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Bachelor's thesis in

AEROSPACE ENGINEERING

AILERON MODIFICATION ON A RC AIRCRAFT FOR ROLL PERFORMANCE TEST

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Abstract

The purpose of this thesis is to study the effect of aileron spanwise extension on roll performance of a small radio-controlled aerobatic aircraft.

Dividing each aileron in three parts, three different wing configurations are obtained:

-configuration 1 SHORT–LENGHT AILERON: in this configuration, the roll is controlled by the movement of the external part of each original aileron;

-configuration 2 MIDDLE-LENGHT AILERON: in this configuration, the external and the central part of each aileron are joined together to control the roll;

-configuration 3 FULL-LENGHT AILERON: this time, the three parts of each aileron move together to control the roll, as the original aileron configuration.

The aircraft is also equipped with the PIXHAWK, by 3DS ROBOTICS, a commercially available flight controller and data recorder, in order to conduct a flight test for each wing configuration collecting data related to roll performance.

The first part of this work focuses on the design and building process of the aircraft used for the test, the SB-03 “ACRO”, following with the detailed report of the modification applied to the ailerons. Then, a brief description of the instrumentation and its installation on the aircraft. The final part of this thesis deals with the flight test and the analysis of the data collected in flight by the PIXHAWK.

Table of contents

Introduction

In the history of aviation, thanks to the continuous development of reliable remote-control systems, unmanned-scale aircraft have become an important resource for testing innovative technologies, materials and aerodynamic solutions, minimizing the risk of human and economic losses.

Another great advantage, especially with small model aircrafts, is the possibility of operating in restricted areas at low altitudes, without interfering with any air traffic; moreover, the latest electric power systems allow to conduct 0-emission and low-noise-level flight tests.

Such as real scale aircrafts, the flight characteristics of a small radio controlled aeroplane depend on its shape, power-to-weight ratio, balancing and many other factors; this fact leads to the necessity of choosing the right aircraft for each kind of test flight.

In this case, a roll-performance test is conducted by rolling the aircraft bank-to-bank and/or making it perform full rotations on its roll axis; for this purpose and due to the need of recovering safely from unusual attitudes, maneuverability is the key feature of the test aircraft.

For all these reasons, the SB-03 “ACRO” electric aerobatic aircraft was chosen.

Chapter 1

SB-03 “ACRO” Aerobatic aircraft

1.1 Aircraft Design

The SB-03 “ACRO” is a small radio-controlled aerobatic aircraft, its design is inspired by the popular Extra 300 and Zyvko Edge 540, with middle wing configuration, bicycle landing gear and balsa/plywood classic construction, with 3D printed engine cowl and plexiglass thermo-formed canopy.

The design process started in May 2017, using the software AutoCAD®, with the aim to build a light aerobatic airplane powered by a 350 Watt electric motor and 3 cells lithium polymer batteries.

To define the main dimensions of the aircraft, two parameters were took as reference:

- P/W power to weight ratio (Watt/Kg): this parameter was set at the average value of 300 Watt/Kg, as suggested in an Electric Flight Manual available on the Internet[1]. Since the model aircraft is powered by a 350 W motor, its weight has to be set at the value of 1.16 Kg, according to the desired P/W.

- W/b weight to wingspan ratio (Kg/m): this parameter was obtained statistically by analysing a sample of 10 commercially available, classic construction aerobatic models, with a mean value of 0.85 Kg/m. According to this value and on the estimated flying weight, the wingspan was set at 1.2 m.

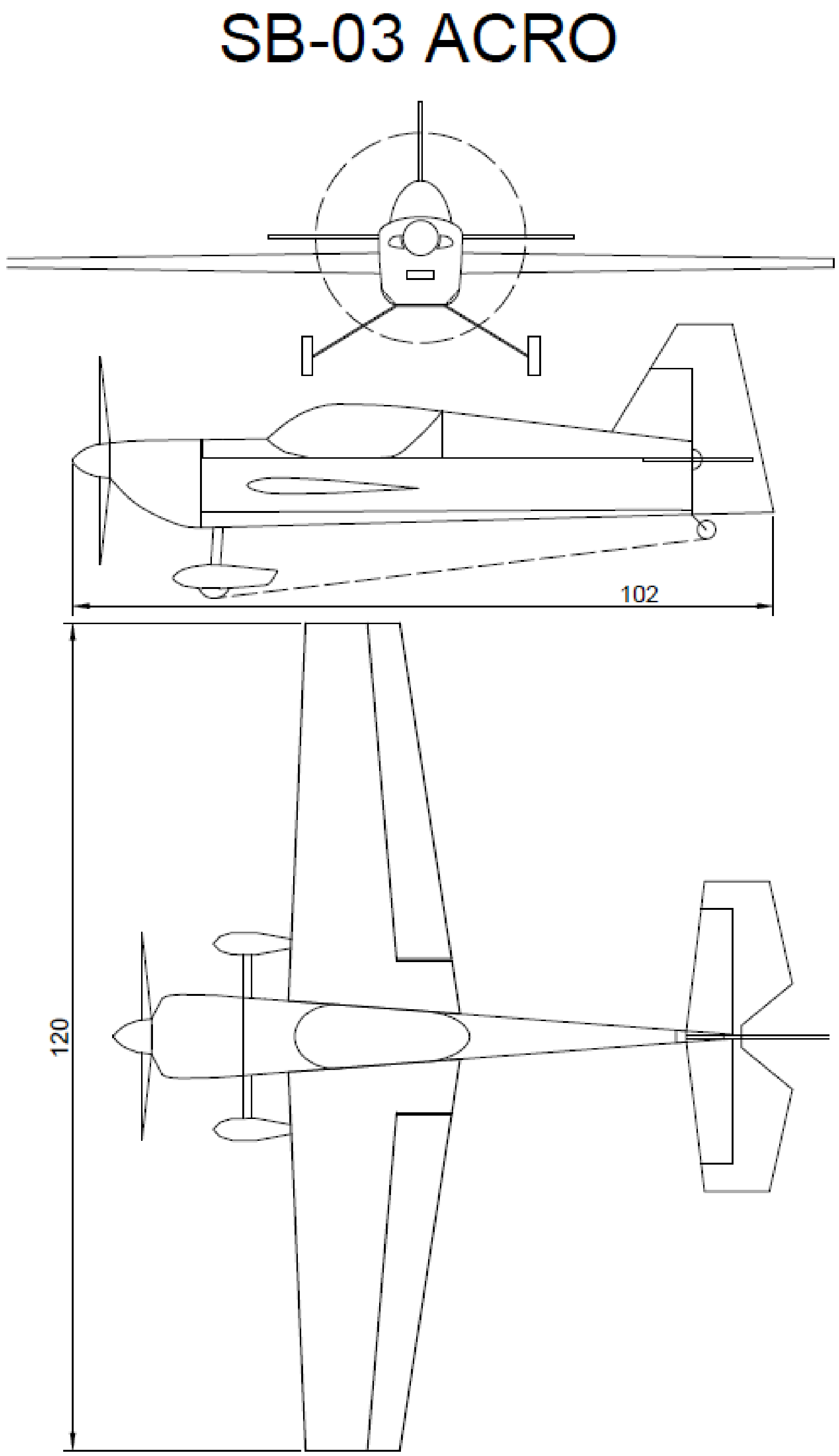

Figure 1: General views of the aircraft.

The shape of the SB-03 was determined only by taste, but always keeping in consideration all the principles of physics, aerodynamics and flight-dynamics in order to obtain a stable, but manoeuvrable aircraft, capable of flying at a wide range of speed.

1.2 General airframe design

The main goal of a structural design process is to obtain a light but strong structure capable of satisfying the most varied requirements:

- ease of construction;
- reliability;
- ease of replacing broken/worn parts;
- ease of ground operation;
- affordability;

According to all these requirements, the airframe was divided in the following assembled components:

- fuselage body;
- engine cowl (screwed to the fuselage body);
- canopy (hold to the fuselage by 8 strong magnets);
- wing (divided in two parts, joint to the fuselage by a single carbon rod and secured by two nuts);
- vertical tail (screwed to the fuselage);
- horizontal tail (locked to the fuselage by the vertical tail);

1.3 Fuselage design

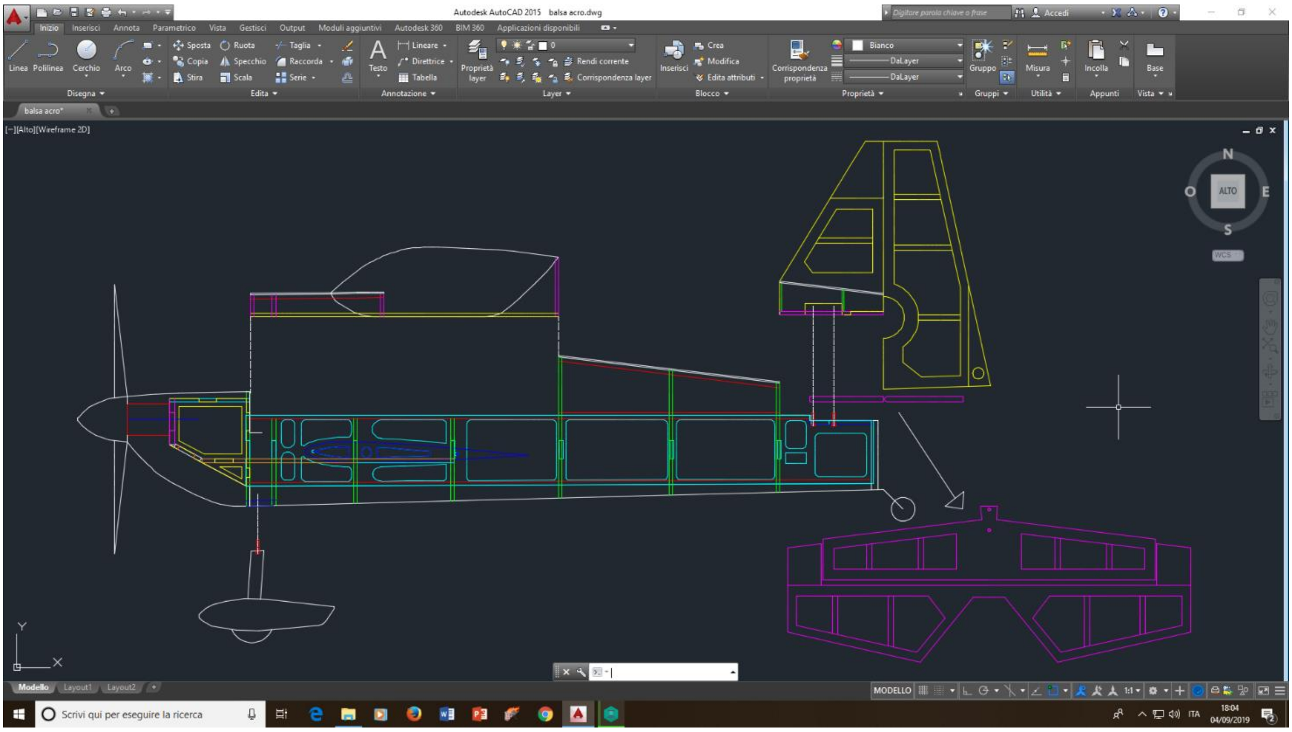

Figure 2: Side view of the aircraft in the AutoCAD® Design Environment, all the fuselage components are separated to highlight the mounting scheme.

The fuselage is the most complicated component of the airframe, due to the various tasks it has to fulfil; in fact, it carries all the stresses coming by the powerplant, the wing, the tail surfaces and the landing gear, and it must be a reliable joining structure for all these parts.

Another fundamental role of the fuselage is that it has to contain and protect four electronic components that are essential to flight:

- Powerplant: brushless motor + ESC (see Chapter 3), these two elements are both positioned in the front of the airframe, not only because a tractor configuration was adopted, but also to use the incoming air for cooling (at high rpm and with no cooling system a brushless motor could melt due to overheating);

- Receiver: this small and light component transmits the command signals to all the other electronic devices on board, allowing the aircraft to be remote controlled;

- Servo(s): this mechanism is used to move a control surface. In order to get precise movements, its base has to be firmly locked;

- Battery pack: this component is relatively heavy, hence its position strongly influences the aircraft balance. For this reason, it is convenient to design a long battery housing platform (Fig. 3) inside the fuselage, on which the battery can be moved (forward or aft) and locked (generally with Velcro stripes), depending on the balance configuration of the airplane.

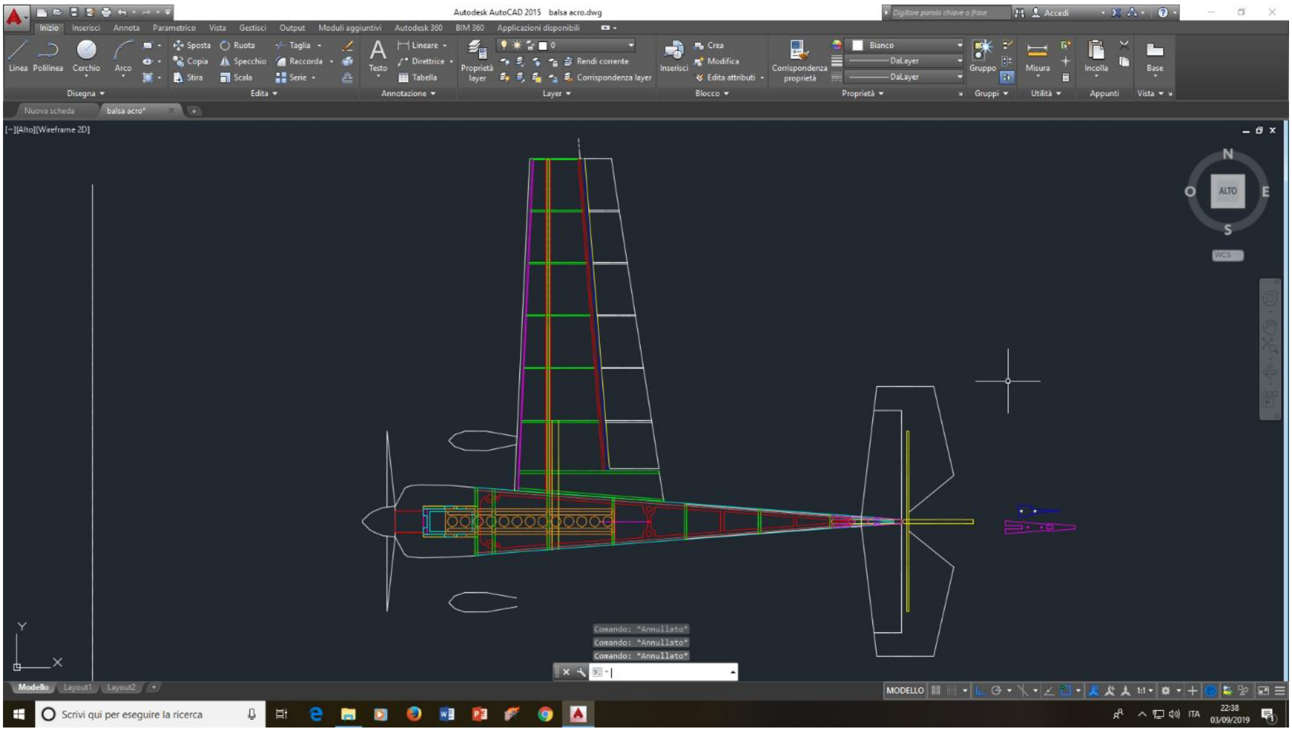

Figure 3: Top view of the aircraft in the AutoCAD® Design Environment; the battery housing platform is located in the front part of the fuselage (coloured in orange) and features many lightening holes. In the rear part, the tail-junction bases are shown: the one coloured in magenta is glued to the vertical tail and it is screwed to the blue one, glued to the fuselage body. The horizontal tail is tightly locked between the two bases.

In order to have a light and strong airframe, the fuselage body was made at 95% of 4 mm plywood, with balsa stiffeners and thin panels on the upper part, between the canopy and the tail surfaces.

Each component was accurately designed with lightening holes and slits, to minimize weight without renouncing to structural strength, and to ease the building.

All the joints between the main parts of the airframe were designed to be user-friendly, making the assembly fast and easy, with the need of a simple screwdriver only.

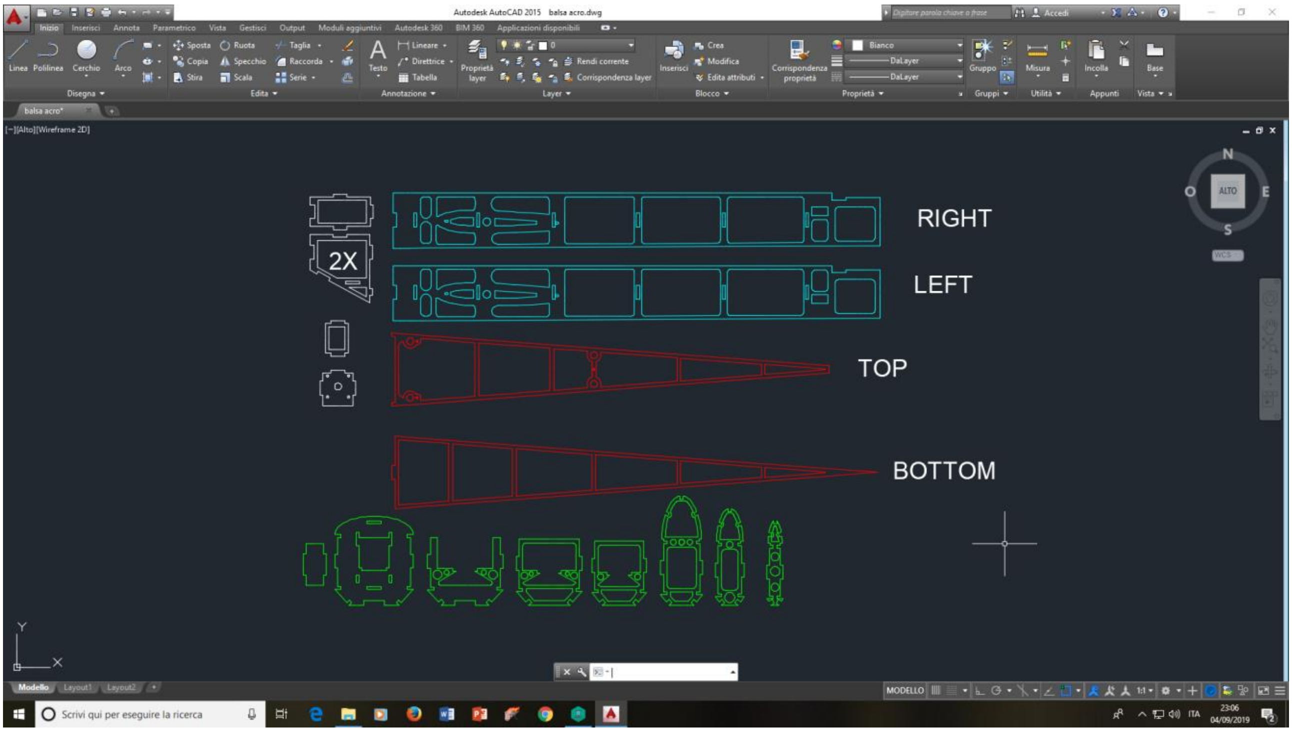

Figure 4: The two sides (coloured in blue), the two horizontal reinforcements (coloured in red) of the fuselage, the formers (coloured in green) and the parts of the motor mount (coloured in white), all made of 4 mm plywood.

1.4 Wing design

The wing prototype of this aircraft featured a thin airfoil that caused flutter problems. For this reason, its design and building process will not be discussed.

The definitive wing of the SB-03 was designed using Catia™ V5, by Dassault Systèmes®.

First, the chordwise position of the spar flanges was determined to make them straight and orthogonal to the roll axis , avoiding any kind of curvature that would complicate the building process.

Then, a symmetrical airfoil (typical of aerobatic aircraft), was designed with its maximum thickness in correspondence of the spar flanges, and a 1.5 mm balsa layer was included, in order to create the wing external surface.

The wing mounting angle (referred to the fuselage) was set at the value of 1 degree.

For structural reliability, the square section of the balsa spar flanges was approximately sized considering a maximum load factor of 12G, with the conservative hypothesis that all the bending is carried by the main spar (the maximum bending moment is actually carried by the carbon rod).

Other two spars were added:

-front spar: a 2 mm balsa strip , useful to carry torsion stresses and to ease the alignment of the ribs with the leading edge (a 5mm hand-sanded balsa strip)

- rear spar: 1 mm thicker than the front one, to carry torsion and to host the nylon aileron hinges (see Fig. 6 and Fig. 7).

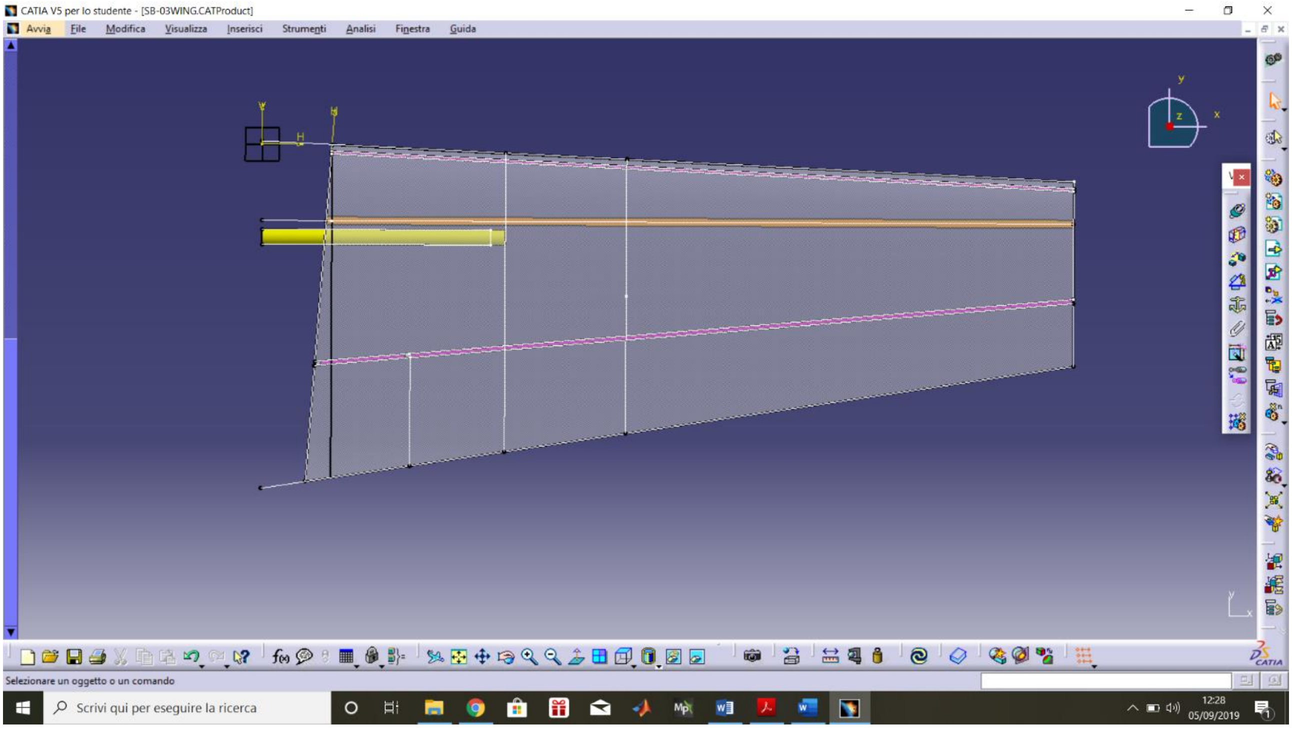

Figure 5: Top view of the wing in the Catia™ V5 Environment, the spar flanges are coloured in orange, while the yellow rectangle is the brass tube containing the carbon rod, used to join the wings to the fuselage.

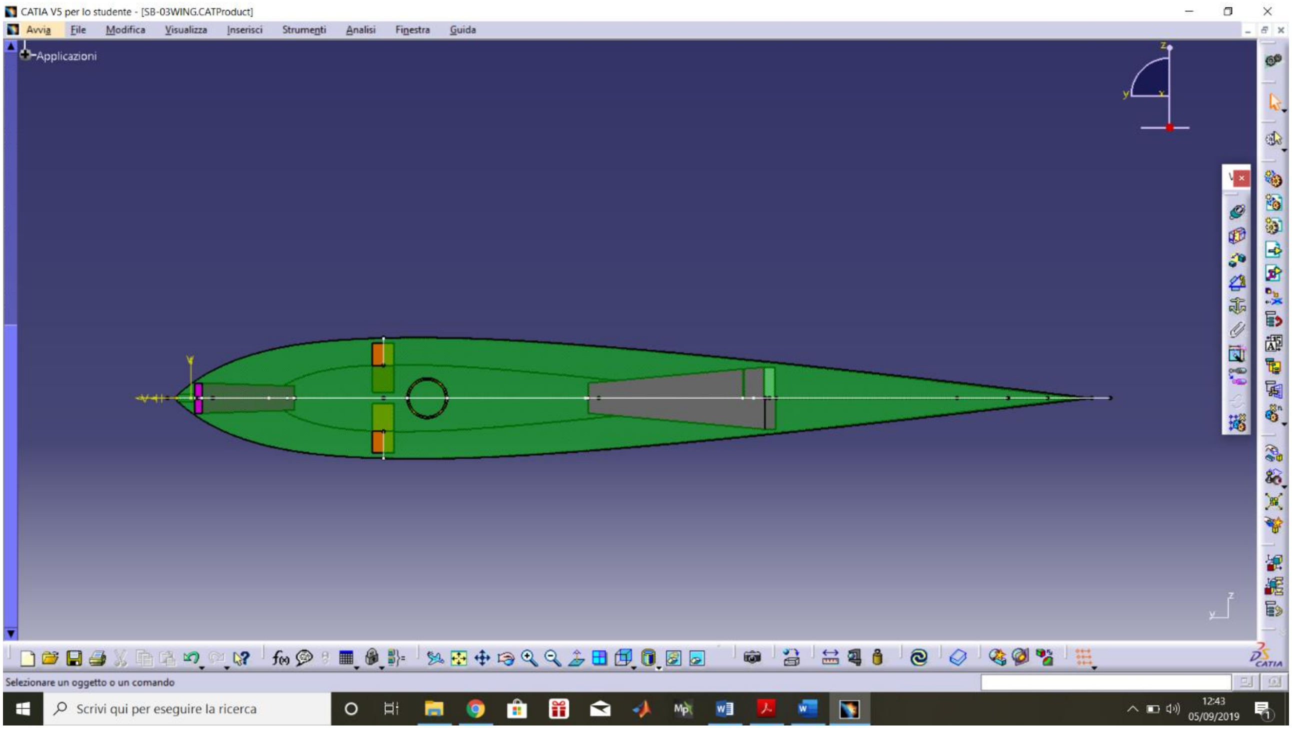

Figure 6: Side view of the wing, the square section-spar flanges (6mm x 6mm balsa) are coloured in orange, the front spar (2mm balsa) and the rear spar (3mm balsa) are coloured in magenta.

Each wing features nine ribs, divided in two categories:

- force ribs, made of 4 mm plywood: the first three ribs, which host the brass tube containing the carbon rod, and the last one;

- form ribs, made of 2 mm balsa: these ribs just carry torsion stress.

Some of the differences between plywood and balsawood is that the first one is tougher, more resistant and heavier than the first one.

For these reasons, the plywood is suitable for components which has to carry intense stresses (for example the ones coming from the carbon rod) and for making parts joinable with self-tapping screws (such as an optional winglet screwed to the tip rib).

Even in this case, all the ribs were accurately designed with holes and slits to obtain the lightest but strongest result.

To prevent buckling, the main spar was reinforced with 2 mm balsa webs.

At the end, the wing balsa surface was lightened with slits, in correspondence with the form ribs.

The aileron is made of the following parts:

- 1,5 mm balsa skins;

- 2mm balsa ribs;

- 2mm front spar;

- 6mm hand-sanded leading edge.

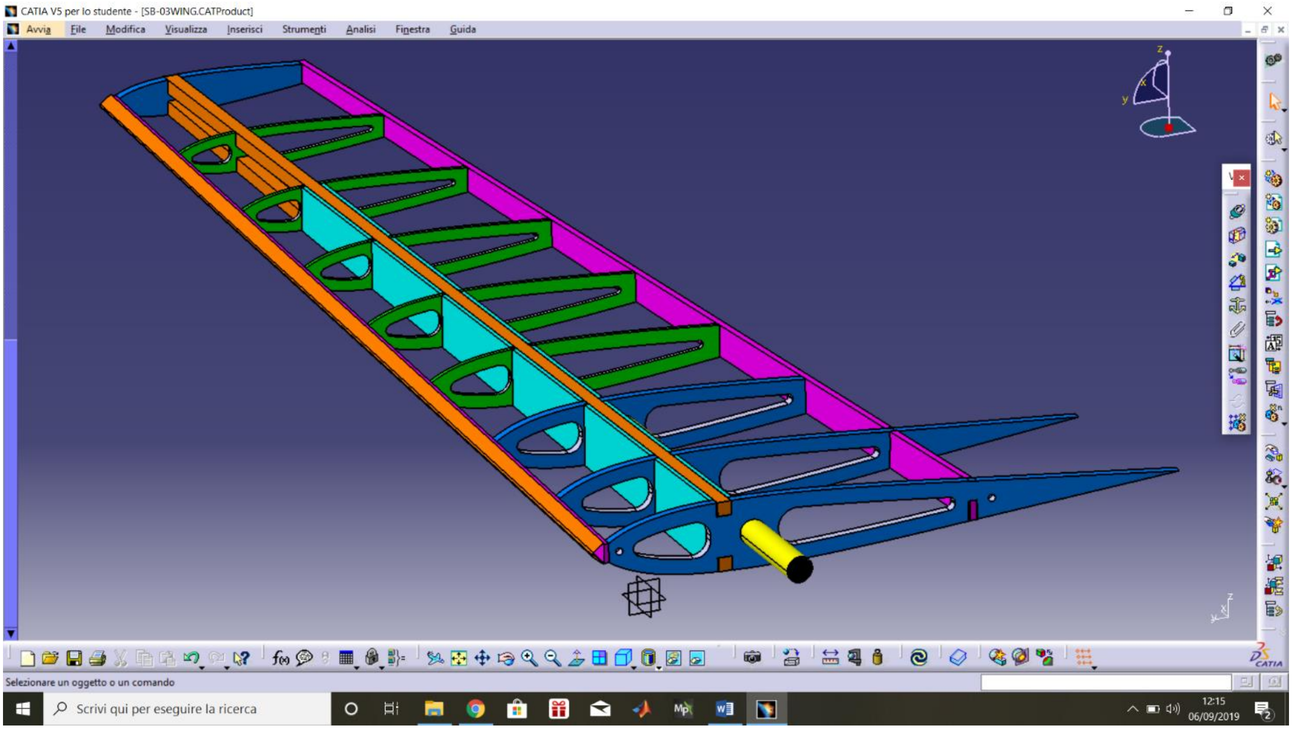

Figure 7: Isometric view of the wing: the form ribs are coloured in green, the force ribs in blue, the spar flanges in orange, the spar webs in light blue.

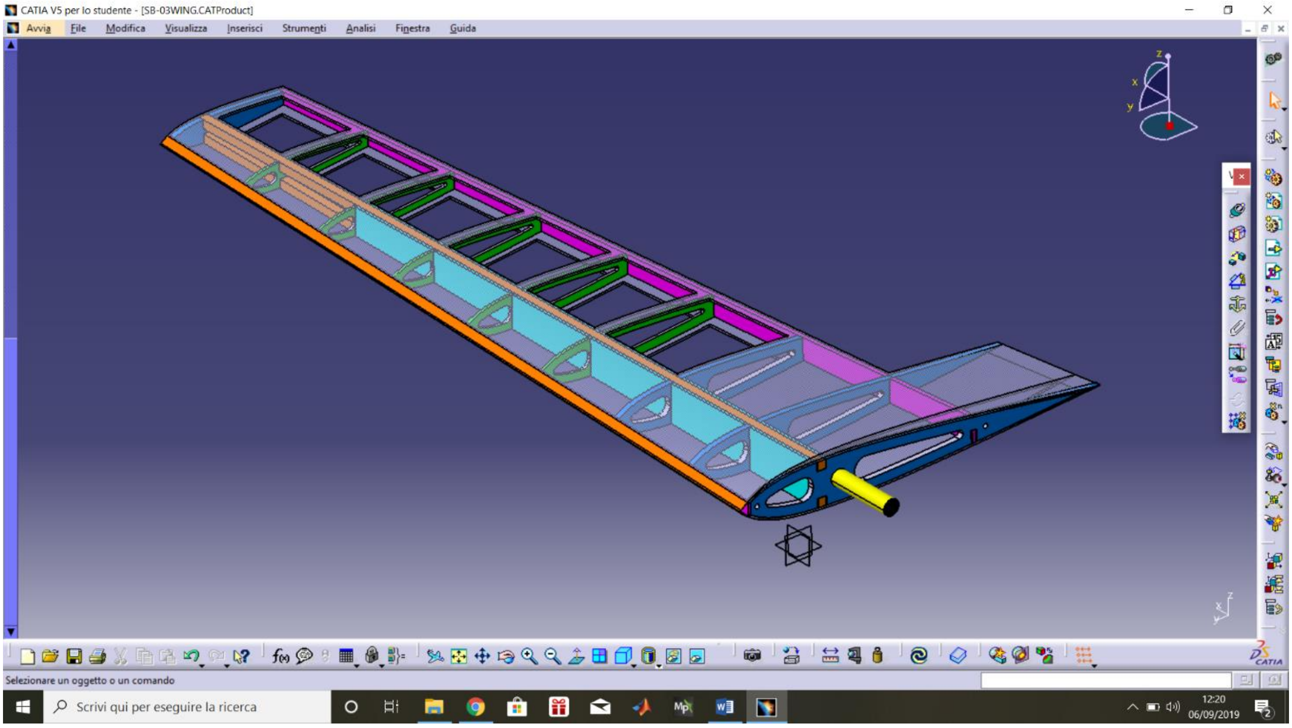

Figure 8: Isometric view of the wing, the 1.5 mm balsa external surface is coloured in transparent grey.

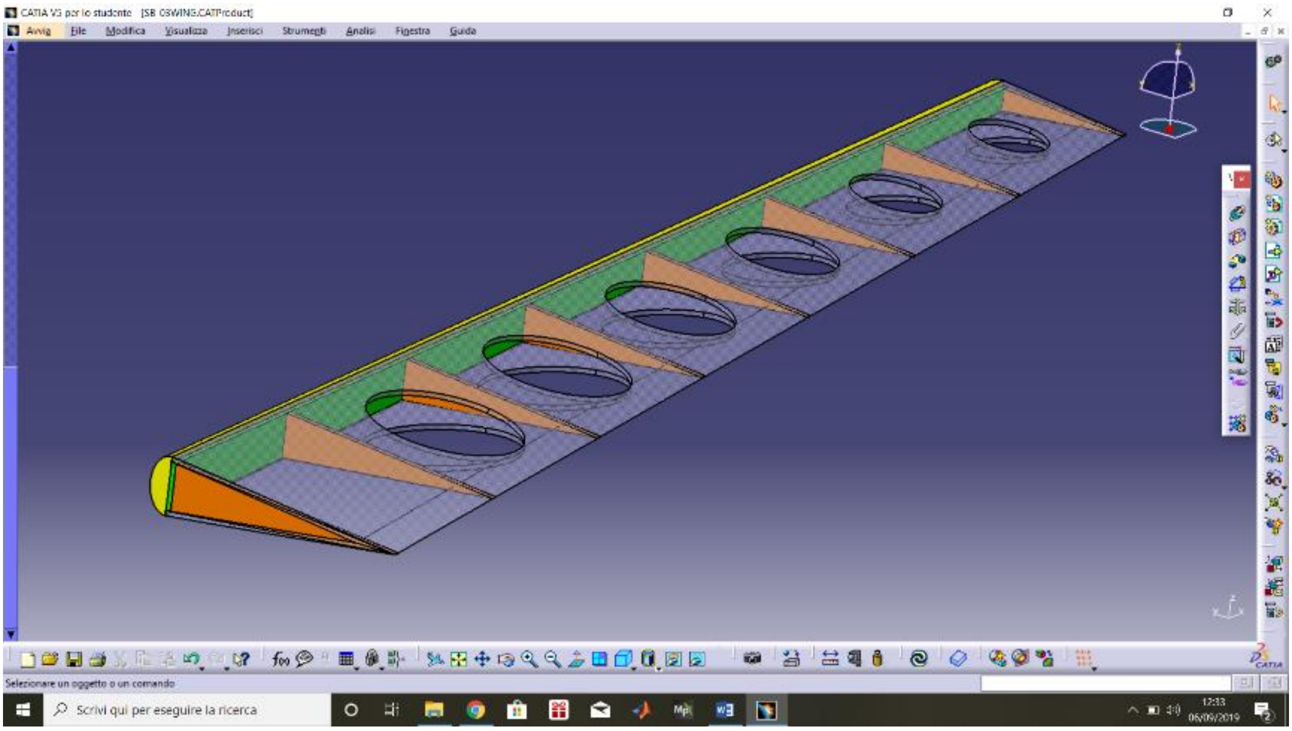

Figure 9: Isometric view of the aileron with all its components.

1.5 Engine cowl design

The engine cowl was designed using Catia™ V5, adopting a top-down modelling technique based on the original cowl AutoCAD® sketches.

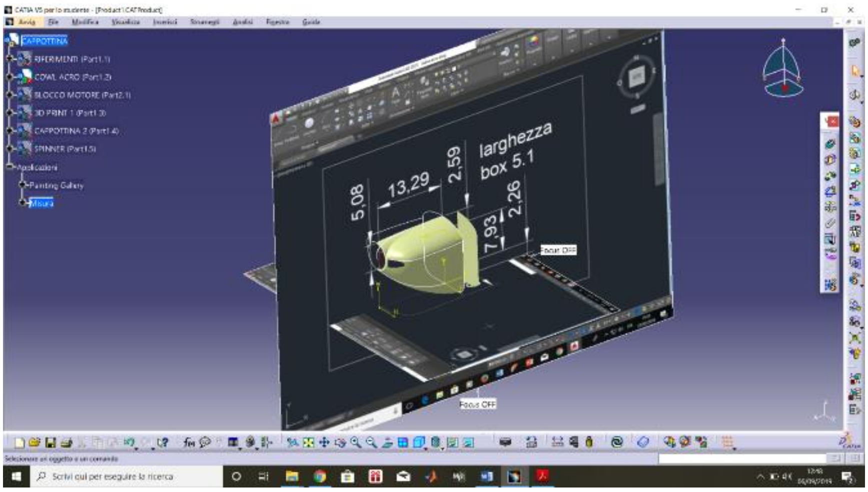

Figure 10: Top-Down modelling technique.

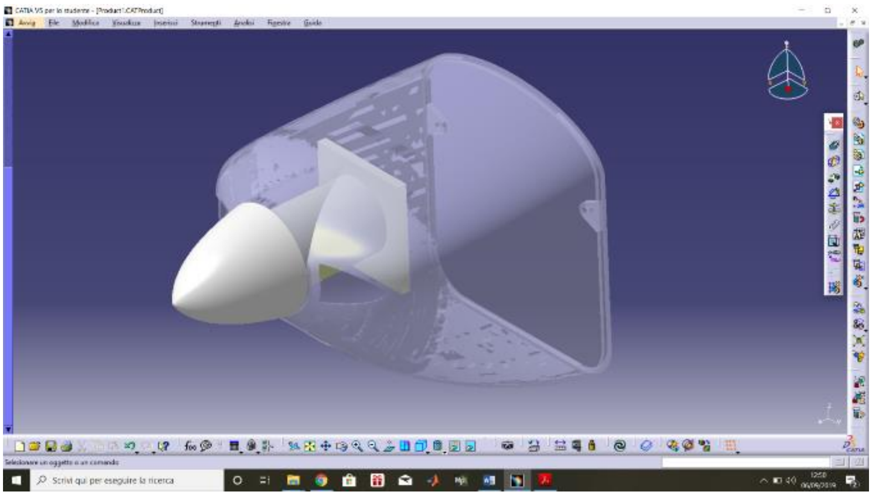

Figure 11: The spinner and the motor mount were taken as reference element to prevent any interference between the cowling and the powerplant.

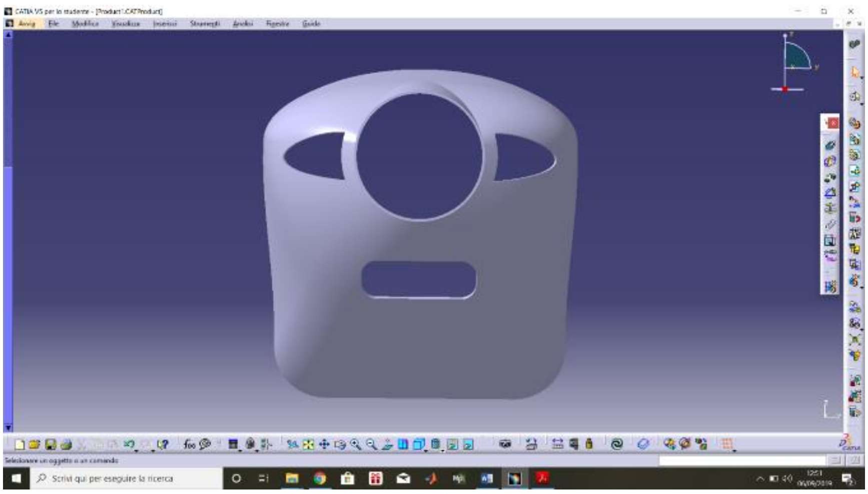

Figure 12: Three air intakes were designed for cooling the motor and the ESC.

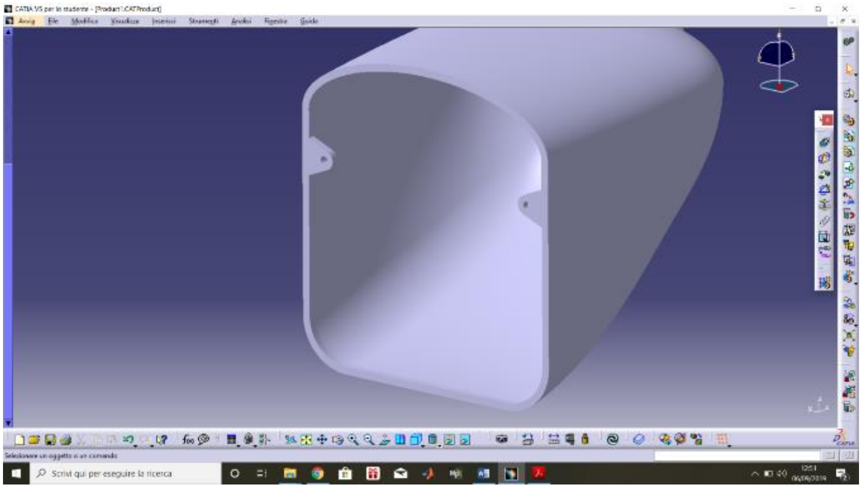

Figure 13: The engine cowling is locked to the fuselage firewall by two self-tapping screws, passing through the holes shown in the picture.

1.6 Build

Many manufacturing techniques were adopted for the realisation of the airframe parts:

- the plywood components were CNC milled;
- the balsa ribs and panels were hand cut;
- the engine cowl was 3D printed;
- the Plexiglas canopy was thermoformed on a polystyrene CNC milled mould.

At the end, the whole airframe was covered with a specific covering film .

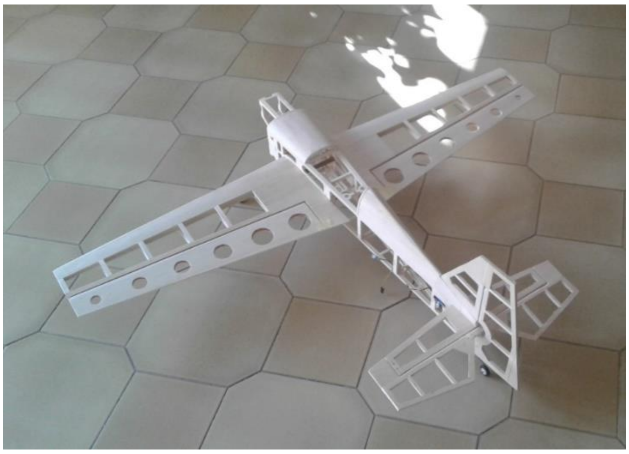

Figure 14: The airframe without covering and electronic system.

Figure 15: The complete and finished aircraft, ready to fly.

1.7 Tech Specs

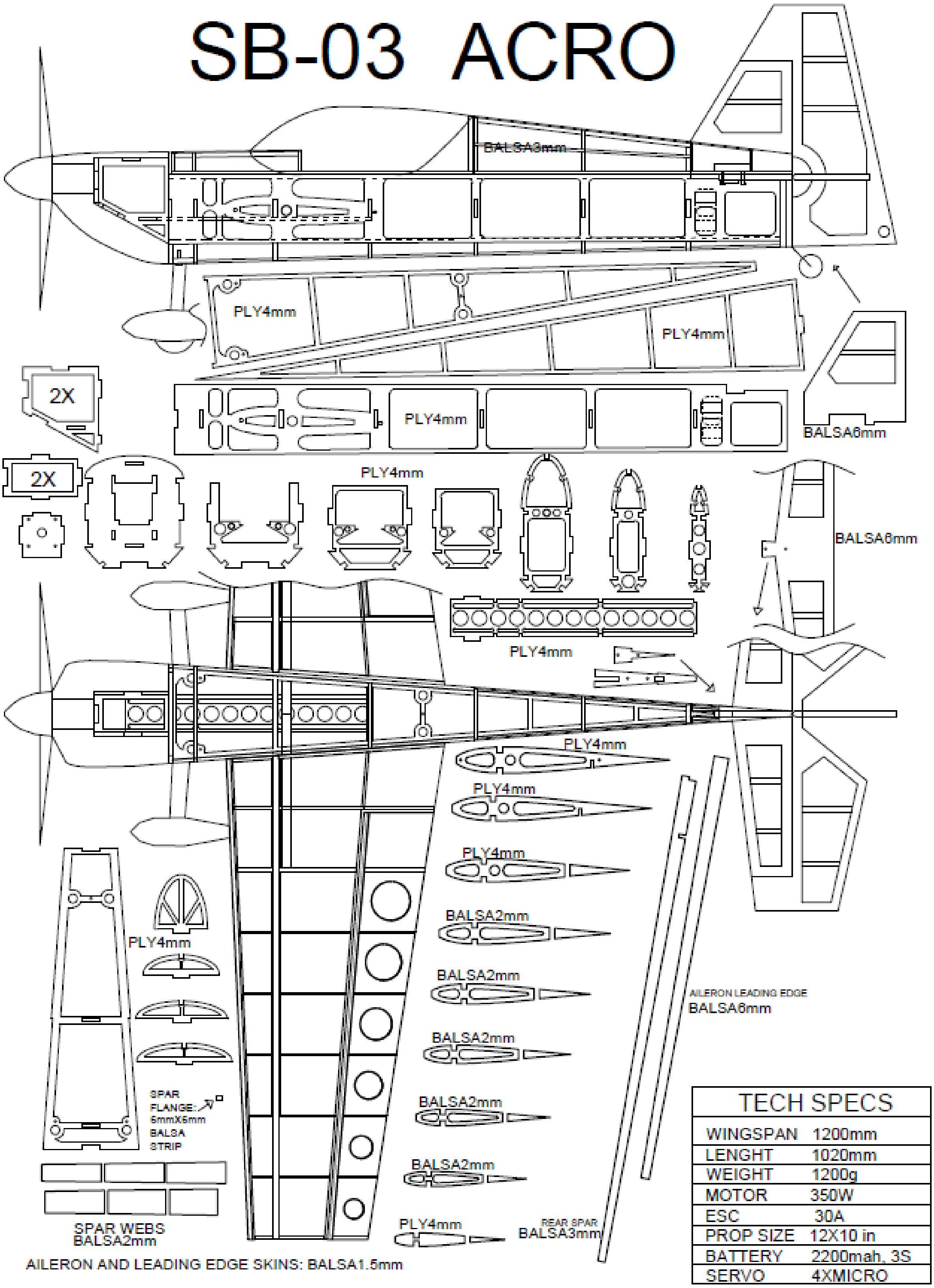

Figure 16: Aircraft Technical Specifications.

Chapter 2

Aileron Modification

2.1 Modification Design

The aim of the modification is to divide each aileron in three independent parts, with the purpose of moving them in three different configurations (see Abstract at page 2).

In order to make the configuration change easy and fast, and to avoid adding weight to the aircraft, a new tripartite aileron was designed and the only wing servo was moved from its original position (near to the wing root) to the wing tip and mechanically connected to the most external section of the new control surface, joinable to the other two with a simple stripe of scotch tape.

Each aileron section is hinged to the wing and separated from the others by a 2 mm gap, a distance long enough to rotate freely, but short enough to make the scotch tape an excellent joiner.

This solution allows to use only the same servo for each configuration, keeping the aileron deflection angles unchanged and preventing any weight gain related to additional servos; it is also possible to change the aileron configuration in an easy, fast way due to the excellent compatibility between the scotch tape and the covering film.

The aileron structure is the same as the original (see Fig. 9), with few differences on the ribs positioning, due to the separation gaps.

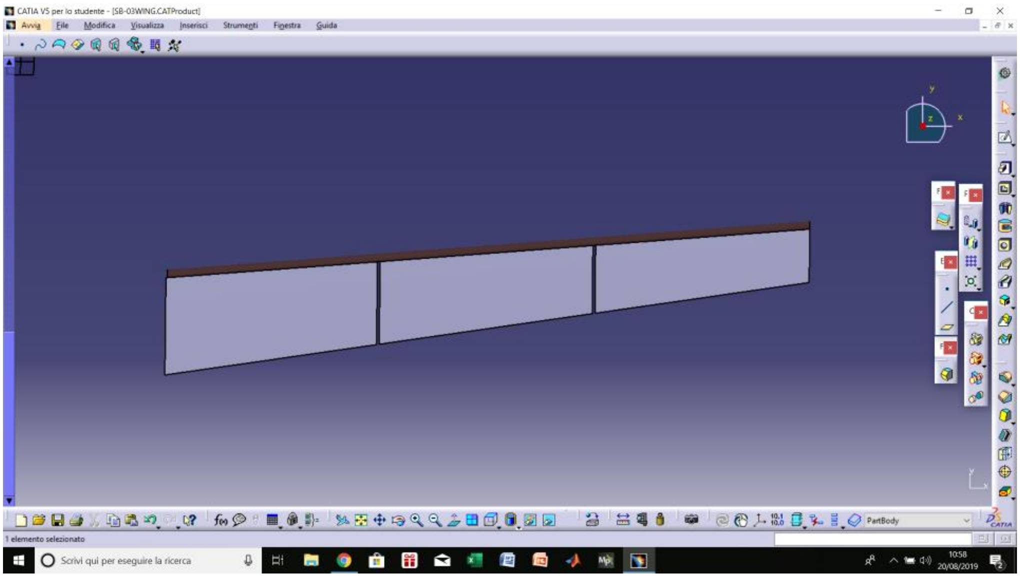

Figure 17: The three-parts aileron was designed starting from the original one. The top view allows to show the 2mm gaps, essential for each section to work properly. The spanwise extension of each aileron is the same.

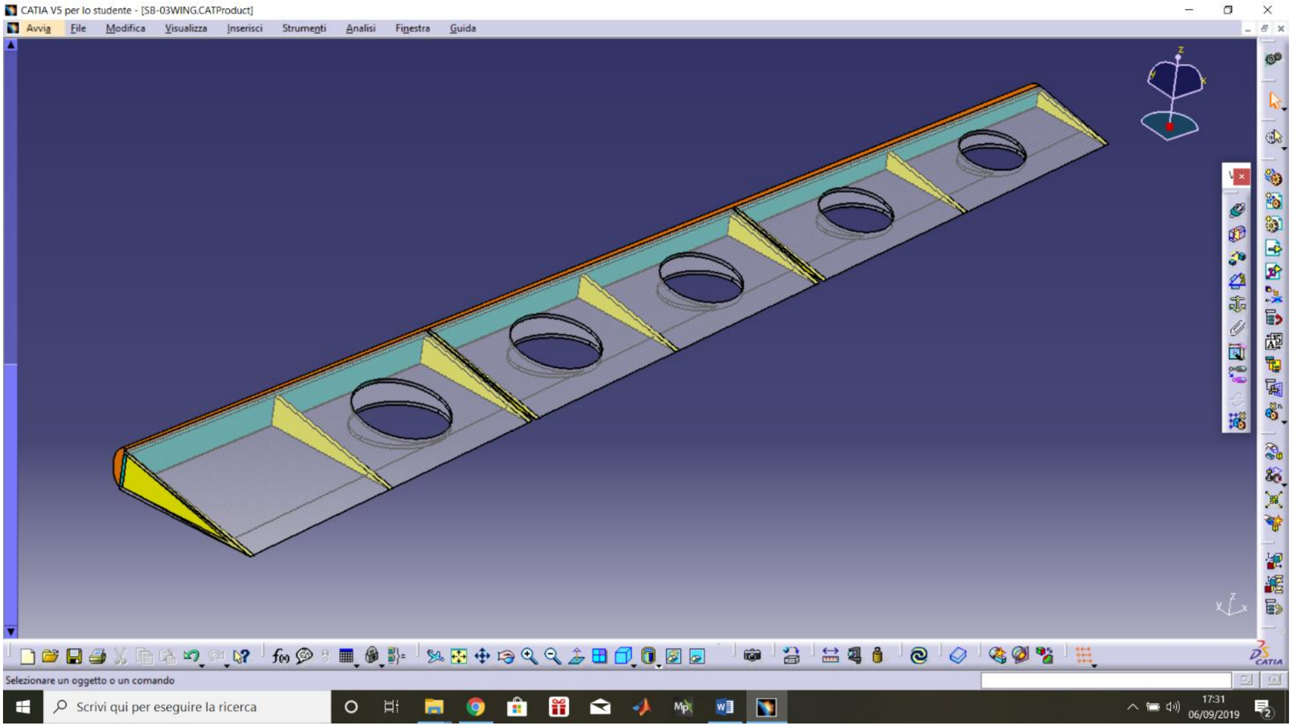

Figure 18: Isometric view of the new aileron. Each aileron section features three ribs and lightening holes, to save more weight as possible keeping the structure solid and reliable.

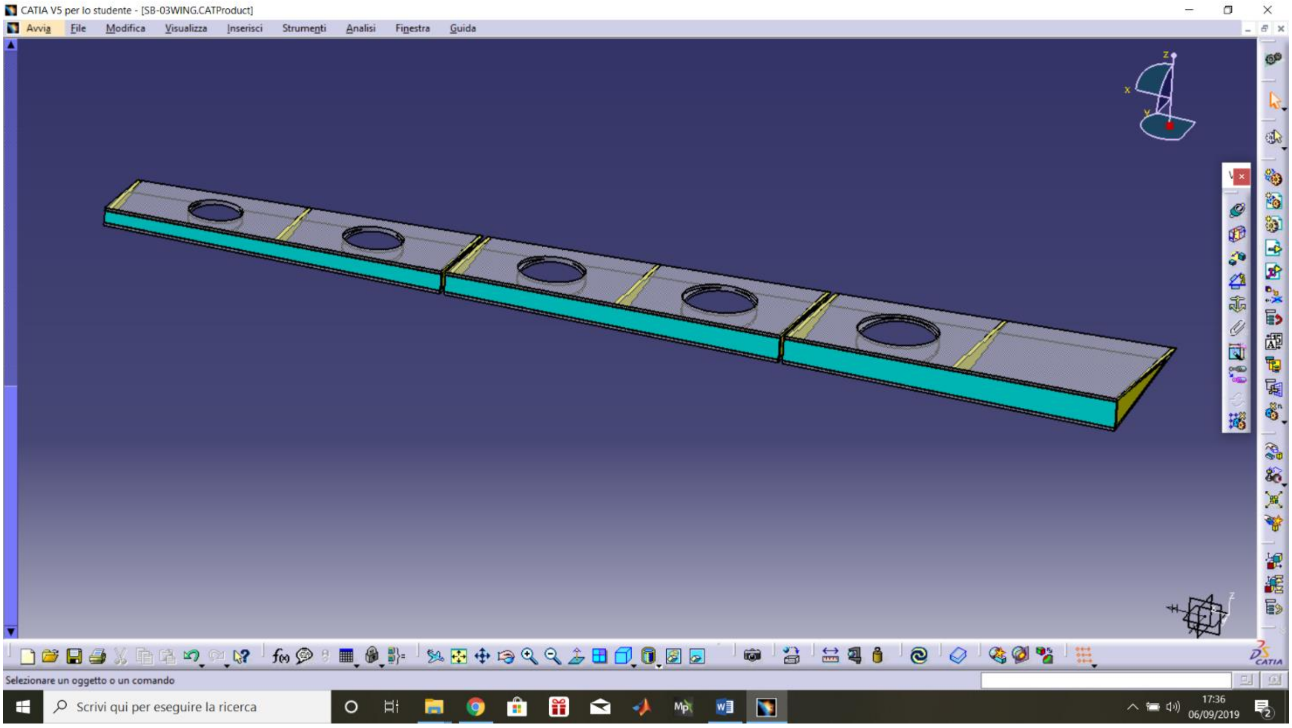

Figure 19: The aileron spar, coloured in light blue, is divided in three parts, while the aileron leading edge (coloured in orange in Fig. 18) is one piece.

2.2 Aileron build and installation

Due to the simplicity of design, all the parts of the new aileron were hand-cut and the complete build and installation of the six sections required less than a week.

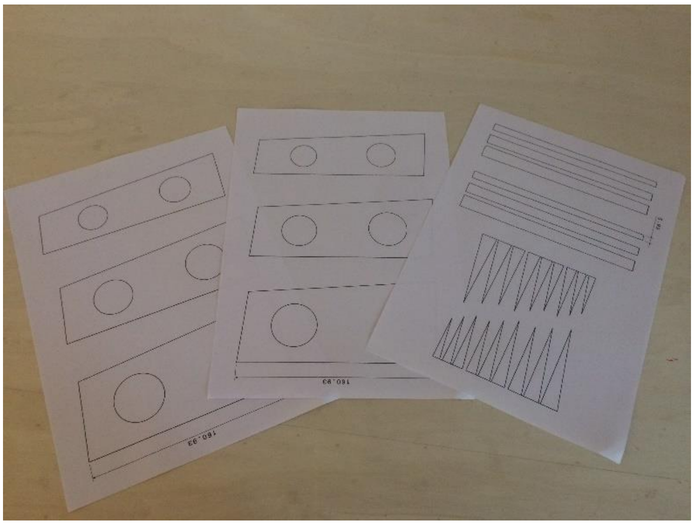

Figure 20: All the parts were printed on standard A4 paper sheets, then glued on balsa sheets in order to be precisely cut using a cutter and a ruler.

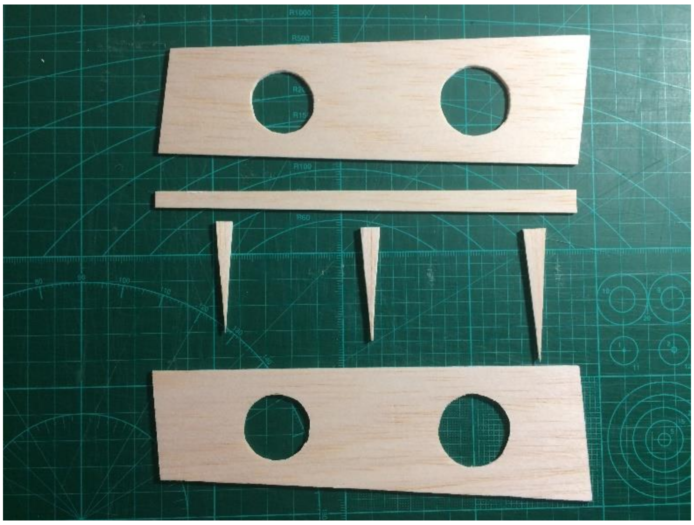

Figure 21: The printed sheets were removed from the balsa parts after the cutting. All these components were glued together using cyanoacrylate glue.

Figure 22: The six sections ready to be glued to the leading edges.

The six sections were glued to two leading edges (LE), one for each wing, and pre-hinged; then the LEs were hand sanded and, finally, each aileron was cut in three parts. Gluing the aileron sections to two LEs instead of six (one for each), pre-hinging and sanding before separation allowed to obtain, for each aileron, a straight hinging line and a uniform LE shape from section to section

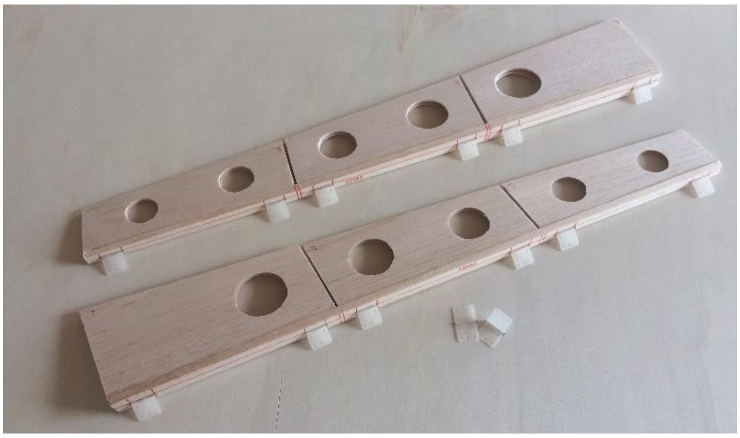

Figure 23: The pre-hinged ailerons, before sanding and separation.

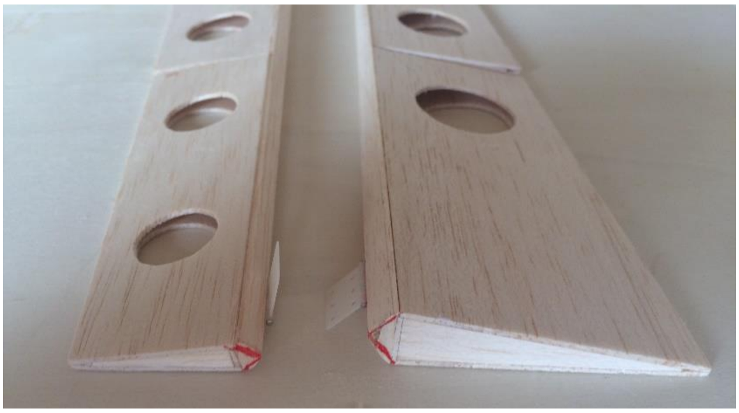

Figure 24: The ailerons after sanding, the LEs shape allows a maximum deflection of about 40 degrees.

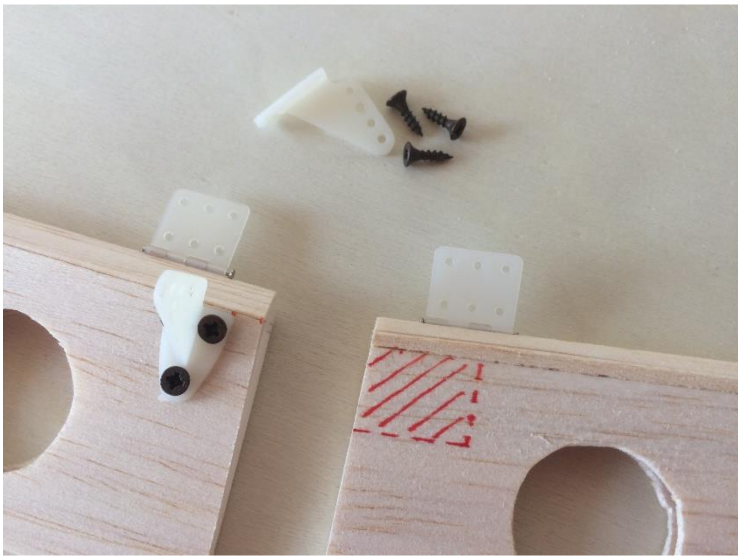

Figure 25: Each external section was reinforced with a 4 mm plywood base, glued under the balsa skin, in order to place a nylon control horn locked by self-tapping screws.

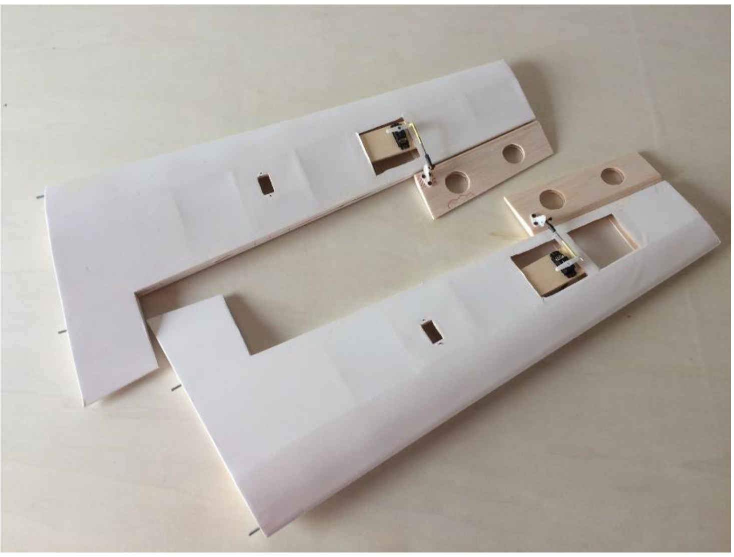

Figure 26: A new servo plywood base was mounted on the wing, closer to the wingtip, in order to move the external section of the aileron. The original servo mounting holes were covered with tape.

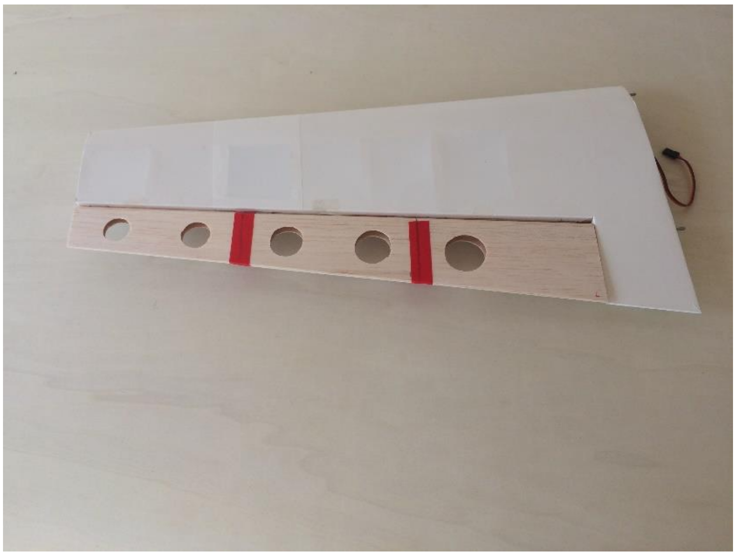

Figure 27: Semi-completed wing, with uncovered ailerons and temporary tape stripes.

An accurate ground test of the mechanism in the three flight configurations was conducted to check the servo-aileron linkage and the aileron deflection angles.

After the test, the six aileron sections were covered with covering film and the hinges were locked to the wing using scotch-tape.

Figure 28: SHORT aileron configuration.

Figure 29: MEDIUM aileron configuration.

Figure 30: FULL aileron configuration.

Chapter 3

Instrumentation

3.1 Flight basic instrumentation

To fly an electric remote-controlled aircraft, the following devices are needed:

- Servos: small electric actuators used to deflect the control surfaces and to activate all optional mobile parts (e.g. doors, retractable landing gears);

- Motor: except for pure gliders;

- Battery: Lithium-Polymer are the most used;

- ESC (Electronic Speed Controller): an electronic circuit which controls the speed (in terms of RPM) of the motor, it is connected to the battery and, through an embedded BEC (Battery Eliminator Circuit), to the receiver;

- Radio Transmitter: it features two control sticks and several switches;

- Receiver: a small and light box with two antennas and an output rail to which all the servos and the ESC are connected, many receivers also feature a BUS port for connecting to other devices;

The signal is transmitted by the radio to the onboard receiver, which controls the servos and the motor allowing the aircraft to fly. Each output port on the receiver, except the bus port, is a channel. Thus the number of channels stands for the number of independent devices controllable by the receiver.

For the “Mode 2” control configuration (throttle and yaw on left stick, pitch and roll on the right):

- CHANNEL 1 : aileron , two servos linked to the receiver by a “Y” connector;

- CHANNEL 2: elevator;

- CHANNEL 3: throttle;

- CHANNEL 4: rudder.

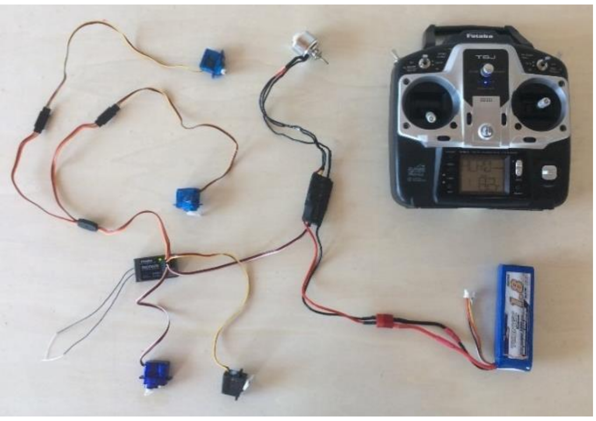

Figure 31: Flight basic instrumentation.

For the SB-03 the following components were used:

- Futaba T6-J Radio

- Futaba 2008 receiver

- Hitec HS-53 servos

- Fullpower/Turnigy 2200 mAh, 3S LiPo

3.2 PIXHAWK

The PIXHAWK, by 3DR, is a commercially available flight controller and data recorder, largely used for flying remote controlled aircrafts due to its wide range of functions (it also is an autopilot) and to its small size and low weight.

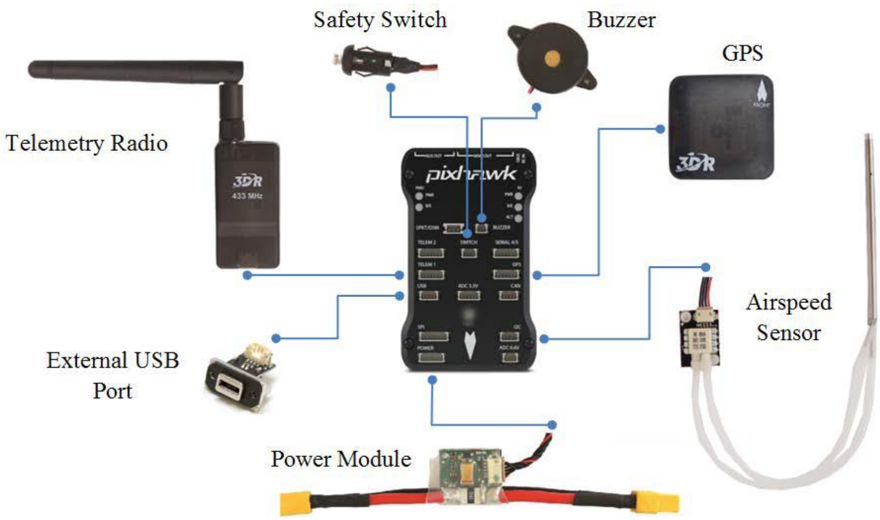

Figure 32: PIXHAWK complete system.

The system is made up by the following components:

- FLIGHT MANAGEMENT UNIT (FMU): this is the “brain” of the whole system, it features an ARM® Cortex®-M4 processor, two accelerometers, a gyroscope, a barometer, an SD Card for recording flight data, an INPUT/OUTPUT RAIL for connecting servos, the ESC and a receiver, an external USB port for linking to a ground station/computer;

- GPS Module;

- Power Module: it is connected to the battery and to the ESC and powers the servo rail and the FMU at different voltages;

- Safety Switch: for arming the motor;

- Buzzer: it emits acoustic signals to report the status of the system;

- Airspeed Module: a small Pitot connected to a pressure sensor by two tubes (static and dynamic);

- Telemetry Radio: for transmitting live flight data, it will not be used in this flight test.

When the PIXHAWK is installed, the servos and the ESC are connected to the FMU (with the same channel configuration shown before) instead of the receiver, which is linked to the “RC” port.

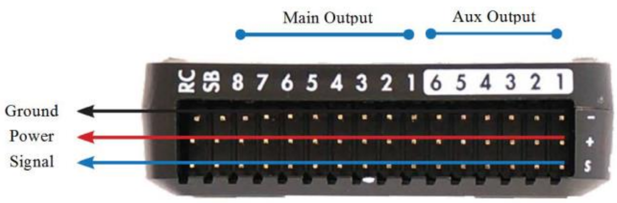

Figure 33: Servo (Main) output rail and RC input port are located on the rear face of the FMU.

Table 1 – PIXHAWK components weight.

COMPONENT	WEIGHT (g)
FMU	38
GPS MODULE	30
POWER MODULE	25
BUZZER +SAFETY SWITCH	25
AIRSPEED MODULE	25
TOTAL	143

3.3 Ground Control Station (GCS): MISSION PLANNER

To manage all the options and data of the FMU and to monitor flight parameters, a standard computer is employed as a ground control station, with the aid of a software which, in this case, is MISSION PLANNER, a free and open source application developed by Michael Oborne.

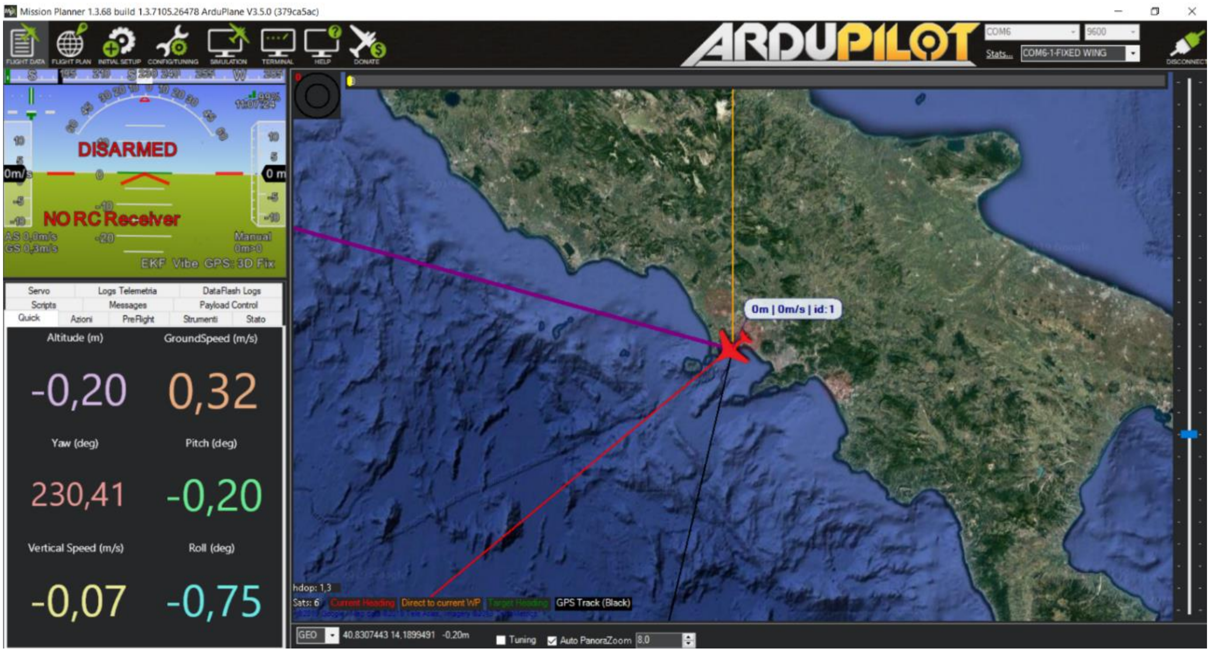

Figure 34: MISSION PLANNER main screen.

As shown in Fig. 34, the main screen of Mission Planner features a Map, a HUD (Head Up Display) and a table with the numerical values of six selectable parameters.

There are two ways of linking Mission Planner to the FMU:

- via telemetry, with the Telemetry Radio;
- via USB cable, provided with the PIXHAWK kit, for ground operations only.

Whether the system is connected to the GCS or not, it is possible to arm it with the Radio and start recording the flight data.

3.4 Accelerometer and Compass calibration

Before flying, it is essential to calibrate the PIXHAWK by following a simple procedure on MISSION PLANNER. Thus, in order to perform each step with the maximum precision and ease, it was built a wooden test-bench capable of mounting the whole system.

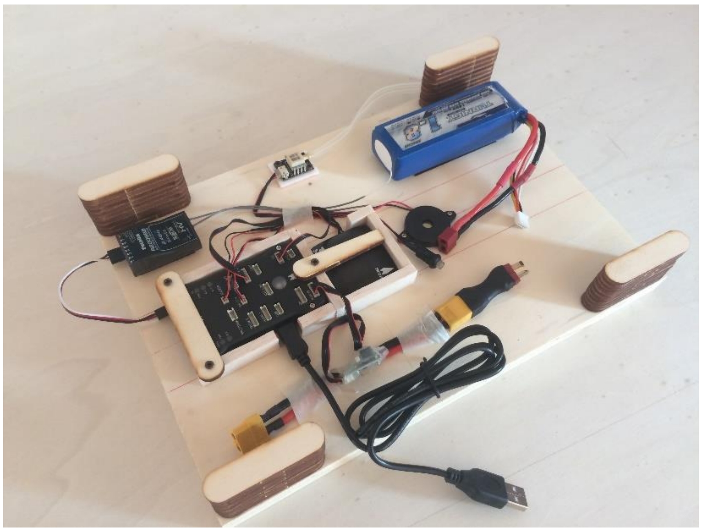

Figure 35: PIXHAWK on bench. This facility is also useful to check if each component is in good working condition.

The first two steps are:

- Accelerometer Calibration: the FMU, which hosts the accelerometers, is positioned in six different orientations (level, right side, left side, nose up, nose down and back);

- Compass Calibration: the FMU and the GPS rotate together on the three axis until the calibration is completed.

3.5 Radio Calibration

This operation consists in moving each control stick and switch on the Radio in all directions, at maximum excursions, allowing the software to associate to each position of the stick a signal value expressed in PWM (Pulse Width Modulation).

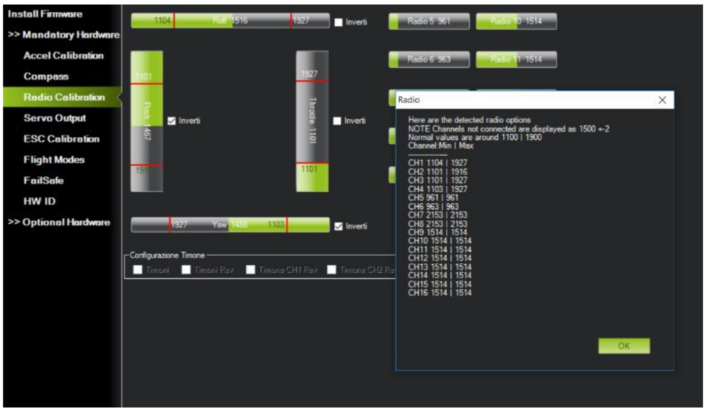

Figure 36: Radio calibration screen on MISSION PLANNER, with Min/Max PWM values for each channel. The calibration was executed two times: the first time, with the PIXHAWK on bench, to verify the good working condition of the system and the second time, with the PIXHAWK installed on the aircraft, to properly set each channel with the correct movement of the respective control surface.

3.6 Airspeed Sensor Calibration check

The airspeed module provided with the kit is factory calibrated, so, in order to verify its good working conditions before installing it on the aircraft, a test was conducted:

The Pitot probe was locked to a kraft rod fixed outside a car and the PIXHAWK was linked to the CGS, then the whole system was armed during a car ride in calm wind and good weather conditions.

Figure 37: Pitot tube.

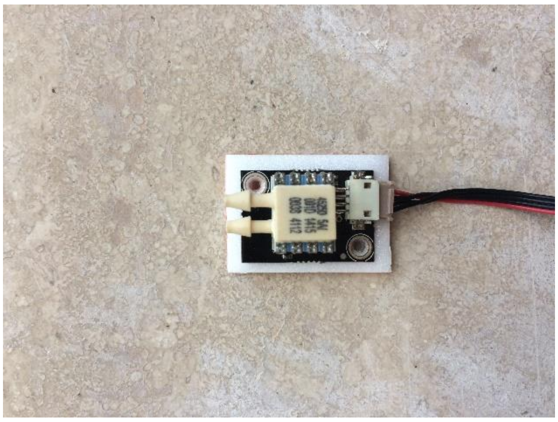

Figure 38: pressure sensor on Depron® base.

The results of this test show that the airspeed measured by the Pitot probe is in good agreement with the ground speed measured by the GPS module.

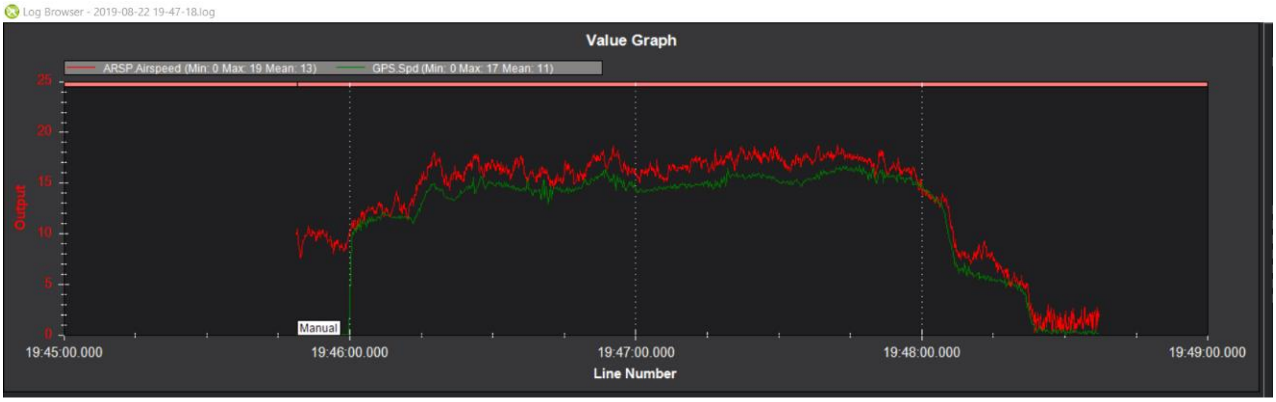

Figure 39: Airspeed measured by Pitot probe (red) vs Ground Speed measured by GPS (green).

Chapter 4

Installing the instrumentation on the Aircraft

4.1 FMU and GPS module housings

The FMU is the most important component of the system, it has to be placed in a specific position (as close as possible to the CG of the aircraft) and orientation (level, with the servo rail oriented backwards). Due to the embedded accelerometers, it also has to be protected and dampened to prevent any effect of vibrations on its integrity and on the quality of recorded data.

To ensure the proper operating conditions of the FMU, a light, but strong balsa housing was built and locked to the fuselage horizontal platform using double-sided tape and a 3 mm Depron® base for dampening.

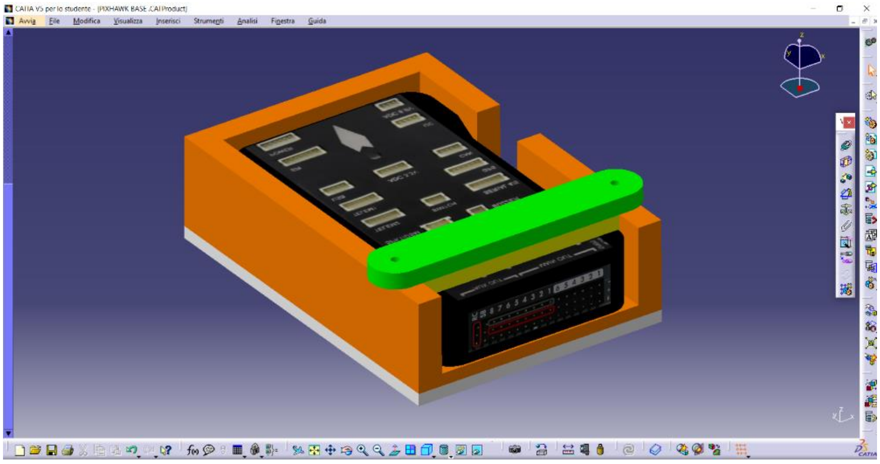

Figure 40: PIXHAWK housing in the CATIA™ Design Environment. The balsa parts are colored in orange, the Depron® base is white. A 4 mm plywood locking bar (colored in green) is screwed to the balsa frame.

The same kind of housing was built for the GPS module.

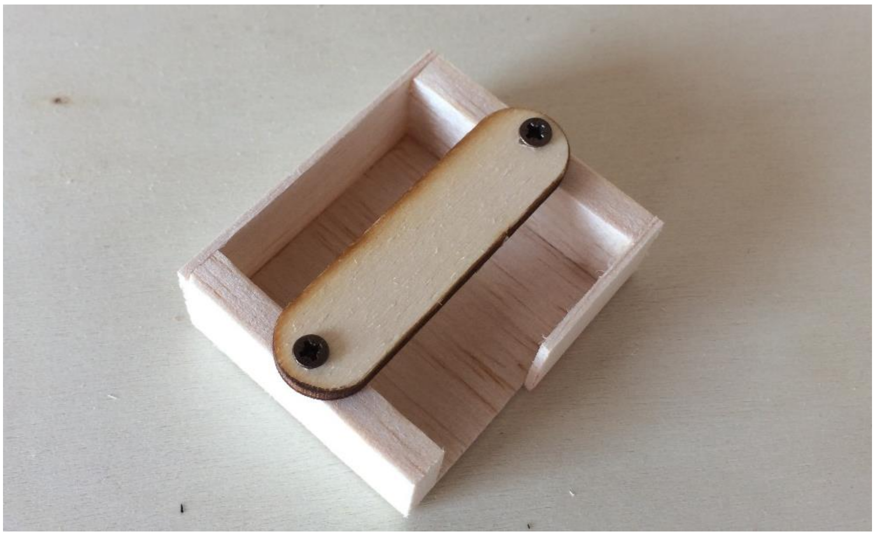

Figure 41: GPS module housing.

4.2 Pitot probe mount

With the aim to provide the Pitot with an airflow free from any effect of the propeller, a specific ABS 3D printed mount was designed, manufactured and screwed to the wingtip rib; making the pressure tubes pass through the wing ribs slits. The pressure sensor was screwed to the fuselage body, next to the wing root, in order to shorten its distance from the Pitot and reduce the pressure losses due to the length of the tubes.

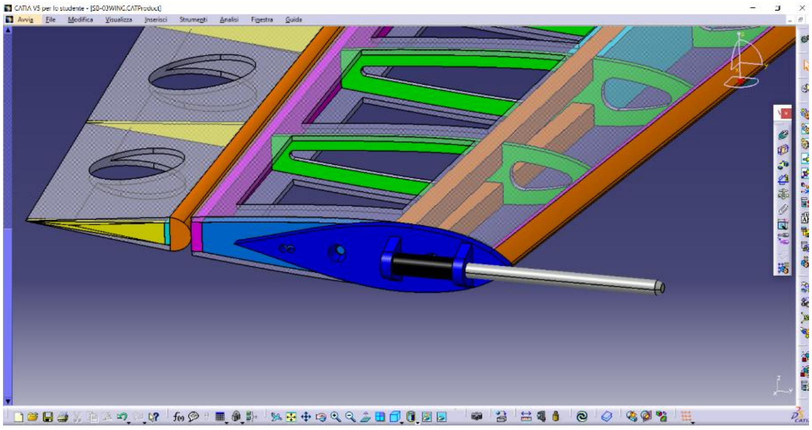

Figure 42: Pitot mount (colored in blue) in the CATIA™ Design environment. The Pitot is locked to its support with a silicone tube (colored in black).

Figure 43: Pitot tube installed and connected to the pressure sensor. The wingtip was highlighted with a striped tape and a silicone tube with a safety message was used for protecting the Pitot holes from any kind of dust.

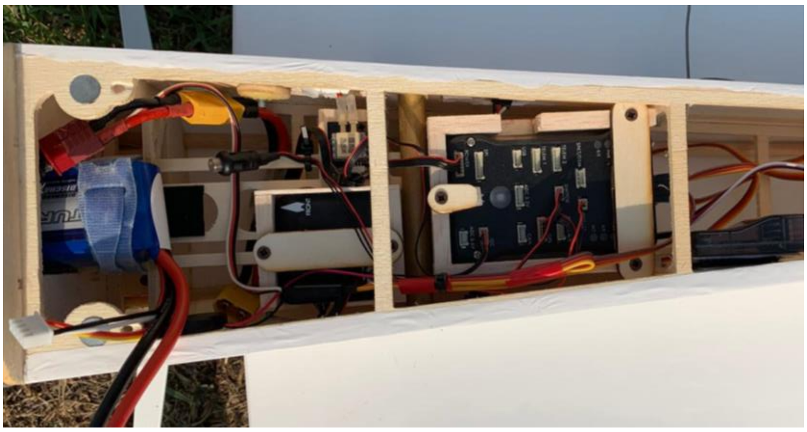

Figure 44: The PIXHAWK fully installed on the aircraft. The FMU is positioned behind the brass tube containing the carbon rod, close to the CG. Next to the GPS, the pressure sensor of the airspeed module, with the tubes directed spanwise. The battery is locked to the platform with velcro stripes. The receiver is behind the FMU.

Due to the installation of the PIXHAWK, the final weight of the aircraft was 1400g, with an increase of 16%.

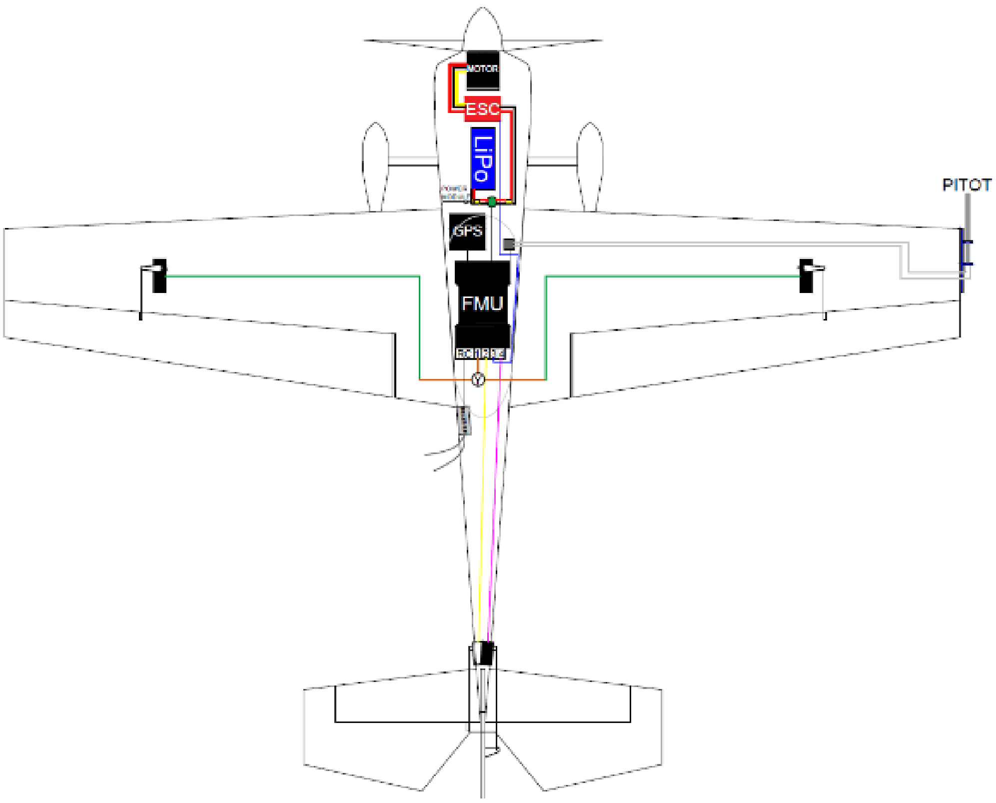

Figure 45: PIXHAWK mounting scheme.

4.3 Control surfaces set-up

Once the system was fully installed on the aircraft, the radio calibration was performed again, in order to get the correct movement of each control surface, in particular:

- RIGHT STICK UP/DOWN: elevator DOWN/UP, for pitching;

- RIGHT STICK to the RIGHT/LEFT: right aileron UP/DOWN, left aileron DOWN/UP, for rolling;

- LEFT STICK DOWN/UP : THROTTLE TO IDLE/ FULL POWER;

- LEFT STICK to the RIGHT/LEFT: rudder deflected to the RIGHT/LEFT, for yawing.

In this occasion, the control surfaces maximum deflection were approximately measured using hand-cut cardboard angles, with the following results.

Table 2 – Control surfaces deflection angles.

CONTROL SURFACE	ELEVATOR	RUDDER	AILERON
MAXIMUM DEFLECTION	+34.0	+31.0	+36.5
MINIMUM DEFLECTION	−34.0	−31.0	−31.0

Chapter 5

Flight Test

5.1 Flight pattern and maneuvers

For each aileron configuration, the same flight test was conducted: the plane took off upwind and turned left to start a counterclockwise flight pattern, at the altitude of above 100m.

The maneuver zones are the upwind and downwind parts of the pattern (to avoid any crosswind effect), in which the aircraft performed bank-to-bank rolls and *Tonneau* (complete rotations around the roll axis).

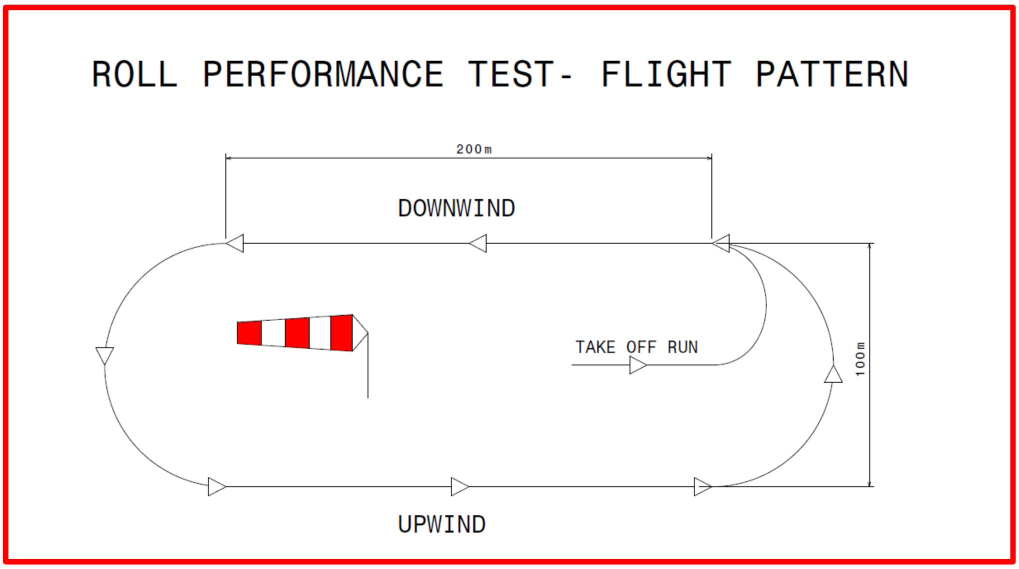

Figure 46: Flight pattern.

Each test was made up by 18 maneuvers:

- bank-to-bank roll with 50%, 75%, 100% aileron deflection, performed at 60%, 80%, 100% throttle;

- tonneau with 50%, 75%, 100% aileron deflection, performed at 60%,80%,100% throttle.

All the test flights were conducted the same day, with good visibility conditions and relatively calm wind (5 m/s with 7m/s gusts); all data collected by the PIXHAWK were downloaded during the aileron configuration change operations.

5.2 Flight data post processing

The flight data recorded by the PIXHAWK were processed using MATLAB® , thanks to the "create MATLAB file" function in MISSION PLANNER.

The δ_A angles were obtained with an interpolation between Max/Min PWM values and the Max/Min aileron deflections, whose mean values were estimated with the following formula, in order to have a symmetrical result and prevent the effects of the aileron differential deflection (see Table 2, Table 3):

$$|\delta_A|_{\max} = 0.5\ (|\delta_A^{up}| + |\delta_A^{down}|)$$

Table 3: aileron deflection angles.

AILERON DEFLECTION ANGLE	EFFECTIVE (roll right)	EFFECTIVE (roll left)	SYMMETRICAL (roll right)	SYMMETRICAL (roll left)
RIGHT	+36.5	−31.0	+33.75	−33.75
LEFT	−31.0	+36.5	−33.75	+33.75

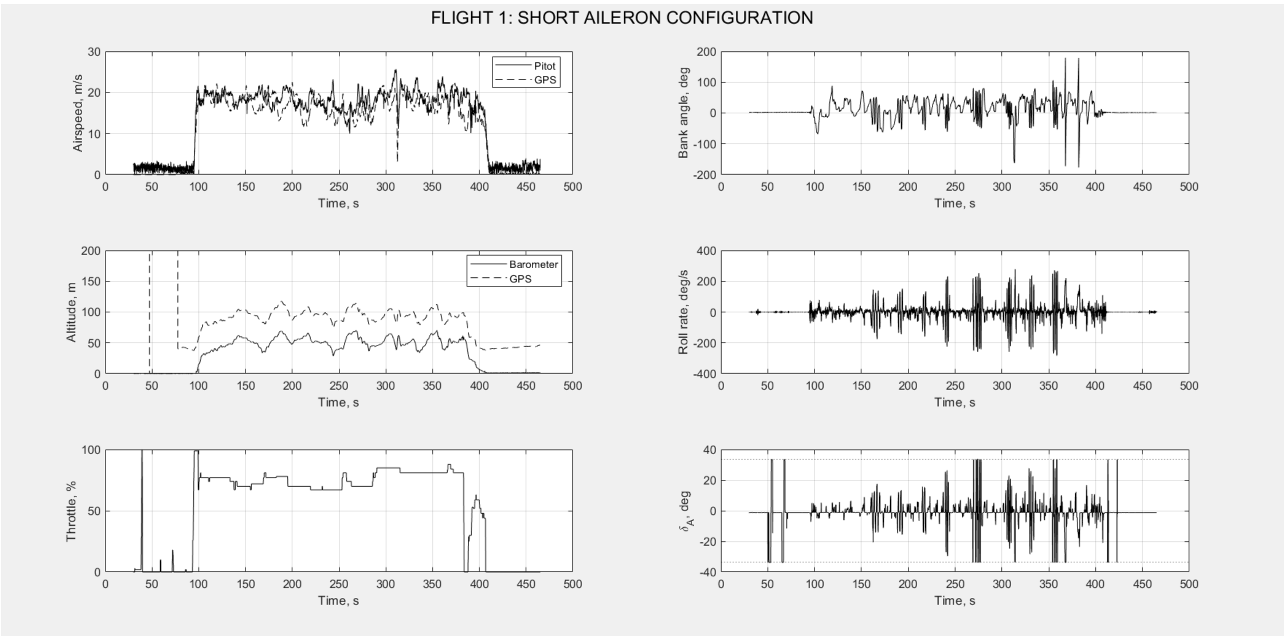

Figure 47A: Time histories of the first flight, the parameters in the plots are airspeed, ground speed, altitude, throttle, bank angle, roll rate (p) and aileron deflection (δ_A).

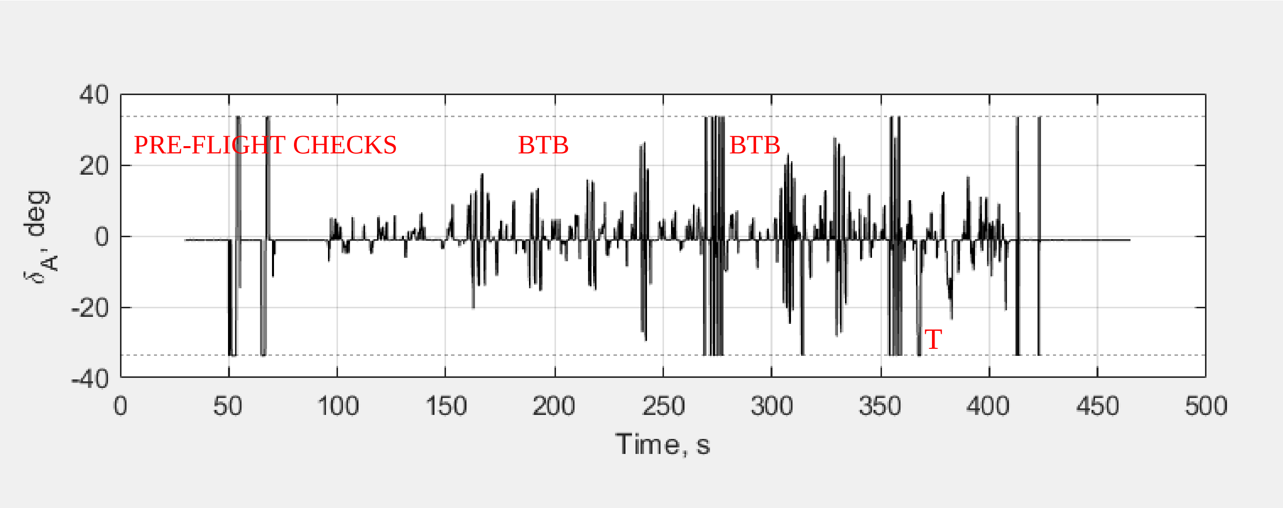

Figure 47B: detail of the δ_A plot, some phases of the flight are highlited in red; BTB=bank-to-bank, T=tonneau.

In order to estimate the roll performance of the aircraft for each configuration, the three flights were divided in various time windows to highlight all the maneuvers; in particular, for each window two or three relevant time instants (e.g. high aileron deflection) were took as reference for estimating δ_A, p and v (airspeed) and calculate AEI (Aileron Effectivenes Index), with the formula:

$$AEI = pb/2v \qquad (b \text{ is wingspan, m})$$

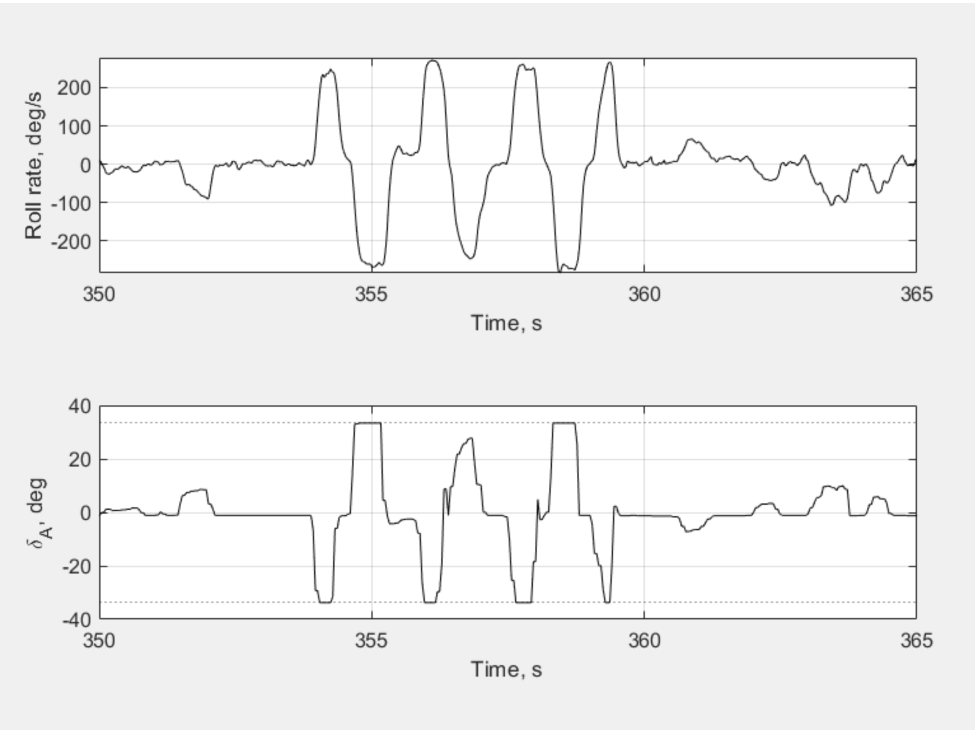

Figure 48: Flight 1 (short aileron configuration), time window 9, BTB roll.

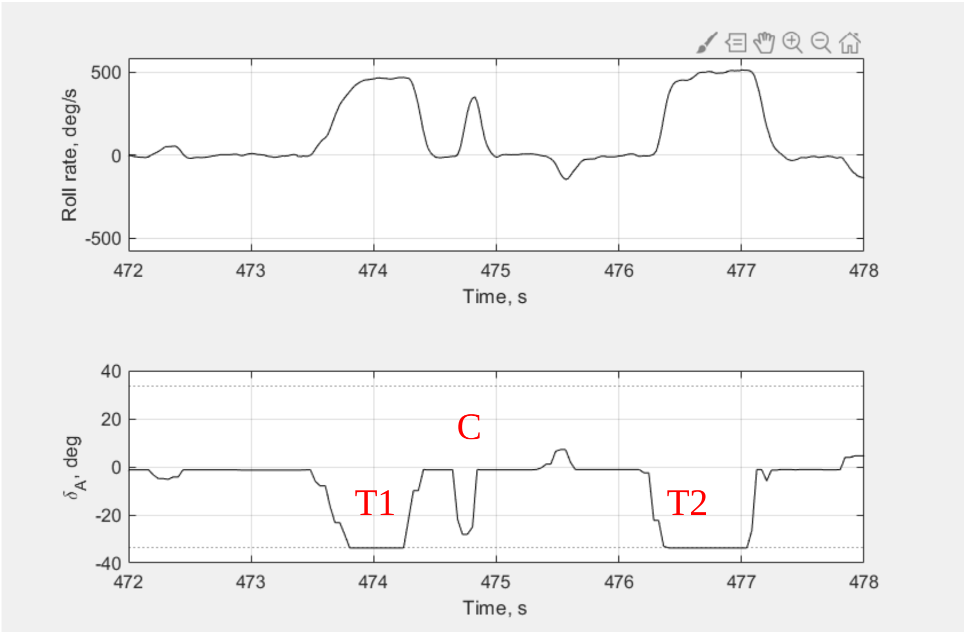

Figure 49: Flight 2 (medium aileron configuration), time window 13, 2 Tonneau. C=bank correction.

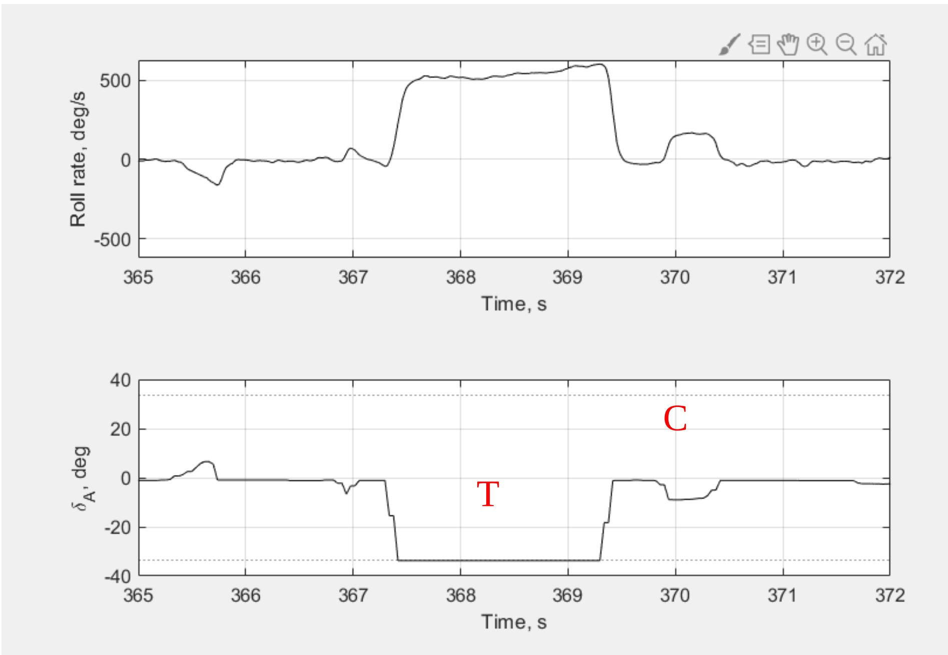

Figure 50: Flight 3 (full aileron configuration), time window 11, 1 Tonneau.

As shown in Fig. 49 and Fig. 50, after each tonneau an attitude correction on the roll axis is required, because is difficult to stop the rotation exactly when the aircraft is leveled, due to the high roll rate.

The previous figures also show that, in agreement with the expected results, the roll rate grows as the aileron deflection increases.

The values of *p*, δ_A and *v* in correspondence of the selected time instants were reported, for each flight configuration, in an EXCEL (see Appendix A) table, in order to estimate AEI and obtain the plots.

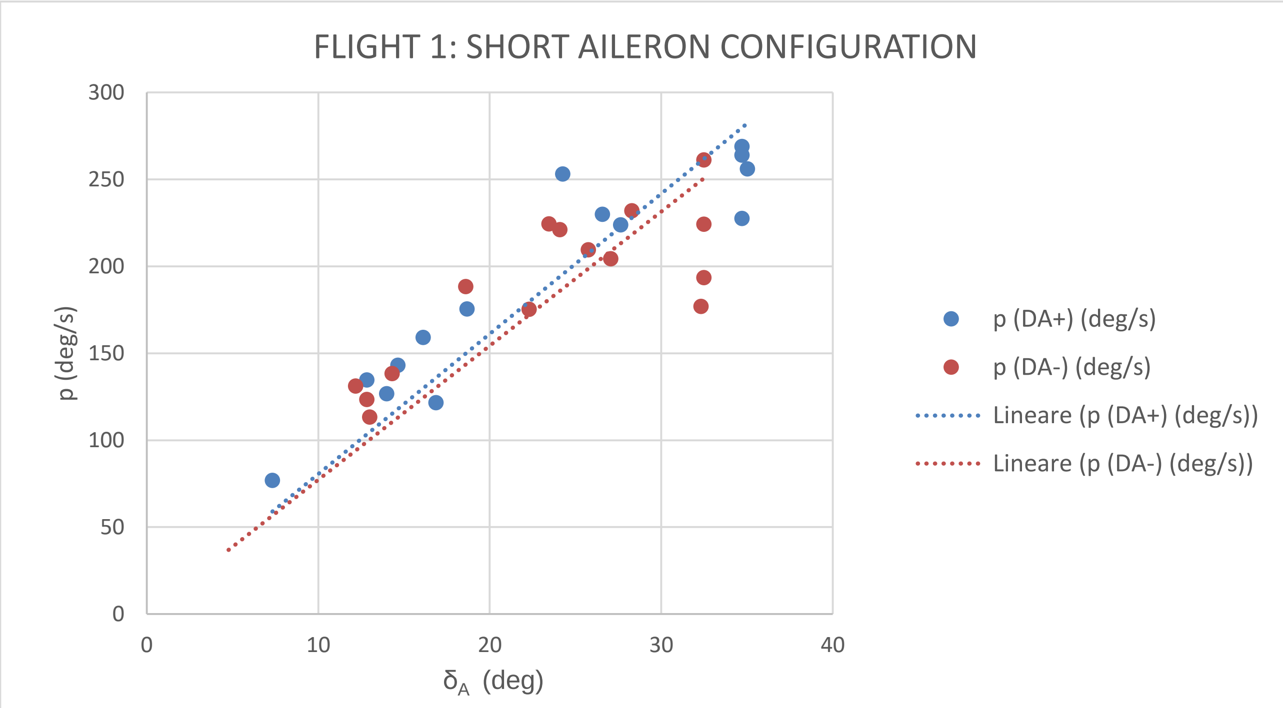

Figure 51: Roll rate plot, short aileron configuration.

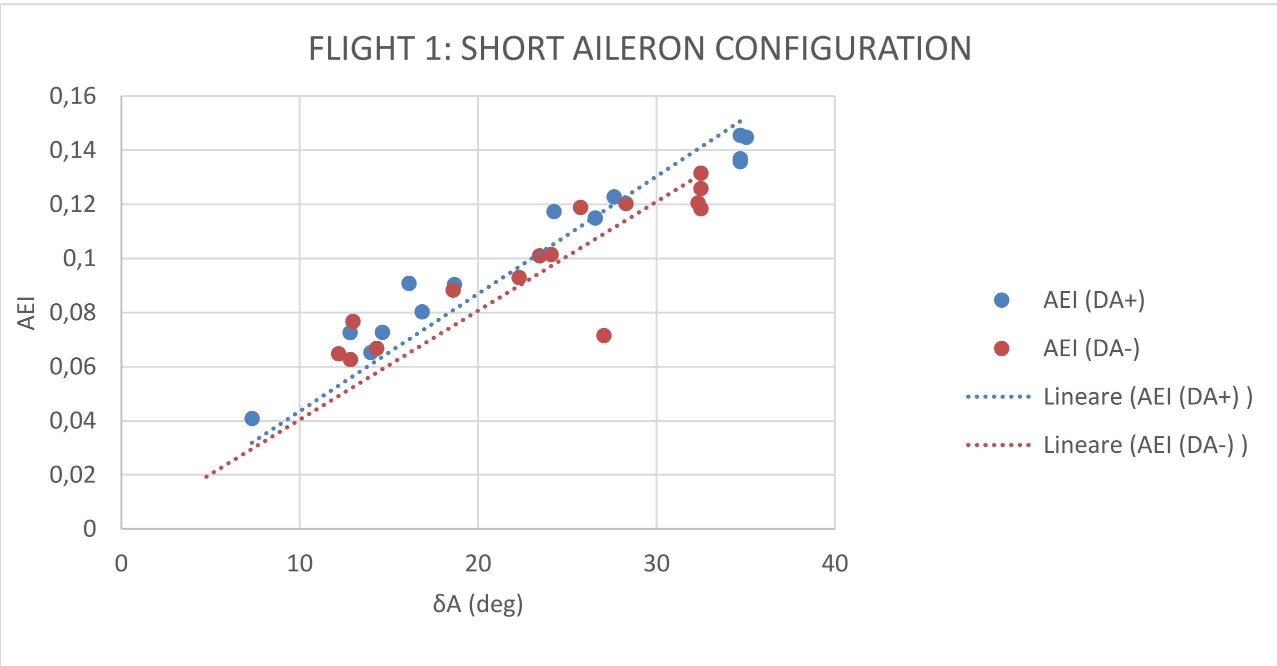

Figure 52: Plot of the aileron efficiency index, short aileron configuration.

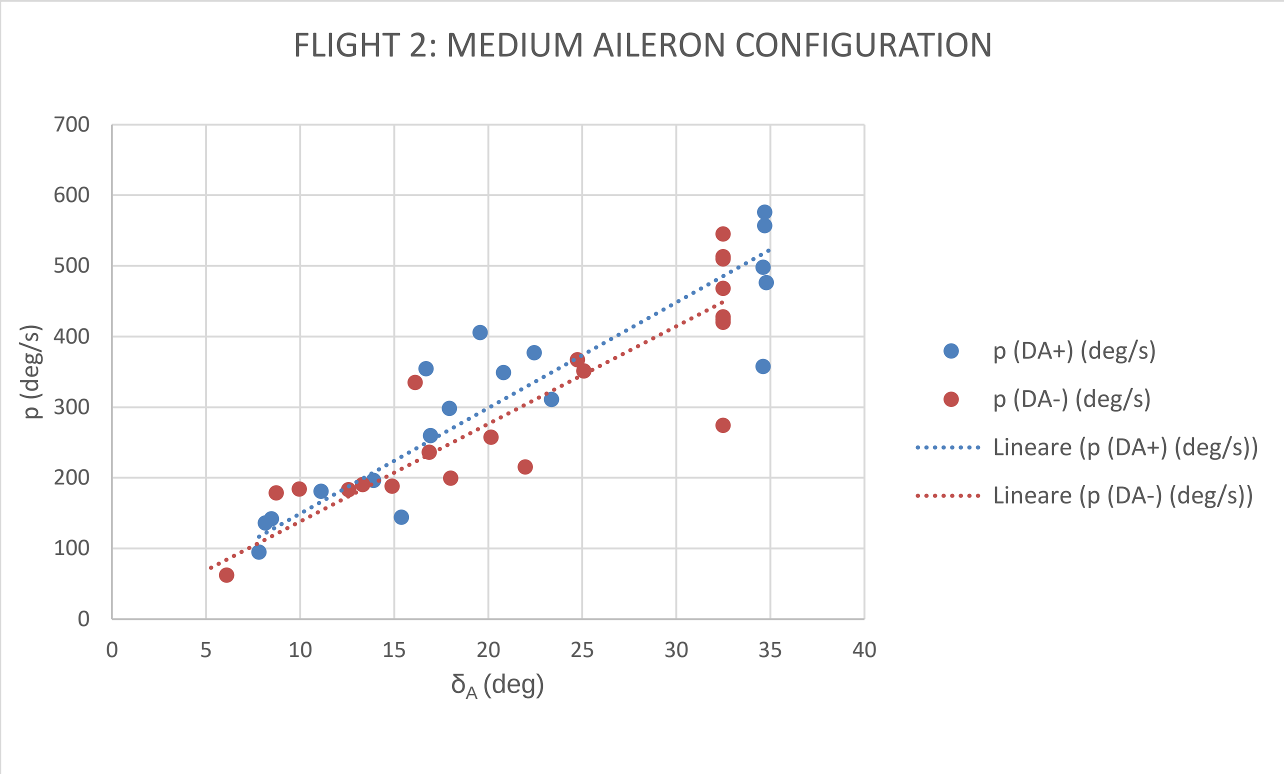

Figure 53: Roll rate plot, medium aileron configuration.

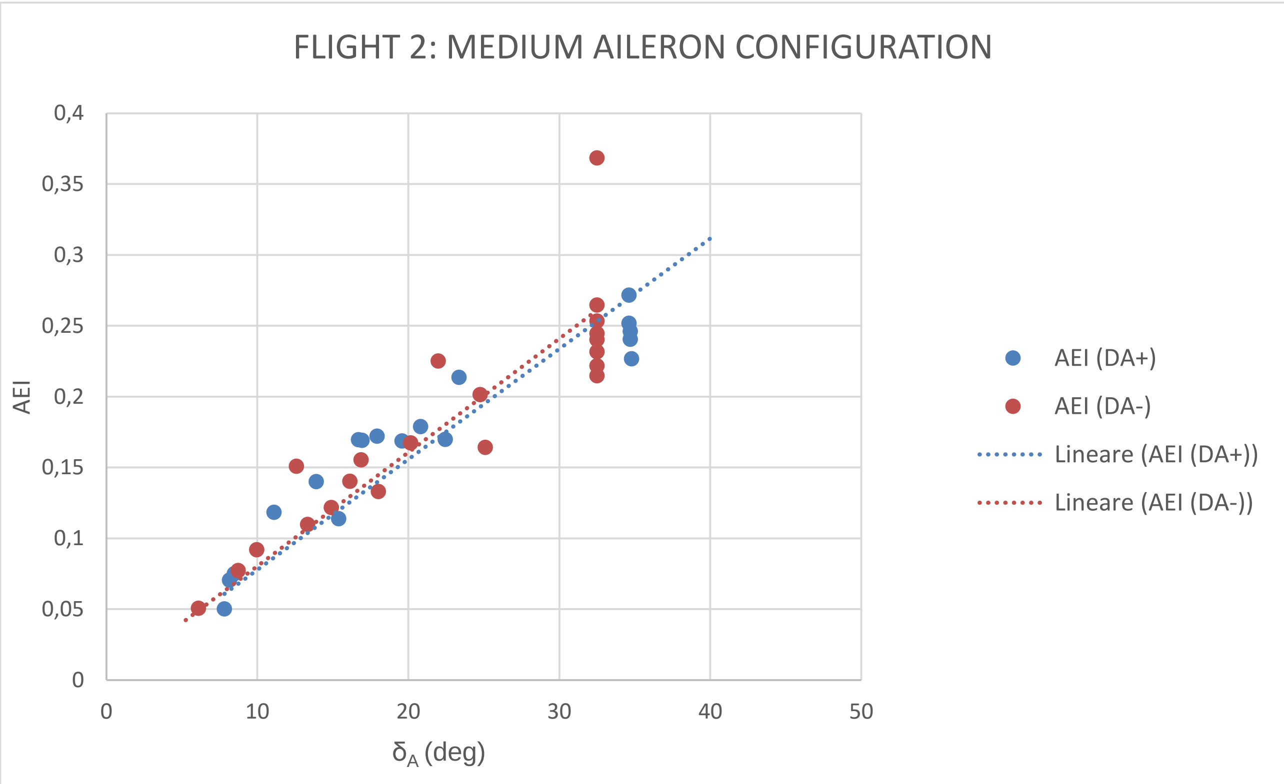

Figure 54: Plot of the aileron efficiency index, medium aileron configuration.

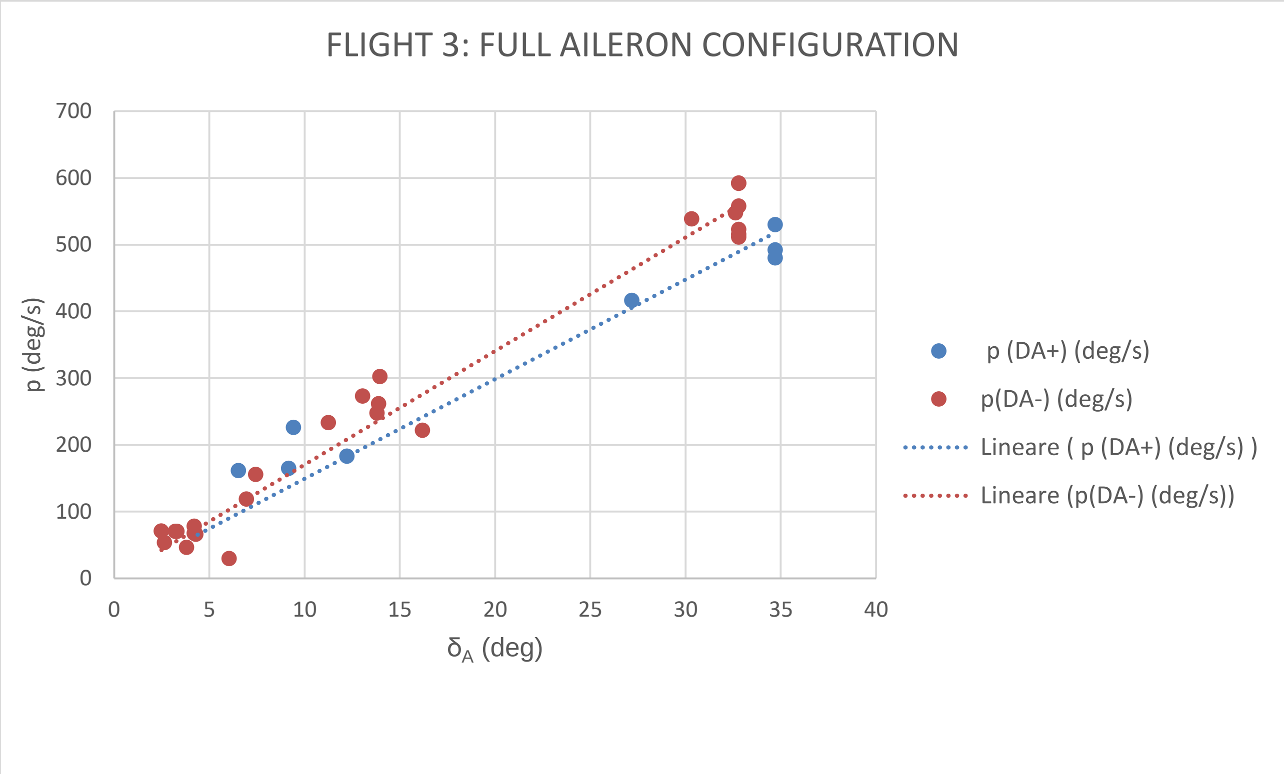

Figure 55: Roll rate plot, full aileron configuration.

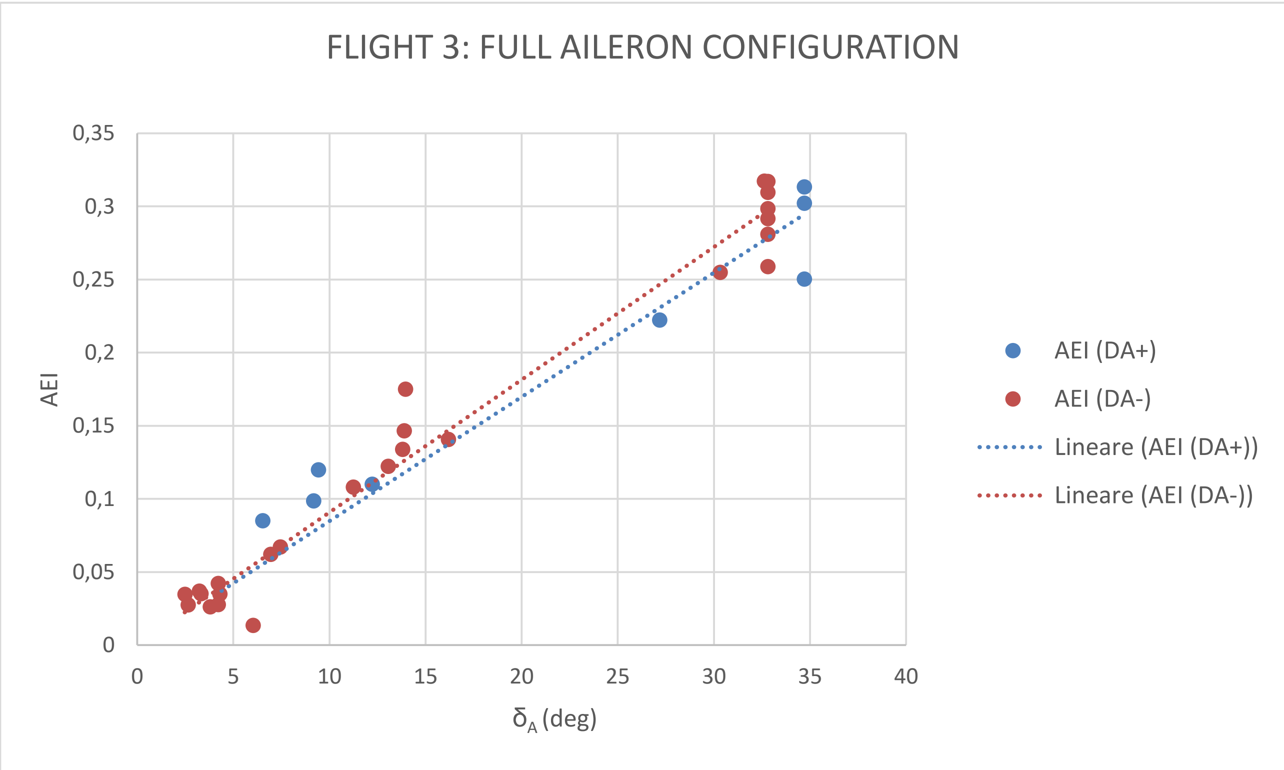

Figure 56: Plot of the aileron efficiency index, full aileron configuration

Conclusions

The test flight showed, as expected, that the aircraft roll sensibility grows considerably as the aileron spanwise extension increases. A short aileron allows a smooth and more precise maneuvering of the aircraft, while a long aileron leads to a strongly roll-reactive aircraft, capable of performing nearly two complete rounds (on the roll axis) per second.

Comparing the roll performance tests of the small SB-03 and of a real scale Tecnam P92 Echo[2], it is observed that the roll behaviors are very similar. This fact confirms that remote-controlled aircraft are suitable for conducting research and test activities that lead to reliable results, with an extremely low level of risk and without a considerable economical effort.

Although the roll rate p of the SB-03, even in the smaller aileron configuration, is an order of magnitude higher than an equivalent full-scale aircraft, the aileron efficiency AEI index achieve similar values. The max values of both quantities double from short to medium configuration, while the full span aileron is not much more effective than the medium span configuration. Data scatter in the roll rate plot is due to the different airspeed achieved during fixed throttle operations in a windy day. Such scatter is reduced in the AEI plot, since this quantity is independent of airspeed and the initial direction of turn.

Appendix A – Flight data tables

FLIGHT 1: SHORT AILERON CONFIGURATION

MANEUVER	TIME(s)	AIRSPEED (m/s)	|DA|	p (DA+) (deg/s)	p (DA-) (deg/s)	AEI (DA+) (rad/s)	AEI (DA-) (rad/s)
1	163.8	20.37	12.7	126.8	#N/D	0.065181575	#N/D
1	165.20	20.68	14.1	#N/D	123.5	#N/D	0.062533545
1	166.7	20.37	17.39	175.5	#N/D	0.090215824	#N/D
2	191.2	21.25	13.44	#N/D	131.2	#N/D	0.064650447
2	192.4	20.65	13.36	143.2	#N/D	0.072613871	#N/D
2	193.5	21.71	15.58	#N/D	138.4	#N/D	0.066753324
3	215.1	15.88	15.58	121.7	#N/D	0.08024846	#N/D
3	216.4	15.49	14.26	#N/D	113.4	#N/D	0.076658138
3	217.7	18.37	14.84	159.2	#N/D	0.090746636	#N/D
4	240.4	18.48	27.01	#N/D	209.6	#N/D	0.118764307
4	241.4	19.11	26.35	223.9	#N/D	0.122684595	#N/D
4	242.2	20.19	29.56	#N/D	231.9	#N/D	0.120271038
5	272.7	17.42	33.42	227.6	#N/D	0.136810911	#N/D
5	273.5	17.85	33.75	#N/D	224.2	#N/D	0.131520671
5	274	18.52	33.75	256	#N/D	0.144742347	#N/D
6	306.8	22.34	19.86	#N/D	188.4	#N/D	0.088306843
6	307.5	22.61	22.98	253.1	#N/D	0.117216355	#N/D
6	308.2	23.28	24.71	#N/D	224.5	#N/D	0.100978752
7	314	15.38	33.59	#N/D	176.9	#N/D	0.120439273
7	315.2	19.46	11.55	134.7	#N/D	0.072480535	#N/D
8	329.8	29.96	28.32	#N/D	204.3	#N/D	0.071404106
8	330.9	20.95	25.28	230	#N/D	0.114958328	#N/D
8	331.6	22.83	25.36	#N/D	221.2	#N/D	0.101455557
9	355	19.37	33.42	269	#N/D	0.145418375	#N/D
9	356	23.12	33.75	#N/D	261.3	#N/D	0.118344535
9	358.5	20.36	33.42	264	#N/D	0.135775929	#N/D
10	368	16.1	33.75	#N/D	193.5	#N/D	0.125849566
10	373.4	19.74	6.05	76.84	#N/D	0.04076025	#N/D
10	382.8	19.77	23.56	#N/D	175.3	#N/D	0.092847855

FLIGHT 2: MEDIUM AILERON CONFIGURATION							
MANEUVER	TIME(s)	AIRSPEED (m/s)	|DA|	p (DA+) (deg/s)	p (DA-) (deg/s)	AEI (DA+)	AEI (DA-)
1	212.2	14.7	12.62	196.6	#N/D	0.140043452	#N/D
1	213.1	15.93	18.13	#N/D	236.4	#N/D	0.155391881
1	214.3	16.07	15.66	259.8	#N/D	0.169285554	#N/D
2	239.8	16.13	21.42	#N/D	257.8	#N/D	0.167357498
2	240.8	15.25	22.08	311.1	#N/D	0.213612565	#N/D
2	241.8	19.08	26.02	#N/D	367.2	#N/D	0.201521288
3	260.7	13.29	14.1	144.5	#N/D	0.113851693	#N/D
3	262.1	18.17	14.59	#N/D	190.6	#N/D	0.10984103
3	264.4	18.17	16.65	298.6	#N/D	0.172080439	#N/D
4	284.7	13.37	33.75	#N/D	274.3	#N/D	0.214828071
4	285.5	13.8	33.34	358	#N/D	0.271644283	#N/D
4	286.3	18.32	33.75	#N/D	420.4	#N/D	0.240288987
5	317.6	20.45	19.53	349.3	#N/D	0.178855336	#N/D
5	319.5	22.39	26.35	#N/D	351.4	#N/D	0.164340382
5	321.3	23.26	21.17	377.4	#N/D	0.169898214	#N/D
6	324.9	10.01	23.24	#N/D	215.3	#N/D	0.225219806
6	325.9	12.71	13.85	#N/D	183.3	#N/D	0.151012724
6	326.6	12.83	7.358	#N/D	62.3	#N/D	0.050846143
7	348.8	16.17	16.16	#N/D	188.2	#N/D	0.121872642
7	349.6	15.98	9.825	180.9	#N/D	0.118538225	#N/D
7	353.3	20.97	11.22	#N/D	184.4	#N/D	0.092078686
8	381.7	21.86	15.42	354.5	#N/D	0.169809784	#N/D
8	382.6	25.01	17.39	#N/D	335.1	#N/D	0.140299901
8	383.3	25.15	18.29	405.6	#N/D	0.168871587	#N/D
9	388.3	16.79	33.75	#N/D	424.4	#N/D	0.264680111
9	389.9	19.71	6.536	94.74	#N/D	0.050331907	#N/D
10	410	24.21	9.989	#N/D	178.8	#N/D	0.0773338
11	429.2	22.01	33.5	476.68	#N/D	0.226779355	#N/D
11	430	24.08	33.75	#N/D	509.9	#N/D	0.221730358
11	430.6	24.26	33.42	557.2	#N/D	0.240501029	#N/D
12	441.8	12.16	33.75	#N/D	427.9	#N/D	0.36847272
12	442.4	15.71	19.28	#N/D	199.6	#N/D	0.133039615
12	443	20.22	6.865	136.3	#N/D	0.070584823	#N/D
13	474.2	19.35	33.75	#N/D	468.3	#N/D	0.253419376
13	475.6	19.81	7.194	142.1	#N/D	0.075111465	#N/D
13	477	21.95	33.75	#N/D	513	#N/D	0.244725638
14	489.4	20.72	33.34	498.4	#N/D	0.251874912	#N/D
14	491	24.65	33.75	#N/D	545.6	#N/D	0.231768317
14	492.7	24.49	33.42	576.1	#N/D	0.246323427	#N/D

FLIGHT 3: FULL AILERON CONFIGURATION							
MANEUVER	TIME(s)	AIRSPEED (m/s)	|DA|	p (DA+) (deg/s)	p(DA-) (deg/s)	AEI (DA+)	AEI (DA-)
1	173.5	17.5	8.221	164.9	#N/D	0.098668661	#N/D
1	174.3	18.71	14.83	#N/D	261.9	#N/D	0.146574472
1	174.9	17.4	11.28	183.1	#N/D	0.110188361	#N/D
2	199.5	16.52	17.14	#N/D	222	#N/D	0.140714729
2	201.5	19.61	26.23	416.5	#N/D	0.22239962	#N/D
2	202.1	22.11	31.27	#N/D	538.4	#N/D	0.254984004
3	226.5	17.06	33.75	492.2	#N/D	0.302105903	#N/D
3	227.2	21.15	33.75	#N/D	522.9	#N/D	0.258883814
3	227.7	22.16	33.75	530	#N/D	0.25043945	#N/D
4	236.9	18.08	14.91	#N/D	302.5	#N/D	0.175195756
4	238.3	19.87	4.172	#N/D	70.43	#N/D	0.037115597
4	239.5	20.3	3.594	#N/D	53.58	#N/D	0.027637789
5	249.1	18.45	4.751	#N/D	46.51	#N/D	0.026396515
5	250.4	18.07	33.58	#N/D	547.7	#N/D	0.317381214
6	266.5	17.02	33.75	#N/D	515.5	#N/D	0.31715075
6	267.1	19.75	8.468	226.4	#N/D	0.120034462	#N/D
7	291.3	17.29	33.75	#N/D	511.3	#N/D	0.309654523
7	292.7	20.88	4.255	#N/D	70.4	#N/D	0.03530521
8	307.8	19.73	5.246	#N/D	66.21	#N/D	0.035139302
8	309.3	22.05	33.75	#N/D	591.6	#N/D	0.280941696
9	330.3	23.39	14	#N/D	273.2	#N/D	0.122305814
9	331.3	25.35	5.164	#N/D	67.72	#N/D	0.027972779
10	346	19.3	5.164	#N/D	78.12	#N/D	0.042383962
10	347.9	22.59	12.19	#N/D	233.5	#N/D	0.108234891
10	349	23.08	6.981	#N/D	29.9	#N/D	0.013565382
11	365.7	19.83	5.577	161.3	#N/D	0.085174243	#N/D
11	369.3	21.26	33.75	#N/D	592.1	#N/D	0.291627469
11	370.3	24.27	8.386	#N/D	155.8	#N/D	0.06721935
12	377	19.57	33.75	#N/D	557.7	#N/D	0.298405241
12	377.5	20.05	7.89	#N/D	119	#N/D	0.062148294
13	391.1	16.04	33.75	480	#N/D	0.313352744	#N/D
13	391.7	19.38	14.75	#N/D	248	#N/D	0.133996834
13	392.7	21.24	3.429	#N/D	70.91	#N/D	0.034958243

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