Accuracy of UAV Pitot-Static System

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I. Abstract

Though they are unnecessary for the structural integrity of the aircraft, an error in the pitot-static system can cause inaccuracies in flight and eventually lead to aircraft failure. Through a series of tests, the University of Minnesota's UAV pitot-static system error was calculated and graphed. This allows the pressure sensors built into the pitot-static system to be calibrated for error, which prevents harm to the aircraft and operators. The equation for negative angles of attack is a linear function: $y = -0.0174x + .8804$. The equation for positive angles of attack was a polynomial function: $y = -0.0002x^2 + 0.0001x + .8833$.

II. Introduction

Planes use a pitot-static system to determine the vehicle's altitude and airspeed, but there could be numerous errors that could affect the readings, and therefore the overall accuracy, of the sensors in this system. Two types of error that can occur are called inherent sensor error and position error. Inherent sensor error is any error that the sensor has when it leaves the factory. Position error is caused by a disruption in the air flow entering the pitot-tube. To correct for these errors, it is necessary to calculate the error and build functions into the flight computer to compensate for that error. In order to test for inherent pressure sensor error and position error in the pitot-static system of the UAV Research Group's UAVs, two types of experiments were conducted. These experiments also tested the agreement between sensors and the difference in sensor pressure between positive and negative angles of attack.

III. Experiment Setup

The first experiment tested for inherent pressure sensor error and consisted of attaching a pitot tube to the sting in the University's wind tunnel. Placing the pitot tube far ahead of the sting allowed the inherent error to be determined and the error due to position error to be ignored. To accomplish this, the pitot tube was attached to a long cylinder which reached far in front of the sting.

The set up for the first test is pictured on the left; this picture shows how the tube was attached to a long cylinder and attached to the sting to prevent obstruction of air flow. A close up of the mounted pitot-tube is pictured on the right.

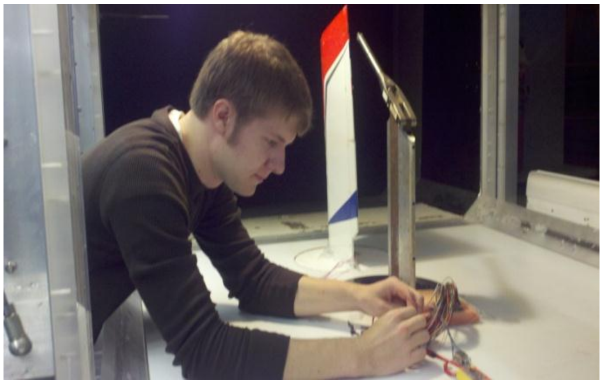
The experiment tested the probe at various wind speeds and angles of attack using the wind tunnel's built in pitot probe to measure air speed and sting to calculate the exact angle of attack. Originally, the plan was to run the tunnel at increments of five meters per second for every two degrees ranging from negative six to positive ten degrees, but after initial testing (Runs 1-3) it was concluded that only increments of ten degrees were needed.

During the initial set up, long tubes were used to carry the air from the probe to the sensor, which was placed outside of the wind tunnel, however after further consideration the tube lengths were shortened in case the length of the tubes caused error. Because of the shortened tubes, the sensor was placed in the wind tunnel and was connected to the microprocessor with long wires. The sensor was shielded with a cone of foam and attached to the cylinder. The cone worked well, but the wires were too long for the data to travel through.

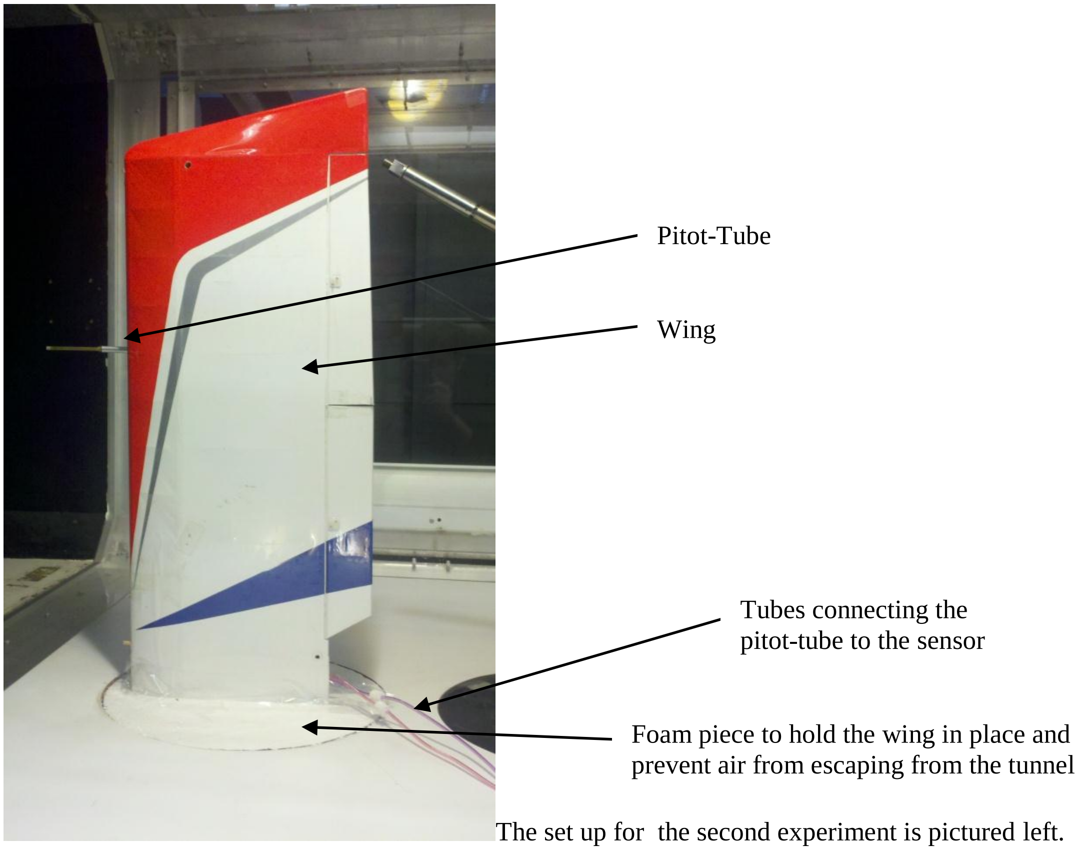
After many attempts, the microprocessor, battery, and sensor array were placed in the wind tunnel, taped down and hidden from the powerful wind. A single cord ran out of the wind tunnel to attach to the computer which was taking the data after being dumped from the microprocessor. This was the set up used to complete Runs 4-12 where more conclusive data about the sensor error and how sensor error varied from sensor to sensor was found.

The second experiment tested for position error, the error produced by disturbances in the air flow caused by the probe being attached to the wing. There was a problem in designing the experiment because the wing span was too large to fit in the wind tunnel. A hole cover was removed in the wind tunnel's floor to allow the wing to sit half in and half out of the wind, keeping the probe in the tunnel but the rest of the wing outside of the tunnel.

A circular piece of foam was cut to fit into the hole in the wind tunnel and then a hole was cut in that piece in an air foil shape. Placing the wing through the hole, the probe mounted on the wing was exposed to the wind while preventing air from passing through. Runs 13-20 were completed with this configuration.



The UROP student is pictured above connecting the microprocessor to the sensor.

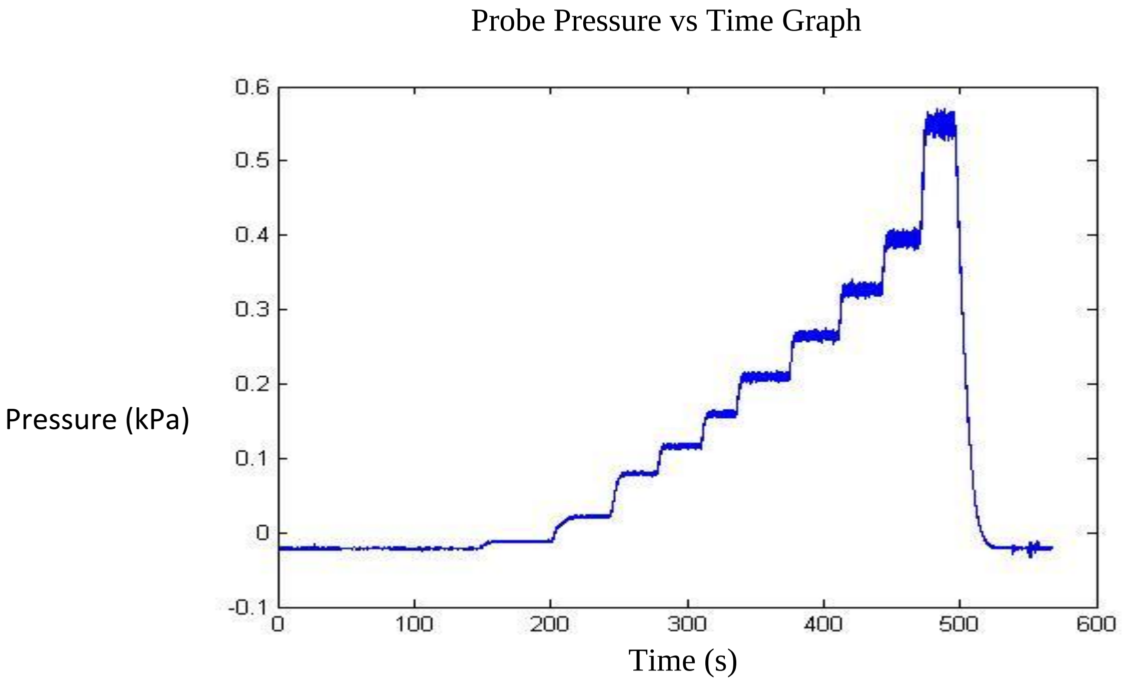


The set up for the second experiment is pictured left.

Using a similar set up as in the first experiment, the sensor, microprocessor, and battery were placed in the wind tunnel and a single cord ran out to the computer to collect the data. Because the wing produces lift, the maximum speeds in the wind tunnel were much less. As the air speed increased, the wing began to buffet. The experiment was ended to prevent damage to the wing or tunnel.

Both experiments generated large amounts of data, such as temperature, static pressure, dynamic pressure, air density, and wind speed, as well as data that the probe collected. The dynamic pressure from the tunnel was converted into the same units as the probe (in kPa). This was then used for the x axis of the graphed results.

To calculate the pressure that the mounted probe read, MATLAB was used to produce a graph of pressure over time. Because the airspeed at each time was known, pressure values were averaged at each plateau (refer to figure below) and these values were compared to the wind tunnel pressure probes by making them the y-axis. The standard deviation was also found for each run.



A MATLAB plot is pictured above. Each plateau depicts a different wind speed in the tunnel.

IV. Experiments

Run	**Configuration**	**Angle**
1	Probe	2.5
2	Probe	2.5
3	Probe	12.5
4	Probe	0
5	Probe	10
6	Probe	20
7	Probe	0
8	Probe	20
9	Probe	10
10	New Probe (Pd)	0
11	New Probe (Pd_aos)	0
12	New Probe (Pd_aoa)	0
13	Wing	0
14	Wing	-10
15	Wing	10
16	Wing	20
17	Wing	15
18	Wing	-5
19	Wing	30
20	Wing	40

V. Analysis:

Probe Error:

Probe error was found using the data from just the probe (runs that didn't have the wing attached). The equations of the trend lines for Runs 4-9 are very similar, so it can be concluded that the probe error is independent of angle. Because of this, the equations of the trend lines were averaged to find an equation which describes the probe pressure to actual pressure. Runs 4, 5, and 6 were used because they are representative of the three separate angles. Y is the pressure the probe read (also seen as Pp) and x is the actual pressure (the pressure recorded by the wind tunnel and also seen as Pt).

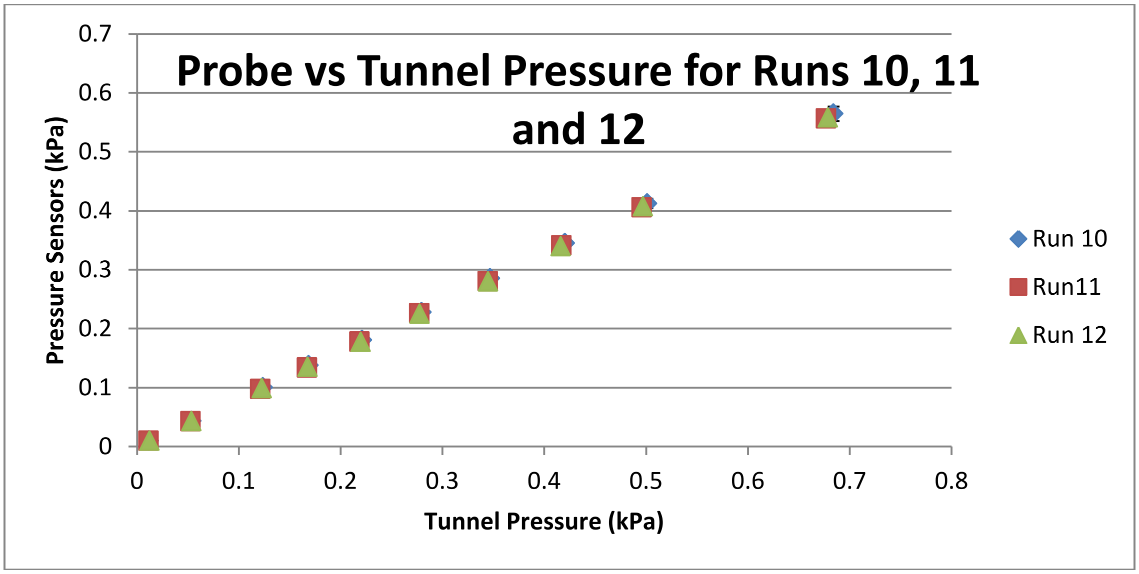
Run 4	0 Degrees	Y=.8211x-.0046
Run 5	10 Degrees	Y=.8369x-.003
Run 6	20 Degrees	Y=.8153x-.0034

Averaged: Pp=.8244(Pt)-.0037

Pt=(Pp+.0037)/.8244

Probe Error- Varying Probes:

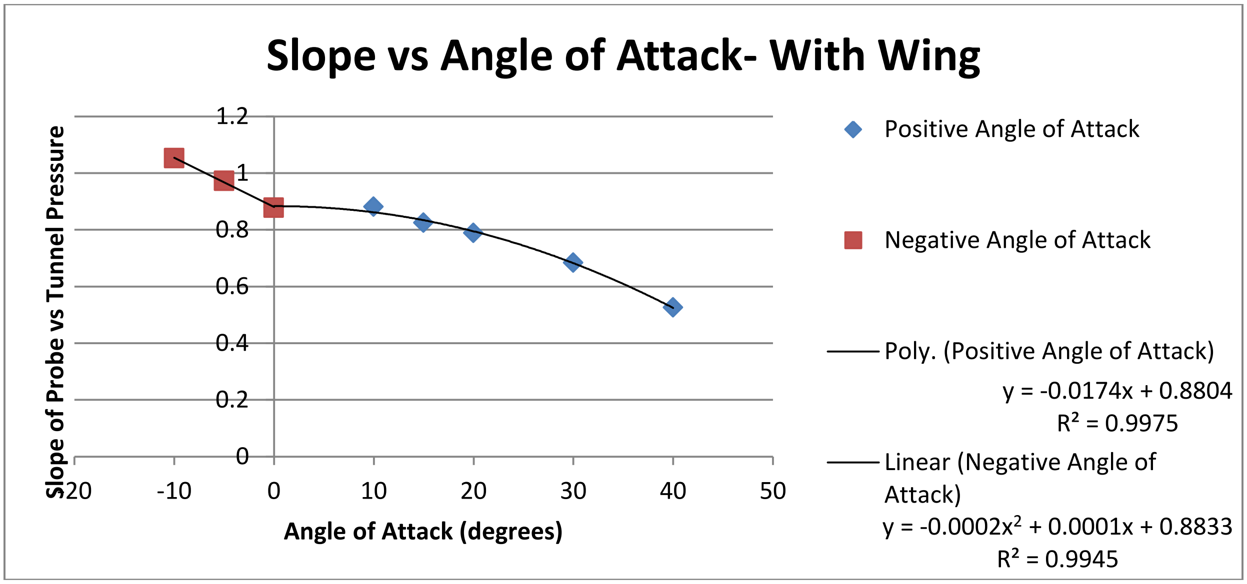
Runs 10-12 used a probe at zero degrees but varied the sensor that the probe was connected to. As seen by the graph below, the variation in sensor readings was within one standard deviation and therefore negligible. It can be concluded that the equation found above is valid for all probes tested in this experiment.



Position Error:

Because the slopes are not the same, the procedure used above is no longer applicable. Instead, the slopes of the trend line equations were graphed against the angle of attack.

Run	Angle of Attack	Slope
Run 13	0 degrees:	.8779
Run 18	-5 degrees:	.9725
Run 14	-10 degrees:	1.0521
Run 15	10 Degrees	.8805
Run 17	15 Degrees	.824
Run 16	20 Degrees	.7885
Run 19	30 Degrees	.6836
Run 20	40 Degrees	.5253



In flight, the flight computer can read what angle of attack the plane is flying at, and use these graphs to find the slope of error to compute the correcting value for the pressure sensor.

Conclusion

This research makes it is possible to calculate the difference between actual dynamic pressure and the pressure read by the UAV sensors. Using this information, the equations of slope from each graph can be loaded into the flight computer and the UAV is able to correct the error of its sensors based on its angle of attack. The equation for negative angles of attack is a linear function: $y = -0.0174x + .8804$. The equation for positive angles of attack was a polynomial function: $y = -0.0002x^2 + 0.0001x + .8833$.

Additional testing as to the reason that the positive and negative angle of attack produces a different function would be beneficial to our understanding of pitot-static systems and aerodynamics.