The Effects of Varying Weight and Height on Parachute Men Drops

Abstract

The goal of this project was to conduct an experiment relating to our field of engineering and analyze the outcome using statistical methods learned in our class. The question our project intended to answer is how different weights and heights affect the time it takes for the parachute men to reach the ground when dropped. The mfit and regression analyses showed that height was the most important and most statistically significant term. Both regression models showed that weight and weight^2 were not significant in either model. Variations in height were determined to be more statistically significant and had the most effect on response time than variations in weight. This could be due to the fact that the changes in mass were negligible when subjected to constant gravitational acceleration over a long period of time. The change in velocity would then not be substantial over large falling distances.

Background and Significance

All three members of our team have taken an engineering dynamics class and learned about free falling objects, so we decided to test this concept with varying weights and heights of falling parachute men. This experiment was designed considering how forces applied to a body affect its movement through space. In this case, 36 identical parachute men were weighted with 3 levels of weights and dropped from 3 levels of heights. As such, the magnitude of the force due to the weight that is applied to each parachute will be varied, as well as the distance over the parachute men are allowed to travel, which thereby affects the total time over which the parachute men are able to be accelerated by gravity. We wanted to determine how the different weights and heights affected the time it took for the parachute men to fall and reach the ground. We also wanted to find out which factor had the most influence on the response variable, time.

Before conducting the experiment, we expected that increased weight would decrease the amount of time it took for the parachute to reach the ground, and that increased height would increase the time. Our a priori expectation was that the 3rd story and an added weight of 2 binder clips would have the shortest free falling time, and the 5th story and no weight would have the longest time. We hypothesized that height is the most important variable and will have the largest effect on the response time, since the added weights are small when compared with the initial weights of the parachute men and the variation in height with each level is large.

Our results showed that the 3rd story drop with the 2 binder clips had the shortest average free falling time, and the 5th story drop with no added weight had the longest average free falling time, as expected. According to the main effect values for the mfit analysis and the regression models of the data, height was the most significant variable to the free falling time.

Methods

The parachute men were all numbered (1-36) and placed in order for testing, according to the sequence generated by MATLAB using the function (sample(36)). The parachutes were then opened one at a time by removing the rubber band, unfolding the parachute, and then pressing a standard plastic water bottle against the underside of the open parachute, such that it was allowed to form around the water bottle and maintain a uniform degree of openness across the parachute men. This is shown in Figure 5 below.

During each test, each parachute man (according to the predetermined order) was taken to its designated floor of SAS Hall, and weighted with the designated number of weights (each binder clip is carefully clipped on the legs of the parachute man, such that the weight is distributed uniformly and the clips are fastened securely). In tandem with the starting of the stopwatch, the parachute man was released from rest from a height parallel to the top of the railing of the designated floor. The horizontal localization of each parachute man was determined such that its displacement from the railing on the floor is equal to the tester's fully-outstretched arm, including the length of a plastic claw toy, when the tester has their body pressed against the railing. This total length of the displacement from the end of the claw toy to the railing was recorded using a tape measure and maintained consistent throughout test by maintaining the same tester and claw toy in use. According to the opening of doors on the 2nd story, passage of students and staff through the atrium, and variability in the SAS HVAC system, it sometimes became necessary to wait in between trials to ensure that air conditions for each trial were as consistent as possible. It is also for this reason that the trials were done on the same day one after the other, such that variability in temperature and moisture content of the air was kept minimal.

If during a trial run the parachute man collided with a solid object (wall, bystander, etc.), then the time was discarded and the trial was re-done with an unused parachute man.

Results

MFIT

The mfit function is useful for predicting the relative importance of factors. As we expected, the mfit suggests that height is the most important factor because it has the largest absolute value for main effect. The largest value for the height main effect is 2.43470, the largest value for weight main effect is 1.55140, and the largest value for the interaction effect is 0.75444. This mfit data suggests that the order of importance of the factors is height, weight, and then interaction. This means that height has the strongest effect on the response variable, time. (See Appendix 1 for complete mfit analysis)

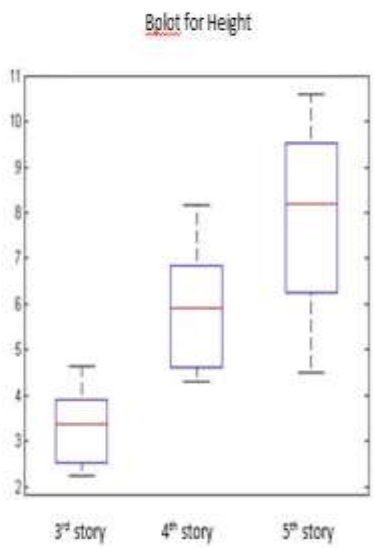
STATS

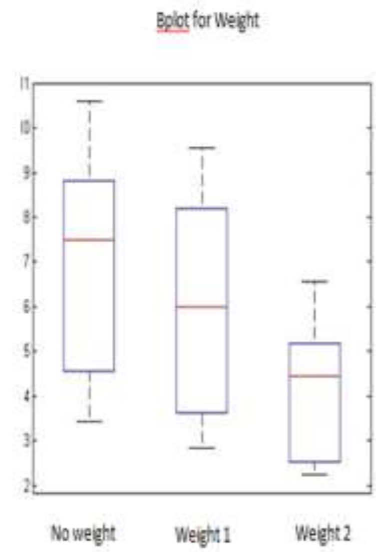
Mean time values increase with increasing heights and with increasing weights. The standard deviations for the height values area lower than the standard deviations for the weight values, suggesting that the different heights more significantly affect the free falling times. (See Appendix 2 for complete stats analysis)

MPLOT AND BOXPLOTS

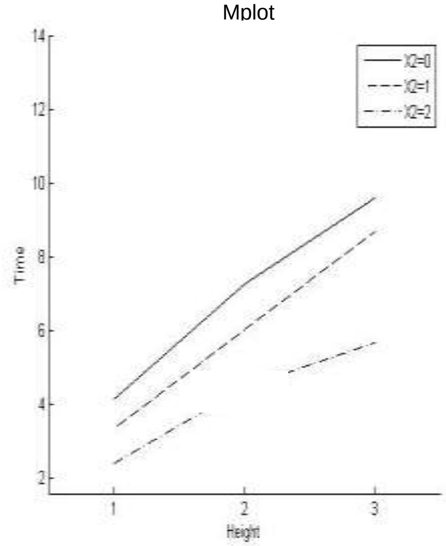
The Mplot (shown below) indicates that there is an interaction because it shows 3 non-parallel lines. The lines, representing the weights, start off with an equal distance apart and then get father away from each other as height increases. This means they have different slopes and the mplot shows that the weight of 2 binder clips has the smallest slope resulting in the smallest effect on the time change between heights.

The boxplot for height shows that as the height increases, so does the free-fall time. The boxplot for weight shows that as the weight applied increases, the free-fall time decreases. The boxplots for height are not very skewed and roguhly show a normal distribution. The boxplots for weight are more negatively skewed because the median values are closer the 3rd quartile. The side-by-side boxplots also suggest that treatments with greater heights had a larger range than those of lower heights, meaning that there was more variation in the times for trial runs over longer distances; this could suggest inconsistencies in our study or additional factors that were not considered in this experiment design. The weight boxplots depicted a slightly larger range of values for the treatments with no weight, but all of these boxplots had larger ranges compared to those of the height boxplots. This suggests that the heights more significantly impacted free falling times.





Mplot



REGRESSION MODELS

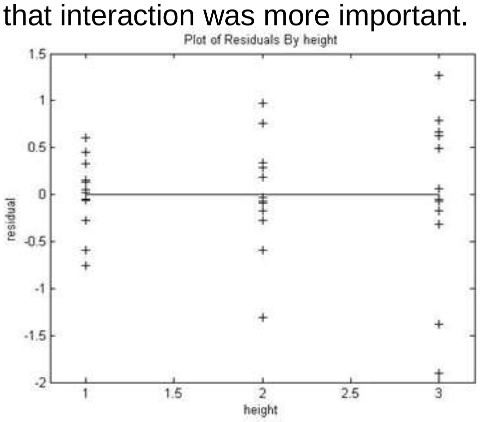
For regression analysis, two models were used:

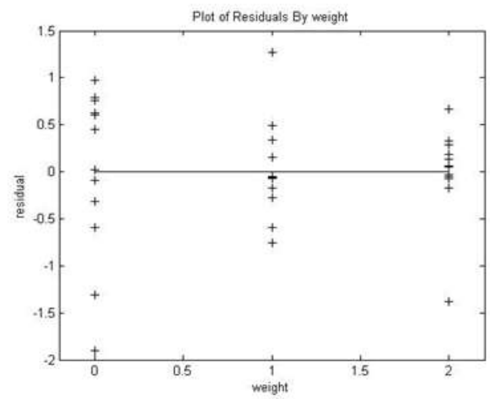
time = height+weight+height*weight + height^2 + weight^2

log(time) = height+weight+height*weight + height^2 + weight^2

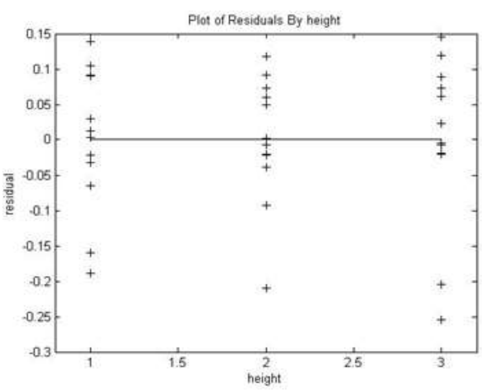
The first model showed that the only significant terms were height and height*weight interaction. The most important term was height which had a p-value of 0.00041557. The R-squared value for this model was 0.92703 and the standard error was 0.69872. For the second model (the log(Y) model), the significant terms were intercept, height, height^2, and weight^2. The most important term was height which had a p-value of 3.5204e-07. The R-squared value for this model was 0.94696 and the standard error was 0.11008. The second model (log(time)) is the better model because the R-squared increased and the standard error decreased, which is also shown in the rplot since the data points were close to the line. The two regression models had different significant terms, but both showed that height was the most important and that weight, weight^2 were not statistically significant. Mfit also showed that height was the most important factor, but it predicted that the order of importance was height, weight, then interaction. This is different from what the regression analysis told us. For example, the first model and second model said that weight was not statistically significant, but the interaction was, meaning that interaction was more important.

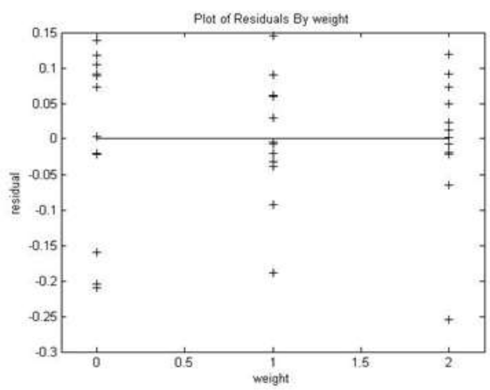
Model 1





Model 2





Discussion

Variations in height were determined to be more statistically significant to the overall free falling time than variations in weight. This could be due to the fact that the changes in mass were negligible when subjected to constant gravitational acceleration over a long period of time. The change in velocity would then not be substantial over large falling distances.

Since the height was shown to be more significant, it would be interesting to examine the effects of running the same experiment with shorter height increments (less than a full story) and greater increments (more massive than binder clips). Additional experiments could look into additional factors such as parachute area, uniformity of parachute deployment, distribution of weights on the parachute men, and alternate testing environments.

Appendices

Appendix 1

Mfit Analysis

```
>> mfit(b.time, b.height, b.weight)
Overall Mean
5.7406

Fitted Main Effect of Y variable , y, by X variable, x1
Source        N Main Effect
3rd_story    12    -2.43470
4th_story    12     0.18944
5th_story    12     2.24530


Fitted Main Effect of Y variable , y, by X variable, x2
Source        N Main Effect
no_weight    12     1.27190
weight_1     12     0.27944
weight_2     12    -1.55140
```



```
Table of 2-way x1 by x2 Interaction Effects
                        x1
                3rd_story    4th_story    5th_story
x2    no_weight    -0.42528    0.080556     0.34472
      weight_1     -0.23528   -0.174440     0.40972
      weight_2      0.66056    0.093889    -0.75444
```

Appendix 2

Stats analysis

```
>> stats(b.time, b.height)

          3rd_story  4th_story  5th_story
N          12.00000    12.0000    12.0000
Mean        3.30580     5.9300     7.9858
Std. Dev.   0.82261     1.3352     1.9447

Q1          2.48000     4.5875     6.1000
Median      3.37500     5.9100     8.2000
Q3          3.97250     6.9700     9.5275

Min         2.25000     4.3100     4.5100
Max         4.64000     8.1700    10.5900
Range       2.39000     3.8600     6.0800
```

```
>> stats(b.time, b.weight)

           no_weight  weight_1  weight_2
N            12.0000   12.0000   12.0000
Mean          7.0125    6.0200    4.1892
Std. Dev.     2.4953    2.3124    1.4822

Q1            4.5200    3.5750    2.4800
Median        7.5050    5.9850    4.4300
Q3            9.1600    8.2050    5.4500

Min           3.4400    2.8300    2.2500
Max          10.5900    9.5400    6.5500
Range         7.1500    6.7100    4.3000
```

Appendix 3

Regression Analysis

time = height+weight+height*weight + height^2 + weight^2
R-square 0.92703
Standard Error 0.69872
Parameter Estimates

Source	Parameter Estimate	Std. Error	t	p-val
Intercept	0.29278	0.96029	0.30488	0.76256000
height	4.02290	1.01350	3.96920	0.00041557
weight	0.51917	0.62169	0.83509	0.41027000
height*weight	-0.54625	0.17468	-3.12720	0.00390420
height^2	-0.28417	0.24703	-1.15030	0.25910000

log(time) = height+weight+height*weight + height^2 + weight^2
R-square 0.94696
Standard Error 0.11008
Parameter Estimates

Source	Parameter Estimate	Std. Error	t	p-val
Intercept	0.5082800	0.151280	3.359700	0.00213810
height	1.0372000	0.159670	6.495600	3.5204e-07
weight	-0.0751230	0.097941	-0.767030	0.44906000
height*weight	0.0023737	0.027519	0.086258	0.93183000
height^2	-0.1498500	0.038918	-3.850400	0.00057498
weight^2	-0.0935350	0.038918	-2.403400	0.02263000

Appendix 4

Predictions based on mfit and regression model

		mfit				**lm**		
		Height				Height		
		1	2	3		1	2	3
Weight	0	4.5778	7.20194	9.2578	0	4.037517	7.266538	9.691314
	1	3.58534	6.20948	8.26534	1	3.418992	6.167968	8.24571
	2	1.7545	4.37864	6.4345	2	2.401255	4.342233	5.818754

Appendix 5

Design Matrix

	No Weight	**Weight 1**	**Weight 2**
3rd story	32, 22, 34, 35	6, 3, 16, 11	30, 33, 7, 28
4th story	17, 14, 8, 5	29, 21, 25, 31	27, 26, 19, 15
5th story	1, 36, 23, 2	4, 18, 24, 13	9, 20, 10, 12

Appendix 6

Images

Figure 1, No Weight

Figure 2, 1 Binder Clip

Figure 3, 2 Binder Clips

Figure 4, Dropping the Parachute

Figure 5, Water Bottle technique

Appendix 7

Raw Data

Run Order	Story	Weight	Time (sec)
1	3	0	7.90
2	3	0	9.49
3	1	1	3.74
4	3	1	9.54
5	2	0	8.17
6	1	1	3.31
7	1	2	2.25
8	2	0	5.89
9	3	2	4.51
10	3	2	5.95
11	1	1	2.83
12	3	2	5.71
13	3	1	8.76
14	2	0	7.11
15	2	2	4.35
16	1	1	3.52
17	2	0	7.96
18	3	1	8.19
19	2	2	4.31
20	3	2	6.55
21	2	1	5.62
22	1	0	4.48
23	3	0	10.59
24	3	1	8.21
25	2	1	5.93
26	2	2	4.56
27	2	2	4.67
28	1	2	2.43
29	2	1	6.55
30	1	2	2.63
31	2	1	6.04
32	1	0	3.44
33	1	2	2.35
34	1	0	4.64
35	1	0	4.05
36	3	0	10.43