‘Wireless sensor practicals’
Microtechnique Section, Bachelor (BA6)
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Pitot probe

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1 Introduction

Our initial idea for a sensor was to build an altimeter with a pressure sensor. After discussing the project in class this was seen as too simple. We therefore decided we would build a pitot static probe in order to measure airspeed. One of our group members is a glider pilot and is familiar with the theory behind how such a probe works. Moreover he was very motivated to build such a probe and was pleased to explain how it works and how it is used. Our goal was to create a functional Pitot probe which could be used in the context of gliding or small powered aircraft.

2 General Sensor Idea and Application

2.1 Overview

Our sensor is a Pitot-static probe. This type of sensor is used to measure the indicated airspeed in various aircraft and as we can see in Fig.(1) airspeed is obtained by measuring a pressure differential. To do this we need either two sufficiently accurate absolute pressure sensors or one accurate differential pressure sensor. In the end the concept is the same : there is one hole (the white one in Fig.(1)) that is used for the total pressure and two other holes (the yellow ones in Fig.(1)) that are used for the static pressure. Then, if we have two absolute pressure sensors we subtract the two pressures and then obtain the velocity of the plane as shown in Fig.(1). If we have one differential sensor the subtraction is already calculated and the velocity can be calculated using the formula.

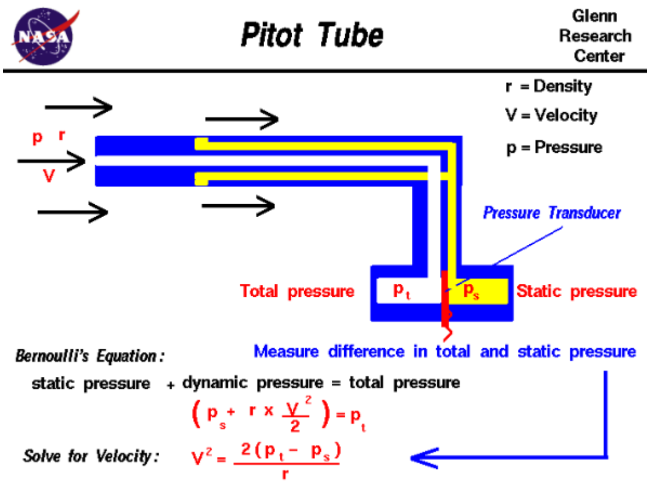


FIGURE 1 – Pitot-static probe overview (Ref. [2])

2.2 Schematic of the Sensor Board

2.2.1 Component Values

Provide the schematic of the sensor board, including component values.

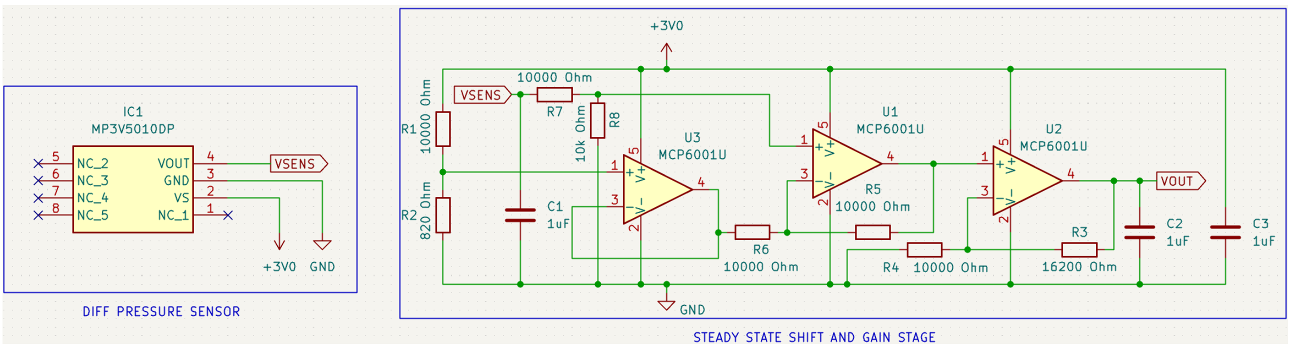


FIGURE 2 – Schematic of our sensor board circuit

2.2.2 Circuit Topology

The output of our sensor has the characteristic seen in Fig.(3). As seen in the curve and formula there is an offset at a zero pressure differential. The values from our sensor allow measurements of up to a $10kPa$ pressure differential. For our application the maximum expected pressure is about $4.3kPa$ which corresponds to about $300km/h$. In order to maximize the useful signal (i.e. use as much of the 0-3V range of our ADC) we will therefore need to shift the curve down and amplify it so that a $3V$ output is obtained for a $4.3kPa$ pressure difference.

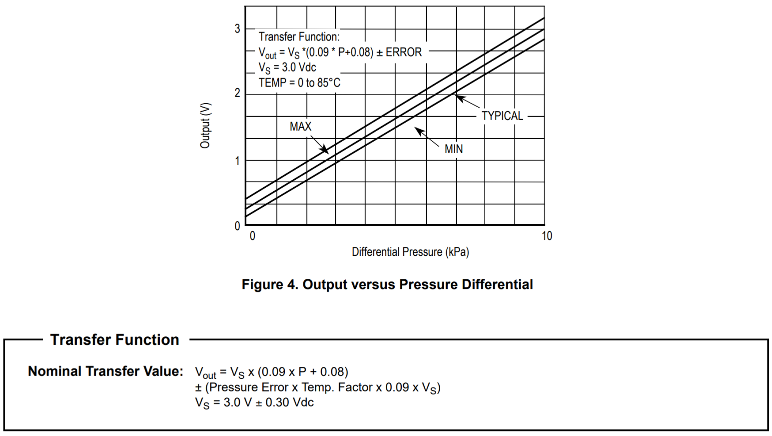


FIGURE 3 – MP3V5010DP characteristic (Ref. [1])

The circuit we use is comprised of two stages. The first stage uses two amp ops and serves as a level shifter to decrease the steady state value by $0.24V$. This gives us a $0V$ output for a null pressure differential. The second stage is a non inverting gain stage made with a gain of $1 + (16200/10000) = 2.62$. This gives us an output of $V_{out} = 2.62 \cdot (3 \cdot (0.09 \cdot 4300 + 0.08) - 0.24) = 3.042V$ which will be saturated down to $3V$.

The circuit transfer function was verified by simulating it with MPLAB Mindi. The results are found in Fig.(4).

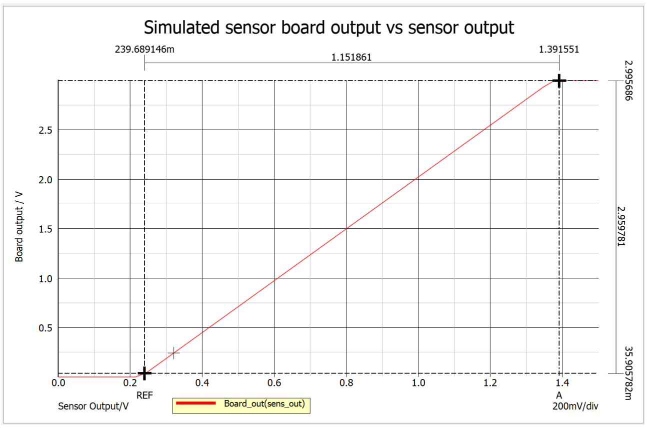


FIGURE 4 – Circuit input vs output voltage simulation

The chosen mode for supplying the circuit with power is the $3V$ power output from the motherboard as the sensor board requires very little power to function properly.

2.2.3 Component selection

The components used on our board were selected using the following criteria :

— MCP6001U Amplifiers : These were selected as they function at low voltages ($> 1.8V$), have a low current draw of about $100\mu A$, and are easily found in small smd packages.

— $1\mu F$ decoupling caps : These were selected in order to have good noise isolation at relatively low frequencies.

— $10k\Omega$ resistors : These were selected for various uses in order to maintain low current draw.

— 820Ω resistor : This was selected in order to have a suitable voltage reference (ends up at $0.227V$) using a voltage divider.

— $16.2k\Omega$ resistor : This was selected in order to have the proper gain of 2.62 on the non inverting gain stage.
— Passive component packages : the resistors and capacitors were all selected in 0402 imperial/1005 metric packages as the small size made it possible to keep the sensor board small.
— MP3V5010DP differential pressure sensor : This sensor was selected as it was one of the only available sensors covering the proper pressure range and providing an analog output.

2.3 PCB Layout

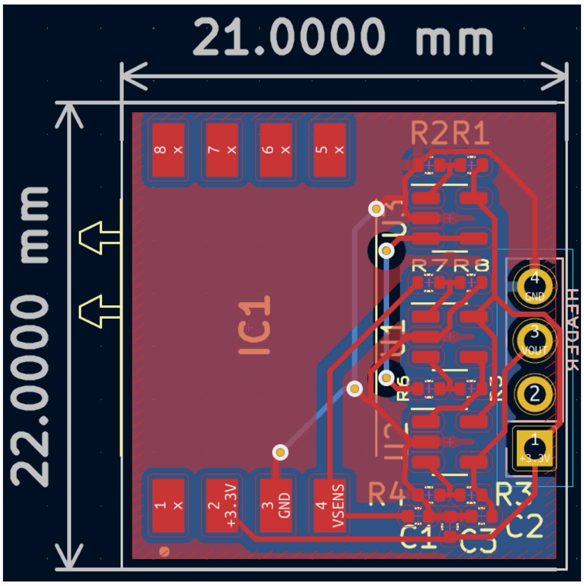


FIGURE 5 – PCB layout

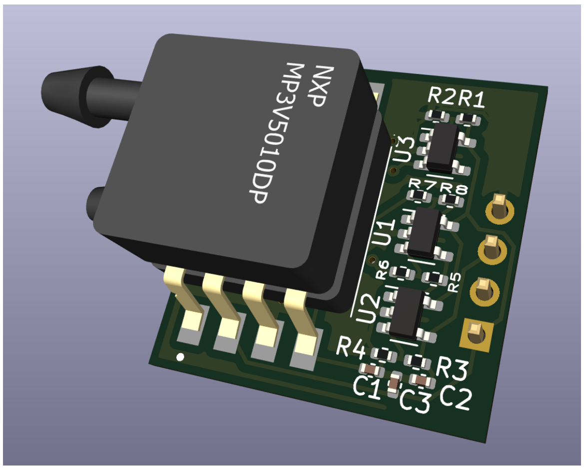


FIGURE 6 – 3D render of the PCB

The goal of the PCB layout was to keep it as small as possible in order to be able to attach the sensor board to the motherboard using the 4 pin header and solder. We ended up choosing to put all components on one face for ease of assembly and managed to keep the lateral dimensions at about $2cm \times 2cm$. The only hard constraint was that the sensor needed to be placed on the edge of the PCB due to the dimensions of the tube fittings. The idea was that the PCB would be stacked vertically with the motherboard and require no additional mounting hardware once the header is soldered to both boards.

2.4 Package Design

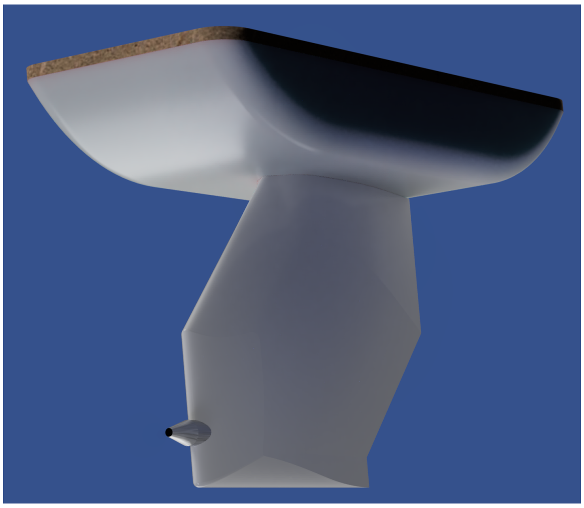


FIGURE 7 – 3D Render of the assembled Package

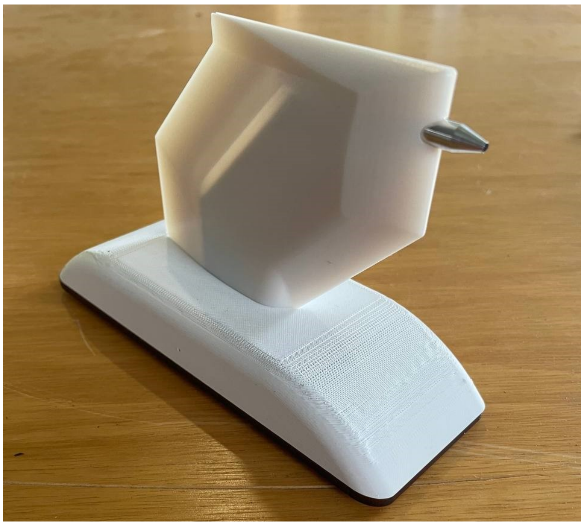


FIGURE 8 – Picture of the assembled Package

2.4.1 Package design constraints

The sensor is designed to be attached to aircraft with speeds of up to $300km/h$. This application creates some specific constraints with regards to the package design. A summary of these would be :

- Boundary layer : The pitot probe which measures total pressure must be far away from other elements to be in undisturbed air. The package must ensure it is out of the boundary layer.
- Static pressure input : The package needs to have an input for the static air pressure. This is achieved by having symmetrically placed holes in the package perpendicular to the airflow in an area of rather undisturbed airflow.
- Aerodynamic package : The package must be sufficiently aerodynamic to avoid excess drag.
- Shockproof : The package must be strong enough to remain undamaged at flight speeds while also being able to sustain an impact from a small object (i.e. bird) without causing the sensor to lose functionality.
- Weatherproof : The package must protect the electronics from phenomena such as rain by providing some protection from water droplets.

2.4.2 Aerodynamic considerations

The package was first and foremost designed in order to place the pitot probe in clean air. Assuming the airflow is laminar (which should usually be the case where the sensor would be placed) the boundary layer is expected to be a few mm deep. The boundary layer can however be much thicker if the flight regime causes the airflow to become slightly turbulent. The package was therefore designed to keep the probe about $4.5cm$ from the main casing (note that in an ideal configuration the top casing containing the electronics would not be necessary as the electronics could be placed inside the aircraft's wing or fuselage).

The static pressure inputs were placed on the side walls of the upper casing which are perpendicular to the airflow. Their position is rather central compared to the casing as this area was not too affected when we observed the CFD simulation results.

The outside shape of the package was designed with aerodynamics in mind. The shrouding on the arm which holds the probe was optimised to be as aerodynamic as possible to reduce induced drag. The quality of its aerodynamics was verified using CFD software. Results for a simulation at $300km/h$ can be seen in Fig.(9). The traces on the image show that the airflow is only minimally disturbed which is a satisfactory result given that the speed used in the simulation is that of the maximum speed at which we can measure values. Another choice made with regards to the shroud was printing it using resin (this ended up being made with MJM printing due to a mistake in the design which made resin printing impossible). These printing methods offer a very high quality in terms of surface smoothness which is beneficial for the overall aerodynamics (note : the casing at the top of the package could have been made with resin but this would have been very expensive due to its size so we used standard FDM).

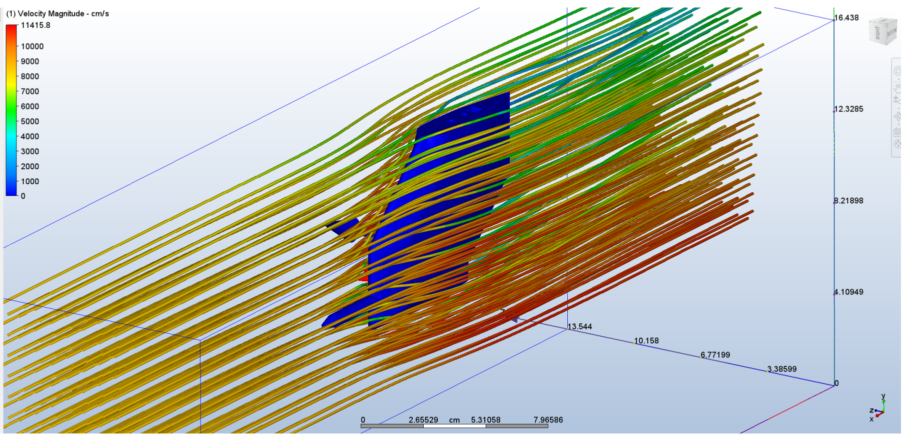


FIGURE 9 – CFD simulation of the aerodynamic shroud

The top section of the package was also designed to maintain reasonable aerodynamics. CFD simulations showed rather significant airflow disturbance compared to the rest of the package however it remains reasonable given the space constraints in the package.

The last notable element is the use of tape to cover the small slits and gaps present in the package. This is a common practice namely with gliders where the junction between the fuselage and wings as various other elements are covered with tape for improved aerodynamics and reduced noise.

2.4.3 Durability considerations

Another important aspect of the package design was ensuring it was resistant to rather large forces. We therefore chose a design which combined parts machined out of metal as well as 3D printed parts. The idea was to have a strong internal structure made out of aluminium which would then be nested in a plastic shroud designed to have good aerodynamics. The end design therefore has a metallic internal structure we machined using the mills and lathes present in the mechanical workshop of the SPOT-DLL. This internal structure is designed to be strong (the arm holding the probe for instance is $\approx 1cm$ thick). The metallic arm is visible in Fig.(10a). These metal parts are then nested in the 3D printed parts fabricated by the AFA shop. The aerodynamic shroud for the arm holding the probe is destined to be glued to the metallic arm while the upper casing is held by the screws connecting the different parts of the metallic chassis.

The weatherproofing aspect was also considered in the package design. Water ingress prevention where the electronics are present is ensured in a few ways :

— The casing containing the electronics is made in two parts (one printed in ABS and one laser cut in MDF) which link along a flat surface.

— The tape used for aerodynamics offers a second layer of protection by sealing some of the gaps.

— A more finished product would have an adhesive which would also seal other gaps in order to keep the casing closed in addition to the existing measures.

The largest point of ingress is therefore the opening at the front of the probe itself. This is however not an issue as water entering the probe would most likely not travel the whole length of the tube to the sensor. If water ended up going all the way to the sensor no damage would occur as the tube linked to the probe is connected to an input of the sensor which is protected from the environment (the internal membrane is protected by a fluorosilicone gel as indicated in the sensor datasheet [1]).

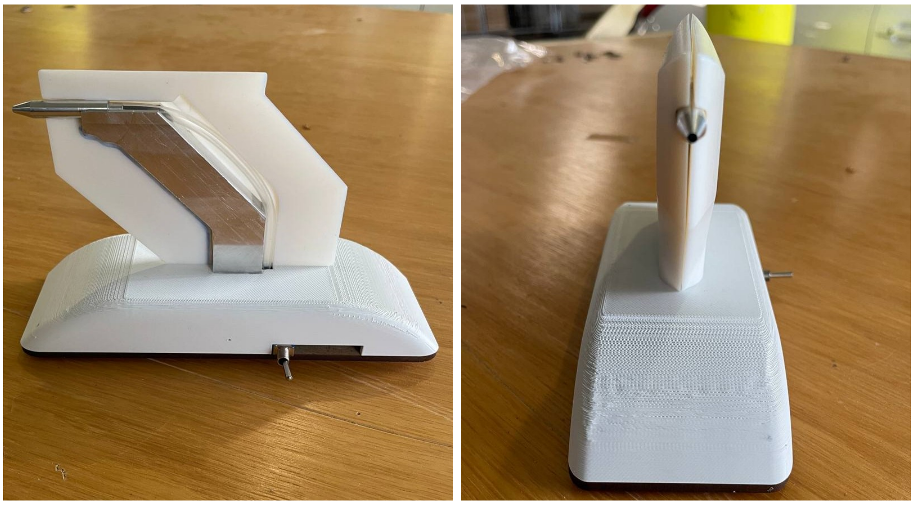
2.4.4 Placement of the electronics in the package

The electronics are placed in the rear section of the top casing. This choice was made mainly out of convenience as the front of the casing is occupied by the metallic chassis and the tube coming from the probe enters the casing behind the chassis. The area behind the chassis in the upper casing was wide enough to accommodate the motherboard with the sensor board piggybacked on it. Another benefit of this position is that it is the furthest point of the package in case of any likely issues such as an impact on the front of the package or potential (although highly unlikely) water ingress. One of the main factors in the placement of the electronics was the large size of the motherboard compared to the rest of the package.

3 Testing and Results

3.1 Sensor Setup

The wireless air speed sensor consists of a main unit with an aerodynamic design, mounted on a stable base as we can see in Fig.(10a) and (10). The sensor tip is designed to measure the air speed accurately.



(a) Side view (partially disassembled) (b) Sensor front view

Figure 10 – Wireless air speed sensor setup

3.2 Testing Procedure

The testing was conducted in a controlled environment to simulate real-world conditions. The sensor was placed inside a vehicle, and air speed measurements were taken while the vehicle was in motion. The test conditions were not the best, it got worse during the test and we could not get a precise wind measurement. An important fact, because to find out our speed we used the car's speedometer, which does not take wind speed into account.

3.2.1 Setup of the probe

Using duct tape and painter's tape, we attached the probe on the mirror of the car as seen in Fig.(11).

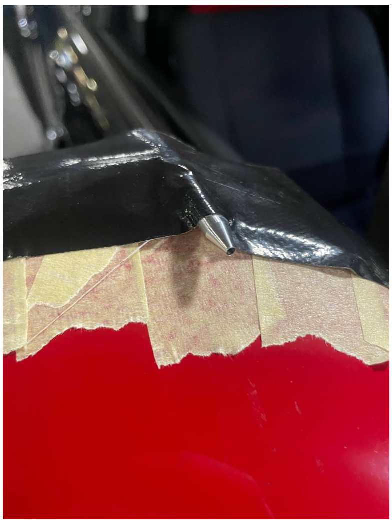


FIGURE 11 – Probe attach to the car

3.2.2 In-Vehicle Testing

A laptop was connected to the sensor to monitor and record the air speed data in real-time Fig. (12a) and (12b). For added measurement security, an average was taken over a continuous measurement time of several seconds.

(a) Monitoring data (b) Sensor electronics on dashboard

FIGURE 12 – Real-time data monitoring during in-vehicle testing

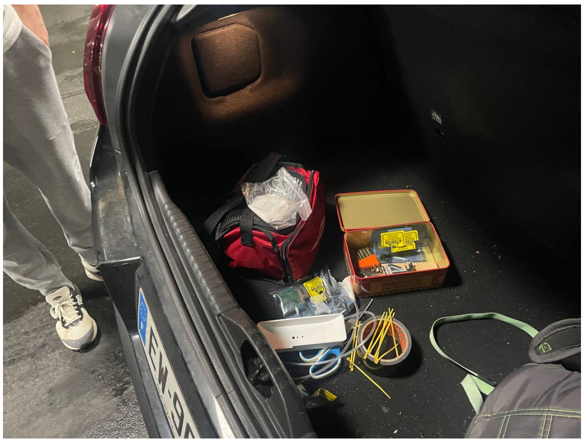
3.2.3 Failure of the tape

Because of the raining condition, the painter's tape got wet and the whole setup was almost detached as we can see in Fig.(13).

FIGURE 13 – State of the tape after the test

3.3 Results and Conclusion

The wireless air speed sensor performed reliably during the tests. The data collected was consistent with the expected air speed values based on the vehicle's speed. This testing procedure demonstrated the sensor's ability to provide accurate air speed measurements in a dynamic environment.



(a) Preparing for test

(b) Final adjustments

FIGURE 14 – Additional setup and adjustments

3.4 Results

The wireless air speed sensor performed reliably during the tests despite the rainy conditions. The graph in Fig.(15) is showing the relationship between the speed and the voltage output from the sensor.

The chart illustrates that as the speed increases, the voltage output from the sensor also increases, indicating a positive correlation between the vehicle's speed and the air speed measured by the sensor. A poor value between 80 and 90 km/h was collected however, but with our non-repeatable test process and conditions beyond our control, an error on a value was quite predictable.

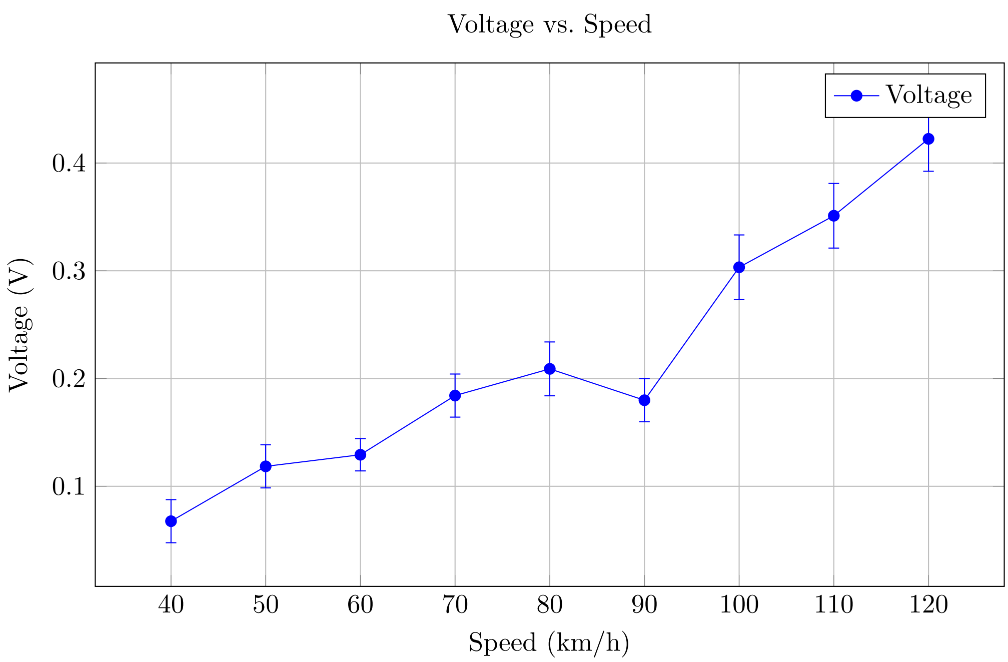


FIGURE 15 – Graph of Voltage vs. Speed

3.5 Improvements

Hindsight allowed us to determine a few areas in which the sensor could be improved. One main improvements would be to change how the two halves of the aerodynamic shroud are printed in order to remove the slit at the front of the "wing" which is not optimal for aerodynamics and requires tape to be shut.
It would also have been better if we had positioned the motherboard and the PCB differently in order to reduce the thickness of the top part of the package.
Another slight improvement would be an improved system for mounting which is separate from the assembly of the package. The current version has screws which must go through multiple parts which cannot easily be held which is not optimal for assembly.
The testing method could also be improved. Although our results were quite concluding, the process was not the most rigorous and scientific. The attachment could be a bit more sophisticated than tape in order to ensure a better reliability of the sensor.
Finally, the use of an aerodynamic wind tunnel would also be interesting in order to get a continuous laminar flow, which would probably provide more precise and reliable measurements than the ones we got on the road.

4 References

[1] Freescale Semiconductor Inc., MP3V5010DP Datasheet, `https://www.nxp.com/docs/en/data-sheet/MP3V5010.pdf`

[2] Tom Benson (NASA),NASA Glenn Research Center website, `https://www.grc.nasa.gov/WWW/k-12/VirtualAero/BottleRocket/airplane/pitot.html`