To the Graduate Council:

I am submitting herewith a thesis written by Travis Mark Kimmins entitled "Design of an Automobile Passenger Weighing System." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

Frank Speckhart
Dr. Frank Speckhart, Major Professor

We have read this thesis
and recommend its acceptance:

John Landes

Joseph Boulet

Acceptance for the Council:

Anne Mayhew
Vice Provost and Dean of Graduate Studies

(Original signatures are on file with official student records.)

DESIGN OF AN AUTOMOBILE PASSENGER WEIGHING SYSTEM

A Thesis
Presented for the
Master of Science Degree
University of Tennessee, Knoxville

Travis Mark Kimmins
May 2003

Abstract

The purpose of this project was to design a low-cost alternative to the current design of a device that weighs the passengers of an automobile in order to determine if the passenger weight is sufficient to deploy an airbag. In addition to designing a system to weigh a passenger, the capability of determining the position of the occupant was also desirable.

Taking into account that seat deflection is a function of weight, linear potentiometers were used to measure deflection. Seven potentiometers were attached to a wire mesh located beneath the foam of the seat. Various weights were applied to locations on the seat and the voltages of the seven potentiometers were recorded. This data was then inserted into several different models in order to find a model that best determined the weight.

It was found that the front-back location of the weight could be accurately determined by a least squares curve fit of the potentiometer voltages. By knowing the location zone of the weight, it was found that the weight could be determined using a different linear curve fit for each particular zone. It was found that fewer than seven potentiometers were required to obtain satisfactory results.

Table of Contents

Chapter		Page
I	Background Information	1
II	Objective	3
III	Experimental Procedure	4
	Theory of Weighing	4
	Technique of Measuring Deflection	4
	Technique of Measuring Voltage and Data Acquisition	7
	Examination of Collected Voltage Data	7
	Rigid Beam Supported by Springs Model	12
	Simply Supported Beam Model	12
	First Order Least Squares Fit Using the Summation of the Center Three Potentiometer Voltages Model	15
	Least Squares Fit of W = C3*V3 + C4*V4 + C5*V5 + C8 Model	15
	Method of Determining the Position of the Weight Using Three Potentiometers	18
	Incremental Approach	21
IV	Results	23
	Number of Potentiometers Utilized	23
	Algorithm to Predict the Weight	23
	Weight Position Prediction Results	23
	Weight Prediction Results	26
V	Future Considerations	29
VI	Conclusions	31
References		33
Appendix		35
Vita		47

List of Tables

Table		Page
1	Effect of Disturbing a 70lb. Weight.....	11
2	Comparison of X and the Correlation Coefficient of a Least Squares Fit Using Equation 4.....	18
3	Comparison of X and the Correlation Coefficient of a Least Squares Fit Using Equation 5.....	20
4	Values of the Constants Used in Equation 7.....	25
5	Values of the Constants Used in Equation 8 for Each Value of X.....	26

List of Figures

Figure		Page
1	Potentiometer Circuit	5
2	Photograph of Potentiometers Connected to Wire Mesh Located Beneath the Car Seat Foam	6
3	Schematic of the 7-Potentiometer Arrangement	7
4	Schematic of the System Wiring	8
5	Effect of Measuring Voltage with Increasing and Decreasing Weight	9
6	Rigid Beam Supported by Two Springs	13
7	Measured Voltage vs. Voltage Predicted Using a Beam Supported by Two Springs Model	14
8	Simply Supported Beam with Symbols Shown	14
9	Measured Voltage vs. Voltage Predicted When Modeling the Seat as a Simply Supported Beam	16
10	Least Squares Fit of Data Taken Over the Entire Seating Range	17
11	Least Squares Fit of Equation 5	19
12	X Prediction by Equation 6 vs. Measured X	20
13	Algorithm Used to Determine the Constants in the Incremental Approach	22
14	Algorithm Used to Predict the Position and Weight of the Car Seat Occupant	24
15	Predicted Position of the Weight vs. Actual Position of the Weight for the Entire Seating Range	25
16	Predicted Weight vs. Actual Weight Over the Entire Seating Range Using the Incremental Approach to Predict the Weight	27
17	Predicted Weight vs. Actual Weight Over a Normal Seating Range Using the Incremental Approach to Predict the Weight	28
A.1	HPVEE Program Used to Read and Record Voltages, Weight, and Position of the Weight	36
A.2	Rigid Beam Supported by Springs Model Equation Derivation	37
A.3	MATLAB Program Used to Predict Weight Using W=m*(V1+V2+V3) + b	39
A.4	Program Used to Determine Weight Using a Least Squares Fit to Find the Constants in the Equation W = C3*V3 + C4*V4 + C5*V5 + C8	41
A.5	MATLAB Program Used to Predict the Weight Using W = C3*V3 + C4*V4 +C5*V5 +C8 Where the Constants Were Determined Using the Incremental Approach	44

List of Symbols

X	Distance in inches from the back edge of the seat to the center of mass of the applied weight
y	Vertical deflection of seat
Vn, V_n	Voltage reading of potentiometer n
Bn, B_n, Cn, C_n	Constant corresponding to potentiometer n used in weight prediction equations
Dn, D_n	Constant corresponding to potentiometer n used in X prediction equations
Wp, W_p	Predicted weight
Wm, W_m, Wa, W_a	Measured or actual weight
Xp, X_p	Predicted X
Xm, X_m, Xa, X_a	Measured or actual X
X0, X_0	Distance in inches from back edge of the seat to a potentiometer
K	Spring stiffness
R	Constant that is proportional to the inverse of the spring stiffness
Cp, C_p	Constant used in the simply supported beam model
m	Slope of a line
b	Y-intercept value
*	Indicates multiplication
$\vec{p}$	Indicates that p is a vector

Chapter I - Background Information

As of October 1, 1999, there have been 84 confirmed child fatalities due to airbag deployment (NHTSA, 1999). The U.S. Federal Motor Vehicle Safety Standard Number 208 requires that by 2004, 35%, and by 2006, 100% of all automobiles sold in the United States must have a means of determining the weight of a car passenger occupant (Delphi, 2000).

There currently is a device that predicts the passenger weight in several makes of cars. The device, invented by Dr. Frank Speckhart, uses a bladder filled with silicon in conjunction with a pressure transducer (US Patent No. 5,975,568). When a weight is applied to the silicon-filled bladder, the change in pressure is used to predict the weight of the passenger. There are several advantages of this design. The device is very thin, measuring approximately 0.33 inches thick. Also, the device is easily installed underneath the seat cushioning. The disadvantages of this product are the fact that it is considered too expensive to produce and that it cannot determine the position of the passenger among other problems. The product costs more than $10.00 to manufacture.

Due to the high cost of the current weight-predicting device, a new design is being researched. There are several design requirements for this new design. First, and perhaps most importantly, is that the manufacturing costs have to be low. Another important design requirement is that the device has to be easily installed. If the device cannot be easily and quickly installed, more man-hours have to be used and this will drive up the total cost. Also, if the device is difficult to install, there is a greater probability that it will be installed incorrectly. If the device were installed incorrectly, it would clearly become an enormous liability. The device must also be reliable. If this device fails in any way resulting in a personal injury, lawsuits would be likely. Finally, the device must be able to predict the weight of the occupant, with limited accuracy, within a certain range. The range of weight where the device needs to be most accurate is the passenger weight where the automobile makers deem that it

is unsafe for the airbag to deploy. Airbag deployment is unsafe when the passenger is of small stature. One attractive feature of the design is to be able to determine the position of the passenger. If the passenger is too far forward on the seat during an accident, airbag deployment could result in a greater injury. This is not a requirement stated in the U.S. Federal Motor Vehicle Safety Standard Number 208, but to be able to approximate the occupant position would be clearly beneficial.

Chapter II - Objective

The main objective of this project was to demonstrate a method capable of determining the amount of weight placed on a passenger car seat. Once a method to predict the weight is found, this technology could then be used to devise a means of predicting the weight of a car passenger occupant. The weight only has to be accurately predicted near the "target weight." The "target weight" is the weight that car manufacturers determine is the minimum allowable weight for airbag deployment. For this project, a "target weight" of 60 pounds was assumed. Another objective, although not required by U.S. Federal Motor Vehicle Safety Standard Number 208, was to be able to predict the location of the weight on the car seat.

Chapter III - Experimental Procedure

Theory of Weighing

The main objective of this project was to determine the weight of an automobile occupant. It was believed that a relationship between the deflection of the seat and the weight on the seat existed. Linear potentiometers use the circuit shown in Figure 1 to give a voltage output that is based on linear motion. It was decided that linear potentiometers could therefore be used to give a voltage that could be used to determine the weight. Ultimately, potentiometers were chosen due to the fact that they can relate displacement and voltage, and are relatively low cost.

Technique of Measuring Deflection

Once potentiometers were chosen, there had to be a means in which to attach them to the seat system. The potentiometers were mounted to a beam and connected to a spring mesh found beneath the foam of the seat as shown in Figure 2. As a weight was applied to the seat, the foam pressed the wire mesh, which then caused the wipers on the potentiometers to move downward, leading to a change in voltage. An arbitrary number of potentiometers, seven, were used. It is likely that less than seven potentiometers could be used to predict the weight, but since the number of potentiometers needed was unknown, a large number of potentiometers were attached to the seat. The potentiometer wipers could travel up to two inches and the resistance varied from 0 to 10 kilo-ohms. For a supply voltage of 5.0 VDC, the potentiometers gave a resolution of 2.5V/in. The potentiometers had a linear output and were designed to be used in audio electronic equipment. The potentiometers were purchased for $3.00 each. If this technology were used in production, custom designed potentiometers costing much less would be used. Figure 3 shows the arrangement of the seven potentiometers and the numbering scheme used in this project. The values, V1 through V7 refer to the voltages of the respective potentiometers.

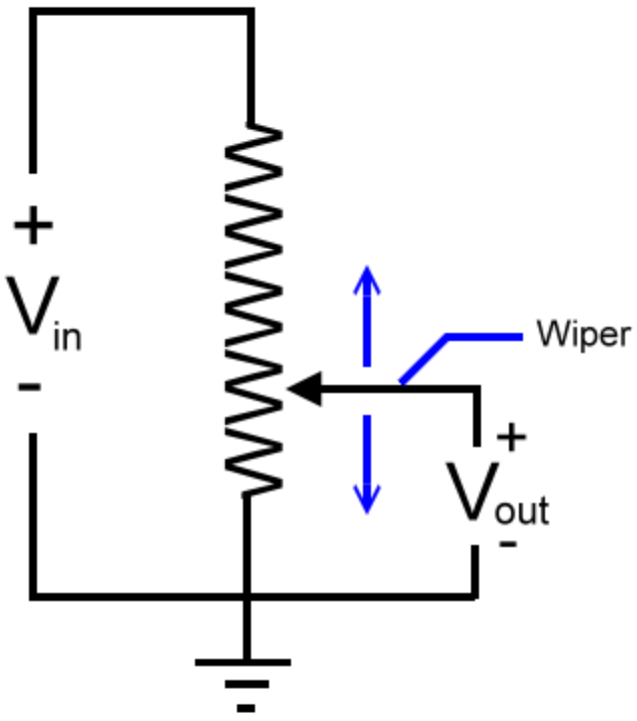


Figure 1 - Potentiometer Circuit

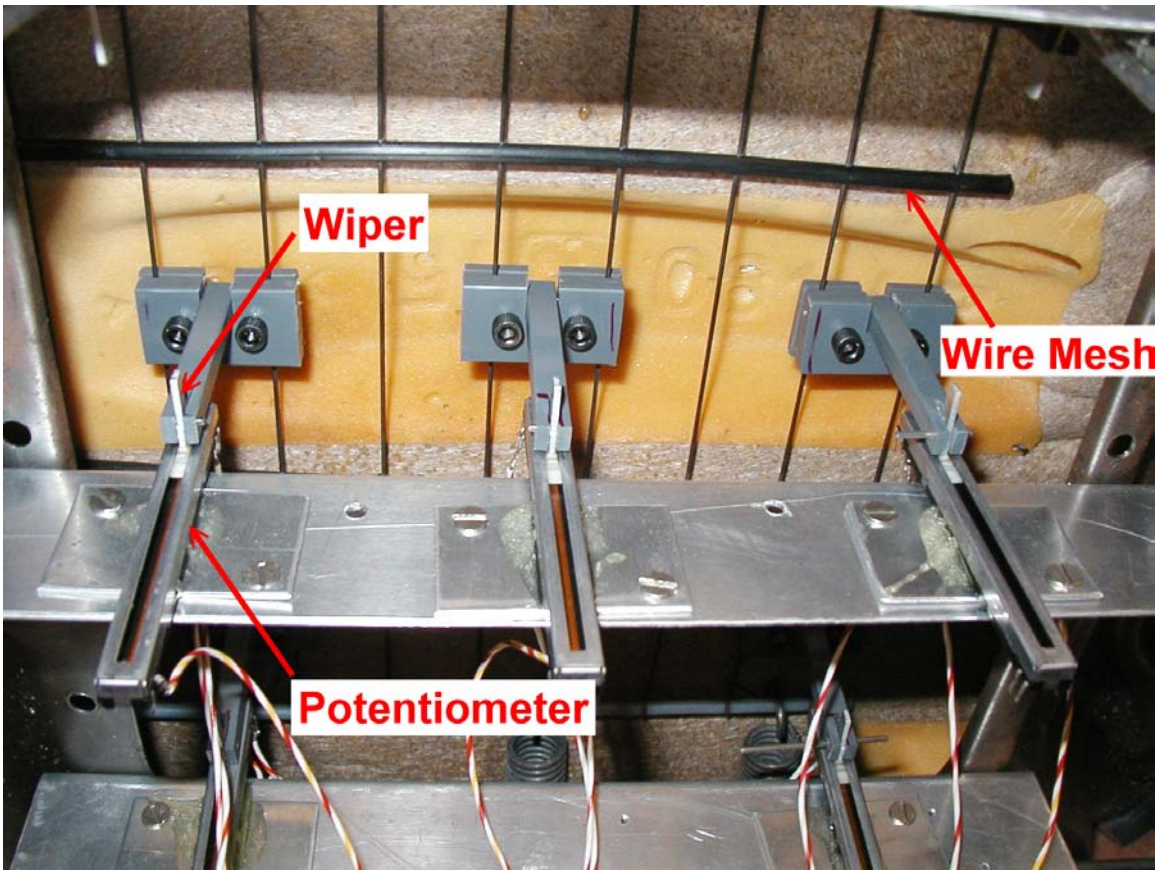


Figure 2 - Photograph of Potentiometers Connected to Wire Mesh Located Beneath the Car Seat Foam

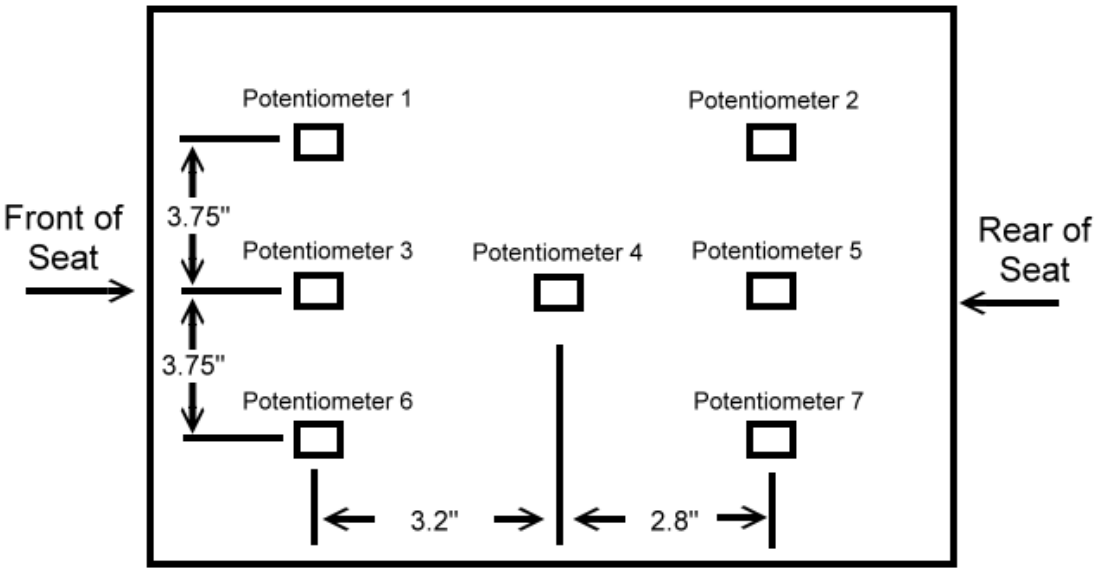


Figure 3 - Schematic of the 7-Potentiometer Arrangement

Technique of Measuring Voltage and Data Acquisition

The system was wired as shown in Figure 4. Varying weights ranging from 25 to 86 pounds were placed on the car seat at different distances from the back edge of the seat. The amount of weight, the distance from the center of the weight to the back edge of the seat and the voltage readings from the seven potentiometers were recorded utilizing a program that was written with HPVEE software. HPVEE is graphical programming software. The program used to record the data can be found in Figure A.1. Measurements were taken by applying various increasing increments of weight going from 25 to 86 pounds. Once the weight total reached 86 pounds, measurements were made as the weight decreased from 86 to 25 pounds. The weight was removed and reapplied in the same manner at different locations.

Examination of Collected Voltage Data

Once the voltage and weight data were recorded, the data was examined in order to find any potential problems in the data collection method. An interesting trend was noted. Figure 5 shows the voltage reading of the center potentiometer

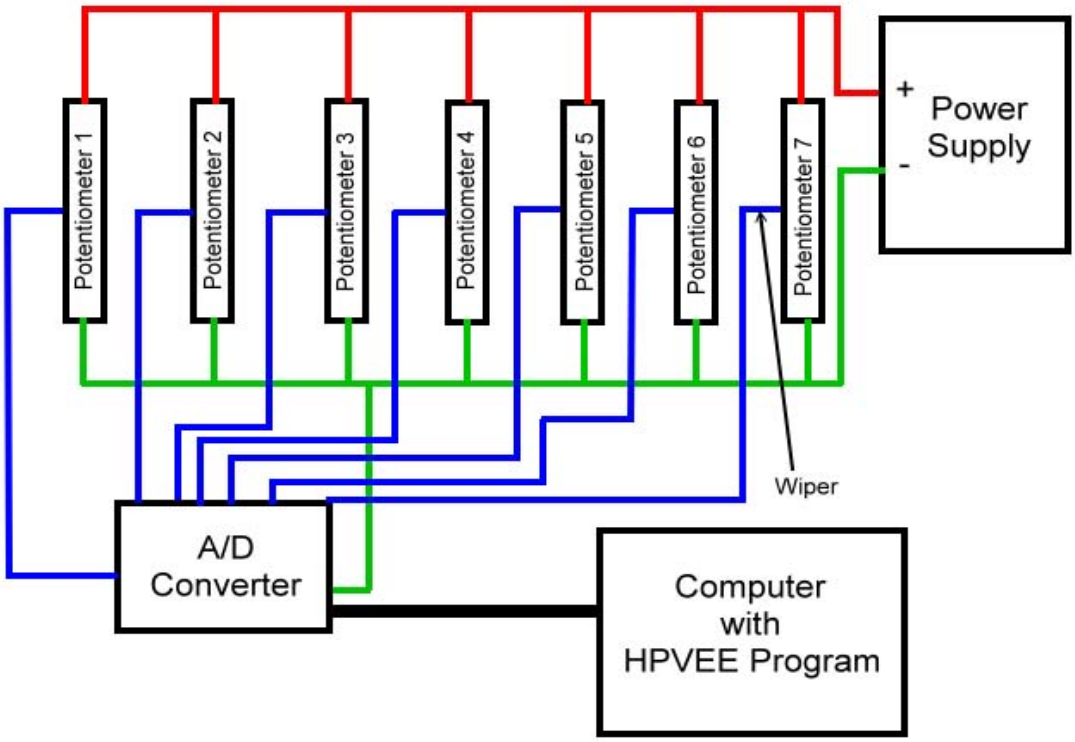


Figure 4 - Schematic of the System Wiring

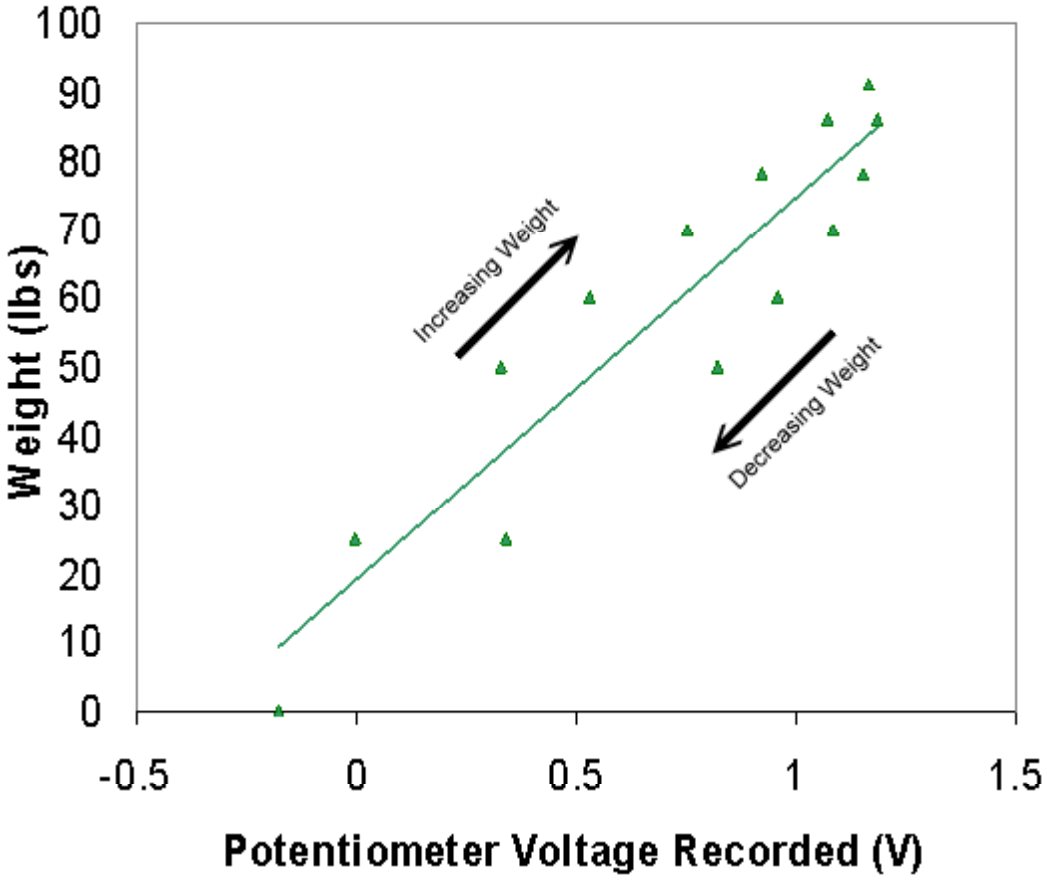


Figure 5 - Effect of Measuring Voltage with Increasing and Decreasing Weight

versus the applied weight at 6 inches from the back edge of the seat. Figure 5 showed that when the weight was increased, it followed a different path than when the weight was decreased. Another interesting thing to note in Figure 5 is the fact that at the same voltage, the weight could vary by approximately 28 pounds. It was identified that this problem would have to be solved before the weight could be accurately predicted.

A test was performed to determine what caused this problem. A weight of 70 pounds was placed on the seat and the distance from the mesh to a reference point on the frame of the seat was measured using a caliper. The weight was then disturbed in different manners and the distance was measured. Table 1 shows the results. It was interesting to note that when the weight was first disturbed, the change in distance from the wire mesh to the reference point on the frame was considerable (0.138 and 0.085 inches). After being disturbed several times though, the change in distance from the wire mesh to the reference point on the frame became insignificant (0.02 inches). From Table 1, it was determined that there was a source of friction that kept the seat from deflecting as far as it should. Once the weight was "shaken," the source of friction was reduced and the seat finally settled near one position. Since it was shown that there was a friction source that tainted the data, new data was taken where the weight was disturbed before measurements were taken in order to have the best possible data. Disturbing the weight when taking data measurements was deemed acceptable due to the fact that a passenger will not sit stationary in the seat.

Upon examining the data, it was noticed that the three center potentiometers, the potentiometers numbered 3, 4, and 5, showed the greatest voltage change. Therefore it was decided that these three potentiometers would be used to determine the weight if possible. If it were found later that three potentiometers would not be sufficient, more potentiometers would then be used.

Table 1 - Effect of Disturbing a 70lb. Weight

Disturbance	Distance to Reference Point (in.)	Change in Distance to Reference Point
None	2.780	
Weight Lifted, Then Replaced	2.775	0.005
Weight Pressed Down Hard, Then Released	2.637	0.138
Weight Pressed Down Hard, Then Released	2.552	0.085
Weight Rapidly Shaken	2.562	-0.010
Weight Pressed Down Hard, Then Released	2.550	0.012
Weight Rapidly Shaken	2.530	0.020
Weight Lifted, Then Replaced	2.521	0.009

Rigid Beam Supported by Springs Model

It was theorized that if the seat were properly modeled, the weight predictions should work over the entire seating range. The first attempt at modeling the seat was to model the seat as a rigid beam supported by two springs as shown in Figure 6. The equation for this system was found to be:

$$V_p = W * \left[R_1 * \left(\frac{-X}{L} + 1 + \frac{X_0 * X}{L^2} - \frac{X_0}{L} \right) + R_2 * \left(\frac{X * X_0}{L^2} \right) \right] \qquad \text{(Eq. 1)}$$

The value of X0 is the distance to the potentiometer. The value of L is the length of the "beam." The value of X refers to the center of mass of the applied weight. The constants, R1 and R2, are proportional to the inverses of the spring stiffnesses, K1 and K2. A least squares fit was used to solve for the constants, R1 and R2, in Equation 1. The derivation of Equation 1 can be found in Figure A.2. A plot of the measured voltage versus the voltage predicted using Equation 1 is found in Figure 7. Figure 7 does follow a linear trend, but there is too much scatter in order to accurately predict the weight. The maximum absolute difference between the measured voltage and the predicted voltage was 0.411 volts or approximately 28% of the predicted voltage range.

Simply Supported Beam Model

Next, it was attempted to model the seat as a simply supported beam as shown in Figure 8. The equations used to model in this matter were:

If X0 < X

$$V_p = C_p * \left[\left(\frac{W * b * X_0}{L} \right) * \left(L^2 - b^2 - {X_0}^2 \right) \right] \qquad \text{(Eq. 2)}$$

If X0 > X

$$V_p = C_p * \left(\frac{W * b}{L} \right) * \left(\frac{L}{b} * \left(X_0 - X \right)^3 - {X_0}^3 + \left(L^2 - b^2 \right) * X_0 \right) \qquad \text{(Eq. 3)}$$

It should be noted that these voltage-predicting equations are proportional to the simply supported beam deflection equations. In order to solve for the constant, Cp, in

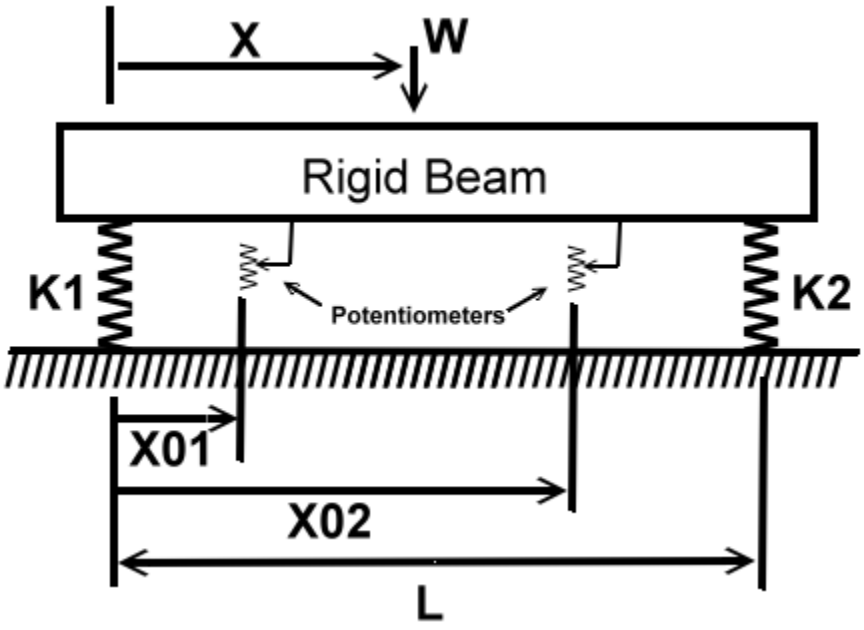


Figure 6 - Rigid Beam Supported by Two Springs

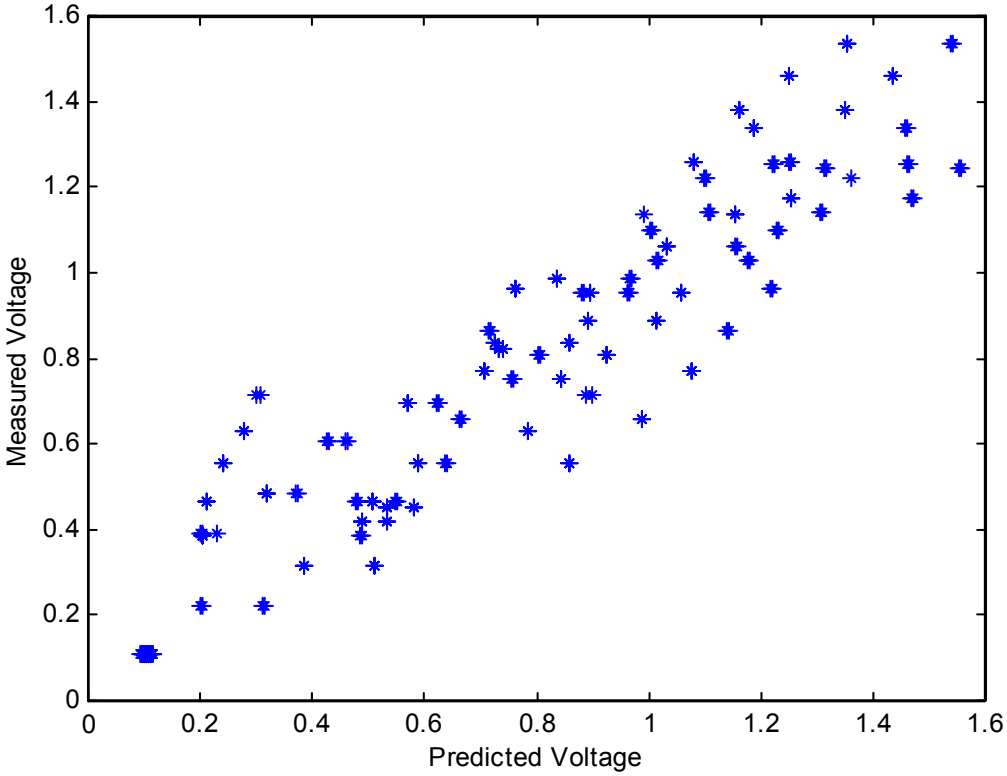


Figure 7 - Measured Voltage vs. Voltage Predicted Using a Beam Supported by Two Springs Model

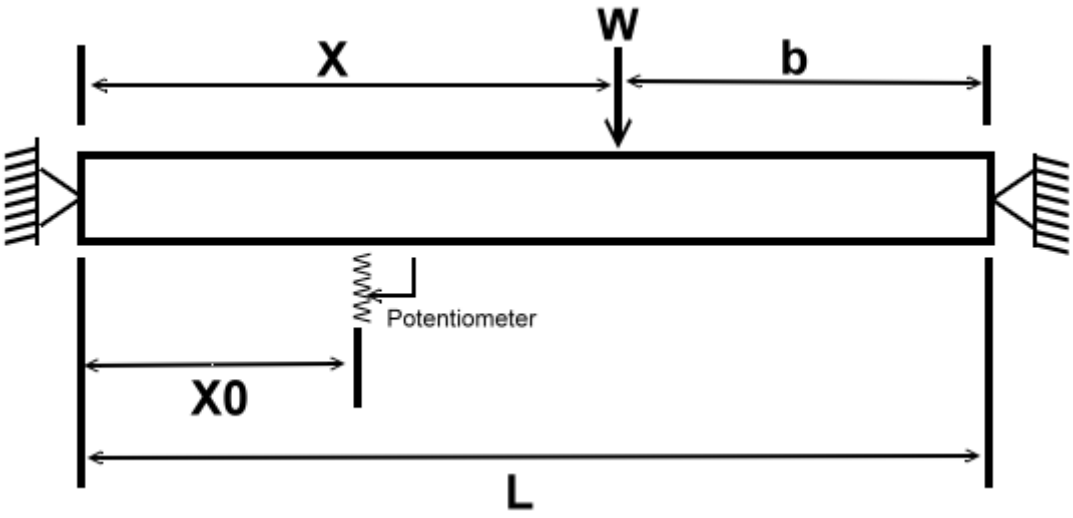


Figure 8 - Simply Supported Beam with Symbols Shown

Equations 2 and 3, a least squares approach was used and the results can be found in Figure 9. In Figure 9, it is noted that there is a linear trend but there is too much data scatter. This model also did not accurately model the seat.

First Order Least Squares Fit Using the Summation of the Center Three Potentiometer Voltages Model

Next, it was attempted to model the seat using the summation of the voltages of the three center potentiometers as shown in the following equation:

$$W = m * \left(\vec{V}_3 + \vec{V}_4 + \vec{V}_5\right) + b \qquad \text{(Eq. 4)}$$

The values V3 through V5 refer to the voltages of the three center potentiometers. A least squares approach was utilized to solve for the constants, m and b using a program written in MATLAB (see Figure A.3). A variable, X, was used to indicate the distance from the back edge of the seat to the center of mass of the weight. Using all values of X, or the entire seating range, weight versus the summation of the voltages was plotted as shown in Figure 10. The correlation coefficient was 0.41075. Obviously, this value had to be improved in order to predict the weight more accurately. Next, the least squares fit was performed using different ranges of X. When different ranges of X were used, the correlation coefficient showed improvement with the exception being at high values of X, which corresponded to the weight being applied to the front edge of the seat. Table 2 shows the correlation coefficients that were found and the corresponding ranges of X. This method had the obvious problem of weighting all of the potentiometers the same.

Least Squares Fit of W = C3*V3 + C4*V4 + C5*V5 + C8 Model

It was noted that when using Equation 4 to model the system that the voltage readings of the 3 potentiometers were all weighted equally. It was determined that weighting the voltages would improve the weight approximations. A new equation was used to predict the weight:

$$W = C_3 * \vec{V}_3 + C_4 * \vec{V}_4 + C_5 * \vec{V}_5 + C_8 \qquad \text{(Eq. 5)}$$

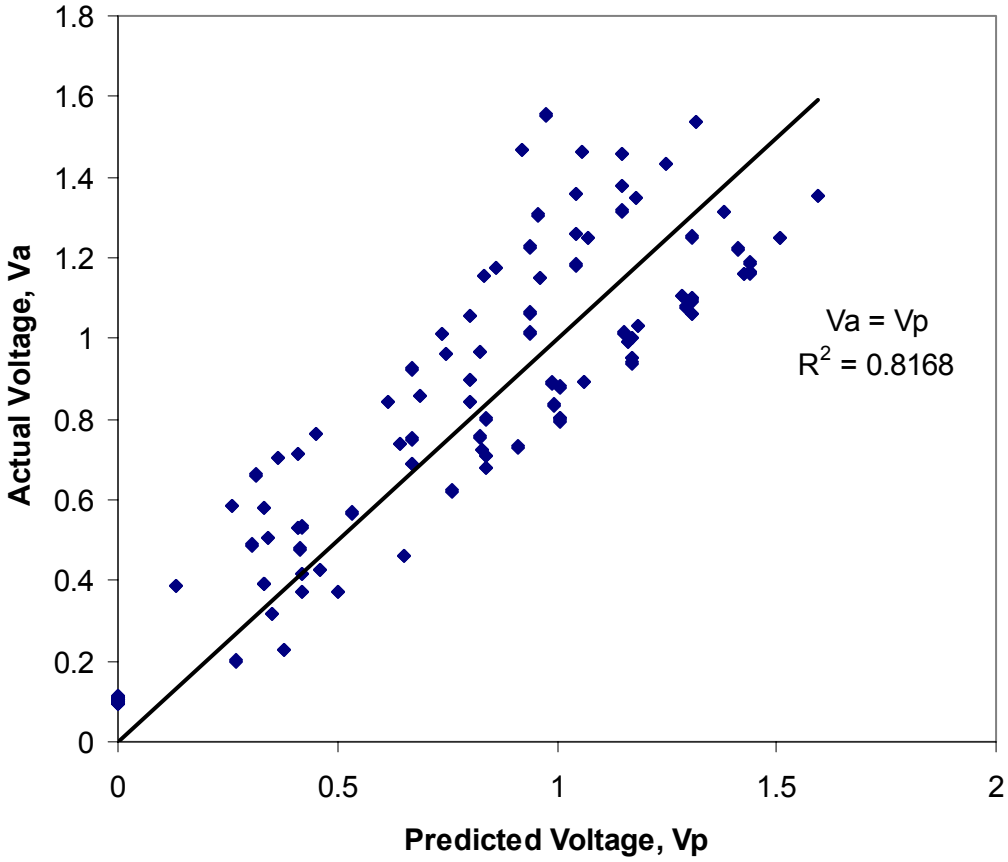


Figure 9 - Measured Voltage vs. Voltage Predicted When Modeling the Seat as a Simply Supported Beam

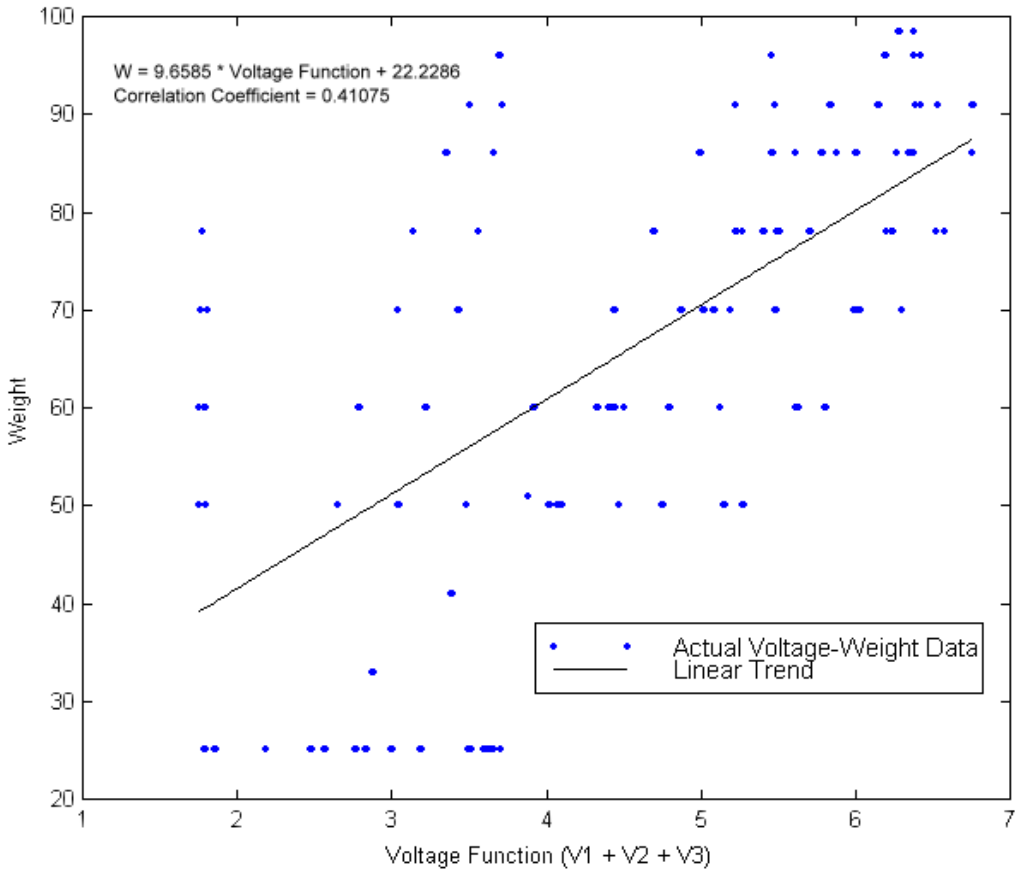


Figure 10 - Least Squares Fit of Data Taken Over the Entire Seating Range

Table 2 - Comparison of X and the Correlation Coefficient of a Least Squares Fit Using Equation 4

Range of X (inches)	Correlation Coefficient
9-11	0.83609
11-13	0.82866
13-15	0.75770
15-17	0.24076
9-13	0.84255
11-15	0.74349
13-17	0.35812

The constants, C3, C4, C5 and C8, were found using a least squares fit. Figure 11 shows data points of the actual weight versus the weight predicted using Equation 5 over the entire seating range. The correlation coefficient was 0.6631. The program used to find the constants can be found on Figure A.4. The program was also run using different ranges of seating position to see how the accuracy could be improved. Table 3 contains the results. Table 3 shows that if the distance from the back edge of the seat to the center of mass is known, the weight can be accurately determined.

Method of Determining the Position of the Weight Using Three Potentiometers

If the position of the weight, X, is known, then it was previously found that the weight could be accurately predicted. The position of the weight was modeled using the equation:

$$X_p = D_3 * \vec{V}_3 + D_4 * \vec{V}_4 + D_5 * \vec{V}_5 + D_8 \qquad \text{(Eq. 6)}$$

The constants, D3, D4, D5 and D8 were found using a least squares approach. Figure 12 shows the results. It was noted that X could be predicted fairly accurately using

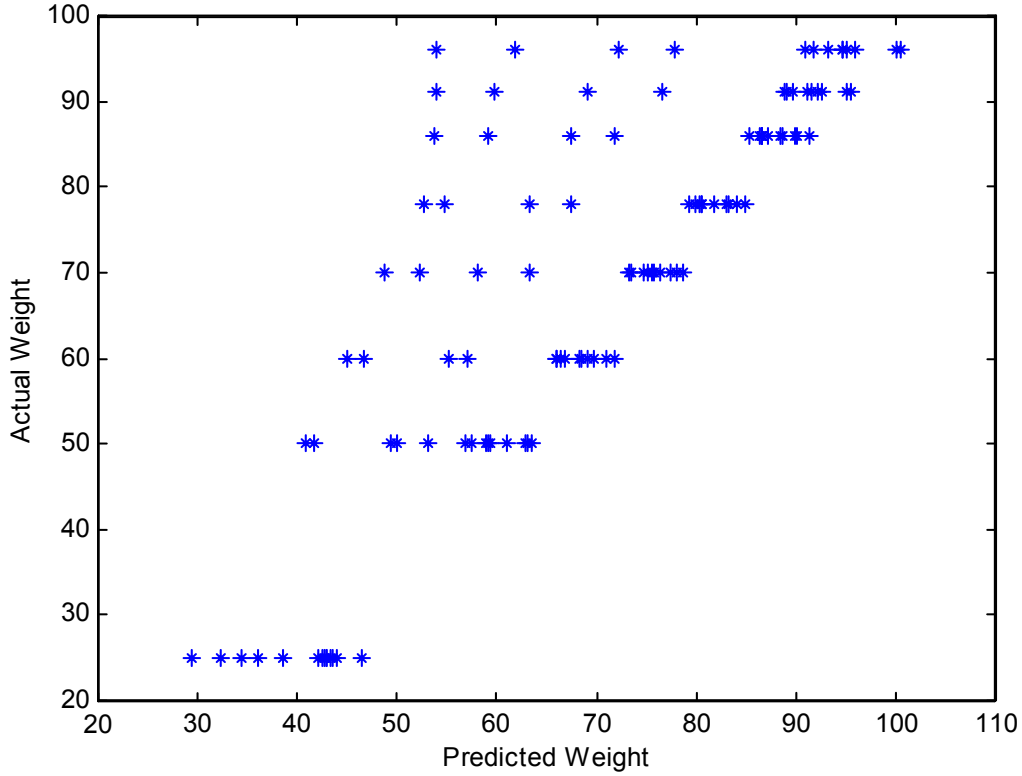


Figure 11 - Least Squares Fit of Equation 5

Table 3 - Comparison of X and the Correlation Coefficient of a Least Squares Fit Using Equation 5

Range of X (inches)	Correlation Coefficient
9-11	0.9968
11-13	0.9949
13-15	0.9926
15-17	0.9801
9-13	0.9962
11-15	0.9908
13-17	0.9789

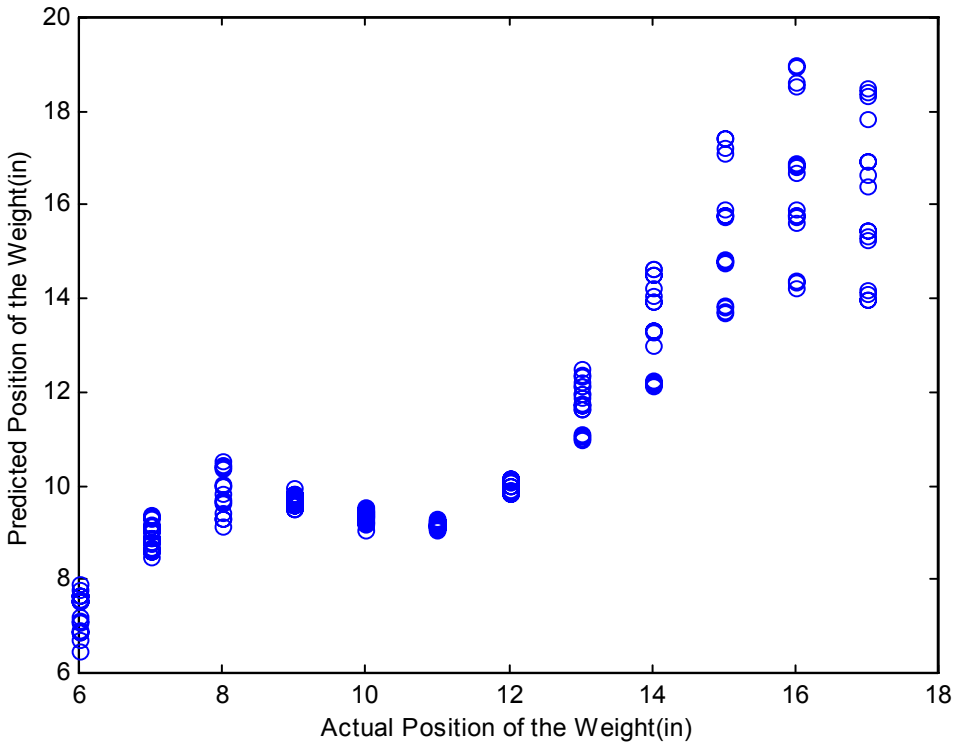


Figure 12 - X Prediction by Equation 6 vs. Measured X

Figure 12. The average error was found to be 1.3348 inches. The maximum error was found to be 3.0083 inches.

Incremental Approach

Using Equation 5, the weight was accurately predicted on paper, but in practice, the weight prediction was as far as 30 pounds off. It was decided that the inaccuracy occurred due to the fact that some of the constants were as large as 230. When a 0.05-volt uncertainty occurred, the weight predicted would change by 11.5 pounds. A program was written in MATLAB to solve this problem (see Figure A.5). In the program, the values of C were forced to fall between an arbitrary range of -60 and 60. The optimal values of the constants were found using a trial and error approach by using four nested for-loops over different ranges of seating position. The algorithm used in this approach is shown in Figure 13. There were two methods used to determine the best weight prediction constants. In one method, the best weight prediction constants were found by minimizing the maximum error when the weight predicted vector of values was subtracted from the actual weight vector of values. In the other method, the best constants were found by minimizing the sum of the errors squared. The second method proved to give better weight predictions. It should be noted that an increment of three was used for the constants. It was found that there was little improvement gained from using an increment of one. Therefore, an increment of three was used in order to keep the computing time shorter. Even with an increment of three being used, the number of iterations that the program in Figure 13 had to go through was 2,825,761.

For C_3 = -60 to 60 in increments of 3

  For C_4 = -60 to 60 in increments of 3

    For C_5 = -60 to 60 in increments of 3

      For C_8 = -60 to 60 in increments of 3

        Weight Predicted $= C_3 * \vec{V}_3 + C_4 * \vec{V}_4 + C_5 * \vec{V}_5 + C_8$

        If (Weight Predicted is better than any previous weight predicted) Then

          Store Constants C_3, C_4, C_5, and C_8

        End If

      Next C_8

    Next C_5

  Next C_4

Next C_3

Figure 13 - Algorithm Used to Determine the Constants in the Incremental Approach

Chapter IV - Results

Number of Potentiometers Utilized

It was determined that the three center potentiometers, potentiometers 3, 4, and 5, would be used to predict the position of the weight and the amount of weight. Three potentiometers were chosen after identifying that the weight could be predicted accurately and consistently. Obviously if more potentiometers were used, the weight and position of the weight could be more accurately predicted. However, it was deemed that three potentiometers were the absolute minimum number of potentiometers that could be used to fit the design requirements.

Algorithm to Predict the Weight

The algorithm used to predict the weight is shown in Figure 14. Initially, the three center potentiometer voltages must be read by a processor. These three voltages are then used to predict the position of the weight. Once the region where the weight is located is known, the weight is predicted using an equation that is predetermined specifically for that region.

Weight Position Prediction Results

The final equation used to predict the position of the weight from the back edge of the seat, Xp, is shown below:

$$X_p = D_3 * V_3 + D_4 * V_4 + D_5 * V_5 + D_8 \qquad \text{(Eq. 7)}$$

The values of the constants, D3, D4, D5 and D8, were found using a least squares fit and are found in Table 4. Figure 15 shows the predicted position of the weight versus the actual position of the weight for the entire seating range. The maximum error was 3.0083 inches. The average error was 1.3348 inches. Over the normal seating range, where the center of mass is between 6 and 14 inches from the back edge of the seat, the maximum error was 2.5663 inches. The average error in the normal seating range was 1.3516 inches.

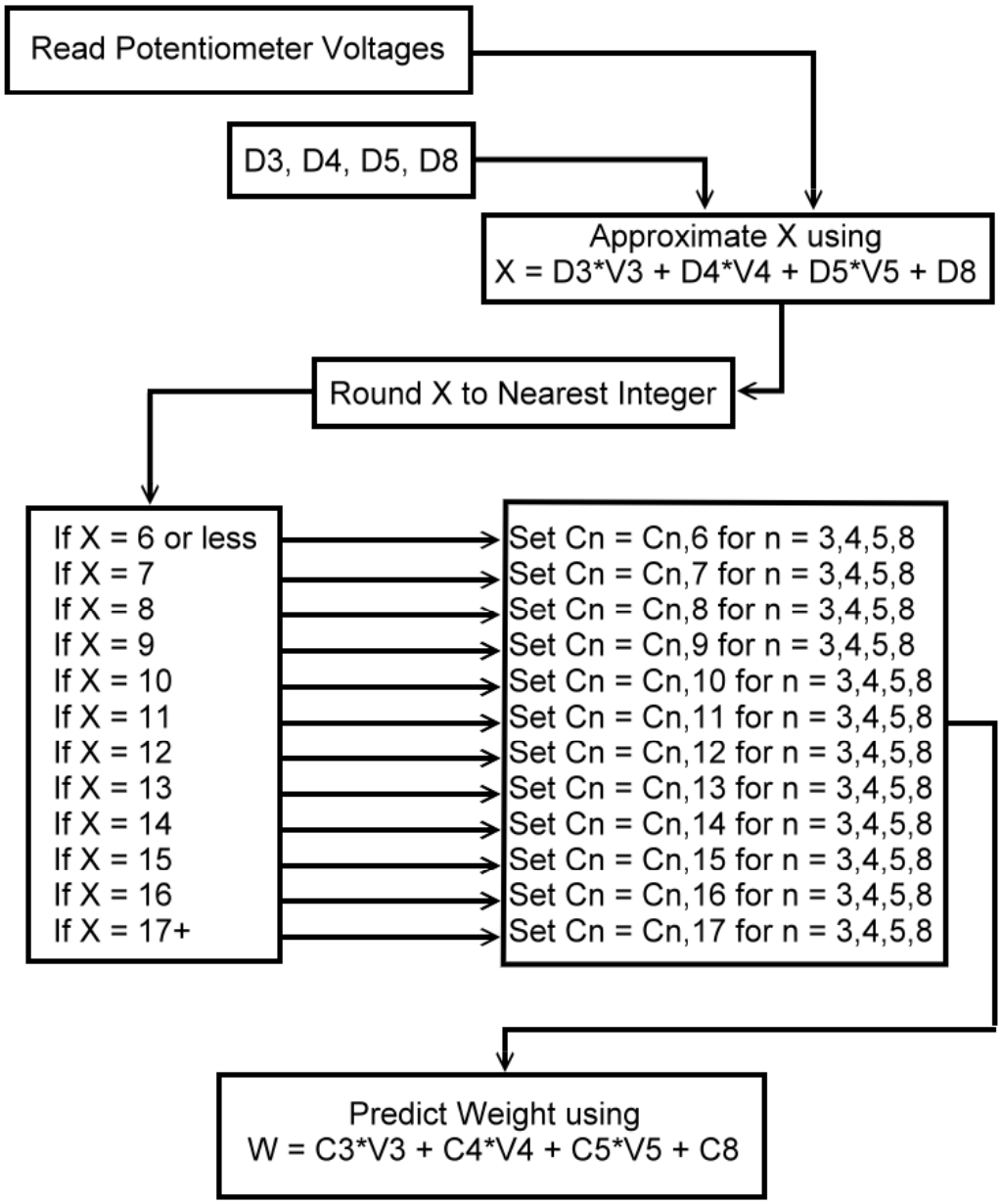


Figure 14 - Algorithm Used to Predict the Position and Weight of the Car Seat Occupant

Table 4 - Values of the Constants Used in Equation 7

D3	-8.15
D4	-5.699
D5	19.81
D8	7.365

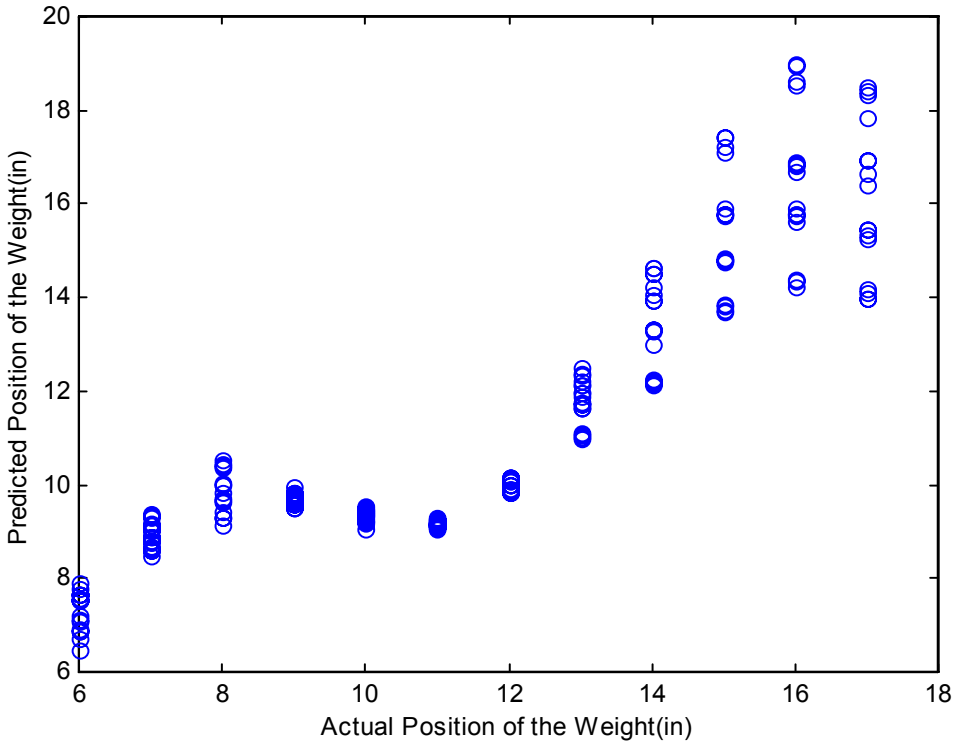


Figure 15 - Predicted Position of the Weight vs. Actual Position of the Weight for the Entire Seating Range

Weight Prediction Results

The final equation used to predict the weight for a given position of the weight, i, is shown below:

$$W_{p,i} = C_{3,i} * V_3 + C_{4,i} * V_4 + C_{5,i} * V_5 + C_{8,i} \quad \text{(Eq. 8)}$$

The values of the constants, C3, C4, C5, and C8, were found using the incremental approach previously described. Table 5 shows the values of the constants for a given value of X. One thing to note about the constants in Table 5 is that all of the values are multiples of 3. An increment of 3 was used in the incremental approach in order to save computing time. It was found that using an increment of 1 provided an insignificant increase in accuracy. Figure 16 shows the weight predicted using the incremental approach versus the actual weight over the entire seating range. The maximum relative error was found to be 7.26 pounds over the entire seating range. The average error over the entire seating range was found to be 2.03 pounds. Figure 17 shows the weight predicted versus the actual weight over a normal seating range where the center of mass of the weight was between 6 and 14 inches from the back edge of the seat. Over a normal seating range, the maximum error was 4.93 pounds while the average error was 1.594 pounds.

Table 5 - Values of Constants Used in Equation 8 For Each Value of X

X	C3	C4	C5	C8
8 or less	27	60	-54	-24
9	-36	57	36	-33
10	12	-6	57	-30
11	18	-12	60	-33
12	12	3	51	-39
13	9	3	57	-42
14	3	0	60	-33
15	-3	-6	60	-15
16 or greater	-45	18	60	-6

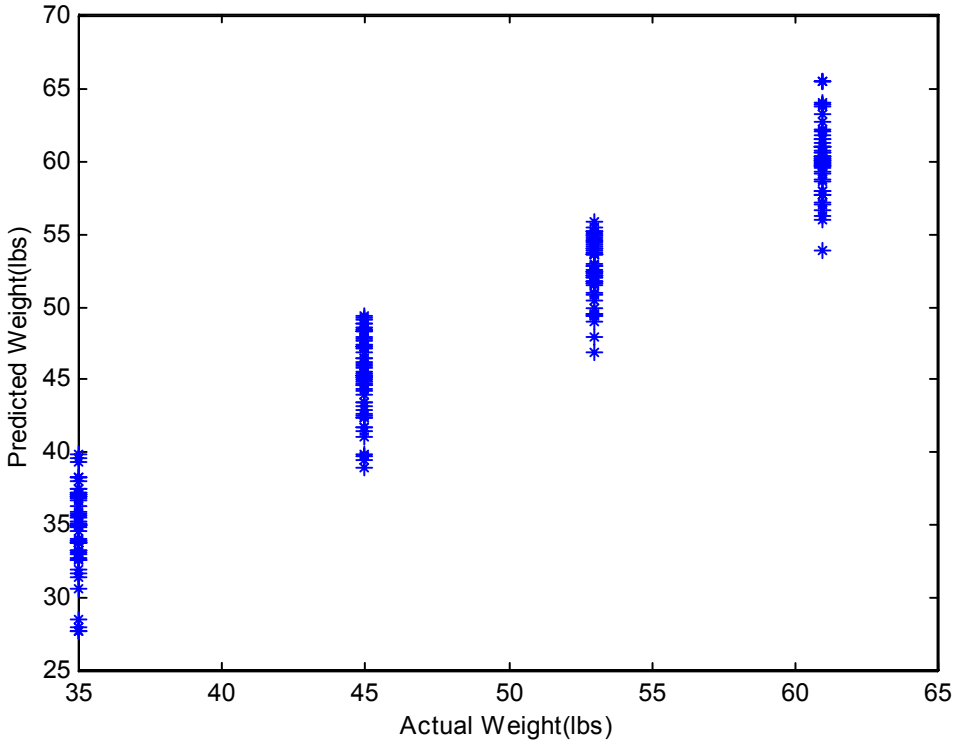


Figure 16 - Predicted Weight vs. Actual Weight Over the Entire Seating Range Using the Incremental Approach to Predict the Weight

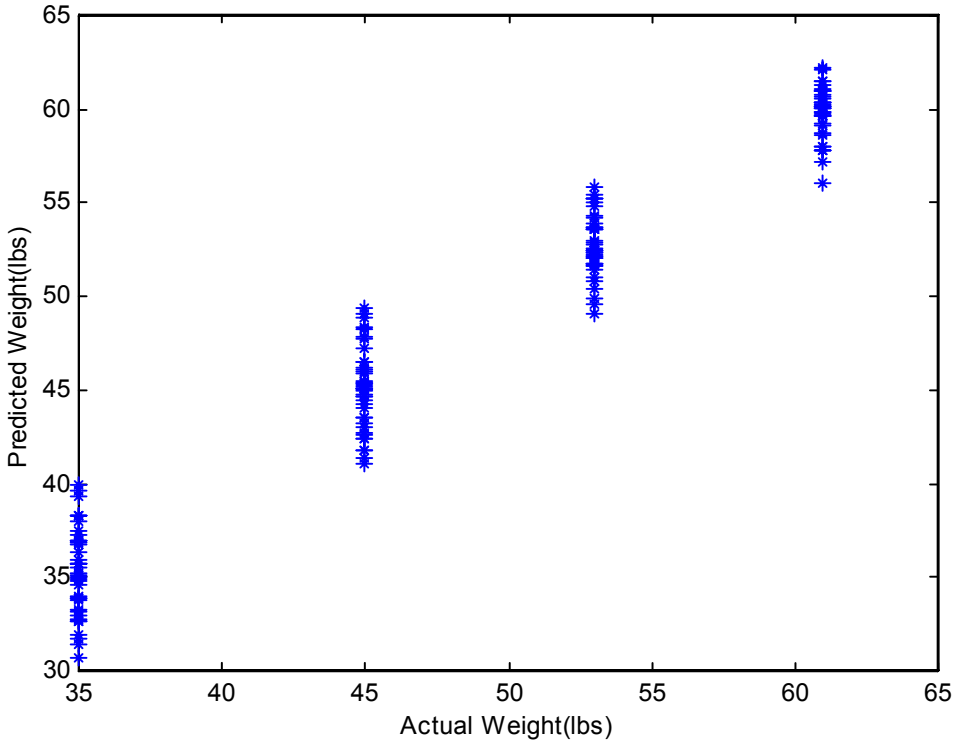


Figure 17 - Predicted Weight vs. Actual Weight Over a Normal Seating Range Using the Incremental Approach to Predict the Weight

Chapter V - Future Considerations

The purpose of this project was to demonstrate a method to determine the amount of weight placed on a car seat. The goal was by no means to make a final product that was ready for industry. With that in mind, there are several things that should be considered if this design were to be improved.

In this project, a means of determining the distance from the back edge of the seat to the center of mass of the weight was demonstrated. In a future design, a similar method could be used to determine the distance that the weight is off-center. This could be useful for two reasons. The weight predictions would be improved for the cases where the weight is off-center. Also, for automobiles with side-impact airbags, the distance between the passenger and the side airbag could be used to determine how hard to deploy the side airbag.

The prototype that was designed was bolted to the frame of the seat. A future design should have a convenient means of attaching the device to many different kinds of seats. Most likely, there would have to be several designs in order to attach the device to the many different types of automobile seats.

The potentiometers were attached to the wire mesh found beneath the foam. Not all automobile seats have a wire mesh to attach to. Therefore, spring loaded potentiometers that press up against the foam of the seat should be considered.

When determining the constants to predict the amount of weight, all of the data was used and weighted equally. The effect of weighting the data near the "target weight" more heavily should be investigated. By weighting those data points, the weight prediction near the "target weight," which is the most important weight to be accurate near, could be improved.

The method of predicting the position of the center of mass worked effectively but could be improved. Using a first order least squares fit, the average error was 1.3348 inches while the maximum error was 3.0083 inches. Other equations could be considered in predicting the position of the center of mass in order to lessen the error.

One negative aspect of this design was the fact that three separate voltages were needed in order to predict the weight. In the future, ways of reducing the number of separate voltages needed to predict the weight should be examined. Perhaps this could be performed by using non-linear potentiometers. Another possible way of reducing the number of separate voltages needed would be to wire the system in a different manner. Ideally, one voltage could be used to predict the weight.

In this project, circular weights were used. The prototype at some point should be tested using human subjects. It is possible that with a different weight distribution that minor changes would have to be made in the weight predicting approach.

The device predicts the amount of static weight on the automobile seat. The device should be tested to see the effect of placing a dynamic weight on the automobile seat. It was assumed that over a period of time that the average weight prediction would be close to the static weight prediction, but this should be tested and verified.

The prototype that was designed was considered a success in that it could approximate the front to back position of the weight and the amount of weight. Also, this product should be able to be manufactured for a significantly lower cost than the previous design. As indicated by these future considerations, there still needs to be more development time before this technology can be instituted into automobiles.

Chapter VI - Conclusions

It was found that the amount of weight set on the seat could be determined by measuring the displacement. The displacement was measured at three places using linear potentiometers. More potentiometers could be used to increase the accuracy of the weight prediction and the position of the weight prediction.

The position of the weight, Xp, could be found using the following equation:

$$X_p = D_3 * V_3 + D_4 * V_4 + D_5 * V_5 + D_8 \quad \text{(Eq. 9)}$$

The constants, D3, D4, D5, and D8 were found using a least squares fit technique. The values of V3, V4, and V5 were the voltages corresponding to three potentiometers located in a line down the center of the seat.

It was found that if the approximate position of the weight was known, the amount of weight on the car seat could be determined. The equation used to predict the weight for a given position of the weight, i, was as follows:

$$W_{p,i} = C_{3,i} * V_3 + C_{4,i} * V_4 + C_{5,i} * V_5 + C_{8,i} \quad \text{(Eq. 10)}$$

The constants C3, C4, C5, and C8, for each position of the weight were found by using what was termed the "incremental approach." Using a least squares technique to find the constants returned constants that could be as large as 230. The problem with this is that when there is even a 0.05-volt uncertainty, the weight prediction would increase by 11.5 pounds. Therefore, a new method of determining the constants was used, the incremental approach. A program was written where the constants were allowed to vary from -60 to +60 in small increments. Essentially what the program did was use a trial-and-error approach to find a combination of the constants that best predicted the weight.

In conclusion, it was found that by using three potentiometers, the distance from the back edge of the seat to the center of mass of the weight as well as the amount of weight on a car seat could be determined by using a minimum of three

potentiometers. The prediction of the distance from the back edge of the seat to the center of the mass of the weight over the entire seating range had an average error of 1.3348 inches. The maximum error in the prediction of the position of the weight over the entire seating range was 3.0083 inches. The weight prediction over the entire seating range had an average error of 2.0263 pounds. The maximum amount the weight prediction was off over the entire seating range was 7.2575 pounds. Over a normal seating range, where the center of mass of the weight was between 6 and 14 inches from the back edge of the seat, the average error in the weight prediction was 1.594 pounds. Also, in the normal seating range, the maximum error in the weight prediction was 4.9297 pounds. The reason that the weight prediction was much better over the normal seating range as opposed to the entire seating range was the fact that when the weight was applied near the front edge of the seat, the three potentiometers showed a very small voltage change. Overall, it was decided that this technology could be used to approximate the position of the passenger. Once the approximate position of the passenger is known, the weight of the passenger can be accurately determined.

References

Delphi. 16 Oct. 2000. Delphi. 7 Nov. 2002.
<http://delphi.com/news/pressReleases/pr221-10162000>.

NHTSA. 2 Nov. 1999. NHTSA. 21 Aug. 2002
<http://www.nhtsa.dot.gov/airbags/factsheets/numbers.html>.

Appendix

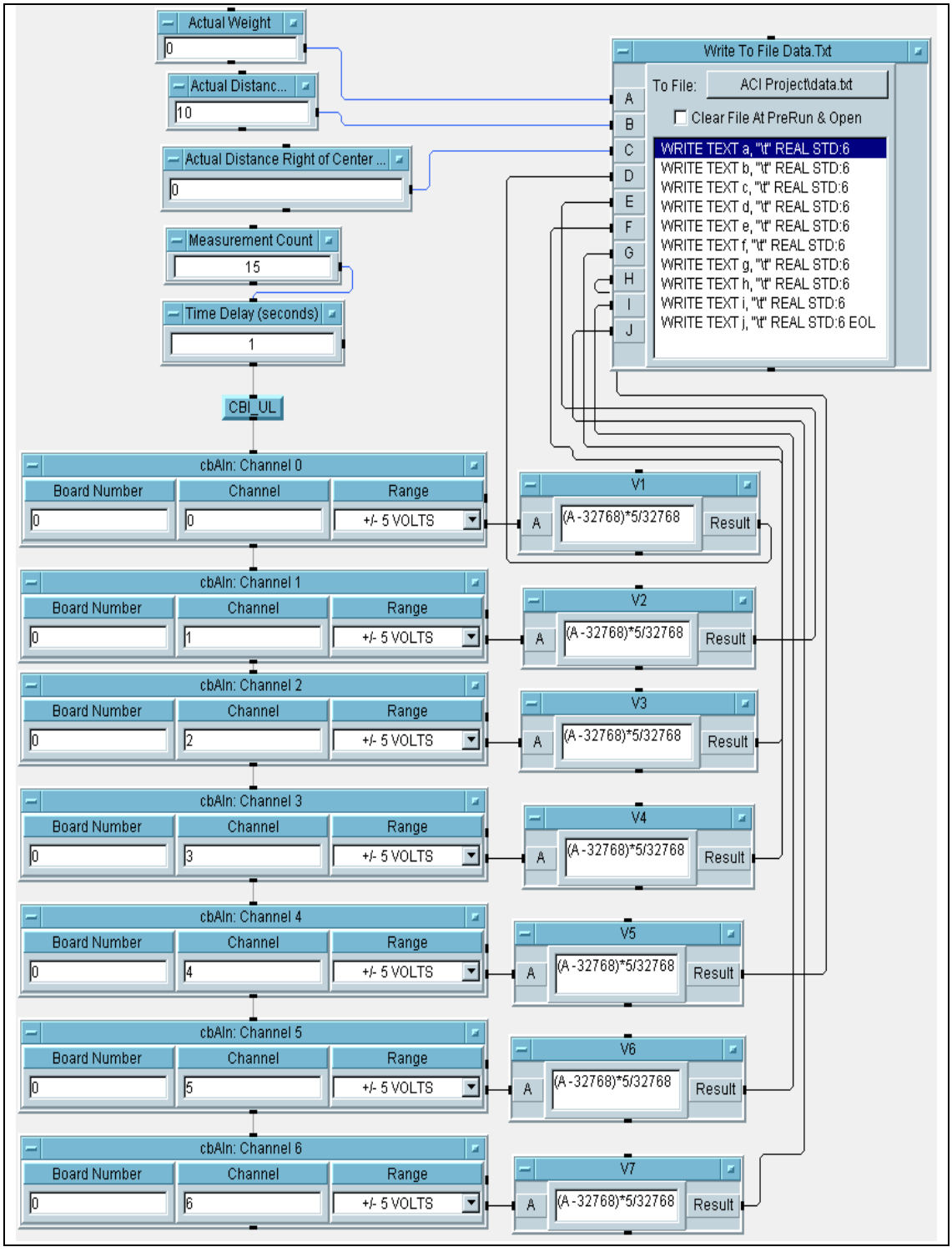


Figure A.1 - HPVEE Program Used to Read and Record Voltages, Weight, and Position of the Weight

Mathematical Model of the seat assuming the mesh is modeled as a stiff beam supported by two springs.

The variables:
X1 = the distance the back spring deflects
X2 = the distance the front spring deflects
X0 = the distance to a potentiometer measuring deflection
y = deflection at a potentiometer
k1 = back spring stiffness (non-linear and unknown)
k2 = front spring stiffness (" ")
F = Force applied (weight)
X = distance from the back edge that the weight is applied
L = Length of the "beam"
y1 = deflection at potentiometer 1

$\Sigma F=0$

$$k_1 \cdot X_1 + k_2 \cdot X_2 = F \qquad (1)$$

Summing the moments around the back edge:

$$L \cdot k_2 \cdot X_2 = F \cdot X \qquad (2)$$

Combining equations 1 and 2 yields:

$$k_1 \cdot X_1 + \frac{F \cdot X}{L} = F \qquad (3)$$

Solving for X1:

$$k_1 \cdot X_1 + \frac{F \cdot X}{L} = F \text{ solve}, X_1 \rightarrow -F \cdot \frac{(X - L)}{(L \cdot k_1)} \qquad (4)$$

Solving for X2:

$$k_1 \cdot X_1 + k_2 \cdot X_2 = F \text{ solve}, X_2 \rightarrow \frac{-(k_1 \cdot X_1 - F)}{k_2}$$

$$\frac{-k_1 \cdot \left[-F \cdot \frac{(X - L)}{(L \cdot k_1)} \right] + F}{k_2} = X_2 \text{ solve}, X_2 \rightarrow F \cdot \frac{X}{(L \cdot k_2)} \qquad (5)$$

Figure A.2 - Rigid Beam Supported by Springs Model Equation Derivation

Writing an equation for y:

y = x1 + y with respect to x1 (see variables above to clarify)

$y = X_1 + \theta \cdot X_0$ For small values of θ

$$\theta = \frac{X_2 - X_1}{L}$$

$$y = -F \cdot \frac{(X - L)}{(L \cdot k_1)} + \frac{\left[F \cdot \frac{X}{(L \cdot k_2)}\right] - \left[-F \cdot \frac{(X - L)}{(L \cdot k_1)}\right]}{L} \cdot X_0 \qquad (6)$$

$$y = F \cdot \frac{\left(-L \cdot k_2 \cdot X + L^2 \cdot k_2 + X_0 \cdot X \cdot k_1 + X_0 \cdot k_2 \cdot X - X_0 \cdot L \cdot k_2\right)}{\left(L^2 \cdot k_2 \cdot k_1\right)} \qquad (7)$$

$$k_2 = F \cdot \frac{\left(-L \cdot X + L^2 + X_0 \cdot X - X_0 \cdot L\right)}{\left(L^2 \cdot k_1\right)} + F \cdot X_0 \cdot \frac{X}{\left(L^2 \cdot k_2\right)}$$

$$\frac{y}{F} = \left(\frac{1}{k_1}\right) \cdot \left(\frac{-X}{L} + 1 + \frac{X_0 \cdot X}{L^2} - \frac{X_0}{L}\right) + \left(\frac{1}{k_2}\right) \cdot \left(\frac{X \cdot X_0}{L^2}\right) \qquad (8)$$

Voltage is proportional to deflection. Therefore:

$$V = C_p \cdot F \cdot \left[\left(\frac{1}{k_1}\right) \cdot \left(\frac{-X}{L} + 1 + \frac{X_0 \cdot X}{L^2} - \frac{X_0}{L}\right) + \left(\frac{1}{k_2}\right) \cdot \left(\frac{X \cdot X_0}{L^2}\right)\right] \qquad (9)$$

Figure A.2 - Continued

```
%Program by: Travis Kimmins
%April 26, 2002
%Modified:May 7, 2002
%Modified to allow certain parts of the text file to be filtered
%out
clear all

%This program reads points from a data file.
%The 3 values of voltages are added together.  A least squares fit
%is made and the correlation coefficient is calculated.

%The restrictions as to which data to use will be placed here
Xmin = 0;
Xmax = 25;
Wmin = 20;
Wmax = 100;

%Read in the data from a text file:
FID = fopen('data.txt','rt')
A = fscanf(FID,'%c');
A=str2num(A);
n = length(A(:,1))  %Length of the array (n also is equal to the
%number of points in each V array)

%Filter out the unwanted x values:
counter = 1;
for i = 1:n
   if (A(i,2)>=Xmin & A(i,2)<=Xmax)
      Temp(counter,:)=A(i,:);
      counter = counter + 1;
   end
end
A=Temp;
counter = 1;
%Filter out the unwanted weight values:
for i = 1:length(A)
   if (A(i,1)>=Wmin & A(i,1)<=Wmax)
      Temp2(counter,:)=A(i,:);
      counter = counter + 1;
   end
end
```

Figure A.3 - MATLAB Program Used to Predict Weight Using W=m*(V1+V2+V3) + b

```
A = Temp2;


W = A(:,1);
X = A(:,2);      %Position of the occupant
V1 = A(:,3);
V2 = A(:,4);
V3 = A(:,5);
n = length(A(:,1));      %Length of the weight array


Rsquared = 0;    %Coefficient of determination initialized

Vt = A.*V1 + B.*V2 + C.*V3;     %Sum of the resistances
% y = mx + b
m = (n*sum(Vt.*W)-sum(Vt)*sum(W))./(n*sum(Vt.*Vt)-(sum(Vt))^2);
b = (sum(W)./n) - m.*(sum(Vt)./n);

%Correlation coefficient calculation:
r=(n*sum(Vt.*W)-(sum(Vt).*sum(W)))/(((n*sum(Vt.*Vt)-
(sum(Vt)^2))^.5).*((n*sum(W.*W)-sum(W)^2)^.5));

Rsquared = r.^2;

%Final Result Plot
plot(Vtkeep,W,'.')
x=[min(Vtkeep):.01:max(Vtkeep)];
y=mkeep.*x+bkeep;
hold on
plot(x,y,'k')
xlabel('Voltage Function')
ylabel('Weight')
title('Weight vs Voltage data with best least squares fit')

fprintf('m: %10.9g\n',m)
fprintf('b: %10.9g\n',b)
fprintf('R^2: %10.9g\n',Rsquared)

%Use the built in Matlab functions to double check the result:
[P, S] = polyfit(x,y,1)
```

Figure A.3 - Continued

```
%Program by: Travis Kimmins
%July 30, 2002
%BestWeightFactors.m


clear all

%This program reads points from a data file.
%The 3 values are multiplied by constants(in other words,
%weighted)
%and added together.  The best values for the constants are found
%using least squares

%The restrictions as to which data to use will be placed here
Xmin = 13;
Xmax = 17;
Wmin = 20;
Wmax = 100;


%Read in the data from a text file created in excel:
FID = fopen('\data.txt','rt')
A = fscanf(FID,'%c');
A=str2num(A);
n = length(A(:,1))  %Length of the array (n also is equal to the
%number of points in each V array)

%Filter unwanted X data
counter = 1;
for i = 1:n
   if (A(i,2)>=Xmin & A(i,2)<=Xmax)
      Temp(counter,:)=A(i,:);
      counter = counter + 1;
   end
end
A=Temp;
counter = 1;

%Filter unwanted W data
for i = 1:length(A)
   if (A(i,1)>=Wmin & A(i,1)<=Wmax)
      Temp2(counter,:)=A(i,:);
      counter = counter + 1;
   end
end
A = Temp2;
```

Figure A.4 - Program Used to Determine Weight Using a Least Squares Fit to Find the Constants in the Equation W = C3*V3 + C4*V4 + C5*V5 + C8

```
W = A(:,1);
X = A(:,2);     %Position of the occupant
V3 = A(:,6);
V4 = A(:,7);
V5 = A(:,8);
n = length(A(:,1));     %Have to redefine this value


%There are 4 equations and 4 unknowns.  The equations will be put
into the form:
%  [Z]*[C] = [B]

Z(1,1) = sum(V3.^2);
Z(1,2) = sum(V3.*V4);
Z(1,3) = sum(V3.*V5);
Z(1,4) = sum(V3);

Z(2,1) = sum(V3.*V4);
Z(2,2) = sum(V4.*V4);
Z(2,3) = sum(V4.*V5);
Z(2,4) = sum(V4);

Z(3,1) = sum(V3.*V5);
Z(3,2) = sum(V4.*V5);
Z(3,3) = sum(V5.*V5);
Z(3,4) = sum(V5);

Z(4,1) = sum(V3);
Z(4,2) = sum(V4);
Z(4,3) = sum(V5);
Z(4,4) = n;
clear B
B(1,1) = sum(W.*V3);
B(2,1) = sum(W.*V4);
B(3,1) = sum(W.*V5);
B(4,1) = sum(W);

C = inv(Z)*B
C3 = C(1);
C4 = C(2);
C5 = C(3);
C8 = C(4);

Wpredicted = C3.*V3 + C4.*V4 + C5.*V5 + C8;
ErrorSum=sum(Wpredicted-W);
```

Figure A.4 - Continued

```
WAvg=sum(W)/n;
Sr = sum((W-Wpredicted).^2);
St = (sum((W-WAvg).^2));
rsquared = (St-Sr)/St



AvgError = (1/n)*(sum(abs(Wpredicted-W)))
MaxError = max( abs(Wpredicted-W) )

t = 1:1:n;

plot(Wpredicted, W,'*')
xlabel('Predicted Weight')
ylabel('Actual Weight')
```

Figure A.4 - Continued

```
%Program by: Travis Kimmins
%September 20, 2002

clear all

%This program reads points from a data file.
%These Voltages are then multiplied by constants.
%The constants are varied using for-loops.


%The restrictions as to which data to use will be placed here
Xmin = 10;
Xmax = 11;
Wmin = 20;
Wmax = 100;


%Read in the data from a text file created in excel:
FID = fopen('\data.txt','rt')
A = fscanf(FID,'%c');
A=str2num(A);
n = length(A(:,1))  %Length of the array (n also is equal to the
%number of points in each V array)


%Filter unwanted X data
counter = 1;
for i = 1:n
   if (A(i,2)>=Xmin & A(i,2)<=Xmax)
      Temp(counter,:)=A(i,:);
      counter = counter + 1;
   end
end
A=Temp;
counter = 1;

%Filter unwanted W data
for i = 1:length(A)
   if (A(i,1)>=Wmin & A(i,1)<=Wmax)
      Temp2(counter,:)=A(i,:);
      counter = counter + 1;
   end
end
A = Temp2;
```

Figure A.5 - MATLAB Program Used to Predict the Weight Using W = C3*V3 + C4*V4 +C5*V5 +C8 Where the Constants Were Determined Using the Incremental Approach

```
W = A(:,1);
X = A(:,2);     %Position of the occupant
V1 = A(:,4);
V2 = A(:,5);
V3 = A(:,6);
V4 = A(:,7);
V5 = A(:,8);
V6 = A(:,9);
V7 = A(:,10);


n = length(A(:,1));     %Have to redefine this value

%Ranges of constants, put "0" for max and min if you do not
%want to use that potentiometer's constant.
C1min = 0;
C1max = 0;
C2min = 0;
C2max = 0;
C3min = -60;
C3max = 60;
C4min = -60;
C4max = 60;
C5min = -60;
C5max = 60;
C6min = 0;
C6max = 0;
C7min = 0;
C7max = 0;
C8min = -60;
C8max = 60;
%The C increments used in the for-loops:
inc1 = 3;
inc2 = 3;
inc3 = 3;
inc4 = 3;
inc5 = 3;
inc6 = 3;
inc7 = 3;
inc8 = 3;

i = 0;
MaxError = 10000000000;
iter=0;
```

Figure A.5 - Continued

```
for C1 = C1min:inc1:C1max
    for C2 = C2min:inc2:C2max
        for C3 = C3min:inc3:C3max
            for C4 = C4min:inc4:C4max
                for C5 = C5min:inc5:C5max
                    for C6 = C6min:inc6:C6max
                        for C7 = C7min:inc7:C7max
                            for C8 = C8min:inc8:C8max
                                iter=iter+1;
                                Wp = C1.*V1 + C2.*V2 + C3.*V3 +
                              C4.*V4 + C5.*V5 + C6.*V6 + C7.*V7 +
                              C8;
                                MaxErrorTemp = sum((Wp-W).^2);
                                if MaxErrorTemp < MaxError
                                    MaxError = MaxErrorTemp;
                                    Wkeep = Wp;
                                    C1Keep = C1;
                                    C2Keep = C2;
                                    C3Keep = C3;
                                    C4Keep = C4;
                                    C5Keep = C5;
                                    C6Keep = C6;
                                    C7Keep = C7;
                                    C8Keep = C8;
                                end
                            end
                        end
                    end
                end
            end
        end
    end
end
C1 = C1Keep
C2 = C2Keep
C3 = C3Keep
C4 = C4Keep
C5 = C5Keep
C6 = C6Keep
C7 = C7Keep
C8 = C8Keep
clear Wp
Wp = C1.*V1 + C2.*V2 + C3.*V3 + C4.*V4 + C5.*V5 + C6.*V6 + C7.*V7
+ C8;
t=1:1:n;
plot(t,Wp,'*',    t,W,'^')
legend('Wpredicted','Wmeasured')
```

Figure A.5 - Continued

Vita

Travis Kimmins was born in West Palm Beach, Florida on August 6, 1979. He attended Lantana Elementary School in Lantana, Florida before moving to Dandridge, Tennessee where he attended Maury Middle School. He then went to Jefferson County High School, and graduated in 1997. From there he attended Carson Newman College in Jefferson City, Tennessee for two years before transferring to the University of Tennessee in Knoxville, Tennessee where he received a B.S. in Mechanical Engineering in 2001.

Currently, Travis is pursuing his Master of Science degree in Mechanical Engineering at the University of Tennessee, Knoxville.