12-2008

ANALYSIS OF IN-FLIGHT VIBRATION FOR A TURBO PROPELLER AIRCRAFT

Kyle Dunno
Clemson University, kyle.d.dunno@gmail.com

ANALYSIS OF IN-FLIGHT VIBRATION FOR A TURBO PROPELLER AIRCRAFT

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Packaging Science

---

by
Kyle David Dunno
December 2008

Accepted by:
Dr. Kay Cooksey, Committee Chair
Dr. Robert Cooksey
Dr. Patrick Gerard
Mr. Gregory Batt

ABSTRACT

A data recorder was utilized to record in-flight vibration of a turbo propeller aircraft. The data recorded produced power spectral density (PSD) profiles which are currently used in laboratory settings to drive vibration tables in order to simulate a particular vehicle type. Overall Grms values from the averaged data were then statistically compared to published standards and other studies to determine if there were differences in overall Grms values.

The data recorder was rigidly mounted to the cargo area of the turbo propeller aircraft. Thirty flights were recorded which varied in flight time from less than one hour to greater than four hours.

When compared to published standards and other standards there was significant evidence to conclude that the overall Grms levels of all studies were different. The general shape of the profile had similarities at given frequencies when compared to the published standards, but all had different overall Grms levels.

The data collected from this research study could be utilized for packaging research when developing products and packages that will pass through a distribution cycle which includes transportation via a turbo propeller aircraft. The PSD profiles which were analyzed from this research could be utilized to simulate in-flight aircraft vibration of the aircraft chassis in a laboratory environment. This will enable further research in the air transport environment and aid in the optimization of package design and testing.

DEDICATION

I dedicate this work to my wife Kristen Dunno, and to the rest of my family. Without their patience, love and devotion none of this would have been possible.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Kay Cooksey, for her guidance throughout this entire process. Her willingness to facilitate learning is truly amazing.

I would also like to the other members of my committee, Dr. Bob Cooksey, Dr. Patrick Gerard, and Greg Batt for their support and willingness to assist in every way possible.

TABLE OF CONTENTS

Table of Contents (Continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Every day millions of packaged products are transported between multiple distribution channels to reach specified destinations. Common transportation channels that a packaged product would pass through are over-the-road truck transportation, rail transportation, and aircraft transportation. Throughout the various distribution channels the packaged products are subjected to three major categories of dynamic hazards: shock, vibration, and compression (Brandenburg and Lee, 2001). While shock and compression hazards cannot be overlooked when designing packages or packaging materials the nature of this project focused on vibration. The intensity of vibration experienced by a packaged product depends on the type of transportation used. Different modes of transport will produce different vibration inputs to the packaged product system.

There are several reasons for the increasing importance of air transportation. For example, in recent years using logistics to manage a supply chain has become more common because companies need to reduce costs of tied up capital investments (Trost, 1988). The logistical way of thinking becomes more and more common, where companies aim to reduce the costs of tied-up capital. The time factor has become more important and faster transport combined with an efficient materials flow means that excess supplies are reduced along with storage costs. Trost states, “this development can be traced to the fact that the amount of highly processed products has increased; e.g. sophisticated electronic products with high price per [pound] have to reach their customers fast” (Trost, 1988). An additional fact is the increasingly intense competition which demands manufacturers to be alert to market changes quicker – which means being able to forecast the flow of goods properly (Akerman, 2003).

Another area which is experiencing an increase in air transportation is the small parcel delivery segment. Companies such as the United Parcel Services (UPS) and Federal Express (FedEx) are some of the major companies specializing in small parcel delivery. With companies like UPS and FedEx offering overnight and next day delivery services to their customers, the only way to move packages vast amounts of miles in one night is through air transportation.

Prior to this research project only two published testing standards were utilized to simulate aircraft vibration. These standards are the American Society for Testing and Materials (ASTM) D 4169 – 08 and the International Safe Transit Association (ISTA) 4AB. The latest research which was published was conducted by Lansmont Corporation and Amgen which produced a vibration profile, but not a standard for testing. These standards and previous research were analyzed against the data obtained from this study to determine if there were statistical differences.

This study examined the air transportation mode of turbo propeller, or feeder, aircraft which move goods to non-major metropolitan areas of the United States of America. Since feeder aircraft have not been studied extensively, the purpose of this study was to develop a vibration profile in order to simulate the transportation of packaged products which would be shipped via aircraft to its final destination. The profile which is produced from this aircraft can be used to operate package testing equipment, which in turn can aid in the optimal package design for a given product. The importance of analyzing and profiling different vehicle types in the small parcel environment, such as a turbo propeller aircraft, allows engineers to develop packages that can properly protect the product throughout a particular distribution segment.

The air vibration profile which was developed from this study was also statistically compared to prior published vibration profiles to determine if there was a significant difference in the overall vibration intensities. The profile was compared using a hypothesis test in order to determine a difference of means.

CHAPTER TWO

REVIEW OF LITERATURE

Evaluation of Aircraft Types and Usage

Multiple types of aircraft are used to transport materials and packages throughout the world. Collectively, these types of aircraft can be summarized into two main categories – jet engine and turbo propeller. Some jet engine aircraft commonly used by the United Parcel Services (UPS) in transporting materials and packages are Boeing 757-200 Freighter and the DC8-70 Freighter (UPS, 2007). While these larger aircraft can transport thousands to millions of packages to major metropolitan cities, the turbo propeller aircraft is utilized to transport small amounts of packages to more remote locations. Examples of turbo propeller aircraft commonly used in transporting materials and packages by Federal Express (FedEx) are the Cessna 208 Caravan and the Beech A100 King Air FedEx (FedEx, 2007). Figures 1 and 2 illustrate a general example of a jet engine and a turbo propeller aircraft.

Figure 1. UPS 767 Jet Engine Aircraft

Figure 2. FedEx Cessna Caravan Turbo Propeller Aircraft (Goleta, 2008)

Multiple aircraft are used to deliver products from the origin of shipment to destination. Large jet aircrafts are used to move packaged products from one major metropolitan city to the next, but some states and regions do not have this option. So, turbo propeller, or feeder, aircraft are utilized in the small parcel delivery industries to delivery overnight and next-day packages to remote locations both in the United States of America and other foreign countries.

In most cases the small parcel delivery companies operate on a lease program where a contractor will lease the aircraft and supply the crew and insurance while a small parcel company like FedEx will supply the aircraft, registration, landing fees, and ground crews (FedEx, 2007). This allows the various delivery companies to utilize different contractors in different regions of the United States of America in order to service the different markets.

Example of Conventional Data Acquisition for Random Vibration

Securing the raw data necessary to quantify the small parcel vibration environment requires using one of the many sophisticated, computer-compatible field data recorders. Offered by several manufacturers, these devices are battery powered for taking data over several weeks, and typically include internal or external accelerometers as dynamic sensors. They may also include temperature and relative humidity sensors for recording these non-dynamic parameters. These recorders are capable of recording vibration, drops, and impacts with high speed analog-to-digital conversion.

Vibration input from vehicles in motion produces continuous random vibrations. Figure 3 shows a representative sample of vehicle vibration from an aircraft, displayed as acceleration vs. time. To characterize this type of vibration with a field data recorder requires a sampling technique. For example to record all the vibration time in a twenty hour trip, more than 150 megabytes (MB) of on-board computer memory would be required. Since this is such a large amount of memory storage, these environments are sampled instead of continuously recorded. This technique is appropriate when the event being measured changes slowly and sampled data will be representative of un-sampled periods. Timer trigger data periods are usually taken in response to an on-board timer, so that a sample is taken every ten seconds or five minutes depending on the various applications. The interval timer is set to fill the available memory during the intended duration of the measurement trip. For example, during the acquisition of data from a truck, the instrument can be set for an interval of ten minutes. After each data sample is taken, the instrument repeatedly records data every ten minutes. Each time data is taken, the record is called an event. Data may also be recorded based on the vibration signal exceeding a pre-set threshold, which is commonly referred to as signal trigger data. This technique is used to record the highest intensity events in a particular trip. From each individual event collected for a given frequency, a power spectral density (PSD) profile is created which is a representation of the actual shipping environment.

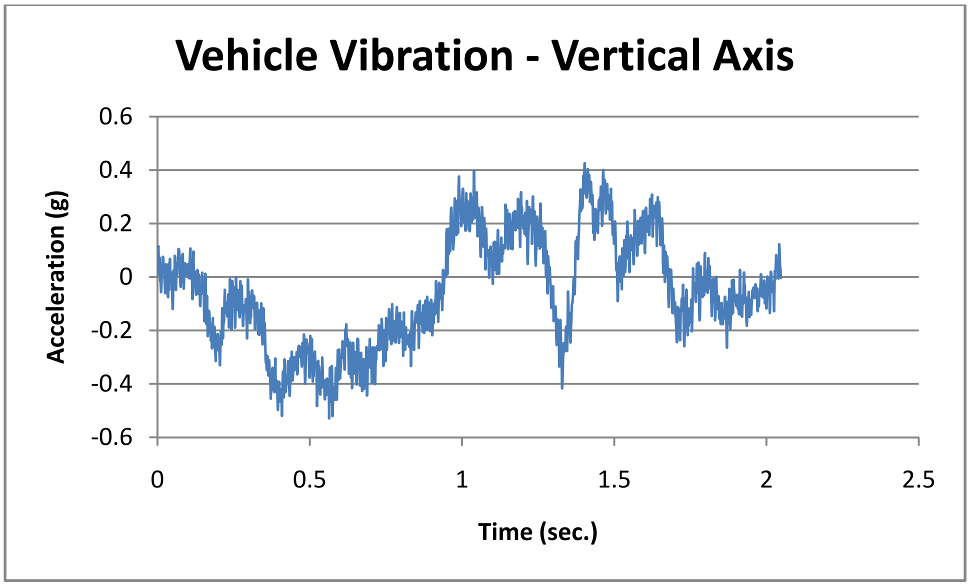


Figure 3. Acceleration vs. Time Plot

In order to accurately represent the input vibration to a package, the data recorder must be secured to a location that would produce the input accelerations. The location used for most truck transit studies is the rear axle of the trailer. This accurately represents the vibration due to the rear axle being the connection between the tires and the trailer. The data recorder must be securely fastened to the truck and this can be accomplished through bolting the unit directly to the truck or by using a magnetized base. The purpose is to not allow any decay of the accelerations from the input source to the data recorder. Figure 4 displays a data recorder mounted to a semi-truck.

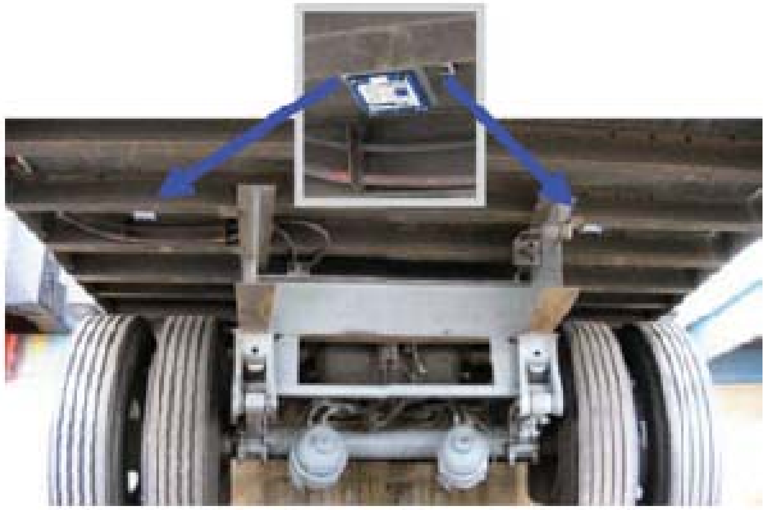


Figure 4. Data Recorder Mounted to Truck (Singh et. al, 2007)

Many of the published vibration profiles are time compressed in order to decrease the overall test time required for laboratory testing. As a general rule of thumb, the profile should not exceed a compression of more than 5:1; where five is the number of actual truck hours and one is the number of laboratory test hours. The commonly used equation (equation 1), displays the method for accelerating, or time compressing a vibration test. When time compressing a profile the shape of the given profile remains unchanged; it simply gets increased in overall intensity (Grms) to permit compression of the testing time (Kipp, 2002).

Equation 1: $$I_T = I_0 \sqrt{\frac{T_0}{T_T}}$$

Where I_T = overall intensity of the test lab profile (expressed in Grms)

I_0 = field-measured intensity of transport profile (in Grms)

T_0 = time duration of the transport vibration

T_T = the test time

Previous Research in Aircraft Vibration

While numerous research studies have been conducted to measure an aircraft's acceleration, the majority of this research has involved service and fatigue data for the aircraft (Trost, 1988) as well as wing flutter during takeoff and landing (Berman, 1979). During the past twenty years numerous research studies have been conducted for the truck and rail environment in order to better characterize the profile for each mode of transportation, but the same cannot be said for aircraft vibration. These research studies have led to the development of updated and vehicle specific profiles that are currently accepted for use of package testing. Due to the lack of research in the air vibration environment, the most widely used and accepted air vibration test power spectral density profiles are located within the American Society for Testing and Materials (ASTM) D 4169 – 08 Standard Practice for Performance Testing of Shipping Containers. The data used for the ASTM D 4169 – 08 are undefined, which confirms why research should be conducted to better understand and characterize this environment. Figure 5 depicts the following three PSD profiles: ASTM D 4169 – 08 Air Assurance Level II and data collected from the Young/UPS study and the Lansmont/Amgen study. In Figure 6 all of the profiles are different from each other, but there are similarities between the Young and Amgen profiles when the comparing the frequency domain signature (Joneson, 2008). From this, there is a definite need for future research studies of the air transportation environment to better characterize each aircraft's profile.

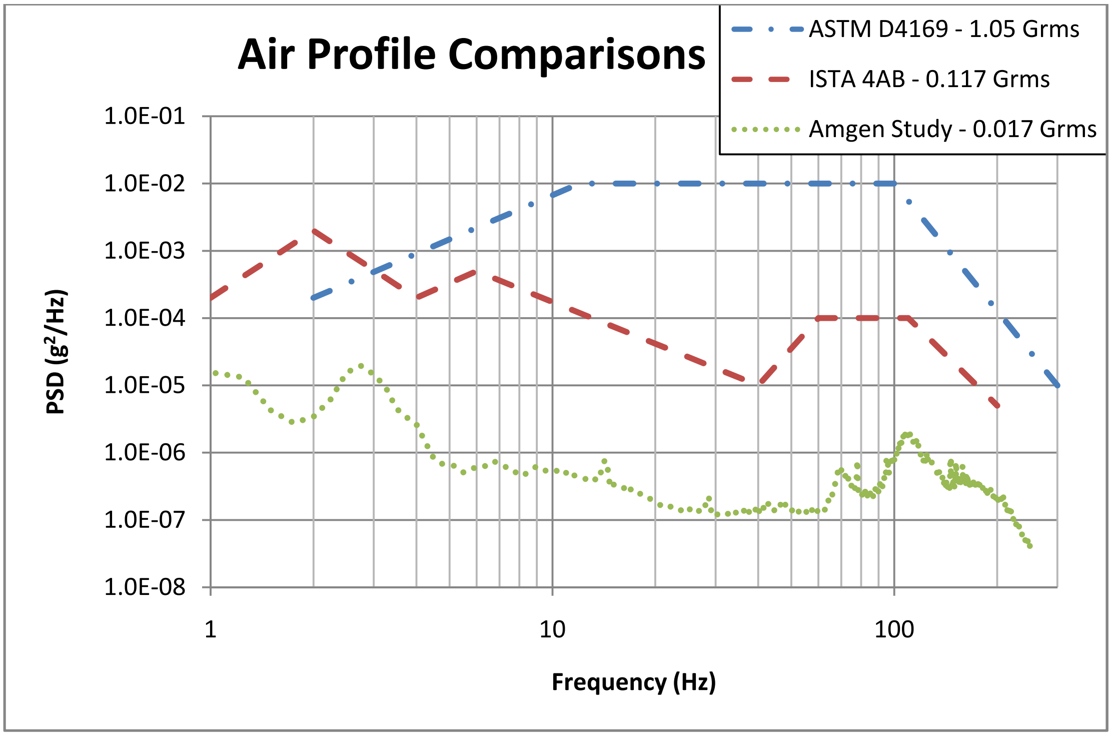


Figure 5. Comparison of Air Vibration Profiles

Major in-flight and ground aircraft studies which have been performed over the past 30 years include the following published studies: the General Technical Report FPL 22, Dennis Young and UPS study, and the Lansmont/Amgen study.

The Forest Products Laboratory's (FPL) General Technical Report 22 was an assessment of the common carrier shipping environment. The assessment included all major shipping hazards including vibration. The FPL 22 Report was one of the early studies of aircraft vibration reporting taxi, takeoff/landing, and cruise mode. The vibration environment on cargo aircraft can be broadly classified due to internal or external sources. "The excitation frequencies are highly dependent on the type of aircraft engine (turbojet, turboprop, reciprocating engine, or helicopter) while the amplitudes depend more on the flight mode (takeoff, climb, cruise, and landing)" (General, 1979).

For a particular aircraft, many of the acceleration peaks can usually be associated with internal sources. The internal sources are a result of periodic excitation from rotating shafts such as propeller blades or rotating engines. The external sources for acceleration can occur from air turbulence, air pockets, and weather patterns.

The turbo propeller aircraft environment is different from the jet aircraft in that it has a characteristic single-frequency, high amplitude excitation (General, 1979). The FPL 22 Report stated that "for a given turboprop aircraft, the engine normally operates at a relatively narrow speed range with the propellers producing a sinusoidal-type input" (General, 1979). These frequencies therefore will be fixed relative to the other excitations which will vary in frequency and magnitude. Another difference is the different airframes which are used to construct a turbo propeller aircraft versus a jet aircraft. Turbo propeller airframes are generally smaller than those of jet aircraft.

While the FPL 22 Report was ground breaking in being one of the first research studies to publish data from an aircraft, the data included all aspects of a flight, and no overall Grms level was reported for this particular study. Some of the data published was used to develop the ASTM Air Vibration Profile, but the FPL 22 Report itself did not produce a Grms level which was used for lab simulation. The ASTM Air Assurance Level II breakpoints are displayed in Table 1.

Table 1. Frequency and PSD Breakpoints for ASTM D 4169 Air Assurance Level II

Frequency (Hz)	**PSD (g^2/Hz)**
2	0.002
12	0.01
100	0.01
300	0.00001

The International Safe Transit Association (ISTA) 4AB PSD profile was developed from the study presented at TransPack 1997 (Young, 1997). This study mounted the data recorder to the floor of an unit load device (ULD), and recorded three shipments aboard a UPS 757 jet engine aircraft. The initial vibration data from the Young/UPS study was time compressed in order to lower laboratory test time. The ISTA 4AB data when compared to the ASTM D 4169 Air Assurance Level II, has a lower overall vibration intensity. While the study does show lower levels of vibration intensity than the ASTM D 4169 Air Assurance Level II, it does not accurately show the characteristic of the aircraft because it shows the response of the ULD to the aircraft vibration, not the input vibration. The resulting vibration profile which was published from this study had an overall intensity level of 0.117 Grms. Table 2 states the break points used to generate the ISTA 4AB PSD.

Table 2. Frequency and PSD Breakpoints for ISTA 4AB

Frequency (Hz)	**PSD (g^2/Hz)**
1	0.0002
2	0.002
4	0.0002
6	0.0005
40	0.00001
60	0.0001
110	0.0001
200	0.000005

The Amgen Air PSD profile was developed from the study conducted by Lansmont and Amgen and was presented at the ISTA and IOPP International Forum on Transport Packaging. This study mounted the data recorder to the floor of a ULD, container type LD3, and recorded eight shipments aboard a jet engine aircraft. Again, this study revealed even lower vibration intensity when compared to the ASTM D 4169 Air Assurance Level II and the ISTA 4AB profiles, but this data was recorded from a LD3 container that was being shipped between California and Switzerland. This was due to the vibration profile only including in-flight air vibration from each flight. While this is the purpose for the current research study, the location of the LD3 container inside of the aircraft as well as how it was secured to the aircraft were unknown during the test shipments. The resulting PSD which was published from this study had an overall intensity level of 0.017 Grms.

The ISTA 4AB profile as well as the Amgen profile was conducted with a package placed inside of the cargo area. The package in both instances was a ULD. Both of these studies measure the packages response to the vehicle vibration, not the input to vehicle. Current data collection techniques for obtaining vibration data on an over-the-road truck require the attachment of the recorder to the chassis, and using that profile to drive a vibration table. The current research study accomplishes that by measuring the vehicles vibration input into the cargo area of a turbo propeller aircraft, which to date has not been conducted in the turbo propeller aircraft environment.

Method for Determining Statistical Difference of Two Means

Statistics are used widely for verifying information and research conducted in the area of engineering and science. A common procedure which is used to determine a statistical difference is a hypothesis test. A statistical hypothesis is a claim either about the value of a single population characteristic or about the values of several population characteristics. In any hypothesis testing problem, there are two contradictory hypotheses under consideration. The objective is to decide, based on sample information, which of the two hypotheses is correct.

The problem will be formulated so that one of the claims (hypotheses) is initially favored. This initially favored claim will not be rejected in favor of the alternative claim unless sample evidence contradicts it and provides strong support for the alternative assertion. The claim initially favored or believed to be true is called the null hypothesis and is denoted by H_o. The other claim in a hypothesis test is called the alternative hypothesis and is denoted by H_a.

Scientific research often involves trying to decide whether a current theory should be replaced by a more plausible and satisfactory explanation of the phenomenon under investigation. A conservative approach is to identify the current theory with H_o and the researcher's alternative explanation with H_a. Rejection of the current theory will then occur only when evidence is much more consistent with the new theory. In many situations H_a is referred to as the researcher's hypothesis since it is the claim that the researcher would like to validate (Devore, 1991). H_o should be identified with the hypothesis of no change (from current opinion), no difference, no improvement, and so on (Devore, 1991).

Before satisfactory test procedures can be obtained, the results of using one rejection region as opposed to another must be understood. The basis for choosing a particular region lies in an understanding of the errors that one might be faced with in drawing the conclusion. The two types of error utilized most for hypothesis testing are

Type I error and Type II error. A Type I error is committed when one rejects the null hypothesis when it is true (Ott and Longnecker, 2001). The probability of a Type 1 error is denoted by the symbol α. A Type II error is committed when one accepts the null hypothesis when it is false and the alternative hypothesis is true (Ott and Longnecker, 2001). The probability of a Type II error is denoted by the symbol β. Table 1 displays the conclusions and consequences for a test of hypothesis.

Table 3. Conclusion and Consequences for a Test of Hypothesis

Conclusion	**True State of Nature**	
	H_o True	**H_a True**
H_o True	Correct Decision	Type II Error
H_a True	Type I Error	Correct Decision

A test procedure is specified by a test statistic, in this case, t observed (t_{obs}) and a rejection region. A test statistic is a function of the sample data on which the decision to either reject or not reject H_o is based. The following equation is used to compute the t_{obs} for a hypothesis test for a single mean (equation 2).

Equation 2 $$t_{obs} = \frac{\bar{y} - \mu_o}{\frac{s}{\sqrt{n}}}$$

A rejection region is the set of all test statistic values for which H_o will be rejected, and is based on a value of α (for a significance level of 5%, α=0.05). For sample sizes smaller than 30, the Student's t-distribution table (found in most statistics textbooks) is recommended to identify the critical ***t*** value of the statistic that would determine the borders of the rejection region, for the hypothesis test, based on the chosen value of α

(Freund and Wilson, 1997). The following equation is used to properly compute the critical $\boldsymbol{t}$ value for a two-tailed test (equation 3).

Equation 3 $$t_{crit} = t_{\frac{\alpha}{2}}, n - 1$$

The t-observed is compared to the t-critical from the Student's t-distribution table and a decision to either reject or not reject H_o is made depending on whether the observed value falls in the rejection region of the t-distribution curve. An assumption is made that the values for the parameter in question are normally distributed, and have equal variance. When interested in finding whether an observed value is statistically different than that of another, the hypothesis testing is set up so the null hypothesis says it is a certain value, and the alternative hypothesis is not equal to that value. This creates a two-tailed test, where the rejection region, which has an area of α, is made up of two regions each with area equal to α/2 at each tail end of the t-distributed curve. Figure 6 illustrates this concept. If the numerical value of the test statistic falls in the rejection region, one rejects the null hypothesis and concludes that the alternative hypothesis is true. If the test statistic does not fall in the rejection region, one does not reject H_o, but fails to reject. One other way to reach a conclusion for the test is to compare the p-value of the test to the alpha set in the beginning of the experiment. For example, if one would like to have a significance level of 5% for a test, one would set the alpha, α, for the experiment to be 0.05, and would compare the p-value from the results to the 0.05. If the p-value is less than alpha one rejects the null hypothesis, and if the p-value is greater than alpha one fails to reject the null hypothesis.

Through statistics it is possible to compare different means along with multiple other styles of test procedures. The statistics used in this study allow for different vibration levels to be compared to one another and determine if the mean vibration levels were different.

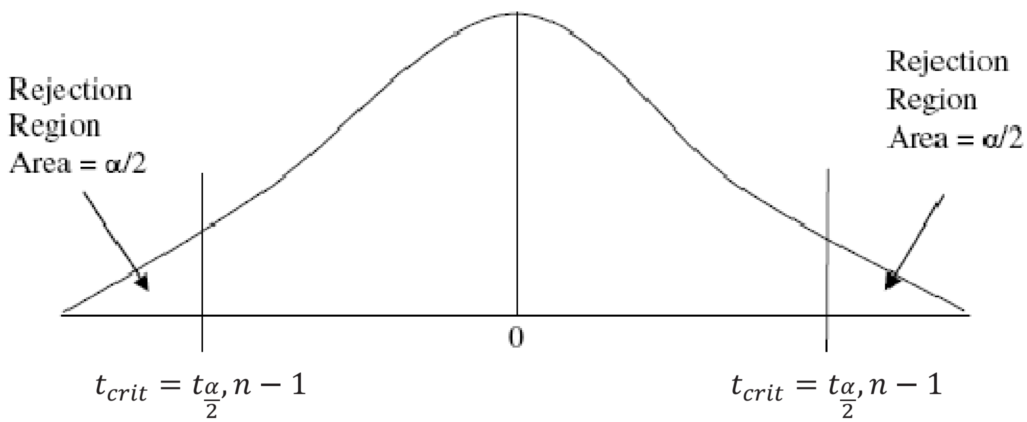


Figure 6. Rejection region of a two-tailed hypothesis test

CHAPTER THREE

MATERIALS AND METHODS

Objectives

Research was conducted for in-flight aircraft vibration which occurs during the shipment of packaged products. With the advent of more powerful and versatile data recorders the study better characterized in-flight and ground data for feeder aircraft. By utilizing updated and improved technology, it was possible to *separate ground data from air data to create separate vibration profiles*. This data will enable further research in the air transport environment and aid in the optimization of package design.

The purpose of the research was to capture and characterize the aircraft's input vibration in hopes of better understanding this distribution channel which is currently becoming used more frequently due to the abundance of overnight and next day shipments. From the findings reported from the data acquired, a PSD profile would be provided to simulate the actual shipping environment of packaged products being transported via aircraft. The PSD profile would be used by vibration test apparatuses in order test products and packages in a laboratory environment. Although the study was limited to only one type of aircraft, the goal was that it would provide a sufficient amount of data to pursue further studies capturing multiple types of aircraft as well as different engine types.

Aircraft

The aircraft used for this project was a Rockwell Turbocommander Twin Engine 690B AC90. It was built in 1976 in Oklahoma City, OK at the Rockwell Manufacturing

Plant. Each engine was a single shaft with an operating rotational speed of 1900 ± 5% RPM throughout the duration of all flights. This means that the engines rotated at approximately 31.6 ± 5% Hz. The aircraft had an unpressurized cargo area where the data recorder was mounted. The unpressurized cargo area allowed for the internal atmospheric pressure gauge to record actual altitude during the flights. Figure 7 represents the actual aircraft used for the project. The aircraft was stationed at the Oconee County Regional Airport (ICAO ID: CEU) located in Seneca, SC.

Figure 7. Rockwell Turbocommander Twin Engine 690B AC90

Test Equipment

A field data recorder was utilized for this project. The type of data recorder which was used for this research had to be able to record vibration and altitude in order to separate in-flight data from ground data. The recorder utilized was the Shock and Vibration Environment Recorder (SAVER™) manufactured by Lansmont Corporation

(Monterey, CA). The model of data recorder chosen for this was the SAVER™ 9X30 with SaverXware software package. A front view of the SAVER™ 9X30 is depicted in Figure 8. This instrument provides users with the ability to capture up to nine dynamic channels of data (three internal and six external), while also recording temperature, humidity and atmospheric pressure. The SAVER™ 9X30 continuously measures up to thirty days of shock (impact/drop), vibration, temperature, humidity, and atmospheric pressure conditions. SaverXware is the companion software package for the SAVER™ 9X30. It was used for programming the instrument, transferring information between the instrument and host computer, and analyzing and exporting all recorded data. This software package included features such as:

- Event Classification
  - Automatically categorize each event as *shock*, *drop*, *vibration* or *general* and concentrate the summary events into a pertinent subset.
- Event Processing
  - Process and provide a full analysis for all recorded shock, drop, and vibration events.
- Simultaneous Trip Analysis
  - Create an event database to concurrently analyze multiple instruments and trips.
- Enhanced Summary Selection
  - Build event selection criteria to quickly search the database and find desired information.

Figure 8. SAVER™ 9X30

SAVER™ 9X30 Setup

SaverXware was used to program the SAVER™ 9X30 for all data acquisition. The data recorder was setup to record and analyze vibration. It recorded both signal and timer triggered data. Signal triggered data refers to the data recorded during an event in which the intensity exceeded a preset threshold. In this case, the trigger threshold was 0.50 g. At any time during the project, if the data recorder experienced higher than 0.50 g it would record that data point. Timer trigger data refers to the data recorder waking up at a preset frequency and recording a preset duration. For this project, the timer trigger was set at 30 second intervals. The record time for both the signal and timer triggered data was set at 2.048 seconds. This would allow for the recorder to capture points below a frequency of 1 Hz. Tables 4 and 5 display the recording parameters used for this research.

Table 4. Recording parameters for Timer Trigger Data

Parameter	Setup
Wakeup Interval	Every 30 s
Sampling Rate	1000 samples/sec
Record Time	2.048 s
Data Retention Mode	Fill/Stop
Memory Allocation	80%

Table 5. Recording parameters for Signal Trigger Data

Parameter	Setup
Trigger Threshold	0.50 G
Signal Pre-trigger	20%
Sampling Rate	1000 samples/sec
Record Time	2.048 s
Data Retention Mode	Max Overwrite
Memory Allocation	20%

The remaining advanced setup details can be obtained from Figure 9.

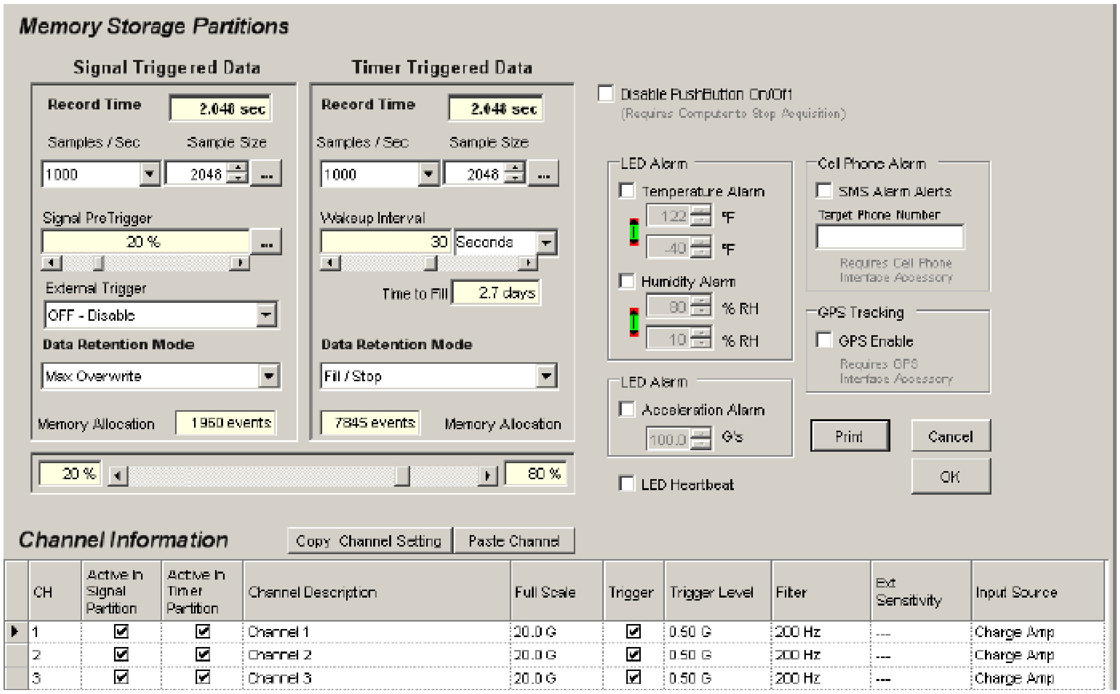


Figure 9. Advanced Instrument Setup for the SAVER™ 9X30

Once the data recorder was setup, the unit was rigidly mounted to the cargo area of the Rockwell Turbocommander Twin Engine. The data recorder was mounted to the frame of the cargo area with a specialized fixture that was designed for this application. The fixture containing the data recorder was held in place with 3 – 2 inch steel C-Clamps. The fully mounted recorder was located in the cargo area next to the left wing of the aircraft. Figure 10 represents the location of the data recorder from the top and side views of the aircraft. Figure 11 displays the fully mounted data recorder in the cargo area of the aircraft.

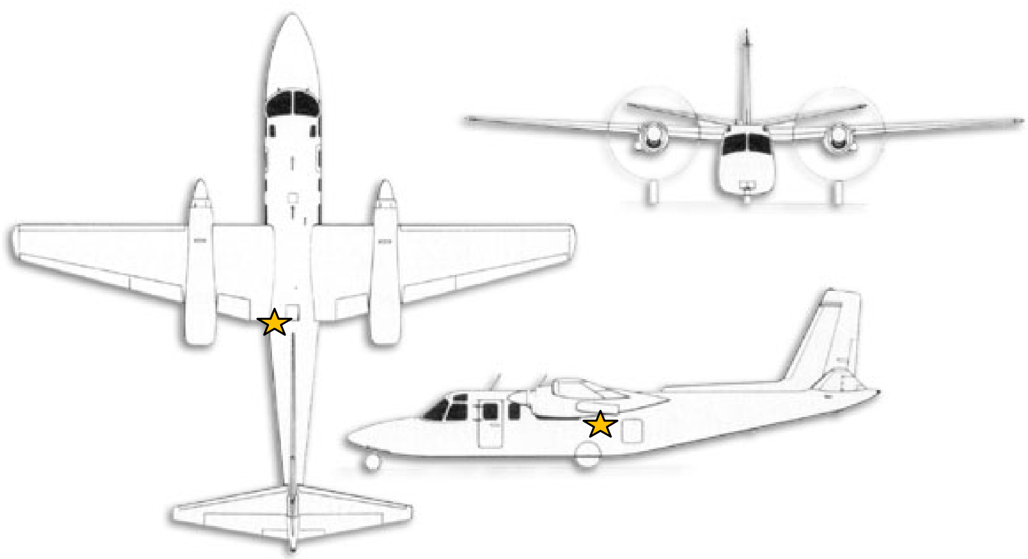


Figure 10. Location of the data recorder (represented by star)

Figure 11. SAVER™ 9X30 securely mounted in the cargo area

Project Design

The project was designed to properly record and analyze data from thirty individual flights. Throughout the thirty flights, the aircraft ranged in travel distances from less than one hour to greater than four hours with the majority of flights ranging in between. Also, with thirty flights it was possible to look at external sources of vibration such as air pockets, turbulence, and how weather affected the flights. The thirty flights allowed for a wider sample size in hopes of making the data statistically valid.

Once the data was recorded it was analyzed using the SaverXware programming software. The resulting PSD profile from this research would be statistically analyzed against the previous studies published PSD profiles to determine if there was a significant difference. If the data recorded from this research was statistically different, the different vibration profiles would be analyzed to determine if the overall intensity (Grms) was lower or higher. Also, individual flight summaries would be provided as well as a cumulative flight summary for a traditional PSD profile.

With the cumulative PSD, the goal would be met that the data could be utilized in operating test equipment for product and package testing for in-flight aircraft shipments. This would allow for optimum package design for packaged products shipped via aircraft.

CHAPTER FOUR

RESULTS AND DISCUSSION

In-Flight Results

A total of thirty individual flights were recorded and analyzed for this project. Having thirty sets of aircraft vibration was thought to provide the statistical validity needed to properly characterize the environment. Once the data was obtained and analyzed it was statistically compared to the ASTM D 4169, ISTA 4AB and the Amgen vibration profiles. A hypothesis test was performed to determine if the means of the overall Grms values were different.

While the data reported in the ASTM D 4169 and ISTA 4AB data was time compressed, the data obtained from the Amgen study was not time compressed. When the data collected from this study was compared to the ASTM D 4169 profile, the shape and overall intensity levels are extremely different. The data collected from this study (turbo propeller aircraft) had approximately the same general shape and intensity levels as the ISTA 4AB data (jet aircraft). This was an interesting phenomenon. While, when the data from this study is compared to the Lansmont/Amgen data (jet aircraft) the two have very different shapes and different levels of overall intensity.

The flights recorded in this study varied in length from one to four hours. Most of the flights were recorded in the Southeast U.S., but some flights were recorded as far as New York and Tennessee. Some flights also experienced the external excitations mentioned earlier, which were, air turbulence, air pockets, and weather patterns. Interestingly, the internal excitations due to the propellers rotating at 31.6 ± 5% Hz are not visible. This was possibly due to vibration absorbers built into the engine that absorbed the energy at the operating frequency. Table 6 shows the individual flights (from city to city), the corresponding overall Grms values from that particular flight, and the maximum acceleration from each flight. While the maximum accelerations recorded were as high as 2.11g, these levels represented discrete events occurring during takeoffs and landing; whereas the typical steady state vibration did not exceed 0.2g. Note in Table 6 that not all flights recorded a signal triggered overall Grms value. This was due to the aircraft not experiencing any acceleration over 0.50 G during that particular flight.

Table 6. Individual Flight Recordings

Flights		Overall Grms		Maximum Acceleration (g)
Origin	**Destination**	**Timer Trigger**	**Signal Trigger**	
Oconee, SC	Columbia, SC	0.065	0.170	1.13
Columbia, SC	Oconee, SC	0.050	No Data*	0.32
Oconee, SC	Charleston, SC	0.054	0.190	1.27
Charleston, SC	Oconee, SC	0.054	0.119	-0.63
Oconee, SC	Saluda, SC	0.047	No Data*	-0.33
Saluda, SC	Charleston, SC	0.068	0.184	0.86
Charleston, SC	Oconee, SC	0.058	0.173	0.74
Oconee, SC	Memphis, TN	0.063	0.139	0.82
Memphis, TN	Oconee, SC	0.059	No Data*	0.31
Oconee, SC	New York, NY	0.060	0.153	-1.48
New York, NY	Oconee, SC	0.068	0.168	-0.77
Oconee, SC	Knoxville, TN	0.079	0.192	-2.11
Knoxville, TN	Charleston, SC	0.082	0.166	0.93
Charleston, SC	Columbia, SC	0.067	0.173	-0.67
Columbia, SC	Oconee, SC	0.060	0.166	0.98
Oconee, SC	Jacksonville, FL	0.088	0.174	-0.61
Jacksonville, FL	Atlanta, GA	0.063	0.161	-0.94
Atlanta, GA	Oconee, SC	0.079	0.156	1.38
Oconee, SC	Atlanta, GA	0.070	0.156	-0.91
Atlanta, GA	Oconee, SC	0.061	0.153	0.74
Oconee, SC	Saluda, SC	0.054	No Data*	0.47
Saluda, SC	Oconee, SC	0.049	0.111	0.51
Oconee, SC	Atlanta, GA	0.060	0.116	0.73
Oconee, SC	Charleston, SC	0.053	No Data*	-0.24
Charleston, SC	Oconee, SC	0.052	No Data*	-0.41
Oconee, SC	Atlanta, GA	0.086	0.169	0.79
Oconee, SC	Columbia, SC	0.054	No Data*	-0.43
Columbia, SC	Oconee, SC	0.046	0.167	0.81
Oconee, SC	Charleston, SC	0.055	0.061	0.51
Charleston, SC	Oconee, SC	0.057	0.156	0.68
	Average	**0.062**	**0.155**	**N/A**
	Std. Dev.	**0.011**	**0.030**	**N/A**

*No Signal Trigger Data Recorded

While data from the X, Y and Z axes were recorded and analyzed, only the vertical (Z axis) data was reported due to the vertical acceleration being more intense than the other two axes – lateral and longitudinal (X,Y respectively). Both the lateral and longitudinal accelerations were minimal in comparison to the vertical response. Figure 12 illustrates the averaged vertical intensity level with the lateral and longitudinal levels from one flight. The accelerations of the measured vibration levels in the vertical axis was analyzed and reported in the form of a power spectral density profile. The PSD profiles represent the vibration intensity measured in the cargo area.

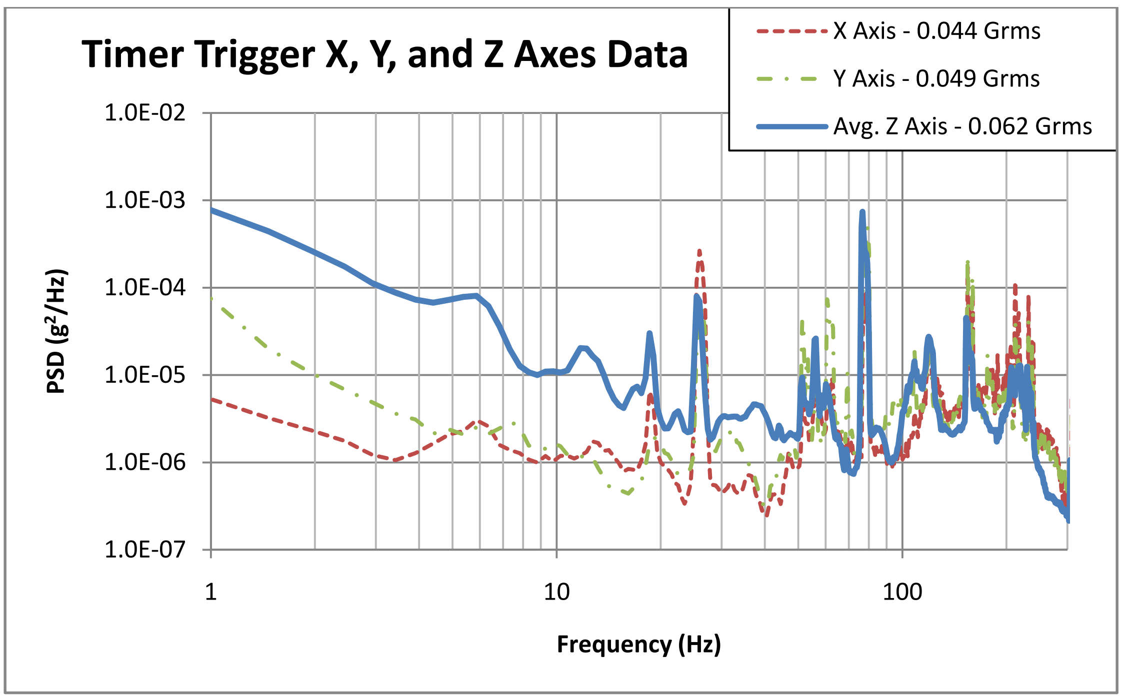


Figure 12. PSD profile of the X, Y and Z Axes

Figures 13 and 14 represent the average of the timer triggered data and the signal triggered data, displaying a cumulative overall Grms. The overall Grms level of the thirty flights for the timer trigger data was 0.062, while the overall Grms level of the thirty flights was 0.155 for the signal trigger data. The overall Grms values represent the averaged vibration data from all thirty flights.

Figures 15 and 16 represent the average of the timer triggered data and the signal triggered data respectively. The figures also illustrate the maximum PSD value at each individual frequency which displays the most severe accelerations recorded over the thirty flights.

Figure 17 represents the timer and signal triggered data overlaid to show the difference in the two intensities. Although the two PSD profiles have a similarly shaped curve the intensity of the signal triggered data was greater than that of the timer triggered data.

Figures 18 and 19 display the averaged signal and timer triggered data overlaid with the data collected from the ASTM D 4169, ISTA 4AB, and the Amgen study. This was to depict the similarities in the shape of the curves for the data collected in this study with that of the ISTA 4AB and Amgen study. It also shows the vast difference not only in the shape of the curve from the data collected in this study to the ASTM D 4169 – 08 PSD profile, but also the tremendous difference in Grms levels.

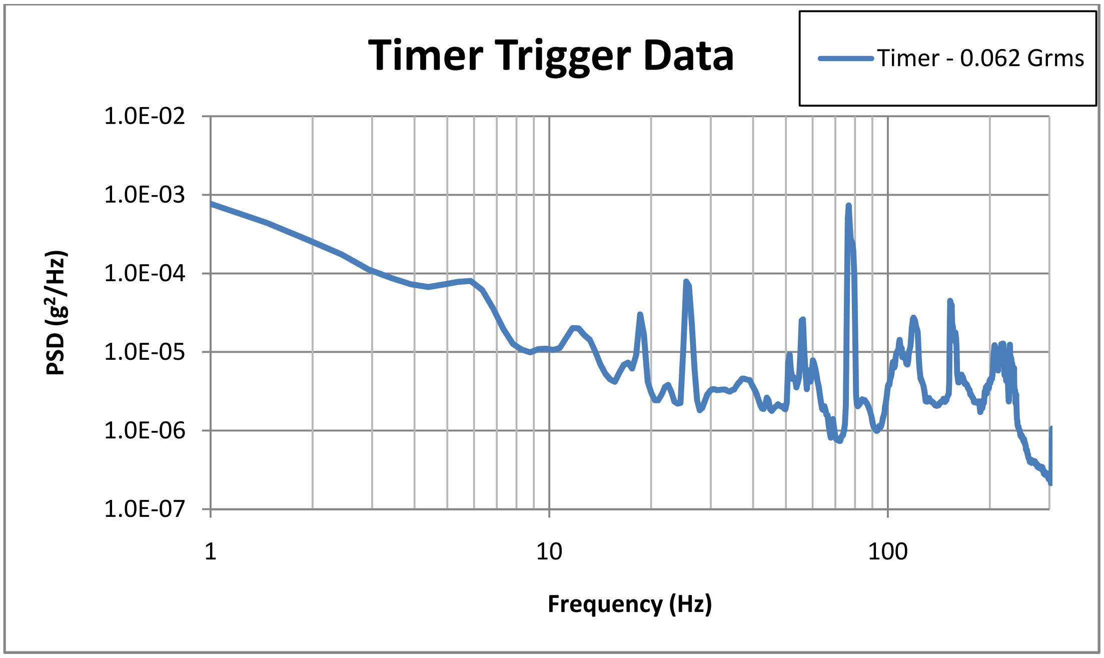


Figure 13. PSD profile of the Average Timer Trigger Data

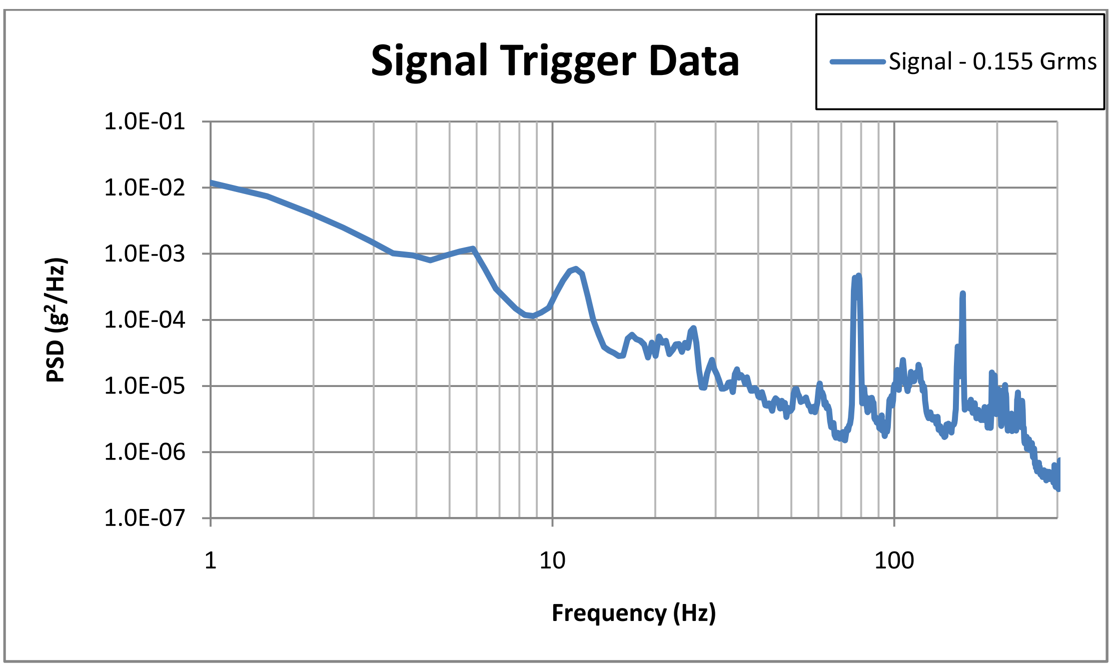


Figure 14. PSD profile of the Average Signal Trigger Data

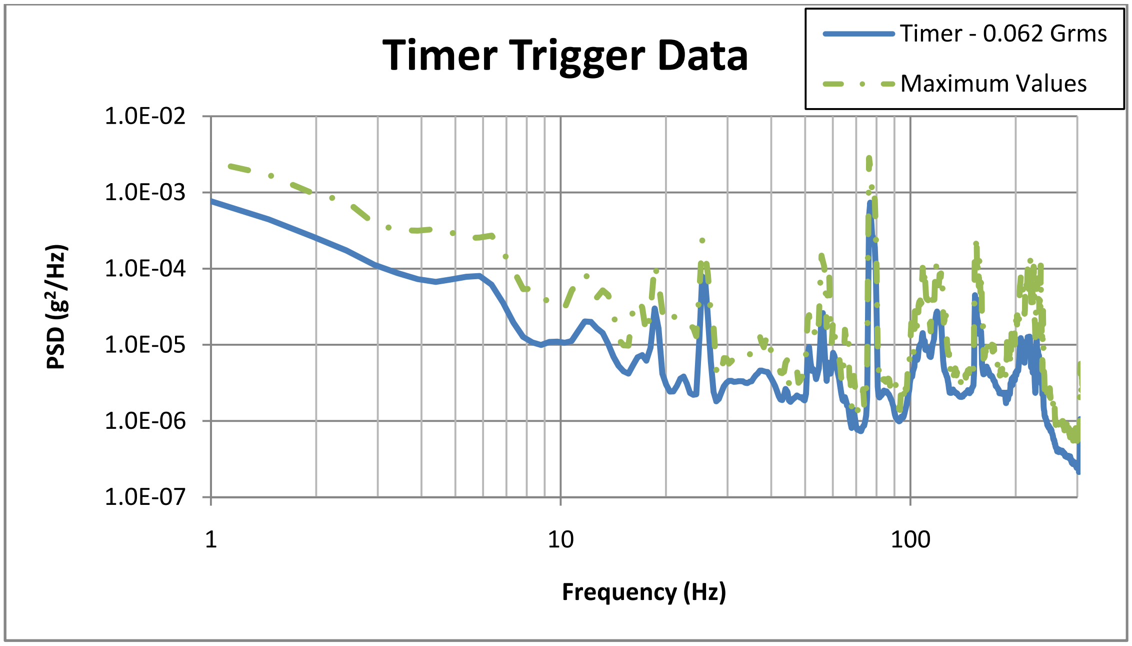


Figure 15. PSD profile of the averaged Timer Trigger Data and the maximum PSD value at that frequency

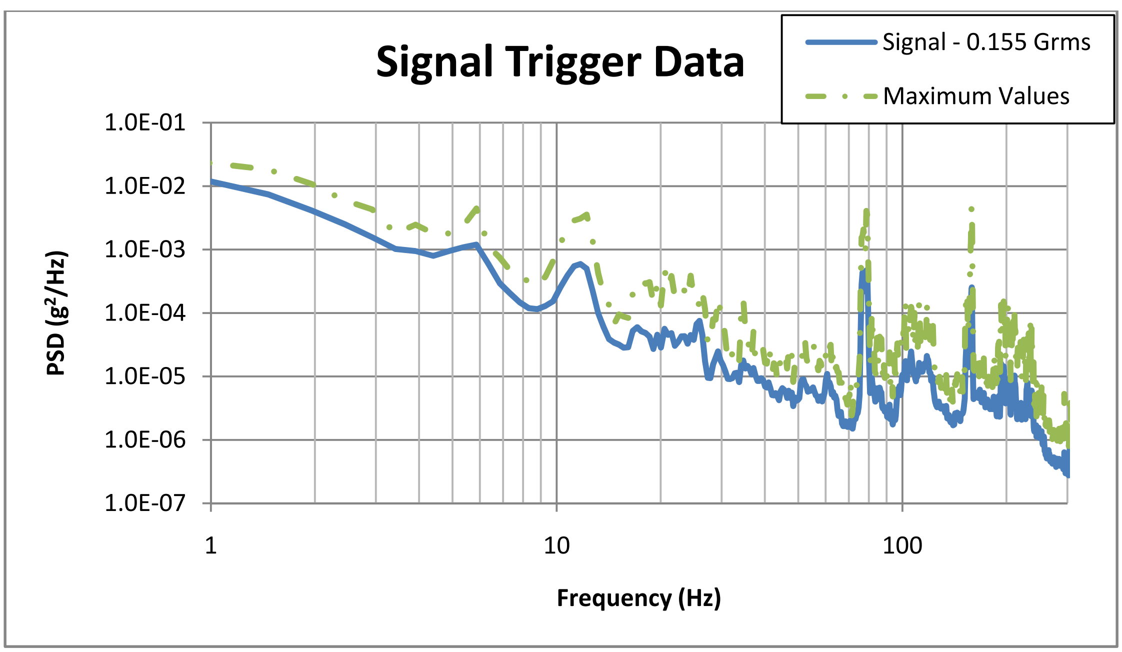


Figure 16. PSD profile of the averaged Signal Trigger Data and the maximum PSD value at that frequency

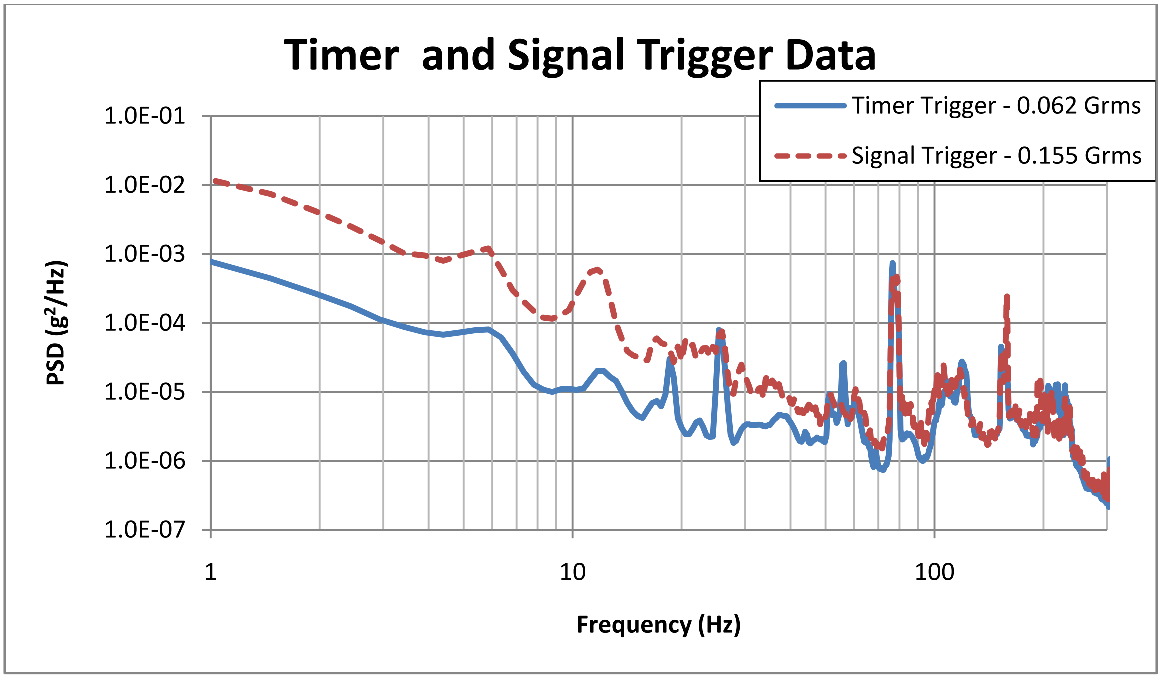


Figure 17. PSD profiles for Average Timer and Signal Trigger Data

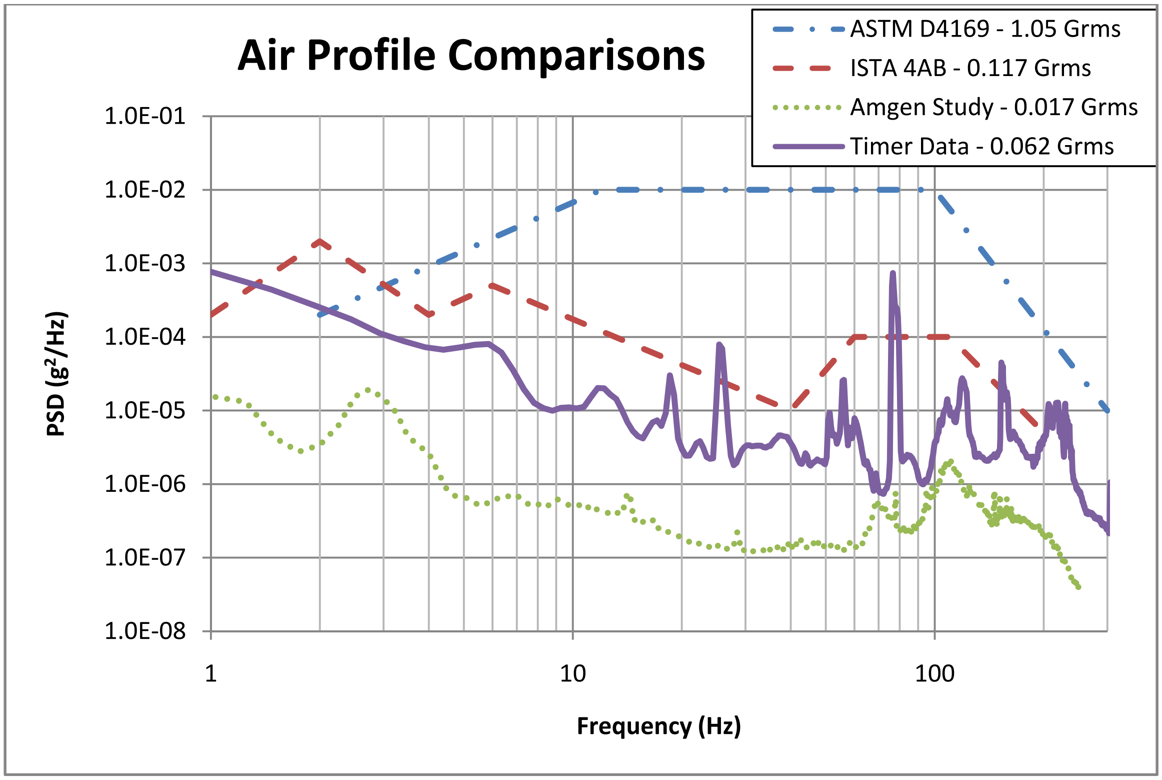


Figure 18. Timer Trigger Data, ASTM D 4169, ISTA 4AB, and Amgen Profiles

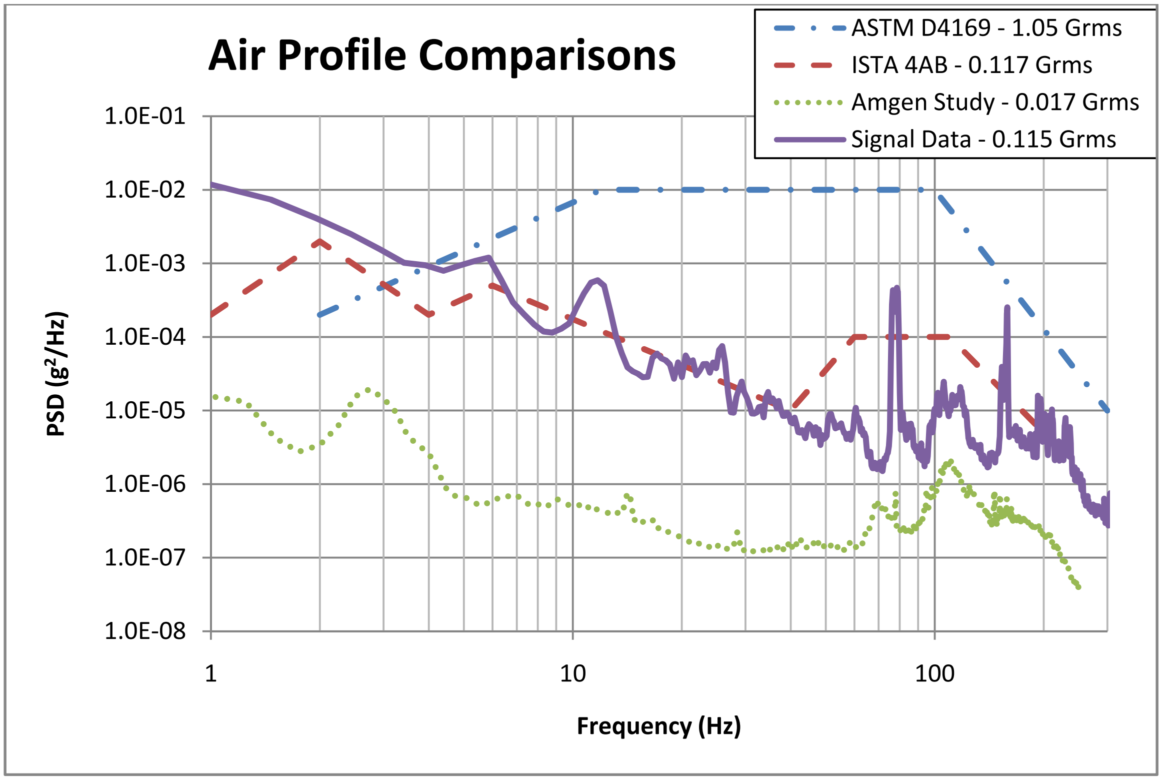


Figure 19. Signal Trigger Data, ASTM D 4169, ISTA 4AB, and Amgen Profiles

Statistical Analysis for Timer Data

The statistical analysis software, SAS, was used to perform hypothesis tests on the overall mean from all thirty flights, using timer data, and compare each Grms level with previous studies to determine if the research performed, produced a different Grms value than those of previous studies. The SAS code used to perform these separate calculations can be found in Appendix A. The SAS output from the code can be found in Appendix B.

The timer triggered data was statistically compared with the published ASTM D 4169 – 08 standard for Air Assurance Level II. The overall Grms levels were analyzed to decide if the research performed here had a statistically lower Grms than that of the Air Assurance Level II which is the most commonly used air vibration simulation profile.

The test statistic for the hypothesis test was -476.19. The decision was to reject the null hypothesis since the p-value of <0.0001 is less than an alpha of 0.05. So, in conclusion, at a significance level of 5%, there was sufficient evidence to conclude that the mean Grms level was statistically different and less than 1.05 (p-value <0.0001).

The timer triggered data was statistically compared with the published ISTA 4AB data. The overall Grms levels were analyzed to decide if the research performed here had a statistically different Grms than that of the ISTA 4AB study. The test statistic for the hypothesis test was -26.49. The decision was to reject the null hypothesis since the p-value of <0.0001 is less than an alpha of 0.05. So, in conclusion, at a significance level of 5%, there was sufficient evidence to conclude that the mean Grms level was statistically different than 0.117 (p-value <0.0001).

The timer triggered data was statistically compared with the published Amgen study. The overall Grms levels were analyzed to decide if the research performed here had a statistically different Grms than that of the Amgen study. The test statistic for the hypothesis test was 21.71. The decision was to reject the null hypothesis since the p-value of <0.0001 is less than an alpha of 0.05. So, in conclusion, at a significance level of 5%, there was sufficient evidence to conclude that the mean Grms level was statistically different than 0.017 (p-value <0.0001).

Table 7. Hypothesis test results from Timer Trigger Data for a difference in means

Previous Study	**Test Statistic**	**P-Value**	**Decision**
ASTM D 4169	-476.19	<0.0001	Reject H_0
ISTA 4AB	-26.49	<0.0001	Reject H_0
Amgen	21.71	<0.0001	Reject H_0

Statistical Analysis for Signal Data

The statistical analysis software, SAS, was used to perform hypothesis tests on the overall mean from all thirty flights, using signal data, and compare each Grms level with previous studies to determine if the research performed here in this study produced a lower Grms value than those of previous studies. The SAS code used to perform these separate calculations can be found in Appendix C. The SAS output from the code can be found in Appendix D.

The signal triggered data was statistically compared with the published ASTM D 4169 – 08 standard for Air Assurance Level II. The overall Grms levels were analyzed to decide if the research performed here had a statistically different Grms than that of the Air Assurance Level II. The test statistic for the hypothesis test was -144.83. The decision was to reject the null hypothesis since the p-value of <0.0001 is less than an alpha of 0.05. So, in conclusion, at a significance level of 5%, there was sufficient evidence to conclude that the mean Grms level was statistically different and less than 1.05 (p-value <0.0001).

The signal triggered data was then statistically compared with the published ISTA 4AB data. The overall Grms levels were analyzed to decide if the research performed here had a statistically lower Grms than that of the ISTA 4AB. The test statistic for the hypothesis test was 6.21. The decision was to reject the null hypothesis since the p-value of < 0.0001 is less than an alpha of 0.05. So, in conclusion, at a significance level of 5%, there was sufficient evidence to conclude that the mean Grms level was statistically different than 0.117 (p-value <0.0001).

The signal triggered data was statistically compared with the published Amgen study. The overall Grms levels were analyzed to decide if the research performed here had a statistically lower Grms than that of the Amgen study. The test statistic for the hypothesis test was 22.40. The decision was to reject the null hypothesis since the p-value of <0.0001 is less than an alpha of 0.05. So, in conclusion, at a significance level of 5%, there was sufficient evidence to conclude that the mean Grms level was statistically different than 0.017 (p-value <0.0001).

Table 8. Hypothesis test results from Signal Trigger Data for a difference in means

Previous Study	**Test Statistic**	**P-Value**	**Decision**
ASTM D 4169	-144.83	<0.0001	Reject H_0
ISTA 4AB	6.21	<0.0001	Reject H_0
Amgen	22.40	<0.0001	Reject H_0

CHAPTER FIVE

CONCLUSIONS

Recent technological advances in data recording have made it possible to record more data faster and separate different segments of an aircraft's flight using pressure change. Being able to separate these segments makes it possible to individually characterize and analyze a particular aircraft's environment.

The analyzed data from the environment and aircraft shows that the current test methods for aircraft vibration simulations exceed the actual environment for which the simulations are meant to represent. When data from previous studies was compared with that which was collected from this study, the results showed that the ASTM D 4169 air profile exceeds the actual environment. The time compressed ISTA 4AB profile which was meant to represent jet aircraft has a similar shape, but has a higher overall vibration intensity. Also, the Amgen profile was much lower in overall intensity when compared with this study.

The excitation from the engines rotating at 31.6 ± 5% Hz was not visible on the PSD spectrums. This was believed to be due to vibration absorbers built into the engine which produce a smoother, more comfortable ride for the passengers and cargo at typical operating engine speeds.

The maximum accelerations recorded in Table 6 occurred predominantly during the ascent and descent of the aircraft. The maximum accelerations recorded were as high as 2.11g. These levels represented discrete events occurring during takeoffs and landing; whereas the typical steady state vibration did not exceed an intensity of 0.2g. Only three maximum accelerations were recorded while the aircraft was at its cruising altitude. This was the result of the aircraft experiencing sudden changes during the ascent and descent, and few abrupt changes during the cruising altitude.

This method of collecting data could be used to understand the vibration in different aircraft in order to generate vehicle specific vibration profiles. By having multiple vibration profiles which exhibit the random vibrations experienced on an aircraft, the goal of a more optimized package and product system could be met.

The data collected from this research study could be utilized for packaging research when developing products and packages that will pass through a distribution cycle which includes transportation via a feeder turbo propeller aircraft. The PSD profiles which were analyzed from this research could be utilized to simulate in-flight aircraft vibration of the aircraft chassis in a laboratory environment. This will enable further research in the air transport environment and aid in the optimization of package design and testing.

CHAPTER FIVE

RECOMMENDATIONS

Future research in the area of aircraft vibration could be conducted using similar research methods on multiple types of aircraft and engine types. Different styles of aircrafts could be analyzed which will produce vehicle specific vibration data, much like are available for truck vibration. The same methods used for this study will be implemented to obtain the vibration data from the different aircraft chassis's. Along with different styles of aircrafts and engine types, the location of the data recorder in the aircraft will be studied to determine how location affects the data.

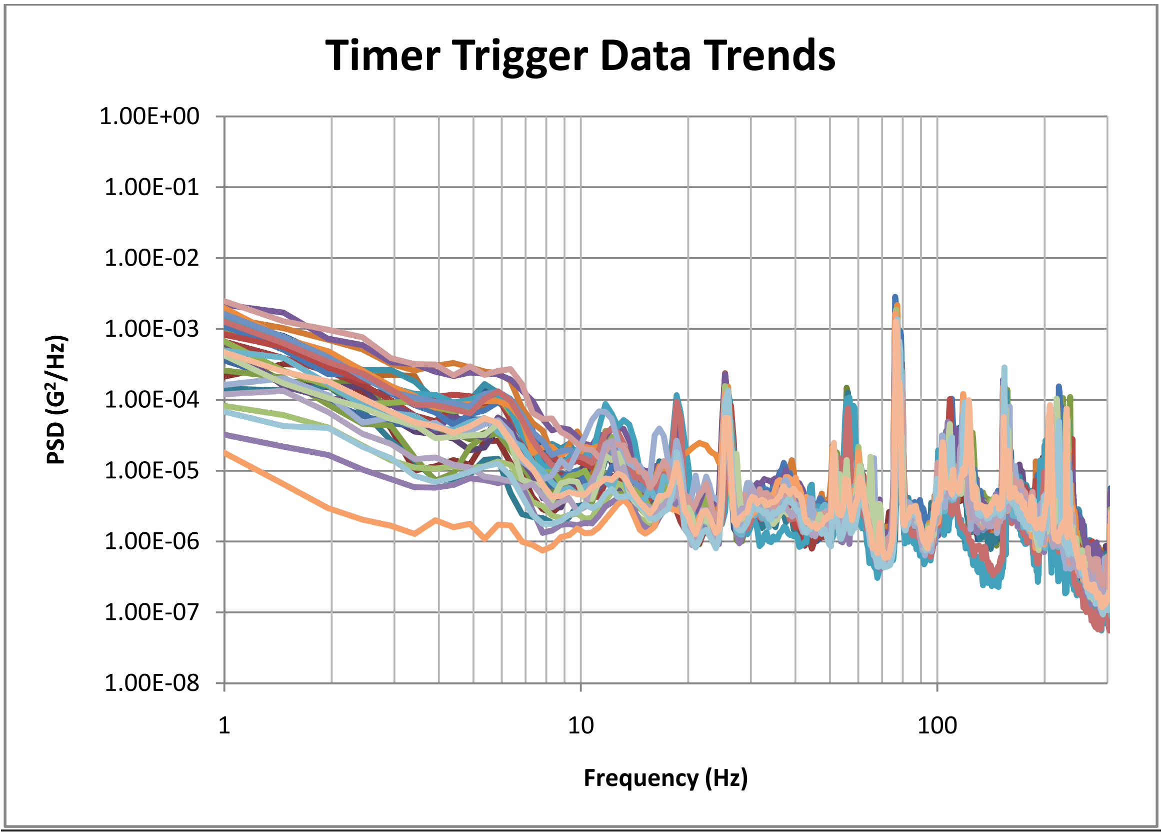
One could also look at the shocks which take place during takeoff and landing as these were not analyzed during this research. Through evaluating the different shocks which occur during takeoff and landing a procedure could be developed to simulate the various shocks in a laboratory environment.

The different temperature and relative humidity environments could be evaluated in order to understand an aircraft's cargo environment for shipments. With this research, it would be possible to generate an environmental conditioning requirement for shipments via an aircraft.

APPENDICES

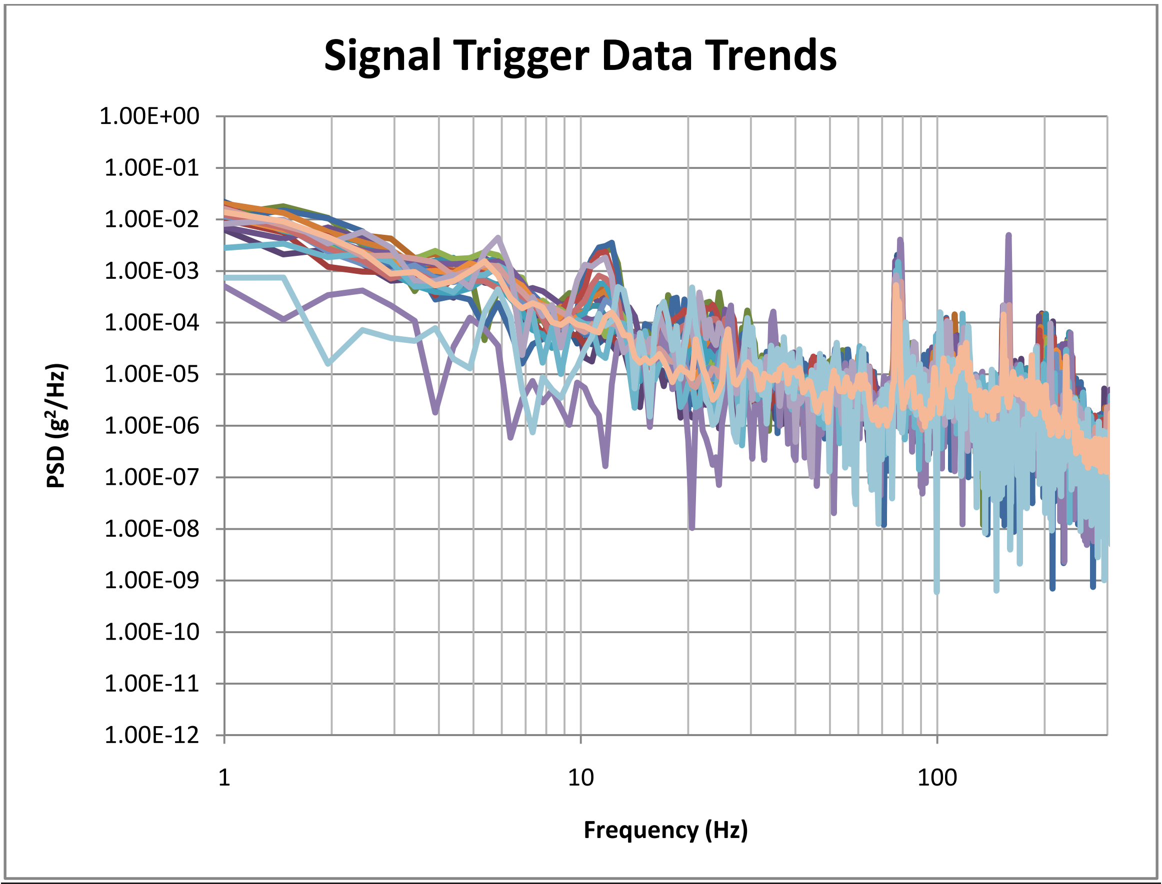
Appendix A

Timer Trigger Data Trends – Thirty Flights



Appendix B

Signal Trigger Data Trends – Thirty Flights



Appendix C

SAS Program for Timer Data

```
OPTIONS NODATE PAGENO=MIN LINESIZE=85;

Title1 Kyle Dunno;
Title2 MS RESEARCH;

Data Timer;
Input Flight $ Grms;
Datalines;
1       0.065
2       0.050
3       0.054
4       0.054
5       0.047
6       0.068
7       0.058
8       0.063
9       0.059
10      0.060
11      0.068
12      0.079
13      0.082
14      0.067
15      0.060
16      0.088
17      0.063
18      0.079
19      0.070
20      0.061
21      0.054
22      0.049
23      0.060
24      0.053
25      0.052
26      0.086
27      0.054
28      0.046
29      0.055
30      0.057
;

Proc Print;
```

```
Proc Univariate Plot;
Var Grms;

Proc ttest h0=1.05;
Var Grms;
Title3 Hypothesis Test for ASTM Level II;

Proc ttest h0=.117;
Var Grms;
Title3 Hypothesis Test for Young UPS (ISTA 4AB);

Proc ttest h0=.017;
Var Grms;
Title3 Hypothesis Test for Lansmont/Amgen Study;

Run;

Quit;
```

Appendix D

SAS Output for Timer Data

Kyle Dunno
MS RESEARCH

Obs	Flight	Grms
1	1	0.065
2	2	0.050
3	3	0.054
4	4	0.054
5	5	0.047
6	6	0.068
7	7	0.058
8	8	0.063
9	9	0.059
10	10	0.060
11	11	0.068
12	12	0.079
13	13	0.082
14	14	0.067
15	15	0.060
16	16	0.088
17	17	0.063
18	18	0.079
19	19	0.070
20	20	0.061
21	21	0.054
22	22	0.049
23	23	0.060
24	24	0.053
25	25	0.052
26	26	0.086
27	27	0.054
28	28	0.046
29	29	0.055
30	30	0.057

Kyle Dunno
MS RESEARCH

The UNIVARIATE Procedure
Variable: Grms

Moments

N	30	Sum Weights	30
Mean	0.06203333	Sum Observations	1.861
Std Deviation	0.01136384	Variance	0.00012914
Skewness	0.86083749	Kurtosis	0.02143289
Uncorrected SS	0.119189	Corrected SS	0.00374497
Coeff Variation	18.3189198	Std Error Mean	0.00207474

Basic Statistical Measures

Location		Variability	
Mean	0.062033	Std Deviation	0.01136
Median	0.060000	Variance	0.0001291
Mode	0.054000	Range	0.04200
		Interquartile Range	0.01400

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	29.89928	Pr > |t|	<.0001
Sign	M	15	Pr >= |M|	<.0001
Signed Rank	S	232.5	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	0.0880
99%	0.0880
95%	0.0860
90%	0.0805
75% Q3	0.0680
50% Median	0.0600
25% Q1	0.0540
10%	0.0495
5%	0.0470
1%	0.0460
0% Min	0.0460

```
                    Kyle Dunno
                   MS RESEARCH

             The UNIVARIATE Procedure
                Variable:  Grms

               Extreme Observations

     -----Lowest----        ----Highest----

      Value      Obs         Value      Obs

      0.046       28         0.079       12
      0.047        5         0.079       18
      0.049       22         0.082       13
      0.050        2         0.086       26
      0.052       25         0.088       16


      Stem Leaf                     #             Boxplot
         8 68                       2                |
         8 2                        1                |
         7 99                       2                |
         7 0                        1                |
         6 5788                     4             +-----+
         6 000133                   6             *--+--*
         5 5789                     4             |     |
         5 0234444                  7             +-----+
         4 679                      3                |
           ----+----+----+----+
        Multiply Stem.Leaf by 10**-2


                        Normal Probability Plot
   0.0875+                                              *   *++++
         |                                            * +++++
         |                                        * *+++
         |                                      +*++
   0.0675+                                 ++***
         |                             +****
         |                        ++****
         |                  * ***+*
   0.0475+     *   * *+++
          +----+----+----+----+----+----+----+----+----+----+
               -2        -1         0        +1        +2
```

Kyle Dunno
MS RESEARCH
Hypothesis Test for ASTM Level II

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Grms	30	0.0578	0.062	0.0663	0.0091	0.0114	0.0153	0.0021

T-Tests

Variable	DF	t Value	Pr > |t|
Grms	29	-476.19	<.0001

Kyle Dunno
MS RESEARCH
Hypothesis Test for Young UPS (ISTA 4AB)

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Grms	30	0.0578	0.062	0.0663	0.0091	0.0114	0.0153	0.0021

T-Tests

Variable	DF	t Value	Pr > |t|
Grms	29	-26.49	<.0001

Kyle Dunno
MS RESEARCH
Hypothesis Test for Lansmont/Amgen Study

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Grms	30	0.0578	0.062	0.0663	0.0091	0.0114	0.0153	0.0021

T-Tests

Variable	DF	t Value	Pr > |t|
Grms	29	21.71	<.0001

Appendix E

SAS Program for Signal Data

```
OPTIONS NODATE PAGENO=MIN LINESIZE=90;

Title1 Kyle Dunno;
Title2 MS RESEARCH;

Data Signal;
Input Flight $ Grms;
Datalines;
1  0.170
2  0.190
3  0.119
4  0.184
5  0.173
6  0.139
7  0.153
8  0.168
9  0.192
10 0.166
11 0.173
12 0.166
13 0.174
14 0.161
15 0.156
16 0.156
17 0.153
18 0.111
19 0.116
20 0.169
21 0.167
22 0.061
23 0.156

;

Proc Print;

Proc Univariate Plot;
Var Grms;

Proc ttest h0=1.05;
Var Grms;
Title3 Hypothesis Test for ASTM Level II;
```

```
Proc ttest h0=.117;
Var Grms;
Title3 Hypothesis Test for Young UPS (ISTA 4AB);

Proc ttest h0=.017;
Var Grms;
Title3 Hypothesis Test for Lansmont/Amgen Study;

Run;

Quit;
```

Appendix F

SAS Output for Signal Data

Kyle Dunno
MS RESEARCH

Obs	Flight	Grms
1	1	0.170
2	2	0.190
3	3	0.119
4	4	0.184
5	5	0.173
6	6	0.139
7	7	0.153
8	8	0.168
9	9	0.192
10	10	0.166
11	11	0.173
12	12	0.166
13	13	0.174
14	14	0.161
15	15	0.156
16	16	0.156
17	17	0.153
18	18	0.111
19	19	0.116
20	20	0.169
21	21	0.167
22	22	0.061
23	23	0.156

Kyle Dunno
MS RESEARCH

The UNIVARIATE Procedure
Variable: Grms

Moments

N	23	Sum Weights	23
Mean	0.15534783	Sum Observations	3.573
Std Deviation	0.02962586	Variance	0.00087769
Skewness	-1.7166859	Kurtosis	3.65470684
Uncorrected SS	0.574367	Corrected SS	0.01930922
Coeff Variation	19.070664	Std Error Mean	0.00617742

Basic Statistical Measures

Location		Variability	
Mean	0.155348	Std Deviation	0.02963
Median	0.166000	Variance	0.0008777
Mode	0.156000	Range	0.13100
		Interquartile Range	0.02000

Tests for Location: Mu0=0

Test	-Statistic-		-----p Value------	
Student's t	t	25.14769	Pr > |t|	<.0001
Sign	M	11.5	Pr >= |M|	<.0001
Signed Rank	S	138	Pr >= |S|	<.0001

Quantiles (Definition 5)

Quantile	Estimate
100% Max	0.192
99%	0.192
95%	0.190
90%	0.184
75% Q3	0.173
50% Median	0.166
25% Q1	0.153
10%	0.116
5%	0.111
1%	0.061
0% Min	0.061

```
                    Kyle Dunno
                   MS RESEARCH

             The UNIVARIATE Procedure
                Variable:  Grms

               Extreme Observations

  -----Lowest----        ----Highest----

   Value      Obs         Value      Obs

   0.061       22         0.173       11
   0.111       18         0.174       13
   0.116       19         0.184        4
   0.119        3         0.190        2
   0.139        6         0.192        9


 Stem Leaf                     #             Boxplot
   18 402                      3                |
   16 1667890334              10             +-----+
   14 33666                    5             +--+--+
   12 9                        1                |
   10 169                      3                0
    8
    6 1                        1                *
      ----+----+----+----+
      Multiply Stem.Leaf by 10**-2


                    Normal Probability Plot
 0.19+                                  +++*++*    *
     |                        ** ***+**+ *
     |                  **+*+*+++
 0.13+              +++*++
     |       +++*++* *
     |+++++++
 0.07+      *
     +----+----+----+----+----+----+----+----+----+----+
             -2        -1         0        +1        +2
```

Kyle Dunno
MS RESEARCH
Hypothesis Test for ASTM Level II

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Grms	23	0.1425	0.1553	0.1682	0.0229	0.0296	0.0419	0.0062

T-Tests

Variable	DF	t Value	Pr > |t|
Grms	22	-144.83	<.0001

Kyle Dunno
MS RESEARCH
Hypothesis Test for Young UPS (ISTA 4AB)

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Grms	23	0.1425	0.1553	0.1682	0.0229	0.0296	0.0419	0.0062

T-Tests

Variable	DF	t Value	Pr > |t|
Grms	22	6.21	<.0001

Kyle Dunno
MS RESEARCH
Hypothesis Test for Lansmont/Amgen Study

The TTEST Procedure

Statistics

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Grms	23	0.1425	0.1553	0.1682	0.0229	0.0296	0.0419	0.0062

T-Tests

Variable	DF	t Value	Pr > |t|
Grms	22	22.40	<.0001

REFERENCES

ASTM International. (2008) Selected ASTM Standards on Packaging. Philadelphia

Berman, A and Hannibal, A. (1979) "Passenger Vibration in Transportation Vehicles", The American Society of Mechanical Engineers.

Brandenburg, Richard and Lee, Julian June-Ling. (2001) Fundamentals of Packaging Dynamics. L.A.B. Equipment, Inc.

Devore, Jay. (1991) Probability and Statistics for Engineering and the Sciences. Pacific Grove, CA.

FedEx Air Cargo Services. (2007) Air Cargo Services. Accessed from http://www.fedex.com/us/services/expressfreight/intl/aircargo.html on July 25, 2008.

Freund, Rudolf and Wilson, William. (1997) Statistical Methods Revised Edition. San Diego, CA

General Technical Report FPL 22. (1979) Forest Products Laboratory, U.S. Department of Agriculture. Madison, WI.

Goleta Air and Space Museum. (2008) Santa Barbara Airport. Accessed from http://www.air-and-space.com on August 12, 2008.

ISTA Resource Book. (2008) "ISTA Preshipment Test Procedure 4AB." ISTA.

Joneson, Eric. (2008) Conversation concerning Air Vibration Study. Conducted on April 14, 2008.

Joneson, Eric. (2006) Development of Testing Standard for Vibration Simulation. *Procedings of Dimensions 06*. International Safe Transit Association: San Antonio, TX.

Kipp, William I. (2002) "Accelerated Vibration Testing of Packaged-Products", TEST Engineering & Management Magazine.

Ott, R.L. & Longnecker, M. (2001). An introduction to statistical methods and data analysis (5th ed.). Pacific Grove, CA: Duxbury.

Singh, P., Joneson, E., Singh, J., Grewal, G. (2007) Dynamic Analysis of Less-than-truckload Shipments and Test Method to Simulate This Environment. *Packaging Technology and Science*,

Soroka, Walter (2002). Fundamentals of Packaging Technology. Institute of Packaging Professionals.

Trost, T. Stresses in Air Cargo Transportation. *Packaging Technology and Science*, 1988; Vol. 1: 137-155.

U.S. Department of Transportation Federal Aviation Administration Type Certification Data Sheet P15BO. (2007)

Young, D.E., Cook B.J., and Gordon, R.D. (1997) Quantifying the Vibration Environment of a Small Parcel System. *Proceedings from Transpack 1997*, Orlando, FL.

UPS Air Cargo (2007). Aircraft. Accessed from http://www.ups.com/aircargo/using/services/services/domestic/svc-aircraft.html on July 25, 2008.