UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

SCUOLA POLITECNICA E DELLE SCIENZE DI BASE

CORSO DI LAUREA IN INGEGNERIA AEROSPAZIALE

DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

MASTER THESIS

DESIGN AND TESTING OF A REMOTELY PILOTED MODEL AIRCRAFT

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ANNO ACCADEMICO 2014/2015

EXPERIENCE IS THE MOTHER OF ALL SCIENCES
GALILEO GALILEI

Dedicated to my parents:
Antonino and Elisabetta

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A	aspect ratio
c	chord
C_d , C_D	drag coefficient (2D, 3D)
CG	center of gravity
C_l , C_L	lift coefficient (2D, 3D)
C_m , C_M	pitching moment coefficient (2D, 3D)
C_N	yawing moment coefficient
CNC	computer numerical control
e	Oswald factor
ESC	electronic speed controller
MDF	medium density fiberboard
N	neutral point (aircraft aerodynamic center)
R	tail volume coefficient
RC	radio controlled
RX	receiver
S	planform area
t	thickness
TX	transmitter
V	airspeed
x	abscissa
α	angle of attack
β	angle of sideslip
Δ	difference or shift
Λ	sweep angle
λ	taper ratio

SUFFIXES	SYMBOL REFERS TO
ac	aerodynamic center
f	fuselage
h	horizontal tail
v	vertical tail

1. INTRODUCTION

This master thesis deals with a technical design review of a remotely piloted aircraft, which took part to the 9th Season of the AIAA Design Build Fly (DBF) Competition.

This design competition is addressed to academic students and it is organized every year by the American Institute of Aeronautics and Astronautics (AIAA) together with an external sponsor, which in 2005 was the Office for Naval Research of the U.S. NAVY.

Every year the Organizing Committee provides a technical specification where the participating teams have to develop their concept, build it in a few months and finally fly it in the U.S.A. to compete in a number of flight missions.

The 2005 Rules & Vehicle Design to realize the challenging technical level and the specific mission requirements are reported in Appendix A.

The high profile experience made, the technical issues analyzed and the current fast growing of the commercial use of remotely piloted aircraft systems, led the author to focus on these small flying vehicles during all its Course of Study.

The prototype designed by our team has been a competitive rival for other participants, however it did not express the expected performance due to stability and control issues.

This master thesis aims to identify and solve these troubles first in the preliminary design stage and consequently drive the prototype modifications in order to perform flight tests, which will confirm the previous critical design review.

Realize a model aircraft compliant to a technical specification is a challenge that requires both scientific and technical skills. If aerodynamics, light structures, avionics, and propulsion are the more relevant, knowledge of the radio controlled (RC) systems, computer, and manufacturing skills - not to mention safety and regulations - are mandatory to build a flying model. In this sense, aeromodelling is complementary to aeronautic engineering: the author has brought years of experience and study in this project.

The state of the art of model aircraft materials and manufacturing has been used in this work, from the balsa wood to the sandwich composites, from aeronautic aluminum to homemade cured fiberglass layers, from the conventional structural layout to the ribless wing concept.

All the available scientific tools have been used in this work: from Computer Aided Design (CAD) to Computer Aided Manufacturing (CAM), with Computer Aided Engineering (CAE) in the analysis phase. The author has acquired more confidence with semi-empirical methods and aerodynamics software for preliminary design.

The model aircraft, as product of this work, has been designed as a flying test bed, with a large payload bay to accommodate a variety of scientific tools and avionics systems.

A useful software for the recording of working hours of each phase of the design, manufacturing, and report editing has been used.

Chapter 2 is the original technical report issued by our team in 2005, which describes the original design and, at the end, the lessons learned from the competition. Chapter 3 is a critical design review where the original design is broke down and reviewed step by step. A new configuration is there laid down, analyzed, designed in CAD, built in wood and fiberglass. Chapter 4 describes the manufacturing sequence. Flight testing, conclusion, and future development are reported in Chapter 5.

2.THE 2005 AIAA DBF COMPETITION REPORT

2.1 Executive Summary

This technical report contains the ERACLE Team's design for the *2004/2005 AIAA CESSNA/ONR Design/Build/Fly Competition*. ERACLE Team has to thank the Department of Aeronautic Design (DPA, Dipartimento di Progettazione Aeronautica), now Department of Industrial Engineering (DII), and the AB Technologies for their support.

Eracle Team also thanks the advisors who oversee our design: the Eng. Fabrizio Nicolosi and the Eng. Fabrizio Ricci. A special thank is awarded to Mr. Salvatore Iannone who gave ERACLE Team lots of his experience in building flight composite aircrafts. Eracle Team also thanks Franco Crispino, Fulvio Ernani, Simone Figliolia, Umberto Maisto, and Ferdinando Scherillo for their support.

2.1.1 Development Design

The ERACLE Team was founded in September 2004 by five aerospace students with the aim to take part to the AIAA CESSNA/ONR Design/Build/Fly Competition. The first phase of the project was the feasibility study in which the Team evaluated his skill level as far as both theoretical and manufacturing capabilities concern. In addition to this a precise cost estimation was developed with reference to main areas like: the Aircraft Development, the Mission Travel and Logistics.

	Item	*€*	*Q.ty*	*SubTot*	*TOTAL*	*Each person*
MISSION	Alitalia Flight	€ 465,00	6	€ 2.790,00	€ 6.240,00	€ 1.040,00
	Car Rental	€ 400,00	1	€ 400,00		
	Accomodation	€ 470,00	2	€ 940,00		
	Lunch	€ 1.260,00	1	€ 1.260,00		
	Gasoline	€ 500,00	1	€ 500,00		
	Model delivery	€ 350,00	1	€ 350,00		
A/C CONSTRUCTION	CNC mold	€ 500,00	1	€ 500,00	€ 1.750,00	€ 291,67
	Radio & receive	€ 400,00	1	€ 400,00		
	Engine	€ 300,00	1	€ 300,00		
	Engine regulator	€ 150,00	1	€ 150,00		
	Servos	€ 150,00	1	€ 150,00		
	Batteries	€ 150,00	1	€ 150,00		
	Other	€ 100,00	1	€ 100,00		
	Wing material			€ -		
	Fuselage material			€ -		
Logistic	Highway Taxes	€ 0,65	85	€ 55,25	€ 372,25	€ 62,04
	Parking Taxes	€ 2,00	16	€ 32,00		
	Fuel	€ 10,00	27	€ 270,00		
	Public Transport	€ 1,00	15	€ 15,00		
				€ -		
				€ -		
						€ 1.393,71

Table 1: Cost planning.

The evaluation of the *"2005 Rules and Vehicles Design"* document and the previous edition winner reports and their mission led the Team to ask for support in order to face the total costs requested to the design success. In a preliminary design phase all the possible A/C configurations were investigated with reference to the *Rated Aircraft Cost* sheet in order to choose the one performing the best results in each mission. In particular two missions were selected for the design optimization: the Sensor Reposition (SR) and the Re-Supply (RS) mission. Obviously a particular importance was given to the payload quick release & reload system due to reduce the whole mission time. In addition to this the storage box was a hard restraint for the A/C design. The detailed design phase aimed to verify the characteristics discussed in the preliminary one. As a consequence a scale model of the A/C was tested in the wind tunnel, a static stress analysis of the employed composite material and a FEM analysis were performed. Then A/C dimensions, avionics and propulsion systems were defined. The chosen materials, the control and power systems were selected with reference to a lower specific weight.

2.1.2 Investigated Alternatives

For each investigation field, structures, aerodynamics, avionic & power system, propulsion, different options were taken into consideration. The alternatives evaluation, above all as far as avionic & power system concerns, started from a market analysis in order to choose the best system with reference to the *2005 Rules and Vehicles Design* limitations and compare their technical characteristics. The opportunity of self-building systems was taken into consideration but it often results in a more expensive solution both for cost and working hours.

In addition to this the self-made parts precision should not be guaranteed. All the options were evaluated on the basis of a comparing matrix thanks to which the best solution was found.

2.2 Mission Highlight

Among the three missions suggested by the contest rules the SR and the RS ones were considered for the design optimization. In fact it is convenient to optimize the A/C for two missions whose nature is very similar rather than only one mission which requires a plane with a configuration devoted to velocity but less flexible. It is important to remind that the final score is given by the sum of the two best different mission flown. Another important main feature of the design is represented by the take-off distance (TOD): thrust to weight ratio, higher $C_{L\ max}$ and low weight to surface ratio are required to reduce this length. ERACLE Team’s design focuses attention also on power consumption and the hard load factor due to payloads. In the end a Take Off Gross Weight of 55 lbs have not to be exceed. According to the mission profile an A/C high stability was desired. Ground crew coordination is important for a smaller mission time.

2.3 Management Summary

The ERACLE Team is composed by both junior and senior aerospace engineering students. To ensure the right development of the design and the manufacturing process a timetable was organized in order to divide the workload in the best way.

2.3.1 Design Team Organization

To take advantage of the skill of each member on a specific branch the Team has foreseen to split into two groups: the one delegated to theoretical design and the one devoted to the construction of the A/C. In this way each member is the leader of a specific design branch and he is the direct responsible of it. The whole organization is supervised by the advisors who are directly informed by the two crew chiefs.

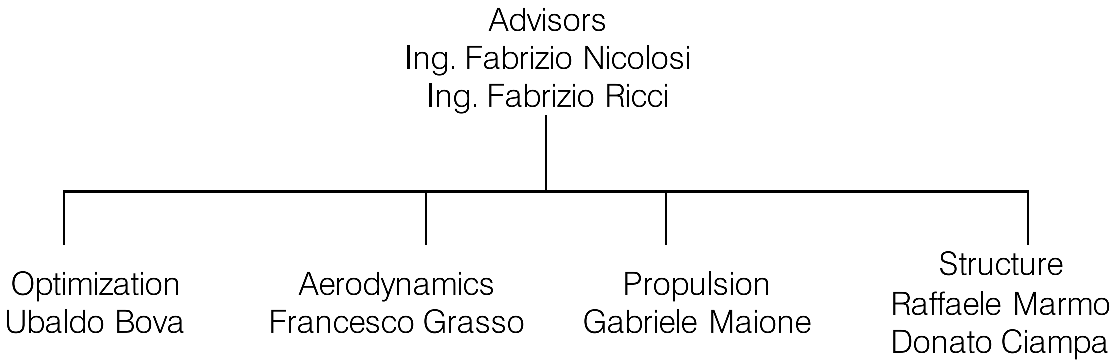


Table 2 : Design team organization

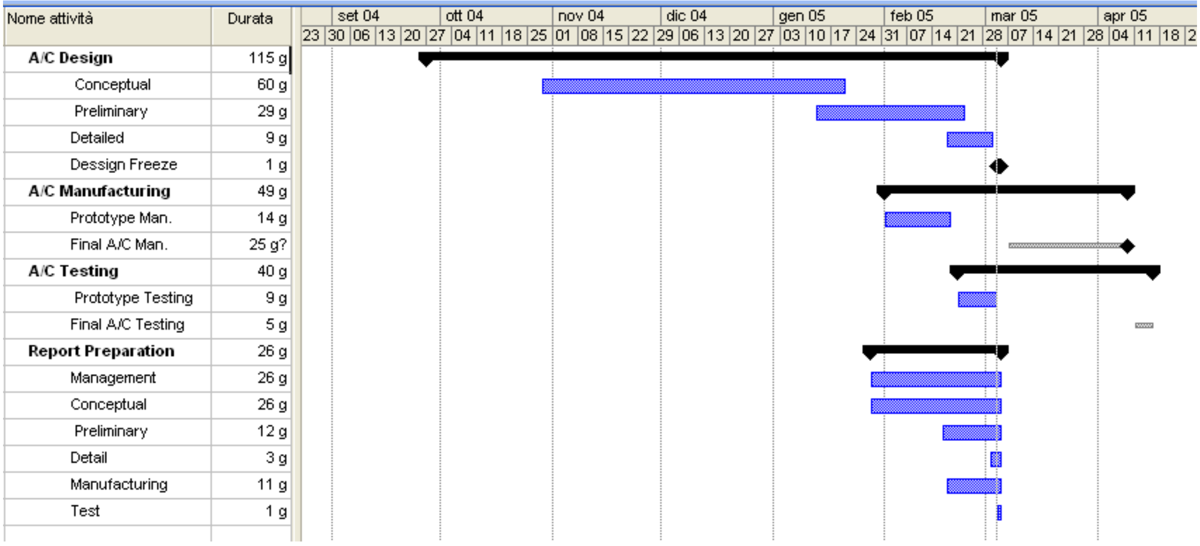
2.3.2 Logistic Management

As the composite parts manufacturing, the technical meeting, the testing operations and the material supply took place in four different locations due to the specialized areas offered by our department. So that the logistic aspect was an important part of the Team organization. The crew chiefs were responsible of the respective group demands.

2.3.3 Design Timetable

Since the foundation of the team to the contest accomplishment it was esteemed a six months engagement. The first month was dedicated to the feasibility study after that there was the preliminary design analysis. Then the detailed design was completed and followed by an A/C scale model manufacturing. Finally the construction of the final A/C and the pilots training was started. An important aspect of the design was the financial support which kept busy the Team for the whole preparation period.

Table 3: Design Timetable.



Nome attività	Durata
A/C Design	115 g
Conceptual	60 g
Preliminary	29 g
Detailed	9 g
Dessign Freeze	1 g
A/C Manufacturing	49 g
Prototype Man.	14 g
Final A/C Man.	25 g?
A/C Testing	40 g
Prototype Testing	9 g
Final A/C Testing	5 g
Report Preparation	26 g
Management	26 g
Conceptual	26 g
Preliminary	12 g
Detail	3 g
Manufacturing	11 g
Test	1 g

2.4 Conceptual Design

The conceptual design phase represents the first step for the correct evaluation of the contest missions and, as a consequence, of the optimal A/C configuration for their successful development. A number of Figure Of Merit helped the trade-off process to the final most advantageous configuration discarding the other ones.

2.4.1 Mission Requirements

The *2004/2005 AIAA CESSNA/ONR Design/Build/Fly Competition* demands an A/C capable of 10 minutes endurance with and without a 6 lbs payload. The importance of the installed power system is underlined by the limitation to use an electric brush or brushless engine supplied by a 3 lbs maximum weight battery pack/packs. In addition to this the A/C must be capable of a TOD equal to 150 ft wheels off the runway. The SR and RS missions require an aircraft capable of carrying at most two, external or internal, payloads released and reloaded after each flight cycle (i.e. after each take-off and landing). The aim of this analysis is to find an aircraft optimized for the selected missions while having an optimal RAC. The final score is computed by the Written Report Score, the Total Flight Score and the Rated Aircraft Score:

$$SCORE = \frac{WRS \cdot TFS}{RAC}$$

As indicated above the best Score is obtained maximizing the TFS and reducing the RAC value. A detailed review of each mission explains how the Single Flight Score is calculated:

- SR mission:
    1. Aircraft will begin the mission with 2 EXTERNAL sensor payload packages
    2. Aircraft will take-off and fly 1 lap. On all laps flown the aircraft must complete a 360° turn in the direction opposite of the base and final turns on the downwind leg of each lap
    3. After landing the aircraft will remotely deploy 1 sensor package at each of 2 separate release locations
    4. Aircraft will take-off and fly 1 lap
    5. After landing the aircraft will taxi to a specified reload location where the ground crew will save the propulsion system and manually re-load the payload
    6. The aircraft will taxi to the second reload location, and the ground crew will repeat the sensor reloading process
    7. Aircraft will take-off and fly 1 lap
    8. On landing the aircraft must cross the take-off start line and come to a complete stop. The ground crew will retrieve the aircraft, return it to the "box" area, disassemble the aircraft and store it in the box.
    9. Time stops when the box lid is closed and latched
    10. Single Flight score is: $SCORE = DF \cdot (12 - Mission\ Time),\ \ DF = 2$

Mission one: Sensor reposition

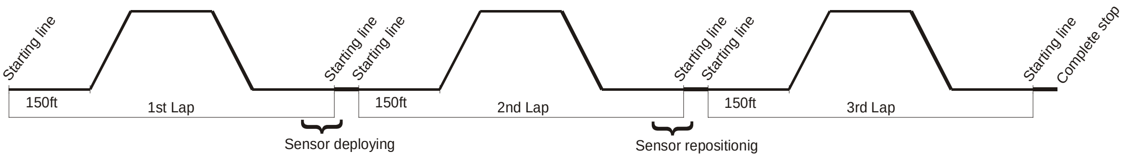


Figure 1 : First selected mission

- RS mission:
  1. Aircraft will begin the mission with 2 INTERNAL sensor payload packages
  2. Aircraft will take-off and fly 1 lap. On all laps flown the aircraft must complete one 360° turn in the direction opposite of the base and final turns on the downwind leg of each lap
  3. On landing it must cross the take-off start line and come to a complete stop. The ground crew will remove the payload
  4. Aircraft will take-off and fly 1 lap
  5. On landing it must cross the take-off start line and come to a complete stop
  6. The ground crew will go out to the aircraft and re-install the payload
  7. Aircraft will take-off and fly 1 lap
  8. On landing it must cross the take-off start line and come to a complete stop. The ground crew will remove the payload
  9. Aircraft will take-off and fly 1 lap
  10. On landing it must cross the take-off start line and come to a complete stop. The ground crew will retrieve the aircraft, return it to the “box” area, disassemble the aircraft and store it in the box
  11. Time stops when the box lid is closed and latched
  12. Single Flight score is: $SCORE = DF \cdot (12 - MissionTime),\ DF = 1.5$

If only 3 of the 4 sorties are completed: $SCORE = DF \cdot (6 - Mission\ Time)$

If only 2 of the 4 sorties are completed: $SCORE = DF \cdot (3 - Mission\ Time)$

Mission three: Re-supply

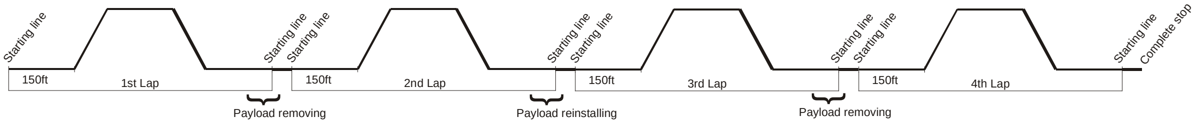


Figure 2 : Second selected mission

So the total score, in the best case, will be calculated as follow:

$$SCORE = \frac{WRS \cdot \left\{ \left[2.0 \cdot \left(12 - Mission\ Time \right) \right] \cdot \left[1.5 \cdot \left(12 - Mission\ Time \right) \right] \right\}}{RAC}$$

While, in the worst, case it will be:

$$SCORE = \frac{WRS \cdot \left\{ \left[2.0 \cdot \left(12 - Mission\ Time \right) \right] \cdot \left[1.5 \cdot \left(3 - Mission\ Time \right) \right] \right\}}{RAC}$$

As a consequence an efficient release system, a ground crew high trained in Remove & Reload (R&R) payload and a good control of the A/C were esteemed the key factor for the mission success.
The A/C structural design had to consider wing loading, components integrity, in a word, high performance materials. The A/C aerodynamic design had to take into consideration a wing with STOL capabilities and a stable configuration for all the critical phases of the planned missions.

2.4.2 Alternative Configurations

Different configurations were taken into account as far as A/C shape, propulsion system, empennage, payload and landing gear are concerned. The best option was chosen through a trade-off matrix quoting the most important Figures Of Merit (FOM).

2.4.2.1 A/C Configuration

The first assumption made was to consider a plane operating with the lowest number of engines and having the lighter structure that is possible. The various configurations were evaluated awarding the same aerodynamic characteristics to each of them. The shapes analyzed are the following:

1. CONVENTIONAL: this shape results stable and, as a consequence, reliable. It is convincingly maneuverable and has a contained weight in an easily building structure.
2. CANARD: the canard configuration offers a good stall quality on the contrary it requires a more complex structure, it has a higher drag with obvious bad influence on the TOD.
3. FLYING WING: a flying wing represents an optimal choice as far as the RAC value is concerned. In fact it has a lighter structure due to the absence of the fuselage that is integrated in the whole design. In addition to this the flying wing has a good aerodynamic qualities. On the other hand it requires a sophisticated control system in order to solve stability needs and, as a consequence, its low manoeuvrability.
4. BI-PLANE: a bi-plane configuration has a higher lift with a smaller wing and so a low value of the TOD. On the other hand it has a higher drag and a great penalty as far as the RAC value is concerned.
5. THREE LIFT SURFACES: this configuration allows a high lift value but the excessive drag and the higher RAC influence limit the advantages of its performances due to its stability.

The FOMs used for the A/C alternatives trade-off are the following:

- ✓ RAC: a good contest score is obtained flying well all the chosen mission but it is hardly affected by the RAC value. A configuration capable of a lower RAC value has to be preferred among the proposed ones.
- ✓ TOD: a 150 ft wheels off the runway TOD is mandatory for each mission.

- ✓ Handling Qualities: a plane with a good maneuverability, both at ground and in flight, will reduce the whole mission time.
- ✓ Drag Efficiency: A/C configurations with a lower drag allow a higher aerodynamic performances and, as a consequence, limit the battery consumption.
- ✓ A/C reliability: as in this year competition there is no time for repairing operations during the missions, the A/C configuration has not to be too complex in order not to be too delicate. In addition to this, as there is a clear distinction between "critical" and "significant" damage, the aim was to reduce drastically the critical ones which could occur to neither replaceable nor repairable devices.

Table 4: A/C configurations comparison.

FOM	*WGF*	*CONVENTIONAL*	*CANARD*	*FLYING WING*	*BI-PLANE*	*THREE LIFT SURFACE*
RAC	0,30	1	-1	1	-1	-1
TOD	0,25	0	1	0	1	0
HANDLING QUALITIES	0,20	0	1	-1	0	1
DRAG EFFICIENCY	0,10	0	-1	1	-1	-1
A/C RELIABILITY	0,15	1	0	-1	-1	-1
TOTAL	1	0,45	0,05	0,05	-0,3	-0,35

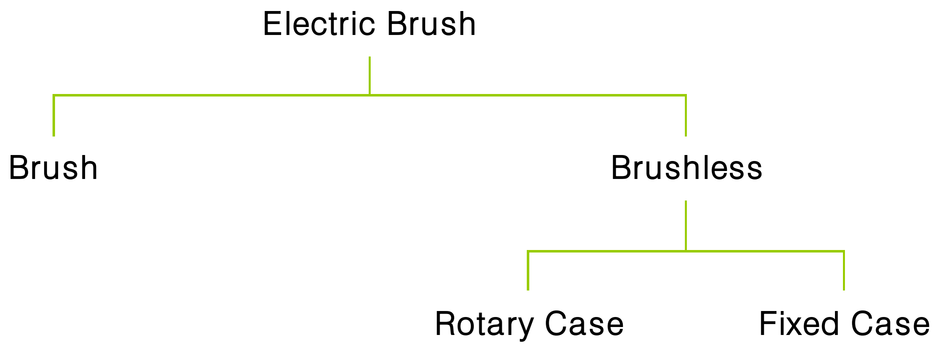
As shown by the previous matrix the best choice is represented by the conventional configuration. The Flying Wing has not enough handling capabilities to assure the right mission course. The remaining configurations pay their high RAC value and a more elaborate mission optimization than the one requested by the conventional one.

2.4.2.2 Propulsion System

This year competition requires the use of an electric engine as propulsion device. Electric engines can be classified in two big categories:

- ✦ *Brush Engines*: these are engines supplied by continuous current and characterized by a low battery consumption as a result of the lower power developed. They are less efficient than the brushless type.
- ✦ *Brushless Engines*: these are highly efficient engines distinguished by the previous ones by the considerable voltage needed to be supplied. They can be splitted into two groups:
  - ⌘ Fixed Case: the high round per minute (RPM) value characterizes this brushless engine which is very efficient but it needs a gearbox with a little weight increase.
  - ⌘ Rotary Case: the rotary case electric engine is capable to transmit a higher torque to the propeller, with a lower RPM value and maintaining a good operational efficiency. Moreover it results lighter than the previous engine as a result of the gearbox absence.

Table 5: Electric engine classification.



As far as the engine and battery pack configuration is concerned the following shapes were taken into consideration:

1. Two engines & two battery packs: this configuration causes both a considerable increasing in weight and in the RAC value. On the other hand it allows the most amount of power.
2. Two engines & one battery pack: the two engines with only one battery pack configuration presents a minimal weight reduction with reference to the previous one maintaining almost the same powerful capabilities. However the RAC value is still high due to the twin engines weight.
3. One engine & one battery pack: this represents the most advantageous configuration as far as the weight is concerned even if the single battery pack requires a lot of fuselage space.
4. One engine & two battery packs: this configuration makes use of the advantages offered by a low engine number (i.e. a lower weight) with a more easily setting battery packs. In addition to this a series connection of the same battery packs allows a higher voltage (it will be shown the importance of this parameter in the Detailed Design Chapter).

The FOMs used for the engine & battery packs configuration are the following:

- ✓ RAC: the propulsion system has a strong influence on the RAC value.
- ✓ WEIGHT: this is a fundamental parameter because it can impose a great handicap on RAC.
- ✓ EFFICIENCY: it is important to avoid any kind of energy dissipation which could led to a performance loss
- ✓ POWER: this is an engine fundamental parameter in fact a powerful engine will translate into a higher thrust, a shorter TOD and better handling qualities.

Table 6: Engine configurations comparison.

FOM	*WGF*	*TWO ENGINE + TWO PACK*	*TWO ENGINE + ONE PACK*	*ONE ENGINE + TWO PACK*	*ONE ENGINE + ONE PACK*
RAC	0,35	-1	-1	0	0
WEIGHT	0,3	-1	-1	1	1
POWERFUL	0,20	1	1	0	0
EFFICIENCY	0,15	0	0	1	0
TOTAL	1,00	-0,45	-0,45	0,45	0,3

The best choice is represented by the “One Engine & Two Battery Packs” configuration which results the best compromise among power, weight and RAC. Although a two engines configuration results safer than the single one, two engines are too heavy and has a significant RAC influence.

2.4.2.3 Empennage

On the subject of the empennage the trade-off process saw the following configuration:

1. CONVENTIONAL: this configuration is easy to produce and assure good control qualities and stability of the A/C. Its structure results larger than the one of other shapes. As far as the conventional shape is concerned it is possible to consider two different kinds:
    - STABILATOR: a stabilator offers a good maneuverability without any significant weight increase
    - TAILERON: as this system means independent mobile parts a sophisticated control system is required for its management to avoid stability troubles. For these reasons this device will not considered.
2. T-TAIL: a T-tail configuration is heavier than the conventional ones due to the reinforced fin but it allow a smaller horizontal stabilizer. The structural problems includes the difficulty in setting the empennage servo. As far as the aerodynamics is concerned a T-tail enter the wing wake with the increasing of the angle of attack: as a consequence the T-tail loses efficiency when an higher empennage efficiency is required.
3. CRUCIFORM TAIL: this configuration represents a compromise between the T-Tail and the conventional one. Although it avoids the T-Tail weight increase but also the lighter conventional configuration structure, it is neither efficient as the conventional empennage nor dangerous as the T-Tail. Manufacturing difficulties has to be taken into account.
4. V-TAIL: a V-tail configuration allows a lower both RAC and weight value because of the two surfaces instead the three of the conventional one. The V-tail aerodynamic is advantageous as it will not be suffer completely the wing wake effects. On the other hand the pitch-yaw coupling lowers the handling qualities which is translated in a greater pilot workload.

For the empennage trade-off process the following FOMs were considered:

- ✓ RAC: this value is directly affected by the servos number, so a structure having the best performances with a lower servo number is a key factor for a sharp choice.
- ✓ WEIGHT: a heavier structure limits a good RAC value.
- ✓ STRUCTURAL COMPLEXITY: an easy-to-build structure offers time saving.
- ✓ EFFICIENCY: a good compromise between maneuverability and stability is requested to perform better the planned missions without neglecting a fine drag evaluation which will allow a better power spent.

Table 7: Empennage configurations comparison.

FOM	*WGF*	*CONVENTIONAL*	*STABILATOR*	*T-TAIL*	*CRUCIFORM TAIL*	*V-TAIL*
RAC	0,35	0	0	0	0	1
WEIGHT	0,30	1	1	-1	1	0
EFFICIENCY	0,20	0	1	0	0	-1
STRUCTURAL COMPLEXITY	0,15	1	1	-1	1	0
TOTAL	1,00	0,45	0,65	-0,45	0,45	0,15

The above matrix shows that the best device is represented by the Conventional empennage which results in a lower manufacturing cost and time, it has the lower weight among the other configurations with reference to the same material use (i.e. a lower RAC value). Moreover it maintains good handling qualities.

2.4.2.4 Payload

A key feature of the A/C design is represented by the payload system with particular attention to the loading, removing and reloading operations. It has been already discussed the importance of their fast execution that is directly involved in the total contest score. This year contest requests a payload whose weight is heavier than the one demanded for the previous edition so the locking device has a relevant influence for the mission success. Each payload is a 12” long 3” (metric 75mm) PVC tube (minimum length of the tube proper, without any ends/caps/fairings). Ends must be closed and faired in the best way possible. The same payload must be used for both the internal and external payload missions. The payload weigh must be at least 3 lbs. External payload must be carried on a hard-point located within 3 inches of the wing tip of the largest span wing: one payload hard-point will be located at each wing tip.

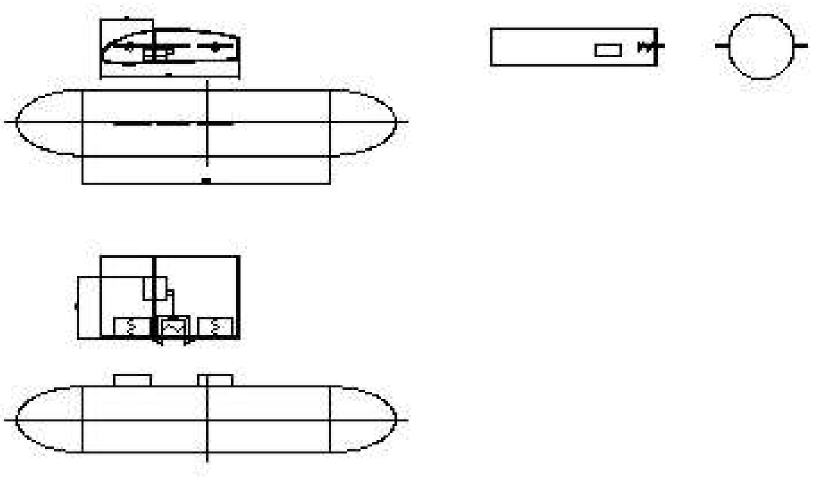


Figure 3: Payload configuration.

As the external payload release must use a dedicated servo, the RAC value will be permanently conditioned by this requirement. As the internal payload must be carried fully inside the fuselage and because of the fact that payload must be symmetric to the fuselage centerline the same fuselage will have a generous section. In addition to this the precise evaluation of the Center of Gravity (CG) is another key factor for an A/C which needs to be stable with or without payload. Moreover the requirement of a remote release for the external payload, while the internal one is removed manually, led the design Team to consider different devices for the two procedure.

Among the possible R&R systems the ones selected for the trade-off process are the following:

1. ELECTRO-MAGNETIC SYSTEM: this R&R system is based on a simple magnet electrically supplied by a battery that warrants a solid connection between the A/C structure and the one of the payload. It is obvious that to avoid any kind of relative rotation the payload will be provided by two plugs. On the other hand this system requires its own battery with a consequent wing's weight increase and, as a consequence, a rising RAC value. It is important to observe that any electrical failure to this system can take to the payload separation.
2. PNEUMATIC SYSTEM: a pneumatic R&R system allow a reasonable, quick and reliable payload removal. On the other hand to be operational it requires a pressurized tin with electronic valves to control the emission of the compressed air. The electronic valve has on RAC the same impact of a servo. The pneumatic system add some weight to the whole A/C with a difficult payload reload operation due to the absence of remote control in this phase.
3. DOUBLE LEVER SYSTEM: this mechanical system consists of two levers having a "L" shape joined together in a fulcrum linked to a servo which commands their simultaneous rotation. The levers are locked in their safe position by a spring which allows the payload reload operation with the main power shut off. In addition to this two plugs were located from each side of the double lever device in order to help the payload jettison. The plug's sites contains two cylindrical bearings which avoid any possible jam of the payload stroke. This system requires a small volume to be placed in with a lower weight increase.
4. SPRING SYSTEM: this device, similar to the previous one, allow the payload lock thanks to a well calibrated spring inserted in a proper wing's tip site. The payload jettison is obtained by a servo which ejects it. This system uses two plugs located from each side of the spring device with two cylindrical bearings which avoid any possible jam of the payload stroke. The accurate spring setting is the fundamental parameter of the system reliability.

The FOMs used for the payload R&R analysis are the following:

- ✓ RAC: its value is directly affected by the servos number and the device weight which involves the whole A/C weight.
- ✓ RELIABILITY: the R&R device has to be simple and resistant enough to assure its full operability in the safer way.
- ✓ WEIGHT: it is important to have a lighter device in order not to stress the wing tip.
- ✓ EFFICIENCY: it is required a system capable of low energy consumption with restricted costs.

Table 8: Payload release configurations comparison.

		ELECTRONIC SYSTEM	*PNEUMATIC SYSTEM*	*MECCANICAL SYSTEM*	
FOM	WGF	ELECTRO-MAGNETIC	PNEUMATIC	DOUBLE LEVER	SPRING
RAC	0,30	-1	-1	1	1
RELIABILITY	0,26	-1	1	1	0
WEIGHT	0,24	-1	-1	1	1
EFFICIENCY	0,20	0	0	1	0
TOTAL	1,00	-0,8	-0,28	1	0,54

As indicated by the previous comparing matrix the best solution is represented by the double lever system which is stronger and more reliable than the other ones. Moreover it has a contained RAC value together with a low manufacturing cost. Although very innovative the other devices show low reliability or weight limits.

2.4.2.5 Landing Gear

The landing gear represents a key feature for the whole A/C integrity and above all both for the ground procedures and TO & LND maneuvers. Different landing gear configurations offer dissimilar performances combined to various connection systems to join it to the fuselage. It is important to take into consideration the landing gear aerodynamics which has a direct influence on power consumption. Moreover the storing capabilities of the A/C represent an important parameter as far as the landing gear removal is concerned. The practicable solutions offered to the problem are listed below:

1. TAIL DRAGGER with BOW-TYPE MAIN GEAR: this configuration offers manufacturing and removal simplicity with a good ground stability. It is also lighter as the smaller wheels mounted on this gear configuration. On the other hand it results a little more difficult to manage during ground operations. Moreover it absorbs well the loads due to LND.
2. TAIL DRAGGER with INDEPENDENT MAIN GEAR: a tail dragger with independent main gear gives more complexity to the design due to the reinforcement needed by the A/C structure. This means weight increase. The ground crew spend more time for its removal.
3. TRICYCLE GEAR with BOW-TYPE MAIN GEAR: although this configuration result stable it involves a weight increase on the A/C structure which is against RAC. In fact the landing gear is higher than the tail dragger one due to avoid propeller troubles. Moreover it needs more time to be removed by the A/C for the storage operations.
4. TRICYCLE GEAR with INDEPENDENT MAIN GEAR: a tricycle gear with independent main gear presents both structural and weight troubles due to the three-point A/C reinforcement . In addition to this too much time spent for its removal will punish the whole mission time.

In order to compare the above landing gear configuration the following FOMs were employed:

- ✓ WEIGHT: a lower weight means a poorer RAC value.

- TO & LND PERFORMANCES: a solid structure is required to absorb TO & LND shocks.
- GROUND HANDLING: ground handling qualities are required to reduce mission time and ground operations.
- A/C INTEGRATION: a good implementation with the A/C structure allows a more reliable system with the opportunity of a better control system linkage. Moreover it is important to avoid aerodynamic interferences between the landing gear and other A/C structures.

Table 9: Landing gear configurations comparison.

		TAIL DRAGGER		*TRYCICLE*	
FOM	WGF	BOW	INDIPENDENT	BOW	INDIPENDENT
WEIGHT	0,30	1	0	0	-1
TO & LND PERFORMACE	0,26	1	1	0	0
A/C INTEGRATION	0,24	1	1	0	1
GROUND HANDLING	0,20	0	1	1	1
TOTAL	1,00	0,8	0,7	0,2	0,14

The tail dragger with bow type landing gear configuration was chosen for the A/C design. This configuration presents a low manufacturing cost with optimal performances. Moreover it incorporates the best feature as far as the servo link is concerned. In fact it is possible to use only one servo to control both rudder and tail wheel movement.

2.4.2.6 Structure & Materials

The manufacturing process is strictly enforced by the material chosen for the specific part construction. This section examines each main airframe component.

Fuselage

The fuselage structure has to resist to a 3 lbs internal payload and has to be capable of working well under structural stresses. The employed material has to assure a high both in flight and ground performance with a low weight which means a lower RAC value.

The following structures were analyzed:

1. KEELSON: a fuselage based on a keelson as main structural component is strong enough with reference to the mission requirements but limits the number of aerodynamic geometries which is possible to create. The weight of this structure is restricted.
2. STRINGERS: a fuselage based on stringers creates a more aerodynamic geometry with a little weight amount due to the bulkheads presence. On the other hand the manufacturing time spent for it is not tolerable.
3. MONOCOQUE: a monocoque structure, or reinforced skin fuselage, represents the faster manufacturing method for an A/C fuselage. It offers a higher strength with a reduction of the whole structure weight.

On the other hand it requires a perfect mold in which sandwich structures can be developed.

The FOMs for the fuselage manufacturing analysis are the following:

- STRENGH to WEIGHT RATIO: it is obvious that a strong structure with a lower weight has to be preferred in the trade-off process.
- CONSTRUCTION EASE: this parameter is important as far as the manufacturing time is concerned and due to the possible troubles caused by a more complex structure.
- QUALITY to COST RATIO: a low-cost structure can appear more convenient but it is important to understand if its characteristics meets the mission requirements.
- AERODYNAMICS: a good superficial finish and the accuracy in following the fuselage shape are desired for high-quality A/C flight characteristics (i.e. lower energy consumption).
- RELIABILITY: the fuselage has to resist to high load factors also due to the payload presence. Moreover as there is not repairing time between the missions, maintenance operations have not to include heavy damages on the A/C structure. In fact a "significant" damage will stop the A/C in its contest participation.

Table 10: Fuselage manufacturing comparison.

FOM	*WGF*	*KEELSON*	*STRINGERS*	*MONOCOQUE*
STREINGT/WEIGHT	0,32	0	-1	1
COSTRUCTION EASE	0,26	1	0	0
AERODYNAMICS	0,18	-1	0	1
RELIABILITY	0,14	0	1	1
QUALITY/COST	0,10	-1	0	-1
TOTAL	1,00	-0,02	-0,18	0,54

As shown in the previous table the monocoque manufacturing fuselage represents the best choice as far as the strength to weight ratio is concerned. The monocoque has a higher cost than the other structures but its advantages are really great.

Wing & Empennage

The wing is required to sustain a 3 lbs load during its missions and a 2.5 g load during the static technical tests. At the same time the empennage needs a structure strong enough to work properly without any failure. The trade-off process analyzed the following manufacturing method:

1. FOAM CORE: this technique represent a compromise between the high strength offered by the monocoque manufacturing and the contained weight of the foam material. On the other hand its characteristics depend by the precision with which the material is cut while its weight depends from the foam type. It requires a low time manufacturing.
2. CLASSICAL STRUCTURE (i.e. RIBS & SPAR): this structure even if lighter than the foam core, requires plenty of time for its development. This method offers a good precision as far as the geometric shapes is

concerned but a “critical” failure imposes the whole part replacement (i.e. re-building)

3. MONOCOQUE: a monocoque structure represents the faster manufacturing method for a wing. It offers a higher strength with a reduction of the whole structure weight. On the other hand it requires a perfect mold in which sandwich structures can be developed. The internal structure maintains only the wing’s geometry and it is useful for servos accommodation.

The FOMs analyzed are listed below:

- ✓ STRENGH to WEIGHT RATIO: it is obvious that a strong structure with a lower weight has to be preferred in the trade-off process.
- ✓ CONSTRUCTION EASE: this parameter is important as far as the manufacturing time is concerned and due to the possible troubles caused by a more complex structure.
- ✓ AERODYNAMICS: a good superficial finish and the accuracy in following the wing shape are desired for high-quality A/C flight characteristics (i.e. lower energy consumption).
- ✓ RELIABILITY: the wing has to resist to high load factors also due to the payload presence. Moreover as there is not repairing time between the missions, maintenance operations have not to include heavy damages on the A/C structure. In fact a “significant” damage will stop the A/C in its contest participation.
- ✓ QUALITY to COST RATIO: a low-cost structure can appear more convenient but it is important to understand if its characteristics meets the mission requirements.

Table 11: Wing manufacturing configurations.

FOM	*WGF*	*FOAM*	*CLASSICAL*	*MONOCOQUE*
STRENGTH/WEIGHT	0,32	0	-1	1
COSTRUCTION EASE	0,26	1	0	0
AERODYNAMICS	0,18	-1	0	1
RELIABILITY	0,14	0	1	1
QUALITY/COST	0,10	-1	0	0
TOTAL	1,00	-0,02	-0,18	0,64

The selection winner is the monocoque structure with its great strength to weight ratio and a perfect superficial accuracy in spite of its higher cost. In addition to this the high reliability of the monocoque structure warrants a lower probability to incur in critical damages.

Payload

As stated in the *2005 Rules and Vehicles Design* the payload has to be a 12” long 3” PVC tube (minimum length of the tube proper, without any ends/caps/fairings). It was achieved a PVC tube whose internal diameter is 75 mm with faired ends made up by epoxy resin. As the payload weigh must be at least 3 lbs a ballast is necessary to meet the technical requirements.

2.4.3 Final Configuration

The ERACLE's design is the result of all the considerations made about the contest rules, the mission requirements, the RAC evaluations and all the possible structural configurations. The final product of this study is an A/C with a monocoque fuselage and high wing with a conventional tail. A tail dragger with bow-type main gear was chosen as landing gear. The propulsion system consists of a brushless engine supplied by two battery packs. The A/C is capable of a 3 lbs payload which can be placed fully inside the fuselage or to the wing tips.

2.5 Preliminary Design

After the conceptual stage the next one was the sizing phase of the A/C whose main segments were committed to each Team member. The investigation areas were identified in aerodynamic, propulsion, structure and payload matter. In each of them the most critical parameters were found in order to obtain an accurate refining process. The use of specific Team-made programs helped the analysis development.

2.5.1 Design Parameter and Sizing Trade Summary

Each group identified the main feature to be defined. In particular the aerodynamic group investigated about:

- WING AREA: this parameter is fundamental for a shorter TOD and to obtain a higher Lift value.
- WINGSPAN: this parameter has a great influence on RAC and on the A/C efficiency. In fact a rectangular wing allows a lower RAC value than the one obtained by an elliptical or tapered ones.
- AIRFOIL: the airfoil choice has a great importance because it affected directly both take-off and cruise performances. Two airfoils were analyzed: the first one was optimized for medium-low attitudes while the second one for high lift conditions.
- FUSELAGE LENGTH & EMPENNAGE SIZE: it was requested a maximum length of 4 ft due to the storage box limitations. The empennage dimensions have to be capable of stabilizing the A/C. Both these parameters influence the RAC value. However as the contest rules requires an A/C capable of fully internal payload storage the fuselage length to maximum width ratio will not be so small.

The propulsion group investigated the following parameters:

- BATTERY Selection and Number of Cells: battery weight has a wide effect on RAC. Its capacity must be enough for the right mission development without unacceptable weight improvements. In addition to this the number of cells is function of the required capacity.
- PROPELLER PITCH & SIZE: propeller pitch and size influence the thrust produced. A propeller with high pitch to diameter ratio will be more efficient at higher air-speeds than a one with a low value of this parameter. The propeller choice has to be based on a comparison between take-off and flight performances.
- TAKE-OFF & Cruise Power: take-off & cruise power has to be optimized in order to minimize the flight mission time. The power supplied during TO has not to exceed 40 A due to the cut-off fuse system.

2.5.2 Design optimization

A specific study about each design area introduced before is analyzed below. The optimal choices are now selected as far as their finest size is concerned.

2.5.2.1 Aerodynamics

Wing airfoil

For a first trade-off process a number of airfoils were selected. Their geometric and aerodynamic characteristics are listed in Table 12. In particular the C_{lmax} and the are C_{dmin} experimental data while the $C_{mc/4}$ is a numerical one (XFoil 6.91). The selection guideline criteria was to obtain a C_{lmax}value not inferior to 1.6 trying later to obtain a C_{dmin} and $C_{mc/4}$ not too incompatible with the previous one.

Table 12: Examined airfoils characteristics; Re=300000, M=0.

AIRFOIL	*t/c (%)*	*CAMBER (%)*	C_{lmax}	C_{dmin}	$C_{mc/4}$
SD7062	13.98	3.97	1.61	0.0091	-0.08
SG6043	10	5.5	1.607	0.0106	-0.16
GOE 624b135	13.5	5.	1.64	0.00939	-0.1
USNPS4	11.94	5	1.602	0.0101	-0.1
E423	12.34	9.92	1.94	0.0172	-0.246
FX63-137	13.59	5.94	1.657	0.0123	-0.17
S1210	11.87	7.2	1.77	0.0124	-0.25
S1223	11.93	8.67	2.1	0.0182	-0.29

Airfoils S1210, S1223, FX63-137 e E423 were discarded due to their too high $Cm_{c/4}$, the SD7062 and the GOE624b135 airfoils were selected. While the first one was optimized to have a high aerodynamic efficiency to the medium-low attitudes, the second one is more indicated in high lift conditions.

As far as the airfoil optimization is concerned, in order to improve the aerodynamic characteristics of the GOE624b135 both in terms of C_d , at low attitudes, and in terms of C_m a large number of modifications were made to the geometry profile acting to the pressure distribution. In particular, in order to improve the low attitudes C_d it was tried to obtain a more gradual transition process (see Figure 4). The resulting airfoil was named GLS3. Figure 4 to Figure 6 show the results of the aerodynamic analysis made by Xfoil on the selected profile. The Reynolds Number was fixed to 300000, the Mach Number is equal to zero, the free transition on the upper part of the profile and the imposed one on the lower part of the profile was fixed to 70% to simulate the discontinuity induced by the flap presence.

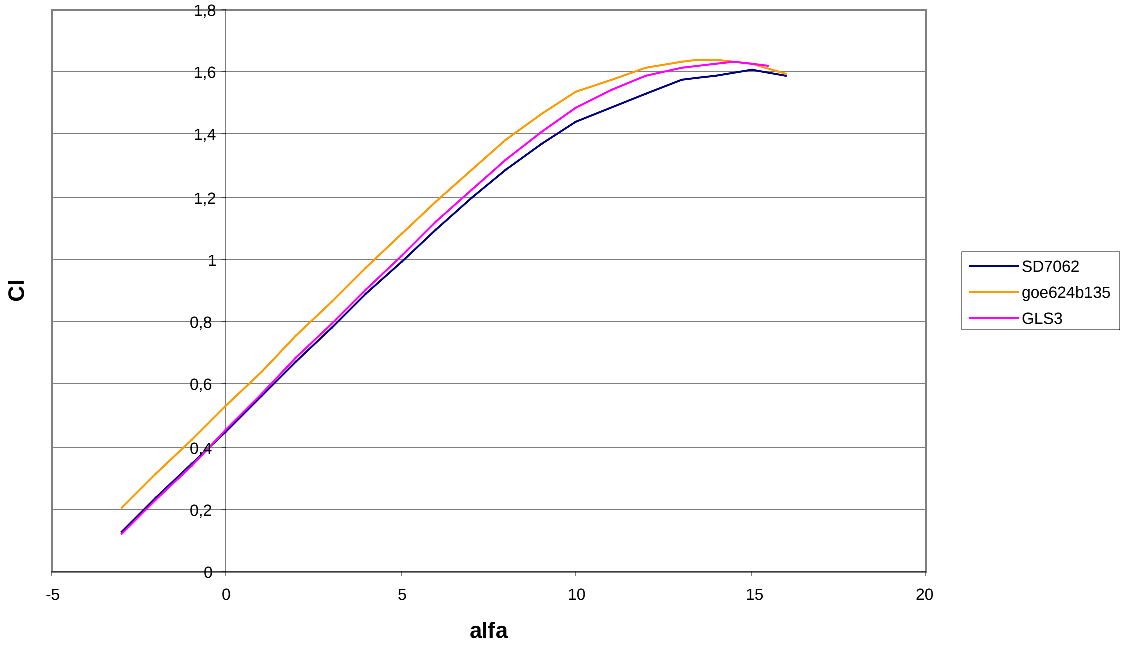


Figure 4: Comparison between lift curves; Re=300000, M=0.

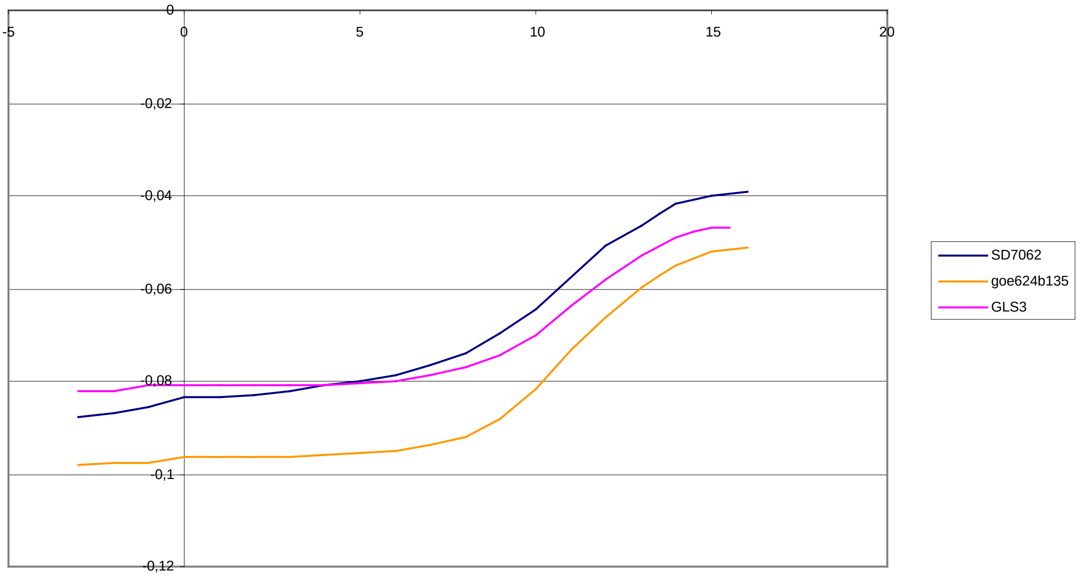


Figure 5: Pitching moment curves of the GLS3 profile; Re=300000, M=0; free transition on the upper surface, fixed transition (70%) on the lower surface.

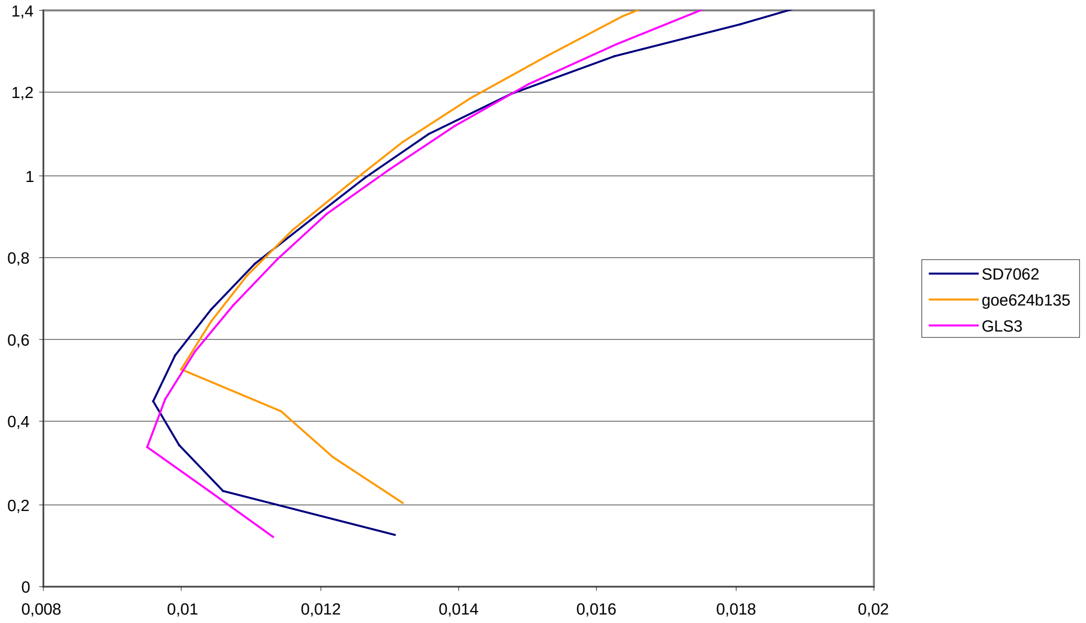


Figure 6: Profile GLS3 polar; Re=300000, M=0; free transition on the upper surface, fixed transition (70%) on the lower surface.

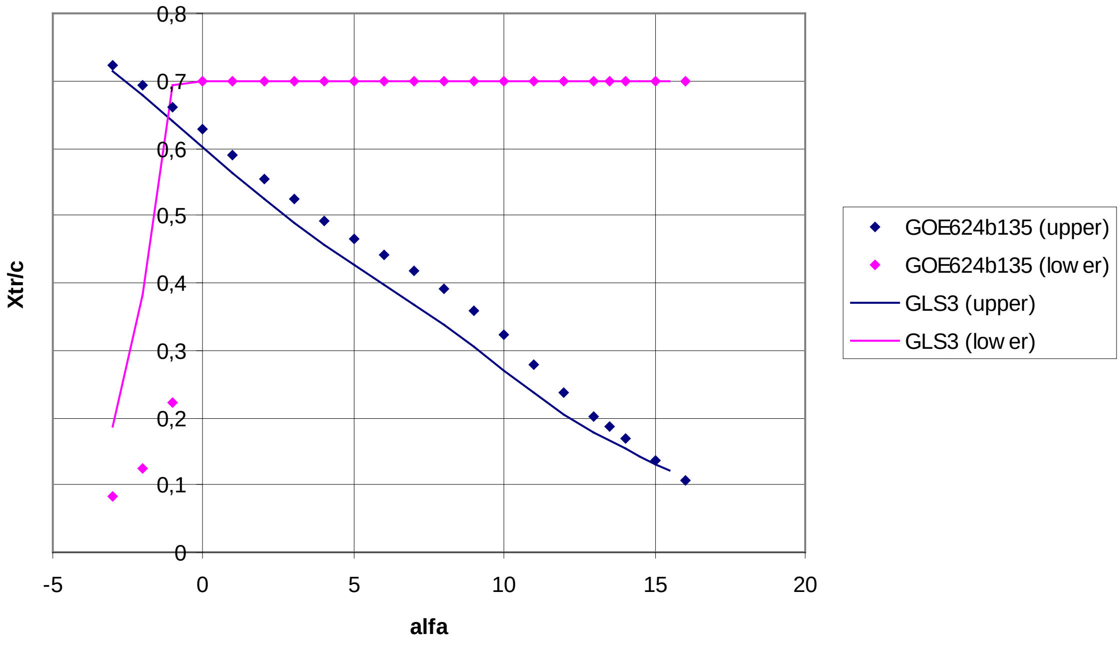


Figure 7: Transition abscissa variation to the attitude variation; free transition on the upper surface, fixed transition (70%) on the lower surface.

In order to simplify the flap manufacturing, both the upper and the lower part of the airfoil were modified on the trailing edge rectifying its geometry starting from the 70% of the chord. This led to both a little C_m improvement and stall regularity. The airfoil was called GLS3b (Figure 8).

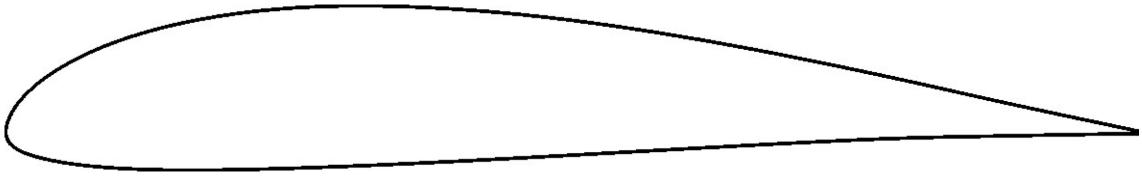


Figure 8: GLS3b profile.

Flap & Ailerons

As far as control surface is concerned the lower surface control number induces a good RAC value. Without ailerons it is impossible to control any maneuvers on roll axis. The best compromise between RAC and performance in the all mission phases is chosen. It gives particular attention to the take-off and landing phase because of imposed limitation. The GLS3b is a high-lift airfoil even so it is considered to set a flap configuration in particular a flaperon configuration. This choice have the following advantage:

- lower impact on RAC than the other flap configuration (i.e. Aileron + flap, aileron + flap + spoiler)
- low servos number
- easy construction

35% flap chords is selected because the drag increase gives a breaking action and there is the packed of boundary-layer suction mechanism.

Empennage

As far as the empennage is concerned a rectangular shape was chosen due to its manufacturing simplicity without any taper-in-thickness ratio. The selected airfoil was the NACA 0012. The horizontal surface is fully movable in this way the maximum efficacy of the part is granted above all at low velocities, minimizing the boundary layer effects on the control power. In order to dimension the empennage a Visual FORTRAN program was developed to analyze the equilibrium and the stability condition of the A/C when the wing and fuselage contributions are known. In Figure 9 it is shown the empennage's necessary surface vs its span for the two conditions.

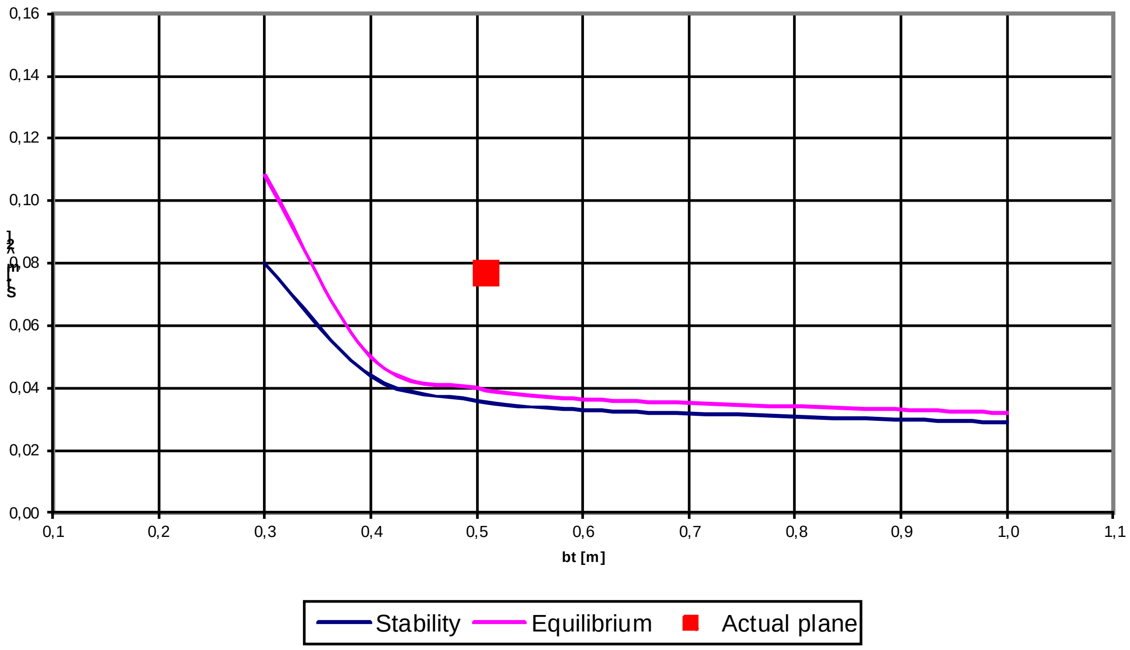


Figure 9: Empennage chosen surface.

The red square represents the combination developed for the A/C. This choice was made with the aim to limit greatly the required surface with reference to the need of maintaining a certain safety margin from the critical conditions. It was also taken into consideration the RAC limitations as far as the reference volume evaluation of the fuselage and the empennage span which, if too big, could led to consider it as a second wing.

Fuselage

The fuselage is designed around the payload bay and then the aerodynamics is optimized to have the lowest possible drag.

2.5.2.2 Propulsion

The propulsion system layout includes an electrical engine, an engine battery pack and a voltage regulator for the rpm regulation. The selected battery is a Ni-MH type chosen for its capacity to weight ratio. The preferred engine is brushless type chosen for its power to weight ratio greater than the brushes one. The voltage regulator is chosen as a consequence of the adopted engine and the number of battery pack cells.

Engine battery pack

Due to the 40 Amps limitation on the current absorbed by the engine and considering 5 Amps of safety margin, the aim was to maximize the voltage applied to the engine in order to have a greater power. This means a greater number of cells needed for the engine battery pack within the 3 lbs limitation. The batteries considered for the trade-off analysis are listed below.

Table 13: Battery comparison.

	Type	Capacity (mAh)	Weight (g)	Capacity / Weight	# Cells	Total weight (g)	Voltage (V)	Max Power (W)	Time (min)
POWER SONIC PS-CX	NiCd	2500	75	33,33	16	1200	19,2	768	3,75
POWER SONIC PS-DH	NiCd	4000	125	32,00	9	1125	10,8	432	6,00
POWER SONIC PS-CXF	NiCd	2500	72	34,72	17	1224	20,4	816	3,75
POWER SONIC NH-3700A	NiMH	3700	53	69,81	23	1219	27,6	1104	5,55
SANYO N-3000CR	NiCd	3200	84	38,10	14	1176	16,8	672	4,80
SANYO HR-4/3AU	NiMH	4000	55	72,73	22	1210	26,4	1056	6,00
SANYO HR-4/3FAU	NiMH	4500	62	72,58	19	1178	22,8	912	6,75
SANYO HR-4/3FAUP (3600)	NiMH	3600	58	62,07	21	1218	25,2	1008	5,40
SANYO HR-SCU	NiMH	3000	61	49,18	20	1220	24,0	960	4,50
SANYO RC-3300HV	NiMH	3300	60	55,00	20	1200	24,0	960	4,95
CELLCON Stilo NiMH 2300 mAh	NiMH	2300	24	95,83	20	480	24,0	960	3,45

A battery with the greater capacity to weight ratio. This means that the engine battery pack is made up by SANYO RC-3300 mAh which assure 6.87 minutes of running at 35 Amps (flight time is limited at 10 minutes). At this point it was necessary to decide how many cells the engine battery pack is made by in order to choose the better power supply available. Calculations are listed below.

Table 14: battery pack performance.

# of cells	*Voltage (V)*	*Weight (g)*	*Weight (lbs)*	*Power (W)*
20	24	480	1,07	840
22	26,4	528	1,17	924
24	28,8	576	1,28	1008

The engine battery pack will be made up of 22 cells arranged as in the figure below.

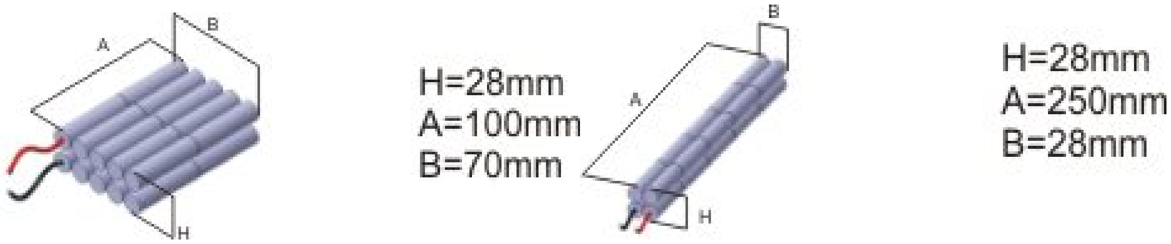


Figure 10: possible battery packaging.

Engine

The first thing to do was to understand how a brushless motor works and then it was possible to proceed with a market analysis. Engine manufacturers of brushless motors for A/C models are listed below:

- Aveox
- Hacker
- Pehner
- Mega
- Plettenberg

A number of engines were taken into consideration for each producer. All the selected engines have a current peak under 60 Amps. With engine data (i.e. RPM/V, internal resistance, no-load current) the efficiency and torque versus current were calculated. Then the best motor of each producer was chosen and compared with the others.

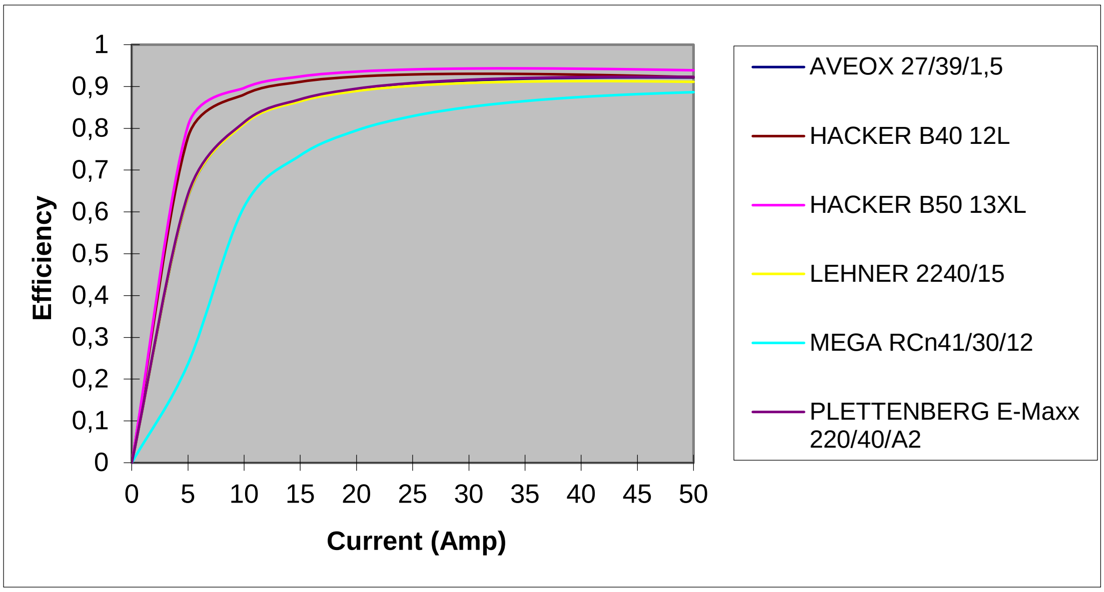


Figure 11: Engine efficiency.

Hacker motors are the ones with the best efficiency. All motors, apart from the MEGA motors, need a gearbox to reduce the engine at shaft RPM to a more acceptable value. The analyzed Hacker motors are listed below:

Table 15: comparison between Hacker engines.

Voltage (V)	26,4			
Engine	Gearbox ratio	RPM	Weight (g)	h_{max} (Amp)
Motore HACKER B40 10S	4,4	25560	172	50
Motore HACKER B40 10L	5,2	15231	315	45
Motore HACKER B40 12L	4,4	15000	212	35
Motore HACKER B50 10L	5,2	12261	315	50
Motore HACKER B50 11S	6,7	13038	256	50
Motore HACKER B50 11XL	3,7	10239	395	45
Motore HACKER B50 13XL	6,7	4784	331	35

The chosen engine is the is Hacker B50-11XL due to its high efficiency and torque at 35 A and at 10000 RPM.

Voltage regulator

As far as the voltage regulator is concerned it was necessary a device capable to manage 20 cells with a maximum operating current of 40 A. However regulators working with a so high cell number allows an operating current of 77 A. The one chosen for this design is the Hacker Master 77A Opto.

Propeller

Due to the current limitation the A/C need a propeller with a low power coefficient but capable to take-off in 150 ft. It is also required a medium-high thrust coefficient. Numerical calculations were implemented to choose some propeller that were tested in the wind tunnel of the D.P.A. A model of nine propellers have been made changing the diameter from 12 to 14 in. and the pitch from 7 to 9 in. due to obtain a graph of C_t, C_p and η to advance ratio. The results are listed below.

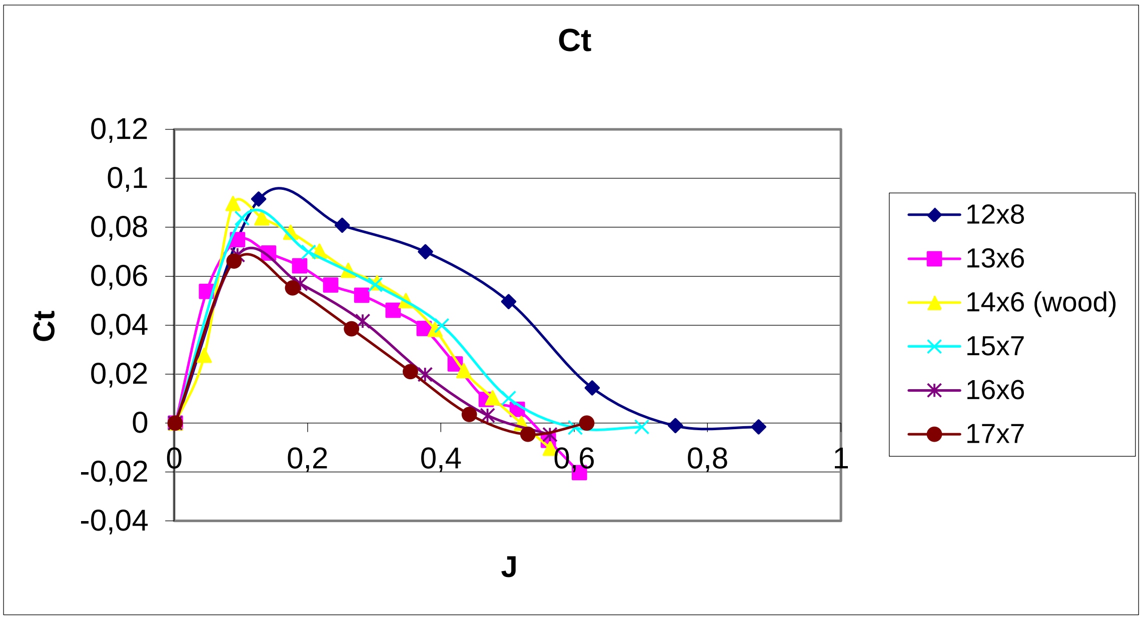


Figure 12: Thrust Coefficient.

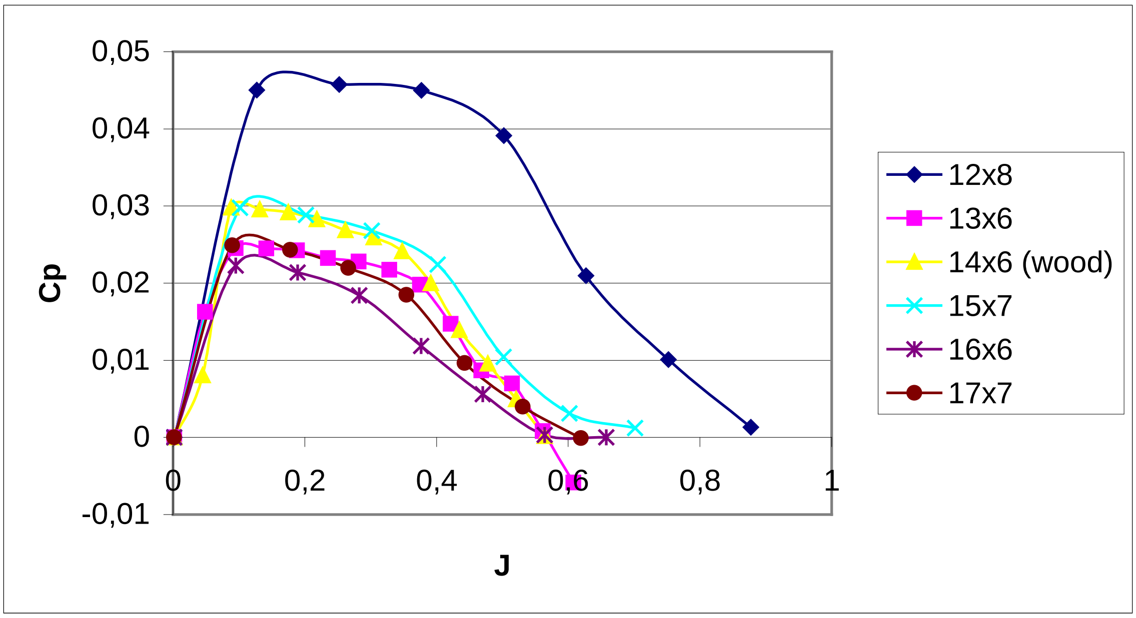


Figure 13: Power Coefficient.

Three of these propellers have been tested in the wind tunnel to correlate and validate the calculus made and to choose the right propeller for each mission. Experimental results are shown below.

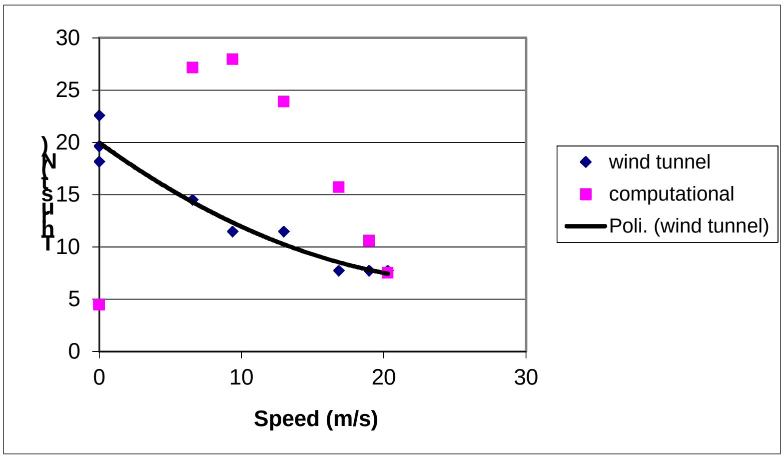


Figure 14: 14 x 6 propeller thrust.

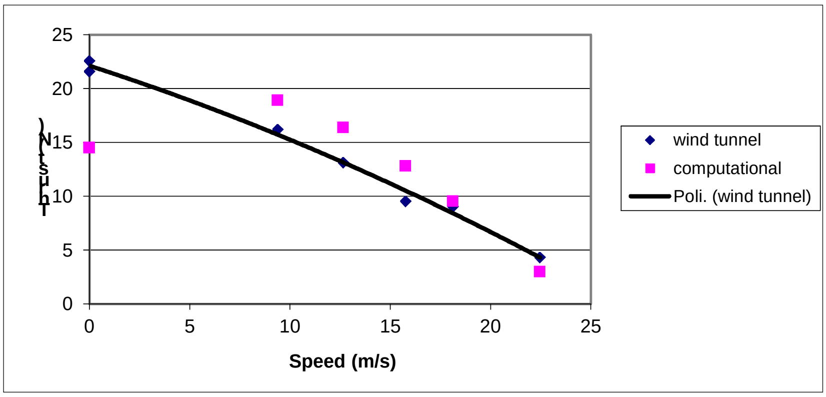


Figure 15: 13 x 6 propeller thrust.

Conclusions

The propulsion system has been defined as follow:

- Engine: the best one for the design is the HACKER B50 11XL with the provided gearbox by the same Hacker;
- Regulator: Hacker Master 77A Opto
- Battery Pack: 20 cells CELLCON NiMH 2300 mAh
- Propeller: 18 X 10 APC-E

2.5.2.3 Structures

A number of coupons have been realized to perform tensile and bending tests on the sandwich materials used for the wing structure. The tests have been carried out in order to evaluate the ultimate tensile stress and the elastic moduli. Tests have been conducted according to the ASTM standards. In order to evaluate the fiberglass face sheets elastic moduli of the sandwich coupons the following formula has been used:

$$(EI)_{eq} = E_f\left(\frac{bt^3}{6}+\frac{btd^2}{2}\right)+\frac{E_c bc^3}{12}$$

where $(EI)_{eq}$ is the sandwich beam equivalent bending stiffness, E_f the face sheet (fiberglass) elastic modulus, b the beam width, t the face sheet thickness, d the center face sheets distance, E_c the core (balsa) elastic modulus and c the core thickness.

Table 16: coupon test results.

Bending Coupon n°	F1	F2	F3	F4	F5	F6
Leinght [mm]	120	110	100	120	120	120
Weidht [mm]	19,6	19,2	19	19,5	20	19,5
Total tickness [mm]	3,8	4,1	4	4,1	4,1	4
Fiber tickness [mm]	0,8	1,1	1	1,1	1,1	1
Fiber section [mm^2]	15,68	21,12	19	21,45	22	19,5
Eb total[MPa]	8,605	11,634	15,392	10,855	15,707	16,038

2.5.2.4 Payload

The Payload system requires a PVC tube with fairings to avoid drag implications. The R&R system has a great importance for the design success. In particular the selected device is simple and strong enough to assure a good reliability and durable utilization. The following drawings show the correct wing installation and the whole mechanism running:

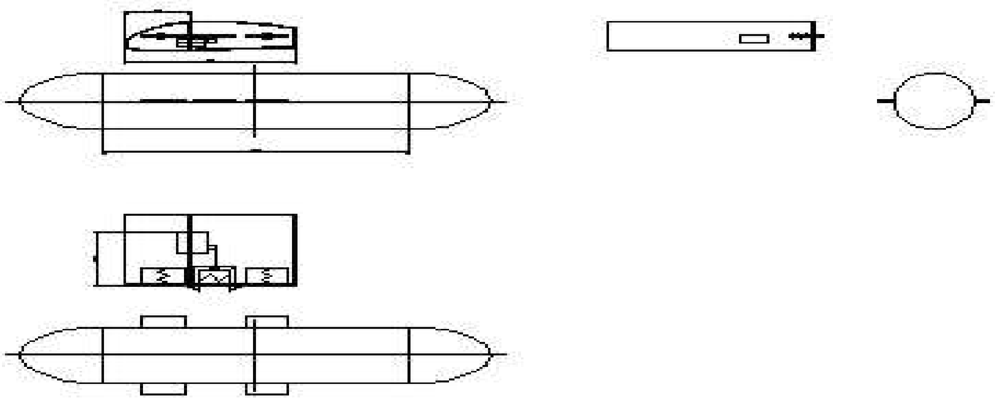


Figure 16: external payload and release system.

As the R&R of the internal payloads does not need a remote control, the system developed is more simple than the other applied for the wing.

As far as the internal fuselage installation is concerned the following drawings will show the connection system:

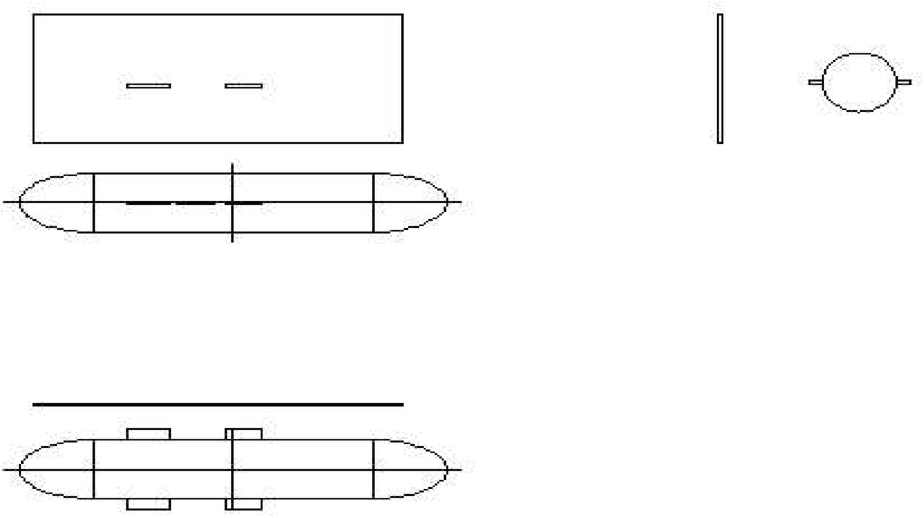


Figure 17: Internal payload and release system.

As the requested weight is considerable higher than the one of the PVC faired tube it is necessary to ballast the payload. In particular as the CG of the A/C has not to change with their removal, payloads are ballasted in an opportune point of their length and not in the middle. This assures A/C stability not to be function of the payload presence.

2.5.3 A/C Configuration

The final configuration results in a conventional A/C with high mounted wing. The fuselage has been streamlined around the interior components creating a low-drag body. The wings was designed with a span of 1 meter and a chord of 0.26 meter and an aspect ratio of 8.6. The flaperons extend for the whole wing span and occupy 30% of the chord. The tail has a conventional configuration sized with a 0.55 meters of span and a chord of 0.16 meters.

2.5.4 A/C Predicted Performance

The mission performance of the definitive A/C was esteemed from the performance code developed for the optimization phase. The mission profile was splitted into main segments to be analyzed. An analysis software has been developed to esteem overall A/C performances and to evaluate consumption and time for each mission. This software is divided in two parts: an input part, which is made by several worksheets, one for each A/C system such structure, propulsion, or aerodynamics where the characteristic of the design are specified. The output part is composed by worksheets and graphs that show the A/C performances such as TOD, ROC, ROT, consumption, mission time, the relative score and the RAC value obtained. Every change in the input part leads to modifications in the output one. In this way it was easy to compare different configurations and different propulsion systems as far as different mission procedures is concerned due to evaluate the best ways in developing a mission.

2.5.4.1 Numerical Analysis

After single-components design phase, a numerical analysis on aircraft has been done. This analysis has divided in two sections: numerical analysis on partial-aircraft (wing and fuselage) and numerical analysis on complete aircraft.

Analysis on partial aircraft

In this phase a tridimensional panel code developed by DPA has been used; purpose of this section is obtain aerodynamic and structural characteristics of wing. In order to optimize general aerodynamics of aircraft pressure distribution over fuselage-wing surface has been considered. Analysis has been done at Reynolds number fixed to 300000, Mach number fixed to 0, varying angle of attack between –2° and 8°.
Oswald factor and dCM/dCL have been determined also. Figure 18 to Figure 20 show wing aerodynamic and structural characteristics.

Table 17: Results of aerodynamic analysis.

α	CL	CMy	CDt	Oswald factor e	dCM/$\delta\alpha$	δCL/$\delta\alpha$	δCM/δCL
-2	0.151	-0.094	0.013	0.71			
-1	0.244	-0.088	0.014	0.73	0.01	0.09	0.059002
0	0.336	-0.083	0.016	0.74	0.01	0.09	0.059718
1	0.428	-0.077	0.019	0.74	0.01	0.09	0.060501
2	0.519	-0.072	0.024	0.74	0.01	0.09	0.061287
3	0.611	-0.066	0.029	0.74	0.01	0.09	0.061967
4	0.702	-0.060	0.035	0.74	0.01	0.09	0.062678
5	0.793	-0.054	0.042	0.74	0.01	0.09	0.063396
6	0.883	-0.049	0.051	0.74	0.01	0.09	0.063898
7	0.973	-0.043	0.060	0.73	0.01	0.09	0.064477
8	1.062	-0.037	0.070	0.73	0.01	0.09	0.065022

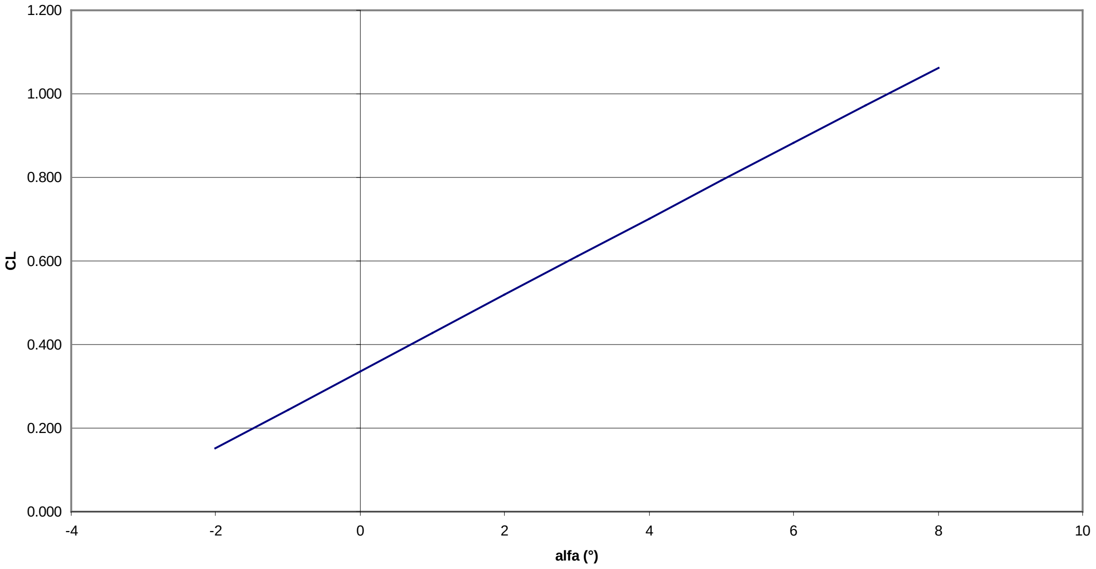


Figure 18: Wing lift curve.

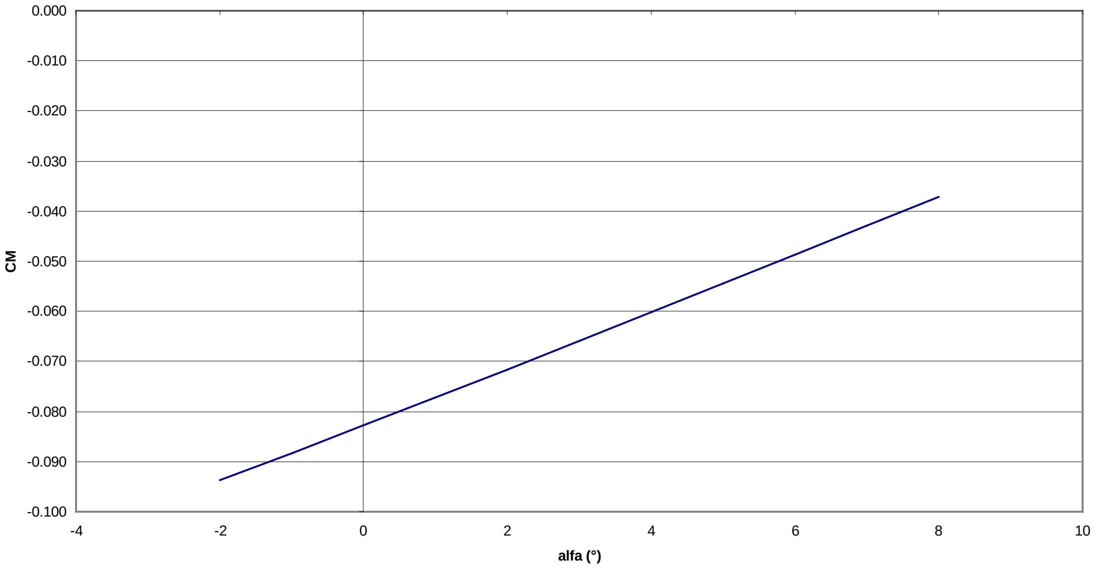


Figure 19: Wing moment curve.

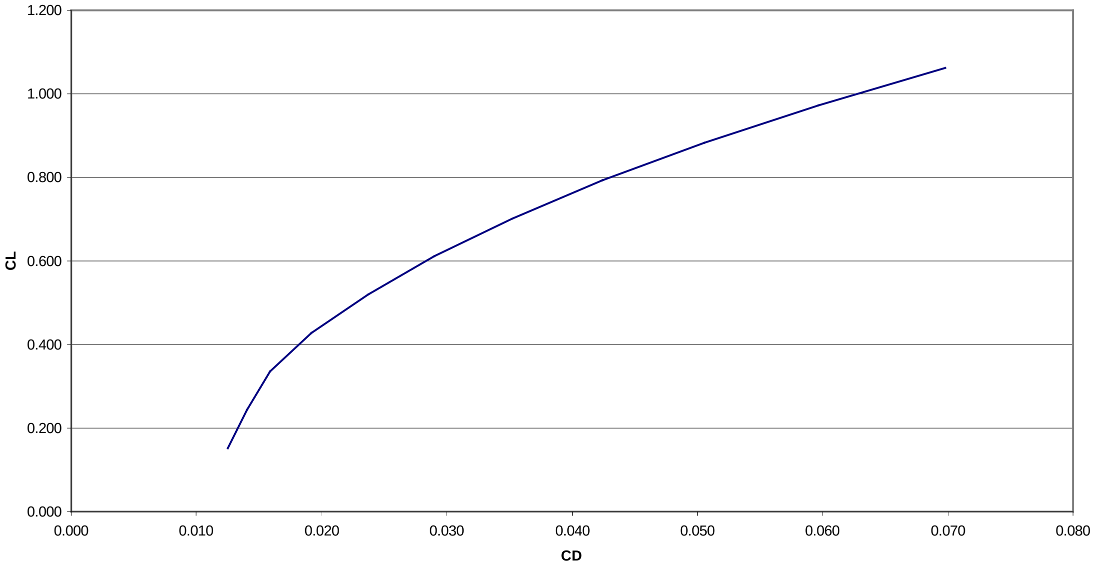


Figure 20: Wing polar.

Shear and momentum characteristics along wingspan has been determined; in order to simulate landing configuration, loading factor has been fixed to 2.5. Speed has been fixed with varying angle of attack. Figure 21 to Figure 23 show results.

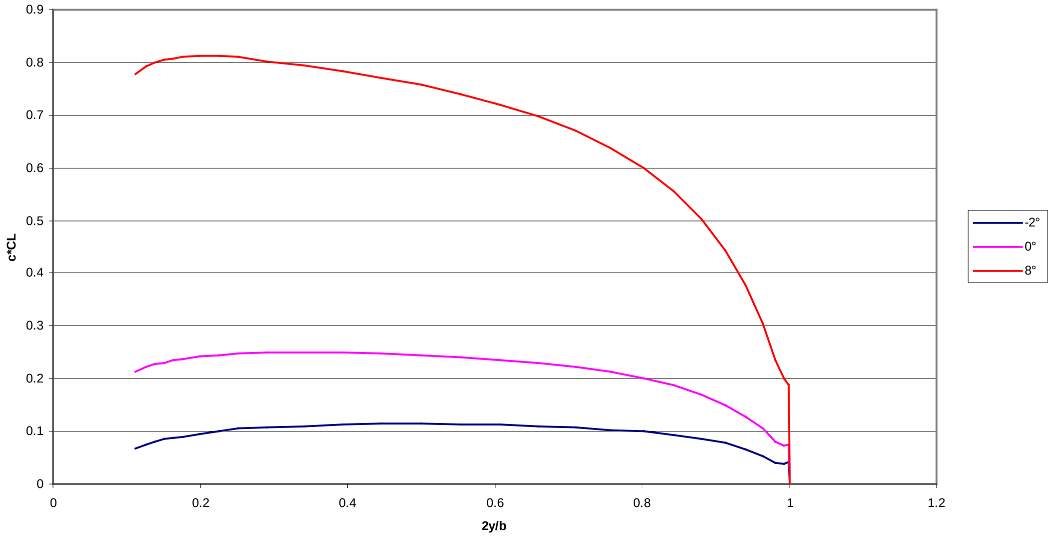


Figure 21: Spanwise load distribution.

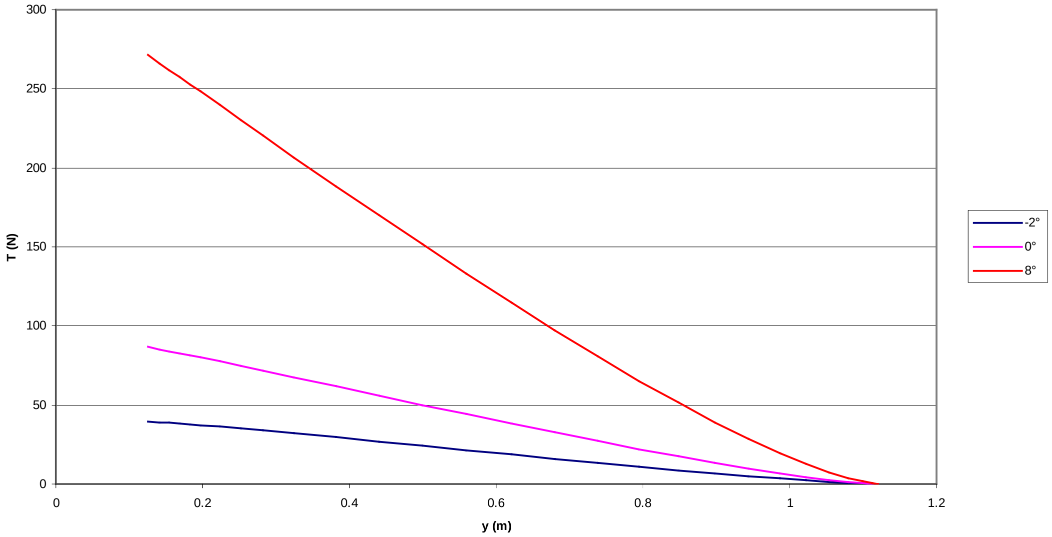


Figure 22: Spanwise shear distribution.

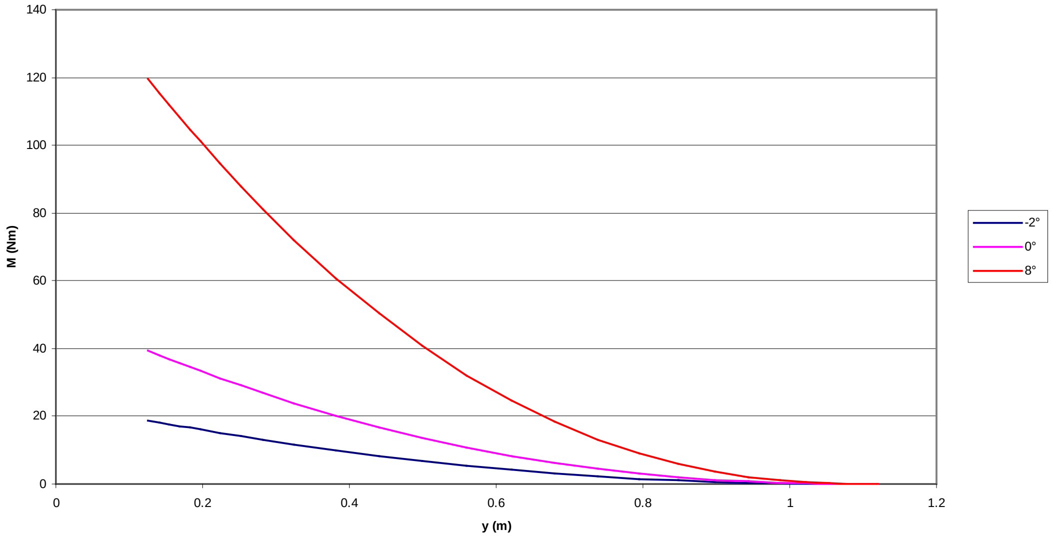


Figure 23: Spanwise moment distribution.

Regularity of pressure distribution over model surface has been analyzed; results are show in Figure 24 to Figure 27.

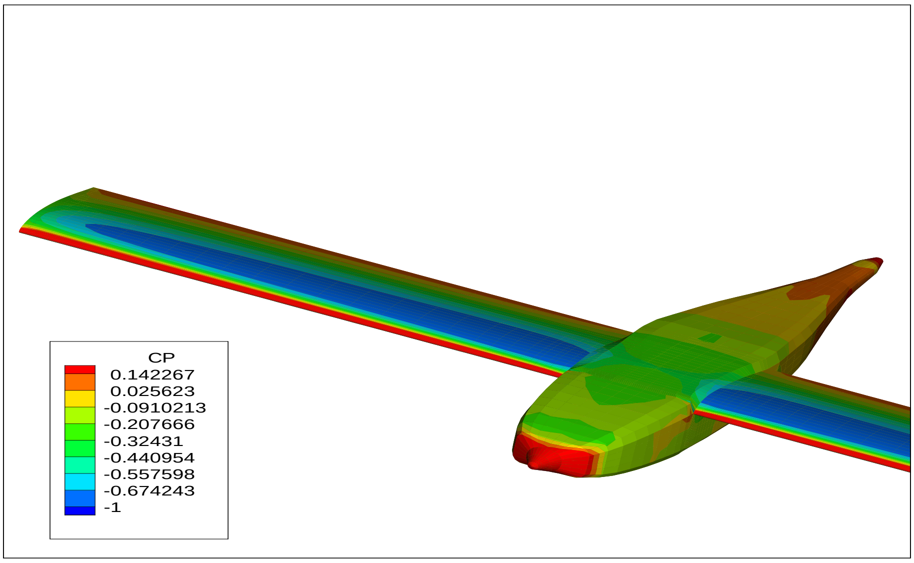


Figure 24: Pressure distribution over surface ($\alpha=0$).

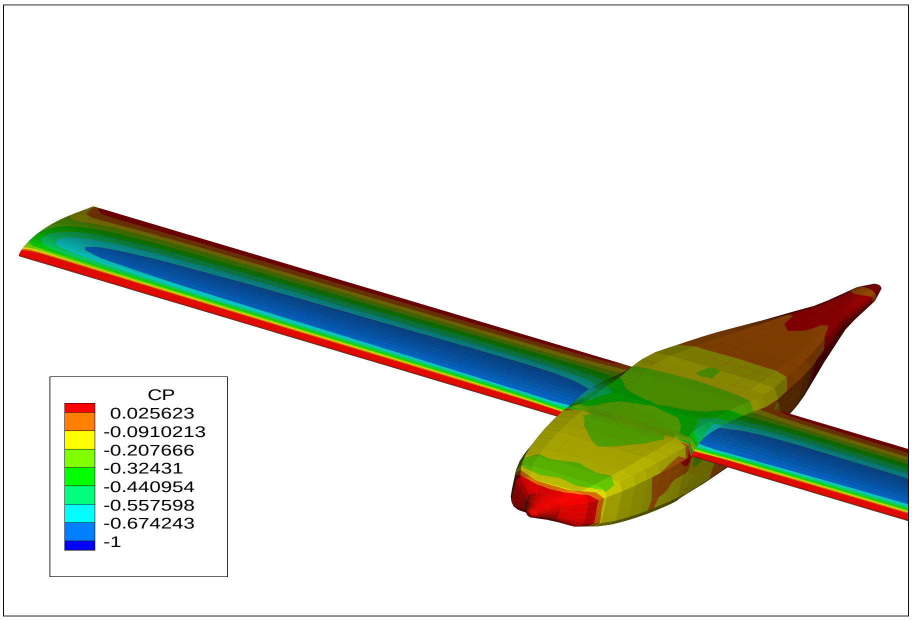


Figure 25: Pressure distribution over surface; $\alpha = 8°$.

Analysis on complete aircraft

In this section CMARC 3D panel code has been used; analysis purpose is to obtain, in cruise condition, aerodynamic characteristics, Oswald factor and pressure distribution over aircraft surface. Figure 26 and Figure 27 show results, the value of Oswald factor is 0,78.

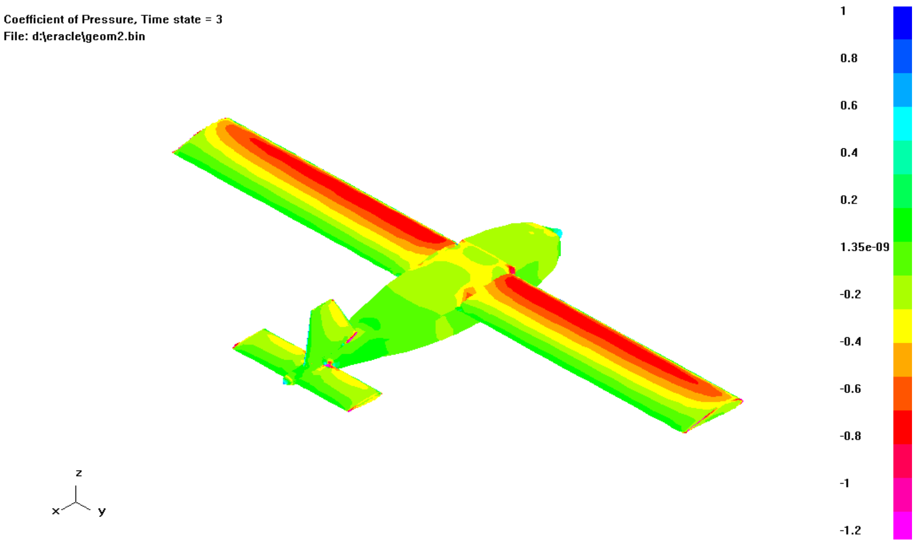


Figure 26: Pressure distribution over complete aircraft.

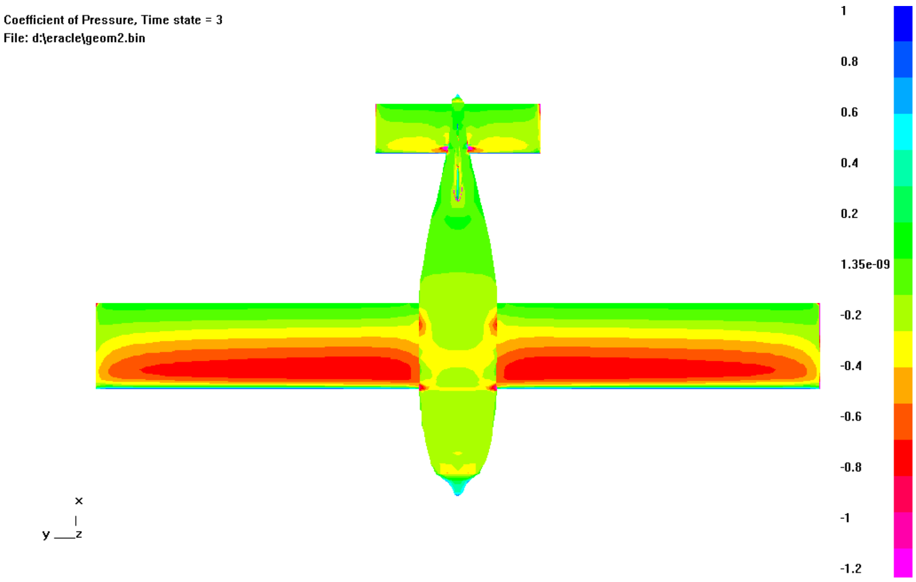


Figure 27: Pressure distribution over complete aircraft.

2.5.4.2 Wind tunnel tests

In order to test complete aircraft, a 65% reduced aircraft model has been realized; various test purposes have been considered:

- Complete aircraft aerodynamic characteristics in realistic conditions varying angle of attack and angle of yaw, also using fin and flaps.
- Numerical analysis results validation and extension.
- Experimental tests about drag reduction and high lift performance increment using suction system on wing surface installed.
- Experimental tests about engine and propellers performances

In order to achieve these goals, mobile payloads, mobile flaps, horizontal plane and fin, fully operating engine and suction system have been installed.

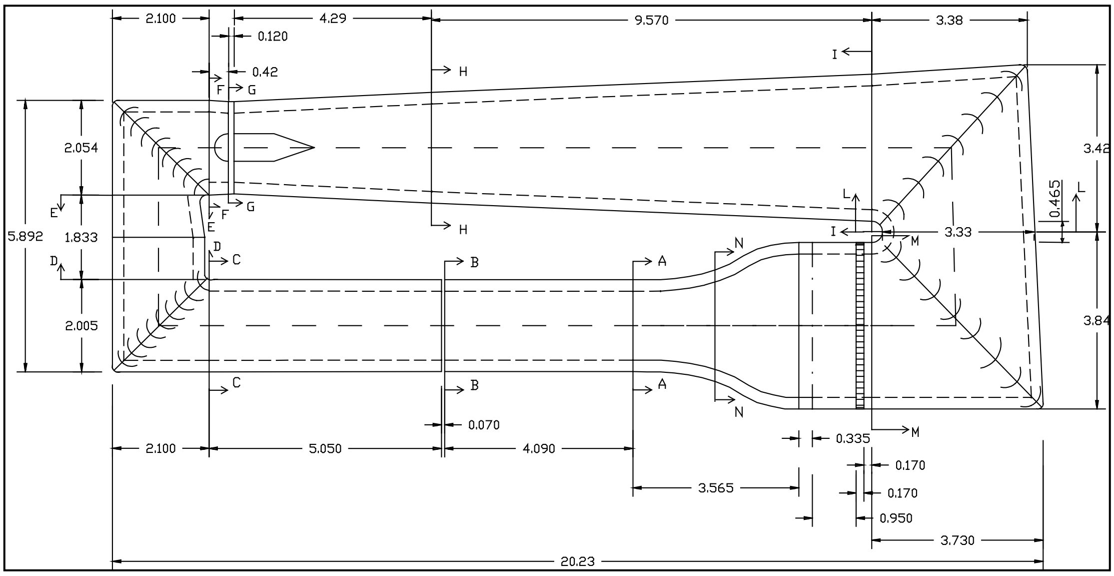


Figure 28: Wind tunnel.

Figure 29: The reduced model in the wind tunnel.

Tests

Longitudinal stability – Aerodynamic characteristics
Test conditions:
Reynolds number: 380000
External payloads: installed
Flaps not deflected
Landing gear: installed

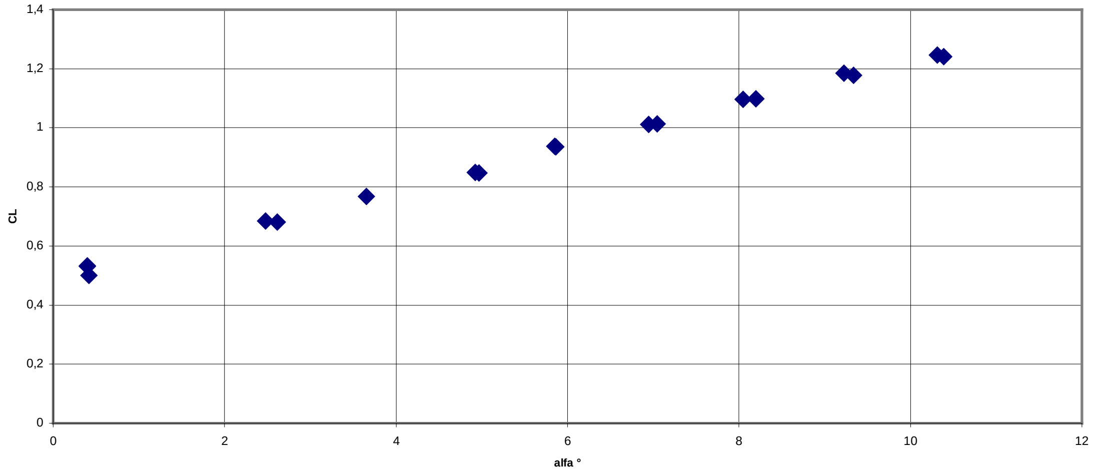


Figure 30: lift curve.

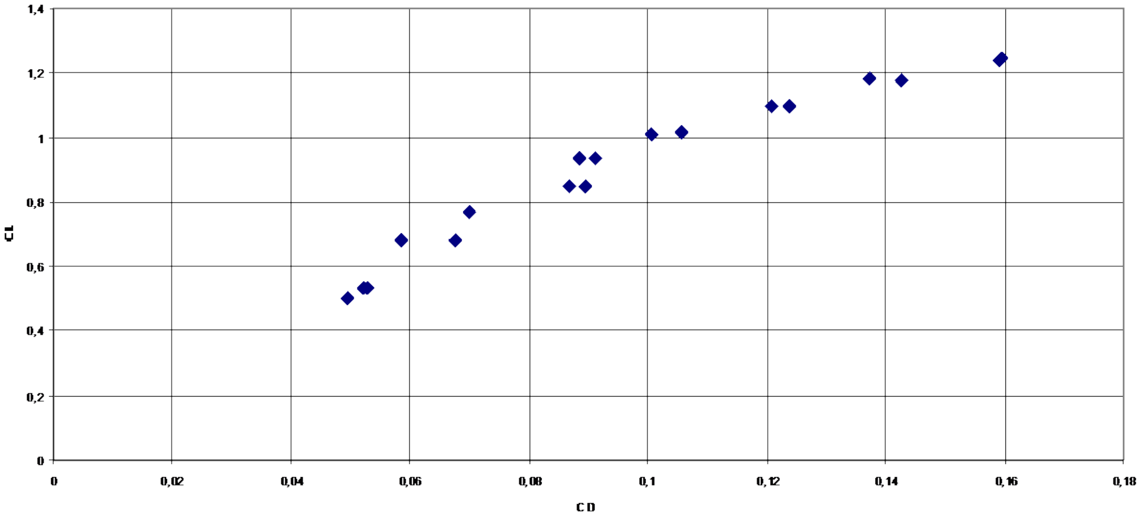


Figure 31: polar curve.

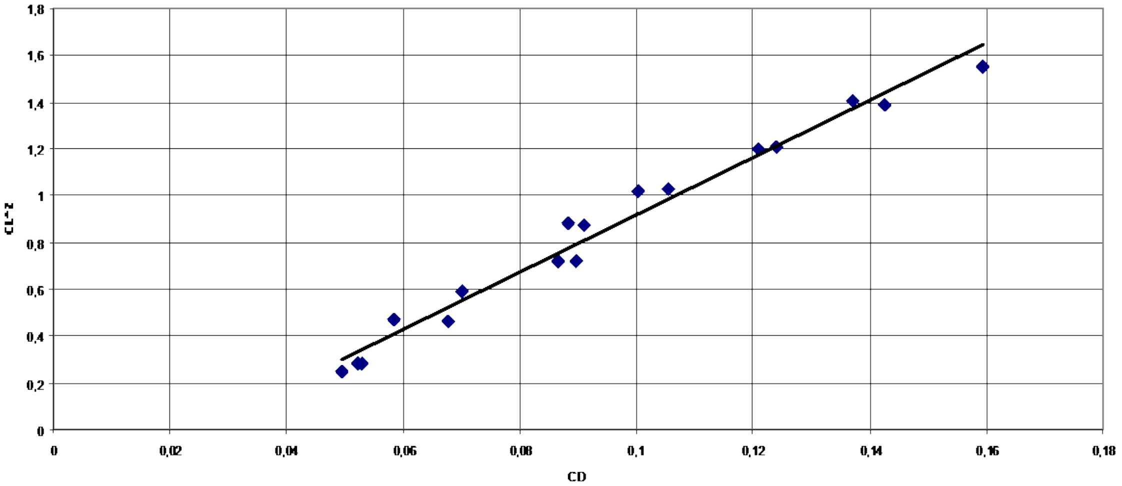


Figure 32: polar curve.

From $CL^2(CD)$ curve has been obtained equation of fitting curve; this equation represents equation of induced approximate polar. Oswald factor has been found; the value is 0,66, while Oswald factor value obtained by numerical analysis was 0,74.

Longitudinal stability - deflection flap effect analysis
Test conditions:
Reynolds number: 300000
External payloads: installed
Flap deflection: 0°, 15°, 30°
Landing gear: installed

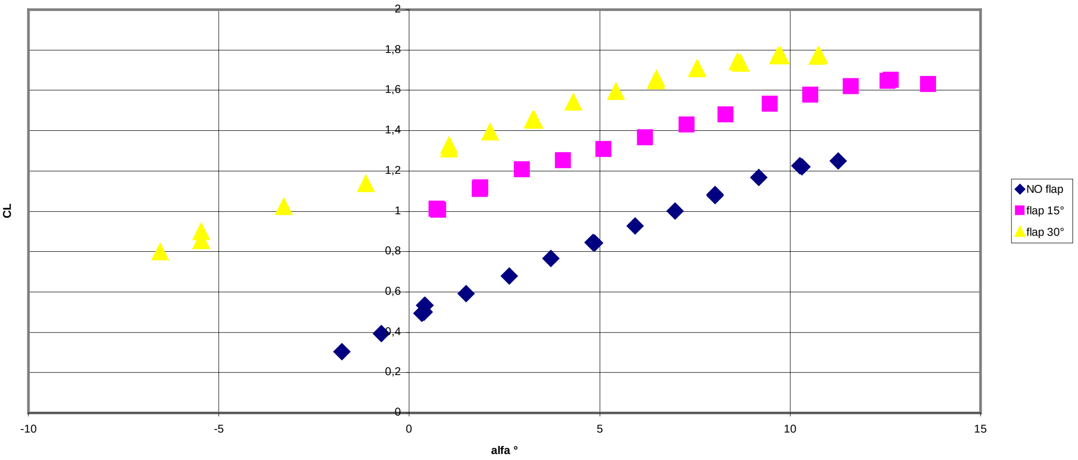


Figure 33: lift polar curve.

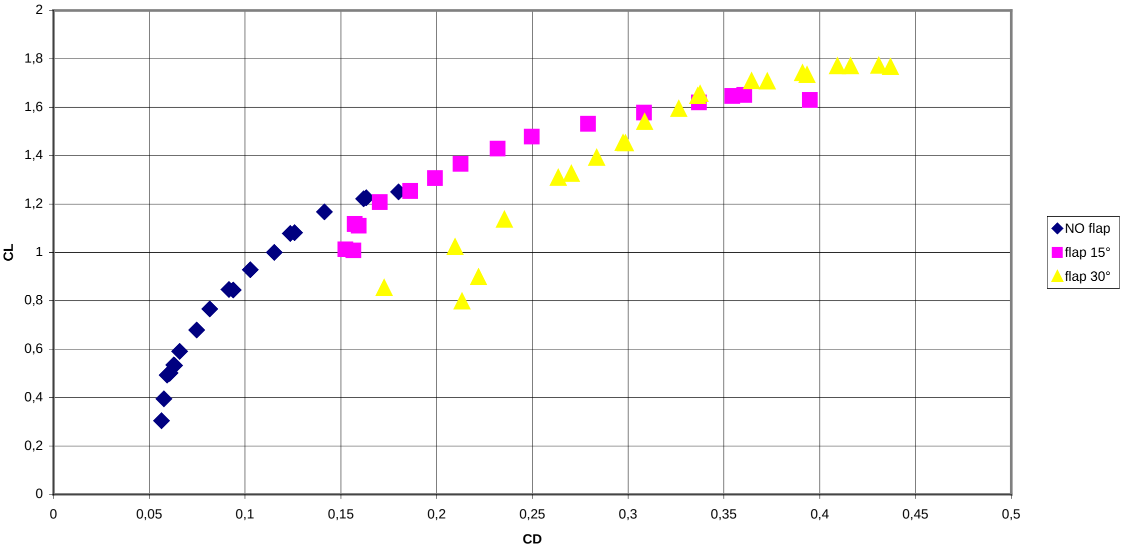


Figure 34: polar curve.

Directional stability – fin deflection effect
Test conditions:
Reynolds number: 300000
Beta: 0°, 15°
External payloads: installed
Flaps not deflected
Landing gear: installed

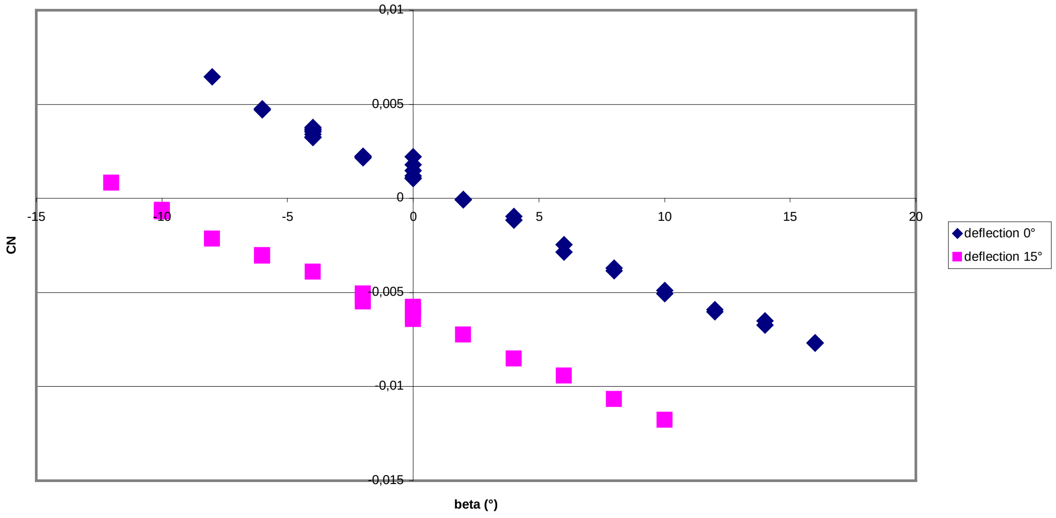


Figure 35: CN curve.

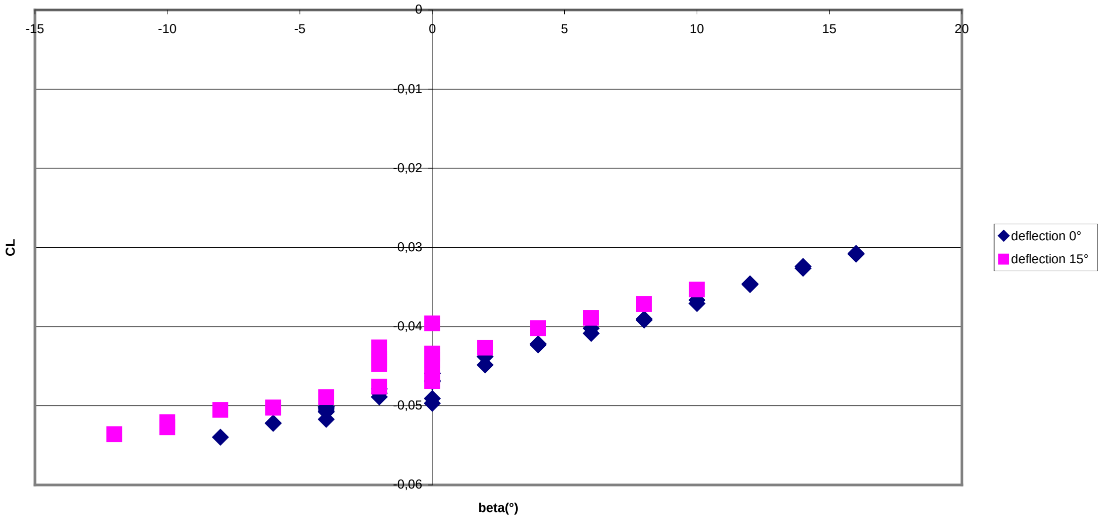


Figure 36: CL curve.

From test results dCN/dβ and dCL/dβ have been determined also.
dCN/dβ: -0.005
dCL/dβ: 0.0016

2.6 Detail Design

The aim of this phase design is to conclude the A/C design and the manufacturing methods starting from the preliminary phase data. The A/C architecture was defined and the avionic systems were chosen with reference to a contained weight and drag.

2.6.1 System Architecture

The A/C characteristics summary containing all the geometric, aerodynamic, systemic and weight characteristics are listed in the table below.

Table 18: System architecture.

GEOMETRY	*VALUE*	*PERFORMANCE*	*VALUE*
CG	0,27 m	C_{Lmax}	1,3
FUSELAGE		L/D_{max}	10,9
Length	1,20 m	GROSS WEIGHT CONDITION	
Width	0,24 m	Maximum climb rate	3,32 m/s
Height	0,15 m	Stall speed	8 m/s
WING		Maximum speed	21,14 m/s
Airfoil	GLS3b	Take-off distance	21 m
Span	2,24 m	EMPTY WEIGHT CONDITIONS	
Chord	0,26 m	Maximum climb rate	2,7 m/s
Area	0,58 m^2	Stall speed	10,64 m/s
Aspect Ratio	8,65	Maximum speed	22,5 m/s
Incidence Angle	0 °	Take-off distance	11 m
Flaperon Area for wing	0,0083 m^2	WEIGHT STATEMENT	
HORIZONTAL STABILIZER		Payload	2,7 kg
Airfoil	NACA 0012	Empty weight	3,2 Kg
Span	0,51 m	Gross Weight	6,2 Kg
Chord	0,15 m	AVIONICS	DETAIL
Area	0,076 m^2	Engine	Hacker B50
Incidence Angle	0°	Battery Configuration	20 x 3300 SANYO
VERTICAL STABILIZER		Gear Box	Maxton Ceramic
Airfoil	NACA 0012	Gear Ratio	3,7:1
Span	0,18 m	Speed Controller	Hacker Master
Chord	0,24 m	Propeller	18 x 10 APC-E
Area	0,31 m	Radio	Futaba T9CAP
Incidence Angle	0°	Receiver	Futaba FP R149DP
		Servos	Hitech HS85MG

2.6.1.1 Propulsion

The propulsion system configuration allows the specific power values indicated in Section 2.5.2.2. They have been evaluated by splitting the mission profile in appropriate flying segments.

2.6.1.2 Structures

The A/C structural design was divided into main categories that are: main wing, fuselage, empennage, payload system & landing gear structure. The internal structure of the wings consists of a “simulated” rib and spar configuration. The spar is 0.84 meters long carrying through the fuselage and 0.30 meters in each wing. Ribs will be placed at the root, the tip and the middle of the wing both to increase torsional rigidity and to place both flaperons and R&R servos. In addition to this two shear webs will be placed at 30% and the 70% of the chord in order to strengthen the structure in bending. The forward shear web will continue the course of the main spar. A number of bulkheads will reinforce the fuselage structure. In particular two of them will be placed on the leading and the trailing edge of the wing. The empennage and the vertical surfaces will be manufactured with the same system of the wing.

2.6.1.3 Payload

The payload R&R system is so simple that it does not require any particular stiffener on the wing tip. The servo is mounted on a “false” rib placed within 75 mm from the wing tip. As the payload weight it is possible to occur in friction phenomena. For this reason the two plugs places, which are stored in the wing tip, will be provided with cylindrical bearings to improve the removal action. Moreover the plug sites are provided with springs for an immediate ejection.

2.6.2 Final RAC Evaluation

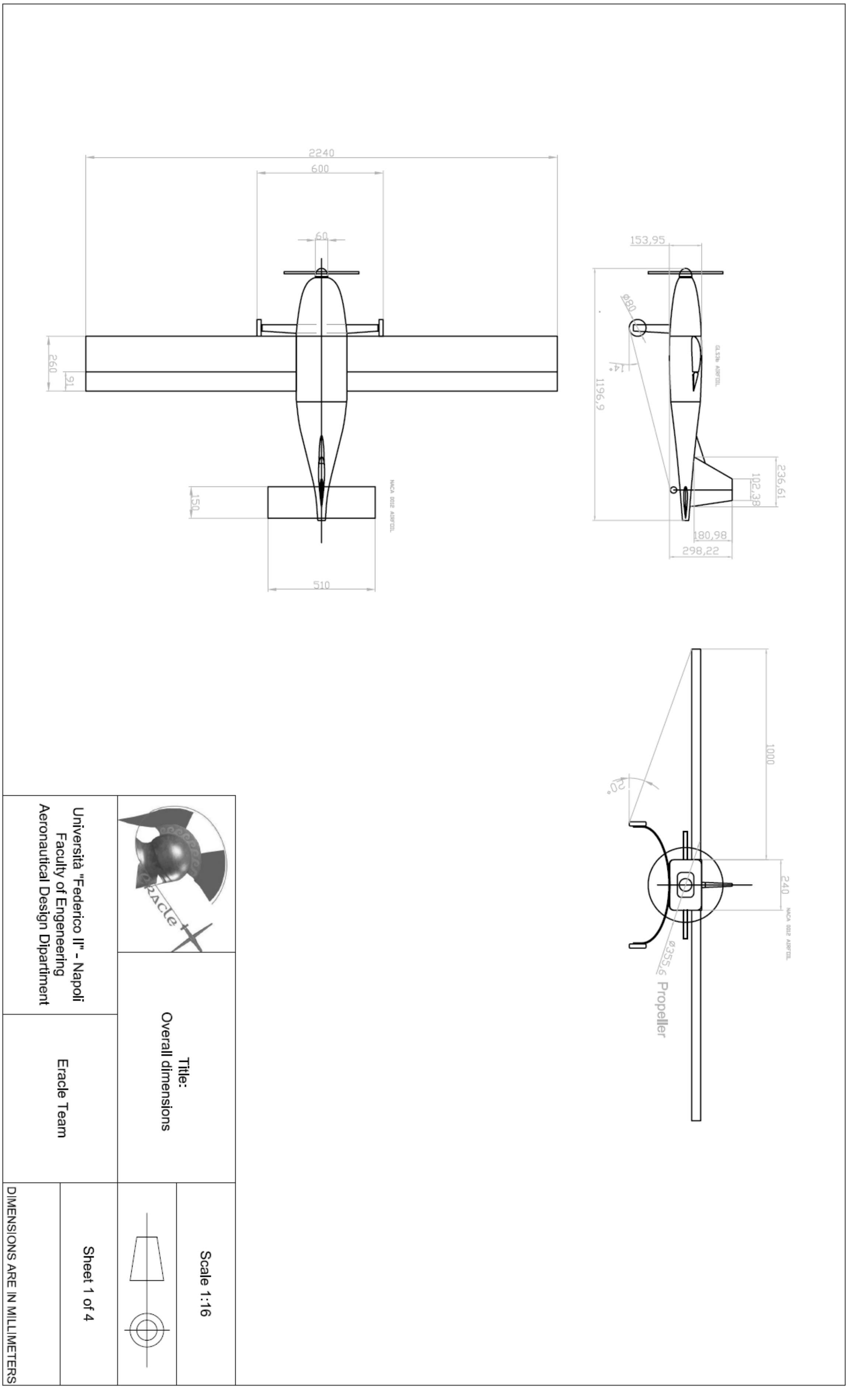
At the end of all the design process the following RAC value was calculated.

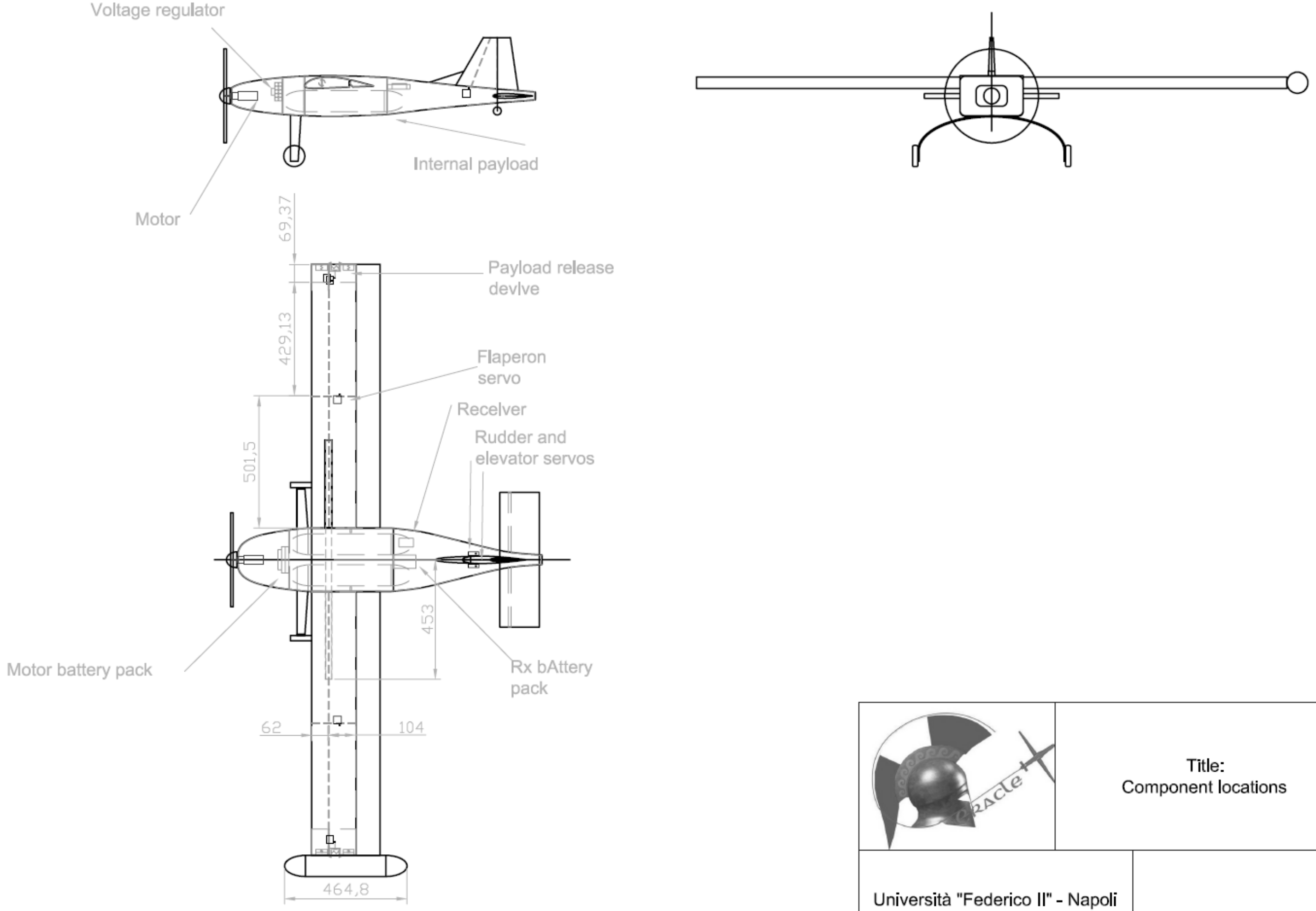
Table 19: Final RAC evaluation.

ITEMS	*MULTIPER ($)*	*MAN HOURS*	*VALUE*	*HOURS*	*COST*
Manufacturers Empty Weight	500				
Aircraft Weight			7 lb		
Rated Engine Power	1000				
Battery Weight			1.1 lb		
Manufacturing Cost	20				
Wing Area		10hr/ft^2	90208 in^2	70,14	
Flaperons		5	1,5		
Fuselage		20hr/ft^3	2631 in^2	30,45	
Vertical tail		10hr/V	1	20	
Horizontal tail		10hr/H	1		
Servos		5hr/servo	7	35	
Total MFHR			155,6		
Total RAC					7,66

2.6.3 Drawing Package

Next are the three view of the ERACLE model and the containment package.


2240
600
60
260
91
150
510
NACA 0012 AIRFOIL
153,95
Ø80
14°
1196,9
GLS3b AIRFOIL
236,61
102,38
180,98
298,22
1000
20°
240
NACA 0012 AIRFOIL
Ø355,6 Propeller
Università "Federico II" - Napoli
Faculty of Engeneering
Aeronautical Design Dipartiment
Title:
Overall dimensions
Eracle Team
Scale 1:16
Sheet 1 of 4
DIMENSIONS ARE IN MILLIMETERS



Title:
Component locations

Scale 1:16

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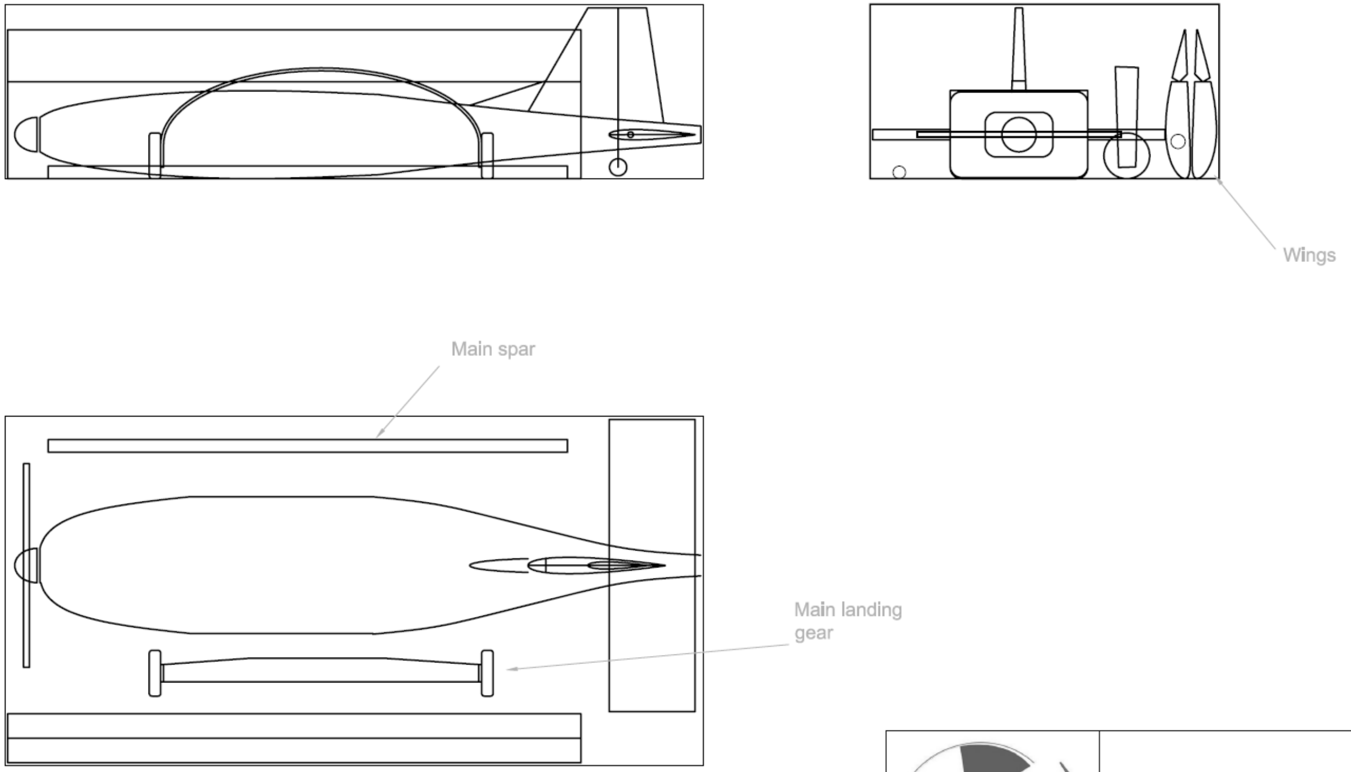
Aeronautical Design Dipartiment

Eracle Team

Sheet 2 of 4

DIMENSIONS ARE IN MILLIMETERS



Title:
Stored configuration

Scale 1:8

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Eracle Team

Sheet 3 of 4

DIMENSIONS ARE IN MILLIMETERS

2.7 Manufacturing Plan & Processes

As indicated in the previous chapters the main components of the A/C structure were monocoque manufactured. As a consequence the trade-off process takes into account only manufacturing methods concerning monocoque.

2.7.1 Manufacturing Processes Trade-off

In this paragraph a number of manufacturing processes were evaluated:

1. LOST FOAM MOLD: this is the easiest method in monocoque manufacturing. Once a foam cut-out was built it has to be covered by fiberglass. Later the foam core can be removed. The result is a lightweight structure which has not the highest stiffness characteristics.
2. MALE MOLD: a male mold requires an accurate outer image of the part to be constructed. This mold requires a high skill both in wood or aluminum working and joining plies. Moreover the best surface is the inside one of the structure while the outer one requires finish works.
3. FEMALE MOLD: a structure built by female mold requires a high skill as composite materials is concerned. The final product has an outer surface well finished without any additional refining work need.
4. MALE & FEMALE MOLD: this mold system combines the advantages coming both from the male and from the female mold manufacturing systems. In fact the male mold presence allows good surface finish control without the complexity of other devices (i.e. bag molding). The final product results precise and stiff enough even if manufactured by a cheaper system.

The FOMs involved in this trade-off process are the following:

- ✓ WEIGHT: RAC analysis shows the importance of a lighter structure.
- ✓ STRENGHT: this is a fundamental parameter as this kind of construction will not be able to be stiffen in a second time.
- ✓ QUALITY to COST RATIO: an important aspect is to contain cost without any quality loss.
- ✓ SKILL: it is essential in order to obtain a good quality structure to have a certain experience in composite material manufacturing.

Table 20: Manufacturing processes trade-offs.

FOM	*WEIGHTING FACTOR*	*LOST FOAM*	*MALE*	*FEMALE*	*MALE & FEMALE*
WEIGHT	0,34	-1	0	0	1
STRENGHT	0,26	0	1	1	1
QUALITY/COST	0,22	-1	0	0	1
SKILL	0,18	0	1	0	-1
TOTAL	1,00	-0,56	0,44	0,26	0,64

2.7.2 Component Manufacturing

In this paragraph the manufacturing process of the fuselage, empennage, wing and landing gear is summarized.

2.7.2.1 Fuselage

The fuselage will be constructed with the same process used for the wing and the empennage. A CNC MDF male & female mold was prepared to lodge the sandwich in its preparation process. Each half of the fuselage mold will lay-up independently. After the lay-up operation the fuselage will bring into a heater for half a day. The internal reinforcement structure will be fixed to one of the two half and then joined together.

2.7.2.2 Empennage

Also the empennage employs a CNC MDF male & female mold.

2.7.2.3 Wing

Also the wing employs a CNC MDF male & female mold. Its bigger surface requires plenty of attention to avoid bubbles formation.

2.7.3 Production Analysis

A production analysis was performed in order to help the manufacturing process. This analysis has as main feature the cost evaluation, the required skill and a timetable to check production course.

2.7.3.1 Costs

After the design process it is possible to define with more precision the whole A/C cost. Splitting the A/C in its main field of interests it is possible to underline the most expensive device for each area.

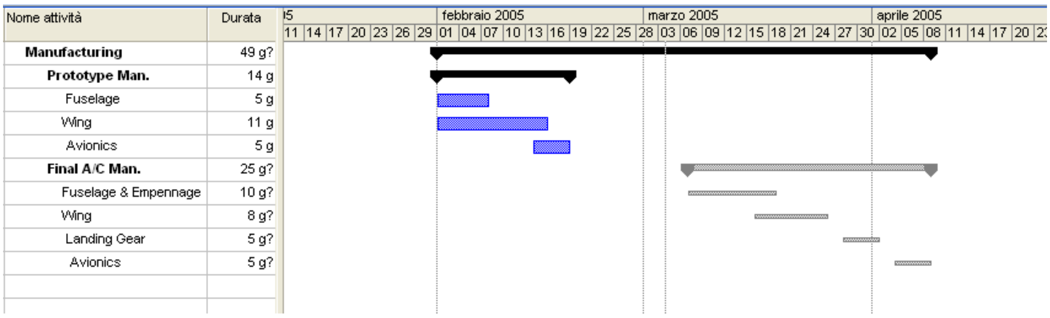
2.7.3.2 Skill

During the production process it is important, as in the design phase, to assign a task with reference to the personal competence of each member. A matrix can be used to compare and evaluate personal skills and then in the task instruction.

2.7.3.3 Timetable

To warrant a right development of the design a timetable was planned.

Table 21: Construction timetable.



Nome attività	Durata
Manufacturing	49 g?
Prototype Man.	14 g
Fuselage	5 g
Wing	11 g
Avionics	5 g
Final A/C Man.	25 g?
Fuselage & Empennage	10 g?
Wing	8 g?
Landing Gear	5 g?
Avionics	5 g?

2.8 Testing Plan

Flight tests will be an important check of the design. They will be able to validate the data analysis and theoretical calculations. For this reason a flight testing list and then a flight test checklist were set up. Two main areas were investigated: Ground Test and Flight Test. As far as Ground Test is concerned the right working of each component will be analyzed while Flight tests will be useful to verify system integration and performances.

2.8.1 Ground Test

Before the A/C Flight Test the Ground Test will be executed to verify the functionality of all A/C component, the following points will be considered.

Table 14: Ground test Check List.

Ground Test			
AVIONICS	1	Visual Inspection	All components integrity
	2	Radio / Receiver	On-Off / Answering Delays
	3	Servos	Left-Right Rotations / Executing Precision / Fail safe check / Aerodynamic Surface Throw Check
	4	Engine	Startup / Shut off
			Throttle test - calibration
			Throttle min-Max RPM check
			Max Current Absorption at Max RPM
	5	Battery	Battery Duration
STRUCTURES	1	Visual Inspection	All structures integrity
	2	G check	Maximum Load test
	3	C.G.	C.G. check / Regulation

2.8.2 Flight Test

After the A/C Ground Test the Flight Test will be execute to verify the Interoperability and A/C performance of all component, the following point will be considered:

Table 15: Flight Test Checklist.

Flight Test		
1	Taxing	Velocity & Ground Turning Check
		High velocity Test
2	Take-off	TOD / Time Required
3	Flight Envelope	Level Flight
		Basic Turn
		360° Turn
		Climbing check
		Approach
		Touch and go
		Landing

2.8.3 Checklist

Flight Test Checklist and Ground Test Checklist will be completed with the real performances shown by the A/C in order to define an opportune Pre-flight Checklist.

2.9 Lessons learned

So far, Chapter 2 is the report presented at the 2005 AIAA DBF Competition[1].
The winning team is the one who get the highest score in both report and flight. Our team made the 32th place. A key factor was the disassembly and packaging time, ours was higher than competitors. This strongly reduced the score of the flight phase. More training was required the overcome this issue.
Any aspect not deeply considered or taken with overconfidence can evolve in a problem. Such issues become apparent during maiden flight, hence at the end of the project. In this case:

- the tailwheel was not linked to a servo;
- the wing control surface (flaperon) has been oversized;
- the payload was not fixed correctly;
- the empennage surface were not sufficient.

The first three items have been solved immediately after the maiden flight. However, it was not possible to design and realize a bigger tailplane, because of tight schedule. Thus, the aircraft was not fully stable and controllable in all the flight envelope. This led to difficulty in piloting and larger flight times, giving a penalty on the final score.
Further flight tests, performed after the AIAA DBF Competition, confirmed the poor flying qualities and the need to replace the stabilizers. During the last test, a loss of control at slow speed during approach led the model to crash.

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[1] www.aiaadbf.org

3. CRITICAL DESIGN REVIEW

In this chapter, a critical review to the original design is made. As previously highlighted, the original model aircraft did not possess good dynamic stability and flying qualities. Step by step, the aircraft configuration and its components are here discussed and, eventually, redesigned. The new model is named UB-6 XC-3 “Rainbow Chick”.

3.1 Aircraft configuration

Although the general aircraft configuration is held, the wing position has been modified. In fact, further analyses on the ERACLE model revealed that the horizontal tailplane was in the wing wake. This condition, in addition to the short arm of the horizontal stabilizer, resulted in poor longitudinal stability and control characteristics. For this reason, the wing has moved to the mid position in fuselage.

The proportion among aircraft components is based on empirical tables used in aeromodelling (see Figure 37) and on a statistical basis reported in Ref. [5]. The reference unit is the wing chord. A first sketch of fuselage and tailplane has been made following these indications.

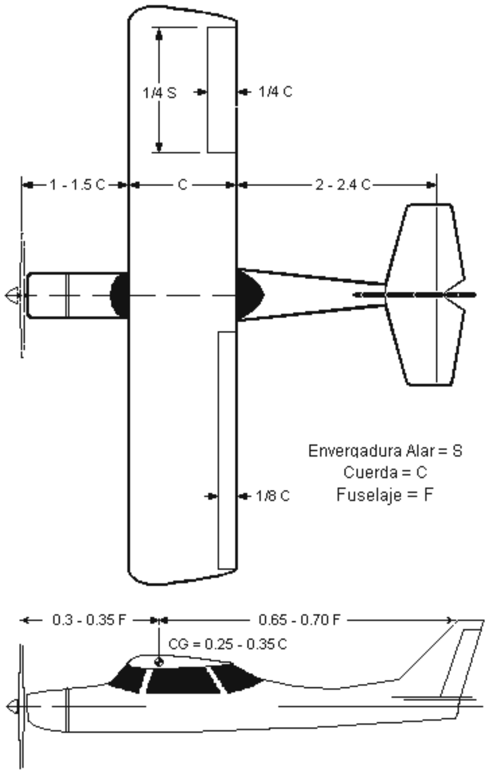
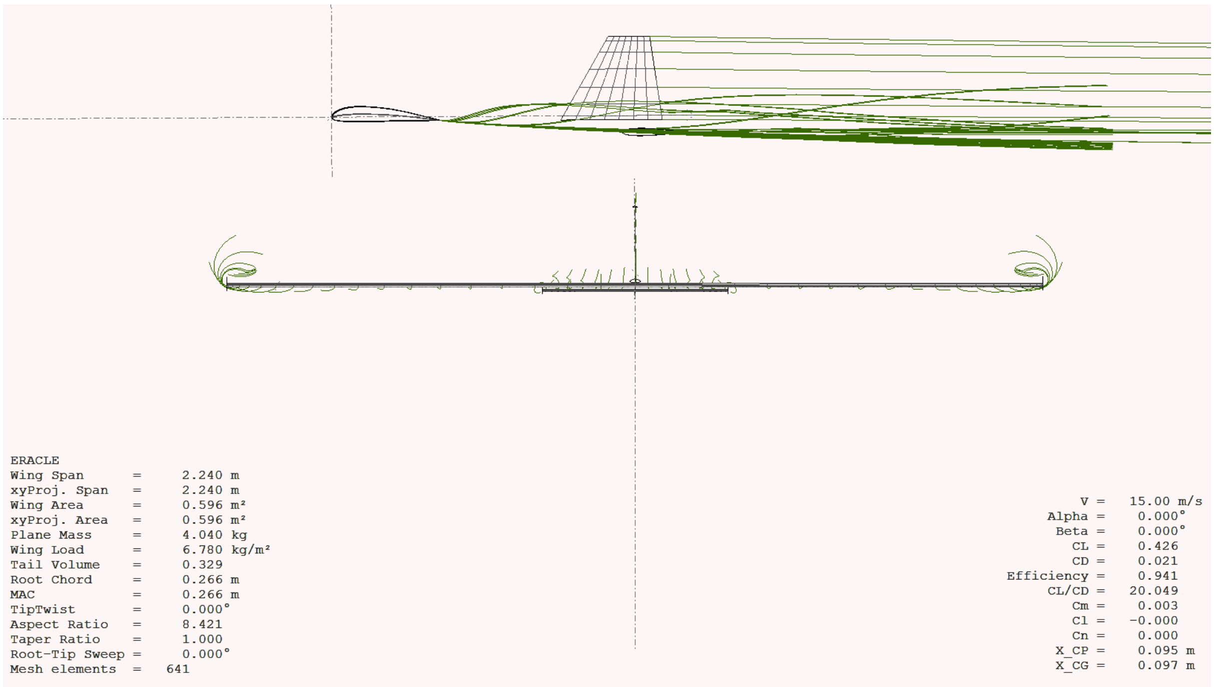


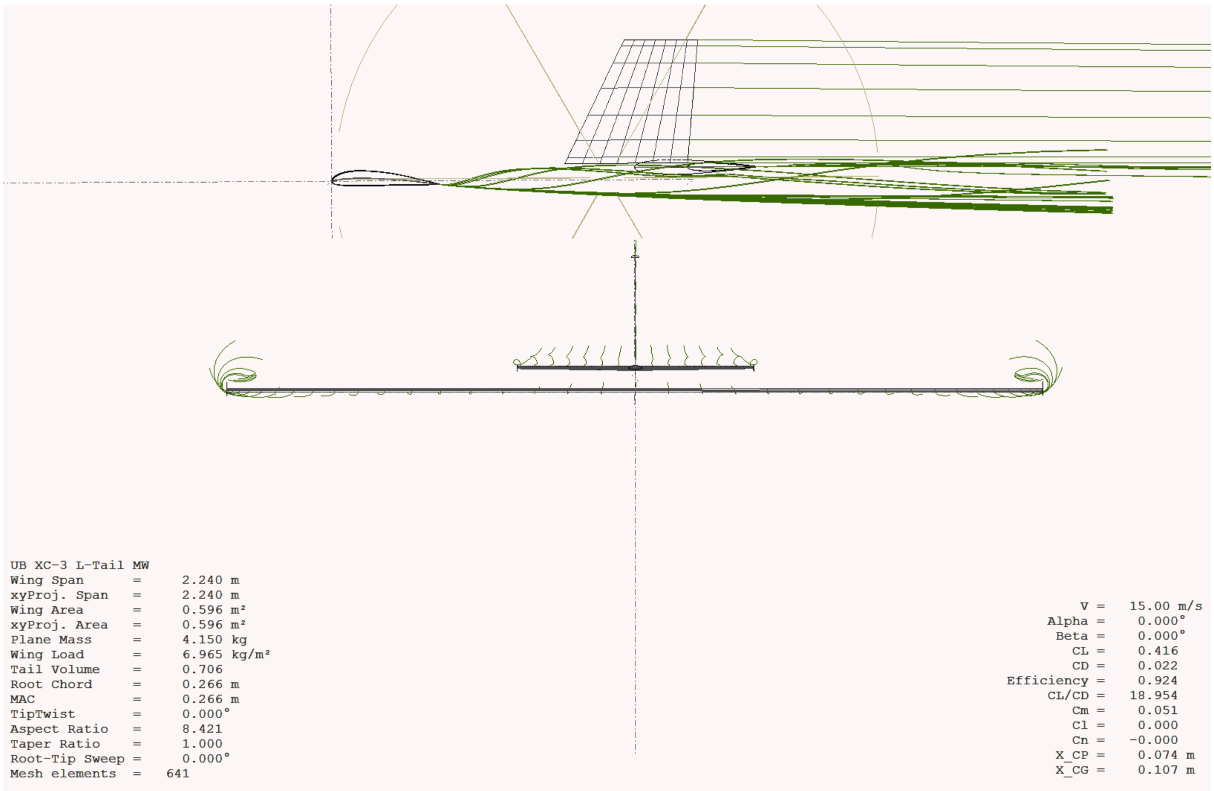
Figure 37: Empirical dimensions for RC model aircraft.



```
ERACLE
Wing Span       =     2.240 m
xyProj. Span    =     2.240 m
Wing Area       =     0.596 m²
xyProj. Area    =     0.596 m²
Plane Mass      =     4.040 kg
Wing Load       =     6.780 kg/m²
Tail Volume     =     0.329
Root Chord      =     0.266 m
MAC             =     0.266 m
TipTwist        =     0.000°
Aspect Ratio    =     8.421
Taper Ratio     =     1.000
Root-Tip Sweep  =     0.000°
Mesh elements   =   641
```

```
         V =    15.00 m/s
     Alpha =     0.000°
      Beta =     0.000°
        CL =     0.426
        CD =     0.021
Efficiency =     0.941
     CL/CD =    20.049
        Cm =     0.003
        Cl =    -0.000
        Cn =     0.000
      X_CP =     0.095 m
      X_CG =     0.097 m
```

ERACLE



```
UB XC-3 L-Tail MW
Wing Span       =     2.240 m
xyProj. Span    =     2.240 m
Wing Area       =     0.596 m²
xyProj. Area    =     0.596 m²
Plane Mass      =     4.150 kg
Wing Load       =     6.965 kg/m²
Tail Volume     =     0.706
Root Chord      =     0.266 m
MAC             =     0.266 m
TipTwist        =     0.000°
Aspect Ratio    =     8.421
Taper Ratio     =     1.000
Root-Tip Sweep  =     0.000°
Mesh elements   =   641
```

```
         V =    15.00 m/s
     Alpha =     0.000°
      Beta =     0.000°
        CL =     0.416
        CD =     0.022
Efficiency =     0.924
     CL/CD =    18.954
        Cm =     0.051
        Cl =     0.000
        Cn =    -0.000
      X_CP =     0.074 m
      X_CG =     0.107 m
```

UB-6 XC-3

Figure 38: Comparison of the wing downwash for the two model aircraft with XFLR5.

3.2 Wing

The wing has not been modified because has been compliant to the mission. The aerodynamic performance are satisfactory, hence the wing airfoil and planform have not changed, also to save time and money. See Table 22 for a review of the geometric parameters.

Table 22: Wing parameters.

Parameter	*Value*
Airfoil	GLS3b
Chord, *c*	0,266 m
Span, *b*	2,24 m
Area, *S*	0,6 m^2
Aspect ratio, *A*	8,4
Sweep angle, Λ	0 deg
Taper ratio, λ	1

3.3 Empennage

As previously stated, the poor stability and control capabilities of the ERACLE model were due to the insufficient tail area. The new tail sizing has been accomplished according to Raymer [3], by evaluating the tail volume coefficients of similar aircraft [1]. The tail volume coefficients are defined as follows (see also Figure 39):

$$R_h = \frac{S_h l_h}{Sc} \qquad R_v = \frac{S_v l_v}{Sb}$$

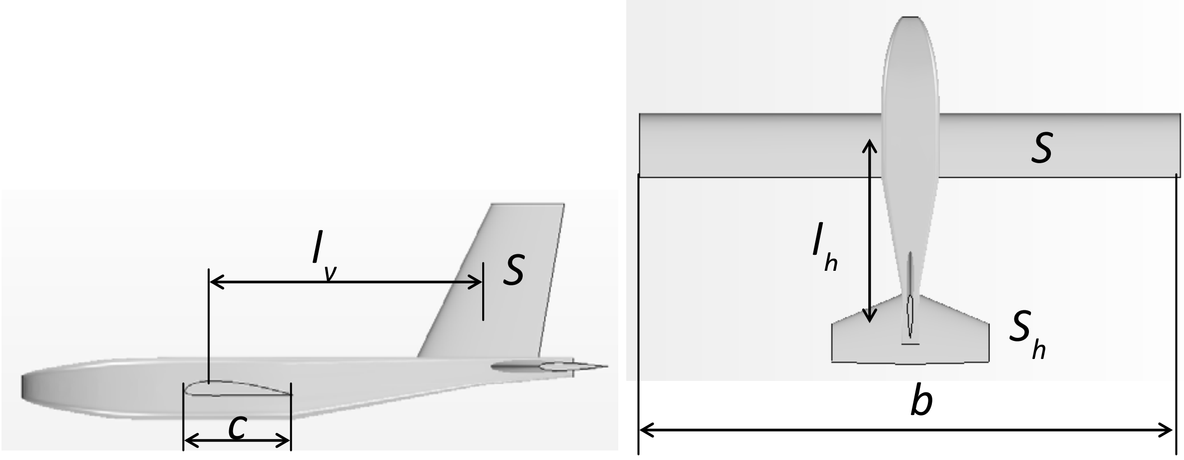


Figure 39: Parameters for the definition of the tail volume coefficients.

Table 23: Tail volume coefficients.

Model	R_H	R_V	S_h (m^2)	S_v (m^2)
ERACLE	0,321	0,015	0,077	0,036
BLACK STALLION	0,427	0,033	0,090	0,060
UB-6 XC-3	0,739	0,034	0,154	0,074

Data are reported in Table 23. The chosen values have been checked with results of other design procedures (from [4] to [8]).The horizontal tailplane sizing has been verified with the scissor plot reported in Figure 40, generated by defining the conditions of longitudinal stability in cruise (blue curve, where a static margin of 5% has been assigned) and control in landing (red curve, with flaps deployed) [10]. Dashed lines indicates the anticipated center of gravity range, whereas the solid black line represent the planform area value chosen by the horizontal tail volume coefficient. The intersection between the dashed lines with the red and blue lines represent the minimum required value of the horizontal to wing surface ratio. As the figure clearly show, the horizontal black line (tail sized by volume coefficient) is higher than those intersections, hence the chosen surface ratio satisfies the imposed longitudinal stability and control requirements. Table 24 reports the empennage geometric parameters.

The longitudinal stability for the chosen tailplane has also been verified by eulerian CFD simulations, whose results are reported in Figure 41. A static margin of 10% is held with the center of gravity in the most rearward position, at 1/3 of the wing chord. Results of longitudinal stability analysis are reported in Table 25. The control configuration has changed from stabilator (ERACLE) to stabilizer and elevator ($c_h/c = 0.3$).

There is no particular requirement for the vertical tailplane, except the spin recovery provided by the empennage configuration. Results of directional stability analysis are reported in Table 26. Usually, fuselage directional instability is half the vertical tail contribution [10]. In this case, the fuselage size is small compared to the vertical tail span, hence its contribution is much smaller. The effects of wing and horizontal tailplane are negligible. The vertical tail contribution to directional stability calculated by DATCOM method [9] is in good agreement with eulerian CFD calculations, whereas the semi-empirical method does not predict well the aerodynamic interference among aircraft components [11]. Results of Table 26 are provided by numerical simulations.

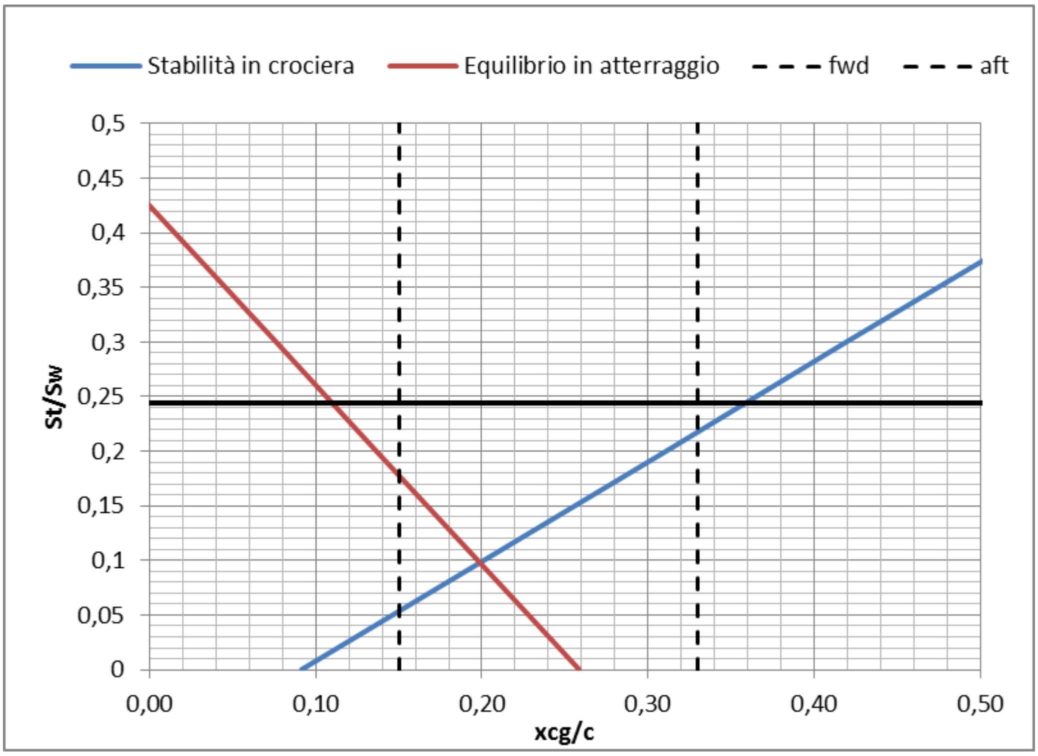


Figure 40: Scissor plot, horizontal tail sizing.

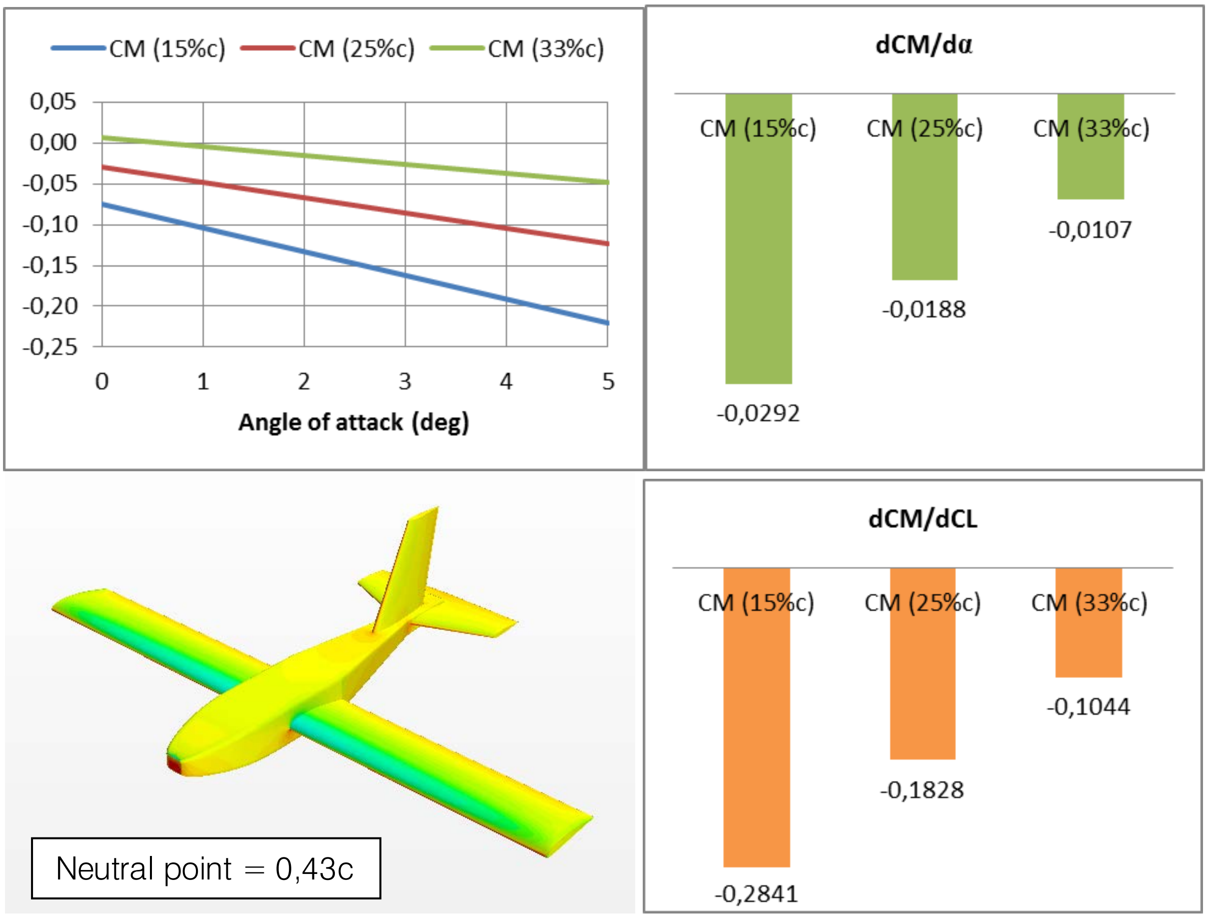


Figure 41: Longitudinal stability evaluated by eulerian CFD simulations.

Table 24: Empennage geometric parameters.

Horizontal tail		*Vertical tail*	
Parameter	Value	Parameter	Value
Airfoil	NACA 0012	Airfoil	NACA 0012
Root chord	0,3 m	Root chord	0,3 m
Tip chord	0,16 m	Tip chord	0,18 m
Elevator chord ratio, c_h/c	0,3	Rudder chord ratio, c_r/c	0,3
Span, b_h	0,65 m	Span, b_v	0,3 m
Area, S_h	0,154 m^2	Area, S_v	0,074 m^2
Aspect ratio, A_h	2,7	Aspect ratio, A_v	1,2
LE Sweep angle, Λ_h	23 deg	LE Sweep angle, Λ_v	26 deg
Taper ratio, λ_h	0,533	Taper ratio, λ_v	0,6

Table 25: Longitudinal stability. Eulerian CFD analysis.

Parameter (at $x_{cg}/c = 0.33$)	*Symbol*	*Value*	*Unit*
Wing aerodynamic center	x_{ac}/c (wing)	0,18	-
Aerodynamic center shift due to fus.	$\Delta x_{ac}/c$ (fus)	0,04	-
Airplane lift curve slope	$C_{L\alpha}$ (total)	0,089	/deg
Airplane pitching curve slope	$C_{M\alpha}$ (total)	$-0{,}0107$	/deg
Airplane longitudinal stability	dC_M/dC_L	$-0{,}1044$	-
Neutral point	N	0,43c	-

Table 26: Directional stability. Eulerian CFD analysis.

Parameter (at $x_{cg}/c = 0.33$)	*Symbol*	*Value*	*Unit*
Fuselage contribution	$C_{N\beta f}$	0,0003	/deg
Vertical tail contribution	$C_{N\beta v}$	−0,0026	/deg
Airplane directional stability	$C_{N\beta}$	−0,0024	/deg

3.4 Fuselage

The need of a new fuselage led to a design which shape is similar to the ERACLE's one. Materials have been changed (see Chapter 4). The wet surface has increased because the fuselage has been lengthened to allow a bigger tail volume coefficient for stability and control. The front section has been kept rectangular to maximize the payload capability and for ease of load/unload, access, and maintenance. A particular attention has been given to the internal layout and structural design, to allow an easy avionics and control system installation (wires, plugs, linkage, and servos).

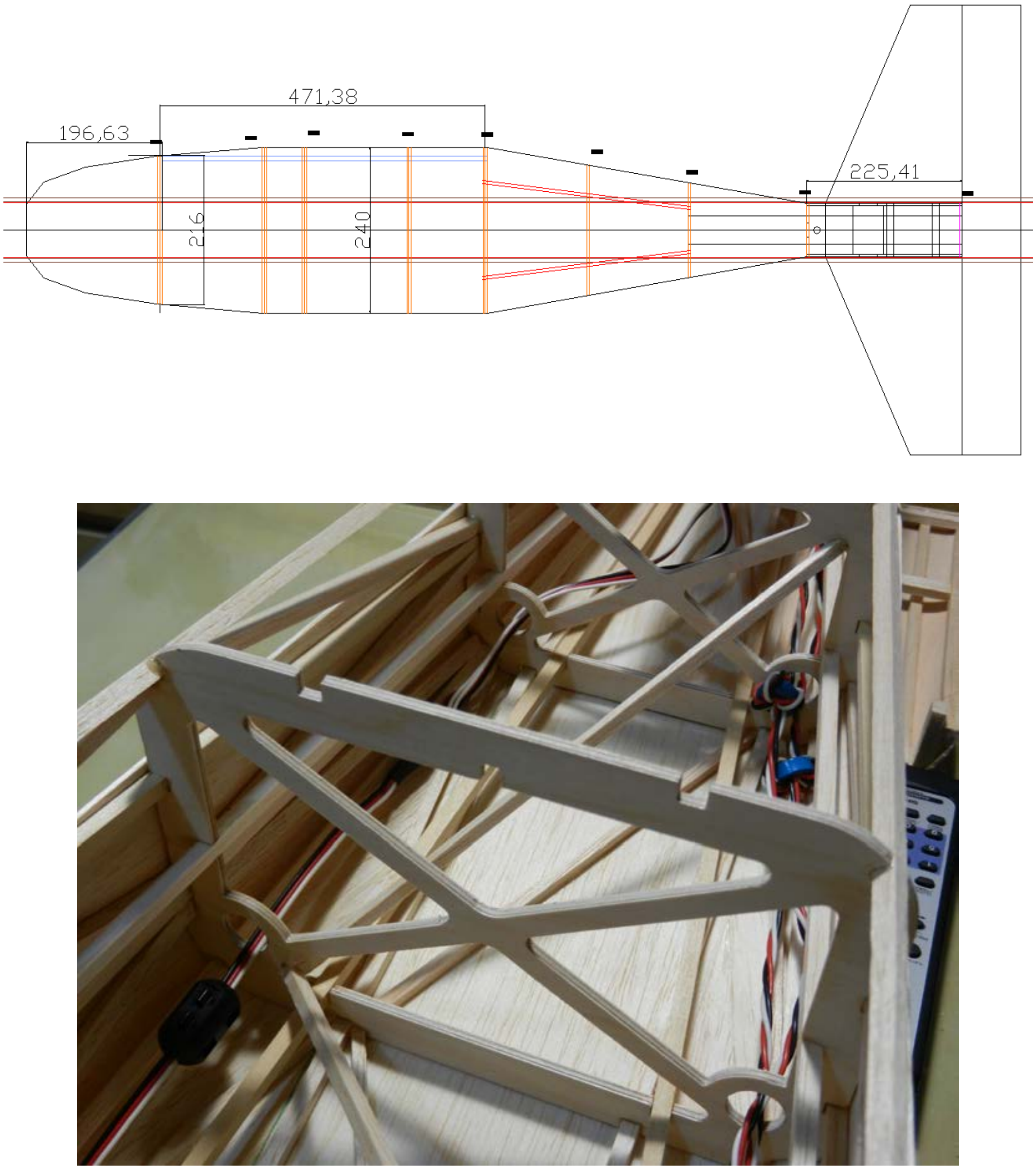


Figure 42: The fuselage internal layout.

3.5 Propulsion

In order to contain a complexity, time, and to save money, the chosen power plant was the same of the ERACLE design. This choice was also made to compare flight test results with the ERACLE model. The propeller is an APC-E 18/10. Batteries have changed from NiMh to LiPo. This led to a weight saving (800 gr vs 1575 gr) and an increase of instantaneous current up to 40x5000 mAh = 200 A.

3.6 Avionics

3.6.1 Flight control system

The flight control system layout is that typical of a RC model aircraft. This means, that a receiver (RX) processes the incoming signals from the transmitter (TX) controlled by the pilot. The radio signals are converted into electric impulses sent to the servos and the Electric Speed Controller (ESC), which in turn controls the engine.

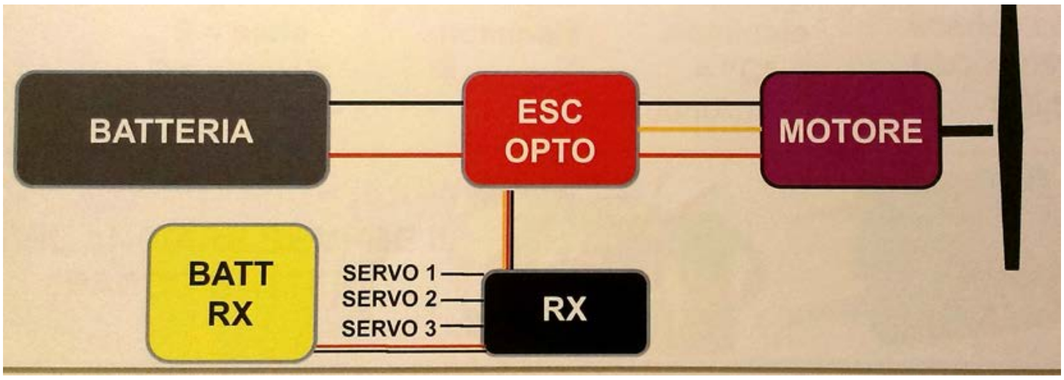


Figure 43: Flight control system scheme.

The servos have been replaced to have a bigger servo torque and speed on the flaperons and because of bigger tail area on the empennage.
Servos and control horns have been mounted inside wing and empennage to have short linkages and reduce aerodynamic drag.

3.6.2 Data acquisition

3.6.2.1 Electric motor logger

An electronic micro logger (EAGLE TREE) has been installed to record the power system data: voltage, current, instantaneous and total power, battery consumption, and temperature.

3.6.2.2. PixHawk flight control system

The PixHawk flight control system has been selected to record flight data as airspeed, altitude, GPS position, accelerations. It can also be used as autopilot system.

3.7 Structures

The aim of this design phase is the definition of a systematic method to correctly size the aeromodelling structures with engineering methods. The following considerations are applied to the items built with woods. Later on, every single component has been designed in detail. This design phase required about 75 hours as reported in Table 31.

3.7.1 Method description

The main source followed in this design phase has been Ref. [12]. The joints and the coupling among plates have been realized following Ref. [13]. The remainder of the structures have been designed by the 20-years old author's experience in dynamic aeromodelling.

3.7.2 Materials

Characteristics of some wood materials for primary structures are reported in Table 27 compared by a quality parameter.

Table 27: Wood materials for primary structures.

ID	*Description*	*Minimum ultimate load at normal stress (kg/cm²) [thickness up to 3mm]*		$Q_C = \frac{\sigma_T}{\nu}$
		Parallel to ext. fibers	Orthogonal to ext. fibers	
1	birch plywood	560	360	$11{,}76 \cdot 10^5 cm$
2	poplar plywood	400	280	$10{,}37 \cdot 10^5 cm$

It seems that the best compromise between strength and weight is provided by poplar, however the final choice has been made considering the specific structural functions, dimensions, and loads. Thus, the birch plywood 3 mm thick has been selected, because of the higher figure of merit and to get a bigger safety factor.

For the secondary structures, e.g. the covering of the primary structures, the balsa wood has been chosen for his low density and ease of manufacturing on complex geometries. Several types of balsa have been characterized in Table 28. Table 29 reports the applications according to specific weight.

Table 28: Balsa characteristics.

ID	*Type*	*Balsa elasticity*	
		Young modulus kg/cm^2	Specific weight kg/cm^3
1	Very light	8.000	$9 \cdot 10^{-5}$
2	Light	20.000	$9 \cdot 10^{-5} - 13 \cdot 10^{-5}$
3	Medium light	25.000	$13 \cdot 10^{-5} - 15 \cdot 10^{-5}$
4	Medium	28.000	$15 \cdot 10^{-5} - 16 \cdot 10^{-5}$
5	Medium hard	30.000	$16 \cdot 10^{-5} - 19 \cdot 10^{-5}$
6	Hard	35.000	$19 \cdot 10^{-5} - 25 \cdot 10^{-5}$
7	Extra hard	45.000	$> 825 \cdot 10^{-5}$

Table 29: Balsa applications according to specific weight.

ID	*Application*	*Specific weight (kg/cm^3)*
1	Terminals	$60\cdot10^{-6}-100\cdot10^{-6}$
2	Cowlings	$60\cdot10^{-6}-110\cdot10^{-6}$
3	Ribs	$110\cdot10^{-6}-160\cdot10^{-6}$
4	Spars	$180\cdot10^{-6}-280\cdot10^{-6}$
5	Trusses	$140\cdot10^{-6}-240\cdot10^{-6}$
6	Sides	$120\cdot10^{-6}-220\cdot10^{-6}$
7	Leading edges	$100\cdot10^{-6}-190\cdot10^{-6}$
8	Rods	$240\cdot10^{-6}-280\cdot10^{-6}$
9	Trailing edges	$90\cdot10^{-6}-210\cdot10^{-6}$
10	Rib slabs	$60\cdot10^{-6}-100\cdot10^{-6}$
11	Spar slabs	$180\cdot10^{-6}-280\cdot10^{-6}$
12	Anti-torque panels	$140\cdot10^{-6}-220\cdot10^{-6}$
13	Spar panels	$160\cdot10^{-6}-280\cdot10^{-6}$

3.7.3 Aerodynamics and performance

A preliminary performance evaluation by semi-empirical method and panel methods has been performed. Assuming a Reynolds number of 200.000, a parasite drag coefficient of $C_{D0}=0{,}0325$ has been calculated with the USAF DATCOM method [9]. By a panel method code, the induced drag polar of the entire aircraft has been computed, see FIGURE. The Oswald factor is $e=0{,}7$.

A very simple estimation of aircraft performance has been made. By assuming a static propeller thrust of 13 Kgf (= 127 N), a maximum speed of 30 m/s is available, see FIGURE. Clearly, the propeller has a fixed pitch, hence the thrust is not constant with airspeed and the maximum speed will be lower. The minimum thrust required for level flight (maximum aerodynamic efficiency) occurs at 19 m/s.

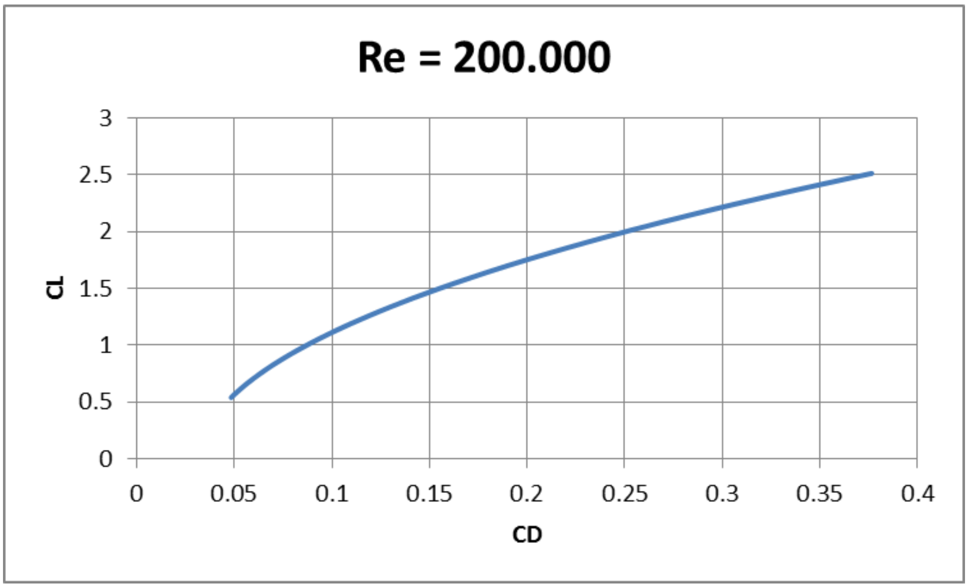


Figure 44: Drag polar calculate by panel method.

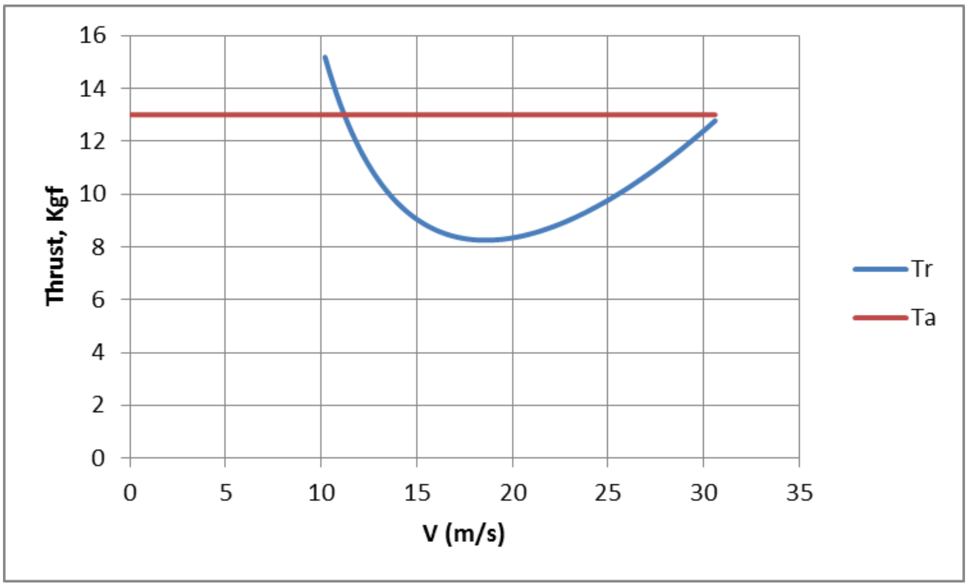


Figure 45: Thrust versus airspeed curves.

3.7.4 Aerodynamic loads

To correctly size each structural component, it is mandatory to determine the aerodynamic loads. Aerodynamic loads have been determined by Schrenk method [2]. The wing has been modeled as a clamped-free beam, with a distributed load due to aerodynamics plus weight. Aerodynamic loads have been determined by Schrenk method at stall conditions ($C_L = 1.3$). Structural characteristics (shear and bending) have been reported in the following figures.

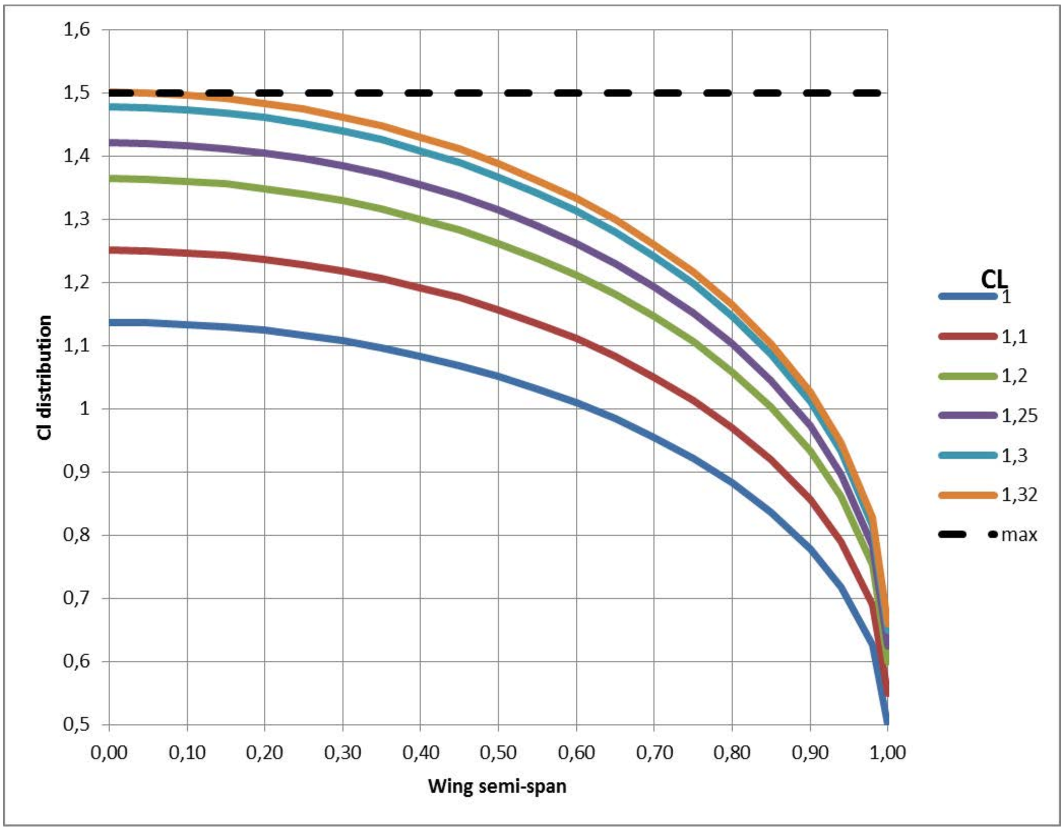


Figure 46: Lift coefficients distribution.

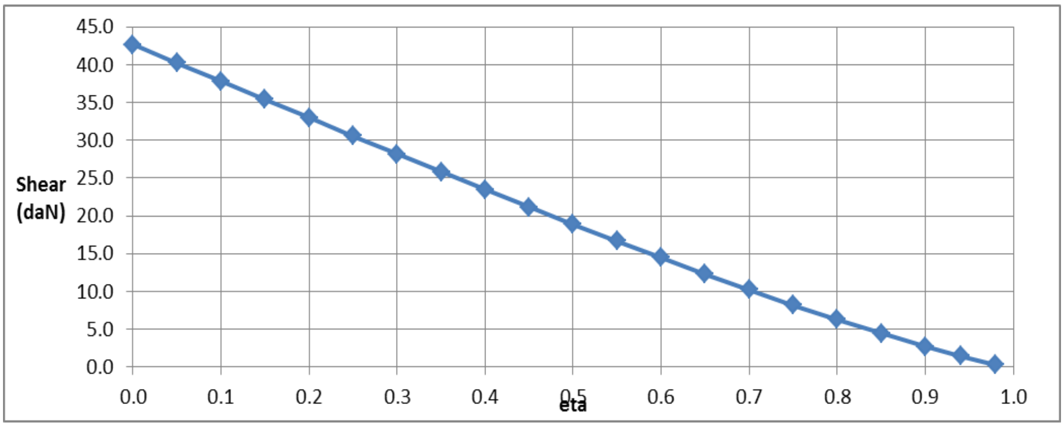


Figure 47: Wing shear loads distribution.

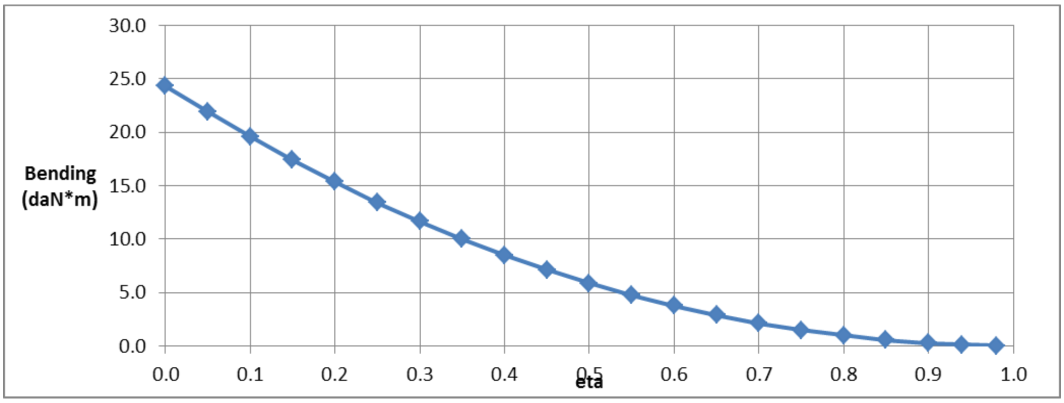
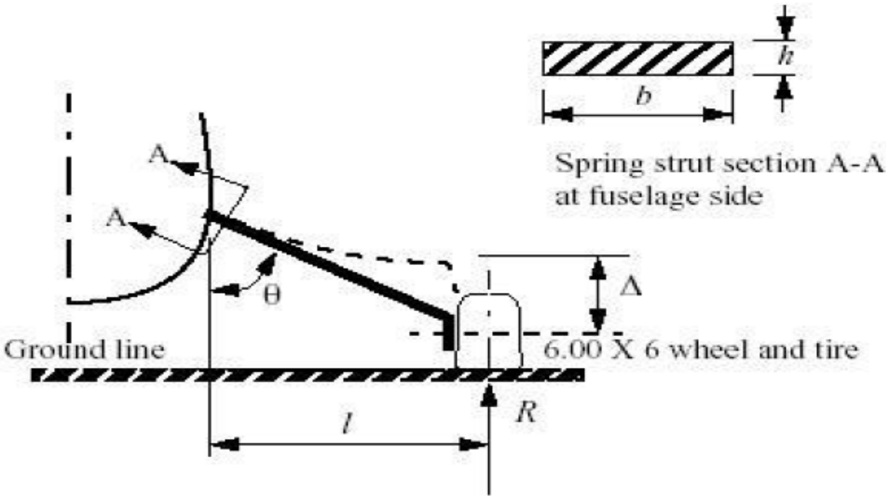


Figure 48: Wing bending moment distribution.

3.7.5 Landing gear

The landing gear is a tailwheel configuration. Its general arrangement and position with respect to CG has been performed following Ref. [4]. A structural assessment of the main landing gear has been made on a spreadsheet, to verify that the chosen material, its mechanical characteristics, and its dimensions were complaint to support the aircraft during the taxi phase and to absorb the impact loads due to landing.

The material is Aluminum 6082 Anticorodal, chosen for its commercial availability, cheap price, good mechanical characteristics, and strength to corrosion.



Schema di calcolo del carrello a balestra

Figure 49: Landing gear scheme.

Table 30: Landing gear data.

AL 6082 Anticorodal	
Density (kg/m^3)	2,70E3
Young modulus (N/m^2)	69,0E6
Load factor	3
Max landing weight (Kg)	10
Width b (mm)	50
Height h (mm)	5
Displacement x (mm)	12
Displacement y (mm)	17
Angle θ (deg)	45
Weight (gr)	333

3.8 Timetable

Working hours have been recorded. The critical design review lasted about 100 hours. The following table reports details.

Table 31: Critical design review timetable.

Task	*Time (h:min)*
Wing airfoil	12:26
XFLR5 configuration analysis	3:35
Aerodynamic analyses	8:00
Tail structural design	21:38
Fuselage structural design	51:48
Landing gear design	3:10
Total	100:40

3.9 Modular design solutions

The new design has been realized in a way that gives the possibility to replace some of its components at a later stage. This is called *modular design*.

3.9.1 Wing

With the actual fuselage layout, it is possible to replace the wing and change airfoil and planform. The wing joiner tube passes through the fuselage to form a carry-through structure, while the two half wings can be separated both for packaging and replacing.

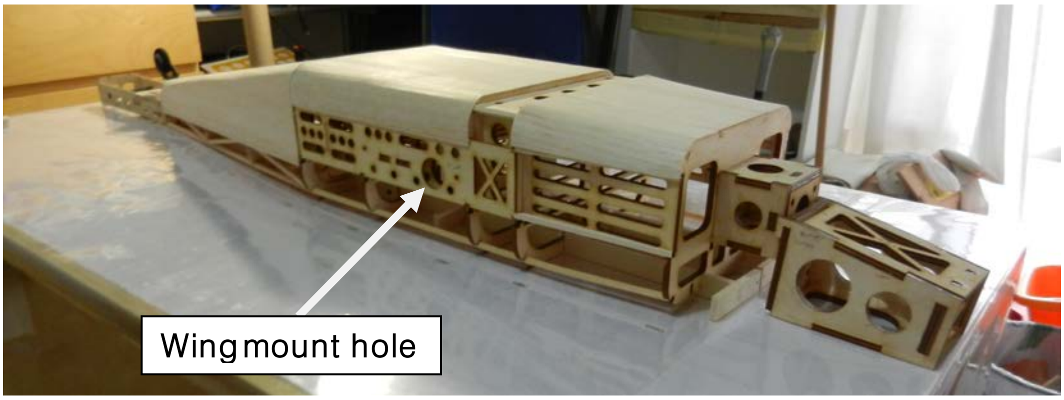
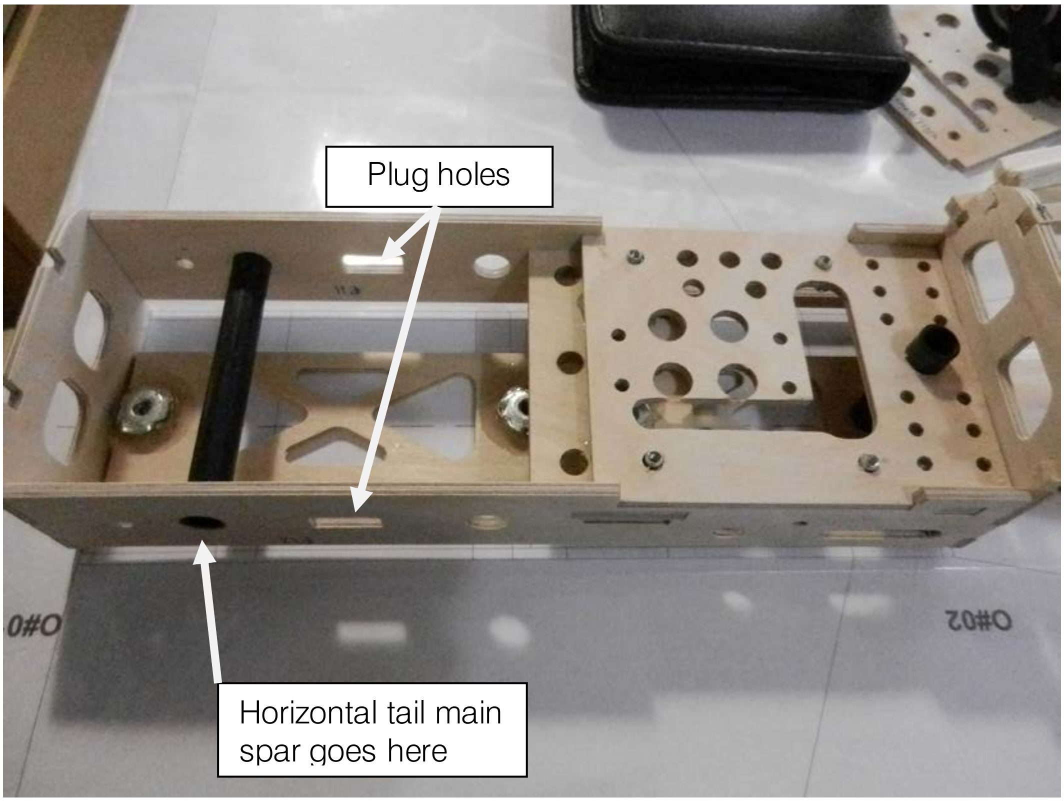


Figure 50: Wing-fuselage joint.

3.9.2 Empennage

Following the same philosophy of the wing-fuselage joint, the empennage can change airfoil, planform or even configuration, i.e. from the classic body-mounted horizontal tailplane to the T-tail and the V-tail.



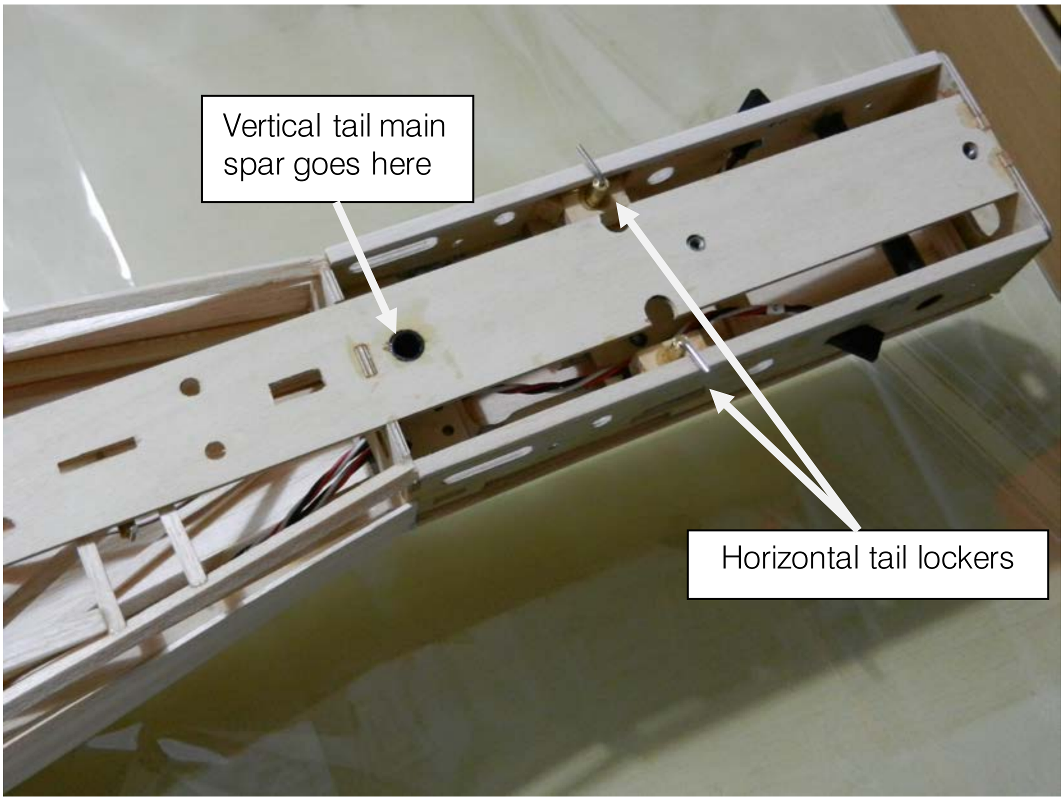


Figure 51: Tailplane joints.

3.9.3 Propulsion

The propulsion group can be easily changed, since the engine mount is divided in two parts: one fixed to the fuselage, the other fixed to the engine. The latter can be replaced with another one mounting a different engine. Obviously the propeller can be easily changed too. This leads to an easy customization according to the payload/mission.

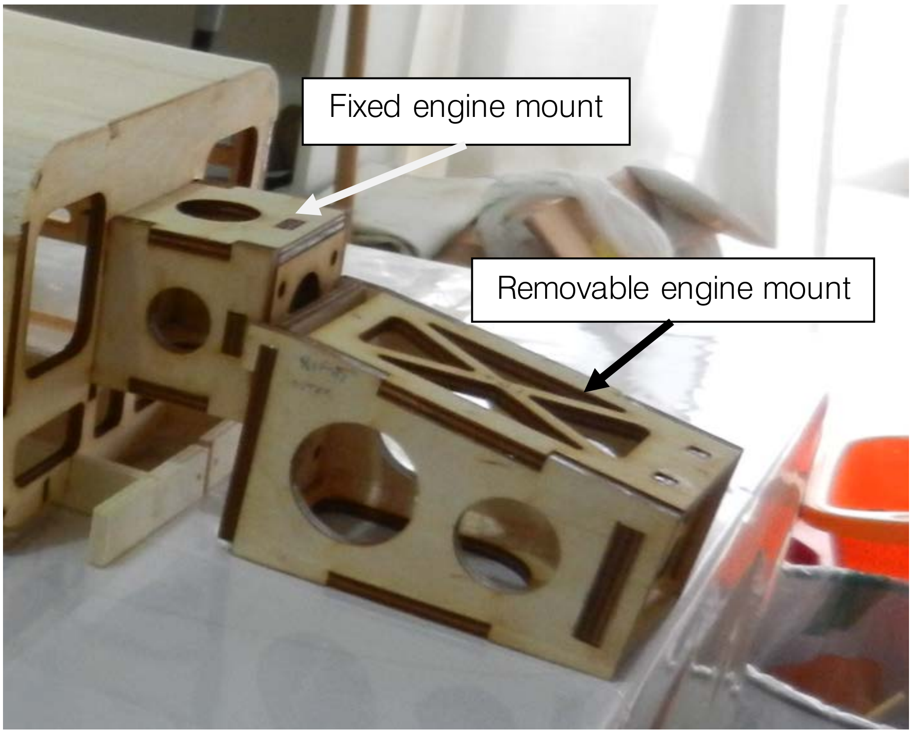


Figure 52: Engine mounts.

3.9.4 Endurance

The big available space left in the fuselage allows to easily install two battery pack, reaching a capacity of 10000 mAh and doubling the flight time. Each battery pack weighs 800 gr. Endurance is estimated in about 20 min with two battery pack at 50 A.

Figure 53: Fuselage bay.

3.9.5 Distinctive features

For the reasons stated throughout Section 3.8, the new design, named UB-6 XC-3 “Rainbow Chick”, has these interesting features:

- fast replacing of the main parts (wing, tail, engine)
- wide payload bay
- ease of assembly
- possibility to mount an autopilot and a data acquisition system.

4. MANUFACTURING

4.1 Technology and material processes

Material selection is strongly linked to the function and loads that the part must hold. For this reason, for each structural component, it has been selected the material that unite lightness, toughness, and ease of manufacturing.
A key aspect of this work is that the assembly is based by 95% with glue, only the landing gear and the engine mount present bolted joints. The choices made for each aircraft components are described in the following sections.

4.2 Wing

Since the wing must support the aircraft weight and flight loads, it was decided to realize it in fiberglass sandwich and balsa wood. To get the best surface skin, a composite manufacturing technology by male-female mold has been used. These have been realized in medium density fiberboard (MDF) wood by a computer numerical control (CNC) milling machine. This solution permits both the lowest surface roughness and a high structural strength. The innovative concept is the absence of wing ribs (*ribless structure*), except for the wing caps at root and tip. Thus, the skin and the main (and only) wing spar, located at 30% chord and used as hollow for the wing joiner, must bear torque, shear, and bending moment respectively.
The control surfaces (flaperons) have been realized in the same way, except for the absence of a spar.

Figure 54: Wing structure.

4.3 Empennage

It was not economically convenient to realize molds to build the tailplanes as done for the wing (which is the same of the ERACLE model). Thus, a conventional manufacturing technique, with spar, ribs, and covering panels with balsa sheet, has been chosen. The whole empennage has been covered with 50 gr/mm^2 fiberglass layer.

To have a quick building phase, a building jig which exploits the two horizontal tailplane spars has been used as support to assembly. At the end of the covering with balsa panels, it was sufficient to cut the remainders of the spars to detach the tailplane from the building jig. The assembly procedure is here reported:

1. put the drawings scale 1:1 on the working table and protect it with an acetate sheet;
2. lock the building jig on the drawings;
3. position of the spars;
4. insert the ribs in line with the drawings;
5. verify orthogonality and space among ribs;
6. verify absence of twist along the span axis;
7. bond the servo panel;
8. bond the remaining ribs on the spar;
9. bond the leading edges and the rear spar for the hinge of the control surfaces;
10. develop the covering panels surface and cut it;

11. bond the covering panels;
12. open the servo inspection panels;
13. sand the leading edge with a shaped abrasive pad;
14. carve the hinge slots on the hinge spars;
15. verify the coupling with the control surface;
16. set fiberglass lamination;
17. smooth the skin;
18. plaster the skin;
19. smooth again;
20. polish the skin;
21. paint.

A similar procedure has been followed for the control surfaces, without a building jig because of the simplicity of the part, but directly on the drawings, by taking care to constantly verify the ribs positions, their orthogonality and the sweep angle with respect to the spar and covering panels.

A torsion rod in birch plywood has been sunk along the hinge spar to equally share the mechanical stress due to servo actuation. This solution avoids the relative rotation of those sections close to the control surface in case of strong aerodynamic loads and reaction moments by the servo.

All of the bonding joints have been made by medium density cyanoacrylate glues specific of the dynamic modeling. To reduce the cure time, a specific catalyzer spray has been used. This solution has allowed to shorten the assembly time to 5 hours for each component, hence 15 hours for the whole empennage.

The composite lamination is discussed, for all the aircraft components, in Section 4.6.

Figure 55 to Figure 60 show some of the assembly sequence.

Figure 55: Parts detached from plywood.

Figure 56: Assembly and bonding of the ribs.

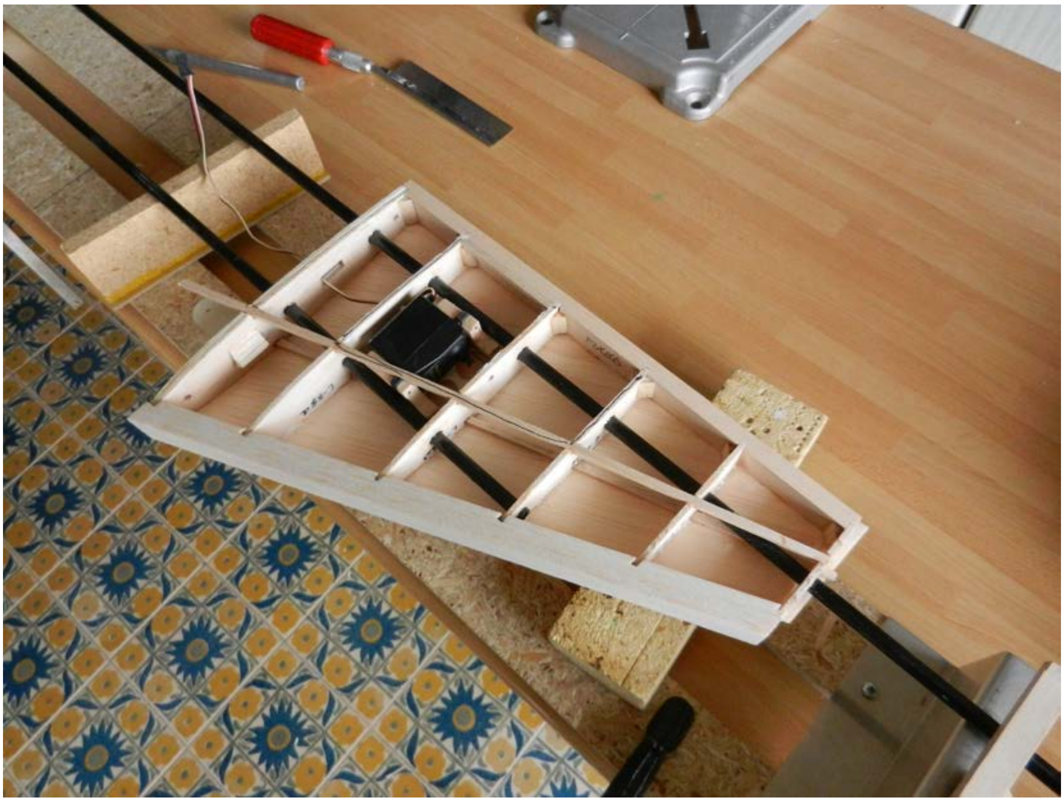


Figure 57: Verify servo position and covering panels.

Figure 58: Comparison of tailplane tips (rough and sanded).

Figure 59: Tail laminate sheet.

Figure 60: Tailplane covered with fiberglass.

Table 32: Horizontal tail weight breakdown.

Item	*Quantity*	*Weight (gr)*	*QxW (gr)*	*Rib*	*Weight (gr)*
Leading edge	1	10	10	1	9
Hinge (internal)	1	12	12	2	2
Hinge (esternal)	1	6	6	3	1
Anti-torque bar	1	7	7	4	1
Servo panel	1	10	10	5	1
Stringer 4x4	2	2	4	6	0,8
Main spar	1	10	10		
Rear spar	1	6	6		
Joiner	1	8	8		
Futaba S3010	1	41	41		
Total dry		129	sum of the previous weights		
Total assembled		152	includes glue		
Total covered		173	includes fiberglass covering		

Table 33: Vertical tail weight breakdown.

Item	*Quantity*	*Weight (gr)*	*QxW (gr)*	*Rib*	*Weight (gr)*
Leading edge	1	13	13	1	11
Hinge (internal)	1	8	8	2	3
Hinge (esternal)	1	8	8	3	2
Anti-torque bar	1	9	9	4	2
Servo panel	1	10	10	5	2
Stringer 4x4	2	2	4	6	1
Main spar	1	12	12		
Futaba S3010	1	41	41		
Total dry		126	sum of the previous weights		
Total assembled		137	includes glue		
Total covered		156	includes fiberglass covering		

4.4 Fuselage

Since the wide size of the fuselage, the composite manufacturing technique would have brought the use of big and expensive molds. Thus, it was chosen to proceed with a traditional layout with frames, plates, and stringers. Here it is remarked the key aspect around which the fuselage has been realized:

- general avionics arrangement;
- Landing gear configuration and landing loads;
- Loads distribution;
- motor support;
- battery disposition;
- tailplane weight and loads transferred to fuselage;
- ease of access to avionics;
- ease of inspection;
- ease of maintenance;
- ease and of construction.

To shorten the manufacturing and assembly time, the structural parts have been made by CNC machines. About 30% of the components have been manufactured by a homemade 3-axes CNC milling machine. The parts produced with this method had two issues: a dimensional tolerance bigger than 0,2 mm (typical value for the coupling) and a relatively long manufacturing time (1 plywood, area 0,3 m^2, 3 mm thick, with 10 items requires 3 hours, except issues). The remaining 70% has been manufactured with a professional laser CNC machine. This technique is 40% more expensive, but precision and manufacturing time are such that the costs are compensated and dimensional tolerance are compliant, dramatically reducing the assembly time.

Figure 61 to Figure 66 show the fuselage assembly sequence. Joints and coupling among plates have been made following the indications and examples of Ref. [13].

To guarantee alignment and space among frames, the assembly line is a realized with two rails made of 3 mm poplar plywood, cheap and easy to manufacture. This is called *jigless method*. The assembly sequence is here reported:

1. put the drawings scale 1:1 on the working table and protect them with an acetate sheet;
2. lock the rails on the drawings;
3. position of the frames;
4. insert the plates in line with the rail joints;
5. verify orthogonality and space among frames;
6. verify absence of twist along the longitudinal axis;
7. bond the parts;
8. insert and bond the stringers;
9. assembly the tail truss;
10. position the servo wires for the tailplanes;
11. bond the covering panels;
12. cut the fuselage bay door;
13. plaster the panels joints;
14. sand with abrasive pad;
15. set fiberglass lamination;
16. smooth the skin;
17. plaster the skin;
18. smooth again;
19. plaster again;
20. polish the skin;
21. paint.

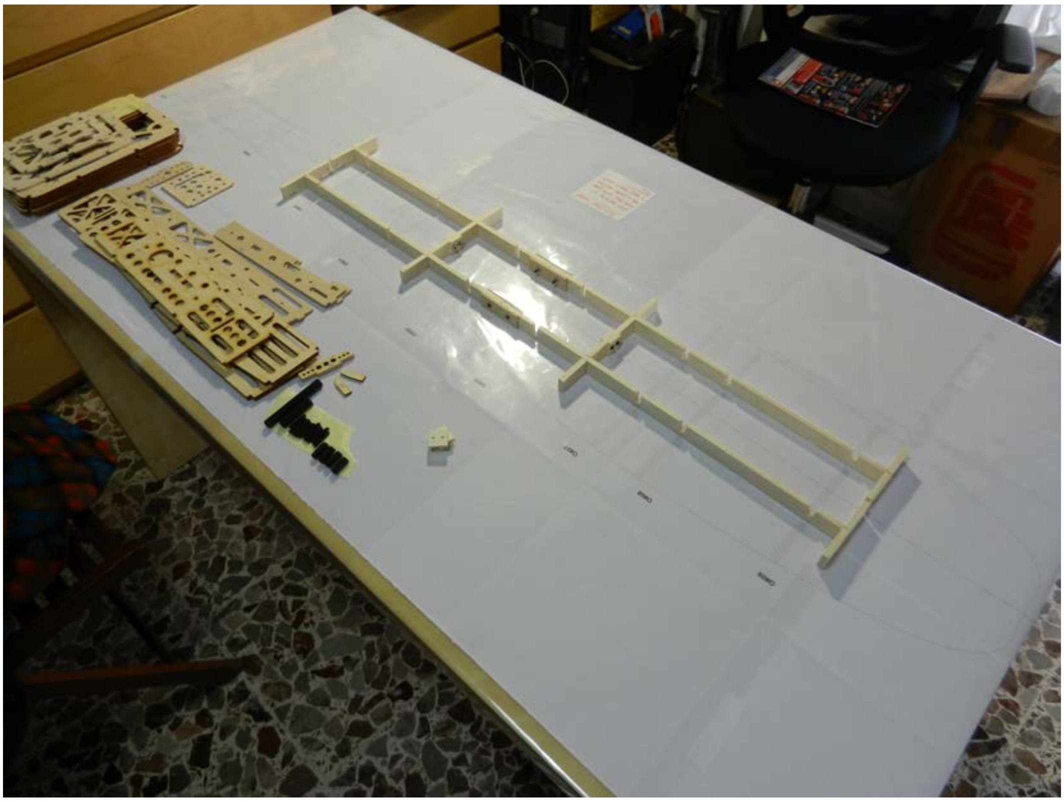


Figure 61: Fuselage assembly rail.

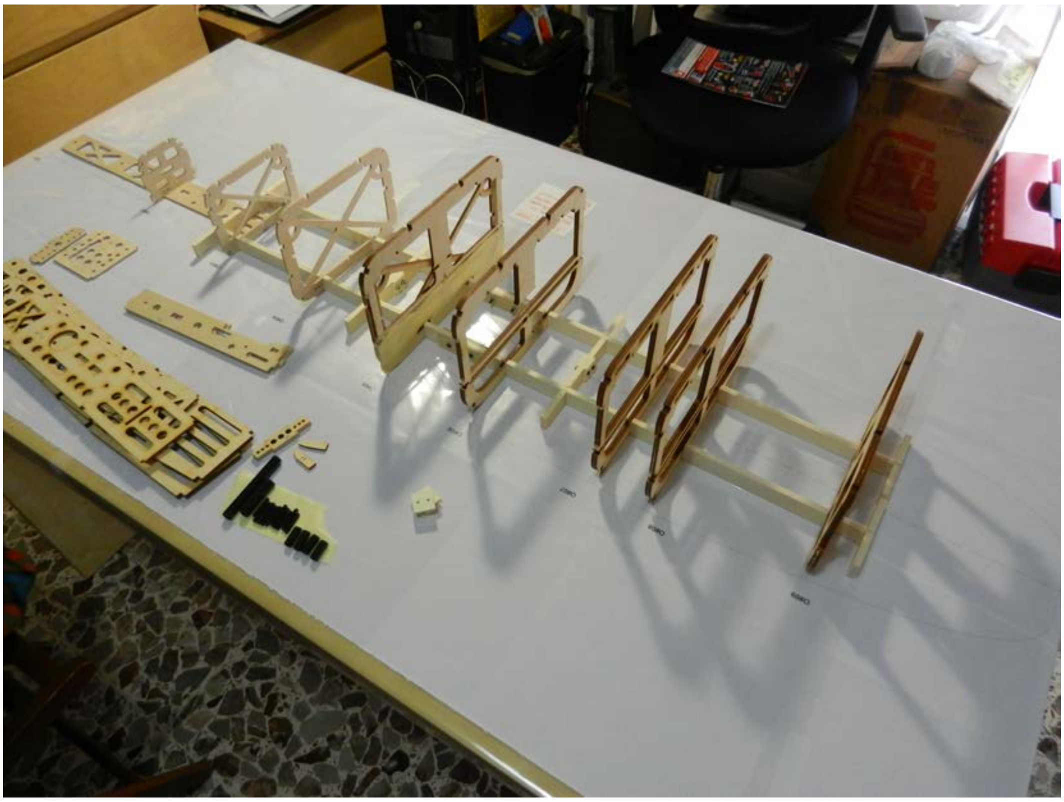


Figure 62: Frames assembled on the rails.

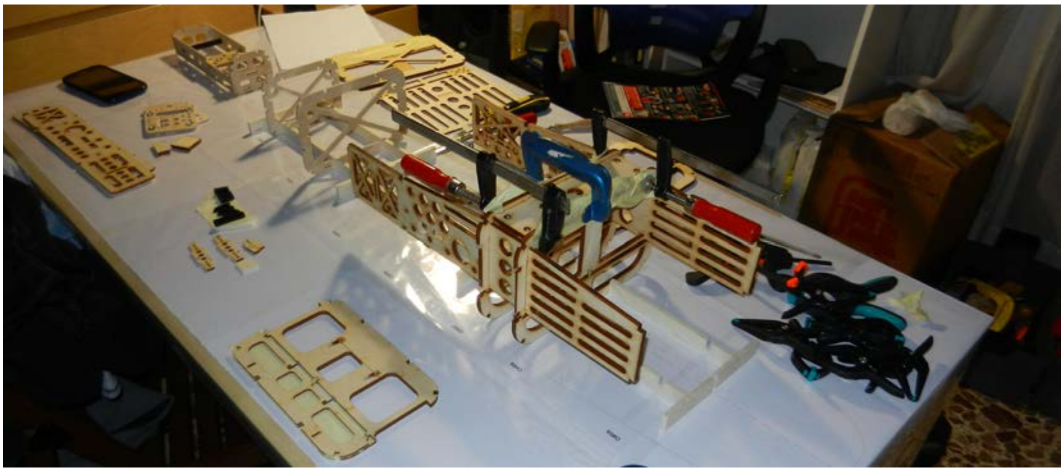


Figure 63: Bonding and clamping panels with rails.

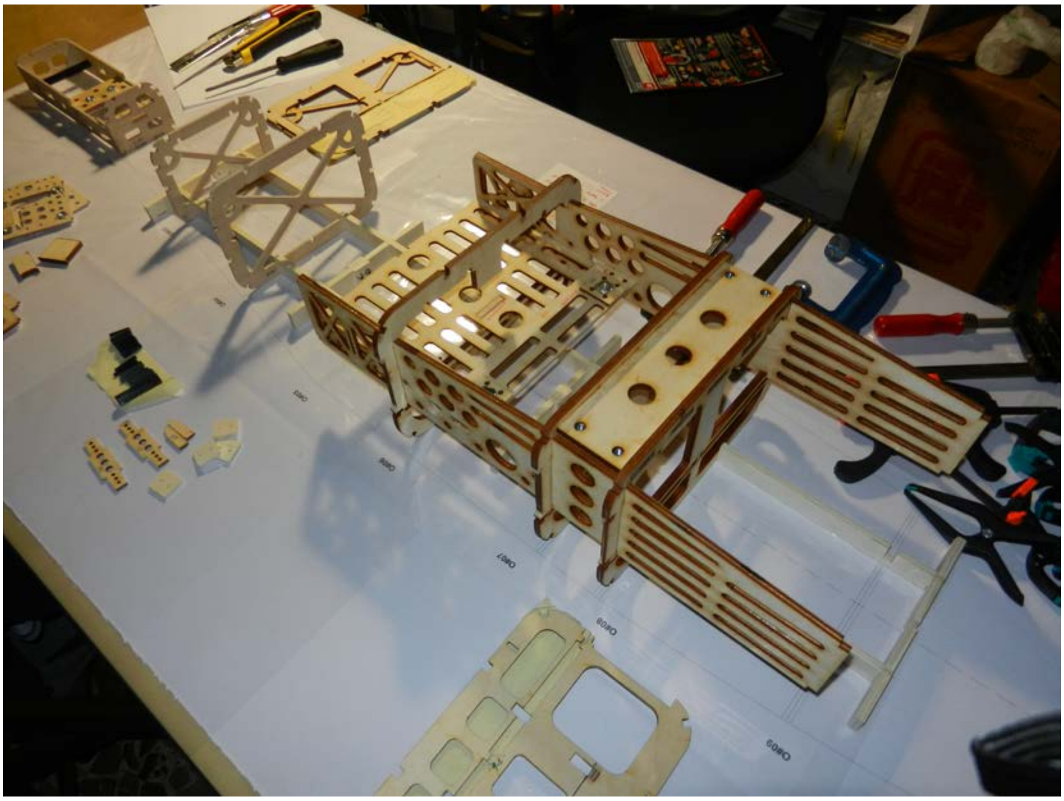


Figure 64: Assembly of the payload bay.

Figure 65: Precise alignment of the CNC machined parts.

Figure 66: Fuselage assembly almost complete.

Table 34: Fuselage weight breakdown.

Frame	*Weight (gr)*	*Plates*	*Weight (gr)*	*Engine mount*	*Weight (gr)*
1	7	INT1	107	B1	13
2	9	INT2	106	B2	13
3	16	EXT1	30	B3	14
4	25	EXT2	31	B4	14
5	71	LG	45	B5	11
6	61	AVIONICS	52	B6	9
7	59	TAILWHEEL1	13	FW1	19
8	60	TAILWHEEL2	11	FW2	27
9	71	P9	4	FW3	27
		P10	12	FW4	22
		P11	15	FW5	23
		P12	15	FW6	11
		P13	28		
		FWD BATT	55		
Total dry		1106	sum of the previous weights		
Total assembled		1300	includes glue and stringers		
Total covered		1615	includes fiberglass covering		

4.5 Engine cowling

To allocate the engine mount and to keep the ESC cold, a cowling has been designed and manufactured with these key aspects: frontal air inlet and lateral outlet.

The cowling has been made in fiberglass on a handmade male mold in Styrofoam, shaped with abrasive paper, on which two inserts to realize the air outlet have been mounted. On this mold, three layers of release agent followed by two 80 gr/m^2 fiberglass layers have been applied. Then, this part has been separated from the mold and its surface has been smoothed and cleaned. The cowling weight is 104 gr.

Figure 67: The shaped Styrofoam mold.

Figure 68: Cowling air outlet.

Figure 69: Fiberglass on the engine cowling.

4.6 Surface treatment

This phase is necessary both for improving the skin collaborating capability to stress and to reduce aerodynamic drag by smoothing the surface. Tailplanes and fuselage have been covered with a 50 gr/m^2 fiberglass layer, by the classic hands lay-up technique [14][15]. A specific epoxy resin has been used for the following reasons: permits strong and elastic bonds, does not present shrink phenomena or residual stress, it is easy to work after the cure; with respect to a polyester resin: it is less toxic, easily wetted, and less fragile. The stratification procedure is here listed:

1. smooth the surface;
2. clean the surface
3. proceed to the positioning of the fiberglass sheet on the item;
4. lay the resin on the sheet, taking care to equally distribute it on the surface, avoiding excesses or dry areas;
5. the best cure requires an oven temperature between 50°C and 100°C and a variable time between 24 and 5 hours respectively;
6. remove resin excess by smoothing the surface;
7. plaster the skin;
8. smooth it;
9. clean it;
10. paint.

In this way, the part presents good mechanical characteristics and an appreciable quality of the finish, although it brings a light weight penalty.

4.7 Landing gear

A tailwheel configuration has been chosen for the following reasons:

- operation above grass-terrain fields
- simplicity
- ease of manufacturing

The leaf spring has been manufactured from a rectangular Aluminum 6082 Anticorodal plate, cut and bent by an industrial press able to apply up to 400 tons.

Figure 70: Bending of the landing gear plate.

4.8 Weight distribution and CG location

The expected center of gravity is located at 33% wing chord. An eventual off-design condition can be recovered by moving the battery pack in the payload bay.
The model dry weight is about 5,7 Kg. Max takeoff gross weight is 7,7 Kg (double battery pack configuration).

4.9 Timetable

Working hours have been recorded. The manufacturing lasted about 150 hours. The following table reports details.

Table 35: Manufacturing timetable.

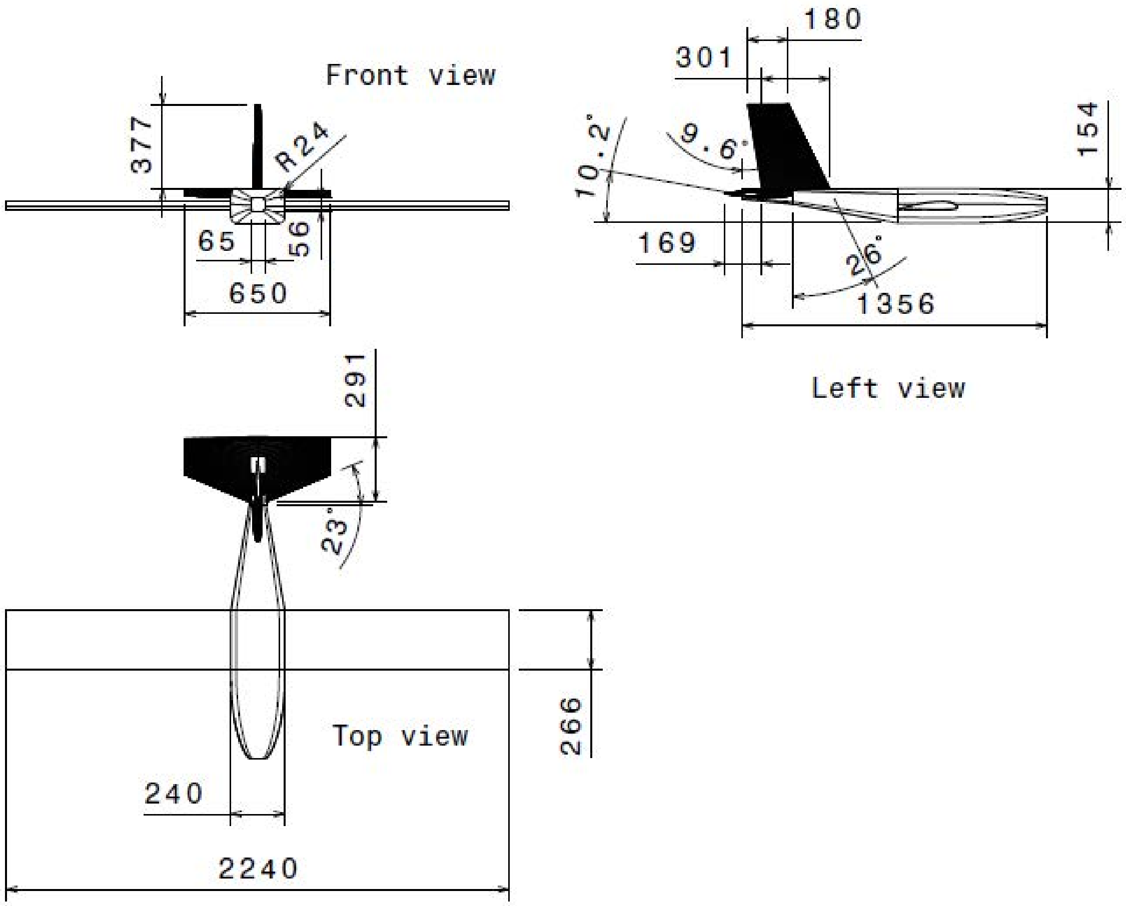
Task	*Time (h:min)*
Horizontal stabilizer	42:30
Landing gear	2:15
Vertical stabilizer	23:10
Fuselage	49:25
Wing	3:00
Engine cowling	11:15
Wiring and soldering	4:30
Weight breakdown	1:30
Smoothing and painting	3:00
Miscellaneous	10:00
Total	150:20

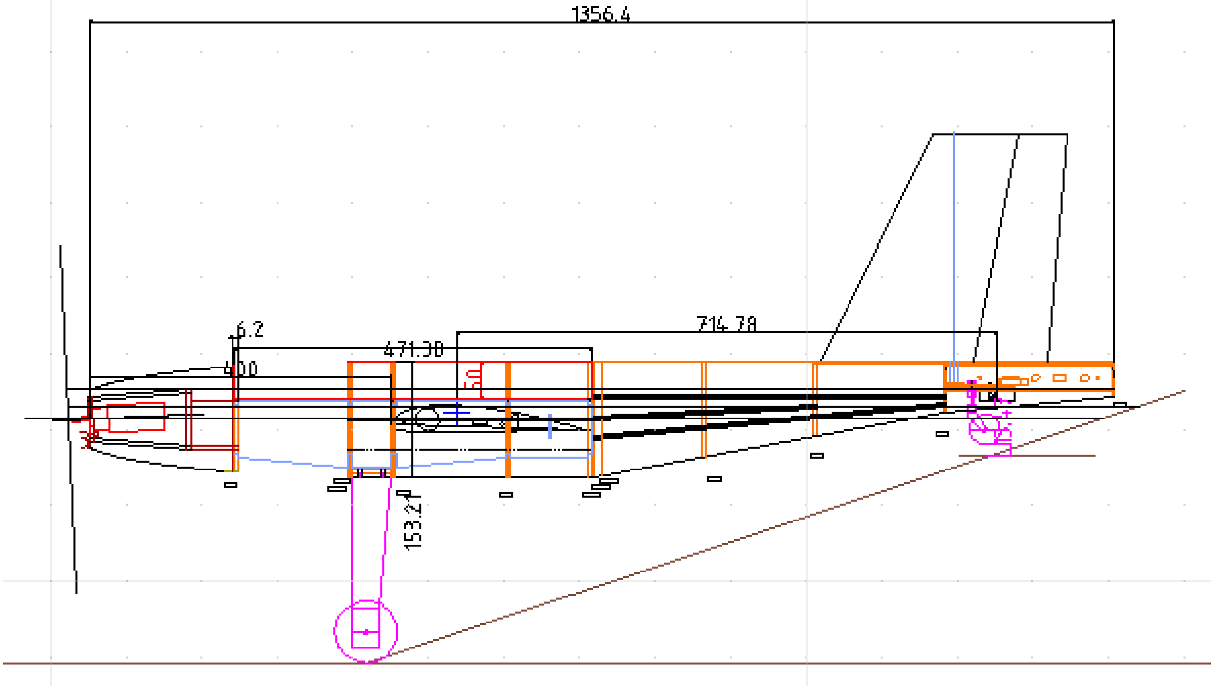
5. FLIGHT TESTING, CONCLUSION, AND FUTURE DEVELOPMENT

In conclusion, the ERACLE model, which participated in 2005 at the AIAA Student Design, Build, Fly Competition, has been redesigned and built after a critical design review. Issues found in the previous model have been solved, mainly by relocating the wing and increasing the size of the empennage. Aerodynamic analyses resulted in promising stability and performance. A complete flight test could not be done, because of tight schedule. However, the maiden flight was successful and engine data has been acquired and here reported.

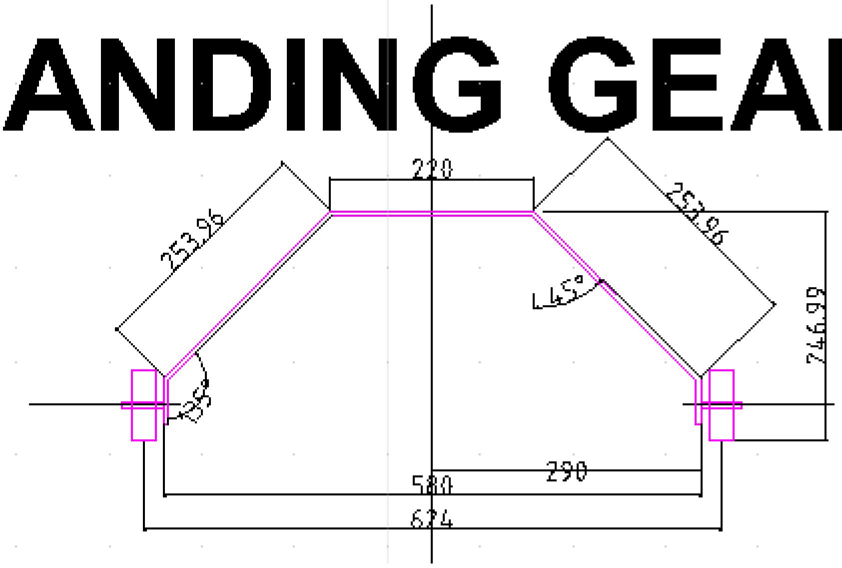
Future development requires the installation of the PixHawk data acquisition and autopilot system, investigation about flaperon vs aileron and flap configuration, experimental determination of flight envelope in various configurations.

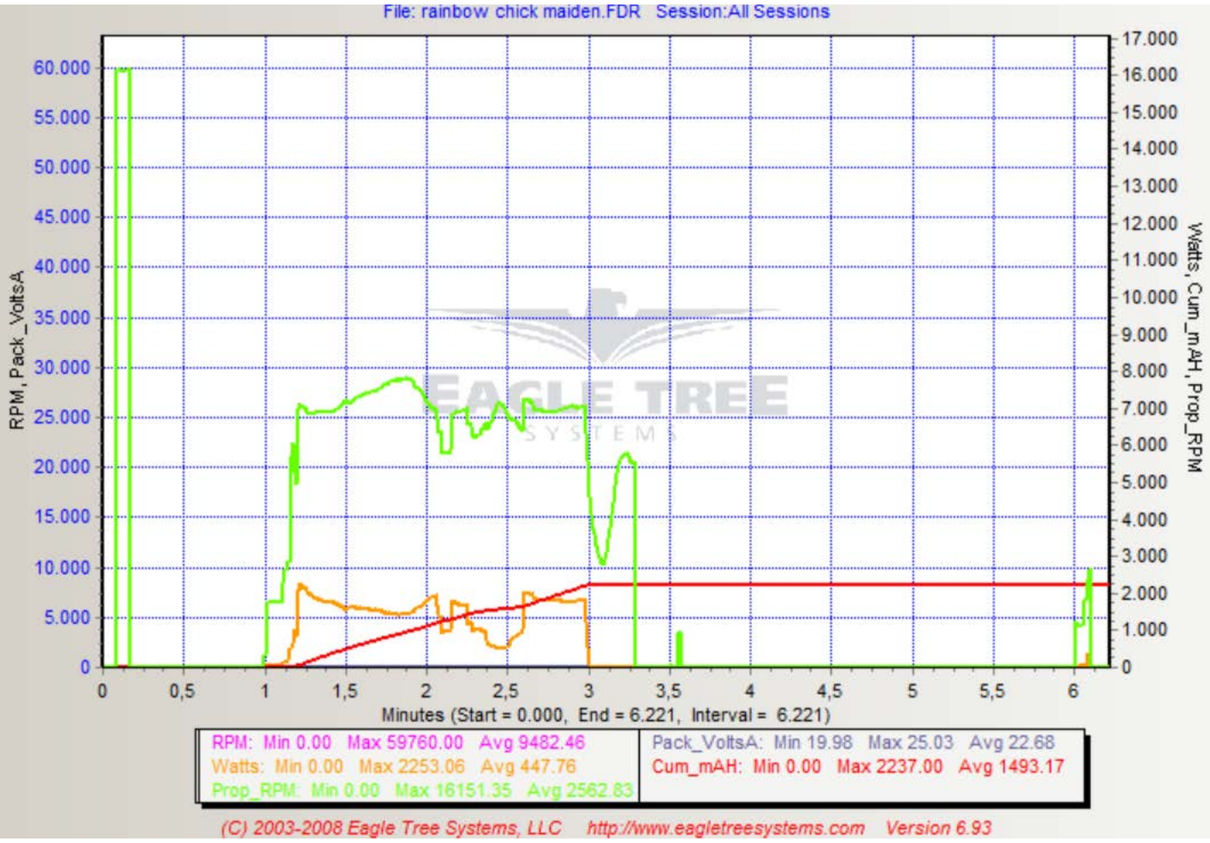
A three-view of the complete model aircraft is here shown. Units are in mm.





LANDING GEAR





RPM: Min 0.00 Max 59760.00 Avg 9482.46
Watts: Min 0.00 Max 2253.06 Avg 447.76
Prop_RPM: Min 0.00 Max 16151.35 Avg 2562.83
Pack_VoltsA: Min 19.98 Max 25.03 Avg 22.68
Cum_mAH: Min 0.00 Max 2237.00 Avg 1493.17

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Rainbow chick


Rainbow Chick

APPENDIX A

CESSNA/ONR
STUDENT DESIGN/BUILD/FLY COMPETITION
An AIAA Student Activity

2005 Rules and Vehicle Design

Note: Rules are "Draft" until 31 October 2004

Summary:

The AIAA through the Applied Aerodynamics, Aircraft Design, Design Engineering and Flight Test Technical Committees and the AIAA Foundation invites all university students to participate in the Cessna/ONR Student Design/Build/Fly Competition. The contest will provide a real-world aircraft design experience for engineering students by giving them the opportunity to validate their analytic studies.

Student teams will design, fabricate, and demonstrate the flight capabilities of an unmanned, electric powered, radio controlled aircraft that can best meet the specified mission profile. The goal is a balanced design possessing good demonstrated flight handling qualities and practical and affordable manufacturing requirements while providing a high vehicle performance.

To encourage innovation and maintain a fresh design challenge for each new year, the design requirements and performance objectives will be updated for each new contest year. The changes will provide new design requirements and opportunities, while allowing for application of technology developed by the teams from prior years.

Cash prizes are $2500 for 1st, $1500 for 2nd and $1000 for 3rd place. Winners will be invited to present their designs at the 2005 Aircraft Technology, Integration and Operations Conference.

Judging:

Students must design, document, fabricate, and demonstrate the aircraft they determine as best capable of achieving the highest score on the specified mission profile(s). Flight scores will be based on the demonstrated mission performance obtained during the contest.

Each team must also submit a written Design Report. A maximum of 100 points will be awarded for the team design report. Scores for the written reports will be announced at the beginning of the fly-off.

Each aircraft will have computed a Rated Aircraft Cost, reflecting the complexity/technology of the design.

The overall team score is a combination of the Design Report, Rated Aircraft Cost and Flight scores. The team with the highest overall team score will be declared the winner.

Scores will be DECLAIRED FINAL 7 working days after the completion of the contest. This period will allow for review of the scores in a timely fashion following the contest.

Contest Site:

Host for the competition will be the Office of Naval Research. The fly-off is planned to be held at Webster Field at St Inigos, MD.

You can check on weather historical conditions at www.weatherbase.com or www.weatherunderground.com.

Team Requirements:

All team members (except for a pre-approved designated pilot) must be full time students at an accredited University or College and student members of the AIAA. The team must be composed of both under classmen and upper classmen, with at least 1/3 of the members being under classmen (Freshman, Sophomores or Juniors). The pilot must be an AMA (Academy of Model Aeronautics) member. Teams may use a non-university member for the pilot if desired. We will also provide qualified pilots on the contest day for any teams who are unable to have their pilot attend.

Past Year Reports:

The top scoring report from the past years competition will be available for reference on the contest web site. The team with the top scoring report from this years contest will be required to submit an electronic copy of their report following the competition, which will be placed on the contest web site for the next years competition.

Sponsorship:

Teams may solicit and accept sponsorship in the form of funds or materials and components from commercial organizations. All design, analysis and fabrication of the contest entry is the sole responsibility of the student team members.

Schedule:

A completed electronic entry form is due to the contest administrator on or before 31 October 2004.

The entry form for the DBF is different than that used for all other AIAA student competitions. The DBF entry form is a MS-Word file and can be found on the contest web site. It must be submitted by e-mail to the contest administrator at gregory.s.page@nrl.navy.mil . Be sure to include the Phone and FAX number for your team advisor and at least one student contact so we may reach you in case of any last minute problems or changes. All teams are required to provide two point-of-contact e-mail addresses with their contest application, one of which must be the teams advisor. *It is the teams responsibility to make sure the e-mail contact addresses they supply remain active during the entire period from entry to the close of the competition, as e-mail will be the primary means to provide information and updates.*

Please Note: *The Entry Name* may not be changed once the form is submitted, but must be retained and used in all reports and correspondence during the competition year.

Written reports (5 hard copies, electronic reports will not be accepted), are due to the Chief of Scoring by COB 8 March 2005. Reports will be judged “as received”, no “corrections/additions/page changes” will be made by the organizers so check your reports carefully before sending them. COB is taken as 5 pm local time at the address provided for delivery of the written reports. Scores for the written reports will be announced at the beginning of the fly-off.

(A note primarily for foreign entrants but also allowed for domestic teams. If sending the report by courier is prohibitive you may send it electronically to a commercial printer (KINKO’s comes to mind) local to the report submission address and have them print/collate and DELIVER the reports to meet the deadline. No deadline exceptions will be made, but this may be easier than international courier service.)

The contest is scheduled for 22-24 April 2005. The competition will run from noon to 5PM on Friday, and 8AM to 5PM on Saturday and Sunday. Final awards will be presented at the end of Sunday's competition. All teams are encouraged to stay and attend the awards presentations on Sunday.

Please note that tech inspections will be available on Friday 22 April. Teams are encouraged to be prepared to have your plane inspected on Friday. Inspections will also be available on Saturday, but waiting until Saturday to go through tech may mean that your team will miss one or more rounds through the flight queue. If we have a full turnout you may not be able to get in a full set of scoring flights unless you are "ready to fly" at every opportunity.

Late entries will NOT be accepted. Late or incomplete report submissions will NOT be judged. Teams who do not submit the required written reports will NOT be allowed to fly. It is the teams responsibility to assure that all deadlines are met, as they will be strictly enforced.

Communications:

The contest administration will maintain a World Wide Web site containing the latest information regarding the contest schedules, rules, and participating teams. The contest web site will also contain a list of potential suppliers for materials and equipment available to build an entry. The contest web site is located at:

http://www.ae.uiuc.edu/aiaadbf

Questions regarding the contest, schedules, or rules interpretation may be sent to the contest administrator by e-mail at:

gregory.s.page@nrl.navy.mil

The contest administrator will provide e-mail copies of questions received and their answers to all teams of record.

Written reports (only) should be sent to the Chief of Scoring at:

AIAA Design/Build/Fly Contest/Report Judging
Greg Page Bldg 210
ITT / AES
2560 Huntington Ave.
Alexandria, VA 22303
202-404-1251
202-767-6194 FAX

Aircraft Requirements - General

- The aircraft may be of any configuration except rotary wing or lighter-than-air.
- No structure/components may be dropped from the aircraft during flight.
- No form of externally assisted take-off is allowed. All energy for take-off must come from the on-board propulsion battery pack(s).
- Must be propeller driven and electric powered with an unmodified over-the-counter model electric motor. May use multiple motors and/or propellers. May be direct drive or with gear or belt reduction.
- *NEW*: Motors may be any commercial brush or brushless electric motor.
- For safety, each aircraft will use a commercially produced propeller. Teams may modify the propeller diameter by clipping the tip, and may paint the blades to balance the propeller. No other modifications to the propeller are allowed. Commercial ducted fan units are allowed.
- Motors and batteries will be limited to a maximum of 40 Amp current draw by means of a 40 Amp fuse (per motor or pack) in the line from the positive battery terminal to the motor controller. Only ATO or blade style

plastic fuses may be used. (e.g. "Maxi" size Slow Blow, 1.15"x0.85". Available online www.Mcmaster.com part #7460K51 $1.66 each)

- *NEW*: Must use over the counter NiCad or NiMH batteries. For safety, battery packs must have shrink-wrap or other protection over all electrical contact points. The individual cells must be commercially available, and the manufacturers label must be readable (i.e. clear shrink wrap preferred). All battery disconnects must be "fully insulated" style connectors.
- *NEW*: Maximum battery pack weight is 3 lb. Battery pack must power propulsion and payload systems only. Radio Rx and servos MUST be on a separate battery pack. Batteries may not be changed or charged between sorties during a flight period.
- Aircraft and pilot must be AMA legal. This means that the aircraft TOGW (take-off gross weight with payload) must be less than 55 lb, and the pilot must be a member of the AMA.
- Since this is an AMA sanctioned event, the team must submit proof that the aircraft has been flown prior to the contest date (in flight photo) to the technical inspection team. Contest supplied qualified pilots will be available to teams who require them.
- *NEW*: Teams must use the contest supplied RAC calculation sheet. This Excel file will be available for download from the contest web site. Teams must use the file “as-is” for print inclusion in the Design Report, and must supply a separate signed (by the teams faculty advisor) copy of their Rated Aircraft Cost worksheet to the judges during technical inspection for verification.

  The RAC sheet presented at the tech inspection should match the final aircraft configuration being flown at the contest, and may differ from the one submitted with the Design Report. During tech inspection the judges will determine an independent RAC value. The Rated Aircraft Cost obtained at the technical inspection will be used for the competition and may not be modified during the event.

Aircraft Requirements - Safety

All vehicles will undergo a safety inspection by a designated contest safety inspector prior to being allowed to make any competition or non-competition (i.e. practice) flight. All decisions of the safety inspector are final. Safety inspections will include the following as a minimum.

- Physical inspection of vehicle to insure structural integrity.
    1. Verify all components adequately secured to vehicle. Verify all fasteners tight and have either safety wire, locktite (fluid) or nylock nuts.
    2. Verify propeller structural and attachment integrity.
    3. Visual inspection of all electronic wiring to assure adequate wire gauges and connectors in use. Teams must notify inspector of expected maximum current draw for the propulsion system.
    4. Radio range check, motor off and motor on.
    5. Verify all controls move in the proper sense.
    6. Check general integrity of the payload system.

- Structural verification. All aircraft will be lifted with one lift point at each wing tip to verify adequate wing strength (this is "roughly" equivalent to a 2.5g load case) and to check for vehicle cg location. Both upright and inverted wing lift tests will be performed. Teams must mark the expected empty and loaded cg locations on the exterior of the aircraft fuselage. Special provisions will be made at the time of the contest for aircraft whose cg does not fall within the wing tip chord. This test will be made with the aircraft filled to its *maximum payload capacity*.
- Radio fail-safe check. All aircraft radios must have a fail-safe mode that is automatically selected during loss of transmit signal. The fail-safe will be demonstrated on the ground by switching off the transmit radio. During fail safe the aircraft receiver must select:

Throttle closed
Full up elevator
Full right rudder
Full right (or left) aileron
Full Flaps down (if so equipped)
During Fail Safe the payload release system must NOT activate.
The radio Fail Safe provisions will be strictly enforced.

- All aircraft must have a mechanical motor arming system separate from the onboard radio Rx switch. This MUST be the contest specified "blade" style fuse. This device must be located so it is accessible by a crewmember standing ahead of the propeller(s) for pusher aircraft, and standing behind the propeller(s) for tractor aircraft (i.e. the crew member must not reach across the propeller plane to access the fuse). The "Safety Arming Device" will be in "Safe" mode for all payload changes. The aircraft Rx should always be powered on and the throttle verified to be "closed" before activating the motor arming switch. Fuses MUST be accessible from outside the aircraft and act as the "safeing" device.

  Note: The aircraft must be “safed” (arming fuse removed) any time the aircraft is being manually moved, or while loading/unloading payload during the mission. The arming fuse must be removed anytime the aircraft is in the hanger area.

Mission Profile:
Teams must complete the flight missions as outlined in the mission matrix below. Teams will have a maximum of 5 flight attempts. A flight attempt is defined as advancing the throttle “stick” for take-off, or going past the 2 minute preparation time. The best *Single Flight Score* from each of 2 different mission types will be summed for the team's *Total Flight Score*.

In the event that, due to time or facility limitations, it is not possible to allow all teams to have the maximum number of flight attempts, the contest committee reserves the right to ration and/or schedule flights. The exact determination of how to ration flights will be made on the contest day based on the number of entries, weather, and field conditions.

Each team's overall score will be computed from their *Written Report Score, Total Flight Score*, and the *Rated Aircraft Cost* using the formula:

$$\text{SCORE} = \frac{\text{Written Report Score} * \text{Total Flight Score}}{\text{Rated Aircraft Cost}}$$

Mission Task Matrix

Mission	Description
	General Mission Information - Aircraft must fit in a 2-ft wide by 1-ft high by 4-ft long (interior dimensions) box. The aircraft will be returned to the box at end of the flight as a part of each timed mission. *The aircraft must not be damaged in any way during the "return to box" task.* Note: There is no timed-repair of damage allowed in this years competition. - The aircraft MUST be configured to support both wing tip EXTERNAL payload carriage and fuselage INTERNAL payload carriage, even if the sensor re-position mission is not flown. Wing tip lift tests will be performed with the INTERNAL payload only. - Each payload is a 12" long 3" (metric 75mm) PVC tube (minimum length of the tube proper, with out any ends/caps/fairings). Ends must be closed. Ends may be faired in any manor desired. The identically same payload must be used for both the INTERNAL and EXTERNAL payload missions (any fairings, fins or other structures used for the external mission must also be in place during the internal missions). Each payload must weigh at least 3 lbs. - EXTERNAL payload must be carried on a hard-point located within 3 inches of the wing tip of the largest span wing. One payload hard-point will be located at each wing tip. The aircraft will NOT be required to fly with only one wing tip payload package loaded. External payload must be capable of remote (RC) release, but will use only manual reloading. *Payload release must use a dedicated servo, it can not be integrated with any flight control servo.* - INTERNAL payload must be carried fully inside the fuselage. Payload must be symmetric to the fuselage centerline. (ie. They can be side-by-side and symmetric to the fuselage centerline, or they may be one above the other and on the fuselage centerline). For dual-fuselage configurations one sensor package will be in each fuselage, on that fuselage's plane of symmetry. - The Entry Name and University Name must be clearly visible on the upper surfaces of the upper-most wing. Font used should be large enough to

	allow easy identification in photographs of the aircraft (does not apply to in-flight photos). • Teams must select one of the following missions for each flight. Teams may select a different mission for each of their scoring flight attempts. • Take-off distance is 150 ft wheels off the runway. For each take-off of a multi-sortie mission the aircraft may be returned to the start line for each new take-off, or may start where it is. In either case the maximum take-off allowance is MEASURED from the start line. • On landing the aircraft must land on the runway (but may roll off) to obtain a score for that flight. • All payloads must be adequately secured using mechanical means. Tape and Velcro are not acceptable forms of restraint. • Each team will be issued a Flight Scoring sheet when they complete the technical inspection (along with their DBF flight approval decal). The TEAM is responsible for maintaining the Flight Scoring sheet. They must present it to the flight line scoring judge before beginning each mission. They must present it to the main scoring judge for recording within 5 minutes of the completion of each flight. Scores reported later than 5 minutes from the recorded end-of-flight time will be scored as 0. Duplicate scoring sheets will NOT be available. • Maximum mission time is 10 minutes.
Sensor Reposition	DF = 2.0 • Mission Profile: 1. Aircraft will begin the mission with 2 EXTERNAL sensor payload packages. 2. Aircraft will take-off and fly 1 lap. After landing the aircraft will remotely deploy 1 sensor package at each of 2 separate release locations. 3. Aircraft will take-off and fly 1 lap. After landing the aircraft will taxi to a specified reload location near the first release location. The ground crew will, when instructed by the flight line judge, go out to the aircraft, safe the propulsion system, and manually re-load the payload. The ground crew will return to their “box” after reloading the first sensor package. The aircraft will taxi to the second reload location, and the ground crew will repeat the

	sensor reloading process. 4. Aircraft will take-off and fly 1 lap. On landing the aircraft must cross the take-off start line and come to a complete stop. 5. When instructed by the flight line judge the ground crew will retrieve the aircraft, return it to the “box” area, disassemble the aircraft and store it in the box. 6. Time stops when the box lid is closed and latched. • One release location will be along the runway edge furthest from the pit crew “box”, the other location will be along the runway centerline. Locations will be marked on the pavement by 10 ft x 10 ft rectangles. If the sensor package rolls out of the marked area it will be scored as an incomplete flight. • On all laps flown the aircraft must complete a 360° turn in the direction opposite of the base and final turns on the downwind leg of each lap. • *For this task there is no score for a partial mission* • For this task there is no score if the aircraft is not successfully returned to the box at the end of the mission. • Single Flight Score is: SCORE = DF *(12-Mission_Time)
Maximum Utilization	DF = 1.0 • Mission Profile: 1. Aircraft will begin the mission with 2 INTERNAL sensor payload packages. 2. Aircraft will take-off and fly as many laps as the team deems possible. 3. On landing the aircraft must cross the take-off start line and come to a complete stop. 4. When instructed by the flight line judge the ground crew will retrieve the aircraft, return it to the “box” area, disassemble the aircraft and store it in the box. 5. Time stops when the box lid is closed and latched. • The total mission Time limit is 6 minutes. • A Penalty of 1 lap will be assessed for each 15 seconds or portion thereof beyond the 6 minutes before the box is closed and latched. • On all laps flown the aircraft must complete two

	(2) 360° turns in the direction opposite of the base and final turns on the downwind leg of each lap. • For this task there is no score if the aircraft is not successfully returned to the box at the end of the mission. • Single Flight Score is: SCORE = DF * Number_of_Laps
Re-Supply	DF=1.5 • Mission Profile: 1. Aircraft will begin the mission with 2 INTERNAL sensor payload packages. 2. Aircraft will take-off and fly 1 lap. On landing it must cross the take-off start line and come to a complete stop. When instructed by the flight line judge the ground crew will go out to the aircraft and remove the payload. 3. Aircraft will take-off and fly 1 lap. On landing it must cross the take-off start line and come to a complete stop. When instructed by the flight line judge the ground crew will go out to the aircraft and re-install the payload. 4. Aircraft will take-off and fly 1 lap. On landing it must cross the take-off start line and come to a complete stop. When instructed by the flight line judge the ground crew will go out to the aircraft and remove the payload. 5. Aircraft will take-off and fly 1 lap. On landing it must cross the take-off start line and come to a complete stop. When instructed by the flight line judge the ground crew will retrieve the aircraft, return it to the "box" area, disassemble the aircraft and store it in the box. 6. Time stops when the box lid is closed and latched. • On all laps flown the aircraft must complete one (1) 360° turn in the direction opposite of the base and final turns on the downwind leg of each lap. • For this task there is no score if the aircraft is not successfully returned to the box at the end of the mission. Single Flight Score is: SCORE = DF * (12-Mission_Time). If only 3 of the 4 sorties are completed

	SCORE = DF * (6 - Mission_Time) If only 2 of the 4 sorties are completed SCORE = DF * (3 – Mission_Time) (Scores less than 0 will be counted as 0)

Aircraft that run off the runway before reaching the start line may be returned to the runway to taxi back to the line or may be carried to the line by the ground crew.

Aircraft Cost Model:

Rated Aircraft Cost, $ (Thousands) = (A*MEW + B*REP + C*MFHR)/1000

Coef.	Description	Value
A	Manufacturers Empty Weight Multiplier	$500 (NEW)
B	Rated Engine Power Multiplier	$1000 (NEW)
C	Manufacturing Cost Multiplier	$20 / hour
MEW	Manufacturers Empty Weight	Actual airframe weight [lb] with all flight and propulsion batteries but without any payload.
REP	Rated Engine Power	(1+.25*(# engines-1)) * *Total Battery Weight [lbs]* "*Total Battery Weight*" will be the weight of the propulsion battery pack(s) as determined by the judges scale during technical inspection. Total propulsion battery pack weight may not exceed 3 lb, but it may be lighter.
MFHR	Manufacturing Man Hours	Prescribed assembly hours by WBS (Work Breakdown Structure). MFHR = ☐ WBS ho WBS 1.0 Wing(s): (NEW) 10 hr/ft^2 Wing Span * Chord * # wings Note: All inputs on RAC worksheet in inches. Wing Span is longest distance perpendicular to fuselage axis

		on any wing. Chord is maximum exposed wing chord on any wing. For a blended wing-body, exposed wing starts 9 inch out from the body centerline. 5 hr * control_function_multiplier ailerons = 1 flaperons = 1.5 ailerons + flaps = 2 ailerons + spoilers = 2 ailerons + flaps + spoilers = 3 WBS 2.0 Fuselage 20 hr/ft^3 Body Length x Width x Height Note: All inputs on RAC worksheet in inches. Length is maximum body length. Width is maximum body width. Height is maximum body height (does not include landing gear height). Maximum body width and maximum body height may occur at different fuselage locations. For a blended wing-body, body width is fixed at 18 inch. Note: Maximum length of the body is defined to be the longest longitudinal length possible to measure on the aircraft, and may include spinner and part of vertical or horizontal surfaces. WBS 3.0 Empennage 5 hr/Vertical Surface (Any vertical surface, including winglets, struts, end plates, ventral etc) with no active control 10 hr/Vertical Surface (Any vertical surface) with an active control

		10 hr/Horizontal Surface. A horizontal surface is a "wing" if it is more than 25% of the span of the greatest span horizontal surface.) A "V" tail is considered to be a Vertical surface without control (5 hr) plus a horizontal surface with controls (10 hr), for a total of 15 hr. WBS 4.0 Flight Systems 5 hr/servo or motor controller WBS 5.0 (Deleted)

Rated Aircraft Cost must be supplied when the aircraft enters the technical inspection. The RAC worksheet must be signed by the team advisor. RAC may not be changed during the competition unless it is determined by the contest officials to be inaccurate or inappropriate. The contest officials reserve the right to audit and revise the RAC for omissions or errors at any time.

General Mission Specification and Notes:

- Aircraft are to remain assembled while waiting in the queue. Teams will install the propulsion batteries once reaching the 3rd “On Deck” position (i.e. when the aircraft is 3rd in the queue, the team must begin to install the batteries).
- Aircraft may not have any work performed in the starting line queue, other than as specified above at the 3rd On Deck position. Aircraft propulsion batteries may be left out of the aircraft when in line.
- Aircraft batteries may be charged while the aircraft is in the queue IF AND ONLY IF the batteries are removed from the aircraft.
- The aircraft propulsion system(s) must be disarmed or "safed" during any time when crew members are preparing the aircraft.
- Maximum flight support crew is: pilot, observer, and 3 ground crew. Only the designated ground crew may reload the aircraft payload . Pilot and observer may be members of the ground crew, provided total ground crew size remains 3 people.
- Observer and all ground crew must be students. Only the pilot may be a non-student.
- The upwind turn will be made after passing the upwind pylon. The downwind turn will be made after passing the downwind pylon. Upwind and downwind pylons will be 500 ft from the starting line. Aircraft must be "straight and level" when passing the pylon before initiating the turn.
- Aircraft must land on the paved portion of the runway. Aircraft may "run-off" the runway during roll-out.
- After landing, aircraft may taxi back to the starting line. Alternatively, aircraft may be carried back to the starting line; however, the team may not leave the pit area to retrieve the aircraft until the aircraft has come to a

complete stop, and they are signaled it is "Ok" to retrieve the aircraft by the flight line judge. *Aircraft experiencing significant damage during landing will be considered to have completed their flight where they come to rest and may not be "carried" to the starting line to "complete" a lap. Determination of "significant –vs- non-critital" damage will be made by the flight line judges. Aircraft with "significant" damage will not receive a score for that flight. Aircraft with "non-critical" damage may continue to the disassembly task with no penalty.*

- Flight altitude must be sufficient for safe terrain clearance and low enough to maintain good visual contact with the aircraft. Decisions on safe flight altitude will be at the discretion of the flight line judges and all rulings will be final.

Additional information is included in the FAQ (Frequently Asked Questions).

Protest Procedures

Submitting a protest against a competing team is a serious matter and will be treated as such. Teams may submit a protest to the Contest Administrator at any time during the competition. Protests must be submitted in writing and signed by the team advisor (if present at the competition) or the team captain if a faculty advisor is not present. Protests will be posted for all teams to review.

If the protest is rejected, the submitting team(s) will forfeit one of their remaining flight attempts. If all flight attempts have been used, the team(s) will forfeit their lowest Single Flight score.

Protests and the appropriate penalty (ranging from a requirement to repeat a flight for minor infractions to disqualification from the contest for deliberate attempts to misinform officials or violate the contest rules) will be decided by the Contest Administrator and the Contest Director, in consultation with other Contest Officials. The decision of the Contest Administrator and Contest Director is final.

Design Report:

Each team will submit a judged design report as outlined below. The submission date is contained in the schedule section of this document. Reports must be bound. (Simple spiral bindings are sufficient and preferred; 3-ring binders are not allowed.) All information used for scoring must be in the outlined sections.

Absolute maximum page count for the report is 60 pages, including text, tables, and figures (cover/title page and table of contents is extra). Drawing package may not comprise more than 5 of the pages of the report page limit. All reports will be at least one and one half line spacing, 10-pt Arial font. Tables and figures will also be at least 10-pt Arial font. Margins are at least 1 inch on all sides. All figures must be either half (1/2) page or full (1) page format. No exceptions. Report pages will be 8 1/2 x 11 inch with the exception of the drawing package. The drawing package may be on 11 x 17 inch pages. The 3-view drawing must be on an 11 x 17 inch page. Appendices may not be included. Reports not meeting these requirements will be scored as "1 of 100".

Please note that the judges will be using this same report outline for evaluating reports. ALL items listed will be expected to be present, easy to locate and identify, and be well documented in the report for a maximum score.

Design Report

1. Executive Summary: (5 points):
   Provide a summary of the development of your design. This should be a narrative description highlighting the major areas in the development

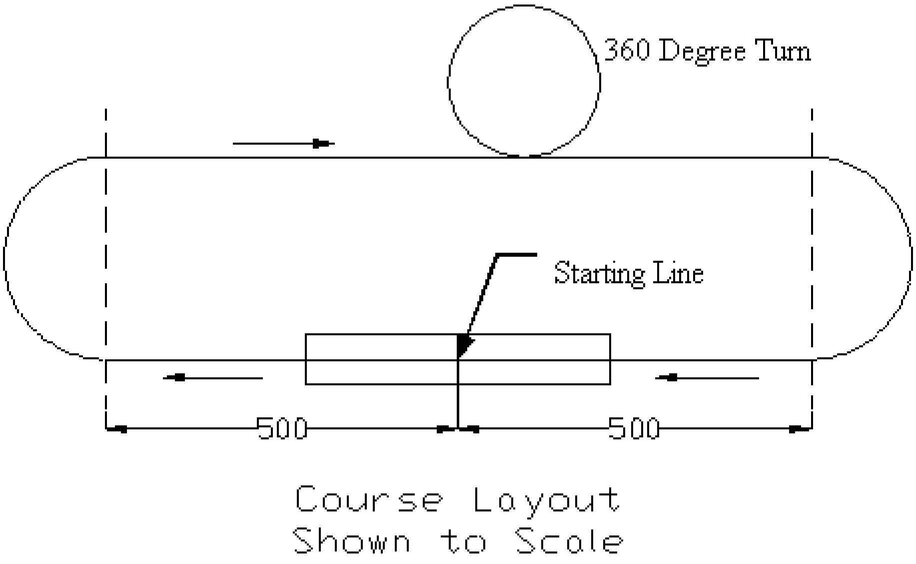
process for your final configuration and a broad description of the range of design alternatives investigated.

2. Management Summary (5 points):
   Describe the organization of the design team. Provide a chart of design personnel and assignment areas. Include a (single) milestone chart showing planned and actual timing of major elements of the design process, including as a minimum the conceptual design stage, preliminary design stage, detailed design stage, flight testing and report preparation periods.
3. Conceptual Design (20 points):
   Describe the key elements of the mission requirements (problem statement). Document the alternative configuration concepts (e.g. biplane, canard, flying wing, pusher -Vs tractor, number of engines etc.) investigated during the conceptual design stage and the reason why each concept was considered. Describe and document the numerical figures of merit (FOM's) used to screen competing concepts, and the mission feature each FOM was selected to support. *Rated Aircraft Cost* should be one of the FOM's used during the trade-off process. Numerical data need not be extensive at this stage, but should include as a minimum: a final ranking chart giving the quantitative value of each design for each FOM.
4. Preliminary Design (30 points):
   Document the design parameter and sizing trades investigated during the preliminary design stage, and why each was felt to be important to the mission. Describe the analysis methods used. Describe the mission model used and the predicted performance. Provide estimates of the aircraft lift, drag and stability characteristics. Document the design optimization and trade studies conducted and their results.
5. Detail Design (15 points for discussion items, 10 points for drawing package, 25 points total for the section):
   Document component selection and systems architecture selection. Include your final competition aircraft's *Rated Aircraft Cost* using the contest supplied cost model. RAC table should include all input parameter, intermediate and final computation.

   Include a table giving data for the sized aircraft. A copy of this table must be posted by the team at their "pit" area (poster board). The table should include;
   Geometry: length, span, height, wing area, Aspect Ratio, control volumes
   Performance: CL max, L/D max, maximum Rate of Climb, stall speed, maximum speed, take-off field length (two sets, empty and gross weight)
   Weight Statement (airframe, propulsion system, control system, payload system, payload, empty weight, gross weight)
   Systems (radio used, servos used, battery configuration used, motor used, propeller (nominal), gear ratio (if used))

   The Drawing Package will be included with this section and must contain as a minimum a 3-view drawing of the design in sufficient detail to indicate aircraft size and configuration; primary structure component size and location; payload size, location and restraint method; and location of propulsion and flight control system components.

6. Manufacturing Plan and processes (10 points): Document the process selected for manufacture of major components and assemblies of the final design. Detail the manufacturing processes investigated, and describe the FOM's used (including but not limited to: availability, required skill levels and cost) to screen competing concepts. Describe the analytic methods (cost, skill matrix, scheduling time lines) used to select the final set of manufacturing processes. Include a manufacturing milestone chart showing scheduled event timings.
7. Testing Plan (5 points): Detail testing objectives, schedules, check-lists, results and any lessons learned for component and full aircraft testing, both static and dynamic (ie. in flight).



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SPECIAL THANKS – RINGRAZIAMENTI