

# Long-Endurance UAV Glider for Topography Application

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## Abstract

We are actually developing a long-endurance glider. The aim of this application is to create an UAV for a topography application. We want to recreate by computer way a site (200\*200m) in 3D. This could only be done with special photography of the zone. These photos will be taken by our drone in an altitude of 300m. We had to develop an extra-light glider with high aerodynamics performance to ensure an automatic flight of 1h. In the following paper, we will explain the design, the CAD and composite conception and the choice we have made to create it and how it is electronically controlled.

## 1 Introduction

This project has been developed in the INSA Strasbourg's school, a french engineering school based in Strasbourg. It last two years and the aim is to design and create a long-endurance UAV for topography application. The team is composed by 6 students. The work presented in the following pages has begin 18 months ago and is part of the mechatronic cursus (4 hours per week).

This paper will be divided such as presented below :

1. First of all, the constraint of our application will be explained.
2. The specifications, which results from the constraint and some choices.
3. The mechanical part of the UAV especially the fuselage and wings.
4. The electronic design, the choice of the component and the control will be explained.
5. The current state of the project and the results of first flight will be commented, and we will give the perspective of the project in the following months.

## 2 Constraint

This project is developed for a topography application because it is a specialization at INSA Strasbourg. It is born of a need : having a long flight to recreate 3D landscapes where the topographs could eventually not placed their devices. The plane must be able to hover a field, to take pictures of it but also to travel from a site to another to ensure a good landing for example.

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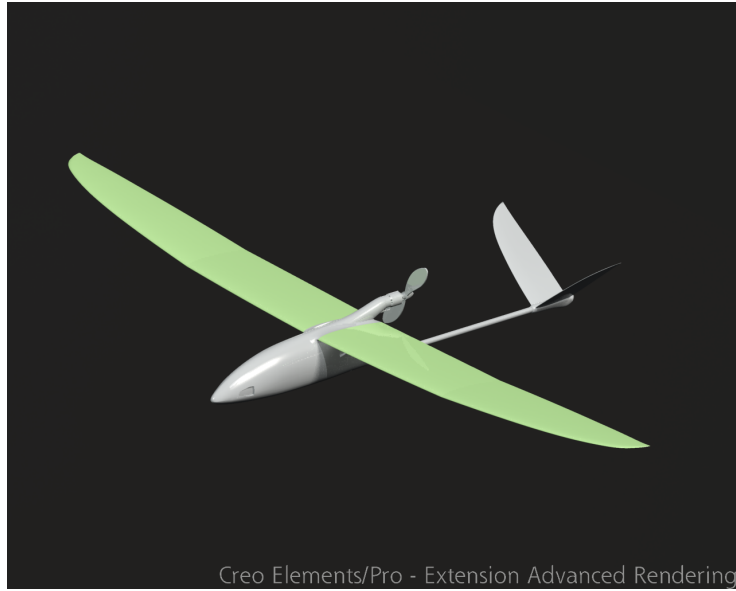


Figure 1: glider's CAD

The goal is to cover a 200m\*200m zone. The spot has to be captured with pictures which recovered themselves for 60% in width and 30% in height. The minimal resolution is about 1 pixel for a 10\*10cm in the field. The camera has to be always parallel to the ground ( $\pm 5$ ).

### 3 Specifications

With the constraint explained in the last section 2, the specifications have been built.

To ensure to have enough energy to flight in and out the zone, we have fixed a minimum flight of 1 hour. The wingspan has been fixed to 3m. The weight of the system has to be lighter as possible. The wing loading has been chosen of 4kg. This data is the consequence of the weight of the battery and the motor we want to board in, and of an estimation of the structure weight, plus a security margin.

Besides that, we need to have a very high resolution for the vision, and a safety mode in case of emergency to avoid the crash of our UAV.

#### 3.1 Dimensionning the motor and the battery

To calculate it, we have based our calculation on the Newton's second law of motion. The result of this equation is :

$$P = \frac{\rho_{wind} * S * C_x * V^3}{2} + m * g * \sin(\alpha) * V \quad (1)$$

with :

- $P$  the power,
- $\rho_{wind}$  the wind density
- $S$  the wing surface (0.82kg/dm<sup>2</sup>)
- $C_x$  the drag coefficient
- $V$  the speed (km/h)
- $m$  the weight of the system (4kg)
- $g$  the gravity
- $\alpha$  the angle between the plane and the ground in degree (null when the flight is horizontal)

By placing the speed and the angle  $\alpha$  as parameters we have found the optimum to have more power by using the less energy.

The battery has been calculated with this optimum to ensure to have enough energy for the long-endurance flight. The weight of the battery highly impact the weight of the whole system, we have to verify if we do not exceed the total weight of the system with the battery (according to the specifications section 3 4kg).

The optimization reveal that it is better to take off with a "high" angle but during a short period rather than with a "small" angle during a long time. Take off is made with  $\alpha = 35$ . This optimum has been found with the following value as parameters :

$S$ (kg/dm <sup>2</sup> )	$C_x$	$V$ (km/h)	take-off time (s)	$\alpha$ (°)	total power (W)
0.82	0.02087	54	17.43	35	626.5

The values has been established with a motor efficiency of 0.88 and a propeller efficiency of 0.6. The notation corresponds to those introduced for the equation 1

The chosen elements are :

**battery** : 2 will be placed in parallel to provide enough energy : 4000mAh, 40C each.

**motor** : brushless motor with a nominal power of 800W.

## 4 The Mechanical Parts of the UAV

### 4.1 Choice of the camera

As exposed in section 2, there is a need to have a high resolution and a very light weight for the camera. The criteria of comparison were mainly the resolution, the weight and the price. A ranking of the market solution has been made. To be short, in this paper, we will not give all the possibilities we have studied but just the one we have finally chosen : the GoPro.

Its advantages are :

- the weight : 100g
- the resolution is good : 1080p
- It can take until 30 images/s (film mode)

Nevertheless, it also has its disadvantages, the main one is its fish-eye effect. This effect is really annoying in the corner of the picture. The center is not really distorted. After a quantification of the distortion with a line of sight, a crop will be necessary. The original images taken are 1920\*1080 and after the operation, the resolution will be : 1600\*900.

This gives the result of 1px in the image correspond to 6\*6cm in the field at the desired altitude : 300m.



Figure 2: crop made around the non-distorted zone, image taken during a flight test

### 4.2 Fuselage's study

We have thought the fuselage to have the best access to the inside component, and naturally to have the smaller drag force as possible.

The original idea was to observe the nature. Which form is the most aerodynamic ? It reveals that the drop was the best one. So we began to draw a fuselage close to this shape. After some fluid analysis, comparison between different shapes the final shape has been made.

Its characteristics are the following :

- drag force : 2.5N
- estimated weight : 300g with composite material (Carbon,Kevlar)
- total length (with the tailplane) : 1370mm
- height : 210mm
- width : 100mm

It is made by two parts (as shown below) : the body which will be holding the inside component and a head to protect them against the outside conditions.

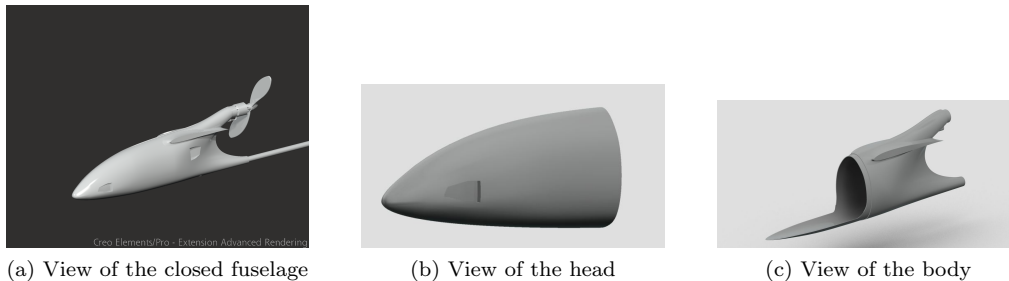


Figure 3: CAD of the fuselage and its parts

Because of the heat loss of the battery, we have to design a wing. We have chosen the normalised NACA inlet and outlet. To ensure a correct flow, the outlet NACA is 2.5 bigger than the inlet one. Its size has been dimensioned with an estimation of the loss due to the Joule effect.

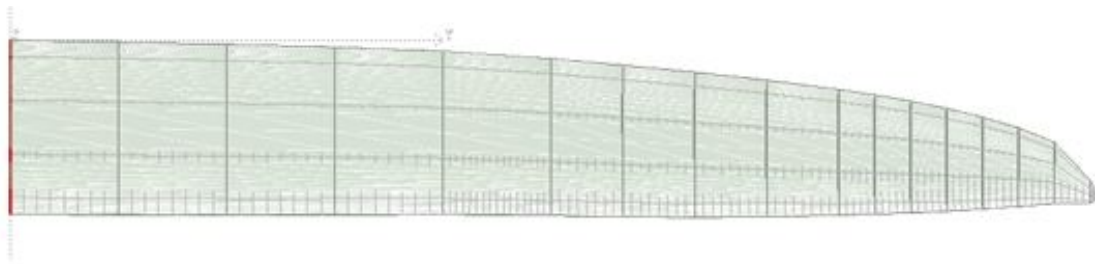
### 4.3 Wings' study

The wings are inspired by F3F and F3B competition models, because their performances are enhanced to have the highest lift-to-drag ratio. This ratio is for the application also very important because of the will to have a long flight.

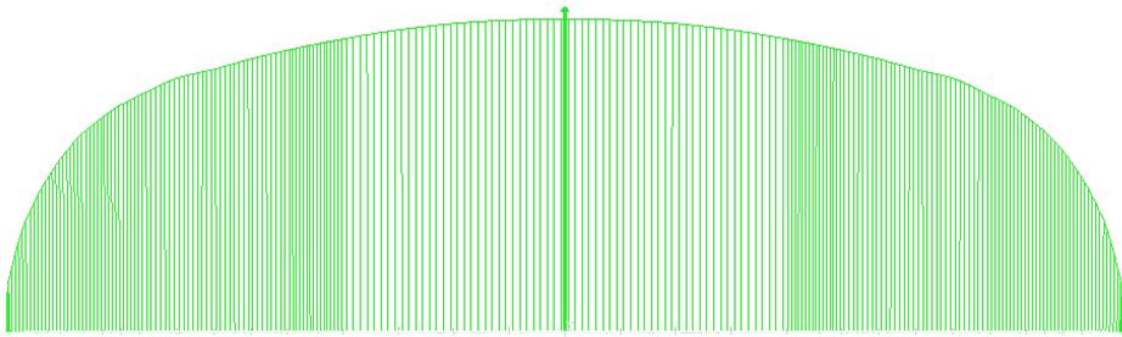
The shape is pseudo-elliptic, there is a dihedral of 1 at the butt and 4 at the middle. In order to have the best output, the wings have been designed with an elliptic lift distribution (evolution of the airfoils shape along the wing). This has been tested with XFLR5 under two incidences : 0.5 and 1. We have only tested these values because we thought that they were the optimal one. The graphics 4b shows the results.

We have used the XFLR5 software to determine the characteristics of the wings :

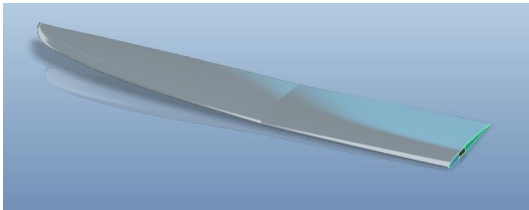
- lift-to-drag ratio maximal with an incidence of 0.8
- The power factor is maximal with an incidence of 1.2
- The lift coefficient of 0.1 at an incidence of 1



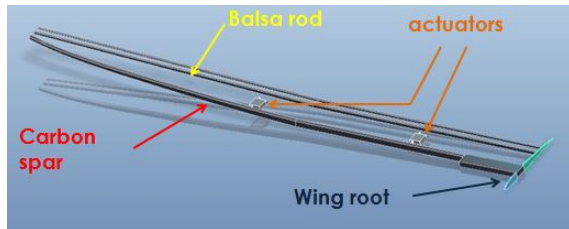
(a) XFLR5's modelisation



(b) lift distribution of the wings (Cz vs wingspan)



(c) CREO's modelisation of the wing



(d) CREO's modelisation of the inside of the wing

Figure 4: CAD of the wings

These simulations have helped us to the elaboration of an aerodynamic model of the flight. This is useful to enhance the control. This model is actually under development.

The wings have been modeled in a CAD software to integrate the actuators inside.

The wings are made of a sandwich composite material : Carbon - Airex - Glass fibers. The carbon and the glass fibers are used in flexion and the airex is placed to rigidify the structure in traction and compression. We have also placed a carbon spar and a balsa rod to rigidify the whole wing.

## 4.4 Realisation of the fuselage and the wings

The choice of a composite structure has been made because it combines a light weight and good mechanical properties. But it also means that the parts have to be moulded. The wings have been made by contact molding. To do so, we made a wood master, this master have been moulded to create the mould. Then the material have been put layer by layer to make the wing.

To make the fuselage, the same steps has been required. Actually, the master has been made and the mould will be create very soon.

# 5 Electronics Design

## 5.1 Electronic components

To provide an automatic flight, we are using the following component :

- The motherboard is a DSPIC33F
- Three axis accelerometer to determine the angular velocity of the plane
- One gyroscope for each axis
- 4 servomotors as actuators to move the aileron
- 2 servomotors in the fuselage to control the stabilization's aileron
- 1 servomotor to trigger the camera
- 1 brushless motor
- 1 GPS to acquire the position of the plane and a first value of the altitude (incertitude :  $2.5m^1$ )
- 1 barometer to acquire the altitude (incertitude  $1m^1$ )
- 1 telemeter to have a precise altitude measure for take off and landing (incertitude :  $0.01m^1$ )
- 1 GoPro to take the pictures
- 1 radiocommand and its controller
- 1 xBee module to ensure the communication to the ground during flight.

During the testing phases and to allow developping the electronic while the fuselage is not moulded, we use a polystyrene glider. Every component are integrated in it and we can test the fonctionning of our electronic. To allow a quicker development we have also used the UDB4 of SPARKFUN[4] : it is a development board which contains the gyroscope and accelerometer. Part of the code we have implemented can be found in gentlenav [2].

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<sup>1</sup>this incertitude has been experimentally verified

## 5.2 Control

The glider has four flight mode :

**manual** : There is no control of the output. The board take the PWM from the RC receiver and transmit it to the actuators without treating the information. This mode needs a pilot. It has been developped in emergency case, to avoid a crash of the UAV. It has the priority to any other mode.

**semi-automatic** : In this mode, there is still the need of a pilot, but the plane is regulated in angular speed. It means that the plane is forced to stay in an angle cone for roll and pitch. Yaw angle is not critic to avoid a crash so this angle is not controlled. This mode was a first step in the development of the control. It can be use by unexperimented pilots to avoid a crash. The angles has been chosen to be harmless for the plane ( $\pm 30$ ). The most interesting part of this control mode is that it correct automatically its trajectory when an external perturbation come.

**automatic** : This mode is the most important for our final aim. It allows an automatic flight without pilot. The goal is that the glider take off on his own, go on the wanted site, take the pictures of the zone and come back with an automatic landing. To do that, the waypoints have to be program before the flight. The yaw, pitch and roll are electronically controlled with the informations of the sensors. It will be developped in the next section.

**return to launch** : If the glider lost the RC contact, it has stored the initial position in its memory and goes back on its own to the initial point, where it could land by circling down until the ground.

To switch from one mode to another, a switch on the RC controller has been program. With three positions, we can easily change the flight mode if there is a problem.

## 5.3 An automatic flight

The control is made by the DSPIC33F. It receives the information for the gyroscope and accelerometer, these informations are averaged, if some are too far from this average they are not taking into account. The state of the plane is determined with the DCM algorithm of gentlenav [2]. This algorithm update the 3\*3 Matrix with the informations of the sensors.

Depending on the goal the pane has to reach (the next waypoint), it corrects if necessary its trajectory. The acquisition of this parameter is made at 8Hz. It means that we have 8 sets of data per seconds. That allows the control to be reactive to an external perturbation.

The control is made by a PID controler on each axis. The coefficients of these controlers are, for the moment, empirically found. We are currently working on a Matlab model of the plane to optimize the control coefficient. This work is not yet finish so I will not present it in this paper.

The waypoints are coded in the program and we can change it by reprogramming the part of the program which contains it. We can also add some waypoints during the UAV flight. To do so, we have a link to the ground with an xBee module, this is the object of the following part.

To code the waypoints we have two possibilities, to indicate it with the GPS coordinate (longitude, latitude) in degrees and altitude in meters or we can also program it relatively to the points where the UAV has been started. Indeed at the start of the glider, an initialization of all the sensors is made.



The initial point is given by the GPS and is stored in the memory. So we could indicate the waypoints relatively to this point by indicating the distance toward East, North and the altitude in meters. This is usefull to make a route without searching the exact GPS coordinate.

## 5.4 A link to the ground

The xBee Pro module is a device which allows serial data transfer with a range of 1500m [1]. Datas can go both ways, from the computer to the plane and vice versa. We receive the data from the location and orientation of the plane at 8Hz. This data are send to an interface in Labview which returns the position, speed and the battery level of the plane. It also returns, with these datas, graphics of the last orientation of the UAV. We can follow it by seeing these graphics.

We also used an interface developped in open source found on the internet called HK Ground Control Station [3]. This interface needs to have an internet connection to work but it allows a map visualisation of the drone with the same data as ours. The altitude is symbolised with a parallelogram which has a bigger side according to the altitude. It is very convenient but the one developped with labview has the advantage to work without an internet connection and to provide graphics of the angle evolution which is usefull to optimize certain parameter empirically. Some snapshot of these interfaces are displayed below, figures 5a and 5b .

On the HK figure 6, the red circle shows the place of the waypoints in a test flight done in april. This shows that the UAV goes throw the waypoint. Between, if there is wind or external perturbation, it will only correct its trajectory to be on the next waypoint. To have a precise trajectory, it needs to have a lots of waypoint not far away from each other (30 to 50m). Here in the picture, the waypoints are separated by 200m from one another.

The xBee module allows both-ways data transfer so we have an interface to send some datas to the UAV. This is used to change the coefficient of our PIDs controllers. Indeed, actually they are empirically found, we can change it on flight. It is more convenient than reprogramming all the device. We can also send waypoints to the UAV. This waypoint will be add in place of the last and will be taken at the end of the other waypoints. These information are send at 1Hz, so every second we can send a data set of information to either modify the reactivity of the UAV or add waypoint to the route.

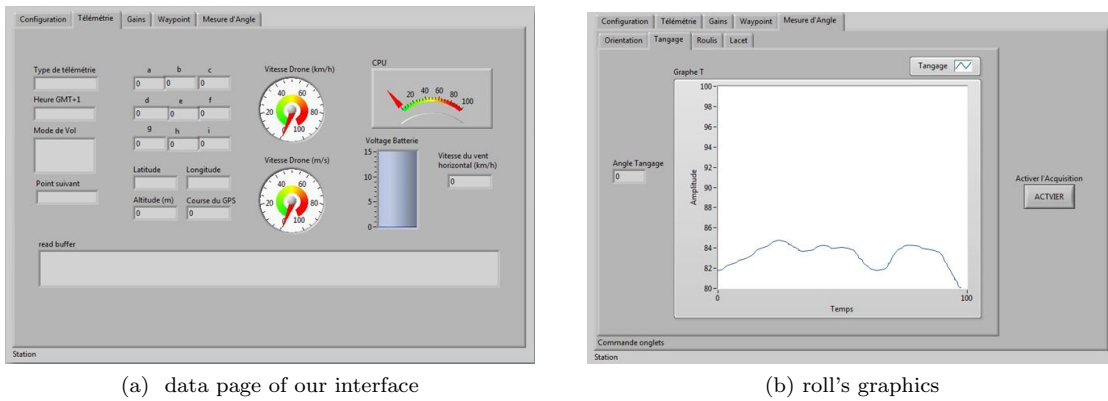


Figure 5: Labview Interface



Figure 6: HK Ground Control Station

## 6 Current State of the Project

There is still six months of work on the project, so everything is not yet finished. The points beneath resume the achievement and the following to come.

**mechanical part :** The wings are now produced, we are currently making the mould for the fuselage. Once it will be finished, we have to mould the fuselage with the composite fibers. Then all

components could be integrate in it and a test flight with the final structure could be done (all the actual test flight has been made with a polystyren structure).

**electrical part :** All the three flight modes are fonctionnal, we are currently working on the integration of the barometer, the altitude is given only by the GPS for the moment, the incertitude is too big. The telemeter is fonctionnal but the lack of barometer made the landing impossible. Once it will be fonctionnal, we will integrate the landing in the automatic mode. We are also working on a model of the flight to optimize it.

## 7 Conclusion

In this paper, we have tried to synthetise the work done by a team of students in the INSA Strasbourg's school. The main point of our application are the long-endurance and the acquisition of images automatically for the topographs. For the first point, it means a big battery to provide enough energy for the whole flight and a design which allows to have very low friction and asperity to be the most aerodynamic as possible. The shape and the roughness of the UAV are very important. For the second one, we have worked on the control of the drone to allow an automatic flight, and also on the interface to permit a visualisation of the flight. This visualisation is usefull to detect the problems and the possible improvement. The specificity of our project is that it is entirely develop by engineering students. From the design of the prototyp to the realisation of it.

*Thanks :*

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**Ulrich Nsenguét :** *For his particular work on the ground station.*

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