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AN UAV DESIGN FOR THE SUPERVISION AND PREVENTION OF FIRES

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Abstract. *The savanna vegetation type, original of the Central Brazilian Region, every year faces an increasing number of uncontrollable fires. Firefighters of the region are continuously trying to improve their response time and strategy to extinguish fires. Recently, Unmanned Aerial Vehicles (UAVs) have become an alternative solution to search fires and take action against them. The presented work aims to design an UAV platform radio controlled using FPV (First Person View) systems to monitor fires in the open forest area of the Federal District region. The project has as goal a low-cost and easy to build solution equipped with GPS and audio/video systems which will give the firefighting operation a real-time view of the monitored area and a capability of responding quickly in order to control the fire threat to the local communities. The design methodology is based on conventional techniques and norms of construction for small airplanes aided by low-fidelity computational mechanic models. Due to onboard system restrictions, a prototype is under construction and test for a short range of operation and small flight autonomy. However, the design is flexible enough to allow for modifications and improvements when necessary and its documentation is prepared as a source of information and also to be a reference for future works.*

Keywords*: forest fire, firefighters UAV, monitoring, FPV, design*

1. Introduction

Forest fires have the potential of destruction of fauna, flora, water sources, soil and air quality, in addition to the damage to properties and natural goods and materials, because of that they must be prevented and controlled by individual or government actions (Lagares, 2007). Some ways for prevention of forest fires are, especially, activities that prevent the fire from starting, and also ways of rapid detection of the initial outbreaks that prevent the fire from spreading causing greater damage.

The surveillance of the forests can be fixed, mobile or auxiliary, with different degrees of sophistication, such as the use of sorting infrared equipment, video equipment, aircraft, and employment of shelters in strategic points and towers equipped with automatic systems for detection. One of the most practical methods of detection and location of forest fires is the use of towers of surveillance, and there are others, such as patrolling, land or air, or through satellite pictures in almost real time.

The towers of surveillance are built in structures of wood, steel or concrete and are required only in areas with great visibility, due to their high cost of installation. Their location is chosen so as to have easy access to and to cover a large area, aiming to have the lowest possible number of towers covering the same area. The towers must be equipped with binoculars, radio or telephone and a goniometer, device used for determining the location of the fire, but also may have automatic systems for the detection of the fire.

The mobile surveillance is executed in the Federal District by the Fire Brigade mainly with the use of crewed helicopter that makes air vigil during almost the whole period of drought in the region, mainly in the days in which the relative humidity of the air is very low.

Prevention is the first line of defense against forest fires. The fight against forest fire involves several stages and all are related to time, because the rapid action to fight, the smaller the damages and losses caused by fire (Soares, 2001). The stages are the following:

- Detection: time between the ignition and the time it is viewed by someone.
- Communication: time between the detection and the receipt of information by the teams responsible for fighting.
- Mobilization: time between receiving the information and the exit of the personnel for the fire fight.
- Displacement: after mobilization, it is the time between the exit of the personnel to fight and the arrival at the outbreak of the fire.
- Planning to fight: the stage also very important in the fight, because attitudes taken without prior determination can make the fight ineffective and the time for the evaluation of the situation and the best ways to combat.
- Fight: time spent in the operation of extinguishing the fire.

The rapid detection of a fire increases the chances of its extinction without major losses, and thus avoiding the maximum damage to flora and fauna.

Although, efforts are not spared for the preservation of the forests and parks against fire, several tools used for surveillance, all involve a high cost of implementation, operation and maintenance, and in addition a great number of people is employed to perform these tasks.

The present work brings as an alternative the design of an unmanned aircraft to carry out the task of detection of fires, because it is a cheap alternative and agile enough to carry out surveillance of such areas.

2. The Unmmaned Aerial Veihcle

UAVs are taken as the future of the aircraft design and are studied by several countries for several years, and there are records of such vehicles even previous to manned flights. The UAVs can be used for completion of the most diverse missions, as well as those known as 3ds missions (dirty, dummy and dangerous).

The versatility of its use makes an UAV equipped with the appropriate systems useful as a tool of surveillance of large areas, thus, a good tool for the detection of outbreaks of fire and smoke.

UAVs are aircraft that do not need crew and are controlled via radio or even fully autonomous, from a pre-programmed set of commands to perform specific missions in a variety of different ways, from research to industrial espionage.

According to the *Associação Brasileira de Aeromodelismo*, the definition for Unmanned Aerial Vehicle is a vehicle capable of flying in the atmosphere, outside the ground effect region, which has been designed or modified to not carry a human pilot and which is operated by remote control or autonomous.

As a conventional aircraft, the UAV also has to meet several requirements as well as those related to the use of the airspace, safety and reliability, in addition to economic factors, such as costs involved in each mission and the cost of development and construction of the equipment.

On the use of airspace, each country has its own laws, and the responsibility for compliance with these legal requirements is of the team who will make use of the equipment. In some situations, which take into account the time of flight and the altitude necessary, the flight plan has to be approved beforehand by the appropriate offices, which can often limit the use of the equipment for certain types of mission, as in the case of those who work on climatic influences. For the surveillance of fires, the design is not affected because the small size of the mission and lower flight altitudes necessaries.

3. Aircraft Design

This article is presented as the report of a project developed for the construction of a UAV for the use in surveillance of ecological reserves existent in the Distrito Federal. Thus, following a step-by-step to how a project has to be executed to meet the definitions and pre-requirements for the type of mission that the equipment has to carry out.

A project is basically divided in a few areas, and is always an iterative method that should be reassessed undergoing several changes until the final development of the product. The areas in which a project is usually divided are: mission and requirements, possible solutions, conceptual design, preliminary design, solution evaluation, detailed design, and construction and test of the product.

For the detailed design and construction of the UAV presented in this article, the design framework was divided in four main areas: aerodynamics, performance, stability and structure, and every characteristic and aspect of each area are capable of influencing the others.

The definitions of the design requirements basically involve the type of mission to be performed, the flight autonomy and range, and the capacity of load transportation. Always, the design is developed strictly for the mission that has to be accomplished. However, it is also necessary to have a product versatile to ensure its greater applicability.

3.1. Conceptual Design

By following the mission and the necessary requirements previously devised, the UAV design has to execute two stages of the procedure to fight forest fires, which are the detection and planning to fight. To meet these requirements the UAV must be capable of transporting the equipment of video, transmission, geo-positioning and radio control.

As a design requirement, the UAV for surveillance has to have a mass not greater than 2.0 kg, already taking into account the mass of equipment which must be carried to completion of the mission, also called payload. Another requirement is that the aircraft be launched from the hand, making unnecessary the use of clearings or runways and landing gear for takeoffs.

The model must have reduced dimensions, considering a sufficient space to carry all the necessary equipment, with few parts to completely mount it. Also, the model must be easy to manipulate by people with little experience, but that from a brief training will be able to control the aircraft.

The autonomy, time of flight of the model, is estimated as of at least 60 minutes, which allows a wide scan of the area in search of outbreaks of fire and smoke, and because the need to consider both the time to finish the mission and return to the point of launch. Also, a great autonomy allows the execution of more than one mission with shorter duration without the need for new battery recharge. Another important parameter to be considered is a propulsion system with low consumption of energy. Therefore, the aircraft also must have a great lift to drag ratio, reducing the drag by using coated surfaces and low drag profiles, which allows for long range flights.

The camera must be positioned in a way to be protected in cases of falls and to have a broad area of vision to enable the view of vast areas with few adjusting maneuvers.

3.2. Preliminary design

The preliminary design consists of one of the initial phases of the design framework in which is defined the configuration of the aircraft based on the requirements of size, shape, weight, form of takeoff and landing, control and stability. Other aircraft of similar dimensions and missions are also employed as design basis.

The conceptual design consisted of the confluence of requirements, limitations and goals of the main design framework, and then, from the compilation of this information, the preliminary design starts the determination of the characteristics and specific aspects of the aircraft such as propulsion and geometry of the aerodynamic surfaces and fuselage.

The choice of propulsion for the model was an electric motor, which has several advantages over the traditional combustion engines, among them: the lowest weight; lower risks of dry pane, because it is easier to monitor by telemetry the load of the battery than the fuel quantity; lower level of vibration, because it has less moving parts, lower inertia and lowest unbalance; shorter response time than that of the combustion engine; and the efficiency does not vary with altitude and air quality.

For the sake of design simplification and the existence of a vast literature, it was chosen a conventional aircraft configuration, which is an aircraft with wing prior to tail and with control functions. The aircraft possesses ailerons for rollover control and rudder for yaw control, and in addition has horizontal and vertical stabilizers positioned in the tail. Other aircraft configurations such as tandem, canard and flying wing were not considered due to the difficulties of stability (Pazmany, 1963).

The internal dimensions of the fuselage were evaluated based on the dimensions of the embedded system, thinking about the location of the equipment to avoid electromagnetic interference that can be generated due to the closeness among them. The maximum size of the aircraft was devised in order to make easy to transport and to handle. Therefore, the aircraft must not have more than 1.40 m of wingspan and no more than 1.20 m in length.

4. Detailed Design

The design framework follows a certain line of thought; there is already a step by step known by the renowned designers of the area. The line of development starts from the definitions of the conceptual and preliminary design and goes to the detailed design starting with aerodynamic design, then, in sequence, it goes to the stability and control design, and after the performance and structure designs, noting that the process is iterative and this line of thought guides only a well-known way of thinking.

4.1. Aerodynamic

According to Raymer (1992), the design of an aircraft begins with the definition of the loads to which an airplane in balanced flight is subjected. Thus, we have the equation to begin to dimension the lift surfaces.

The steps of the design involve definition of the aerodynamic profile, wing geometry (dimensions, shape, sweeping angle, dihedron) and from the geometry of the fuselage, definition of form drag and thus the development of the propulsion system capable of lifting and overcoming the opposing forces to the movement.

Due to the existence of a great literature developed in the last century, the selection of a profile goes basically through the analysis of a database containing the geometries and the relevant data of the profiles, such as C_l, C_d and C_m, respectively lift, drag and moment coefficients.

From studies presented in the literature and previous UAV designs, we selected some profiles for testing and evaluation to be used in this project. The profiles are: Eppler423, Selig1223, NACA9412 and NACA4412.

To obtain the data of C_{lmax}, C_l/C_d and C_l/C_d x α of those profiles selected, we used the software XFLR5 v5.00 to simulate the profiles on a range of speeds between 5 m/s and 15 m/s (Re = 6.0×10^4 and Re = 2.4×10^5), varying the angle of attack, the relative angle between the wing and the direction of flow, from -3° to 20°. The software XFLR5 v5.00 uses algorithms based on the method of the panels to solve the potential flow and computes the drag force employing correction methods for the flow in the boundary layer,

Aspects such as profile lift curve, graphic C_l x α, profile lift over drag curve, graphic C_l/C_d, are the basic parameters for the selection analysis of the profile, Figure 1. It is observed that the profiles Eppler423 and Selig1223 have a high lift coefficient and a reasonable lift over drag ratio.

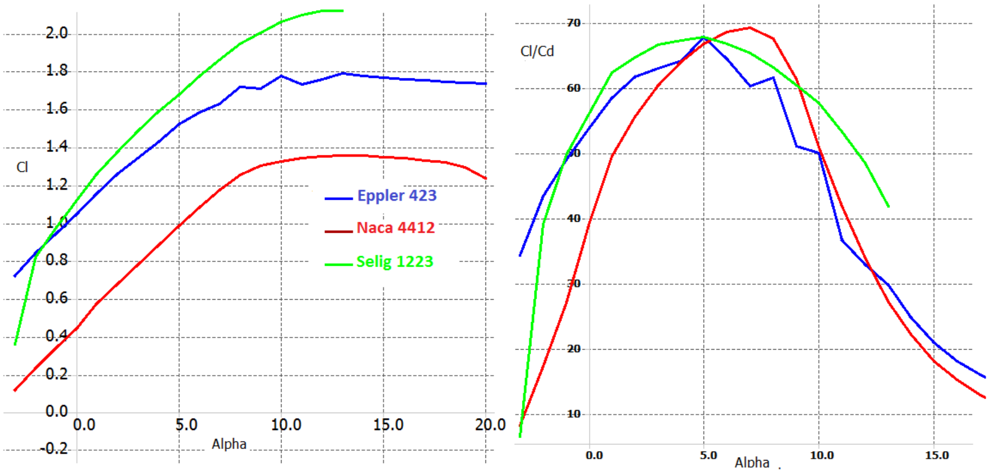

Figure 1. Diagram of lift and lift over drag for each profile, Re = 2.0 x 10^5.

However, the lift characteristics are not the only ones that must be analyzed, but also the moment coefficient of the profile, because a profile with a high moment coefficient requires a large tail boom to maintain stability.

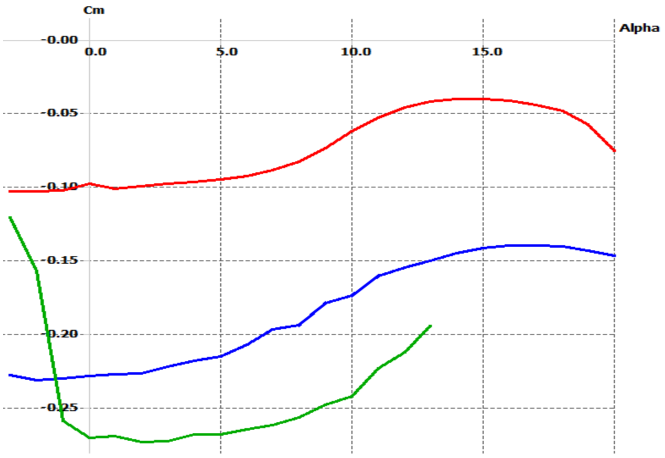

Figure 2. Moment coefficient for each profile, Re = 2.0 x 10^5.

Figure 2 shows that the profile NACA4412 has the lowest moment coefficient, requiring a smaller tail boom (Etkin and Reid, 1996), which allows for a lighter and more efficient aircraft. In search of a wing with high efficiency, it was developed a MDO (Multidisciplinar Design Optimização) to produce from iterative optimization methods a first design perspective.

The tail was conceived in order to give greater stability and control to the aircraft with the use of a few commands, for that, the configuration thought for the tail was in shape of a cross. The tail controls would allow movement in every direction for a larger working area, while the rudder would be a portion of the vertical stabilizer at the upper part. According to Etkin and Reid (1996), a large lateral area below the center of gravity increases the horizontal stability of the aircraft, therefore, the use of the tail in cross and not only a conventional configuration, a upside down “T” shape.

The stabilizer surfaces may be only flat plates or may have a simple profile. For the development of this design the NACA0012 profile was used to build the rudder, and the inverted Clark Y profile was employed in the elevators, Figure 3. For control surfaces, the airfoil shape is preferred because the flat plate in a flow has a tendency of early detachment of the boundary layer, which increases the aerodynamic drag (Karman, 1954) and decreases the autonomy of the aircraft.

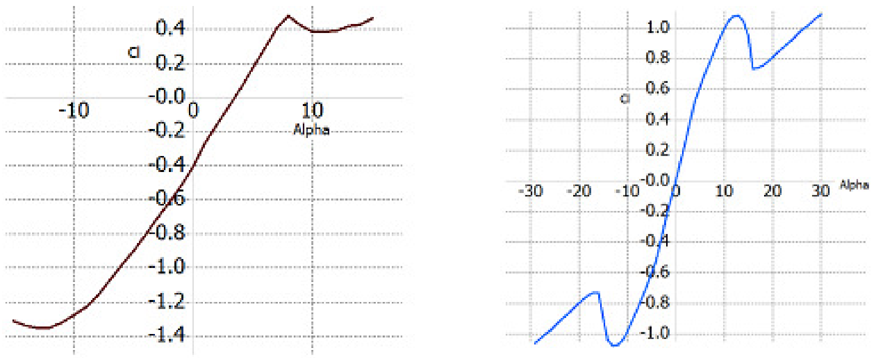

Figure 3. Diagrams of lift for the Clark Y (left) and NACA0012 (right) profiles, Re = 2.0 x 10^5.

4.2. Performance

For the propulsion, we chose propellers powered by an electric motor for reasons already mentioned previously. In order to have a slow flight to allow for the cameras installed a smooth and stable filming, we decided to use propellers of large diameter and a shorter step. Because these allow a higher thrust at low speeds, for that, the choice of electric motor was based on the engine Kv factor of known commercial aircraft models, Table 1.

Among the various commercial models that were analyzed, we sought for brushless motors, once they are considered more efficient, given the absence of brush for the rotor movement.

Table 1. Types of electrical engines analyzed

Name	Type	Kv (RPM/Volt)
Hacker A30-28S	*brushless; outrunner*	1140
Hacker B20-12L	*brushless; inrunner*	4630
Himfire	brushless;	1300

From the analysis of Kv of the proposed models, we chose the engine Hacker A30-28S that has a low Kv and thus can move propellers larger in a slower flight, desired for low altitude surveillance activities.

To carry out the selection of propeller, bench tests were performed to extract data of maximum rotation and static thrust generated, Table 2. Several propellers were bench tested. The static thrust is maximum thrust that a propeller can generate, because without the presence of a relative wind velocity, the traction is pure.

Table 2. Experimental data of the propeller

Mark	Type of propeller	Diameter x pitch (inches)	Propeller rotation (RPM)	Power of engine (W)	Thrust (g)	Efficiency (g/w)	Velocity (Km/h)	Velocity (m/s)
GWS	Slow	12x6	5010	212	787	3,71	61,1	16,97
APC	Slow	9x7,5	7200	203	882	4,34	82,3	22,86
GWS	Slow	10x8	6150	213	903	4,24	75	20,83
APC	Slow	12x6	4620	139	940	6,76	42,2	11,72
APC	E Pusher	9x6	9060	196	948	4,84	82,8	23,00
APC	Slow	12x6	5010	210	1127	5,37	45,8	12,72
GWS	Slow	11x4,7	6690	209	1161	5,56	47,9	13,31
GWS	Slow	10x4,7	8220	212	1202	5,67	58,9	16,36
APC	Slow	11x4,7	6690	202	1255	6,21	47,9	13,31
APC	Electric	11x5,5	7980	209	1293	6,19	66,9	18,58

Propellers of larger diameter and step produce great thrust, as it can be seen in the graphic below, Figure 4, determined through the analysis of efficiency obtained and thrust produced.

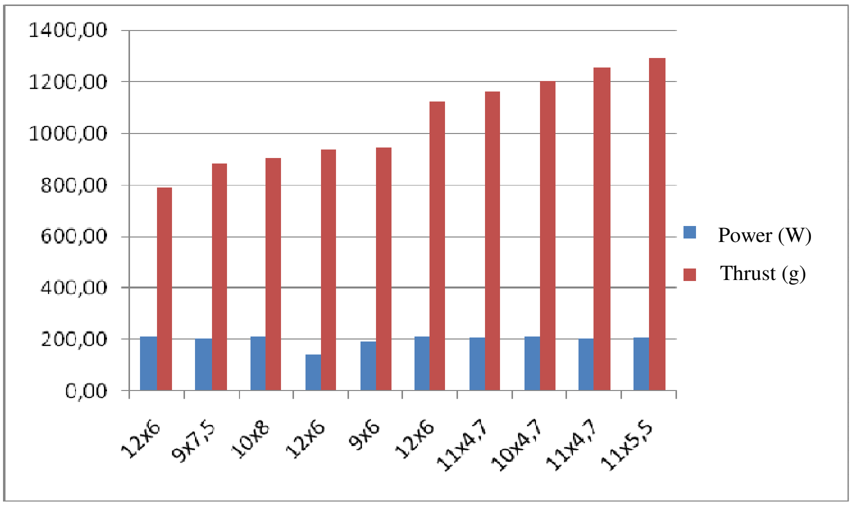

Figure 4. Power and thrust of a variety of propellers tested.

For the analysis, by comparing to the literature (Rosa, 2006), it is noticed that the larger the diameter, greater will be the thrust generated. The propeller chosen for the propulsion of the UAV was the propeller of dimensions 11x5,5, because it has the higher thrust produced to the same power consumed, almost equally among all propellers.

A complete evaluation of the performance is done in Figure 5 with performance curves, made from the data of aerodynamics and propulsion, by analyzing the power required and comparing with the power available. Another curve with respect to critical speeds of the aircraft, which are stall speed (vStall), minimum speed (vMin) and maximum speed (vMax).

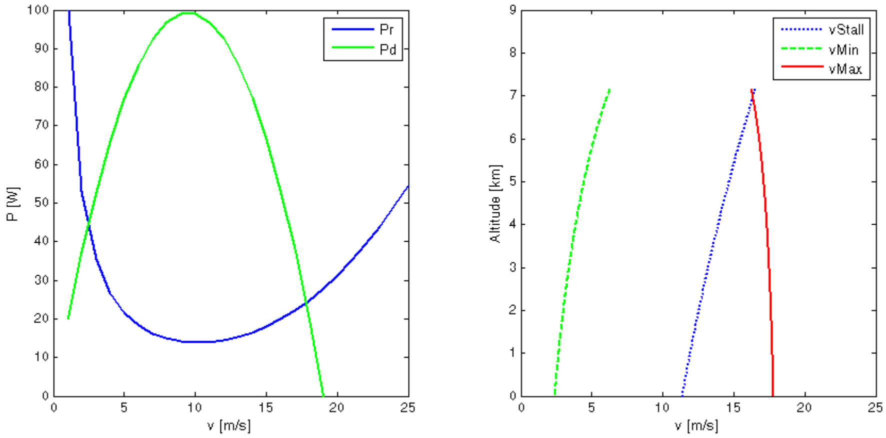

Figure 5. Pr (Power required) x Pd (Power available)

4.3. Stability

The stability design begins by considering the longitudinal static stability, as previously discussed, from the definition of the horizontal and vertical tail boom and then the design of the configuration of tail to be used.

In the case of aircraft that need good control and slow flight, Pazmany (1963) indicates a horizontal tail boom of 0.45 and the vertical tail boom was chosen based on analyzes of existing designs, such as the Cessna 150, and then, we opted for a value of 0.03.

For evaluation of the stability was used a software programed in Matlab, Tornado vT135, able to make evaluations of lateral and longitudinal static stability, but without evaluating the dynamic stability that will be evaluated on the basis of flight tests using telemetry. The evaluation of the aircraft dynamic stability requires the real mass data and location of the equipment inside the aircraft.

After the definitions of the area and dimensions of the entire aircraft, the static stability was calculated by the software Tornado vt135 in flight conditions to which it is expected that the aircraft be subjected, like relative winds of 20 m/s.

For a situation of cruise flight, about 10 m/s, the largest trimming angle, angle of attack constant, the elevator angle is of -27 °, deflected downward. The trimming angle represents the deflection required for the control surface when the aircraft wing reaches the stall angle, for the elevator be capable of executing a stabilization maneuver at that speed and take the wing back to equilibrium position, as shown in the graphic in Figure 6:

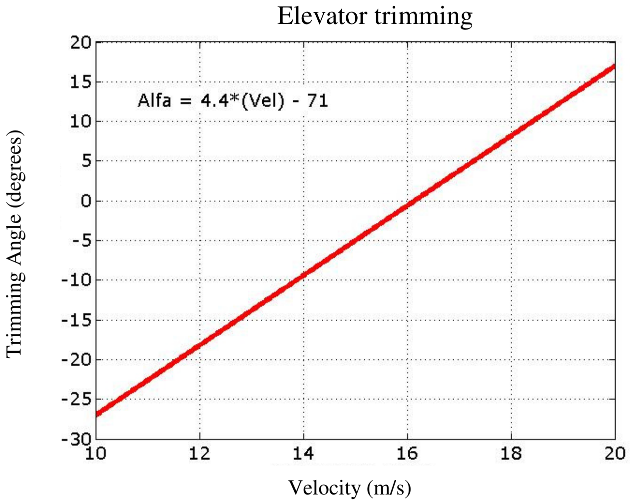

Figure 6. Elevator trimming

The lateral stability was not assessed, it is less important than the longitudinal stability, however, because of the effects of geometrical positive dihedron, positive sweeping angle, positioning of the CG below the center of pressure and large lateral area above the vertical position of the CG, we have an aircraft with stable tendency.

Due to the fact that the aircraft has lateral-directional control surfaces, and with the use of ailerons and rudder, and there is a considerable good control. To ensure the lateral stability, we can install a device known as gyroscope, electronic equipment capable of compensating for the lateral balance of the aircraft with counterbalance movements, acting on the control surfaces.

4.4. Structure

As a design requirement presented previously, we considered to build the aircraft structure from light and robust materials. Taking into account, also, the use of materials easily found and cheap to purchase, then as a proposal for making the model is the use of EPS reinforced with glass fibers for construction of fuselage and the control surfaces.

By using the initial values based on the standard FAR 23 and proposed by Raymer (1992), we applied a loading factor of positive 2.5 and negative -1, chosen because of the flight characteristics of the aircraft. Adopting upper and lower gust speeds limits of 4.5 m/s and 2.25 m/s, respectively, associated to the theoretical data of aerodynamics, stability and the flight test, a V-n diagram is devised and presented in Figure 7:

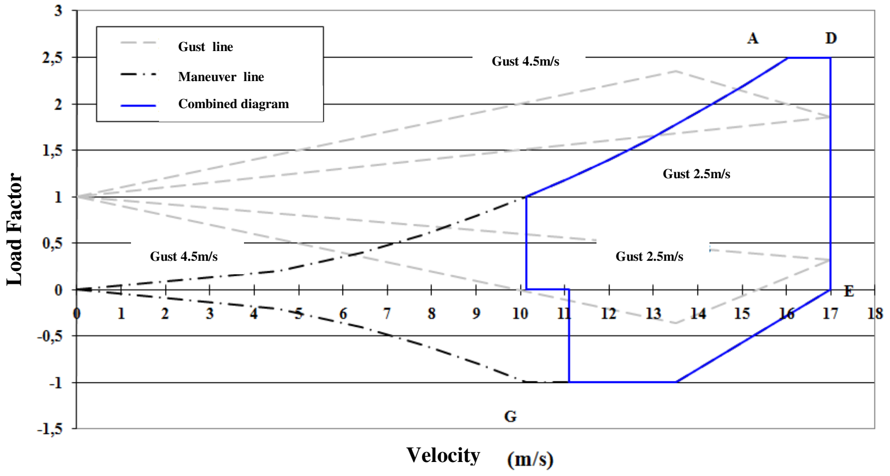

Figure 7. V-n diagram.

The distribution of loads on the wing can be considered, for the design purpose, as a uniform distribution over the wing length on the mean aerodynamic center, leading the wing to have a behavior of an in balance beam clamped at the fixing point of the fuselage.

As the EPS has a behavior totally anisotropic and fragile for the loads present in the design, given the high weight of the aircraft, we decided to use a glass fiber spar, many times more resistant than the EPS.

For the construction of the fuselage was also thought the use of EPS. By employing plates of 15 mm of thickness on the sides and 10 mm of thickness on the upper and lower surfaces, united by glue appropriate for the material, and without any structural internal strengthening, such as caves or tubular structures.

According to the calculations carried out for the control and the V-n diagram, which provided values of efforts in the order of 20 N, we discovered that the fuselage mounted only with the use of EPS is not sufficient to resist the efforts. For the solution of the structural problems of the styrofoam EPS, we studied the application of glass fiber tapes to strengthen the structure, which can increase the resistance to flexion and compression efforts, because the modulus of elasticity of the fiber is many times greater than that of the EPS.

By the fact that this material is fully anisotropic, due to its granular structure, it would not be possible to make theoretical estimates as for the efforts that the structure would be capable of withstanding, for that we carried out experimental flexion tests on a box beam body, Figure 8.

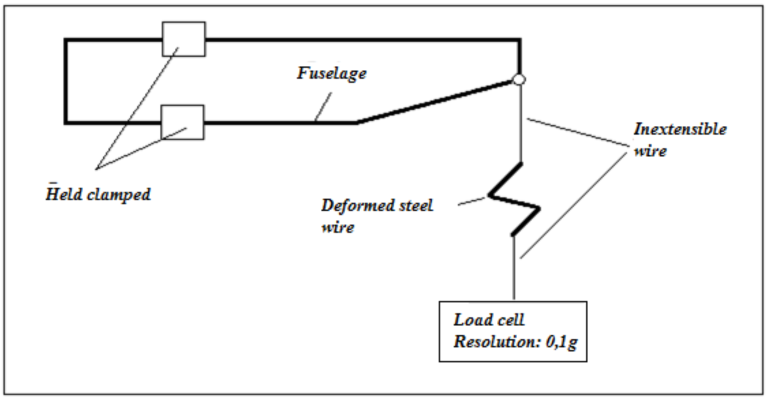

Figure 8. Fuselage bending test.

The test consisted in simulating a clamped fuselage in the situation of an active elevator, which would cause flexion in the stretch between the wing and the tail. A load cell, with a resolution of 0.1 g, fixed to a bench, was united to the fuselage by an inextensible line tied to a steel wire. To the extent that the steel wire was folded, decreasing its length, an effort was generated on the tail of the fuselage and its value was measured by the load cell.

As the objective of the test was to know the maximum effort that the fuselage could endure, the wire was folded several times. The failure criterion used was that of coupling of deformations, i.e., by the fact that the styrofoam be an anisotropic material, pure efforts of flexion result also in torsion.

When the fuselage presented deformation by twisting, the load was 1.8 kg, being defined as the maximum load endured by the styrofoam fuselage, because torsion can generate unwanted aerodynamic effects.

5. Construction and Tests

The full pusher model, engine impeller placed on the tail of the aircraft, generates a great moment, that raises the nose of the aircraft due to the weight of the engine and the great distance from the wing mean aerodynamic center (MAC).

The project of an aircraft in the full pusher configuration is not commonplace because of the difficulty of positioning of the CG, which according to the theory of stability, should be positioned in front of the MAC of the wing.

In order to determine the total length of the aircraft and to have an initial estimate of the total mass, in addition to determine the positioning of the equipment inside the aircraft, it was developed a spreadsheet to calculate the moments generated by the equipment with respect to the MAC.

From the mass of the equipment onboard, we performed the computation of the sum of the moments generated by the equipment distributed over the longitudinal axis of the fuselage with respect to the wing mean aerodynamic center.

Thus, using a method based on attempts, from an initial estimate of the total length, the positioning of the equipment is defined in a way that the sum of moments becomes as close to zero as possible.

For the total sum of moments, we employed a coordinate axes where the point zero is located at 25% of the chord of the root of the wing, being the negative moment clockwise turning the tail of the aircraft downward and the positive in the opposite direction. The moment that lows down the nose of the aircraft is considered positive while the moment that raises up is negative. The masses locations are represented by "m_n" and their distances to the origin of the coordinate axes by "d_n", in Figure 9.

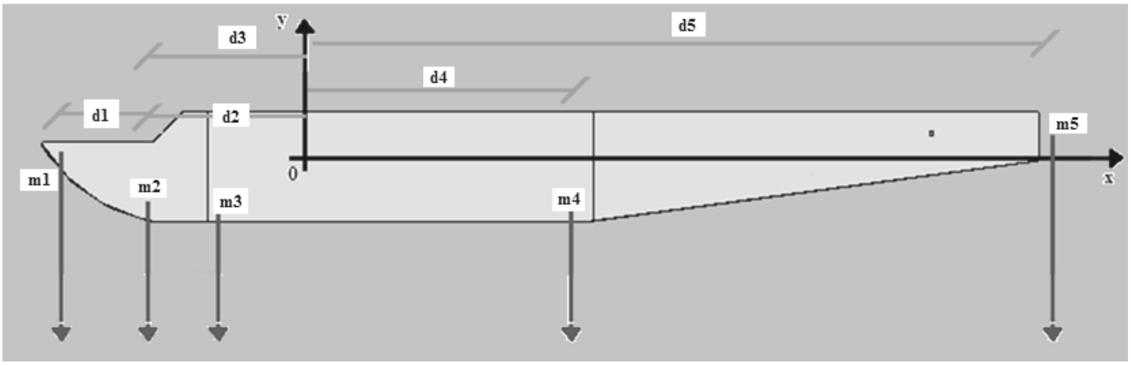

Figura 9. Diagram of the equipment position

Table 3. Position of equipment with respect to MAC

Embedded System			
Equipment	**Mass (kg)**	**Distance to MAC (cm)**	**Moment (kgf cm)**
Propeller (m_5)	-0.022	65	-1.4300
Motor (m_5)	-0.125	62	-7.7500
Battery (m_3)	-0.189	-20	3.7800
Aileron Servos (m_3)	-0.032	-1.5	0.0480
Rudder Servo (m_5)	-0.016	16	-0.2560
Elevator Servo (m_5)	-0.016	16	-0.2560
Speed control (m_2)	-0.025	-37	0.9250
Receptor (m_1)	-0.015	-18	0.2700
Tail (m_5)	-0.035	55	-1.9250
Landing gear (m_4)	-0.085	14.5	-1.2325
Total			***-7.8265***

From this initial analysis and plan of the location of the equipment, Table 3, the constructive process of the aircraft using materials such as styrofoam, fiberglass, epoxy resin and aluminum, was performed resulting in an aircraft relatively light, about 1.170 kg, capable of carrying equipment for FPV, such as camera, GPS and the necessary telemetry.

The aircraft was tested using the equipment of FPV and telemetry, which sent to the operator in real time, the information about the altitude, speed, battery consumption, georeferenced position and distance until the operator. The screen view by the pilot, which can be a LCD monitor, the screen of a laptop computer or glasses of immersion is that shown in Figure 10.

6. Conclusion

The aircraft built in full pusher configuration showed to be stable, proving the possibility of the use of this type of aircraft. This configuration also presented a long range gliding flight capability and great autonomy, which allow for a long duration flight needed for visualization and surveillance of large areas.

The prototype has achieved the requirements of the design, showing to be resistant, robust, easy to build and cheap, when considering only the construction of the prototype. This because, the entire electronics involved have a high cost of acquisition, due to its use primarily by practicing the radio controlled aircraft models.

The construction of the prototype is easy, there are only difficulties on the steps of assembling servo engines and manufacturing of the control surfaces. But those steps may be performed by people with experience in modeling, or simply with practice in building prototypes.

This work is a proof of the effectiveness and applicability of the use of unmanned aircraft FPV systems. This system can be used for remote sensing and surveillance, as the images are transmitted in real time. When the acquisition of an OSD (On Screen Date) system is possible, the control and the planning of the mission become better, because knowing the total consumption and the distance of the aircraft to the pilot allow better planning of the flight for the inspection of the target area.

From the use of a good video camera positioned in front of the aircraft with a clean field of vision, one can have the distinction of several geographic formations that enable the pilot to know the position of the aircraft with respect the ground base and with respect to a geographic point easily identifiable.

Future research work leads to the improvement of the set aircraft and FPV systems and optimize the aircraft design for the several types of missions that one can apply FPV technology. Another research area would be the implementation of autonomous flight with the help of GPS or similar georeferenced technique, at least for certain period of the flight, to make the work of piloting an aircraft feasible for a long range of applications and people with different backgrounds.

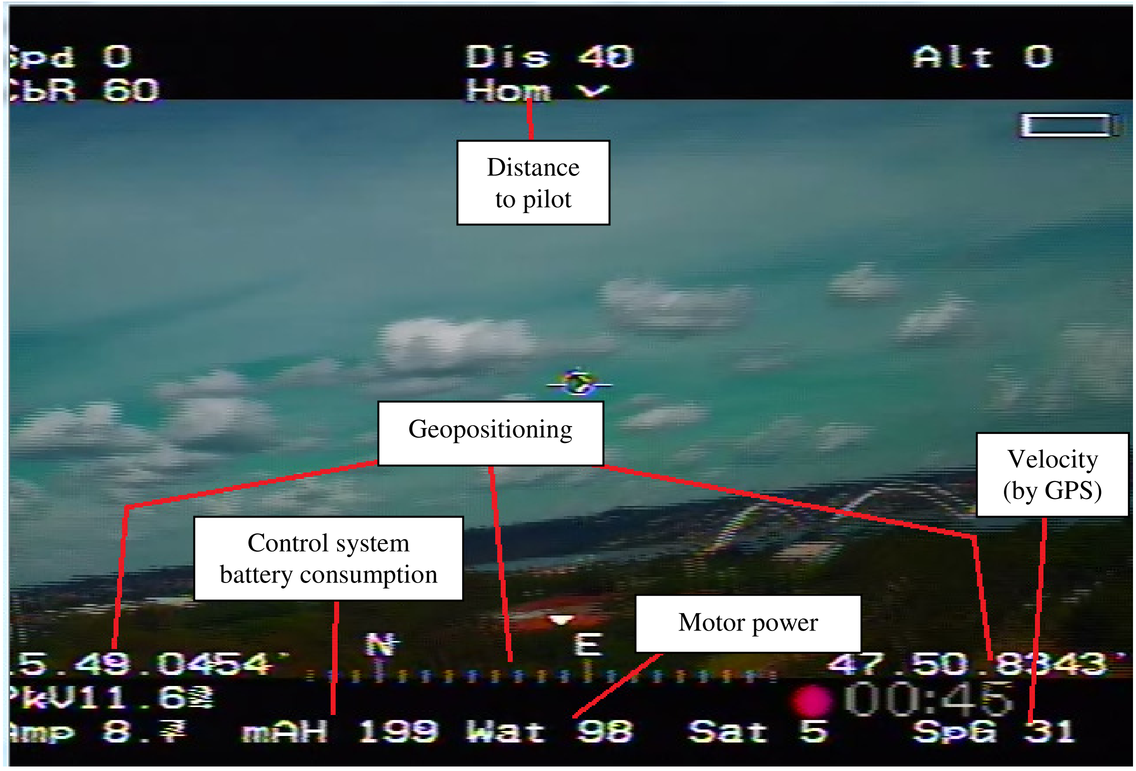

Figure 10. First Person View.

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Software Tornado T135, developed in a collaboration among KTH, University of Bristol and University of Liköping <http://www.redhammer.se/tornado/>.