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Feasibility study of the use of Rapid Manufacturing Technology in a new Unmanned Air Vehicle design

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3 NOMENCLATURE

UAV	Unmanned Air Vehicle
RMS	Rapid Manufacturing System
SLS	Selective Laser Sintering
DMLS	Direct Metal Laser Sintering
FDM	Fused Deposition Modeling
SLA	Stereo-lithography
LOM	Laminated Object Manufacturing
EBM	Electron Beam Melting
PP	Plaster-Based 3D Printing
CAD	Computer-aided Design
CNC	Computer Numeric Control
STL	STereoLithography file format
PA	Nylon
PLA	PolyLactic Acid
NIST	National Institute of Standards and Technology
ABS	Acrylonitrile butadiene styrene
MD	Machine Direction
TD	Transverse Direction
NIST	National Institute of Standards and Technology

1 INTRODUCTION

1.1 AIM

The aim of the study is to investigate the feasibility of the use of rapid manufacturing technology in a new Unmanned Air Vehicle design for the CATUAV[1] Tech Center.

1.2 SCOPE

The scope of the study is to select the optimum rapid manufacturing system (RMS) for the requirements of CATUAV and define the specific methodology and process for its optimum implementation.

Empirical research of materials, printing configurations, UAV 3D printed parts and real experience tests, have been used in this study to develop the Barcelona 3D printed UAV.

Barcelona UAV has been designed, 3D printed, assembled and flight tested in order to demonstrate the feasibility of 3D printing technology for UAV applications. New fuselage concept design has been developed to become a lightweight UAV while supporting functional requirements.

Barcelona UAV has been flight tested and compared with worldwide existing 3D printed UAV and traditional technologies to evaluate the result of this study.

This study has finished the demonstration of the feasibility of the use of rapid manufacturing technology in a new UAV design by:

- Testing Barcelona UAV with different 3D printers.
- Locking for worldwide beta-testers of Barcelona 3D printed UAV.
- Testing advanced 3D printing materials.

[1] *CATUAV. Private Company dedicated to Earth observation. http://www.catuav.com/ca/*

1.3 BASIC REQUIREMENTS

The idea to develop the 3D printed UAV came originally from Jordi Santacana, the director of CATUAV. In the summer of 2013 he participated at a Washington conference on 3D printing and came back to Barcelona with the idea of adapting this new, rapid and low cost technology for UAV applications.

Therefore the basic requirements for the RMS has been defined according to this scenario.

1.3.1 Basic requirements for the rapid manufacturing system

- Application for UAV models.
- Multi material system.
- Low cost technology
- Rapid technology.
- Low maintenance.
- Upgradable system.

Barcelona UAV has been developed to become a real experience of the feasibility of the use of rapid manufacturing technology in a new UAV design. The new concept has been designed to take advantage of RMS technology by manufacturing a complex shape difficult and expensive to be moulded with traditional systems.

Since the philosophy of this document is to become an environmental friendly study, it has been required a biodegradable material because many excess part will be generated during the complete cycle of the UAV.

Lightweight requirement is important for a UAV application because reducing all-up weight the payload weight can be increased while maintaining the operation.

1.3.2 Basic requirements for the Barcelona UAV

- Complex shape.
- Low cost UAV.
- Biodegradable material.
- Lightweight UAV.
- Support UAV functions and adapted to AESA[2].

1.4 JUSTIFICATION

CATUAV is a private company dedicated to terrain observation using Unmanned Aerial Vehicles (UAV). Founded in 2003 and located in Moià, during the last decade CATUAV has been carrying on an R&D[3] process that has led to a complete and functional UAV system. Some of the main developments are: [1]

- Design and production of 6 different UAV platforms.
- Design and production of a ground control station.
- Design of the communication protocol and control software.
- Design of the communication modem and telemetry link.
- Payload design: multispectral cameras and atmosphere sensors.
- Development of mission specific flight planning software.

[2] AESA. Agencia Estatal de Seguridad Aérea.

http://www.seguridadaerea.gob.es/media/4229776/el_uso_de_los_drones.pdf

[3] R&D. Research and technical development.

The philosophy of CATUAV and its commitment have brought the Company to the dreamed scenario: the availability of its own Temporary Segregated Airspace (TSA-31 CTC-MOIA), approved by Spanish airspace authorities and activated by NOTAM. This extraordinary event discovers a whole new range of targets for CATUAV and the Company is studding new facilities in order to become a European reference with the new Tech Center for UAV development.

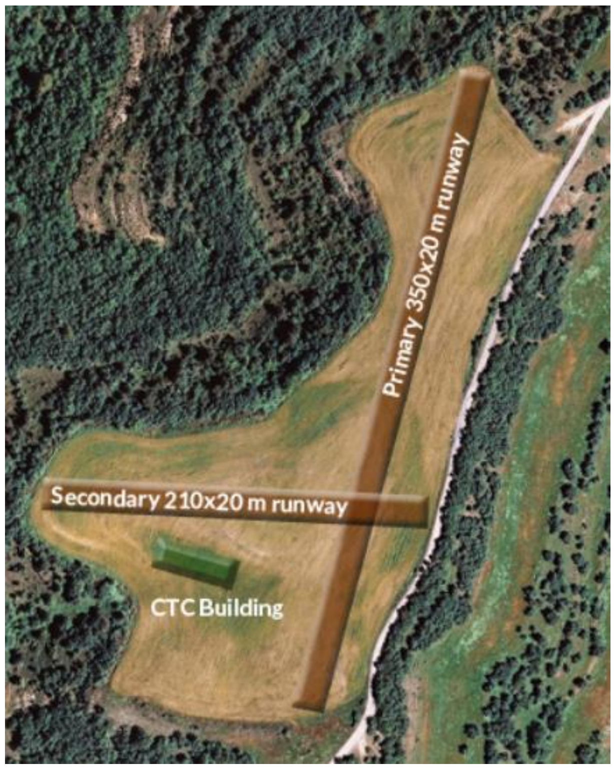

Figure 1 CATUAV services [2]

TSA new scenario has brought CATUAV to build a new hangar (see Figure 1), the CATUAV TECH CENTER (CTC), located inside TSA. This new bioclimatic building will have a UAV Laboratory equipped with a rapid, low cost and recyclable manufacturing technology. The development of this technology is the aim of the study.

The UAV models designed and produced for CATUAV have been enumerated and compared, see Table 1, in order to have a preliminary idea of similar UAV models.

UAV model	Image	Range	Autonomy	Payload	Cruise Speed	Engine
Atmos 6		15 km	60-120 min	500 g	45 km/h	Electric
Argos Electric		15 km	100-200 min	5880 g	60 km/h	Electric
Argos		15 km	14 h	6250 g	68 km/h	Fuel
Furos		15 km	6 h	5000 g	70 km/h	Fuel
Basal 1		300 m	18 min	500 g	5 km/h	Electric
Heli500		4 km	18 min	500 g	35 km/h	Electric

Table 1 CATUAV models [3]

2 DEVELOPMENT

This study has been developed following a basic strategy:

- STATE OF THE ART research and existing RMS technology for UAV applications analysis.
- Study and selection of the optimum RMS for UAV applications.
- 3D printing technology knowledge and selection of the optimum device and material. Deeper study and analysis of the selected one.
- UAV design and manufacturing process: wing, tail and fuselage.
- 3D printed UAV flight test and upgrading.

2.1 STATE OF THE ART

The state of the art has been developed in the attachment: ANNEX I. This bibliographic document analyzes the existing aerospace vehicles manufactured by RMS. The most important references, specifically for UAV applications with similar features, are SULSA [4], WENDY [5], VAST [6] and AMRC [7].

UAV	University	Year	Wingspan	Weight	Cruise Speed	Engine
			[mm]	[Kg]	[Km/h]	
SULSA	Southampton	2011	1200	3	70	Electric
WENDY	Virginia	2012	1981	4	72,4	Electric
VAST	Massachusetts	2013	2032	3,175	96,48	Electric
AMRC	Sheffield	2014	1500	2	Glider	No engine

Table 2: Features of the existing 3D printed UAV

Table 2 shows an important information for this study:

- The feasibility of the use of 3D printing technology in UAV design, the aim of this study.
- Recognized Universities have develop this technology in UAV application and have been supported for Private Companies or/and State Governments.
- First 100% 3D printed UAV was tested in 2011, it is a new technology.
- 1500 mm wingspan is an interesting dimension in order to compare the result of this study with existing 3D printed models.
- Weight is the key factor of this technology. The weight versus wingspan [g/mm] ratio has been reduced from 2.02 in 2012 WENDY project to 1.33 in 2014 with AMRC-BOEING project.
- Endurance and Cruise Speed are not important features for this study since those do not depend on the manufacturing process.

Next stage is the study of existing RMS and the selection of the optimum one for UAV applications.

2.2 RAPID MANUFACTURING SYSTEMS

RMS are rapid manufacturing methods of components or industry systems, of polymer or metal material, from a digital supported information, CAx technologies. The basic target for this fabrication systems is the cost reduction of final products by rapid initial prototyping in the concurrent engineer applications. [8]

Rapid manufacturing techniques depends on the component type and the process:

1. The subtractive process of removing materials such as steel, stainless steel, aluminum or titanium using multi-axis CNC machining centers to turn, mill, rout, cut and drill components down to the width of microns from huge lumps of bar stock, forgings or castings is expensive and requires a lot of energy, time and space. [9]
2. The additive manufacturing is increasing a migration away from traditional metal-based manufacturing techniques. The innovative companies are currently applying it to their products and taking advantage of its potential by having low-cost tooling especially for parts made with composite materials. [8]

Types of additive manufacturing [10]:

- Selective Laser Sintering (SLS)
- Direct Metal Laser Sintering (DMLS)
- Fused Deposition Modeling (FDM)
- Stereo-lithography (SLA)
- Laminated Object Manufacturing (LOM)
- Electron Beam Melting (EBM)
- Powder Bed and Inkjet Head 3D Printing
- Plaster-Based 3D Printing (PP)

Attachment: in Annex II RMS systems are analyzed and the optimum one is selected (see page 29 of this document). The selection has been supported by a Press take decision method. Optimum system for UAV application has been 3D printing RMS because it is a new, rapid, multi material and low cost technology.

The next stage has been the analysis and knowledge of 3D printing technology in order to use it in a new UAV design.

2.3 3D PRINTING TECHNOLOGY

3D printing technology have been developed in Annex III attachment. This document explains 3D printing situation, Patents analysis and a selection of the optimum machine for CATUAV applications is done.

Optimum 3D printing device has been the RepRap[4] BCN 3D+ [11], see Figure 2, a self-replicating printer and OPEN SOURCE made in Barcelona for the Fundació CIM[5].

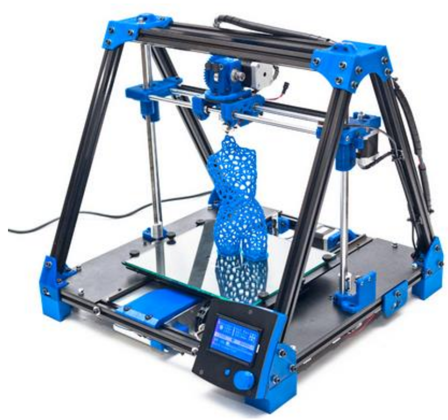

Figure 2: RepRap BCN 3D+ [11]

Key attributes of this 3D printing model have been compared with ULTIMAKER[6] 2 and AW3D HD. The result has showed that RepRap is the best option in *cost* and *support* because it is not assembled and its R&D office is located in the Barcelona UPC Campus, 1 hour from the CTC location. About the *accuracy*, *Z axis height* and *printing speed* features the best option has been the new model of the Airwolf 3D[7] Company, but it is too expensive and made in the USA, becoming its leading time unacceptable.

[4] RepRap is an open source 3D printing community. http://reprap.org/wiki/RepRap

[5] Fundació CIM, Company attached to Barcelona TECH of knowledge engineering and technology management http://www.fundaciocim.org/es

[6] ULTIMAKER. Netherlands 3D printing manufacturer. https://www.ultimaker.com/

[7] AIRWOLF 3D. USA 3D printing manufacturer. http://airwolf3d.com/

This study has considered that home 3D printing technology requires a close user's community because this is a new technology under daily updates. Engineering experience demonstrates that close technical service is a mandatory rule for a delicate new machine. [12]

RepRap BCN 3D+ basic features have been enumerated, see Table 3. This information shows the Open Source philosophy, the low cost device, the close support service, the high speed performance and the accuracy, the big printing volume and the multi-material availability.

Feature	Value	Units
MODEL	RepRap BCN 3D+	
MANUFACTURER	Fundació CIM	
PATENTS	Open Source	
COST	740	€
SPEED	200	mm/s
PRINT LAYER HEIGHT	0,1	mm
PRINT TOLERANCE	0,05	mm
MAX BUILT HEIGHT	200	mm
MAX BUILT WIGHT	210	mm
MAX BUILT LENGTH	240	mm
NOZZLE DIAMETER	0,4	mm
FILAMENT	ABS-PLA-NYLON	

Table 3: RepRap BCN 3D+ printing features [11]

Once a conclusion for 3D printing selection was reached, the author of this study had to buy a 3D printing system and install it at home with own investment. It was a critical path of this study because daily testing is an important stage to develop 3D printing technology for UAV application.

2.4 MATERIAL

Reprap 3D+ printer supports ABS, PLA and NYLON as basic and recommended materials. This study have tested all them comparing the resultant mechanical properties and the printing performance in order to know the optimum material for UAV applications, see attachment: ANNEX IV.

2.4.1 Material Selection

A Press method have been used in order to select the optimum material for the 3D printed UAV manufacturing stage.

ABS	1,17
PLA	1,46
NYLON 6	0,53

Table 4: Material selection. Press method result [ANNEX IV]

The take decision method shows that **PLA** is the most interesting option for the application of this study, UAV, because it is biodegradable while has acceptable mechanical properties, but operational empty weight of the estimated UAV will be 16% greater than the same ABS model and a heat transfer study could be required in the next engine parts.

Since this moment this study will use white PLA material for all 3D printed parts. The philosophy of this study is to create and develop environment friendly technology because it is not possible to know future applications and repercussion of present researching studies.

2.4.2 PLA tensile test

PLA material tensile test, see attachment: ANNEX IV, has been made in the ETSEIAT materials laboratory in March, 9th 2014 with the support and help of Dra. Silvia Illescas[8], an ETSEIAT materials science professor. Standard ASTM D638[9] has been

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[8] Dra. Silvia Illescas. ETSEIAT's professor of materials department silvia.illescas@upc.edu

[9] Standards ASTM website: http://www.astm.org/Standards/D638.htm

used in this test where the tensile testing machine pulls the sample from both ends and measures the force required to pull the specimen apart and how much the sample stretches before breaking. [13]

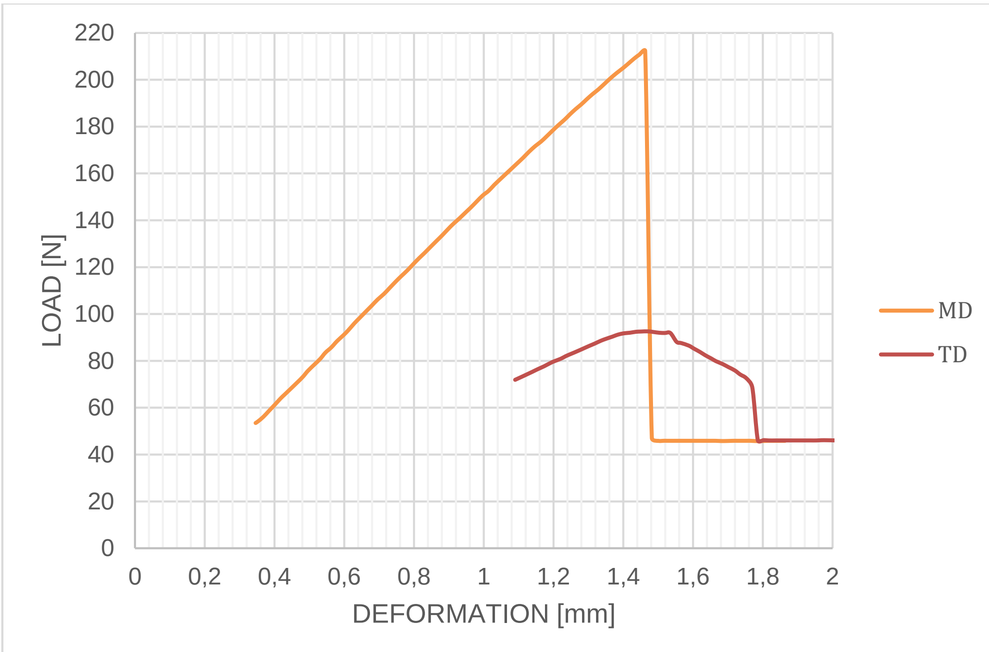

Figure 3: PLA Tensile Test graphic [ANNEX IV]

PLA tensile test result, see Table 5, shows the difference between MD and TD elastic modulus. The test result has been 968MPa for PLA Young Modulus, inside the PLA referenced range (350-2800 MPa) [14]. MD sample is 2.3 times TD, this result is the justification of the tensile test because 3D printing designer must take into account that final part will become anisotropic with a half reduction of mechanical properties in the transversal direction, the Z printing axis.

	width	Thickness	Maximum load	Maximum tensile	Modulus
Units	[mm]	[mm]	[N]	[MPa]	[MPa]
MD	10	0,8	212,297	26,5	968
TD	10	0,8	92,599	11,6	420

Table 5: PLA Tensile Test results [ANNEX IV]

Since PLA material has been selected and the anisotropic behavior of 3D printed parts has been evaluated, this study has been able to start the testing stage of the RepRap BCN 3D+ printing technology.

2.5 RepRap BCN 3D+ ANALYSIS

UAV application performance will directly depends on the skill and knowledge of new 3D printing technology, see attachment: ANNEX IV. The required targets of this stage have been:

- STL exportation
- G-Code programming
- Lineal model approximation of the printing configuration performance
- Nonsupport material, complex parts methodology
- Printing time and cost estimation
- Help & support community

STL exportation tests has developed methodology to fix **100 µm precision** for UAV applications in the 3D printed aerodynamic design, see attachment: ANNEX IV. This result is useful in order to define constrains in a computed iteration algorithm.

G-Code[10] is used in CNC programming language. It was first developed by MIT Servomechanisms Laboratory in 1950. 3D printing firmware is usable for CNC milling following the NIST[11] RS274NGC G-code standard [15]. Attachment: ANNEX IV, shows the 3D printing configuration parameters in order to slice to G-Code the UAV parts.

The linear model approximation is a statistic method to estimate the functional relationship between a process result and those control factors [16]. In this study, see attachment: ANNEX IV, it is an equation to adjust 3D printer configuration in function of the specific requirements. Linear model tool will allow users to analyze tested parts and be able to define an analytic algorithm to preview printed features.

Last computed coefficients have been:

$$\hat{Y} = 0.207093 - 0.18918X_1^{\,2} \qquad (I)$$

[10] G-Code is a numerical control (NC) programming language

[11] NIST is the National Institute of Standards and Technology. webpage: http://www.nist.gov/manuscript-publication-search.cfm?pub_id=823374

This linear model can only be applied in the tested range and it shows that Z height is a more significant parameter than printing speed parameter for the answer: weight.

High performance with no supporting material requires a specific CAD design methodology. According to this, this study have developed three strategies for 3D printing designers, see attachment: ANNEX IV:

- TREE
- CHEDDAR
- CLICK
- STOP PRINTING

Cost estimation has been checked in this study. Fundació CIM has an accurate information about Reprap 3D printer energy cost since they have a 3D printing service for the UPC community with a 0.12 €/cm^3 cost. The estimated cost for home printing, since the costumer has the 3D printer, has been 0.05€/cm^3 (material and power). [17]

3D printing technology requires a continued updating, configuration and calibration. R&D Fundació CIM department [18] has helped this study in the device assembly and performance for UAV applications.

2.6 PRINTING TEST

Testing stage is a 3D printing process with the most interesting models to know 3D printing technology performance. Red Eyed Tree Frog is a small part with a perfect shape in order to evaluate infill, accuracy and printing angles in the critical direction, see Figure 4.

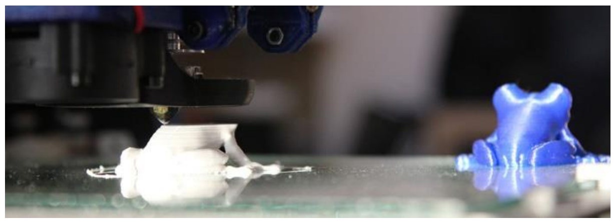

Figure 4: Red Eyed Tree Frog printing test

Another model has been used for mechanical properties, the standard beam shapes. During this process this study has been focused in the next factors:

- Starting print calibration and Bed fixation
- Fluid mechanic analysis
- TREE
- CHEDDAR
- CLICK
- STOP PRINTING
- Lattice 3D honeycomb
- Airfoil
- Maximum Z axis printing

All this stage has been developed in the attachment: ANNEX IV.

2.7 BARCELONA 3D PRINTED UAV DESIGN

With the previous results of the study now is possible to design, manufacture and test in flight the first 3D printed UAV. Therefore, since this moment, this document has become a project of the Barcelona 100% 3D printed UAV. The reasons of this daring step have been:

- Barcelona has become the worldwide city of Design and HP 3D Printing [19]. For this reason the UAV has been called Barcelona.
- ETSEIAT University will have its own 3D printed UAV, becoming the 5th University that has designed a 3D printed UAV. Previous Universities have been: Virginia, Southampton, Sheffield and Massachusetts Institute of Technology.
- CATUAV will be able to pilot the developed technology in order to know the actual feasibility.
- Author will be able to design, 3D print, test and promote a new UAV, becoming the complete cycle of 3D printing technology for UAV application.

Barcelona 3D printed UAV concept has to become: biodegradable, the best weight performance in its technology and only able to be manufactured by 3D printing technology.

2.7.1 Requirements definition

Barcelona 3D printed UAV requirements have been:

- PLA material, because it is biodegradable.
- 1500mm wingspan and 1000mm fuselage length, to be compared with existing 3D printed UAV.
- Less than 2000 g weight, because it is the worldwide best weight performance in similar 3D printed UAV.
- Payload capacity for CATUAV applications.

- Low cost, because this project do not have any private and/or governmental economical support.

- Maximum 120 m level flight, the new limit flight according to AESA[12].

2.7.2 Market reference: MULTIPLEX Easy Star II

Multiplex Easy Star II, see Figure 5, is a high density foam aero model with similar features to Barcelona UAV. Jordi Santacana, CATUAV director, has suggested it as a good reference since it has good flying characteristics and it has been a sales success in the world market.

Barcelona 3D printed UAV will be compared with the nowadays best lightweight UAV technology, foam injection, and with its most popular model, the Easy Star II.

Figure 5: Multiplex Easy Star II

Main characteristics of Multiplex Easy Star II, see Table 6, are:

- Good-natured flying characteristics.

- Strong, ready-made components moulded in tough, resilient ELAPOR® [13] foam.

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[12] *AESA. Agencia Estatal de Seguridad Aérea.*

http://www.seguridadaerea.gob.es/media/4229776/el_uso_de_los_drones.pdf

[13] *ELAPOR®. Is the MULTIPLEX registered high density foam*

- Protected power unit location above the wing.
- Specially matched brushless power set.
- Excellent airborne platform for lightweight cameras.
- Detachable two-parts wing, removable tailplane.
- Rudder, elevator and throttle controls, plus optional ailerons.
- Propeller blades fold back when motor stops, good gliding performance.
- Three-cell LiPo battery for long time flight times.

Wingspan	1385	mm
Fuselage length	880	mm
All-up weight	720	g
Wing area	24	dm^2

Table 6: MULTIPLEX Easy Star specifications

2.7.3 Conceptual Design

Barcelona 3D printed UAV concept design has been based in a standard wing configuration combined with a lightweight and naked fuselage, see Figure 6.

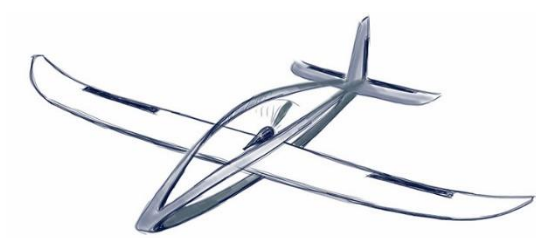

Figure 6: Barcelona 3D printed UAV concept design

The 1500mm wingspan main wing, see Figure 7, has been designed with the most complex shape: with taper, twist, dihedral and winglets. The reason has been that if this type of wing can be manufactured, anyone can demonstrating the feasibility of this technology for UAV applications.

Wing has evolved to the optimum weight versus aerodynamic and structural requirements. Since wing volume has been fixed, the only 3D printing method to optimize weight performance has been the perimeter thickness and the infill.

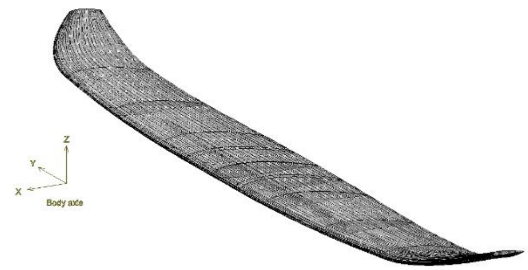

Figure 7: Wing CAD design

The 1000m fuselage has become a new concept design taking advantage of 3D printing new technology. The requirements of the fuselage have been to reduce weight versus typical fuselages, support payload and be only feasible to be 3D printed instead of balsa wood, high density foams or composites.

Fuselage concept, see Figure 8, has consisted in breaking the typical vessel shape, centered in the X body axis, into 3 beams: curved, tapered and twisted. The reason has been to move away materialized area from the Y and Z body axis in order to reduce area while supporting bending and shear.

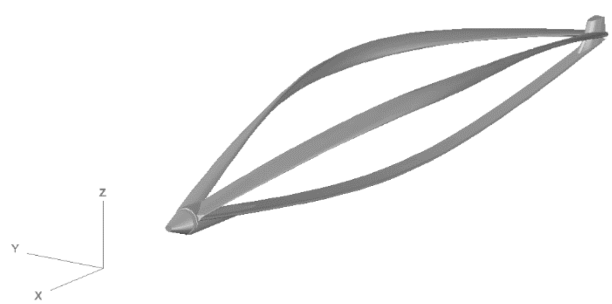

Figure 8: Fuselage CAD design

Barcelona 3D printed UAV new fuselage has reduced weight comparing with the standard fuselages while has allowed the payload safeguard by recovering the 3 beams with a light weight plastic shrink wrap film. This material is used to cover and form the surfaces of an aeromodel. This material is cut to size and applied to the airframe surfaces using a hobby iron or heat gun.

Upper beams have been designed with an elliptical shape because of its high stability performance in buckling. Lower beam has been designed with a planar up-side to take avionic devices and a V shape in the down-side in order to help structural stabilization.

Tailplane, see Figure 9, has been designed with the previous wing requirements and mobile parts. Elevator and rudder have been designed to be 3D printed. This project has tested this performance for the purpose of 3D print fix and mobile part together while allowing the designer control of deflection angle.

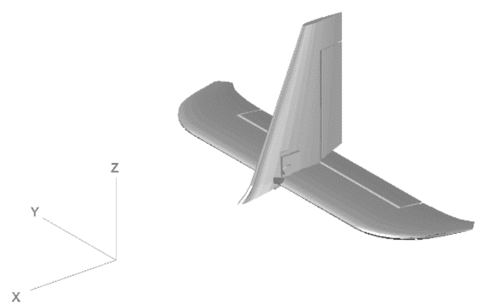

Figure 9: Tail CAD design

Avionics system, see Figure 10, has been designed with the same architecture than the MULTIPLEX model. The same devices have been used in order to compare the final result. Easy Star avionic devices, besides wires and mobile-part horns, are:

- Brushless engine
- Engine speed controller
- Battery
- Receiver
- Servos

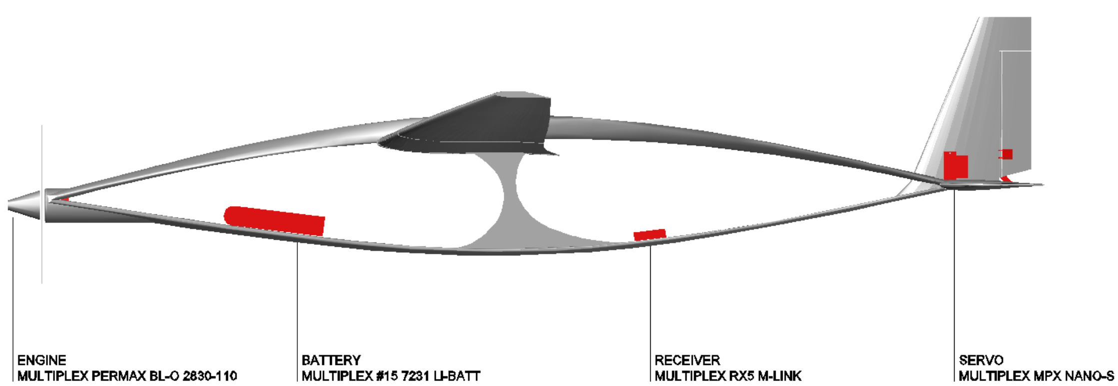

Figure 10: Avionics CAD design

Barcelona 3D printed UAV, see Figure 11, has been designed to start a new 3D printing strategy for UAV applications and other lightweight devices. 3D printing technology is able to print complex shapes that would not be possible by molding with composites or injection foam technologies.

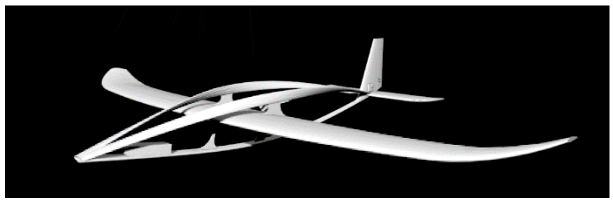

Figure 11: Barcelona 3D printed UAV concept design

Upper estimated weight range, comparing with the 3D printed references, has been 2000g as stated in requirements definition section. The justification is that VAST UAV, designed by MIT Lincoln Laboratory engineers and sponsored by the USA Air Force and Rapid 3D Imaging[14], has this weight performance.

Lower estimated weight range, in order to be competitive with ELAPRON, the German Company registered high density foam, has been 886 g. This value has been computed as a linear scale of Easy Star weight for Barcelona 3D printed wingspan and fuselage length parameters.

Model type	UAV
RMS	3D printing
Printer	RepRap BCN 3D+
Material	White PLA
Wingspan	1500 mm
Fuselage length	1000 mm
Operational empty weight	886-2000 g

Table 7: Barcelona 3D printed UAV design specifications

Since this design, next developed phases of the design have been: Wing, Fuselage, Tail, Aileron and Flight test.

[14] *Rapid 3D imaging is Detroit Exhibition Org. Detriothttp://rapid.sme.org/2014/public/enter.aspx*

2.8 WING

In this project a wing has to be 3D printed from DATA file airfoil. A complex wing shape, with taper, different airfoil transition, twist and dihedral, has been designed to be manufactured. As stated before, the reason of this design complexity is that if it is demonstrated to be possible for this project, simple wings will be possible too.

2.8.1 Design

Barcelona 3D printed wing dimensions are 1500mm wingspan and 200 mm root-chord. Similar dimensions than STATE OF THE ART references and the Easy Star aeromodel.

The main characteristics of the wing design are:

- High performance of aerodynamic efficiency in a wide range of angles of attack. Maximum efficiency in the cruise conditions.

- Tapered configuration. A suitable value of the taper ratio controls the start of the stall in the wing while reducing the mass distribution in the wingtip. Therefore wing has a tapered plan form to the leading and trail edge, variation along the wing

- High wing position. Taking into account the landing stage because this design does not have landing gear.

- The wing has been designed with zero sweep angle because of the low Reynolds, but taper gives an unexpected negative sweep angle since this is the angle between Y body axis and the quarter-chord line.

- Torsion has been added to regulate the stall.

- Dihedral has been designed to add lateral stability.

- Wing incidence angle has been adjusted by moving the curves of efficiency and lift coefficient in order to optimize the cruise conditions.

- Winglet has been designed to add lateral stability since this UAV do not have ailerons.

Parameter	Symbol	Value
Wing area	S_W	25.2 dm2
Wing position		High wing
Airfoil (similar)		NACA 2412
Aspect ratio	AR	8.93
Taper ratio	λ	0.3
Tip chord	C_t	0.6dm
Root chord	C_r	2dm
Mean Chord	MAC	1.68dm
Span	b	15dm
Twist angle	α_t	2.75º
Sweep angle	Λ	7º
Dihedral angle	Γ	2º
Incidence angle	i_w	3º

Table 8: Wing parameters

Wing parameters have been shown on Table 8. This values, according to its definition, have been evaluated since nonlinear equations of a complex shape. Twist angle has been designed in the winglet part, taper has been designed from different edges and dihedral follows a 5^{th} order equation of the Z value along the wingspan:

$$Z = 2E\text{-}12Y^5 - 3E\text{-}09Y^4 + 1E\text{-}06Y^3 - 0.0002Y^2 + 0.0135Y - 0.0295 \qquad (II)$$

High lift devices, ailerons or flaps, have been eliminated from the main wing because 3D printed mobile parts are reduced to elevator and rudder devices only. This concept has allowed the development of a pure wing test and manufacture four wing versions while optimizing weight performance, a basic feature for the aim of this study.

2.8.2 Aerodynamics

Barcelona 3D printed UAV is a low Reynolds number aeromodel. Aerodynamic study is not the aim of this project, thereby this study has used a software developed in previous projects, Albatross UAV, in order to obtain a high aerodynamic performance for 120m level flight.

The starting airfoil, for the iteration method [20], has been NACA 2412, the estimated by measurements Easy Star's airfoil. The result of the study is a 400 points DATA file, see attachment: ANNEX V, that allows start the wing CAD design.

Resulting data file is a complex shape to become extruded and/or lofted in order to design the wing. Since this airfoil is able to be 3D printed the maximum accuracy of the 3D printing technology has been used for the best performance in the aerodynamic computation.

2.8.3 Structure

The wing has been designed as a composed body since it has various requirements. The main loads over the wing are aerodynamic loads, where lift is the highest, leading and trailing edge loads and static pressure loads [21]. The wing elements have been the skin and the core.

A Press selection method has been used to select the optimum structure system for the 3D printed wing. Alternatives that accomplish the requirements have been: monocoque, ribs & spars and foam core systems.

Monocoque	1.30
Ribs and spars	3.40
Foam core	0.29

Table 9: Wing structure selection result by press method [ANNEX V]

Selected wing structure has been the ribs and spars system: results in Table 9. 3D printing technology is able to print internal structure by CAD design or Infill strategy. CAD designed structure has been a difficult process and large in time that sometimes it is not able to be computed. Infill strategy is a rapid strategy with less than 3 iterations to adjust the designed structure. Therefore this project has 3D printed wing parts by Infill iteration method to adjust wing design specifications.

Wing parts supports the maximum loads and torque at the union between wing and fuselage. Moving toward the wing tip, there is a distance where the skin is able to withstand the loads itself. From this distance monocoque would be able to support structural requirements without spars, but testing stage has justified that the minimum perimeter is 600 μm thickness, not enough to ensure aerodynamic airfoil shape. Therefore Infill has been used inside all the wing parts.

2.8.4 Manufacturing

Manufacturing stage has been detailed in the attachment: ANNEX V. This stage has become an interesting evolution of wing weight while optimizing printer parameters and joining parts technology. 3D printed wing parts, see Figure 12, have been adjusted for print size of the RepRap 3D+ printer while any another printing size device only requires a union and subtraction process from CAD software.

The basic wing design has been modified in the root zone for the fuselage union. The reason is that the wing was tested in flight operation with a high density foam fuselage of the Easy Star model during this project.

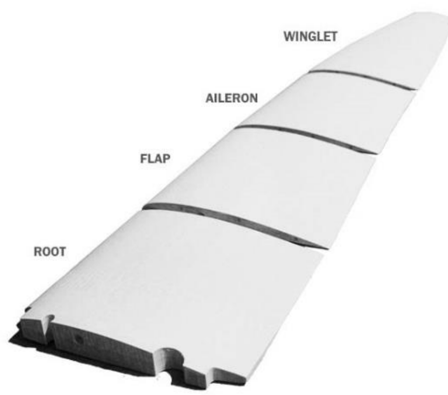

Figure 12: Wing parts

The same wing has been 3D printed four times during the project while developing the optimum performance for UAV applications. These versions have been:

- 1st wing manufacturing test has been focused on 3D print designed complex shape with RepRap BCN 3D+. Beginning from 4000 points DATA file, result has been an airfoil accuracy of ±50 μm because there are 2000 points in a 200 mm chord. This version demonstrates the feasibility of this technology for aerodynamic shape requirements. Wing weight has been measured in 582g.

- 2nd wing manufacturing test has been focused on reduce weight. Infill orientation parameters have been iterated in order to optimize the total weight of the wing. Mechanical properties have not been checked in this stage. Result has been 91% of previous weight while maintaining shape performance.

- 3rd wing manufacturing test has been focused on develop a fast and lightweight union methodology between printed parts. The reason is the bad weight performance of the CFRP connectors and the need of 8 hours to cure the glue adhesive. Result has been a heat welding technology obtaining a 73% of previous weight while maintaining shape performance and union mechanical properties.

- 4th wing manufacturing test has been focused on G-Code programming in order to reduce perimeter thickness. The estimated linear model has been a key tool for this printing performance. Result has been 79% of previous weight while maintaining shape performance, union mechanical properties and perimeter bucking behavior.

This high performance in weight, of the 3D printed wing, shows the interest of the own developed printing methods and the parts union. Wing weight has been reduced from 582g to 308g, obtaining a 53% ratio. Table 10 shows the weight evolution.

The 3D printed wing is 2 times heavier than high density material wing. This value offers a first estimation of the total weight becoming two times the 720g of the Easy Star model. This value, 1440 g, is inside the required weight range, but the new concept of lightweight fuselage could change this estimation becoming a better weight performance.

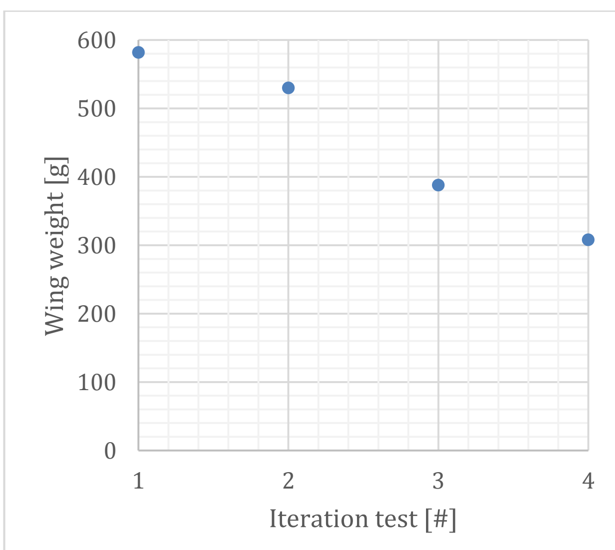

Table 10: Wing weight evolution [ANNEX V]

At the end of this manufacturing process the best wing, see Figure 13, has been 3D printed in a RepRap device during 39h 30min and 12.34 € cost. Used material has been PLA. Wing performance, for specific UAV applications, have been 300 g weight, 50 µm accuracy in the X and Z body axis, 100 µm accuracy in the Z axis and a smoothed shape with print layering in the airstream direction.

Figure 13: 100% 3D printed wing

2.8.5 Ultimate Load wing test

The Ultimate Load test of the 3D printed wing has been made in the Mechanical Properties Department LAB of the ETSEIAT University. Testing tools, method and help, see Figure 14, has been facilitated by Dr. Lluís Gil Espert, professor of this Department.

Figure 14: ETSEIAT Structures department laboratory

The aim of this stage has been to test the wing in order to know if an extra reinforcement is required. Ultimate load of the half wing test showed that the wing has been broken, after more than 3 seconds, in the 1159 g weight step. Therefore total wing in static operation, not flying, supports 2318g. This load performance has been related to the supported G factor by estimated UAV weight.

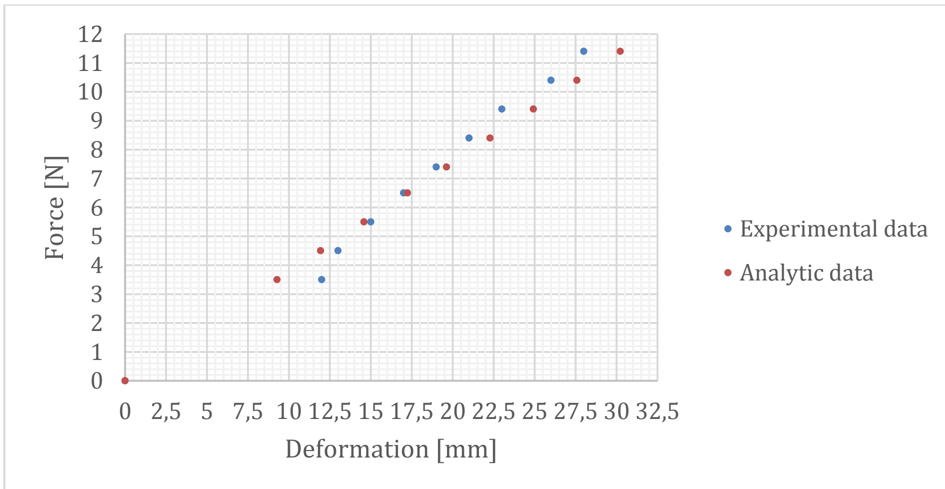

Table 11: Data comparative graph [ANNEX V]

G factor estimation, with 1440g operational weight, has been +1.60G. This is a poor value that could only support cruise operation, but not turbulence, climbing or looping. Since project aim is to flight a 100% 3D printed UAV, the wing must be reinforced to avoid wing collapse, see Figure 15.

Figure 15: Destructive Ultimate Load test

Wing joiner has been designed with GRP (Glass Reinforced Polymer). It has a tubular shape of 8mm diameter, 1mm thickness and 579mm length, the same that Easy Star II aeromodel.

2.8.6 WING Flight test

On April, 10th 2014 in the CTC TSA, Jordi Santacana, CATUAV director, has piloted the 3D printed wing with a MULTIPLEX model fuselage and avionics. Flight tested wing has been the 2nd version for the left side and the third version for the right side, thereby an extra weight, in the right one, has been required for the equilibrium balance, see Figure 16.

3D printed wing tested has been measured in 530g and the mixed UAV in 1085g OEW. Best operation performance has been a looping test with and estimated structural requirement of 3.5G factor.

The success of the flight test has justified that this study becomes a project because the feasibility of 3D printing technology in UAV applications has been demonstrated and real tested.

Figure 16: Wing flight test

2.8.7 WING result

Barcelona 3D printed UAV wing will be the best performance of this study. The 1500mm wingspan wing of the last version has been 3D printed in 40 hours with 8 stages, the estimated cost has been 12,34€ and total weight near 300g, see Table 12.

	UNITS	VOLUME	PLA FILAMENT	TIME	COST	WEIGHT
		cm3	mm	h:m:s	€	g
WINGLET	2	21.2	3167	4:42:22	1.06	26.08
AILERON	2	30.4	4546	4:35:29	1.52	37.39
FLAP	2	32.6	4869	4:44:11	1.63	40.10
ROOT	2	39.15	5845	5:43:57	1.96	48.15
TOTAL		**246.7**	**36854**	**39:31:58**	**12.34**	**303.44**

Table 12: Wing information

2.9 TAIL

Barcelona 3D printed tail has been designed with a fuselage mounted configuration, conventional aft tail and one aft vertical tail. Barcelona UAV longitudinal stabilizer has been designed as a negative lift tail. This document will not detail the design process for the whole Tail configuration since this is not the aim of the study.

Airfoil symmetric selection has been a WORTMANN FX 76-120. Reason for this airfoil choice has been the low Reynolds performance [22]. Data alignment in the thickness direction has been designed in CAD software in order to optimize computation while obtaining high accuracy, see Figure 17.

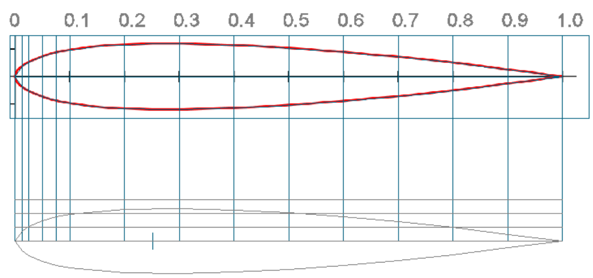

Figure 17: WORTMANN FX 76-120

First Tail design specifications have been evaluated taking as reference the volume coefficient of a motor glider UAV [23].

HORITZONTAL TAIL		
V_h	0.6	
L_h	5.84	dm
S h	4.5	dm^2
S h / S	0.17	
Airfoil	WORTMANN FX 76-120	
i_h	0	
AR_h	4.5	
Taper ratio	1	
Sweep angle	0	º
Dihedral Angle	0	º
b_h	4.72	dm
C_r	1	dm
C_t	1	dm

ELEVATOR		
S_e / S_h	0.24	
C_e / C_h	0.35	
b_e / b_h	0.64	
δ_e +	25	º
δ_e -	30	º

Table 13: Horizontal Tail specifications

Reliably of computed specifications, see Table 13, has been checked comparing with referenced models becoming near 95% of accuracy versus MULTIPLEX. However Barcelona UAV has a new fuselage concept with a different aerodynamic interference between fuselage and tail that would require a new Tail designing process from wind tunnel tests, dynamic tests of the material (PLA) and flight tests.

Horizontal tail design has been modified to customize its tip, see Figure 18. The reason is to show 3D printing potential without interfering significantly the performance of the design. Longitudinal stability computation has modified fuselage length to 1135mm instead of 1000mm first estimation.

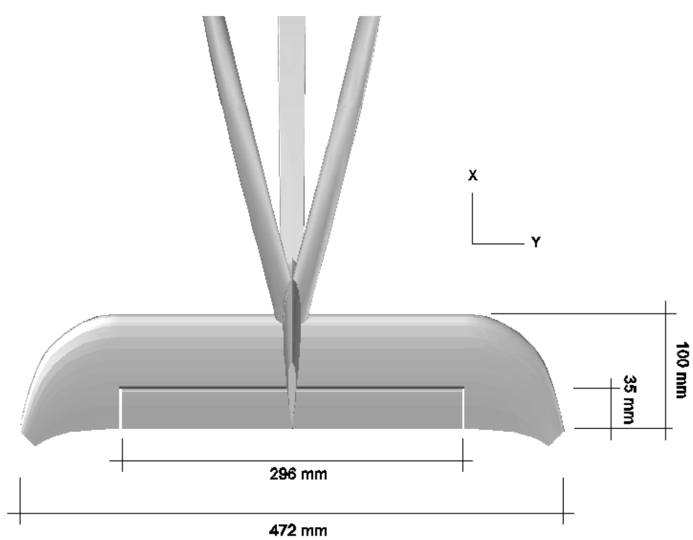

Figure 18: Horizontal Tail dimensions

VERTICAL TAIL		
V_v	0.03	
L_{vt}	5.84	dm
S v	1.8	dm^2
S v / S	0.07	
Airfoil	WORTMANN FX 76-120	
i_h	0	
AR_h	1.95	
Taper ratio	0.45	
Sweep angle	15	º
Dihedral Angle	0	º
b_h	1.84	dm
C_r	1.31	dm
C_t	0.58	dm
RUDDER		
S_r / S_v	0.26	
C_v / C_v	0.37	
b_r / b_v	0.71	
δ_r +	25	º
δ_r -	25	º

Table 14: Vertical Tail specifications

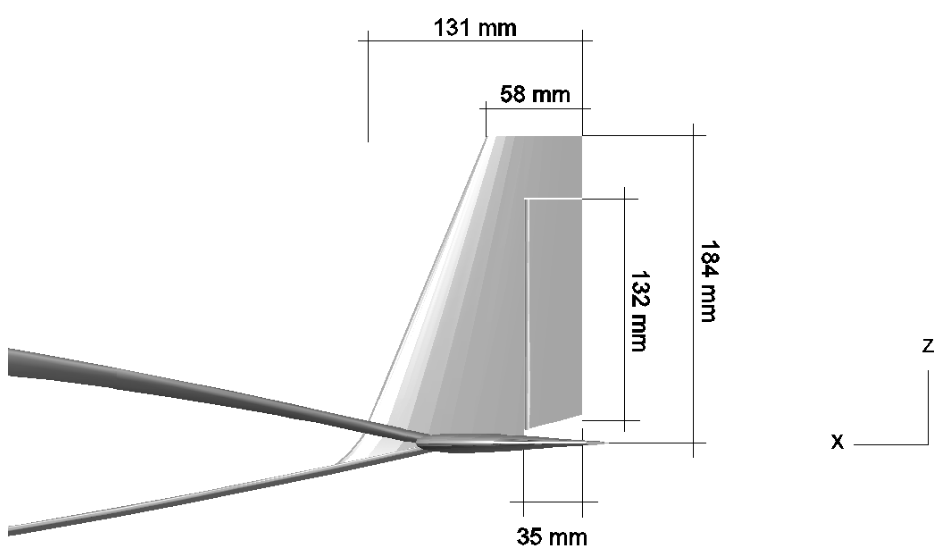

Figure 19: Vertical tail dimensions

2.9.1 Tail parts

The tail has been divided in 6 STL parts to be printed with the RepRap BCN 3D+. Fixed and mobile parts have been printed together, see Figure 20.

Horizontal tail has been divided from the UAV axis for symmetry precision performance. Horizontal tail and tip have been divided because of the 200mm maximum Z axis length.

Vertical tail has been printed in only one STL file in invert position, starting from tip, because of the SERVOs[15] subtract and non-planar surface of the root. TREE method and bed fixation are key tools for its implementation.

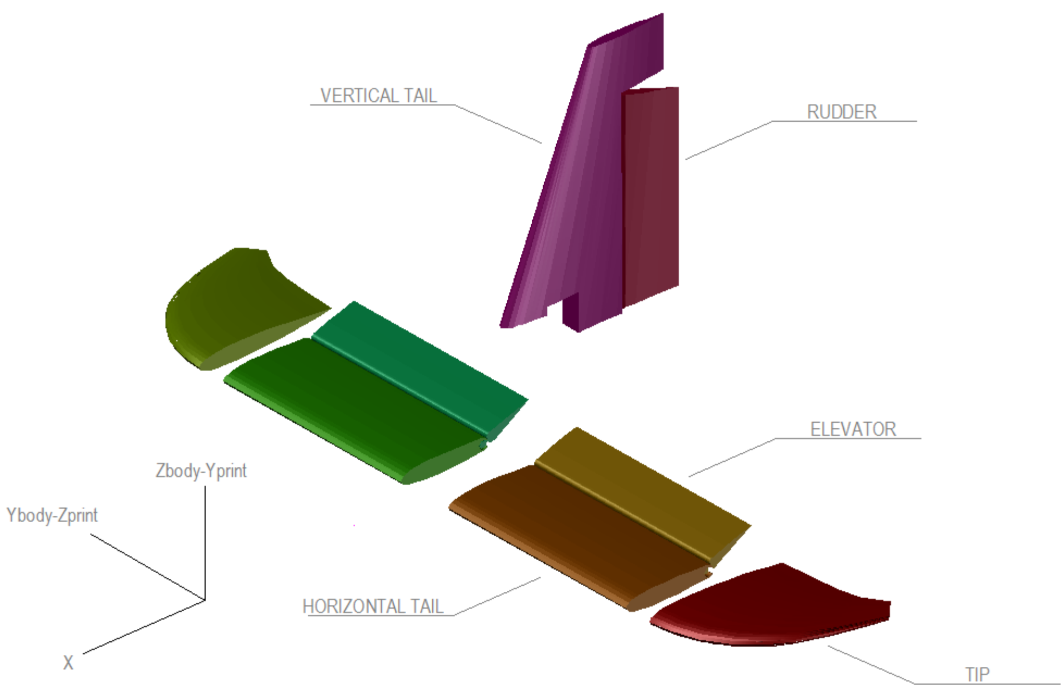

Figure 20: Tail parts

[15] *SERVO rotary actuators used for radio control and small robotics.*

2.9.2 G-Code configuration

G-code parameters has been designed with one only perimeter, 0.25 layer heath and 90 mm/s perimeter speed. Top and Bottom caps has not been printed, but tips, where only one layer cap has been supported using CHEDDAR method , see attachment: ANNEX IV.

; layer_height = 0.25
; perimeters = 1
; top_solid_layers = 0
; bottom_solid_layers = 0
; fill_density = 0
; perimeter_speed = 90
; infill_speed = 60
; travel_speed = 120
; nozzle_diameter = 0.4
; filament_diameter = 2.92
; extrusion_multiplier = 1
; perimeters extrusion width = 0.40mm
; infill extrusion width = 0.53mm
; solid infill extrusion width = 0.50mm
; top infill extrusion width = 0.30mm
; first layer extrusion width = 0.39mm

2.9.3 3D printing

Tail printing process has required more than 12 hours to obtain an excellent weight performance, near 70g. See Table 15.

	PLA Volume	**PLA Filament**	**Time**	**Cost**	**Weight**
	cm3	**mm**	h:m:s	€	**g**
Vertical	14.8	2216.6	3:57:40	0.74	18.20
Horizontal	28.5	4248.7	5:51:32	1.43	35.06
H tips	11.4	1706.3	2:44:30	0.57	14.02
TOTAL	**54.7**	**8171.6**	**12:33:42**	**2.74**	**67.28**

Table 15: Tail 3D printing performance

2.10 FUSELAGE

Fuselage design of the Barcelona 3D printed UAV is a new concept only able to be manufactured by 3D printing technology. The reason of this development is weight performance. Since the better wing weight, in the wing testing stage, has been 300g, the avionics: engine, propeller, throttle, receiver, servos and wire have been estimated in 330g and tail weight 70g. Thereby fuselage required weight is near 200 g in order to obtain the target of have an excellent weight performance compared with high density foam Easy Star II.

3D printed wing versions have justified a 10% factor of PLA weight versus part volume. Computing a standard 1000m fuselage with slice surface of 4000 mm^2, similar to the referenced aeromodel, the first estimation of fuselage weight has been 400g. According to this, the total weight in operation would be near 1100g, better than the same size existing 3D printed UAV but not feasible to become a competitor of the successful ELAPOR® technology.

2.10.1 Concept design

New fuselage concept, see Figure 21, has been designed by dividing the standard fuselage in three parts and separating them from the X body axis but YZ plane.

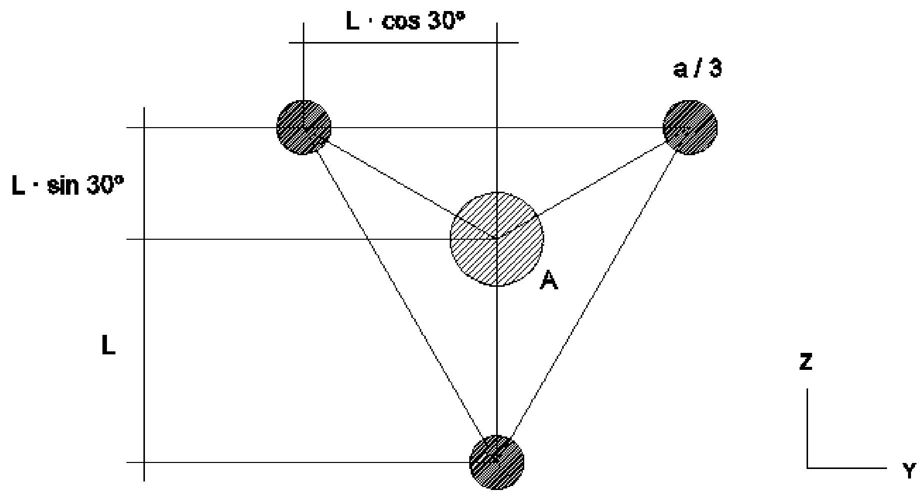

Figure 21: Fuselage new concept

With the hypothesis of the same material, PLA, and with the target of 70% weight reduction:

$$0.3\,A = a \qquad (III)$$

Where: A = π R^2 (standard fuselage area), R= standard fuselage radius, a = π r^2 (Barcelona 3D printed fuselage area), r = Barcelona 3D printed fuselage radius and 30º = π/6 rad. In order to find L(R) and using the second moment of inertia balance between two fuselages with parallel axis theorem (Huygens-Steiner theorem[16]) for the new one:

$$I_Y = \iint_A z^2\,dydz \qquad (IV)$$

$$I_Y = I_{Y'} + Ad_z^2 \qquad (V)$$

$$\frac{\pi R^4}{4} = \frac{\pi r^4}{4}[2\pi r^2(\,L\,sin\frac{\pi}{6})^2 + \pi r^2\,L^2] \qquad (VI)$$

Solving previous equation:

$$L = \sqrt{\frac{2\cdot 10^4}{3\pi\,R^4}} \qquad (VII)$$

This relationship has been used in any differential of distance along the fuselage in function of the structural requirements to support engine load, ahead of the wing, and aerodynamic loads of the tail, from behind the wing.

Before computing, maximum eccentricity (L) of the 3 beams has been estimated by fuselage requirements:

[16] *Huygens-Steiner theorem. Theorem to determine the mass moment of inertia or the second moment of area of a rigid body about any axis*

- Allows the standard payload used for UAV applications, according to Jordi Santacana suggestion.
- Allows the engine position behind the wing, see Figure 22, like the Easy Star model.

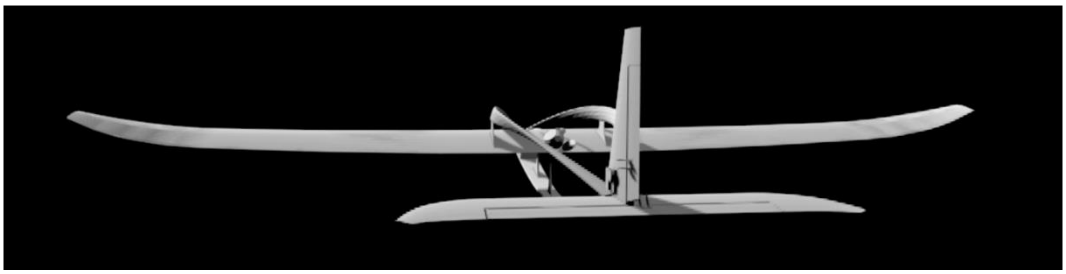

Figure 22: Engine behind the wing

Since propeller diameter is related to the L_{min}=85mm limitation, 5% safety factor has been considered to avoid collision when beams deformation, becoming L_U=90mm. Structural design has been computed with the same equations than the wing test and tail force has been estimated by Easy Star referenced model approximation in order to fix fuselage design in this stage. Result has been 93.6mm, 104% L_U.

Adjusting previous result to ultimate L has been designed by tapering beams with a rounded factor of 70%, from X_{wing} to X_{tail}, and curving them. New computing has not been necessary since the extra 4% was less than safety one.

At this moment the required area for each beam has been evaluated but slice shape. The 2 upper beams have been designed as twisted elliptical beams with a curved path and tapered, with the same area as computed according to 600 μm perimeter thickness. Down beam has been designed flat in the upper side to avoid avionics support and triangulated in the lower side for landing performance requirements, see Figure 23 and Figure 24.

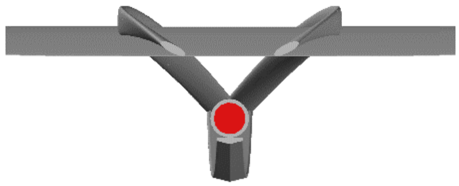

Figure 23: Section X=600mm

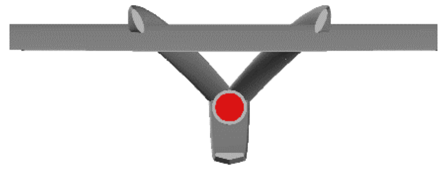

Figure 24: Section X=800mm

2.10.2 3D printing process

The new 1135 mm fuselage of the Barcelona UAV has been divided in 5 parts in order to be printed in the 200mm Z axis orientation. G-Code parameters has been adjusted with only one perimeter and 0% Infill. Printing parameters, according to the studied linear model, has been adjusted for the best speed performance.

Figure 25: Nose 3D printed

Nose part has been an amazing printing process, see Figure 25, because process has been started with 3 different pieces in the bed that when growing on a curved path, they have been twisting and negative tapering while approaching along the Z axis process until they join. Three beams of the middle parts have been printed close to each other, see Figure 26, in order to reduce transition path length of the extruder.

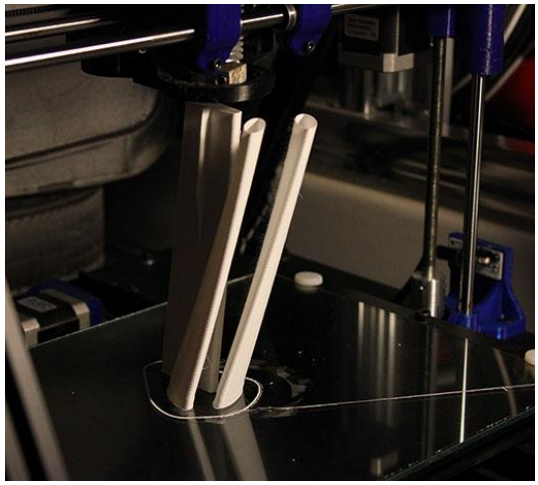

Figure 26: Fuselage beams 3D printed

2.10.3 Avionics

Fuselage has a specific requirement in the engine part because PLA Tg value is 60º and operating engine temperature has been 50º measured while 100% throttle operation. Testing experimentation has been enough to show that fuselage shape has been maintained, see Figure 27, while engine operation in a static position, thereby in flight operation heat interference will be lower because of the airstream. A heat transfer analysis has not been necessary.

Figure 27: Fuselage nose avionics

Wire net, between receiver, servos and speed controller, has not been hidden inside the avionics beam because this model has not been still tested. In case of upgrading or evolution, naked net allows designer to access them.

The assembly process, see Figure 28, has required 12 parts union joined by heat welding, this method has been developed in the wing assembly. Alignment performance has been checked during welding parts because of the uncontrolled material retraction.

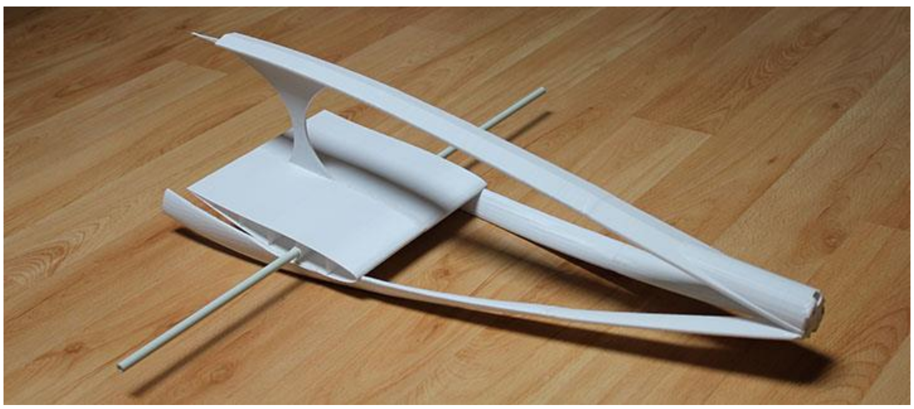

Figure 28: Fuselage assembly

2.10.4 Result

Final fuselage, see Table 16, has been 3D printed with PLA material during 26 hours and 16 minutes. The material cost has been 3.56 € and total weight near 90g. This lightweight fuselage justifies the new designed concept specifically developed for 3D printing technology.

	PLA Volume	**Filament used**	**Printing Time**	**Cost**	**Weight**
	cm3	mm	h:m:s	€	g
NOSE	16.4	2444	5:01:50	0.82	20.17
X200	16.1	2404	4:57:40	0.81	19.80
X400	14.8	2206	4:38:15	0.74	18.20
X600	12.8	1917	4:05:10	0.64	15.74
TAIL	11.1	1656	3:33:39	0.56	13.65
FUSELAGE	**71.2**	**10628**	**22:16:34**	**3.56**	**87.57**

Table 16: Fuselage 3D printing performance

2.11 ASSEMBLY

The assembly process is the joining of the 30 parts of the Barcelona UAV, see Figure 29. The joining technology and process has been the heat welding explained in the wing development (see attachment: ANNEX V).

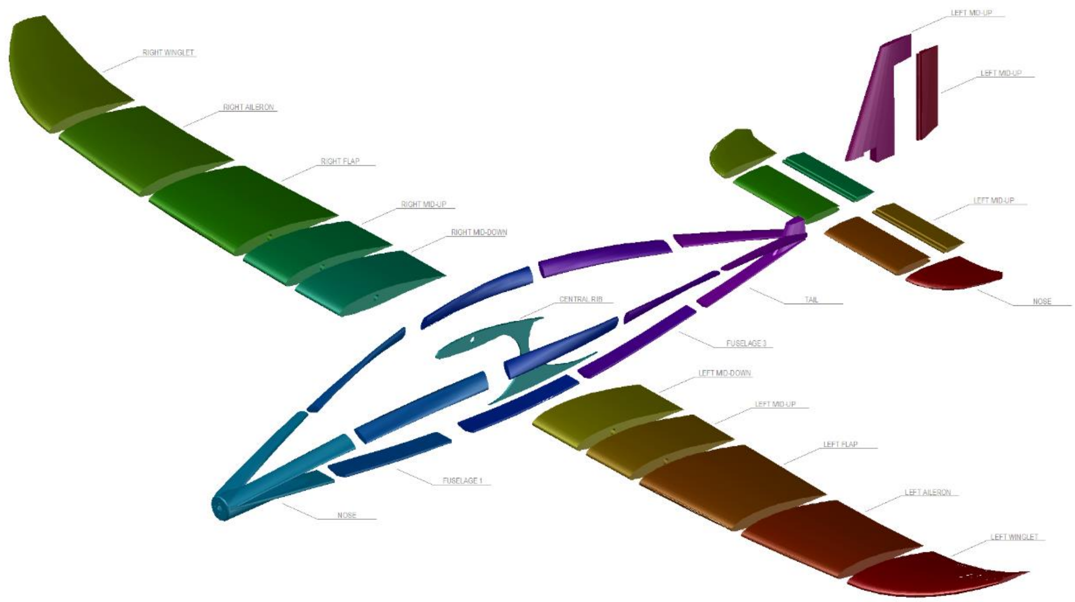

Figure 29: Barcelona UAV parts

Since the parts have been printed, see Figure 30, the only requirement is to check the correct alignment between UAV elements in order to become symmetric and parallel and/or perpendicular in the body axis.

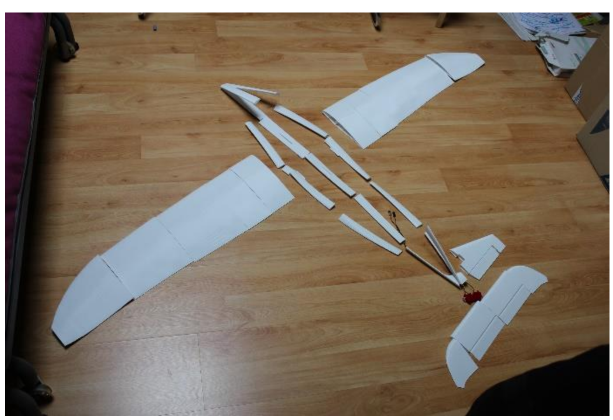

Figure 30: 3D printed parts

2.12 BARCELONA 100% 3D printed UAV flight test

On May, 9th 2014 in the CTC Temporary Segregated Airspace (TSA-31 CTC-MOIA), Jordi Santacana, CATUAV director, has piloted the BARCELONA 100% 3D printed UAV, see Figure 31.

During the transport stage tail of the UAV has been broken. It has been welded in the hangar of the CTC using the same method as assembly.

First flight test, around 5 minutes, has been a contact between pilot and new UAV concept and technology. According to pilot suggestions rudder has been 10mm extended. Second flight test, around 15 minutes, has been a complete test evaluation including a near 3.5G looping. The nose part has been broken when landing.

Figure 31: Barcelona UAV Flight test

CATUAV evaluation has been excellent since it is the first design of this model. The estimated upgrading has been to increase power control by resizing rudder and vertical tail. Other features have been accepted.

2.13 UPGRADE

The flight test has become an evaluation of Barcelona UAV flying performance. Pilot suggestions have been analyzed and adapted to the beta design. Rudder has been extended to total vertical tail length, in order to increase rudder power control. Ailerons have been added in the wing, in order to improve maneuverability.

2.13.1 RUDDER upgrade

The aim of this upgrade is to improve control power by extending rudder to the top of the vertical tail. The reason is a poor rudder control in flight operation. Estimated cause has been the turbulent airstream because of the fuselage and the wing interference. The solution has been to look for the laminar airstream in the upper part of the vertical tail. See Figure 32.

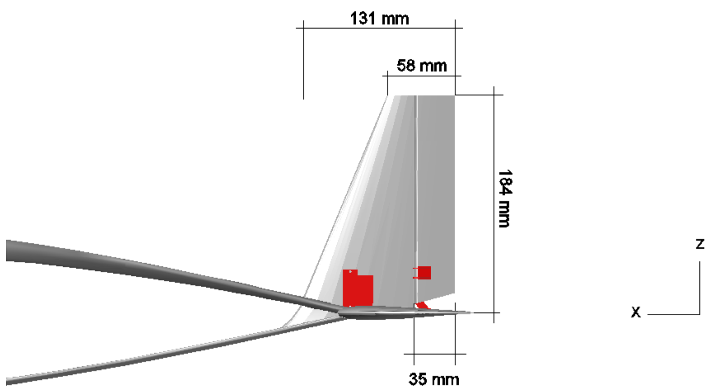

Figure 32: Rudder upgrade

RUDDER UPGRADE 1		
S_r / S_v	0.35	
C_v / C_v	0.37	
b_r / b_v	1.00	
δ_r +	25	º
δ_r -	25	º

Table 17: Rudder upgrade specifications

2.13.2 AILERONS upgrade

According to CATUAV suggestion, 3D printed aileron has been developed. The basic requirements have been:

- High aerodynamic performance.
- One printing stage.
- Independent deflection design.

CLICK method is explained in ANNEX IV, showing the steps for CAD design in order to 3D print an aileron part together with the fix wing, see Figure 33. The fix wing has a cylinder inside the mobile part with an arm length. The mobile part has a specific hole with the same angle as the inverted deflection for the free movement, see Figure 34.

Figure 33: Aileron 3D printing process

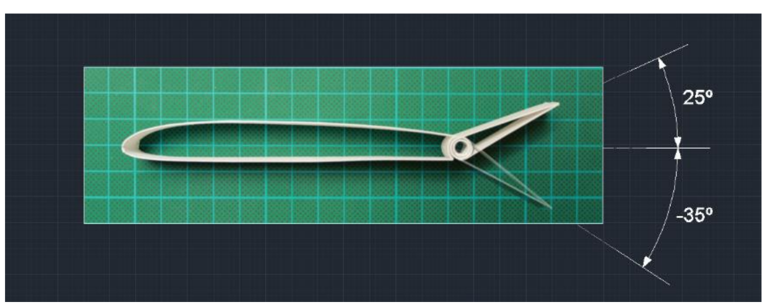

Figure 34: Independent deflection angle

Barcelona 3D printed aileron has been awarded for the UPC Challenge of 3D printing design for engineering applications. Comher[17], STRATASYS Platinum Partner, has manufactured the Barcelona UAV with a FORTUS 400mc 3D printer, see Figure 35. The model has been divided in only 8 parts, instead of 39, and have been printed all together during 130 hours. Barcelona UAV, by ABS30 material, has been presented in the BIEMH[18] 2014. Pavilion 2, STAND F23.

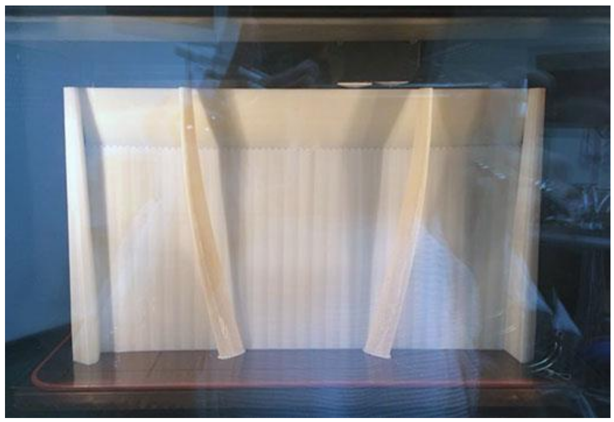

Figure 35: STRATASYS Fortus 400mc printing Barcelona UAV

[17] Comher. STRATASYS Platinum Partner. http://comher.com/

[18] BIEMH. "Bienal Española de Máquina-Herramienta". http://www.biemh.com/

3 RESULT

The result of this study has been the justification and the demonstration of the feasibility of the use of rapid manufacturing technology in a new Unmanned Air Vehicle design.

3.1 BARCELONA UAV

Barcelona 100% 3D printed UAV has been designed with AUTODESK software, 3D printed with PLA material in a RepRap BCN 3D+ and flight tested in the CTC TSA. Table 18 shows its final specifications.

Model type	UAV
RMS	3D printing
Printer	RepRap BCN 3D+
Material	White PLA
Wingspan	1500 mm
Fuselage length	1135 mm
All-up weight	845 g
Wing area	25,2 dm^2
PLA Material & Manufacturing Energy Cost	18,63€

Table 18: Barcelona 3D printed UAV specifications

The weight distribution is 55% PLA biodegradable material, 39% Avionics (engine, speed controller, receiver, servos, horns and wires) and 6% Composites reinforcement. See Figure 36: Barcelona UAV weight ratios

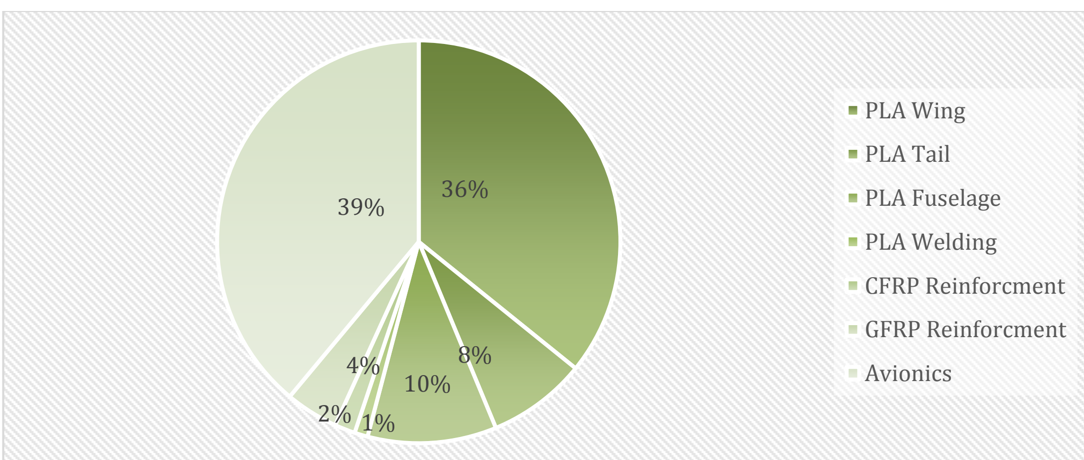

Figure 36: Barcelona UAV weight ratios

Finally it is possible to evaluate Barcelona UAV comparing it with the 3D printed referenced models and the nowadays best weight performance in this technology UAV, the high density foam MULTIPLEX Easy Star II aeromodel. See Table 19.

UAV	Year	Manufacturing System	Weight	Wingspan	Weight/Wingspan	[g/mm] vs Barcelona
			[g]	[mm]	[g/mm]	
SULSA	2011	FDM	3000	1200	2.50	4.44
WENDY	2012	FDM	-	1981	-	-
VAST AUAV	2013	FDM	3175	2032	1.56	2.77
ARMC	2014	FDM	2000	1500	1.33	2.37
Barcelona UAV	2014	**FDM**	**845**	**1500**	**0.56**	**1.00**
EASY STAR II	2012	HD Foam	720	1385	0.52	0.92

Table 19: Referenced UAV comparative results to Barcelona UAV

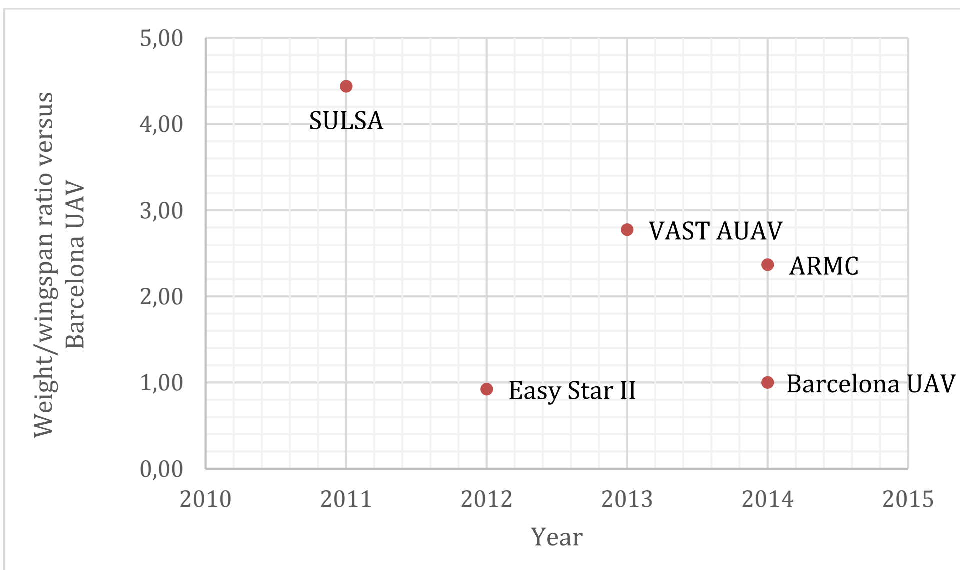

Figure 37: Comparative graphic between referenced UAV

This comparison, see Figure 37, shows that Barcelona UAV is the best 3D printed UAV in weight performance, the aim of this project.

Advanced Manufacturing Research Center [7], in the University of Sheffield, and BOEING[19] developed 3D printed UAV, see Figure 38, which has been the 2nd best weight performance, but it is a flying wing glider. Taking into account that the other references have been evaluated with engine weight included, VAST AUAV or SULSA seem to be considered the 2nd best weight performance.

Figure 38: AMRC 3D printed UAV

Massachusetts Institute of technology [6], Lincoln laboratory, developed VAST AUAV in 2013, see Figure 39. This project was sponsored by the Air Force under contract number FA8721-05-C-002, therefore with the United States Government sponsoring. The other sponsor of this project was *rapid* 3D IMAGING[20].

Figure 39: VAS AUAV

[19] BOEING COMPANY is an American multinational corporation that designs, manufactures and sells fixed-wing aircraft, rotorcraft, rockets and satellites

[20] Rapid. USA Exhibition on 3D: printing, scanning and additive manufacturing. Produced by sme. http://rapid.sme.org/2014/public/enter.aspx

This interesting UAV has a CFRP fuselage beam from 3D printed nose to tail, becoming a composites lightweight performance. For this reason this study has considered that in case of VAST would be a 100% 3D printed UAV it would be heavier than the designed with mixed technology.

Therefore SULSA, see Figure 40, has been the 2^{nd} best weight performance in the balanced comparison of the weight performance for existing 100% 3D printed UAV.

Figure 40: SULSA

University of Southampton has develop SULSA [4], a UAV that is the 1^{st} 3D printed plane and the 2^{nd} best weight performance in the world of a propelled 100% 3D printed UAV. SULSA, with 6.174,68 € budget, has been sponsored by a UK-based 3D-printing firm, 3T RPD[21].

Barcelona 3D printed UAV is only a 28% of SULSA weight and, taking into account the different wingspan, it is 22% of SULSA weight/wingspan ratio. Becoming an amazing result of this project.

Comparing with the MULTIPLEX Easy Star II, it is required to compare the ratio of the weight / total span (wing + fuselage), see Table 20.

[21] 3D RPD. Rapid prototypes Company, Berkshire. http://www.3trpd.co.uk/

UAV	Manufacturing System	Weight	Wingspan	Fuselage span	Weight / total span
		[g]	[mm]	[mm]	[g/mm]
Barcelona UAV	**FDM**	**845**	**1500**	**1135**	**0.32**
Easy Star II	HD Foam injection	720	1385	880	**0.32**

Table 20: Barcelona UAV comparison with the best weight performance in traditional technology

Barcelona 3D printed UAV has the same weight performance that injection technology of high density foam, ELAPRON®. Since this evaluation has balanced the alternatives, the fuselage, wing and tail cost have been compared in order to tiebreaker them.

Multiplex Easy Star II is 78.90 € cost, including taxes and excluding avionics. Barcelona UAV is 18.63€ cost, including taxes and energy cost and excluding the RepRap BCN 3D+ printer cost. Taking into account that RepRap has a 3D printing service in the Barcelona UPC Campus with a cost of 0.12 €/cm^3, the cost of the Barcelona UAV is 44.71€, including taxes. Therefore the Barcelona UAV cost is 57% of the Easy Star II.

Worldwide costumers or Companies, without Barcelona UPC campus access, have to buy a 3D printer and, in case of the RepRap BCN 3D+, the number of 3D printed UAV to equal the cost performance of the Easy Star II is 7.58 units.

This is an amazing result of this project because it demonstrates the feasibility of 3D printing technology in UAV applications. This document has demonstrated that the 3D printing service of the Barcelona UPC Campus is the best option for 7 or less units and in case of more than 7 units of the 3D printed UAV the best option is to buy your own low cost 3D printer.

3.2 ENVIRONMENT

This study development and result have used a low cost 3D printer: RepRap BCN 3C+, a renewable resource material: PolyLactic acid (PLA) and a low energy cost technology.

This environmental friendly study has had a total PLA material and energy cost of near 18.63 € for the Barcelona UAV manufacturing, see Table 18, near 40.85 € for the wing evolution tests, see attachment: ANNEX V, and near 5.42 € for testing stage 3D printing. Total white PLA material used in this study has been 2Kg, becoming 2 filament coil units.

3.2.1 Standards

There are currently few international organizations which have established standards and testing methods for compostability:

- American Society for Testing and Materials — ASTM-6400-99
- European Standardization Committee (CEN) — EN13432
- International Standards Organization (ISO) (only for biodegradation) — ISO14855
- German Institute for Standardization (DIN) — DIN V49000

The ASTM, CEN and DIN standards specify the criteria for biodegradation, disintegration and eco-toxicity for a plastic to be called compostable. This study has used the ASTM reference.

In the United States, the Federal Trade Commission[22] and the EPA[23] are the authoritative Institution for biodegradable standards.
ASTM International defines methods to test for biodegradable plastic, both anaerobically and aerobically as well as in marine environments. The specific subcommittee responsibility for overseeing these standards falls on the Committee D20.96 on Environmentally Degradable Plastics and Bio based Products. [24]

There are two testing methods for anaerobic environments they are the ASTM D5511-12 or ASTM D5526 - 12 Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under Accelerated Landfill Conditions [25].

3.2.2 Environmental benefits

The total carbon, fossil fuel and water usage in manufacturing bio plastics from natural materials and whether they are a negative impact to human food supply has not been evaluated in this study since it has not the knowledge and data for it, but it has been referenced.

The material used in this study: PolyLactic acid, takes 2.65 kg [14] of corn to make 1 kg of this common commercially compostable plastic.

3.2.3 Energy cost for PLA production

PolyLactic acid (PLA) has been estimated to have a fossil fuel energy cost of 54 - 56.7 from two sources, [26] [27] but recent developments in the commercial production of PLA by Nature Works[24] has eliminated some dependence of fossil fuel-based energy by supplanting it with wind power and biomass-driven strategies.

[22] Federal Trade Commission to prevent business practices that are anticompetitive or deceptive or unfair to consumers. http://www.ftc.gov/about-ftc

[23] EPA is the United States Environmental Protection Agency. http://www.epa.gov/

[24] Nature Works LCC is an independent company invested in by Cargill and PTT Global Chemical, which efforts in green chemistry and bio refinery. http://www.natureworksllc.com/

They report making a kilogram of PLA with only 27.2 MJ [28] of fossil fuel-based energy and anticipate that this number will drop to 16.6 MJ/kg in their next generation plants.

In contrast, polypropylene and high density polyethylene require 85.9 and 73.7 MJ/kg [29], respectively, but these values include the embedded energy of the feedstock because it is based on fossil fuel.

3.2.4 PLA – PP – PET - EPS energy comparison

This study has make a comparison between energy cost of PolyLactic acid PLA, the material used in this study, Polypropylene (PP), Polyethylene terephthalate (PTE) and Expanded Polystyrene (EPS). Materials commonly used in transversal industry production.

Resin	Energy	Emissions	Water
	KWh	Kg CO2	L
PLA (Corn)	16.31	0.27	69.27
PP (Plastic)	20.42	1.70	43.11
PET (Plastic)	22.45	2.80	62.16
EPS (Styrofoam)	24.66	2.50	171.54

Table 21: From Earth to Resin. Resources required to produce 1 Kg of material [28] [29]

Resin	Energy	Emissions	Water
PLA (Corn)	100%	100%	100%
PP (Plastic)	125%	630%	62%
PET (Plastic)	138%	1037%	90%
EPS (Styrofoam)	151%	926%	248%

Table 22: From Earth to Resin. PLA values have been set at 100% for benchmarking

Conclusions:

- PLA requires the least amount of energy to produce. PP requires 25% more, PET requires 38% more and Styrofoam requires 51% more.

- PLA releases the least amount of carbon dioxide during production. PP releases 6.3 times more, Styrofoam releases 9.26 times more and PET releases over 10 times more.

- PLA requires more water to produce than PP and PET, but less than Styrofoam. PP requires 38% less, PET requires 10% less but Styrofoam requires 2.48 times more.

Finally this energy study has demonstrated that biodegradable material has been an environmental friendly selection since PLA energy cost is the least amount of energy to produce. Table 23 shows the total energy cost of this study, for 2Kg of PLA.

	Energy	Emissions CO_2	Water
PLA	32.62 KWh	0.54 Kg	138.54L

Table 23: Energy cost of the PLA used in this study

3.3 MARKETING

Taking advantage of the 3D printing technology the Barcelona UAV has been worldwide presented and promoted. The key marketing events have been a Youtube channel and thinginverse website.

3.3.1 Barcelona UAV *Youtube* channel

Barcelona UAV wing flight test and 100% 3D printed flight test videos have been uploaded into a Youtube channel [30]. This channel has had more than 10000 views in the first month. The interest of this website is to analyze the TOP 10 viewers by geographies, see Table 24.

United States	24.0%
Spain	13.0%
Germany	6.7%
France	4.8%
United Kingdom	4.1%
Australia	3.7%
Canada	3.4%
Netherlands	3.3%
Italy	2.6%
Switzerland	2.2%
Others	32.2%

Table 24: Barcelona UAV Youtube channel top 10 geographies views

USA is the most interested country in 3D printing technology for UAV applications. Youtube channel analytics is able to show the connecting states ranking from the USA and California has been the first viewer of Barcelona UAV. Therefore this project that has started from a trip of Jordi Santacana, CATUAV director, to Washington is now being mainly followed in the country where it was born.

3.3.2 Barcelona UAV *Thinginverse* website

This new marketing concept has worked by uploading Barcelona 3D printed UAV STL files[31] to *thinginverse*[25] website. This is a Makerboot[26] page that allows to download 3D printing parts. The result has been more than 1000 downloads in the first month.

This is a new design concept because it means that there are more than one thousand beta-testers, see Figure 41, and developers of the Barcelona 3D printed UAV. At this moment it is a worldwide project and nobody knows the new aims, scope and result of this OPEN SOURCE design.

Figure 41: Red winglet part 3D printed by Barcelona UAV beta-tester

[25] *Thinginverse is a Makerboot website of 3D printing STL parts. http://www.thingiverse.com*

[26] *Makerboot is a USA 3D printer's manufacturer. https://www.makerbot.com/*

3.4 STUDY PLAN

3.4.1 Tasks identification from work breakdown structure (WBS)

A. CUSTOMIZED RMS FOR CATUAV APPLICATION
   1. Requirements understanding
   2. RMS study
   3. UAV manufacturing study
   4. State of the art
   5. RMS CATUAV application decision

B. KNOWLEDGE AND AVAILABILITY OF THE SELECTED SYSTEM
   1. Ready to use technology
   2. Study of Digital to CN files
   3. Learning tests and prototypes

C. PROTOTYPE MANUFACTURING
   1. CAD design development
   2. Parts union system
   3. Prototype manufacturing
   4. Measurements
   5. Validation
   6. Recycling efficiency

D. FEASIBILITY
   1. Feasibility of the use of RMS in UAV design Documents review

3.4.2 Brief tasks description

A1 Requirements understanding: Request CATUAV meetings (via Skype) in order to perfectly understand requirements of the study and desires.

A2 RMS study: Knowledge of the rapid manufacturing systems by technical sources, patents, reviews, books and industry meetings (workshops and/or exhibitions)

A3 UAV manufacturing study: Knowledge of the UAV regulations by EASA Policy Statement Airworthiness Certification of UAS.

A4 State of the art: Study of the nowadays UAV existing models manufactured with RMS.

A5 RMS CATUAV application decision: Selection de optimum RMS for UAV application.

B1 Ready to use technology: Availability of existing technology in order to develop the study.

B2 Study of Digital to CN files: Study the main parameters and limitations of SLT files created by CAD software.

B3 Learning tests and prototypes: Trial and error process to acquire the required performance for the development of this study.

C1 CAD design development: Design a new UAV model to be manufactured by the proposed RMS.

C2 Parts union system: Develop a joining method for manufactured parts.

C3 Prototype manufacturing: Assembly process.

C4 Measurements: Define the precision and accuracy of the used technology.

C5 Validation: Compare the results with the traditional UAV manufacturing system.

C6 Recycling efficiency: Evaluate environmental and energy cost of the study.

D1 Feasibility of the use of RMS in UAV design: Final evaluation of the study.

3.4.3 Interdependency relationship among tasks

Code of task	Task identification	Plan start [week]	Plan Duration [weeks]	Preceding task(s)
A1	Requirements understanding	Start	1	Start
A2	RMS study	1	2	A1
A3	UAV manufacturing study	1	1	A1
A4	State of the art	1	1	A1
A5	RMS CATUAV application decision	3	1	A2, A3 & A4
B1	Ready to use technology	4	2	A5
B2	Study of Digital to CN files	4	1	A5
B3	Learning tests and prototypes	6	1	B1
C1	CAD design development	5	1	B2
C2	Parts union system	7	2	B3
C3	Prototype manufacturing	9	3	C1 & C2
C4	Measurements	12	1	C3
C5	Validation	13	2	C4
C6	Recycling efficiency	12	1	C3
D1	Feasibility of the use of RMS in UAV design	15	1	C5 & C6

Table 25 Interdependency relationship among tasks

3.4.4 Precedence Diagram AON (Activity on Node Method)

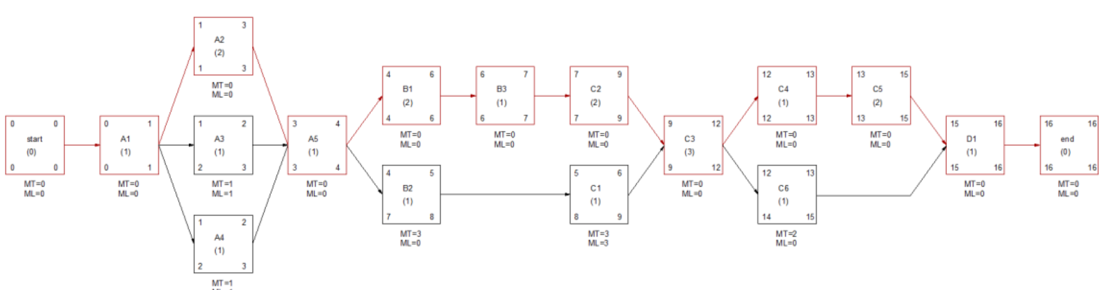

Figure 42: AON Diagram

3.4.5 GANTT Diagram

PROJECT: Feasibility study of the use of rapid manufacturing technology in a new Unmanned Air Vehicle design

DATE: June, 2nd 2014

Task	ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
A1	Requeriments	0	1	0	1	100%
A2	RMS study	1	2	1	2	100%
A3	UAV study	1	1	1	2	100%
A4	STATE OF THE ART	1	1	1	2	100%
A5	RMS decision	3	1	4	1	100%
B1	Ready to use tech	4	2	5	1	100%
B2	Digital CNC files	4	1	5	1	100%
B3	Tests and prototypes	6	1	7	1	100%
C1	CAD design	5	1	6	1	100%
C2	Parts union system	7	2	6	2	100%
C3	Prototype manufacturing	9	3	9	5	100%
C4	Measurments	12	1	12	1	100%
C5	Validation	13	2	13	2	100%
C6	Recycling efficiency	12	1	12	1	100%
D1	Feasibility	15	1	15	1	100%

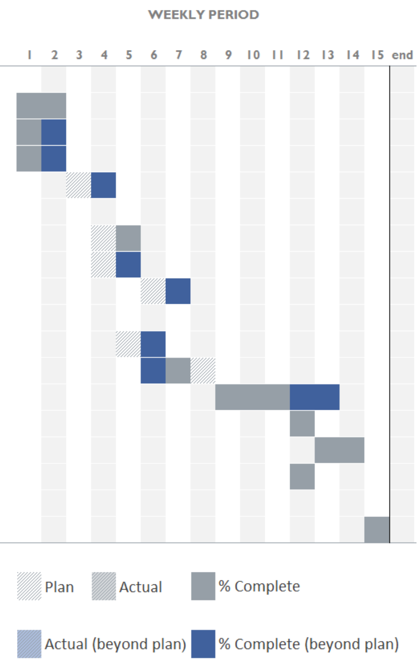

Table 26: Gantt diagram (100%)

The critical paths of this project have been the 3D printer selection and the prototype manufacturing.

The RMS selection, Task A5, has been actual started one week later because there are a lot of 3D printing models and it is difficult to select the optimum one, but this extra week of reflexion and workshop events has been the key of the study because RepRap BCN 3D+ has been able to manufacture Barcelona UAV.

The UAV 3D printing stage, task C3, has become 5 weeks of duration instead of 3. The reason has been the complexity of the UAV design with the new fuselage concept, but the consequence of this decision has been the best weight performance in 100% 3D printed UAV of the world.

3.5 IMPLEMENTATION PLAN

The implementation plan of 3D printing technology for UAV applications has been designed specifically for CATUAV, taking into account the new bioclimatic hangar inside the TSA-31 CTC-MOIA, see Figure 43.

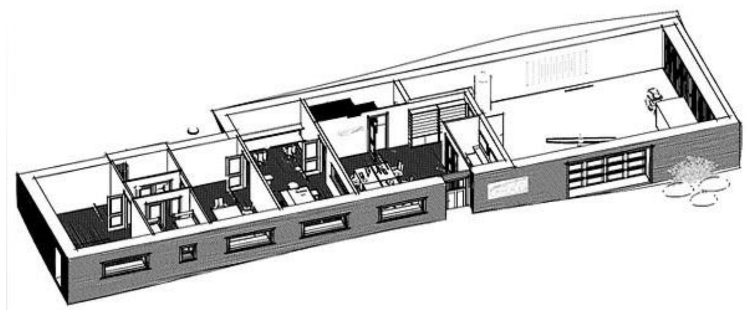

Figure 43: CTC hangar [32]

From right to left the floor layout is: hangar, office, meeting room, laboratory, lounge room and accommodation room. The CTC laboratory is suggested for the 3D printing technology with the RepRap BCN 3D+, the material coils and the welding tools, the office is suggested for the CAD design and hangar is the UAV parking.

3.5.1 3D printing implementation for CATUAV

New 3D printing manufacturing process for CATUAV has been designed to be 100% implemented in the CTC. See Figure 44.

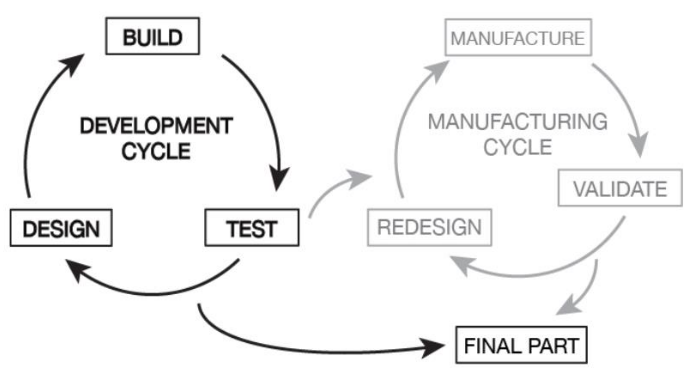

Figure 44: 3D Printing Manufacturing Design Process

3.5.2 Tasks location in the CTC

Office: Design and redesign tasks.
Laboratory: Build, manufacture tasks (this tasks include assembly process).
TSA: Testing and validation tasks.

This study suggests an outside segregated space of 1 cubic meter for excess parts located next to the accommodation room. PLA biodegradable material has 180 days of life in the outside environment [14].

3.5.3 Interdependency relationship among tasks

Code of task	Task identification	Plan start [week]	Plan Duration [weeks]	Preceding task(s)
DC	DEVELOPMENT CYCLE	Start	2	Start
MC	MANUFACTURING CYCLE	2	4	DC
FP	FINAL PART	4	1	DC and/or MC

Table 27: Interdependency relationship among tasks for CATUAV implementation

3.5.4 Precedence Diagram AON

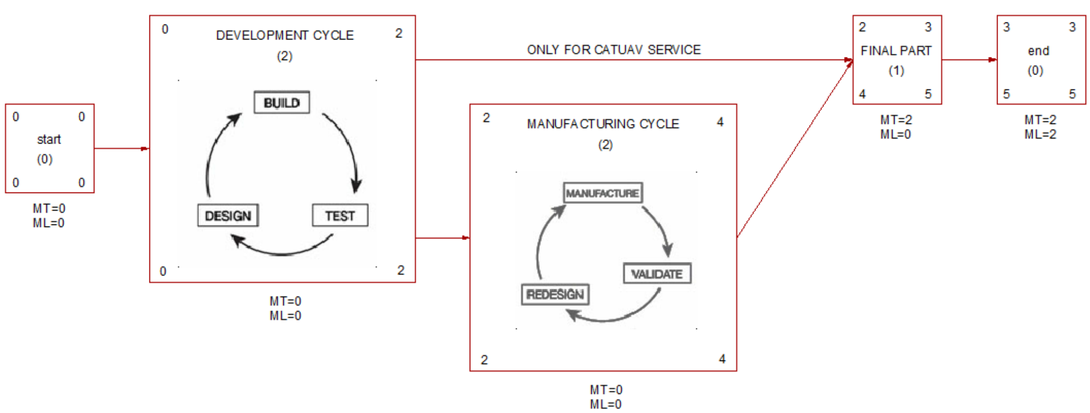

Figure 45: AON Diagram for CATUAV implementation

This is an estimated planning considering one skilled designer for all tasks with no other design coupled. The ending time has been 3 weeks in case of UAV design for CATUAV services or 5 weeks in case of short production series.

3.6 SUMMARY BUDGET OF THE STUDY

The budget of this study has been estimated by the tools, the material, the sources and the software used for its development, see Table 28. Attachment: Budget document shows the measurements, unitary prices and the detailed budget.

Concept	Code	Definition	Cost
Tools	T	Tools required for the study	1255,45 €
Material	M	Material required for the study	97,25 €
Direct cost			**1,352.70 €**
Tasks A	010	Study time	7,309.33 €
Tasks B	011	Engineering time	3,851.39 €
Tasks C	012	Manufacturing time	7,268.00 €
Tasks D	011	Engineering time	3,851.39 €
Indirect cost			**22,280.11 €**
TOTAL BUDGET			**23,632.81 €**

Table 28: Study budget estimation

The estimated budget of this study has been **23,632.81 €** (twenty-three thousand six hundred and thirty-two point eighty-one euros). State taxes, 21% VAT, are not included.

Jonatan Domènech Arboleda
Santpedor June, 4^{th} 2014

3.7 CONCLUSIONS

3.7.1 About the study

Feasibility study of the use of rapid manufacturing technology in a new Unmanned Air Vehicle design has been made by Jonatan Domènech Arboleda, student of the ETSEIAT University in partial fulfilment of the requirements for the Bachelor's degree in Aerospace Vehicle Engineering.

The lead to developing Barcelona 3D printed UAV has been Jordi Santacana, CATUAV director. In the summer of 2013 he assisted to a Silicon Valley conference about 3D printing and came back to Barcelona with the idea of adapting this technology for UAV applications.

The conclusion about the study is that collaboration between University and Private Companies is necessary. In this study: the mix between a devoted student, the University environment and an enterprising man has become to the 1st 100% 3D printed UAV in Barcelona, the 3rd in Europe and the 5th in the world.

3.7.2 About the 3D modelling

Barcelona 3D printed UAV has been designed using Autodesk software, with a student license, the availability of powerful software is a key tool for the knowledge application. 3D modeling skills can only be achieved with a clear target. In this case the target has been to 3D print a new UAV design, only able to be manufactured using this technology. According to this, many CAD softwares have been tested until AUTOCAD, INVENTOR and 3DS MAX became as the best tools to design it, since the community of users and beta testers support and help to get designing skills.

3.7.3 About the 3D printing technology

This new technology is becoming the 3rd Industrial revolution [33]. The future of the consumer market is to buy an internet STL file and print it at home or in a 3D printing service. This new concept affects the traditional industry and the employment, thereby this technology must be analyzed in global terms instead of local. [34]

3D printing technology is a low cost system, comparing with other RMS, to transferring things from the world of the ideas (Platonic concept) to the real one. The 3D printer device selection is an important phase of this study and critical if there is a delivery date of the project. The main requirements for the alternatives of this selection must be the cost, multi material availability, double extruder availability, the open source philosophy and the supplier proximity. The best performance in the previous requirements will allow designer to create something economically feasible, be able to use future new materials, mix different material properties to customize part requirements, configure firmware in order to improve the technology for the specific application and solve stop printing stages in less than 24 hours.

The implementation of a 3D printing specific methodology, adapted to the desired applications, is recommended for the designing team. This study has developed TREE, CHEDDAR, CLICK and STOP PRINTING methods and these have become design standards for high performance UAV development and for an easy communication when sharing experiences.

Linear model is a sadistic tool recommended to know the 3D printing features in function of G-Code parameters. In this study case, linear model has been a useful equation to develop lightweight performance in function of the Z axis height and the printing speed. The maximum Z axis height is the key parameter to reduce part weight.

Direct relationship between time, weight and cost. 3D printing is a technology where investing time in weight reduction has a direct relationship with the cost reduction and the manufacturing time reduction. Some traditional technologies increase cost in function of the weight and manufacturing time reduction.

Joining parts method is an important stage for 3D printing in UAV applications. Since 3D printing technology has a small printing volume comparing with a standard UAV, the part must be joined. UAV specific application requires the development of a heat system able to fuse the slices and become a 100% contact for feasible weight performance.

3.7.4 About the materials

Materials research will be the most important development of 3D printing. Materials with different flexibility, mechanical properties, color and recyclability will be soon available for 3D printing users.

Flexibility is an important development of the materials because double extruder 3D printing will be able to print anisotropic parts. The possibility of 3D print a blade using root flexibility for the first material and tip flexibility for the second and a controlled mix of them along the longitudinal axis, will become an improvement for fluid mechanic engineering.

Mechanical properties of the material can be modified by adding CF nanotubes or similar reinforcements. Nowadays there are ABS materials with high mechanical properties. The minimum perimeter thickness, near 500 μm, and the maximum part size of 3D printing technology are the main limits for the scenario of applications. Therefore improving Young modulus or stiffness new applications will appear.

Color of the filament is an interesting feature for 3D printers with multi extruder because RGB or CYMK basic colors can be mixed to become any color appearance in the differential of surface. This feature will increase 3D printing applications.

Recyclability is the most important performance for 3D printing technology. The reason is that this technology allows user to have a low cost and rapid manufacturing tool. As a consequence a lot of useless pieces are printed to do testing and upgrading. Therefore the possibility of refill coil with waste material is an environmental friendly performance.

Biodegradable material, PLA, is the one used in the Barcelona UAV. Specific applications where your printed parts can be missed in the world must be printed with PLA biodegradable material because it is self-degraded in atmospheric ambient. Be careful with new PLA upgrades because this basic feature depends on the properties of the additive.

3.7.5 About the Barcelona UAV

Barcelona UAV is the lightest 3D printed UAV of the world. Since it has been made with 0.5 Kg PLA and RepRap device, we can see that 3D printer cost is not an important factor, but designer skills.

New fuselage concept is a key design for Barcelona UAV weight performance. During the preliminary design stage this fuselage had some detractors because of the aerodynamics performance and using an expensive manufacturing technology it would not be made. 3D printing allows you to low cost manufacture your ideas and evaluate them in real operation to see if they work properly or not.

3.7.6 About transversal skills by working through this project

Select, think, design, manufacture, test, upgrade and promote something is the complete cycle. Using this technology some transversal skills have been required:

- Aircraft design, in order to design the UAV.
- C++ programming, in order to optimize firmware configuration and G-Code parameters for a high performance for the specific application of the part.
- Statistics, in order to analyze characteristics of the printed pieces in function of the configured parameters. In this study case, the weight in function of the Z axis height and printing speed.
- Fluid mechanics, in order to analyze the deposition behavior of the fused material in the 3D printing and to design cooling requirements for PLA parts in contact with engine.
- Materials, in order to compute structural requirements for the used materials and sizing the design.
- Flight mechanics, in order to compute the operational requirements for the remote control of the UAV.
- DIY, in order to join parts and assembly the UAV.

3.7.7 About the biggest limitations and greatest opportunities

Biggest limitation is the PLA material because of its stiffness and mechanical properties in general and its density. New PLA materials with specific properties must be developed while maintain the biodegradability.

Greatest opportunities are:

- 3D printing is able to create shapes than would be not feasible with standard systems.
- Since you have the basic design it can be printed in any place of the world, becoming a worldwide beta testers net.
- Manufacture your own homemade UAV with only a 3D printer and 0.5 Kg of PLA.

3.7.8 About the next steps for 3D printed UAV

Since the development of this study and the Barcelona UAV project, the author have seen that the next steps for 3D printed UAV will be:

- Conductive materials for the avionics connection, because double extruder could by charged by the UAV material and a conductive one that would only print the avionics wire requirements.
- Anisotropic parts, because propeller blades or wings could be designed with specific flexural behavior according to aerodynamic optimization.
- Specific Infill for lightweight parts, because the existing patterns are only focused on support material and mechanical properties. This study has designed a lattice 3D honeycomb which is interesting for this development.
- Joining system, because UAV requires parts joining and heat welding is a simple technology. This new system must be a heat technology able to be configured by temperature adjustment and surface selection, inside or outside the slices.

3.7.9 ETSEIAT University

ETSEIAT University has its own 3D printed UAV. Since this study, 3D printing for UAV applications would be an interesting subject for the last year of the Aerospace Vehicles Degree. This subject would consist in the design, 3D printing process and testing of UAV developed by teams.

With this program, ETSEIAT would become an expert institution in this discipline and would be able to supply UAV for specific applications, design 3D printing technology for other applications and develop 3D printing materials in the CCP.

3.7.10 3D printing Companies

3D printing industry is developing a new technology that must be specified by the application. The UAV specific application requires from 3D printing:

- New materials, because of the weight performance, the mechanical properties and the recyclability.
- Double extruder, because anisotropic parts will improve this technology for engineering applications.
- OPEN SOURCE, because it is the most configurable device.

3.7.11 CATUAV

CATUAV has bet for 3D printing in UAV applications timely. This study has developed the complete cycle of the new concept of 3D printing: the design, a linear model for weight performance, materials analysis, 3D printing methods, joining, avionics, assembly, tests and promotion. The cycle stages require only practice but promotion.

Promotion of the 3D printing concept requires a change in philosophy to understand the scope of your idea. The author of this study cannot suggest what these changes mean, instead these will appear during the 3D printing adaptation.

This author suggests to CATUAV the promotion of the INTERNATIONAL 3D printed UAV EVENT. Consisting in a one week event in the CTC location with:

- New models presentation and tests.
- 3D printing Workshops and demonstrations.
- Specific courses.
- 3D printed UAV market.
- New materials tests.

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