PRESSURE SIGNATURES BENEATH AIRCRAFT

Final Report

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Abstract

This project sought to explore the use of a pressure transducer system to detect the arrival of landing aircraft and give information regarding the aircraft weight class. Where the NASA Wake-Vortex studies currently require a human presence to trigger data collection, an autonomous aircraft detection method would provide a more robust means of data collection. A weather-resistant pressure transducer system was developed and employed at Logan International Airport in order to determine whether or not a pressure signature was measurable. Results showed that a distinct pressure signature was reliably detectable, and that for most cases, the pressure signature and estimated altitude could predict the weight class of the aircraft. The use of a pressure transducer system would provide a robust, reliable method for detecting the arrival of landing aircraft and could be used in the future to trigger data collection for wake-vortex and other studies.

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1.0 Background and Motivation

As the need for joint FAA-NASA wake vortex studies increases, there exists an even greater need for the incorporation of an autonomous aircraft detection scheme. At present, much of the wake vortex work requires that sensors collecting data be on and recording at all times. If a reliable, all-weather detection system were in place, when an aircraft is detected, the sensors being used for wake vortex studies could be triggered and collect data only when necessary. This would reduce human time and effort spent collecting data, and it would also provide a more reliable means of data collection. With a more reliable means of data collection, the FAA-NASA wake vortex studies will have a better understanding of aircraft wakes. This in turn will make future air travel safer, as worldwide air traffic continues to increase.

Prandtl and Tietjens[1], proposed a theory for the transfer of aircraft weight to the surface of the earth modeled by the aircraft vortex system. The theory indicates that there should be a pressure rise beneath the aircraft that is proportional to the weight and dependent upon the height of the aircraft and the radial distance from the aircraft.

2.0 Hypothesis/Objectives/Success Criteria

The hypothesis for this project is that landing aircraft have a pressure signature that can be used to detect an aircraft's arrival and give information regarding the weight class of the aircraft. The primary objective of the project is to determine the measurability of the pressure signature beneath landing aircraft. If the pressure signatures recorded by the pressure transducer system are accurate and reliable, then a secondary objective of the project will be to extract the weight class of the aircraft from the associated pressure signature. The project will be a success if it is determined whether or not the pressure signature of a landing aircraft can be measured given different weather conditions and variations in aircraft position.

3.0 Literature Review

In 1972, Sullivan and Burnham published a paper entitled “Ground Wind Vortex Sensing System Calibration Tests.”[2] The research described in the paper is based on work completed concerning thetracking and detection of aircraft vortices. To detect aircraft vortices, Sullivan and Burnham used a pressure sensor that enabled them to detect the pressure rise caused by a passing aircraft. In attempting to detect the vortices associated with the aircraft, they succeeded in detecting the presence of the aircraft itself.

The research was conducted with a differential pressure sensor that consisted of instantaneous ambient pressure vessel and an average ambient pressure vessel. Data collected by the pressure sensor was used qualitatively to examine the pressure signatures of landing aircraft. Sullivan and Burnham were able to determine aircraft arrival time and, from measuring the difference in time between peaks of different pressure sensors placed at different locations, they were able to find some indication of flight speed.

By placing pressure sensors at different distances from the flight path, they were also able to see decay in the pressure signal amplitude. This information supports the analysis by Prandtl and Tietjens on the distribution of pressure beneath an aircraft.[1]

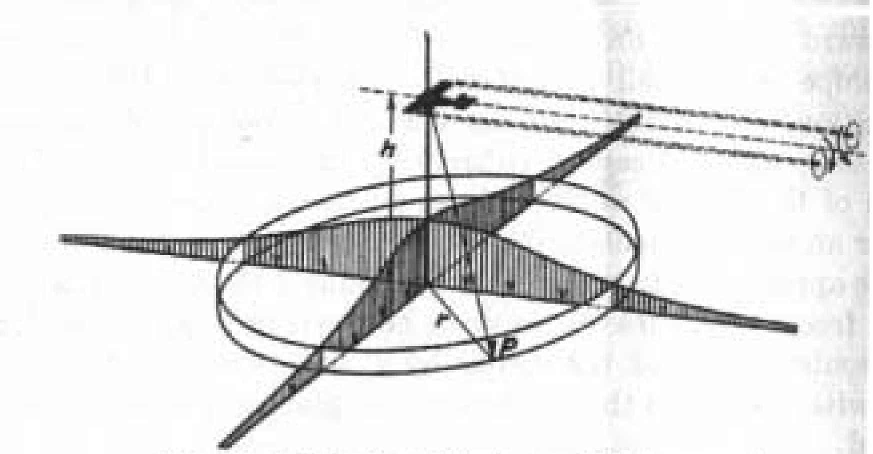

FIG. 150.—Transfer of airplane weight to ground.

Figure 1: Theorized Pressure Distribution[1]

Figure 1, taken from Prandtl and Tietjens[1], shows the predicted pressure distribution decreasing with increasing radial distance, “r,” beneath the aircraft.

The problems associated with the research conducted by Sullivan and Burnham dealt with interrupted pressure signals caused by leaks in the average ambient pressure vessel and by the effects of wind.

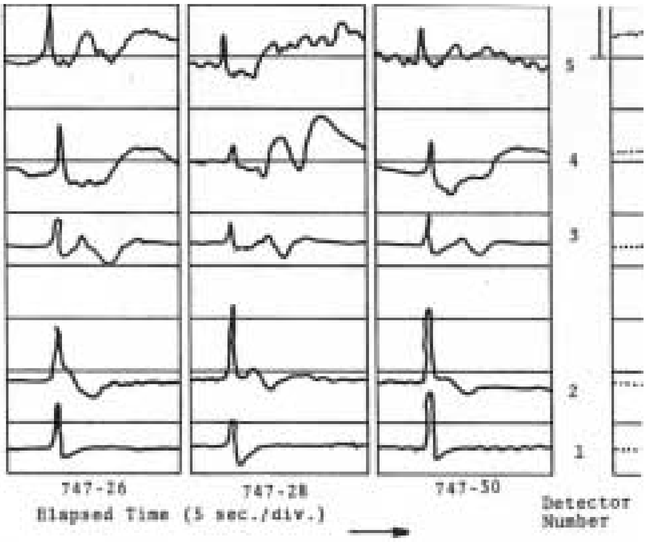

Figure 2: Pressure Signatures of Boeing 747s[2]

Figure 2 shows some of the data collected by Burnham and Sullivan on three Boeing 747s. Traces one through five correspond to five different pressure sensors. The predicted pressure change caused by an overhead aircraft is a single pressure pulse that reaches a maximum when the aircraft is directly overhead. Figure 3 depicts the expected pressure rise for a 747 aircraft at 20 meters landing altitude, as predicted by the Prandtl and Tietjens theory.

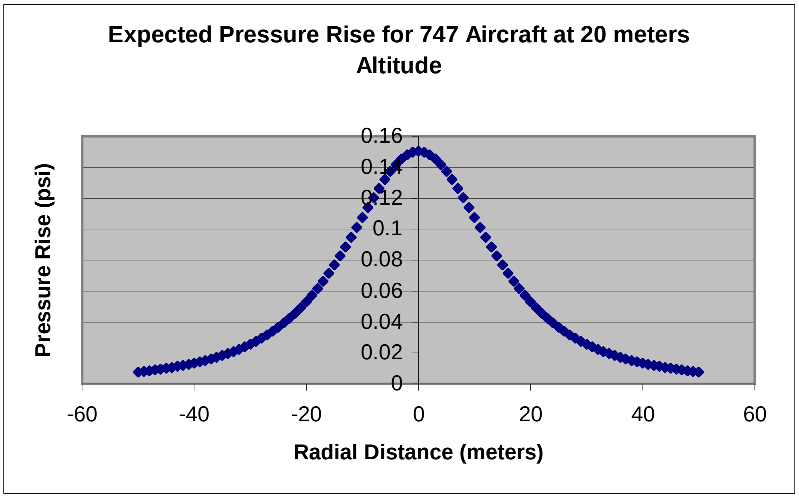

Figure 3: Expected Pressure rise for 747 Aircraft

The data collected in the Sullivan and Burnham study shows how much effect the environment can have on the pressure readings. Leaks in the average ambient pressure vessel caused the time constants of the sensor to be too short to ensure a full response to the aircraft pressure. Windy conditions while collecting data caused interference on the pressure signal related to landing aircraft, which makes the data difficult to interpret.

The research conducted by Sullivan and Burnham fell short of being an adequate measure of how well a pressure transducer can be used to detect aircraft. The data they collected had several problems associated with it, and they did not pursue work in this area to determine whether or not these shortcomings could be addressed. Therefore, whether or not the winds can be blocked from affecting data collection and whether or not a more advanced pressure transducer system would make the aircraft detection system more viable is not yet known.

Although Sullivan and Burnham conducted the only field research on the pressure signature beneath an aircraft, other helpful work has been carried out by Dr. Frank Wang.[*] Dr. Wang, through the Volpe Transportation Center, has made connections with people at the JFK International Airport that will allow for further research to be conducted there. Dr. Wang has also looked at candidate pressure transducers to get an idea of where a transducer can be found with the appropriate specifications for further research.

The previous work done on this topic provides a firm base for aircraft detection via pressure sensors. Sullivan and Burnham have already helped to highlight the ability to use a pressure sensor to detect an associated pressure signature for landing aircraft. Prandtl and Tietjens theory reveals the ideal pressure signature and, therefore, the inaccuracies of Sullivan and Burnham’s data due to wind effects and equipment shortcomings. From the knowledge gathered from these two sources, a modified transducer system can be implemented to yield more accurate and reliable results.

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[*] Personal communication with Dr. Frank Wang

4.0 Summary of Proposed Project and Expected Value to Scientific Community

The intention of this project is to use a pressure transducer at a well-trafficked airport where there will be a variety of aircraft in different weight classes. The team also expects different weather considerations and possible variance in lateral and vertical location of the pressure transducer with respect to landing aircraft. The measurability of the theorized pressure rise will be assessed in this real-world operational environment, as well as the potential of the pressure signature for providing the weight class of an aircraft. If a means of easily measuring the pressure signature of an aircraft is devised, then a low-cost method of detecting landing aircraft may be possible. This will make data collection for the FAA-NASA Wake Vortex Studies more efficient and accurate.

5.0 Experimental Overview

The project took place in three main testing phases. Phase I testing, which took place in the Wright Brother's Wind Tunnel, Intermediate Phase testing, in which testing was done at Hanscom Airforce Base, and phase II testing, which was conducted at Logan Airport.

6.0 Phase I Testing Approach

From Sullivan and Burnham's work it was clear that reducing wind effects would be necessary to obtain useful data. The purpose of phase I testing was too use the Wright Brother's Wind Tunnel to determine which method of mitigating wind effects would be the most optimal for Phase II testing. Four main wind reduction methods were tested and included using a wind housing box, an acoustical microphone wind screen, the addition of a modified lid to the housing, and all possible combinations of these.

6.1 Phase I Test Apparatus

In order to measure the pressure changes associated with changes in wind speed in the wind tunnel, a pressure transducer was acquired. The pressure transducer that was used was a Series 760-16B Field Standard from Paroscientific, Inc. The transducer is digital and came with a laptop interface and its own software. It also had an internal battery capable of operating for forty hours, which would allow for long term field testing. This transducer has a pressure range from 11.5 to 16 psia. This is an adequate range for collecting data for the project because the expected maximum pressure rise is 0.16 psi (pressure rise associated with a Boeing 747-400 at an altitude of 20 meters).

Figure 4: Selected Pressure Transducer

Figure 4 shows the pressure transducer that will be used in the project. Further information on the pressure transducer can be found in Appendix C.

To mitigate the effects of wind on the pressure transducer, various methods of wind reduction were proposed. The first of these was the use of a box housing with no top, which places the transducer in a cavity. The underlying principle was that the housing would block sharp pressure changes caused by wind gusts while allowing for the pressure rise of an overhead aircraft to still be measure accurately. However, the team expected that cavity noise would pose serious problems. Therefore, it was necessary to test different sized box housings in order to determine how large the final housing should be to keep the noise levels sufficiently low.

Cardboard boxes of three different sizes were chosen to test this technique of wind mitigation, because they were readily available and easily transportable to and from the Wright Brother's wind tunnel. The different sizes were denoted small, medium, and large during the testing. The small box measured,14"x13"x10", length, width, and depth respectively. The medium box measured, 15"x14.5"x17", and the large box measured, 20"x20"x22".

The second method tested for wind mitigation was the use of acoustical microphone wind screens around the pressure transducer. It was suspected, from personal experience with microphones, that a wind screen would dampen the effects of wind. It was anticipated that the microphone screen would accept noise and suppress the effects of wind. This can be easily understood by considering a singer whose words are clearly heard, but the intermittent breathing is not.

To adequately determine how the wind screens would affect the pressure transducer, two different sizes of wind screen were purchased. These different sizes were tested to indicate whether or not the wind screen was dampening all pressure signals and not just wind changes Dampening all pressure signals would be detrimental to phase II testing in that it could affect the pressure signature left by landing aircraft. Figure 5 depicts a typical microphone wind screen.

Figure 5: Microphone Wind Screen

The third method tested for wind mitigation was the use of a modified lid on the housing surrounding the pressure transducer. This lid had several randomly placed holes with diameters of approximately three inches to allow for the pressure changes to be felt inside the box while reducing the effects of cavity noise. The holes were placed randomly because understanding the underlying physics behind the possible reduction of cavity noise by this method was deemed beyond the scope of the project. This method of wind reduction was denoted the “swiss cheese” method.

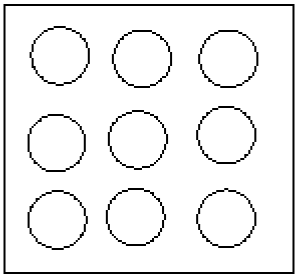

Figure 6: “Swiss cheese” method lid

As mentioned previously, all of the phase I testing was completed in the Wright Brother’s Wind Tunnel at MIT. This facility was chosen because of the relative ease with which wind speeds could be altered and controlled to simulate expected phase II testing conditions. Using this facility also allowed the project team to work with the aid of Dick Perdichizzi, an MIT laboratory technician.

6.2 Scope of Phase I Testing

Phase I testing was developed to determine which wind reduction method would work best for this project and was not intended for determining how or why wind reduction techniques work. The wind mitigation techniques tested were based on ideas developed from personal experiences in everyday life and not from rigorous theoretical considerations.

6.3 Phase I Testing Method

In the Wright Brother’s Wind Tunnel, the team tested wind reduction methods at different wind speeds. For each method, wind speed was increased incrementally from zero wind velocity to ten knots, then fifteen knots, and finally twenty knots. Figure 7 depicts the test matrix for the Phase I testing. It is important to note that the small, medium, and large housings were also be tested with the “swiss cheese” method lid.

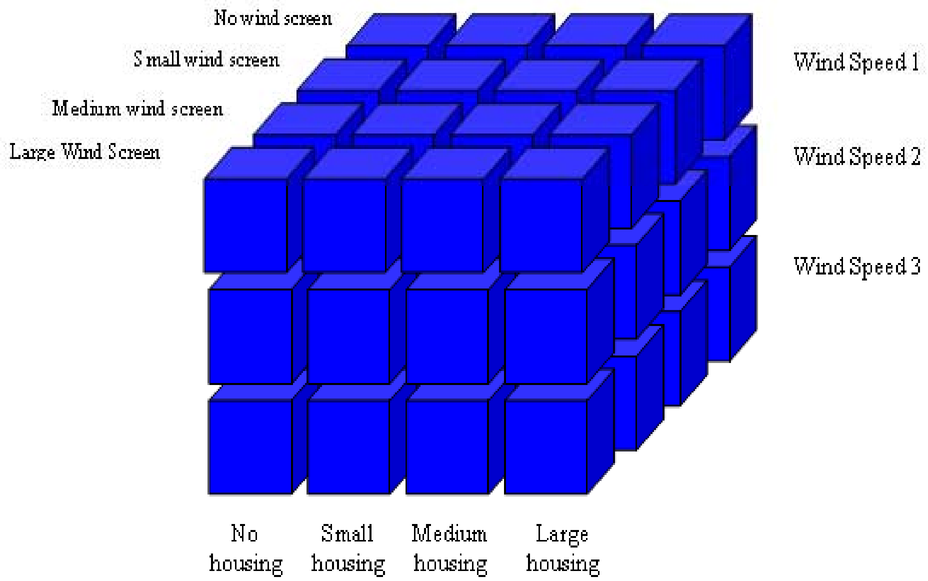

Figure 7: Phase I Test Matrix

The various pressure transducer systems were placed in the center of the wind tunnel in such a way to minimize possible noise effects of the wind tunnel. It was expected that the pressure transducer would track a drop in static pressure. The pressure transducer system that most accurately tracked this decrease in pressure while minimizing any outside effects would be selected.

6.4 Phase I Results

Based on the Phase I testing, the team selected the medium-sized housing along with the “swiss cheese” lid method. Figure 8 shows a comparison between pressure readings for the case in which there was no wind housing and no wind screen, and the case in which there was a medium wind housing, medium-sized wind screen, and the “swiss cheese” method.

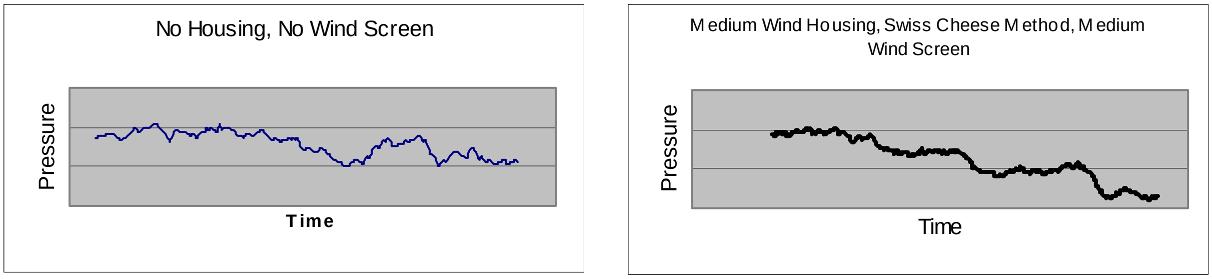

Figure 8: Wind Reduction Method Comparison

The results presented in Figure 8 are on similar time and pressure scales, however, the actual numbers have been removed for readability. As the graphs show, the chosen pressure transducer system did a much better job of tracking the decrease in static pressure.

The medium-sized housing provided comparable results to the large-sized box and would allow for easier transportability, a key factor in getting to Hanscom and Logan airport for Intermediate and Phase II testing. The team was unable to make a decision regarding the effectiveness of the microphone wind screen. Though it helped to improve results, it was unknown whether or not the wind screen would dampen the results of passing aircraft. The team decided to further test this during the Intermediate Phase testing at Hanscom Airforce Base.

7.0 Intermediate Phase Testing Approach

The inconclusive results of Phase I testing on the use of microphone wind screens made it necessary to continue wind screen testing in an operational environment more similar to Logan Airport. Therefore, the Intermediate Phase testing took place at Hanscom Airforce Base. The immediate goal of this testing phase was to determine whether or not a microphone wind screen should be used during Phase II. The team also hoped to expose any problems with the experiment in a fully operational environment prior to the actual Phase II testing.

7.1 Intermediate Phase Test Apparatus

In testing at Hanscom Airforce Base, one of the problems that the team recognized was that jet-blast would pose a new challenge that would not be encountered at Logan International Airport. Because Hanscom Field had only one runway on which both take-offs and landings would be occurring, jet-blast from aircraft taking off might have potentially destroyed the pressure transducer housing. The wind housing selected from Phase I testing would have to be constructed out of plywood. Figure 9 depicts the pressure transducer housing setup used during the intermediate phase. The medium housing has been placed on a 4’x6’ baseboard that has been loaded with seven cement blocks, weighing 20 pounds each. The baseboard along with the added weight kept the housing stable during the testing.

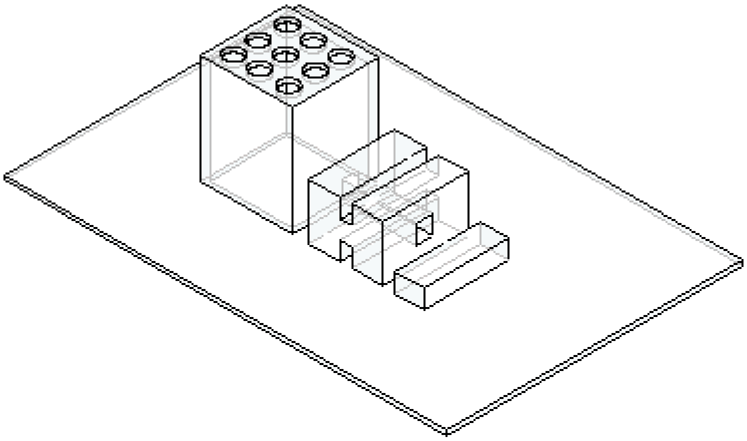

Figure 9: Hanscom Airforce Base Transducer Setup

The figure also shows the pressure transducer housing with its “swiss cheese” lid and the seven cement blocks weighing it down on the plywood baseboard. The plywood housing was constructed in the Gelb Laboratory with the aid of Dave Robertson and Don Weiner. For a detailed engineering drawing of this setup refer to Appendix B.

The team also had to order 150 feet of RS-232 cable to attach the laptop computer to the pressure transducer that was located at the runway centerline, approximately fifty feet from the runway threshold. Although the pressure transducer was capable of operating for forty hours on an internal battery, the laptop would only operate for two to three hours. Therefore, the team connected an AC/DC inverter to an on-site vehicle to power the laptop computer for the duration of the Hanscom testing.

The microphone wind screens used in the Intermediate Phase were the same as those used in Phase I testing. These screens needed to be retested to determine if they were dampening out the pressure signatures of overhead aircraft.

For Hanscom testing, the team was unable to procure a laser range finder. To account for this, the team was estimating the landing altitudes.

On-site, the team was accompanied by a Hanscom employee for safety reasons. However, he did not interfere with the testing in any way. During testing, the tail numbers of landing aircraft were recorded, along with landing time to coordinate the data. Keith Leonhardt, who worked with the team at Hanscom, later sent a file matching the tail numbers to aircraft types.

7.2 Scope of Intermediate Phase Testing

The majority of landing aircraft at Hanscom Airforce Base fall into the small weight class. However, because the team was focusing on the use of the microphone wind screens, this did not pose much of a problem. The other aim of the Hanscom testing was to expose possible problems that the team would face during testing at Logan. One of these problems that was highlighted through Intermediate Phase testing was the sampling rate of the pressure transducer. Due to software limitations at the time, the team was unable to increase the sampling rate of the pressure transducer over 1.5 hertz.

7.3 Intermediate Phase Testing Method

For Intermediate Phase testing at Hanscom Airforce Base, the project team was located in an on-site vehicle approximately 150 feet from the runway threshold. The pressure transducer system was placed at the runway centerline, approximately fifty feet from the runway threshold. The team was on-site recording data for three hours. Halfway through the testing, the wind shifted, and the team moved to the other side of the runway where landings where to occur for the rest of the day. Over the course of the day, the team recorded data for 18 aircraft. These aircraft ranged in mass from 1,200 to

25,000 kilograms. The altitude, which was estimated by the experimenters, ranged from ten to fifty meters.

7.4 Intermediate Phase Results

Based on the Intermediate Phase testing, the team was able to collect promising data and was also able to highlight a number of shortcomings. Figure 10 depicts the pressure data collected during Intermediate Phase testing for a Gulfstream IV aircraft.

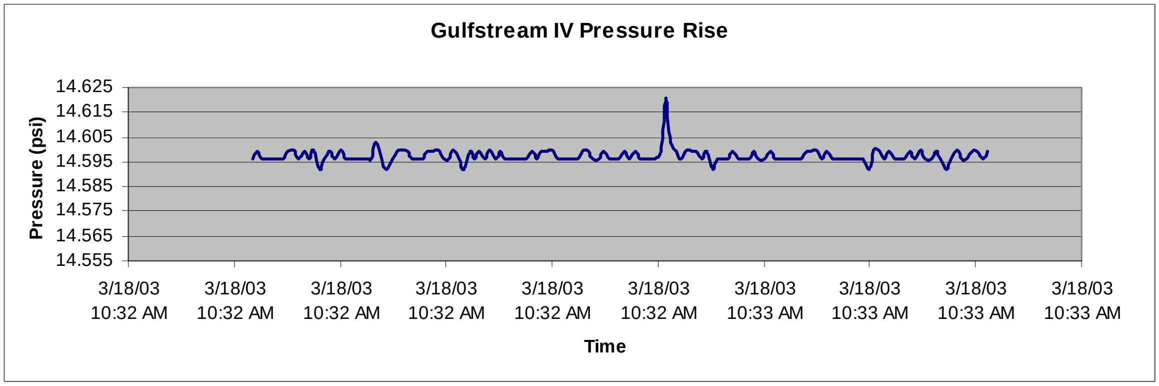

Figure 10: Pressure Rise for Gulfstream IV Aircraft

The team estimated the landing altitude to be approximately 15 meters. The associated pressure rise was approximately 0.0205 psi. Based on these numbers, the team estimated a landing mass of 20,369 kilograms. The approximate landing mass of a Gulfstream IV aircraft is 20,000 kilograms. The data showed that not only could a pressure transducer system record pressure data beneath landing aircraft, but that the data could be used to find an approximate landing mass.

Based on the tests, the team decided not to use the microphone wind screen. It provided negligible benefits, and whether or not it would dampen aircraft pressure signatures was still unknown.

One problem exposed by the Hanscom testing was the need to significantly increase the sampling rate of the pressure transducer. Due to the slow sampling rate of 1.5 hertz, the team was unable to record a pressure rise for some smaller aircraft. Based on calculations, it was found that an aircraft could pass over the pressure transducer system in less than one second. Without a larger sampling rate, the team might not be to determine the maximum pressure rise. However, before Phase II testing at Logan, by switching software, the team was able to increase the sampling rate to 12 hertz.

8.0 Phase II Testing Approach

The bulk of the data in assessing the hypothesis was to be collected at Logan International Airport, where a variety of aircraft in different weight classes could be assessed in a real-world operational environment. The results from the Logan experimentation would determine whether a pressure transducer system could be used to reliably predict aircraft arrival and if pressure data could be used to determine landing aircraft weight class.

8.1 Phase II Test Apparatus

The Phase II testing apparatus was similar to that used on-site at Hanscom Airforce Base. The team was able to acquire a laser range finder through the Volpe Center. This was connected to a car battery, which would provide power for the duration of the testing period. The range finder was housed in a protective casing to guard the sensitive optical lenses. The team was unable to reconfigure the properties of the laser range finder, so a maximum sampling rate of 3 hertz was recorded.

The pressure transducer housing system used during Phase II testing was very similar to that used at Hanscom Airforce Base. For the Phase II testing the baseboard was not as large because there was no need to worry about aircraft taking off therefore there was also no need for the cement blocks. However, the car battery and laser range finder, which had a combined weight of fifty pounds, were placed atop the plywood base to anchor it firmly to the ground.

The Phase II wind housing can viewed in figure 11.

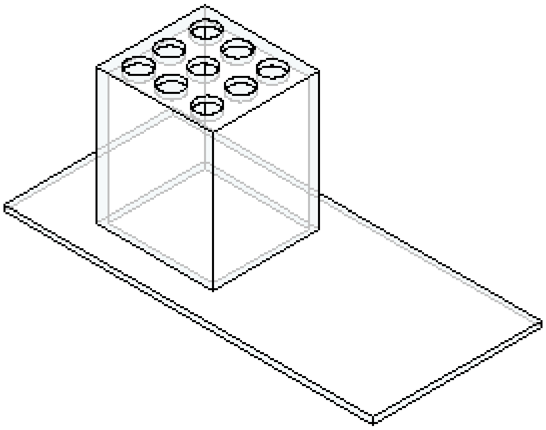

Figure 11: Logan transducer housing setup

The figure shows the wind housing on one end of the plywood baseboard. The laser range finder and range finder battery were placed on the other end. For a detailed engineering drawing of the Logan transducer housing setup, refer to Appendix B.

The pressure transducer system and laser range finder were to be located on the runway centerline, approximately 50 feet from the runway threshold. Picture 1 depicts the pressure transducer, laser range finder, and battery as set up during testing.

Picture 1: Pressure Transducer Housing System, Laser Range Finder, and Battery

The team would be located approximately 250 feet from the equipment. In order to connect both the laser range finder and the pressure transducer to the laptop to accurately correlate the data, an additional 350 feet of RS-232 cable had to be purchased, so that both pieces of equipment could be connected to the laptop computer. The laptop computer did not have an additional RS-232 port, so the team used a Keyspan device to convert the second cable to a universal serial bus (USB) cable type. The 250 feet was well within the operating limits of the RS-232 cable. An extension cord was used to provide power to the laptop computer from the on-site safety vehicle.

Picture 2 depicts the entire setup at Logan Airport. The pressure transducer system, laser range finder, and battery can be seen in the distance. In the foreground, Doug Allaire is seen recording the aircraft tail number near the laptop computer, which is recording the data for the landing aircraft.

Picture 2: Complete Logan Test Setup

8.2 Scope of Phase II Testing

The main goal of the Phase II testing at Logan International Airport was to characterize the pressure signature beneath landing aircraft and to attempt to quantify any associated pressure rise. This was to be conducted in a real-world environment, similar to what would be encountered if used in the NASA Wake Vortex Studies. It was also meant to experience typical on-site situations, including a variety of wind conditions and varying degrees of lateral offset in landing aircraft. Precipitation conditions were not recorded as they were beyond the scope of the project. The overlying goal was to reliably detect a pressure signature for all types of landing aircraft. The secondary goal was to determine whether this pressure signature could give information regarding the weight class of the landing aircraft.

8.3 Phase II Testing Method

For Phase II testing, the team was on-site collecting data at Logan Airport for approximately five hours. During this time span, the team collected data for thirty-four aircraft. The team began the day collecting data for aircraft landing at runway 33L. After approximately three hours of data collection, the wind shifted and the team moved to runway 4R to continue tracking landing aircraft. The landing masses ranged from 2,500 to 199,000 kilograms. At runway 33L, the laser range finder recorded a range of landing altitudes of fifteen to twenty-one meters. At runway 4R, the range finder recorded a range of altitudes from thirty-six to forty-six meters.

On-site, the team members had a variety of roles. Aircraft tail numbers were recorded for ease of comparison at later stages of data analysis. These tail numbers would be used to determine aircraft type and then correlated with aircraft types found via an online tool that tracks Logan air traffic. Pictures were taken of each landing aircraft to clear up any resulting inconsistencies. Also, data acquisition was triggered by turning data logging on and off on the laptop, in order to minimize the amount of extra data.

8.4 Phase II Results

Over the course of the day, the team saw thirty-four landing aircraft. The team expected to see more landings, but the early morning testing time was the only data collection period that could be arranged. However, it was found, during data analysis that the small number of planes was enough to adequately assess the project hypothesis.

Table 1 depicts a breakdown of the aircraft landings over the course of the day.

Runway 33L	
Heavy	*0*
757	*2*
Large	*7*
Small	*17*
Total	**26**

Runway 4R	
Heavy	*1*
757	*0*
Large	*1*
Small	*6*
Total	**8**

Table 1: Landing Aircraft Breakdown

In general use, the weight classes are broken down via take-off weight. In order to set ranges for these weight classes for data analysis, the team used the operational empty weight for the smallest aircraft in each of these classes. The operational empty weight of the aircraft is the minimum theoretical weight that a landing aircraft could have. The smallest aircraft used in the large category was the ATR-72 with a minimum operational mass of 19,700 kilograms. Anything lighter than this was assumed to be a small aircraft. Typically, the 757 is included in a weight class of its own, anything lower than the minimum operational mass of the 757 (59,738 kilograms) was considered a large aircraft, and anything above the maximum landing weight of the 757 (89,811 kilograms) was considered a heavy aircraft.

Because the range finder only had a sampling rate of 3 hertz, it was only able to capture altitude data for 13 of the 34 aircraft. However, in a real-world operating environment, a laser range finder would probably not be used. Altitude would be estimated based on a typical three degree landing path. For the landings at runway 33L, the team predicted a landing altitude of approximately eighteen meters at our position using this three degree criteria. Using the average of the data collected for the landings, the team found that the actual landing altitude was 18.14 meters. For the landings at runway 4R, the team expected a landing altitude of 41.9 meters. The average of the range finder data collected returned an altitude of 39.9 meters. The inconsistency of the range finder allowed the team to further test the robustness of the system by analyzing uncertainty in altitude.

Another issue surrounding uncertainty in aircraft altitude is that landing aircraft descend nose up, at an angle to the horizontal, when landing. For this reason, for a number of the landing aircraft, multiple altitude values were returned. In order to account for this, the team averaged the altitude values to attempt to find the approximate altitude of the aircraft's center of mass.

9.0 Analysis of Results

Figure 12 presents a graph of the typical results. The results shown are for an A320 aircraft, landing at approximately 17.56 meters. It can also be seen that the results are similar to those predicted by the theory of Prandtl and Tietjens presented in figure 3.

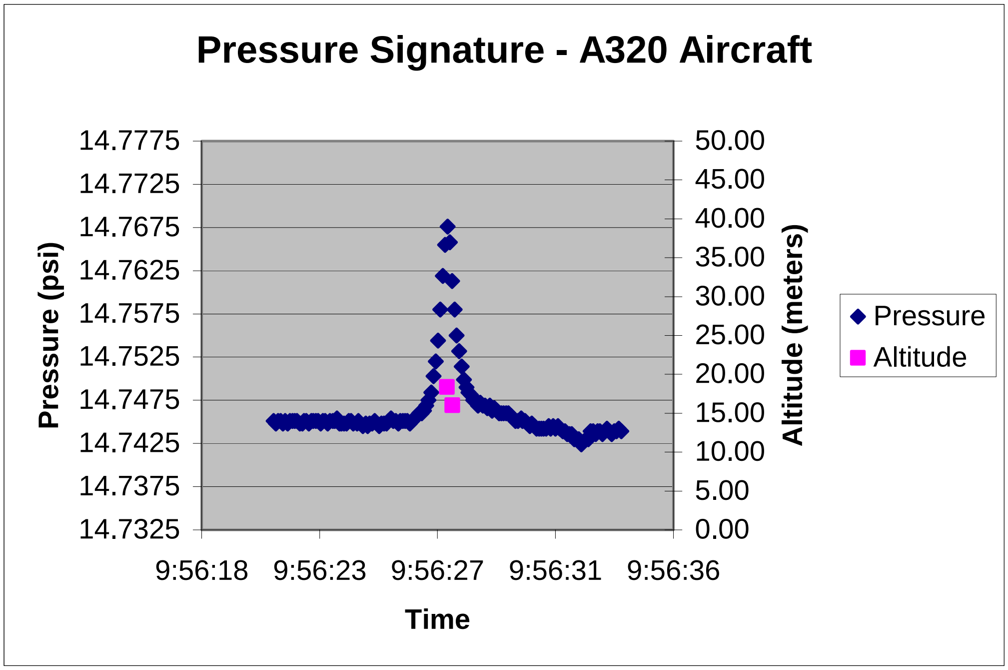

Figure 12: Pressure signature for an A320 aircraft

Upon analyzing the data, the team found that unique pressure signatures had been recorded for each of the aircraft landings that were seen over the duration of the testing process. These pressure rises where identified for landings at both the 33L location, which had an average altitude of approximately 18 meters, and the 4R location, which had an average altitude of approximately 40 meters. The team also recorded data when no landing aircraft where present. Figure 13 presents pressure transducer data recorded in the absence of landings on the same scale as presented in figure 12.

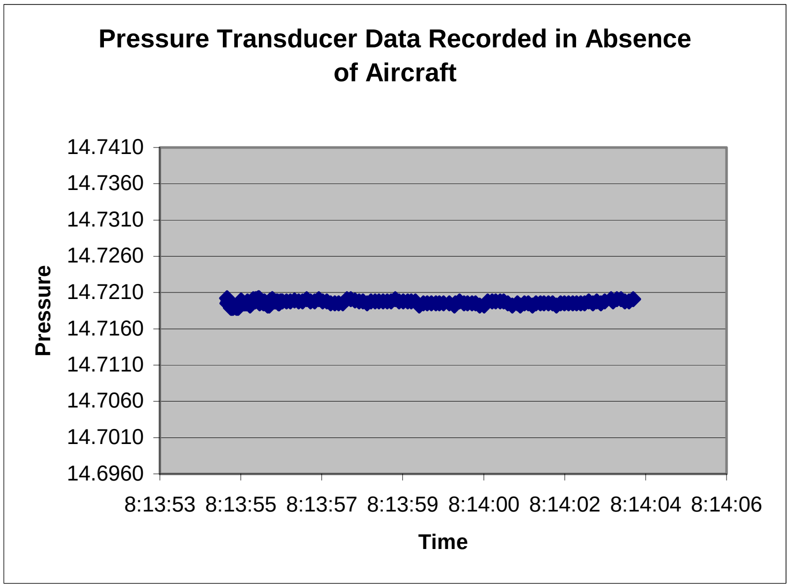

Figure 13: Pressure transducer data recorded in absence of landing aircraft

It can be seen by comparing figures 12 and 13 that the pressure signature associated with a landing aircraft differs from pressure effects experienced through natural phenomena.

Using equation 1, shown below, which relates the maximum pressure rise to the mass and altitude of the landing aircraft, the team attempted to use actual and estimated altitude data and maximum recorded pressure to approximate the landing mass of the landing aircraft.

$$P_{\max} = \frac{mg}{2\pi h^2}$$ **Equation 1.**

Here, $P_{\max}$ is the maximum associated pressure rise, m is the aircraft mass, g is the acceleration due to gravity, and h is the aircraft altitude.

The resulting predicted mass was then compared to the mass range for landing aircraft and grouped by the weight class previously discussed. The mass range for a landing aircraft varies from the operational empty mass to the maximum landing mass. Table 2 presents sample data for landings on both runway 33L and runway 4R. Aircraft type presented with an asterisk indicates landings for which altitude data was recorded and used in mass calculation. Shaded rows indicate weight class.

Runway 33L (Altitude approximately 18 meters)

Aircraft Type	Empty Operational Mass	Maximum Landing Mass	Predicted Mass	Predicted Weight Class
J328	9420	14390	7261.6442	Small
C402	1800	2858	2323.7262	Small
B738*	41413	66361	38376.693	Large
J328*	9420	14390	7784.9804	Small
B752*	59738	89811	48397.539	Large
B738*	41413	66361	28270.785	Large

Legend
Small
Large
757
Heavy

Runway 4R (Altitude approximately 40 meters)

Aircraft Type	Empty Operational Mass	Maximum Landing Mass	Predicted Mass	Predicted Weight Class
MD11*	129680	199000	170734.1	Heavy
J328	9420	14390	15426.435	Small
B737*	90580	145149	48416.418	Large
E135*	11469	18500	18623.058	Small

All masses presented in kilograms.

Table 2: Selected data for various landings

As shown, the weight class was accurately predicted for all aircraft except for the B757-200 aircraft. The 757 weight class provided too small of a margin of error to be predicted reliably. Many of the predicted masses are outside of the operating range. This occurs due to uncertainty in the actual altitude of the aircraft and to the difference between near- and far-field theory. Far-field theory models the aircraft as a point mass, not taking into account the mass distribution over the length of the aircraft. A unifying near-field theory might take into account this mass distribution, ground effects, and any other effects present at low altitudes. Introduction of a more robust theory may bolster the results and provide more consistent mass predictions.

Figure 14 presents data for an E135, which is a small aircraft. The approximate landing altitude was 40 meters.

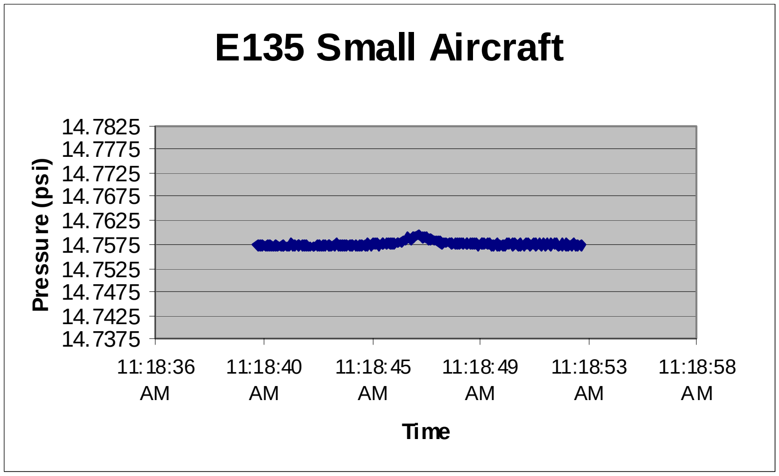

Figure 14: Pressure Signature for E135 – Small Aircraft

Figure 15 presents the pressure signature for a B737, which is a large aircraft. The landing altitude was approximately 40 meters.

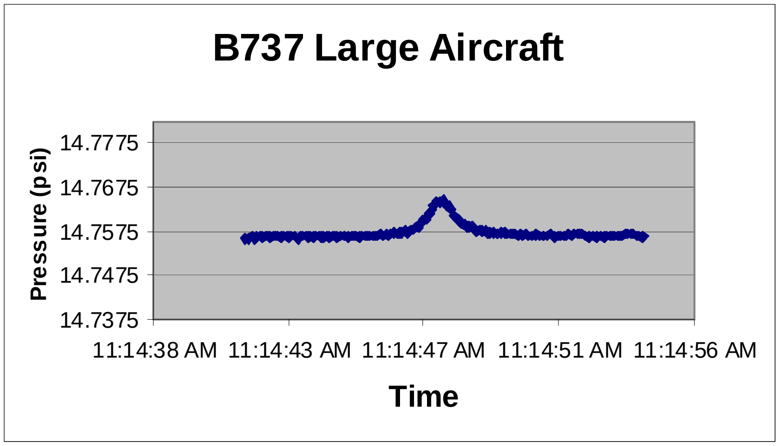

Figure 15: Pressure signature for a B737 – Large Aircraft

Figure 16 presents the pressure signature for an MD-11, which is a heavy aircraft. The landing altitude is approximately 40 meters.

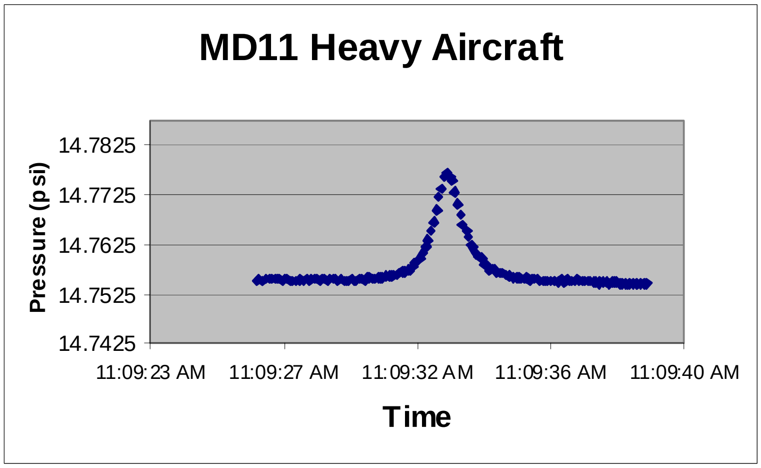

Figure 16: Pressure signature for an MD11 – Heavy Aircraft

Because the aircraft weight classes were accurately predicted for all aircraft seen during the day, it can be shown that this method can be used as a weight class predictor. As can be seen in figures 9, 10, and 11, there is a distinct difference in the pressure signature recorded for aircraft in various weight classes. Figures 14, 15, and 16 are all shown on the same vertical and horizontal scale. The only problems that may be encountered occur for aircraft near the extreme edges of the weight class ranges. However, for common aircraft, which exist well within these ranges, this method can be used to accurately predict weight class.

10.0 Conclusions

From the work done on this project it can be concluded that landing aircraft have a pressure signature associated with them that can be measured with a pressure transducer. Furthermore, this pressure signature may be used to determine the weight class of most landing aircraft. Finally, the data provided by this experiment proves that the pressure rise associated with landing aircraft can be used as an aircraft detector.

11.0 Suggestions for Future Work

In the future, this work would be beneficial in that it might lead to an integrated computer system that could autonomously detect aircraft and trigger data acquisition systems. By looking at the average pressure data over a small number of samples, a sharp rise in pressure could be detected by a computer and used to indicate aircraft arrival. The pressure data could then be computationally analyzed to determine aircraft weight class. During this time, wake-vortex sensors would record data for a predetermined period of time. When this period of time elapses, the system could reset itself in order to collect data for the next landing aircraft. In such a manner, the need for human presence would be eliminated.

It would be highly beneficial to develop a near-field theory for the pressure rise associated with landing aircraft. This project was completed using the far-field theory proposed by Prandtl. This far-field theory does not take into account the distribution of an aircraft's weight, because it considers the aircraft to be a point mass. With a more accurate theory the weight class predictions will be much more robust, because the predicted aircraft masses will be much closer to the actual masses.

Another suggestion is that the experimental setup be made precipitation proof. This would be very easy to implement given that the "swiss cheese" lid is in place. The development of such a setup would allow for wake vortex study under conditions that have not been studied in detail.

12.0 Acknowledgements

- Dr. Frank Wang – Project Advisor
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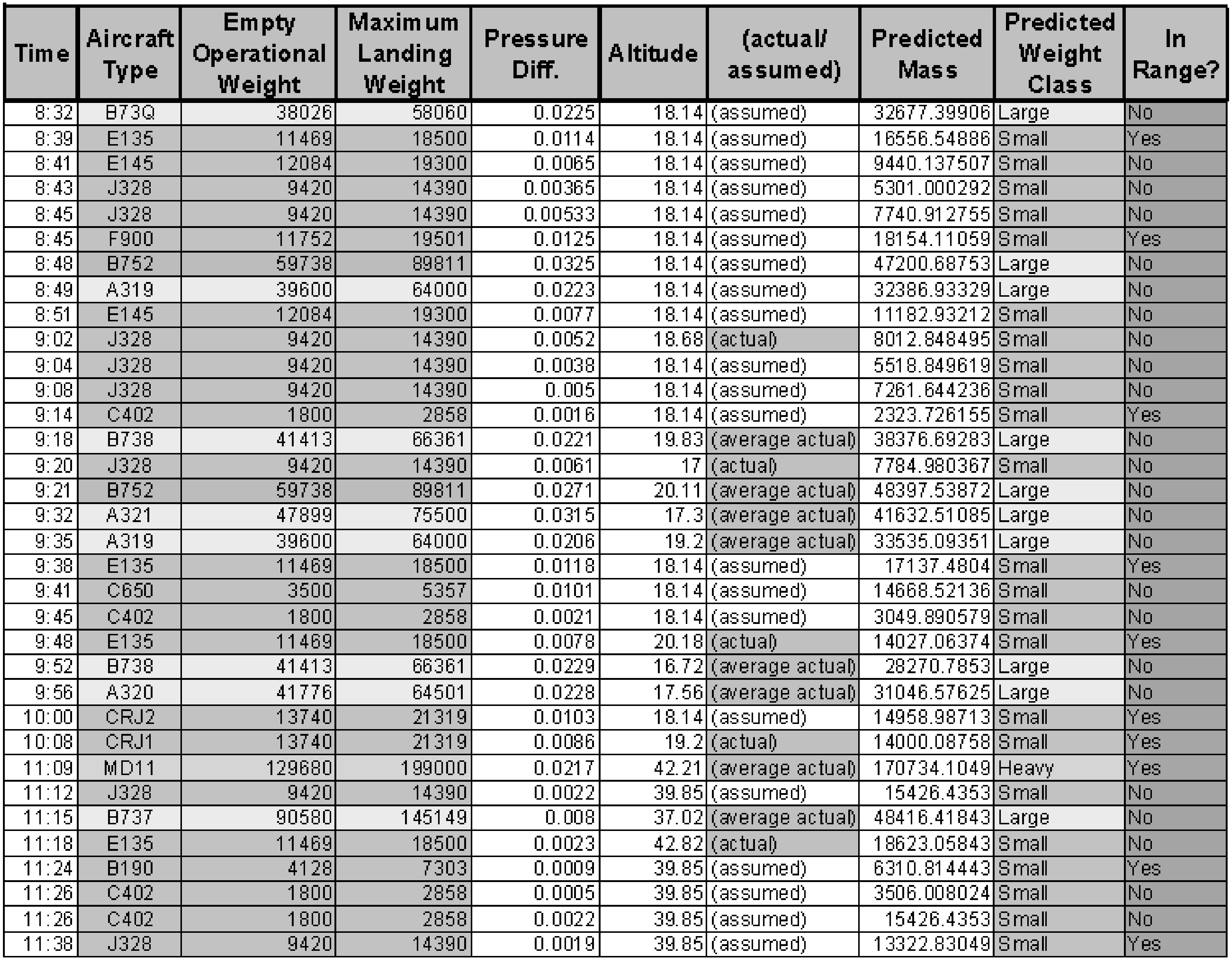
- 16.622 Faculty and Staff
- Local FAA and Massport
- Keith Leonhardt – Hanscom Airforce Base
- Vincent Cardillo and Alan Wade – Logan Airport Staff
- Volpe Transportation Center

13.0 References

[1] Prandtl, Ludwig, Tietjens, O.G., *Applied Hydro-and Aeromechanics*, United Engineering Trustees, Inc., Canada, 1934, pp. 186-189.

[2] Sullivan, T.E., Burnham, D.C., “Ground Wind Vortex Sensing System Calibration Tests,” 1972. U.S. Department of Transportation, Report No. FAA-RD-80-13.

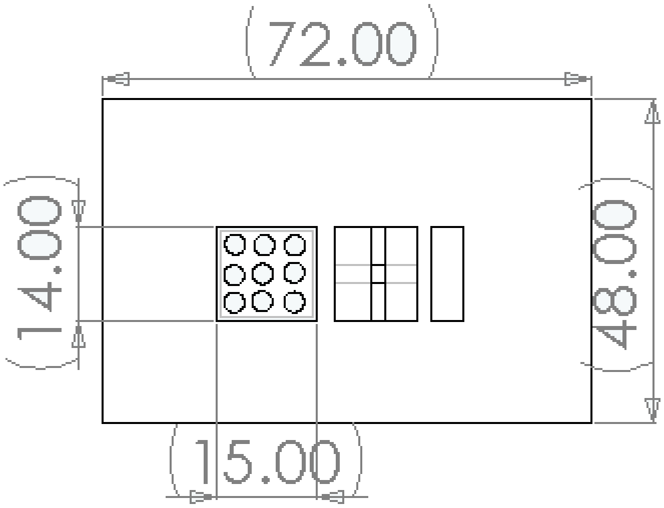
Appendix A: Supporting Data



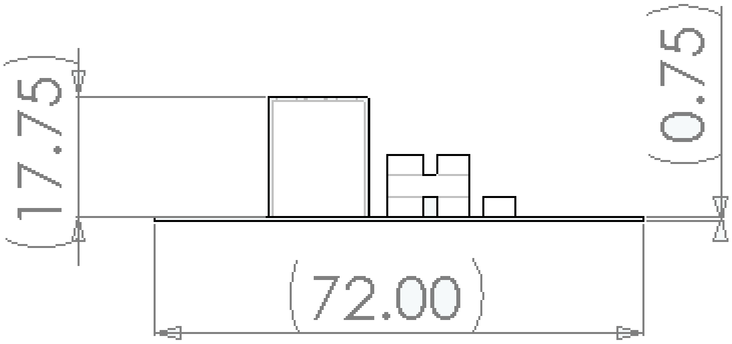
Time	Aircraft Type	Empty Operational Weight	Maximum Landing Weight	Pressure Diff.	Altitude	(actual/ assumed)	Predicted Mass	Predicted Weight Class	In Range?
8:32	B73Q	38026	58060	0.0225	18.14	(assumed)	32677.39906	Large	No
8:39	E135	11469	18500	0.0114	18.14	(assumed)	16556.54886	Small	Yes
8:41	E145	12084	19300	0.0065	18.14	(assumed)	9440.137507	Small	No
8:43	J328	9420	14390	0.00365	18.14	(assumed)	5301.000292	Small	No
8:45	J328	9420	14390	0.00533	18.14	(assumed)	7740.912755	Small	No
8:45	F900	11752	19501	0.0125	18.14	(assumed)	18154.11059	Small	Yes
8:48	B752	59738	89811	0.0325	18.14	(assumed)	47200.68753	Large	No
8:49	A319	39600	64000	0.0223	18.14	(assumed)	32386.93329	Large	No
8:51	E145	12084	19300	0.0077	18.14	(assumed)	11182.93212	Small	No
9:02	J328	9420	14390	0.0052	18.68	(actual)	8012.848495	Small	No
9:04	J328	9420	14390	0.0038	18.14	(assumed)	5518.849619	Small	No
9:08	J328	9420	14390	0.005	18.14	(assumed)	7261.644236	Small	No
9:14	C402	1800	2858	0.0016	18.14	(assumed)	2323.726155	Small	Yes
9:18	B738	41413	66361	0.0221	19.83	(average actual)	38376.69283	Large	No
9:20	J328	9420	14390	0.0061	17	(actual)	7784.980367	Small	No
9:21	B752	59738	89811	0.0271	20.11	(average actual)	48397.53872	Large	No
9:32	A321	47899	75500	0.0315	17.3	(average actual)	41632.51085	Large	No
9:35	A319	39600	64000	0.0206	19.2	(average actual)	33535.09351	Large	No
9:38	E135	11469	18500	0.0118	18.14	(assumed)	17137.4804	Small	Yes
9:41	C650	3500	5357	0.0101	18.14	(assumed)	14668.52136	Small	No
9:45	C402	1800	2858	0.0021	18.14	(assumed)	3049.890579	Small	No
9:48	E135	11469	18500	0.0078	20.18	(actual)	14027.06374	Small	Yes
9:52	B738	41413	66361	0.0229	16.72	(average actual)	28270.7853	Large	No
9:56	A320	41776	64501	0.0228	17.56	(average actual)	31046.57625	Large	No
10:00	CRJ2	13740	21319	0.0103	18.14	(assumed)	14958.98713	Small	Yes
10:08	CRJ1	13740	21319	0.0086	19.2	(actual)	14000.08758	Small	Yes
11:09	MD11	129680	199000	0.0217	42.21	(average actual)	170734.1049	Heavy	Yes
11:12	J328	9420	14390	0.0022	39.85	(assumed)	15426.4353	Small	No
11:15	B737	90580	145149	0.008	37.02	(average actual)	48416.41843	Large	No
11:18	E135	11469	18500	0.0023	42.82	(actual)	18623.05843	Small	No
11:24	B190	4128	7303	0.0009	39.85	(assumed)	6310.814443	Small	Yes
11:26	C402	1800	2858	0.0005	39.85	(assumed)	3506.008024	Small	No
11:26	C402	1800	2858	0.0022	39.85	(assumed)	15426.4353	Small	No
11:38	J328	9420	14390	0.0019	39.85	(assumed)	13322.83049	Small	Yes

Appendix B: Engineering Drawings

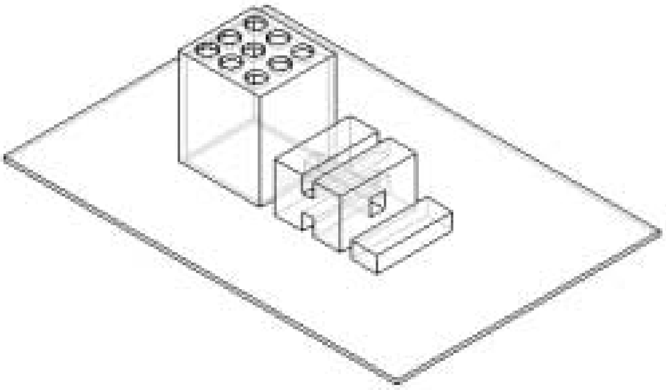
Engineering Drawing: Hanscom Airforce Base Housing Setup: All measurements in inches



Top View

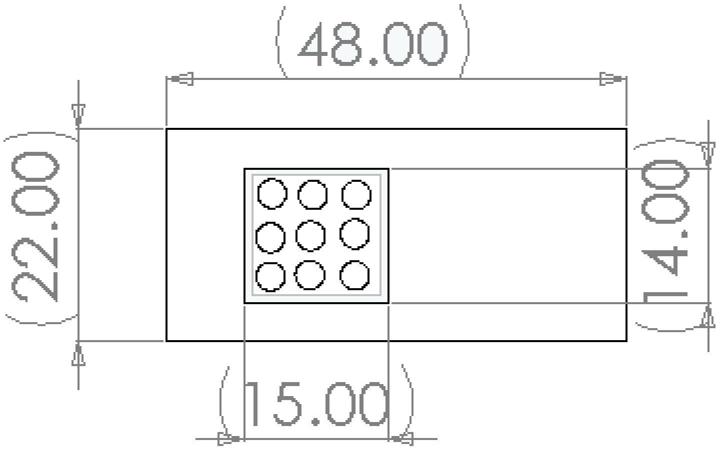


Side View

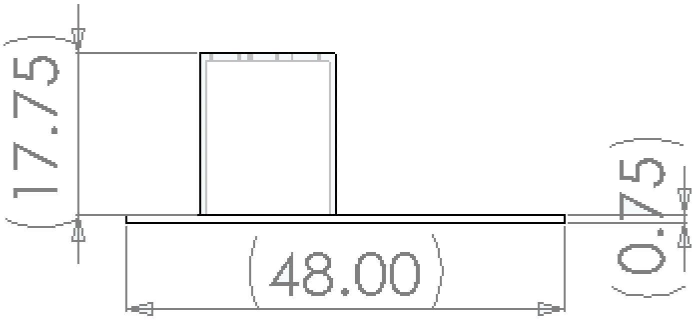


Isometric View

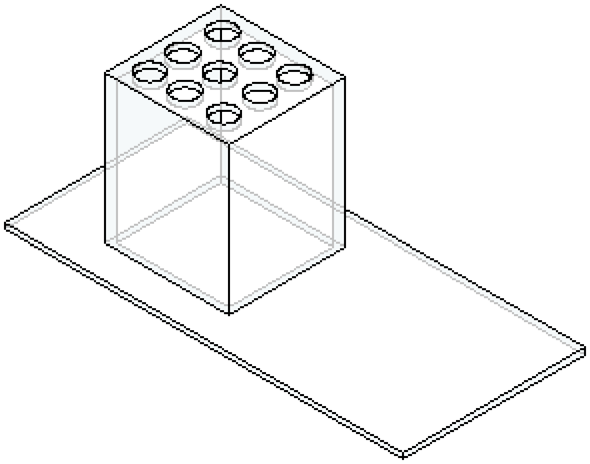
Engineering Drawing: Logan Airport Setup: All measurements in inches



Top View

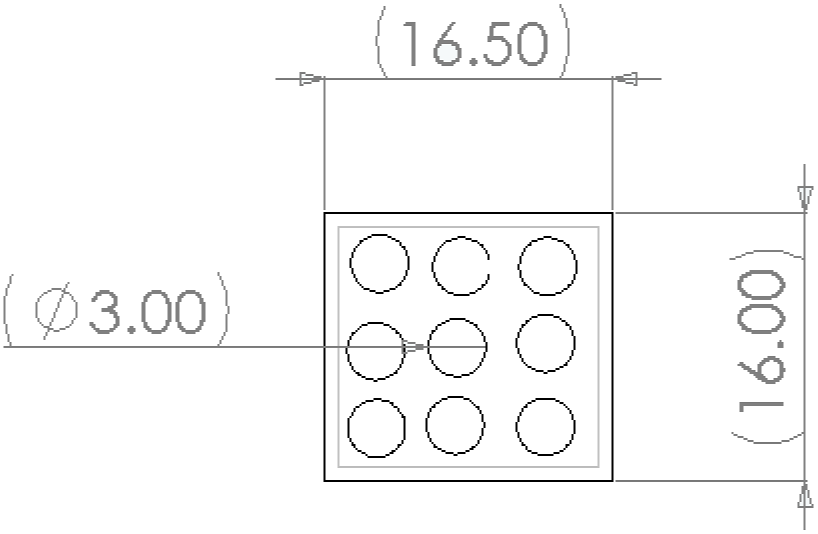


Side View

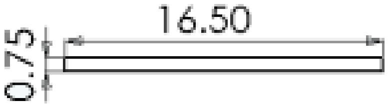


Isometric View

Engineering Drawing: “Swiss Cheese” Lid: All measurements in inches



Top View (All circles of the same diameter)



Side View

Appendix C: Pressure Transducer Data Sheets