Honeywell Oil Chip Detector Housing

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Flow Velocity Analysis

Team B1- Honeywell
Capstone Section 007

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INTRODUCTION

The oil chip detector housing, hereinafter referred to as OCDH, project is a chance for team Honeywell here to design and build a housing for their oil chip detector on a TPE331 turboprop engine. The housing is a relatively simple unit that both holds and the orients the chip detector and controls flow such that the detector's probe sees a specified flow rate range of 1-4ft/s [1]. Key elements of the design include stress, temperature dissipations, and flow analysis.

A flow analysis for this OCDH could be tested in one of two ways: experimentally or computationally. For the purpose of this report, all analysis of the OCDH was completed experimentally. The experimental setup used to find the flow profile in the OCDH included the OCDH, sets of pitot tubes, a dial pressure gauge, and three pressure transducers. Essentially, the setup imitates the oil back pressure and flow rate expected from the inlet and return lines on the actual engine.

The velocity in any pipe flow can be calculated at different points knowing just the dynamic pressure. The pressure taken at the inlet to each pitot tube is a stagnation pressure, or total head, so the dynamic pressure will be derived from Bernoulli's equation [2]:

$$P_e + \frac{1}{2}\rho V_e^2 = P_0 \tag{1}$$

In this equation, the term P_e represents static pressure, $\frac{1}{2}\rho V_e^2$ represents dynamic pressure, and P_0 is the stagnation, or total pressure. Velocity can be derived from the dynamic pressure term in Bernoulli's equation as follows:

$$V = \sqrt{2 \times \frac{\Delta P}{\rho}} \tag{2}$$

Where V is velocity in ft/s, ΔP is the dynamic head in lbf/in^2, and ρ is the density of the turbine oil in lbf/in^3. Also used in the calculations of this experiment for justification of the plotted flow profiles is the formula for Reynold's number [3]:

$$Re = \frac{\rho V d_h}{\mu} \tag{3}$$

Where Re is the Reynolds number, ρ is the density of the turbine oil in lbf/in^3, V is velocity in ft/s, d_h is the hydraulic diameter of the pipe in inches and μ is the viscosity[4] of the turbine oil in reyn.

DATA ACQUISITION APPARATUS

The experimental apparatus required a fair amount of metal fabrication and time spent meshing all items together with a LabView virtual instrument in the thermal-fluids lab. Initial calculations and rough sketches to determine overall dimensions can be found in Appendix A. Original attempts at forming glass manometers were abandoned in favor of the higher resolution pressure transducers (claimed accuracy of 2%). The apparatus, as functioning on the first testing day, is shown below.

Figure 1 – The apparatus(left), with power supplies(middle), and National Instruments data acquisition equipment(right).

The following picture depicts the pitot tube arrangement on the prototype OCDH.
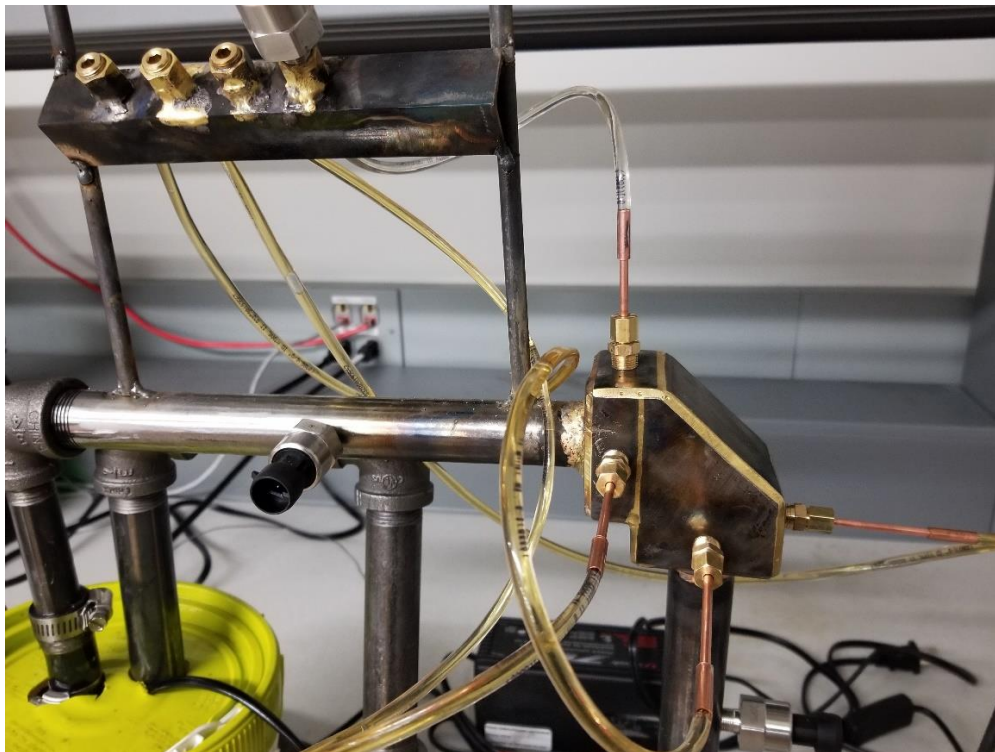

Figure 2- The pitot tube, tapped compression fittings, and the pressure transducer used to record pressures across the OCDH.

The 3/32" inch pitot tubes are adjustable for depth and orientation in the housing. Although practical compromises were made in the placement of the pitot tubes, the data collected will be considered reflective of the flow profile for the inlet and outlet pipes, although the outlet pitot tubes couldn't actually be placed directly in the outlet due to the size of the compression fittings and a 90° bend at the end of the tubes. Pressure measurements were made by moving the pressure transducer, pictured at the top of figure 2, to the different ports and recording the signal voltage each time at a certain depth. All measurements were recorded over a constant static pressure, verified by the dial gauge (claimed accuracy of 1.5%) at the left side of figure 1. The apparatus also has a transducer before and after the housing that could be used to record static pressure fluctuations with time.

RESULTS & DISCUSSION

The actual results of this experimental data acquisition are mixed compared to expected values. One major issue plagued the experiment and was accommodated due to time and budget shortages; two of the pressure transducers immediately failed. As a result, the remaining transducer was used for the pitot tube measurements and static flow head was left solely to the dial gauge. The calibration for the one functioning pressure transducer is recorded as follows:
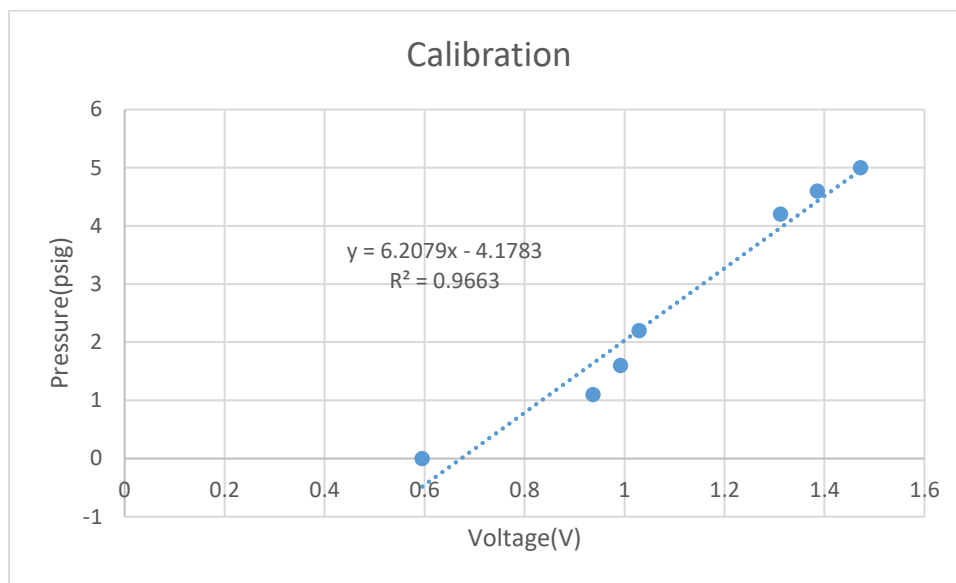

Figure 3- The calibration curve for the transducer used in the pitot tube measurements. The linear regression equation represents the voltage response to known pressures.

The transducer was calibrated against the dial gauge by moving it to the port on the pipe before the OCDH and logging the voltage changes as the pressure was increased to 5psig by closing the globe valve located on the bottom of the apparatus. The curve is short a few points intentionally for fear of burning out the pump, which happened on the first day of testing. A new pump was ordered in and replaced in the apparatus for all remaining measurements. After bringing the system to a steady flow at 1.4 psig static pressure, the following figures were created in excel to visualize the flow velocity at distances offset from the center of the flow using the inlet and outlet pipes as a datum. Raw data can be found in Appendix B.
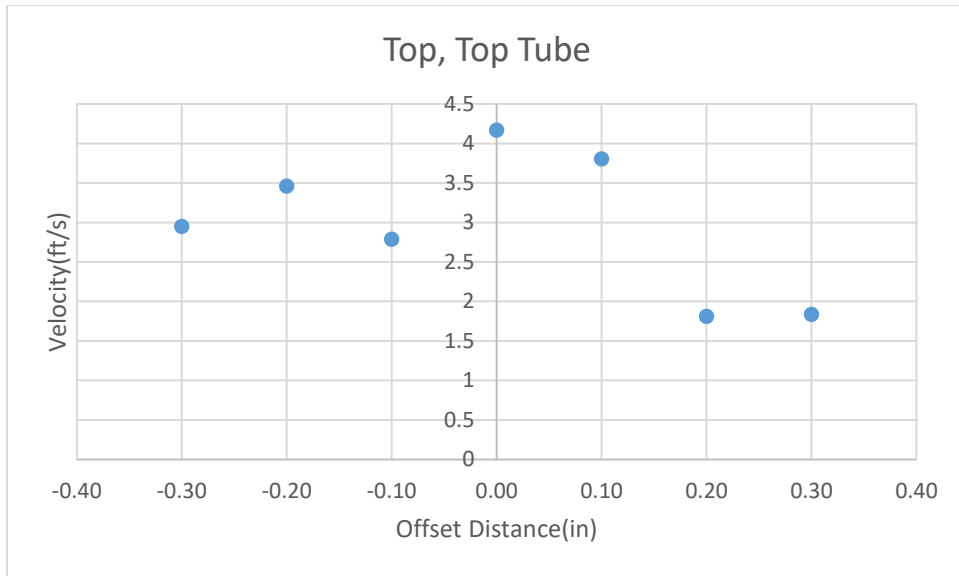
Figure 4 -A plot of the flow velocity at different points measured vertically across the inlet where positive distance values indicate upwards.
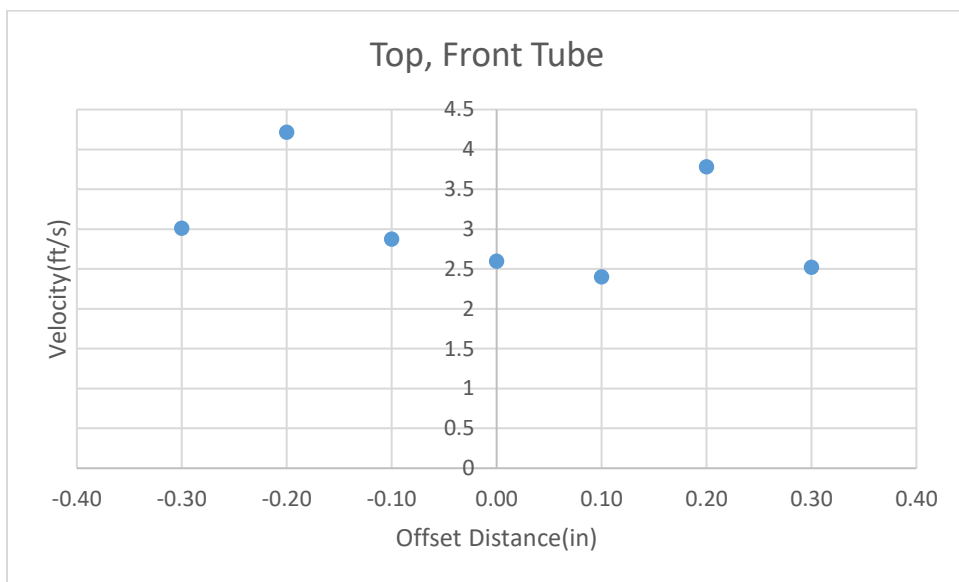
Figure 5 -A plot of the flow velocity at different points measured horizontally across the inlet where positive distance values indicate the right side of the OCDH as viewed from the inlet face.
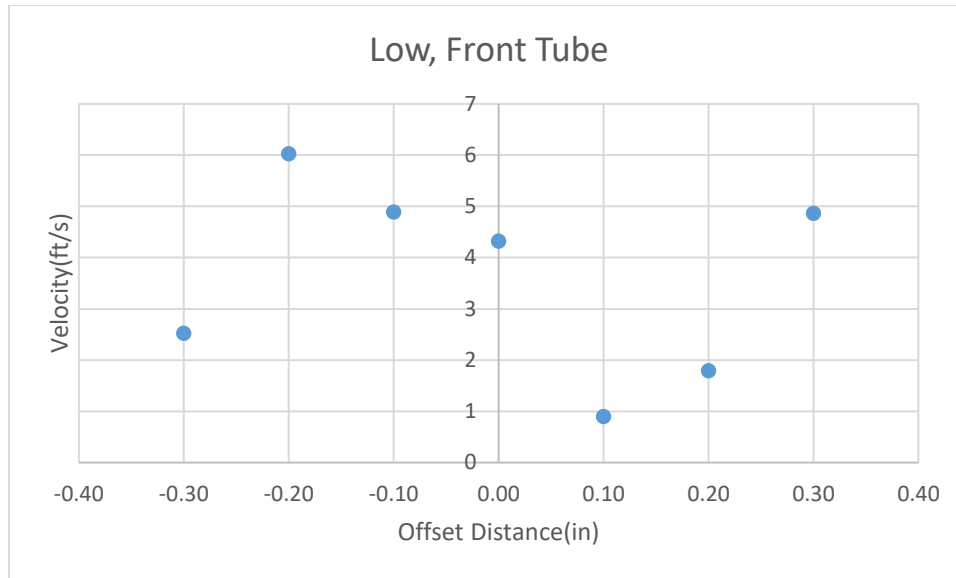
Figure 6 - A plot of the flow velocity at different points measured inwards across the outlet where positive distance values indicate the close side of the OCDH as viewed from the front face.
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One note of significance here: the remaining pressure transducer failed when the oil pump was turned on for the last run of data acquisition. I came back to the lab for a 4th day of testing to try the transducer again, but it was just burned out; the ground wouldn't register so the signal voltage seen by the DAQ card could only be nixed. First off, it's good to see that the velocity ranges are nearly perfectly in-line with the 1-4ft/s goal. This means that if the static pressure of the apparatus is still comparable to the inlet oil line on the engine, the sensor could be mounted on the housing without modification. Estimating the flow profile changes through the OCDH as linear between comparable points on the inlet and outlet, it appears as though the team should plan on keeping the full 1 inch of the probe exposed to the flow.

For the average flow velocity of 3.01±0.37ft/s and hydraulic diameter of 0.75 in, the Reynolds number is 4728±573. Accounting for the uncertainty of the pressure measurements, the Reynolds number is still greater than the Re = 4000 threshold for turbulent flow. Coupled with disturbances caused by the pressure transducer probe sticking into the flow ahead of the OCDH and only a 10 inch run to develop the flow, the high Reynolds number explains the turbulent flow profiles in figures 4,5,6. Therefore, conclusions on the flow profile changes in this experiment will need to verified against the ANSYS and Solidworks simulations, but the overall experiment does verify the overall performance of the OCDH for the designated flow rate again with the velocity ranges satisfying Honeywell's goal.

CONCLUSIONS

Within a reasonable budget (~$200), this experimental apparatus is a sufficient way to go about plotting the flow profile change in and out of the OCDH. The team will also be conducting ANSYS simulations, to which these results can be compared. Ideally, all the pressure transducers would have worked continuously, but the cost of each was $18 compared to the industry standard Omega's budget-friendly transducer price of $180. Considering the flow was turbulent, all data recorded in LabView is perfectly reasonable.

This experiment's impact on the project as it stands will be that the detector can be directly mounted to the OCDH in the current design, This information verifies the prototype's ability to keep the sensor probe within the flow velocity ranges as well as keep the sensor as deep as possible into the housing to maximize the clearance around the OCHD and detector as space is very limited on the side of the engine.

The whole apparatus, of which several breakdown photos are in Appendix C, will continue to be used as the group's physical prototype and presentation centerpiece. Also, it can be adapted for the final design and be used again for presentations next semester. In all, the experimental usefulness of this apparatus is far from depleted and will continue to be used in testing for the team.

REFERENCES

[1] Honeywell, "Procurement Specifications for the Oil Chip Detector Housing," Honeywell Aerospace, Phoenix, 2019.

[2] "Bernoulli's Equation," *Princeton University*. [Online]. Available: https://www.princeton.edu/~asmits/Bicycle_web/Bernoulli.html. [Accessed: 30-Nov-2019].

[3] Engineering ToolBox, (2003). *Reynolds Number*. [online] Available at: https://www.engineeringtoolbox.com/8eynolds-number-d_237.html [Accessed 27 Nov. 2019].

[4] Engineering ToolBox, (2008). *Industrial Lubricants – Viscosities equivalent ISO-VG Grade*. [online] Available at: https://www.engineeringtoolbox.com/iso-vg-grade-d_1206.html [Accessed 27 Nov. 2019].
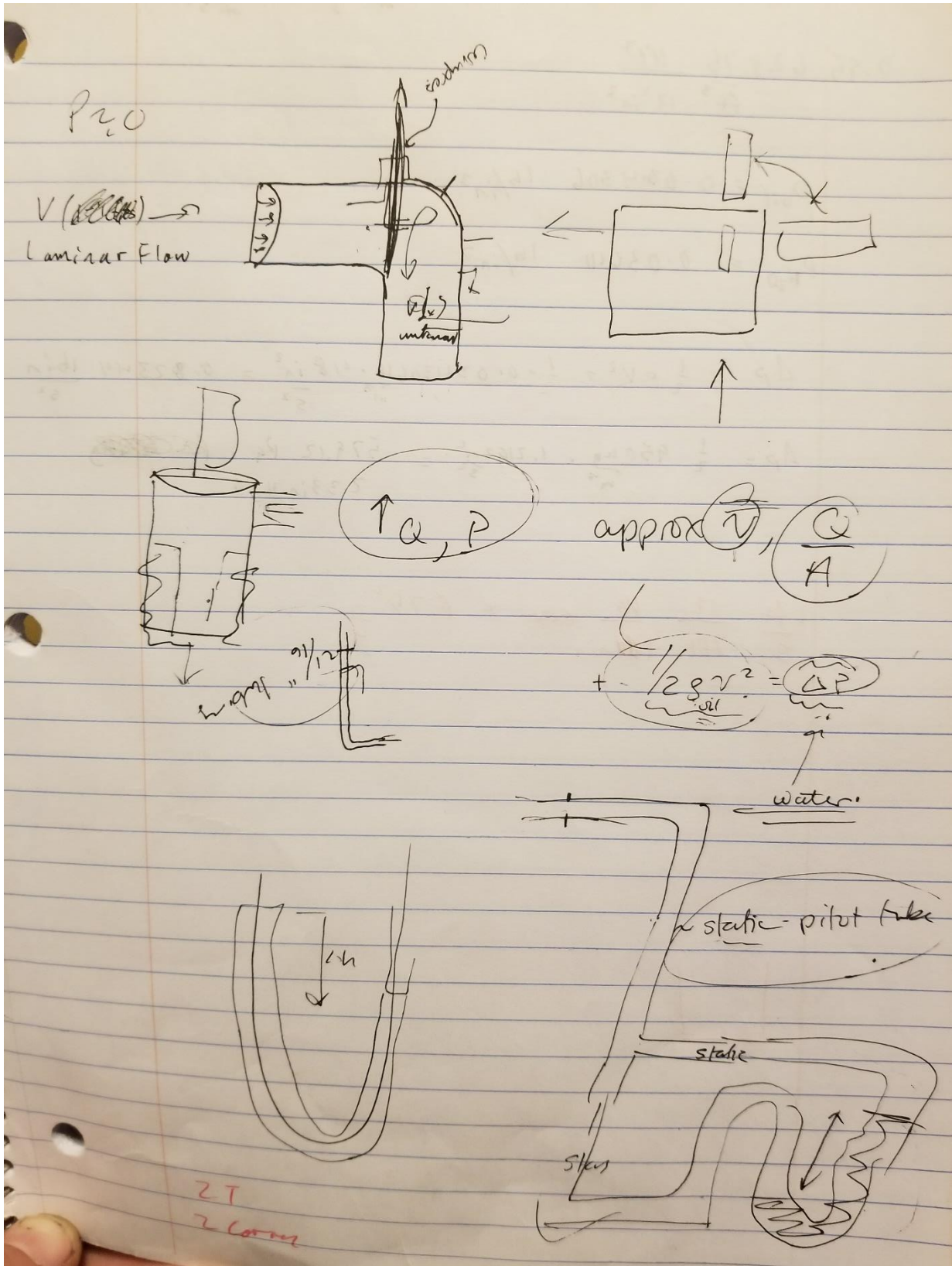
Units   lbs, in, s

$$\frac{kg}{m^3} \cdot \frac{m^2}{s^2} = \frac{kg}{m \cdot s^2} = N$$

$$0.95 \cdot 62.4 \frac{lb}{ft^3} \cdot \frac{1 ft^3}{12^3 in^3}$$

$$\rho_{oil} = 0.034306 \quad lb/in^3$$

$$\rho_{H_2O} = 0.036111 \quad lb/in^3$$

$$\Delta_P = \frac{1}{2} \rho V^2 = \frac{1}{2} \cdot 0.034306 \frac{lb}{in^3} \cdot 48 \frac{in^2}{s^2} = 0.82344 \frac{lb \cdot in}{s^2}$$

$$\Delta_P = \frac{1}{2} \cdot 950 \frac{kg}{m^3} \cdot 1.2192 \frac{m^2}{s^2} = \frac{579.12 \ Pa}{2.33 in \ H_2O}$$

$$\frac{1 ft}{s} \cdot \frac{ctin}{1 ft} \cdot \frac{lbs}{1 \ min} \times 0.75^2 \frac{\pi}{4}$$

1.055

6-

$\frac{3}{4} = \frac{24}{32}$

= 8 measurements

2.07"

7/32

0.6"   0.8"

0.12

0.63"

Top

↑

0.55"

$\frac{4'' - 0.55 - 1.055}{2} =$

0.67
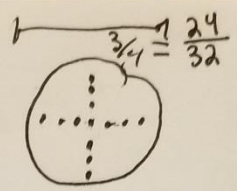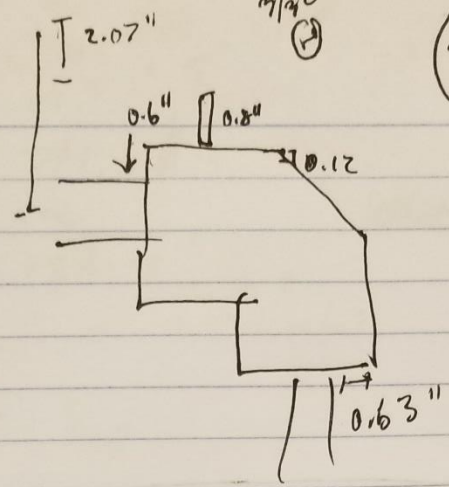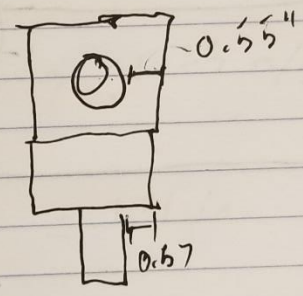
T_{op} Top

then Moving the Pitot Tubes inwards = negative

B

Top Top	Distance	Voltage	PSIG	Static	Delta	Velocity		Average Velocity(ft/s)	3.015712
3	0.30	0.906827	1.452821	1.4	0.052821	1.835449		Viscosity(reyn)	0.000015
2	0.20	0.906612	1.451488	1.4	0.051488	1.812133		Roe(lb/ft^3)	0.031359
1	0.10	0.934869	1.626954	1.4	0.226954	3.804573		Characteristic Length(in)	0.75
0	0.00	0.942211	1.672547	1.4	0.272547	4.169254		Reynolds Number	4728.41
-1	-0.10	0.917958	1.521941	1.4	0.121941	2.788771			
-2	-0.20	0.928534	1.587618	1.4	0.187618	3.459189		Gauge Accuracy	0.015
-3	-0.30	0.920259	1.53623	1.4	0.13623	2.947636		Transducer Accuracy	0.020
Top Front								Static Average	1.4
3	0.30	0.914396	1.499828	1.4	0.099828	2.523264		Dynamic Average	1.581
2	0.20	0.934445	1.624325	1.4	0.224325	3.782479		Static Uncertainty	0.1011
1	0.10	0.912861	1.490295	1.4	0.090295	2.399773		Dynamic Uncertainty	0.02
0	0.00	0.915373	1.505889	1.4	0.105889	2.598742		Velocity uncertainty	0.37
-1	-0.10	0.919161	1.529417	1.4	0.129417	2.87298		Re Uncertainty	572.70
-2	-0.20	0.943171	1.678507	1.4	0.278507	4.214594			
-3	-0.30	0.921214	1.542162	1.4	0.142162	3.011127			
Low Front									
3	0.30	0.958093	1.77117	1.4	0.37117	4.865457			
2	0.20	0.890183	1.349469	1.4	0.050531	1.795214			
1	0.10	0.900364	1.41269	1.4	0.01269	0.899622			
0	0.00	0.945533	1.693179	1.4	0.293179	4.324182			
-1	-0.10	0.95874	1.77519	1.4	0.37519	4.891738			
-2	-0.20	0.989999	1.969299	1.4	0.569299	6.025703			
-3	-0.30	0.914409	1.499905	1.4	0.099905	2.524246			
Low Side									
3	0.30	-0.01644	-4.28042	1.4	-5.68042	#NUM!			
2	0.20	0.009273	-4.12072	1.4	-5.52072	#NUM!			
1	0.10	0.014449	-4.08858	1.4	-5.48858	#NUM!			
0	0.00	-0.02469	-4.3316	1.4	-5.7316	#NUM!			
-1	-0.10	0.023252	-4.03391	1.4	-5.43391	#NUM!			
-2	-0.20	0.000277	-4.17658	1.4	-5.57658	#NUM!			
-3	-0.30	-0.00125	-4.18604	1.4	-5.58604	#NUM!			

C