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DESIGN OF A TEST BENCH FOR ELECTRIC PROPULSION SYSTEMS OF UNMANNED AERIAL VEHICLES

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Abstract. *In the conception of an aircraft project, it is essential to perform a detailed performance analysis in all phases of flight to affirm whether the aircraft will obtain the performance required to meet the project requirements. Therefore, it is important to get accurate data regarding the performance characteristics of the propulsion system that will be used. The present work aims to present a methodology for constructing a low-cost test bench capable of characterizing the performance of electric propulsion systems. To assist in the selection of the engine and propeller that best meet the needs of the Unmanned Aerial Vehicles (UAVs) designed by the Uirapuru Aerodesign UFPA team, intended for the SAE Brazil Aerodesign competition. First, the sizing of the structures took place after the analysis did the Ansys® software, selecting components and sensors, and then the fabrication and realization of tests. The projected bench can simultaneously measure data of electrical power, rotation, and thrust generated by electric motors for the different propellers analyzed and presents as a priority the simplification of the structure and the use of components and sensors that enable a high precision of the collected data. This guarantees the resistance of the bench; a structural analysis was performed using the Finite Element Method (FEM) in the Ansys® software. For the operation of the electrical circuit, the simulation of the electrical components was conducted in the Proteus® software. Due to its low construction cost, structural simplicity, easy implementation, high precision, and reliability in the results obtained, the proposed test bench proved to be a viable and practical solution to get performance data from electric propulsion systems, such as thrust, rotation, and electric power, allowing to characterize the most efficient propulsion system for flight.*

Keywords: *Test bench, Electric Propulsive Systems, Thrust, Rotation*

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) perform flight missions without a pilot on board, operated remotely, or serve autonomous flights (ANDERSON JR, 2015). In recent years, with the advance of research and development of new technologies, UAVs have been increasingly requested to perform various types of missions to reduce costs and perform operations where the use of crews is dangerous or even unnecessary.

Due to their enormous monitoring and inspection potential, combined with automation and communication capabilities, unmanned aerial vehicles have various military and commercial applications. This technology is used in the topographic survey (RODRIGUES *et al.*, 2018) , monitoring and inspection of large structures (CHIU *et al.*, 2017) , search and rescue operations (Półka *et al.*, 2017) and surveying and mapping forests and and biodiversity (KOH and WICH, 2012).

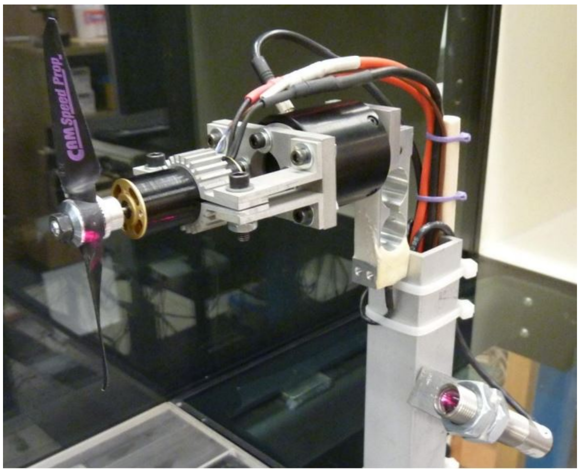
The Society of Automotive Engineers (SAE) Brazil annually holds the SAE Brazil AeroDesign competition to develop new technologies for the aeronautical industry and encourage the dissemination and exchange of techniques and knowledge in aeronautical engineering. By participating in the SAE AeroDesign program, the engineering student is involved with a confirmed case of aeronautical project development, from its conception, detailed design, construction, and testing. The participating teams are challenged each year with new regulations based on real challenges facing the aviation industry such as multidisciplinary optimization to meet conflicting requirements, weight reduction through structural optimization, instrumentation, and flight tests of prototypes, among others (SAE BRAZIL, 2021).

The Uirapuru Aerodesign team participates annually in the SAE Brazil Aerodesign competition, designing and manufacturing remotely piloted aircraft following the competition regulations. The team is divided into sub-teams aerodynamics, performance, stability and control, loads and aeroelasticity, structures, and electrical design. The performance sub-team initially selects the motor and propeller that best meets the project's needs and later conducts performance analyses related to the aircraft's mission.

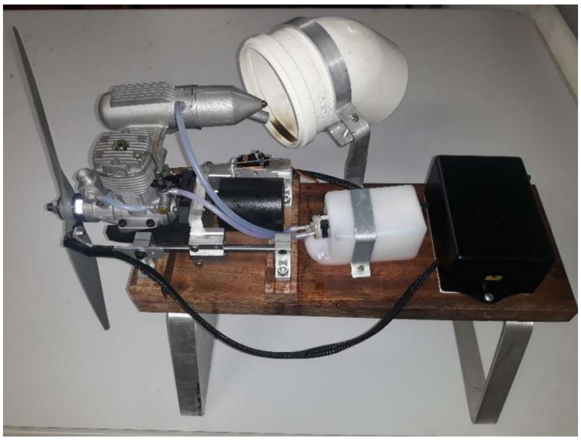
In the conception of an aircraft project, the team must conduct a detailed performance analysis in all aircraft flight phases. The primary function of performance analysis is the validation of the project, aiming to confirm if the aircraft will obtain the necessary performance to reach the project requirements and comply with all the rules of the competition regulations. For this purpose, it is essential to get accurate data regarding the performance characteristics of the propulsive system used.

The propulsion system is composed of the engine and propeller, the engine primary function is to provide the power to give the propeller rotation movement. This movement generates the thrust for the model aircraft to move (RODRIGUES, 2014). Therefore, it is necessary to use a test bench to collect enough data to determine the best configuration of the propulsive system used.

A test bench can collect data such as torque, power, thrust, and rotation of the propulsive system. When used in conjunction with a wind tunnel, it is possible to carry out dynamic analyses to obtain performance parameters as a function of speed, simulating flight conditions. The use of test benches allows recreating engine usage behavior under controlled conditions to calibrate, monitor, and evaluate its operation characteristics (PADILHA, 2007).



(a)



(b)

Figure 1. a) Brezina (2012) test stand and b) Júnior (2019) test stand.

Several types of test benches are available, with different methods for collecting thrust, torque, and rotation data from the analyzed propulsive system. Brezina (2012) presents a test bench capable of measuring thrust from a beam-type load cell, engine torque from a cylindrical torque cell, and rotation with an optical sensor (Figure 1(a)). Another configuration is presented in Júnior (2019), which can be seen in Fig. 1(b), where the motor is coupled to support mounted on a linear guide shaft, limiting the acquisition of thrust data from a load cell and rotation from a reflective sensor, with a construction cost of approximately R\$484.98. In Virginio *et al.* (2018) is presented a low cost test bench capable of collecting mainly thrust, torque, RPM, voltage and current data, with a total cost of IDR 1,589,500.00, which converted into Brazilian currency is around R\$580.00. The test bench structure is mainly made of wood, and is intended for small-diameter propellers of small-scale electric propulsion systems.

Therefore, the present work aims to present a methodology for building a low-cost test bench capable of measuring thrust, rotation, and electrical power data of propulsive electrical systems that will be used in remotely piloted aircraft designed by the Uirapuru Aerodesign UFPA team, intended for the SAE Brazil Aerodesign competition. The collected data will be used to select the propulsive system with the highest performance and subsequent analysis related to the aircraft's performance area.

2. METHODOLOGY

Figure 2 show how did development the methodology for this project.

To design a test bench capable of collecting thrust, rotation, and electrical power data, it is necessary, initially, to determine the most viable structure configuration with the lowest manufacturing cost. Based on the analysis of existing projects (BREZINA 2012 and JÚNIOR 2019) and commercial test benches available on the market, an initial configuration that met the needs of the team was determined.

Then, based on the design requirements defined by the team from the configurations of the main electric propulsive systems used by the team (Table 1), a careful selection of which sensors and devices would be used and the sizing of the structure was carried out. In addition, it is also necessary to validate the effectiveness of the project through tests to verify the reliability of the data to be obtained.

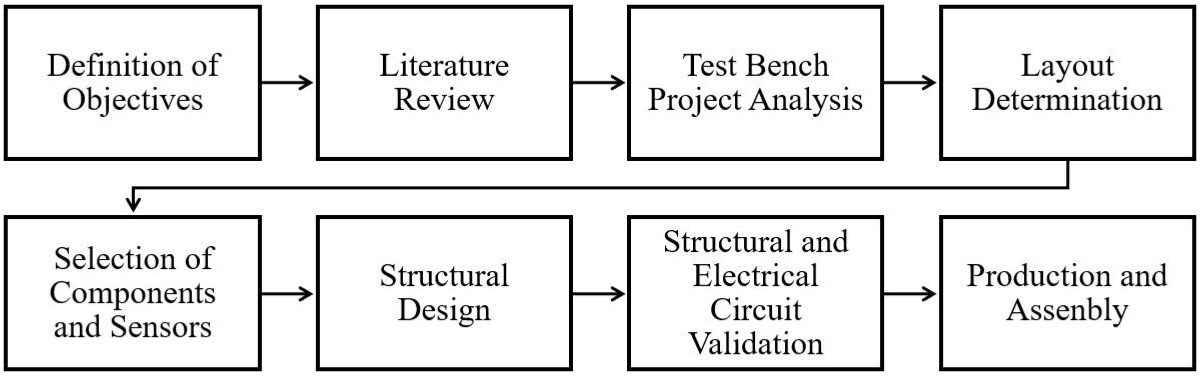


Figure 2. Project formulation flowchart.

Table 1. Test bench design requirements.

Design Requirements	
Maximum diameter of the propellers	20 inches
Maximum rotation speed	12000 RPM
Maximum electrical power	1950 W
Maximum thrust	5 kg
Maximum voltage	22.2 V

2.1 Instrumentation

The designed test bench uses a series of measuring instruments for data collection (Figure 3). Such instruments will be described as follows.

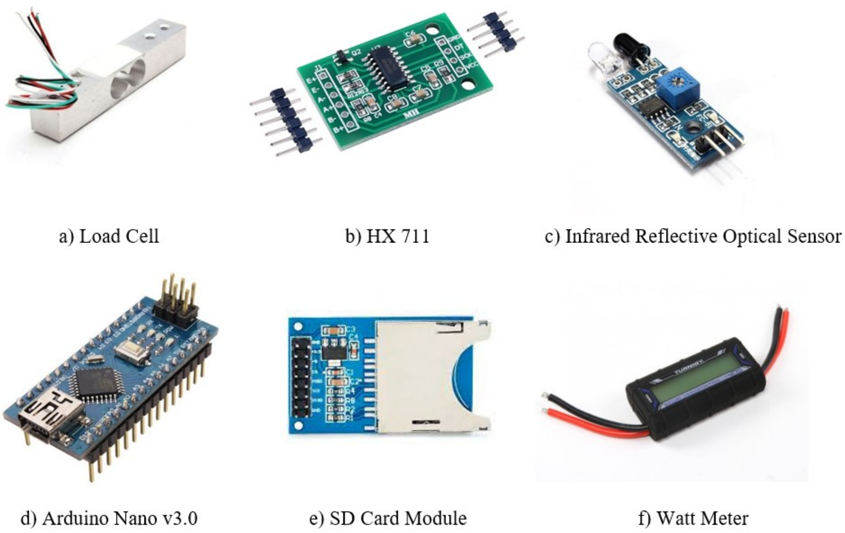


Figure 3. Components used for the test bench.

The load cell has the function of determining the thrust provided by the powertrain. This instrument is a force transducer whose fundamental property is to measure the deformation or bending of a body, converting it into a small potential difference. With this information, the load cell uses the strain gauge (extensometer) and the Wheatstone bridge, which together convert the strain into an electrical signal in the order of microvolts that is proportional to the weight or force applied to its structure (LEICHTWEIS, 2016). As indicated in Duvall (2016), it is preferable to use load cells with loads around 50% of the full scale of the load cell, to obtain more accurate results and to ensure that measurement errors do not occur when trying to measure loads much smaller than the maximum load of the load cell. In this way, a load cell with a measurement range of up to 10 kg was selected, which is capable of measuring the maximum thrust indicated in table 1.

The signals produced by the load cell need to be amplified, as the potential difference generated is too low for a microcontroller to process the information. Therefore, the 24-bit digital-analog amplifier converter module HX711 was used, this device is often used to amplify signals from force transducer devices. In addition, its internal multiplexer allows more than one load cell to be connected together at terminals +A -A and +B -B.

The measurement of the rotation speed of the engine used is by means of an infrared reflective obstacle sensor. Its circuit consists of an emitter and a receiver. The emitter is an infrared LED that emits a signal in this range of the spectrum, and the receiver is a phototransistor that reads the reflected signal. When any obstacle is placed in front of the sensor, the phototransistor reflects the infrared signal, and the output pin (OUT) is set to a logic low level (LOW).

The Arduino Nano v3.0, based on the ATmega328 microcontroller, is used to process the data obtained from the load cell and the infrared reflective obstacle sensor and store them on the SD card. The microcontroller features 14 digitals pins I/O, 8 analog pins, a 32 KB flash memory, a clock speed of 16MHz, and SPI communication support.

The SD card module is used to store the data collected by the load cell and the infrared reflective obstacle sensor. This device allows reading and writing to an SD card, but the module only supports files in FAT16 or FAT32 format. The communication between the microcontroller and the machine occurs through the SPI (Serial Peripheral Interface) protocol through MOSI, MISO, CLK, and CS pins.

The SAE competition limits the power of the electric motors during the flight competition in the regular class, being mandatory the use of one of the wattmeter models listed in the competition regulations. Therefore, it was decided to use one of the allowed wattmeters, being used only to visually indicate the electrical power and compliance with the power restriction during the tests. For the measurement of the electric power, a Turnigy 180A wattmeter was selected, capable of indicating in real time parameters such as current, voltage, and electric power consumed by the motor during the test. The wattmeter features an analysis range for voltage from 0 to 60V, and for electric current from 0 to 180A, in addition to a maximum power of 10800W, being able to measure the electrical parameters indicated in table 1.

As shown in Fig. 4, all the above components were used with their respective functions. However, it was necessary to add a push button, an LED, and two resistors of 220Ω and 10KΩ. The LED and the button helped store data on the SD card because when the button is pressed once, the LED is lit to indicate that all data is being saved to the card. Still, when the button is pressed again, the LED turns off to tell that data is not being committed to the SD card. The operation of the controller can be compared to an on and off button.

The flow of the developed code to the microcontroller is shown in Fig. 5. It is possible to observe that when the Arduino Nano is turned on, the SD card is first initialized, and then the load cell is calibrated and reset. In the main loop of the code, the data is constantly updated and stored on the SD card. However, this happens only when the button is pressed, as mentioned above. The data stored on the SD card is saved in a file in TXT format, which can easily be imported into Microsoft Excel to perform the analysis of the collected data.

The structure of the test bench was made of aluminum 1100, from a plate with dimensions of 30cmx20cmx4mm.Table 2 presents a list of all components used and the total cost of building the test bench.

Table 2. Cost of materials needed to build the test bench.

Components	Cost (R$)
Aluminum plate	50.00
10kg load cell + HX 711	37.44
Infrared reflective obstacle sensor	15.90
Arduino nano v3.0	39.90
SD card module	8.90
Wattmeter	132.45
220Ω and 10KΩ resistors	1.00
LED	0.50
Cutting and welding services	80.00
Drills and screws	30.00
Total	396.09

Therefore, the total cost for the construction of the test bench was R$396.09, lower value than other projects with similar characteristics analyzed in this work, and can be categorized as low cost, in addition to having easy construction and structural simplicity, and being able to operate with high diameter propellers (20 inches).

3. RESULTS

3.1 Final layout

It was observed that the simplest and most viable way to build a test bench would be using only support for the motor and a simple fixed base, restricting data acquisition to just thrust from a load cell and rotation to from a sensor attached to the bracket. The bench was designed to be portable, where the base can be fixed using screws on a table. The position of the holes in the motor support can be modified to enable tests to be carried out with engines of different dimensions,

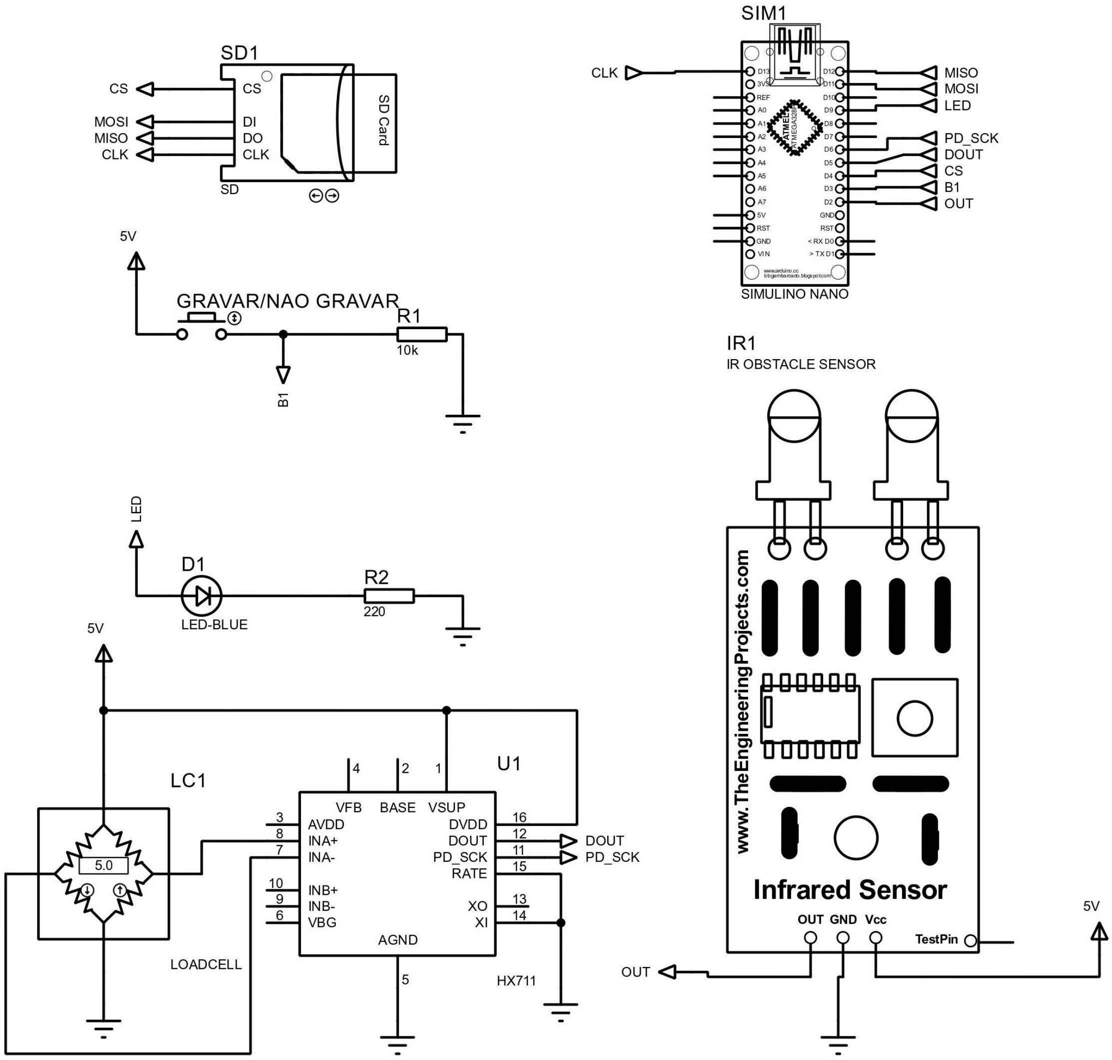


Figure 4. Circuit developed in Proteus® software.

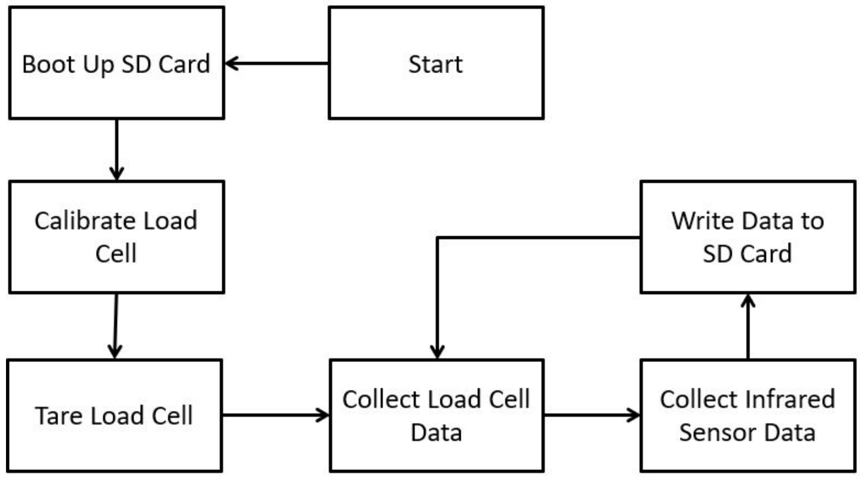


Figure 5. Flowchart of the code developed.

as the SAE BRAZIL Aerodesign competition is composed of three categories: regular, advanced, and micro, and each class has specific requirements, which can change the model of the used motor. Figure 6 presents the final layout of the developed project.

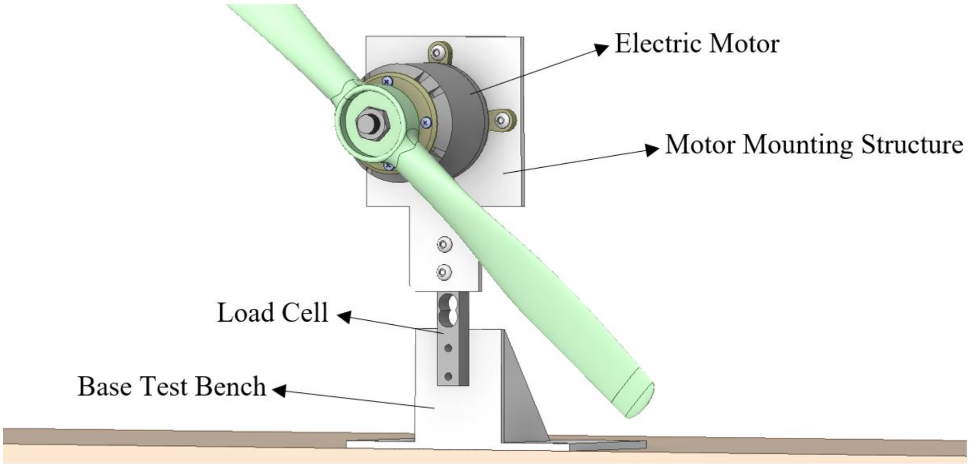


Figure 6. Final layout project of test bench.

3.2 Simulation in Proteus

The developed data collection system receives the signals from the load cell and rotation sensor, and stores them on the SD Card in a file in TXT format. To validate the operation of the proposed data acquisition system, it was simulated in Proteus® software. A pulse generator replaced the infrared sensor, as shown in Fig. 7, in this way, it is possible to adjust the pulse frequency before starting the simulation. Thus, the accuracy of the speed in RPM obtained is verified. The data saved on the SD card in the columns are respectively: the time in milliseconds since the microcontroller started running the program (t_1), the time in milliseconds from the start of data recording enabled by the push button (t_2), the thrust in kilos returned by the load cell, and the speed in RPM, according to Table 3.

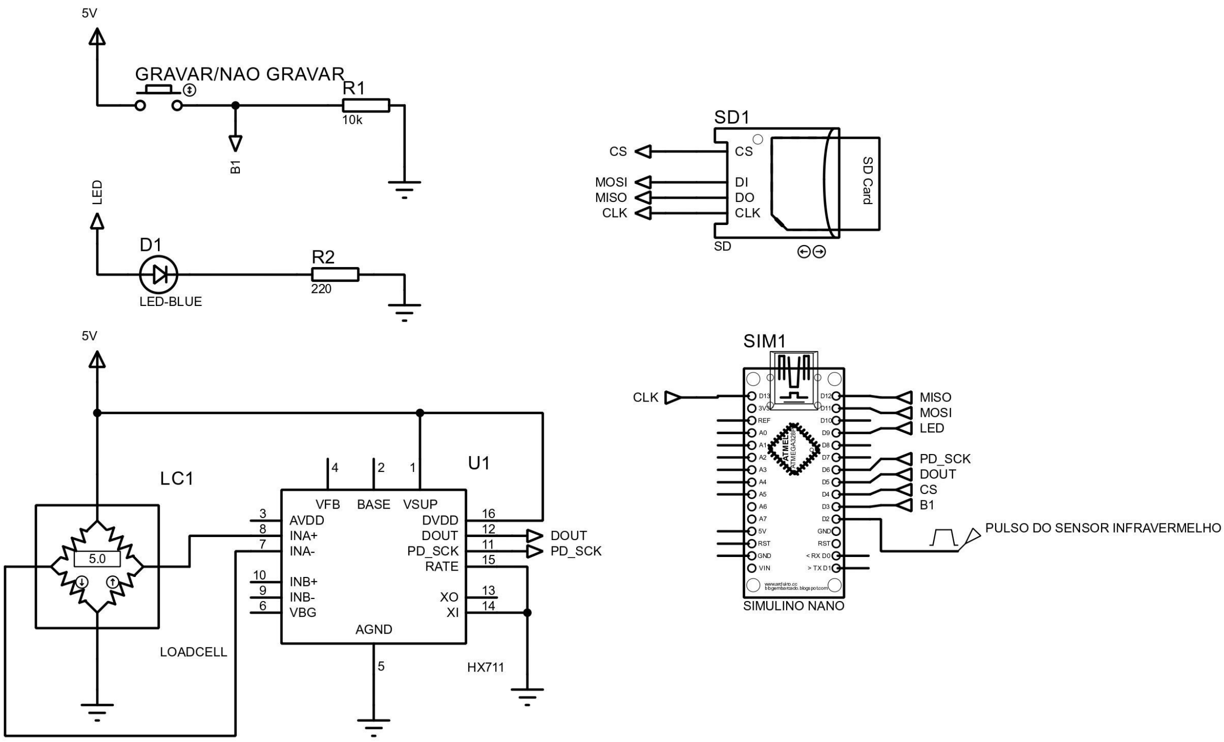


Figure 7. Simulation of data collection in Proteus® software.

Table 3. Data of simulation of data collection in Proteus® software.

t_1 (ms)	t_2 (ms)	Thrust (kg)	Speed (RPM)
5.000	1.000	0.000	6.000
6.000	2.000	0.030	6.000
7.000	3.000	0.150	6.000
8.000	4.000	0.150	6.000
9.000	5.000	0.150	6.000
10.000	6.000	0.272	6.000
11.000	7.000	0.300	6.000
12.000	8.000	0.300	6.000
13.000	9.000	0.360	6.000
14.000	10.000	0.420	6.000
15.000	11.000	0.420	6.000
16.000	12.000	0.420	6.000
17.000	13.000	0.426	6.000
18.000	14.000	0.450	6.000
19.000	15.000	0.450	6.000
20.000	16.000	0.450	6.000
21.000	17.000	0.528	6.000
22.000	18.000	0.540	6.000
23.000	19.000	0.540	6.000
24.000	20.000	0.540	6.000
25.000	21.000	0.570	6.000
26.000	22.000	0.570	6.000
27.000	23.000	0.594	6.000
28.000	24.000	0.612	6.000

Therefore, from the simulation performed, it was possible to validate the operation of the proposed data collection system, ensuring that it is able to accurately measure and store in a file the thrust and rotation generated by the propulsive system during the tests in the bench.

3.3 Motor mounting structure

The motor support serves as a platform to attach the propulsion system to be tested. With the dimensions provided by the manufacturer of the motor used by the team, it was possible to dimension the motor support considering the position and coupling form defined in the final layout. Figures 8 and 9 show the results obtained from the structural analysis of the component performed in the ANSYS WORKBENCH® software when loaded with the maximum thrust of the propulsive systems used by the team, and indicated in table 1.

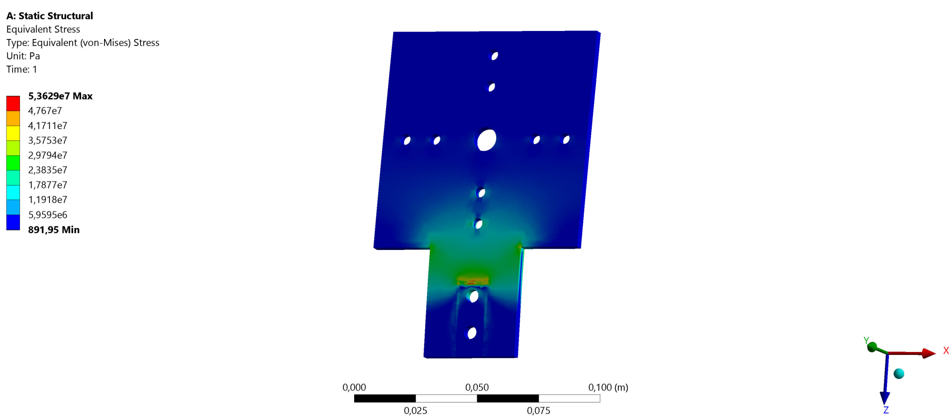


Figure 8. Equivalent (von-Mises) stress results.

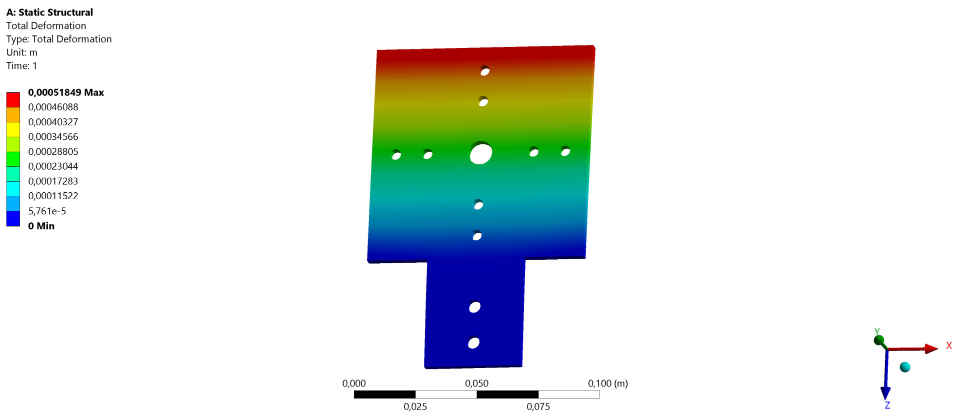


Figure 9. Total deformation results.

Therefore, there was a stress concentration on the motor support with a maximum stress of 53.6 MPa. As the yield strength of the aluminum alloy used varies between 90 and 115 MPa, it is concluded that the maximum stresses found are smaller than the yield stress of the material used.

3.4 Test bench base

The test bench base support is designed to be rigid and securely fastened, minimizing vibrations while maintaining a simple design. However, it was observed that the test bench could present a high bending effort that would cause the deformation of the entire structure and not only the load cell, as well as low stability and rigidity due to the influence of the motor in operation, therefore, it was necessary implement ribs at the base of the bench, to reduce stress concentrations in the component, besides preventing such interference from harming, even minimally, the accuracy of the data collected by the load cell, since it uses strain values to calculate the force generated by the powertrain. Figures 10 and 11 show the results obtained from the structural analysis of the bench base when loaded with the maximum thrust of the propulsive systems used by the team, and indicated in table 1. And the Figure 12 show the real photo the test bench.

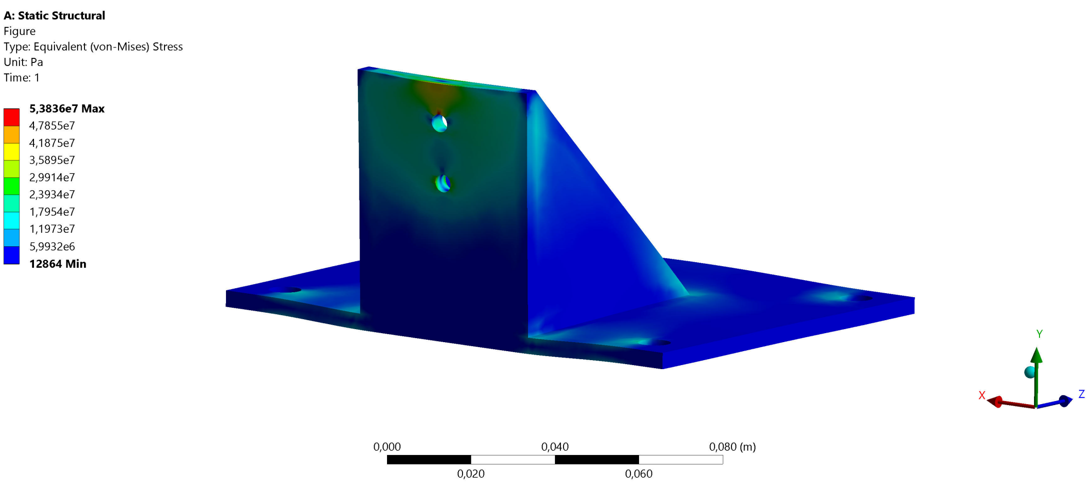


Figure 10. Equivalent (von-Mises) stress results.

According to the simulation, the maximum stress presented in the support was 53.8 MPa, which is lower than the yield strength of the material used, therefore, as well as the motor support, the base of the test bench will support the applied loads, in addition to not occurring high deformations that could affect the measurements of the load cell.

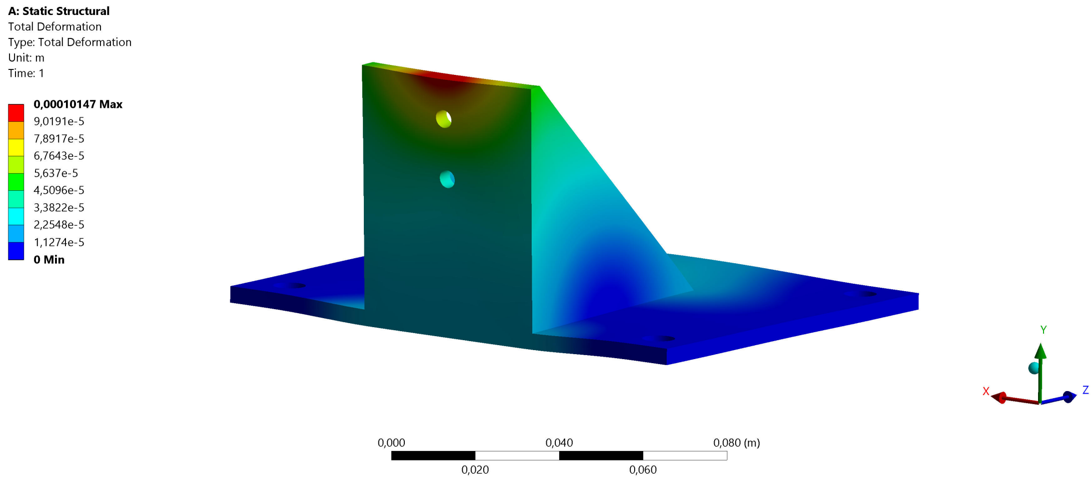


Figure 11. Total deformation results.

Figure 12. Real photo of the test bench made.

4. CONCLUSION

This work presented the design of a test bench capable of measuring thrust, electrical power, and RPM data of electric propulsion systems of unmanned aerial vehicles. The developed data acquisition system stores the data collected by the load cell and the infrared reflective optical obstacle sensor on an SD card, saving them in a file .TXT format, in addition to allowing real-time monitoring of the electrical power of the motor from a wattmeter. The proposed test bench complied with the design requirements defined by the team, being able to accurately measure the parameters of the main propulsive systems used by the team. The project presented a low construction cost of approximately R$396.09, lower value than other similar projects analyzed, and easy implementation and structural simplicity. The results obtained from the structural analysis performed in the Ansys® software and the simulation of the electric circuitry in the Protheus® software validate the effectiveness of the project, proving to be a reliable solution for obtaining performance characteristics of the propulsion systems, aiding in the selection of the motor and propeller used by the Uirapuru Aerodesign UFPA team, in the SAE Brazil Aerodesign competition.

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