6-2011

Development of a System to Quantify Perpendicular Forces between the Foot and a Shoe

Samuel W. Barstow
Union College - Schenectady, NY

Development of a System to Quantify Perpendicular

Forces between the Foot and a Shoe

By

Sam Barstow

* * * * * * * * *

Submitted in partial fulfillment

Of the requirements for

Honor in the Department of Mechanical Engineering

UNION COLLEGE

June, 2011

ABSTRACT

BARSTOW, SAMUEL The development of a system to quantify perpendicular forces between the foot and a shoe. Department of Mechanical Engineering, June 2011

ADVISOR: William Keat Ph.D.

There are a variety of fit systems available in the outdoor footwear industry. Each of these fit systems tightens the shoe around the wearer's foot in a different way. In this project an apparatus was developed to quantify perpendicular forces between the foot and a shoe. This apparatus utilized piezoresistive sensors that, when combined with an excitation voltage and an inverting operational amplifier, pass a voltage that is proportional to the force applied to the sensing area. A significant section of this project was dedicated to troubleshoot this apparatus in order to produce nearly linear calibration curves.

The apparatus was then used to collect data on the force distribution between four shoes featuring unique fit systems. The shoes were a North Face Ultra 104 GTX XCR laced in a wide set of eyelets, a Treksta Sidewinder, a North Face Ultra 104 GTX XCR laced in a narrow set of eyelets, and a Merrell light hiking shoe. Nine sets of data were collected with these shoes in four conditions: the foot outside of the shoe, the foot inside the shoe with the fit system fully loosened, the foot inside the shoe with the laces tightened only by the loose ends, and finally the foot inside the shoe with the fit system fully tightened.

The data collected was then analyzed to draw conclusions on the effects each fit system had on the force distribution between the foot and the shoe. Specifically, it was found that the North Face shoe laced in the narrow set of eyelets provided the most

uniform distribution of force between the foot and the shoe when fully tightened. The data also verified the performance of the low friction eyelets and lace featured on the Treksta. The fit system on the Treksta directly incorporates the heel of the shoe, but this was found to have no effect on the pressure distribution on the heel of the foot. The data also demonstrated that the fit system of the Merrell focuses the force on applied to the foot on the tongue area.

Contents

Project Objective

Footwear “fit” is not clearly defined, and is subjective because everyone’s foot is different. The causes of short term discomfort in footwear, however, are much clearer, and can be experienced by anyone. The main causes of short term discomfort are pressure points on the foot and rubbing between the foot and shoe. Typically rubbing between the foot and shoe is a result of an uneven pressure distribution. The foot slips in low pressure areas, and is held tightly in high pressure areas. This causes the skin to become irritated in these areas and blisters may develop. The hypothesis investigated in this report is that a shoe that provides an even pressure distribution on the foot will provide the best fit.

The way a shoe fits the shoe is a function of the fit system it features. The fit system is what tightens the shoe around the wearer’s foot. The most common is the traditional lace system, but there are a variety of other systems available in the outdoor footwear industry. The objective of this project was to develop a system to analyze and quantify the fit of a shoe. In order to do this an apparatus was developed to collect quantitative data and evaluate different fit systems available in outdoor footwear.

Background

Outdoor Footwear

High performance outdoor footwear manufacturers have always pursued technologies to push their products to the next level. Advancements have been made in the technical fabrics, cushioning, and sole design of outdoor footwear. One of the few elements that has remained unchanged in the vast majority of shoes is how they are

tightened, or the "fit system". This fit system is the traditional lace up design. Laces have always been located above the top of the foot, run through about five sets of eyelets, and been tied with a simple knot. The eyelets and lace material have changed, but the basic geometry has remained the same.

Figure 1: 1960's hiking boot [1]

Figure 2: 2010 hiking shoe [2]

In the past few years, several companies have started to branch out from this traditional setup, incorporating new elements into the fit system. The deviations from the traditional lace up system have involved using a toggle mechanism, low friction eyelets, low friction lace material, and incorporating the heel into the fit system.

Toggle Mechanism

Several companies now feature a toggle on the shoe to lock the laces once the shoe is tightened. Most of these toggles are simple plastic pieces that lock down on the laces and can be released by squeezing (see figure 3). This provides a quick alternative to tying a knot, and does not allow the laces to slip. One example of a technically advanced version of the toggle is the Boa system pictured in figure 4. The Boa system consists of a circular reel that winds the cable lace as the user spins the dial. The system releases when the circular dial is pulled outward. This system allows the user to tighten and loosen their shoes with one hand.

Figure 3: Simple Toggle Mechanism[3]

Figure 4: Advanced Toggle Mechanism[4]

Low Friction Eyelets

Another new element outdoor footwear companies are beginning to incorporate into their shoes is low friction eyelets. Traditional eyelets featured on shoes are simply holes punched through the material on either side of the tongue. This system often requires the wearer to tighten the laces at several sets of eyelets before they can pull on the ends of the lace to achieve a uniform fit. Low friction eyelets allow the shoe to be tightened much more uniformly by only pulling on the ends of the laces. These eyelets are often wider allowing a more gradual redirecting of the lace. This can be seen on the shoe in figure 4.

Low Friction Lace

In order to reduce as much friction as possible, the laces have been redesigned. The goal is again to allow the user to achieve a uniform fit by only pulling on the loose ends of the laes. These new laces are a metal cable with a colored coating. Cable laces are much stronger than traditional cloth laces, so they can be made much thinner (figure 5).

Figure 5: Shoe with low friction laces[5]

Incorporation of Heel into Fit System

The most common area of a shoe that causes discomfort is the heel. If the heel of a shoe does not fit the user well, the foot slips during the walking motion and blisters develop. Few footwear companies have addressed this problem by directly incorporating the heel into the fit system. One design concern is that a completely new lace system would have to be developed. Incorporating the heel requires a longer lace and more components so there is more friction and it becomes more difficult to tighten the shoe. This has led several manufacturers to incorporate the heel indirectly into the fit system. This is typically done by keeping the same lace system on the tongue of the shoe, but having the top set of eyestays run to the heel of the shoe. When the laces are tightened, the eyestays pull together, and pull the heel forward (see figure 6). The shoes are made out of fairly rigid materials, however, so this system has little effect on the fit of the shoe.

Figure 6: Indirect incorporation of heel [6]

One footwear company, however, does produce a shoe that directly incorporates the heel into the fit system. This fit system features a Boa toggle and combines all of the components mentioned above. The low friction components and Boa toggle allow the shoe to be tightened easily. The low friction cable lace is also thin, so incorporating the heel does not add cumbersome bulk to the shoe (figures 4&7).

Figure 7: Boa fit system with heel incorporated (same shoe as figure 4) [4]

Fit Quantification Techniques

In order to scientifically analyze the fit of a shoe, quantitative data must be collected. This is typically done by analyzing the perpendicular forces between the foot and shoe. There are several systems that do this. One is Dr. Scholl's Foot Mapping Technology that uses 2200 force sensors integrated into a mat that a person stands on with their shoes off. A force reading is taken and a color coded image is produced that illustrates the pressure distribution on the bottom of their feet (figure 8).

Figure 8: Sample image produced by Dr. Scholl's Foot Mapping Technology [7]

Another system, Novel Pedar, features a highly conforming elastic sensor insole that is placed over the foot bed inside of a shoe. The user can then put the shoe on and perform activities while the system collects data on the pressure distribution inside of the shoe (figure 9). This system allows the user to analyze the pressure distribution in real time and has been used in many different applications such as in the Temple School of Podiatry's research center (figure 10). The Novel Pedar system does offer sensor pads for the medial (inside) lateral (outside) and dorsal (top) areas of the foot, but it was very expensive and not a feasible option for this project. There are also experimental

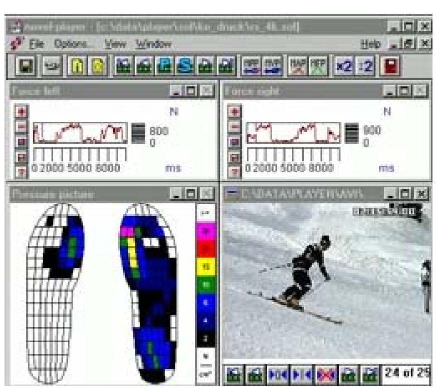


Figure 10: Temple School of Podiatry Research Facilities [9]

Figure 9: Novel Pedar system in use [8]

apparatuses that have been developed for specific medical studies. Each of these apparatuses was developed specifically for their respective studies, and was not available. The focus of this project therefore became the development of a test apparatus that quantifies the perpendicular forces in between the foot and the shoe.

Areas of the Foot to Analyze

In order to generate this test apparatus, the areas where the sensors should be located were determined. In consulting a podiatrist, Dr. Mike Krajick, the locations selected were the:

1. Joint of the 1st metatarsal and phalange on the medial side (sensor will be vertical)
2. Joint of the 5th metatarsal and phalange on the lateral side (sensor will be vertical)
3. Middle of the tarsometatarsal joint on the top of the foot
4. Medial side of where the tarsometatarsal joint and 1st metatarsal meet
5. Lateral side of where the tarsometatarsal joint and 5th metatarsal meet

6&7. Either side of the Achilles tendon at the top of the calcaneus

8. Back of the calcaneus (heel)

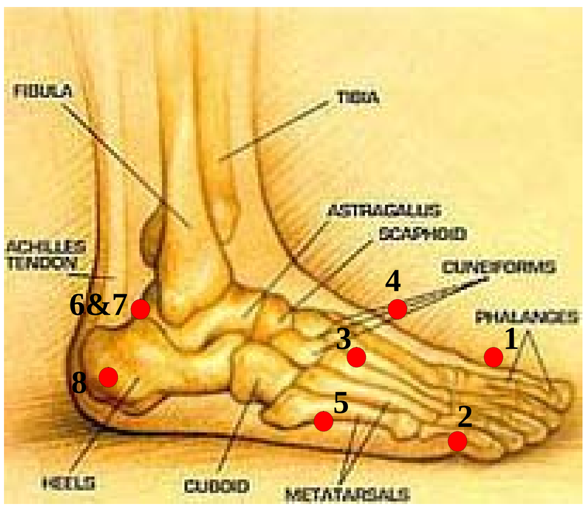


Figure 11: Sensor locations [10]

These locations were selected because they are the most sensitive, or load bearing areas of the foot. The first and second locations are on either side of the major joint of the foot, so they are among the main load bearing areas. These areas are also among the most likely to feel pressure in a shoe, and generate blisters. Locations three, four, and five are located on the tarsometatarsal joint of the foot. This is another major load bearing areas of the foot because it is a joint, but minimal motion occurs. When the heel is off the ground and all of the weight of the body is on the ball of the foot, this joint is under a large amount of stress.

The heel of the foot is one of the main problem areas in shoe fit. If the heel is not held in place properly by the shoe, it slips during the walking motion and blisters develop. Shoes are therefore shaped to grab the area were the Achilles tendon meets the calcaneus, the heel bone, to prevent this slippage. Sensors six and seven will be located on either side of the Achilles tendon at this location. The eighth sensor will be on the back of the heel to provide data on this slippage. If the heel is successfully held in place, the force at this location should remain fairly constant during the walking motion.

Customer Profiling

The final element of the background research was to conduct a customer profiling study. The goal of this project is to produce a fit system that could be featured on production footwear, so there must be an understanding of who the product is designed for. This official target customer is age 16 to 28 years old; however the main group is in the college ages of 18 to 22. In order to gain basic knowledge about the existing behaviors of this group, a survey was created. The survey and results are attached in Appendix A. This survey consisted of eight questions and was taken by 40 participants.

1. Age:
2. Gender:

These first two questions were to classify the participants. All of the people who took the survey were between the ages of 17 and 23 years old. 75% of the participants were male, and 25% were female.

3. What is the brand of the shoes that wear most often?

This question was asked to gain a basic understanding of what the participants like in terms of footwear. The question asks for the brand of the shoes worn most often because this is most likely the pair that the participant likes the most. The answers to this question consisted of 13 different brands, but 20 out of the 40 responses were Nike.

4. What general category do these shoes fall under?

This question was asked to see what type of shoe the participant uses. This is another general categorization question. The results were:

Athletic sneaker:	57.5%
Skateboard Shoe:	17.5%
Other fashion oriented shoe:	12.5%
Flats:	7.5%
Slippers/clogs:	5%
Boots:	0%
Outdoor shoe:	0%

This is an interesting trend. None of the participant's most worn shoes are boots and outdoor shoes. This suggests that boots and outdoor shoes are too specialized to be worn as everyday shoes, yet skateboard shoes are specialized footwear and they were the second largest category. This supports the hypothesis that skateboard shoes are worn more for their fit and style than for their intended purpose.

5. Do you tie the laces on your shoes every time you put them on? Choose N/A if the shoes you wear most do not have laces.

This question was added to gain information on the traditional lace system that is used on most footwear. The results show that 32.5% tie their shoes every time the put them on, 55% don't, and 12.5% wear shoes without laces. This clearly shows that the majority of participants do not use the traditional lace system as it is intended. This supports the argument for using toggle systems, which are a faster alternative to traditional lace systems where the user must tie a knot to fix the laces. Based on the results a fit system that will appeal to this group is one that requires the least effort and time.

6. If yes [to question 5], do you tighten between the eyelets or just pull on the loose ends of the lace?

This question again was intended to collect information on the goals of a lace system. 64.7% of the participants of the survey tighten their shoes by only pulling on the loose ends of the laces. The best fit system for this group is therefore one that can tighten effectively when the user pulls on the ends of the lace. In order to accomplish this, low friction components must be used.

7. What do you like about these specific shoes in terms of fit?

The goal of this question was to collect information on what fit features the participants value most. The question was answered in varying amounts of detail, but useful information was collected. The general consensus was that comfort and convenience is valued over performance; the majority of the answers referred to the fit of their most worn shoes as plush, comfortable and easy to put on and take off. A significant amount of the answers, however, referred to the fit as snug and offering support.

8. What do you dislike about these specific shoes in terms of fit?

This question was intended to highlight the downsides to the type of fit referred to in the previous question. For example, if a shoe is easy to get on and off and is plush and comfortable, it will not have good performance in applications such as running, walking along a slope, or other application that require a tight fitting shoe. The question was fairly successful in this regard, but there were many comments about how the shoe wears over time and many that indicated that the user does not dislike anything about the fit of their shoes. Most of the useful answers were comments about the lack of support, which corresponds with the answers to the previous question.

Sensor Selection for the Apparatus to Quantify Perpendicular Forces in a Shoe

The first step in developing this system was to research sensors that could be used in such an apparatus. This is a demanding application; the sensors must be small to fit between the shoe and the foot without affecting the fit of the shoe, sensitive enough to quantify minor differences in fit between shoes, and cheap enough to purchased on a limited budget. Three options were explored: gauge pressure sensors, compression load cells, and piezoresistive force sensors.

Gauge Pressure Sensor Apparatus

An apparatus was devised that utilized gauge pressure sensors to measure the pressure in air or water bladders. These bladders would be small and low profile so that they could be placed on a foot inside of a shoe without having a large affect on the fit. The bladders would be integrated into a sock, so that bladders could be placed in the locations described in the "Areas of the Foot to Analyze" section above. For the air system, a single hose would connect the bladder to a gauge pressure sensor. When the

foot is inside the shoe with the bladders in place, the gauge pressures would be measured and compared directly to each other. A pressure sensor option is an Ashcroft precision digital test gauge pictured in figure 12.

Figure 12: Ashcroft Precision Digital Test Guage [11]

This system could also be used with water filled bladders instead of air. Water is a much less compressible fluid than air, so there would be less loss in the system. If water were used, another option would be to have two hoses running to each of the bladders and use a syringe located outside of the shoe to fill the bladders and tubing with water once the foot is inside the shoe. The bladders would then be filled with enough water to reach a predetermined pressure. The measurements being compared would be the volume of water injected into each bladder to have reached a pressure. Sketches of the air and water bladder apparatuses are included in Appendices B and C respectively.

Compression Load Cell Apparatus

Compression load cells feature a piston that is depressed by a load. These sensors come in many different sizes. The smallest I was able to find is a Futek miniature compression load cell, pictured in figure 13. These load cells convert the depression of the piston to a measurable voltage output with a metal foil strain gauge. These cylindrical load cells could then be placed directly on the previously described locations

and the loads could be measured. These load cells, as figure 13 clearly illustrates, are too large to be placed inside of a shoe. Holes would have to be cut at each location and the sensor would be fixed to the outside of the shoe, with the sensing area protruding through the hole to the inside of the shoe. Another downside to this system is that these sensors are $575 each.

Figure 13: Ashcroft Precision Digital Test Guage [12]

Piezoresistive Force Sensor Apparatus

A piezoresistive force sensor is a variable resistor that uses the piezoresistive effect to quantify a mechanical applied force. The piezoresistive effect is a property of semiconductors that allows their electrical resistance to change due to an applied mechanical stress. The sensor can therefore be integrated into a circuit with the voltage drop across the sensor measured as the output. A calibration curve can then be generated to convert the output voltage to units of force. The piezoresistive force sensors used for this apparatus are FlexiForce Sensors (figure 14). These sensors are extremely thin and flexible. They can therefore be placed on the foot inside of the shoe without having a large effect on the fit of the shoe. These sensors are also inexpensive at $15 each. This sensor comes in three different load ranges: 0-1 pound, 0-25 pound, and 0-100 pound. The forces inside of the shoe were not previously known, but were estimated to be around

a pound. The middle option was therefore chosen. A preliminary sketch of this apparatus can be seen in Appendix D.

Figure 14: FlexiForce Sensor [13]

Preliminary Apparatus Development

Once the sensors were selected, the next step in the development of the apparatus was to create and optimize the circuit to run them. The manual for these sensors (Appendix E) gives a suggested circuit that utilizes an inverting operational amplifier to amplify the output voltage so that minor changes in the resistance are more measureable. This suggested circuit is pictured in figure 15 below.

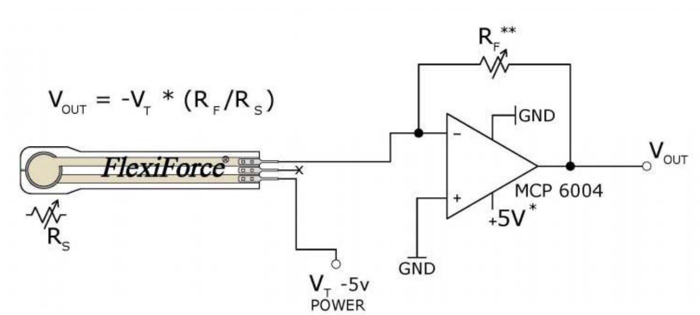


Figure 15: Recommended Circuit for FlexiForce Sensor [13]

This is an excitation circuit, meaning that a negative voltage is supplied to the sensor. The resistor R_f at the top of the circuit is the reference resistor that has a resistance from 1kΩ to 100kΩ. The resistance of R_f can be adjusted within this range to tune the sensor. A small resistance tunes the sensor to accept a large load range so that it saturates at up to 25 pounds of applied force. A large resistance tunes the sensor to the

lower load range so that it saturates closer to one pound of applied force. A 10 turn 1kΩ to 100kΩ potentiometer was used in the circuit.

The first obstacle encountered in building this circuit was in producing the -5V excitation voltage. The DC power supplies cannot produce this with the standard configuration. After consulting the manual the supply voltage to the sensor and op-amp were configured by connecting the two adjustable outputs in series and grounding the positive lead of the first channel, the negative lead of which supplies the negative voltage. The positive lead of the second channel was then the +5V drive voltage for the op-amp. This configuration can be seen in figure 16.

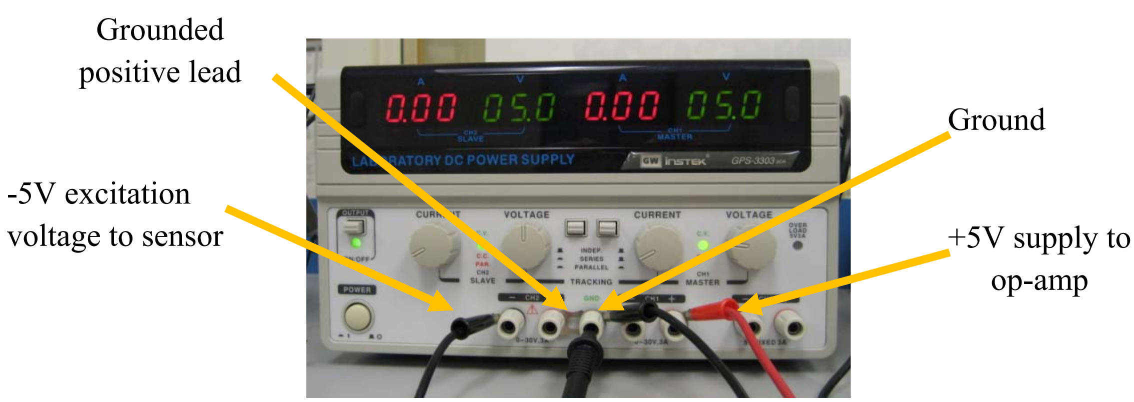


Figure 16: Power Supply Configuration

Once the supply voltage was set up, the op-amp circuit was constructed on a breadboard. This can be seen in figures 17 and 18 below.

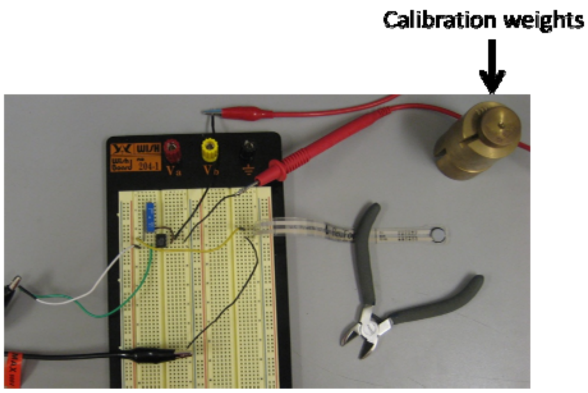


Figure 17: Full Preliminary Test Apparatus

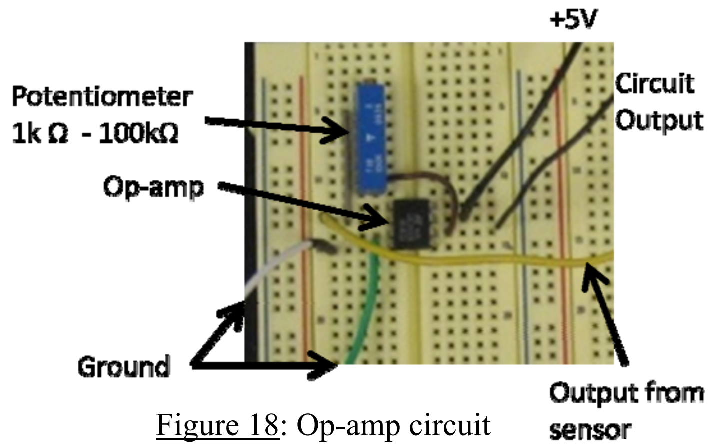


Figure 18: Op-amp circuit

Before any testing was done, a problem with the apparatus was addressed. The FlexiForce Sensors have a circular sensing area one centimeter in diameter from which a single resistance is generated. The load being measured should therefore be applied to this area only, and be as uniformly distributed as possible. In order to accomplish this, small plastic pucks were found. These pucks, pictured below in figures 19 and 20, concentrate the load between the shoe and foot on the sensing area. The pucks purchased are intended to prevent metal feet on an object from scratching the surface it sits on. They have a thin layer of adhesive on one side so they were stuck directly on the sensing area on either side of each sensor.

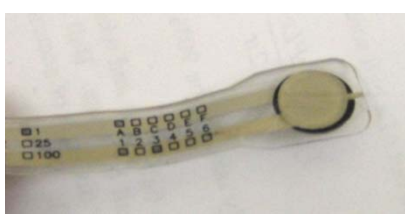


Figure 19: Pucks on Sensing Area

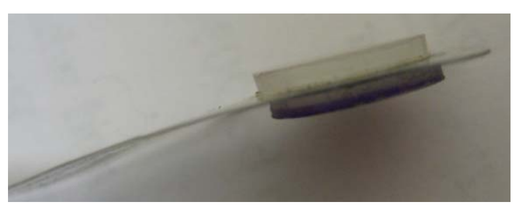


Figure 20: Pucks on Sensor

Next, calibration curves were generated by applying weights (pictured in figure 17) to the sensor. Plots were then produced of the voltage over the load applied in 50 gram increments. The potentiometer was initially set to a low resistance, and then

increased in the following calibrations. These curves can be seen in figures 21, 22 and 23 below.

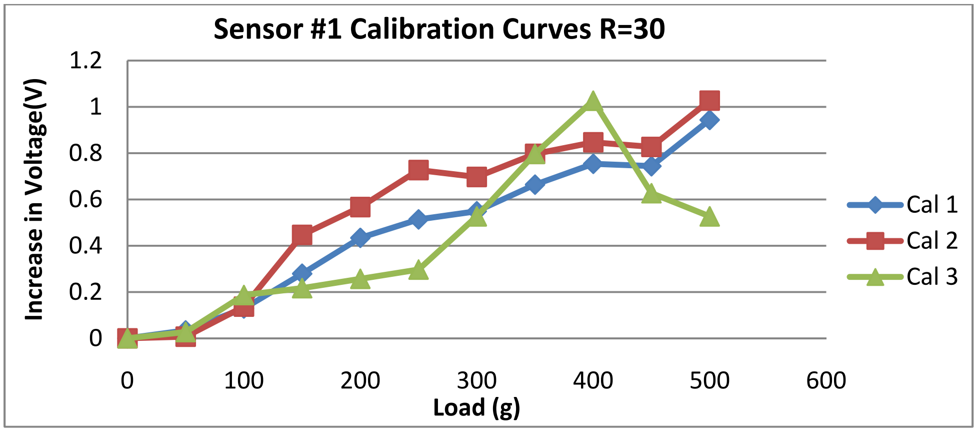


Figure 21: Calibration Curve with Potentiometer Set to 30 kΩ

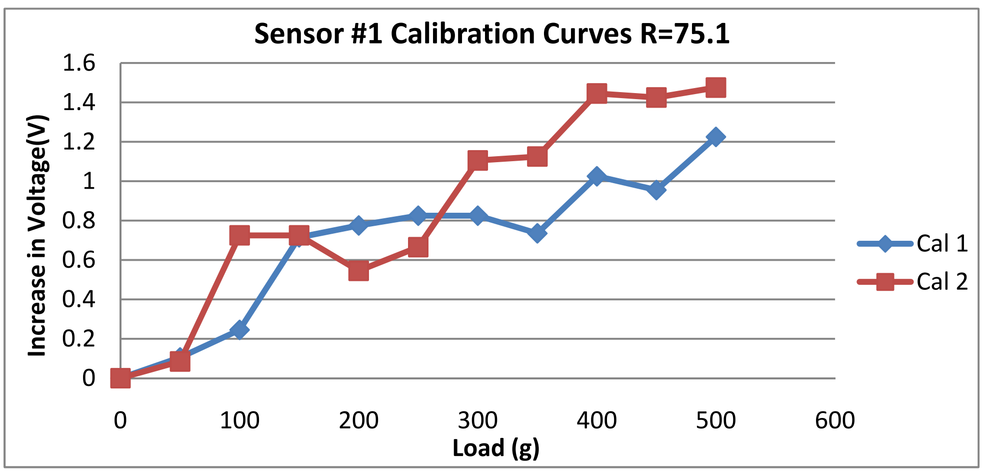


Figure 22: Calibration Curve with Potentiometer Set to 75.1 kΩ

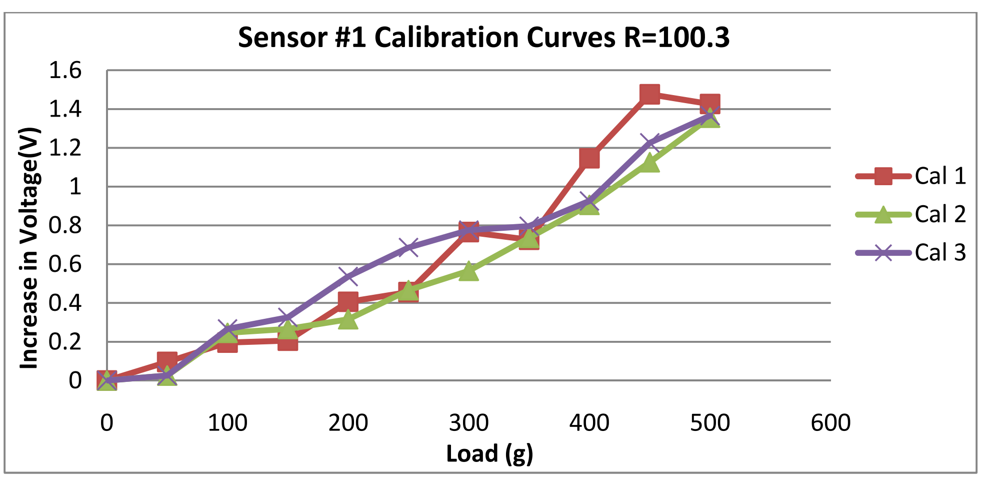


Figure 23: Calibration Curve with Potentiometer Set to 100.3 kΩ

It is clear that setting the potentiometer to its highest resistance produced the least noisy calibration curve. This makes sense because at a high reference resistance, the sensor saturates with less applied force, so more of the sensor's range is used when a 0 to 500 gram (1.1 lb) load is applied.

Troubleshooting the Test Apparatus

MCP-6004 4-Channel Inverting Op-amp

Even this last, most refined calibration curve has noise. The differences in pressure measured with this apparatus are minimal, so the goal was to make it as sensitive as possible to produce accurate results. An example calibration curve, pictured in Figure 24, shows that the curve should be very close to linear and have no noise. Talking with a technical support employee at Tekscan, the makers of the FlexiForce Sensor, and troubleshooting the circuit revealed that the op-amp being used was a likely source of noise. The op amp used in these calibrations was an inverting op amp model LM741 which runs on a Vcc drive voltage of 18 volts (see data sheet in Appendix F). The circuit constructed supplies a drive voltage of only five volts to the op-amp, so it was operating at less than a third of its optimal drive voltage. In order to resolve this problem, new op-amps had to be selected and purchased.

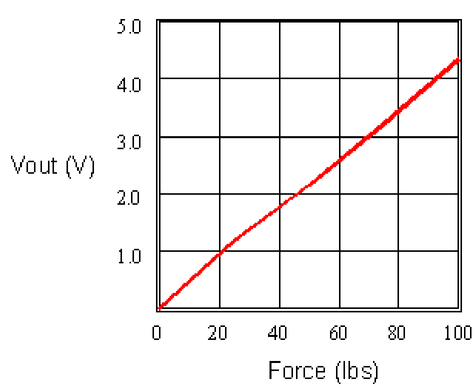


Figure 24: Example Calibration Curve for 100 lb Sensor [13]

The first progress made in winter term was therefore to select and purchase new inverting op amps that would operate at a Vcc drive voltage of 5 volts. In order to ensure that the best op amp for this application was selected, a technical support employee was consulted again. The op amp selected was a MCP-6004 (see Appendix G). This inverting op amp contains four channels that run off a Vcc drive voltage of 5 Volts. The system of eight sensors therefore only required two of these op amps. This saved a significant amount of space for the op amps themselves and avoided additional wiring that would have been required to run 8 individual op amps in parallel.

New calibrations were then performed to see if the new op amps had solved the noise problem. After two sets of three calibrations with the feedback resistor set to 50.7 kΩ and then 100.7 kΩ, it was clear that there was still an unacceptable amount of noise in the system and that the data produced by the sensors would not be reliable. The next step in trouble shooting the perpendicular force apparatus was then to purchase a new set of eight one pound sensors to replace the first set of eight 25 pound sensors that were used up to this point.

<u>1 lb FlexiForce sensors</u>

Once the new sensors arrived, calibrations were run to optimize the feedback resistance of the inverting op-amp circuit. As stated above, this resistance tunes the sensor; the higher the resistance, the more sensitive the sensor becomes. The estimated loads on the sensor ranged from zero to one pound, so the feedback resistance was initially set to a low value to utilize the full capacity of the one pound sensors. In order to select the best resistance, five calibrations were performed with the feedback resistance set to 2, 5, 7, 10, and 15 kΩ (See Appendix H). The resistance value of 5 kΩ was found

the best optimize performance with the least noise and most linear load to output voltage curve from zero to 450 grams of applied load. At this point it was clear that the one pound sensors were more appropriate for this application and that the apparatus would be reliable enough to produce usable data.

The next step in the development of the apparatus was to wire eight of the sensor circuits on the breadboard so that all eight sensors could be run simultaneously (see Figure 25). The eight sensors were wired to the power source in parallel so that they each received an identical negative five volt excitation voltage. The sensors each draw a very low amount of current, so only one power source was needed to meet the power demand of the eight sensors. The two four channel op amps also drew a small amount of current, so they were wired in parallel to achieve identical drive voltages for the op amps. Once the circuits were assembled and the eight potentiometers were set to 5 kΩ, the output from each op amp was connected to a channel on a Data Studio Personal Daq data acquisition system. This system takes in the amplified voltage produced by the sensor circuit and records the values in a format that can be imported into Excel and analyzed on a computer. For all of the tests done from this point forward 10 scans were taken, one per second, and then averaged to provide the most reliable data points for calibrations and data collection.

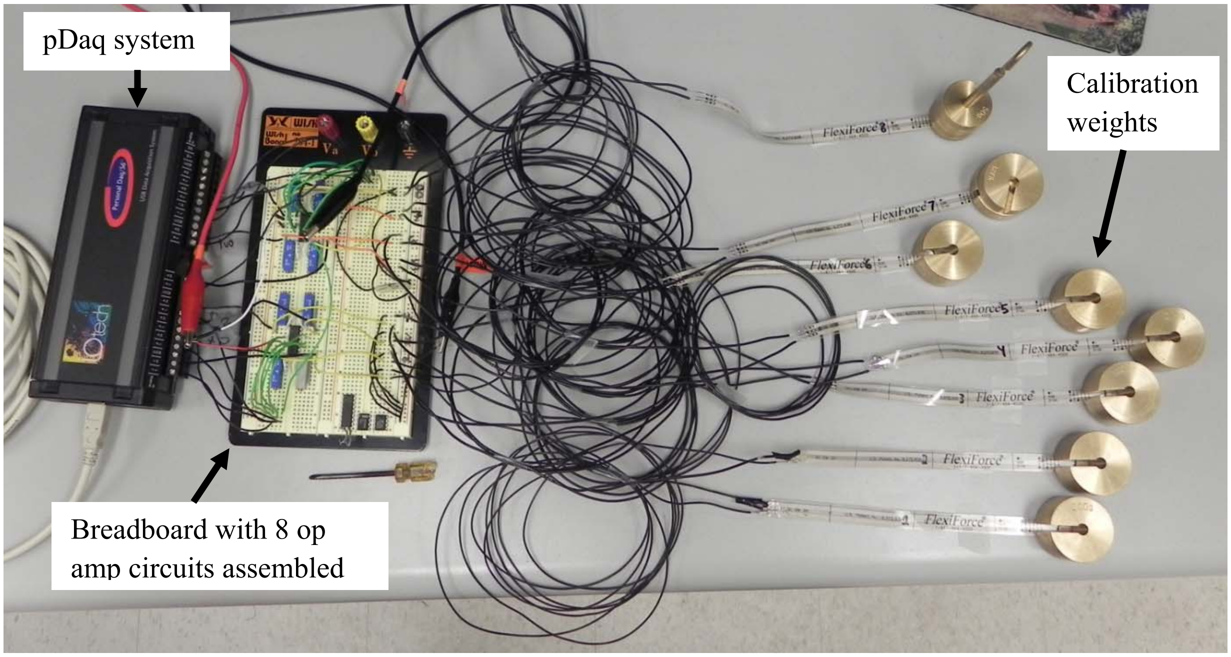


Figure 25: Apparatus during calibration

Once the system was assembled, calibrations were performed on the eight sensors simultaneously to simulate the actual operating conditions during data collection. The calibrations were once again performed by placing weights onto the sensing area of each sensor in 50 gram increments from zero to 450 grams as pictured above in Figure 25. The calibration process was completed three times and a plot was made for each sensor (see Appendix I). The three calibrations were then averaged to produce one calibration plot for each sensor where each point was the average of 30 data points. Each calibration curve was fitted with a second order polynomial trendline to produce a calibration equation for each sensor. Figure 26 pictures the calibration curve and equation for sensor #6. The calibration curves and equations for the all eight sensors can be seen in Appendix J. These eight equations were used from this point forward to convert the output voltage of their respective sensor to the load applied in grams.

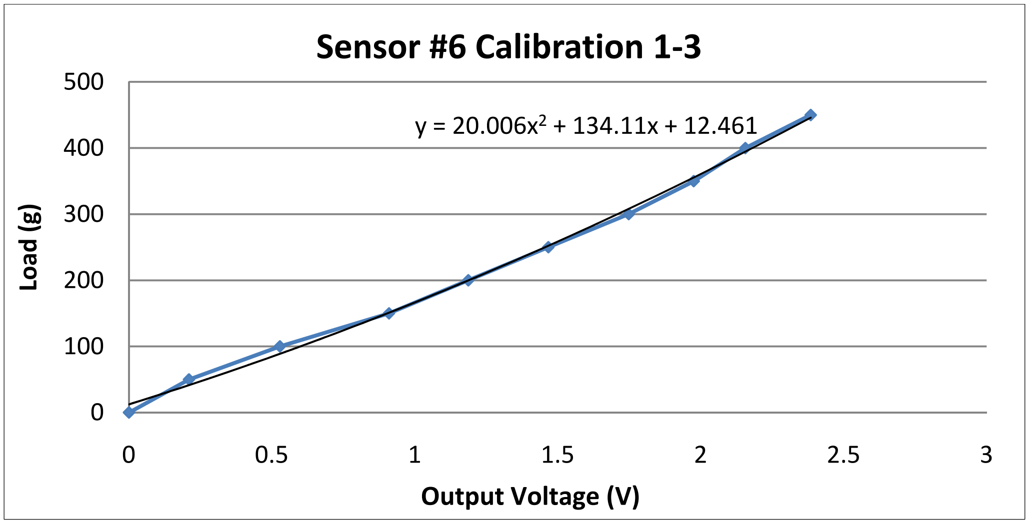


Figure 26: Apparatus during calibration

The accuracy of the calibrations was checked by performing a simple test. 200 gram weights were placed on each sensor and 10 output voltages were recorded in one second increments. These 10 voltage readings were averaged and the calibration equations found in the previous step were used to convert the average output voltage to a load in grams. The amount the calculated load on each sensor was off in grams was then found as well as the percentage off from the actual 200 grams applied. This process was completed five times and the overall averages for calculated load, amount off in grams, and percentage off from the actual applied load were found. These values are shown in Table 1 below. The raw data can be seen in Appendix K.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Ave mass (g)	174.7	196.9	189.8	203.7	193.7	177.3	192.6	178.2
Ave off (g)	25.3	11.6	10.2	6.9	6.6	22.7	11.7	26.9
Ave % off	12.7	5.8	5.1	3.4	3.3	11.4	5.8	13.5

Table 1: Calibration Check Results

As shown in the plot above, the calculated load numbers were as much as 13.5% off of the actual applied load. However since the calibration curves were very close to

linear and so many data points had gone into their development, it was assumed that the perpendicular force measuring apparatus had been optimized as much as possible. The next step then was to proceed with the calibration equations generated and begin collecting data.

<u>Data Collection</u>

In this project, four sets of data were collected on three test shoes: a North Face Ultra 104 GTX XCR laced with the wide and narrow options (Figure 27), a Treksta Sidewinder (Figure 4), and a Merrell light hiking shoe (Figure 35). These test shoes represent a variety of fit systems available today in outdoor footwear and were selected to collect data on specific features. The North Face shoe features two different lacing options that are both examples of the traditional lace fit system. The traditional lace fit system allows the shoe to be tightened by pulling the two sides of the shoe together over the tongue as the laces are tightened. The two lacing options available on this shoe allowed the effect of narrow versus wide eyelet orientation to be directly tested without manipulating the shoe itself.

Figure 27: North Face Ultra 104 GTX XCR with Wide (left) and Narrow (right) Lace Options

The Treksta shoe features low friction lace and eyelets, directly incorporates the heel, and utilizes a Boa toggle mechanism to fix the laces (Figures 4 and 7). This shoe represents the combination of the most technically advanced features currently used in outdoor footwear. The testing of this shoe will quantify the effect of these features compared to the more traditional fit systems. Hypothetically, this shoe should produce the most even distribution of force.

The Merrell shoe features a fit system that, when tightened, applies the pressure on the foot directly through the tongue. This is done with webbing that connects the eyelets to the tongue through slots in the sides of the shoe (see Figure 28). As the laces are tightened, the webbing is pulled through the slotted hinge points and the tongue is synched down on the top of the foot.

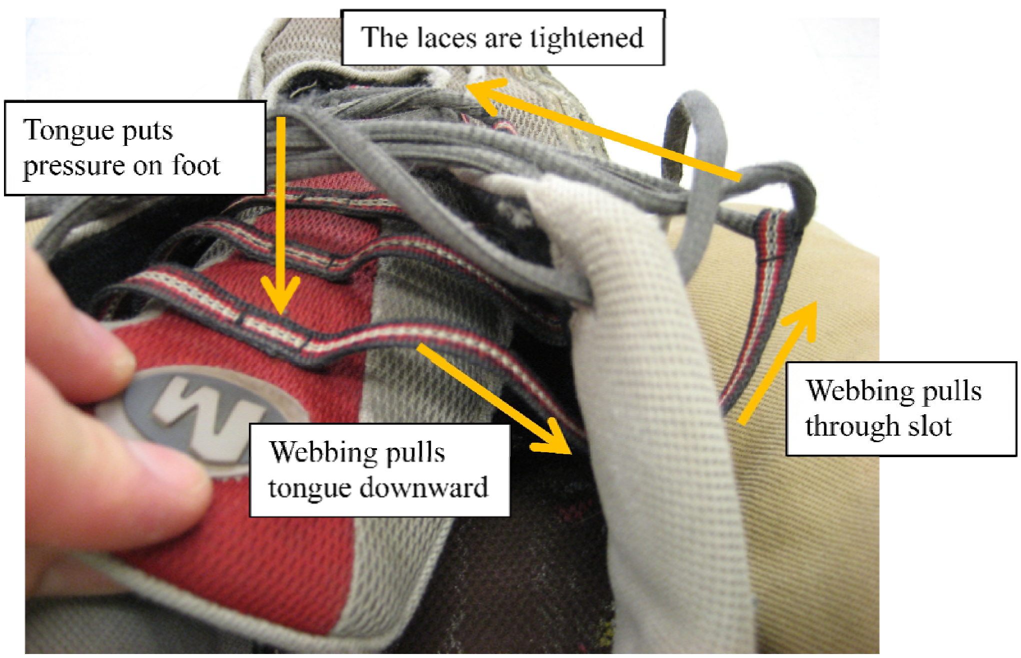


Figure 28: Fit System on Merrell

The first step in the data collection process was to attach the eight force sensors to the foot in the previously mentioned locations. This was done with first aid bandage tape

to ensure that proper adhesion to the skin was achieved. It was decided that no sock would be worn during the data collection process to minimize the amount of material between the shoe and the foot. A sock would absorb some of the force between the shoe and the foot and would therefore affect the data collected by the force sensors. Once the sensors were taped in place, the wires were taped to the calf area of the leg to minimize stress on the soldered attachments points between the leads of the sensors and the wires that connect them to the bread board. See Figures 29 and 30 below.

Figure 29: Sensors taped to foot in locations 1 – 5

Figure 30: Sensors taped to foot in locations 6 – 8

At this point the power source was turned on and configured to produce the five volt drive voltage for the op amps and the negative five volt excitation voltage to run the sensors. The data acquisition unit was then turned on and its computer software was started. As in the calibration runs, the data acquisition system was set to collect ten data points over a ten second interval when triggered.

Once the perpendicular force quantification apparatus was set up, the data collection process was started. Data was collected on the four shoe configurations mentioned above while in four conditions: the foot outside of the shoe, the foot inside the shoe with the fit system fully loose, the foot inside the shoe with the laces tightened only

by pulling on the loose ends, and finally with the fit system of the shoe fully tightened. Condition one, with the foot outside of the shoe, allowed data to be collected with no load on the sensors. This data was used as a check to ensure all eight of the sensors were working properly and producing the no-load voltage recorded during the calibration process. Figure 31 below pictures the sensors on the foot during data collection for this condition.

Figure 31: Data Collection Condition 1

The second condition, with the foot inside the shoe with the fit system fully loose, allowed data to be collected on the initial fit of the shoe before the fit system was employed to tighten it to the foot. In order to ensure that the fit system of each shoe was not affecting the data, the laces were loosened at each set of eyelets so that there was no tension on any section of the laces. The tongue was also pulled away from the foot to ensure the fit system would not have any impact on the data. This condition is illustrated in Figure 32 below.

Figure 32: Data Collection Condition 2 for Treksta Shoe

The third condition, the foot inside the shoe with the laces tightened only by pulling on the loose ends, was intended to collect data on the fit of a shoe that is not thoroughly tightened. The results of the customer profiling study explained above show that the majority of college age students only pull on the loose ends of the laces when they tie their shoes. The goal of this condition was to collect data on how well each of these fit systems perform under these circumstances. In order to make the tightness of the laces in this condition as repeatable as possible, a sharpie was used to mark the point on the lace that was just above the top eyelet when the laces were tightened. In between each set of data points collected, the laces were loosened and then retightened by pulling on the ends of the laces until the sharpie mark returned to its position just above the top eyelet. This method could not be applied to the low friction lace and toggle mechanism of the Treksta shoe, so the tightness level was defined as one full rotation of the Boa dial from the fully loose state. Figure 33 shows the North Face shoe during condition three data collection.

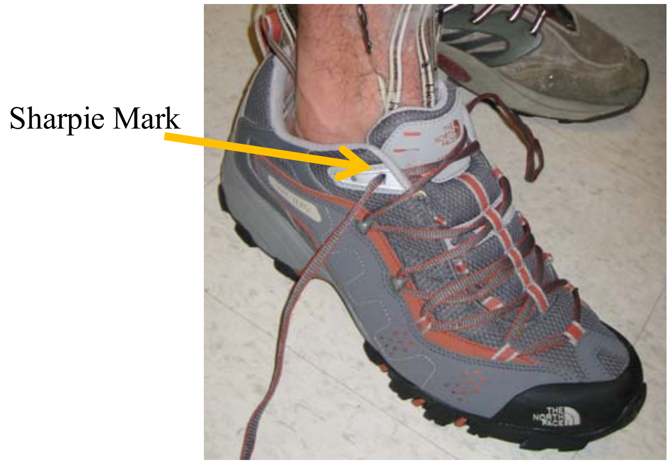


Figure 33: Data Collection Condition 3 for North Face Shoe (wide lace)

The final condition for which data was collected was with the foot in the shoe and the fit system fully tightened. For the fit systems without a toggle, this was achieved by tightening the laces at each set of eyelets. In order to make this level of tightness as repeatable as possible, a sharpie was used to mark the lace just above each eyelet. In between each set of ten data points collected, the laces were fully loosened and then retightened until each of the sharpie marks were just above their respective eyelet (see Figure 34). This system again could not be applied to the Treksta shoe, so in order to ensure repeatability, the Boa toggle was rotated far as possible with the right hand of the tester. Figure 35 shows the Merrell shoe during data collection for condition four.

Figure 34: North Face Shoe (wide lace) with Shapie Marks

Figure 35: Merrell Shoe during Condition 4 Data Collection

Data

Data was collected on the four conditions for each shoe. As in the calibration process, data points were collected for all eight sensors simultaneously in sets of 10. The 10 data points for each sensor were then averaged to generate a single voltage value for each. The average load on each sensor was then found by plugging each voltage into its corresponding calibration equation. For each shoe, a total of nine sets of data were collected on each of the four conditions. The overall average load was then calculated for the eight sensors in each of the four conditions. This process was then repeated for each shoe. All of the load and percent load values presented in the Tables 2 – 9 below are therefore the average of 90 data points. The error bars illustrate the standard deviation of each of these 90 points. A second set of tables and plots was also generated that illustrate the percent of the total load on each of the eight sensors.

Condition 1

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	Load (g)	0	0	0	0	0	0	0	0
	Std Dev	0	0	0	0	0	0	0	0
Treksta	Load (g)	0	0	0	0	0	0	0	0
	Std Dev	0	0	0	0	0	0	0	0
NF Narrow	Load (g)	0	0	0	0	0	0	0	0
	Std Dev	0	0	0	0	0	0	0	0
Merrell	Load (g)	0	0	0	0	0	0	0	0
	Std Dev	0	0	0	0	0	0	0	0

Table 2: Condition 1 Final Load Values

Condition 2

Load Data

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	Load (g)	4.0	247.1	0.3	0.0	0.0	36.0	68.5	10.1
	Std Dev	2.2	64.1	0.7	0.0	0.0	14.7	19.6	6.4
Treksta	Load (g)	0.4	83.4	0.0	0.0	0.0	0.0	0.0	1.8
	Std Dev	1.5	28.3	0.0	0.0	0.0	0.0	0.0	2.9
NF Narrow	Load (g)	4.7	58.9	0.0	0.6	0.0	26.1	25.6	5.2
	Std Dev	4.5	11.8	0.0	0.0	0.0	2.5	7.3	3.3
Merrell	Load (g)	22.5	83.4	0.0	35.1	0.0	5.7	14.0	6.1
	Std Dev	12.1	4.5	0.0	5.6	0.0	7.0	1.3	0.5

Table 3: Condition 2 Final Load Values

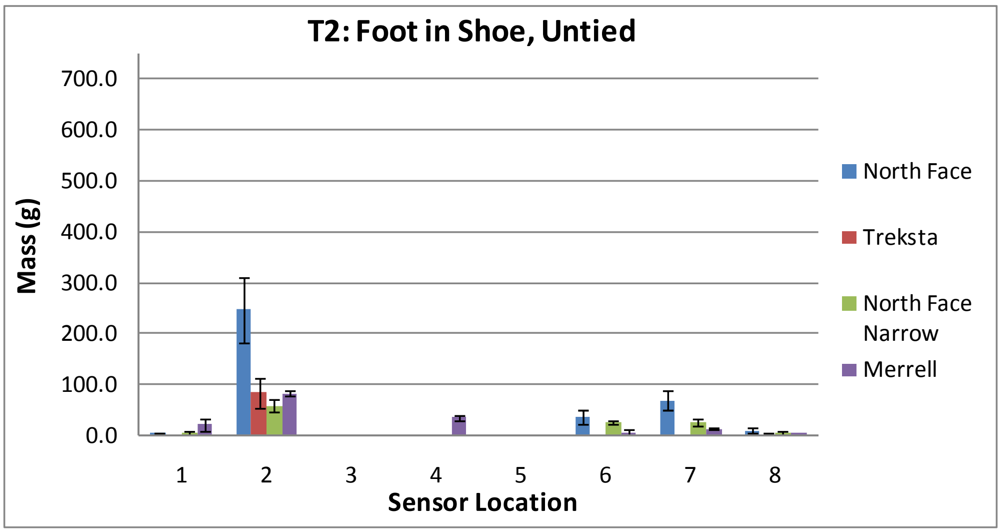


Figure 36: Condition 2 Final Load Values Represented Graphically

Percent of Total Load Data

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	% of Total Load	1.0	67.7	0.1	0.0	0.0	9.8	18.6	2.8
	Std Dev	0.5	3.3	0.1	0.0	0.0	2.8	1.4	1.3
Treksta	% of Total Load	0.7	97.1	0.0	0.0	0.0	0.0	0.0	2.2
	Std Dev	2.1	3.5	0.0	0.0	0.0	0.0	0.0	3.3
NF Narrow	% of Total Load	4.1	48.8	0.0	0.4	0.0	21.7	20.9	4.0
	Std Dev	3.5	3.9	0.0	1.2	0.0	1.5	3.4	3.2
Merrell	% of Total Load	13.2	50.3	0.0	21.2	0.0	3.3	8.4	3.6
	Std Dev	9.1	5.5	0.0	4.8	0.0	3.9	0.9	0.4

Table 4: Condition 2 Percent of Total Load Values

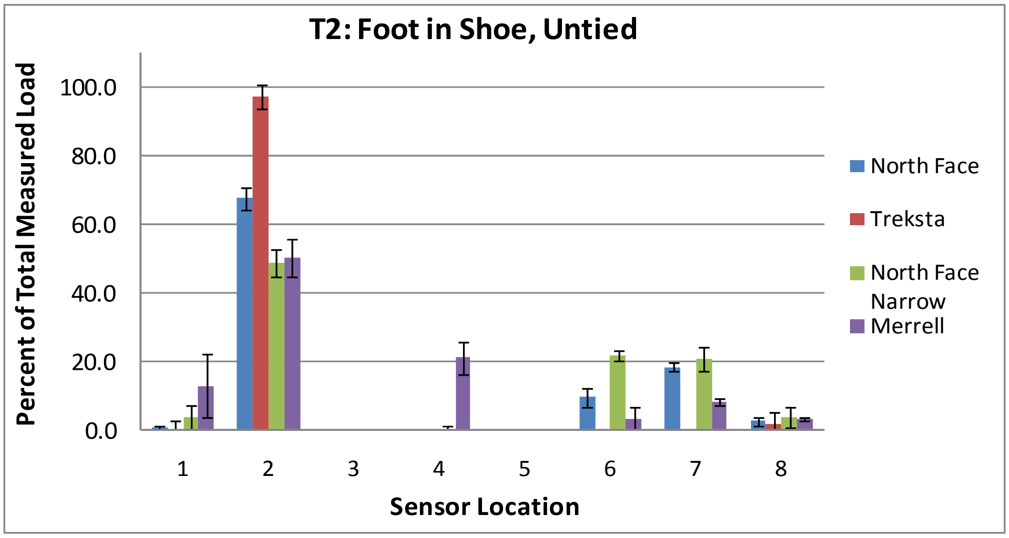


Figure 37: Condition 2 Percent of Total Load Values Represented Graphically

Condition 3

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	Load (g)	2.4	221.5	0.5	10.7	0.0	25.5	51.2	4.3
	Std Dev	1.8	87.9	1.6	4.6	0.0	9.6	28.3	2.5
Treksta	Load (g)	1.2	98.5	19.8	58.6	0.0	5.3	0.0	4.1
	Std Dev	1.8	21.7	10.7	55.0	0.0	8.1	0.0	5.3
NF Narrow	Load (g)	3.7	79.0	11.8	49.7	0.0	20.7	22.3	2.8
	Std Dev	3.5	37.8	11.1	63.9	0.0	4.7	4.0	3.4
Merrell	Load (g)	12.9	60.4	20.8	143.7	11.3	7.7	14.2	5.2
	Std Dev	8.4	10.2	7.0	13.9	0.1	7.3	2.7	3.0

Table 5: Condition 3 Final Load Values

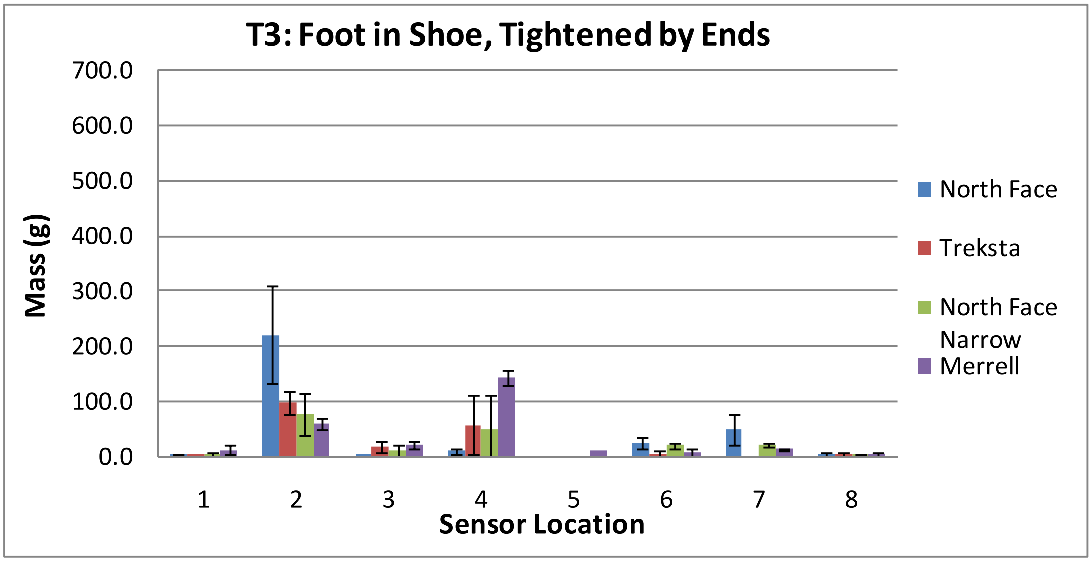


Figure 38: Condition 3 Final Load Values Represented Graphically

Percent of Total Load Data

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	% of Total Load	1.0	69.8	0.1	3.5	0.0	8.2	16.0	1.3
	Std Dev	0.9	3.8	0.3	1.3	0.0	1.6	4.0	0.9
Treksta	% of Total Load	0.4	60.1	10.2	25.7	0.0	1.9	0.0	1.7
	Std Dev	0.6	23.3	2.8	17.8	0.0	3.0	0.0	2.1
NF Narrow	% of Total Load	1.8	43.1	5.4	19.7	0.0	13.3	14.5	2.1
	Std Dev	1.4	4.7	2.1	13.5	0.0	5.6	6.0	2.6
Merrell	% of Total Load	4.7	22.0	7.4	52.1	4.1	2.7	5.1	1.9
	Std Dev	3.2	4.3	2.1	4.5	0.2	2.6	0.8	1.1

Table 6: Condition 3 Percent of Total Load Values

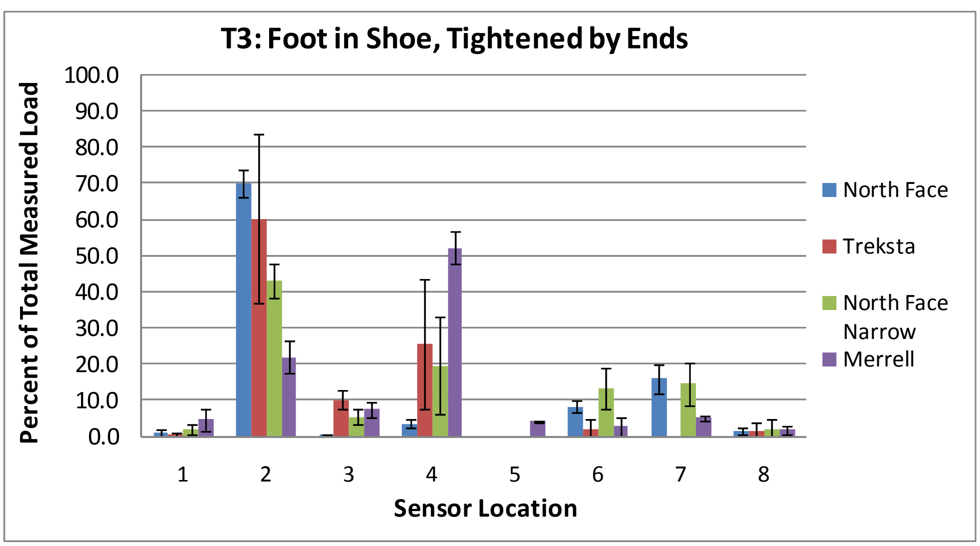


Figure 39: Condition 3 Percent of Total Load Values Represented Graphically

Condition 4

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	Load (g)	7.9	325.0	20.2	195.6	0.0	28.1	42.5	4.8
	Std Dev	1.8	116.7	6.6	54.2	0.0	6.1	12.9	2.8
Treksta	Load (g)	34.9	196.4	105.0	307.4	0.0	16.8	8.0	17.3
	Std Dev	38.8	23.5	28.6	155.3	0.0	11.1	7.6	19.6
NF Narrow	Load (g)	58.8	224.9	54.8	272.0	0.0	26.9	25.0	8.3
	Std Dev	41.2	48.9	20.9	52.3	0.0	6.8	6.1	4.9
Merrell	Load (g)	23.6	130.3	97.6	554.2	14.3	14.8	14.2	8.1
	Std Dev	13.1	26.0	12.6	113.4	3.9	1.8	2.2	2.9

Table 7: Condition 4 Final Load Values

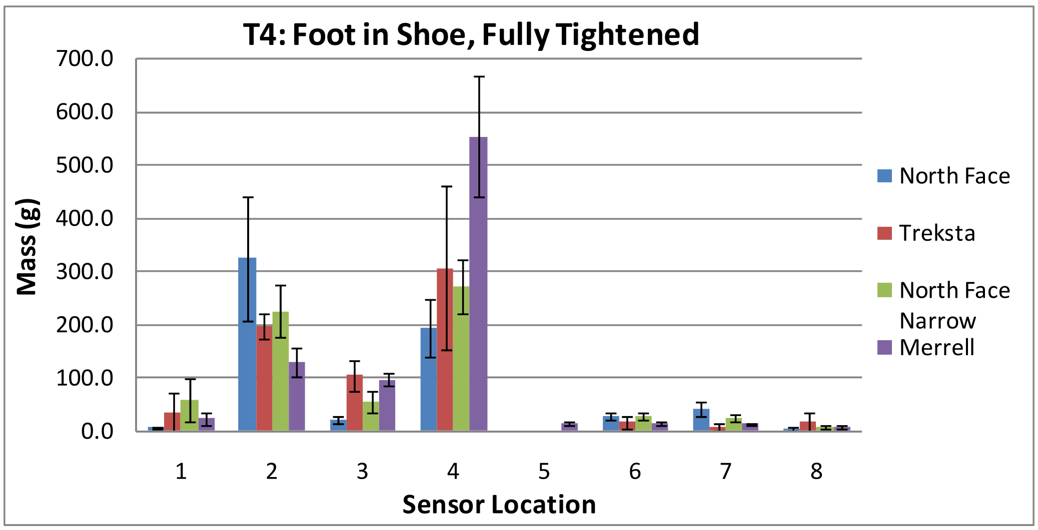


Figure 40: Condition 4 Final Load Values Represented Graphically

Percent of Total Load Data

	Sensor	#1	#2	#3	#4	#5	#6	#7	#8
North Face	% of Total Load	1.4	51.4	3.2	31.5	0.0	4.8	6.9	0.8
	Std Dev	0.5	5.2	0.6	5.3	0.0	1.6	0.9	0.6
Treksta	% of Total Load	4.5	32.0	15.7	42.4	0.0	2.2	1.0	2.1
	Std Dev	3.8	12.6	2.4	10.7	0.0	1.3	1.0	2.2
NF Narrow	% of Total Load	8.2	33.6	8.0	40.9	0.0	4.2	3.9	1.3
	Std Dev	4.7	3.4	2.2	6.3	0.0	1.6	1.5	0.9
Merrell	% of Total Load	2.7	15.6	11.4	64.2	1.7	1.8	1.7	1.0
	Std Dev	1.5	4.1	0.7	4.6	0.3	0.4	0.4	0.4

Table 8: Condition 4 Percent of Total Load Values

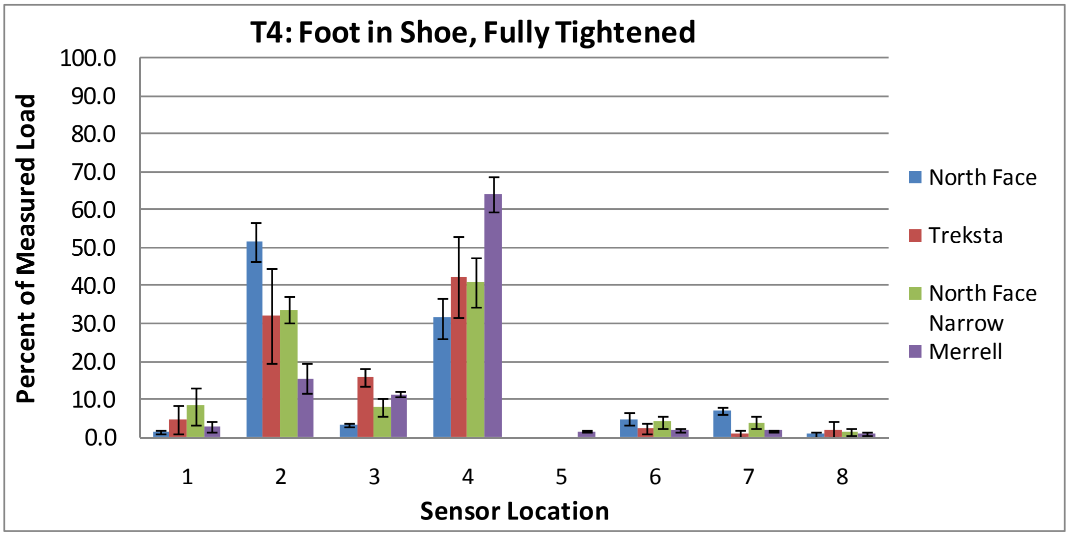


Figure 41: Condition 4 Percent of Total Load Values Represented Graphically

Data Analysis

Condition 1 – Foot outside of shoe

As expected, the eight sensors correctly measured the applied load to be zero.

Condition 2 – Foot in shoe with fit system fully loosened

Figures 36 and 37 illustrate the fit of the four shoes when it the fit systems are fully loosened. It is clear in Figure 36 that the North Face shoe with the wide lacing option provides the tightest initial fit with the highest loads of the four shoes at locations two, six, and seven. Figures 36 and 37 also show that the force distribution of the North Face shoe is different when lace with the narrow or wide option. Theoretically the force distribution should be the same for this condition because the laces were fully loosened when data was collected. Figure 37 shows that the two North Face shoes were fairly comparable when only the the percent of the total load at each point is taken into account. This is most likely a more accurate representation of the data at this condition because there was no way to ensure the sides of the shoe were in repeatable positions when the fit systems were fully loosened.

The data also shows that the 97 percent of the total load recorded from the Treksta shoe was focused on location two for this condition. The Merrell however had a fairly uniform distribution of force with no location bearing more than 50% of the total load. The data shows that locations three and five registered no load for this condition in all four shoes.

Condition 3 – Foot in shoe with laces tightened only by the loose ends

This condition was the most difficult to make repeatable. In between each of the nine sets of data the laces of the shoe being tested were fully loosened and then retightened until the lace running through the top set of eyelets was in the designated position. The positions of laces running through the other eyelets, however, were unmonitored. Therefore each time the laces were tightened, the fit system was at a slightly different state of tightening. The data clearly shows this uncertainty with very high values for standard deviation relative to the load values (see Table 5). Some of the uncertainties were even over 100 percent of the overall average load. The data for the percent of the total load at each location is slightly more reliable, but again exhibits very high standard deviations relative to the percent load values. It is therefore impossible to draw specific conclusions from this condition.

The overall trends in the force distributions depicted in Figures 38 and 39, however, are reliable. Both figures illustrate force concentrations at locations two and four. The percent load plot also shows that the North Face shoe, laced in both the narrow and wide options, applies force on either side of the heel at locations six and seven.

Condition 4 – Foot in shoe with fit system fully tightened

This condition was the most relevant to the fit of a shoe during an actual outdoor application. Although people leave their shoes loose for casual walking applications, they must tighten their shoes in order for them to perform in the varied terrain of the outdoors. As expected, this condition produced the highest loads at nearly all of the eight locations. This condition also allowed the most direct analysis of each fit system tested by the perpendicular force apparatus.

The hypothesis was that the shoe with the most even force distribution will have the most optimized fit. The fit system featured on this shoe would therefore be the most effective. By this criterion, Figure 41 shows that the North Face shoe with the narrow lacing option has the most effective fit system with no more than 41 percent of the total measured load concentrated on one location. The argument of which for system is the most effective is not that one dimensional however. The Treksta shoe had the second most even force distribution with no more than 42.5 percent of the total measured load concentrated on one location. The Treksta features a Boa toggle system that winds the ends of the lace to tighten the shoe. It therefore achieved this force distribution by only tightening via the ends of the lace while the lace of the North Face shoe was tightened at each set of eyelets. This also proves that the low friction eyelets and lace featured on the Treksta do allow the fit system to tighten more evenly than the traditional lace system when only the ends of the lace are pulled. For this reason, the Treksta shoe would provide the best fit for those only willing to tighten their quickly by the ends of the laces such as the majority of the participants in the customer profiling survey.

One feature of the fit system utilized on the Treksta shoe, however, is proven to have little or no effect by the data. The Treksta features a fit system that directly incorporates the heel as pictured in Figure 7. Figures 40 and 41 show that locations six, seven, and eight on the heel of the foot were subject to minimal loading in conditions two, three, and four. If the fit system pulled the heel in as it is intended to, the load at these three locations would increase from conditions two to four. Although the data shows that the load values did increase, the loads are extremely small (at most 2% of the total measured load) and therefore have little to no effect on the fit of the shoe.

The effect of the fit system featured on the Merrell shoe is clear in Figures 40 and 41. As explained above, the when the fit system of the Merrell is tightened the force is focused on the tongue area. This is verified by data as location four, which is directly under the tongue, experienced a load nearly twice the magnitude of those provided and any point by the other three shoes. This load was 64 percent of the total measured load for the Treksta.

In a head to head comparison of the two lacing options featured on the North Face shoe, Figure 41 shows that the narrow option provides a more even force distribution. The wide option's load concentration on location two that was first evident in second condition persisted through the final condition. The narrow option is therefore the better of the two options.

Conclusion

The goal of developing an apparatus to quantify perpendicular forces between the foot and a shoe through this project was accomplished. The system developed, however, has limitations. The final load values generated have uncertainties that make the values themselves unreliable. Fortunately, the purpose of developing this system was not to find the exact loads on the eight locations tested in this project; the goal was to investigate the overall characteristics of the force distribution. To that end the data on the percent of the total measured load at each point and the corresponding plots were the most informative. The system also provided usable data on how the fit systems featured on each of the shoes tested affect the fit of the shoe. These were the most valuable conclusions drawn from the project and will impact the product line developed by Elevation Footwear.

Acknowledgements

This project would not have been possible without the help of my advisor, Professor Keat, and the technical assistance of Stan Gorski. I would also like to acknowledge the IEF for providing the funding to support the project and Rhonda Becker for helping me with the logistics.

References

[1] http://image.rakuten.co.jp/sworld/cabinet/00252947/img56247154.jpg

[2] http://www.merrell.com/US/en-US/Product.mvc.aspx/M-F-F/17931M/37152/Men/Footwear/Filters/Mens/Chameleon3-Ventilator-GORE-TEX/Gunsmoke/J87767

[3] http://www.merrell.com/US/en-US/Product.mvc.aspx/M-F-F/17932M/0/Men/Footwear/Filters/Mens/Chameleon3-Stretch

[4] http://www.trekstausa.com/p-18-mens-sidewinder-trail-running-shoe-with-icelock.aspx

[5] http://www.salomon.com/us/product/xa-pro-3d-ultra-gtx%C2%AE.html

[6]http://www.keenfootwear.com/product/fw10/shoes/men/trailhead/targhee%20ii/black%20!%20dark%20shadow

[7] http://www.footmapping.com/footmapping/about-the-kiosk/foot-assessment-demo.jspa

[8] http://novel.de/novelcontent/pedar/downhill-skiing

[9] http://podiatry.temple.edu/gaitlab/facilities/pedar.html

[10] http://www.batazambia.com/tips_feet.html

[11] http://www.gaugestore.com/prodinfo.asp?number=35252

[12] http://www.futek.com/product.aspx?stock=FSH01555

[13] http://www.tekscan.com/flexible-force-sensors

Appendix A: Customer Profiling Survey and Results

barstows123 Sign Out Help

+ Create Survey

My Surveys Address Book My Account

You have a BASIC account | To remove the limits of a BASIC account and get unlimited questions, upgrade now!

Footwear Questions Edit

Default Report + Add Report

Response Summary

Total Started Survey: 40
Total Completed Survey: 40 (100%)

PAGE: QUESTIONS

1. Age: Download

	Response Count
Hide replies	40

1.	22	Sat, Nov 6, 2010 4:51 PM	Find...
2.	18	Wed, Nov 3, 2010 4:13 PM	Find...
3.	21	Wed, Nov 3, 2010 11:59 AM	Find...
4.	21	Wed, Nov 3, 2010 11:59 AM	Find...
5.	21	Wed, Nov 3, 2010 10:15 AM	Find...
6.	21	Wed, Nov 3, 2010 9:39 AM	Find...
7.	22	Wed, Nov 3, 2010 8:23 AM	Find...
8.	21	Wed, Nov 3, 2010 6:07 AM	Find...
9.	22	Wed, Nov 3, 2010 5:52 AM	Find...
10.	23	Wed, Nov 3, 2010 5:16 AM	Find...
11.	21	Wed, Nov 3, 2010 4:55 AM	Find...
12.	21	Tue, Nov 2, 2010 8:59 PM	Find...
13.	22	Tue, Nov 2, 2010 8:39 PM	Find...
14.	21	Tue, Nov 2, 2010 8:30 PM	Find...
15.	21	Tue, Nov 2, 2010 8:19 PM	Find...
16.	21	Tue, Nov 2, 2010 8:00 PM	Find...
17.	22	Tue, Nov 2, 2010 7:50 PM	Find...
18.	21	Tue, Nov 2, 2010 7:24 PM	Find...
19.	21	Tue, Nov 2, 2010 7:23 PM	Find...
20.	21	Tue, Nov 2, 2010 7:03 PM	Find...
21.	21	Tue, Nov 2, 2010 6:57 PM	Find...
22.	21	Tue, Nov 2, 2010 6:53 PM	Find...
23.	21	Tue, Nov 2, 2010 6:52 PM	Find...
24.	21	Tue, Nov 2, 2010 6:50 PM	Find...
25.	22	Tue, Nov 2, 2010 6:45 PM	Find...
26.	21	Tue, Nov 2, 2010 6:43 PM	Find...
27.	21	Tue, Nov 2, 2010 6:31 PM	Find...
28.	21	Tue, Nov 2, 2010 6:24 PM	Find...
29.	22	Tue, Nov 2, 2010 6:15 PM	Find...
30.	21	Tue, Nov 2, 2010 6:03 PM	Find...
31.	21	Tue, Nov 2, 2010 5:56 PM	Find...
32.	21	Tue, Nov 2, 2010 5:52 PM	Find...

50 responses per page

answered question	40
skipped question	0

1. Age: Download

33.	20	Tue, Nov 2, 2010 5:51 PM	Find...
34.	22	Tue, Nov 2, 2010 5:46 PM	Find...
35.	21	Tue, Nov 2, 2010 5:45 PM	Find...
36.	21	Tue, Nov 2, 2010 5:40 PM	Find...
37.	21	Tue, Nov 2, 2010 5:39 PM	Find...
38.	17	Tue, Nov 2, 2010 5:38 PM	Find...
39.	21	Tue, Nov 2, 2010 5:37 PM	Find...
40.	21	Tue, Nov 2, 2010 5:37 PM	Find...

50 responses per page

answered question	40
skipped question	0

2. Gender Create Chart Download

	Response Percent	Response Count
Male	75.0%	30
Female	25.0%	10
answered question		40
skipped question		0

3. What is the brand of the shoes that you wear most often? Download

	Response Count
Hide replies	40

1.	Nike	Sat, Nov 6, 2010 4:51 PM	Find...
2.	Nike all day son and Jordons of course	Wed, Nov 3, 2010 4:13 PM	Find...
3.	converse	Wed, Nov 3, 2010 11:59 AM	Find...
4.	nike	Wed, Nov 3, 2010 11:59 AM	Find...
5.	nike	Wed, Nov 3, 2010 10:15 AM	Find...
6.	nike	Wed, Nov 3, 2010 9:39 AM	Find...
7.	Nike	Wed, Nov 3, 2010 8:23 AM	Find...
8.	Nike	Wed, Nov 3, 2010 6:07 AM	Find...
9.	New Balance	Wed, Nov 3, 2010 5:52 AM	Find...
10.	All Day I Dream About Soccer (adidas--obviously)	Wed, Nov 3, 2010 5:16 AM	Find...
11.	Adidas	Wed, Nov 3, 2010 4:55 AM	Find...
12.	asics	Tue, Nov 2, 2010 8:59 PM	Find...
13.	Sperry's	Tue, Nov 2, 2010 8:39 PM	Find...
14.	Sperrys	Tue, Nov 2, 2010 8:30 PM	Find...
15.	L.L. Bean	Tue, Nov 2, 2010 8:19 PM	Find...
16.	Nike	Tue, Nov 2, 2010 8:00 PM	Find...
17.	new balance	Tue, Nov 2, 2010 7:50 PM	Find...
18.	nike	Tue, Nov 2, 2010 7:24 PM	Find...

50 responses per page

answered question	40
skipped question	0

A2

3. What is the brand of the shoes that you wear most often? Download

19.	Nike	Tue, Nov 2, 2010 7:23 PM	Find...
20.	Nike	Tue, Nov 2, 2010 7:03 PM	Find...
21.	timberland, nike	Tue, Nov 2, 2010 6:57 PM	Find...
22.	Nike	Tue, Nov 2, 2010 6:53 PM	Find...
23.	Asics and Nike	Tue, Nov 2, 2010 6:52 PM	Find...
24.	converse	Tue, Nov 2, 2010 6:50 PM	Find...
25.	asics	Tue, Nov 2, 2010 6:45 PM	Find...
26.	Nike	Tue, Nov 2, 2010 6:43 PM	Find...
27.	Birkenstock sandals	Tue, Nov 2, 2010 6:31 PM	Find...
28.	Supra, Asics,	Tue, Nov 2, 2010 6:24 PM	Find...
29.	LL Bean	Tue, Nov 2, 2010 6:15 PM	Find...
30.	Adidas	Tue, Nov 2, 2010 6:03 PM	Find...
31.	New Balance	Tue, Nov 2, 2010 5:58 PM	Find...
32.	Vans, Nike, Bass (similar to sperry's)	Tue, Nov 2, 2010 5:52 PM	Find...
33.	nike 6.0	Tue, Nov 2, 2010 5:51 PM	Find...
34.	adidas	Tue, Nov 2, 2010 5:46 PM	Find...
35.	Sperry, Nike	Tue, Nov 2, 2010 5:45 PM	Find...
36.	Nike SB/ 6.0	Tue, Nov 2, 2010 5:40 PM	Find...
37.	asics	Tue, Nov 2, 2010 5:39 PM	Find...
38.	Nike	Tue, Nov 2, 2010 5:38 PM	Find...
39.	toms	Tue, Nov 2, 2010 5:37 PM	Find...
40.	Steve Madden	Tue, Nov 2, 2010 5:37 PM	Find...

50 responses per page

answered question	40
skipped question	0

4. What general category do these shoes fall under? Create Chart Download

	Response Percent	Response Count
Athletic sneakers	57.5%	23
Outdoor shoes	0.0%	0
Skateboard shoes	17.5%	7
Slippers/clogs	5.0%	2
Flats	7.5%	3
Boots	0.0%	0
Other fashion oriented shoes	12.5%	5
answered question		40
skipped question		0

5. Do you tie the laces on your shoes everytime you put them on? Choose N/A is your shoes do not have laces Create Chart Download

	Response Percent	Response Count
answered question		40
skipped question		0

A3

5. Do you tie the laces on your shoes everytime you put them on? Choose N/A is your shoes do not have laces

Create Chart Download

Yes	32.5%	13
No	55.0%	22
N/A	12.5%	5
	answered question	40
	skipped question	0

6. If yes, do you tighten between the eyelets, or just pull on the loose ends of the lace?

Create Chart Download

	Response Percent	Response Count
I tighten between the eyelets too	35.3%	6
I just pull on the loose ends of the lace	64.7%	11
	answered question	17
	skipped question	23

7. What do you like about these specific shoes in terms of fit?

Download

Response Count

Hide replies 40

1.	They have great ankle support and and snug toe room	Sat, Nov 6, 2010 4:51 PM	Find...
2.	real comfortable with fat tongue and high or semi high tops provide ankle cover	Wed, Nov 3, 2010 4:13 PM	Find...
3.	they are just really comfortable	Wed, Nov 3, 2010 11:59 AM	Find...
4.	conform to feet	Wed, Nov 3, 2010 11:59 AM	Find...
5.	they fit my foot and are comfortable	Wed, Nov 3, 2010 10:15 AM	Find...
6.	I knot the ends of the shoe laces right when i get them, so i dont have to do it again and turn them into slip on	Wed, Nov 3, 2010 9:39 AM	Find...
7.	I like a snug fit, so there isn't any real wobble when I move in my shoes	Wed, Nov 3, 2010 8:23 AM	Find...
8.	Overall conformity to foot - comfort	Wed, Nov 3, 2010 6:07 AM	Find...
9.	That they don't flop of my foot but that they aren't to tight.	Wed, Nov 3, 2010 5:52 AM	Find...
10.	super comfy (my foot slides right in), very break-in-able, narrow	Wed, Nov 3, 2010 5:16 AM	Find...
11.	When I tie them, they tighten around my foot evenly	Wed, Nov 3, 2010 4:55 AM	Find...
12.	good support on arch, comfortable to stand in for long periods of time.	Tue, Nov 2, 2010 8:59 PM	Find...
13.	conform to my foot size	Tue, Nov 2, 2010 8:39 PM	Find...
14.	Diversity of conditions they can be worn in. Summer, Winter, with socks, without socks, etc.	Tue, Nov 2, 2010 8:30 PM	Find...
15.	Comfy, fuzzy, warm.	Tue, Nov 2, 2010 8:19 PM	Find...
16.	Support and comfort	Tue, Nov 2, 2010 8:00 PM	Find...
17.	comfortable, and long lasting	Tue, Nov 2, 2010 7:50 PM	Find...
18.	comfortable soles	Tue, Nov 2, 2010 7:24 PM	Find...
19.	Comfort	Tue, Nov 2, 2010 7:23 PM	Find...
20.	a shoe that is snug on the foot but you can still slide into without having to tie and untie the shoe	Tue, Nov 2, 2010 7:03 PM	Find...
21.	not too tight, good support,	Tue, Nov 2, 2010 6:57 PM	Find...

50 responses per page

answered question	40
skipped question	0

7. What do you like about these specific shoes in terms of fit? Download

22.	They are comfortable from the time I buy them to the time I get rid of them.	Tue, Nov 2, 2010 6:53 PM	Find...
23.	They are light, comfortable running shoes.	Tue, Nov 2, 2010 6:52 PM	Find...
24.	comfy interior	Tue, Nov 2, 2010 6:50 PM	Find...
25.	snug fit, not too much of an arch, provide ankle support but not too high top. Would rather some ankle support than just have nothing and focus on just being light.	Tue, Nov 2, 2010 6:45 PM	Find...
26.	form-fitting without laces	Tue, Nov 2, 2010 6:43 PM	Find...
27.	They mold to the form of my foot and have god support. They also last forever	Tue, Nov 2, 2010 6:31 PM	Find...
28.	The shoes I generally wear are fashion-oriented and the primary focus of the shoes is look and secondary they must be comfortable and able to wear with the laces no tied	Tue, Nov 2, 2010 6:24 PM	Find...
29.	They are are comfortable	Tue, Nov 2, 2010 6:15 PM	Find...
30.	They're nice and snug.	Tue, Nov 2, 2010 6:03 PM	Find...
31.	I like that they are light and fairly small (that is they are not too bulky/clumsy).	Tue, Nov 2, 2010 5:58 PM	Find...
32.	Nice insoles and slight arch. Ability for shoe to be both loose fitting (while untied) and snug when (laces, both between the eyelets and at the loose ends, are tied). But durable materials are attractive for fun activities like skateboarding.	Tue, Nov 2, 2010 5:52 PM	Find...
33.	they are tight but i can just throw them on. they have a good amount of padding inside.	Tue, Nov 2, 2010 5:51 PM	Find...
34.	lost but never fall off.	Tue, Nov 2, 2010 5:46 PM	Find...
35.	comfortable soles, not tight around the side of the foot	Tue, Nov 2, 2010 5:45 PM	Find...
36.	soft and comfortable at all times. no pressure points or hot spots. Can slip on and off easily and without retying	Tue, Nov 2, 2010 5:40 PM	Find...
37.	good arch support for running!	Tue, Nov 2, 2010 5:39 PM	Find...
38.	I like them to be snug, but it would nice to be able to slip on and slip off without ruining the back/untying the shoes	Tue, Nov 2, 2010 5:38 PM	Find...
39.	they are comfortable	Tue, Nov 2, 2010 5:37 PM	Find...
40.	Comfort, easy to slip on and off	Tue, Nov 2, 2010 5:37 PM	Find...

50 responses per page

answered question	40
skipped question	0

8. What do you dislike about these specific shoes in terms of fit? Download

	Response Count
Hide replies	40

1.	the flat, tough soles making walking around for extended periods of time uncomfortable	Sat, Nov 6, 2010 4:51 PM	Find...
2.	not enough arch support	Wed, Nov 3, 2010 4:13 PM	Find...
3.	on the sides, the rubber wears and breaks leaving holes	Wed, Nov 3, 2010 11:59 AM	Find...
4.	racking	Wed, Nov 3, 2010 11:59 AM	Find...
5.	they wear out pretty easily....support weakens at a fast rate	Wed, Nov 3, 2010 10:15 AM	Find...
6.	hi sam	Wed, Nov 3, 2010 9:39 AM	Find...
7.	Some of my shoes "fit" me better than others	Wed, Nov 3, 2010 8:23 AM	Find...
8.	too narrow/wide of a shoe. needs to be just right.	Wed, Nov 3, 2010 6:07 AM	Find...
9.	If they don't just feel like part of my foot.	Wed, Nov 3, 2010 5:52 AM	Find...
10.	zero arch support	Wed, Nov 3, 2010 5:16 AM	Find...
11.	nothing	Wed, Nov 3, 2010 4:55 AM	Find...
12.	not enough ankle support. a good shoe needs good ankle support.	Tue, Nov 2, 2010 8:59 PM	Find...

50 responses per page

answered question	40
skipped question	0

8. What do you dislike about these specific shoes in terms of fit? Download

13.	too much room at the toes	Tue, Nov 2, 2010 8:39 PM	Find...
14.	Can get sweaty when hot. Need more adequate ventilation system while not compromising established style.	Tue, Nov 2, 2010 8:30 PM	Find...
15.	Sometimes my feet get sweaty...	Tue, Nov 2, 2010 8:19 PM	Find...
16.	Nothing	Tue, Nov 2, 2010 8:00 PM	Find...
17.	a	Tue, Nov 2, 2010 7:50 PM	Find...
18.	sometimes too narrow	Tue, Nov 2, 2010 7:24 PM	Find...
19.	nothing	Tue, Nov 2, 2010 7:23 PM	Find...
20.	one that doesn't offer enough support so you slide around in it.	Tue, Nov 2, 2010 7:03 PM	Find...
21.	too tight around toes	Tue, Nov 2, 2010 6:57 PM	Find...
22.	Really nothing as Nike has never disappointed me	Tue, Nov 2, 2010 6:53 PM	Find...
23.	They get wet easily. I have basket ball sneakers that don't get wet because they have a plastic/leather outside, but they are heavier and I like the running shoes better.	Tue, Nov 2, 2010 6:52 PM	Find...
24.	loose around heel	Tue, Nov 2, 2010 6:50 PM	Find...
25.	i don't like when the toe of the shoe sticks up too much	Tue, Nov 2, 2010 6:45 PM	Find...
26.	tend to be too long for their width as i have wide feet	Tue, Nov 2, 2010 6:43 PM	Find...
27.	The buckles/straps get stretched out after while and the sandals do not fit as tightly to my foot as before	Tue, Nov 2, 2010 6:31 PM	Find...
28.	For athletic-oriented shoes, I find shoes with extra tightening gadgets often get too tight around the center of the foot and leave the heel/ankle loose and give an unbalanced feeling	Tue, Nov 2, 2010 6:24 PM	Find...
29.	nothing	Tue, Nov 2, 2010 6:15 PM	Find...
30.	Not enough arch support, but they're just plain old walking shoes so they're not supposed to be that supportive.	Tue, Nov 2, 2010 6:03 PM	Find...
31.	I wish they had more arch support.	Tue, Nov 2, 2010 5:58 PM	Find...
32.	When the swade/sewn seams/poopy materials rip on side the shoe (nearest to pinky toe) as a result of intense rubbing against grip tape - a rubber or thick tough leathery material would be a nice replacement. Also i dislike when i realize my shoes aren't ghetto high tops - it reveals my cankles and offers less support for fun activities (also nice in snow). hmm. that is all sammy. buenos noches	Tue, Nov 2, 2010 5:52 PM	Find...
33.	i wish they were a little more breathable	Tue, Nov 2, 2010 5:51 PM	Find...
34.	Hey sam.. good ride today	Tue, Nov 2, 2010 5:46 PM	Find...
35.	they smell really bad	Tue, Nov 2, 2010 5:45 PM	Find...
36.	The fit is really loose. Feet swim a bit when running or on steep slopes. Can't tighten them too easily - there is too much padding for a snug fit.	Tue, Nov 2, 2010 5:40 PM	Find...
37.	sometimes the front of the shoe, where my toes are, is a little too wide	Tue, Nov 2, 2010 5:39 PM	Find...
38.	I don't like when they're just flat, and don't fit to the contours of my feet, and also when they're too narrow	Tue, Nov 2, 2010 5:38 PM	Find...
39.	they get looser over time (the fabric stretches out)	Tue, Nov 2, 2010 5:37 PM	Find...
40.	They slip off the back of the heel sometimes and they aren't warm	Tue, Nov 2, 2010 5:37 PM	Find...

50 responses per page

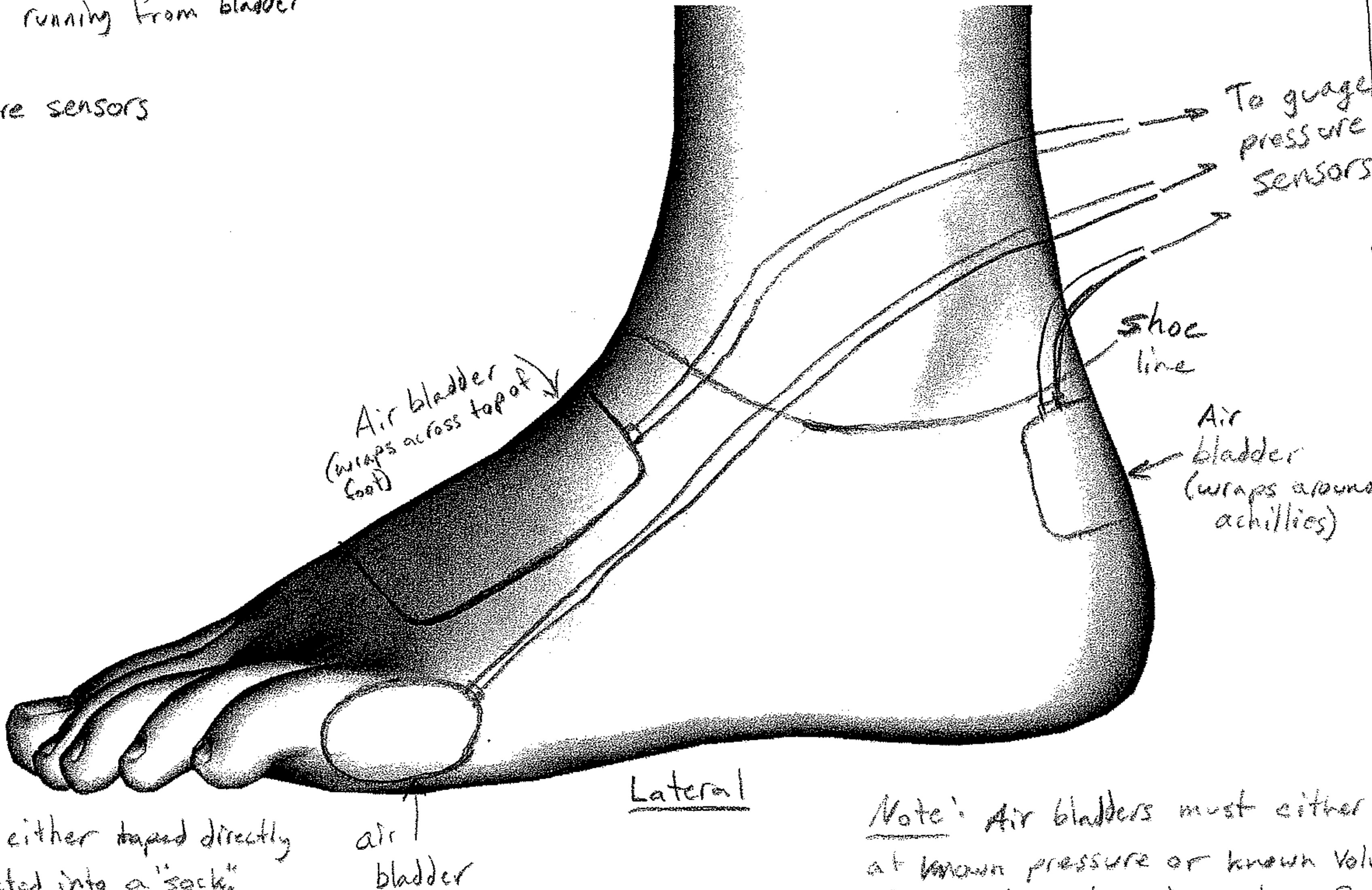
answered question	**40**
skipped question	**0**

Appendix B: Preliminary Sketch of Apparatus with Air Bladders

Air Bladder Fit Test System

Elements

- 4 uniquely sized bladders, as thin as possible
- 4 small air tubes running from bladder out of shoe
- 4 guage pressure sensors



Air bladders will be either taped directly to foot or integrated into a "sock." tubes will run up foot and to external guage pressure sensors. tubes may be able to exit shoe via tongue area.

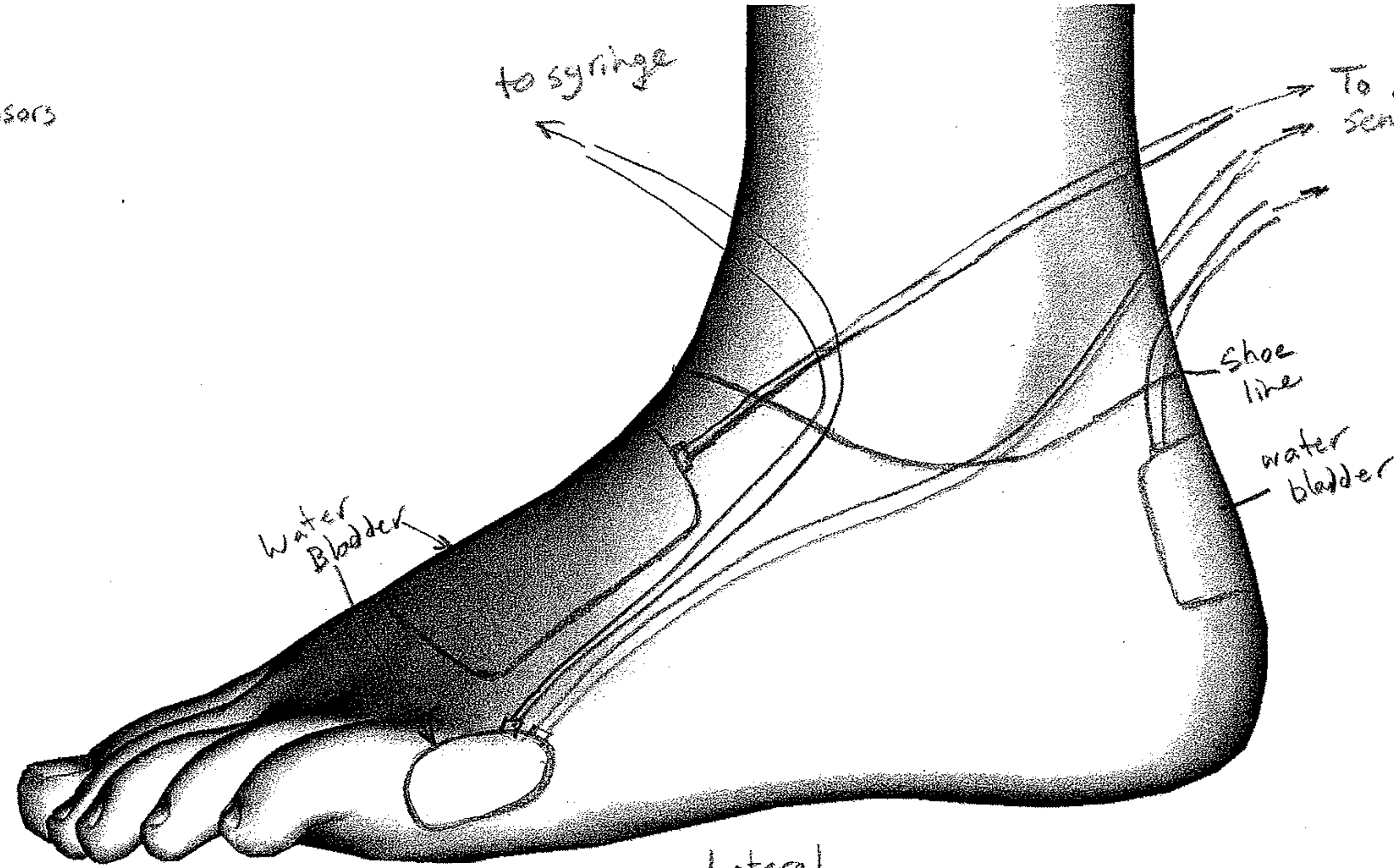
Note: Air bladders must either be at known pressure or known volume of air when shoe is put on for test to be repeatable

Appendix C: Preliminary Sketch of Apparatus with Water Bladders

Water Bladder Fit Test System

Elements

4 uniquely sized bladders, as thin as possible
4 syringes
8 lengths of tube
4 water pressure sensors



Lateral

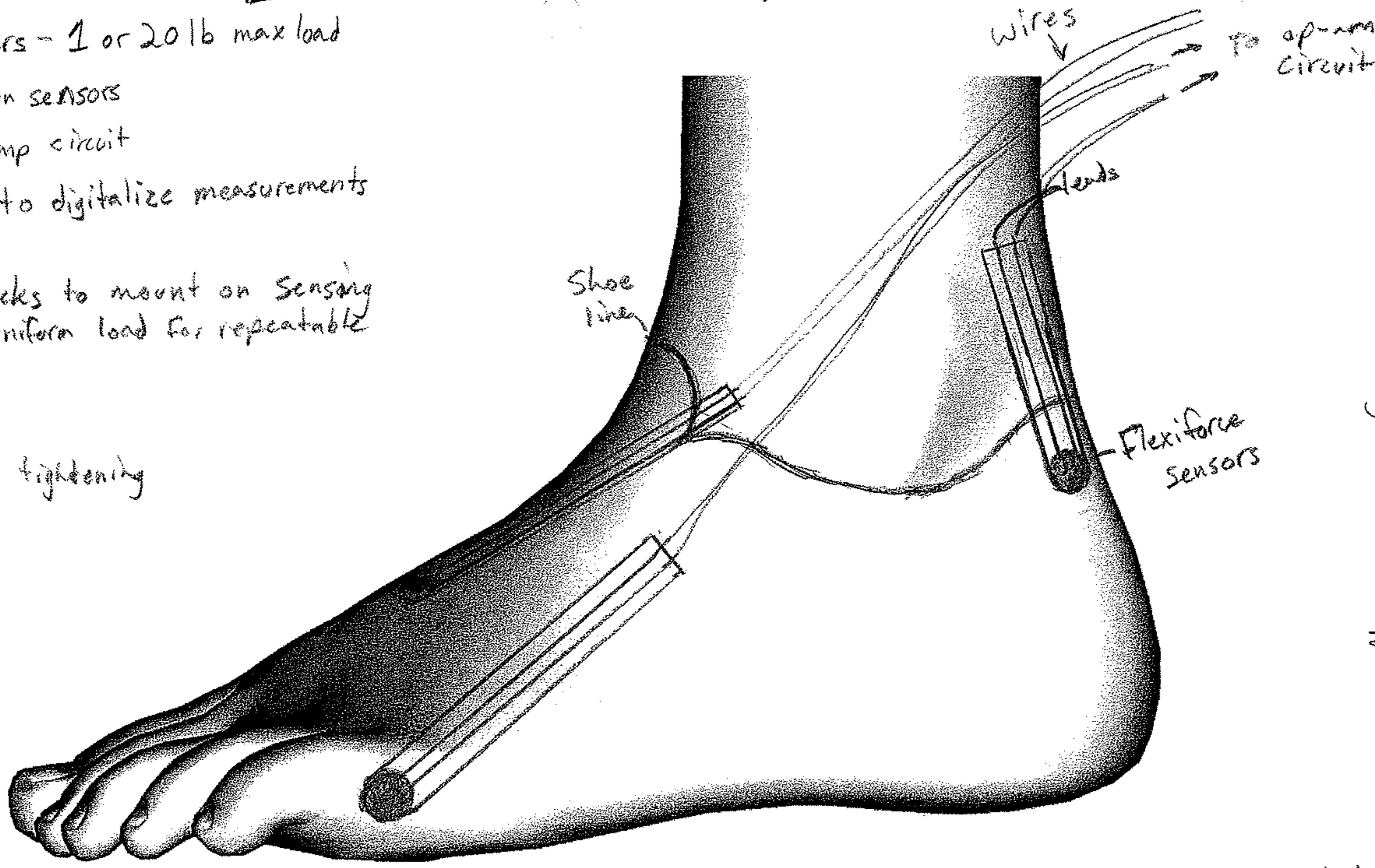
Bladders attached directly to foot or integrated into "sock." Tubes run up foot and to external syringe or pressure sensor. Syringe has water inside and is injects water into bladder until predetermined pressure is reached while foot is outside of shoe. Bladders are then drained back into syringe, and → Shoe is put on. Once shoe is on and laced tight, syringe is depressed until same volume of water is in bladder. Pressure readings are then collected.

Appendix D: Preliminary Sketch of Apparatus with FlexiForce Sensors

Flexiforce fit test system

Elements

- 6 Flexiforce Sensors - 1 or 20 lb max load
- wires to leads on sensors
- Recommended op-amp circuit
- DaqView system to digitalize measurements for analyzation
- hard material pucks to mount on sensing area. Provides uniform load for repeatable measurements
- collect data while tightening



Lateral

Note: System will have to be calibrated taking heat into account.

Sensors will be mounted directly on the skin of the foot. Sensor and puck will be taped in place on key areas of the foot. Shoe will then be put on and tightened.

INTRODUCTION

This manual describes how to use Tekscan's ***FlexiForce Sensors***. These sensors are ideal for designers, researchers, or anyone who needs to measure forces without disturbing the dynamics of their tests. The ***FlexiForce*** sensors can be used to measure both static and dynamic forces (up to 1000 lbf.), and are thin enough to enable non-intrusive measurement.

The ***FlexiForce*** sensors use a resistive-based technology. The application of a force to the active sensing area of the sensor results in a change in the resistance of the sensing element in inverse proportion to the force applied.

GETTING ASSISTANCE

Tekscan, Inc. will provide technical assistance for any difficulties you may experience using your ***FlexiForce*** system.

Write, call or fax us with any concerns or questions. Our knowledgeable support staff will be happy to help you. Comments and suggestions are always welcome.

FlexiForce
a division of Tekscan, Inc.
307 West First Street
South Boston, MA 02127-1309

Phone: (617) 464-4500
Fax: (617) 464-4266
E-mail: flexiforce@tekscan.com

OVERVIEW

This section outlines Sensor Construction and Application.

FLEXIFORCE SENSORS

The ***FlexiForce*** sensor is an ultra-thin and flexible printed circuit, which can be easily integrated into most applications. With its paper-thin construction, flexibility and force measurement ability, the ***FlexiForce*** force sensor can measure force between almost any two surfaces and is durable enough to stand up to most environments. ***FlexiForce*** has better force sensing properties, linearity, hysteresis, drift, and temperature sensitivity than any other thin-film force sensors. The "active sensing area" is a 0.375" diameter circle at the end of the sensor.

The sensors are constructed of two layers of substrate. This substrate is composed of polyester film (or Polyimide in the case of the High-Temperature Sensors). On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the sensor. The silver circle on top of the pressure-sensitive ink defines the "active sensing area." Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads.

FlexiForce sensors are terminated with a solderable male square pin connector, which allows them to be incorporated into a circuit. The two outer pins of the connector are active and the center pin is inactive. The length of the sensors can be trimmed by ***Tekscan*** to predefined lengths of 2", 4" and 6" or can be trimmed by the customer. If the customer trims the sensor, a new connector must be attached. This can be accomplished by purchasing staked pin connectors and a crimping tool. A conductive epoxy can also be used to adhere small wires to each conductor.

The sensor acts as a variable resistor in an electrical circuit. When the sensor is unloaded, its resistance is very high (greater than 5 Meg-ohm); when a force is applied to the sensor, the resistance decreases. Connecting an ohmmeter to the outer two pins of the sensor connector and applying a force to the sensing area can read the change in resistance.

Sensors should be stored at temperatures in the range of 15°F (-9°C) to 165°F (74°C)

Standard FlexiForce Sensors

The Standard A201 sensor is available in the following force ranges:

- Sensor A201-1 (0-1 lb. force range)
- Sensor A201-25 (0-25 lb. force range)
- Sensor A201-100 (0-100 lb. force range)*

**** In order to measure forces above 100 lbs. (up to 1000 lbs), apply a lower drive voltage and reduce the resistance of the feedback resistor (1kΩ min.). See the sample drive circuit below.***

F2

High-Temperature FlexiForce Sensors

The High-Temperature HT201 sensor is available in the following force ranges* (as tested with the sample drive circuit).

- Sensor HT201-L Low: 0-30lb (133N) force range
- Sensor HT201-H High: 0-100lb (445N) force range

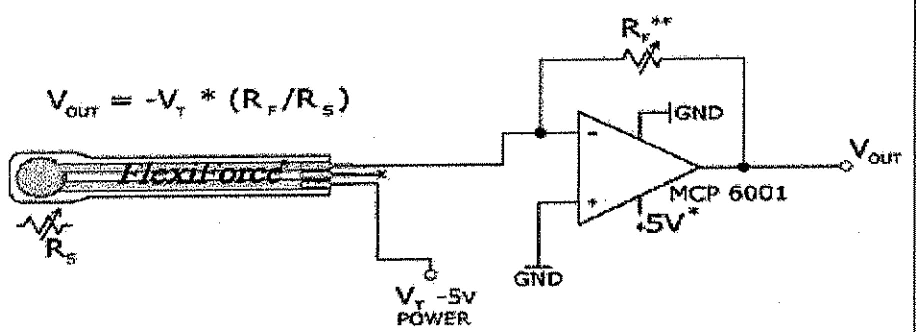
In order to measure forces outside specified ranges, use recommended circuit and adjust drive voltage and/or reference resistance

APPLICATION

There are many ways to integrate the ***FlexiForce*** sensor into an application. One way is to incorporate it into a force-to-voltage circuit. A means of calibration must then be established to convert the output into the appropriate engineering units. Depending on the setup, an adjustment could then be done to increase or decrease the sensitivity of the sensor.

An example circuit is shown below. In this case, it is driven by a -5 V DC excitation voltage. This circuit uses an inverting operational amplifier arrangement to produce an analog output based on the sensor resistance and a fixed reference resistance (R_F). An analog-to-digital converter can be used to change this voltage to a digital output. In this circuit, the sensitivity of the sensor could be adjusted by changing the reference resistance (R_F) and/or drive voltage (VT); a lower reference resistance and/or drive voltage will make the sensor less sensitive, and increase its active force range.

Recommended Circuit



- * Supply Voltages should be constant
- ** Reference Resistance R_F is 1kΩ to 100kΩ
- Sensor Resistance R_S at no load is >5MΩ
- Max recommended current is 2.5mA

In the circuit shown, the dynamic force range of the sensor can be adjusted by changing the reference resistor (R_F) or by changing the Drive Voltage (V_O). Refer to the Saturation section for additional information.

SENSOR LOADING CONSIDERATIONS

The following general sensor loading guidelines can be applied to most applications, and will help you achieve the most accurate results from your tests. It is important that you read the ***Sensor Performance Characteristics*** section for further information on how to get the most accurate results from your sensor readings.

SENSOR LOADING

The entire sensing area of the ***FlexiForce*** sensor is treated as a single contact point. For this reason, the applied load should be distributed evenly across the sensing area to ensure accurate and repeatable force readings. Readings may vary slightly if the load distribution changes over the sensing area.

Note that the sensing area is the silver circle on the top of the sensor only.

It is also important that the sensor be loaded consistently, or in the same way each time.

If the footprint of the applied load is smaller than the sensing area, the load should not be placed near the edges of the sensing area, to ensure an even load distribution.

It is also important to ensure that the sensing area is the entire load path, and that the load is not supported by the area outside of the sensing area.

If the footprint of the applied load is larger than the sensing area, it may be necessary to use a "puck." A puck is a piece of rigid material (smaller than the sensing area) that is placed on the sensing area to ensure that the entire load path goes through this area. The puck must not touch any of the edges of the sensing area, or these edges may support some of the load and give an erroneous reading.

The ***FlexiForce*** sensor reads forces that are perpendicular to the sensor plane. Applications that impart "shear" forces could reduce the life of the sensor. If the application will place a "shear" force on the sensor, it should be protected by covering it with a more resilient material.

If it is necessary to mount the sensor to a surface, it is recommended that you use tape, when possible. Adhesives may also be used, but make sure that the adhesive will not degrade the substrate (polyester) material of the sensor before using it in an application. Adhesives should not be applied to the sensing area; however, if it is necessary, ensure that the adhesive is spread evenly. Otherwise, any high spots may appear as load on the sensor.

SATURATION

The **Saturation** force is the point at which the device output no longer varies with applied force. The saturation force of each sensor is based on the maximum recommended force specified by Tekscan, which is printed on the system packaging or the actual sensor, along with the "Sensitivity."

E1

The saturation value is based on using the circuit and the values shown in the example circuit in the 'Application' section. In this example, the saturation force (maximum force) of each sensor is related to the RF (reference resistance), and can be altered by changing the sensitivity. The sensitivity of the sensor would be adjusted by changing the reference resistance (RF); a lower reference resistance will make the system less sensitive, and increase its active force range.

It is essential that the sensor(s) do not become saturated during testing.

CONDITIONING SENSORS

Exercising, or **Conditioning** a sensor before calibration and testing is essential in achieving accurate results. It helps to lessen the effects of *drift* and *hysteresis*. Conditioning is required for new sensors, and for sensors that have not been used for a length of time.

To condition a sensor, place 110% of the test weight on the sensor, allow the sensor to stabilize, and then remove the weight. Repeat this process four or five times. The interface between the sensor and the test subject material should be the same during conditioning as during calibration and actual testing.

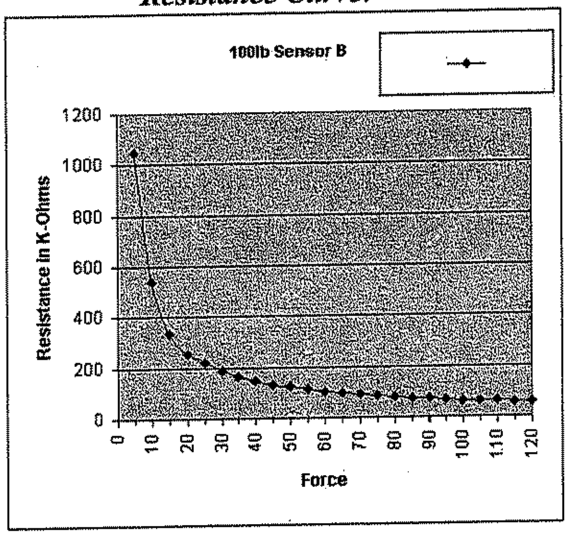
IMPORTANT! Sensors must be properly conditioned prior to calibration and use.

E5

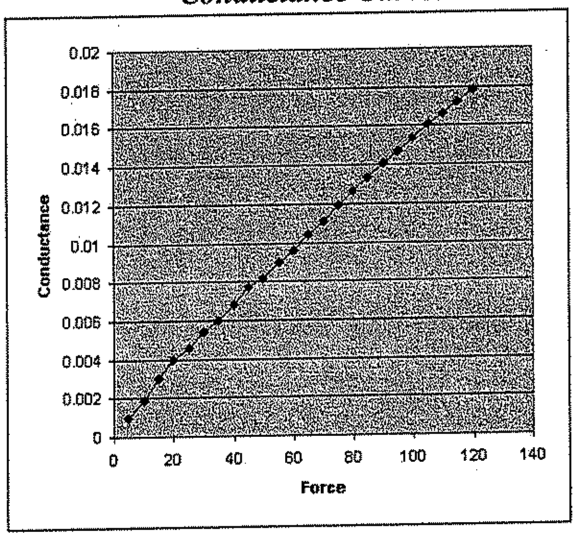
CALIBRATION

Calibration is the method by which the sensor's electrical output is related to an actual engineering unit, such as pounds or Newtons. To calibrate, apply a known force to the sensor, and equate the sensor resistance output to this force. Repeat this step with a number of known forces that approximate the load range to be used in testing. Plot **Force** versus **Conductance (1/R)**. A linear interpolation can then be done between zero load and the known calibration loads, to determine the actual force range that matches the sensor output range.

Resistance Curve:



Conductance Curve:



CALIBRATION GUIDELINES

The following guidelines should be considered when calibrating a sensor:

- Apply a calibration load that approximates the load to be applied during system use, using dead weights or a testing device (such as an ***MTS*** or ***Instron***). If you intend to use a "puck" during testing, also use it when calibrating the sensor. See Sensor Loading Considerations for more information on using a puck.
- Avoid loading the sensor to near saturation when calibrating. If the sensor saturates at a lower load than desired, adjust the "Sensitivity."
- Distribute the applied load evenly across the sensing area to ensure accurate force readings. Readings may vary slightly if the load distribution changes over the sensing area.
- Sensors should be calibrated at the same temperature for which testing will occur. This is especially important for High-Temp Sensors, as these sensors have a wide operating temperature range. If multiple temperatures are used during testing, calibrate the sensors at those same multiple temperatures.

Note: Read the Sensor Performance Characteristics section before performing a Calibration.

F.

SENSOR PERFORMANCE CHARACTERISTICS

There are a number of characteristics of sensors, which can affect your results. This section contains a description of each of these conditions, and recommendations on how to lessen their effects.

REPEATABILITY

Repeatability is the ability of the sensor to respond in the same way to a repeatedly applied force. As with most measurement devices, it is customary to exercise, or "condition" a sensor before calibrating it or using it for measurement. This is done to reduce the amount of change in the sensor response due to repeated loading and unloading. A sensor is conditioned by loading it to 110% of the test weight four or five times. Follow the full procedure in the **Conditioning Sensors** section.

LINEARITY

Linearity refers to the sensor's response (digital output) to the applied load, over the range of the sensor. This response should ideally be linear; and any non-linearity of the sensor is the amount that its output deviates from this line. A calibration is performed to "linearize" this output as much as possible. ***FlexiForce*** standard sensors are linear within +/- 3%. ***FlexiForce*** High-Temperature sensors have a linearity that is 1.2% of full scale.

HYSTERESIS

Hysteresis is the difference in the sensor output response during loading and unloading, at the same force. For static forces, and applications in which force is only increased, and not decreased, the effects of hysteresis are minimal. If an application includes load decreases, as well as increases, there may be error introduced by hysteresis that is not accounted for by calibration.

DRIFT

Drift is the change in sensor output when a constant force is applied over a period of time. If the sensor is kept under a constant load, the resistance of the sensor will continually decrease, and the output will gradually increase. It is important to take drift into account when calibrating the sensor, so that its effects can be minimized. The simplest way to accomplish this is to perform the sensor calibration in a time frame similar to that which will be used in the application.

TEMPERATURE SENSITIVITY

In general, your results will vary if you combine high loads on the sensor with high temperatures.

To ensure accuracy, calibrate the sensor at the temperature at which it will be used in the application. If the sensor is being used at different temperatures, perform a calibration at each of these temperatures, save the calibration files, then load the appropriate calibration file when using the sensor at that temperature.

E

SENSOR LIFE / DURABILITY

Sensor life depends on the application in which it is used. Sensors are reusable, unless used in applications in which they are subjected to severe conditions, such as against sharp edges, or shear forces. ***FlexiForce*** sensors have been successfully tested at over one million load cycles using a 50 lb. force.

Rough handling of a sensor will also shorten its useful life. For example, a sensor that is repeatedly installed in a flanged joint will have a shorter life than a sensor installed in the same joint once and used to monitor loads over a prolonged period. After each installation, visually inspect your sensors for physical damage.

It is also important to keep the sensing area of the sensor clean. Any deposits on this area will create uneven loading, and will cause saturation to occur at lower applied forces.

SENSOR PROPERTIES

STANDARD FLEXIFORCE SENSOR (MODEL A201)

Sensor Properties	
Thickness	0.008 (0.208 mm)
Length	8" (203 mm) 6" (152 mm) 4" (102 mm) 2" (51 mm)
Width	0.55" (14 mm)
Sensing Area	0.375" (9.53 mm) diameter
Connector	3-pin male square pin (center pin is inactive)
Typical Performance	
Force Ranges	0-1 lb (4.4 N) 0-25 lbs (110 N) 0-100 lbs (440 N)*
Operating Temperature Range	15°F to 140°F (-9°C to 60°C)
Linearity (Error)	+/- 3%
Repeatability	+/- 2.5% of full scale (conditioned sensor, 80% force applied)
Hysteresis	<4.5% of full scale (conditioned sensor, 80% force applied)
Drift	<5% per logarithmic time scale (constant load of 90% sensor rating)
Response Time	<5 microseconds
Output Change/Degree F	Up to 0.2% (~0.36% / °C). Loads <10 lbs, operating temperature can be increased to 165°F (74°C).

HIGH-TEMPERATURE FLEXIFORCE SENSOR (MODEL HT201)

Sensor Properties	
Thickness	0.008" (0.203 mm)
Length	7.75" (197 mm) *Optional:* 6" (152 mm) *Trimmed:* 4" (102 mm) *Lengths:* 2" (51 mm)
Width	0.55" (14 mm)
Sensing Area	0.375" (9.53 mm) diameter
Connector	3-pin Male Square Pin (center pin is inactive)
Substrate	Polyimide (ex: Kapton)
Typical Performance	
Force Ranges	0-30 lbs (133N) 0-100 lbs (445N)
Operating Temperature Range	15°F to 400°F (-9°C to 204°C)
Repeatability	+/- 3.5% of full scale
Linearity	+/- 1.2% of full scale
Hysteresis	3.6% of full scale
Drift	3.3% per log time
Output Change/Degree F	0.16%

E9

Appendix F: LM741 Inverting Op Amp Data Sheet

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

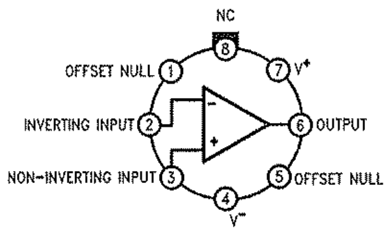
The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Features

Connection Diagrams

Metal Can Package

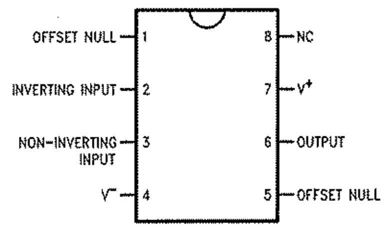


00934102

Note 1: LM741H is available per JM38510/10101

Order Number LM741H, LM741H/883 (Note 1), **LM741AH/883 or LM741CH**
See NS Package Number H08C

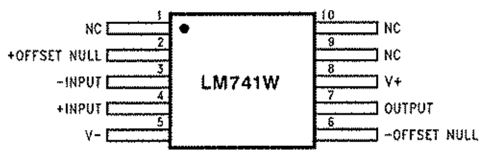
Dual-In-Line or S.O. Package



00934103

Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

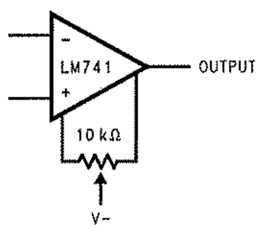


00934106

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



00934107

F1

Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
N-Package (10 seconds)	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C
See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.			
ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \leq 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \leq 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 50\Omega$			4.0							mV
	$R_S \leq 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	$T_A = 25°C$, $V_S = \pm20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25°C$, $V_S = \pm20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $V_S = \pm20V$	0.5									MΩ
Input Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \leq T_A \leq T_{AMAX}$				±12	±13					V

F2

Appendix G: MCP 6004 Data Sheet

MICROCHIP

MCP6001/2/4

1 MHz Bandwidth Low Power Op Amp

Features

- Available in SC-70-5 and SOT-23-5 packages
- 1 MHz Gain Bandwidth Product (typ.)
- Rail-to-Rail Input/Output
- Supply Voltage: 1.8V to 5.5V
- Supply Current: I_Q = 100 µA (typ.)
- 90° Phase Margin (typ.)
- Temperature Range:
  - Industrial: -40°C to +85°C
  - Extended: -40°C to +125°C
- Available in Single, Dual and Quad Packages

Applications

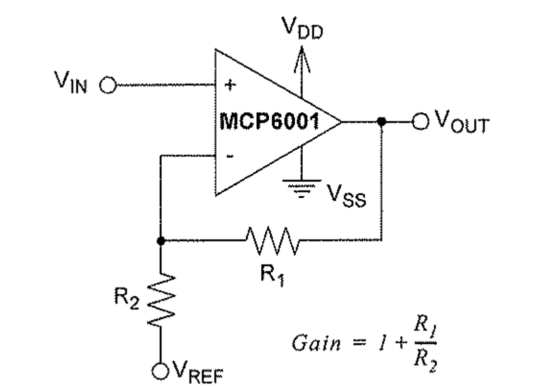
- Automotive
- Portable Equipment
- Photodiode Pre-amps
- Analog Filters
- Notebooks and PDAs
- Battery-Powered Systems

Available Tools

Spice Macro Models (at www.microchip.com)

FilterLab® Software (at www.microchip.com)

Typical Application



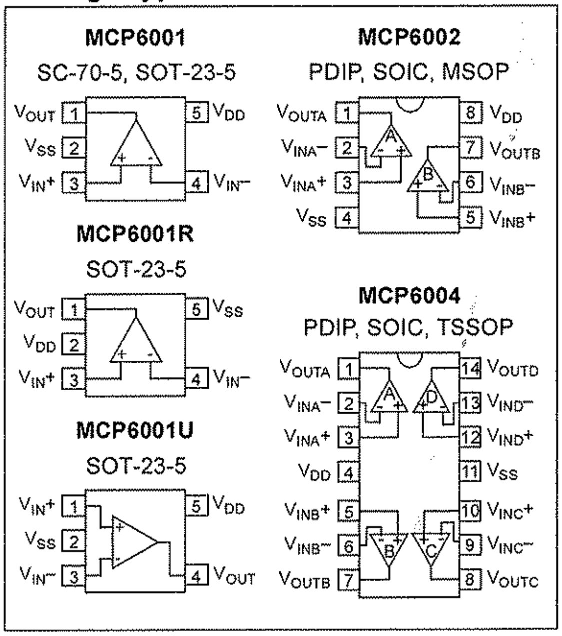
Non-Inverting Amplifier

Description

The Microchip Technology Inc. MCP6001/2/4 family of operational amplifiers (op amps) is specifically designed for general-purpose applications. This family has a 1 MHz gain bandwidth product and 90° phase margin (typ.). It also maintains 45° phase margin (typ.) with 500 pF capacitive load. This family operates from a single supply voltage as low as 1.8V, while drawing 100 µA (typ.) quiescent current. Additionally, the MCP6001/2/4 supports rail-to-rail input and output swing, with a common mode input voltage range of V_{DD} + 300 mV to V_{SS} - 300 mV. This family of operational amplifiers is designed with Microchip's advanced CMOS process.

The MCP6001/2/4 family is available in the industrial and extended temperature ranges. It also has a power supply range of 1.8V to 5.5V.

Package Types



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

V_{DD} - V_{SS} 7.0V
All Inputs and Outputs .... V_{SS} -0.3V to V_{DD} +0.3V
Difference Input Voltage .... $|V_{DD} - V_{SS}|$
Output Short Circuit Current .... continuous
Current at Input Pins .... ±2 mA
Current at Output and Supply Pins .... ±30 mA
Storage Temperature .... -65°C to +150°C
Maximum Junction Temperature (T_J) .... +150°C
ESD Protection On All Pins (HBM;MM) .... ≥ 4 kV; 200V

† Notice: Stresses above those listed under "Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

PIN FUNCTION TABLE

Name	Function
$V_{IN}+$, $V_{INA}+$, $V_{INB}+$, $V_{INC}+$, $V_{IND}+$	Non-inverting Inputs
$V_{IN}-$, $V_{INA}-$, $V_{INB}-$, $V_{INC}-$, $V_{IND}-$	Inverting Inputs
V_{DD}	Positive Power Supply
V_{SS}	Negative Power Supply
V_{OUT}, V_{OUTA}, V_{OUTB}, V_{OUTC}, V_{OUTD}	Outputs

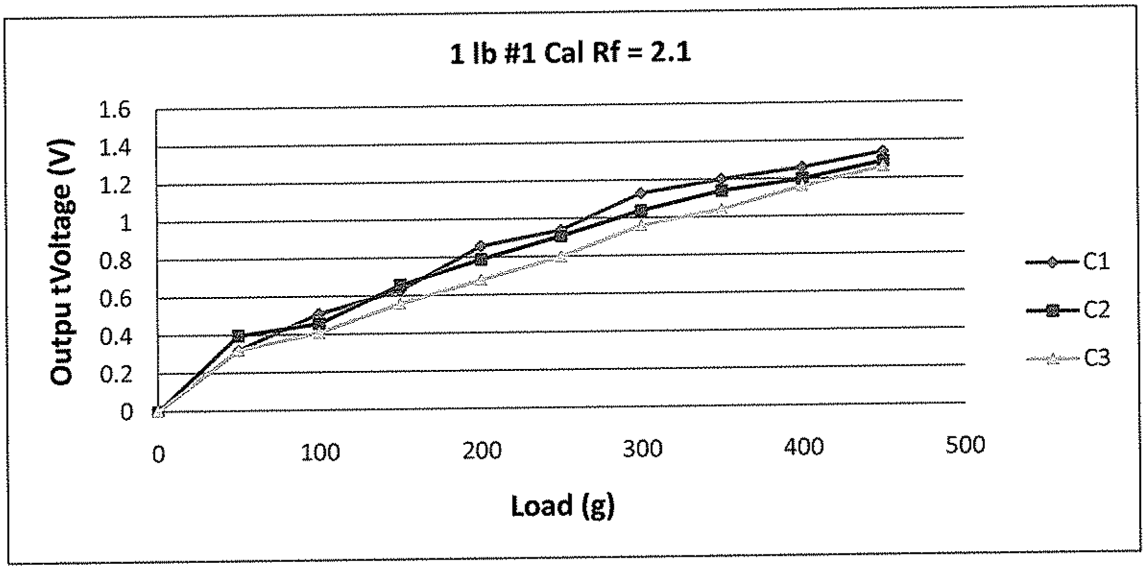
DC ELECTRICAL SPECIFICATIONS

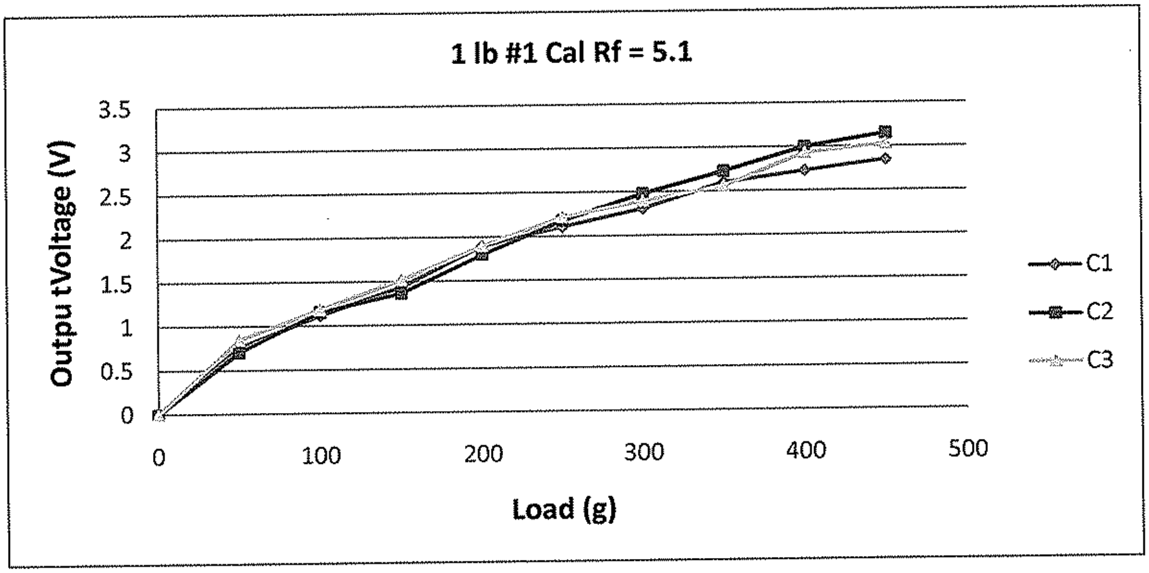
Electrical Characteristics: Unless otherwise indicated, T_A = +25°C, V_{DD} = +1.8V to +5.5V, V_{SS} = GND, V_{CM} = $V_{DD}/2$, R_L = 10 kΩ to $V_{DD}/2$, and $V_{OUT} \sim V_{DD}/2$.

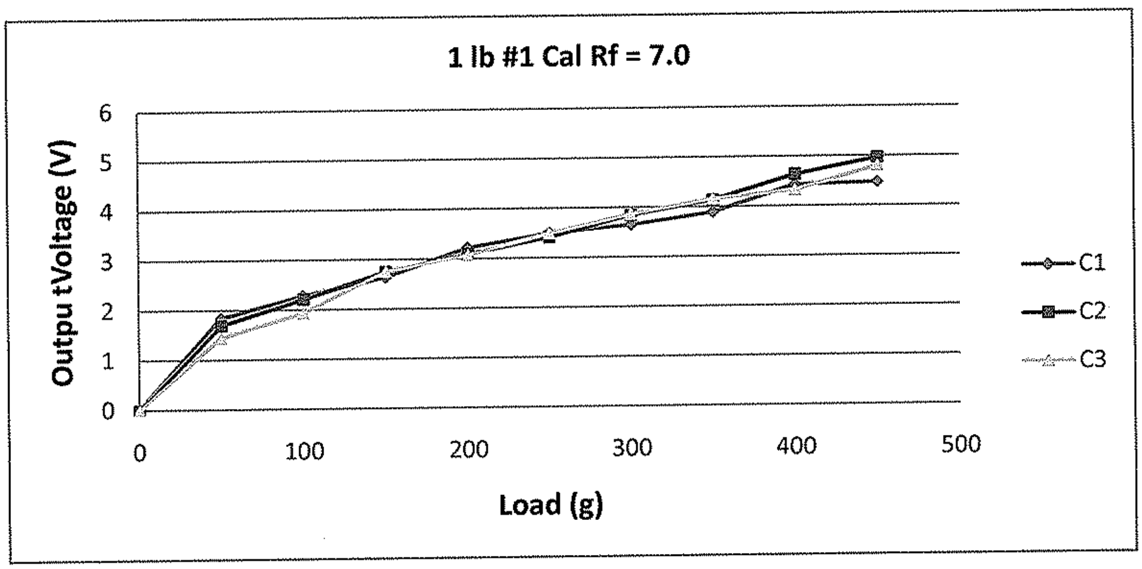
Parameters	Sym	Min	Typ	Max	Units	Conditions
Input Offset						
Input Offset Voltage	V_{OS}	-7.0	—	+7.0	mV	$V_{CM} = V_{SS}$
Input Offset Drift with Temperature	$\Delta V_{OS}/\Delta T_A$	—	±2.0	—	µV/°C	T_A= -40°C to +125°C, $V_{CM} = V_{SS}$
Power Supply Rejection	PSRR	—	86	—	dB	$V_{CM} = V_{SS}$
Input Bias Current and Impedance						
Input Bias Current:	I_B	—	±1.0	—	pA	
Industrial Temperature	I_B	—	19	—	pA	T_A = +85°C
Extended Temperature	I_B	—	1100	—	pA	T_A = +125°C
Input Offset Current	I_{OS}	—	±1.0	—	pA	
Common Mode Input Impedance	Z_{CM}	—	10^{13}||6	—	Ω||pF	
Differential Input Impedance	Z_{DIFF}	—	10^{13}||3	—	Ω||pF	
Common Mode						
Common Mode Input Range	V_{CMR}	$V_{SS} - 0.3$	—	$V_{DD} + 0.3$	V	
Common Mode Rejection Ratio	CMRR	60	76	—	dB	V_{CM} = -0.3V to 5.3V, V_{DD} = 5V
Open-Loop Gain						
DC Open-Loop Gain (large signal)	A_{OL}	88	112	—	dB	V_{OUT} = 0.3V to V_{DD} - 0.3V, $V_{CM} = V_{SS}$
Output						
Maximum Output Voltage Swing	V_{OL}, V_{OH}	V_{SS} + 25	—	V_{DD} – 25	mV	V_{DD} = 5.5V
Output Short-Circuit Current	I_{SC}	—	±6	—	mA	V_{DD} = 1.8V
		—	±23	—	mA	V_{DD} = 5.5V
Power Supply						
Supply Voltage	V_{DD}	1.8	—	5.5	V	
Quiescent Current per Amplifier	I_Q	50	100	170	µA	I_O = 0, V_{DD} = 5.5V, V_{CM} = 5V

62

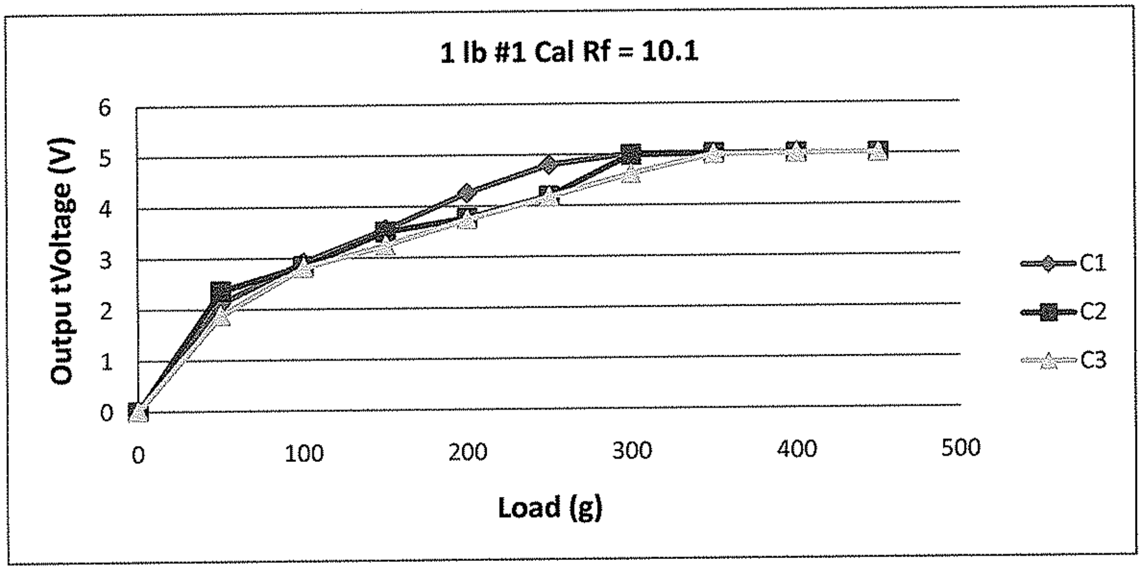
Appendix H: Optimization of Feedback Resistor

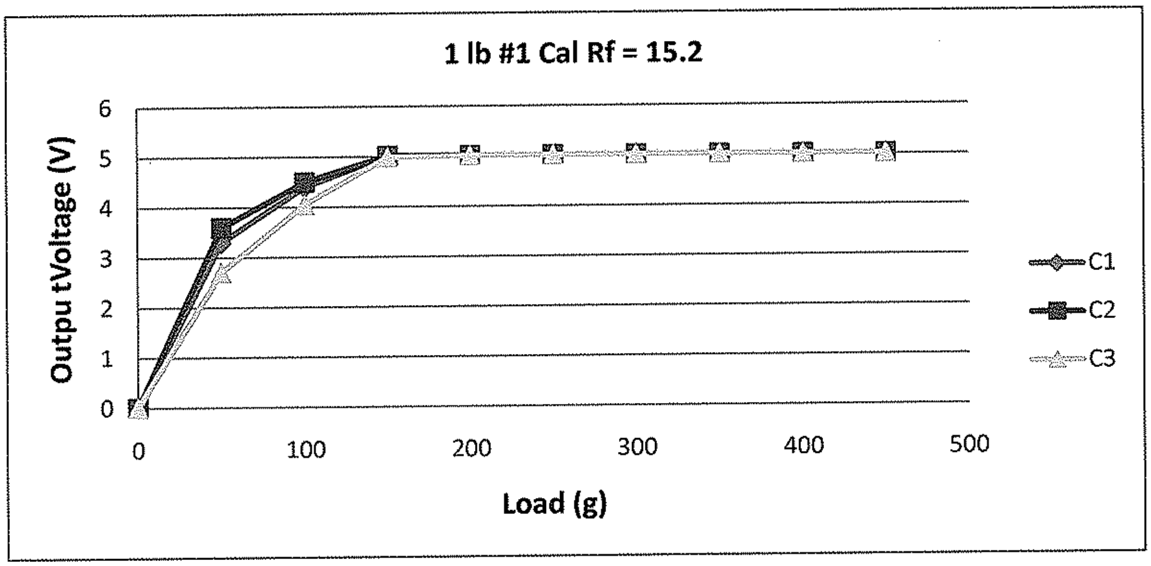




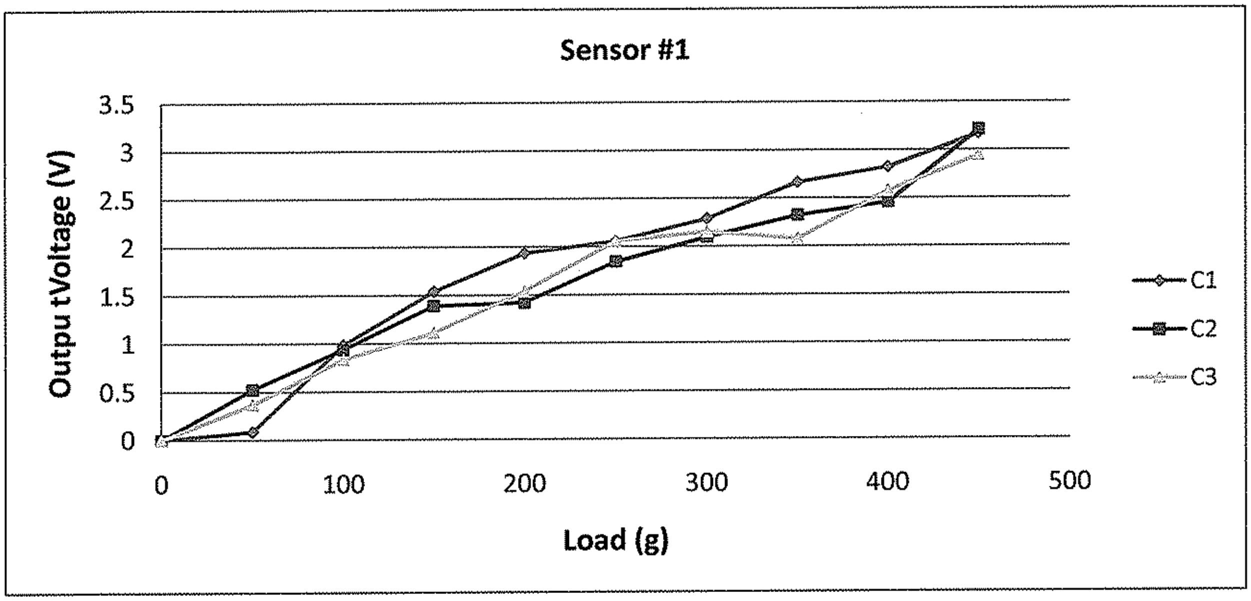


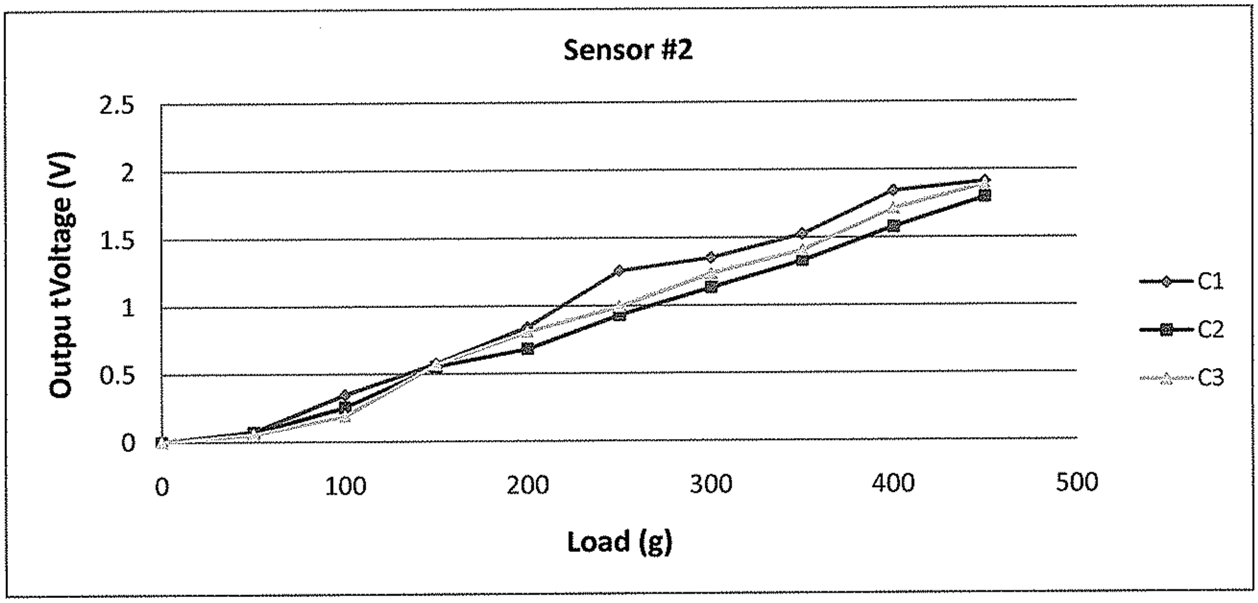
Appendix H: Optimization of Feedback Resistor

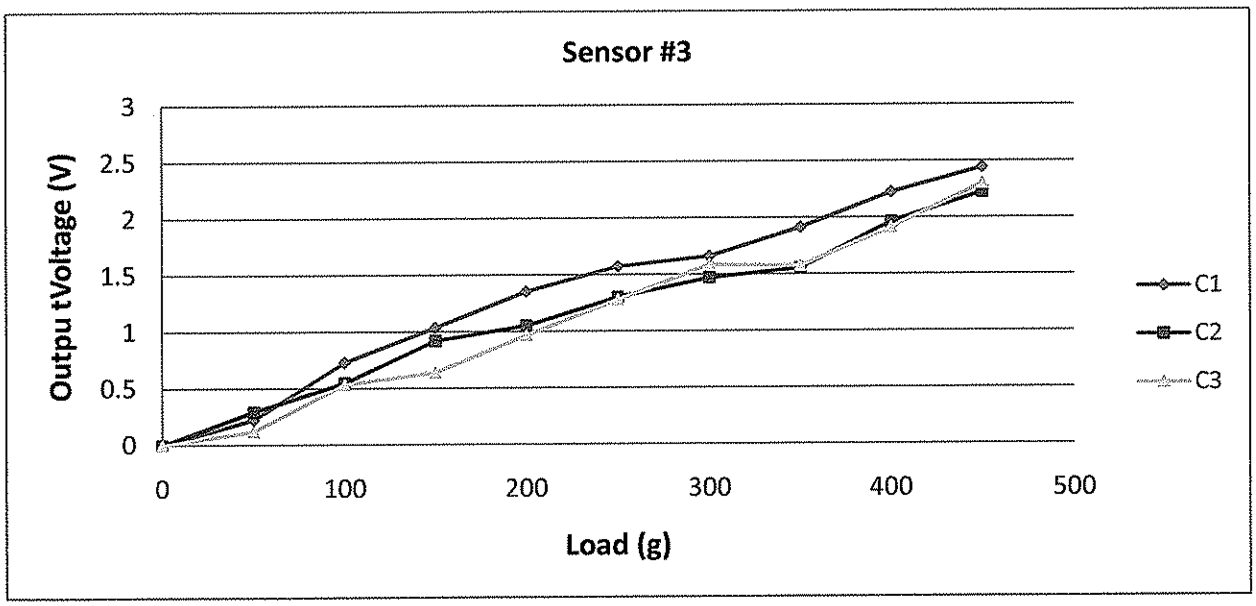




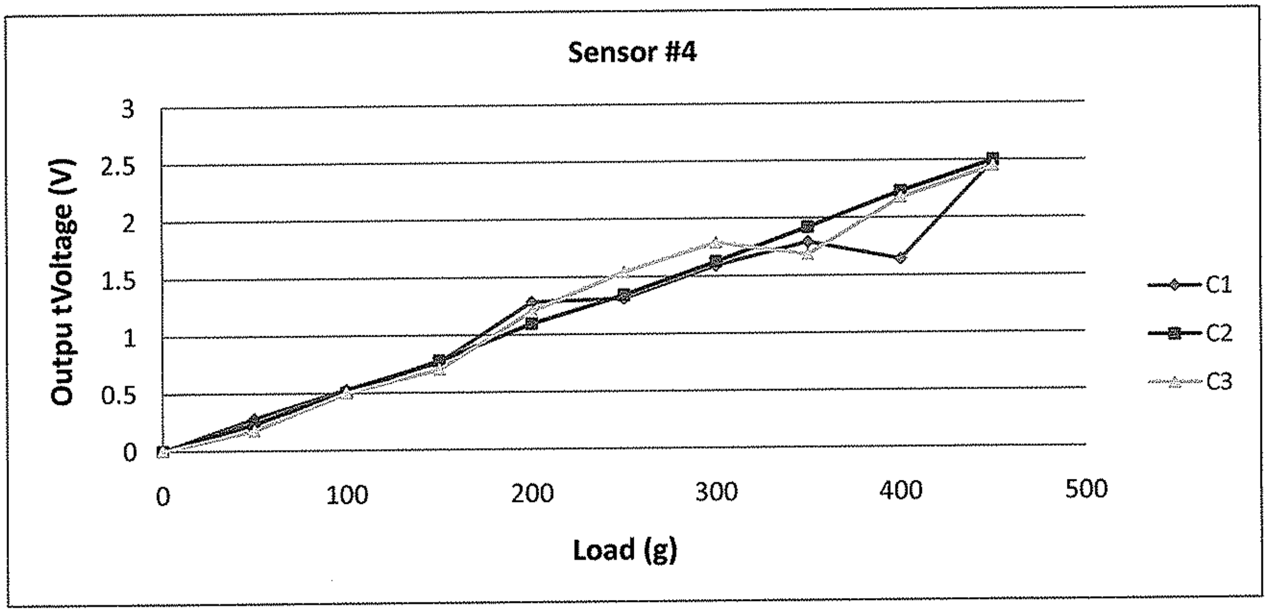
Appendix I: Final Calibration Curves

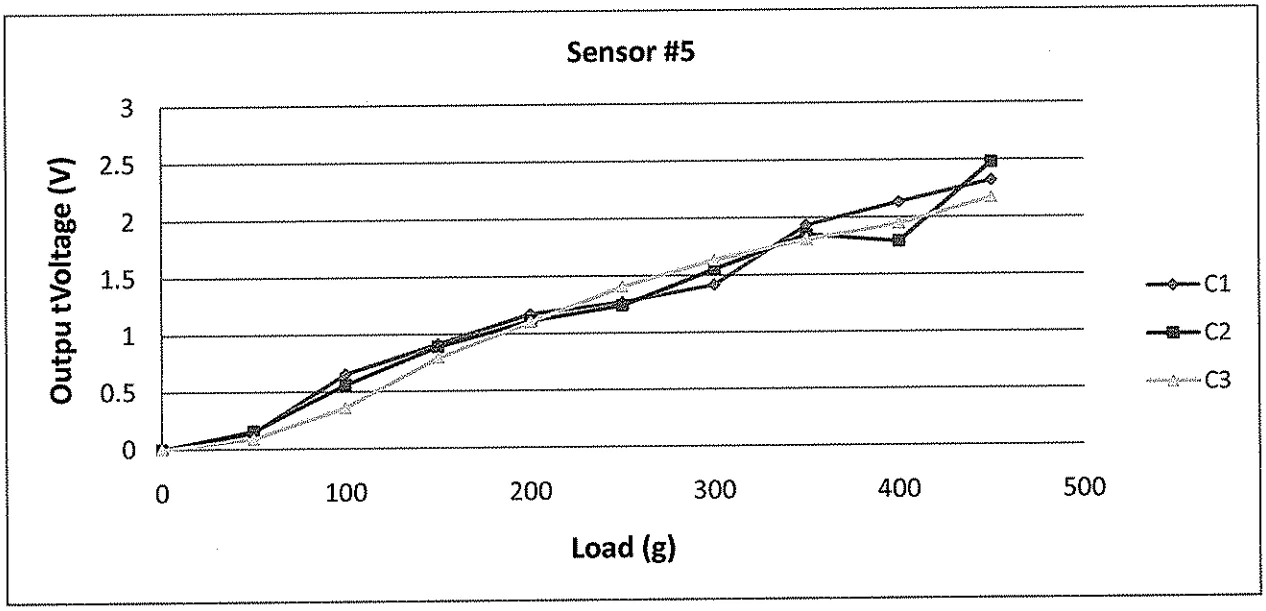


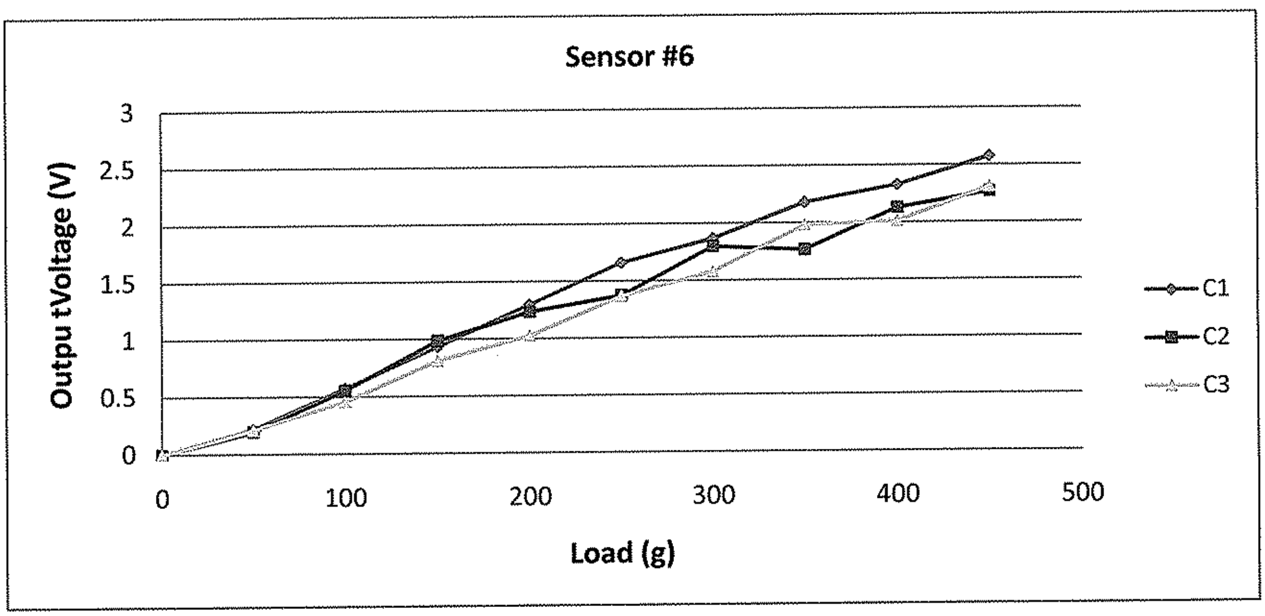




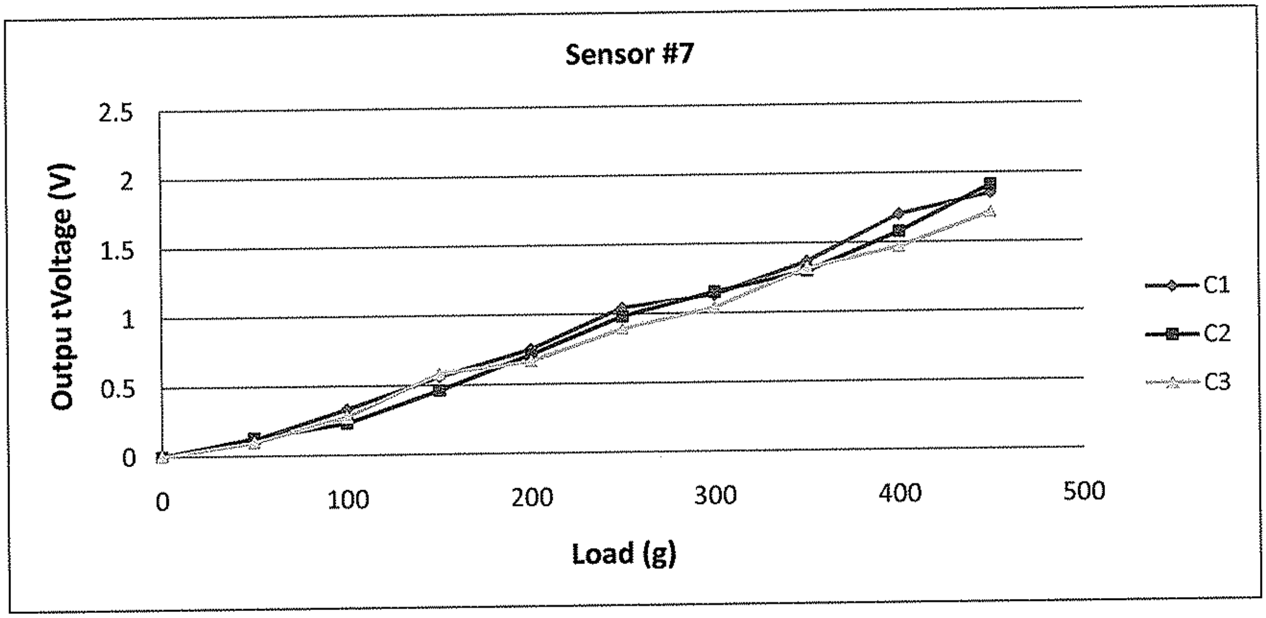
Appendix I: Final Calibration Curves

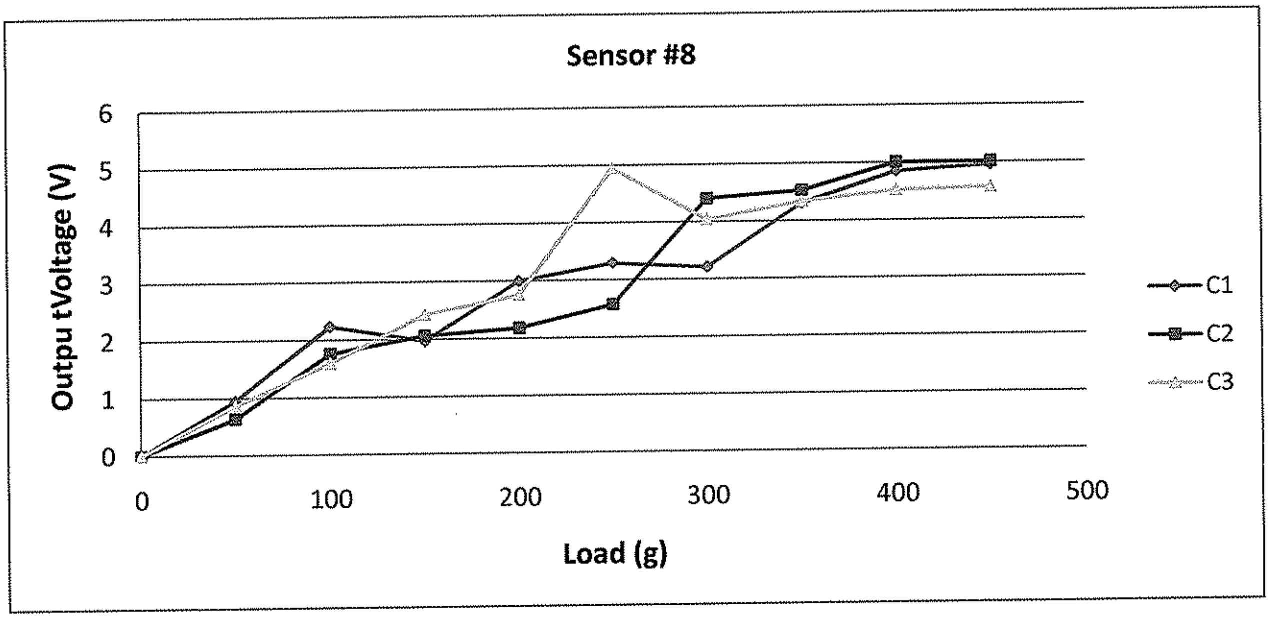




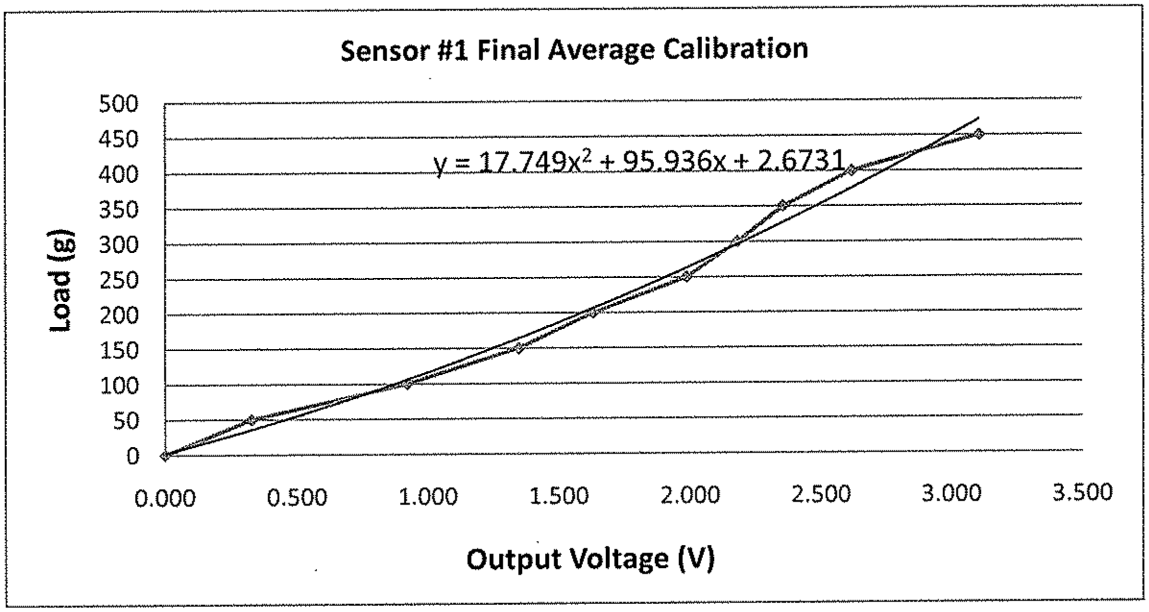


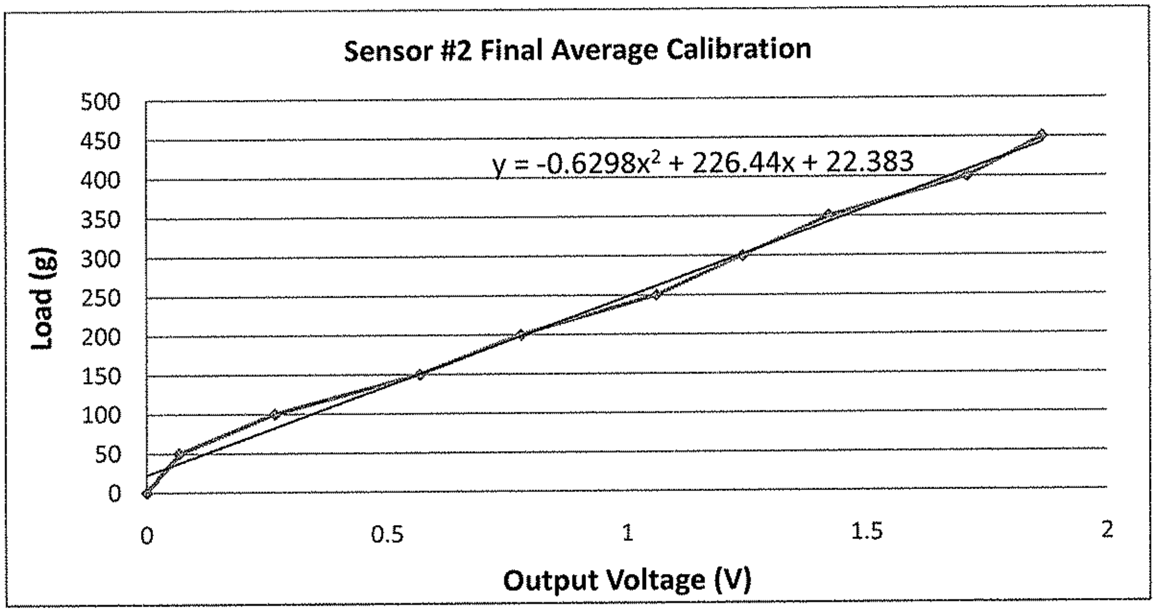
Appendix I: Final Calibration Curves

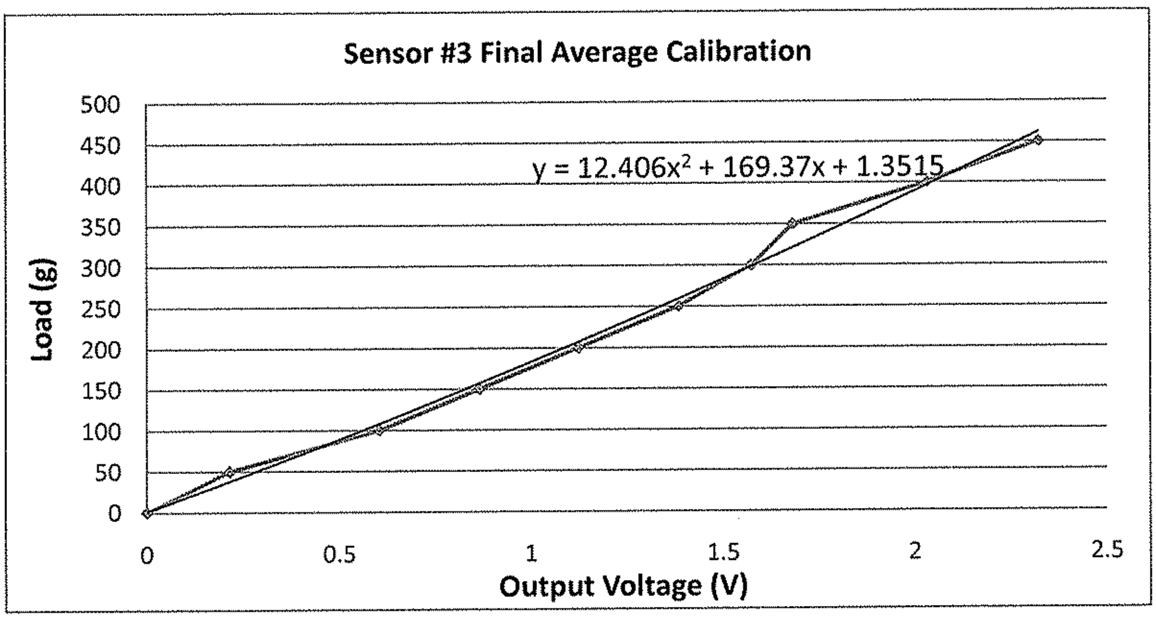




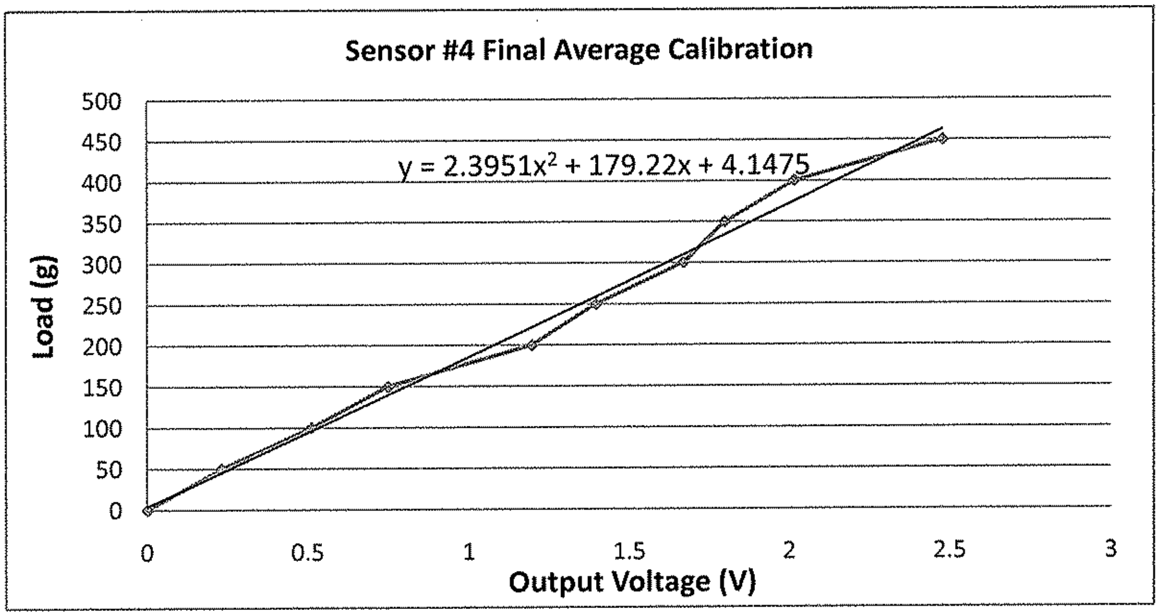
Appendix J: Final Average Calibration Curves and Equations

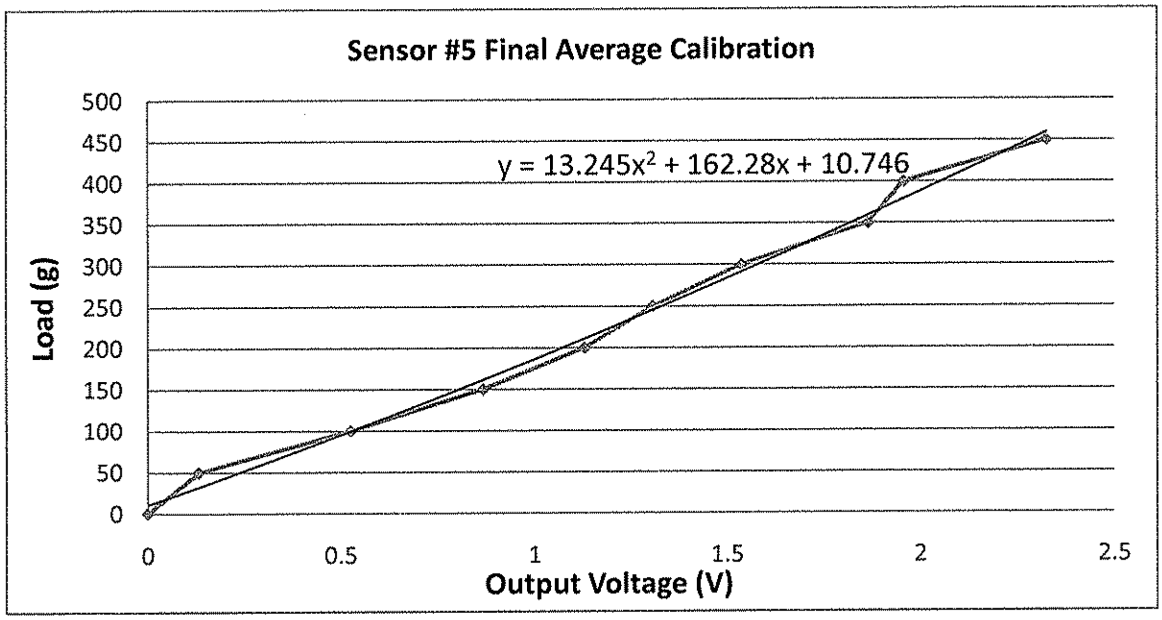


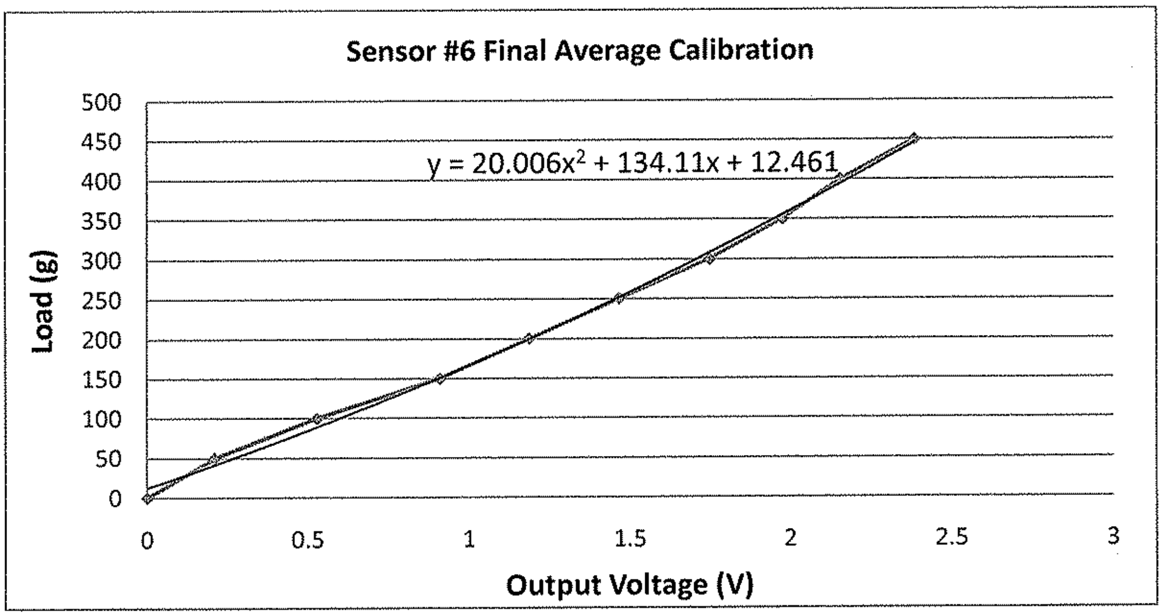




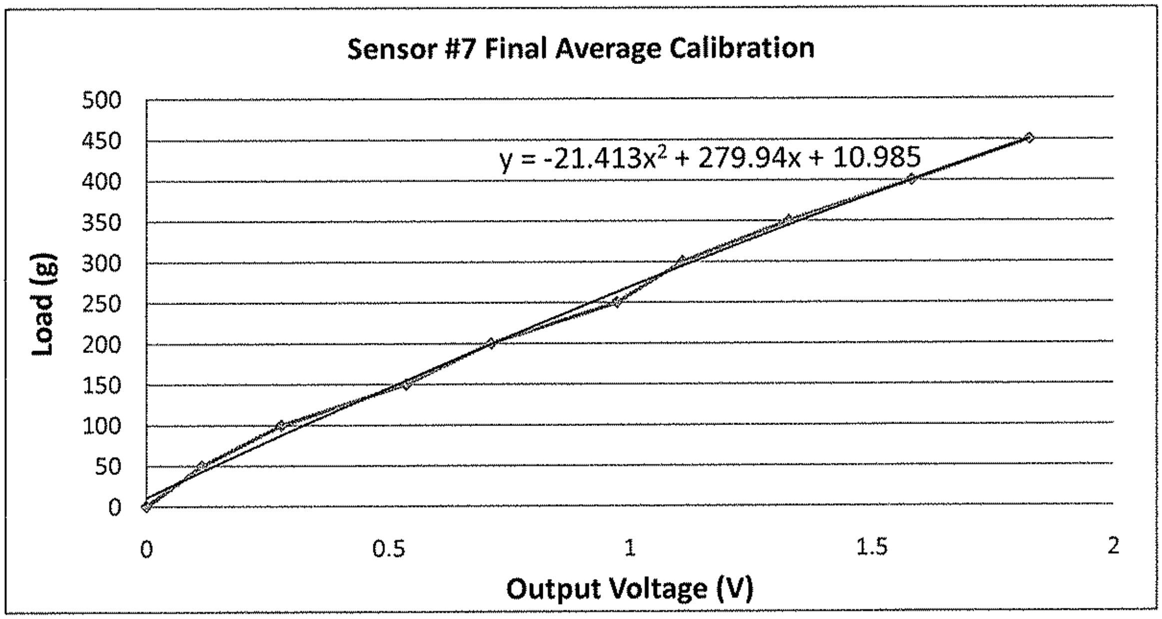
Appendix J: Final Average Calibration Curves and Equations

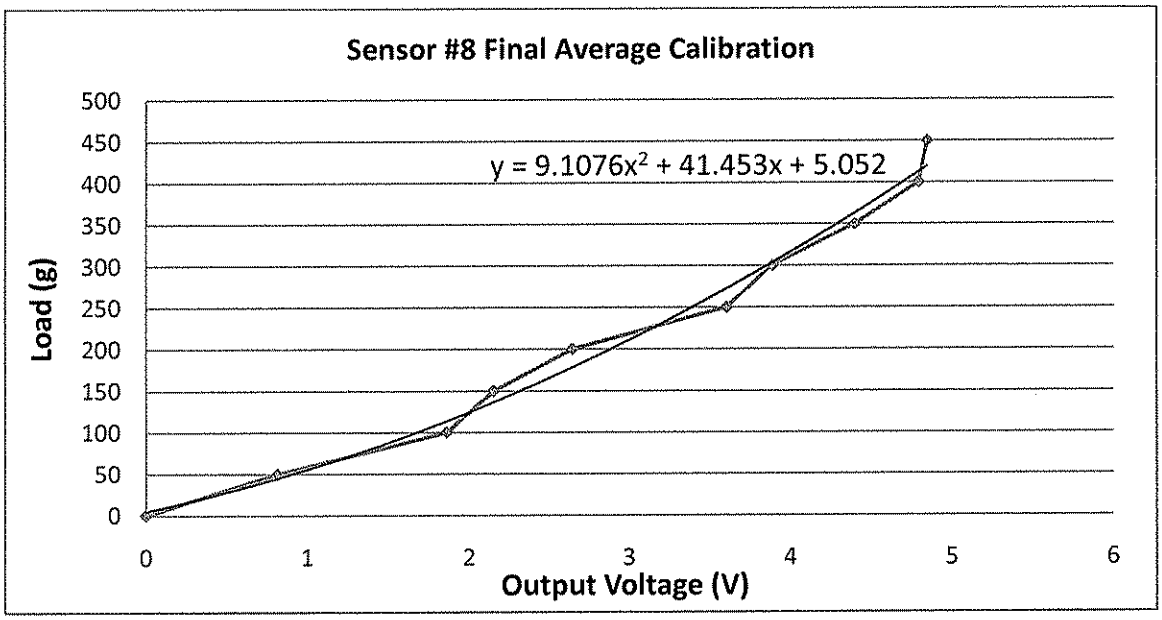






Appendix J: Final Average Calibration Curves and Equations





Appendix K: Calibration Check Raw Data

Final Cal Trial 1 200g on each

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
	1.496	0.816	1.056	1.067	1.032	1.163	0.643	2.661
	1.494	0.820	1.057	1.067	1.030	1.164	0.642	2.646
	1.513	0.821	1.053	1.066	1.029	1.162	0.640	2.641
	1.485	0.821	1.055	1.074	1.030	1.161	0.639	2.629
	1.483	0.824	1.056	1.070	1.030	1.160	0.638	2.616
	1.482	0.824	1.055	1.071	1.027	1.161	0.637	2.611
	1.496	0.827	1.057	1.071	1.033	1.157	0.637	2.614
	1.498	0.827	1.056	1.068	1.036	1.161	0.626	2.613
	1.493	0.825	1.056	1.068	1.030	1.160	0.624	2.634
	1.501	0.826	1.056	1.068	1.029	1.162	0.626	2.625
Average (V)	1.494	0.823	1.056	1.069	1.031	1.161	0.635	2.629
Mass (g)	185.6	208.3	194.0	198.4	192.1	195.1	180.2	177.0
Off (g)	14.4	8.3	6.0	1.6	7.9	4.9	19.8	23.0
% Off	7.2	4.1	3.0	0.8	4.0	2.4	9.9	11.5

Final Cal Trial 2 200g on each

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
	1.393	0.826	1.035	1.091	1.073	1.058	0.684	2.947
	1.390	0.825	1.036	1.089	1.075	1.057	0.684	2.978
	1.388	0.827	1.037	1.090	1.076	1.054	0.682	2.996
	1.390	0.824	1.033	1.087	1.077	1.053	0.685	2.986
	1.392	0.824	1.033	1.080	1.076	1.060	0.683	2.981
	1.392	0.826	1.030	1.082	1.076	1.055	0.682	2.979
	1.397	0.826	1.034	1.082	1.079	1.054	0.680	2.979
	1.397	0.828	1.033	1.084	1.075	1.050	0.677	2.958
	1.395	0.828	1.032	1.083	1.074	1.053	0.675	2.963
	1.393	0.829	1.026	1.082	1.081	1.053	0.676	2.952
Average (V)	1.393	0.826	1.033	1.085	1.076	1.055	0.681	2.972
Mass (g)	170.7	209.1	189.5	201.4	200.7	176.2	191.6	208.7
Off (g)	29.3	9.1	10.5	1.4	0.7	23.8	8.4	8.7
% Off	14.6	4.5	5.2	0.7	0.4	11.9	4.2	4.3

Final Cal Trial 3 200g on each

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
	1.403	0.799	1.017	1.148	1.015	0.987	0.661	2.924
	1.403	0.802	1.020	1.151	1.017	0.989	0.658	2.937
	1.407	0.801	1.018	1.153	1.016	0.986	0.664	2.912
	1.404	0.803	1.020	1.151	1.017	0.985	0.663	2.926
	1.403	0.802	1.022	1.151	1.016	0.982	0.662	2.894
	1.404	0.803	1.023	1.148	1.014	0.985	0.659	2.929
	1.401	0.804	1.021	1.146	1.014	0.984	0.662	2.935
	1.399	0.803	1.022	1.149	1.015	0.984	0.659	2.943
	1.407	0.804	1.018	1.145	1.014	0.985	0.662	2.923
	1.406	0.805	1.021	1.137	1.015	0.985	0.664	2.925
Average (V)	1.404	0.803	1.020	1.148	1.015	0.985	0.661	2.925
Mass (g)	172.3	203.7	187.1	213.0	189.2	164.0	186.8	204.2
Off (g)	27.7	3.7	12.9	13.0	10.8	36.0	13.2	4.2
% Off	13.8	1.9	6.5	6.5	5.4	18.0	6.6	2.1

Appendix K: Calibration Check Raw Data

Final Cal Trial 4 200g on each

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
	1.437	0.741	1.051	1.045	1.057	0.974	0.692	2.573
	1.437	0.742	1.053	1.044	1.055	0.970	0.693	2.577
	1.437	0.741	1.049	1.044	1.054	0.977	0.691	2.583
	1.437	0.741	1.051	1.042	1.053	0.976	0.691	2.577
	1.439	0.741	1.052	1.044	1.057	0.973	0.690	2.600
	1.435	0.742	1.049	1.043	1.056	0.971	0.686	2.603
	1.433	0.742	1.047	1.044	1.053	0.973	0.686	2.588
	1.433	0.741	1.047	1.039	1.050	0.974	0.690	2.599
	1.434	0.741	1.047	1.037	1.052	0.975	0.687	2.592
	1.435	0.742	1.047	1.041	1.053	0.975	0.685	2.606
Average (V)	1.436	0.741	1.049	1.042	1.054	0.974	0.689	2.590
Mass (g)	177.0	189.9	192.7	193.6	196.5	162.0	193.8	173.5
Off (g)	23.0	10.1	7.3	6.4	3.5	38.0	6.2	26.5
% Off	11.5	5.1	3.6	3.2	1.7	19.0	3.1	13.3

Final Cal Trial 5 200g on each

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
	1.374	0.668	1.015	1.141	1.016	1.130	0.759	2.046
	1.369	0.668	1.014	1.139	1.021	1.131	0.758	2.050
	1.371	0.666	1.014	1.141	1.017	1.127	0.760	2.040
	1.379	0.666	1.007	1.144	1.020	1.126	0.759	2.041
	1.375	0.668	1.014	1.143	1.020	1.126	0.756	2.044
	1.373	0.668	1.012	1.140	1.018	1.127	0.754	2.048
	1.373	0.669	1.013	1.140	1.018	1.128	0.756	2.040
	1.374	0.670	1.013	1.142	1.017	1.127	0.758	2.037
	1.370	0.670	1.013	1.142	1.019	1.127	0.758	2.041
	1.370	0.671	1.016	1.141	1.024	1.127	0.757	2.043
Average (V)	1.373	0.668	1.013	1.141	1.019	1.127	0.757	2.043
Mass (g)	167.8	173.4	185.7	211.8	189.8	189.1	210.7	127.8
Off (g)	32.2	26.6	14.3	11.8	10.2	10.9	10.7	72.2
% Off	16.1	13.3	7.2	5.9	5.1	5.5	5.4	36.1

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6	Channel 7	Channel 8
Ave mass (g)	174.7	196.9	189.8	203.7	193.7	177.3	192.6	178.2
Ave off (g)	25.3	11.6	10.2	6.9	6.6	22.7	11.7	26.9
Ave % off	12.7	5.8	5.1	3.4	3.3	11.4	5.8	13.5