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Unmanned Aerial Vehicle (UAV): Flight Performance

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ABSTRACT

It is important that when measuring the sideslip angle and angles of attack during flight test performance of a UAV (Unmanned Aerial Vehicle), to fully understand that the Angles of attack and sideslip are parameters that aid in determining the safety of the flight as they improve stability and control of the aircraft. The disadvantage of the measurement of these angles using this method is low accuracy of measurement due to friction to the potentiometers in connection with the vanes. To counter this, a new sensing method was developed to minimize friction and collect more accurate data. The method is based on a pivoted vane type sensor. Findings from this research will later be used to advance other graduate research projects.

INTRODUCTION

This research paper discusses the importance of sideslip and angle of attack on the flight dynamic and control of an Unmanned Aerial System (UAS). It is important to state what is a UAV, the effect of using Hall Effect Potentiometer to measure angle of attack (AoA) and sideslip angle (SA), the calibration and computation process utilized to work with seven-hole pressure probe in the wind tunnel, and UAV flight stability and control. An Unmanned Aerial Vehicle has the capability of flight without human constant interaction. The UAV consists of onboard autopilots and navigation systems, which enable autonomous flight between the operationally defined waypoints. The UAS is a simple system that contains a ground control station with pilot, communication and support equipment. In the first directional pressure probes, the determination of the flow direction was based upon the equalization of two or more pressure taps placed in symmetrical positions. The seven-hole probe is composed of a cylindrical tube with a conical or hemispherical extremity, where seven holes are drilled, one in the center and the remaining six placed around it on an axis-symmetrical arrangement. Each is a pressure tap connected to a measuring device [2]. This research paper will emphasize the importance of the seven-hole probe and how it was used during wind tunnel testing. FIG. 1 below display the geometry of the probe.

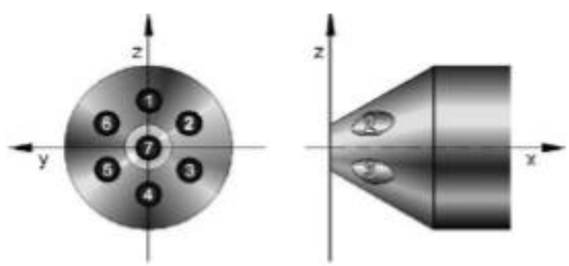

Fig. 1. Seven-hole probe geometry.

METHOD AND PROCEDURES

PART I

It is essential to know that Aerodynamic is the study of forces and the resulting motion of objects through the air. Studying the motion of air around an object allows for the proper measurement the forces of lift, which allows an aircraft to overcome gravity, and drag, which is the resistance an aircraft encounters as it moves through the air. Everything moving through air (such as aircrafts, missiles, and birds) are affected by Aerodynamics [2]. Throughout the experiment, a hand-built wind data collector called the Air Data Boom (ADB), model shown in FIG.2, was connected to pressure sensors that measured the pressure for each corresponding angle of attack(alpha) and sideslip angle (Beta). Moreover, each pressure sensors were connected to 7 ports. These seven ports, were identified as the seven-hole air data boom calibration.

The purpose behind the calibration was to obtain all essential data in a method or procedure that allows the computation of the variables resembling the flow (in two direction angles, total pressure and dynamic pressure) based on the pressure values computed in the probe's seven taps. In the calibration procedure, the probe is exposed to a set of well-established incoming air flow inside a wind tunnel with the provenience path characterized by the estimations of two angles. FIG.2 display the wind tunnel set up.

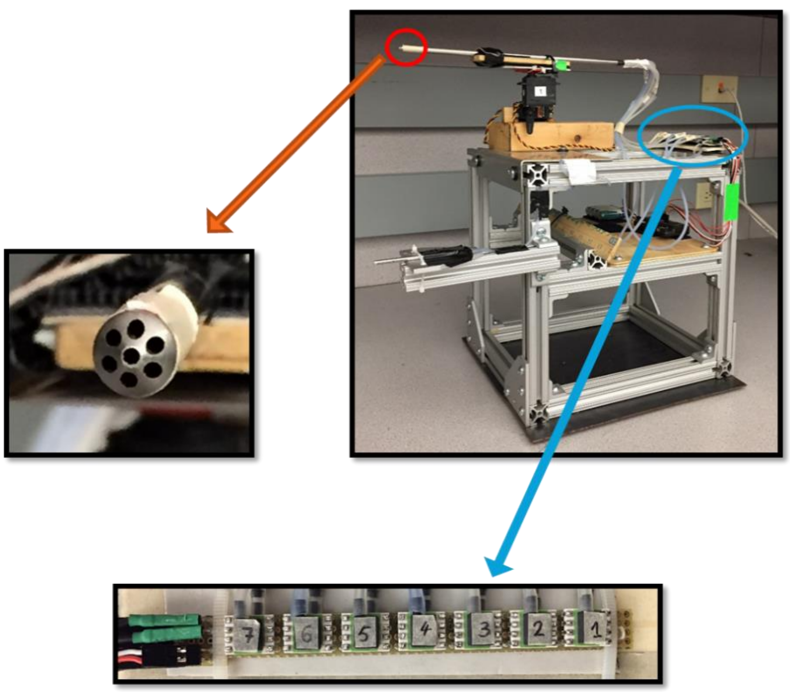

Figure 2: Wind tunnel setup

Moreover, a Simulink code was place on the mini onboard computer (APM 2.6) to initialize data logging procedures. The Air Data Boom (ADB) is positioned in the wind tunnel to gather data for various wind speeds. Mounted on a test bed along with the pressure sensors, the ADB can place itself at different angles of attack and sideslip angles to collect as much data for a wide range of angle combinations. The ADB is commanded to move between [-25°; +25°] for both AoA and SA and to stay at each point for 10 seconds, totaling 121 data points to cover in about 20 minutes. This test was performed for different wind speeds: 10 m/s, 15 m/s, 20 m/s and 25 m/s. The data collected is then saved for post-processing and analysis.

PART II

USING HALL EFFECT SENSORS TO COMPUTE AOA AND SA

Compiled data collection has shown that a pivoted vane type sensor is not the most effective means of computing angle of attack and sideslip due to the friction in the vane type sensors. Thereby, it is understood that when measuring angle of attack and sideslip angle of a UAV that the best method is to use a Hall Effect Potentiometer that enables more accurate data collection and greatly reduces the friction within the potentiometer sensors.

HALL EFFECT/POTENTIOMETER APTITUDE

It is essential that one understands what a Hall Effect/Potentiometer is. Hall Effect is a moving magnet that creates changes in magnetic field strength that are detected by an electromagnetic sensor. The raw signal is converted into a stable voltage output which can be rotary or linear. Whereas, the Potentiometer or “pot” for short is a variable resistor in which an electrical contact moves across a conductive plastic element. Typically, it is used as a voltage divider. It can be either rotary or linear.

During the research experiment, Hall-Effect sensors were used as optical encoders and captive sensors for the positioning of the angle of attack and sideslip angle while the plane (named Skywalker) was in flight. It was reported that a potentiometer has resistors which would decrease the frictionless motion of the vanes which related to the potentiometer, thereby interfering with data collection accuracy [2] as shown in FIG. 3 below:

FIG.3: Display a plane with an AOA and SA vanes connected to a Hall-Effect sensor.

The pivoted vanes were each connected with a Hall-Effect sensor, in which one was connected at AOA positioning and the other at SA positioning. Ultimately, when flight performance came the Hall-effect sensor was superior on achieving data collection accuracy and durability

EQUATION AND CALCULATION

The AoA and SA are obtained from the following formulas:

$$\boldsymbol{C_{P_\alpha} = C_{p_{t_a}} + \frac{C_{p_b} - C_{p_{t_c}}}{2}} \quad ; \quad \boldsymbol{C_{P_\beta} = \frac{C_{p_b} + C_{p_{t_c}}}{\sqrt{3}}}$$

$$with\ C_{P_{t_a}} = \frac{P_4 - P_1}{P_7 - P_{avg}} \ ; \ C_{P_{t_b}} = \frac{P_3 - P_6}{P_7 - P_{avg}} \ ; \ C_{P_{t_c}} = \frac{P_2 - P_5}{P_7 - P_{avg}} \ \ and\ P_{avg} = \frac{\sum_{i=1}^{6} P_i}{6}$$

Cp represents pressure coefficients. The pressures obtained from the various wind speeds in the calibration process will help in correlating an angle to a specific wind speed [5].

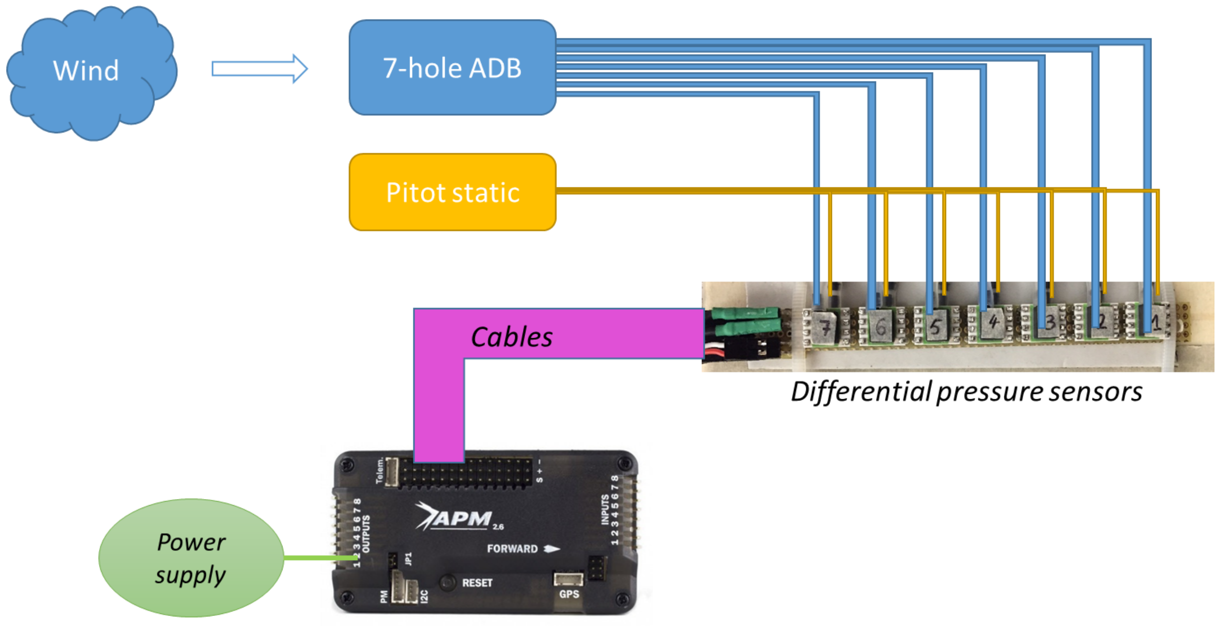

FIG. 4: Flow of Logging data from 7-hole AD

DISCUSSION/DATA ANALYSIS

Throughout the lab experiment, it was recognized that many statistical disseminations have been measured to model or illustrate wind speed data. Since Weibull and Rayleigh statistical distributions are the most broadly used methods for analyzing wind speed measurements and wind energy [4], the used of the ADB was established as effective hands-on engineering calibrated tool that aided in the process of compiling wind speed and pressure in a wind tunnel. The compiled data were logged using a software called Arduino shown in Fig. 5 below:

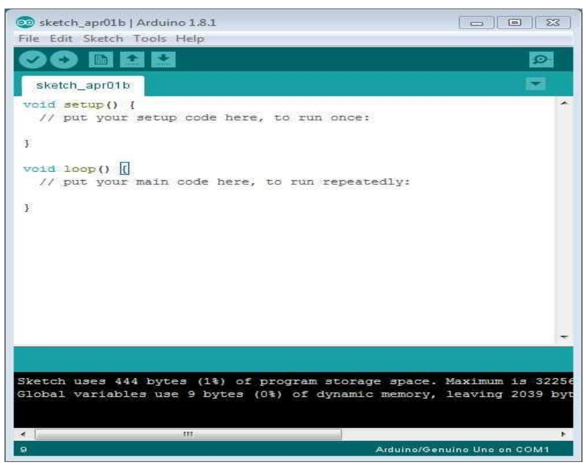

Fig. 5: Arduino Software compiled wind tunnel data

Arduino was an essential tool combine with the ADB that help compiled data from seven pressure sensors. During the experiment it was imperative that a ADB was set up properly with weights on in the wind tunnel with a connected ethernet cord extruded out in connection to a laptop that had Arduino software on ready to log data. One important aspect about the experiment previously mentioned, was that The ADB was commanded to move between [-25°; +25°] for both AoA and SA and to stay at each point for 10 seconds, totaling 121 data points to cover in about 20 minutes. This test was performed for different wind speeds: 10 m/s, 15 m/s, 20 m/s and 25 m/s. The data collected was then saved for post-processing and analysis. The Fig. 6 below give a vivid display on how the experiment was set up.

Fig. 6: Wind tunnel set up

It was quite rewarding after compiling logged data in the wind tunnel to export for further analysis. This table below display logged data pressure sensors extracted from Arduino and used in excel.

Data logged from the 7 pressure sensors									
time	**alpha**	**beta**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
0	0	0	534	524	506	524	525	536	532
0.02	0	0	534	524	506	525	524	534	532
0.04	0	0	536	527	510	529	526	535	533
…	…	…	…	…	…	…	…	…	…
9.98	0	0	533	526	510	531	525	531	532
10	25	25	533	527	514	533	526	530	533
10.02	25	25	533	526	512	530	524	529	532
10.04	25	25	533	524	510	529	524	530	532
…	…	…	…	…	…	…	…	…	…
1209.96	-25	-20	540	523	504	518	525	543	532
1210	-25	-25	543	525	503	515	520	547	533
1210.04	-25	-25	539	520	501	514	519	545	530

TABLE 1: Logged data in the pressure sensors

Preforming a statistical Weibull analysis on the wind speed data [1][3] was not an analytical method performed throughout the data analysis process but was highly considered. The wind speed data was process in excel in compare to the dynamic pressure in KPa or inH2O as shown in table 2.

Date	**6/16/2017**			
Velocity [m/s]	**5**	**10**	**15**	**20**
Dynamic P [KPa]	0.015	0.059	0.134	0.237
Dynamic P [inH2O]	0.060	0.238	0.537	0.954
Time (s)				
0	0.072	0.234	0.558	0.947
50	0.073	0.222	0.567	0.945
100	0.04	0.208	0.554	0.933
150	0.069	0.23	0.53	0.913
200	0.077	0.263	0.523	1
250	0.051	0.208	0.504	1.051
300	0.042	0.21	0.569	0.953
350	0.111	0.267	0.542	0.965
400	0.48	0.237	0.59	0.992
450	0.047	0.269	0.65	0.906
500	0.051	0.241	0.55	1.054
550	0.054	0.225	0.58	0.928
600	0.051	0.223	0.533	1.027
650	0.061	0.262	0.608	0.902
700	0.072	0.248	0.513	0.966
750	0.066	0.234	0.522	0.958
800	0.07	0.235	0.539	0.908
850	0.03	0.254	0.85	1.058
900	0.082	0.212	0.494	0.839
950	0.066	0.238	0.524	0.936
1000	0.079	0.254	0.564	0.952
1050	0.079	0.279	0.54	0.956
1100	0.073	0.294	0.583	0.95
1150	0.081	0.225	0.523	1.053

1200	0.024	0.226	0.559	0.92
1250		0.246	0.515	0.981
Avg. dyn pressure	**0.080**	**0.240**	**0.561**	**0.961**
mps	**5.702**	**9.877**	**15.095**	**19.761**
km/h	18	36	54	72

TABLE 2: wind speed tunnel data analysis.

Thus, after analyzing the data from excel a commanded AoA by ADB vs. the APM or the computer was effectively plotted. Frankly, the commanded SA vs. ADB measured sideslip were computed and analyzed for an effective plot display in Figure 8.

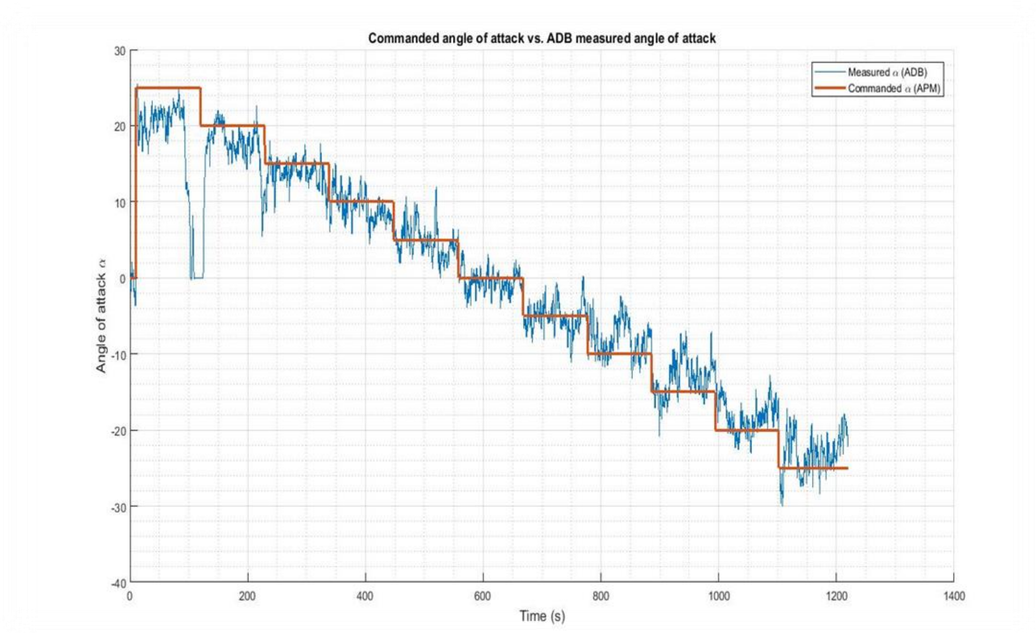

Fig. 7: Shows the measured AoA by ADB Vs. APM or the computer.

According to Fig. 7 above, the data that was gathered from the Air Data Boom (ADB) is the blue up and down line showing how real-life data varies when measuring the angle of attack (AOA) in contrast to the APM or the computer motherboard that convert the data from the (ADB) into an input system that manipulate the data using calibration formulas to obtain the perfect red line that has a steady flow. More importantly, by observing how the red line moves to the right staying constant for 150 seconds you should also know that the sideslip angle is changing for those 150 seconds. Next, it then drops down changing its angle of attack from 25 degrees to 20 degrees and again the Sideslip angle changed for those 150 seconds for every angle of attack.

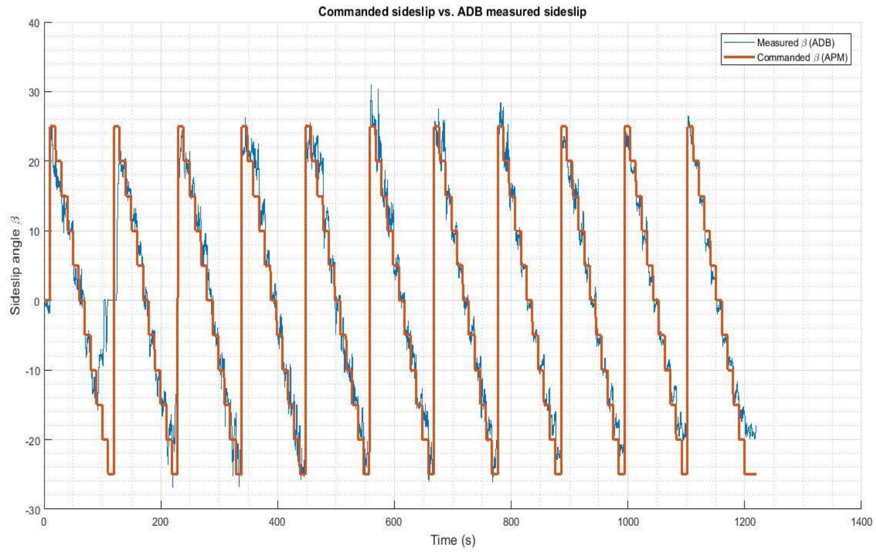

Fig. 8: Displays the measured Sideslip angle by ADB and APM.

Furthermore, Fig. 8 as shown above shows the measured data of sideslip angle using the ADB, represented by the blue line, in comparison with APM or computerize motherboard system, represented the red line.

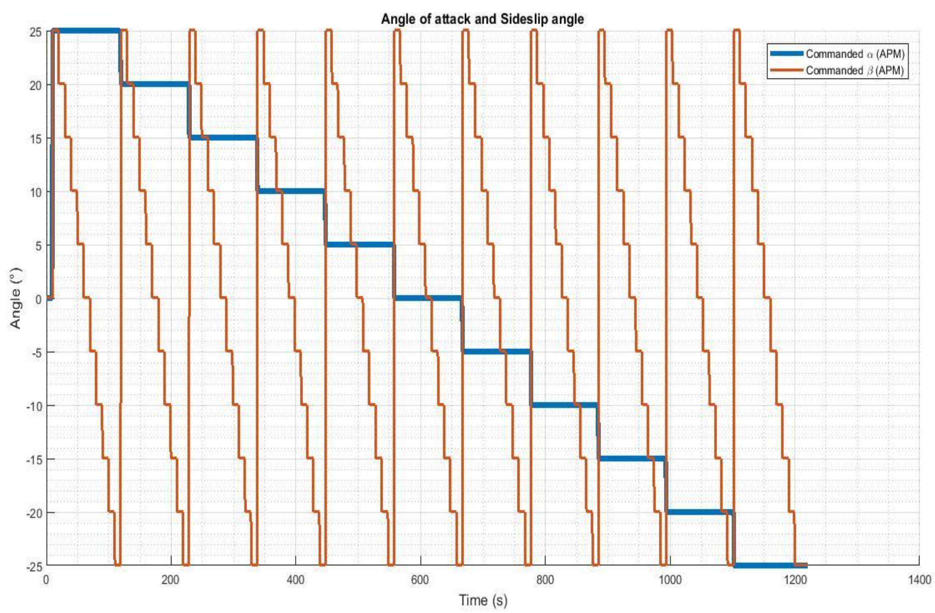

Fig. 9: Shows the AOA and Sideslip Angle data combine

Ultimately, Fig.9 above shows the AOA in comparison to Sideslip angle data measured using the APM or computerized motherboard system. To begin with, the blue line displays the AOA and the red line represent the Sideslip angle. As previously discussed, for every constant line for the AOA, the Sideslip angle changes for a set time interval of about 150 seconds. Then as the AOA transition to a lower angle for a set time of 150 seconds the Sideslip angle reposition itself from its initial starts and then changes for that 150 seconds.

CONCLUSION

Ultimately, the air data boom in the wind tunnel brought clarity to the use of Hall-Effect when it came to analyzing plane performance at each angle of attack and corresponding sideslip angle. The calibration process helped to obtain all the essential data in a method or procedure that were inputted into the motherboard of the plane via connection with the ground station to properly measured the angles in which the plane path of flight operated.

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