

Taguchi Exercise

STEFAN JAREMA | Systems Engineering| ACDA5021

Table of Contents

Objective	3
Method and apparatus	4
Experimental data and analysis.....	6
Front position values Factor A	7
Band Anchor position Factor B	7
Stop position Factor C.....	8
Pull back Factor D	8
Operator Factor E	9
Overall effect	9
Taguchi Prediction.....	11
Conclusion	12
Reflections.....	12
References.....	13

Objective

The objective of this experiment is to apply the Taguchi method to find the key control factors of the catapult that would affect the distance the projectile would travel horizontally. Once identified, the aim is to validate the method's ability to accurately predict the distance the projectile will travel on a previously untested configuration of the catapult system.

Method and apparatus

The apparatus consisted of a Small wooden catapult similar to Figure 1 that would use a stretched elastic band to launch a small plastic ball shaped projectile under controlled conditions. The apparatus could be adjusted by independent variables which become the control factors.

Table 1 Control factors

Band front position	Factor A
Band anchor position	Factor B
Stop position	Factor C
Pull-back distance	Factor D
Operator	Factor E

In addition to these control factors, the interaction effects between factors AB and BC would be calculated

A Taguchi orthogonal array also known as a L8 was the method used for this experiment. This allows for multiple control factors to be tested at the same time, reducing the number of experiments conducted overall. Each of these factors were controlled at two levels. [1][2]

Table 2 Populated L8 Array

Experiment	1	2	3	4	5	6	7
	Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator
1	1	2	1	1	140	1	A
2	1	2	1	3	170	2	B
3	1	4	2	1	140	2	B
4	1	4	2	3	170	1	A
5	3	2	2	1	170	1	B
6	3	2	2	3	140	2	A
7	3	4	1	1	170	2	A
8	3	4	1	3	140	1	B

For each experimental run the catapult would be set up according to the Taguchi matrix with care taken to prevent unwanted noise to be added to the data collection in the form of subtle environmental changes that were not controlled such as the placement of the catapult.

At the beginning of each run, the catapult would be adjusted to the correct factor levels, a test launch would be conducted so that spotters could get in the correct position to observe the location of where the projectile would land, this would allow for a more accurate measurement of the horizontal distance that the projectile would travel in the experiment. With the observers in place, each experimental run would be conducted 3 times so that an average of the values taken could be calculated to improve the overall accuracy The averages would then be added to the results section within the table (test launch data is not included.) [Table 3].

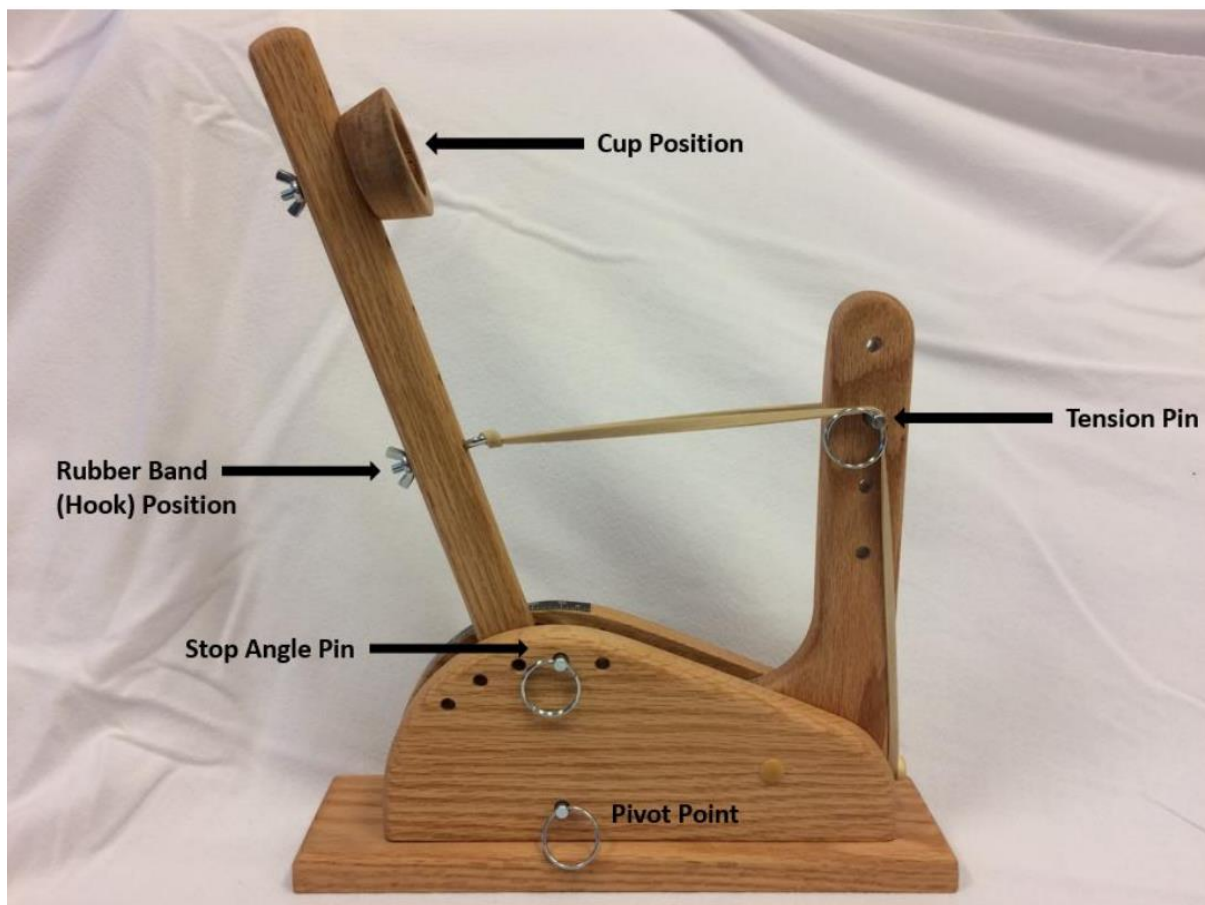


Figure 1 Catapult

Experimental data and analysis

The experimental data collected allowed for the Identification of the key control factors that effect the distance the projectile would travel.

Table 3 Part one experimental results

Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator	Variable Range cm	Average calculation cm
1	2	1	1	140	1	A	100.33	100.33
1	2	1	3	170	2	B	192.67	192.67
1	4	2	1	140	2	B	86.33	86.33
1	4	2	3	170	1	A	145.67	145.67
3	2	2	1	170	1	B	110.00	110.00
3	2	2	3	140	2	A	39.67	39.67
3	4	1	1	170	2	A	99.67	99.67
3	4	1	3	140	1	B	36.33	36.33

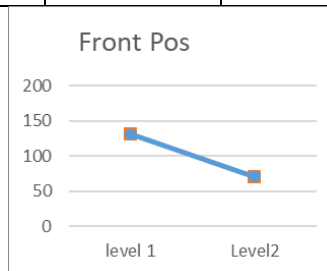
However, in order to interpret the data clearly the data from each level was split, where the mean of each factor would be calculated for each level and then plotted against each other in a chart to demonstrate the impact of the change.

Front position values Factor A

Front band position had a significant effect on the distance the projectile would travel this being the second most impactful factor. The theory for this is that when the elastic band front position is moved the tension the elastic band experiences during the pull back changes dictating the amount of elastic energy that can be stored under its tension.

Table 4 Factor A effect

	Band front position	Overall effect
Level 1	131.25	≈ 60
Level 2	71.416667	

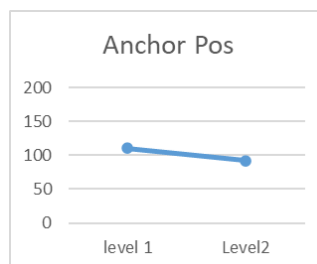


Band Anchor position Factor B

Band anchor position had a moderate effect. This can be explained in a similar way to the front band position as by increasing the distance of the elastic band's stretch it increases the tension within the band. The band anchor also changes this distance, but to a lesser extent than the front band position. As a result, its impact on the distance the projectile travelled was smaller.

Table 5 Factor B effect

	Band Anchor position	Overall effect
Level 1	110.66667	≈19
Level 2	92	

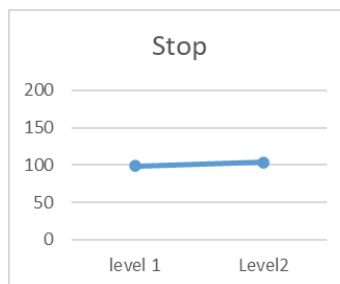


Stop position Factor C

Stop position had a minor effect on the distance the projectile travelled. This is likely because, when the operator releases the catapult, the elastic energy is rapidly transferred to the arm's acceleration. By the time the arm encounters the stop, most of the stored elastic energy has already been transferred to the arm and the projectile, resulting in only a small effect on the overall distance the ball travels.

Table 6 Factor C effect

	Stop Position	Overall effect
Level 1	99.083333	≈5
Level 2	103.58333	

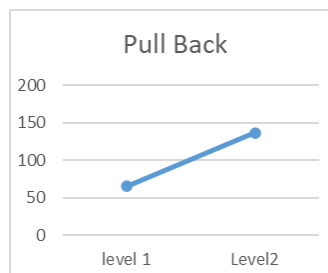


Pull back Factor D

Pull-back had the largest effect on the distance the projectile travelled. As previously explained, the greater the distance the elastic band is stretched, the more elastic energy can be stored. meaning, the further the catapult's arm is pulled back, the greater the stretch in the band, increasing its tension and resulting in more stored elastic energy, this being the case until plastic deformation occurs.

Table 7 Factor D effect

	Pull back	Overall effect
Level 1	65.666667	≈71
Level 2	137	

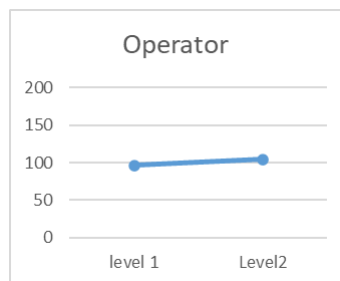


Operator Factor E

Operators had a minimal effect on the projectile's distance. This is likely because of the attempt to keep the operating procedures consistent, reducing the possible noise. However, a small effect was still observed. This could be due to slight differences in grip, causing friction during release and reducing the efficiency of energy transfer, as some energy could be lost as heat and kinetic energy to the operator's hands.

Table 8 Factor E effect

	Operator	Overall effect
Level 1	96.333333	≈9
Level 2	104.58333	



Overall effect

From the data collected, level two had on average the greatest impact on the distance the projectile would travel. From the analysis conducted, this was mainly due to factor D, the pull-back distance, as the data showed that pull-back distance had the greatest effect on how far the projectile would travel as can be proven by the following equations.

Velocity equation

$$Velocity = \frac{Displacement}{Time}$$

$$v = \sqrt{\frac{ke^2}{m}}$$

V = velocity

ke = Kinetic energy

m = Mass

Range equation

$$R = \frac{V^2 \sin(2\theta)}{g}$$

Where:

- R = The horizontal range (distance).
- V = The initial launch velocity (speed).
- θ = The launch angle.
- g = The acceleration due to gravity (9.81 m/s^2).

Elastic Potential Energy equation

$$E = \frac{1}{2} kx^2$$

Where:

- E = Elastic Potential Energy
- k = Spring constant of the rubber band.
- x = Distance the band is stretched.

As the Elastic Potential Energy equation proves, the greater the distance the band is stretched, the more potential energy can be stored. Due to the conservation of energy, this is converted to Kinetic Energy (assuming no losses) which increases the velocity (per the velocity equation). Since the projectile was the same weight, the increase in Kinetic Energy from the elastic band was the only factor that would increase the speed of the arm and ball. When looking at the range equation, the only two control factors that would change the distance are the velocity (from the potential energy of the band stretch) and the launch angle (the stop position). Because the velocity is squared in this equation, the velocity of the ball has a greater impact on the final horizontal distance than the angle does. This proves that the greater the band stretches, the further the projectile will horizontally travel.

Taguchi Prediction

The Taguchi method allows for the prediction of system performance by combining the effects of individual control factors. To validate the model's accuracy, a prediction was made by identifying the key factors influencing the projectile's range and calculating their respective means and mid-points Table 9 Table 10

Table 9 Key feature's identified

	Key Feature 1	
	Level 1	Level 2
Front position	1	3
	Key Feature 2	
	Level 1	Level 2
Pull back	140	170

Table 10 Prediction calculations

	front position	pull position		1	2	3	Ave		
Firing 1	1	140	range	94	110	107	103.6667	KF 1 :1	KF2 :1
Firing 2	3	140	range	63	64	72	66.33333	162	85
Firing 3	1	170	range	216	219	226	220.3333	KF 1 :2	KF2 :2
Firing 4	3	170	range	168	171	173	170.6667	118.5	195.5
								mid each factor	
								140.25	140.25
								mid combined	
								140.25	

The predicted performance was calculated by combining the mid-point values of each significant factor. This calculation represents the theoretical range the projectile should achieve if the experiment were conducted using the median settings for all control factors.

To verify the predictive model, a physical validation test was performed. The results showed strong correlation between the predicted and observed values.

Table 11 Part two experimental results

								difference
Fring 5	2	155	range	147	133	140	140	-0.25

The resulting error margin of -0.25 is considered negligible. This minor difference could be from uncontrolled noise factors affecting the experimental environment rather than the Taguchi model.

Conclusion

The experiment successfully fulfilled the objective of identifying the key control factors affecting the horizontal distance traveled by the projectile. These were identified as the Pull-back Distance and Front Band Position. Based on the analysis, this correlation exists because elastic potential energy increases as the elastic band is stretched.

Additionally, the model predicted the projectile's travel distance within a minimal margin of error of 0.25. This result validates the method’s accuracy and demonstrates its ability to generate reliable predictions even when using a limited experimental dataset.

Reflections

On reflection of the experiment conducted, introducing noise reduction methods could further enhance the experiment’s accuracy [4]. An example of noise mitigation could be done by replacing human observation with digital tools, such as cameras or sensors. Alternatively, physical indicators like aluminum foil or flour could be placed on the landing surface to capture the precise impact point of the projectile, reducing the human error in distance recording.

Table 12 Noises identification

Obvious Noises identified	Possible solutions
Human observers	Camareas to record/sensors
Non fixed catapult	Claps to secure catapult
Catapult platform unsecured (Table wobble)	Stable platform used
Measuring equipment	Grid measurement system
Changes in air resistance	Controlled room (Close windows and turn off fans)

References

[1]

University of York, “Orthogonal Arrays,” *www.york.ac.uk*, May 2004.
<https://www.york.ac.uk/depts/maths/tables/orthogonal.htm>

[2]

N. Li, C. Shi, Z. Zhang, H. Wang, and Y. Liu, “A review on mixture design methods for geopolymer concrete,” *Composites Part B: Engineering*, vol. 178, p. 107490, 2019, doi: <https://doi.org/10.1016/j.compositesb.2019.107490>.

[3]

Air Academy Associates, “STATAPULT® MANUAL A Simple Guide for Using the Statapult® Catapult.” Accessed: Apr. 26, 2026. [Online]. Available: <https://sixsigmaproductsgroup.com/wp-content/uploads/2019/04/Statapult-User-Guide.pdf>

[4]

S. Salam, T. Choudhary, A. Pugazhendhi, T. N. Verma, and A. Sharma, “A review on recent progress in computational and empirical studies of compression ignition internal combustion engine,” *Fuel*, vol. 279, p. 118469, 2020, doi: <https://doi.org/10.1016/j.fuel.2020.118469>.