



INSTRUMENTATION OF A SUBSCALE GROUND EFFECT VEHICLE, VOLITAN, TO MEASURE FLIGHT PROPULSION EFFICIENCY

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Abstract

With the development of electronics and programming in recent years, the possibility of aeronautical projects is being studied by academia and industry, with the aim of improving and adapting them to different projects for new applications and realities. One of these cases is the adaptation of projects such as the ground effect vehicles developed by the Soviet Union during the Cold War. This is an aircraft capable of flying close to the surface of the water and whose advantage is the energy saving of the propulsion of up to 40%. There are several companies developing projects of this type around the world, adapting them to the capacity and operating conditions of the different realities. In Brazil, the startup Aeroriver is developing a ground effect vehicle, the Volitan. This project aims to improve the transportation of people and cargo on the rivers of the Amazon. For the project to be successful, it is necessary to know up to what altitude this aircraft can fly to demonstrate energy savings, safety and maneuverability. A sub-scale prototype has been developed for initial testing and is currently being tested to determine the range and flight efficiency improvement of the Volitan in ground effect. Propulsion is provided by electric motors and power is supplied by a battery bank, allowing 15 minutes of flight autonomy. In this paper, the development of the electronics and instrumentation of a prototype is presented. In order to measure the efficiency of Volitan in flight, it will be equipped with load cells to measure the thrust force, RPM, the voltage and current consumed by the motors. Lidar to precisely measure the altitude in relation to the water, and a PixHawk controller used to record accelerations, speeds, position, attitude of the aircraft, etc. As results are presented the energy consumption of the batteries as a function of altitude, in flight condition in ground effect, as well as the thrust force generated by the motors, in addition to determining up to which altitude that the ground effect has a good performance and improves the efficiency of energy consumption of the Volitan.

Keywords: Ground Effect, Electric Propulsion, Data acquisition, System Identification

1. Introduction

Since the period when wing-in-ground effect vehicles passed through their most intensive development during the 70's and 80's, considerable technological advancements have occurred in electronics and programming. Some of these have made the creation of small-scale unmanned prototypes feasible to the point that these can be equipped with consumer electronics, from components ranging from servo actuators to inertial measurement units and gyroscopes to form a full flight control system, including many additional sensors and subsystems that allow for the characterization of the dynamics of the vehicle. AeroRiver is a Brazilian company that is developing a ground effect vehicle to be used in the Amazon basin, where all cities are located near wide rivers. In this region, roads and highways are basically nonexistent, and their construction destroys the very thing that makes the region rich and unique, nature. Due to these points, ground effect vehicles present a unique opportunity to close the gap between slow boat transport and expensive airplane transport, in order to do this a subscale prototype has been constructed using many off-the-shelf electronics whose accuracies are

regarded as sufficient to provide a general understanding of the physical interactions of the elements that compose these vehicles, one important element of which is the electric propulsion subsystem, whose parameters can be measured in the form of current drawn, voltage, propeller revolutions per minute (RPM), and even thrust force present at the engine mount point. Combining these variables with information obtained from inertial measurement units, gyroscopes, barometers, a pitot-static system, a LIDAR and GPS, we can determine their relation to the ground effect and provide valuable information for the continued development of the vehicle.

Figure. 1 presents the conceptual design, the Volitan, of the ground effect vehicle developed by the startup Aeroriver for use in Amazonian rivers. This project is designed to meet the operating conditions and local operating requirements in the Amazon, such as the type of fuel to be used and the conditions for docking at existing ports. The studies in this paper are based on a sub-scale of this project, which is used to validate the operational efficiency of this vehicle.



Figure 1 – Volitan conceptual design

2. DEVELOPMENT

Flight tests are conducted using a sub-scale vehicle with a scale factor of 16.7 %. Constructed of composite materials such as fiberglass, carbon fiber, aluminum, balsa wood, and styrofoam. This prototype served as a test platform for various tests, including stability and control, navigation, and embedded systems testing. This vehicle was updated for each flight test where issues were raised, a solution was investigated, and an action was implemented. In Fig. 2 is the image of the current composition of Volitan, showing the change in the position of the thrusters.

The data acquisition system used to study the ground effect of a scale aircraft must be capable of obtaining measurements of thrust as well as power consumed by the engines, engines RPM, accelerations, attitude, airspeeds and ground speed, position, real-time monitoring system, radio control, high-precision measurement of altitude, control surface commands.

The main system for data acquisition is pixhawk 4, this autopilot made for Holybro@ Fig. 3, this platform has the following features and integrated sensors. wo Processor one STM32F765 32 Bit Arm® Cortex®-M7, 216MHz, 2MB memory, 512KB RAM and one IO Processor STM32F100 32 Bit Arm® Cortex®-M3, 24MHz, 8KB SRAM. Three accelerometers, gyroscope on-board sensors none Magnetometer, one Barometer, off-board dedicated connect one GPS with integrated magnetometer. Interfaces, 16 PWM outputs, 5 general purpose serial ports, 3 I2C ports, 4 SPI buses. The Power System Power module output: 4.9 5.5V. [1]

The thrust of the Volitan is generated by two brushless electric motors of 450 KV. The motors used are SII-4035 from Scorpion, with ESC aerostar 150A OPTO HV, with 14x7 nylon propellers, this set is capable of generating up to 7 kg of thrust. The information obtained from the propulsion system is the



Figure 2 – Subscale Volitan



Figure 3 – Pixhawk 4. [1]

RPM of each motor, the thrust in N and the power consumed. In Fig. 4, the components mounted on the support structure and the motor control unit such as the load cell, the motor temperature sensor, the coupling with ESC, the motor and ESC are positioned so that the air flow generated by the vehicle displacement can cool the thrust system.

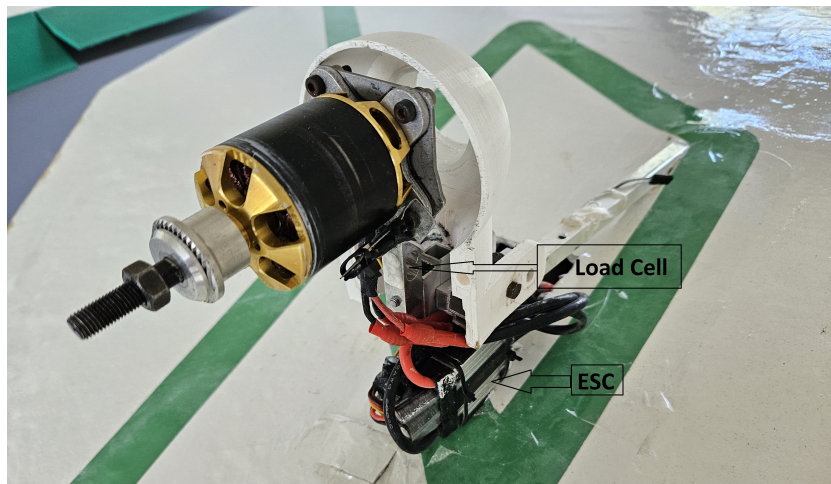


Figure 4 – Volitan's propulsion system

To measure thrust, a 20 kg load cell is used with a transducer board for the analog signal generated by the load cell, the HX711 [2], is used to measure the thrust, which is connected to a Raspberry Pi 4 to record the traction force during flight. It also receives temperature data from the engine via the infrared sensor, the temperature from ESC and a range sensor, the Lidar TF02-Pro [3]. This is used to guarantee the altitude of the flight test to provide traction data as a function of altitude in the ground effect region.

To measure the RPM, a KY-003 [4] Hall-effect sensor is coupled to pick up the field effect of the motor's rotor magnets and sends these pulses to the Pixhawk, which calculates the RPM value. In addition to the propulsion system data acquisition system, there is the telemetry system used to monitor in real time some variables of interest during flight tests, the GPS, the radio control system used by the pilot to control the aircraft, and all the surface servos. All data collected by pixhawk from these external and internal sensors is logged and written to the sdcard at a rate of at least 100 Hz. Figure. 5 shows the scheme of the drive system of the Volitan. The motor power measurement system has a PM02 v3 Power Module sensor that measures the instantaneous current and voltage consumed by each motor directly connected to the Pixhawk 4. This sensor is also responsible for powering the Pixhawk. Two 5200 mAh LIPO 4S batteries are connected in series for each motor to power the drive system.

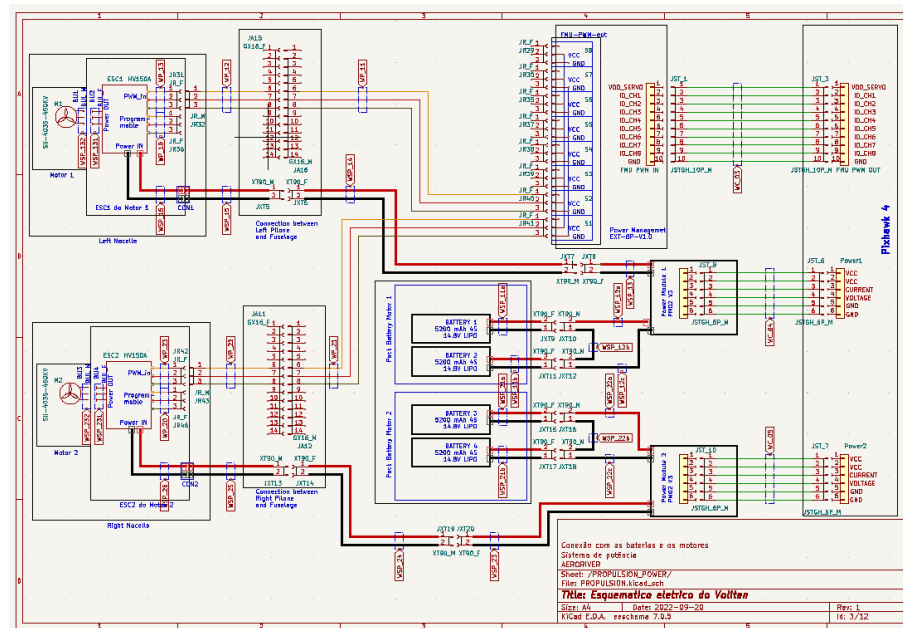


Figure 5 – Propulsion electrical schematic.

3. RESULTS

First tests take place and Fig. 6 shows the power in watts, the current in amperes, the thrust in newtons and the percentage deflection of the power lever for a standing thrust test.

In Figure. 7 the collected data are shown together with the artificial horizon and the position of the Volitan along with the videos from the flight test. This type of data has proven to be very useful in analysing the difficulty of maintaining the ground effect of this type of aircraft in flight, and is an option for scale aircraft analysis and design.

All data is recorded at a minimum frequency of 100 Hz, and some sensors have an acquisition rate of 400 Hz, such as accelerometers and gyroscopes. To make this acquisition rate possible, the ArduPilot's open source firmware has been modified so that the variables of interest have this acquisition rate.

4. CONCLUSION

At the moment, this work is still in progress. Test trials have not yet been conducted to collect data from altitude sensors, which will be presented in the final version of this paper. As preliminary results, we have found that the data collected for measuring thrust and power of the thrusters are very promising, as they are able to efficiently measure all the necessary data for the identification of the propulsion model as a function of the flight altitude of the Volitan

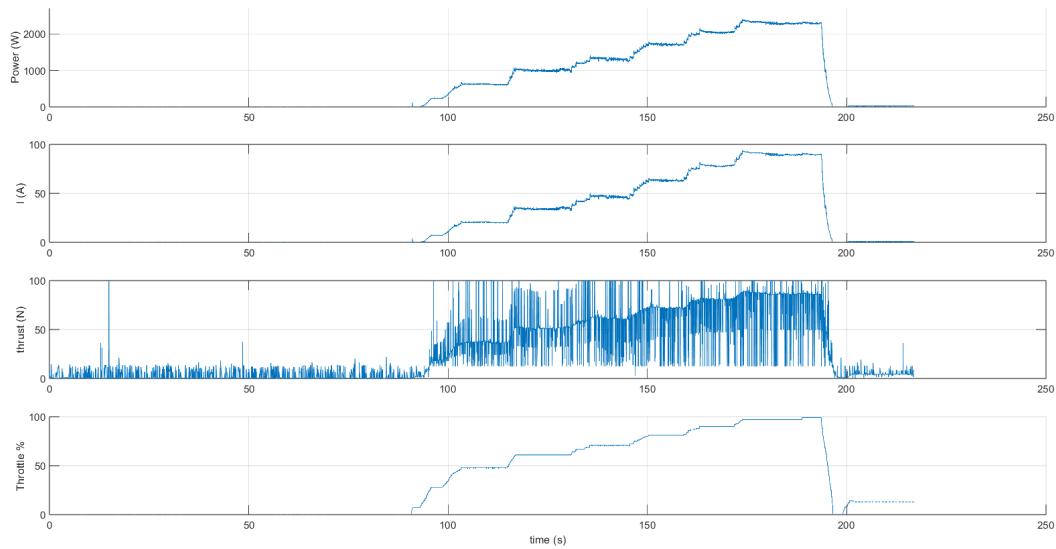


Figure 6 – Results obtained from thrust test.

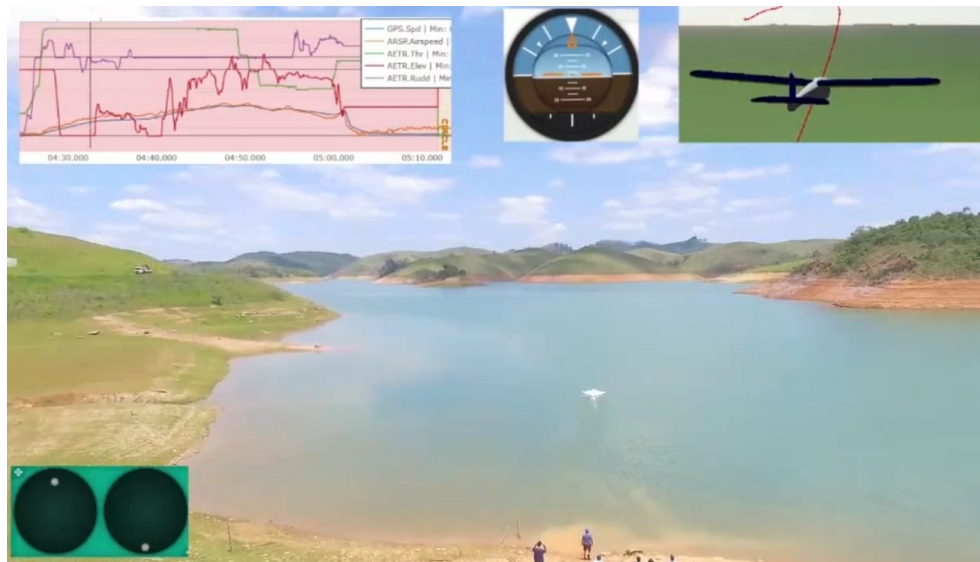


Figure 7 – Acquisition of flight test data.

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