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Lab Report 2: 11-05
Lab Section Tues Morning

The Effect of Pressure on Elasticity

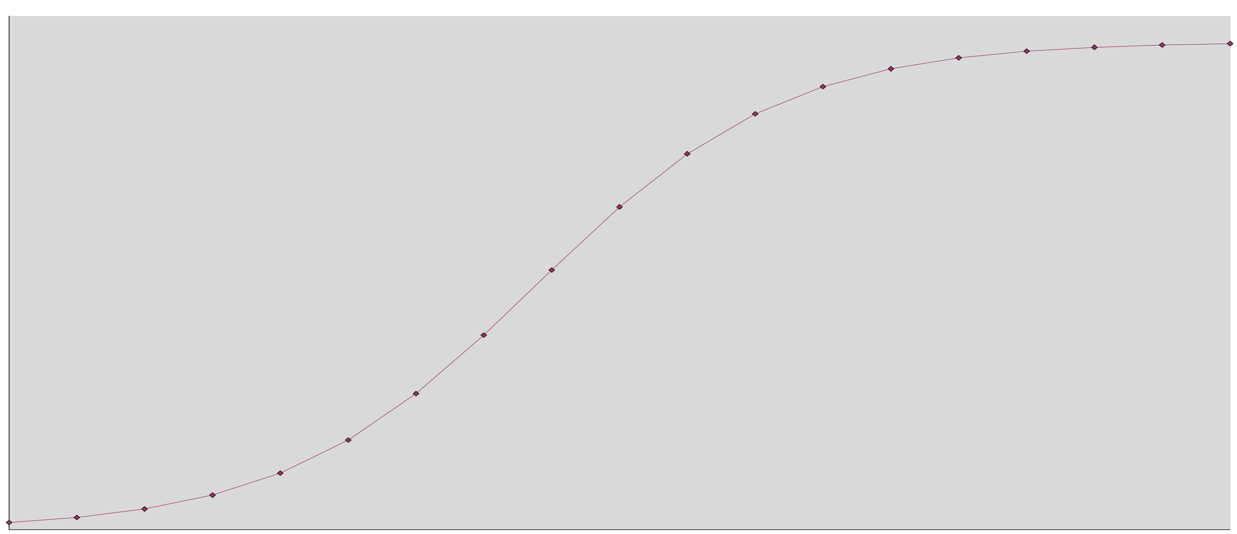
Introduction:

An inflated ball is an important part of many sports. The finely tuned reflexes and skills of the athletes is based on the assumption that the ball will behave the exact same way every time. We decided to investigate what affect the inflation level has on the behavior of a ball, what type of relationship exists between the pressure level and the elasticity of the bounce, and if this relationship is consistent for different types of balls. We will be comparing the return height after a bounce with the pressure, for a basketball and a soccer ball.

Predictions:

We knew that the bounce would not be perfectly elastic, due partially to the deformation of the ball upon collision with the floor as well as friction with the air. Initially, we had expected the return height to appear level off (such as a logarithm) as the pressure increased, but later decided that the behavior would probably be more accurately described by a logistic representation. With the logistic model, we reasoned that if the ball started out at approximately zero pressure, then initially increases in pressure would not increase the bounce height very much. As more and more pressure was added, the graph would appear to increase at a much higher rate, until it would level out as in the logarithmic model. Here is a general graph to better illustrate this particular model:

Sample Logistic Equation



Description of Experiments:

We used a standard basketball and standard soccer ball for our experiments. We went to the stairway balcony located in "The Cube" entrance to Coffman Union. We set up a video camera to record the ball's entire flight. We used an automotive pressure gauge and a bicycle tire pump to inflate, deflate, and measure the pressure in our ball. We used a roll-up tape measure to record the height of the balcony above the ground. We recorded the pressures of the balls in order, to facilitate the paring up of the data during analysis. The overall procedure was fairly straightforward, where we would record the pressure, start the camera recording, drop the ball, and stop the camera after the ball had reached its maximum bounce. We used the graphical analysis software on the lab computers to record the bounce height for each trial. We then transposed the data into a spreadsheet program for analysis and for production of the charts.

Data:

Basketball:

Raw data:

Pressure	Bounce Height	Energy Retained (%)
3.5	1.96	0.39
4	1.91	0.37
4.5	2.01	0.4
5	2.2	0.43
5.5	2.34	0.46
6	2.37	0.47
6.5	2.4	0.47
7	2.4	0.47
7.5	2.61	0.51
8.5	2.64	0.52
9	2.69	0.53
9.5	2.86	0.56
10	2.91	0.57
10.5	2.91	0.57
11.5	2.99	0.59
12	2.99	0.59
12.5	3.05	0.6

We used a graphing calculator to calculate the best-fit curves using various types of equations (linear, quadratic, exponential, logarithmic, logistic, and others), and true to our prediction, the logistic equation was the closest fitting equation.

The equation we produced was:

$$Y = \frac{a}{1 + b \cdot e^{c \cdot x}} + d$$

Where:

Y = Bounce height returned
a = 0.323277
b = 3.48773
c = -0.416014
d = 0.231971

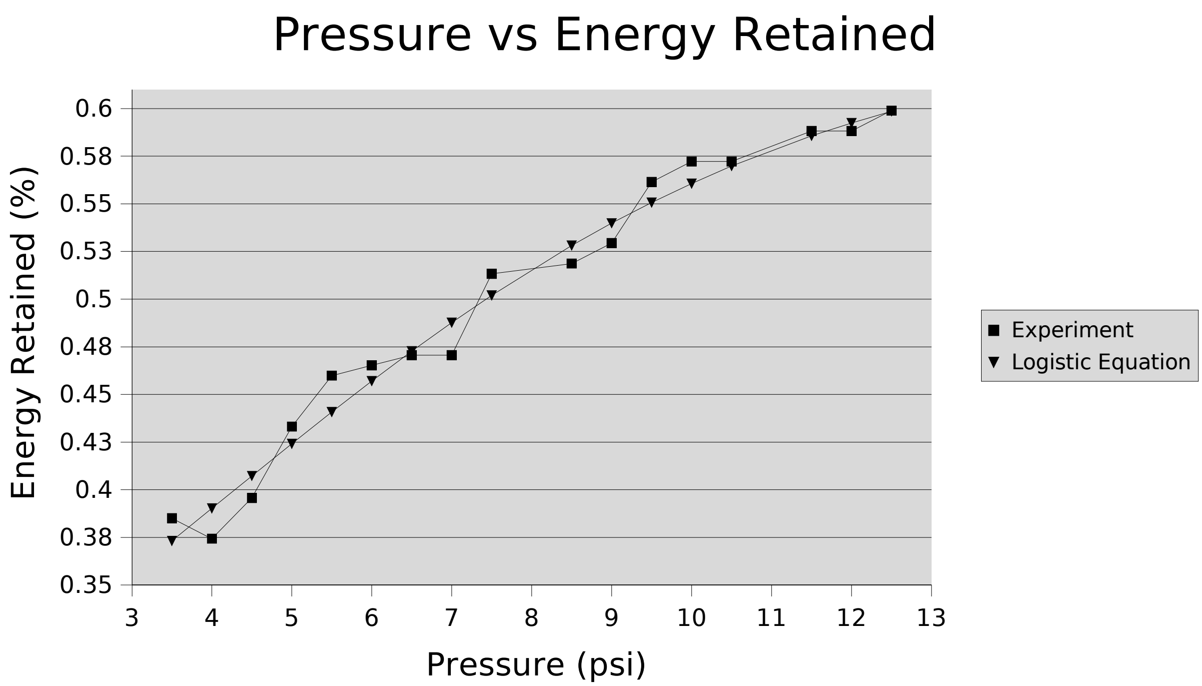
Substituting for the known values, our formula became:

$$Y = \frac{0.323277}{1 + 3.48773 \cdot e^{-0.416014 \cdot x}} + 0.231971$$

We then created data points for the same pressures we used experimentally for the logistic equation, and plotted both on the same chart. The data we produced using the logistic equation is below:

Pressure	Bounce Height
3.5	0.37
4	0.39
4.5	0.41
5	0.42
5.5	0.44
6	0.46
6.5	0.47
7	0.49
7.5	0.5
8.5	0.53
9	0.54
9.5	0.55
10	0.56
10.5	0.57
11.5	0.59
12	0.59
12.5	0.6

We combined this data with the experimentally obtained data to produce the following chart:



Discussion of Results:

The experimental data doesn't quite fit the logistic equation we tried to fit to the data. A more through investigation of the discrepancies between the data and the fit curve will be presented in the error attribution section.

Soccer Ball:

Raw data:

Pressure (psi)	Bounce Height (m)	Energy Retained (%)
1	1.71	0.34
1.5	1.73	0.34
2	1.84	0.36
2.5	1.86	0.37
3	2.02	0.4
3.5	2.15	0.42
4	2.18	0.43
4.5	2.2	0.43
5	2.34	0.46
5.5	2.41	0.47
6	2.47	0.48
6.5	2.52	0.49
7	2.52	0.49
7.5	2.6	0.51
8	2.68	0.53

We used a graphing calculator to calculate the best-fit curves using various types of equations (linear, quadratic, exponential, logarithmic, logistic, and others), and true to our prediction, the logistic equation was the closest fitting equation. The equation we produced was:

$$Y=\frac{a}{1+b\cdot e^{c\cdot x}}+d$$

Where:

Y = Bounce height returned
a = 0.504143
b = 3.029945
c = -0.271351
d = 0.141473

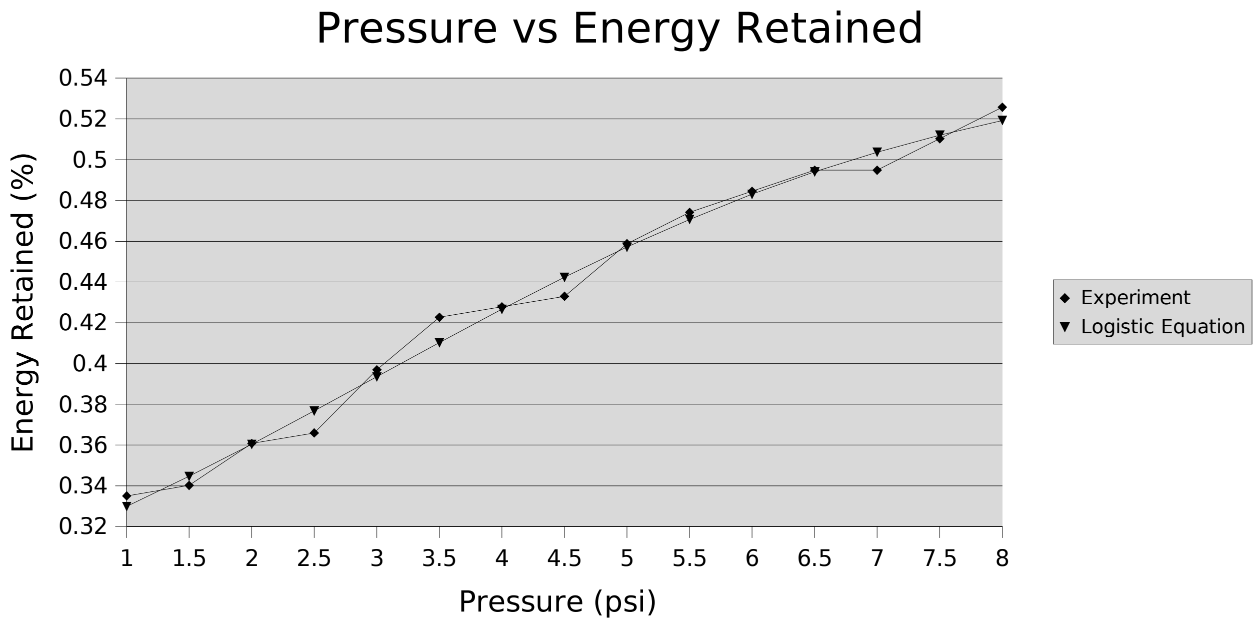
Substituting for the known values, our formula became:

$$Y=\frac{0.504143}{1+3.029945\cdot e^{-0.271351\cdot x}}+0.141473$$

We then created data points for the same pressures we used experimentally for the logistic equation, and plotted both on the same chart. The data we produced using the logistic equation is below:

Pressure	Bounce Height
1	0.33
1.5	0.34
2	0.36
2.5	0.38
3	0.39
3.5	0.41
4	0.43
4.5	0.44
5	0.46
5.5	0.47
6	0.48
6.5	0.49
7	0.5
7.5	0.51

We combined this data with the experimentally obtained data to produce the following chart:



Discussion of Results:

The experimental data doesn't quite fit the logistic equation we tried to fit to the data. A more through investigation of the discrepancies between the data and the fit curve will be presented in the error attribution section.

Results & Analysis:

We decided that although the logistic equation was the best fit for the data that we collected experimentally, that the data was sufficiently random as to not fit any curve very well. If we were able to more accurately measure the pressure, or had a ball with a wider range of safe pressures, we could have created a finer detailed graph, leading to a more accurate formula for representation.

Error Attribution:

For measuring the pressure, we had an automotive pressure gauge, which measures pressure against an internal spring, in the range from 1 to about 30 pounds, with tick marks at every half-pound of pressure. We were dropping the ball over a period of about an hour for each ball, during which the air temperature could have changed, affecting the bounce force, as well as the air density. The needles we had to use were hard to manipulate, since the needle part insisted on separating from the screw-in shank, causing us to often loose all the air in the ball, having to start over. Also, the relatively slow speed of the camera might have caused some ambiguity as to where and when the maximum return bounce height was at. Again, the video analysis program refused to acknowledge our entered scaling calibration, and we had to adjust that by hand.

Estimating Uncertainties:

It is fairly easy to estimate the uncertainty of our measurements from the video footage. We start by estimating the standard mid-range digital video camera's resolution at 320 x 240 pixels. In this experiment we aligned the narrow part of the camera with the path of the projectiles. We used approximately 90% of the screen for the path of the balls, so the balls traveled over a distance of about 215 pixels. Since they traveled a real-world distance of about 5 meters, the conversion factor of meters per pixel is:

$$\frac{5(\text{m})}{215(\text{px})}=\frac{1(\text{m})}{43(\text{px})}\approx 0.023\left(\frac{\text{m}}{\text{px}}\right)\approx 2.3\left(\frac{\text{cm}}{\text{px}}\right)$$

While this uncertainly is most certainly less important than in the last experiment, because we are using much larger balls this time, it is still an important factor to consider in the estimation of uncertainty.

Also, the pressure gauge was tricky to operate, and a small bit of air invariably escaped upon extraction of the needle. If we used a digital pressure gauge, we could have had better luck with measuring the pressure. However, if about the same amount of air leaked out each time, then the graph would only be shifted. Unfortunately, if we assume that the time for air to leak out is constant, then more air will leak out after a higher pressure inflation than a lower pressure inflation.

Conclusion:

The pressure of a sports ball has a very profound effect on the behavior of that ball. It is a characteristic of the logistic equation that in the area of the graph where the ball is most likely to be used, in the middle range, is the area of the curve where the smallest change in pressure will create the largest change in bounce return height. This means that for official sporting events, great care must be made to the accuracy and consistency used in inflating the official game balls beforehand.