Cefiro: An Aircraft Design Project in the University of Seville

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Introduction

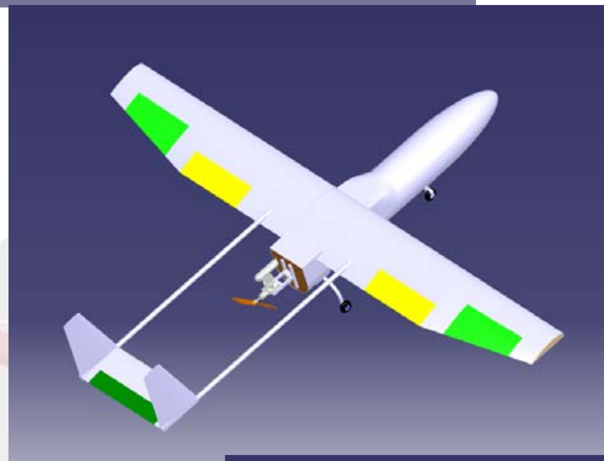
- Motivations:
  - Research
    - Some of the areas of research of the Department of the Aerospace Engineering at the University of Seville are:
      - Trajectory optimization.
      - ATM.
      - Aircraft design.
      - Aircraft dynamics and engine performance modeling.
      - Automatic flight control 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 Cefiro.

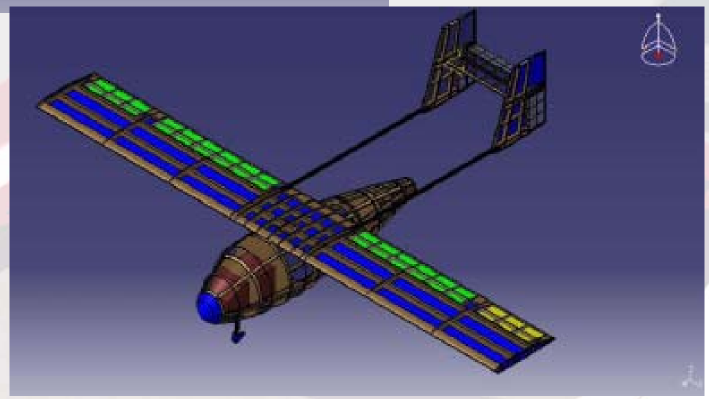
Aircraft Design at the university of Seville

- 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.”

“Cálculo de Aviones” Designs - 2006-07

“Cálculo de Aviones” Designs - 2007-08





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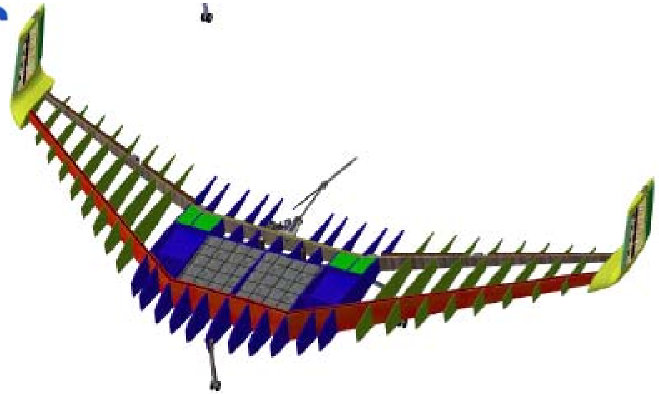
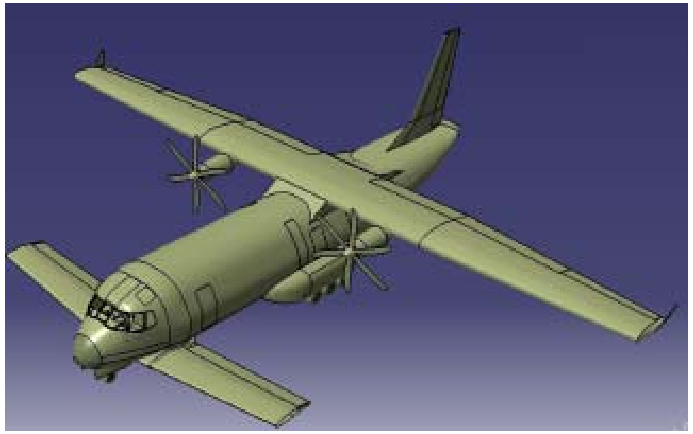
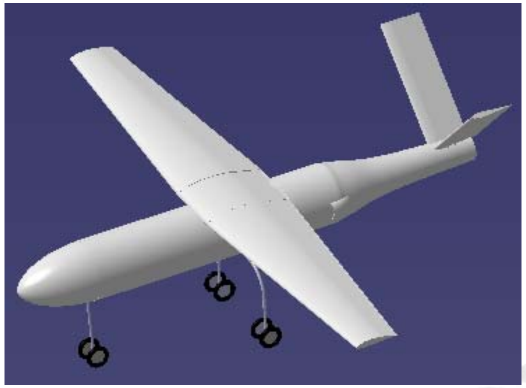
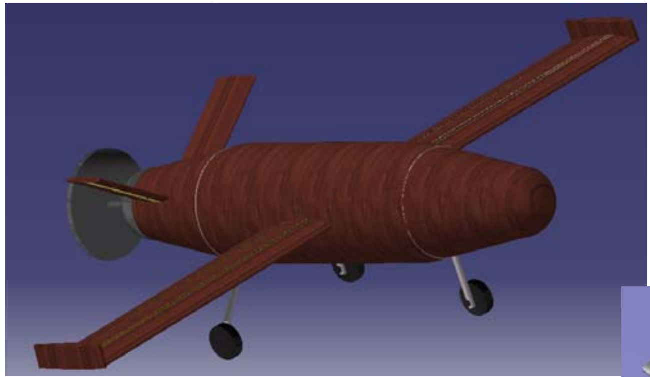
“Cálculo de Aviones” Designs - 2008-09

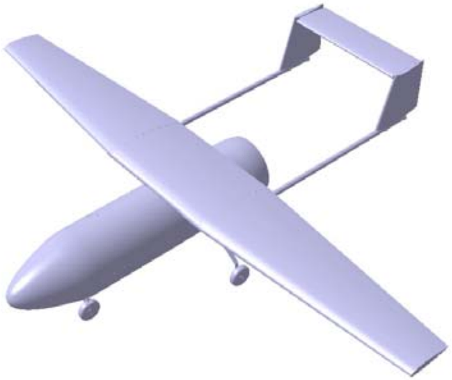
CEFIRO











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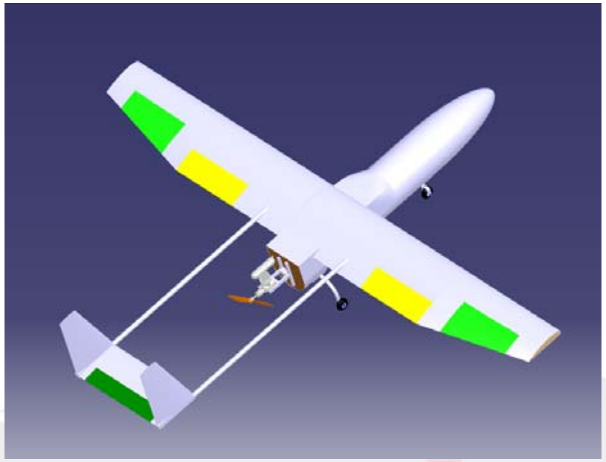
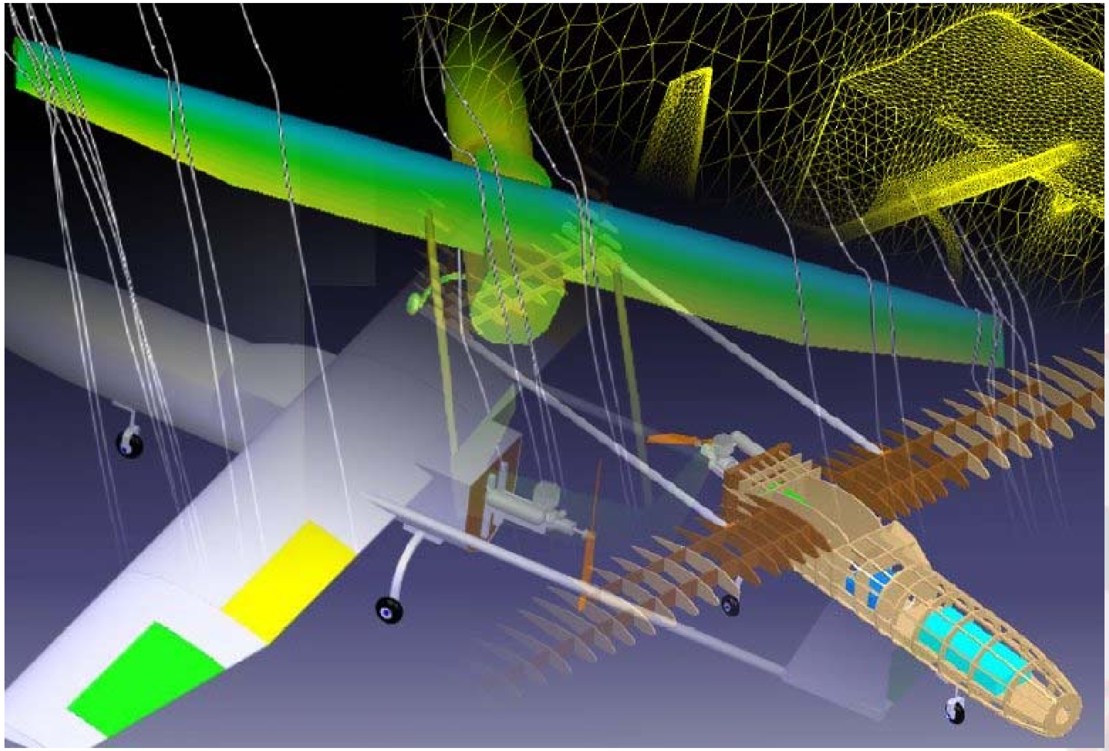
Cefiro: An Aircraft Design Project - I

- 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: 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):

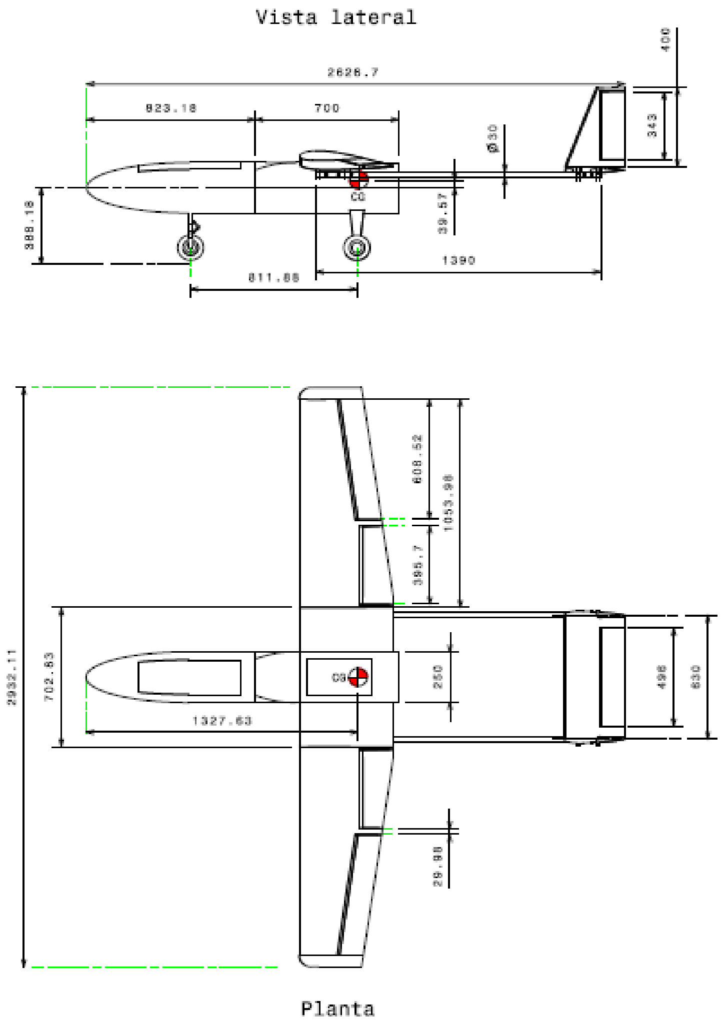


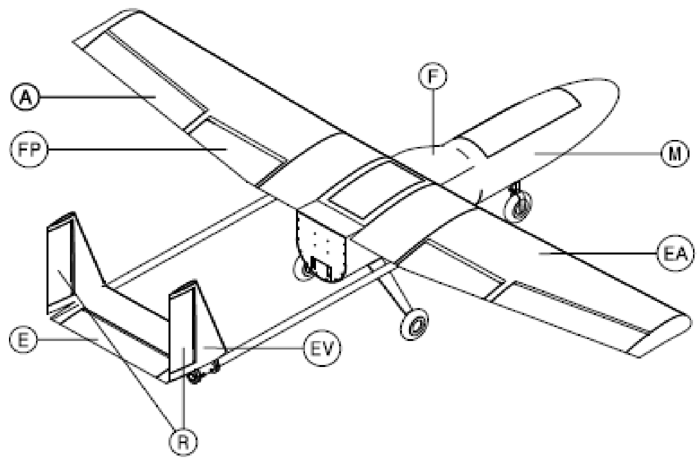
- Structural design and manufacturing process.
- Aerodynamics.
- Stability and control.
- Engine and aircraft performance.
- Production and systems integration.

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.

Cefiro's Geometry





- **Cefiro's Geometry:**
  - **$S = 1{,}088\ m^2$**
  - **$S_t = 0{,}176\ m^2$**
  - **$S_t = 0{,}176\ m^2$**
  - **$c = 0{,}39299\ m$**
  - **Root chrosd - $c_r = 0{,}459\ m$**
  - **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**

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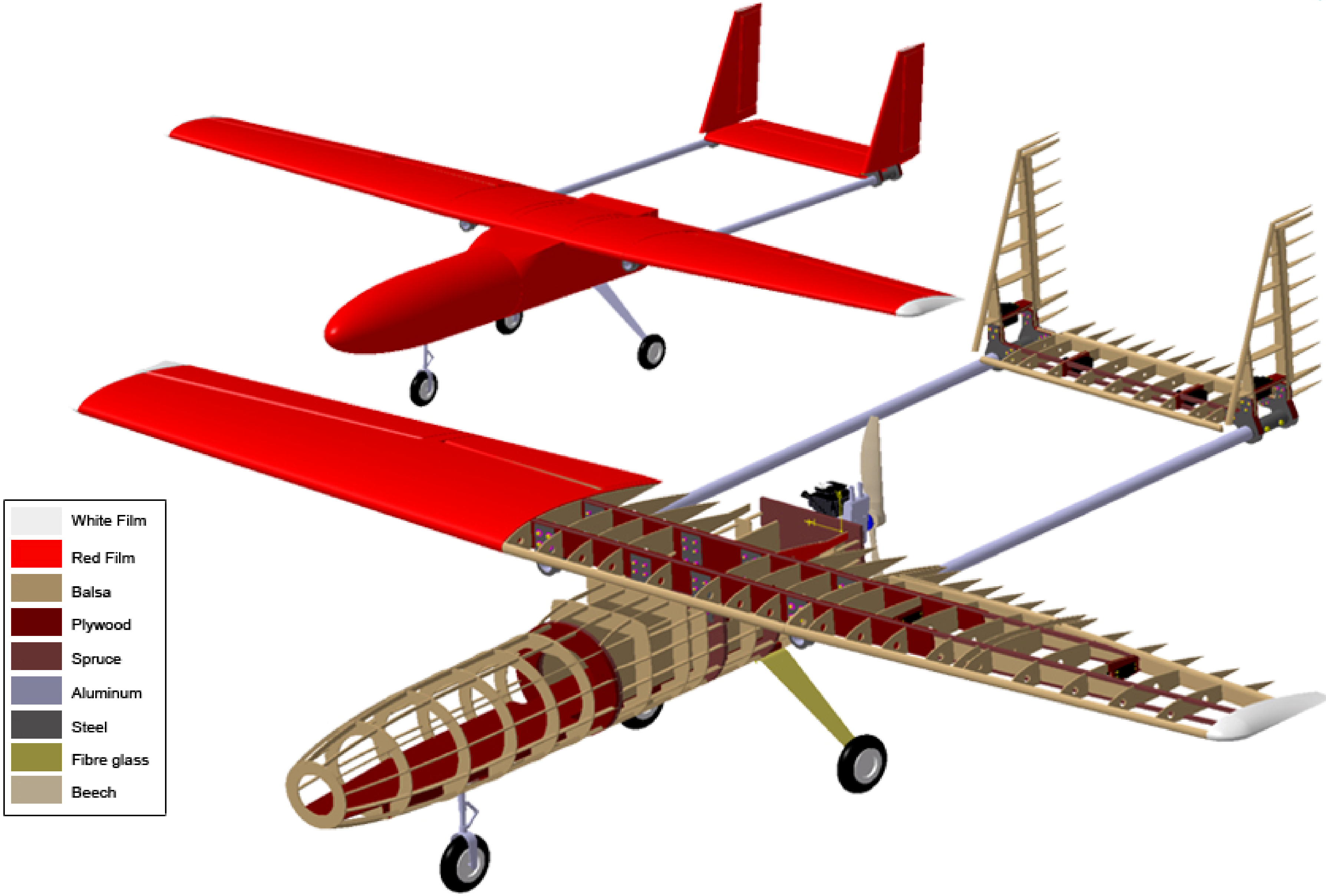
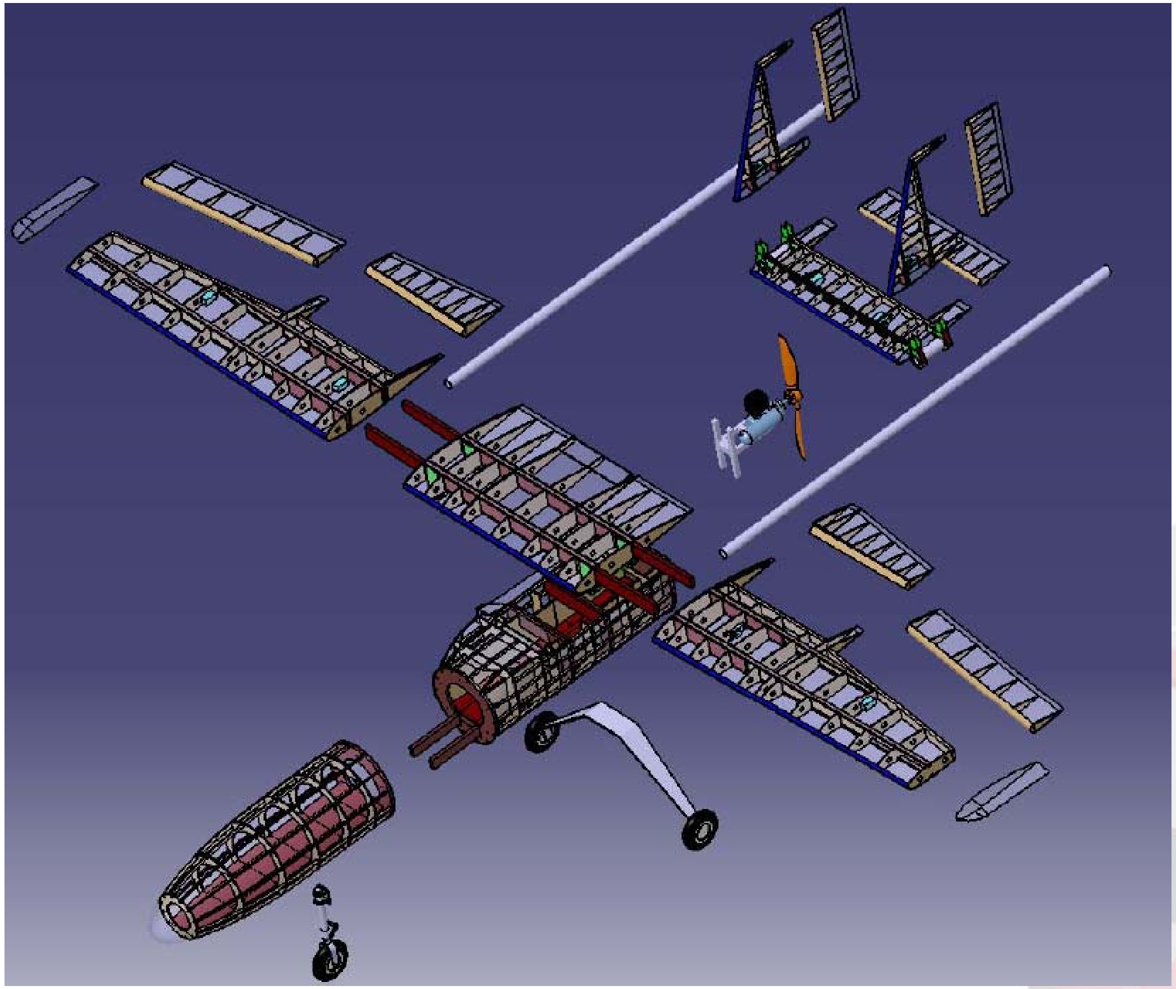
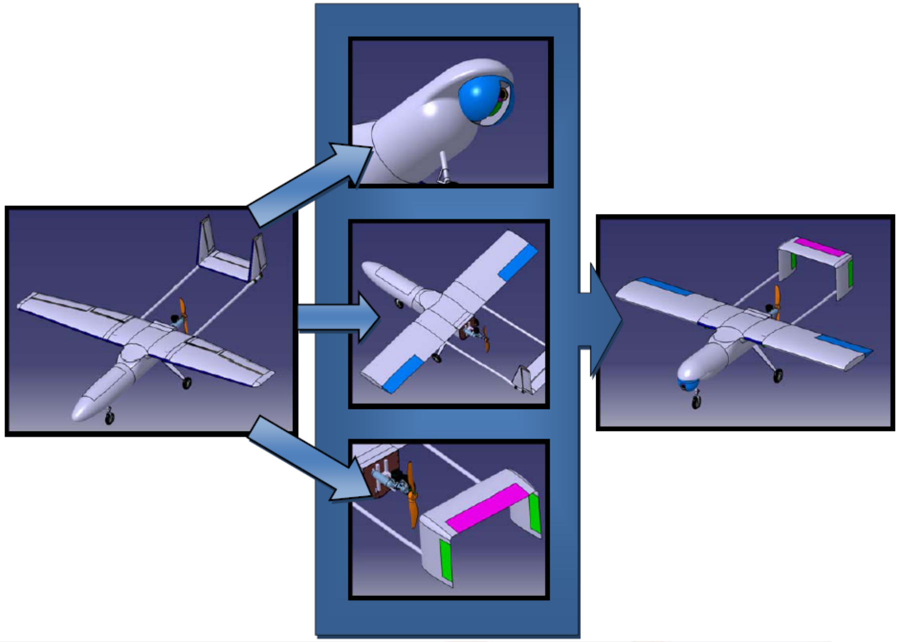
Materials



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

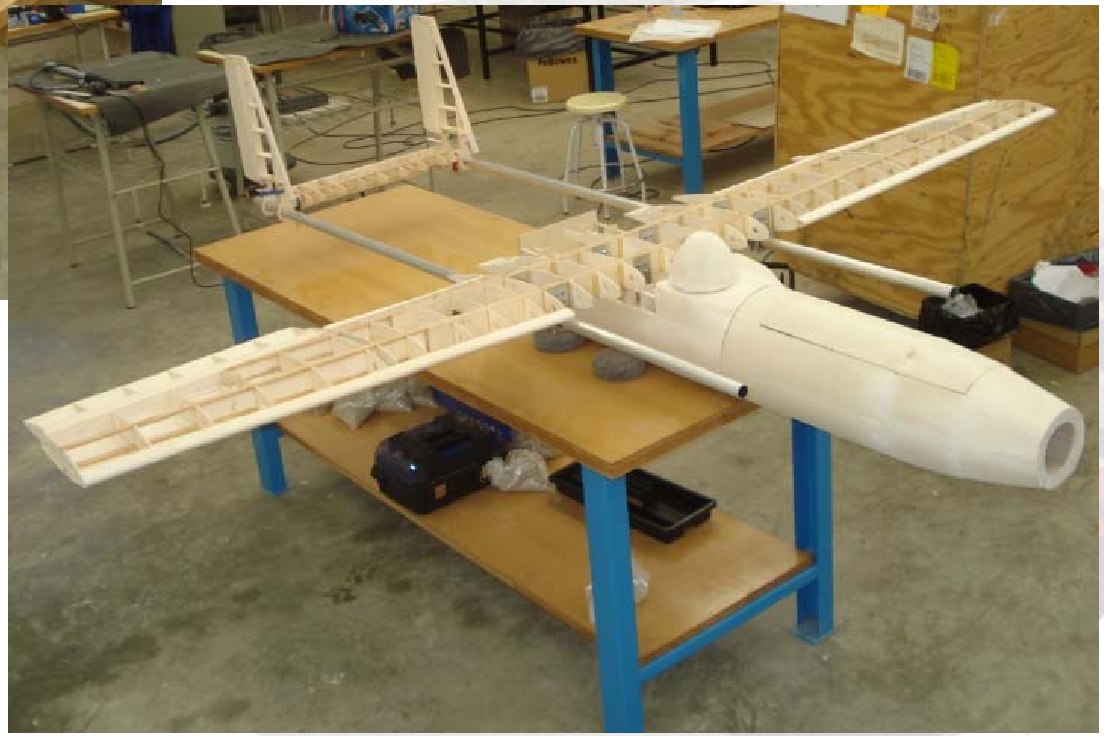
Modular design - I





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

Modular design - II



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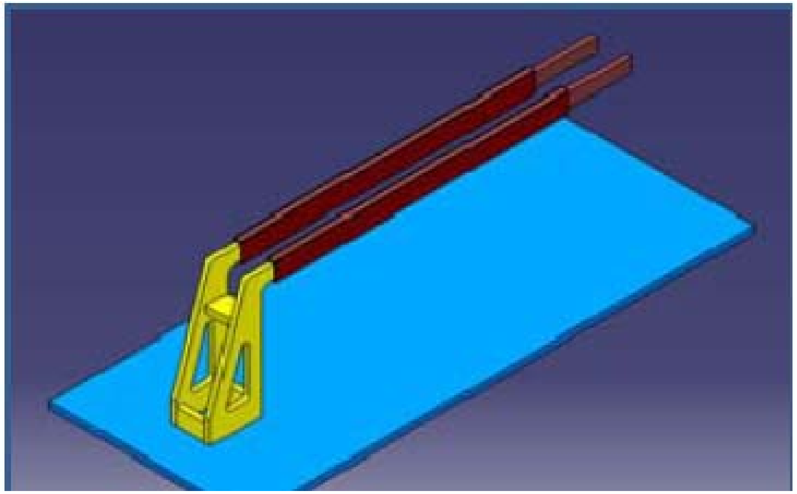
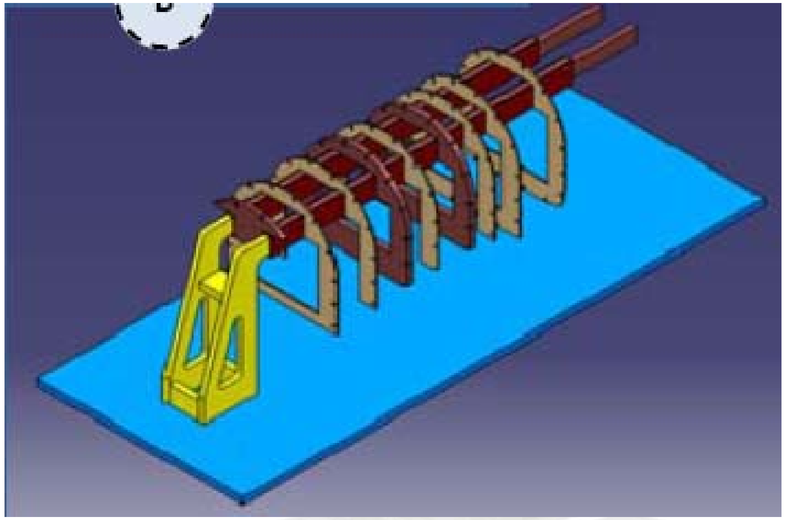
Construction process - I

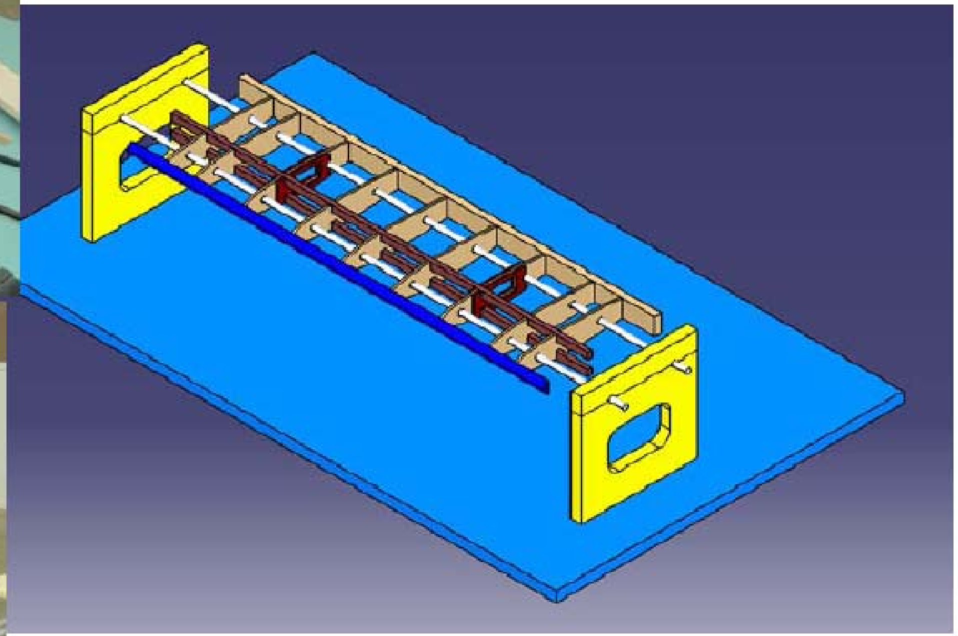




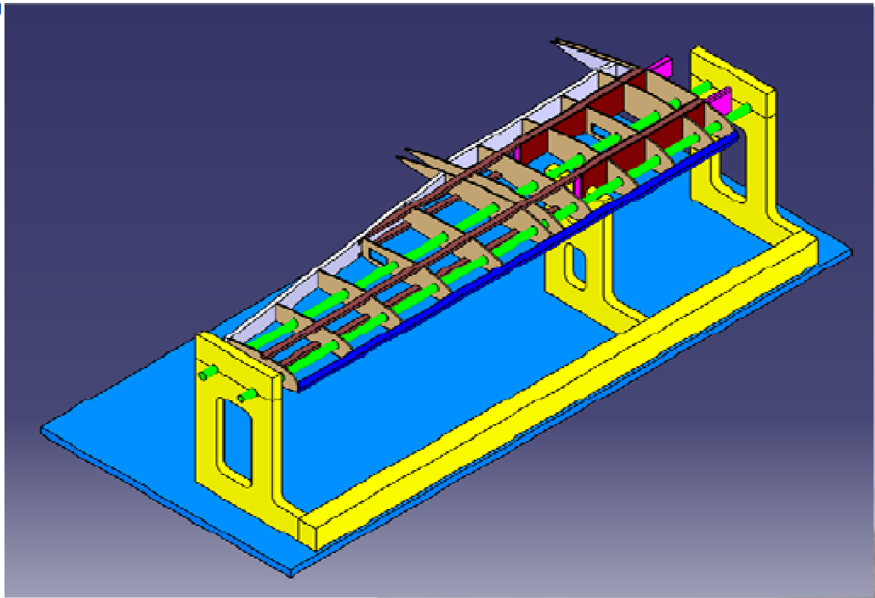
Fuselage

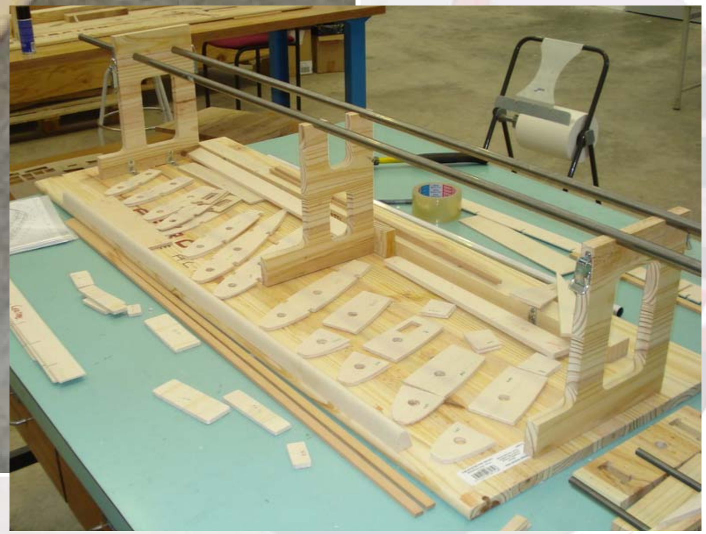
Construction process - II

Horizontal Tail



Construction process - III

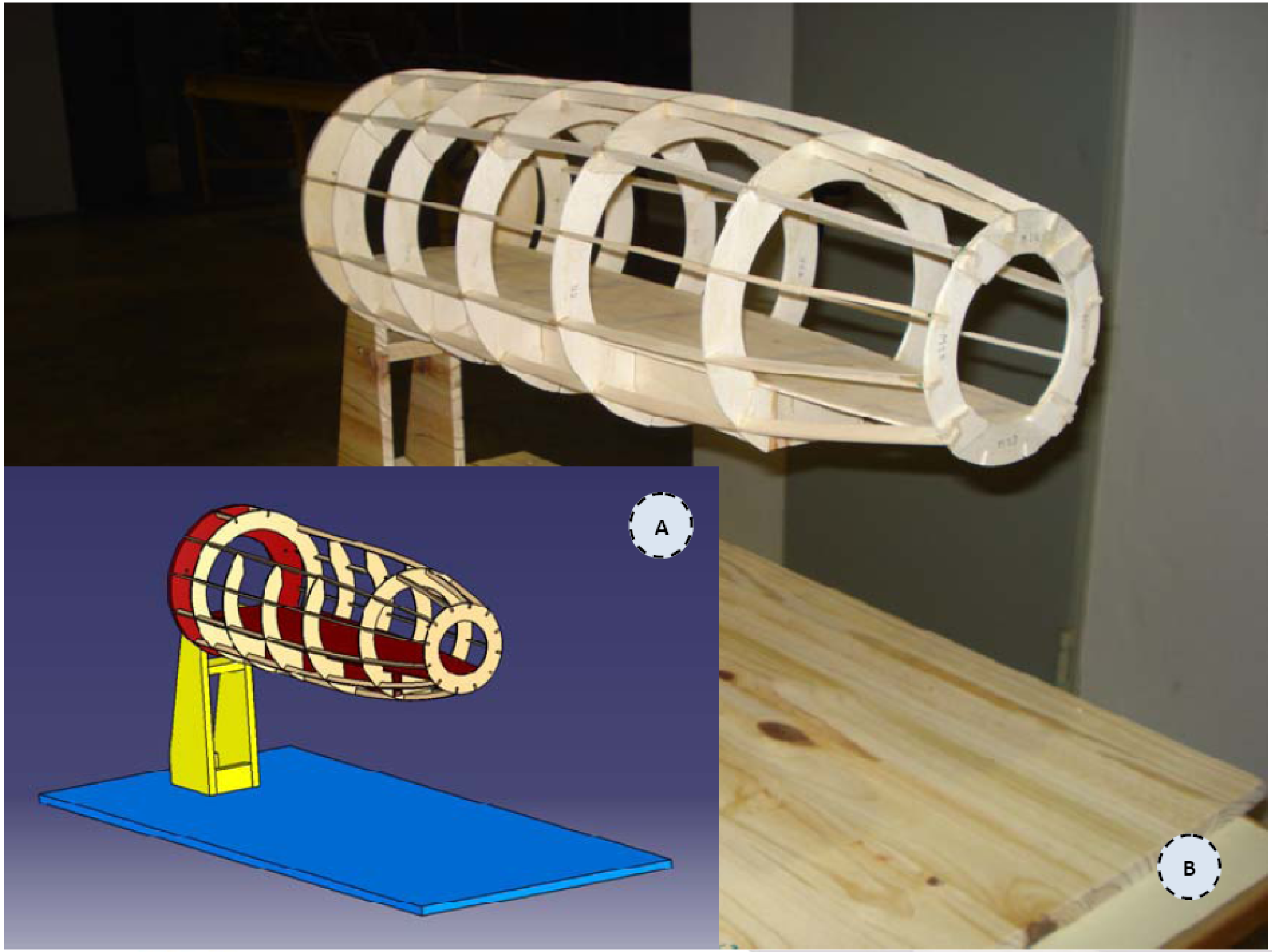




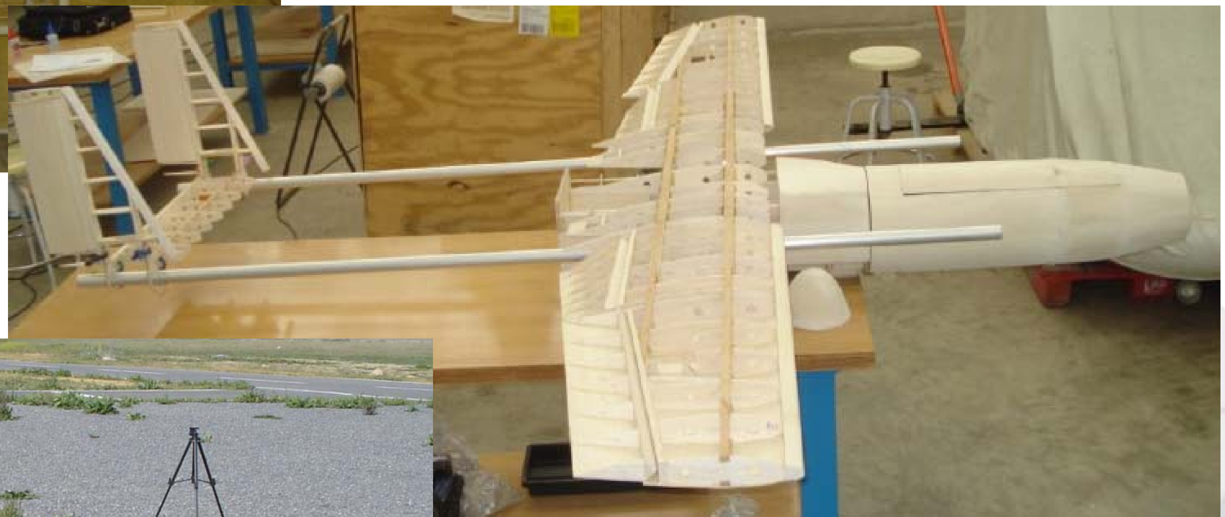
Wing

Construction process - IV

Nose Fuselage

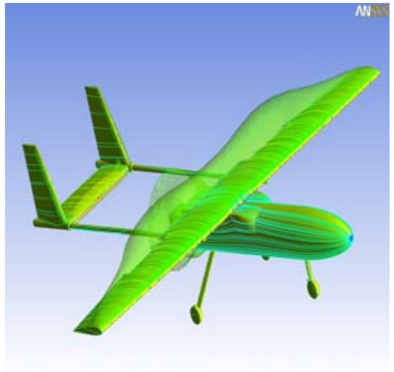


Construction process - V



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.



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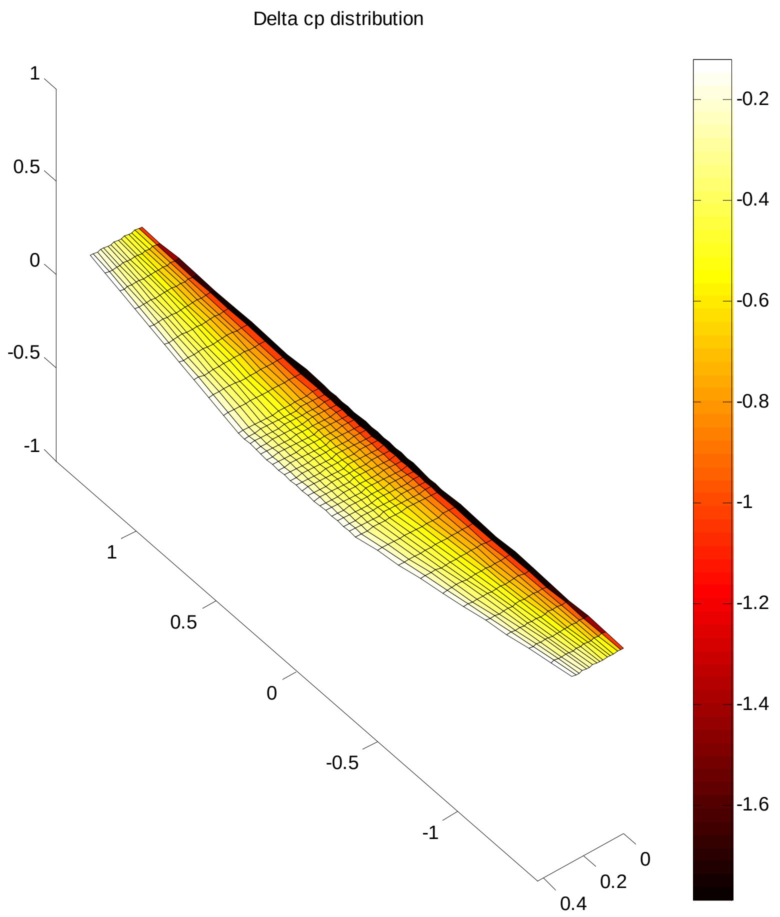
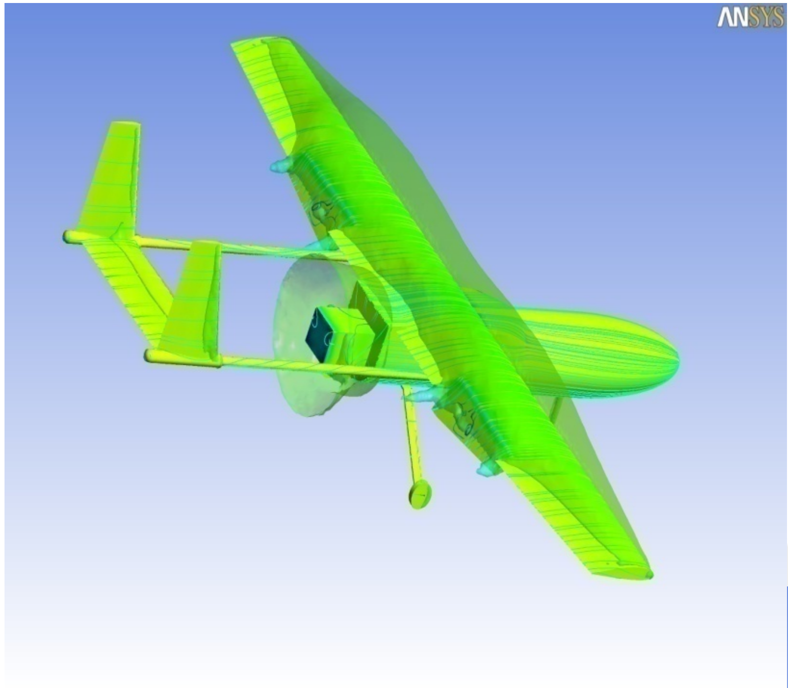
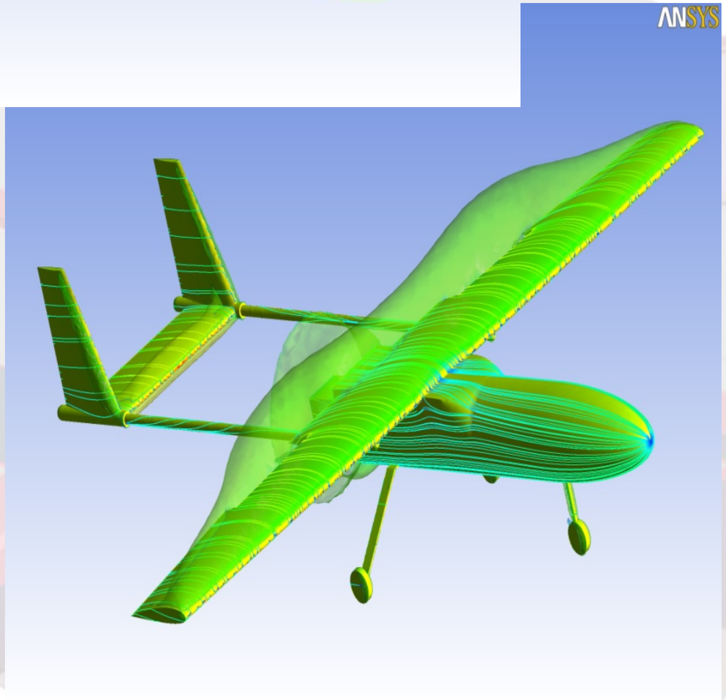
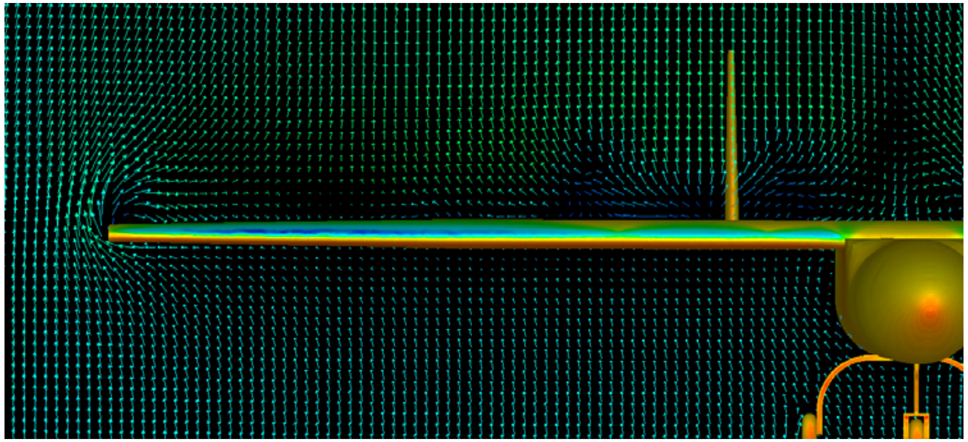
Aerodynamics - II

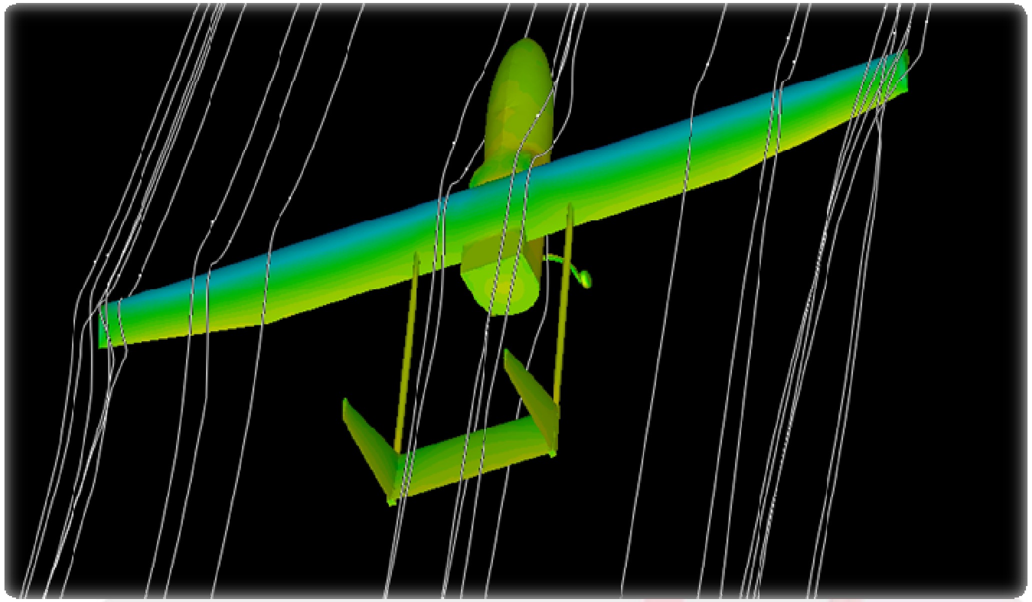


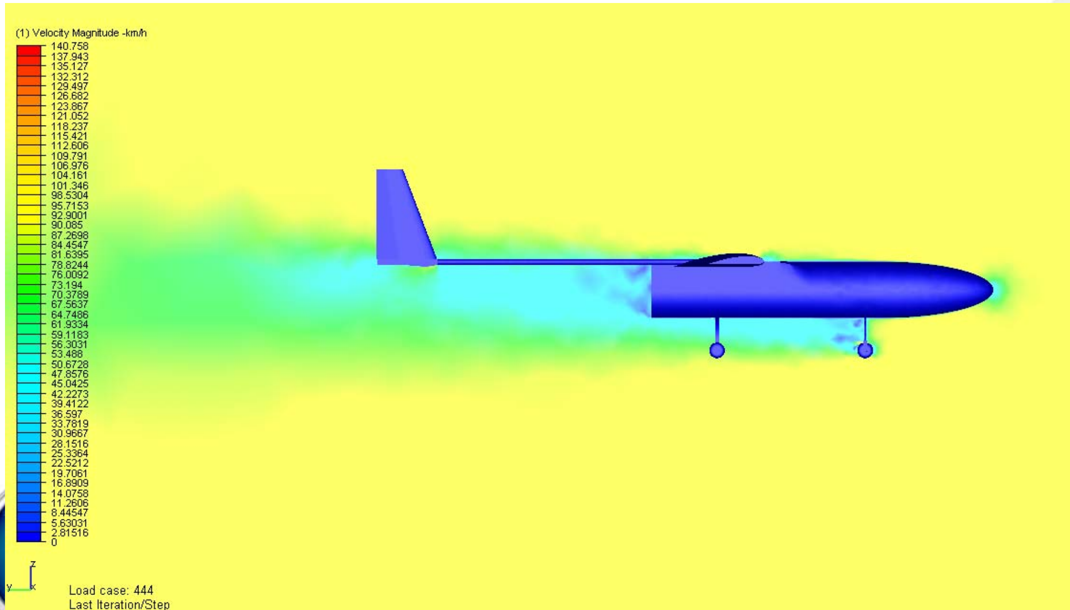


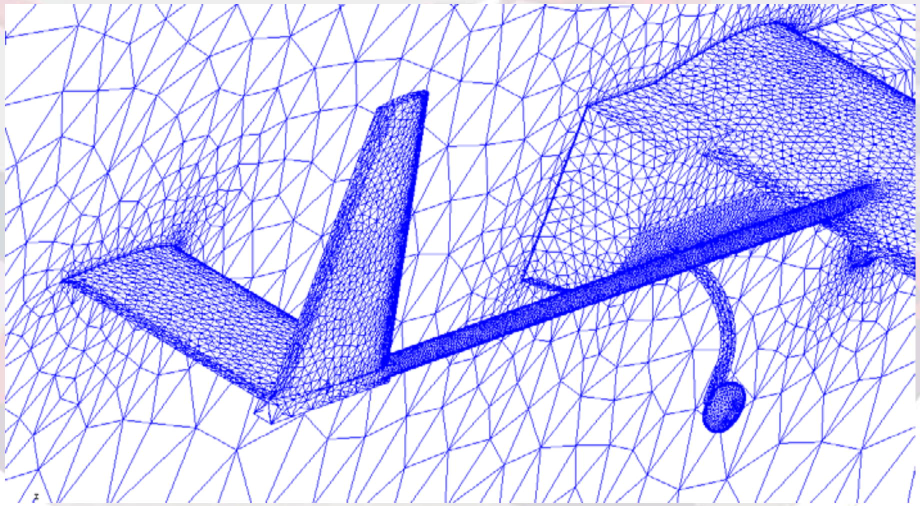


Aerodynamics - III



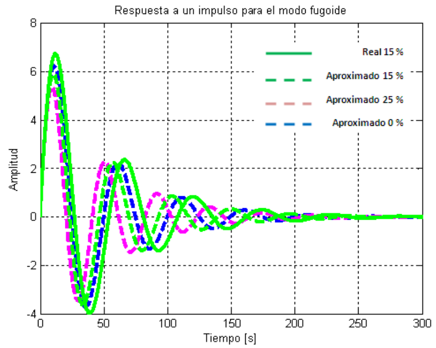






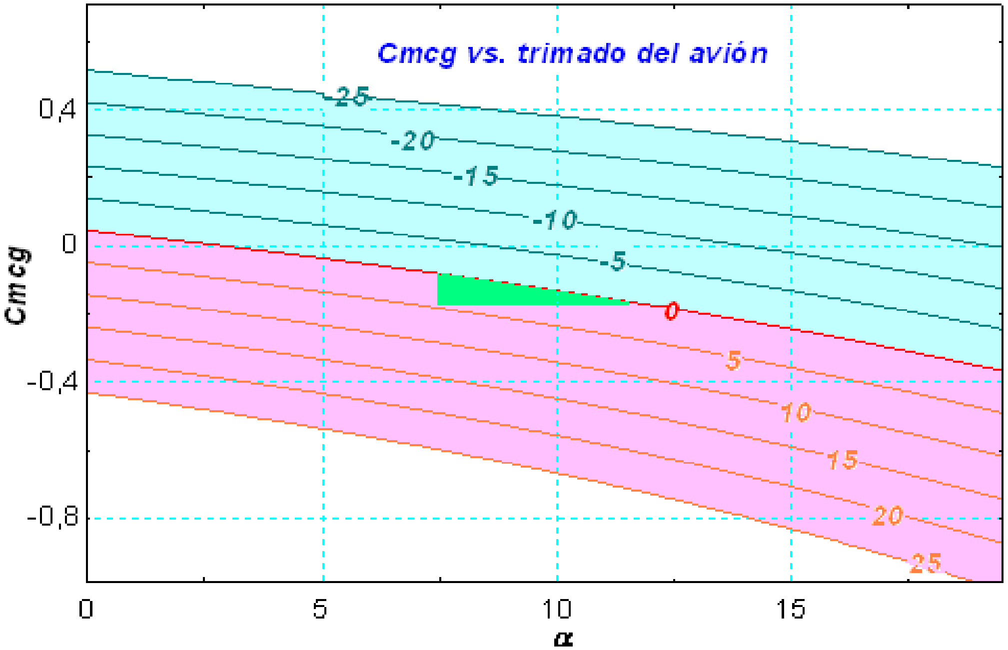
Stability and control

- 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 during critical maneuvers.

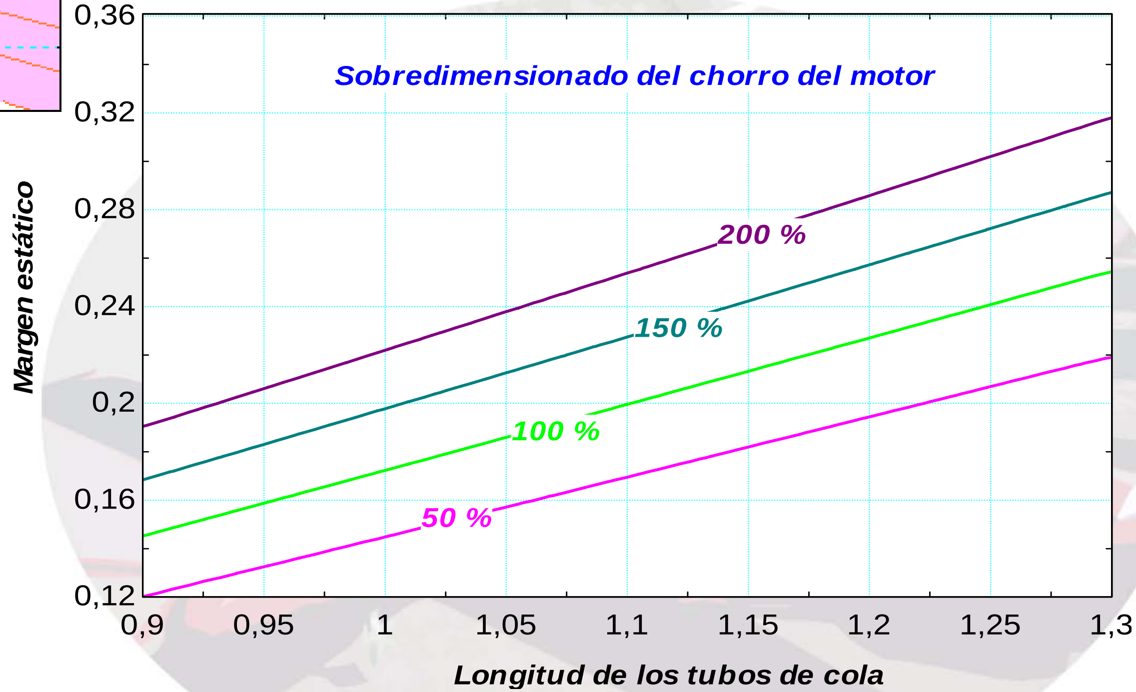


- Great deal of work was directed towards obtaining a parametric model able to estimate the stability derivatives:
  - Merge of the available literature: F. Smetana, B. Pamadi, J. Roskam.
  - Comparison of analytical methods with a real airplane (B-747).
  - Yielded an extensive dynamic study:
    - Dynamic longitudinal stability: Phugoid and Short Period.
    - Dynamic lateral stability: Spiral mode, Dutch roll and Roll subsidence.

Static longitudinal stability



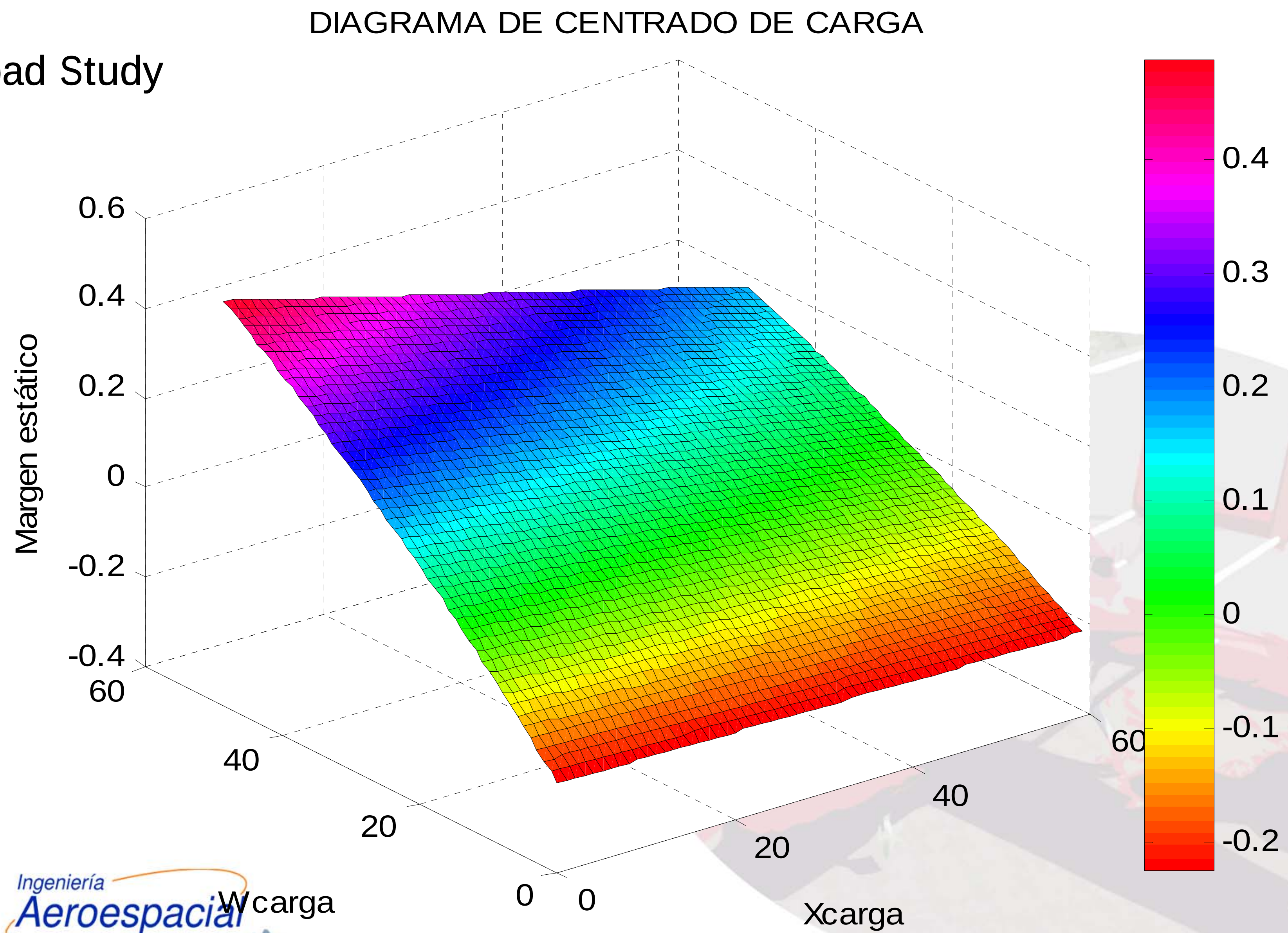
Trim vs. X_{CG}



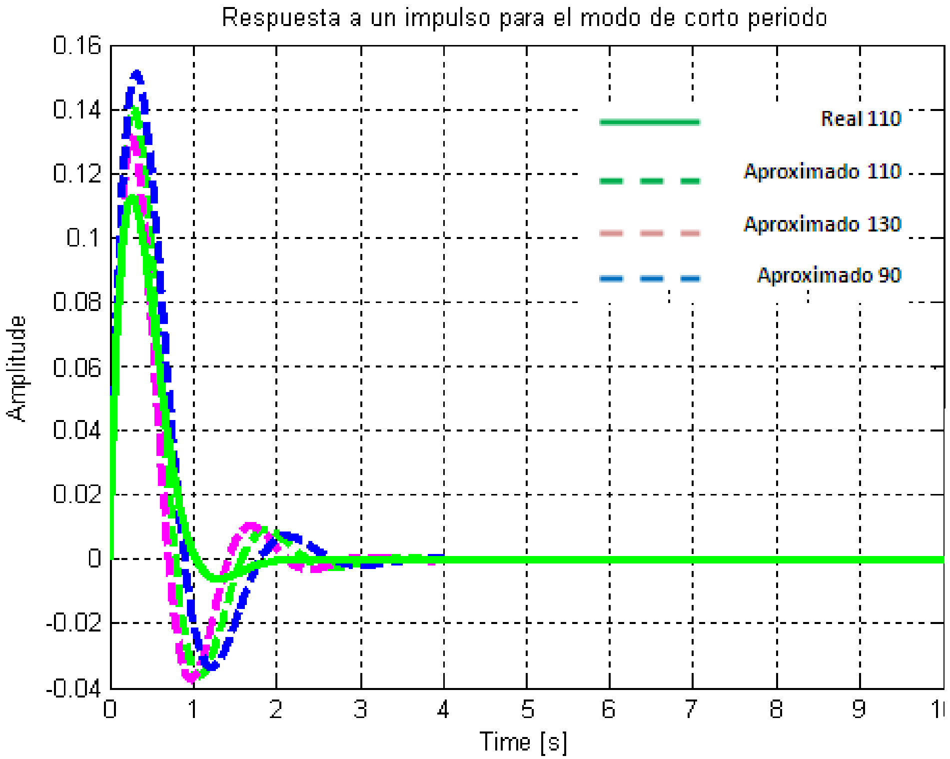
SM vs. Tail-boom length
(with downstream effect)

Static longitudinal stability

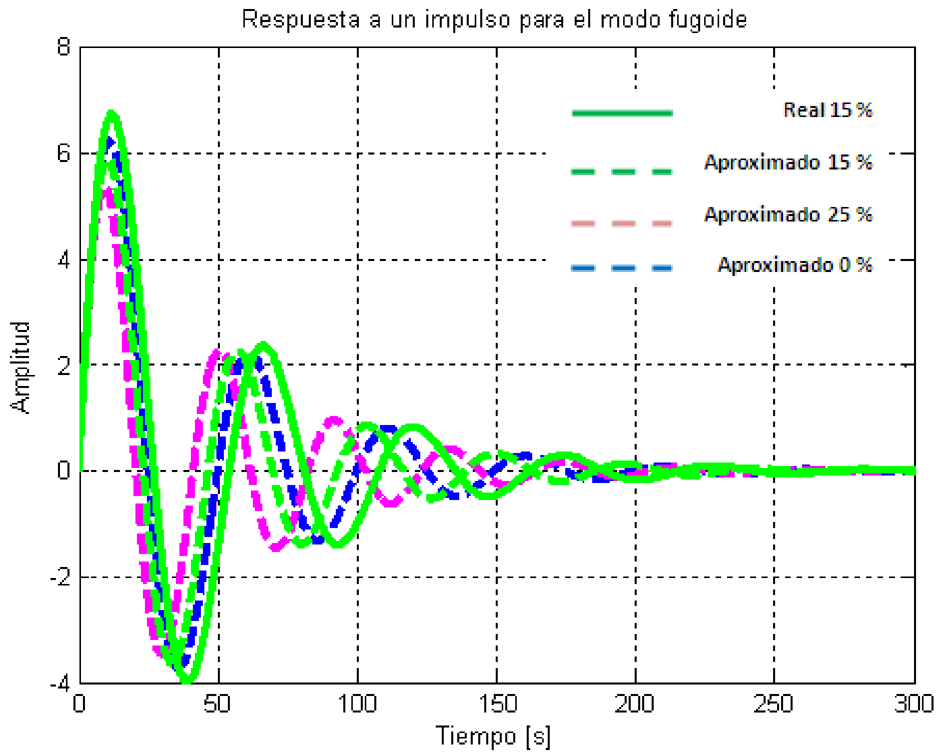
Payload Study



Dynamic longitudinal stability



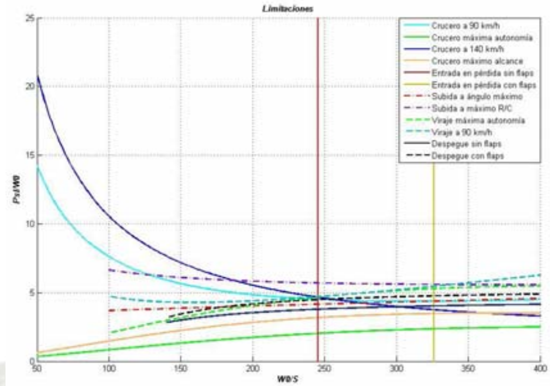
Short Period



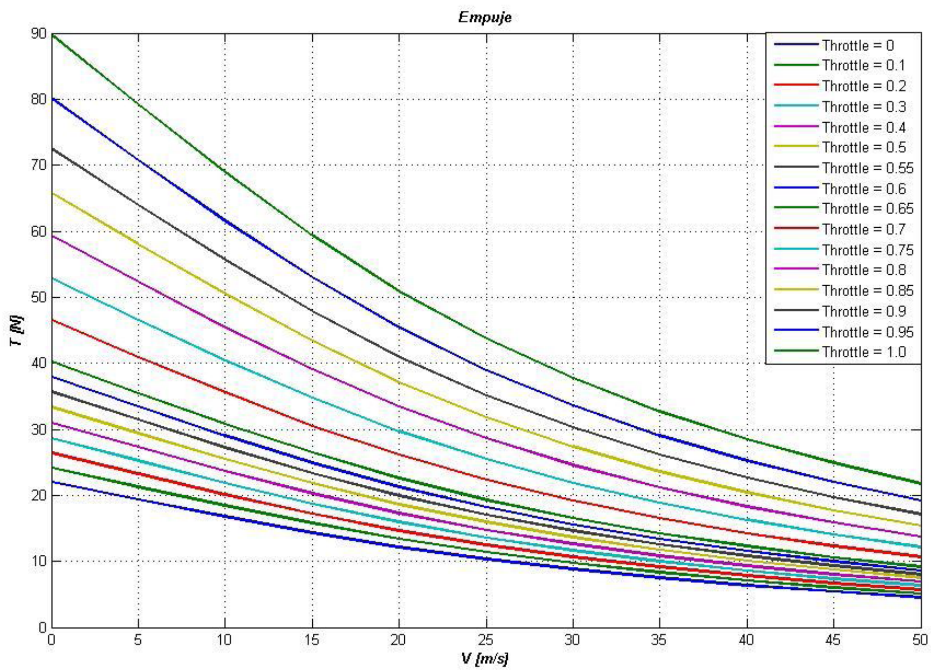
Phugoid Mode

Propulsion and performance analysis - I

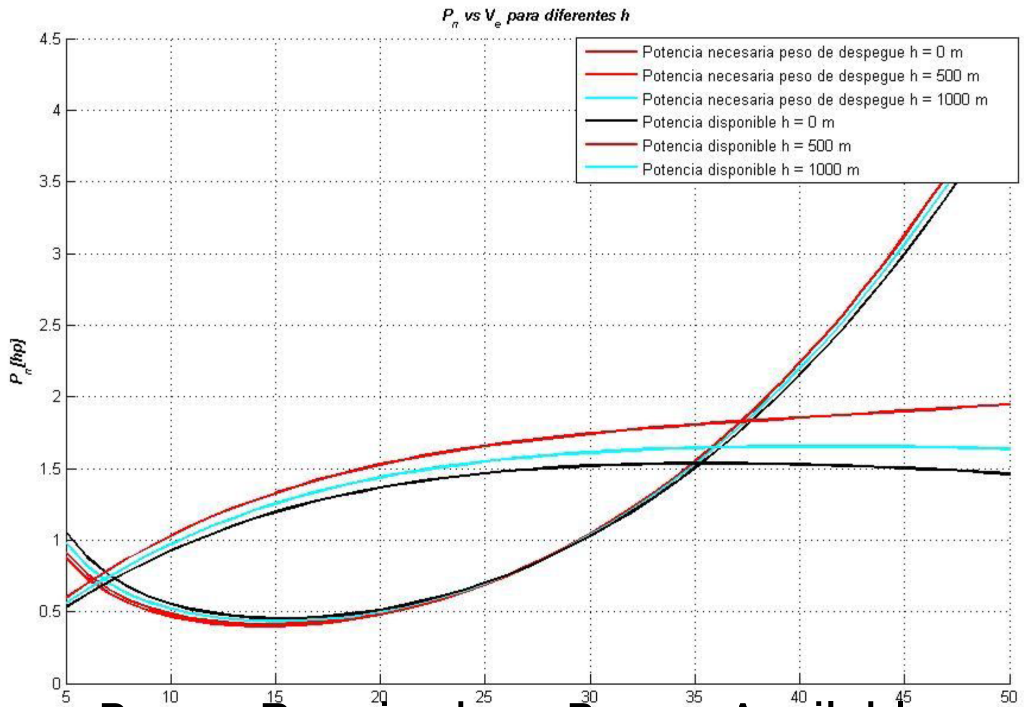
- The necessity of characterizing the performance of Cefiro, required an extensive study:
  - Performance Study:
    - Take off and Landing.
    - Climb and Descent.
    - Cruise.
  - Mission Analysis.
    - Complete study of the performances for the RFP mission.
  - Study of Endurance and Range:
    - Optimization of velocities vs. fuel consumption, altitude and throttle settings (theoretic).
  - 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 (in progress).



Propulsion and performance analysis - II

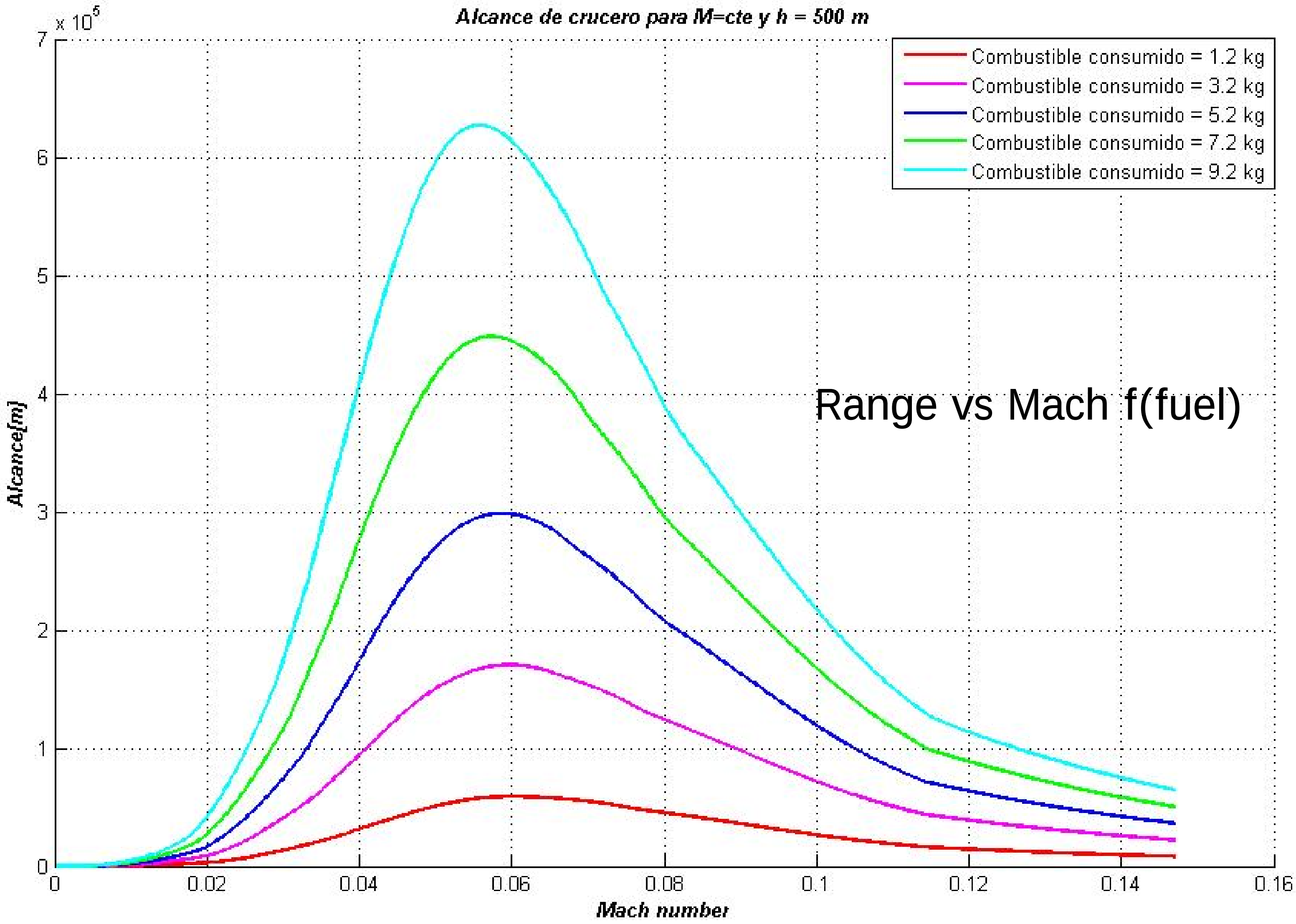


Thrust vs Speed f(throttle)

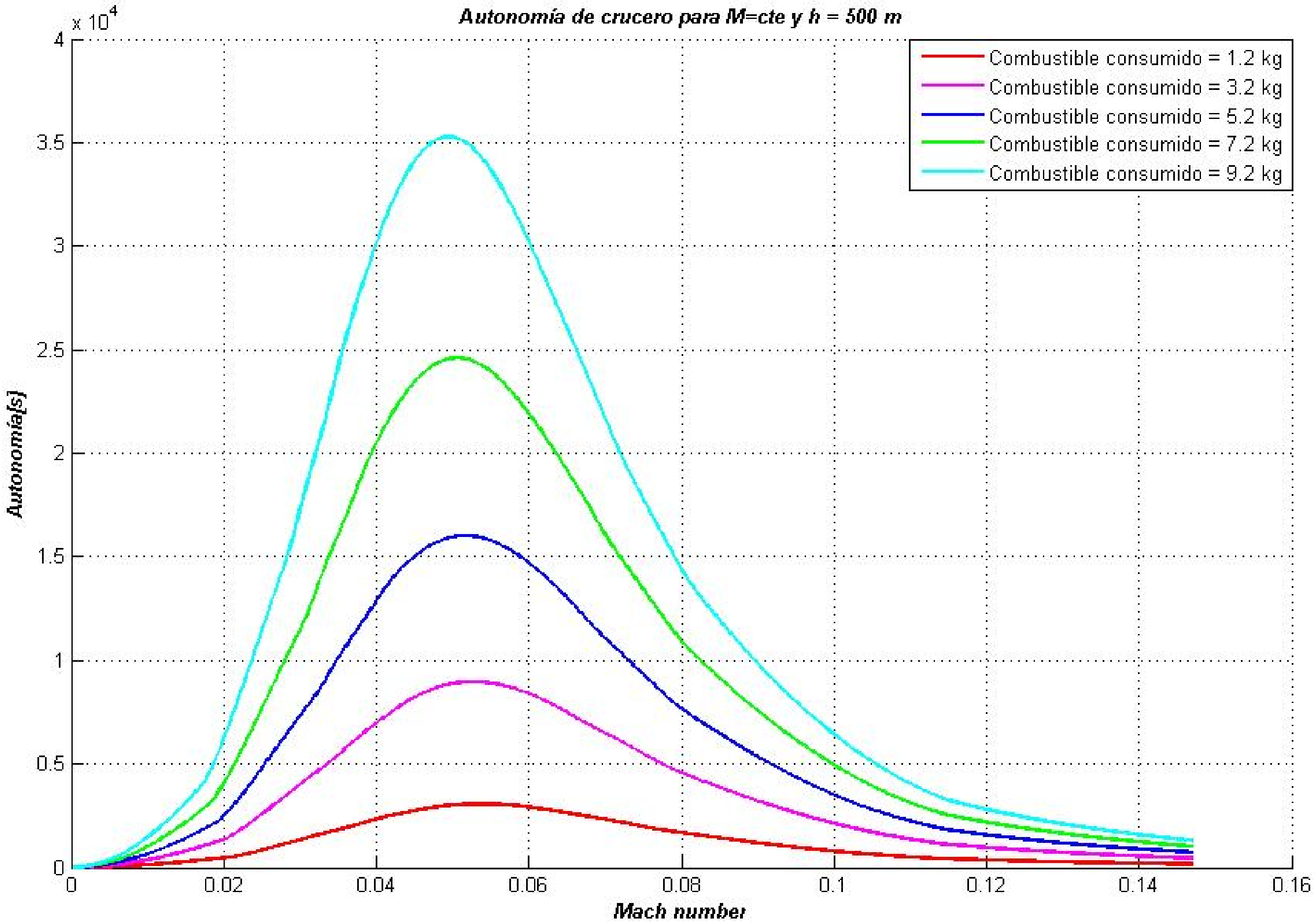


Power Required vs. Power Available f(altitude)

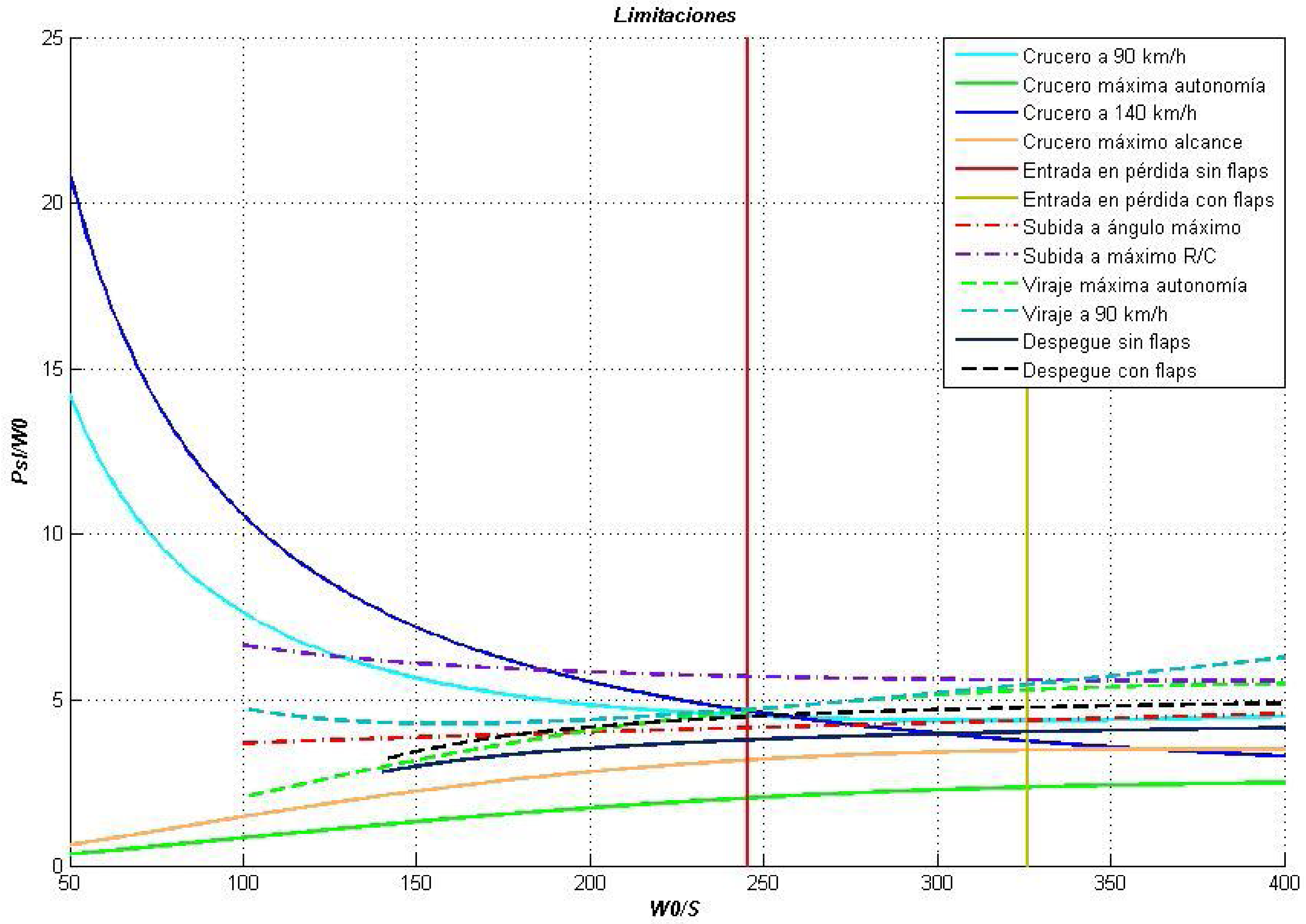
Propulsion and performance analysis - III



Propulsion and performances analysis - IV



Propulsion and performances analysis - V



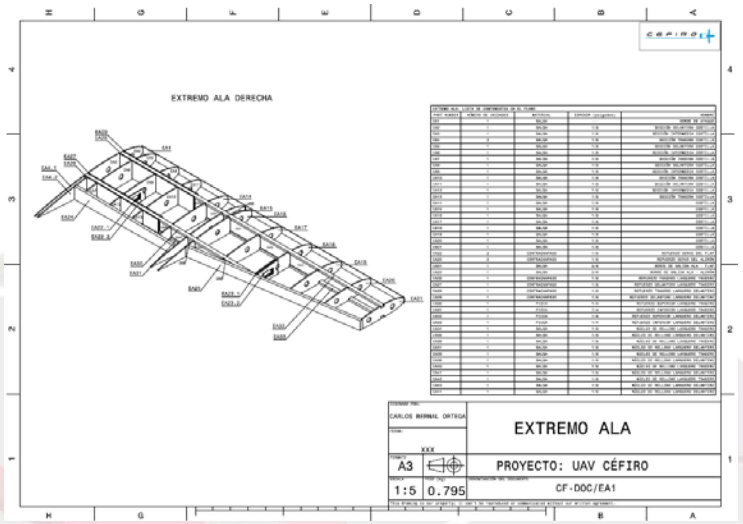
Engine Modelling





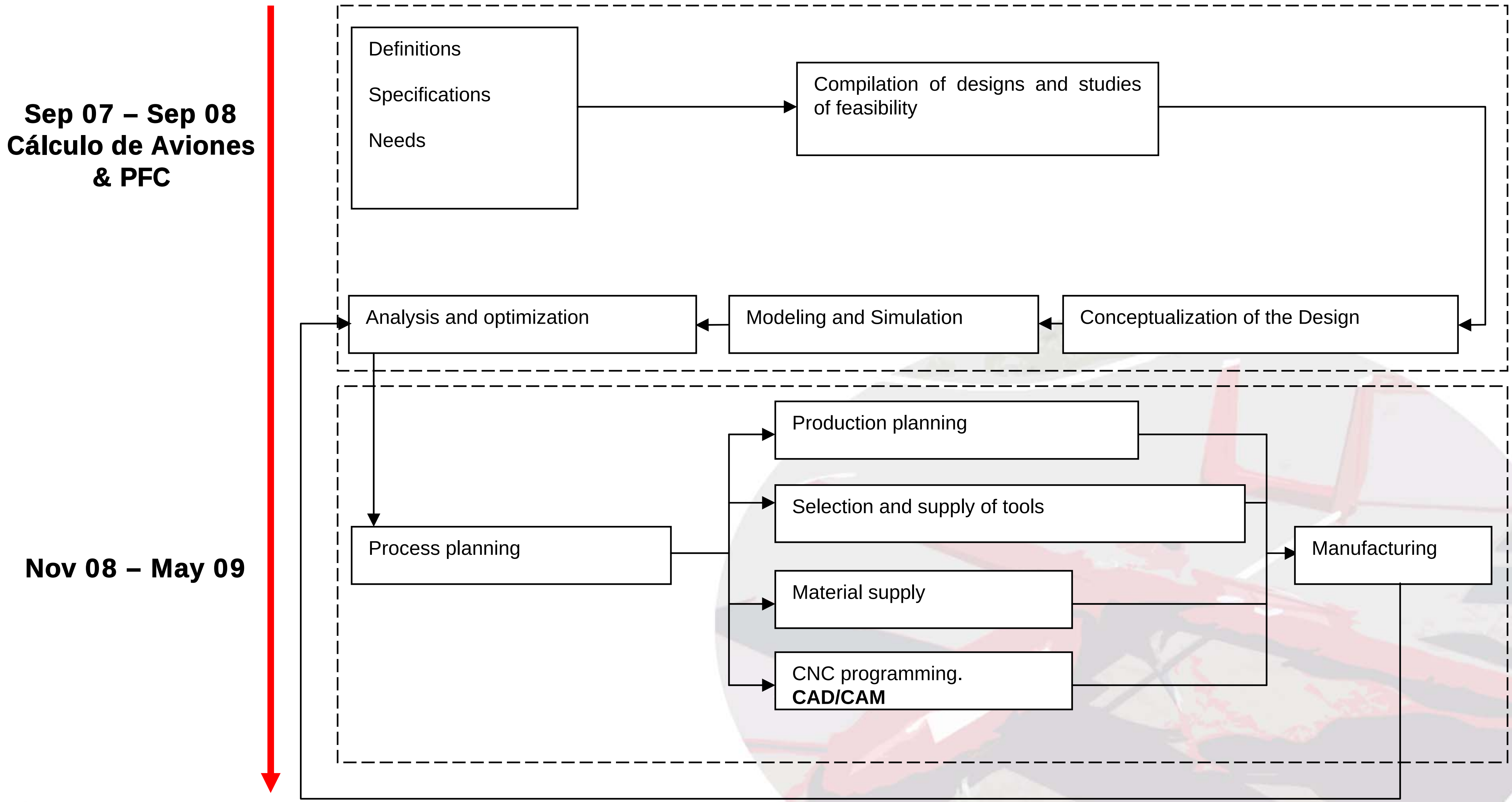

Production and systems integration - I

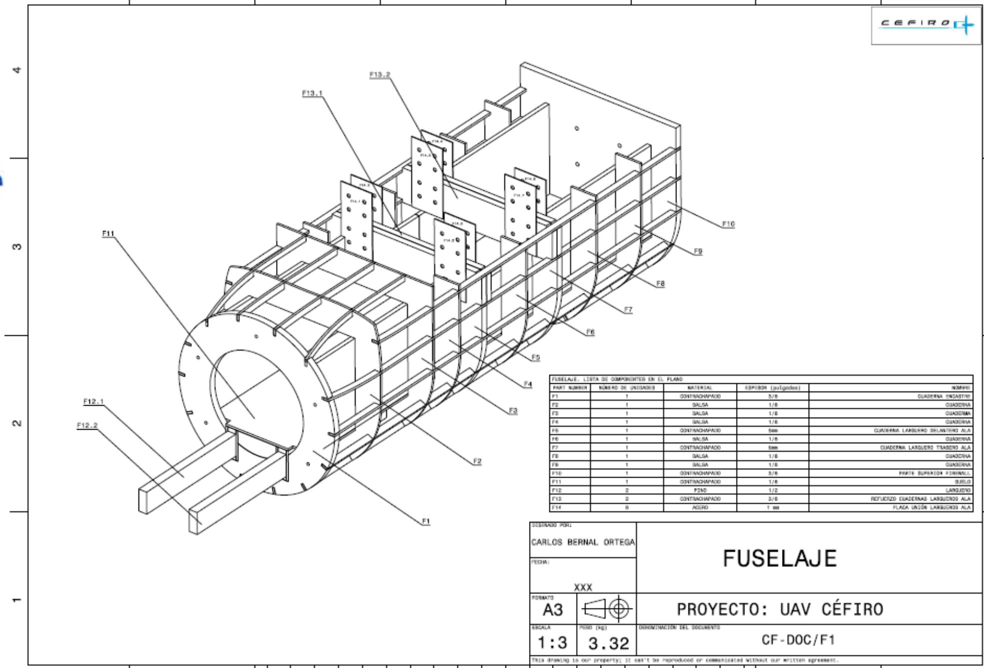
- During the design phase it was identified the importance of optimizing both the construction and fabrication processes.
- In order to do such integration it was identified the need of having a well defined construction and integration of systems sequence:
  - Organization of parts and procedures.
  - 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




FUSELAJE
CARLOS BERNAL ORTEGA
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PROYECTO: UAV CÉFIRO
1:3
3.32
CF-DOC/F1
F1
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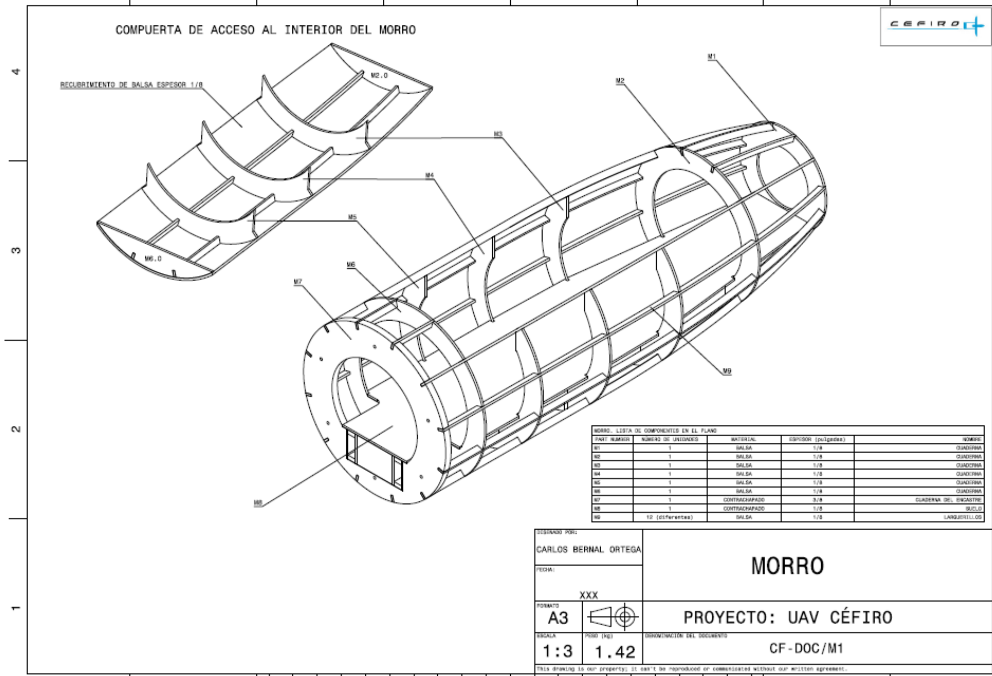
COMPUERTA DE ACCESO AL INTERIOR DEL MORRO
RECUBRIMIENTO DE BALSA ESPESOR 1/8
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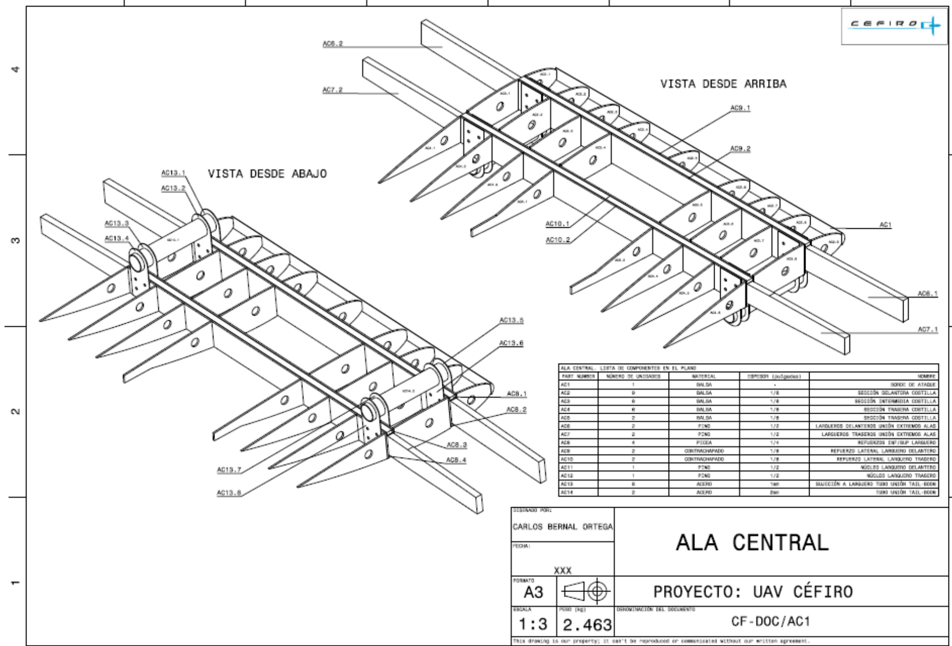
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VISTA DESDE ABAJO
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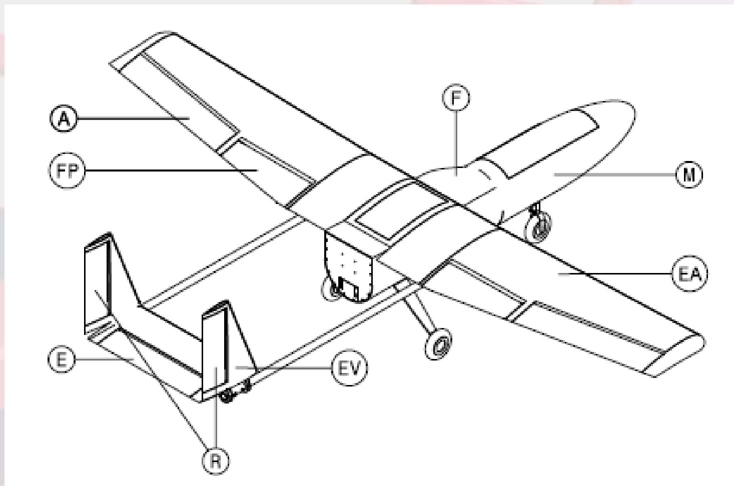
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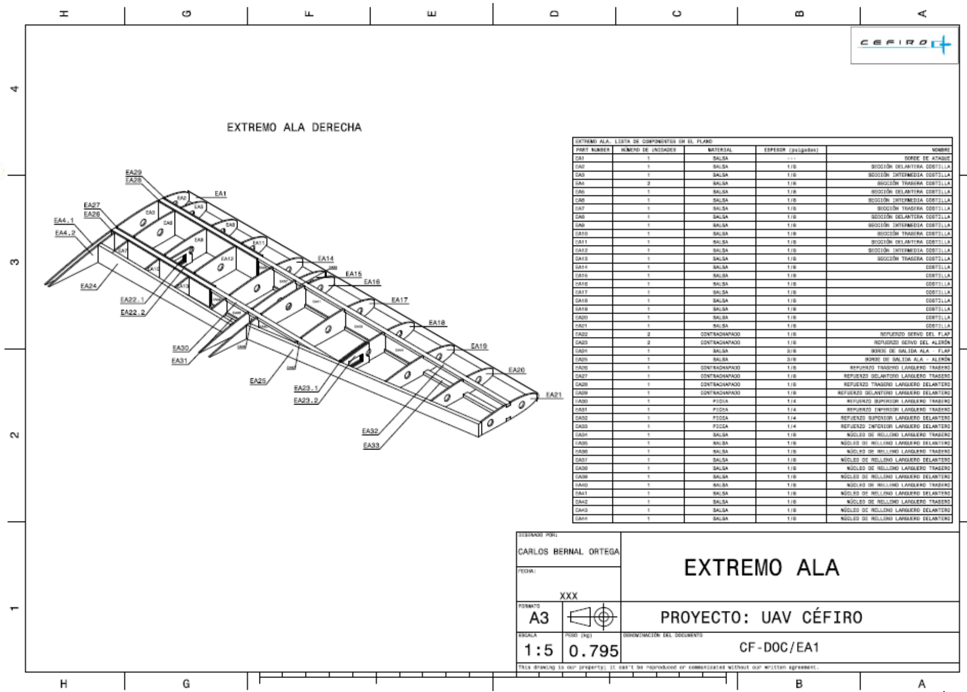
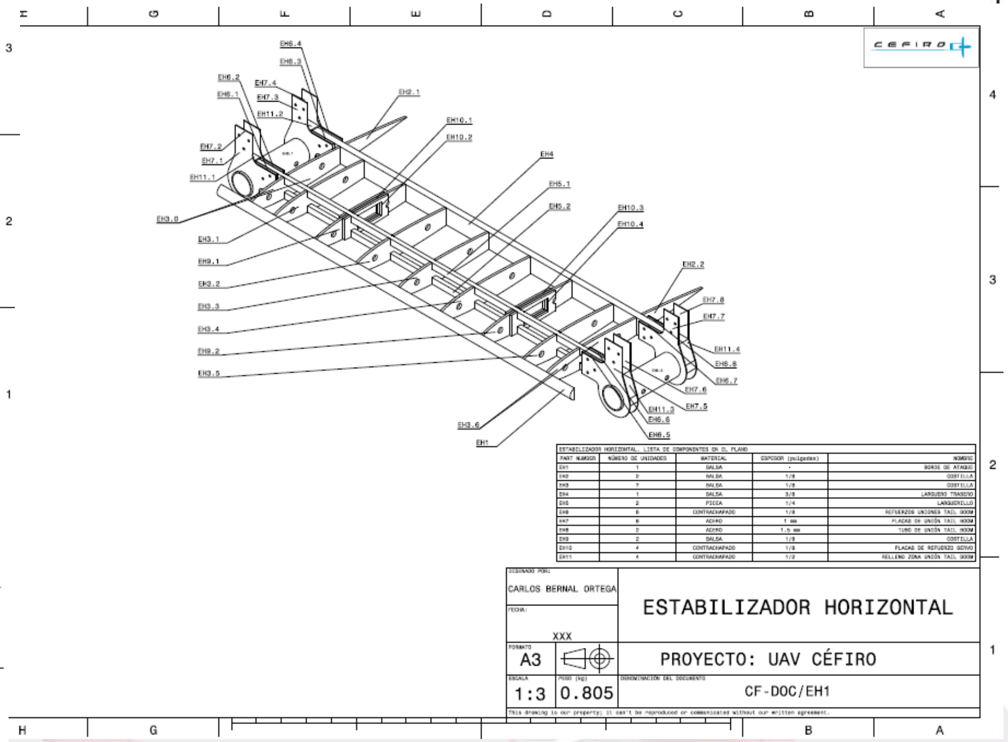

EXTREMO ALA DERECHA
CARLOS BERNAL ORTEGA
EXTREMO ALA
XXX
A3
PROYECTO: UAV CÉFIRO
1:5
0.795
CF-DOC/EA1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ESTABILIZADOR HORIZONTAL
XXX
A3
PROYECTO: UAV CÉFIRO
1:3
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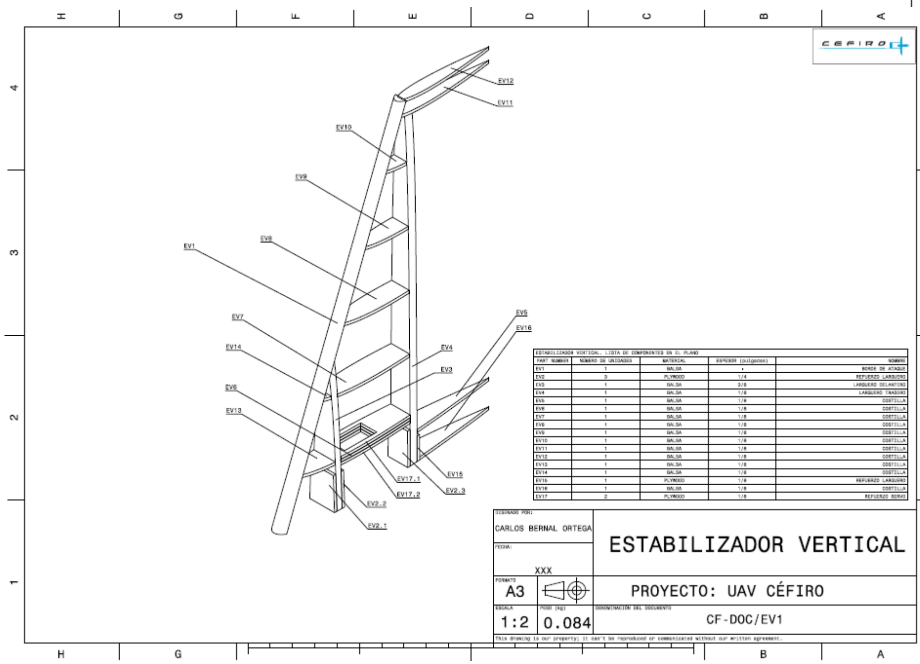
CF-DOC/EH1


CARLOS BERNAL ORTEGA
ESTABILIZADOR VERTICAL
XXX
A3
PROYECTO: UAV CÉFIRO
1:2
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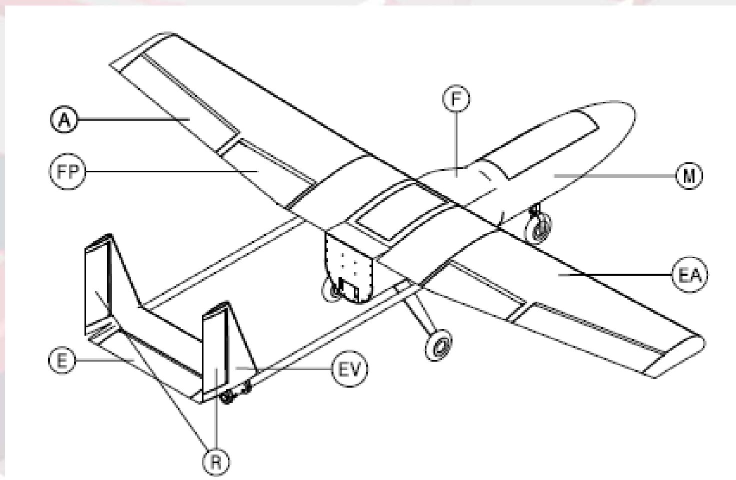
CF-DOC/EV1


A
FP
F
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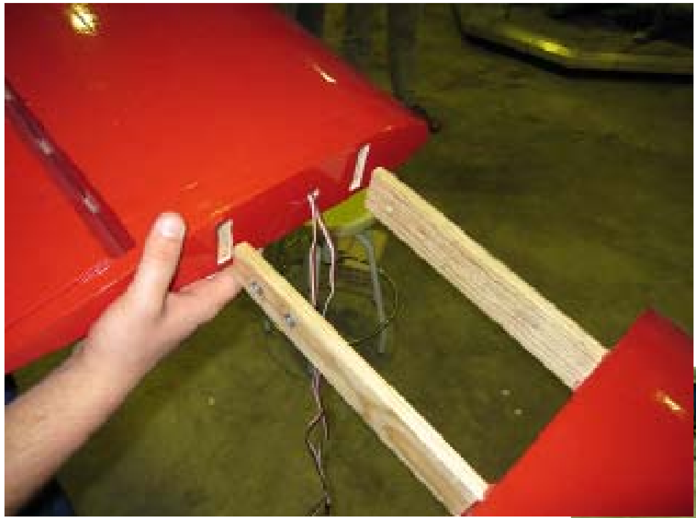
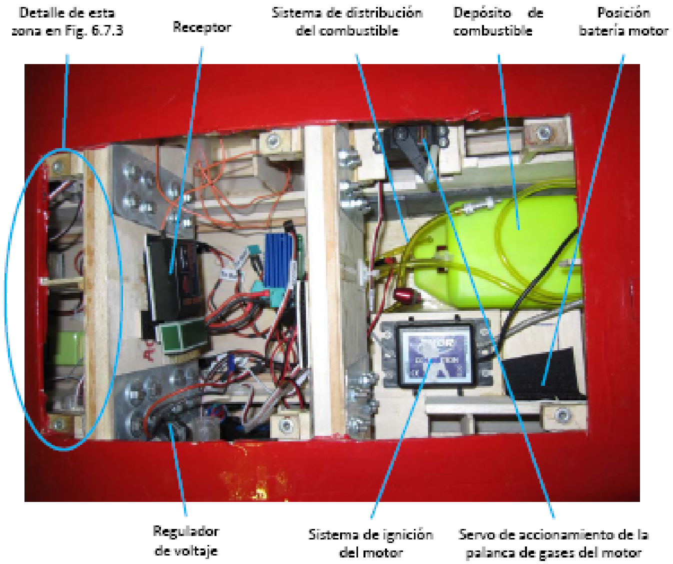
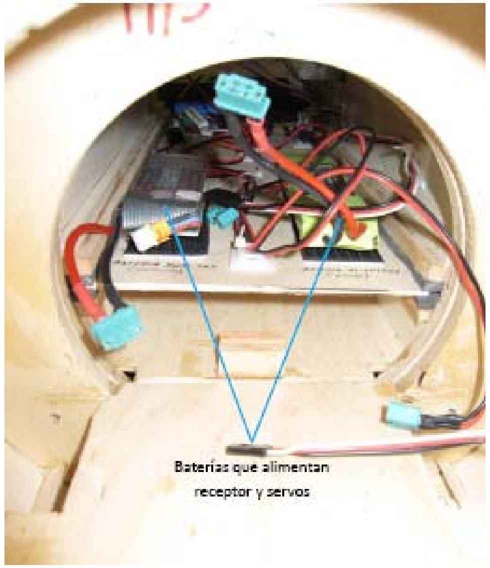
EV
R

Production and systems integration - III

CEFIRO







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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 of an airplane.
- 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.

Cefiro’s Roll out

CEFIRO

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Future work

- Extend the experience to more students.
  - Would be desirable to have bigger facilities and faculty to allow the rest of the students to enjoy the same and invaluable experiences:
- Short Term Actions:
  - Improvements on Cefiro's Design:
    - Weight reductions.
    - Simplification of construction techniques.
    - Progressive implementation of new materials.
  - Model engine performance.
- Long Term Actions
  - Implementation and testing of avionics systems.
    - Modeling aircraft dynamics and performances.
  - Tele-operation via FPV.
  - Autonomous flight.

Questions?

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