UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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Building of a digital Pitot - Static tube

Physics - Aerospace Engineering
UPV - ETSID
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1- INTRODUCTION:

In this project, we will explore the principles behind the Pitot - Static tube as well as its applications in the aviation industry. The main objective is to gain a deep understanding of the different concepts behind its operation and build our own model. We will use two digital barometric sensors and a Raspberry Pi. Furthermore, we also aim to develope skills related with performing experiments.

2- THEORETICAL BACKGROUND

2.1- Bernoulli's theoretical equation

In the 1700s, Daniel Bernoulli investigated the forces present in a moving fluid. He developed an equation that is, nowadays, used in lots of different problems related with fluid dynamics. The equation states that the static pressure in the flow plus the dynamic pressure plus the hydrostatic pressure is equal to a constant throughout the flow, which we call the total pressure of the flow. The equation is given by the formula:

$$P_1 + \frac{1}{2}\rho(v_1)^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho(v_2)^2 + \rho g h_2$$

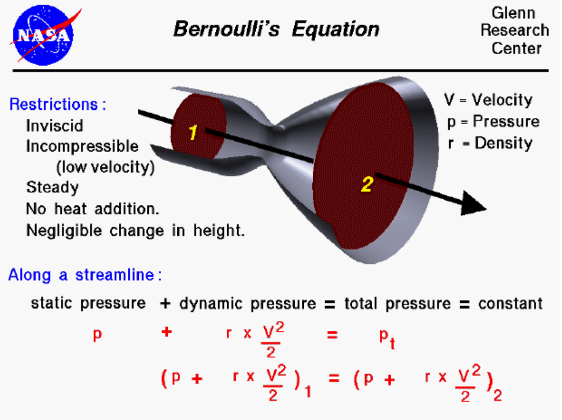

Figure 2.1 - Scheme about the Bernoulli's equation [1]

Conditions:

- Points 1 and 2 are lying on a streamline
- The fluid has constant density
- Steady flow
- No friction
- Inviscid Fluid
- Incompressible

2.2- Pitot tube

A pitot tube or also named "pitot probe" is an apparatus that measures the fluid flow velocity. Nowadays, it is really extended in avionics to determine the airspeed of aircrafts. Still, it is also used to measure the water speed of boats and the flow velocity of liquids, air and gasses in industry.

The basis of its operation consists of a tube with two openings, one of which points directly into the fluid flow (pitot or stagnation port) that measures p_1, and the other perpendicular to the flow (static port) that measures p_2 .

When the apparatus is not moving the pressure in both openings is the same, $p_1 = p_2 = p_{atm}$. As a comment, $p_{atm} = 101325\ Pa$ is the atmospheric pressure caused by the moving of the air molecules.

However, when the plane starts to move the dynamic pressure increases. Since, in addition to the atmospheric pressure, air enters to the pitot tube due to the forward movement of the apparatus.

$$p_D = \frac{1}{2} * \rho * v^2$$
$$p_1 = p_{atm} + p_D = p_{atm} + \frac{1}{2} * \rho * v^2$$

Otherwise, pressure 2 remains constant with the value of the atmospheric pressure (static pressure). So, applying the following calculations, the relative velocity can be obtained.

$$p_1 - p_2 = p_D$$

$$p_1 - p_2 = \frac{1}{2} * \rho * v^2$$

$$v = \sqrt{\frac{p_1 - p_2 * 2}{\rho}}$$

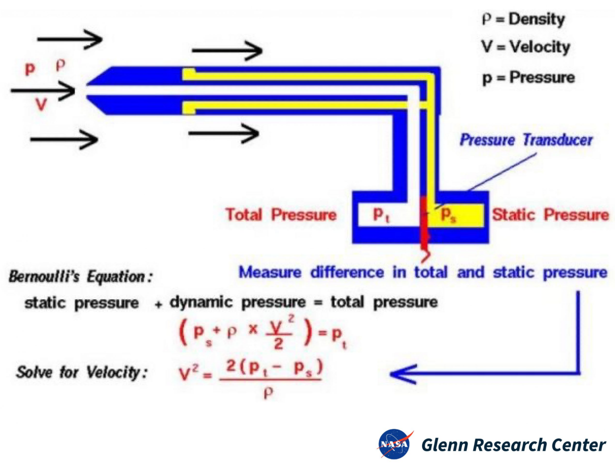

Figure 2.2 -Image of how the pitot works (basis of functionality)

The reason for this interest in airspeed on top of speed with respect to the floor is uncovered by the lift force equation:

$$L = \frac{1}{2} * \rho * A * C_L * v^2$$

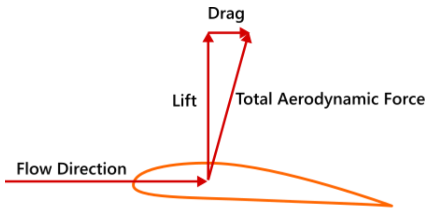

Figure 2.3 -Forces wing diagram

where: L represents the lift force; ρ is the density of the fluid (air);
A is the wing area; C_L is the lift coefficient, and **v is the velocity with respect to the fluid (air).**

As we have commented, this velocity is the one that the aircraft has with respect to the air (what the pitot tube measures), is not the velocity that an apparatus, from a static Reference System, calculates.

For instance, if the plane is moving at 30 km/h but presents a headwind of 20 km/h the velocity that the pitot tube is going to show is:

$$v = v_{plane} + v_{fluid} = 30 + 20 = 50\ km/h$$

The sum is because it is the velocity at which the aircraft is hitting the fluid (air), and that would be the velocity that we should add to the lift equation in order to calculate this parameter.

On the contrary, if we present the reverse case, a plane moving at 30 km/h but presents a tailwind of 20 km/h, the pitot tube is going to show the following result:

$$v = v_{plane} - v_{fluid} = 30 - 20 = 10\ km/h$$

Knowing this, we can understand why if we look at the sky and we see an aircraft in a very windy day (when the air blows from the front), the plane seems not to move (or it moves really slow), nevertheless the pitot tube is showing to the pilot that the plane has a specific velocity (required in order to fly).

This is the reason why we don’t use methods like GPS that don’t take into account the velocity of the fluid. However, there exists an alternative to the pitot tube and it is a laser method that calculates the time it takes for the wave emitted by the laser to bounce into the molecules of the air.

Anyway, this method is a bit more complex than the pitot tube and presents the same problems. A failure in the apparatus can provoke a big accident, for example: if we run out of electricity or a cable stops working.

So, the pitot tube is widely used since it is quite easy to implement, relatively cheap and it works with easy-to-handle variables (pressure, fluid properties, with a determined temperature). Although it has some drawbacks, such as the freezing of the apparatus or the entering of insects in the orifice, it is the best option to calculate the relative velocity that society has invented until these days.

Figure 2.4 -Image of how the pitot tube is capped before flying, in order to avoid accidents.

2.3- Electronics

For measuring the static and dynamic pressures, we are using two barometric sensor BMP-180. They offer the advantages of being easy to program, cheap and light weight. However, their limited precision will limit the accuracy of the final experiment as we will discuss later on.

As the brain of the model we have a Raspberry Pi Pico. This powerful microcontroller will allow us to receive the data from the sensors, process it and display the results. For this last process, we are using a 7-Segment LED Display. It works as 8 LEDs which need to be connected to the controller with a 220 Ω resistance each. For programming it we are using the Thony IDE and MicroPython, the version of Python focused on microcontrollers.

Lastly, an 800 mAh battery will ensure enough energy for all the components during all the experimentation.

In this report, no further comments on the electronics nor the code would be made. Nonetheless, more information concerning these topics can be found in this Github repository we have created and uploaded the code: [Link](#).

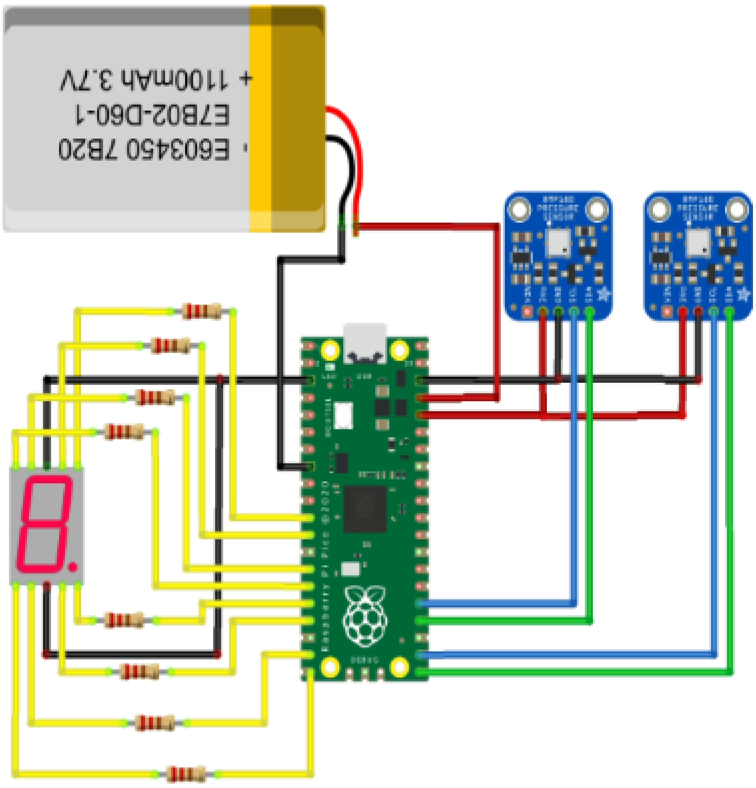

Figure 2.5 -Representation of the electronic components used.

3- EXPERIMENTAL WORK

The electronics were connected with cables and welded with the help of a soldering iron and tin. Next, the program was uploaded to the hardware and tested. Several iterations of the software were tested until all the objectives were fulfilled.

For the assembly, a tennis ball container was used as structure. Some holes were made into the plastic in order to locate all the components inside. Then, the components were secured with tape.

The tube was tested under several conditions. A video with a demonstration can be seen here.

4- CONCLUSIONS

After several experiments, we have reached the following conclusions:

The tube could be more precise. The values that give are far below the true airspeed. This is mainly for the limited precision of the sensors. Nevertheless, the objective of the work was to demonstrate the fundamentals of Pitot - Static tube rather than building an accurate machine. Moreover, despite with values below the real ones, it is demonstrated that it actually works.

Furthermore, this experimental work has served us to increase our knowledge of electronics and experimentation. Checking empirically part of the theory we have learned in class.

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