Project of Monitoring
The Wind Tunnel of the
ETSEIAT’s
Aerospace Engineering
Laboratory (Hardware)

Memory

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d’Enginyeries Industrial i Aeronàutica de Terrassa)
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INTRODUCTION

1. Aim of the project

The aim of this project is to produce the hardware support needed to the mechanization of the wind tunnel located at ETSEIAT (Terrassa) in order to change the current potentiometer for an ARDUINO unit, which based on the signals received from different sensors, evaluates which is the potency needed to get the desired velocity.

Another project (Project of monitoring the wind tunnel of the ETSEIAT’s aerospace engineering laboratory (Software) by Oriol Villanueva Pujol) will take care of the software aspects, both projects have been made in parallel.
2. Scope of the project

This is a project that must be separated in small pieces in order to achieve small actions. One idea of work division and the one that has been followed in this project is the following:

1. Study the wind tunnel and discover which variables are needed to sensor and control the wind tunnel.
2. Check and list the available components
3. Understand how work the wind tunnel and the components available
4. Separate the different values to study them separately
5. Choose the microprocessor and understand its requirements
6. Gather components to design the circuits needed
7. Design the first concept of the circuits of the system
8. Test the circuits
9. Change the circuits to improve its function (this action maybe is made more than one time)
10. Test the circuits again (this action maybe is made more than one time)
11. Select the zone where the hole system will be placed
12. Produce or purchase the base support for all the circuits (for example a PCB)
13. Test the circuits with the base
14. Make all the last adjustments
15. Calibrate the sensors
16. Resume and list de economical budget
17. Write a report with the results
3. Basic requirements of the project

This project doesn't have many requirements, as the objective is that the tunnel must work. But there are some things that must be taken into account:

- The sensors available in the University must be used in the global system because no more sensors will be purchased.
- As far as the University can provide components (resistors, capacitors, sensors...) no more components will be purchased.
- The system will be permanently installed in the University, so it must be installed and placed appropriately in the laboratory.
- The system must be connected to a computer or receive data from a computer.
- It shall give the opportunity to chose between use the actual potentiometer or the new automatic system.
- The software must be programmed in an Arduino board, that is provided by the University.
- The hardware must provide some circuits that can work together with the Arduino.
- The Hardware must be placed in a board (trying to use the smallest wiring amount as possible) that as much as is possible it shall be produced at the University.
4. Necessity of the project

This project isn't vital for the working or investigation of the University, but necessary because the current operation system is obsolete and there is a real need to change the control system to an automatic one, one controlled by a microprocessor that can be used from a computer.

Such is the importance of this project, that many components were already purchased before starting the project, and the opportunity to mechanize the tunnel using the work of the students is a good opportunity for the University, which agreed to help supplying the materials and the installations that are necessary.

Mechanize the wind tunnel and letting it work into low velocities will improve the precision of the future experiments made in the University and maybe help into investigation, which is wanted by the University.
DEVELOPMENT

5. Background and State of art

In this project, all the actions will affect the wind tunnel of the University, so before explain all the circuits used in the wind tunnel it's important to resume the State of Art of wind tunnels and then how they work (in the next point).

Wind tunnels are nowadays widely used there are different types of wind tunnels if we consider the operation speed:

- **Subsonic and transonic wind tunnels:**
  They are open or closed tunnels, and they work at air velocities smaller than Mach=1 (speed of sound). They are the most common tunnels used nowadays because they have more applications, which will be explained later.

- **Supersonic wind tunnels:**
  Supersonic tunnels work at Mach between 1.2 and 5, this numbers can be assumed changing the geometry of the nozzle. This tunnel is used for aeronautic and space purposes, for the high speeds this tunnel archives.

- **Hypersonic wind tunnels:**
  Hypersonic wind tunnels is less used, it has more complexity and is used for example by NASA. It works with Mach between 5 and 15.

The university tunnel is a subsonic tunnel, so the state of art of this type of tunnel will be studied.

Wind tunnels origins are in a invention of Benjamin Robbins (1705-1751) of a whirling arm that can determine drags of some objects. But until 1871 a machine that can be called wind tunnels was designed.

The Wright brothers also build some types of wind tunnel, but was Eiffel who build a machine that can be compared to an actual open-return wind tunnel.

Nowadays the evolution of wind tunnel has helped to the diversification of its different uses.

For example there are two different types of subsonic wind tunnels. Here the two main used will be explained:

1. **Open return wind tunnel(1)**
   The open return wind tunnel is also called Eiffel tunnel, because it is very similar to the one designed by this French engineer, or NPL tunnel, because was on the National Physical Laboratory in England where the
wind tunnel was firstly used. In the open return tunnel, the air that passes through the test section is gathered from the room in which the tunnel is located.

The other main wind tunnel is the closed return and, compared to it, the open return has some advantages and disadvantages:

- **Advantages**
  - Low construction cost
  - Superior design for propulsion and smoke visualization. There is no accumulation of exhaust products in an open tunnel.

- **Disadvantages**
  - Poor flow quality possible in the test section. Flow turning the corner into the bell-mouth may require extensive screens or flow straighteners. The tunnel should also be kept away from objects in the room (walls, desks, people ...) that produce asymmetries to the bell-mouth. Tunnels open to the atmosphere are also affected by winds and weather.
  - High operating costs. The fan must continually accelerate flow through the tunnel.
  - Noisy operation. Loud noise from the fan may limit times of operation.

The wind tunnel of the university is an open return wind tunnel.

2. **Closed return wind tunnel**
   This tunnel is called Prandtl tunnel, for the German engineer, or Gottingen tunnel, for the research laboratory of Gottingen (Germany) where this tunnel was firstly used. Most large research wind tunnels, are closed return. In this tunnels the air is conducted from the exit of the test section to the fan passing through some turning vanes. A after the fan is...
conducted again to the test section (using also turning vanes). With this system the air is continuously circulating through the hole tunnel.

![Closed Return Wind Tunnel](image)

*Figure 2: Closed return wind tunnel*

This kind of tunnels can also operate supersonically, but the tunnel geometry must be changed. At low pressure maybe there could be some condensation in the test section. To avoid that, normally the entering air pass over a dryer bed.

The closed return tunnel has some advantages and disadvantages compared to the open return tunnel.

- **Advantages**
  - Superior flow quality in the test section. Flow turning vanes in the corner and flow straighteners near the test section insure relatively uniform flow in the test section.
  - Low operating costs. Once the air is circulating in the tunnel, the fan and motor only needs to overcome losses along the wall and through the turning vanes. The fan does not have to constantly accelerate the air.
  - Quiet operation relative to an open return tunnel.

- **Disadvantages**
  - Higher construction cost because of the added vanes and ducting.
  - Inferior design for propulsion and smoke visualization. The tunnel must be designed to purge exhaust products that accumulate in the tunnel.
  - Hotter running conditions than an open return tunnel. Tunnel may have to employ heat exchangers or active cooling.

But where are these tunnels nowadays used? They are extended to very different sectors, and industries. And there are different examples:
• **Aeronautical**
  Wind tunnels for planes design maybe is the most known use of them. For example Airbus uses the Filton wind tunnel in England to test their models since 1957.

![Filton wind tunnel](image1)

*Figure 3: Filton wind tunnel*

Normally this tunnels are tested with scale models of the object (a plane for example).

• **Space**
  In space industry the use of wind tunnel isn't much common, because most devices operate without atmosphere, but for some prototypes those studies, for example this year has developed a Space Launch System (SLS) a heavy-lift launch vehicle that will carry crew, cargo and science missions into deep space.

A model of SLS was tested in Langley's Transonic Dynamics Tunnel (TDT).

![NASA engineers testing the SLS model](image2)

*Figure 4: NASA engineers testing the SLS model*

The aerospace industry can also work with bigger wind tunnels, in fact the bigger tunnels are dedicated to aerospace industry.

• **Automotive**
  In automotive the most known use of wind tunnels is in Formula 1. Every year all the teams of F1 test their cars and components in wind
tunnels to improve their results. In fact this is very important for them, for example in 2012 Ferrari announced that they had problems with their car at the beginning of the competition because they had had inconsistency of data in the wind tunnel tests.

But Formula 1 isn't the only one in using wind tunnels. General automotive tends to use the wind tunnel on their cars.

All automotive wind tunnels (also Formula 1 ones) use big wind tunnels to test the final object or a 1:1 model.

For example, the biggest wind tunnel belong to General Motors. Put into operation in 1980, the GM Aerodynamic Laboratory is the largest wind tunnel in the world dedicated to automotive use (the only bigger tunnels are used by the aerospace industry).(4) This wind tunnel features a 4,500 hp fan that can create winds up to 138 miles per hour. The GMAL, located in Warren (Michigan), consists of six laminated spruce wood blades. The 43-foot diameter fan is powered by an extremely powerful electric motor capable of producing hurricane-force winds to aid in the development of future vehicle designs.

GM specialists say the aerodynamic work typically begins in 1/3-scale clay models to test the overall shape of a vehicle, going through a series of stages until moving to full-scale development, often testing aerodynamic changes as small as one millimetre.
But there is one final ambit of use of the wind tunnel and is research and education. In this ambit some Universities have wind tunnels, to make research or to teach fluid mechanics. At this one type is where the ETSEIAT tunnel belongs. This tunnels are normally small, just to test some small foils or models.

5.1. ETSEIAT University’s wind tunnel state of art and precedents

The ETSEIAT University of UPC in Terrassa, has two different wind tunnels for research and education purposes. One is in the fluid mechanics laboratory and the other one is in the aerodynamics laboratory. This project is about the wind tunnel of the Aerodynamics laboratory.

The tunnel is a small open return wind tunnel for small objects, compared with the other wind tunnel, this operates better at low velocities.
The tunnel takes the air from the room where it is installed, and it goes through an asynchronous motor that blows the air with a selected intensity. The air flow through a convergent nozzle until it reaches the test zone, which is cylindrical and can be opened from outside in order to enter here the components to be tested. After the test zone the air flow through a divergent nozzle and then exits to the laboratory.

The intensity is regulated using a velocity selector named Altivar 31. This velocity selector controls the wind tunnel, and just needs an input to select the level of intensity. Before starting this project the level of intensity of the Altivar was regulated using a potentiometer that had a scale from 0 to 10. The aim of the project is directed to change this potentiometer with a computer that will select the amount of power needed to select an appropriate velocity. The system has the necessity to record more values to have a complete study, these are, temperature, ambient pressure and the differential pressure measured in the wind tunnel. These values are measured with different instrumentation, the temperature is measured with a thermometer installed on the laboratory wall, also is on the laboratory wall a barometer to measure the ambient pressure during the experimentation. The differential pressure is different, it is measured using some U shaped tubes filled with water. When the tunnel is working there appear a difference of height in the different arms of the U, that were aligned at the beginning, measuring the difference the pressure is obtained in millimetre water column. In this project those measures will be made using sensors, but the old ones are needed at first moment to calibrate the signals to read the correct value while operating.

Figure 8: Laboratory measure devices
The wind tunnel has also a security circuit installed, it has two security switches (one next to the test zone and one at the exit) than can be pulsed to interrupt the Altivar and stop the tunnel.

As it can be seen, this tunnel works manually, but many tunnels work automatically, for this reason there exist a previous study in the ETSEIAT University to mechanize the wind tunnel. This previous study doesn't arrive very far, just to indicate which variables must be measured, but the tunnels wasn't changed and still worked manually. But as a result to this, some pressure sensors were purchased, some of them specially the pressure transducer, were a bit expensive, and until this project started, remained unused in the laboratory. After this precedent, the intention of this project is to finally achieve the mechanization of the wind tunnel.
6. Physical understanding of the wind tunnel

The University' tunnel is an open-return wind tunnel, as this project is about mechanize the tunnel operation is important to know the operation principles.

The basic principle to evaluate the velocity of a wind tunnel is the Bernoulli equation:

\[ P_{\text{total}} = P_{\text{static}} + \frac{1}{2} \rho v^2 \]

\[ \Delta P = P_{\text{total}} - P_{\text{static}} = \frac{1}{2} \rho v^2 \]

To know which velocity the tunnel shall need the first thing is to divide it in different parts.

![Figure 9: Schematic of a wind tunnel](5)

The important velocity is the obtained in the test section, and to reach it is important to know the starting values.

To obtain the equations of the wind tunnel, the starting point is on the continuity equation. The mass flow during all the wind tunnel is constant.

\[ \dot{m}_1 = \dot{m}_2 \]

\[ \rho_1 A_1 v_1 = \rho_2 A_2 v_2 \]

In this subsonic wind tunnels the density \( (\rho) \) is constant, so we obtain that: \( A_1 v_1 = A_2 v_2 \). After that we take the Bernoulli equation:

\[ p_1 + \frac{1}{2} \rho v_1^2 = p_2 + \frac{1}{2} \rho v_2^2 = p_0 \]

If the calculations start with the static values \( (v=0) \), the results will be in terms of values easy to measure \( (P_{\text{amb}}=P_0, \rho_{\text{amb}}, \text{etc}) \).

\[ \Delta P = P_0 - P_2 = \frac{1}{2} \rho v_2^2 \]

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After that the velocity needed is aisled:

\[ v_2 = \sqrt{\frac{2\Delta P}{P}} \]

Then taking the equation of state \( P\rho = RT \), the density can be excluded from the equation, because it is difficult to measure, then the velocity is:

\[ v_2 = \sqrt{\frac{2\Delta P}{P} RT} \]

Programming this equation and obtaining the data compulsory for that is one objective of the software(6). In order to do this, it is important to known the wind tunnel that will be programmed, in this case, for this project, the people in charge of the wind tunnel were asked, and they helped to obtain the following equation:

\[ v = \sqrt{\frac{2 \cdot \alpha_1 \cdot \Delta P_{s_{tob}}}{\text{Patm} - \alpha_2 \cdot \Delta P_{s_{tob}}} \cdot R \cdot T} \]

Where \( \alpha_1 \) is the calibration of the sensors and \( \alpha_2 \) is the nozzle calibration. \( \text{P}_{\text{amb}} \) the ambient pressure, \( T \) the air flux temperature and \( \Delta P \) the pressure different of the nozzle. After obtaining this equation it is determinate than the measures ha must be recorded with sensors are \( \Delta P \), \( \text{P}_{\text{amb}} \) and \( T \).

Once the physics involved in the wind tunnel are known is easier to understand the different magnitudes and to understand the results and to solve the errors that will appear during testing and calibration of the system.
7. Arduino Board

7.1. Different options

The microprocessor is the heart of the software project, because it analyses all the entries, computes them and exits the control signal for the wind tunnel. For this project (Hardware), the main points to take into account is the number of entries and the voltage that the Arduino can work with. The first problem we face is the selection of the Microprocessor. On that point we have to say that we only considered choosing between Arduino UNO and DUE, because the University could provide them to us.

As is said on the Arduino Webpage "Arduino is an open-source electronics platform based on easy-to-use hardware and software." In summary we use a software free microprocessor that we can program to compute the equations necessary to control the wind tunnel.

First of all, we have this two different microprocessors:

- **Arduino ONE R3**

![Figure 10: Arduino UNO R3 (front and back)](image)

This Arduino is one of the basics, but on its new revision R3, it fulfil all the requirements we could need. These are the features of the Arduino:

<table>
<thead>
<tr>
<th>Microcontroller</th>
<th>ATmega328</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage</td>
<td>5V</td>
</tr>
<tr>
<td>Input Voltage (recommended)</td>
<td>7-12V</td>
</tr>
<tr>
<td>Input Voltage (limits)</td>
<td>6-20V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>14 (of which 6 provide PWM output)</td>
</tr>
<tr>
<td>Analogue Input Pins</td>
<td>6</td>
</tr>
<tr>
<td>DC Current per I/O Pin</td>
<td>40 mA</td>
</tr>
<tr>
<td>DC Current for 3.3V Pin</td>
<td>50 mA</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>32 KB (ATmega328) of which 0.5 KB used by bootloader</td>
</tr>
<tr>
<td>SRAM</td>
<td>2 KB (ATmega328)</td>
</tr>
<tr>
<td>EEPROM</td>
<td>1 KB (ATmega328)</td>
</tr>
<tr>
<td>Clock Speed</td>
<td>16 MHz</td>
</tr>
</tbody>
</table>
ETSEIAT's wind tunnel monitoring

Hardware

<table>
<thead>
<tr>
<th>Length</th>
<th>68.6 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>53.4 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>25 g</td>
</tr>
</tbody>
</table>

Table 1: Arduino UNO characteristics

- **Arduino DUE**

![Arduino DUE (front and back)]

Arduino DUE is bigger than UNO and also has different characteristics, that they are:

<table>
<thead>
<tr>
<th>Microcontroller</th>
<th>AT91SAM3X8E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage</td>
<td>3.3V</td>
</tr>
<tr>
<td>Input Voltage (recommended)</td>
<td>7-12V</td>
</tr>
<tr>
<td>Input Voltage (limits)</td>
<td>6-16V</td>
</tr>
<tr>
<td>Digital I/O Pins</td>
<td>54 (of which 12 provide PWM output)</td>
</tr>
<tr>
<td>Analogue Input Pins</td>
<td>12</td>
</tr>
<tr>
<td>Analogue Output Pins</td>
<td>2 (DAC)</td>
</tr>
<tr>
<td>Total DC Output Current on all I/O lines</td>
<td>130 mA</td>
</tr>
<tr>
<td>DC Current for 3.3V Pin</td>
<td>800 mA</td>
</tr>
<tr>
<td>DC Current for 5V Pin</td>
<td>800 mA</td>
</tr>
<tr>
<td>Flash Memory</td>
<td>512 KB all available for the user applications</td>
</tr>
<tr>
<td>SRAM</td>
<td>96 KB (two banks: 64KB and 32KB)</td>
</tr>
<tr>
<td>Clock Speed</td>
<td>84 MHz</td>
</tr>
<tr>
<td>Length</td>
<td>101.52 mm</td>
</tr>
<tr>
<td>Width</td>
<td>53.3 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>36 g</td>
</tr>
</tbody>
</table>

Table 2: Arduino DUE characteristics
7.2. Making a decision

At this point making a decision is important because all the other components connection and assembly will be affected by the difference between them.

First of all the analogue inputs. For this project the entries needed are 1 for the temperature sensor, 2 for the pressure sensors and 3 for the balance (optional). Which makes a total of six. Which means that both Arduinos have entries enough for this project.

Secondly, the working voltage, this is the second determinant factor. All sensors operate between 0 and 10V, and for this purpose, the Arduino UNO seem to be better. A 5V operating voltage give more facilities, instead of the 3.3V of the Arduino DUE. Divide the voltage by half is easier than a way to reach 3.3 and also having more voltages give more range of voltages of working levels. But is possible to reach the 3.3V, but taking in account that the Arduino DUE costs almost two times the amount of Arduino UNO, here will have a disadvantage.

Finally the resolution. The resolution is the quantity of bits Arduino can work with, Arduino UNO has a resolution of 10 bits, and DUE of 12 bits. A this point the decision must be made in case that 10 bits are not enough for the different values that the Arduino receives, after asking the person in charge of the wind tunnel, and 10 bits are enough. So both Arduinos are enough for our purposes.

Considering that in all points both microprocessors can be used, but Arduino can handle more voltage and is cheaper, the election is to use Arduino UNO.

Selecting Arduino UNO a maximum voltage for inputs and outputs is defined and it must not be exceeded in order to avoid ruining the Microprocessor.
8. Altivar connexion and control

8.1. Main component characteristics

Altivar is a Adjustable Speed Drive Controllers, that is used to select the velocity of the fan. (9) This project will change the current potentiometer by a connection to the ARDUINO unit.

The actual use of the wind tunnel is regulated by the Altivar. And its use is compulsory for the wind tunnel, the objective of this project is change its manual potentiometer, for a circuit with Arduino for its regulation.

In the lab of aerodynamics in ETSEIAT the Altivar is next to a small case with a small box containing a switch and a potentiometer. The switch turns of or on the Altivar, and also the wind tunnel, and the potentiometer regulates the speed. This box will be change to another that allows to change from the manual control to the Arduino control.

The Altivar works as a frequency adapter (velocity selector) alimented by a tree phase net of 200-240V. It consists in two switchers and diodes per phase that change very quickly, to control the frequency and with that the velocity.

The velocity is regulated with a potentiometer connected by three terminals, one at the GND, another to a constant signal of 10 V and the other that contains the control signal, as can be seen on the image below obtained from the Altivar manual.
The objective of this project is to allow to control the wind tunnel, which means controlling the Altivar, with a computer automatically. The solution is to install an Arduino microprocessor, with sensors that will define the current velocity and give the control to reach a desired velocity. During the montage of the system, the university asked to have the possibility to control the wind tunnel either with the potentiometer or with the Arduino.

Replacing the potentiometer by the Arduino, shall be just change the control signal that goes to the port Al1, with an output from the Arduino, this control signal must be between 0 and 10V.

Here comes the first problem, Arduino has two different types of output, one is a simple digital output (0 or 1) or a PWM exit (Pulse Wide Modulation) to recreate an analogue output. But which we need is a constant value that we can regulate between 0 and 10. With this conditions is obvious that the digital output...
isn't enough, so we will have to act over the PWM to have a correct control signal.

The solution proposed is obtain the constant value of the analogue output to have this a constant value. To do that the best is to install a low-pass filter.

A low-pass filter is a construction that cuts all the frequencies higher than a frequency defined by the circuit called cut frequency. If his frequency is very low we will avoid the different harmonics and we will just have the constant value of the wave.

The cut frequency is regulated by the filter construction. The simplest way is to use what is known as an RC filter, that consist in a resistor and a capacitor. With this montage the cut frequency is determinate by:

\[ f_c = \frac{1}{2\pi RC} \]

Where R is the resistor value and C the capacitor value. To obtain this equation the circuit must be:

![Figure 17: RC filter working schematic](image)

Because a frequency between 5 Hz and 10 Hz is acceptable we could choose a capacitor of 100uF and then a R of 300 Ohm, or for example an R of 1kOhm and a C of 22uF. Giving a cut frequency of 5.7Hz and 7.23Hz respectively.

The definitive filter is made with an R of 1kΩ and a C of 22µF.

After this filter the output type is the desired one. But as this signal comes from the Arduino, which can only provide a signal between 0 and 5 V, and we need
to arrive to 10V, then we need to multiply this signal by 2. Which means that we need an Operational amplifier ("op-amp" or OPAM). An Operational amplifier consists basically in a two differential voltage entry circuit with a single exit that has a voltage much higher than at the entry, the amount multiplied rely on the resistors or other components installed in is circuit.

Explaining all the operations and OPAM can do may be long and unnecessary, but, talking about voltage multiplying is necessary because some options has been considered.

For example, there are two main ways to multiply a voltage entering a OPAM:

- Inverting amplifier: In this position the output voltage has the opposite sign than the input voltage and also is multiplied by a quantity determined by the gain, the gain is determinate by the $R_{in}$ and $R_f$ (or realimentation) values.

![Figure 18: Inverting amplifier](image)

In this configuration, the input voltage as well as the resistors are connected to the negative input pin, and the positive input is connected to ground (GND). Due to this configuration the output voltage is:

$$V_{out} = -V_{in} \frac{R_f}{R_{in}}$$

- Non-inverting amplifier: In this case the output voltage has the same sign than the input voltage. This configuration also has a gain defined by the different connections:

![Figure 19: Non-inverting amplifier](image)

The main difference of this mode to the other is the input voltage. The input voltage enters this time to the positive plug, and the resistors that are connected to the negative one are also connected to GND. In this configuration the output voltage is:

$$V_{out} = V_{in} \left( 1 + \frac{R_2}{R_1} \right)$$
At that point a decision was made. The main thought use for the OPAM in this project is to multiply the voltage per 2, without changing its sign. For this reason, normally in this project the non-inverting configuration will be used and the resistors R1 and R2 will have the same value, about 100kΩ.

The operational amplifier selected for this project is the LM358N from Fairchild Semiconductor®. This model consist of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltage. (11)

![LM358N](image)

**Figure 20: LM358N**

The alimentation of the OPAM is made with and external power source. And it must be connected o a certain plug. Its connexion scheme is the following:

![Connection Scheme](image)

**Figure 21: LM358N(11)**

Where Vcc is where the energy source goes (also connected to GND), then connect the output and the input as desired to make the circuit. The Vcc is about 12V which receives from an external power source.

This OPAM circuit comes just after the RC filter, which in global performs this circuit, obtained with the fritzing program.
Which with this circuit we obtain the correct control signal that we need to replace the potentiometer with an Arduino.

As can be seen is a flat constant value, which is what the Altivar needs to command correctly the velocity of the wind tunnel.

But as we said at the beginning of this point, we must have the possibility to use the Arduino or the potentiometer, the solution is to have two signal wires, and connect a commuter that switch between the signal that comes from the Arduino or from the potentiometer. The original potentiometer controller case is modified to have a selector and choose the control system.
To do that, the GND and the Signal wire are duplicated. The signal wires are connected to the selector that just takes the signal from the circuit selected in that moment.

8.3. Testing process and problems

This circuit was the first one to be tested, because is the one that allows to have control over the wind tunnel.

Using the circuit installed in a protoboard and measuring the voltage with a tester and with an oscillator while making the test, the test consist in reach the limit programmed and make sure that the signal is between 0 and 10V. At the beginning of the test the voltage is at 0V and the wind tunnel is still. The voltage increase step by step and also does the tunnel's velocity, at max power of the tunnel the tester measures 9.72V a correct value, but when the voltage slower, it's impossible to reach 0V. When the Arduino is at is lower value (0) the voltage should be 0V, but the tester shows 1.97V, this voltage makes that when the tunnel shall be still it is working.

Some actions were made to solve this problem. First a discharge resistor in parallel to the capacitor was installed, but the result was the same, so it was removed (the PCB has a spot for this resistor in case it must be installed again), then it was thought that the problem is maybe produced by the different grounds in the system (Altivar, power source and Arduino). To solve this, all the grounds were connected to the Arduino GND value, but the result was the same, although this system remains with this connection because is a proper correction for the circuit. Finally the possibility to install a capacitor in the Altivar at the signal value connection, this shall solve the problem with this remaining voltage, but as this problem doesn't appear while using the potentiometer which
ETSEIAT's wind tunnel monitoring

also uses the Altivar, the decision to install this capacitor was delayed until more circuits were tested.

One action that was taken into the connection circuit with Altivar is the alimentation of the Operational Amplifier. In this circuit the power source of 12V was external, to avoid some problems for voltage peaks, two different capacitors were installed, one was an electrolytic capacitor for the larger peaks, and a smaller easier capacitor for the smaller peaks. With that the circuit remains like this:

![Circuit change diagram](image)

**Figure 25: Circuit changes**

After all the other circuits were tested the attention was centred again in the 1.97V that appear during the Altivar connection, when the Altivar was turned to 0 after testing it.

First it was thought that maybe the connections of the circuit were made in a form that allows the current to go for another direction when the Arduino is not connected to the current. Which is shown on the next figure:
As it is shown on the figure there could be an explanation for a strange value when the Arduino is not connected, but when the microprocessor (Arduino) has its power supply this effect shall disappear, and during the test the voltage didn’t disappear, so this explanation is wrong as the origin of those 1.97V.

Then the circuit was conscientiously observed and tested, and everything seem to be correct, so definitively the error appear outside the circuit.

The attention was centred in Altivar. When the oscilloscope was connected between the Altivar terminals the signal that appear was the following:

This signal show that the continuous value is correct, because it is at 0V, but those triangles of 10V of height, integrated by the Altivar are the responsible of that value of 1.97V.
This wave is the typical product of a signal that goes through a capacitor. But all the capacitors seem to be functioning correctly. This capacitor behaviour is produced in the wire. The wiring was installed before this project starts, it wasn't the election made on this project or on the software project. The problem was that the long wire without protection generated this signal.

To solve this the solution was to replace the simple wire that was going from Altivar to the Arduino (installed by a person from the University) for a shielded wire. The result was the same, but when this shielded wire has its shield connected to ground (also the negative voltage wire that it was connected to GND before) the signal received by the Altivar was a straight line. Then the circuit was tested again and the results were correct.

The reason for this problem to appear is a complex idea, and it wasn't easy to detect. There are some consideration that must be done before starting the explanation.

First of all it's important to understand that the Altivar is working at high frequencies. At high frequencies the wiring that normally doesn't affect the circuit, but at high frequencies it develops a induction value.

![Figure 28: High frequency changes](image)

This induction is distributed along the cable longitude. As a result of this two points that have the same voltage at low frequency, at high frequency the voltage is different.

Then there is the problem with long wires. Basically a wire is a conductor, when it is near to another conductor layer, or even the ground, it is a case of two conductor layers with a dielectric layer (air) between them. This is a capacitor. And then this capacitor is distributed along the cable, which made difficult to calculate the value of the loses.
But this by itself doesn't explain the problem, for itself, the Altivar plays an important role. The peaks produced in the voltage are directly related to the peaks of the intensity circulating through the wire. The intensity that goes through this "virtual capacitors" follows the next expression:

$$i = C \frac{dv}{dt}$$

Where $i$ is the intensity through the wire (A), $C$ is the capacitor value (F), $dv$ is the differential increment of voltage and $dt$ the differential increment, resulting $dv/dt$ the variation of voltage in time.

In this case the C value is constant, is unknown, because it is distributed along the wire, but it has a certain value, then the peaks must come from the $dv/dt$ value, this value is high when a high amount of voltage is supplied in a very short time, and this is exactly how Altivar works.

In each phase of the Altivar there are many numbers of switchers (with a diode to avoid the current flowing through the wrong way) commutating at a very high speed (microseconds), added to these the voltage that goes in every phase is high (400V) it makes a very ad combination because there are a $dv$ of 400V and a $dt$ of the order of $10^{-6}$s, then the division of $dv/dt$ gives a great number that even multiplied by the capacitor value could provide high peaks of intensity which at the same time gives peaks in the voltage.
This behaviour shall produce a triangular signal as the observed so it is thought that the problem should be on the wiring system, but just to be sure the idea is tested with capacitors with a signal, as it can be seen on the figure 31.

![Signal modulated](image)

**Figure 31**: Signal modulated

In the case of the signal that is a constant value, the triangles are all in the same direction, as they were on the oscilloscope. But it seems clear that the problem is in the wire used in the installation. Replacing this wiring by another one is possible, because the installation doesn't go through any wall, so it is possible to correct the mistake and solve the error.

The election was use a shielded wire, this time wasn't the first in his project to use this type of wire as it is reflected on the next points of the project. Before installing the wire properly a test was made, the same connections were made, but in that case the long cable connections were with shielded cable. But the result was the same, because this wire, uses as a shield, a conductive layer, which used together with the wire produced the same "capacitor effect".

![Shielded wire](image)

**Figure 32**: Shielded wire

As one of the two long wires was connected to GND and the shield was connected to ground, there existed the potential difference, the solution was to connect the wire also to ground, after that connection the voltage difference disappeared.

After that the peaks on the voltage disappeared, and the wind tunnel worked correctly at all the velocities, which means a real success, then when the 0 is selected, the wind tunnel goes to 0 and stops, without stopping at any point.
9. Pressure transmitter implementation

9.1. Main component characteristics

The pressure sensor will measure the ambient pressure to use it in the calculation of the Arduino. In this project the sensor used will be a Piezoresistive Transmitter form the Keller® company. Exactly one from the Series 21R.(12)

Piezoresistive means that there is a change in the electrical resistance of a semiconductor (or a metal) when applied a mechanical strain.

This type of sensors use a silicon pressure sensor mounted on a stainless steel capsule filled with welded oil, providing a highly stable measuring cell with negligible hysteresis, good linearity, high output and a life of millions of pressure cycles.

This model was previously purchased by the University, and it measures between 0.8 and 1.2 bar, which is enough because this sensor measures the

Figure 33: Keller Pressure sensor, A) schematic, B) real sensor
ambient pressure, and taken into account that an atmosphere is approximately 1.013 bar, having that range is good enough.

The sensors from the Series 21R, as the one of this project have some difference between them if someone look for example at the exit voltage or the number of wires used for the connections, or the voltage supply it needs to work. All the characteristics of this sensor are on the next table.

<table>
<thead>
<tr>
<th>Transmitter</th>
<th>Transducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Output</td>
<td>4.20 mA</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>6...20 Vdc</td>
</tr>
<tr>
<td>Current required</td>
<td>up to 20 mA</td>
</tr>
<tr>
<td>Zero/Span Tolerance</td>
<td>1% FS</td>
</tr>
<tr>
<td>Configuration</td>
<td>2 wire</td>
</tr>
<tr>
<td>Electrical Connection: mPm 1/3 micro or cable 2m.4 core</td>
<td>OUT/GND: Pin 1 / White</td>
</tr>
<tr>
<td></td>
<td>+Vcc: Pin 3 / Brown</td>
</tr>
</tbody>
</table>

**Table 3: Pressure sensor information**

The available sensor available is a transmitter that has the following characteristics:

- 0-10Vdc Signal output
- 8-28Vdc Supply Voltage
- Uses 3 wire connection
- It can work between -20 and 80°C

Is important to know that this sensor has an offset error, that shall be corrected with software, its approximately of 50mV at zero and until it reaches the 1% of it maximum measuring value.

![Offset error](image)

*Figure 34: Offset error*
In the montage of this project, this sensor, the OPAM and the Pressure transducer that will be explained later use and external power supply to work. The OPAM works with 12V and both pressure sensors will use a 24V power supply which is inside the voltage range for both.

For the future montage of the circuit two power sources that can fit in a DIN rail, one of 24V and the other one of 12V.

9.2. Circuit solution implementation and justification

The sensor alone can't connected with the Arduino, because its signal output goes from 0 to 10V, and the Arduino entry only can receive 5 V. To achieve this smaller amount of voltage, a voltage divisor shall be installed.

A voltage divisor is a easy circuit o be implemented. It only needs two resistors. And the output voltage desired will be he voltage that the second resistor receives.

\[ 10V = Vt = I(R1 + R2) = V1 + V2 \]

\[ V_{exit} = V2 = IR2 \]

Joan Pallejà León
\[ I = \frac{V_{\text{exit}}}{R_2} \]
\[ V_t = \frac{R_1 + R_2}{R_2} V_{\text{exit}} \]
\[ V_{\text{exit}} = \frac{R_2}{R_1 + R_2} V_t \]

If both resistors have the same value, then the \( V_{\text{exit}} \) is half the voltage that the resistors in global receive.
\[ V_{\text{exit}} = \frac{R}{R + R} V_t = \frac{R}{2R} V_t = \frac{1}{2} V_t \]

In this circuit, a voltage divisor made with two equal resistors is a good solution because after installing this divisor the voltage that the Arduino receives is between 0-5V, not between 0-10V as it was before.

But to implement the pressure sensor to the Arduino, is something remaining. Just before the voltage divisor, it will be installed an RC filter. This filter this time isn't working as a low-pass filter, this time is working as an anti-aliasing filter.

Aliasing, in signal processing, is an effect that cause that when processing an analogue signal into digital it becomes indistinguishable or its inappropriate received by the analogue-digital converter (Arduino in this case).

For example is the sampling frequency is too slow, the sampled points could not be clear enough for example, the same set of points could refer to more than one different signals, as it can be seen on the next figure:

![Figure 37: Aliasing effect example(13)](image)

For avoiding this kind of problem there is criterion for the sampling frequency. It is known as the Nyquist criterion, it says that the sampling frequency shall be at least 2 times larger than the maximum frequency of the analogue signal.

In the pressure sensor it has been studied the necessity of having an anti-aliasing filter because the sampling frequency is a bit smaller. Because the Arduino has been programmed to make a sample every 0.5s, which is a sampling frequency (\( f_s \)) of \( f_s = 1/0.5s = 2Hz \), which is a small frequency.
Theoretically, the maximum frequency of the signal shall be 1Hz, because it must be halve the sampling frequency. But really in this circuits its common to use a sampling frequency 10 times bigger than the maximum frequency of the analogue signal. In this case the frequency is $f_s/10=0.2\text{Hz}$.

At this frequency the signal must be cut because it is the maximum the converter can afford, so a low-pass frequency is used with a cut frequency equals to $f_s/10$.

In resume its important to have a cut frequency of 0.2Hz, the cut frequency was obtained:

$$f_c = \frac{1}{2\pi RC}$$

So R is 8.2kΩ and the C is 100μC.

With this montage a circuit like he shown at figure 38 is obtained:

With this schematic the pressure signal arrives correctly to the Arduino entry and between the limits it can handle.

Its connexion is made with twisted wire, and its joining gave some problems, because the wire was quite big to the entry ant the montage system with the screws gave some problems of broken wires. But finally it could connect well to the sensor and then to the power supply.

**9.3. Testing process and problems**

The pressure sensor didn't give many problems, just installing the wire, that was a bit difficult for the design of the sensor but except of that, its montage was correct. The only problem that could give is that the RC filter dissipates some voltage that makes that the result of the voltage divisor isn't exactly what it must be. The exact value is needed, after consulting the software expert of the other project, the exact value of voltage only was necessary to be between...
5 and 0V, and with the RC filter dissipation, this condition was also achieved. Which means that is not necessary that when the sensor gives 10V the Arduino receive 5V, it can be another value, because the ambient pressure doesn't have a wide range of variation.

After the testing the results, it was seen that the voltage loss in the RC filter was on the resistor part as it was part of a voltage divisor, which means that that voltage was the R value divided the total value

\[ V_{\text{lost}} = \frac{R_{\text{filter}}}{R_{\text{filter}} + R_1 + R_2} V_{\text{total}} \]

Then the output voltage was the one that leaved the R2, that now it is not exactly halve the value of \( V_{\text{total}} \), no it is:

\[ V_{\text{out}} = \frac{R_2}{R_{\text{filter}} + R_1 + R_2} V_{\text{total}} \]

As a petition of the software expert, the exact resistor value was measured, because it helps to have more precision while programming. These values are:

- \( R_{\text{filter}} = 8.2k\Omega \)
- \( R_1 = 10k\Omega \)
- \( R_2 = 10k\Omega \)

These doesn't affect the lecture value, which corresponds with the emitted by the sensor, and allows to correctly calculate the Ambient pressure.
10. Pressure transducer implementation

10.1. Main component characteristics

The pressure transducer is similar to the pressure sensor but here the measurement is different. It must measure the small over pressures that gave on the wind tunnel when an object is inside or when the velocity rises. Its measurement is made nowadays with two U tubes placed on the laboratory. It measures the pressure difference at the nozzle.

![U tubes from the laboratory](image)

**Figure 39:** U tubes from the laboratory

The objectives is to obtain the differential pressure measured in the U tubes installing this transducer on it, and then sending the signal the entry.
The pressure transducer is the most expensive component of the project, because it must measure with precision a differential change in pressure. The available model for this project is a type DS 1-010 from LTR®.

It is a piezoresistive sensor (just like the pressure sensor), it needs three wires to make its connections and the output signal is between 0 and 10V.

All the information needed for pressure measurement can be found on the next table, because the transducer of the project works in the range on 0 to 100 mbar.

<table>
<thead>
<tr>
<th>Pressure Range (mbar)</th>
<th>Pressure Range (kPa)</th>
<th>Over-pressure (mbar)</th>
<th>Linear error max</th>
<th>Temp. error (max) 0-50°C</th>
<th>Longtime Stability</th>
<th>Repeatability</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 2.5</td>
<td>0 - 0.25</td>
<td>250</td>
<td>± 1% FS</td>
<td>± 2% FS</td>
<td>2% / year</td>
<td>0.3% FS</td>
<td>1 ms</td>
</tr>
<tr>
<td>0 - 5</td>
<td>0 - 0.5</td>
<td>375</td>
<td>± 1% FS</td>
<td>± 1% FS</td>
<td>1% / year</td>
<td>0.2% FS</td>
<td>1 ms</td>
</tr>
<tr>
<td>0 - 10</td>
<td>0 - 1</td>
<td>750</td>
<td>± 0.6% FS</td>
<td>± 0.7% FS</td>
<td>0.1%/year</td>
<td>0.1% FS</td>
<td>1 ms</td>
</tr>
<tr>
<td>0 - 25</td>
<td>0 - 2.5</td>
<td>1125</td>
<td>± 0.6% FS</td>
<td>± 0.7% FS</td>
<td>0.1%/year</td>
<td>0.1% FS</td>
<td>1 ms</td>
</tr>
<tr>
<td>0 - 100</td>
<td>0 - 10</td>
<td>triple</td>
<td>±0.9 mbar</td>
<td>±2.3 mbar</td>
<td>0.1%/year</td>
<td>0.1% FS</td>
<td>1 ms</td>
</tr>
<tr>
<td>70 - 100 absolute</td>
<td>70 - 10 absolute</td>
<td>triple</td>
<td>±0.9 mbar</td>
<td>±2.3 mbar</td>
<td>0.1%/year</td>
<td>0.1% FS</td>
<td>1 ms</td>
</tr>
</tbody>
</table>

Table 4: Pressure ranges and overpressure of DS 1-010(14)

10.2. Circuit solution implementation and justification

The circuit of the pressure transducer is the same as the pressure sensor, and for the same reasons. It also need the RC anti aliasing filter and the voltage divisor. Also the power supply it needs is 24V, so it takes the power form the same power supply that the pressure sensor.
Here only change the wiring, because in this case is much easier. Its top can be removed, then the 3 wires are installed (+, -, out) as can be seen on the next figure:

![Transducer's wiring](image)

**Figure 41:** Transducer's wiring A) schematic, B) real sensor

The zero is also adjusted, and then the top is putted again. After that the pressure transducer circuit is made.

### 10.3. Testing process and problems

Mounting the pressure transducer didn't gave many problems, the wiring was easy to install and the signal was received correctly, but a problem appeared while the sensor was tested with the tunnel. The pressure transducer signal can be between 0 and 10V, and with that idea the voltage divisor was installed. But then during the test the maximum voltage observed when the wind tunnel was working at full power was about 5V. For this reason the current voltage divisor is useless, because all the values will be below 2.5V. To use the maximum range of the Arduino (from 0 to 5V), the voltage divisor was changed so the maximum voltage of the Arduino is about 4.5V, this 0.5V is a security difference for any big perturbations that could appear during a test.

So a new configuration was studied. First, the requirements must be clear. The idea to reducing this voltage to 4.5V is a bit difficult, because the resistor of the RC filter implies losing some voltage. The concrete amount is:

\[ V_{lost} = \frac{R_{filter}}{R_{filter} + R_1 + R_2} V_{total} \]

As it will be shown later, this number has tried to be reduce at maximum, until it was achieved to have a voltage of 4.5V after the RC, but then there was the divisor. A divisor was needed to prevent any over currents on the circuit. As a very low division was needed, it was thought to have a great difference between
R1 and R2, being R2 the bigger one, because the output voltage depends on it, and it was searched to have the maximum as possible. It was exactly:

\[ V_{out} = \frac{R2}{R_{filter} + R1 + R2} V_{total} \]

The values are \( R_{filter} = 8.2 \text{ k}\Omega \), \( R1 = 5.6 \text{ k}\Omega \) and \( R2 = 68 \text{ k}\Omega \), with these resistors, the exit value, when the sensors is giving 5V is 4.16V, which is a good value to give. Which is correct to work with at it was lately made sure with the calibration. Which was correct.
11. Temperature sensor implementation

11.1. Main component characteristics

The temperature sensor will be made using a thermistor. It could be produced by other ways, but a thermostat is the cheapest because the university can provide this material.

Although in all the memory the references to this component will be "NTC", it is important to know that it is a thermistor, a thermistor is a resistor that changes its value depending on the temperature. And there are two different types.

- PTC: Positive Temperature Coefficient, it raises its resistor value as the temperature raises.
- NTC: Negative Temperature Coefficient, it lowers its resistor value as the temperature raises.

The selected type is the NTC, because it is cheaper and is most commonly used, having more values of resistor at room temperature. The NTC is picked from the ETSEIAT. The device consists of a chip with two solid copper tin plated leads. It is grey lacquered and colour coded, but not insulated. This NTC is a Vishay® product.

![Figure 42: NTC from Vishay®](image)

From its colour code and the manufacturer's guide we can obtain the information about it.

The NTC used in this project has the reference code of NTCLE100E3104JT2. With this code, the temperature curves are obtained.
Figure 43: Resistance vs. Temperature graphic

This curves aren’t all the information of the NTC. For example, the resistance value at room temperature (25 °C) is 100kΩ and it has a tolerance of the 5%. (16)

11.2. Circuit solution implementation and justification

The circuit of the NTC is simple, it just need an additional resistor of the same order, for example one of 100 kΩ. it must be of the same order to avoid an excessive current on the NTC. The montage can be seen on figure 44.
With this circuit the output voltage that will go to the Arduino is the voltage passing though the NTC, to calculate this voltage the procedure is:

\[ V_t = V_{NTC} + V_{R0} = I(NTC + R0) \]

\[ I = \frac{V_{NTC}}{NTC} \]

\[ V_{NTC} = V_t \left( \frac{NTC}{NTC + R0} \right) \]

With this we obtain the following graphic:

![Temperature vs Voltage graphic](image)

**Figure 45**: Temperature vs. voltage graphic

It can be seen that between 0°C and 40°C the relation between temperature and voltage follows a linear distribution which can help the programming of Arduino. And this range is the range where the system will always work.

The NTC will be placed inside the wind tunnel, and its connection to the circuit will use twisted wire to reach the Arduino board. The use of twisted wire is made to avoid current loses. The connection will be made in a way that makes possible the replacement of the NTC without having to produce a new circuit.
11.3. Testing process and problems

The test of the NTC didn't have such problems, the main problems were finding the values of the temperature curves, because the exact name of the component was missing, after that the circuit is easy and the test didn't have problems, after that the calibration was made without errors also.
12. Other basic components

To perform the different circuits it is necessary to have other small components. This is the case of resistors and capacitors. They will be present in every circuit on this project, and their values can't be random. They must have a certain commercial value in order to purchase them. For this reason is important to know this components before starting with the project.

- **Resistor**
  A resistor is a very common component in a circuit and also is very simple. It is a passive electrical component that consists in a bobbin that reduce the current flow in a circuit. As higher is its value less flow can pass through it. In the schemas of the project the resistors can be seen with a colour code that is the following:

  ![Resistor colour code](image)

  **Table 5:** Resistors colours code

  They will be largely used in this project. Always trying to use the most commercial values of them in order to make easy its supply.

- **Capacitor**
  A capacitor is another passive electrical component. It stores energy electrostatically in an energy field. They are used to block the direct current but allowing the alternating current. Used together with a resistor they can work as a frequency filter.

  They are made with to plates of conductor material separated by a dielectric. The narrowest the dielectric layer is, the capacitor has more capacity.
Capacitors don’t have all the possible values of capacity, so it’s important to work with the commercial values of the capacitors to know which can be obtained.

<table>
<thead>
<tr>
<th>Capacitors commercial values</th>
</tr>
</thead>
<tbody>
<tr>
<td>uF</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>0.1</td>
</tr>
<tr>
<td>0.12</td>
</tr>
<tr>
<td>0.22</td>
</tr>
<tr>
<td>0.33</td>
</tr>
<tr>
<td>0.47</td>
</tr>
<tr>
<td>0.56</td>
</tr>
<tr>
<td>0.68</td>
</tr>
<tr>
<td>0.82</td>
</tr>
</tbody>
</table>

| Table 6: Capacitors commercial values(17) |

- **Wiring**
  Connecting all the components isn’t as easy as it can seem. The type of wire is important to reduce voltage losses and to prevent the Arduino from giving bad results while reading the signal sent from the different sensors. The selected type of wire selected for the long distance connections is the Shielded cable.

*Figure 47: Shielded cable example*
This type of cable is perfect for this long distance connections. It has a shield envelope that can be connected to a concert voltage, for example to GND, and with that aisle the cables from perturbations and noises.

Other options is use twisted wire to reduce the loses, but this type of connection is good for prevent the current and voltage loses compared to the simple wire. A best connection will be use a shielded twisted wire, that have less losses than the other wire types. But as long as in the laboratory only normal shielded wire was available and that the distance weren't long enough to notice the difference, that cable was used.

- **Box**

A polyester box is used to contain all the components of the project in one place. This box was available in the laboratory before the project starts, is a very simple objects to contain all the components and it can be drilled to make possible that the different wires came into the box.

The box consists in a polyester reinforced with glass fibres, this gave different properties to the material, it is auto extinguishable until 960°C, but its use temperatures are between -30 to 60°C. In this box another polyester sheet will be located inside the box at a small distance of the bottom to give some space to locate the screws. The components are mounted in this sheet. And after all the wires are connected, this box can be closed, because there is no need to open it until everything is set.

In this box some holes will be made to install two different ventilation grilles one per each side, to let the air flow into the box and refresh the components inside it.

![Box used](image.png)
Wire terminals

In the definitive montage the wire will have some metallic ends that are used to ensure that the connection with the wire is correctly done. There are different types of wire terminals, and there exists a colour code based on the diameter of the terminal. This diameters are ruled by the norm DIN 46228/4 and using the French colour code (19), they are:

- 0.25 mm²: violet
- 0.34 mm²: pink
- 0.5 mm²: white
- 0.75 mm²: blue
- 1 mm²: red
- 1.5 mm²: black
- 2.5 mm²: gray
- 4 mm²: orange
- 6 mm²: green
- 10 mm²: brown
- 16 mm²: white ivory

The different terminals can be found in the Annex H.
13. Circuit connexion into a cooper board

13.1. Solutions studied

All the circuits explained before shall be placed somewhere. Connecting everything with the Arduino by wiring will be a mess. The solution thought is to create a Printed Circuit Board (PCB) to locate all the components there and save all the wiring.

The first solution investigated was to use an Arduino shield. An Arduino shield is a board with the same shape as the Arduino that can be connected and on this board several circuits are already installed, like loudspeakers, sensors, lights... The one that was studied is the protoboard shied, this shield doesn't contain anything, but over this board, a circuit can be implemented.

This idea was denied because this type of shield is just like a protoboard but in small size, which means that it will need wire to connect the different components and the idea was to avoid using wire. And also it has a cost, because it shall be purchased, although its price isn't high.

The second solution thought was printing a new PCB with cooper using the materials of the University, which can print a PCB. The only thing they need is the Gerber of the PCB to print it. So this board shall be designed.

13.2. Selected solution implementation

To design this PCB a program called Fritzing. This program was used before to design the circuits of each component and to join it together to measure a parameter (Temperature, pressure...) . With these a PCB can be designed.

One requirement that could be grate is that if the ground entry of the Arduino is connected to the mass of the PCB all the components also connected to the
mass will be connected to ground, which can help because in every circuit a lot of components are connected to ground.

When in this project is said "connected to mass" it means that it is connected to the cooper layer that forms the PCB. The different components that aren't connected to mass, have a cooper way between them aisled from all the other cooper, and this cooper way isn't connected to mass.

For anyone that doesn't use fritzing, designing a PCB isn't very hard but it also isn't easy. For example, the first PCB done for this project was something like that:

![Figure 50: First PCB attempt](image)

There are some mistakes on this PCB, for example:

- All the components and the connections are on the upper layer of the PCB which means that he components are inserted and soldered in the same layer, which is not so good.
- The connections to mass (GND) are bad made, all those yellow lines that go to the top left corner where though to be the mass connection but it isn't true, so those lines mustn't be there and all the connections to mass aren't really made.
- The five points bellow shall be the connections with Arduino that are in use, but the unused one shall also be there because the PCB will be connected to the Arduino but those pins, which means that all the pins remaining on the top and down the PCB are missing.
• The connection with the Arduino are made with vias (holes) nor with pins that is the correct connection.
• The Arduino connection pins have a small circle of cooper, which means that the machine that will produce the PCB hasn't so precision and it could destroy this thin cooper ring, making this connection unusable.
• There are cooper ways very long, which isn't desirable.
• There is an element without connections.

After all the corrections were made the final PCB result is:

![PCB Top layer](image)

*Figure 51: PCB Top layer*

Here the top layer can't be correctly seen because it is empty. On this layer just the components will be mounted, all the connections aren't made in this layer, because here there is any cooper. The option of having just cooper in one layer of the PCB is a cheaper option and also easy to produce.
On the lower layer, all the connections are made. In this layer the components are soldered, that won't disturb the elements on the upper layer. The cooper ways are made on the bottom layer, and the mass connections are made properly.

The cooper ways are shorter, which is better and they are better distributed all along the PCB, also the lines that were connected to the left top corner of the previous PCB have disappeared.

Some parameters have been changed to adequate to the specification of the machine that will produce the PCB. The cooper ways have a wider isolation. The connections with Arduino are made with pins (not vias) and the cooper circle of the pins are bigger enough to be produced by the machine.

The final PCB just have a cooper layer (the bottom layer), and it will be connected to the GND of the Arduino, because the port of GND in the Arduino is connected to mass at the PCB.

The final result of the PCB is this cooper board (figure 53) that has the same size as a Arduino board.
Then all the components has to be joined on it, for example elements like the OPAM need a special component to fix it.

After all the component are installed the PCB is ready to use and to connect it to Arduino, connecting the global circuit of the project.

After that the hardware work is almost complete, it only remains the changes made during calibration and during the wind tunnel testing and montage.

**13.3. PCB producing problems**

The production of this PCB maybe is an easy issue for a professional. But for the production of this PCB the only thing that was produced by professionals was the board itself, all the connections and solders were made by students. Here the problems during the crafting of the final result will be explained, because it can maybe help in further projects.
The first point is that there was no previous experience in soldering. After soldering for the first time, not all the welding was correctly made, they were what is known as "cold welding". This kind of welding are very fragile and they broke easily. To correct this many of them were funded and soldered again. During this process, most of them were now correctly done, but some of them joined zones with different voltages (mass and cooper way). This welding was removed for the aisle zone, splitting the welding in a zone at the mass and one at the cooper way.

This one was the most common problem of all, but not the biggest. The biggest was when the welding layer removed some of the cooper. When that happens, the best would be take another board, if this isn't possible one thing to do in small amounts is trying reconnect the cooper with welding. This where the main problems during soldering, but there are other small actions to take into account, that can make the procedure more easy:

- Leave the smallest quantity of component connection as possible, try to fit the component the next to the board as possible, and cut the connectors after the soldering
- Test before manufacturing the board that all components can fit correctly and easy to the board
- If there are pins, make sure before start how they will be attached to the board (entering through the upper layer or the bottom layer) because depending on which the pin length can be not enough after soldering.
- Fix properly the board while soldering, this may sound obvious but sometimes is difficult to have a proper subjection

This help to the correct development of the PCB. Although the resultant PCB is far from perfection, the connections work, so the first to do before starting again is check the connections, because in some cases, may appear bad soldered, but work perfectly.

But which can be interesting for further designs of PCB with Fritzing is trying to act on the defect values of the hole diameter and cooper diameter. Because the cooper ring is very small to solder properly, although is possible to do it. The diameter of pins can be easier changed, which helped to solder this components.
14. Calibration process

The calibration process is made after all the circuits are correctly installed on the wind tunnel. For deeper knowledge of the calibration process look in the software project.(6) Because is where the calibrating process is important, but from the hardware project, there has been some help and changes made to adapt to a good calibration, and this will be shortly summarized here.

Temperature sensor NTC didn’t require any extra calibration, because it was made using a properly calibrate with its conditioning circuit, which consisted in another resistor of 100kΩ.

The pressure sensors required more calibration. For the atmospheric pressure sensor, the first attempt of calibration was using a meteorological station situated on the University, next to the laboratory. Because it was thought to have a greater precision than the barometer installed in the laboratory. But after noticing that the different measures between the meteorological station and the sensor. So, although the barometer can’t offer the same resolution, it has resolution enough to help the calibration, and as it is installed in the same laboratory, the measures will be very similar. The calibration process consisted almost in installing the barometer, because it was new and still unused. After breaking the seal, the barometer is opened, and the mercury flux starts, after 3 or 4 hours after the first operation the mercury is stable and the measuring scale can be correctly adjusted. After that, three or four different measures in different days are taken. Then the pressure must be corrected with the temperature, because the temperature may change the density, and offer different measures. Also correct it with latitude, gravity and high. After that it is compared with the value taken from the sensor (after correcting this signal too), and then some Software adjustments are made,(6)

The differential pressure sensor is different to calibrate. First it was thought to calibrate the measure that come from the sensor with the values obtained from the U tubes on the laboratory. The measures were made four times, trying that different people looked at the U tube, to made the observations the more impersonal as possible. After the measurement were made, the laboratory personal suggest that the measures weren’t correct, because the U tube must be by the sinus of the U tubes with the inclination of the tubes and also with the temperature. To improve the calibration method, a precision barometer is regulated with two levels to have a 90º inclination. After that the measure must be corrected with the temperature. Then the values are compared to the ones obtained from the sensor. Then the values must be adjusted with software.(6)
15. Wind tunnel testing and montage memory

After all the circuits are thought and produced the circuit is not complete, during the montage and installation man changes are made, this small changes that doesn't change the circuit, just small things, but this small changes help to improve the project and to correct the errors that appear.

This point just resume the modification explained before and place it in a chronological order to give an idea of the continuous work that the wind tunnel implies.

The first thing was the box placing, it was decided to install all the components in a boxed that will be closed, because the Arduino and the power sources don't need to be manipulated during the normal function of the wind tunnel. The box available in the University was very big, its much bigger that the space needed, but it was unused and free. It finally was placed in vertical under the divergent nozzle.

After that it was thought that some professors maybe prefer to use the wind tunnel with the potentiometer, so they must have the option to work without it. Next, the two power supplies were installed, in the first moment it was thought to use the 10V the Altivar gave as the OPAM power source. But because the sensors needed an alimentation of 24V, an one power source was needed, a second one of 12V was used instead of the 10V of the Altivar.

Then the different circuits were tested separately in a protoboard, to make sure they work, first the connection to Altivar, then the temperature sensor, and finally the atmospheric pressure sensor, the differential sensor couldn't be tested at this level.

After the first corrections where made the PCB was produced, tested and installed. During this process many corrections were made to the PCB, which implies ah in further changes the PCB components changed, and it must be soldered again.

The second tests of the Altivar connection were made, and after the results were correct, the definitive installation of the circuits were prepared.

The box was drilled to install in it the wires coming from the Altivar, and the net, with two holes, then there was made a hole for the ventilation system. And after that some holes to install the components in vertical were made. This components were the explained before and some connectors, to allow the connection of the sensors with the PCB a with the long wires that connected the system with the Altivar.
Then the tunnel has also drilled to allow inside it the NTC to measure the temperature inside the tunnel. After all this the system distribution was the following, that can be seen in the figure 55.

![Components distribution in the box](image)

Figure 55: Components distribution in the box

Then the final tests were made, specially the one involving the Altivar and the wire changing for shielded wire. And when all those tests were successfully made, the last step was the calibration process.

With that the wind tunnel testing was finished and the tunnel was ready to be controlled using the Arduino microprocessor.
RESULTS RESUME

16. Results analysis

This project seems to accomplish the requirements made for the monitoring of the wind tunnel. Taking into account the hardware, the wind tunnel control system has changed significantly. The tunnel, is regulated with the Altivar, but the circuit that controls the Altivar is the difference between the old and the new tunnel. The old tunnel had a box where an on/off switcher was installed with a potentiometer that controlled the wind tunnel velocity.

![Old control circuit](image1)

**Figure 56: Old control circuit**

After this project the system is now completely different, it can be controlled with a computer. With the sensors of pressure and temperature the system can select the desired velocity or it can go through different velocities gathering pressure and temperature data. Just for the hardware the control systems looks very different.

![Final control circuit](image2)

**Figure 57: Final control circuit**

The three sensors gave the information to the Arduino, that send the velocity signal to the Altivar. All this components are installed together in a box placed below the divergent nozzle of the tunnel, placing this box with all the components was one of the objectives, that is accomplished.
Another requirement successfully accomplished is the possibility to control the tunnel with the old potentiometer or with the PC. This possibility is studied and both control systems work. There has been made a division of the signal wire and installed a switcher to choose between the two modes of operation. There have been tests made with both systems, and they work correctly. The switcher is located in the same box that the on/off switcher, giving the opportunity to the operator choose before to start (or during) with which system the tunnel is controlled.

But all this effort would be useless if the software doesn't work correctly, the software work has been correctly done, and after the calibration all the systems respond correctly to the magnitude measured or the velocity selected. Before the first giveaway date the atmospheric sensor wasn't working. But it was solved lately, and to the final date, the whole system was working perfectly.

With both, Software and Hardware, working and being coherent with the physical magnitudes, seem that the results can be good, because the tunnel can now work correctly with this automatism. And with that the aim of the project will be achieved after some corrections will be made to solve the final problems with the atmospheric pressure sensor calibration.
17. Economic and environmental impact study

17.1. Economic Study

The full economic study of the project can be seen in the Economical budget, but here is a summary of the economic investment necessary.

<table>
<thead>
<tr>
<th>Component</th>
<th>Units</th>
<th>Unitary price</th>
<th>Total price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino</td>
<td>1</td>
<td>22€</td>
<td>22€</td>
</tr>
<tr>
<td>Passive components</td>
<td></td>
<td></td>
<td>2€</td>
</tr>
<tr>
<td>PR21S-80549.3</td>
<td>1</td>
<td>320€</td>
<td>320€</td>
</tr>
<tr>
<td>DS 1-010</td>
<td>1</td>
<td>270€</td>
<td>270€</td>
</tr>
<tr>
<td>PCB</td>
<td>1</td>
<td>17€</td>
<td>17€</td>
</tr>
<tr>
<td>PCB elements</td>
<td></td>
<td></td>
<td>26€</td>
</tr>
<tr>
<td>Power source</td>
<td>2</td>
<td>23.3€</td>
<td>46.6€</td>
</tr>
<tr>
<td>Wire</td>
<td>1 (10m)</td>
<td>10€</td>
<td>10€</td>
</tr>
<tr>
<td>Other components</td>
<td></td>
<td></td>
<td>2.2€</td>
</tr>
<tr>
<td>Microsoft Word</td>
<td>1</td>
<td>80€</td>
<td>80€</td>
</tr>
<tr>
<td>Matlab</td>
<td>1</td>
<td>500€</td>
<td>500€</td>
</tr>
<tr>
<td>Laptop amortization</td>
<td>4 months</td>
<td>710€</td>
<td>60€</td>
</tr>
<tr>
<td>Others (energy)</td>
<td></td>
<td></td>
<td>50€</td>
</tr>
<tr>
<td>Software hours</td>
<td>325h</td>
<td>25€/h</td>
<td>8125€</td>
</tr>
<tr>
<td>Hardware hours</td>
<td>300h</td>
<td>25€/h</td>
<td>7500€</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>17060.8€</td>
</tr>
</tbody>
</table>

Table 7: Economical budget

So the total budget for the project compiling Software and Hardware is 16610.8€.

17.2. Environmental impact study

Elaborating an environmental study of the hardware project is possibly more important than in the software project, but even though isn't easy, because all the components used are produced in mass and that difficulties the precision of the impact of this project in particular.

The components that produce more pollution and waste in the project are the PCB's (the cooper Board and also the Arduino, that also has a microprocessor chip) and the wires. This is a reason to only talk about this components in this point.

17.2.1. Contaminating actions and agents

The products used in this project can be included in a recent concept in the actual society, the E-Waste. E-waste is used as a generic term embracing all types of waste containing electrically powered components. e-Waste
ETSEIAT's wind tunnel monitoring

Hardware

contains both valuable materials as well as hazardous materials which require special handling and recycling methods. (18)

The next table resumes the environmental hazard of the components that can be found on the project.

<table>
<thead>
<tr>
<th>E-Waste Component</th>
<th>Process Used</th>
<th>Potential Environmental Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Printed circuit board (image behind table - a thin plate on which chips and other electronic components are placed)</td>
<td>De-soldering and removal of computer chips; open burning and acid baths to remove final metals after chips are removed.</td>
<td>Air emissions as well as discharge into rivers of glass dust, tin, lead, brominated dioxin, beryllium cadmium, and mercury</td>
</tr>
<tr>
<td>Chips and other gold plated components</td>
<td>Chemical stripping using nitric and hydrochloric acid and burning of chips</td>
<td>Hydrocarbons, heavy metals, brominated substances discharged directly into rivers acidifying fish and flora. Tin and lead contamination of surface and groundwater. Air emissions of brominated dioxins, heavy metals and hydrocarbons</td>
</tr>
<tr>
<td>Plastics from printers, keyboards, monitors, etc.</td>
<td>Shredding and low temp melting to be reused</td>
<td>Emissions of brominated dioxins, heavy metals and hydrocarbons</td>
</tr>
<tr>
<td>Computer wires</td>
<td>Open burning and stripping to remove copper</td>
<td>Hydrocarbon ashes released into air, water and soil.</td>
</tr>
</tbody>
</table>

Table 8: Potential environmental hazard for E-waste components

17.2.2. PCB recycling methods

As there exist different materials in a PCB, there exist different methods to obtain the different materials separately from the board to recycle them. Some of the materials are hazardous, there is the relation of the different materials in a PCB.
Nowadays there exist different possibilities to obtain the material from the PCB. This are some of the used in Taiwan with this printed circuits(18):

- Recovery of copper metal from edge trim of printed circuit boards: Edge trim is first treated with stripping solution to strip and dissolve precious metals, typically gold (Au), silver (Ag) and platinum (Pt). After adding suitable reductants, the ions of precious metals are reduced to metal form. Then the different materials are mechanically separated to be recycled.
- Recovery of tin metal from tin/lead solder dross: Tin is melted in reverberatory furnace and then the Fe and Cu is removed, leaving the tin or the lead as a product.
- Recovery of copper oxide from wastewater sludge: The sludge is heated to 600-750°C to remove the excess amount of water and to convert the copper hydroxide to copper oxide. The copper oxide is then sold to the smelter to produce copper metal.

Table 9: Waste characterization of PCB components

<table>
<thead>
<tr>
<th>Item</th>
<th>Waste</th>
<th>Characterization in Taiwan</th>
<th>kg/m² of PCB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Waste board</td>
<td>Hazardous</td>
<td>0.01~0.3 kg/m²</td>
</tr>
<tr>
<td>2</td>
<td>Edge trim</td>
<td>Hazardous</td>
<td>0.1~1.0 kg/m²</td>
</tr>
<tr>
<td>3</td>
<td>Hole drilling dust</td>
<td>Hazardous</td>
<td>0.005~0.2 kg/m²</td>
</tr>
<tr>
<td>4</td>
<td>Copper powder</td>
<td>Non-hazardous</td>
<td>0.001~0.01 kg/m²</td>
</tr>
<tr>
<td>5</td>
<td>Tin/lead dross</td>
<td>Hazardous</td>
<td>0.01~0.05 kg/m²</td>
</tr>
<tr>
<td>6</td>
<td>Copper foil</td>
<td>Non-hazardous</td>
<td>0.01~0.05 kg/m²</td>
</tr>
<tr>
<td>7</td>
<td>Alumina plate</td>
<td>Non-hazardous</td>
<td>0.05~0.1 kg/m²</td>
</tr>
<tr>
<td>8</td>
<td>Film</td>
<td>Non-hazardous</td>
<td>0.1~0.4 kg/m²</td>
</tr>
<tr>
<td>9</td>
<td>Drill backing board</td>
<td>Non-hazardous</td>
<td>0.02~0.05 kg/m²</td>
</tr>
<tr>
<td>10</td>
<td>Paper (packaging)</td>
<td>Non-hazardous</td>
<td>0.02~0.05 kg/m²</td>
</tr>
<tr>
<td>11</td>
<td>Wood</td>
<td>Non-hazardous</td>
<td>0.02~0.05 kg/m²</td>
</tr>
<tr>
<td>12</td>
<td>Container</td>
<td>Non-hazardous</td>
<td>0.02~0.05 kg/m²</td>
</tr>
<tr>
<td>13</td>
<td>Paper (processing)</td>
<td>Non-hazardous</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>Ink film</td>
<td>Non-hazardous</td>
<td>0.02~0.1 kg/m²</td>
</tr>
<tr>
<td>15</td>
<td>Wastewater treatment slurry</td>
<td>Hazardous</td>
<td>0.02~3.0 kg/m²</td>
</tr>
<tr>
<td>16</td>
<td>Garbage</td>
<td>Non-hazardous</td>
<td>0.05~0.2 kg/m²</td>
</tr>
<tr>
<td>17</td>
<td>Acidic etching solution</td>
<td>Hazardous</td>
<td>1.5~3.5 L/m²</td>
</tr>
<tr>
<td>18</td>
<td>Basic etching solution</td>
<td>Hazardous</td>
<td>1.8~3.2 L/m²</td>
</tr>
<tr>
<td>19</td>
<td>Rack stripping solution</td>
<td>Hazardous</td>
<td>0.2~0.5 L/m²</td>
</tr>
<tr>
<td>20</td>
<td>Tin/lead stripping solution</td>
<td>Hazardous</td>
<td>0.2~0.6 L/m²</td>
</tr>
<tr>
<td>21</td>
<td>Sweller solution</td>
<td>Hazardous</td>
<td>0.05~0.1 L/m²</td>
</tr>
<tr>
<td>22</td>
<td>Flux solution</td>
<td>Hazardous</td>
<td>0.05~0.1 L/m²</td>
</tr>
<tr>
<td>23</td>
<td>Microetching solution</td>
<td>Hazardous</td>
<td>1.0~2.5 L/m²</td>
</tr>
<tr>
<td>24</td>
<td>PTH copper solution</td>
<td>Hazardous</td>
<td>0.2~0.5 L/m²</td>
</tr>
</tbody>
</table>
- Recovery of copper from spent basic etching solution: Copper hydroxide is obtained as a result of crystallizing and centrifugation of copper in a sulphate solution.
- Recovery of copper hydroxide from copper sulphate solution in PTH process: The solution is agitated while the temperature is lowered by a cooler to 10-20°C, at which the copper sulphate crystal precipitates out of solution. The copper sulphate crystal is recovered by centrifugation. The pH of the effluent is further readjusted to basic condition to recover the remaining copper as copper sulphate.
- Recovery of copper from the rack stripping process: Copper pass through an Electric wining reactor, and exits as copper metal.
- Recovery of copper from spent tin/lead stripping solution in the solder stripping process: Through different electro winning, the PCB can be separated between Copper metal and Tin metal.

Recycling those materials is important to reduce the huge amount of E-Waste that is generated nowadays, that starts to being dangerous to people and animals.
18. Planning and Future development

The realisation of this project has followed the planning established on the project charter. Although it has suffered changes due to problems with the montage or with calibration. Although the global planning with its final date until knowing the presentation date has been accomplished. The original plan was:

<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 13th</td>
<td>Election of the ARDUINO board, between UNO and DUE</td>
</tr>
<tr>
<td>March 20th</td>
<td>Connect Altivar 31 with ARDUINO and test the connection</td>
</tr>
<tr>
<td></td>
<td>Implement the NTC circuit and connect it to ARDUINO</td>
</tr>
<tr>
<td>April 10th</td>
<td>Implement a pressure sensor to the wind tunnel and ARDUINO</td>
</tr>
<tr>
<td></td>
<td>Implement an amplificatory system to the balance</td>
</tr>
<tr>
<td>April 26th</td>
<td>ARDUINO programming</td>
</tr>
<tr>
<td></td>
<td>Readapt the system to operate correctly with ARDUINO</td>
</tr>
<tr>
<td>May 1st</td>
<td>Connect the system with a computer</td>
</tr>
<tr>
<td>May 5th</td>
<td>Test the wind tunnel</td>
</tr>
<tr>
<td>May 10th</td>
<td>Make a budget estimation</td>
</tr>
<tr>
<td></td>
<td>Results analysis</td>
</tr>
<tr>
<td>May 15th</td>
<td>Redaction of the first document</td>
</tr>
<tr>
<td>May 29th</td>
<td>Application of corrections</td>
</tr>
<tr>
<td>June 12th</td>
<td>Redaction of the final document</td>
</tr>
<tr>
<td>*June 22th</td>
<td>Oral presentation</td>
</tr>
</tbody>
</table>

Table 10: Planning

All the statements followed correctly its planning until May-June, where all the final assembly and calibration was made, this must be made on the laboratory, which can slow the document writing. But in global the dates has been respected.
When this project is finished, the wind tunnel is fully operative and can work in all its range, compiling information and controlling the wind tunnel. But there is still one action that can be made to close all the measurements made in the wind tunnel. This refers to a balance installation. The balance is a specific one, it is a 3-component "sting" internal Force/Moment balance, a top mounted manually-operated (pitch angle) model positioning system and a custom made Data Acquisition (DAQ) System from AEROLAB LLC, Laurel, Maryland, U.S.A.

The balance montage process is already explained on its manual, that can be found on the Annex C. The actions required to this is connect the data acquisition system to the Arduino microprocessor.

The future development is in the data acquisition mode. This balance has its own acquisition data board made by Texas Instruments. And this board has its own software environment that tracks perfectly the signal given by the balance.

As a result of that the action that must be taken will be headed into developing a new data acquisition board and connecting it correctly to the Arduino microprocessor. If it is possible, there are three free Analogue inputs, it could be use one input for each axis. Maybe it is needed to amplify the signal with an OPAM before connecting to the Arduino board, but it must be studied before. But this is a good point to start, because it will provide the tunnel with a very complete sensor map that will help to a perfect monitoring of the hole tunnel and the phenomenon developed inside it.
19. Conclusions

A wind tunnel is a very useful tool in aerodynamics. Then an University like ETSEIAT, where their students study aerodynamics, having a functional wind tunnel is basic. For this reason it is not strange that there are the willing to upgrade the wind tunnel, and replace a potentiometer control, which doesn't give much precision, for a monitored tunnel, that works with the computer. This will from the University has been reflected in this project, that has received many help from the University's personnel.

In this point the results of the analysis aren't commented, this is done on the "Results analysis", and for the hardware part everything is working correctly, the problem appears when trying to correctly control the tunnel at low velocities, but the problem didn't come from hardware nor from software, it may come that at that regime velocity, the motor doesn't allow to easily control it with a PID.

As it is shown in this project, the monitoring of the wind tunnel requires many specific knowledge (electronics, soldering, programming, physics knowledge, practise with sensors and measuring instruments...), such is this, that a person alone couldn't manage to prepare everything alone, at some point help will be needed. Looking just at hardware, in every circuit montage, that in theory seem correct, appear lots of problems, that some times are only solved until many hypothesis are suggested. For those reasons, in the future the recommendations for projects like these is to divide the project in many parts, and select one person for each, and then that they assemble the project all together, this gave more specialization for the individual tasks, for example the PCB winding, that will be very easy for an expert, but almost impossible for a novice. And then all this "created experts" can find errors when all the components are connected, that there is where almost all the problems appear in this project.

More conclusions that this project gives, apart from that the correct networking could solve most problems, is that monitoring a wind tunnel (and other machines by extension) is possible and that the scope marked in this project was right, because it has been made in the time established, although there is a lot of work in this type of project that is difficult to evaluate before starting, like calibrating, which gave a lot of problems, because using the instruments that will be replaced to calibrate the new ones isn't always easy, incongruence or lecture errors appear, and all this work can be unnoticed, because it is difficult to quantify the study of measure instruments to adequate the digital values to the real ones, because in this society, there exist the idea that the electronic devices work perfectly by themselves. In this project the difficulties appeared in actions that seem unexpected before starting, like soldering a PCB or measuring with a sensor. But all the difficulties has been overtaken and the project has been successfully ended.

After the project realisation, the wind tunnel is fully operative, and it can be controlled with the Arduino and provide more accurate data that the ones that
provided before. With these it can be assumed that the aim of this project has been accomplished and this is very important, not only for this project or the project software, it also is important for the future, because it opens the door to new research at ETSEIAT or to a better didactic explanation of aerodynamics to the future students.
20. Bibliography


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