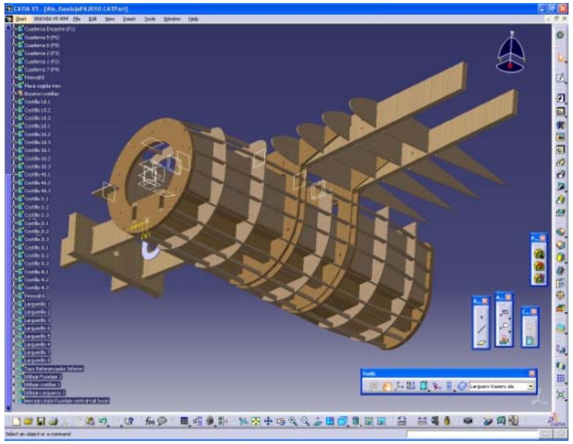
Céfiro II - Requirements

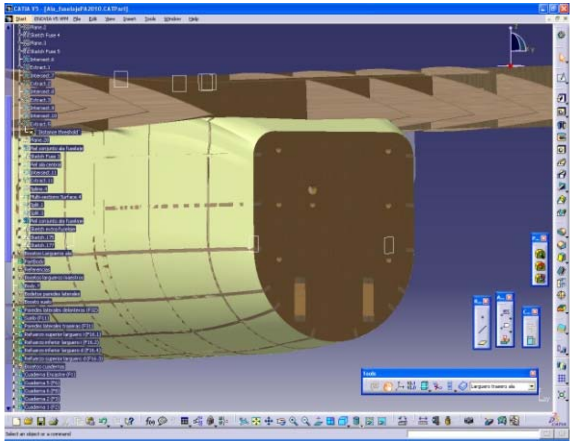
- Once validated the design ⇒ Modifications such that permits to accomplish goals of the GIA Group:
  - Automatic flight control
  - Trajectory optimization.
  - Air Trafic Management.
  - Aircraft dynamics and engine performance modeling.
- Improvements on the 2nd prototype:
  - Design Improvements
  - 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)








CEFIRO

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

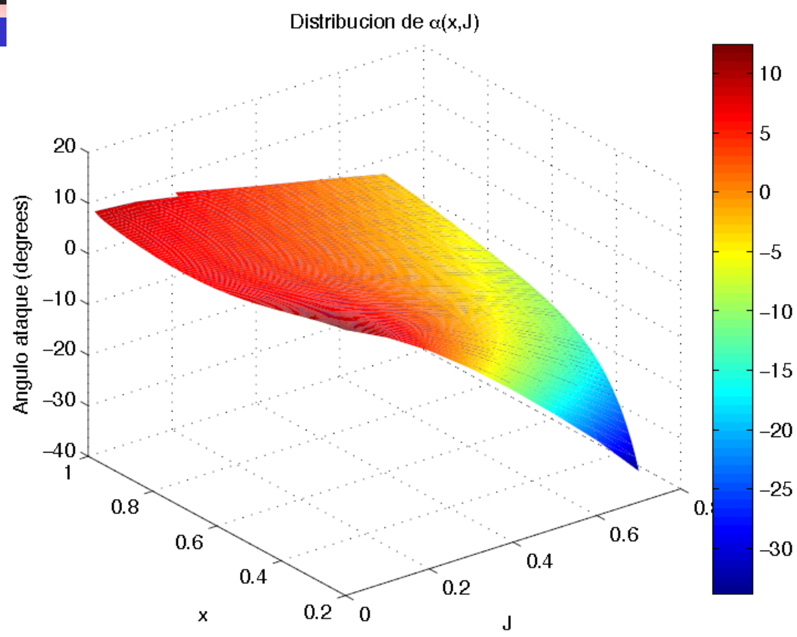


Figura 49 Distribución del ángulo de ataque (x,J)

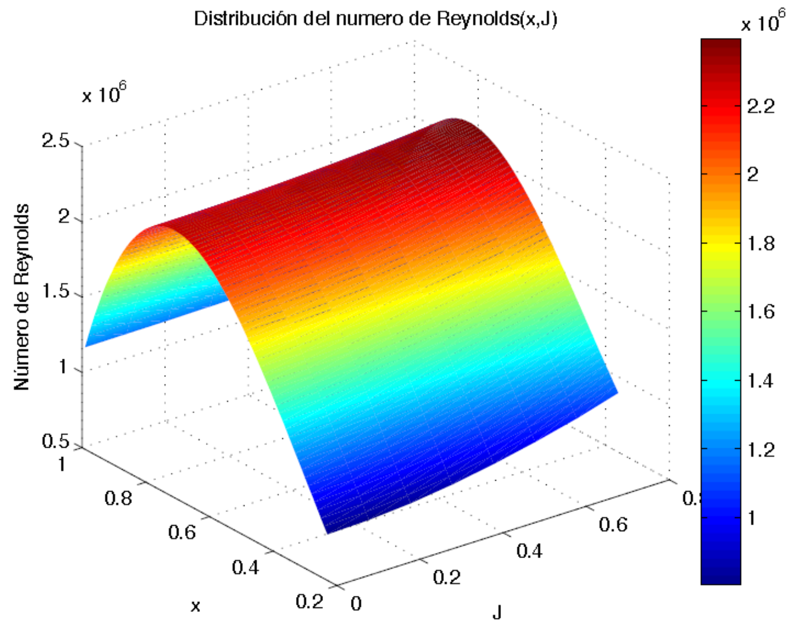


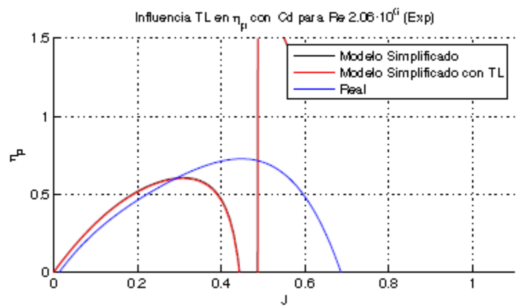
Figura 52 Distribución número de Reynolds (x,J)

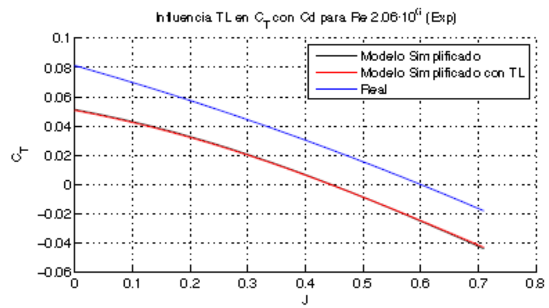
$$C_T = \int_0^1 \frac{1}{2}\sigma(x)\sqrt{x^2 + \left(\lambda_c + \lambda_i(x)\right)^2}\left(C_{l_\alpha}\alpha(x)x^2 - \left(\lambda_c + \lambda_i(x)\right)C_d(x)\right)dx$$

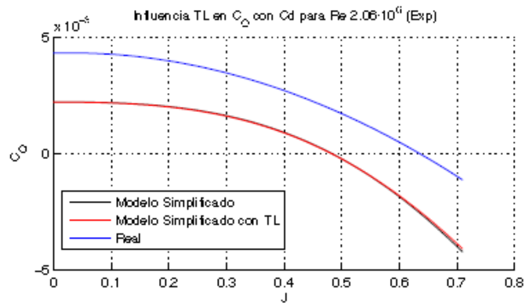
$$C_P = \int_0^1 \frac{1}{2}\sigma(x)\sqrt{x^2 + \left(\lambda_c + \lambda_i(x)\right)^2}\left(C_l\left(\lambda_c + \lambda_i(x)\right)x + C_d(x)x^2\right)dx$$

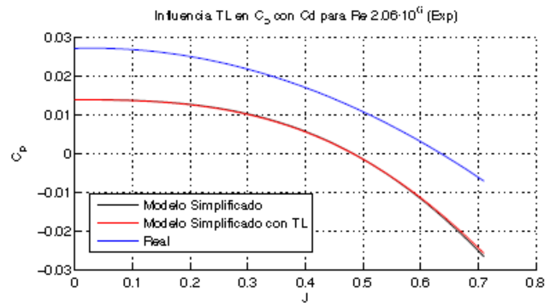
$$C_l(x) = C_{l_\alpha}(\alpha - \alpha_0) = C_{l_\alpha}\left(\theta - arctan\left(\frac{\lambda}{x}\right) - \alpha_0\right)$$

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

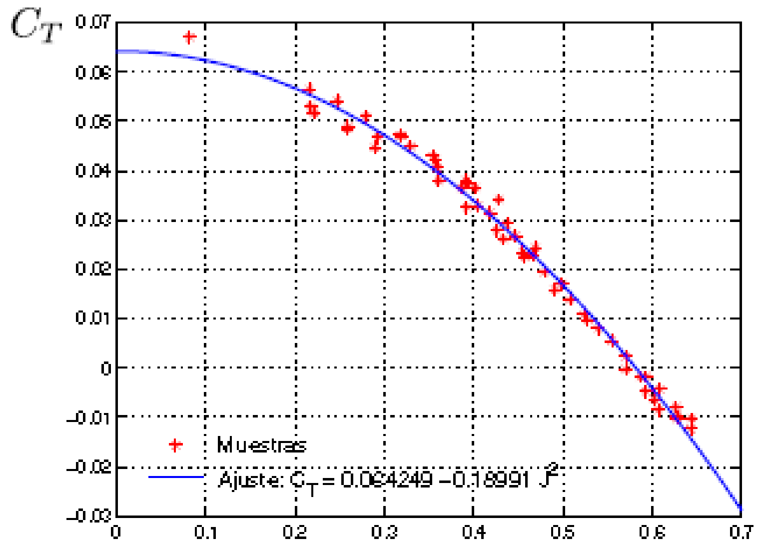








Wind Tunnel Engine Experiments - I



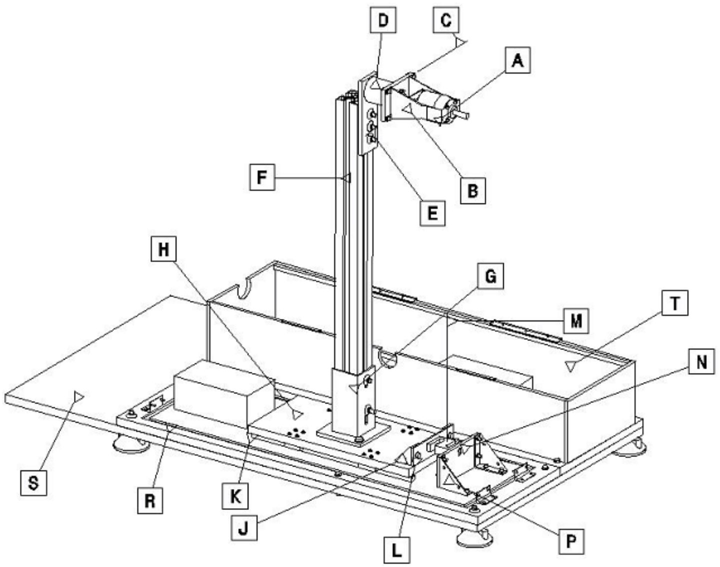
$$J = \frac{V_a}{4\pi R\Omega}$$

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

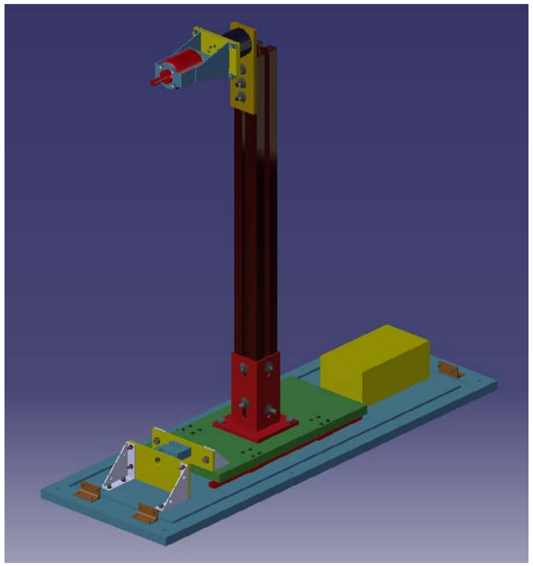
$$\Downarrow$$

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

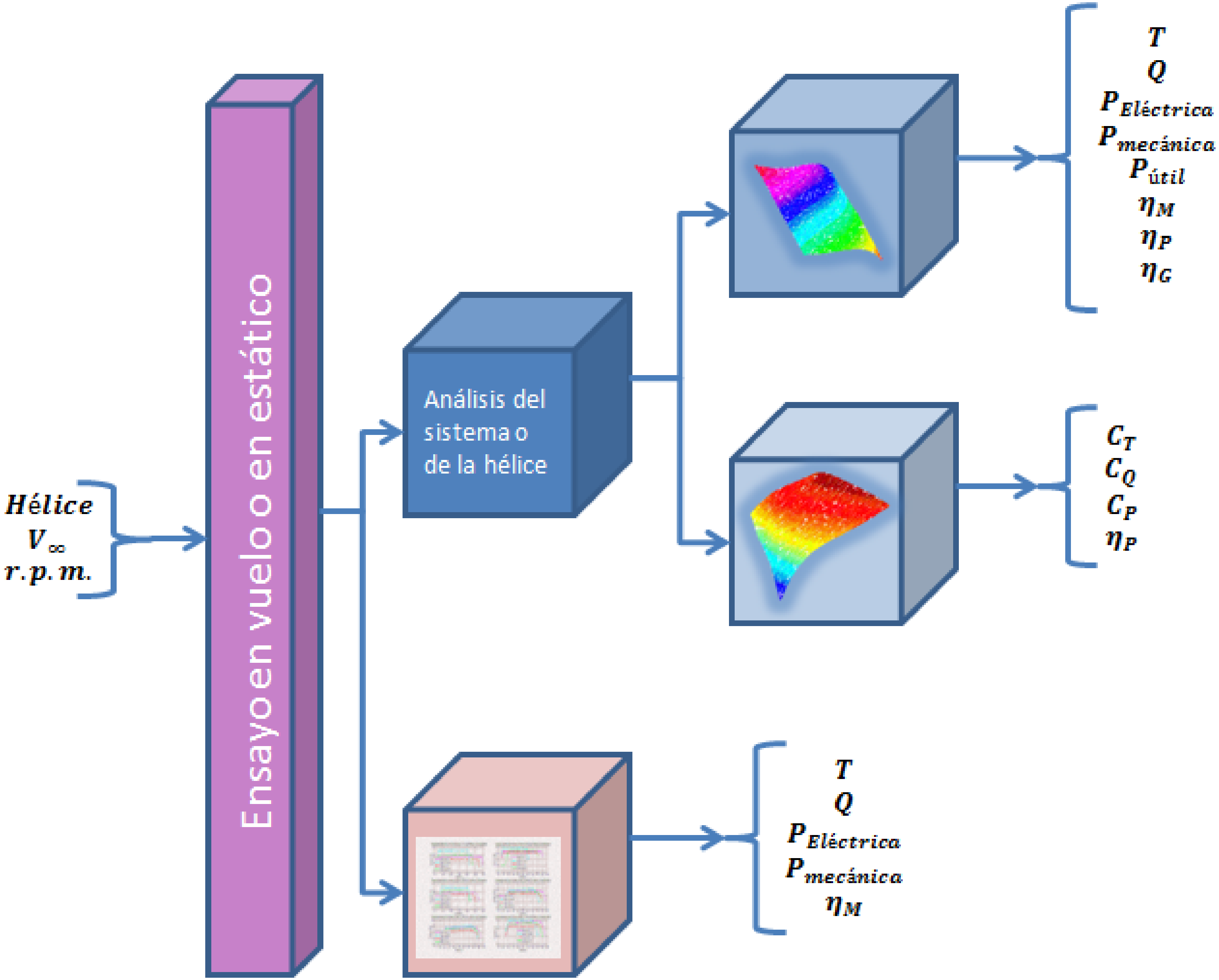
$$F_T = \pi\rho R^4 C_{T_0}\Omega^2 - \frac{\rho R^2 C_{T_2}}{16\pi} V_a^2$$



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

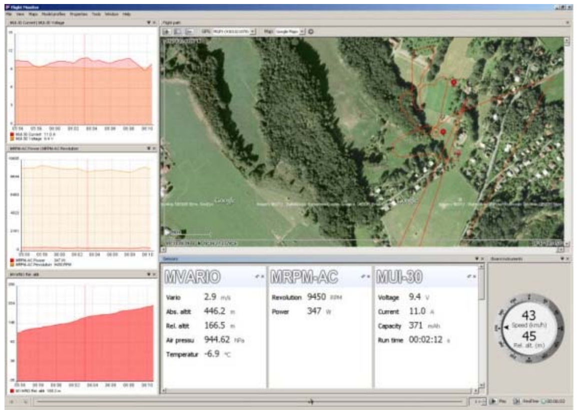


Wind Tunnel Engine Experiments - II



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



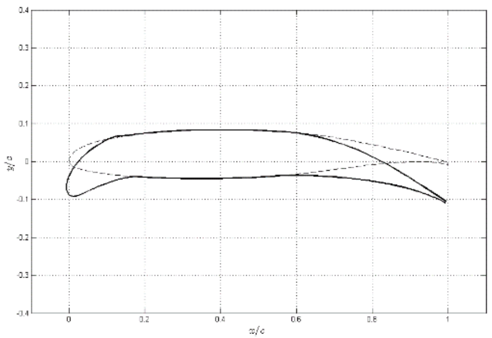
Students' Production

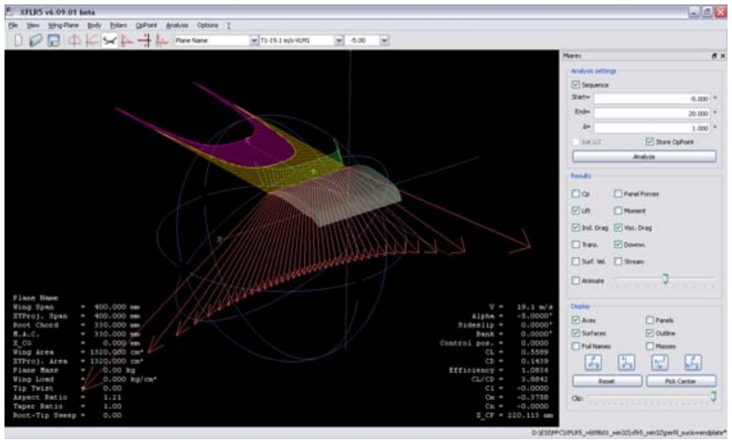
- Creation of 3 Thesis Projects (Proyectos Fin de Carrera)

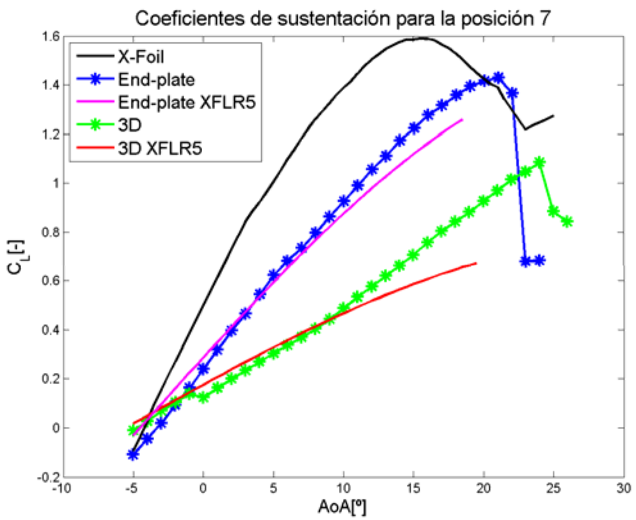
- Theoretic Electrical Engine Performance Models:
  - Alberto García Martínez, "Caracterización de un sistema de propulsión por hélice con motor eléctrico." Advisor: Sergio Esteban
- Design and construction of a test-bench for prop-testing:
  - Hugo López Pérez, "Diseño y construcción de una bancada 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

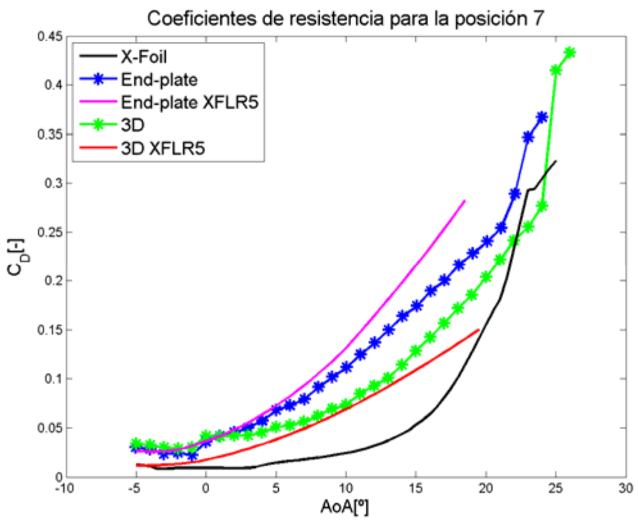
Wind Tunnel Aerodynamic Experiments

- 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









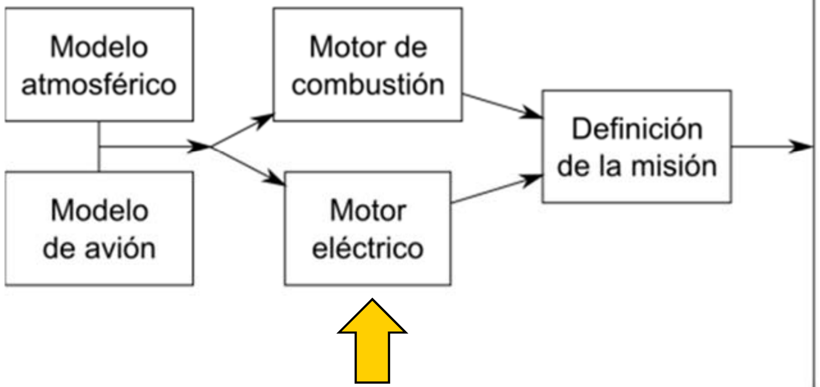
Students' Production

- 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



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

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

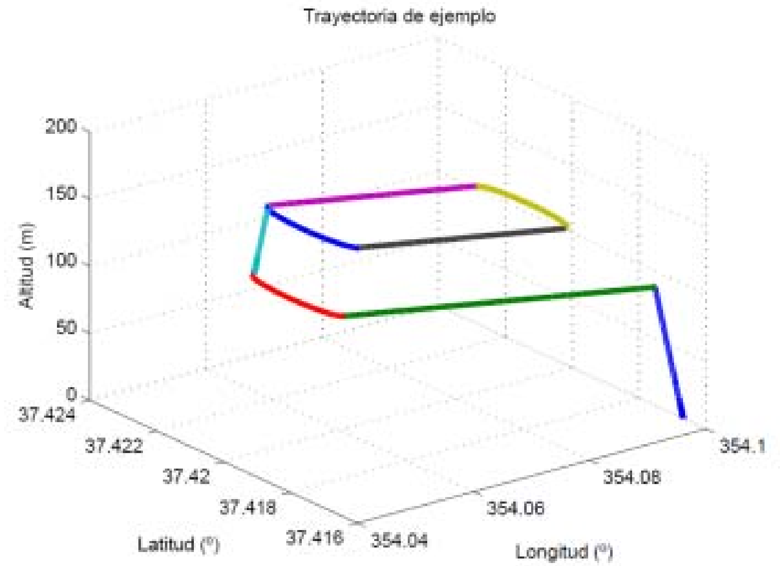
$$m \cdot V \cdot \frac{d\gamma}{dt} = L \cdot \cos\mu - m \cdot g \cdot \cos\gamma$$

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

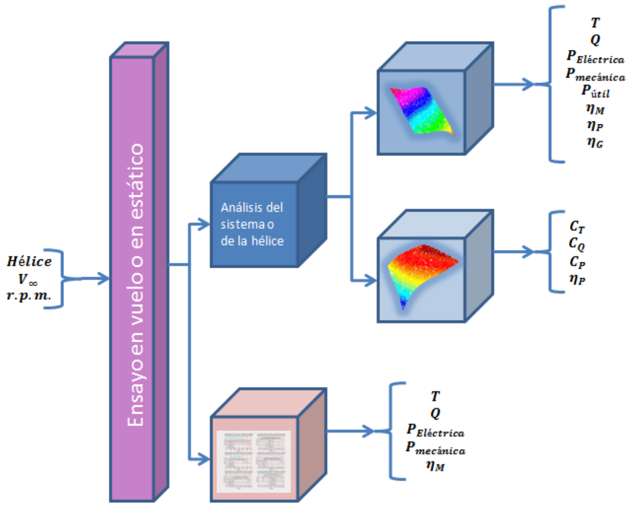
$$\frac{dx}{dt} = V \cdot \cos\gamma \cdot \cos\chi$$

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

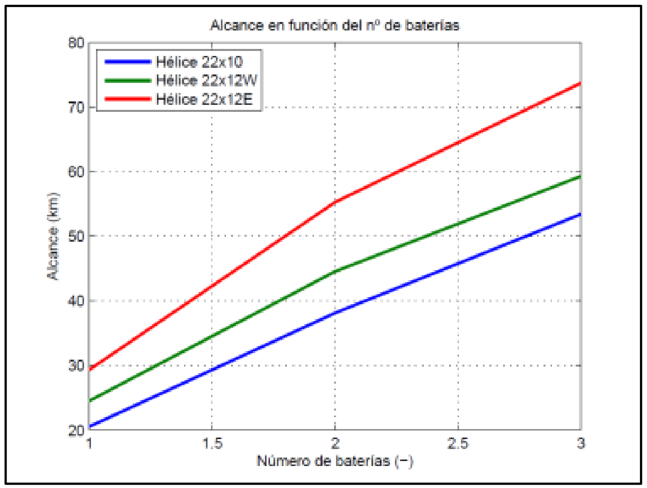
$$\frac{dh}{dt} = V \cdot \sin\gamma$$



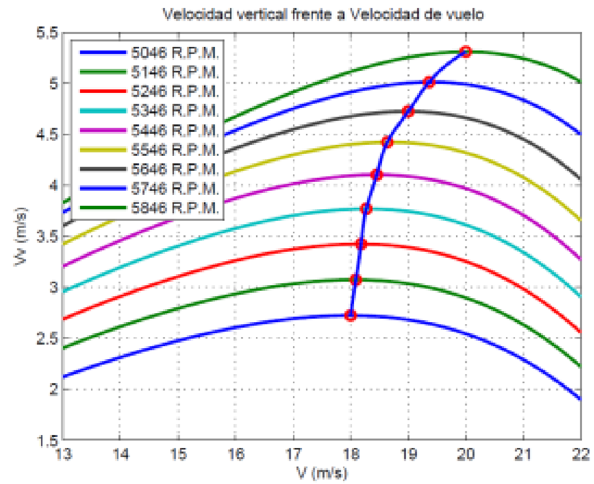
Complete flight profile



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

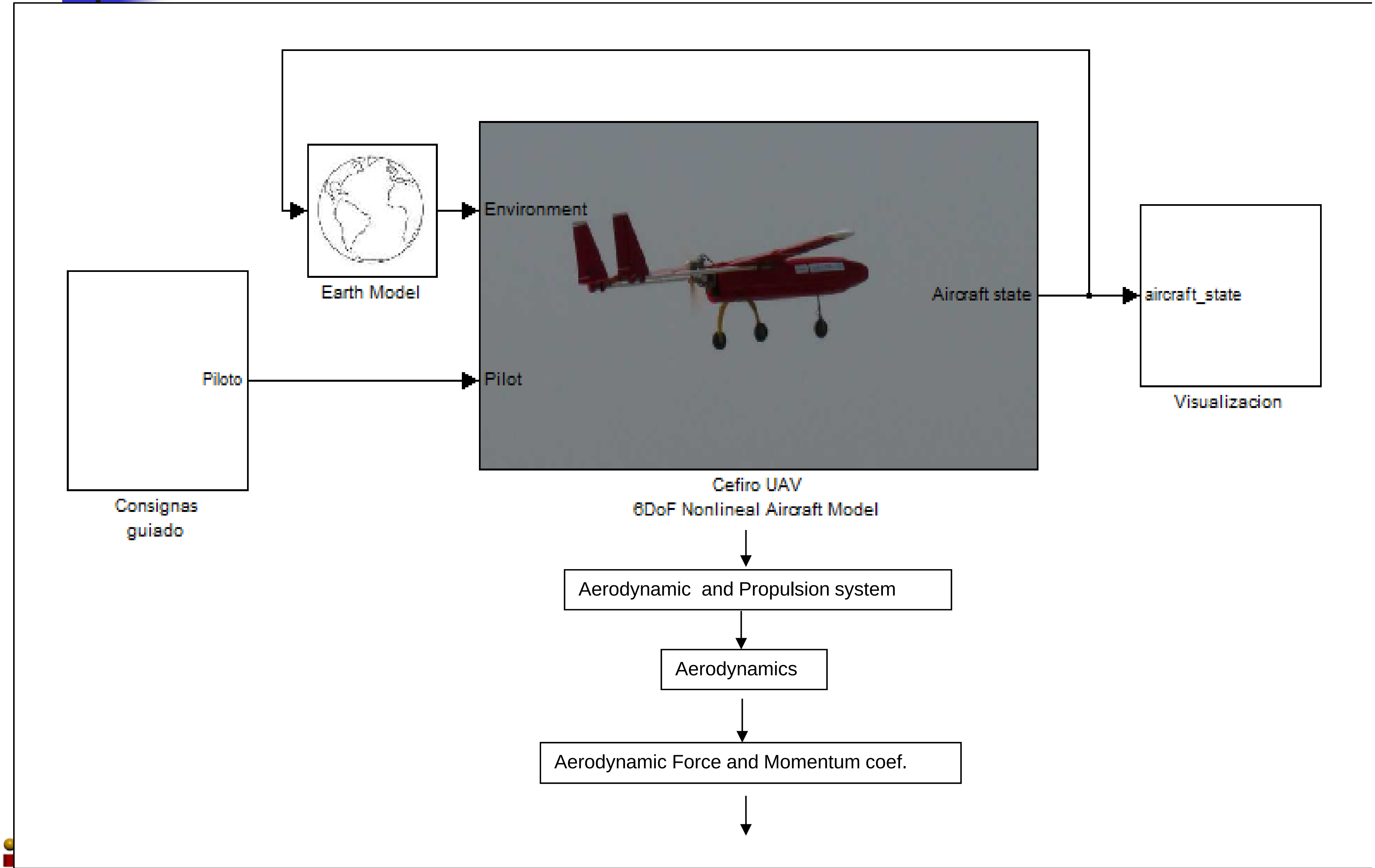
Advanced Aircraft Modelling

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

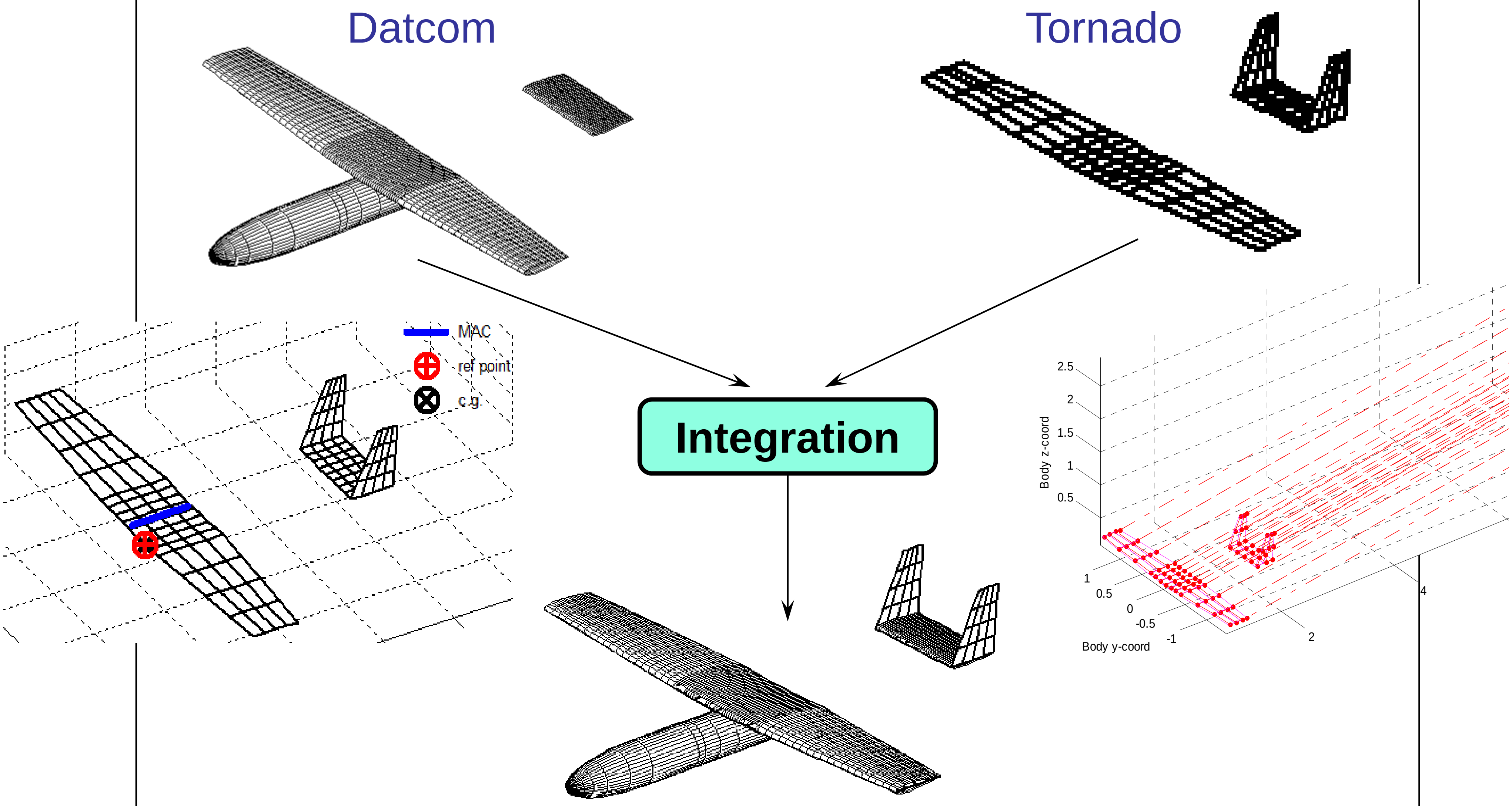
- Design of Custom-made Software: Able to estimate:
  - Force and moment coefficients
  - Stability Derivatives
  - Control derivatives

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

Advanced Aircraft Modelling



Advanced Aircraft Modelling



Custom-made integration Software

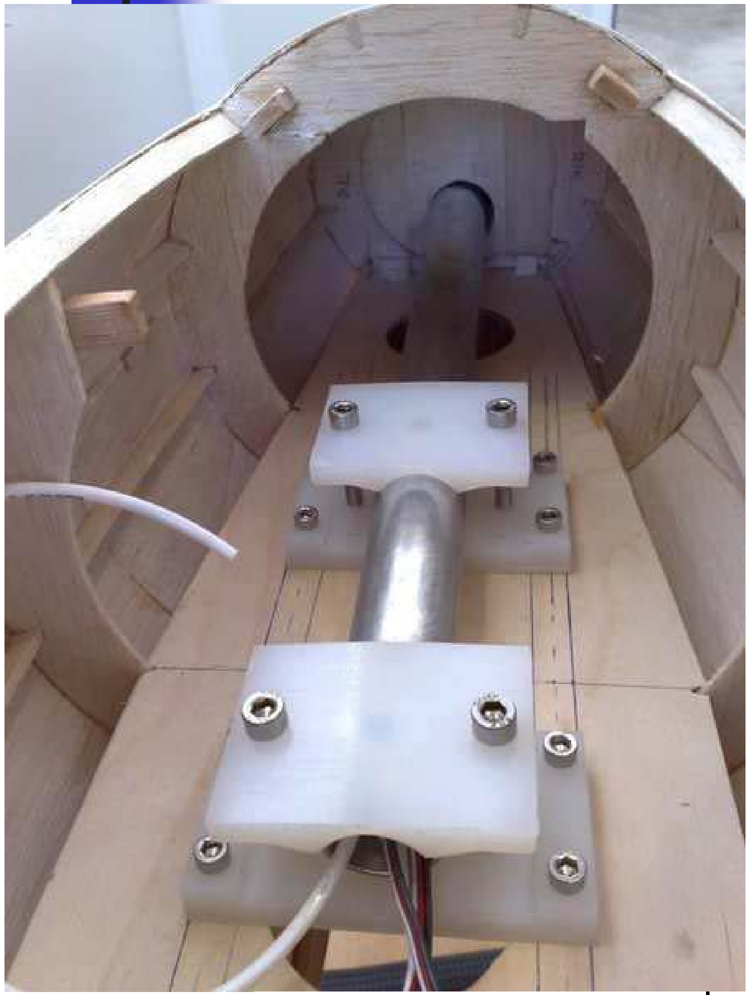
Students' Production

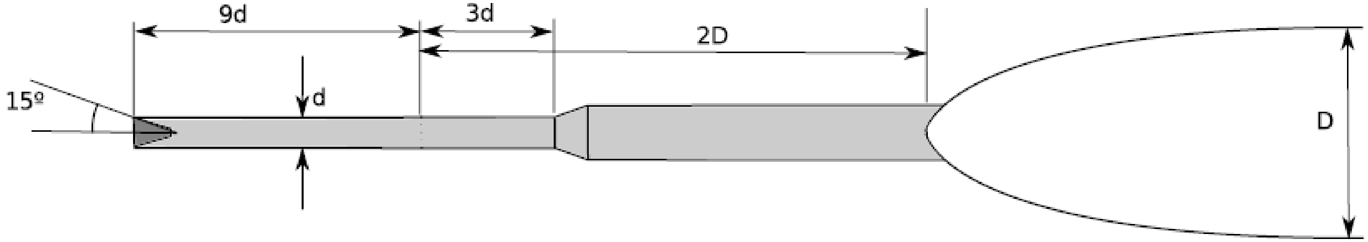
- Creation of Thesis Projects (Proyectos Fin de Carrera)
- Advanced Aircraft Modelling:
  - Manuel Jiménez Guerrero, "Diseño de herramientas para el análisis de modelos aerodinámicos de aviones." Advisor: Francisco Gavilán
- Creation of a Ph.D. Thesis:
- Advanced Aircraft Modelling:
  - Francisco Gavilán, "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

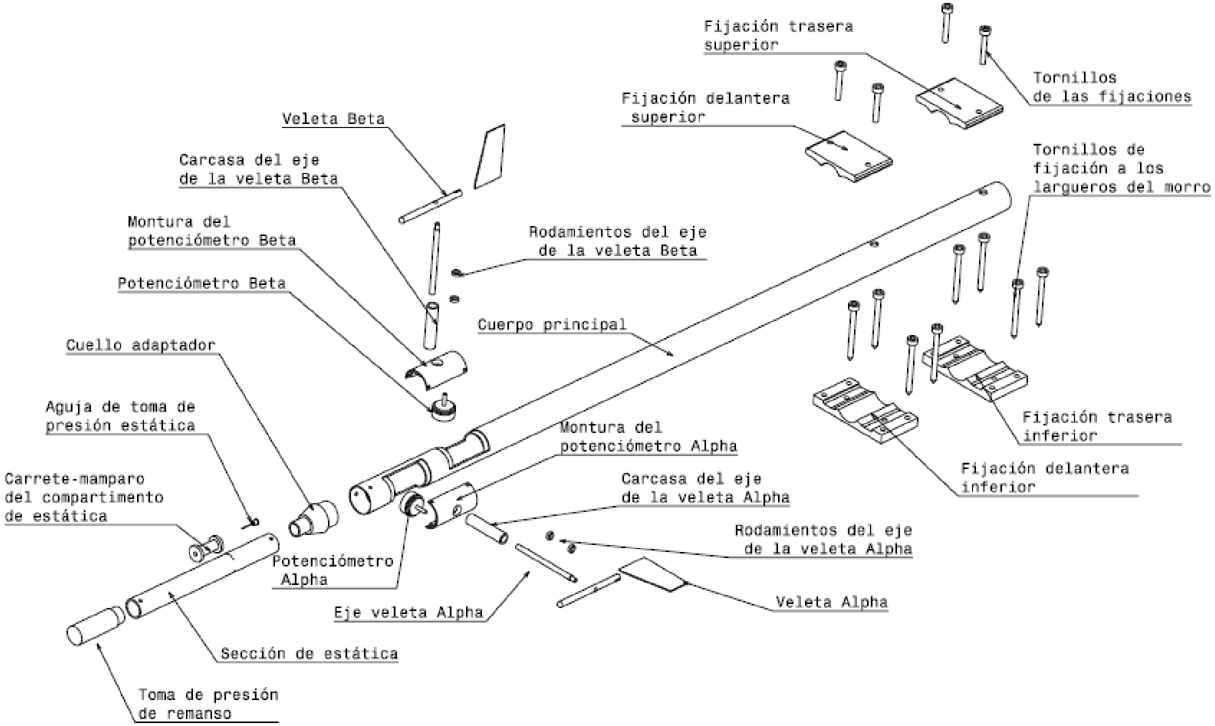
Aerodynamic Sensors - I

- Motivation:
  - To predict aircraft perfromance models ⇒ meassure airspeed
  - Ensure Céfiro maintains flight envelope.
  - Use it as input ⇒ 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 €! ⇒ entire anemoetry system designed and built by GIA.
  - Need to demonstrate high precision ⇒ wind tunnel testing

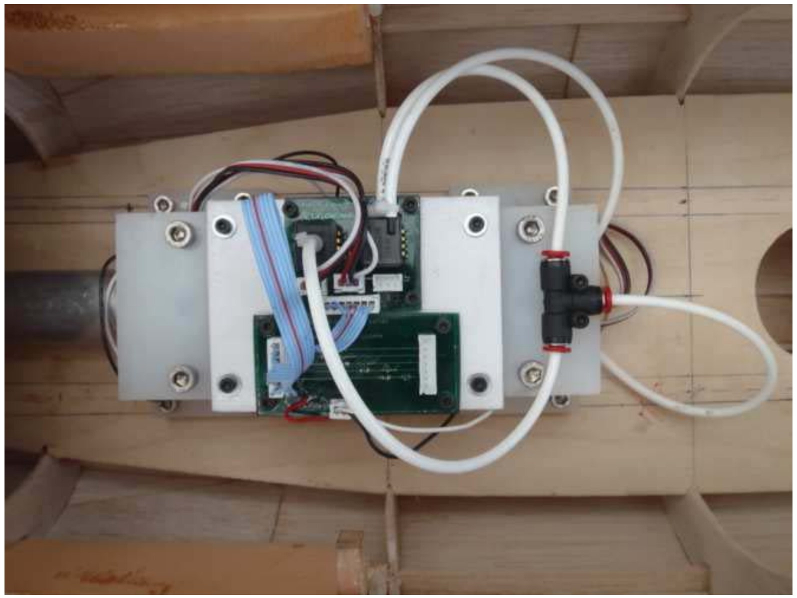
Aerodynamic Sensors - II

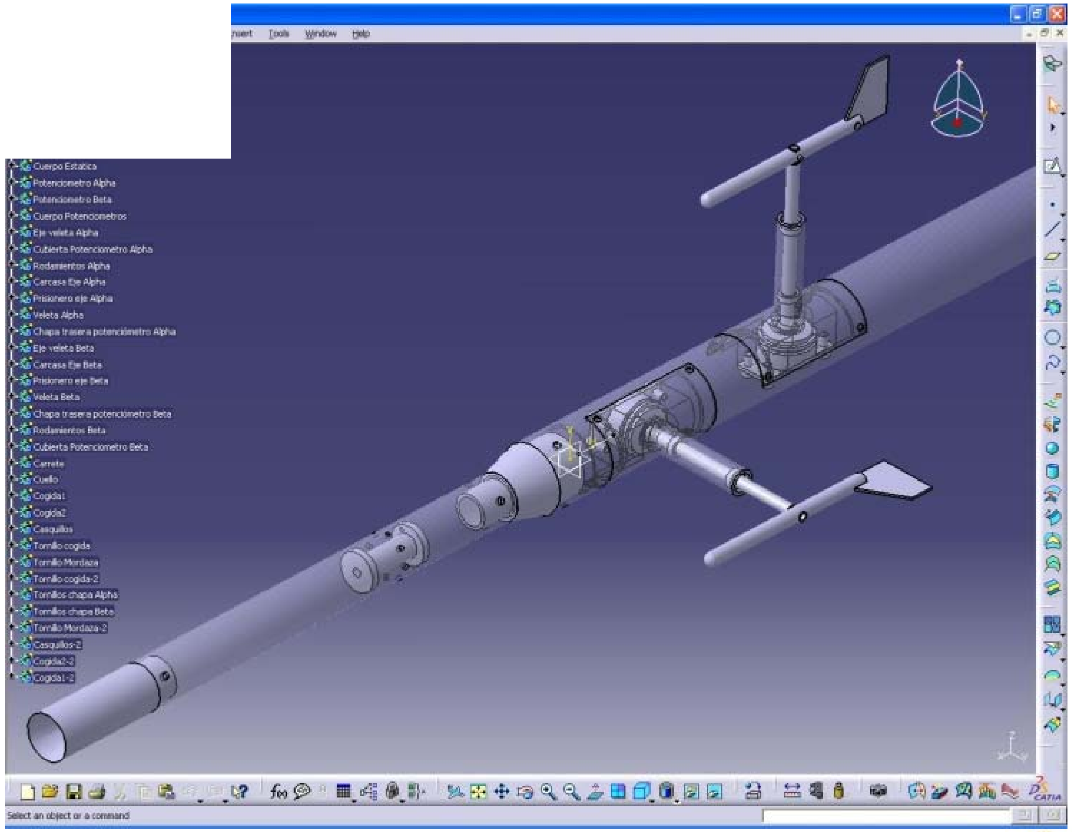






Fijación trasera superior
Tornillos de las fijaciones
Fijación delantera superior
Veleta Beta
Carcasa del eje de la veleta Beta
Tornillos de fijación a los largueros del morro
Montura del potenciómetro Beta
Rodamientos del eje de la veleta Beta
Potenciómetro Beta
Cuerpo principal
Cuello adaptador
Aguja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

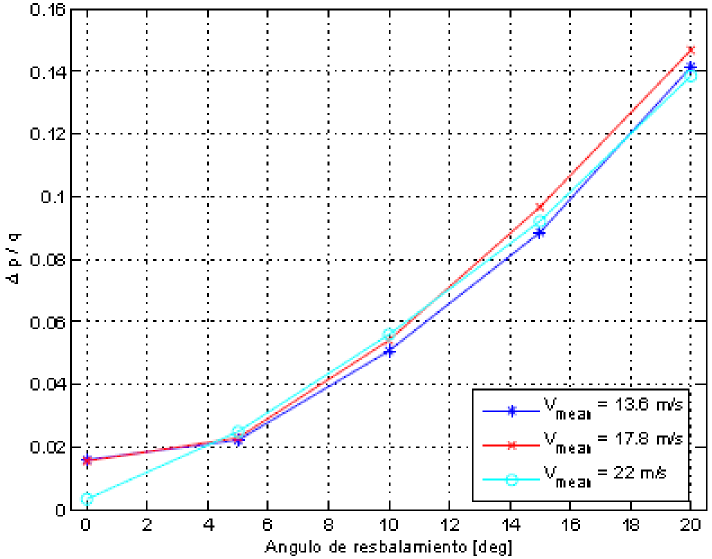


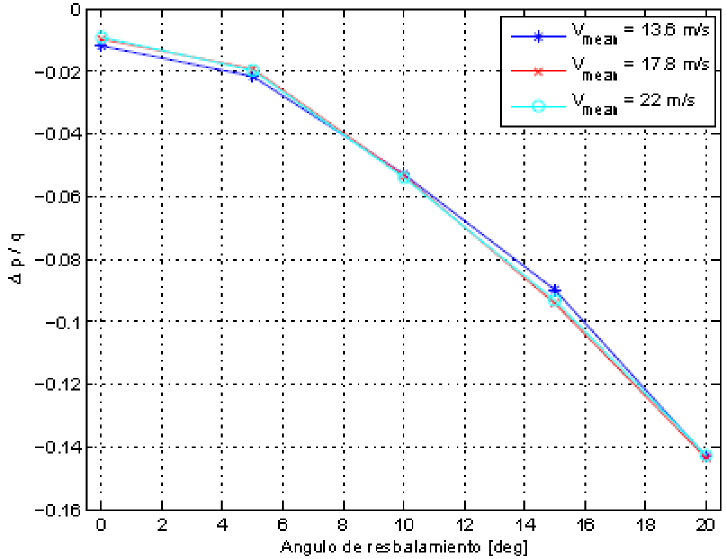


Tools
Window
Help
Cuerpo Estatica
Potenciometro Alpha
Potenciometro Beta
Cuerpo Potenciometros
Eje veleta Alpha
Cubierta Potenciometro Alpha
Rodamientos Alpha
Carcasa Eje Alpha
Prisionero eje Alpha
Veleta Alpha
Chapa trasera potenciómetro Alpha
Eje veleta Beta
Carcasa Eje Beta
Prisionero eje Beta
Veleta 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
Select an object or a command

Wind Tunnel Measured error α and β

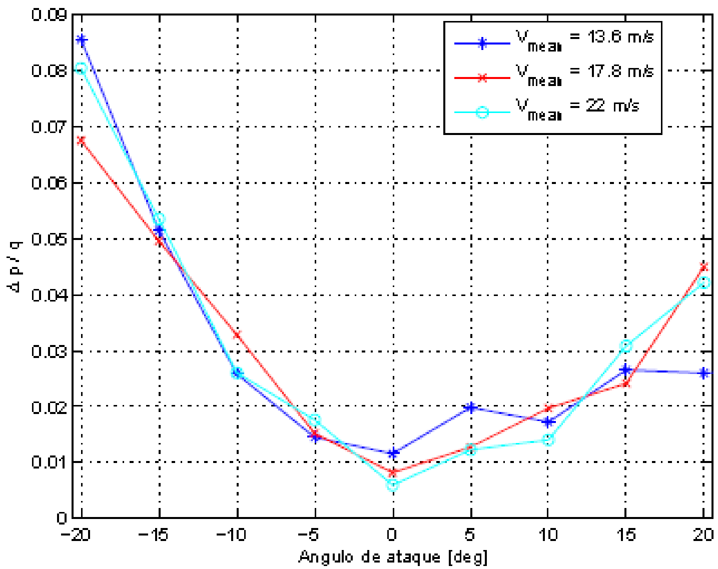
Angle of attack sensitivity (α)

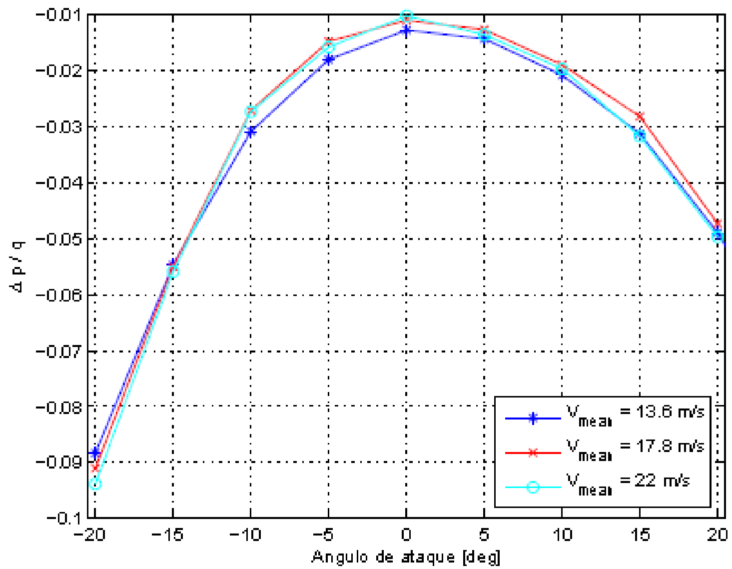




Dynamic Pressure

Static Pressure





Side-slip sensitivity (β)

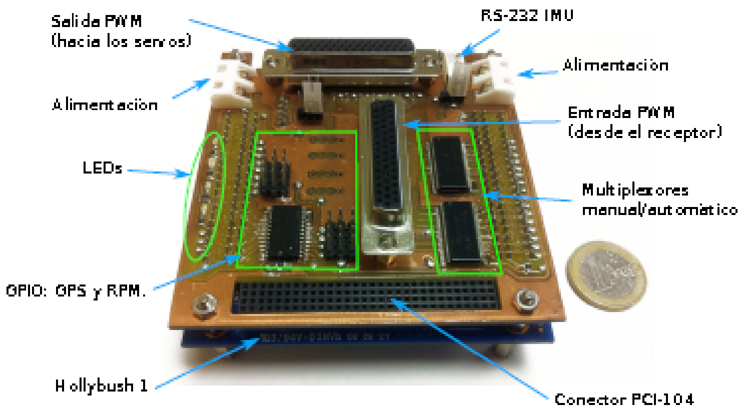
Students' Production

- 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

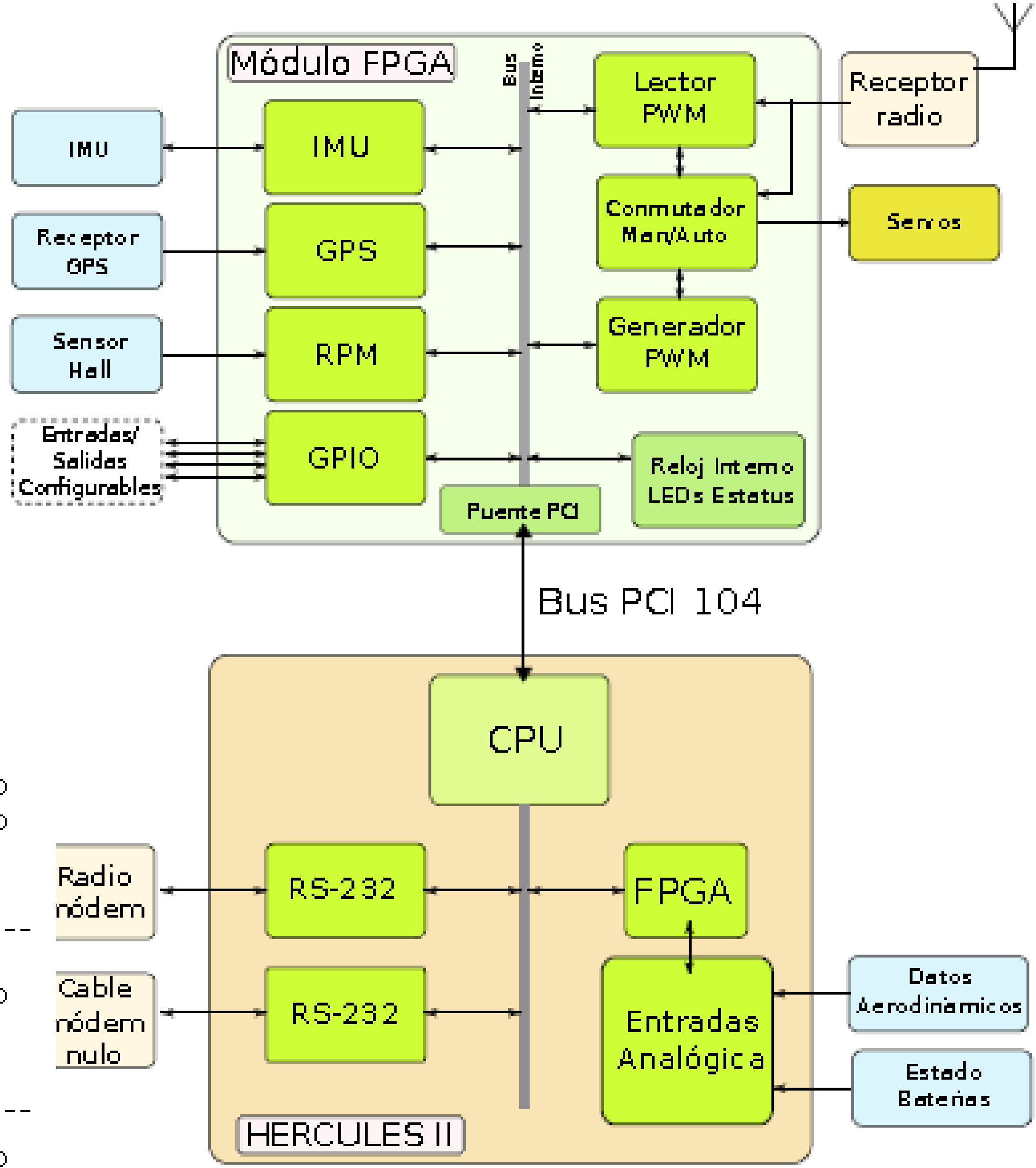
- Need of a hardware platform to implement control strategies:
  - High computing power
  - Versatility
  - Robustness
  - Size and weight compatible with Céfiro
  - Low cost

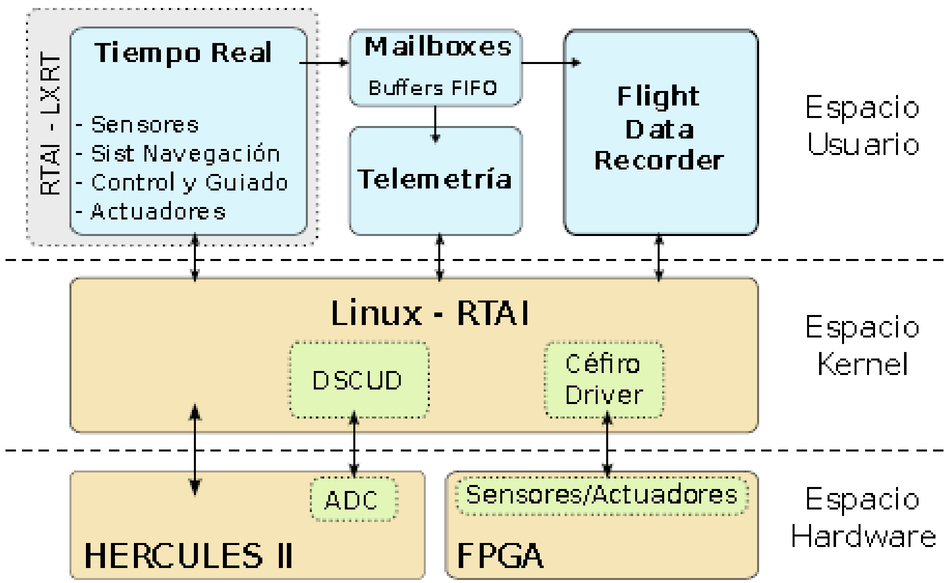
- Needed Functionability:
  - Implementation of control strategies and Navigation systems
  - Manage communications and onboard sensors
    - IMU, GPS, pressure sensors, Pitot-tube…
  - Able to generate PWM signals to control servo-actuators
  - Able to read PWM signals generated by the radio
  - Multiplexor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

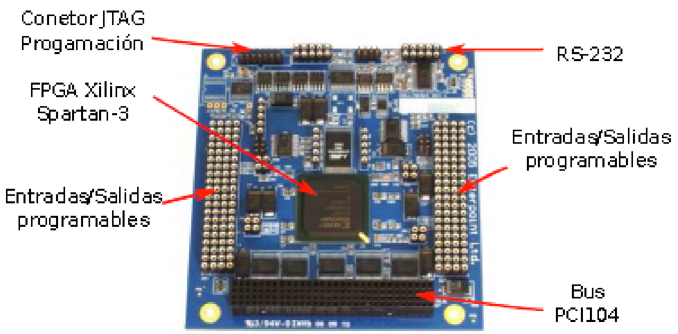


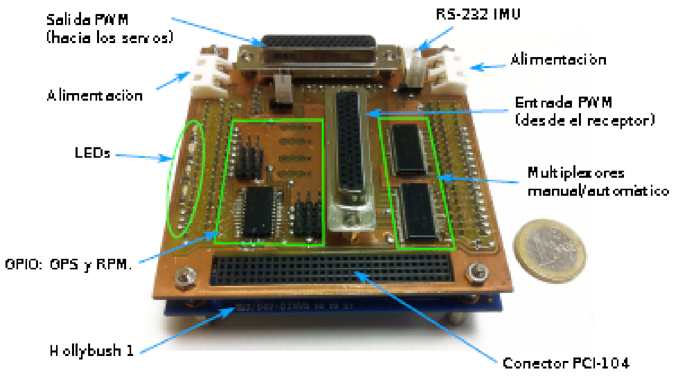
Flight Computer System - II

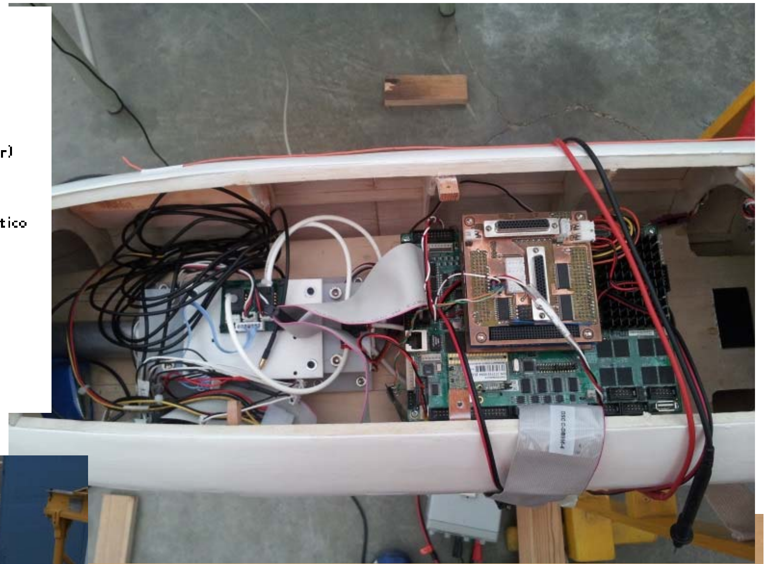
- FPGA (embedded Hollybush)
  - Power control
  - Tension adaptation
  - Multiplexors MAN/AUTO
- Real Time Software
  - Periodic execution of control laws
  - Linux 2.6.23, patched with RTAI 8
  - Development of own integrated drive SO kernel for communications with Fl
  - Recording of state variables

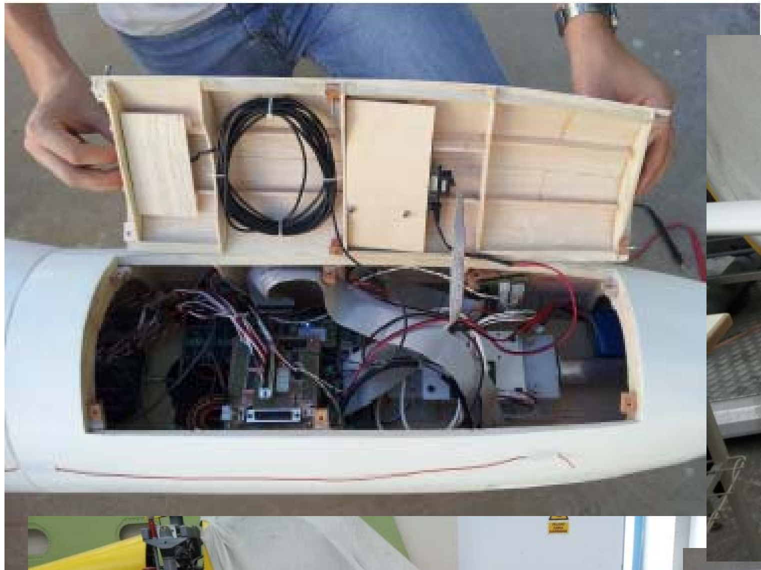





Conetor JTAG
Progamación
FPGA Xilinx
Spartan-3
Entradas/Salidas
programables
RS-232
Entradas/Salidas
programables
Bus
PCI104


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






3DM-GX1
MicroStrain

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

Flight Control Strategies & Navigation Control Strategies

- Lines of research/production being conducted by the members of the GIA:
  - Design Control Strategies:
    - Model-free adaptive (backsteeping) control strategies for longitudinal and lateral control of UAVs.
    - Singular-perturbations Time-scale control strategies for longitudinal and lateral control of UAVs
  - Design Navigation Estrategies:
    - Cruise optimization with trajectory patters
    - Optimization of ascent trajectories
    - Minimum fuel-cruise for flight constrains
    - Compressibility effects on range cruise
    - Optimization of unpowered descent
    - Optimal trajectory optimization with singular arcs
    - Optimal trajectory generation with dynamics trajectory modeling
    - Conflict resolutions

Conclusions

- Have demonstrated:
  - Capability of implementing the design improvements.
    - Electric Propulsion
    - Aerodynamics improvements
  - Design and construct low cost aerodynamics sensors.
    - Tested in wind tunnel experiments.
    - Demonstrated precision in wind tunnel experiments.
  - Designing and constructing a custom-made Flight Control System
    - Flight Computer
    - Advanced Aircraft Modeling.
    - Flight Computer Systems.
    - Flight Control Strategies & Navigation control strategies.

Future Work - I

- Conduct the campaign flight:
  - Obtain data for engine and aircraft performance modeling.
  - Demonstrate MAN/AUTOMATIC flight (trials starting in Spring 2014)
  - Test control and navigation strategies (trials starting in Spring 2014)
  - Tele-operation via FPV
  - Autonomous flight (trials starting in Summer 2014).
- Current Projects in progress: 4 Thesis (PFC) being conducted
  - Designing a smaller UAV version (No-convenctional design): José Carlos García Hiniesta, Advisors: Francisco Gavilán and Sergio Esteban
  - Parametric Estimation of Stability Models for UAVs: Pablo García Mascort, Advisor: Sergio Esteban
  - Developing Stability Analysis Tools for small UAV's: XFLR5: David Gomez Mingorance, Advisor: Sergio Esteban
  - Developing Tools for the Study of Aerodynamic and Estability Characteristics of Flying Wings: Jorge Narbona González, Advisor: Sergio Esteban
  - Developing Advanced Propulsion Wind Tunnel Models for Determining UAV's Performance : Juan Manuel Moral Gámez, Advisor: Sergio Esteban
  - Developing Advanced Propulsion Wind Tunnel Models for tilt-rotor engines for Determining UAV's Performance during transition: Raimundo Blanco Hácar, Advisor: Sergio Esteban

Project Céfiro