Design and development of an unmanned aerial vehicle for agricultural spraying in Brazil

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Abstract

This paper presents the development of the unmanned aerial vehicle (UAV) and its configurations as a platform for agricultural sprayers, with a hopper with a capacity of 100 kg, which can perform better maneuvers than conventional agricultural aviation, for precision spraying on small and medium Brazilian properties agricultural. The development and construction focused on precision spray agriculture, taking into account the reduction of costs and accident risks, modernizing, and complementing the activity. Prince Air Models Ltd. made the prototype with resources from FAPESP under Brazilian patent number PI 0404045-7 B1. It presented acceptable results for all flight situations requested with 100 kg of payload and flying in typical maneuvers and agricultural patterns.

Keywords: Unmanned Aerial Vehicle; Precision agriculture; Sprayer;

1. Introduction and Objectives

Brazil is one of the world's largest exporters of grains, particularly for crops such as soybean and corn. Although allowing cultivation during all seasons, the climate also favors developing pests, diseases, and weeds without having their cycles interrupted in the winter. Crop protection is essential to maintain high productivity levels, so sprays are applied when necessary during the growing season [1]. Nowadays, there are currently two spraying techniques in Brazil, one aerial and the other terrestrial.

According to [2], aerial application is a technology that is more economical and advantageous, as it reduces the application time; apply the product in adverse conditions of irrigated or waterlogged soils; it allows for higher quality and uniformity of application and does not cause damage to the crop's kneading and soil compaction. However, despite the advantages, there are some disadvantages, such as more excellent environmental conditions. Therefore it is necessary to fly at very low altitudes, in operational terms, to avoid dispersion of pesticide in the application; the planes even fly just three or four meters from the ground, which makes the operation even riskier. Another disadvantage is the high cost of aircraft investment and the lack of pilots specialized in agricultural flights.

Therefore, to meet these circumstances, agricultural UAV is developed quickly, providing robust support for promoting agricultural production security, quality and safety of agricultural products, agricultural ecological security, and agricultural trade security [3].

UAV is the acronym of Unmanned Aerial Vehicle and refers to a class of aircraft that can fly without a pilot's onboard presence. They can be flown by electronic equipment present on the vehicle and a GCS (Ground Control Station) or directly from the ground. In this last case, it is common to associate the system with RPV expression (Remotely Piloted Vehicle) since it is remotely piloted and operated by radio-controlled devices [4].

According to [5], "A small Unmanned Aerial Vehicle (SUAV) is well suited for missions that are dangerous to perform with human pilots or inconvenient to carry out with larger UAVs. It has a limited range and payload capacity, but it is a low-cost system and does not require a specially trained air force pilot and extensive logistics. The SUAV is designed to perform high-risk missions like monitoring radioactive fallout due to nuclear accidents, searching for people lost in hostile environments (fires, mountains, ocean, etc.), and surveillance of borders, pipelines, and power lines. Such types of tasks require a reliable aircraft with a high-performance flight computer and advanced payloads/sensors. A normal mission layout is to take off, climb to mission altitude, navigate to the target area, perform the assigned task, return home, and land."

This paper aims to develop a UAV for agricultural spraying to eliminate risks and reduce operating and investment costs. They are mainly idealizing to ensure low weight via compact solution, small size, and simplicity, restricting the equipment to its operational need. Although there is a wide variety of unmanned aircraft in operation today, there is still a significant lack of approach to their agricultural use, making a comprehensive and detailed study in this field essential.

2. Literature Review

The history of unmanned aerial vehicles began in 1883, when Douglas Archbald installed a wired anemometer on a kite to measure wind speed at different altitudes, reaching a height of 1200 feet. On June 20, 1888, in France, Arthur Batat attached a photographic camera to a pipe, therefore being the first recorded photographic by aircraft [5].

In 1935, Reginald Denny designed and tested the RP-1 or RPV (Remote Piloted Vehicle), the first radio-controlled unmanned aerial vehicle. From that moment, the search for improvement began, so that, in the following years, the RP-2 and RP-3 prototypes appeared, with several flight tests. In November 1939, the RP-4 prototype was completed, so that, at that time, it was the most complete of the RPVs. The US Army has ordered 53 units, giving them the designation OQ-1.

In the meantime, in 1938, the German company Ruhrstahl AG started developing "Fritz X" guided glider bombs, adopted from a rocket engine and 300 kg of an explosive charge, for the attack against battleships. It was used in combat for the first time on September 9, 1943, sinking the Italian battleship Roma.

Another historic milestone in UAVs' use was during the Lebanon war, in 1982, in the Bekaa Valley, when Israel Air Force destroyed 17 of the 16 Syrian anti-aircraft batteries after reconnecting with an unmanned aerial vehicle, model IAI Scout [6].

In 2002, an American unmanned aerial vehicle, Predator RQ1, was used during the Afghanistan war. This was considered the first real use of an unmanned vehicle with a missile launch.

In Brazil, the first reports of UAVs occurred in the 1980s, when the Aerospace Technological Center (CTA) developed the Acauã project (Figure 1), whose main objective was the development of a testbed platform to increase the level of knowledge in the area of electronics (control, remote control and telemetry). As a secondary objective, it aimed to develop a UAV prototype with the potential for several other militaries or civilian applications, such as tactical reconnaissance at low altitude, identifying radar operation frequencies, and sensing natural resources. In total, five cells (four metallic and one made of composite material) were built for use in ground and flight tests [7].

Figure 1. Brazilian UAV Acuã

The University of São Paulo (USP), on the campus of São Carlos, develops the ARARA project with support from Embrapa - a Brazilian agricultural research company. The objective is the development of model airplanes for obtaining aerial images for environmental and agricultural monitoring. The ARARA (Radio-Assisted and Autonomous Recognition Aircraft) project focuses on developing and using SUAVs for aerial monitoring. Its main objective is to replace conventional aircraft used to obtain aerial photographs, for monitoring agricultural areas and areas subject to environmental problems, with small UAVs that carry out pre-established missions by users [8]. The ARARA SUAV (Figure 2) was built entirely of fiberglass cloth and resin. It has the following characteristics: 2.3 m long and 3.2 m wide and is equipped with a 40 cm^3 gasoline engine with 4.8 hp power [9].

Figure 2. Brazilian SUAV ARARA

Research in this area in Brazil is still very recent and the main work with UAVs is aimed at civilian applications, such as police surveillance of urban and border areas, inspections of power transmission lines, road monitoring, activities in agricultural areas like crop monitoring, pest control and forest fire [10].

3. Material and Methods

3.1 Development of prototype

The AgroRobot aerial platform project was developed by Prince Air model Ltd. in Tupã, São Paulo, with resources from the PIPE program - FAPESP - São Paulo State Research Support Fund, process no. 02 / 07889-9 under Brazilian invention patent no. PI 0404045-7 B1. The aircraft was developed from the technical data of an ultralight KR2 aircraft. The aircraft design methodology is described by [11], whose steps can see in figure 3.

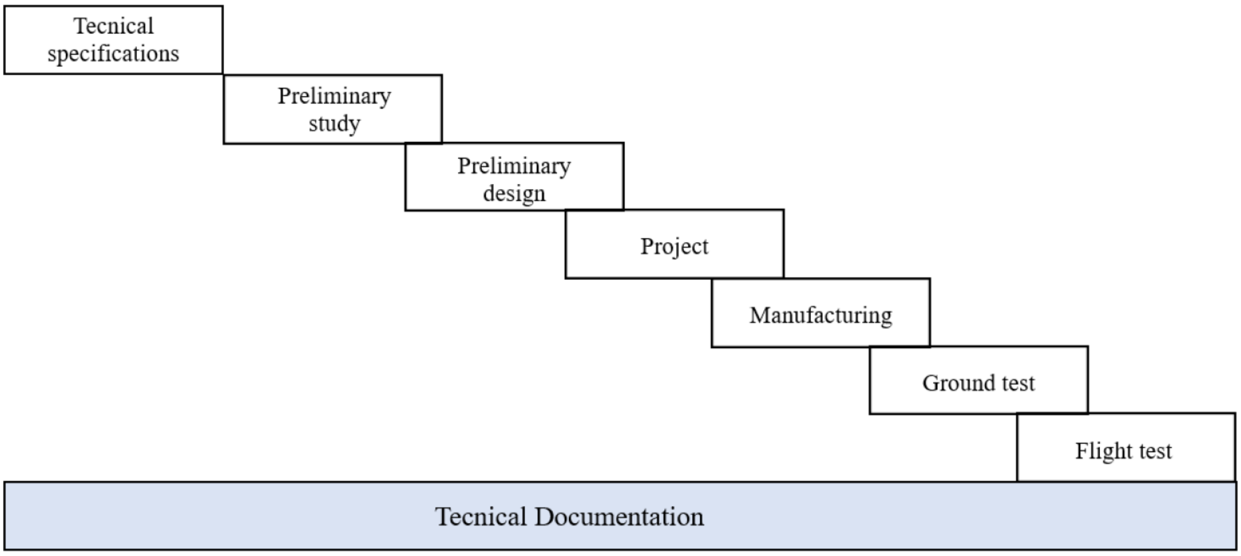

Figure 3. Aircraft development steps arrangements

As for aircraft design philosophies, two essential concepts stand out, called Minimum Solution and Free Solution. The concept of Minimum Solution, defended by many designers (especially from the European current), is based on the assumption that the aircraft must be the smallest and lightest possible capable of fulfilling the mission for which it is destined [11].

Kovacs, in his work Philosophy of Design, explains this concept stating that the aircraft must be the leanest, the most spartan as possible. Still in the minimum solution contest, highlights the famous expression of Bill Stout, "simplify and add Lightness," which remains an essential warning to this day. Such principles could be applied to airplanes of any size [12]. This design philosophy, adapted for this paper, can be summarized in four topics:

i) Ensure low weight via compact solution, small size, and simplicity;

ii) Restrict equipment to the level of operational need;

iii) Combining more than one function (whenever possible) for the largest possible number of airplane components;

iv) Adopt a powerplant with reduced dimensions and low specific weight and specific consumption.

The concept of Free Solution can be defined as the one in which the aircraft is designed without meeting any of the four topics listed above. The philosophy of the project used in the development of AgroRobot was that of the minimum solution, ensuring low weight and low cost with performance within the projected for agricultural spraying missions.

3.2 Materials

The parts that integrated the AgroRobot prototype were professionally manufactured at the Prince Air Model Ltd. factory. Various materials were used, and for that, the AgroRobot was divided into four main components (wing, fuselage, landing gear, and empennage), with their respective materials. Figure 4 shows the materials used in each manufactured component.

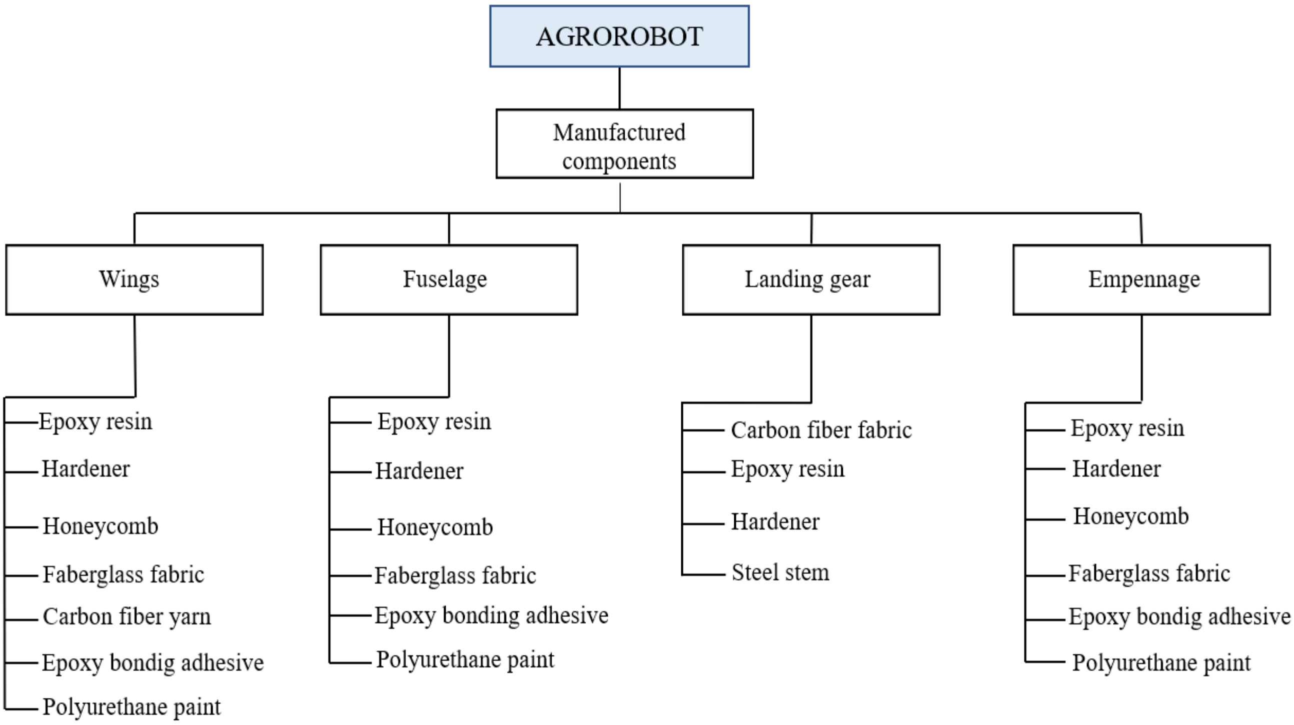

Figure 4. Materials used in the AgroRobot.

3.3 Flight Control Systems

UAVs have as their main component a control system capable of keeping the aircraft stabilized and executing maneuvers that lead it through a selected route and mission [13]. Presently, the development of flight control systems for this type of aircraft is being favored and facilitated by the tremendous technological development verified in recent years and mainly by reducing the costs of electronic components allowing a large number of companies to build UAVs with flight control systems for commercialization. The following describes the flight control system used in AgroRobot.

The AgroRobot aerial platform was adopted within several flight control systems, the MP2128g UAV autopilots manufactured by MicroPilot Co.

The MP2128g series of controllers developed by MicroPilot Co. of Manitoba / Canada is designed to stabilize and guide a wide variety of fixed-wing UAVs. This autopilot consists of altitude maintenance and speed maintenance system, a turn coordination system, a GPS navigation system, an automatic takeoff and landing system, and all the sensors necessary for complete control of the aircraft.

The control board (Figure 5) has thirty-two PID controllers Proportional-Integral-Derivative configurable by the user, which can be adjusted independently. The MicroPilot systems also have telemetry capabilities, with data transmission at a rate of 100 definable fields per second. The controllers are capable of driving up to twenty-four servos. It also allows the installation of an ultrasound wave altimeter, which is very important for low-altitude flights, in the case of the AgroRobot.

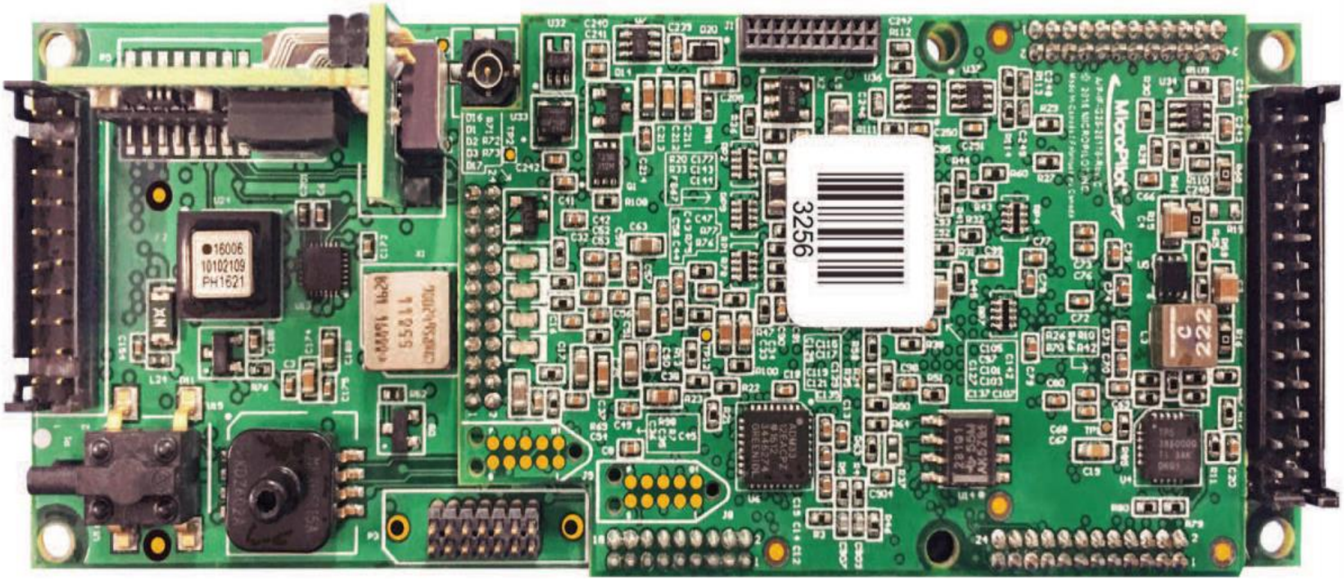

Figure 5. MP 2128g MicroPilot flight control board

The illustrated flowchart showing all the connection possibilities between radio control, ground station, and control of flight surfaces by radios modem is shown in Figure 6.

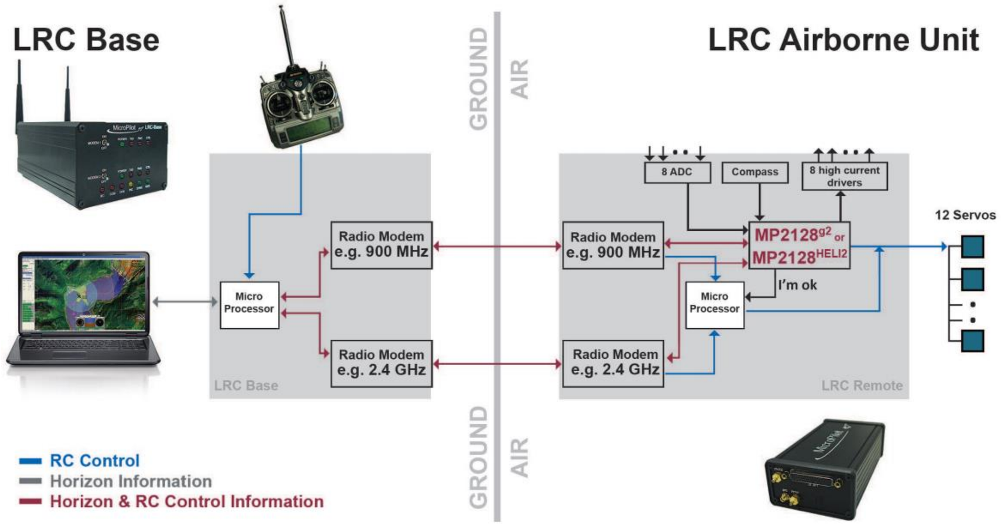

Figure 6. Flowchart showing all the connection between LCR base and LCR airborne

The system with active autopilot enables autonomous object control with the possibility of the current PID controller settings' current correction. However, it is still possible to take manual control over the mini-plane by switching into radio receivers, ensuring the RC signal transmission [14]. The system items were attached inside the AeroRobot in the way shown in Figure 7, where S1, S2, S3, S4, S5, S6, servomechanism, B1, B2, B3 Power sources, BEC, Battery eliminator circuit, AO, autopilot MP2128g, and RC, the receiver of the remote radio control signal, BW water bomb with a brushed engine.

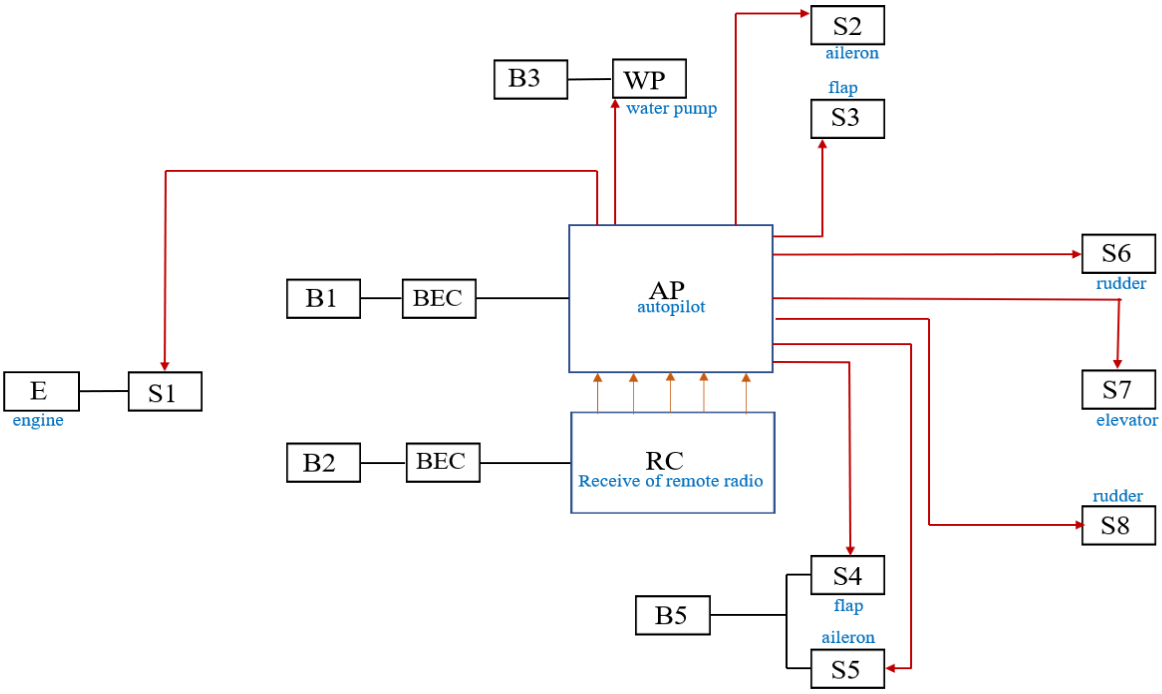

Figure 7. Block diagram of the avionics arrangements on AeroRobot

MicroPilots systems provide a ground station (Ground control), as shown in Figure 8, which allows you to receive telemetry data, images in real-time, flight in R / C radio control mode, control embedded equipment, and edit flight routes and missions.

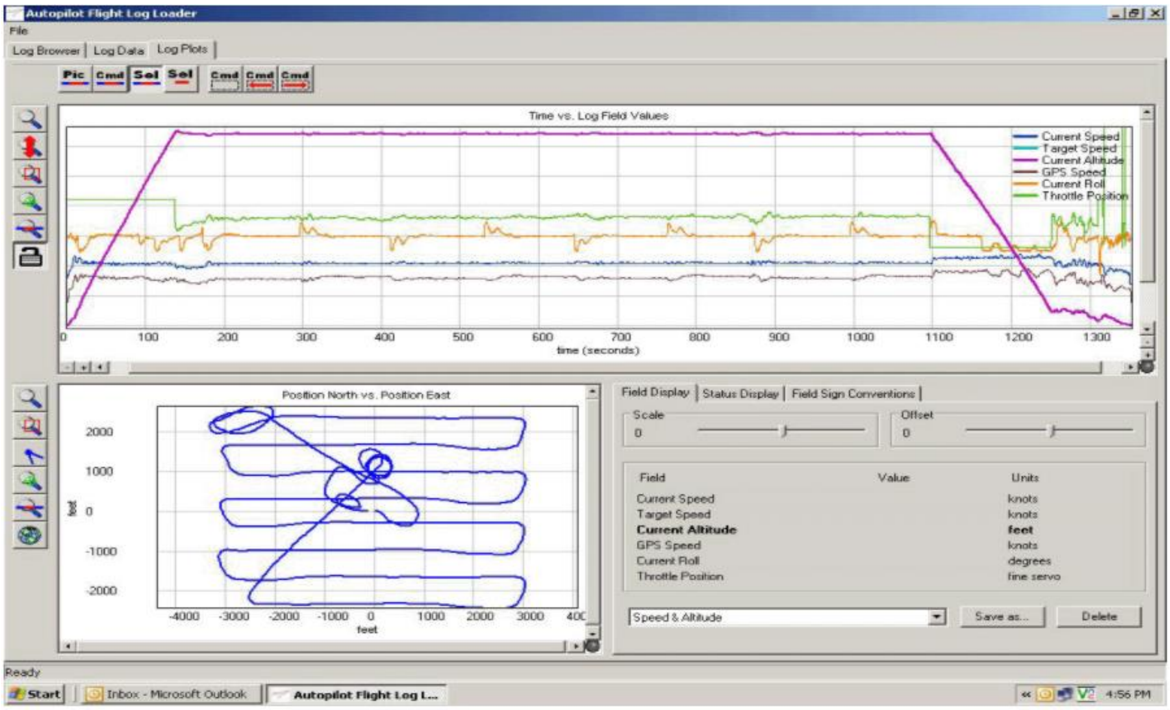

Figure 8. MP 2128g MicroPilot ground station screen

3.4 Spraying system

The spraying system is activated by the autopilot and consists of a 100-liter tank connected to a centrifugal pump driven by a Brushed motor. This pump feeds the two sprayers AU 5000 LD. The flowchart in Figure 9 shows the spray system.

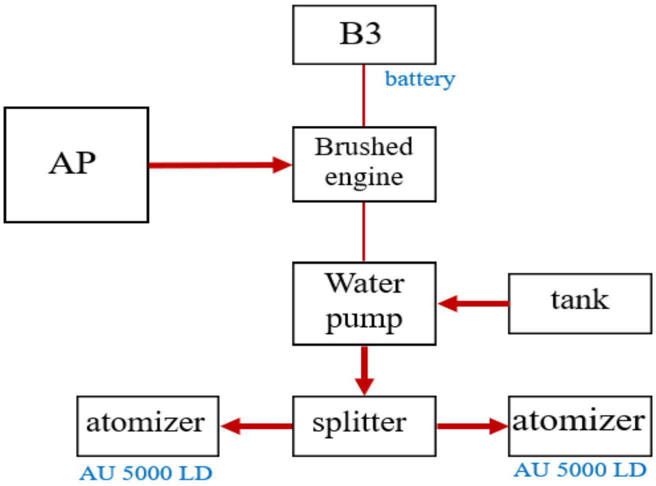

Figure 9. Flowchart of the spraying system

The Micronair AU5000 LD atomizer, produced by Bromyard Industrial Estate - England, is the latest development in rotary atomizer technology, designed to minimize drift in spraying. The flow to each atomizer is controlled by a variable restrictor unit (VRU). It provides finger-tip control of the flow by the adjustment of a 7-position control knob.

The lightweight and low drag of AU5000 atomizers enable them to be fitted directly onto the standard spray booms of most agricultural aircraft without any structural modification (Figure 10).

Figure 10. AU5000 LD atomizer

The airflow drives the atomizer past the aircraft through three highly efficient fan blades. These are adjustable in pitch, enabling the rotational speed to be varied to produce the required droplet size. Each atomizer can handle a flow of 0 – 23 liters/minute (0 – 6 USG/min). It enables the same installation to be used for a wide range of output rates from ultra-low volume (ULV) to the conventional application at 20 – 50 liters/ha (2 – 5 USG/acre).

3.5 Design of wings

The mission to be performed by the AgroRobot, which is to transport a large payload and having to perform maneuvers typical of conventional agricultural aviation, the design of the AgroRobot wing was optimized with the choice of the RAF 48 airfoil, shown in Figure 11, which has a high lift coefficient and a low drag coefficient for the predicted attack angles.

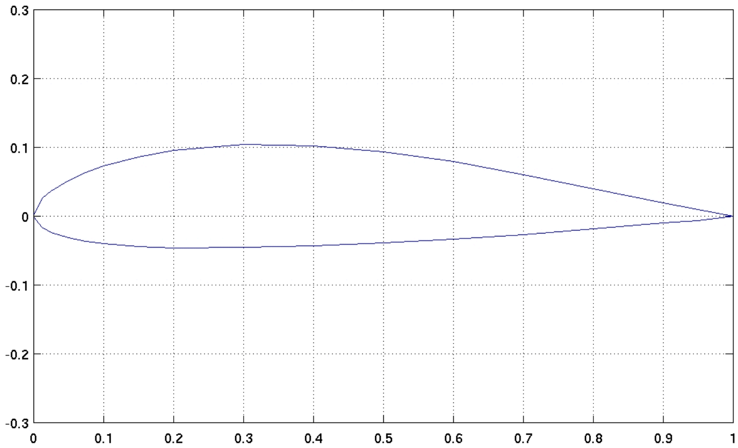

Figure 11. RAF 48 airfoil

Flaps have been designed to increase lift at low speed, thus reconciling a high CLmax for landing and takeoff and low drag for cruising and spraying speed. In addition to evaluating the CLmax of the profile used, we also verified the behavior of the CLxα curve to analyze the flight behavior close to stall speed. Figure 12 shows a graph with the characteristics of the RAF 48 airfoil.

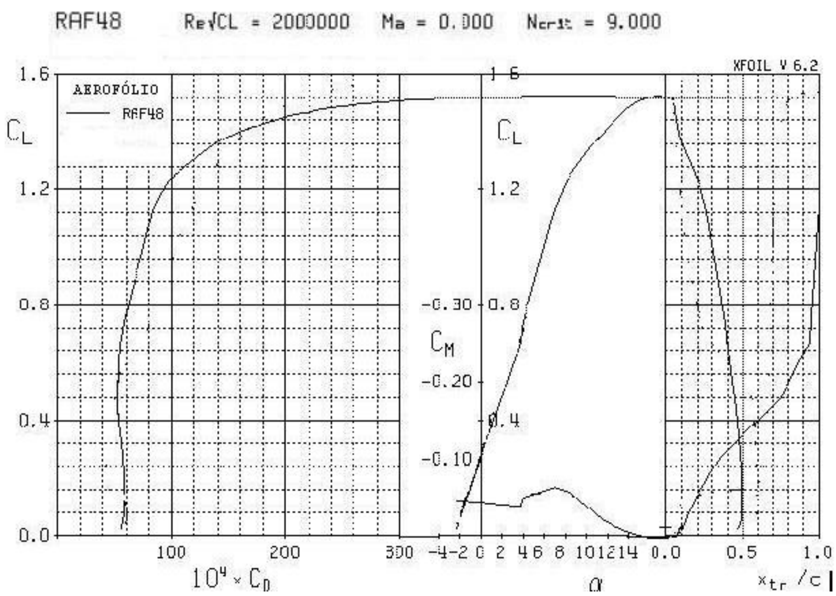

Figure 12. RAF 48 airfoil characteristic curves

3.6 Engine

The AgroRobot propulsion system consists of a Simonini Mini 3 engine (Figure 13), two-stroke, single-cylinder, air-cooled Otto cycle, and a speed reduction system pulleys and V-belts, 24Vdc electricity generator, built-in starter, and rated power of 33 Hp. The graph (Figure 14) shows the power and torque curves provided by the Mini 3 engine.

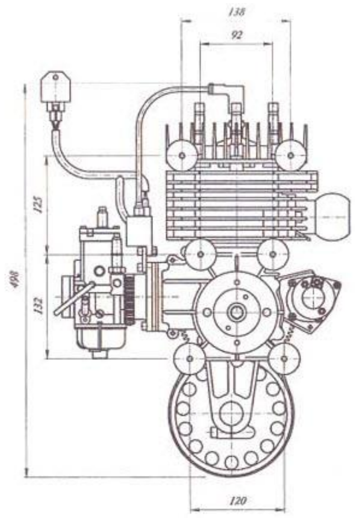

Figure 13. Mini 3 engine by Simonini

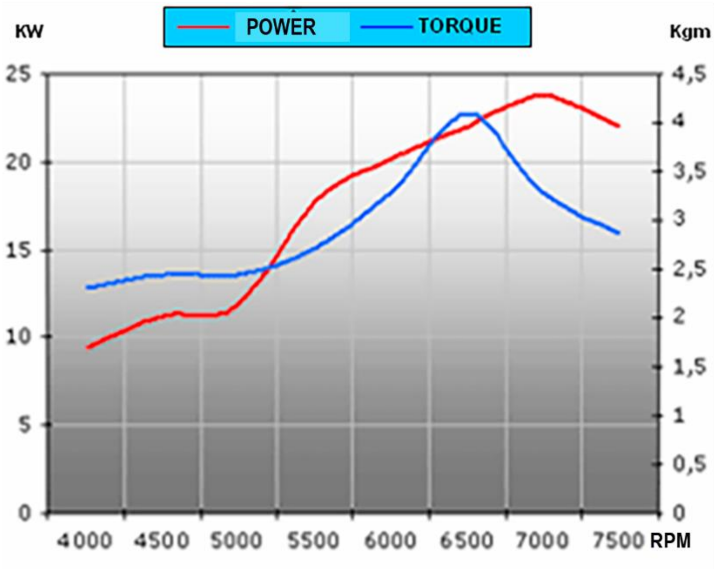

Figure 14. Graphs of power and torque of Mini 3 engines

The airflow drives the atomizer past the aircraft through three highly efficient fan blades. These are adjustable in pitch, enabling the rotational speed to be varied to produce the required droplet size. Each atomizer can handle a flow of 0 – 23 liters/minute (0 – 6 USG/min). It enables the same installation to be used for a wide range of output rates from ultra-low volume (ULV) to the conventional application at 20 – 50 liters/ha (2 – 5 USG/acre).

4. Results and Discussion

4.1 General data

The AgroRobot has an empennage with a double-tailed tail (H-Tail). The powertrain assembly is installed on the front of the fuselage. The shape and size of the fuselage have space to carry a 100 kg hopper tank. The upper part of the fuselage is removable, allowing easy access inside of the aircraft.

The fuel is conditioned on the wings' inside through two tanks' built-in material composed of fiberglass and epoxy resin. The wings are fixed to the fuselage through the central stringer and screws.

The front landing gear is attached directly to the fuselage, in front of the wing stringers junction. The rear landing gear is attached to the fuselage and controlled by a servo motor independent of the servo motors that act on the rudders. The AgroRobot has eight flight control surfaces (two flaps, two ailerons, two elevators, and two rudders).

The propulsion system consists of an air-cooled Simonini Mini 3 two-stroke Otto cycle engine, with a pulley and V-belt speed reduction system, a 24Vdc electricity generator, built-in starter, and rated power of 33 Hp. The propeller is manufactured by the engine manufacturer, Simonini Flying S.R.L, with two blades, wood, and a radius of 65 cm.

The wing was designed using the RAF 48 airfoil, which has a good lift coefficient and a low drag coefficient for the predicted attack angles.

The spraying system consists of a spray tank, a pressurization pump, a turbine (flow meter), an electric valve, and a control box, which is connected to the DGPS of the Autopilot. The atomizers planned to be installed are AU5000 LD. The technical characteristics and dimensions of the AgroRobot are shown in Table 1.

Table 1. AgroRobot UAV technical features

Description	Extent
Wing span (m)	6.00
Wing surface (m^2)	4.20
Length (fuselage, m)	4.05
Height (fuselage. m)	0.94
Weight (body, g)	37,000.00
Payload capacity (g)	100,000.00
Fuel weight (g)	3,600.00
Flight envelope sea level (m/s)	10.00 - 20.00
Cruise altitude (m)	150.00
Cruis speed (m/s)	25.00
Range limits (km)	15.00
Endurance limites (h)	1.00

4.2 AgroRobot UAV platform design

The final design resulting from the development of the AgroRobot is shown in figures 15, 16, and 17 [9].

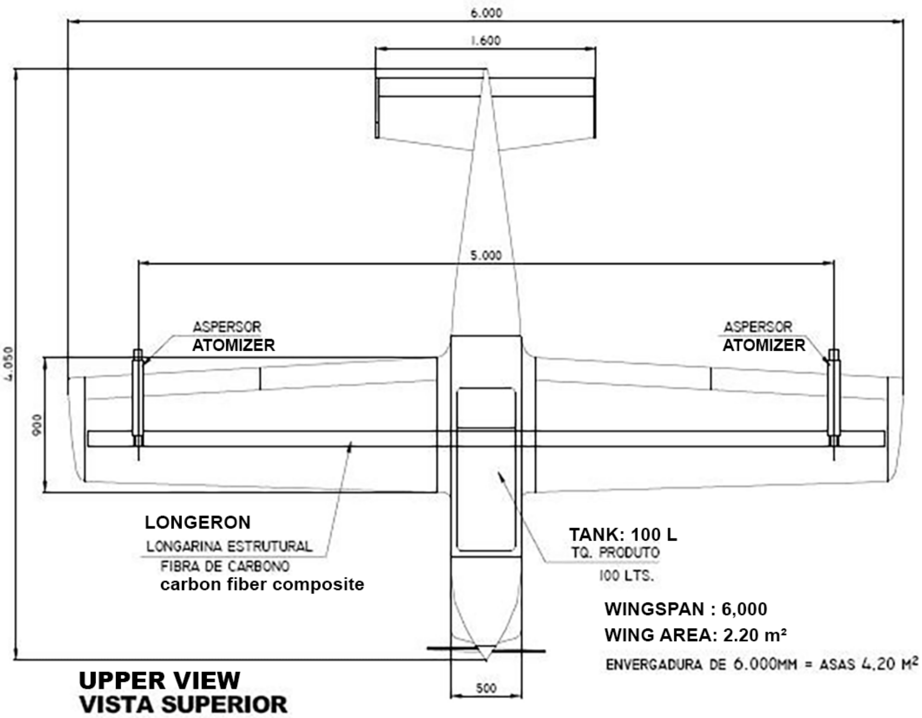

Figure 15. The AgroRobot plan view

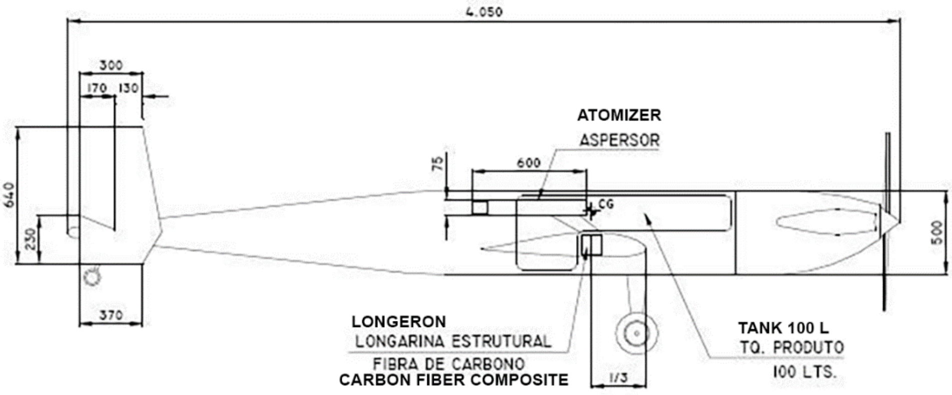

Figure 16. The AgroRobot side view

Figure 17. The AgroRobot 3D view

5. Conclusion

The prototype showed satisfactory results for the situations required in the project, for takeoff and landing. In-flight, the prototype demonstrated excellent performance, doing return curves (180º), with excellent wing inclination, fully coordinated, with directional stability at low-altitude flight, and presented excellent empennage efficiency. The fuselage demonstrates excellent structural rigidity, and the wings resisted the loads due to maneuvers typical of agricultural flight, carrying 100 kg of payload.

It was concluded that the AgroRobot is an autonomous flying platform with a large payload capacity and sufficient maneuverability to carry out agricultural spraying flights.

The wing longeron's structural rigidity made of a composite of carbon fiber and epoxy resin is sufficiently strong and rigid enough to install the rotary atomizers' support without causing rotational and dimensional deformation of the wing.

6. Acknowledgements

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Appendix

Appendix 1.

Brazilian Patent number PI 0404045-7 B1

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(54) Título: **SISTEMA DE PULVERIZAÇÃO DE LAVOURAS POR MEIO DE AEROMODELO DE ASA FIXA TELECOMANDADO.**

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