

# Spud Speed Test

William Eric Marsh

November 17, 2005

# Contents

<b>1</b>	<b>Introduction</b>	<b>4</b>
1.1	Background . . . . .	4
1.2	Construction . . . . .	4
1.3	Operation . . . . .	5
<b>2</b>	<b>Experiment</b>	<b>7</b>
2.1	Design And Objectives . . . . .	7
2.2	Assumptions . . . . .	8
2.3	Variables . . . . .	8
2.3.1	Input Variables . . . . .	8
2.3.2	Dependent Variable . . . . .	9
2.4	Hypotheses . . . . .	9
2.5	Test Launcher Design . . . . .	9
2.6	Performing The Experiment . . . . .	10
<b>3</b>	<b>Results</b>	<b>11</b>
3.1	Analysis . . . . .	11
3.1.1	Checking Assumptions . . . . .	14
3.2	Interpretation . . . . .	14
3.2.1	Intuitive Interpretation . . . . .	16
3.3	Future Work . . . . .	16

# List of Tables

3.1	Run order and recorded data. . . . .	12
3.2	Anova table. . . . .	13
3.3	Parameter estimates. . . . .	13
3.4	Summary of fit. . . . .	13

# List of Figures

1.1	Ishikawa diagram showing some factors affecting muzzle velocity. . . . .	5
1.2	Potato launcher from experiment. . . . .	6
3.1	Histogram of the data. . . . .	14
3.2	Residuals vs. Run Order. . . . .	15
3.3	Residuals vs. Fitted Values. . . . .	15

# Chapter 1

## Introduction

### 1.1 Background

People have been enjoying potato guns (launchers) for many years. A potato gun is relatively inexpensive entertainment if you have access to a large piece of land to use it. Many people have informally experimented with different designs to maximize the range and/or velocity of their potatoes. Some factors which have been altered in articles on the internet and in the author's own experiments include barrel length, chamber volume, fuel type, ignition mechanism, barrel porting, and type of potatoes. There are certainly other factors which will affect the performance, but these are the easiest to control. Figure 1.1 is an Ishikawa diagram showing some of the factors that affect the muzzle velocity of a potato fired from a potato gun.

### 1.2 Construction

A potato gun is a pretty simple device. Figure 1.2 is a photograph of the potato launcher used in the following experiment. It has two main parts, the chamber and the barrel. The chamber is where the combustion takes place. It has a clean-out cap on the end and an ignition system of some sort near the center. The ignition system can be either two points connected to a power source to generate a spark or an old flint-style lantern lighter. The chamber is

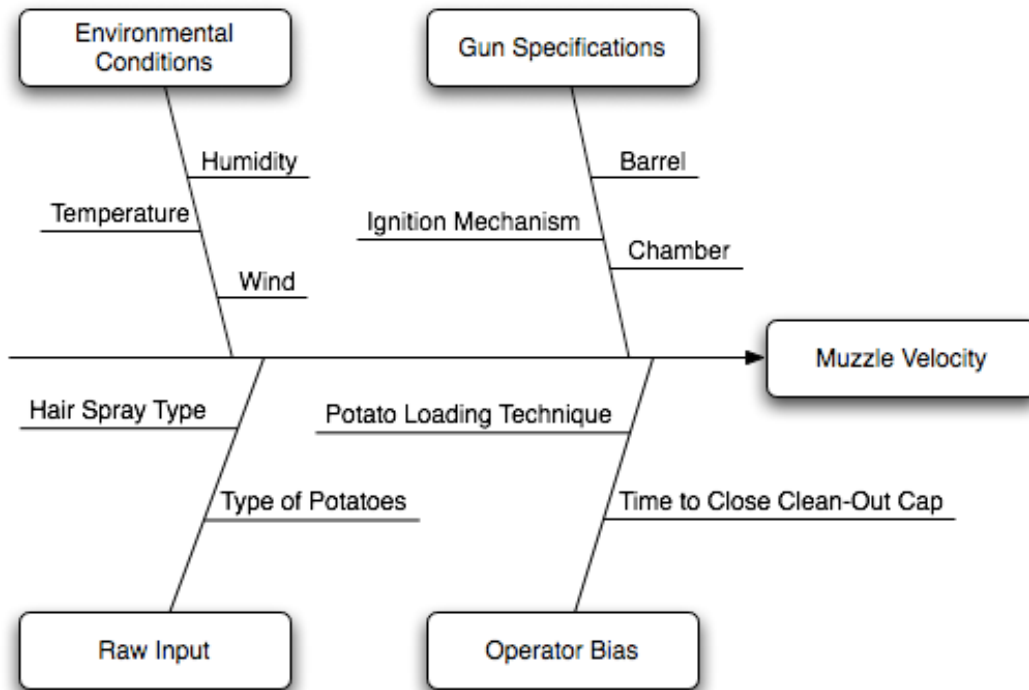


Figure 1.1: Ishikawa diagram showing some factors affecting muzzle velocity.

connected to the barrel with a reducer. The barrel should have a diameter smaller than that of the potato (unless shooter plans to shoot other items). The end of the barrel closest to the chamber should have a nail or screw through it to stop the potato from entering the chamber. The barrel is sharpened at the end in such a way as to cut the potato down to size as it is loaded. Some builders port their barrels. This has the potential to allow air to clear out of the potato's way, thus reducing deformation of the potato. Also this could help to equalize the pressure for when the potato exits the barrel. Barrel porting can potentially lead to a straighter, longer flight.

### 1.3 Operation

Operation of a potato gun is a simple four-step process.

1. Remove clean-out cap from chamber.
2. Load the potato into the barrel. This is easily accomplished by using a long rod to push the potato down the barrel. One should be careful, when pushing the potato into

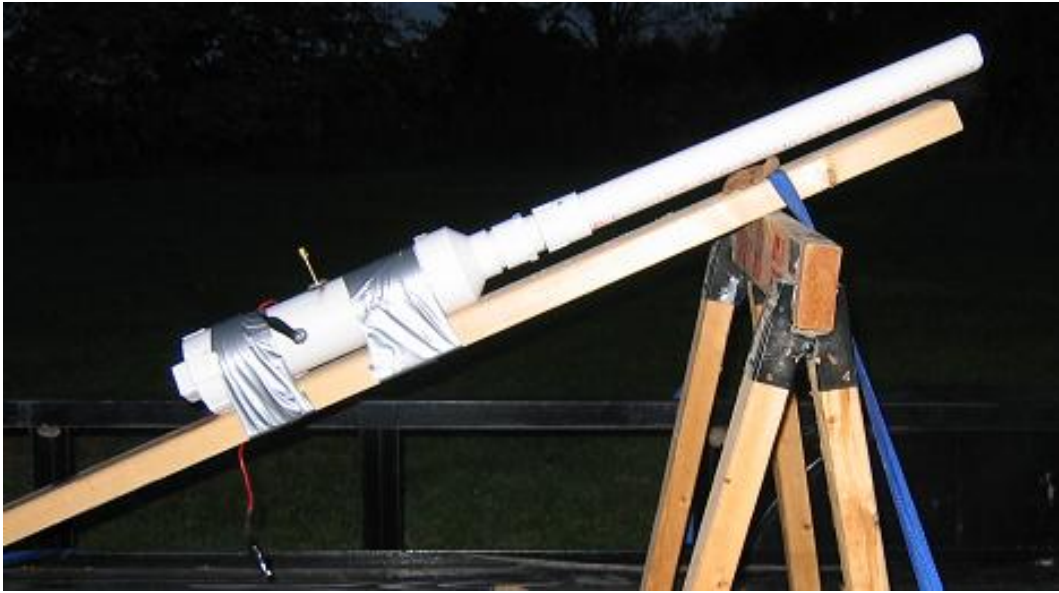


Figure 1.2: Potato launcher from experiment.

the sharpened end of the barrel, to ensure that the potato is loaded such that a good seal exists around the potato. When looking in the chamber, no light should be visible around the potato.

3. Spray fuel (hair spray is safest and recommended) into the chamber. A three-second burst is usually adequate, but this depends on the chamber size. Quickly screw clean-out cap back on after spraying hair spray.
4. Operate ignition mechanism.

# Chapter 2

## Experiment

### 2.1 Design And Objectives

This experiment was conducted using a  $2^3$  factorial design. Four replications were performed, for a total of 32 test-runs. The three factors of interest were:

- barrel length: 35.25in vs. 21.5in<sup>1</sup>
- fuel type: Rave vs. Suave
- ignition mechanism: Flint Lantern Lighter vs. Stun Gun

These factor levels were not chosen arbitrarily. The barrel lengths were chosen based on wisdom regarding the domain. The longer barrel is predicted to work better than the shorter one. The shorter barrel is short enough that the potato will probably usually leave the barrel while combustion is still taking place. The hair sprays were chosen because they are the cheapest available at Kroger. Typically, potato gun experts recommend using the cheapest available not only because of the cost but because it is not as sticky. The aerosol is what causes the combustion and if the hair spray is too sticky, it doesn't seem to work as well. Also sticky hair spray will be more likely to gum up the flint ignition mechanism, which could cause problems in the experiment. The sparking mechanisms were chosen because they are the most popular among hobbyists.

---

<sup>1</sup>Barrel length is measured from the tip of the barrel to the stop-nail at the chamber entrance. This is the distance that the potato travels while in the barrel.

Knowing the significance of each of these factors on the muzzle velocity could be useful for improving future designs.

## 2.2 Assumptions

The following assumptions were made when designing this experiment.

- The paintball chronograph used is 100% accurate.
- The slight difference between the mounting positions of the two sparking mechanisms will not affect the quality of the combustion.
- Kick from the gun will not affect orientation or launch angle.
- Residue from previous launches will not affect the velocity.

In the event that the last two assumptions are untrue, randomization will hopefully cancel out any effect on the experiment.

## 2.3 Variables

### 2.3.1 Input Variables

#### Controlled

- barrel length
- fuel type
- ignition mechanism

#### Uncontrolled

- size/mass of the potato
- environmental conditions
- error in the amount of hair spray administered

### 2.3.2 Dependent Variable

The dependent (response) variable of interest was the muzzle velocity (measured in feet-per-second) of the potato. It was measured with a chronograph made for use in paintball. The chronograph was hung from the end of the barrel and reset before each run.

## 2.4 Hypotheses

Null Hypothesis: The barrel length, ignition type, and hair spray type have no effect on the muzzle velocity of the potato.

$$H_0 : \tau_A = \tau_B = \tau_C = 0$$

Alternate Hypothesis: The barrel length, ignition type, or hair spray type has an effect on the muzzle velocity of the potato.

$$H_1 : \tau_i \neq 0, \text{ for at least one } i$$

## 2.5 Test Launcher Design

The launcher used in this experiment was specially designed to allow for the use of common parts in order to reduce error. The gun has the following special features:

- Exchangeable barrels: The barrels and the chamber are threaded to allow for barrel swapping. Normally the barrel is permanently fixed to the chamber.
- Dual ignition mechanisms: The chamber features both a flint lantern-lighter and posts for use with a stun gun (or other power source).

## 2.6 Performing The Experiment

Care was taken in performing the experiment in an attempt to reduce bias. The potato gun was secured to a board with duct tape and the board was placed at a fixed angle. This was to eliminate bias due to the angle of the gun. The experimenter enlisted the help of an assistant because there is a lot to do in little time when shooting potatoes. The experimenter and the assistant were each assigned tasks to do during each run. This helped to reduce bias caused by differences in technique between people. Following is a list of the steps taken by the experimenter (Eric) and the assistant (Roger) during each run:

1. Eric removed the clean-out cap from the end of the chamber. This step ensured that the air could escape from behind the potato without affecting the seal created by the potato in the barrel.
2. Roger swapped the barrel if needed and loaded a potato into the barrel.
3. Eric sprayed the appropriate hair spray into the chamber for approximately three seconds.
4. Roger quickly sealed the cap at the back of the chamber to prevent leakage of hair spray while Eric reset the chronograph and ensured that it was aimed properly.
5. Eric activated the appropriate ignition mechanism.
6. Once the potato left the barrel, Eric read and recorded the reading from the chronograph.

# Chapter 3

## Results

Table 3.1 shows the randomized run order used in the experiment along with the velocity observed for each run. The run order was randomized automatically by JMP IN. The following sections provide an analysis and an interpretation of the data.

### 3.1 Analysis

Data analysis was conducted with JMP IN and Excel.

Table 3.2 is the ANOVA table for the experiment. We can see from this table that, at 90% confidence, the only significant factors are the length of the barrel and the interaction between spark mechanism and barrel length. It also seems that hair spray type may be worth investigating further.

Table 3.3 shows the parameter estimates calculated by JMP IN. These are the regression coefficients that will be used in forming a model with the significant factors.

Table 3.4 shows the Summary of Fit table computed by JMP IN. We can see from the *R-Square* value of approximately 0.402 that the chosen factors are somewhat important, but there are probably other factors that also affect the dependent variable. The regression analysis also tells us that the p-value of the analysis is 0.0598. This tells us that the regression model is significant at the 90% confidence level.

Table 3.1: Run order and recorded data.

<i>Run</i>	<i>Pattern</i>	<i>Spark Mechanism</i>	<i>Barrel</i>	<i>Hair Spray</i>	<i>Velocity (fps)</i>
1	112	Flint Lantern Igniter	Long	Suave	226
2	212	Stun Gun	Long	Suave	188
3	221	Stun Gun	Short	Rave	183
4	111	Flint Lantern Igniter	Long	Rave	202
5	211	Stun Gun	Long	Rave	143
6	112	Flint Lantern Igniter	Long	Suave	224
7	121	Flint Lantern Igniter	Short	Rave	131
8	212	Stun Gun	Long	Suave	130
9	122	Flint Lantern Igniter	Short	Suave	188
10	222	Stun Gun	Short	Suave	197
11	222	Stun Gun	Short	Suave	152
12	121	Flint Lantern Igniter	Short	Rave	151
13	211	Stun Gun	Long	Rave	246
14	212	Stun Gun	Long	Suave	185
15	112	Flint Lantern Igniter	Long	Suave	223
16	112	Flint Lantern Igniter	Long	Suave	197
17	122	Flint Lantern Igniter	Short	Suave	172
18	211	Stun Gun	Long	Rave	165
19	221	Stun Gun	Short	Rave	134
20	222	Stun Gun	Short	Suave	173
21	111	Flint Lantern Igniter	Long	Rave	230
22	121	Flint Lantern Igniter	Short	Rave	141
23	212	Stun Gun	Long	Suave	153
24	211	Stun Gun	Long	Rave	142
25	221	Stun Gun	Short	Rave	121
26	122	Flint Lantern Igniter	Short	Suave	166
27	222	Stun Gun	Short	Suave	169
28	121	Flint Lantern Igniter	Short	Rave	159
29	122	Flint Lantern Igniter	Short	Suave	159
30	111	Flint Lantern Igniter	Long	Rave	121
31	111	Flint Lantern Igniter	Long	Rave	208
32	221	Stun Gun	Short	Rave	167

Table 3.2: Anova table.

<i>Source</i>	<i>Sum of Squares</i>	<i>DF</i>	<i>F Ratio</i>	<i>p-value</i>
Mean	961191.1250	1		
Spark	1953.1250	1	2.1965	0.1513
Barrel	5512.5000	1	6.1993	<b>0.0201</b>
Hair Spray	2080.1250	1	2.3393	0.1392
Spark * Barrel	2964.5000	1	3.3339	<b>0.0803</b>
Spark * Hair Spray	861.1250	1	0.9684	0.3349
Barrel * Hair Spray	450.0000	1	0.5061	0.4837
Spark * Barrel * Hair Spray	544.5000	1	0.6123	0.4416
Error	21341.0000	24		
Total	996898.0000	32		

Table 3.3: Parameter estimates.

<i>Term</i>	<i>Estimate</i>
Intercept	173.3125
Spark	7.8125
Barrel	13.125
Hair Spray	-8.0625
Spark * Barrel	9.625
Spark * Hair Spray	-5.1875
Barrel * Hair Spray	3.75
Spark * Barrel * Hair Spray	-4.125

Table 3.4: Summary of fit.

R-Square	<b>0.402328</b>
Adjusted R-Square	0.228007
Root Mean Square Error	29.8196
Mean of Response	173.3125
Observations	32

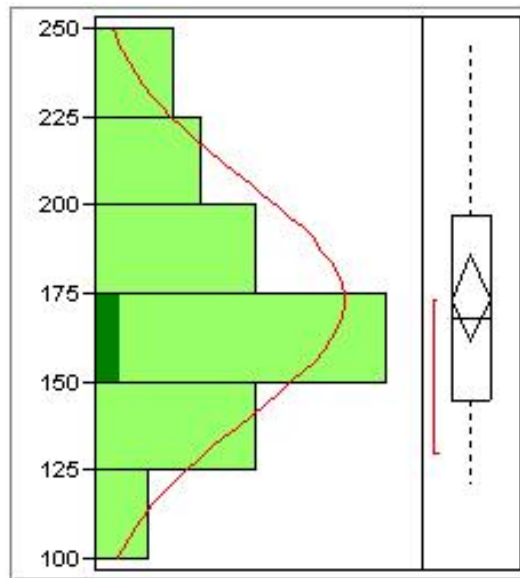


Figure 3.1: Histogram of the data.

### 3.1.1 Checking Assumptions

The normality assumption must now be checked. Figure 3.1 shows a histogram of the data. It appears to be normally distributed. To confirm that, we can look at the goodness-of-fit test. The p-value for this test is 0.3170, which means we fail to reject the null hypothesis (that the data is normally distributed).

The independence and constant variance assumptions should also be checked. Figure 3.2 shows a plot, generated in Excel, of residuals vs. run order. There does not seem to be any clear pattern of correlation present in the data. Figure 3.3 shows a plot, generated by JMP IN, of residuals vs. fitted values. There are no clear patterns so this provides evidence to support the constant variance assumption.

## 3.2 Interpretation

After analyzing this data, it is possible to draw certain conclusions about the model. The first thing that we notice is that the null hypothesis should be rejected because there are p-values that are significant. We can see that the barrel length and the interaction between the barrel length and the spark mechanism are the only significant factors. With this knowledge, it is

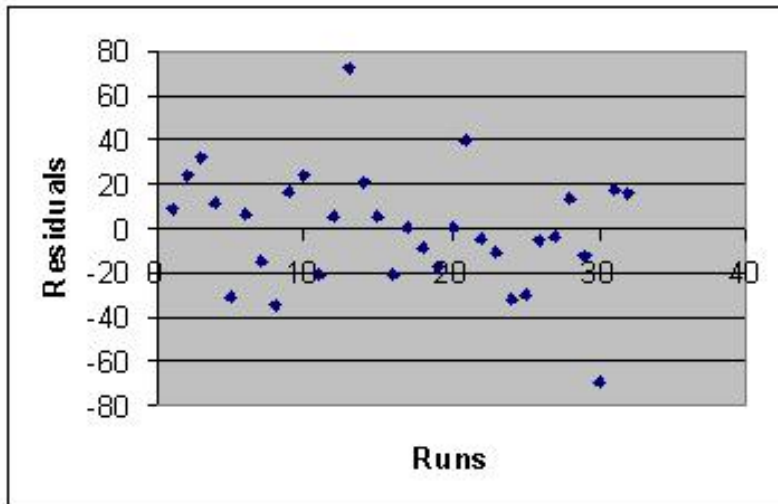


Figure 3.2: Residuals vs. Run Order.

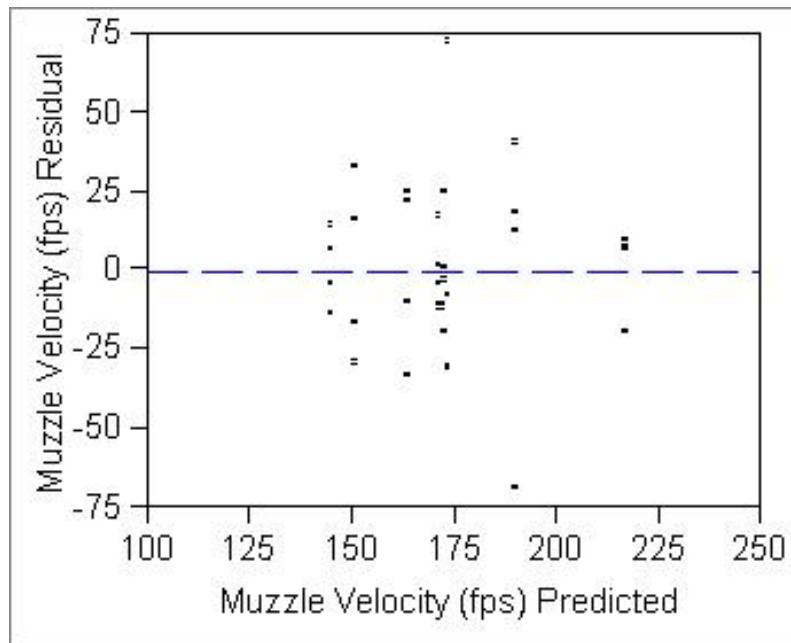


Figure 3.3: Residuals vs. Fitted Values.

possible to create a model using the calculated regression coefficients. Assuming that factor A is spark mechanism and factor B is barrel length, the regression model is:

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_2 B + \hat{\beta}_{12} AB + \varepsilon$$

or

$$\hat{y} = 173.3125 + 13.125B + 9.625AB + \varepsilon$$

This tells us that factors A and B should be at the +1 level in order to maximize the muzzle velocity of the potato. This is the flint lantern igniter and the long barrel.

### 3.2.1 Intuitive Interpretation

The previous interpretation is somewhat intuitive and somewhat a mystery. It makes sense that the longer barrel increased the velocity. It is commonly understood among potato gun builders that ideally *barrel volume*  $\approx 1.5 * \textit{chamber volume}$ . This is thought to be because the potato should be in the barrel for the duration of the combustion. With the short barrel used in this experiment, the combustion was probably still happening after the potato exited the barrel. Confusion arises when we consider the interaction between the barrel length and the spark mechanism. The spark mechanisms couldn't be placed at exactly the same spot in the barrel and the size of the spark emitted by each differs. With this in mind, it is possible that the interaction has something to do with air pressure in the chamber. If that is the case, it may be impossible to apply this model to all potato launcher designs.

## 3.3 Future Work

Time and expense constraints limited this experiment to three factors at two levels each. To fully understand the science of potato-launching, further experimentation is needed. Some things that might be interesting to look at in future experiments are:

- Barrel length could be a quantitative parameter.
- Barrel porting could be a factor.

- Chamber volume could be a factor.
- Different types of fuel could be tried (other hair sprays, ether, etc...).
- Type of potatoes could be a factor.
- While not very controllable, environmental factors such as weather could be examined.
- Find a better way of measuring fuel quantity.

# Bibliography

- [1] Hill, R. R. (2005). EGR705: Design And Analysis Of Engineering Experiments,  
[http://www.cs.wright.edu/~rhill/EGR\\_705/Syllabus\\_705.htm](http://www.cs.wright.edu/~rhill/EGR_705/Syllabus_705.htm)
- [2] Montgomery, D. C. and Runger, G. C. (2003). *Applied Statistics And Probability For Engineers*, 3rd Edition. John Wiley & Sons, Inc.